Atlantic States Marine Fisheries Commission

Tautog Management Board

February 5, 2015
12:30 – 2:30 p.m.
Alexandria, Virginia

Draft Agenda

The times listed are approximate; the order in which these items will be taken is subject to change; other items may be added as necessary.

1. Welcome/Call to Order (*J. Gilmore)* 12:30 p.m.
2. Board Consent 12:30 p.m.
   - Approval of Agenda
   - Approval of Proceedings from May 2013
3. Public Comment 12:35 p.m.
4. 2015 Tautog Benchmark Stock Assessment **Action** 12:45 p.m.
   - Presentation of Stock Assessment Report (*J. Brust*)
   - Presentation of Peer Review Report (*C. Jones*)
   - Consider acceptance of benchmark stock assessment and peer review report for management use
5. Discuss Next Steps for Management in Response to the Benchmark Assessment (*J. Gilmore*) 2:00 p.m.
6. Consider 2014 FMP Review and State Compliance (*M. Yuen*) **Action** 2:20 p.m.
7. Other Business/Adjourn 2:30 p.m.

The meeting will be held at the Westin, 400 Courthouse Square, Alexandria, Virginia; 886-837-4210

Vision: Sustainably Managing Atlantic Coastal Fisheries

MEETING OVERVIEW

Tautog Management Board Meeting
February 5, 2015
12:30 p.m. – 2:30 p.m.
Alexandria, Virginia

Chair: Jim Gilmore (NY) *Assumed Chairmanship: 04/13*	Technical Committee Chair: Jason McNamee (RI)	Law Enforcement Committee Representative: Jason Snellbaker
Vice Chair: Adam Nowalsky	Advisory Panel Chair: VACANT	Previous Board Meeting: May 23, 2013
Voting Members: MA, RI, CT, NY, NJ, DE, MD, VA, NC, NMFS, USFWS (11 votes)		

2. Board Consent
- Approval of Agenda
- Approval of Proceedings from May 23, 2013

3. Public Comment – At the beginning of the meeting public comment will be taken on items not on the Agenda. Individuals that wish to speak at this time must sign in at the beginning of the meeting. For agenda items that have already gone out for public hearing and/or have had a public comment period that has closed, the Section Chair may determine that additional public comment will not provide additional information. In this circumstance the Chair will not allow additional public comment on an issue. For agenda items that the public has not had a chance to provide input, the Section Chair may allow limited opportunity for comment. The Section Chair has the discretion to limit the number of speakers and/or the length of each comment.

4. Consider 2015 Tautog Benchmark Stock Assessment (12:45 – 2:00 p.m.) Action
Background • The Tautog Stock Assessment Sub-Committee completed the benchmark stock assessment in 2014. A Peer Review Panel reviewed and accepted the assessment in November 2014 (**Briefing Materials).**
Presentations • Presentation of Stock Assessment Report by J. Brust • Presentation of Peer Review Report by C. Jones
Board Action for Consideration • Consider acceptance of the assessment and peer review reports for management use.

5. Discuss Next Steps for Management in Response to the Benchmark Stock Assessment (2:00 – 2:20 p.m.)
Background • Based on acceptance of the stock assessment and peer review reports for management use, the Board will consider management response to the assessment results.
Board Action for Consideration • Consider management response to the 2015 benchmark stock assessment.

- continued next page –

6. Consider 2013 FMP Review Report and State Compliance (2:20 – 2:30 p.m.) Action

Background

- State Compliance Reports are due on May 1 (**Each state compliance report can be found in the compliance binder in the back of the meeting room**).
- The Plan Review Team reviewed each state report and compiled the FMP Review report (**Supplemental Materials).**

Presentations

- Overview of FMP Review Report by M. Yuen

Board Action for Consideration

- Approve 2013 FMP Review and State Compliance reports.
- Approve Delaware and North Carolina’s request for *de minimis* status for commercial and recreational fisheries.

7. Other Business/Adjourn

DRAFT PROCEEDINGS OF THE

ATLANTIC STATES MARINE FISHERIES COMMISSION

TAUTOG MANAGEMENT BOARD

Crowne Plaza Hotel - Old Town
Alexandria, Virginia
May 23, 2013

These minutes are draft and subject to approval by the Tautog Management Board
The Board will review the minutes during its next meeting

TABLE OF CONTENTS

INDEX OF MOTIONS

1. **Approval of Agenda by Consent** (Page 1).

2. **Approval of Proceedings of October, 2012 by Consent** (Page 1).

3. M**ove the board approve the 2012 FMP Review and state compliance reports and at the same time approve Delaware and North Carolina's request for de minimis status for 2013** (Page 3). Motion by Pat Augustine; second by Kyle Schick. Motion carried (Page 3).

4. **Move that the board approve the terms of reference for the tautog benchmark stock assessment as presented today** (Page 8). Motion by Mark Gibson; second by Pat Augustine. Motion carried (Page 8).

5. **Move to nominate and close nominations and cast one vote for Adam Nowalsky vice-Chair of the Tautog Management Board** (Page 8). Motion by Mark Gibson; second by Pat Augustine. Motion carried (Page 8).

6. M**otion to adjourn by Consent (**Page 8).

ATTENDANCE

Board Members

Paul Diodati, MA (AA)
William Adler, MA (GA)
Jocelyn Cary, MA, proxy for Rep. Peake (LA)
Mark Gibson, RI, proxy for R. Ballou (AA)
Dave Simpson, CT (AA)
James Gilmore, NY (AA)
Pat Augustine, NY (GA)
Peter Himchak, NJ, proxy for D. Chanda (AA)
Tom Fote, NJ (GA)
Adam Nowalsky, NJ, proxy for Asm. Albano (LA)
Bernie Pankowski, DE, proxy for Sen. Venables (LA)
John Clark, DE, proxy for D. Saveikis (AA)
Roy Miller, DE (GA)
Tom O'Connell, MD (AA)
Bill Goldsborough, MD (GA)
Rob O'Reilly, VA, proxy for J. Travelstead (AA)
Kyle Schick, VA, proxy for Sen. Stuart (GA)
Bill Cole, NC (GA)
Bill Archambault, USFWS
Peter Burns, NMFS

(AA = Administrative Appointee; GA = Governor Appointee; LA = Legislative Appointee)

Ex-Officio Members

Jason McNamee, Technical Committee Chair

Staff

Bob Beal
Melissa Yuen
Marin Hawk
Katie Drew

Guests

The Tautog Management Board of the Atlantic States Marine Fisheries Commission convened in the Presidential Ballroom of the Crowne Plaza Hotel Old Town, Alexandria, Virginia, May 23, 2013, and was called to order at 10:20 o'clock a.m. by Chairman James Gilmore.

CALL TO ORDER

CHAIRMAN JAMES GILMORE: Good morning, everyone. My name is Jim Gilmore. I'm the administrative commissioner from New York. I will be chairing the Tautog Board today. I'm assuming the chairmanship today, and I would just like to thank Bill Goldsborough for his past two years of chairing this board through some pretty volatile times in terms of mortality rates. Thanks, Bill, for that, and you did all the work. I just have to follow along now.

APPROVAL OF AGENDA

CHAIRMAN GILMORE: The first order of business will be the approval of the agenda. We do have one change. If you do have the older copies, there was a proposal under Item 5 from Maryland. Maryland has withdrawn that, so we are not going to consider that today and that is not going to be part of the discussion.

CHAIRMAN GILMORE: Are there any other changes to the agenda? Seeing none; we will take that as approved. Is there going to be any new business or anything that anybody wants to add later on?

PUBLIC COMMENT

CHAIRMAN GILMORE: For each meeting we offer public comment. Seeing none; we will move on.

APPROVAL OF PROCEEDINGS

CHAIRMAN GILMORE: I will take that we have approval of the proceedings by consent. Thank you. The next order of business to consider the 2012 FMP Report and State Compliance, and Melissa is going to do a presentation on this.

2012 FMP REVIEW AND STATE COMPLIANCE

MS. MELISSA YUEN: I will now go over the FMP Review and State Compliance for the 2012 fishing year. First, a review of the stock status; tautog is currently managed as a single coast-wide stock. The most recent stock assessment was an update completed in 2011 and included data up to 2009. The assessment update concluded that tautog is overfished.

The spawning stock biomass has remained about the same level since 1994 with a very slight upward trend in recent years. In 2009 it was estimated at 23.5 million pounds. This is about 40 percent of the threshold and 53 percent of the target levels. This graph shows the fishing mortality rate.

The black line represents the target fishing mortality rates as required by management documents over time. Every time you see the red above the black line, overfishing is occurring. In 2009 tautog was determined to be experiencing overfishing. Moving on to status of the fishery, tautog is mainly a recreational fishery.

Since this time series began in 1981, an average of 91 percent of the total harvest was attributed to the recreational fishery by weight. Landings peaked in 1986 at nearly 18 million pounds and have generally declined. Since the FMP was implemented in 1996, total harvest averaged 33.4 million pounds per year.

Just looking at the recreational sector, 1998 and 2011 had the lowest landings on record with just over 1.5 million pounds in each of those years. Last year recreational landings increased by 46 percent from 2011. The sector breakdown varies at the state level. In recent years the commercial sector is increasing in proportion for some states such as Massachusetts and New York.

In 2012 the coast-wide recreational sector accounted for 91 percent of landings by weight, which is the as the time series average. At the state level the recreational fishery ranged from

99 percent in Connecticut and Delaware to 41.7 percent in Massachusetts. Taking a closer look at the commercial fishery, which has a time series starting in 1950, tautog was historically considered a trash fish and landings rarely surpassed 200,000 pounds until the late 1970's.

Commercial landings quickly peaked in 1987 with nearly 1.2 million pounds and then sharply declined even before states began implementing regulations in the early 1990's. In 2012 commercial landings is roughly 18 percent of the peak. Around the same time the landings began to rise so did the value of tautog, which is represented by the red line.

In 1950 the price was five cents per pound. In 1988, one year after the peak commercial landings, it was fifty cents a point, and last year it passed three dollars a pound for the first time. Now I will go over the management plan for tautog. The most recent management document was Addendum VI approved in March 2011.

It reduced the fishing mortality target to 0.15 in order to end overfishing and to rebuild the stock. It also required states to implement a coast-wide reduction of 39 percent harvest reduction relative to the 2008/2009 average by January 1, 2012. Each state must implement board-approved regulations in commercial and/or recreational sectors.

In addition to Addendum XVI's requirements, the FMP specifies a 14-inch minimum size limit for tautog. It also requires fish traps and pots to have biodegradable fasteners and for states to provide fisheries data under the Atlantic Coastal Cooperative Statistics Program. States can also implement seasonal closures and possession limits to reduce fishing mortality.

The plan review team finds that all states have recreational and commercial measures consistent with the FMP. The FMP also requires states to collect 200 opercula for aging each year. In 2012 most states collected 200 or more samples. Some states were not able to collect the 200 samples. For example, New York's sampling program was disrupted by Hurricane Sandy.

The plan review team finds that all states met or tried to the best of their ability to meet the biological sampling requirement. The plan review team also looked at how the 2012 total harvest compared to 2008 to 2009 average. Coastwide there was a 53 percent reduction based on the number of fish.

At the state level the difference ranged from a reduction of 81 percent in Maryland to an increase of 48 percent in Connecticut largely attributed to the large increase in recreational landings in that state. On average, states had a 44 percent reduction. Rhode Island and Massachusetts were not required to implement regulations to meet the required reduction as approved by the board in its March 2012 conference call.

Requests for de minimis status; Amendment 1 to the FMP provides the criteria for de minimis status. A state must demonstrate that its most recent commercial landings is less than 1 percent of the coast-wide landings or 10,000 pounds, whichever is greater. If approved, states with de minimis status will still have to implement the 14-inch minimum size limit and regulations for the biodegradable fasteners.

For 2012 the 10,000 pound figure is greater than 1 of coast-wide landings. Delaware and North Carolina requests de minimis status as they have in previous years and have been approved. The plan review team recommends the board grant de minimis status to these two states based on their most recent commercial landings. Both are well below the 10,000 pound criteria. This concludes my presentation. Thank you, Mr. Chairman.

CHAIRMAN GILMORE: Thanks, Melissa, great report. Are there any questions for Melissa?

MR ADAM NOWALSKY: In recent years and recent addendums there has been a lot of focus on illegal and unreported harvest. What is the PRT doing to try to include some updated information about that in these FMP reviews?

MS. YUEN: It is assumed that most of the illegal harvest is coming from the commercial fishery; and so for the 2011 stock assessment update the technical committee looked at projections to see like how many illegal fish is needed in order to have an impact on the fishery, and it was estimated to be like a relatively low amount. That is being considered in the upcoming stock assessment which is going on right now. I don't know if Jason has anything to add.

MR. JASON McNAMEE: It is a good question. I think maybe you're wondering if there is anything specifically in the plan, almost like a term of reference, that addresses it, and I don't know that there is. From the technical standpoint we are working with – and I will talk a little bit more about this in a minute, but we're working with techniques and things of that nature that will account for some uncertainty in harvest estimates or the take estimates.

I think we're covered on that side; but as far as having something that is kind of going into the plan review reports and things like that, I don't know if that is an element in there. It might be a good recommendation if enforcement reports or something like that could be an element in these reports.

MR. NOWALSKY: I would certainly recommend doing that in the future as we go through these reviews to have some input from law enforcement as well as what the PRT's thoughts are on the contribution of that impact to both the harvest levels as well as what the impacts could be on stock status.

CHAIRMAN GILMORE: Yes, a good suggestion, Adam. That is the big issue here so the sooner we get a handle on that the better we end up managing this fishery. Pat.

MR. PATRICK AUGUSTINE: Mr. Chairman, a follow-on comment to Adam's comment is as you recall last year we had the LEC put together a white paper for us as to what the recommendations were that they thought we might want to consider. Unfortunately, at that time we did not adopt any way of tracking. Contrary to what people think and what your report is on all this black market is commercial fishing, we find it to be contrary to that. There are an awful lot of recreational people that are selling to the black market live. With those comments, Mr. Chairman, I would like to make a motion if you ready.

CHAIRMAN GILMORE: Go ahead, Pat.

MR. AUGUSTINE: **All right, I move the board approve the 2012 FMP Review and state compliance reports and at the same time approve Delaware and North Carolina's request for de minimis status for 2013.**

CHAIRMAN GILMORE**: Seconded by Kyle. Is there any discussion on the motion? Is there any objection to the motion? Seeing none; we will accept that as approved.** The next item on the agenda – again, we're skipping Item 5 – we're going to Item 6. We're going to consider terms of reference and Jay McNamee is going to do a presentation on this.

TECHNICAL COMMITTEE REPORT

MR. McNAMEE: I'm Jason McNamee. I work for the Rhode Island Division of Fish and Wildlife. I have just a real summary of the stock assessment process to this point, and then I'll quickly go through the terms of reference for you all to take a look at as well, so I'll try to go through this and catch you back up.

Okay, just way of summary, the Tautog Technical Committee and stock assessment subcommittee met at the end of March of this year. That was our data workshop. We reviewed and evaluated all of the available datasets. This was done for the benchmark stock assessment process that we are now in the midst of.

We looked at evaluated all sorts of data, fishery dependent, independent, as well as tautog life history information. It is kind of nice for this benchmark process to really kind of lay it all out and reevaluate all of the data sources that we have been working with and we have also introduced a whole suite of new information that we're going to try and consider for this benchmark.

The next thing aside from the data that we talked about were the modeling techniques that we're going to employ. As you may remember, we have been using a virtual population analysis as the main technique, and we're hoping to consider that, but we're going to try and move away from that as well. We're doing some techniques that can be more spatially explicit. We have a whole suite of modeling approaches that we're going to take a look at.

Another interesting piece for this stock assessment is that we will be engaging independent peer reviewers, so that is something for the board to kind of keep track of to get a sense of what you think about that process. I believe it has been done by the commission at least one other time for eel, so this will be the next iteration for that process to see how that works out.

From the stock assessment committee and technical committee's view it has been pretty good so far. We've have got some good feedback. We developed a set of terms of terms of reference which I will go into in more detail in a moment, but we drafted those up after the actual meeting. We had a lot to cover in that meeting so we spent the time looking at the data and talking about models and things like that and caught up with the terms of reference piece afterwards.

I have got a couple of slides on that for you. Just in summation, the stock assessment is moving in the right direction, especially considering tautog is a pretty data-poor species certainly in some areas of the stock range. We feel pretty good. We have some new faces on the committee, some old faces as well, but it is a good group and we're looking forward to working together and things have been going well so far.

The technical committee members will contribute additional data and analyses and we will be holding another conference call prior to the assessment workshop in October of this year. Just a quick overview; these are all of the steps that we intend on hitting during this process. We have gone through the first three. The data workshop, again, was in March.

We talked a lot about data so now we're in the kind of final collection phase of the data and then the analyses will follow that. Then we will get into the actual stock assessment process and should end up with a review in the summer of next year. Okay, terms of reference; they're fairly standard but there are some really good ones for tautog as well, so I will kind of step through these one by one.

The first important step is to characterize the precision and accuracy of the fishery-dependent and independent data used in the assessment. This includes things like just providing a description of the data source, what type of survey it is, what state it is in, how the methodology works, all of that sort of stuff.

Then we will talk about the calculations. We talked a lot about standardization of our abundance indices, something we haven't done too much of with tautog, so we talked a lot about that. We will be talking about that more and describing that as one of the terms of reference. Continuing on with the first term of reference, we will also discuss any trends and associated estimates of uncertainties; standard errors, things like this that uncertainty estimates surround abundance indices or commercial catch or what have you.

We will also, and importantly, include a justification for any removals of any datasets that we drop out of the analyses, so we will have a justification for any of that. Then we will also discuss the strengths and weaknesses of each of the data sources. Okay, this is a very important one for tautog and I think is one that is on a lot of the board members' minds, but we're going to talk a lot about and justify the assumptions about the stock structure and the geographical scale at which the population is assessed.

We currently have kind of a bifurcated process. We've have got a coast-wide assessment and we have then a regional assessment that is occurring in Rhode Island and Massachusetts. The point of all of that is we don't believe that tautog should be assessed on a coast-wide basis. They're more discrete than that, so we're looking at modeling techniques and data sources at a finer resolution so that we can get to a better place for assessing the tautog stock.

Okay, Term of Reference Number 3 is to develop models to estimate population parameters, things like fishing mortality, biomass, numbers at age, things like that, depending on the model approach used. We talked a bit about the types of models so when we get into the actual process, we will be picking careful notes of each of the modeling types that we're going to look at and strengths and weaknesses of each of them.

Under Sub-Bullet A there we will be describing the model structure, the assumptions, the parameterization for both the population and the reference point of the models. We will be clearly describing the strengths and weaknesses of each modeling type. Some of the types we're going to look at are data-poor methods and some are a little more data-intense methods.

We will be justifying our choice of uncertainty estimates, effective sample sizes, the weighting schemes that we use, so those will be explicitly justified. We will be describing the stability of the model, how it performs, can we get it to converge on a solution. Then we will also be testing the various assumptions that we make for whichever model ends up being our preferred model by running retrospective analyses and sensitivity runs to test the various assumptions that we might make for each modeling type.

Another important thing that we will do is to make sure that we run a continuity run; so even though we don't prefer to run this again on a coast-wide level, we will run where we can some of the models as also a coast-wide set of data and compare it to the coast-wide VPA. It just gives you a level of confidence that the model is not wildly out of sync with what we've looked at in the past.

Then in the end we're going to pick our preferred model and then justify why we've picked that model. Okay, two more; we're going to characterize the uncertainty of the model estimates and biological or empirical reference points; so we will be talking about uncertainty around the reference points that come out of the model outputs.

Then Number 5 is we will be making recommendations on the stock status; so where it is relative to fishing mortality, stock abundance, things like that. The final two; we will be developing in the end a detailed short- and long-term prioritized of research needs. We will talk about what research is underway, our critical research needs and what is something that doesn't exist yet that could really benefit the tautog stock assessment and management of the species.

Then the final thing we will do is recommend the timing of the next benchmark assessment. We will come out of this process with a preferred model, and we will have some sense of a cycle to kind of run this model. Given the data intensity of the model and the life history characteristics of the species, we can recommend a cycle to reassess the species. With that, that is all I have for you. I'm happy to take any questions you might have. Thanks.

CHAIRMAN GILMORE: Thanks, Jay, that was great. Obviously, the technical committee has done a great job in including everything I could think of. Are there any questions? Mark.

MR. MARK GIBSON: Jason, on Term of Reference 2, the stock structure and spatial scales, would you talk about that a little bit more. I'm interested in what the thinking is right now on how we can simultaneously drill down on smaller spatial scales versus having to assess on a coast-wide basis to cover areas which are more data poor than others.

We do that now I think with two separate analyses. One is a coast-wide set of data and then an extraction of area-specific or zone-specific data in another model run. Is that still where your thinking is on this term of reference?

I don't want to lose the Massachusetts/Rhode Island locality that we have.

MR. McNAMEE: Yes, a very good question. I think the idea here is to not lose that. In fact, we would like to have a similar situation for all of the states. One of the things we have looked at already is some additional tagging information that has come out of the Mid-Atlantic just to, again, support this notion that tautog don't migrate very far.

They kind of go inshore/offshore and not north/south very far. What has constrained us in the past is data and the level of data that exists. For this benchmark we're looking at data-poor models that could – each individual even might have enough data to feed into these; things such as the DB-SRA, which I think was used for eel.

It is not very data intensive so that is a technique that could be used and most states will have enough information to kind of feed into that model. Other techniques as well – one of the ones we're going to look at is a Bayesian Surplus Production Model. That is another one that as long as you can develop some sort of standardized abundance index, even if it is a recreational CPUE or something like that, we can crank that model and see what comes out of it. The idea here is to we'll run a coast-wide iteration just to do a continuity run, but the idea is to assess the species on a more realistic spatial scale, so that is what we're trying to move.

MR. GIBSON: As it relates to Term of Reference Number of 5; so to the extent that region-specific or even state-specific models come forward that you're comfortable with, those stock status determinations would be at that scale or would we still be in a coast-wide mode.

MR. McNAMEE: I think we would intend on having them viewed on that more discrete scale. I guess that would be a decision for the management board in the end as to how you want to work with that. We will work to produce biological reference points at these more discrete scales.

MR. AUGUSTINE: As a follow-on to Mark, he explained it in such wonderful terms that it went over my head, but I knew what we was talking about. Is it the likelihood then that the result of your assessment could actually regionalize – I will use the word regionalize – let's say regionalize bag sizes and season as opposed to coastal?

In other words, we have made some – we have accepted what Massachusetts did and your survey up there and they set different parameters. Would this lead in that direction; or as you had said it would then give the board an opportunity to either go with a coastwide or go on, again, state by state or regional basis for setting their bag size and season? That sounds like that is the direction we're going, and I think is what Mark was asking, but he asked it more eloquently than I did. Could you help me with that?

MR. McNAMEE: Sure, I'll try. I think you're right. Again, I think it is a choice for the management board in the end, but what we will try to produce for you to be able to make that decision are good estimates at as fine a scale as we can. All of this hinges on our ability to be successful with some of these other approaches.

I guess the first tier is a modeling technique that is not too dissimilar from the current VPA. It will be a statistical catch-at-age model, and that is a little more data intense, and how far we can break down this assessment spatially is sort of up in the air. We're not sure yet. It will depend on the modeling type, but in the end the goal will be to get finer resolution on these more discrete populations and then develop biological reference points on those, and then you would adjust from those discrete parameters.

MR. AUGUSTINE: Thank you for that; and when you're ready for a motion, Mr. Chairman.

MR. DAVID SIMPSON: Actually not a question; just to share with the board that as Jay knows and as of two days ago Katie knows, the University of Connecticut is seeking Sea Grant funding to do a stock assessment for the Long Island Sound area. I only learned fairly recently that it is much more ambitious than I thought and would be more toward the full analytical assessment than I envisioned that – I know one of their interests is – you know, they have information about fecundity being much higher than we previously thought – disproportionate of benefit potentially of larger females and their egg contribution relative to smaller females.

In other words, a four pound fish may produce three times as many eggs as – well, five times as many eggs as the fish that is half as big. In other words, a pound is not a pound. We will look forward to that. I think it is in the next couple of years and hopefully I'm going to make sure they integrate closely. I know Jay has been talking with the folks at UConn but I just wanted people to be aware of it, including you.

MR. ROB O'REILLY: Jason, I guess just two questions. One would be more intensive data needs of a statistical catch-at-age approach. How do you see improvements in the independent data in that it is really lacking for the most part south of New Jersey would be one question. Maybe you could respond to that and I will have a followup.

MR. McNAMEE: Good question. That has been one of the big stumbling blocks all along, particularly in the southern extent of the species' range. One of the things that we're looking at are alternate ways of getting at an abundance index, so things like recreational CPUEs. We looked at VTR data.

We're kind of thinking outside of the box and not being completely dependent on scientific surveys to inform the independent stock abundance that we would normally use in a stock assessment. We're thinking about that. How we make out with that sort of information will dictate the level at which we're able to do things with more data-intensive methods like statistical catch-at-age models. We're trying to accommodate that.

MR. O'REILLY: Thank you very much. A second question would be tagging data; how is it planned to utilize tagging data. Not every state has tagging data, but could that be developed into some type of an index? It is a volunteer tagging system, but at the same time I mean it is used for other purposes. Do you see something there?

MR. McNAMEE: We talked about tagging already a little bit. There were some done in Maryland and I know Virginia also has a pretty robust tagging program that has been going on. The way we have been talking about it so far has been to look at movement, so give ourselves a little more confidence that throughout the range they're not migrating very far and things like that.

There does appear to be that kind of information coming out of the Maryland study that Alexei I Sharov brought forward during our data workshop. We didn't talk too much about this so I can't give you too many details, but we do have as one of our elements to look at the tagging information to see if we can do something a little more analytical with that aside from just kind of looking at species' movement. It is on our radar. I don't have too much other information at this point on that.

MR. O'REILLY: Does anyone typical look other than growth characteristics for an index with the mark and then the recapture sizes as any indication that could be useful?

MR. McNAMEE: Yes, that is actually one of the areas that is kind of problematic. The reason for that is you will frequently – because the reporting is coming from the fishery itself in many cases and not from a scientific survey, the reporting measures are coming in inches and we will get like a negative growth a lot, so there are problems with using it in that way. We have looked at that.

MR. NOWALSKY: Questions in two areas. The first is what was the impetus for the decision to go with the independent peer reviewer and what are the risks/advantages of going in that direction?

MR. McNAMEE: I'm going to take a shot at it; and if anyone else wants to jump in on this, feel free. I believe the idea was to – with the normal process you have a lot of work that gets done, you kind of move through this process, and then you go into peer review and you go in kind of blind and you don't have any idea of what the reviewers might be looking for or if you've really gone off the rails on some aspect of it.

With tautog we felt this was a good species to do this experiment, and the idea is to get the peer reviewer kind of in working with the actual team and providing advice along the way. If that peer reviewer who is going to be a part of the final peer review team, although not a voting member or something like that – yes, so they're involved but just in a sort of advisory way. But in any case the idea is to get advice along the way so you're not going in blind right at the end. Tautog they felt was a good species to kind of test on and eel was another one to see how the process works.

MR. NOWALSKY: Well, we'll see how the process works; I look forward to that. The second component that is now having had the advantage of having had the data workshop; would you characterize this stock assessment as likely being more of the same or is there something for yourself from a technical nature as well as us as managers to maybe get excited about is this is something different and a step in a better way to assess and facilitate better management of this species?

MR. McNAMEE: Yes, well, I get excited about tautog all the time, so it is always exciting for me. I think there is a lot of reason to be optimistic as far as assessing this species in a more realistic biologically feasible way. Some of the techniques that have been kind of brought forward I think are a big improvement over what we've been doing, even the statistical catch at age; just being able to entertain uncertainty and some of the harvest estimates.

A virtual population analysis assumes your harvest – especially with recreationally dominated species like this, a VPA assumes your harvest is known and that is how it kind of builds its population numbers from that kind of starting point. A statistical catch-at-age model does some something different. It entertains uncertainty, which we know we have in these estimates, so it is a vast improvement in that regard. Then some of the other modeling techniques I am most familiar with – somewhat familiar with I think are going to help us with regard to this spatial component that we talk about a lot with tautog. I'm optimistic. I think it is going to be a good process and I think it will improve management of this species.

CHAIRMAN GILMORE: Are there any other questions for Jason? Go ahead, Pat.

MR. AUGUSTINE: **Mr. Chairman, I move that the board approve the terms of reference for the tautog benchmark stock assessment as presented today.**

CHAIRMAN GILMORE: **Second by Mark Gibson. Is there any discussion on the motion? Is there any objection to the motion? Seeing none; we will accept that as approved.**

ELECTION OF BOARD VICE CHAIR

The last agenda item we have is I have ascended to the throne here, so there is a vacancy in the vice-chairmanship. I need some nominations from the board for vice-chair. Mark Gibson.

MR. GIBSON: **I'm pleased to nominate Adam Nowalsky for vice-chair.**

MR. AUGUSTINE: **I second that and move to close nominations and cast one vote for Adam Nowalsky as vice-chair.**

CHAIRMAN GILMORE: Congratulations. Adam; welcome to the team. We're really glad to have you aboard. (Applause)

ADJOURNMENT

Are there any other issues to come before the board? If not, I will take a motion to adjourn from Mr. Augustine and seconded by everyone. Thank you.

(Whereupon, the meeting was adjourned at 11:00 o'clock a.m., May 23, 2013.)

Stock Assessment Report No. 14-01
of the

Atlantic States Marine Fisheries Commission

Tautog Benchmark Stock Assessment

This draft has been peer-reviewed and is intended for Board approval for management use
February 2015

Vision: Sustainably Managing Atlantic Coastal Fisheries

Prepared by the
ASMFC Tautog Stock Assessment Subcommittee:

Mr. Jeffrey Brust (Chair), New Jersey Division of Fish and Wildlife
Mr. Paul Caruso, Massachusetts Division of Marine Fisheries
Mr. Jason McNamee, Rhode Island Division of Fish and Wildlife
Mr. Scott Newlin, Delaware Division of Fish and Wildlife
Dr. Alexei Sharov, Maryland Department of Natural Resources
Mr. Joe Cimino, Virginia Marine Resources Commission
Dr. Katie Drew, Atlantic States Marine Fisheries Commission
Ms. Melissa Yuen, Atlantic States Marine Fisheries Commission

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA10NMF4740016

DRAFT DOCUMENT DO NOT CITE

DEDICATION

Dedicated to Paul Caruso, long-serving member of the Tautog Technical Committee and irreplaceable fount of institutional knowledge. This assessment one was his last in a long career of fisheries science. Thank you for the many years of service and friendship!

ACKNOWLEDGEMENTS

This stock assessment cannot be possible without
the Tautog Technical Committee and
Stock Assessment Sub-Committee,
who dedicated many hours of hard work and good humor to this benchmark assessment:

Jason McNamee, Rhode Island Division of Fish and Wildlife
Jeffrey Brust, New Jersey Division of Fish and Wildlife
Paul Caruso, Massachusetts Division of Marine Fisheries
Michael Bednarski, Massachusetts Division of Marine Fisheries
Deborah Pacileo, Connecticut Department of Energy and Environmental Protection
Sandra Dumais, New York State Department of Environmental Conservation
Linda Barry, New Jersey Division of Fish and Wildlife
Scott Newlin, Delaware Division of Fish and Wildlife
Dr. Alexei Sharov, Maryland Department of Natural Resources
Joe Cimino, Virginia Marine Resources Commission
Tom Wadsworth, North Carolina Division of Marine Fisheries
Dr. Katie Drew, Atlantic States Marine Fisheries Commission
Melissa Yuen, Atlantic States Marine Fisheries Commission

Special thanks to Dr. Thomas Miller, Chesapeake Biological Laboratory at the University of Maryland Center for Environmental Science, for providing valuable critique and guidance to the Tautog SASC since the first data workshop of this assessment.

Thanks to Patrick Campfield and Toni Kerns for their support throughout the assessment.

Special thanks to the Massachusetts Division of Marine Fisheries
for hosting assessment workshops.

EXECUTIVE SUMMARY

1. **Characterize precision and accuracy of fishery-dependent and fishery-independent data used in the assessment.**

   Tautog are targeted by both commercial and recreational fisheries, but approximately 90% of the total harvest comes from the recreational fishery. Commercial harvest data for tautog are available from 1950 to present, while recreational harvest estimates are available for 1982 to present. Commercial records indicate low harvest levels during the 1950s through 1970s, and the same is assumed for the recreational harvest. As the popularity of the species increased and technological advancements facilitated the identification of hard bottom habitat, a directed fishery developed and landings increased rapidly during the late 1970s and 1980s, but have since declined substantially.

   Total catch included estimates of recreational landings and discards from Marine Recreational Fisheries Statistics Survey/Marine Recreational Information Program (MRFSS/MRIP) conducted by the National Marine Fisheries Service, and commercial landings from the Atlantic Coast Cooperative Statistics Program (ACCSP). Estimates of commercial discards were developed from the Northeast Fishery Observer Program, but due to low sample size, they were considered too uncertain to include in the base run. Tautog are not well-sampled by the MRFSS/MRIP program, resulting in higher PSEs (approximately 20-25% in recent years at the regional level) and large year-to-year swings in catch estimates, often driven by small numbers of intercepts.

   As a hard structure-associated species, tautog are also not well-captured by standard trawl-based surveys. The Technical Committee investigated fishery-independent surveys from Massachusetts through Maryland, of which four adult and three young-of-year surveys met pre-established criteria and were deemed appropriate for use in the assessment, although operate south of New Jersey. In addition, regional fishery dependent indices of abundance (catch per unit effort) were developed from the MRFSS/MRIP intercept data. For this analysis, catch was based on total estimated recreational catch (harvest plus discards), while effort was based on trips that caught any species within a guild of species commonly associated with tautog. Both fishery independent and fishery dependent indices were standardized using GLM to account for interannual survey variability due to environmental covariates.

2. **Justify assumptions about stock structure and the geographical scale at which the population is assessed.**

   Tagging data suggest strong site fidelity across years with limited north-south movement, although they undergo seasonal inshore-offshore migrations in the northern end of their range. For this assessment, the Technical Committee spent considerable time identifying appropriate regional structure based on life history information, fishery characteristics, data availability, and policy. The preferred regional breakdown identifies three regions: Southern New England (MA, RI, CT), New York-New Jersey (NY-NJ), and DelMarVa (DE, MD, VA). Significant concern was raised that this regionalization splits Long Island Sound between the Southern New England (SNE) and NY-NJ regions, so a highly regarded alternative regional scheme was investigated that moves CT from the SNE region to the NY-NJ region.

3. **Develop models to estimate population parameters (e.g., fishing mortality (F), biomass, abundance) and biological or empirical reference points at the coastwide and regional basis, and analyze model performance.**

This stock assessment investigated three different models to assess the regional tautog populations. ASAP (Age Structured Assessment Program) version 3.0.17, available through the Northeast Fishery Science Center (NEFSC) National Fishery Toolbox (NFT) is a "data rich," forward projecting statistical catch at age program. In addition, due to concerns about availability and utility of data at the regional level, two data poor methods were also investigated: the extended Depletion-Based Stock Reduction Analysis (xDB-SRA) and a Bayesian State Space Surplus Production Model. All three models incorporated annual harvest estimates and adult fishery-independent and fishery-dependent biomass indices, while ASAP also incorporated available age structure, size-at-age, and juvenile abundance indices. Within each region, the ASAP model assumed a single fleet with three selectivity periods based on management time blocks. "Base" models were conducted for each model and each region of the preferred regional breakdown. Sensitivity runs were also conducted for each model to evaluate model sensitivity to input data, model configuration, regional structure, and other assumptions.

All three models produced similar trends in fishing mortality and biomass for the SNE and DelMarVa (DMV) regions, although on different scales. ASAP and xDB-SRA models were consistent in the NY-NJ region, but the BSSPM produced unrealistic results. Due to its ability to incorporate available age information and uncertainty in the catch and survey data, and its performance / stability even at small regional scales, the Technical Committee selected the ASAP model under the preferred regional structure as the "preferred" model, with the data poor methods providing corroborating evidence.

Due to uncertainty in recreational harvest estimates which make up the majority of annual landings, trends in fishing mortality exhibit high interannual variability. The Technical Committee therefore determined that three-year moving averages are more appropriate to evaluate fishing mortality. For the SNE region, fishing mortality has exhibited a generally increasing trend since the early 2000s. Increases in fishing mortality were also observed in the NY-NJ and DMV regions beginning around 2000; however unlike the SNE region, F in the southern two regions has declined sharply since 2010. During the most recent three year period (2011-2013) fishing mortality is estimated at $F_{recent} = 0.45$, 0.24, and 0.17 for the SNE, NY-NJ, and DMV regions, respectively.

Trends in biomass are less variable than those for fishing mortality. Consistent with trends in fishing mortality, biomass in the SNE region has been declining in recent years while biomass in the NY-NJ and DMV regions has increased. Spawning stock biomass estimates in each of the three regions were in the range of 1,500-2,000 MT in 2013.

The Technical Committee chose MSY-based reference points for the SNE region, due to the longer time-series of data and the good fit of the stock-recruitment curve for the base run. SSB_{target} was defined as SSB_{MSY} with an $SSB_{threshold}$ of 75% of SSB_{MSY}. This resulted in an SSB_{target} of 3,883 MT and an $SSB_{threshold}$ of 2,912 MT. The F_{target} was defined as F_{MSY} (0.15), and the $F_{threshold}$ was calculated by finding the F that would result that would result in $SSB_{threshold}$ under equilibrium conditions. This resulted in an $F_{threshold}$ of 0.20.

The S-R curve for the NY-NJ and DelMarVa regions did not cover the earliest, least exploited period of those populations, and the TC had concerns about the reliability of the estimated parameters. The TC chose to use SPR-based reference points for those regions, with F_{target} defined as $F_{40\%SPR}$ and $F_{threshold}$ defined as $F_{30\%SPR}$. For NY-NJ, this resulted in $F_{target} = 0.17$ and $F_{threshold} = 0.26$. For DelMarVa, this resulted in $F_{target} = 0.16$ and $F_{threshold} = 0.24$. The TC chose SSB reference points associated with those levels of F by projecting the population forward under equilibrium conditions with recruitment randomly drawn from the observed time-series. SSB_{target} for NY-NJ was 3,570 MT, and $SSB_{threshold}$ was 2,640 MT. For DelMarVa, $SSB_{target} = 2,090$ MT and $SSB_{threshold} = 1,580$ MT.

4. Characterize uncertainty of model estimates and biological or empirical reference points.

Retrospective patterns indicate F in the terminal year is overestimated in SNE and NY-NJ, but underestimated in DMV. Sensitivity runs generally exhibited similar trends in F compared to the base runs, but shifted the scale of the trajectory and provided a range of terminal year estimates.

Retrospective patterns indicate SSB is slightly underestimated in SNE, is generally overestimated but switches to underestimated in the last year in NY-NJ, and is overestimated in DMV. As with fishing mortality, sensitivity runs produced similar trends in SSB, but had varying effects on the scale and slope, resulting in a range of terminal year estimates. Sensitivity runs generally did not result in different assessments of stock status.

5. Recommend stock status as related to reference points (if available).

Relative to these reference points, SSB in the SNE region was estimated to be below $SSB_{threshold}$ (overfished) with fishing mortality above the $F_{threshold}$ (overfishing occurring). The NY-NJ and DMV regions are overfished (SSB_{2013} below $SSB_{threshold}$); however, in both regions fishing mortality is above F_{target} but below $F_{threshold}$ (overfishing not occurring). Similar stock status results were found for the highly regarded alternate regional breakdown.

6. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Identify recommendations that have been addressed since the last assessment, or that are in the process of being addressed. Highlight improvements to be made by next benchmark review.

The Technical Committee compiled a list of prioritized research needs to improve understanding of tautog life history and stock dynamics and aid in development of future stock assessments. High priority needs included improved biological collections across sectors and size ranges, characterization of discarded length frequencies, and development of a comprehensive fishery independent survey that is more appropriate for a structure oriented species.

7. Recommend timing of next benchmark assessment and intermediate updates, if necessary, relative to biology and current management of the species.

The Technical Committee recommends conducting a stock assessment update in 2016 and a benchmark stock assessment in 2019.

TABLE OF CONTENTS

Tables

Figures

TERMS OF REFERENCE

Approved by the ASMFC Tautog Management Board May 23, 2013

1. Characterize precision and accuracy of fishery-dependent and fishery-independent data used in the assessment, including, but not limited to:
    a. Provide descriptions of each data source (e.g. geographic location, sampling methodology, potential explanation for outlying or anomalous data)
    b. Describe calculation and potential standardization of abundance indices.
    c. Discuss trends and associated estimates of uncertainty (e.g. standard errors)
    d. Justify inclusion or elimination of available data sources.
    e. Discuss the effects of data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivity, aging accuracy, and sample size) on model inputs and outputs.

2. Justify assumptions about stock structure and the geographical scale at which the population is assessed.

3. Develop models to estimate population parameters (e.g., F, biomass, abundance) and biological or empirical reference points at the coastwide and regional basis, and analyze model performance.
    a. Describe model structure, assumptions, and parameterization for both population and reference point models. Clearly and thoroughly explain model strengths and limitations.
    b. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    c. Describe stability of model (e.g. ability to find a stable solution, invert Hessian).
    d. Perform retrospective analyses and sensitivity analyses for starting parameter values, priors, major assumptions, etc. and conduct other model diagnostics as necessary for both population and reference point models.
    e. Perform continuity run with approved model from the previous benchmark assessment.
    f. Justify the choice of preferred model and explain any differences in results among models.

4. Characterize uncertainty of model estimates and biological or empirical reference points.

5. Recommend stock status as related to reference points (if available). For example:
    a. Is the stock below the biomass threshold?
    b. Is F above the fishing mortality threshold?

6. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Identify recommendations that have been addressed since the last assessment, or that are in the process of being addressed. Highlight improvements to be made by next benchmark review.

7. Recommend timing of next benchmark assessment and intermediate updates, if necessary, relative to biology and current management of the species.

1.0 INTRODUCTION

The 2014 benchmark stock assessment for tautog (*Tautoga onitis*) was initiated by the Atlantic States Marine Fisheries Commission (ASMFC or Commission) Tautog Management Board and prepared by the ASMFC Tautog Technical Committee (TC), through the Tautog Stock Assessment Subcommittee (SASC), as part of the interstate fisheries management process. The previous stock assessment was completed and peer reviewed through the ASMFC's Stock Assessment Review Process in 2005 (ASMFC 2006), and then updated using the same methodology in 2011. Commission stock assessments are normally conducted at least every five years. This benchmark assessment was delayed one year to allow incorporation of two years of harvest information since the latest management changes enacted in 2012. This assessment includes harvest and survey index data through 2013; however, aging of samples from 2013 is not complete, so the terminal year catch at age (where appropriate) is based on 2012 age-length keys.

1.1 Management Unit Definition

Tautog stocks on the U.S. Atlantic coast are managed through the ASMFC Interstate Fishery Management Plan (FMP) for Tautog (ASMFC 1996). Under this FMP, the management unit is defined as all U.S. territorial waters of the northwest Atlantic Ocean, from the shoreline to the seaward boundary of the exclusive economic zone, and from US/Canadian border to the southern end of the species range. Historically, all states from Massachusetts through North Carolina have a declared interest in the species. Currently, however, Delaware and North Carolina maintain *de minimus* status, and are therefore exempt from certain regulatory and monitoring requirements.

1.2 Regulatory History

The following is a brief review of the history of tautog fishery management through the ASMFC. Additional details are provided in the various amendments and addenda to the original Tautog FMP, which are available online at *www.asmfc.org*.

Prior to the ASMFC interstate FMP, individual states managed tautog on a unilateral basis. Some states had commercial and/or recreational regulations for tautog, such as minimum size limits, possession limits, and effort controls, although most states did not have any tautog regulations. An increase in fishing pressure in the mid-1980s through early 1990s, and a growing perception of the species' vulnerability to overfishing, stimulated the need for a coastwide fishery management plan. Accordingly, in 1993 the ASMFC recommended that a plan be developed as part of its Interstate Fisheries Management Program. The states of Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland Virginia, and North Carolina declared an interest in jointly managing this species through the ASMFC. The Interstate Fishery Management Plan for Tautog was implemented in 1996 (ASMFC 1996), with the goals of conserving the resource along the Atlantic Coast and maximizing long-term ecological benefits, while maintaining the social and economic benefits of recreational and commercial utilization.

The original FMP established a 14" minimum size limit and a target fishing mortality of $F = M = 0.15$. The target F was a significant decrease from the 1995 stock assessment terminal year fishing mortality rate in excess of $F = 0.70$, so a phased in approach to implementing these regulations was established. Northern states (Massachusetts through New Jersey) were to implement the minimum size and achieve an interim target of F = 0.24 by April 1997, while southern states (Delaware through North Carolina) had until April 1998 to do the same. All states were then required to achieve the target F = 0.15 by April 1999.

In response to northern states' difficulty in achieving the interim F by their deadline, Addendum I to the FMP was in passed in 1997 delaying implementation of the interim F and target F for all states until April 1998 and April 2000, respectively.

The 1999 stock assessment incorporated data through 1998, which included only nine months of data under the new regulations. Given the life history of the species, the Tautog Management Board (Board) was concerned the assessment provided limited advice on the effects of the new regulations. Addendum II was therefore passed in Novemeber1999, further extending the deadline to achieve the F=0.15 target until April 2002 to allow additional evaluation of the new regulations.

Addendum II also tasked the Tautog TC with addressing a number of questions raised by the Board, including reference point alternatives, state-wide vs. sector-specific (within a state) compliance, monitoring requirements, and guidelines on developing mode or gear specific management options within a state. The TC provided recommendations to the Board, and the Board's decisions were adopted as Addendum III to the Tautog FMP in February 2002. Most importantly, Addendum III established a new target fishing mortality rate of $F_{target} = F_{40\%SSB} = 0.29$ and mandated that states collect a minimum of 200 age samples per year.

Addendum IV, adopted in January 2007, revised the target fishing mortality rate to F = 0.20, a 28.6% reduction in overall fishing mortality, and established biomass reference points for the first time. The biomass reference points were *ad hoc*, based on the average of the 1982-1991 SSB (target; 26,800 MT) and 75% of this value (threshold; 20,100 MT). In addition, Addendum IV required states to achieve the new target F by reductions in recreational harvest only. Addendum V was subsequently passed in May 2007 to allow states flexibility in achieving the target through reductions in commercial harvest, recreational harvest, or some combination of both. A Massachusetts-Rhode Island model indicated regional F was lower than the coastwide target, therefore these two states were not required to implement management measures to reduce F.

In April 2011, Addendum VI to the FMP established a new F_{target} of F = M = 0.15 on the basis that stock biomass had not responded to previous F levels. The new F_{target} required states to take a 39% reduction in harvest. As in Addendum IV, a regional assessment of Massachusetts and Rhode Island demonstrated a lower regional F using ADAPT VPA, and these states were not required to implement tighter regulations. To achieve the required harvest reduction, all other states adopted higher minimum size limits exceeding the FMP's minimum requirement of 14" in addition to other measures, such as possession limits, seasonal closures, and gear restrictions. Current management measures for the recreational fishery are presented in Table 1.1; regulations for the commercial fishery in Table 1.2. For more details on the regulatory history of tautog and a compilation of the most recent tautog management measures for each state, please see the most recent FMP Review report[1].

1.3 Stock Assessment History

The first tautog stock assessment was performed in 1995 using the ADAPT virtual population analysis (VPA) model (available through NMFS NEFSC toolbox). In order to incorporate perceived regional differences in biology and fishery characteristics throughout the range of the species, the Technical Committee attempted separate regional models for northern (Massachusetts to New York) and southern (New Jersey to Virginia) states. The assessment underwent peer review through the NMFS NEFSC Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) process. Although the assessment was not accepted by the peer review panel, the resulting fishing mortality estimate from the assessment was incorporated into the initial FMP (ASMFC 1996).

The next benchmark assessment, performed in 1999, was also conducted using the ADAPT VPA. The regional approach was used for data consolidation, application of age keys, and preliminary VPA runs of the model. Unfortunately, results for the southern region were unreliable. The preferred run, therefore, was based on catch at age (CAA) developed separately for north (MA-NY) and south (NJ-VA) regions and combined for a total coastwide CAA. The assessment derived coastwide estimates of F, spawning stock biomass and recruitment. In addition, tag based survival estimates were included in the assessment as corroborative evidence. A peer review of the model through the SAW/SARC process determined that the model was suitable for management purposes. That assessment indicated that the terminal F rate had dropped to 0.29, which was attributed to increases in minimum size required in the original FMP. This terminal F was close to the interim FMP target of 0.24, but well above the final plan target of F = 0.15.

A stock assessment update conducted in 2002 using the methods from the 1999 assessment found that recreational catch rates had returned to levels observed prior to the minimum size limit increase, and F had increased to F = 0.41. The Board responded by implementing reductions in recreational harvest in 2003, in an attempt to return F to the FMP target value. The target had been revised to $F_{SSB\ 40\%} = 0.29$ by Addendum III (ASMFC 2002), based upon updated recruitment and weight at age parameters and a desire to adopt a target with more management flexibility.

A benchmark stock assessment conducted and peer-reviewed in 2005 (ASMFC 2006) continued the use of the coastwide ADAPT VPA model based on separate regional (north/south) CAA. The assessment indicated that the coastwide population of tautog had declined about four-fold from 1982 to 1996 and had then remained relatively stable through the terminal year. The stock was considered overfished and overfishing was occurring with a 2003 coastwide fishing mortality estimate of F=0.299. In response to concerns from the Management Board and Technical Committee regarding the utility of a coastwide model on a mostly sedentary species, the 2006

---

[1] ASMFC. 2013. Review of the Atlantic States Marine Fisheries Commission Fishery Management Plan for Tautog (*Tautoga onitis*): 2012 Fishing Year. Access: http://www.asmfc.org/species/tautog

assessment also presented results of state-specific assessments (primarily catch curves) of local tautog populations. The peer review panel generally agreed that local or regional methods were more appropriate given the life history of the species, but expressed reservations about the paucity of data available at small regional scales and the use of catch curves for management purposes. The panel approved the coastwide model for use in management, but encouraged further development and refinement of more localized models for future use (ASMFC 2006).

A “turn of the crank” update assessment was completed in 2011 using the same methodology as the 2006 assessment, with data through 2009. Fishing mortality was estimated as F = 0.23 in 2009, with the three-year average F = 0.31. Both estimates were above the F_{target} = 0.20. SSB was estimated to be 10,663 MT in 2009, well below the target of 26,800 MT and threshold of 20,100 MT. Therefore, the 2011 stock assessment update concluded that tautog was overfished and experiencing overfishing.

Since 2006, many of the compliance elements of the coastwide FMP have served well to increase the knowledge base regarding this species, and the importance of having a coastwide plan is still high, since the influences of the recreational and commercial fisheries on the stocks affect the species over broad geographic areas, even if the stocks are locally discrete. The current stock assessment proposes new regional stock definitions based on localized biological and socioeconomic trends (see Section 2.6), which will provide a suite of tools for managers to address the management needs of tautog for each distinct stock.

2.0 LIFE HISTORY

Tautog is one of over 630 species composing the wrasse or labrid family and is often known by the common name "blackfish" in the Northeastern US, in reference to its common overall coloration. Tautog are also known locally by several other common names such as “white chinner,” slippery, or tog. Most labrids inhabit tropical waters, making tautog, and its close relative the cunner (*Tautogolabrus adsperus*) exceptions to the general rule, as they range along the western Atlantic coast from Nova Scotia to South Carolina (Bigelow and Schroeder 1953). However, they are most abundant from the southern Gulf of Maine (lower Massachusetts Bay and southern Cape Cod Bay) to Chesapeake Bay (Steimle and Shaheen 1999).

It was previously believed that adult tautog migrate seasonally between inshore and offshore waters throughout most of its range. In the northern part of their range, adult tautog move from offshore wintering grounds in the spring, to nearshore spawning and feeding areas, where they remain until late fall when the reverse migration occurs as water temperatures drop below 10°C (Briggs 1977; Cooper, 1966; Olla et al 1974, 1979; Steimle and Shaheen 1999). Populations in the southern region may undergo shorter distance seasonal migrations, and in the southern-most part of the range may not undergo seasonal migrations at all (Hostetter and Munroe 1993, Arendt et al 2001). However, observations suggest that some localized populations, such as those in the lower Chesapeake Bay, eastern Long Island Sound, and Delaware Bay, remain inshore during the winter (Olla and Samet 1977, Ecklund and Targett 1990, Hostetter and Munroe 1993, White 1996, Arendt et al 2001).

There are contradictory studies on the movement of tautog in response to changes in water temperature. It has been suggested that adult tautog may migrate to cooler waters offshore during the summer (Briggs 1969; Cooper 1966). However, other studies report adult tautog are known to remain inshore in Great South Bay, NY, when temperatures reach 19-24°C (Olla et al., 1974) and off of Virginia when water temperature reach 27ºC (Arendt et al 2001).

2.1 Age and Growth

To age tautog, most states use opercular bones following the techniques of Cooper (1967) and Hoestetter and Munroe (1993). Whole opercula are obtained at random from commercial and recreational catches and fisheries independent surveys. Approximately 200 individual samples per state per year have been obtained since 1996. Opercula are most often taken in pairs from each fish, along with a total length and sometimes weight. The dissected opercular bones are boiled in water for one to two minutes and cleaned of tissue. The bones are allowed to dry for two days and then read, usually with transmitted light, without magnification. Annular marks are usually quite distinct, with the exception of the first annuli, which may be obscured by the thick bone growth in the region of the focus in older fish. Hoestetter and Monroe (1993) validated the annual nature of ring formation in opercula with marginal increment analysis. January 1 aging conventions are used and fall aged fish are treated as an age plus group.

Virginia changed their method of reading tautog opercula in 2001 and began using otoliths to standardize readings of tautog opercula (ASMFC 2012). At the 2006 benchmark assessment, concerns were raised over apparent differences in size at age between Virginia data and other datasets. Because the TC could not determine whether the differences were legitimate biological differences in growth between regions or an artifact of differences in ageing methodologies, Virginia age sample from 2001 onwards were not used in the 2006 benchmark stock assessment and subsequent updates. In order to address concerns about consistency in tautog ageing methods among states, the Commission conducted a hard parts exchange and ageing workshop in May 2012. The 2012 ageing workshop concluded that there were no significant differences between Virginia's ages and those of the other states (ASMFC 2012). Therefore, Virginia's age data was deemed acceptable for the current stock assessment. The operculum remains the recommended standard reference for ageing tautog. In 2013, there was a follow-up to the 2012 workshop to ensure continued consistency among state tautog ageing methods. Ageing estimates were found to be consistent across the states.

Age and growth studies indicate a relatively slow growing, long lived fish with individuals over 30 years reported in Rhode Island, Connecticut, and Virginia. Tautog also grow to large sizes, up to 11.36 kg (25 lbs) with males exhibiting faster growth and larger sizes (based on total length) than females (Cooper 1967). Evidence suggests females reach senescence at an earlier age than males, consistent with their smaller maximum size.

Growth rates from the southern part of the range are similar to those in the north, until about age 15 (Cooper 1967), after which growth rates decrease more rapidly in northern waters (Hostetter and Munroe 1993). This work was reevaluated in 1996 using growth equations developed by White (1996). Differences noted between Cooper and Hostetter/ Munroe were attributed to a difference in aging techniques and revealed more similar growth rates at both ends of the range.

The TC compiled age, length, and weight data from all states to examine potential differences in growth rates and size-at-age by region.

2.1.1 Methods

For the 2014 benchmark stock assessment, the SASC analyzed tautog lengths and ages to determine any regional differences in growth patterns to inform stock structure definitions. Von Bertalanffy growth curves were fitted to tautog length and age data for each state based on age and length data from various surveys (commercial, recreational, fishery independent). The SASC eliminated one potentially erroneous data point from Delaware's dataset (a 36-year old fish with a length of 40 cm). Growth curves were assessed for the two-region and three-region scenarios, as defined in Section 2.6, Stock Definitions. The SASC also used all of the data to fit one curve for all data combined (coastwide).

Because of the nonlinear formulation of the von Bertalanffy growth model, Analysis of Residual Sum of Squares (ARSS) was used to compare growth curves:

$$F = \frac{\dfrac{RSS_p - \sum RSS_i}{df_p - \sum df_i}}{\dfrac{\sum RSS_i}{\sum df_i}} = \frac{\dfrac{RSS_p - \sum RSS_i}{k(c-1)}}{\dfrac{\sum RSS_i}{N - kc}}$$

where *RSS* is the residual sum of squares, *df* is the degrees of freedom, the *p* and *i* subscripts are pooled or individual curve, respectively, *c* is the number of curves being compared, *k* is the number of parameters, and *N* is the total number of observations. The SASC compared the Northern and Southern growth curves from the two-region model. For the three-region model, we compared the Southern New England (SNE) and Delaware-Maryland-Virginia (DMV), SNE and New York-New Jersey (NY-NJ), and DMV and NY-NJ growth curves. The SASC compared individual states within the same region in pairs of two (c=2); we also compared all individual states in one ARSS analysis (c=8).

Length-at-Age

The SASC ran three ANOVA models to investigate mean length-at-age for tautog from data provided by Atlantic coastal states (MA, CT, RI, NY, NJ, DE, MD, VA). The null hypothesis was that there was no difference in mean length-at-age between age, year, and region. The response for all models was length-at-age. Age, year and region were factors in each model. In Model 1, region was divided into Northern states (MA, CT, RI, NY) and Southern states (NJ, DE, MD, VA). In Model 2, region was divided into SNE, NY-NJ, and DMV. In Model 3, each state was considered a separate region.

The SASC examined model assumptions and felt comfortable proceeding with the analysis. Length data were negatively skewed due to the fewer than expected number of sampled fish at larger ages but normal Q-Q plots only slightly deviated from expected normal values at the tails (Figure 2.1). Levene's test indicated that there was homogeneity of variance for regions (in Model 1 and 2) and year, but not for age and state. The observed deviations from normality and

HOV were considered minor, especially when considering that these data are representative of an exploited population where the removal of larger fish from each cohort may explain the lack of larger fish in the sample.

Length-Weight Relationship

Parameters of the length-weight relationship for tautog were defined for those states with length and weight data (CT, NY, NJ, MD). For states with no available weight data, the length-weight relationship from the nearest state was used to extrapolate weight. Mean weight-at-age was calculated by state and by region (two- and three-region scenarios)

2.1.2 Results

Growth

The von Bertalanffy assessment of growth revealed that the growth constant (K) decreased and the maximum size (L_{inf}) increased down the north to south gradient (Table 2.1). However, estimated growth curve parameters for each state showed clear similarities and differences that fell along the two-region model division of states, Northern and Southern (Figure 2.2). New Jersey growth parameters closely matched values for the Southern states, and New York closely matched values for the Northern states (Table 2.2). Growth curves from the Southern states (including NJ) did not appear to reach an asymptotic maximum length to the same extent that the Northern states did (Figure 2.3). Data were re-examined considering only ages under 18 years to determine if the differences in growth parameters were due to the greater presence of older fish in the Northern regions, but the results remained the same.

ARSS on the growth curves from all eight states (c=8) indicated that growth of tautog was significantly different ($P<0.0001$). All regional comparisons with ARSS were also significantly different ($P<0.0001$), as were state to state comparisons (c=2) from within the same region ($P<0.0001$).

Length-at-Age

Mean length-at-age was significantly different by age, year and region for all models ($P<0.05$). Tukey's comparison revealed that significant differences in mean length between ages diminished as fish age increased, particularly around age 10. For Model 1, mean length-at-age was significantly different between Northern and Southern states ($P<0.0001$). Mean length (±SD) appeared to differ between the two regions between ages 1 to 5 and 15 to 20 (Figure 2.4). For Model 2, mean length-at-age was significantly different between Northern and Mid-Atlantic States, Southern and Mid-Atlantic States, and Northern and Southern states (for all, $P<0.0001$). Southern states had the highest overall mean length-at-age across all ages. Mean length-at-age for Northern and Mid-Atlantic States were similar to each other but the most different from Southern states between ages 1 and 5 (Figure 2.5). For Model 3, mean length-at-age was significantly different ($P<0.0001$) between all combinations of states except for the following: NY-CT, RI-CT, RI-MA, RI-NY, VA-DE and MD-MA. In general, younger fish in Southern states (particularly DE and VA) are larger than fish from Northern or Mid-Atlantic States, but size differences converge as fish get older (Figure 2.6).

Length-Weight Relationship

The parameters of the allometric length-weight function for each state with weight data were estimated. The *a* parameter ranged from 0.00001 to 0.00003; the *b* parameter ranged from 2.91 to 3.15 (Figure 2.7). Resulting length-weight relationships were applied to neighboring states and used to calculate weight-at-age (Figure 2.8). Mean length-at-age was similar between regions, although southern states had slightly larger lengths; northern states had the highest mean weight-at-age (Table 2.3).

2.1.3 Discussion

The growth curve analyses indicated a clear distinction between growth parameters for tautog in Southern (VA, MD, DE, NJ) and Northern (NY, RI, MA, CT) states. Southern states have higher L_∞ and lower K values than Northern states. Past estimates of von Bertalanffy growth parameters for Rhode Island (L_∞=60.1 cm, K= 0.136; ASMFC 2005) and Virginia (L_∞=73.3 cm, K= 0.09; Hostetter & Munroe, 1993) agree with the values we calculated. The ARSS results indicated that the data sets from each state come from different populations, even states within the same region but we suspect that the large sample size affected the ability to detect differences between sums of squares.

The examination of mean length-at-age identified significant differences in length between regions. As expected, mean length-at-age was significantly different between many Northern and Southern states. MD and MA were the only states in different regions that did not differ significantly. Length-weight parameters were similar to those reported previously (Steimle and Shaheen, 1999). Mean length-at-age was slightly higher in Southern states, and mean weight-at-age was generally higher in Northern states.

Based on this growth analysis, there are regional differences in growth rates, with the dividing line between New York and New Jersey. The von Bertalanffy parameters suggest that New Jersey tautog share similar growth characteristics with southern states while New York tautog share similar growth characteristics with northern states. It is important to note that data availability varies by region; northern states have more data from the earlier parts of the time-series, when more older, larger fish were present in the samples, and the more southern state lack data from fishery-independent sources and thus have limited numbers of samples of the youngest, smallest fish. Further examination of growth rate differences should be explored using data that is more representative of the full size-age structure of the population.

2.2 Maturity

Tautog are gonochoristic and are believed to reach sexual maturity at ages 3 to 4 (Chenoweth 1963, White 1996), with 50% of females maturing by 224 mm total length and 50% of males maturing by 218 mm (White 2003). Unlike most labrids, tautog are heterosexual throughout life, as opposed to being a protogynous hermaphrodite (Olla et. al. 1981). Mature tautog can often be sexed from external characteristics with males having a pronounced lower mandible and more steeply sloping forehead. Females exhibit a more midline mouth position and a more ovoid body shape. Coloration varies by habitat and sex, with males most often grayish in color with a white midline saddle mark common on breeding males. Juveniles and females more often exhibit a mottled and brown toned appearance.

Female tautog begin to mature at age 3, with males beginning to mature earlier at age 2. Chenoweth (1963) found that in Narragansett Bay, Rhode Island, no females were mature at age 2, 80% of female tautog were mature at age 3, and 100% were mature by age 4. White *et al.* (2003) found very similar numbers for tautog in Virginia, with no females mature at age 2, 78% mature at age 3, and >97% mature at age 4.

2.3 Reproduction

The spawning season for tautog occurs from April through September (Arendt et al 2001). The spawning peak was assumed to occur coastwide on June 1 based on observed spawning peaks throughout the range (Cooper 1967, White 1996), although White noted batch spawning with repeated spawning events extending over sixty days. Spawning occurs primarily at or near the mouth of estuaries in nearshore marine waters (Cooper 1967, Stolgitis 1970). Courtship begins between 1300 and 1600 hours (Olla and Samet, 1977). Based on observations, a pair of tautog would rush to the surface and synchronously release gametes into the water column (LaPlante and Schultz, 2007).

2.3.1. Female-to-Male Ratio

Studies indicate that there is a sex-ratio bias towards females (Cooper 1967; Hostetter and Munroe, 1993; White, 2003; LaPlante and Schultz 2007). For example, White’s study of tautog in the lower Chesapeake Bay indicates a 56:44 female-to-male ratio. However, because of concerns for how representative the samples were in these studies, the TC used a 50:50 ratio.

2.3.2. Annual Fecundity

Fecundity is strongly related to female size, with larger females producing significantly more eggs than smaller females. LaPlante and Schultz (2007) estimate that females measuring 500 mm in total length produced 24-86 times more eggs than females half that size. Tautog’s potential annual fecundity was estimated to range from 10 - 16 million eggs for the average female in Long Island Sound (LaPlante and Schultz, 2007) and 0.16 - 10.5 million eggs in the lower Chesapeake Bay across mature females of all ages (White 2003). Based on analysis of data from a 22-year trawl survey in Long Island Sound, LaPlante and Schultz (2007) concluded that the abundance of tautog has decreased and size structure of the population has shifted to smaller fish. However, as the overall population has shifted towards a higher female-to-male ratio, the estimated annual fecundity has not declined further than the index of abundance.

2.3.3. Spawning Site Fidelity

Tagging studies show that tautog utilize the same spawning locales from year to year (Cooper 1967. In Narragansett Bay, mature tautog returned to the same spawning site each year but dispersed throughout the bay after spawning (Cooper 1967). Similar patterns of site fidelity have been observed in the nearshore waters of Massachusetts (Caruso 2004). However, Olla and Samet (1977) found that tautog did not always return to the same spawning site in the south, and that some mixing of the populations occurred on the spawning grounds.

2.4 Natural Mortality

The 2006 stock assessment for tautog estimated a coastwide natural mortality rate of M = 0.15. This estimate was based on the Hoenig age-based (longevity) method and was considered validated by comparison to other methods (e.g., Simpson, 1989) and M estimates for other long-lived, slow growing species. In this stock assessment, 22 age-constant estimators (including variants of estimators) were examined and evaluated for a coastwide estimate of M (Capossela, 2014). Many of these estimators were selected from Kenchington's recent paper (2013), which describes natural mortality estimates for information-limited fisheries. Then et al. (*in press*) recently updated preferred estimators by evaluating them with larger and better datasets, and some of these estimators were included

Tautog length and age data from Virginia, Maryland, Delaware, New Jersey, New York, Rhode Island, Connecticut and Massachusetts were used to derive von Bertalanffy growth parameters and maximum age values for tautog. Sets of parameter values were calculated for use in deriving coastwide as well as area specific M estimates. The age-at-maturity (t_m) was estimated to be 3 years of age (Chenoweth, 1963; Olla and Samet, 1977; Hostetter and Munroe, 1993). The annual temperature value of 12.5°C used to calculate Pauly's and Jensen's 3rd estimates, was derived from the mean bottom temperatures recorded for New Jersey's ocean trawl survey, which samples an area in the center of the tautog coastal distribution.

These methods provided a broad range of M estimates from 0.07 to 0.86 (Table 2.4). Of the 22 methods evaluated, twelve were eliminated based on several factors. Ralston's 1987 estimators (linear and geometric mean regression) were developed specifically for snappers and groupers, and their applicability to tautog was in question. Several methods, (Richter and Efanov 1977, Roff's 1984, Charnov and Berrigan 1990, Jensen's 1996 and Jensen's Third 2001), yielded results which were unrealistically high for a species as long-lived as tautog, ranging from 0.53 to 0.85. Two variants of Pauly 1980 removed the temperature parameter (Then et al., *in press)* but yielded estimates considered unrealistically low (0.07 to 0.09) based on previous estimates for tautog M (range 0.15-0.20; Simpson, 1989; ASMFC, 2006). Hewitt and Hoenig (2005) did not recommend using Hoenig 1983 (rule of thumb) due to its reliance on an arbitrary constant (P) for the proportion of the stock remaining at maximum age (t_{max}), as little data exists to support the assignment of P to any particular quantile of the stock. Following the recommendation in Then et al. (*in press*), the Alverson and Carney 1975 method was eliminated because its use of additional information (i.e., K) provided no additional advantage over other estimators using the t_{max} parameter only. Then et al. (*in press*) recommended the use of their updated one-parameter K estimator ($M=1.686K$) over their updated 2-parameter K estimator ($M=0.094 + 1.552K$) because M can be less than 0.094.

The ten remaining estimators, parameter values and M estimates are detailed in Table 2.5. Coast-wide estimates were calculated using parameter values derived from pooling the entire data set. The recommended coast-wide value of M for this stock assessment is 0.16, which is the average M of all appropriate (non-eliminated) age-constant estimators (range 0.14 to 0.22). It is also the M of Then et al.'s (*in press*) updated one-parameter t_{max} estimator, which was considered the most parsimonious model and one of the best among the t_{max} based models examined. As indicated in Then et al. (*in* press), a single value of M can be a useful representation of mortality over the lifespan of a species. Values derived from age-constant estimators are likely sufficient for representing M over the tautog lifespan.

Regional estimates were also calculated by dividing the data into the regions described in Section 2.6, Stock Definitions: North (Massachusetts, Rhode Island, Connecticut, and New York), South (New Jersey, Delaware, Maryland, and Virginia), Southern New England (Massachusetts, Rhode Island, and Connecticut), New York-New Jersey, and Delaware-Maryland-Virginia. The area specific estimates showed higher values of M for the northerly regions over those areas further south. Estimates for the North ranged from 0.14 to 0.33 with an average of 0.23. Similar results were shown for Southern New England with an average of 0.24 (range 0.14 to 0.34). Estimates for the South yielded the lowest regional average at 0.12 (range 0.08 to 0.19). The New Jersey-New York region estimates averaged 0.15 (range 0.12 to 0.19). The DelMarVa region's estimates matched the coast-wide average of 0.16 and ranged from 0.13 to 0.22.

2.6 Stock Definitions

Historically, the stock unit for tautog has been consistent with the management unit, which includes all states from Massachusetts through North Carolina (ASMFC 1996). With this benchmark stock assessment, the Tautog TC investigated new stock unit definitions based on life history data, fishery and habitat characteristics, and available data sources.

In the past, although regional differences in habitat and fishery characteristics were recognized (ASMFC 2006), genetic analyses showed no discernible genetic structure within the region (Orbacz and Gaffney 2000). This led to development of regional (MA-NY and NJ-NC) catch at age matrices combined into a coastwide population model for assessment and management advice (Steimle and Shaheen 1999, ASMFC 2006, ASMFC 2011).

The TC has considered smaller unit stock definitions in the past, but has always been limited by data availability, in particular the lack of any survey data south of New Jersey to inform a southern region model. As an alternative, the 2006 assessment included state specific models (primarily catch curves; ASMFC 2006). An independent peer review panel supported the use of local/regional models, but expressed several concerns with the use of catch curves (ASMFC 2006).

For the current benchmark assessment, the Tautog SASC spent considerable time addressing concerns that hampered regional management during previous assessments. New work includes development of fishery dependent abundance indices in areas with no fishery independent data (See Section 5.5), and investigation of data poor assessment models that allow quantitative/ statistical analysis of populations with limited data (see Sections 6.2 and 6.3). These innovations have allowed the TC to investigate regional structure that was not possible in the past.

Hilborn and Walters (1992) proposed an idealistic definition of a unit stock as “a homogenous collection of fish that are all subject to the same opportunities for growth and reproduction and the same risks of natural and fishing mortality” (p. 68). Consequences of a poorly specified unit stock are presented in Gulland (1983). Too large of a stock ignores possibly important regional differences in the fishery or life history. Too small of a stock ignores potentially important interactions with neighboring stocks. Each of these may affect the accuracy of a stock assessment and the efficacy of management measures.

Although Hilborn and Walters' (1992) definition of a unit stock is idealistic and unlikely to occur in nature, it is useful in conceptualizing properties of a unit stock. In addition, Gulland (1983) presents a number of criteria to help define a unit stock, including distribution of fishing, spawning grounds, life history parameters, morphological or physiological characteristics, and movement patterns. The Tautog TC evaluated a number of these criteria to help determine appropriate stock units.

- Fishery catch and effort information from NMFS Fishing Vessel Trip Reports (VTRs) was evaluated to identify state-specific fishery characteristics. Results indicate that:
  - States from MA to CT remain primarily within local sounds and bays
  - States from DE to VA remain south of Delaware Bay
  - Fisheries in NY and NJ range from LIS to Delaware Bay, with significant overlap in ocean waters of NMFS statistical areas 612 and 613 (approximately Manasquan River, NJ to Montauk, NY) (Table 2.6).
- Length-weight data were analyzed to develop state specific growth curves. Results suggest that tautog from SNE and NY waters have a significantly lower L_{inf} than fish from NJ to VA. (See Section 2.1 Age and Growth)
- Tagging data indicate that tautog have strong site fidelity and move only short distances longitudinally, if at all, during seasonal migrations (Cooper 1966, Caruso pers. comm., Arendt 2001, Cimino pers. comm.).
- Spawning occurs over a widely distributed geographic scope among local aggregations (White 2003, LaPlante and Schultz 2007).

Based on these results, the Tautog TC has determined that the "coastwide" stock unit is inappropriate. The 2006 assessment proposed regions consisting of only one or two states (ASMFC 2006), but in most cases, available data in regions of this size cannot support a rigorous stock assessment. Appropriate region designations must compromise tautog's sedentary life history with available data and political boundaries. With these considerations in mind, the Tautog TC determined that regions of MA-CT, NY-NJ, and DE-NC would be most appropriate. Within this document, these regions are referred to as Southern New England (SNE), New York-New Jersey (NY-NJ) and DelMarVa (DMV), respectively. During deliberations, the Technical Committee expressed concern that this preferred regionalization splits Long Island Sound between the SNE and NY-NJ regions, so a highly regarded alternate regional breakdown moves CT from the SNE to NY-NJ region.

3.0 HABITAT DESCRIPTION

Tautog are attracted to some type of structured habitat in all post larval stages of their life cycle. These habitats include both natural and man-made structures, such as submerged vegetation, shellfish bed, rocks, pilings, accidental shipwrecks and artificial reefs (Olla et al, 1974; Briggs

1975; Briggs and O'Connor 1971; Orth and Heck 1980; Sogard and Able 1991; Dorf and Powell 1997; Steimle and Shaheen 1999).

Juvenile tautog require shelter from predators and for feeding and are often found in shallow nearshore vegetated areas such as eelgrass beds or algae beds. Newly settled individuals are reported to prefer areas less than one meter deep (Sogard et al 1992, Dorf and Powell 1997), but move out to deeper water as they grow. Juvenile tautog have been shown to have size specific preference when choosing a shelter (Dixon 1994) and appear to have a strong affinity to their home site, rarely venturing more than a few meters away (Olla et al. 1974). During the winter, juveniles are believed to remain inshore at perennial sites and disperse during the spring (Stolgitis 1970; Olla et al. 1979).

Adult tautog prefer highly structured habitat, including rock piles, shipwrecks and artificial reefs which provide food and sheltering sites. Tautog exhibit diurnal activity and enter a torpid state at night during which they seek refuge in some type of structure. Soon after morning twilight, tautog have been observed leaving their night time shelter to feed throughout the day (Olla et al. 1974; 1975).

The overwintering habitat of adult tautog is poorly understood. When water temperatures fall between 5-8°C, tautog enter a torpid state and hide in some type of structured habitat (Cooper 1966, Olla et al 1974, 1979).

Little is known about habitat needs critical to recruitment levels, but given the small percentage of structured habitat, relative to the overall marine habitats along the Northern Atlantic coast, one could safely assume that tautog range is bounded to some degree by available habitat. This may be especially true in the region south of Long Island, NY were relatively little natural rock habitat exists compared to the structure rich northeastern states (Flint 1971).

4.0 FISHERIES DESCRIPTION

4.1 Commercial Fisheries

Records of commercial tautog landings are available back to 1950 through the National Marine Fisheries Service (NMFS) website. Landings were low from 1950 through 1974, averaging less than 80 MT per year coastwide as tautog were typically perceived as a "trash fish" (Figure 4.1). As this perception changed in the late 1970s, a directed fishery was developed. Landings exceeded 100 MT for the first time in 1975 and quickly rose to above 300 MT by 1984, reaching a peak of nearly 525 MT in 1987. The peak was short lived, however, and landings declined below 300 MT by 1993, reaching a relative low of 95 MT by 1999. Since 2000, commercial landings have varied without trend from approximately 110 to 160 MT (Table 4.1). The value (dollars per pound) for tautog has increased since the historic low value of $0.03 in 1962, along with the increasing landings trend. In 2012, value surpassed $3.00 per pound (Figure 4.1).

Commercial landings of tautog occur throughout the year, but the magnitude of the fishery varies by season. Monthly landings (http://www.st.nmfs.noaa.gov/commercial-fisheries/index) back to 1990 indicate that approximately 30% of the annual harvest occurs during May-June, and again during October-November (Figure 4.2). Harvest is lowest during January-March, when less than 5% of the annual catch occurs. Harvest is roughly evenly split among the remaining months.

Since 1982, commercial landings have been dominated by Massachusetts, Rhode Island, and New York, each averaging more than 20% of coastwide harvest. New Jersey and Connecticut, account for the majority of the remaining harvest, averaging 15% and 8%, respectively (Figure 4.3).

Since 1982, trawl, pot/trap, and hand gears have accounted for over 75% of coastwide commercial harvest (Figure 4.4). Trawls were most prevalent in the 1980s, contributing more than 40% of annual harvest between 1984 and 1989. Trawls continued to account for approximately 20% of harvest until 2004, but their contribution has since fallen below 10% of annual harvest. Pots and traps consistently produce approximately 20-30% of total harvest throughout the time series, with the exception of a brief peak over 40% between 1994 and 1998. Hand harvest was mainly constrained below 20% of coastwide harvest during the 1980s and early 1990s, but rose quickly during the remainder of the decade. Since 1999, hand harvest has been the primary gear for tautog harvest, contributing approximately 43% of annual commercial harvest.

4.2 Recreational Fishery

Tautog is predominantly a recreationally caught species, with anglers accounting for about 90% of landings coastwide. Little is known about the recreational harvest of tautog prior to the 1980s, but it is generally considered to have followed a similar pattern as the commercial fishery. Effort and harvest in the early decades was probably low, but increased in the 1970s and 1980s as the desirability of the species increased and technological improvements facilitated identification of hard bottom habitat. Coastwide, anglers caught a historical high of 7,669 MT (16.9 million pounds) of tautog in 1986 (Table 4.3, Figure 4.6). However, 1986 was a unique year in which recreational harvest in Massachusetts was unusually high. Since then, harvest has generally declined. Both 1998 and 2011 had the lowest amount caught, at 671 MT (1.5 million lbs), which equal 9% of the historic landings and 30% of the time series average. There was an increase in 2012 from 2011. In 2012, recreational fishermen caught a total of 486,031 tautog weighing a cumulative 1,000 MT (2.2 million lbs), an increase from 2011. Recreational harvest made up 91.2% of all harvest from all fisheries. On average, recreational catches were 2,256 MT (5.0 million lbs) per year over the time series.

On the state level, Connecticut anglers harvested the most tautog, bringing in 194,101 tautog weighing a total of 446 MT (984,372 lbs) in live weight in 2012. Rhode Island caught the second largest amount with 104,425 fish weighing a total of 242 MT (534,716 lbs). Maryland anglers landed the fewest tautog, with 5,216 fish, while North Carolina anglers harvested the lowest level by weight, at 5 MT (11,676 lbs) (Tables 4.2 and 4.3).

Recreational catch and effort for tautog are estimated by the NMFS Marine Recreational Fisheries Statistics Survey/Marine Recreational Information Program (MRFSS/MRIP) from 1981 to 2013 (*http://www.st.nmfs.noaa.gov/recreational-fisheries/index*). Since 1981, tautog has been a predominantly recreationally caught species, with the recreational sector accounting for an average of 90% of coastwide total harvest during that time period (Figure 4.5). Coastwide harvest generally ranged between 2.5 million and 3.5 million fish per year between 1982 and 1992, except for one extreme harvest estimate of over 7 million fish in 1987 (Table 4.2, Figure 4.6). Recreational harvest declined steadily to a time series low of just 358,000 fish in 1998, but rebounded quickly and has varied without trend between 750,000 and 1.5 million fish for much of the remainder of the time series. However, recreational harvest has experienced a decline in recent years, with an average harvest in 2011-2013 of approximately 500,000 fish per year. Trends in recreational tautog harvest by weight (MT) follow a similar pattern as numbers (Tables 4.2 and 4.3, Figure 4.6), with an average multiplier of 2.64 lb/fish (range 1.72 – 3.15) from 1981 to 1997, and 3.80 (3.22 – 4.51) since implementation of regulations in 1998.

Recreational harvest is dominated by the states of New York and New Jersey, which together average approximately 48.5% of annual harvest over the time series (Table 4.2, Figure 4.7). Massachusetts was also responsible for at least 20% of the annual harvest during most of the 1980s, but has contributed less than 10% of coastwide harvest in most years since 1990. Delaware's contribution has approximately tripled from only 3.5% of coastwide harvest prior to 1995, to 10.5% since 1995. During 2012 and 2013, the proportional contribution of NY and NJ appears to have declined substantially, with the majority of coastwide harvest shifting to southern New England states.

The recreational fishery for tautog is traditionally a late spring and fall fishery. Prior to implementation of regulations in 1998, approximately 40% of the coastwide harvest was taken during September and October, with an additional 20-25% on average coming from both May-June and November-December periods (Figure 4.8). With the advent of regulations in 1998, many states chose to limit their spring fishery in an attempt to protect spawners. This has led to a shift in harvest from May-June to November-December. Since 1998, harvest during September to December has averaged approximately 75% of annual coastwide harvest.

The majority of tautog recreational harvest comes from the private/rental boat mode (Figure 4.9). Over the time series, nearly 70% of total harvest comes from private/rental boat anglers. The remaining 30% is split relatively evenly among the shore mode and for-hire (party/charter boat) mode.

4.3 Current Fisheries Status

During the 1980s, increasing popularity and technological advancements led to increases in both commercial and recreational harvest. In the early 1980s, total harvest averaged approximately 3,000 MT (Figure 4.5), but spiked in 1986 to nearly 8,100 MT coastwide, and averaged over 3,900 MT from 1987 to 1992. These harvest levels were unsustainable, and declining populations led to substantially reduced harvest. By the mid-1990s, harvest was averaging less than 1,900 MT per year. Despite regulatory action on several occasions to constrain harvest in response to overfishing determinations, total tautog harvest appears to have varied without trend around approximately 1,500 MT per year since 1998. As many states have implemented regulations to constrain season length, it is possible that these regulations only concentrated effort into shorter seasons rather than reducing effort.

A stock assessment update conducted in 2011 indicated that coastwide tautog population was overfished and overfishing was occurring. Regulations enacted in 2012 in response to this finding appear to have reduced harvest by approximately 30% coastwide, to around 1,000 MT per year.

Coastwide tautog harvest exhibits high interannual variability, which may mask true trends in harvest. There are several possible sources of variability. The majority of landings occur during the fall and winter which can exhibit highly variable weather patterns between years. Most recreational and commercial fishing boats targeting tautog are smaller vessels and are therefore affected by weather, leading to interannual variability in catch. In addition, tautog is an infrequently encountered species within the MRFSS/MRIP. Low sample sizes result in recreational harvest estimates exhibiting large interannual variation. As recreational harvest dominates total harvest of tautog, this interannual variability persists in total harvest estimates.

Another source of uncertainty in harvest estimates is due to an unquantified illegal live fish market. Anecdotal information suggests that the majority of this harvest is by anglers (*i.e.* without commercial license) selling directly to market, and that a large portion of this harvest is below the minimum size limit. Several states, particularly New Jersey and New York, have expressed concern over the magnitude and apparent increasing trend of these removals.

5.0 DATA SOURCES

Table 5.1 lists the data sets collected and reviewed by the Technical Committee during the data workshop. Each data set was approved or rejected for use in the stock assessment based on the criteria listed below. A data set was rejected if it:

- Had less than 10 consecutive years of data (i.e. was sampling was intermittent or rare),
- Contained a small number of samples,
- Covered a small geographic area that was not representative of the a regional or coastwide stock unit, or
- Employed inconsistent methodologies.

Data sets that were not accepted for the stock assessment modeling may be considered as qualitative information to justify regional stock definitions, characterize life history, and/or describe fisheries in the stock assessment report. For example, tagging data was analyzed to determine migration patterns and growth rates.

5.1. Fishery-Dependent Sampling

5.1.1. Commercial Fishery

Tautog commercial landings data from NMFS and state records exist for 1950 to present. The time series from 1982-2013 will be used for the stock assessment (Table 4.1) to match the available recreational data time series, because tautog is predominantly recreational species. Commercial catch data used for this assessment is gathered by the NMFS dealer canvass system. In some cases that data is augmented by state obtained data from dealers that may not hold federal permits, since federal requirements do not necessitate the licensing of dealers of tautog. Catch data is gathered annually as pounds landed. By-catch estimates are unavailable for the commercial fishery since there is limited sea sampling of the directed fisheries that land tautog.

Biases

A concern is that there may have been underreporting before the 1980s, when tautog was considered a “trash” fish. In some cases the NMFS recorded landings are obtained from the individual states while in other cases the data is obtained directly from NMFS licensed dealers. In the latter case, total state tautog landings may under represent actual landings since there are no federal requirements for dealer licensing of tautog buyers. In addition since tautog are often marketed for the live trade and command a relatively high ex-vessel price the chances that there are unreported landings are believed to be higher than for other species.

Regarding commercial length data, since the commercial catch at length was estimated using recreational catch length frequency data at the annual state level it may not reflect the actual commercial catch at age. This is especially true in fisheries that may low grade fish for the more valuable live market. However, since the commercial harvest is on average only nine percent of historic landings, this bias may not be problematic. Additionally, because hook and line is a significant component of the commercial harvest and the commercial fishery is not separated in space and time from the recreational fishery, catch lengths and ages should be similar to the recreational fishery.

5.1.1.1 Commercial Discards/By-catch

Observer data were obtained from the Northeast Fisheries Observer Program for the years 1989-2012. Observers are deployed on federally permitted vessels from Maine to North Carolina. Observers record information on gear, target species, port landed, total weight of tautog kept and discarded, and total weight of all other species kept. Length data are collected on a subsample of tautog.

Overall sample size of observed trips that either retained or discarded tautog was low (Table 5.2 and 5.3), particularly when broken down by year, gear type, and region (Table 5.4, Figure 5.1). Length sampling was also inconsistent and had a low sample size by year, but where available showed that discarded fish were smaller on average than retained fish (Figure 5.2).

The relationship between the weight (pounds) of tautog discarded and both the weight of tautog retained and the weight of all other species retained was weak (Figure 5.3.A and 5.3.B). The TC chose to use the ratio of discarded tautog to retained tautog to develop estimates of tautog discards by gear type (otter trawl, gillnet, other), region (southern New England, NY-NJ, and DelMarVa), and regulatory period (1982-1996, 1997-2006, 2007-2013). These ratios are presented in Table 5.4. Commercial landings of tautog by region, gear, and year were used to expand the observed ratio to estimates of total discards (Table 5.4).

Discarded-to-observed ratios from the observer data were supplemented with VTR data for some gears and regulatory periods when sample size was less than ten observed trips. VTR data are self-reported by fishers and were not considered as reliable as observer data.

Given the poor observer sample size and the high uncertainty in the estimates of commercial discards, as well as the fact that commercial discards are a small component of total removals of tautog (Figure 5.4), commercial discards were not included in the base model, but were used as a sensitivity run.

5.1.2 Recreational Fishery

Tautog is predominantly a recreationally caught species, with anglers accounting for about 90% of landings coastwide. Recreational data collection began in 1981 with NOAA's MRFSS program. Data from 2004 on was re-estimated using the MRIP methodology which is consistent with the sampling design (see Section 5.1.2.6 for more details). This 2014 tautog benchmark stock assessment used MRFSS data from 1981 to 2004, and MRIP data from 2004 to present.

The MRFSS survey was a two part survey. Telephone intercepts are made within states using random digit dialing of households within coastal counties producing effort estimates by wave (two month sampling time periods), mode and area fished. Effort estimates are combined with intercept data from interviews with anglers at fishing sites and treated by correction factors to produce a catch per trip (angler day), within each state, wave, mode, county sampling cell.

The MRIP program implemented changes to the way recreational fishing data is collected (NOAA Fisheries 2013). A salt water registry program serves as a comprehensive national directory of recreational fishermen and is intended to improve efficiency of surveys. Interviewers routinely sample for biological data during angler intercepts by collecting length and weight measurements when possible. Sampling during night time and accounting for zero-catch trips are now conducted to more accurately capture fishing behaviors and reduce potential for bias from the MRFSS data collection program. Platforms for data collection have expanded to include mail, website, and smartphone technologies to collect catch data from recreational fishermen. MRIP also leverages logbook reporting and tournament sampling to improve quality of data on the distinct for-hire fleet.

Biases

A caveat with recreational data is that the percent standard error (PSE) tends to be poor because recreational data collection designs are not consistent with tautog fishing behaviors, therefore the number of intercepts tend to be low. Tautog are caught by a small number of dedicated anglers and are not well-sampled by the MRIP program. This results in high levels of imprecision and large year-to-year swings in catch estimates, often driven by small numbers of intercepts.

5.1.2.1. Recreational Discards/By-catch

Recreational discards are captured by the MRIP survey. Fish that are reported as released dead (Type B1) are included as part of the harvest weight, while only information on numbers of fish released alive (Type B2) is provided by MRIP.

The weight of recreational discards was calculated from region-specific length-weight relationships and length frequency data of fish released alive from the American Littoral

Society's volunteer angler program (available from 1982-present) and MRIP Type 9 sampling of fish released alive from headboats (available from 2004-present).

5.1.2.2. Recreational Catch Rates (CPUE)

CPUE data from the Marine Recreational Fisheries Statistics Survey/Marine Recreational Information Program (MRFSS/MRIP) is available from 1981 to 2012, and from the Federal Vessel Trip Report (VTR) for 1994 to 2012. Data quality is a concern. Both MRFSS and the VTR data contain thousands of trips and intercepts; a methodology to subset the data to meaningful tautog trips (e.g., through species associations or target species) is necessary. VTR data required vetting to remove data that were very different from what was expected of the tautog recreational fishery and assumed to be errors in data entry.

The Tautog TC investigated the development of fishery dependent abundance indices using a variety of data sources and methodologies. The rationale for developing fishery dependent indices was to provide abundance trends in areas where no fishery independent surveys occur. The fishery dependent indices would not only fill critical data gaps, but also allow assessment on a smaller regional scale, as is consistent with the life history of the species (ASMFC 2006; See Section 2.4, Stock Definitions).

The use of fishery dependent indices in stock assessment is often criticized as "circular logic" because the same data sources are used to develop the abundance indices and the harvest estimates. In addition, fishery dependent indices may be biased due to non-random distribution of fishing effort, which can lead to hyperstability of the index (Hilborn and Walters 1992). The solution to these concerns is to use an indicator of effort that is not indicative of just the catch but of the opportunity for catch of the target species. In other words, the effort indicator must include an adequate representation of all trips where the target species could have been caught. This will likely include trips for species other than the target species, thereby providing a more random distribution of effort and a more representative index of abundance.

Potential sources of information for the analysis included recreational angler data from MRFSS/MRIP and both commercial and recreational data from the VTR program. The VTR program started in 1996, while data from MRFSS/MRIP are available starting in 1982. The MRFSS/MRIP data were therefore considered the primary data source in order to take advantage of the longer time series. In addition, it was determined that changes to VTR reporting requirements, particularly with respect to how effort was reported, and the lack of metadata to correct for the changes, made the commercial VTR data unusable. Reporting changes did not appear to affect the recreational VTR data, but the TC considered these data as secondary to the MRFSS/MRIP data due to the shorter time series.

To identify effort (trips) the TC investigated statistically derived species associations of Stephens and MacCall (2004) and Jaccard (1901), as well as logical species guilds. Indices developed using statistically derived species associations (Stephens and MacCall, Jaccard) produced associations that were considered by the TC as tenuous. It is expected that this is an artifact of anglers splitting trips between highly regarded species (e.g. summer flounder, tunas, striped bass) and species that are more easily captured or retained (e.g. reef species), which might artificially inflate the strength of a relationship among species. In addition, it was discussed how some of the associations appeared to be “one-way.” For example, while it is not uncommon for an angler to catch a striped bass while fishing for tautog on a reef, it is extremely unlikely that an angler targeting striped bass using surface plugs in the back bays would catch a tautog. The TC therefore determined that the universe of “tautog trips” based on these methods was not an adequate representation of effort, and the species association methods were considered inappropriate for use.

“Logically” derived species guilds are similar to the statistically derived species associations, but are based on logical expectation of species associations supported by observed data, rather than on statistical methods. Species guilds were developed from the MRFSS/MRIP database by identifying trips that caught tautog and then ranking the other species caught on those trips from most common to least common. The TC defined “target trips” as any trip that caught any of the top five species encountered (tautog plus the next four most common). Guilds were developed for each state individually (Table 5.5), and target trips from states were merged across states within a given assessment region to develop target trips by region.

The methodology for fishery dependent index development was similar to the methods used for fishery independent indices (See Section 5.5). Indices were developed with GLM methods using the R software package (version 2.15.1; R Development Core Team, 2011). Total catch per trip was modeled against a suite of potentially important covariates (year, state, wave, mode) with an effort offset based on angler hours for the trip. Starting with the full model, covariates were removed sequentially to identify the most appropriate model based on AIC, variance inflation, and other indicators. All models assumed a negative binomial distribution, which Terceiro (2003) found most appropriate for recreational catch per trip data.

For all regions, the full model had the lowest AIC value with no variance inflation concerns. Quantile plots showed some deviance from the assumed distribution at higher quantiles. Investigation of alternate models showed that these anomalies could be fixed by dropping wave and mode from the model, but this resulted in at least a three-fold decrease in predictive power of the model (i.e. R2 dropped from greater than 0.30 to less than 0.10 in nearly all regional analyses when wave and mode were dropped). Based on these findings, the TC concluded that the increase in predictive power outweighed the concerns associated with the observed departure from the assumed distribution. Indices were therefore developed based on the full model of

$$\text{Total catch} \sim \text{Year} + \text{State} + \text{Wave} + \text{Mode},\ \text{offset} = \ln(\text{Angler\_Hours})$$

Results of the regional fishery dependent indices based on MRFSS/MRIP data are shown in Table 5.6 and Figure 5.5.

5.1.2.3. Sampling Intensity

Tautog are caught by a small number of dedicated anglers and are not well-sampled by the MRIP program. The number of intercepted trips that caught tautog are shown in Table 5.7. All three regions averaged about 300 intercepts a year, and ranged from a minimum of 46 and 50 in DelMarVa and NY-NJ (122 in southern New England) to a maximum of 1,068 in NY-NJ (782 and 707 in southern New England and DelMarVa). Number of intercepted trips peaked in the mid-1990s for all three regions. Meanwhile, total angler-trips intercepted by MRFSS/MRIP over this time period average 8,700 – 10,700.

5.1.2.4. Biological Sampling from the Recreational Fishery

Length and weight samples are collected from the recreational fishery through MRIP. As a less commonly encountered species, sample sizes are often low, and average approximately 350-500 lengths of harvested fish per year depending on region (Table 5.7). Age samples are not collected by MRIP. Number of lengths peaked in the mid-1990s for southern New England and NY-NJ, but DelMarVa has increased sampling in recent years, and sample sizes are now higher than the other two regions, despite lower landings.

In addition, states have dedicated short term sampling programs for specific fisheries in New York (head boat mode), New Jersey (head boat and shore mode), and Virginia (a directed fishing mortality study) and in some states that have a significant head boat or shore mode component to their recreational tautog catch. Most state's age samples come from a combination of state-run recreational, commercial and fisheries independent surveys.

In 2004, MRIP implemented observers on headboats to collect lengths of released alive fish (Type 9 measurements). Prior to 2004, the only information on the size of released fish came from the American Littoral Society's (ALS') volunteer angler tagging program, which provides lengths of fish that anglers report they have released alive. These two data sources provide the length frequency information used to develop the catch-at-age for released fish.

Annual numbers of lengths of released fish are shown in Table 5.7. They range from less than 10 in the earliest years to over 1,500 for some years in the DelMarVa region. Overall, SNE averages 52 released alive lengths, NY-NJ averages 190, and DMV averages 510.

5.1.2.5. Recreational length frequency distributions

Due to the low and inconsistent nature of commercial sampling for tautog, recreational harvest length frequencies have been used as a proxy for commercial landings. The length distributions for years where both are available are similar, but the commercial sector catches more smaller fish than the recreational sector in DelMarVa, and vice versa in Rhode Island (the only source of commercial length data for the southern New England region) (Figure 5.6). Although this introduces some bias into the development of catch-at-age matrices, commercial landings are small relative to recreational landings.

MRIP Type 9 and ALS data indicate recreationally released fish are smaller than retained fish (Figure 5.7). The ALS dataset has a higher proportion of larger fish released than MRIP Type 9 dataset does, but is an adequate proxy for recreational releases when MRIP data are not available (Figure 5.8).

5.1.2.6. MRFSS – MRIP Comparison

In 2012, MRIP changed how it calculated estimates of recreational catch and the associated proportional standard error (PSE) from 2004-2011 to correctly account for the clustered sample design and the weighting scheme used to select access point sample sites. However, estimates of catch prior to 2004 could not be corrected, due to missing data. To determine whether to calibrate estimates of catch prior to 2004, the TC examined the estimates of recreational harvest and PSE from both the old MRFSS method and the new MRIP method.

Estimates of recreational harvest were generally similar between the two methods, with most years MRFSS estimates falling with the confidence intervals of the MRIP estimates (Figure 5.9). At the coastwide level, and for the southern New England and NY-NJ regions, there was little evidence of consistent bias in the estimates from year to year: some years the MRIP estimates were lower than the MRFSS estimates and some years they were higher. For the DelMarVa region, the MRFSS estimates were more often higher than the MRIP estimates, but still within the MRIP confidence bounds (Figure 5.9). Because of this, the TC chose not to calibrate older estimates of recreational catch for the base run, but did include calibrated estimates as a sensitivity run.

Estimates of proportional standard error were higher in all years using the MRIP methodology, because the MRFSS method underestimates the variance of the sample design (Table 5.8). Estimates of PSE that were used as inputs to the statistical catch-at-age model (as CVs on the catch) were calibrated. The calibration coefficient was calculated as the sum of the MRIP PSEs from 2004-2011 divided by the sum of the MRFSS PSEs over that time period (Table 5.8). MRIP PSEs were approximately 30% higher for all regions.

5.2 Fisheries-Independent Surveys and Biological Sampling Programs

The state marine fisheries agencies from Massachusetts through New Jersey conduct fisheries-independent surveys that encounter tautog. Individual state survey data sets were obtained directly from the states' lead species biologists as numbers per tow, stratified mean numbers per tow, or geometric mean number per tow, as in past assessments. Select data sets were standardized and used in the stock assessment models (Section 6). The program designs for surveys used in the stock assessment are described for each state below.

Most states also collected limited biological information (i.e. age, length, sex, weight, and some measures of maturity) for tautog as part of their fisheries-independent surveys. However the total numbers captured by most states are low, meaning the data becomes supplemental to other collections and is not sufficient by itself to characterize survey catch at age, with few exceptions. The methods used by each state to collect biological samples are described below.

Since 2002, all states are required to collect 200 age and length samples (five fish per centimeter). There are no requirements about the source of these samples, so most states fulfill their obligations through a combination of fishery-dependent and fishery-independent sampling.

5.2.1 Massachusetts Division of Marine Fisheries

5.2.1.1 Survey Design of the Massachusetts Spring Trawl Survey

The Massachusetts Division of Marine Fisheries runs a synoptic coastal trawl survey performed in the spring and autumn. The bottom trawl surveys of Massachusetts territorial waters have been conducted by the Resource Assessment Project of the Massachusetts Division of Marine Fisheries since 1978. The objective of this survey is to obtain fishery-independent data on the distribution, relative abundance and size composition of finfish and select invertebrates.

The study utilizes a stratified random sampling design and six depth zones. Trawl sites are allocated in proportion to stratum area and randomly chosen in advance within each sampling stratum. Randomly chosen stations in locations known to be untowable due to hard bottom are reassigned. Sampling intensity is approximately 1 station per 19 square nautical miles. A minimum of two stations are assigned to each stratum.

A standard tow of 20-minute duration at 2.5 knots is attempted at each station during daylight hours with a 3/4 size North Atlantic type two seam otter trawl (11.9 m headrope/15.5 m footrope) rigged with a 7.6 cm rubber disc sweep; 19.2 m, 9.5 mm chain bottom legs; 18.3 m, 9.5 mm wire top legs; and 1.8 X 1.0 m, 147 kg wooden trawl doors. The codend contains a 6.4 mm knotless liner to retain small fish.

Environmental variables taken at each station include depth and bottom temperature. Standard bottom trawl survey techniques are used when processing the catch. Bottom temperatures were continuously recorded with an Onset Computer Tidbit TM attached to the net’s headrope.

5.2.1.2 Sampling Intensity

Sampling intensity is approximately 1 station per 19 square nautical miles. A minimum of two stations are assigned to each stratum. Abbreviated tows of 13-19 minute duration were accepted as valid and expanded to the 20 minute standard. The spring survey operates in the month of May.

5.2.1.3 Biological Sampling

MADMF collects biological samples with the trawl survey using standard bottom trawl techniques when processing the catch. The total weight and length-frequency of each species were recorded directly into Fisheries Scientific Computer System (FSCS) data tables. Fish collected in each tow were sorted, identified, counted and measured to the nearest mm (fork or total length). Large catches were subsampled, with length measurement taken on a minimum of 30 randomly selected individual fish of each species. Some samples were stratified by length group such that all large individuals were measured and only a subsample of small (YOY or yearlings) specimens were measured. Subsampled counts could then be expanded by length group for each tow.

5.2.1.4 Biases

This survey was not designed to target tautog. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect tautog catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

5.2.2 Rhode Island Department of Environmental Management

5.2.2.1 Survey Design of the Rhode Island Trawl Survey

RIDEM research trawl survey is conducted with a ¾ high-rise heavy-duty bottom trawl towed for 20 minutes at 2.5 knots. Sampled areas include Narragansett Bay and Rhode and Block Island Sounds. Data include a mixture of fixed and random sampling stations. Data collection has been consistent across seasons from 1990 to the present. Data elements include numbers caught by species and suite of environmental information including bottom and sea surface water temperature, depth, sea conditions, and wind speed/direction.

5.2.2.1.1 Sampling Intensity

The survey has two components, a seasonal survey with a random stratified design which began in 1979, and a monthly fixed station survey which began in 1990 that is conducted monthly throughout the year. For tautog, the survey selected was the seasonal component, specifically the fall seasonal survey. A total of approximately 40 tows are recorded annually during the fall season.

5.2.2.1.2 Biological Sampling

RIDEM collects its biological samples with its trawl survey. All tautog collected are measured in cm and are weighed in aggregate.

5.2.2.1.3 Biases

This survey was not designed to target tautog. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect tautog catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

5.2.2.2 Survey Design of the Rhode Island Seine Survey

The RI Seine Survey has operated from 1986 to the present, with a consistent standardized consistent methodology starting in 1988. The gear type used is a 200 ft long x 12 ft deep beach seine with ¼ inch mesh throughout the net. The seine is set by boat in a “U” shape along the beach and pulled in by hand. The survey takes place throughout the extent of Narragansett Bay Rhode Island. It is a fixed site survey. Environmental information (water temperature, salinity, dissolved oxygen, wind speed, and direction) has been recorded at each station.

5.2.2.2.1 Sampling Intensity

The sampling season is June through October. There are 18 stations that are sampled during each month, leading to a total of 90 stations per year.

5.2.2.2.2 Biological Sampling

Fish collected in each haul were sorted, identified, counted, and measured to the nearest mm (fork or total length).

5.2.2.2.3 Biases

This survey was not designed to target tautog. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect tautog catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis. Stations were added early in the timeseries, but this factor was accounted for in the standardization procedure with the development of a categorical variable called station period.

5.2.3 Connecticut Department of Environmental Conservation

5.2.3.1 Survey Design of the CT Long Island Sound Trawl Survey

Since 1984, the Connecticut Department of Environmental Conservation, Marine Fisheries Division has monitored tautog abundance with a monthly trawl survey in Long Island Sound. The CT Long Island Sound Trawl Survey (LISTS) is conducted from longitude 72° 03' (New London, Connecticut) to longitude 73° 39' (Greenwich, Connecticut). The sampling area includes Connecticut and Massachusetts waters from 5 to 46 m in depth and is conducted over mud, sand and transitional (mud/sand) sediment types.

Prior to each tow, temperature (°C) and salinity (ppt) are measured at 1 m below the surface and 0.5 m above the bottom using a YSI model 30 S-C-T meter. Water is collected at depth with a five-liter Niskin bottle, and temperature and salinity are measured within the bottle immediately upon retrieval (Connecticut DEEP, 2012).

5.2.3.2 Sampling Intensity

Sampling is divided into spring (April-June) and fall (Sept-Oct) periods, with 40 sites sampled monthly for a total of 200 sites annually. The sampling gear employed is a 14 m otter trawl with a 51 mm codend. To reduce the bias associated with day-night changes in catchability of some species, sampling is conducted during daylight hours only (Sissenwine and Bowman, 1978).

LISTS employs a stratified-random sampling design. The sampling area is divided into 1.85 x 3.7 km (1 x 2 nautical miles) sites, with each site assigned to one of 12 strata defined by depth interval (0 - 9.0 m, 9.1 - 18.2 m, 18.3 - 27.3 m or, 27.4+ m) and bottom type (mud, sand, or transitional as defined by Reid et al. 1979). For each monthly sampling cruise, sites are selected randomly from within each stratum. The number of sites sampled in each stratum was determined by dividing the total stratum area by 68 km2 (20 square nautical miles), with a minimum of two sites sampled per stratum. Discrete stratum areas smaller than a sample site are not sampled. The survey’s otter trawl is towed from the 15.2 m aluminum R/V John Dempsey for 30 minutes at approximately 3.5 knots, depending on the tide (Connecticut DEEP, 2012).

5.2.3.3 Biological Sampling

CT DEEP conducts biological sampling during its Long Island Sound trawl survey. At completion of the tow during the, the catch is placed onto a sorting table and sorted by species. Tautog, as well as other finfish and crustacean species, are counted and lengths are recorded to the centimeter.

The number of individuals measured from each tow varies by species, and also depends on the size of the catch and range of lengths. If a species is subsampled, the length frequency of the catch is determined by multiplying the proportion of measured individuals in each centimeter interval by the total number of individuals caught. Some species are sorted and subsampled by length group so that all large individuals are measured and a subsample of small (often young-of-year) specimens is measured. All individuals not measured in a length group are counted. The length frequency of each group is estimated as described above, i.e. the proportion of individuals in each centimeter interval of the subsample is expanded to determine the total number of individuals caught in the length group. The estimated length frequencies of each size group are then appended to complete the length frequency for that species (Connecticut DEEP, 2012).

5.2.3.4 Biases

This survey was not designed to target tautog. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect tautog catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

5.2.4 New York Department of Environmental Conservation

5.2.4.1 Survey Design of the NY Peconic Bay Trawl Survey

NYDEC Peconic Bay trawl survey is designed to target YOY and juvenile finfish species. Sampling station locations for the survey were selected based on a block grid design superimposed over a map of the Peconic estuary sampling area. The sampling area was divided into 77 sampling blocks, each of which measured 1’ latitude by 1’ longitude. The research vessel used throughout the survey was the David H. Wallace, a 10.7m lobster-style workboat. At each location, a 4.9m semi-balloon shrimp trawl with a small mesh liner was towed for 10 minutes at ~2.5 knots. From 1987-1990, nets were rigged using nylon scissors and tow ropes set by hand and retrieved using a hydraulic lobster pot hauler. Following 1990, the research vessel was re-outfitted to include an A-frame, wire cable and hydraulic trawl winches.

At the beginning and end of each tow, location and depth were recorded. At each station the time clock was started when the gear was fully deployed. If a tow was abandoned due to hangs and/or debris, a nearby site within the sampling grid was chosen and the tow redone. Temperature, salinity, and dissolved oxygen have been recorded at each station. Some gaps in the environmental data exist due to equipment malfunction.

5.2.4.1.1 Sampling Intensity

From May through October of each year, 16 stations were randomly chosen each week and sampled by otter trawl weekdays during daylight hours only.

5.2.4.1.2 Biological Sampling

NYS DEC collects its tautog biological samples with its Peconic Bay trawl survey. Fish collected in each tow were sorted, identified, counted and measured to the nearest mm (fork or total length). Large catches were subsampled, with length measurement taken on a minimum of 30 randomly selected individual fish of each species. Some samples were stratified by length group such that all large individuals were measured and only a subsample of small (YOY or yearlings) specimens were measured. Subsampled counts could then be expanded by length group for each tow.

In addition, New York collects length and age samples for the recreational fishery predominantly from the for-hire sector, and for the commercial fishery from samples obtained opportunistically from fish markets. Samples from the private recreational sector are sometimes obtained although rarely. New York also obtains length data from a juvenile finfish trawl survey in Peconic Bay, a striped bass seine survey in the western Long Island Bays and a fish trap study in Long Island Sound. The trawl and seine survey obtain primarily juvenile lengths, while the trap study obtains juvenile and adult lengths.

5.2.4.1.3 Biases

This survey was not designed to target tautog. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect tautog catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

5.2.4.2 Survey Design of the NY Western Long Island Sound Survey

The NYWLI Seine Survey has operated from 1984 to the present, with a consistent standardized consistent methodology starting in 1987. The gear type used is a 200 ft long x 10 ft deep beach seine with ¼ inch square mesh in the wings, and 3/16 inch square mesh in the bunt. The seine is set by boat in a "U" shape along the beach and pulled in by hand. The survey takes place in Little Neck and Manhasset Bay on the north shore of Long Island, and Jamaica Bay on the south shore. Other bays have been sampled on a shorter time frame. It is a fixed site survey. Environmental information (air and water temperature, salinity, dissolved oxygen, tide stage, wind speed and direction, and wave height) has been recorded at each station. Bottom type, vegetation type, and percent cover have been recorded qualitatively since 1988.

5.2.4.2.1 Sampling Intensity

The sampling season is May through October. Prior to 2000, sampling was conducted two times per month during May and June, and once a month July through October. From 2000 – 2002 sampling occurred two times per month from May through October. Generally 5 – 10 seine sites are sampled in each Bay on each sampling trip.

5.2.4.2.2 Biological Sampling

Fish collected in each haul were sorted, identified, counted and measured to the nearest mm (fork or total length).

5.2.4.2.3 Biases

This survey was not designed to target tautog. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect tautog catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis.

5.2.5 New Jersey Department of Environmental Protection

5.2.5.1 Survey Design of the NJ Ocean Trawl Survey

NJ DEP's ocean trawl survey was selected for use in the 2015 stock assessment. New Jersey has conducted a stratified random trawl survey in nearshore ocean waters since August, 1988.
The survey is conducted five times per year (January, April, June, August and October) between Cape May and Sandy Hook, NJ. The sampling area is stratified into 5 areas north to south, that are further divided into 3 depth zones (<5, 5-10, 10-20 fathoms) for a total of 15 strata. During each of the April through October survey cruises, a total of 39 tows are conducted, with 30 tows taken during each January cruise, for a grand total of 186 tows conducted per year. The sampling gear is a two-seam trawl with a 25m head rope and 30.5m footrope. The cod-end has a 6.4mm liner. All tautog taken during these surveys are counted and weighed by tow and measured to the nearest centimeter. Annual indices of tautog abundance and biomass are determined as the stratified geometric mean number and kgs per tow, weighted by stratum area. These indices fell from a series high in 1989 of 0.20 fish and 0.13 kg per tow to the survey low in 1997 of 0.02 fish and 0.02 kg per tow. The survey indices climbed to another peak in 2002 with 0.17 fish and 0.16 kg per tow. Since 2003 the survey indices have leveled off within a range of 0.06 to 0.09 fish and 0.04 and 0.09 kg per tow. Few age zero fish are taken in this survey.

Prior to the January 2011 trawl cruise, surface and bottom water samples were collected with a 1.2 l Kemmerer bottle for measurement of salinity and dissolved oxygen, the former with a conductance meter and the latter by the Winkler titration method. Surface and bottom temperatures are measured with a thermistor. These water samples were collected prior to trawling. Starting January, 2011, and all subsequent trawl cruises thereafter, water chemistry data was collected via a YSI 6820 multi-parameter water quality SONDE from the bottom, mid-point and surface of the water column. Parameters collected included depth, temperature, dissolved oxygen and specific conductance. All water chemistry data was collected prior to trawling (New Jersey DEP, 2013).

5.2.5.2 Sampling Intensity

The New Jersey Bureau of Marine Fisheries conducts five near shore (within the 15 fathom isobath boundary offshore) trawl surveys each year. These surveys occur in January/February, April, June, August, and October. Trawl samples are collected by towing the net for 20 minutes, timed from the moment the winch brakes are set to stop the deployment of tow wire to the beginning of haulback. Enough tow wire is released to provide a wire length to depth ratio of at least 3:1, but in shallow (< 10 m) water this ratio is often much greater, in order to provide separation between the vessel and the net (New Jersey DEP, 2013).

5.2.5.3 Biological Sampling

Since 1993, New Jersey has collected biological data on tautog sampled from various sources and gear types. These data include total length in millimeters, sex, and age (derived from reading opercular bone samples). Collection of weight data for each fish in kilograms was begun in 2007. Of the 5,285 total samples collected through 2012, samples from party and charter boats accounted for 48.6%, with commercial samples accounting for 27.2%. Fishery dependent research conducted by NJ Bureau of Marine Fisheries staff from 1993 through 2003 supplied 20.8% of the samples. Of the rest, 110 fish were obtained from New Jersey’s ocean trawl survey, 68 fish were received from recreational catches confiscated by New Jersey law enforcement and one sample was received from a recreational diver. The vast majority of the fish were caught using hook and line (95.2%), with pots/traps accounting for 2.7%, and otter trawls collecting 2.1%. One fish was caught using a diving spear. All months of the year were represented in the entire time series of the sampling program with the most fish obtained in December (34.2%), followed closely by November (30.9%). The fewest fish were collected in September (0.2%) and March (0.4%). Sampled fish ranged from 73 to 864 mm in length with an average of 369 mm. Ages were obtained from 4,293 fish with an average age of 6 within a range of 1 to 29 years. From 4,921 fish which were sexed, 53.2% were female and 46.7% were male. Weights were obtained from 995 samples yielding an average of 0.84 kg with a range of 0.01 to 10.85 kg (New Jersey DEP, 2013).

5.2.5.4 Biases

This survey was not designed to target tautog. In order to use this data to generate an index of abundance for stock assessment, statistical model-based standardization of the survey data was conducted to account for factors that affect tautog catchability. Potential bias could result if all important factors that affect catchability were not considered in the analysis. In addition, there have been survey design changes through the time series, mainly vessel changes, but it is hoped that the standardization procedure employed accounts for these modifications.

5.2.6 Delaware Division of Fish and Wildlife

Delaware Division of Fish & Wildlife conducted Delaware Bay and Inland Bay surveys from April through October. Data from these surveys were not used for the 2015 stock assessment.

5.2.6.2 Biological Sampling

Delaware does not collect tautog biological samples.

5.2.7 Maryland Department of Natural Resources

5.2.7.1 Survey Design

Maryland Department of Natural Resources (MDNR) conducts an annual trawl and beach seine survey, components of the Investigation of Maryland's Coastal Bays and Atlantic Ocean Finfish Stocks. Trawl sampling is conducted at 20 fixed sites throughout Maryland's Coastal Bays on a monthly basis from April through October. Samples are usually taken beginning the third week of the month. The boat operator takes into account wind and tide (speed and direction) when determining trawl direction. A standard 4.9 m (16 ft) semi-balloon trawl net is used in areas with a depth of greater than 1.1 m (3.5 ft). Seines are used to sample the shallow regions of the Coastal Bays frequented by juvenile fishes. Shore beach seine sampling is conducted at 19 fixed sites beginning in the second weeks of June and September. A 30.5 m X 1.8 m X 6.4 mm mesh (100 ft X 6 ft X 0.25 in. mesh) bag seine is used at 18 fixed sites in depths less than 1.1 m (3.5 ft.) along the shoreline. However, it appears that this multi-species survey is not well suited for determining tautog abundance due to the limitations of gear types used to sample tautog habitat, thus both the trawl and seine gears suffer from low tautog catches. For example, in 2013, tautog were captured in zero of 140 trawls (0%) and in one of 38 beach seines (2.6%) samples conducted on Maryland's Coastal Bays in 2013.

5.2.7.2 Biological Sampling

Fishes and invertebrates are identified, counted, and measured for total length (TL) using a wooden millimeter (mm) measuring board with a 90 degree right angle. A meter stick is used for species over 500 mm. At each site, a sub-sample of the first 20 fish (when applicable) of each species are measured and the remainder counted. On occasion, invertebrate species counts are estimated.

5.2.8 Virginia Marine Resources Commission

5.2.8.1 Survey Design

Virginia does not conduct a fishery-independent survey to monitor tautog.

5.2.8.2 Biological Sampling

Field sampling at fish processing houses or dealers involves multi-stage random sampling. The target number of biological samples to be collected are set each week based on a three-year moving average of landings by gear and month, as adjusted by real-time landings. Each fish is assigned a unique number for identification, while a batch number identifies a subsample from a trip. Weights of individual fish are recorded on electronic scales and downloaded directly to the electronic boards. Subsamples of a catch or batch are processed for gender and gonadal maturity or spawning condition index using visual inspection (macroscopic) of the gonads. Females are indexed as gonadal stage I-V with males I-IV, with stage I representing an immature or resting stage of gonadal development and, stages IV (males) and V (females) representing spent fish. Fish that cannot be accurately categorized by spawning condition are not assigned a gonadal maturity stage.

The goal of otolith/opercula collection is to correspond to the frequency distribution in lengths from past seasons, according to 1-inch length bins. The age sampling is designed to achieve a

CV of 0.2 (Quinn & Deriso 1999), at each length interval. Fish are then randomly selected from each length interval (bin) to process. It is important to note that samples collected for ageing do not fall into a random sampling regime, and are treated accordingly (i.e. are not included in analysis dependent on random sampling).

VMRC collects ancillary data for fish sampled at dealers, including: date harvested, harvest area, gear type used, and total catch (if a subsample was measured). This information would allow for expansion of the sample size to the total harvest reported for a species. Estimates of effort are not typically recorded by this program, but can be extrapolated from mandatory harvest reports sent to VMRC on a monthly basis by harvesters, sometime after a sampling event.

The Virginia Recreational Assessment Program, funded by the Virginia Saltwater Development Fund, began in late June 2007. Chest freezers are located throughout the Tidewater area of Virginia to collect whole or filleted fish. Anglers are instructed to fill out a form with the date and general location the fish was caught, and weight if known (all of the sites are Virginia Saltwater Fishing Tournament Sites with certified scales). Anglers receive a t-shirt or hat as a reward for donating the fish. It should be noted that although some weights are recorded by anglers, the majority of donated samples do not include weights, and the fish were already filleted when processed by VMRC technicians. As such, although this data is exceptionally valuable for length at age analysis, no average weight data are provided from the recreational fisheries.

5.2.9 North Carolina Division of Marine Fisheries

5.2.9.1 Survey Design

NC DMF does not conduct a fishery-independent survey to monitor tautog.

5.2.9.2 Biological Sampling

NC DMF does not collect tautog biological samples.

5.3 Development of Age-Length Keys

Previous assessments created age-length keys for the northern region (MA-NY) and the southern region (NJ-VA). Prior to 1995, raw age data by state were not available. As a result, ALKs for the current regional breakdowns could only be created for 1995 forward for the southern New England and NY-NJ region. This still required some pooling across regional boundaries to ensure the full range of sizes were covered by each regional key. As a result, the southern New England key includes some data from New York, and the NY-NJ key includes some data from Connecticut and Delaware. The southern region ALKs did not contain data from NJ prior to 1995, so the original southern region keys were used for the DelMarVa region.

The sample size and sources for ALKs by region are shown in Table 5.9.

5.4 Tagging Data

The marine fisheries agencies for Massachusetts, Maryland, and Virginia conduct tagging programs that include tautog. The methods used to capture, tag, and track recaptures are described below.

5.4.1 Massachusetts Tautog Tagging Methods

Massachusetts Division of Marine Fisheries tagged adult tautog using Floy internal anchor tags (model # FM-84). Tags were serially numbered on both the streamer and tag button to allow identification of individual fish for growth estimates, and to identify the locations of initial capture and subsequent recapture. Tags were printed with a reward notification and the DMF South Shore Marine Fisheries Research Station phone number. Tag anchors were implanted into the abdominal cavity, on the left side of fish just ventral and posterior to the pectoral fin apex.

Tag number, total fish length in mm and sex was recorded for each fish, along with the latitude and longitude of the release point. Sex was determined by external examination of prominent morphological features. Subsequent recapture information on total length, recapture site, capture method, catch disposition (released, retained) was solicited from tag returnees.

Release and recapture sites were plotted on MapTech chart facsimiles for calculation of predicted straight line travel distance and travel vectors. Daily growth intervals were calculated using the difference between initial capture length and recapture length divided by the days at large, and compared to growth intervals of similar aged fish from the annual DMF Age and Growth Study.

5.4.2 Maryland Department of Natural Resources

Tautog tagging in Maryland and adjacent federal waters is conducted by volunteer anglers for the American Littoral Society (ALS). A yellow dorsal loop tag with the serial number is applied to the fish behind the dorsal fin (Figure attached). Information on the area of capture and release, date and fish size is sent to the ALS. ALS tagging began in 1982 and continues today throughout a number of the Atlantic states, including Maryland. There are about 8,000 records available for tautog tagged in Maryland. There is no specific tagging design, tags are applied to fish on ad hoc basis. No tagging is conducted by the MD Department of Natural Resources.

5.4.3 Virginia Marine Resources Commission

The Virginia Game Fish Tagging Program is a cooperative program of the Virginia Saltwater Fishing Tournament (Marine Resources Commission) and VIMS Marine Advisory Program. Initiated in 1995, it has been funded primarily by Saltwater Recreational Fishing License Funds and matching VIMS funds. This program provides annual training and enables a corps of ~200 experienced anglers to direct tagging effort on select target species important to VA’s marine recreational fisheries. Through 2014, this program’s database (used by researchers, fishery managers, anglers, etc.) includes over 240,000 records for fish tagged and over 25,900 fish recapture records (an overall >11% recapture rate). There are ten target species: black and red drum, black sea bass, cobia, flounder, gray triggerfish, sheepshead, spadefish, speckled trout, and tautog. There have been 17,705 tautog tagged since 1995 with 2,692 recaptures through 2013.

5.5 Methods for Developing Estimates from State Indices

State abundance indices were developed using data obtained through select fisheries-independent surveys (Section 5.2). Methods for developing estimates from the standardized indices, and the results, are described below.

5.5.1 Massachusetts

5.5.1.1 Development of Estimates with the Massachusetts Spring Trawl Survey

Using the approach defined in this section, an abundance index for tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. The details relevant to the model for this survey are described below.

5.5.1.2 Estimates

In each case, a full model that predicted catch as a linear function of year (categorical), station (categorical), stratum (categorical), depth (continuous), and temperature (continuous) was compared with nested submodels using AIC. For the data, a sub model of year, temperature, and depth was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models, and produced favorable diagnostics (Figures 5.10 – 5.11, Table 5.10 and 5.11). The index was variable, but indicates a period of high abundance beginning in the 1980s, a decline to the early 1990s, then a period of stable low abundance to the present (Figure 5.13). Diagnostics identified mainly underprediction by the model of average annual catch per tow. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of tautog caught in this survey.

5.5.2 Rhode Island

5.5.2.1 Development of Estimates with the Rhode Island Trawl Survey

An abundance index for tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. The details relevant to the model for this survey are described below.

5.5.2.1.1 Estimates

In each case, a full model that predicted catch as a linear function of year (categorical), month (categorical), station (categorical), depth (continuous), and bottom temperature (continuous) was compared with nested submodels using AIC.

For the data, a sub model of year, bottom temperature, and depth was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models, and produced favorable diagnostics (Figures 5.14 – 5.16, Tables 5.12 and 5.13). The index was variable, but indicates a period of high abundance beginning in the 1980s, a decline to the early 1990s, then a period of stable low abundance to the present (Figure 5.17). Diagnostics identified mainly underprediction by the model of average annual catch per tow. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of tautog caught in this survey.

5.5.2.2 Development of Estimates with the Rhode Island Narragansett Bay Seine Survey

An abundance index for tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. The details relevant to the model for this survey are described below.

5.5.2.2.1 Estimates

In each case, a full model that predicted catch as a linear function of year (categorical), month (categorical), station (categorical), station period (categorical), salinity (continuous), and temperature (continuous) was compared with nested submodels using AIC.

For the data, a sub model of year, month, station, salinity, and temperature was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models, and produced favorable diagnostics (Figures 5.18 – 5.20, Tables 5.14 and 5.15). The index was variable, but indicates a period times of high abundance including the early 1990s and the early 2000s but indicates a decreasing trend to the present (Figure 5.21). Diagnostics identified both under and over-prediction by the model of average annual catch per tow. Overall, the model exhibited adequate diagnostics given the sample size and high variability in the number of tautog caught in this survey.

5.5.3 Connecticut

5.5.3.1 Development of Estimates for Connecticut's Long Island Sound Trawl Survey

An abundance index for tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. The details relevant to the model for this survey are described below.

5.5.3.2 Estimates

A full model that predicted catch as a linear function of year (categorical), month (categorical), station (categorical), stratum (categorical), depth (continuous), bottom temperature (continuous), and bottom salinity (continuous) was compared to nested submodels using AIC.

For the data, a negative binomial glm sub model of year, month, and stratum was selected because the model achieved convergence and it produced favorable diagnostics (Figures 5.22 – 5.24, Tables 5.16 and 5.17). One important note is that many of the continuous variables did not begin being collected until mid-way through the dataset, so the final model was constructed with the categorical data fields that spanned the entire time series. The index was variable over time, but exhibited a marked decrease during the time series with low catches beginning in the late-

1990s (Figure 5.25, Table 5.17). The index declined from the time series peak in the mid-1980s and has been variable at a low level since the early 1990s. Diagnostics identified slight underprediction by the model of average annual catch per tow, in particular in the most recent years. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of tautog caught in this survey.

5.5.4 New York

5.5.4.1 Development of Estimates with the Peconic Bay Trawl Survey

An abundance index for tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. The details relevant to the model for this survey are described below.

5.5.4.1.2 Estimates

In each case, a full model that predicted catch as a linear function of year (categorical), month (categorical), station (categorical), depth (continuous), salinity (continuous), and temperature (continuous) was compared with nested submodels using AIC.

For the data, a sub model of year, temperature, salinity, and depth was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models, and produced favorable diagnostics (Figures 5.26 – 5.28, Tables 5.18 and 5.19). One note, the year variable produced high variance inflation, but this parameter cannot be dropped when producing annual estimates of abundance. All other variables had favorable variance diagnostics. The index was variable, but indicates a period of high abundance beginning in the 1980s, a decline to the early 1990s, then a period of stable low abundance to the present (Figure 5.29). Diagnostics identified mainly underprediction by the model of average annual catch per tow. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of tautog caught in this survey. One final important note is that the survey was not in operation in 2005. This was directly accounted for in the DBSRA and ASAP modeling frameworks, but to use the index in the Bayesian State Space Surplus Production model, a point was linearly interpolated for the year of 2005 so as to not break the time series in to two datasets, which would have affected the likelihoods of the model. The interpolated estimate for 2005 was 0.527 fish per tow. This estimate was a middling value, and is relatively close in value between 2004 and 2006 estimates (0.485 and 0.568 respectively).

5.5.4.2 Development of Estimates with the New York Western Long Island Seine Survey

An abundance index for tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. The details relevant to the model for this survey are described below.

5.5.4.2.1 Estimates

In each case, a full model that predicted catch as a linear function of year (categorical), month (categorical), station (categorical), salinity (continuous), dissolved oxygen (continuous), and temperature (continuous) was compared with nested submodels using AIC.

For the data, a sub model of year, temperature, salinity, and month was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models, and produced favorable diagnostics (Figures 5.30 – 5.32, Tables 5.20 and 5.21). The index was variable, but indicates periodic times of high abundance including the early 1990s and the early 2000s (Figure 5.33). Diagnostics identified mainly underprediction by the model of average annual catch per tow. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of tautog caught in this survey.

5.5.5 New Jersey

5.5.5.1 Development of Estimates with the New Jersey Ocean Trawl Survey

An abundance index for tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. The details relevant to the model for this survey are described below.

5.5.5.1.1 Estimates

In each case, a full model that predicted catch as a linear function of year (categorical), month (categorical), station (categorical), depth (continuous), bottom temperature (continuous), and bottom salinity (continuous) was compared with nested submodels using AIC.

For the data, a sub model of year, bottom temperature, depth, and bottom salinity was selected because the model achieved convergence and it produced the lowest AIC value of the subset of converged models, and produced favorable diagnostics (Figures 5.34 – 5.36, Tables. 5.22 and 5.23). The index was variable, but indicates a period of high abundance beginning in the 1990s, a decline to the early 2000s, a period of increase early in the 2000s, but then another period of decline to the present (Figure 5.37). Diagnostics identified mainly underprediction by the model of average annual catch per tow. Overall, the model exhibited adequate diagnostics given the low sample size and high variability in the number of tautog caught in this survey.

6.0 STOCK ASSESSMENT MODELS, METHODS, AND RESULTS

The base models used to estimate stock status are Age Structured Assessment Program (ASAP), Extended Depletion-Based Stock Reduction Analysis (X-DBSRA), and Bayesian State Surplus Production Model. The Virtual Population Analysis (VPA) was conducted as a continuity run. Each model was applied to the three proposed regional stock definitions: three region (Southern New England, Mid-Atlantic, and DelMarVa), two region (MA-NY and NJ-VA), and coastwide.

6.1 Age Structured Assessment Program (ASAP)

6.1.1 Background

Two models from the NOAA Fisheries Toolbox were used to estimate population parameters and biological reference points. The population model used was ASAP v. 3.0.17, which produces estimates of abundance, fishing mortality, and recruitment, as well as estimates of biological reference points from input and estimated population parameters. AGEPRO v. 4.2.2 was used to estimate spawning stock biomass threshold and target levels consistent with SPR-based fishing mortality reference points.

Both programs are available for download at http://nft.nefsc.noaa.gov/

6.1.2 Assessment Model Description

ASAP is a forward-projecting catch-at-age model programmed in ADMB. It uses a maximum likelihood framework to estimate recruitment, annual fishing mortality, and abundance-at-age in the initial year, as well as parameters like selectivity and catchability, by fitting to total catch, indices of abundance, and catch- and index-at-age data.

See *Appendix A2: ASAP Technical Documentation* for more detailed descriptions of model structure and code.

6.1.3 Reference Point Model Description

In addition to population parameters, ASAP also calculates some reference points internally, using model estimates of selectivity in the terminal year and stock-recruitment relationship parameters, and the input weight-at-age, maturity schedule, and natural mortality. The TC considered ASAP's estimates of SPR-based F reference points ($F_{30\%SPR}$ and $F_{40\%SPR}$) and MSY proxies (F_{MSY} and SSB_{MSY}) developed from YPR, SPR, and stock-recruit models following Gabriel *et al.* (1989).

In addition, because of concerns about the reliability of the stock-recruitment relationship estimated by the model, and the sensitivity of MSY-based reference points to the estimated S-R parameters, the AGEPRO model was used to project the population forward in time under constant fishing mortality ($F_{30\%SPR}$ and $F_{40\%SPR}$) with recruitment drawn from the model-estimated time-series of observed recruitment to develop an estimate of the long-term equilibrium SSB associated with those fishing mortality reference points.

See *Appendix A3: AGEPRO User Guide* for a more detailed description of model structure.

6.1.4 Configuration

ASAP input files for each region are included in Appendix A3.

6.1.4.1 Spatial and Temporal Coverage

The ASAP model was run for three separate regions:

1. Southern New England region (SNE), which included catch and index data from Massachusetts, Rhode Island, and Connecticut
2. Mid-Atlantic region (NY-NJ), which included catch and index data from New York and New Jersey

3. DelMarVa region (DMV), which included catch and index data from Delaware, Maryland, and Virginia.

The model was run from 1982-2013 for the SNE regions and from 1989-2013 for the NY-NJ region. The MRFSS/MRIP time-series of recreational catch begins in 1982; however, prior to 1995, raw age data by state were not available. Only the final ALKs used in previous assessments were available, which lump NJ with the DMV region and NY with the SNE region to form the previous north-south split. As a result, region-specific catch-at-age matrices were not developed prior to 1995 for the SNE and NY-NJ regions, and the model was fit only to total catch in those years. Index-at-age data were available for those regions from the beginning of the each time-series, however.

Prior to 1995, the southern region ALKs did not include NJ data, so they were de facto DMV ALKs. To improve stability of the model, which does not have other fishery independent index-at-age data, the model was run from 1990-2013, when information on the size structure of recreationally released fish is first available from the DMV region.

6.1.4.2 Selection and Treatment of Indices

See Section 6.1 for a detailed description of how indices were selected and standardized.

The indices used for each region are listed in Table 6.1. The model was fit to both the total standardized index (catch per tow or catch per trip) and index-at-age data. Young-of-year indices were lagged forward one year (e.g., the 1983 age-1 predicted index value was fit to the observed 1982 YOY index value). For the NY trawl index, the standardized index was scaled by the proportion of fish less than 15cm in the catch to make it a young-of-year index.

6.1.4.3 Parameterization

The ASAP model used a single fleet that included total removals in weight and removals-at-age from recreational harvest, recreational release mortality, and commercial catch. Selectivity of the fleet was described by a logistic curve. Three selectivity blocks were used: 1982-1996, 1997-2006, and 2007-2013. Breaks were chosen based on implementation of new regulations.

Adult indices were fit to index-at-age data assuming a single logistic selectivity curve and constant catchability. YOY indices had a fixed selectivity pattern of 1 for age-1 and 0 for all other ages, and also assumed constant catchability.

Recruitment was estimated as deviations from a Beverton-Holt stock recruitment curve, with parameters estimated internally.

6.1.4.4 Weighting of Likelihoods

ASAP uses a lognormal error distribution for total catch and indices, and a multinomial distribution for catch-at-age and index-at-age data.

Likelihood components can be weighted with a lambda value, to emphasize a particular component, and with a CV, which determines how closely an observation is fit. All components had a lambda of 1 in the base run. MRIP PSE values, inflated for missing catch, were used as the CV on total catch, and the CVs of the standardized indices were increased to bring the RMSE of the indices close to 1.

ASAP also allows the use of lambdas and CVs to calculate likelihood components for estimated parameters such as selectivity and stock-recruitment parameters based on deviations from initial guesses. For the NY-NJ region and the DelMarVa region, where catch- and index-at-age data did not go back to 1982, the lambda on the deviations from the initial numbers-at-age was set to 1.0, with a CV of 0.5, to prevent the model from creating a single large age-class at the beginning of the time-series.

Recruitment deviations and deviations from full F in the first year are also included in the likelihood component with an associated lambda and annual CV. These recruitment deviations were given a lambda of 0.5 and a CV of 0.5 for all years. All three regions also had a lambda of 0.5 and a CV of 0.5 on the full F deviations.

The effective sample size for the multinomial distributions was input as the number of sampled tows or trips. ASAP estimates the ESS internally as well, using the method of Francis (2011). When the final model configuration was determined, the input ESS were adjusted using ASAP's estimates of stage 2 multipliers for multinomials.

6.1.5 Estimating Precision

ASAP provides estimates of the asymptotic standard error for estimated and calculated parameters from the Hessian. In addition, MCMC calculations provide more robust characterization of uncertainty for F, SSB, biomass, and reference points. 200,000 MCMC runs were conducted for the base model, of which 1,000 were kept.

6.1.6 Sensitivity Analyses

6.1.6.1 Sensitivity to Input Data

A number of sensitivity runs were conducted to examine the effects of input data on model performance and results. These included:

- Removal of indices from the likelihood to examine the influence of individual data streams on model results
- Use of an age-specific natural mortality instead of an age-constant value
- Different starting values for estimated parameters
- Inclusion of commercial discard time-series

6.1.6.2 Sensitivity to Model Configuration

In addition, a number of sensitivity runs were conducted to examine the effects of model configuration on model performance and results. These included:

- Use of 2 selectivity blocks for the catch instead of 3
- Fixing steepness at 1 (i.e., no relationship to SSB and fitting deviations to an average recruitment value)
- Truncating the time-series to years with full catch-at-age data available

6.1.7 Retrospective Analyses

Retrospective analyses were performed by ending the model in earlier and earlier years and comparing the results to the output of the model that terminated in 2013. The terminal years ranged from 2007 – 2013, since going back further extended into a different selectivity block for the catch.

6.1.8 ASAP Results

6.1.8.1 Goodness of Fit

The total likelihood and index RMSE values are shown in Table 6.1.

Total catch showed some slight patterning in the residuals in the middle of the time series for the southern New England region, with the model overestimating catch for a series of years and then underestimating it for several years after that (Figure 6.1).

The index residuals showed little patterning (Figures 6.1 – 6.4). In the NY-NJ region, the model had trouble fitting the NY YOY seine index and the RMSE for that index was 1.37, even after increasing the CV significantly. This is most likely due to the fact that the NY seine index occasionally shows the opposite trend from the NY YOY trawl index, showing high values when the trawl index is low and vice versa (Figure 6.3).

The overall fit to the catch-at-age was good (Figure 6.5), but model struggled to fit the catch-at-age in some years (Figures 6.6 - 6.8).

In the southern New England region, the model did not fit the RI fall trawl index-at-age data well, but did a better job with the MA trawl, the CT trawl, and the MRIP CPUE index-at-age data (Figure 6.9). Both the NY-NJ and DelMarVa regions fit the total index-at-age data fairly well (Figures 6.10 - 6.11).

6.1.8.2 Parameter Estimates

6.1.8.2.1 Selectivities, Catchability, and the Stock-Recruitment Relationship

In 1997, states implemented minimum size regulations for tautog, and that is evident in the changing selectivity pattern between 1982-1996 and 1997-2006 for the southern New England and NY-NJ regions, but not for the DelMarVa region (Figure 6.12). In 2007, additional regulations were implemented by the states on a coastwide basis. However, these did not appear to have the intended effect, as selectivity on the younger ages increased slightly in the 2007-2013 block for all three regions.

Estimates of index catchabilities are shown in Table 6.2.

ASAP estimated a moderately low steepness for the southern New England region (h=0.48) and the NY-NJ region (h=0.65), but estimated the steepness for the DelMarVa region at almost 1.0 (h=0.999974), suggesting the data are not informative about the S-R relationship in this region. The observed and predicted recruitment is shown in Figure 6.13 for all three regions.

6.1.8.2.2 Fishing Mortality

In the southern New England region, F has been highly variable, with large jumps from year to year in some instances (Table 6.3, Figure 6.14). A three-year average of full F is also shown, which is smoother, and shows a variable but generally increasing trend in F. In 2013, full F was 0.59 and the 3-year average was 0.45. The NY-NJ and DelMarVa regions have also been quite variable, but unlike the SNE region, F has declined sharply since 2010 (Table 6.3, Figure 6.14). Full F was 0.21 in NY-NJ (3 year average = 0.25) and 0.1 in DMV (3-year average = 0.17).

The median full F and the 5th and 95th percentiles from MCMC runs for all regions are shown in Figure 6.15, and likelihood profiles for terminal year F for all three regions are shown in Figure 6.16.

6.1.8.2.3 Abundance and Spawning Stock Biomass Estimates

Both total abundance and spawning stock biomass have declined steadily in the southern New England region since the beginning of the time series, and now remain low but stable (Table 6.4, Figure 6.17). Total abundance decline from a high of 14.2 million fish to the current low of 2.9 million fish in 2013. Spawning stock biomass decreased from over 11,000 MT at the beginning of the time-series to a low of 1,838 MT in 2013.

The NY-NJ region showed a similar pattern, declining from a high of 5,500 MT in 1989 to a low of 1,436 MT in 2011. However, the NY-NJ region has seen an increase in biomass in recent years, with SSB in 2013 estimated to be 2,078 MT.

The DelMarVa region has not seen the large declines that those regions have (Table 6.4, Figure 6.17), but SSB has declined from a peak of 2,851 MT in 1993 to a low of 1,138 MT in 2011. Like the NY-NJ region, SSB has increased in recent years, to 1,530 MT in 2013.

The median SSB and the 5th and 95th percentiles from MCMC runs for all regions are shown in Figure 6.17, and likelihood profiles for terminal year SSB for all three regions are shown in Figure 6.18.

Recruitment was highest in the early years of the time-series for all three regions. It has remained fairly stable since then. The 2011 year-class appeared to be weak in all three regions, but not as low in the DelMarVa region as in the other two. Overall, recruitment has exhibited few extremes (Figure 6.19).

6.1.9.3 Sensitivity Analyses

In southern New England, changes to the input data and model assumptions predominantly changed the initial estimates of SSB, but overall the trajectories remained the same. Using an age-varying M resulted in the highest terminal F and fixing steepness at 1.0 resulted in the lowest. Dropping the Massachusetts trawl resulted in the highest terminal SSB, while using an age-varying M and dropping the MRIP index resulted in the lowest (Table 6.5, Figure 6.20). The run with the truncated time series (1995-present) did not converge. Estimates of overfishing status were consistent, with all runs showing overfishing in 2013.

In the NY-NJ region, dropping the MRIP index resulted in a higher initial SSB and a lower terminal SSB. The highest terminal SSB estimates came from the runs without the NY seine and NJ trawl indices, and from fixing steepness at 1.0. The lowest estimate came from the runs that included commercial discards and dropped the NY trawl index. Overall trends in SSB were similar (Figure 6.20). Fixing steepness resulted in the lowest terminal F, while dropping the NY trawl index resulted in the highest (Table 6.5, Figure 6.21). Only dropping the NY trawl index changed overfishing status.

In the DelMarVa region, upweighting the catch or the CPUE changed the initial estimates of SSB the most, but terminal estimates were similar. Fixing the steepness at 0.5 (similar to what was estimated in the other regions) resulted in the lowest terminal SSB and the highest terminal F (Figure 6.20). While the using the age-varying M resulted in the highest terminal SSB. Estimates of terminal F and overfishing status were similar across all runs (Table 6.5, Figure 6.21).

A set of sensitivity analyses was done to examine the effects of the regional split between southern New England and NY-NJ. Data from CT (landings, length frequencies, and the fishery independent index) were removed from the SNE model and included in the DMV model.

The MA-RI region had a lower SSB over the entire time-series than the base model SNE region. The CT-NY-NJ region had a higher SSB at the beginning of the time-series than the base model NY-NJ, but dropped lower in the early 1990s, ending at a lower terminal SSB than the base model NY-NJ estimate. Overall, the total SSB for both regions combined was lower under the MA-RI/CT-NY-NJ split than under the base model split. However, the trends and magnitude of total SSB were very similar (Figure 6.22A).

Estimates of F were very similar for most years between the new MA-RI region and the base southern New England region. However, the estimate of F in the terminal year was much lower for the MA-RI region than for the MA-RI-CT (SNE) region. Estimates of F were similar for many years between the CT-NY-NJ and the base NY-NJ regions. The CT-NY-NJ region had higher estimates of F for the early 1990s and for the mid- to late-2000s. Estimates of F were very similar between the two regions for the last several years (Figure 6.22B).

6.1.9.4 Retrospective Analyses

The Southern New England region showed a slight retrospective pattern of overestimating F (Mohn's rho=0.13) and underestimating SSB (-0.05) in the terminal year (Table 6.5, Figure 6.23). Recruitment tended to be more variable, and was also underestimated in the terminal year (Mohn's rho=-0.35) (Table 6.5, Figure 6.23).

The NY-NJ region overestimated F in the terminal year (Mohn's rho=0.08), but also overestimated SSB (Mohn's rho=0.20) (Table 6.5, Figure 6.24), although not in all years of the peel. Recruitment was much more variable and did not show a consistent pattern (Mohn's rho=0.03) (Table 6.5, Figure 6.24).

The DelMarVa region showed a strong retrospective pattern, consistently underestimating F (Mohn's rho = -0.20) and overestimating SSB (Mohn's rho=0.25). Recruitment was again more variable, but also underestimated (Mohn's rho=-0.20) (Table 6.5, Figure 6.25).

6.1.9.5 Reference Point Model

6.1.9.5.1 Parameter Estimates

Estimates of $F_{30\%SPR}$, $F_{40\%SPR}$, F_{MSY}, and SSB_{MSY} are shown in Table 6.1.8. F_{MSY} tended to be lower than the SPR-based reference points in the southern New England and NY-NJ regions, due to the lower steepness estimated by the model (h=0.48 in SNE, h=0.65 in NY-NJ). The DelMarVa region estimated a very high steepness (h=0.999974), indicating a poor fit to the S-R model, and thus estimates of F_{MSY} and SSB_{MSY} should be considered very unreliable.

In addition, stochastic projections were carried out to estimate the median long-term SSB expected from fishing at $F_{30\%SPR}$ and $F_{40\%SPR}$ under observed recruitment conditions (Table 6.6).

F_{MSY} was estimated as 0.15 for SNE, 0.18 for NY-NJ, and 0.50 for DMV, with associated SSB_{MSY} values of 3,883 MT, 3,823 MT, and 867 MT, respectively.

$F_{30\%SPR}$ was estimated as 0.44 for SNE, 0.26 for NY-NJ, and 0.24 for DMV, with associated equilibrium SSB estimates of 2,310 MT, 2,640 MT, and 1,580 MT, respectively.

$F_{40\%SPR}$ was estimated as 0.26 for SNE, 0.17 for NY-NJ, and 0.16 for DMV, with associated equilibrium SSB estimates of 3,090 MT, 3,570 MT, and 2,090 MT, respectively.

6.1.9.5.2 Sensitivity Analyses

In general, estimates of $F_{30\%SPR}$ and $F_{40\%SPR}$ and their associated SSB reference points were very similar across sensitivity runs, while estimates of MSY-based reference points were much more variable (Table 6.5). Using the age-varying M in the southern New England region resulted in a much lower SPR-based F values, but did not have as strong an effect in the other two regions.

6.2 Extended Depletion-Based Stock Reduction Analysis (X-DBSRA)

6.2.1 Background on X-DBSRA

Depletion Based Stock Reduction Analysis (DB-SRA) is a modification of the Stock Reduction Analysis (SRA) methodology that can be used in data poor situations. SRA was first introduced by Kimura and Tagart (1982) and improved by Kimura et al (1984). Using catch data and a time series of abundance, the model strives to determine stock size and recruitment rates over time that could have produced the observed population trend given the harvest information. The original model was not widely accepted because it provided only a single, exceedingly unlikely, trajectory of stock size and recruitment (Walters et al 2006). Walters et al (2006) improved the method by incorporating stochasticity through Monte Carlo simulation of input parameters to produce a distribution of potential stock sizes over time, providing the ability to describe the statistical probability of biomass and MSY-based reference points.

While Walters et al (2006) promote stochastic SRA as a useful complement to traditional assessment methodologies, many species do not have sufficient data to run a traditional model or even SRA. In order to provide management advice in these data poor situations, a number of methodologies have recently been developed. One such model is Depletion Corrected Average Catch (DCAC; MacCall 2009), an extension of the potential yield formula that can provide useful estimates of long term sustainable yield. Input requirements are limited to a time series of observed harvest, an estimate of relative stock change during those harvest years, and biologically based life history parameters (M, F_{MSY}:M [hereafter referred to as the F-ratio], B_{MSY}:K [or B-peak]) and their associated uncertainty values. Monte Carlo distributions of the input parameters are developed and used in conjunction with the harvest data to derive a probability distribution of long term sustainable yield (MacCall 2009).

Depletion Based Stock Reduction Analysis was first introduced by Dick and MacCall (2011), borrowing aspects of SRA (Kimura and Tagart 1982, Kimura et al 1984, Walters et al 2006) and DCAC (MacCall 2009). A full description of the model is provided in Dick and MacCall (2011), but is summarized below.

Implementation of traditional SRA requires a time series of abundance (absolute or relative) which is generally lacking in data poor situations. DB-SRA relaxes that requirement by utilizing a distribution of assumed relative abundance (percent stock depletion) in a recent year (Dick and MacCall 2011). Other data inputs include a time series of harvest, age at maturity, and the same suite of biologically based life history parameters used in DCAC (M, F-ratio, and B-peak). A major assumption of the model is that the stock is at carrying capacity (K) at the beginning of the time series.

Implementation of the model is through a delay difference biomass model,

$$B_t = B_{t-1} + P(B_{t-a}) - C_{t-1}$$

where *B* is biomass, *P* is production, *a* is the median age at maturity, and *C* is harvest weight. Any production function can be used, but the original model is based on a hybrid of the Pella-Tomlinson-Fletcher and Schaefer models. Dick and MacCall (2011) argue that this parameterization best captures production rates at all levels of biomass, and the hybridization method is fully described in their manuscript.

For a given initial biomass, the observed catch history, and the production function parameterized with the input parameter values, a time series of biomass and production is produced. A solver routine is required to iteratively solve for initial biomass (K) such that the ratio of recent biomass to K satisfies the input assumed depletion level.

Outputs of the model include a biomass trajectory and estimates of a number of "leading parameters" that are directly useful to management, including K, MSY, B_{MSY}, and F_{MSY}. Statistical distributions of each of these outputs are achieved through Monte Carlo simulation of uncertainty in input parameter values.

Recent advancements

Since development of the original model, additional work has been conducted to improve upon the methodology. Aalto et al. (submitted) present a mortality correction term to account for the time over which mortality has occurred when age at maturity (a) is greater than 1.0. When a is greater than 1.0, using a single time lag for both mortality and fecundity results in overestimating abundance during stock declines and underestimating abundance during times of stock growth (Aalto et al., submitted). The corrected biomass equation can be written as

$$B_t = B_{t-1} + P(B_{t-a}) - C_{t-1} + (1 - \exp(M)) * (B_{t-a} - B_{t-1}) .$$

In addition, Dick et al (in prep.) present a methodology for an extended DB-SRA (xDB-SRA) that bridges the gap between a data poor model and a typical production model through incorporation of survey index data into the model. Using the assumption that

$$\log\left(\frac{I_i}{q}\right) \sim N(B_i, v_i + a)$$

$$\log\left(\frac{I_i}{q}\right) \sim N(B_i, v_i + a)$$

where I_i and v_i are the annual index mean and standard error, q is survey catchability, B_i is annual estimated biomass, and a is an additive process error term, the biomass trajectory from each initial model run is compared against the available index data. The likelihood of each biomass trajectory (and therefore the associated set of input parameter values) is estimated as

$$l(B, q, a; I) = \prod_{i=1}^{n} N\left(\log\left(\frac{I_i}{q}\right); \log(B_i), v_i + a\right).$$

$$l(B, q, a; I) = \prod_{i=1}^{n} N\left(\log\left(\frac{I_i}{q}\right); \log(B_i), v_i + a\right).$$

Likelihood values are converted to weights as $L_i / \Sigma L_i$, and the suite of initial runs (*i.e.* input parameters) is then resampled based on these likelihood weights. In this way, a full Bayesian analysis is conducted, as the resampling of the prior distributions of the inputs produces posterior distributions for these parameters. In addition, uncertainty in both inputs and derived reference points is formally quantified (Dick et al., in prep.).

An independent peer review of these advancements (both the mortality correction term and the xDB-SRA) concluded that both were relevant additions to the base model, and the peer review panel endorsed them for use in upcoming assessments (AFSC 2012).

Development of tautog model

For the 2014 tautog stock assessment, a version of DB-SRA was coded in the R software language, version 2.15.1 for Windows (R Development Core Team, 2011), based on the pseudo-code provided in Appendices A and B of Dick and MacCall (2011). A number of notable deviations were made in the tautog model relative to that presented by Dick and MacCall (2011). First, the biomass equation was modified to incorporate the mortality correction term of Aalto et al (submitted). Second, because the model assumes the population is starting at carrying capacity but credible harvest data for tautog are not available prior to 1982, an additional input parameter was included in the model. B_{start}, defined as the ratio of biomass in 1982 to carrying capacity (B_{1982}: K), accounts for the decline in biomass between carrying capacity and the first year of the model (see *Input Data* section below). This in turn required a modification to how production is calculated in early years. In the original model, production in early years ($t \leq a_{mat}$) is set to 0 as it is based on biomass at carrying capacity. For tautog, since biomass was assumed to be below carrying capacity in early years, production was calculated based on biomass in year 1. Finally, because the majority of tautog harvest is from the recreational fishery, and recreational harvest estimates from the MRFSS/MRIP survey are often imprecise (particularly at smaller regional scales), the tautog model incorporated uncertainty in the catch time series (see *Input Data* section below).

To allow incorporation of available index data, the Bayesian extension to the base model was also developed. Dick et al (in prep.) present two potential methods for the resampling routine: sample intensive resampling (SIR) and adaptive importance resampling (AIS). In addition, the authors present a method that allows integrating the nuisance catchability parameter out of the SIR procedure, thereby reducing the number of parameters and increasing the feasibility of the SIR methodology (Dick et al. in prep). Based on preliminary investigations (see *Model Testing and Sensitivity* section below) and discussions with staff from the NMFS SWFSC (E.J. Dick, pers. comm.), the resampling procedure in the tautog model was developed based on the SIR procedure with q integrated out.

The resulting code was ground-truthed by running the model with data and parameters for copper rockfish (*Sebastes caurinus*) and comparing results with the DB-SRA model code used by the NMFS Southwest Fisheries Science Center (SWFSC) to establish overfishing limits for the species (EJ Dick, NMFS SWFSC, pers. comm.). Results from the two models were nearly identical; differences in results were generally at the second or even third decimal place, resulting in relative differences of much less than 5% in nearly all comparisons. Possible sources of these differences include rounding, version of R being run, a difference in optimization function being used (optimize vs. uniroot), and a slightly different “quality control” procedure to remove runs with “invalid” results. No results of the ground-truthing exercise are provided in this document, but are available from the Technical Committee upon request.

6.2.2 Reference Point Model Description

MSY-based reference points are calculated directly by the model as a product of the randomly drawn input parameter values and derived model quantities (*e.g.* random draw of B_{MSY}: K value multiplied by model estimated K value provides estimate of B_{MSY}). Estimated reference point values are summarized across iterations to produce point estimates and characterize uncertainty.

6.2.3 Configuration

6.2.3.1 Spatial and Temporal Coverage: Input Data

Tautog harvest data back to 1982, including commercial harvest, recreational harvest, and recreational discards, were compiled as described in Section 5.1. Models were run for each of the TCs preferred three regions (SNE, MA, DMV), requiring harvest data to be subset to the appropriate states for each regional run.

6.2.3.2 Selection and Treatment of Indices

Indices of abundance were developed as described in Section 6.1.1 for fishery independent indices and Section 6.1.2 for fishery dependent indices. Only surveys that were considered representative of the entire population were included in the xDB-SRA model runs (*i.e.* no young of year surveys were included). These included the majority of the available trawl surveys and the appropriate regional recreational fishery dependent index (Table 6.7)

6.2.3.3 Parameterization

Given the uncertainty in tautog population characteristics, preliminary runs of the coastwide model were conducted using a diffuse prior on each of the input parameters. This identified ranges of input parameters that produced credible results (*i.e.* annual biomass did not fall below 0 or exceed a maximum threshold), and provided useful information which allowed the Technical Committee to refine the input ranges. Using these result, available information on tautog, and general knowledge of production theory, the Technical Committee established the following distributions for the input parameters.

- Natural mortality, M, was assumed to follow a log-normal distribution, with a mean of ln(0.15) and standard deviation of 0.25. This range captures the variability in M from northern and southern portions of the stock, and is consistent with available data (see Section 2.5).
- Preliminary investigations indicated that valid runs occurred over a wide range of F_{MSY}:M ratios (at least 0.2 to 2.0). For this reason, a uniform distribution was selected. Previous assessments indicated that fishing mortality rates above $F = 0.2$ led to overharvest, so a maximum F-ratio was set at 1.5. An F-ratio of 0.35 was selected as a minimum credible bound on F_{MSY}:M.
- B_{MSY}:K was modeled using a beta distribution to constrain values between 0 and 1.0. Preliminary investigations indicated that the median of the prior distribution tended to exceed 0.5 slightly, but that the proportion of valid runs decreased rapidly above 0.7. The beta distribution was therefore described using shape value 1 = shape value 2 = 7.0. This

produces a roughly normal distribution with a mean of 0.5 and a standard deviation of 0.13.

- B_{start} - the ratio of B_{1982}:K - was also modeled using a beta distribution to ensure it did not exceed 1.0. Expert opinion from the Technical Committee suggests that the stock was not heavily exploited prior to 1982. This is based on the knowledge that commercial value was low and location of offshore hard bottom was imprecise, making directed effort difficult. The TC therefore selected shape parameters of 15 and 5 for the beta distribution. These values produce a roughly normal distribution with mean of 0.75 and standard deviation of 0.09.
- The input range for the ratio of B_{recent}:K assumed a uniform distribution. Previous assessments indicate that the coastwide stock is overfished, so a range of 0.05 to 0.50 was selected.
- Error in harvest estimates was modeled assuming a normal distribution, with a mean of 1.0 and a standard deviation of 0.20. This is consistent with MRIP estimates of error (PSE) on the order of 15-20% at the coastwide level.
- The likelihood fitting procedure in the extended model requires an additional additive variance parameter for each index and iteration. The appropriate additive variance value is unknown and can vary by index. Initial runs of the model used random draws assuming a uniform distribution over a wide range (0 to 2.0). These initial runs provided guidance on optimal ranges to use for each index. In order to optimize the performance of the model, minimum and maximum values were selected for each index based on these preliminary runs, and the final runs assumed a uniform distribution between these index-specific values.

6.2.4 Estimating Precision

Precision in model estimates is evaluated by conducting a large number of iterations with different input parameter values drawn randomly from their described distributions. No criteria are established to determine an adequate number of iterations for the base model; however, in the extended model, sufficient initial iterations need to be conducted to achieve “acceptable” values for likelihood weights. If likelihood weights are too high, resampling may be concentrated on only a small number of iterations, leading to an underestimation of uncertainty. Dick et al (in prep.) reference MacAllister and Ianelli (1997) and “others” as saying that the maximum likelihood weight should not exceed 0.05 or 0.01, respectively, to allow representative resampling. For the tautog stock assessment, a likelihood weight threshold of 0.01 was used. Each regional model was attempted with an initial 150,000 iterations, with an additional 150,000 iterations conducted if the maximum likelihood weight exceeded the threshold. Only the coastwide model (not a preferred model) did not achieve the threshold value with 300,000 runs (Table 6.8).

6.2.5 Sensitivity Analyses

6.2.5.1 Sensitivity to Survey Data

Preliminary runs of the model suggested the model may be sensitive to the indices being used. In particular, the recreational fishery dependent (MRIP) index appeared to have a strong influence on the estimated F_{MSY}:M ratio. Sensitivity runs for the SNE and NY-NJ regions were therefore conducted using only the MRIP index and using all indices except MRIP.

For the DMV region, no fishery independent indices were available to perform the above sensitivity runs. Instead, a second fishery dependent index based on federal vessel trip report (FVTR) data from the recreational fishery was developed for the DMV region using the methods described in Section 5.1.2.3. A sensitivity run using both the MRIP and recreational VTR indices was conducted for this region. Similar runs were not conducted for the other regions since sufficient fishery independent indices were available for these regions.

6.2.5.2 Sensitivity to Model Configuration

In an attempt to understand differences in model results between the two data poor models (xDB-SRA and the Bayesian state space production model), sensitivity runs were conducted for each region using input parameter values consistent with the Bayesian state space production model; specifically B_{MSY}:K = 0.5 (*i.e.* Schaeffer production curve) and B_{start} = 1.0. Sensitivity runs where only one parameter at a time was fixed were also conducted, but these were done using a slightly different harvest data set. Results for these runs are available on request.

6.2.5.3 Sensitivity to Regional Structure

The preferred regions selected by the Technical Committee are acknowledged as a compromise between population dynamics, fishery characterization, and political boundaries (see Stock Structure, Section 2.6). During the deliberation process, an alternative regional breakdown was identified which shifts CT from the SNE region to the NY-NJ region, thereby keeping Long Island Sound within one management unit. Sensitivity runs were conducted under this alternative regionalization scheme, with appropriate changes to harvest and survey data inputs.

Additionally, although the TC prefers the three region structure because it is more consistent with stock biology and fishery characteristics, it was recognized that smaller regions may not be robust to data requirements and model assumptions. Consequently, alternative model runs were conducted for a two region model (historic north / south split) and a coastwide model. Results of these runs are not presented in this report, but are available upon request.

6.2.6 Potential Biases

Two recent studies have shown DB-SRA to be sensitive to the assumed stock depletion level (Wetzel and Punt 2011; Wiedenmann et al 2013). Both simulations showed that when the depletion level was underestimated (*i.e.* stock in recent years closer to K), estimated harvest limits from the model were larger than the true value, increasing the probability of overexploitation. In addition, Wiedenmann et al. (2013) found DB-SRA often estimated harvest limits higher than the true value even when unbiased estimates of stock abundance were used. The authors suggested that selecting lower percentiles of the harvest limit distribution (below the median) could reduce the risk of overfishing. It should be noted that both Wetzel and Punt (2011) and Wiedenmann et al. (2013) conducted their studies on the base DB-SRA model; the sensitivities and potential biases of xDB-SRA have not been investigated.

In addition to model performance uncertainties, there are a number of inputs and assumptions that may affect model results. While most of the input parameters incorporated uncertainty, median age at maturity was assumed known and constant at age 3. Improperly specified age at maturity, or a trend in age at maturity would affect results; however, no sensitivity runs were conducted.

Tautog harvest is primarily recreational, and MRFSS/MRIP harvest estimates for tautog fluctuate greatly, especially at smaller regional scales. Although the model includes uncertainty in harvest estimates, the error is assumed normally distributed around the reported value. Any directional bias or trend in harvest would influence model results.

Model results may also be affected by the indices used in the likelihood fitting procedure. Being a biomass model, the xDB-SRA requires biomass indices. However, the indices used for fitting the xDB-SRA were numerical. The TC found high correlation between nominal indices of abundance and biomass, so it was concluded that the numerical indices were representative of the biomass trends, but any effect of the standardization was not investigated. In addition, the fishery dependent indices were developed using trips (effort) from a suite of species. A different method of selecting guild species may have resulted in different index trends which may affect results.

6.2.7 Results for the Southern New England Region

The initial 150,000 runs were sufficient for the SNE region xDB-SRA model to achieve the likelihood weight threshold. Initial runs were evaluated to identify runs that produced unrealistic or invalid results (biomass less than 0 or greater than 40,000 MT). AFSC (2012) indicated that presentation of valid/invalid runs (*i.e.* post-model/pre-data) distributions is an important step in using the xDB-SRA to show the effect of the biomass constraints on parameter distributions. For the SNE model, fewer than 2,560 runs (1.71%) produced invalid results (Figure 6.26). The remaining runs were fit to available index data and resampled according to likelihood weights.

6.2.7.1 Parameter Estimates (include precision of estimates)

6.2.7.1.1 Input parameters

Distributions of input parameter values for the valid and resampled model runs are shown in Table 6.9 and Figure 6.27. Natural mortality, B_{MSY}:K, and B_{start} roughly approximate their input distributions, although M is shifted slightly left of the prior distribution (median M = 0.14). The model preferred values of F_{MSY}:M less than 0.8, with a median of 0.73 and an interquartile range (IQR) of 0.54 to 0.98. Median B_{MSY}:K was estimated at 0.51, and 50% of the resampled runs indicate starting biomass was 69.7 to 82.1% of carrying capacity. Current biomass is estimated to be approximately 11.6% of carrying capacity, with an IQR of 9.6-14.4%.

6.2.7.1.2 Exploitation Rates

Exploitation rates of tautog in the SNE region during the early 1980s did not exceed u = 0.15 but increased dramatically in 1986 to over u = 0.40 (Figure 6.28). Exploitation remained above 0.25 in most years through 1993, but experienced a steady decline of approximately 75% between

1992 and 1997, dropping from u = 0.42 to 0.09. Annual removals were relatively steady around 10% between 1997 and 2001, but by 2002 exploitation had increased to over 15% where it has remained in most years since then. Median exploitation in 2013 is estimated at u_{2013} = 0.25 with an IQR of 0.19 – 0.33. Median value of the last three years' exploitation is estimated at u_{recent} = 0.20 with an IQR of 0.16 – 0.25.

6.2.7.1.3 Biomass Estimates

Median biomass in the SNE region declined steadily from a peak of approximately 14,500 MT in 1982 to approximately 3,500 MT in 1993 (Figure 6.28). Biomass remained generally stable between 3,500 and 4,000 MT through 2007, after which it resumed a declining trend. Median biomass in 2014 is estimated at 2,278 MT, with an IQR of 1,704 to 2,901 MT.

6.2.7.1.4 Reference Points

Distributions of model estimated parameters for all valid runs and resampled runs are shown in Table 6.9 and Figure 6.29. Generally, distributions of K and B_{MSY} from the resampling procedure are shifted to the right of the distribution of valid runs, while resampled distributions of MSY and u_{MSY} are shifted to the left. The posterior median biomass that produces MSY is estimated at B_{MSY} = 9,295 MT (7,291 – 10,691 MT). Exploitation at MSY is u_{MSY} = 0.09 (0.07 – 0.11), resulting in a maximum sustainable yield of MSY = 817 MT (620 – 1,031 MT).

6.2.7.2 Sensitivity Analyses

6.2.7.2.1 Sensitivity to Survey Data

Including the MRIP survey in the input data had a general effect of increasing carrying capacity and B_{MSY} while reducing u_{MSY} (Table 6.9 and Figure 6.30). The run which included only the MRIP index had higher estimates of K and B_{MSY} and lower estimates of u_{MSY} than the base run, while the opposite was true for the run that excluded the MRIP index. Biomass trends all followed the same pattern but were shifted down for the no MRIP run and up for the only MRIP run relative to the base run. The shifts in B_{MSY} and u_{MSY} virtually offset themselves, resulting in estimates of MSY from the three runs being nearly identical. Median values were estimated at 817, 868, and 779 MT for the base, no MRIP, and only MRIP runs respectively. Results of the sensitivity runs had no effect on stock status determination.

6.2.7.2.2 Sensitivity to Model Configuration

Constraining B_{peak} to 0.5 and B_{start} to 1.0 resulted in a higher starting biomass with a steeper decline over time as well as lower median values and tighter distributions for all output parameter estimates (Table 6.9 and Figure 6.31). Median estimates of B_{MSY}, u_{MSY}, and MSY declined by 3.9, 14.4, and 19.3% respectively relative to the base run estimates. However, model configuration had no effect on stock status determination.

6.2.7.2.3 Sensitivity to Regional Structure

Removing CT from the SNE region resulted in a decrease in all output parameters (Figure 6.32). Biomass trends for the SNE and MARI regions followed similar patterns for 1981 to 2005. From 2005 to present, biomass in the SNE region appears to decline while the MARI biomass remains more stable. Stock status (biomass) is nearly identical for the two regions, while exploitation is shifted noticeably to the left when CT is removed.

6.2.8 Results for the New York-New Jersey Region

Approximately 1.6% of the initial 150,000 runs of the NY-NJ region model produced invalid ($B_i < 0$ or $B_i > 40{,}000$ MT) results (Figure 6.33). The remaining runs were fit to available index data producing a maximum likelihood weight of 0.0053.

6.2.8.1 Parameter Estimates

6.2.8.1.1 Input parameters

Distributions of input parameter values for the valid and resampled model runs are shown in Table 6.10 and Figure 6.34. Resampled distributions of M and B_{start} are shifted slightly left of their initial distributions, while B_{MSY}:K is shifted to the right. Median values of these three parameters are estimated as 0.14, 0.70, and 0.59, respectively. Values of F_{MSY}:M on the lower end of the input range produced better fits to the index data, with 50% of resampled runs having F_{MSY}:M values between 0.49 and 0.97. The median value of $B_{current}$:K = 0.42, with an IQR of 0.36 – 0.46.

6.2.8.1.2 Exploitation Rates

Exploitation rates in the NY-NJ region have exhibited a saw tooth pattern due to high variability in annual harvest estimates, making it difficult to distinguish real trends from noise (Figure 6.35). During the 1980s and early 1990s, exploitation in the NY-NJ region more than doubled, reaching a time series high of u = 0.23 in 1991, before declining to a time series low of u = 0.02 by 1998. The annual removal rate increased rapidly over the next few years to approximately 20% by 2002, before returning to only 3% removals by 2005. Between 2006 and 2010, exploitation rates varied around 10% annual removals before falling back to 5% or less in 2011 to 2013. Median values for both terminal year exploitation and recent (three year average) exploitation are estimated as u = 0.05 with interquartile ranges of 0.04 to 0.07.

6.2.8.1.3 Biomass Estimates

In the 1980s and early 1990s, median tautog biomass declined by approximately 50% in the NY-NJ region (Figure 6.35), from a peak of approximately 14,100 MT in 1982 to 7,077 MT in 1994. Biomass was relatively stable between 7,000 and 8,000 MT during the period 1994 to 2010. Median biomass has increased slightly in recent years to a terminal year biomass of B_{2014} = 8,162 MT, with an IQR of 5,949 to 11,013 MT.

6.2.8.1.4 Reference Points

Distributions of model estimated parameters for all valid runs and resampled runs are shown in Table 6.10 and Figure 6.35. Generally, distributions of K and B_{MSY} from the resampling procedure are shifted to the right of the distribution of valid runs, while the posterior distribution of u_{MSY} is shifted to the left. Post-model/pre-data and posterior distributions of MSY are nearly identical. The posterior median biomass that produces MSY is estimated at B_{MSY} = 10,891 MT (8,7390 – 13,383 MT). Exploitation at MSY is u_{MSY} = 0.08 (0.06 – 0.12), resulting in a maximum sustainable yield of MSY = 923.5 MT (797 – 1,098 MT).

6.2.8.2 Sensitivity Analyses

6.2.8.2.1 Sensitivity to Survey Data

Results of survey based sensitivity runs for the NY-NJ region followed a similar pattern to those for the SNE region (Table 6.10, Figure 6.36). Estimates of MSY for the base, no MRIP, and MRIP only index were 924, 949, and 855, respectively.

6.2.8.2.2 Sensitivity to Model Configuration

Results of the model configuration sensitivity runs in the NY-NJ region were similar to those for the SNE region, except that the median carrying capacity estimate was slightly higher (approximately 1%) for the Schaeffer run configuration than for the base run (Table 6.10, Figure 6.37). Median estimates of B_{MSY}, u_{MSY}, and MSY declined by 5.0, 20.4, and 24.4% respectively relative to the base run estimates. Model configuration had more of an effect on the distributions of stock status than other sensitivity runs, but still had no effect on stock status determination.

6.2.8.2.3 Sensitivity to Regional Structure

Moving CT to the NY-NJ region resulted in slightly decreased estimates of K, had minimal effect on B_{MSY}, and shifted distributions of u_{MSY} and MSY to the right (Figure 6.38). Annual biomass estimates for CTNY-NJ were slightly lower than for NY-NJ. The two trends followed similar patterns for most of the time series, but the divergence increased in recent years. Stock status and exploitation status were both noticeably less optimistic for the CTNY-NJ region.

6.2.9 Results for the DelMarVa Region

Approximately 1.0% of the initial 150,000 runs of the DMV region model produced invalid ($B_i <$ 0 or $B_i >$ 20,000 MT) results (Figure 6.39). The remaining runs were fit to available index data producing a maximum likelihood weight of 0.0012.

6.2.9.1 Parameter Estimates (include precision of estimates)

6.2.9.1.1 Input parameters

Distributions of input parameter values for the valid and resampled model runs are shown in Table 6.11 and Figure 6.40. The posterior distribution of B_{start} is slightly lower than the post-model/pre-data distributions, while B_{MSY}:K is slightly higher. The posterior medians are M = 0.14 (IQR = 0.12 – 0.17), B_{MSY}:K = 0.56 (0.45 – 0.65), and B_{start} = 0.69 (0.62 – 0.76) The posterior distribution of F_{MSY}:M is concentrated on the lower end of the input range, with 50% of resampled runs having F_{MSY}:M values between 0.52 and 1.03. The median value of $B_{current}$:K = 0.42, with an IQR of 0.36 – 0.46.

6.2.9.1.2 Exploitation Rates

Exploitation rates in the DMV region have exhibited a saw tooth pattern due to high variability in annual harvest estimates, but without obvious trend over much of the time series (Figure 6.41). Between 1982 and 2001, exploitation varied around u = 0.10, with lows around 0.05 in 1985 and 1990, and highs around 0.20 in 1988 and 1995. Between 2002 and 2010, exploitation appeared more stable and slightly higher than previous years, with removals ranging from approximately 10 to 15%. Since 2010, exploitation has declined dramatically to approximately u_{2013} = 0.04 (0.03 – 0.05). Median exploitation over the last three (2011 – 2013) years is estimated at u_{recent} = 0.05 with an IQR of 0.04 – 0.08.

6.2.9.1.3 Biomass Estimates

Biomass in the DMV region has declined throughout much of the time series, though in two apparent phases (Figure 6.41). The decline was greatest between 1982 and 1996, during which time median biomass fell by more than 40% from 5,000 MT to 2,880 MT. The decline continued from 1997 to 2011, but at a more gradual rate. During this period, median biomass declined approximately 13% to 2,470 MT in 2011. Since 2011, median biomass has increased slightly, with a terminal year median estimate of B_{2014} = 2,900 MT and an IQR of 2,100 - 4,000 MT.

6.2.9.1.4 Reference Points

Post-model/pre-data and posterior distributions of model estimated parameters are shown in Table 6.11 and Figure 6.42. Resampling produced a thicker right hand tail than the initial distribution of carrying capacity and shifted B_{MSY} and u_{MSY} distributions to the right and left, respectively. Post-model/pre-data and posterior distributions of MSY are nearly identical. The posterior median biomass that produces MSY is estimated at B_{MSY} = 3,756 MT (2,982 – 4,797 MT). Harvesting at U_{MSY} = 0.11 (0.07 – 0.15) provides a maximum sustainable yield of MSY = 351.3 MT (308.9 – 396.0 MT).

6.2.9.2 Sensitivity Analyses

6.2.9.2.1 Sensitivity to Survey Data

Results of the survey sensitivity run in the DMV region was similar to results from the other regions in that runs with just the MRIP index had lower biomass trends, lower K and BMSY, and higher uMSY estimates than runs that included additional survey data (Table 6.11, Figure 6.43). The shifts in these distributions for the DMV region, however, were smaller than for the other regions. Estimates of MSY for the base and MRIP+VTR runs differed by only 2.1%. As with the other regions, the sensitivity runs had no effect on stock status determination.

6.2.5.2.2 Sensitivity to Model Configuration

As with the other regions, constraining B_{peak} to 0.5 and B_{start} to 1.0 resulted in a higher starting biomass with a steeper decline over time as well as tighter distributions for all output parameter estimates (Table 6.11 and Figure 6.44). Median estimates of K and B_{MSY} changed little, while u_{MSY} and MSY declined relative to the base run. The alternate parameterization improve stock status slightly but had minimal effect on exploitation status.

6.3 Bayesian State Space Surplus Production (BSSSP)

6.3.1 Background

Bayesian approaches are becoming increasingly popular in fisheries analysis. It can be a favorable approach because fisheries data is often highly variable, sporadic in nature (i.e. fishery independent surveys can often stop and start at different points during the time series), and often have important pieces of missing information that need to be inferred. The Kalman filter (Kalman, 1960) used to incorporate both observation and process error in a linear dynamic system (Wiener filter), and the extended Kalman filter approach to fit nonlinear state-space models have been studied in the fish population dynamics including the models of catch-at-length (Sullivan, 1992), catch-at-age (Schnute~~,~~ 1994), delay-difference biomass (Kimura et al. 1996), and surplus production (Meyer and Millar 1999a). This section describes the use of a Bayesian approach to analyze fisheries data for tautog.

No Bayesian state space surplus production model exists for tautog, so the analysis was modeled after an approach used by Brodziak et al for silver hake (Brodziak et al, 2001). The initial values for K, q, and r were developed by constructing and running a linear approximation of the Schaefer surplus production model. The prior information used for the analyses were a combination of uninformative and informative priors, though in all cases the distributions were allowed an abundance of statistical space from which to sample. Some of the other information, including the initial biomass estimates used were taken from the most recent stock assessment update (ASMFC 2006) as well as an initial ASAP configuration that was made to mimic the coastwide VPA (See Section 6.1, Age Structured Assessment Program).

The state-space model explicitly models the randomness in both the dynamics of the population and in the observations made on the population (Meyer and Millar 1999a, Meyer and Millar 1999b). This analysis used the Bayesian state-space approach of the Schaefer surplus production model developed by Meyer and Millar (1999a).

$$B_t = B_{t-1} + rB_{t-1}(1 - \frac{B_{t-1}}{K}) - Y_{t-1} \qquad (1)$$

Equation (1) is a discrete form of the Schaefer model with intrinsic growth rate (*r*), carrying capacity (*K*) and B_t, which is the observed biomass in year *t*. The parameter Y_{t-1} is the observed catch in year *t-1*. The Bayesian surplus production model introduces a reparameterized form of the Schaefer surplus production model (Equation 2)

$$P_t = P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{Y_{t-1}}{K} \qquad (2)$$

where P_t is the relative stock biomass ($P_t = B_t / K$), and the other terms are the same as the Schaefer model in Equation 1. The model assumes lognormal error structures, and Equation 2 is the basis of the state equations for the state-space model. Based on Equation 2, the state equations with independent lognormal process errors can be written as

$$\begin{aligned} P_1 &= \exp(\mu_1) \\ P_t &= [P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{Y_{t-1}}{K}]\exp(\mu_t), t = 2,3,...N \qquad (3) \\ Y_t &\sim Uniform[Y_{L(t)}, Y_{U(t)}] \end{aligned}$$

where the independent lognormal process errors for relative biomass are $\exp(\mu_1)$ with $\mu_t \sim N(0,\sigma^2)$ and the annual catch error distribution is a uniform distribution with time-varying upper ($Y_{U(t)}$) and lower ($Y_{L(t)}$) bounds. These upper and lower bounds spanned from 15% below to 15% over the estimated catch value.

The observation equations relate the observed survey indices (Table 6.12) to model parameters via

$$I_t = qKP_t \cdot \exp(\nu_t), t = 1,2,...N \qquad (4)$$

where the independent lognormal observation errors are $\exp(\nu_t)$ with $\nu_t \sim N(0, \tau^2)$, and I_t is a relative biomass index, and q is the catchability coefficient. Relative abundance (I_t) in year t is estimated as described in Sections 5.1 and 5.2 for fishery-dependent and fishery-independent data, respectively.

The various models run were developed using R statistical software (R Core Team, 2013). Gibbs sampling (R2OpenBUGS software, version 3.2-2.2) was used to obtain samples from the posterior distribution of the Bayesian model as the Markov Chain Monte Carlo (MCMC) methods. The model was run with multiple iterations (50,000), a burn in series of 5,000 iterations, and a thinning interval of 300 iterations to break the autocorrelation found after initial runs of the model. Two Monte Carlo chains were initiated for each model run where the starting values for the K, r, and σ^2 (process error) parameters were altered. Diagnostics (autocorrelation plots, trace plots, and kernel density plots) were performed on the model output for the base run models and are presented in Appendix 1.1 – 1.3. Summary statistics were determined from the model outputs (Tables 6.13 – 6.18). In addition, the posterior medians were plotted for some important population parameters against their calculated biological reference points (Figures 6.65 – 6.76).

6.4.2 Configuration

6.4.2.1 Spatial and Temporal Coverage

Consistent with the other modeling approaches in this document, and as described in Section 5.1 of this document, the time frame for the Bayesian State Space Surplus Production model was the years 1982 through 2013. The main reason for selecting this timeframe is due to the predominance of the recreational fishery on this stock and the advent of the recreational fishing monitoring program in 1982. Not all of the fishery independent indices span the entire time frame.

Based on advice from the ASMFC Tautog Technical Committee (TC), models were run for each of the TCs preferred three regions (Southern New England (SNE), New York-New Jersey (NY-NJ) and DelMarVa (DMV)), requiring harvest data to be subset to the appropriate states for each regional run. There was an effort to break the stock units down to the smallest level possible, and the three region breakdown was deemed appropriate and preferred by the TC. In addition to the three region breakdown, a 2 region breakdown (northern region (NR), southern region (SR)) and a coastwide model were also run for comparative analysis amongst models including comparisons to the previous management model which assumed a coastwide stock.

6.4.2.2 Selection and Treatment of Indices

Indices of abundance were developed as described in Sections 5.3. Only surveys that were considered to potentially contain all year classes were used, therefore the existing young of the year surveys were not used in this model as they were not deemed appropriate for this assessment modeling procedure. The surveys used included available fishery independent state trawl surveys and the appropriate regionally configured recreational fishery dependent index. A description of the specific surveys used in each regional model run is included in Table 1.

6.4.2.3 Parameterization

Based on the surveys, with the assumption of constant catchability, the Bayesian State Space Surplus Production model for tautog has five parameters ($r, K, q\ , \sigma^2, \tau^2$). The joint prior density is given by

$$\begin{aligned}&\sum_{i=1}^{2}\sum_{t=1}^{N} p(K, r, q_i, \sigma_i^{\,2}, \tau_i^{\,2}, P_t) = \\ &\sum_{i=1}^{2}\{p(K)p(r)p(q_i)p(\sigma_i^{\,2})p(\tau_i^{\,2})p(P_1 \mid \sigma_i^{\,2}) \times \prod_{t=2}^{N} p(P_t \mid P_{t-1}, K, r, \sigma_i^{\,2})\}\end{aligned} \qquad (5)$$

Where the term "*i*" would indicates multiple surveys (the example above would indicate the use of two surveys), and the term "*t*" indicates year. In addition, the model assumes that the parameters are independent *a priori*. A broad uniform distribution was chosen for the prior distribution for intrinsic growth rate (*r*). The range of the distribution was chosen as a large range as could possibly be seen across a number of fish species, though this range was constrained for the smaller sub regions relative to the coastwide parameterization. A prior distribution for q was chosen to be a high-variance gamma distribution as described in Meyer and Millar 1999a. The inverse of q was assumed to be distributed as Gamma (0.001,0.001). Two components of variance were modeled: the process error variance (σ^2) and the observation error variance (τ^2). Prior distributions for σ^2 and τ^2 were specified using biological knowledge and inferences discussed in Brodziak et al. 2001, and are the following:

$$\begin{aligned}&r_{coastwide} \sim uniform(0.1, 0.5) \\ &K_{tautog} \sim \log normal(\mu_K = TableX, \sigma_K = TableX) \\ &p(q) \propto \frac{1}{q} \\ &\sigma^2 \sim inverse-gamma(4.00, 0.01) \\ &\tau^2 \sim inverse-gamma(2.00, 0.01)\end{aligned} \qquad (6)$$

The sampling distribution for the relative abundance indices (I_t) is written by

$$\begin{aligned}&\sum_{i=1}^{2}\sum_{t=1}^{N}p(I_t \mid K,r,q_i,\sigma_i^{\,2},\tau_i^{\,2},P_t)=\\&\sum_{i=1}^{2}\prod_{t=1}^{N}\{p(I_t \mid P_t,q_i,\tau_i^{\,2})\}\end{aligned} \tag{7}$$

And the joint posterior distribution of the unobservables given the data is determined by the product of prior and sampling distribution (Equation 8).

$$\begin{aligned}&\sum_{i=1}^{2}\sum_{t=1}^{N}p(K,r,q_i,\sigma_i^{\,2},\tau_i^{\,2},P_t,I_t)=\\&\sum_{i=1}^{2}\{p(K)p(r)p(q_i)p(\sigma_i^{\,2})p(\tau_i^{\,2})p(P_1 \mid \sigma_i^{\,2})\times\\&\prod_{t=2}^{N}p(P_t \mid P_{t-1},K,r,\sigma_i^{\,2})\times\prod_{t=2}^{N}p(I_t \mid P_t,q,\tau_i^{\,2})\}\end{aligned} \tag{8}$$

In general all of the parameters are given uninformative priors to give the model plenty of space to statistically sample. The specific parameterization and the values chosen for each regional run are presented in Table 6.19.

6.4.3 Estimating Precision

Precision of the estimates were determined through the use of MCMC sampling and the use of summary statistics on the MCMC samples. Numerous iterations (50,000) were run for each parameter, allowing for a burn in period (5,000 iterations), and multiple chains were also initiated. The posterior distribution provides a number of metrics to determine precision. In this case the median value was selected as the appropriate point estimate for each parameter, and confidence bounds around this median estimate can be determined and plotted to examine uncertainty and precision around the point estimate. In this case the 2.5 and 97.5 percent confidence bounds were selected.

6.4.4 Sensitivity Analyses

One of the efficiencies with the Bayesian State Space Surplus Production model is that sensitivities are determined internally within the modeling framework. The iterative resampling procedure as well as the use of multiple chains tests the models sensitivities and its ability to converge on a single and consistent answer. These procedures as well as some additional sensitivity analyses that were performed are examined in more detail below.

6.4.4.1 Sensitivity to Input Data

The models sensitivity to input data was tested in two ways. The first was to perturb the starting points for the initial values of the various parameters by initiating two chains. Different starting values were given for each of the following parameters: K, r, and process error (σ^2). An accounting of the exact starting values for each of the various runs is given in Table 6.20. In addition to the multiple chains, sensitivity to the different indices was tested by dropping one of the surveys for each region and rerunning the model without said survey. These results are presented in Figures 6.77 – 6.80, and 6.83 – 6.84.

6.4.4.2 Sensitivity to Model Configuration

The models sensitivity to different configurations was also tested in two ways. Different regional versions were run (with the TC settling on the 3 region version as noted above). These different configurations can be compared and contrasted by reviewing Figures 6.81, 6.82 and 6.85, 6.86.

6.4.5 Results

Each results section will be split in to three sub sections for the three separate regions, which was the model configuration preferred by the TC. So for each region (SNE, MA, DMV) a description of parameter estimates and sensitivities will be presented separately.

6.4.5.1 Goodness of Fit

For each parameter, a number of diagnostic plots were produced to visually examine for model convergence. Trace plots were produced to examine whether the two chains are producing similar and consistent estimates for each parameter, density plots are produced to show the parameter estimates peak as well as probability distributions around the median estimate, and auto correlation plots are produced to show whether issues with correlation are accounted for by the thinning interval. In addition to these visual examinations of model convergence, one analytical technique was performed. Convergence of the MCMC samples to the stationary posterior distribution was evaluated using the Gelman and Rubin convergence diagnostic. Gelman and Rubin (1992) proposed a general approach to monitoring convergence of MCMC output in which multiple (more than 1) parallel chains are run with starting values that are overdispersed relative to the posterior distribution. Convergence is diagnosed when the chains migrate away from their initial values, and the output from all chains becomes indistinguishable. The diagnostic test as implemented in R statistical software is based on a comparison of within-chain and between-chain variances, and is similar to a classical analysis of variance. The statistical test as implemented in R was developed by Brooks and Gelman (1997). Outputs from this test for each parameter should be close to 1, and should not exceed a value of 1.1. In all cases, the convergence diagnostics all indicated model convergence for all parameters. The plots for these diagnostics can be found in Appendix 1.1 – 1.3. In addition, the Gelman and Rubin convergence diagnostic indicated good convergence as well, all diagnostic values for each parameter being equal to 1.

Beyond convergence diagnostics, additional diagnostics were also examined including residuals from the indices (Figures 6.67, 6.71, and 6.75) and fit of observed catch to predicted catch (Figures 6.88 – 6.90). None of these diagnostics raised great concerns that the model was not functioning properly.

6.4.5.2 Parameter Estimates

6.4.5.2.1 r and K.

Southern New England (SNE)

Of the three regions, SNE had the highest K value as well as the lowest r value. The SNE K parameter had a median value of 19.11 thousand metric tons (tmt), with a range from 14.43 tmt (2.5% confidence bound) to 24.55 tmt (97.5% confidence bound). The SNE r parameter had a median rate of 0.145, with a range from 0.102 (2.5% confidence bound) to 0.245 (97.5% confidence bound) (Figure 6.65, Table 6.21).

New York – New Jersey (NY-NJ)

The NY-NJ region had the K parameter values that were between the DMV and SNE regions. The NY-NJ region had the highest r parameter values though. The NY-NJ K parameter had a median value of 14.82 thousand metric tons (tmt), with a range from 8.20 tmt (2.5% confidence bound) to 31.36 tmt (97.5% confidence bound). The NY-NJ r parameter had a median rate of 0.276, with a range from 0.109 (2.5% confidence bound) to 0.482 (97.5% confidence bound) (Figure 6.69, Table 6.21).

DelMarVa (DMV)

The DMV region had the lowest K parameter values. The DMV region had r parameter values that were between the SNE and NY-NJ regions, though were similar to the NY-NJ region estimates. The DMV K parameter had a median value of 8.20 thousand metric tons (tmt), with a range from 4.26 tmt (2.5% confidence bound) to 18.62 tmt (97.5% confidence bound). The DMV r parameter had a median rate of 0.235, with a range from 0.108 (2.5% confidence bound) to 0.474 (97.5% confidence bound) (Figure 6.73, Table 6.21).

6.4.5.2.2 Exploitation Rates

Southern New England (SNE)

The SNE region had a period of high exploitation early in the time series, dropping down to low levels in the early 1990s, and then climbing again in the early 2000s until the present. The terminal year exploitation rate is 0.209, with a range from 0.118 (2.5% confidence bound) to 0.374 (97.5% confidence bound) (Figure 6.68, Table 6.21).

New York – New Jersey (NY-NJ)

The NY-NJ region also had a period of high exploitation early in the time series, mainly in the 1980s, which dropped down to low levels in the early 1990s where is has remained, though variable from year to year, until the present. The terminal year exploitation rate is 0.036, with a range from 0.014 (2.5% confidence bound) to 0.089 (97.5% confidence bound) (Figure 6.72, Table 6.21).

DelMarVa (DMV)

The DMV region had a period of highly variable exploitation rates early in the time series, and then has been flat to decreasing up to the present. The terminal year exploitation rate is 0.018, with a range from 0.006 (2.5% confidence bound) to 0.044 (97.5% confidence bound) (Figure 6.77, Table 6.21).

6.4.5.2.3 Abundance or Biomass Estimates

Southern New England (SNE)
The SNE region had a period of high abundance early in the time series, dropping down to low levels during the early 1980s. Some slight increases can be seen in the early 2000s, but the population appears to be stable to decreasing and remains at a low biomass level. The terminal year biomass level is 2.99 tmt, with a range from 1.72 tmt (2.5% confidence bound) to 5.16 (97.5% confidence bound) (Figure 6.65, Table 6.21).

New York – New Jersey (NY-NJ)
The NY-NJ region had a period of increasing abundance early in the time series, the biomass peaks in the early 1990s, but then drops down to low levels during the late 1990s. During the 2000s the population has been variable around a mean value of roughly 11 tmt. The terminal year biomass level is 11.68 tmt, with a range from 4.79 tmt (2.5% confidence bound) to 30.45 (97.5% confidence bound) (Figure 6.69, Table 6.21).

DelMarVa (DMV)
The DMV region had a period of high abundance early in the time series, but then drops down to lower levels during the late 1990s. The trend has been flat to increasing to the present. The shape of the trend is similar to the SNE region, but the magnitude of the population is less. The terminal year biomass level is 5.57 tmt, with a range from 2.31 tmt (2.5% confidence bound) to 16.50 (97.5% confidence bound) (Figure 6.73, Table 6.21).

6.4.5.2.4 Reference Points

The Bayesian State Space Surplus Production model internally produces 3 biological reference points. The three metrics are exploitation of maximum sustainable yield (U_{MSY}), maximum sustainable biomass (B_{MSY}), and maximum sustainable yield (MSY). These three metrics were produced for each of the three regions and compared to the terminal year estimate of biomass and exploitation for that region. In addition, a three year average for biomass and exploitation was calculated and compared to the regional B_{MSY} and U_{MSY} reference points (Figure 6.8.7).

Southern New England (SNE)
The SNE region has a calculated U_{MSY} = 0.073 (range from 0.051 – 0.122 for the 95% confidence bounds). The calculated B_{MSY} = 9.56 tmt (range from 7.22 – 12.27 tmt for the 95% confidence bounds). Finally the estimated MSY = 0.71 tmt (range from 0.52 – 0.96 for the 95% confidence bounds). It is evident when you compare the biological reference points to the terminal year estimates that stock status in this region is poor (overfished and overfishing) according to this modeling approach, despite harvest dropping below the MSY level in the terminal year (Table 6.21).

New York – New Jersey (NY-NJ)
The NY-NJ region has a calculated U_{MSY} = 0.138 (range from 0.055 – 0.241 for the 95% confidence bounds). The calculated B_{MSY} = 7.41 tmt (range from 4.10 – 15.68 tmt for the 95% confidence bounds). Finally the estimated MSY = 1.01 tmt (range from 0.36 – 2.37 for the 95% confidence bounds). It is evident when you compare the biological reference points to the terminal year estimates that stock status in this region is good (not overfished and overfishing not occurring) according to this modeling approach, and harvest is currently below the MSY level in the terminal year (Table 6.21).

DelMarVa (DMV)

The DMV region has a calculated $U_{MSY} = 0.117$ (range from 0.054 – 0.237 for the 95% confidence bounds). The calculated $B_{MSY} = 4.10$ tmt (range from 2.13 – 9.31 tmt for the 95% confidence bounds). Finally the estimated MSY = 0.44 tmt (range from 0.27 – 1.40 for the 95% confidence bounds). It is evident when you compare the biological reference points to the terminal year estimates that stock status in this region is good (not overfished and overfishing not occurring) according to this modeling approach, and harvest is currently below the MSY level in the terminal year (Table 6.21).

6.4.5.3 Sensitivity Analyses

6.4.5.3.1 Sensitivity to Input Data

Overall, it was found that the model was robust to the indices used and the starting values chosen to initiate the chains in the modeling procedure. When looking at the base configurations, convergence on a solution was achieved in all cases (see Appendix 1.1 – 1.3). Minor discrepancies in output were seen from the series of plots which dropped out individual indices (Figures 6.79, 6.80, 6.83, 6.84). One notable exception to this statement was found for the New York – New Jersey region. When the MRIP index was included or removed, significant differences were seen in the output for this region in both the biomass trends and in the exploitation rates (Figures 6.79 and 6.80). In general, the model sensitivity tests indicated that this region was sensitive to the indices included, though the impact on biomass trends was impacted to a greater degree than the impact on exploitation rates.

A second notable sensitivity was found in the Southern New England region when the CT trawl survey was removed. The trend is similar to the other sensitivity runs performed for this region, but the magnitude of both biomass and exploitation is different (Figures 6.83 and 6.84). Stock status does not change but does become less severe.

6.4.5.3.2 Sensitivity to Model Configuration

The model was able to converge on a consistent solution regardless of the initial starting values chosen for the two chains used for the analysis. In addition, the model was able to converge on a solution regardless of the regional configuration used (Figures 6.77 and 6.78), so the approach seems robust to the model configuration. When doing a comparison of the different regional configurations, one test of model performance would be to determine if there are large differences in total biomass between the models for the different configurations, namely does the two region model sum up to the biomass produced by the coastwide model. From a visual inspection it can be determined that in many years, a sum of the two region modeling framework (Northern Region, Southern Region) very nearly sums up to the coastwide total (Figure 6.77). When comparing the 3 region model to the coastwide however, there appears to be some discrepancies, mainly from the biomass being generated from the New York – New Jersey region model (Figure 6.77). On average, the summed biomass for the two region model was 44% greater than that produced for the coastwide model, 67% higher for the baseline three region configuration, and only 12% higher when using the alternate three region configurations (Table 6.21).

When reviewing exploitation rates from different model configurations we see that there are two groupings that seem to correlate, namely that the coastwide, northern region, and SNE regions have similar trends and magnitudes in exploitation rates, while the remaining regions (Southern region, NY-NJ, and DelMarVa) are similar to each other (Figure 6.78). These groupings are logical and indicate some stability in the model under different configurations.

6.4.5.4 Results Uncertainty (i.e. interpretation of model results)

Results from the various regional configurations seem reasonable and relatively stable. The main concern with the BSSSPM modeling approach is found with the New York – New Jersey region. There seem to be two alternate possibilities for stock status and population trends depending on the indices used and the configuration of the region. In addition, even in the base run for the New York – New Jersey region, the probability around the point estimates for the various parameters was fairly large, and some areas within the confidence bounds would actually change the stock status determination, namely the lower bound for the terminal year biomass estimate would fall below the B_{MSY} level (Tables 6.14 and 6.21). The other regions seem more stable despite indices used or regional configuration as stock status doesn't change, however the magnitude of the stock status impairment for the Southern New England region decreases with some of the alternatives.

In addition to the internal diagnostics, a degree of confidence in the BSSSPM modeling approach is also found when comparing the results to the other models used during this benchmark assessment process.

After the analysis, it was discovered that the BSSSPM is sensitive to the indices included in the model. This determination is based on the diagnostics of the regional models in particular the New York-New Jersey region model. Due to this sensitivity, further analysis would be needed before this model could be used for management purposes.

It is not believed that the BSSSPM should be used as the model for management for the tautog stock, however, the development of this model was continued for use as a corroborating approach that was less data intensive than the age structured approach used as the preferred model for this assessment. This approach should be continued and developed for inclusion in future updates and benchmarks because it provides a good frame of reference.

6.5 Virtual Population Analysis (Continuity Run)

6.5.1 Background

NMFS NFT Tool Box VPA version 3.0.1 was used for the runs. This model is a standard Virtual Population Model which projects the population backwards in time from the starting year of 2011. The model uses a Levenburg Marquadt non-linear least squares algorithm to maximize the fit to Popes Catch equation on an annual catch at age matrix and a suite of age-disaggregated fisheries independent indices. Standard outputs are F, January 1 population size (numbers) and SSB (MT). A bootstrap re-sampling function is used to estimate the output CVs and confidence intervals.

Additional information on model structure can be found at http://nft.nefsc.noaa.gov/VPA.html.

6.5.2 Reference Point Model Description

No reference points were developed from this continuity run. Output was compared to the F reference points established in Addendum VI to the Tautog FMP.

6.5.3 Configuration

6.5.3.1 Spatial and Temporal Coverage

The model was run using the catch at age for the Coastwide Region (Massachusetts through Virginia) and state's fisheries independent data (trawl surveys) from Massachusetts – New Jersey. The catch data stream runs from 1982 (the start of reliable recreational catch records) to 2011, while the fisheries independent data streams begin as early 1982 and goes out to 2012. 2012 catch data was not included in the model run as 2013 indices and 2013 age keys were not complete at the time. The model was run both with the original MRFSS recreational catch plus the final year Marine Recreational Information Program estimates and the revised MRIP catch information from 2004 to 2011. New age keys were developed from 1995 to 2012 using all available age samples which included previously unread collections and some otolith age data from Virginia, after an ageing workshop reviewed the appropriateness of the use of that data.

6.5.3.2 Selection and Treatment of Indices

Indices for this run were the same (49) as used in previous VPA runs for comparison to previous stock assessment results. Indices (numbers at length) were aged using the appropriate regional age keys – states Massachusetts through New York with the Northern Region age keys, and New Jersey with the Southern Region age keys.

6.5.2.3 Parameterization

The natural mortality rate M was set at 0.15 based on the previous assessment values. This value is consistent with that used in the other models presented here based on a literature review, modeling work and a model averaging approach. The proportion of natural mortality before spawning and the proportion of fishing mortality before spawning were set at 0.42 and 0.15 consistent with previous VPA runs.

The proportion mature at age and partial recruitment values were the same as used in the 2011 update (Table 6.22). The plus group was set at age 12+ consistent with past assessments. F was calculated using the classic method.

F oldest age in terminal year – F was multiplied by the input partial recruitment, F oldest true age was calculated using the arithmetic mean, and F oldest calculation starting year was set at 8 and the ending year set at 10, consistent with past assessments and prior peer review recommendations.

6.5.3 Estimating Precision

Bootstrapping (500 runs) was used to estimate the precision of estimated parameters and derived quantities.

6.5.4 Sensitivity Analyses

6.5.4.1 Sensitivity to Input Data

A range of M values from 0.10 to 0.20 was explored in 0.05 increments using the models sensitivity option.

6.5.5 Retrospective Analyses

Within model retrospective analysis was performed within the model. A 6 year peel from the terminal year was used.

6.5.6 Results

6.5.6.1 Goodness of Fit

The total model MSR was 0.728 as opposed to previous VPA MSR values around 0.60. The CV for catch weighted F ages 8-10 was 0.18. The CV for the January 1 population number estimate was 0.18. The CV for the spawning stock biomass estimates was 0.14

6.5.6.2 Parameter Estimates

6.5.6.2.1 Selectivities and Catchability

Back calculated partial recruitment is presented in Table 6.98, and catchability estimates are presented in Table 6.23.

6.5.6.2.2 Exploitation Rates (nlls estimates)

Fishing mortality rates have mostly fluctuated without trend over the time series, although the population experienced a period of slightly lower average F rates from 1998-2005, before spiking again. F rates have been declining since a recent high in 2007. The estimated catch weighted F in the terminal year (F_{2011}) is 0.14, CI = 0.11 to 0.16 (Figure 6.93). The three-year average estimate of F was 0.28.

F_{2011} was below the F_{target}= 0.15 established in Addendum IV, but the three-year average was not, indicating overfishing was occurring.

6.5.6.2.3 Abundance or Biomass Estimates

Estimates of total abundance and spawning stock biomass have declined significantly since 1982 (Figure 6.94). SSB stabilized around 1998, while total abundance exhibited a slight upward trend after that. SSB_{2011} was estimated at 8,895 MT (80% CI: 8,058 – 10,278 MT). 2012 Jan 1 numbers were estimated at 10.9 million fish (80% CI: 9.8 – 13.2 million fish).

6.5.6.3 Sensitivity Analyses

6.5.6.3.1 Sensitivity to Input Data

F estimates were less sensitive to M, while estimated biomass levels in the terminal year are sensitive to M. Output F_{2011} estimates ranged from 0.24 to 0.12, SSB_{2011} estimates ranged from 2,000 to 10,000 MT.

Past modeling of catch has been shown the model to be highly sensitive to the catch stream as well, which in this case is measured with considerable variance.

6.5.6.4 Retrospective Analyses

Previous VPA runs had only slight retrospective patterning. Large retrospective patterns emerged with the input of revised 2004-2011 MRIP data. Relative difference values from the retrospective analysis of F ranged from +46% (2007) to -33% (2009), for SSB +35% (2006) to -60% (2010), and for January 1 sock numbers +75% (2006) to -91% (2008) (Figure 6.95).

6.5.6.7 Results Uncertainty

This VPA has historically been used for this species, but the recreational catch accounts for the majority catch and has considerable uncertainty. The VPA model has issues dealing with catch uncertainty and the model fit has declined. In addition, a severe retrospective pattern has emerged. Thus the Technical Committee preferred ASAP's statistical catch-at-age framework as an age-structured model to assess this species. Also, the VPA framework is unable to work with the preferred regional assessment approach. While the Coastwide and Northern Region runs converged, Southern Region runs did not and three region runs, while not implemented, would not be expected to converge.

6.5.7 ASAP Extension of the VPA Continuity Run

The VPA inputs for the coastwide model were used as input to the ASAP model, to examine the effects of model structure on the final output. MRIP PSEs were used as CVs on catch, and index CVs were adjusted to get a RMSE close to one for each index. In addition, index-at-age values were fit assuming a multinomial distribution of proportions at age, rather than treating each index-at-age time series as a separate index, as is done in the VPA.

Overall trends were similar for both models. ASAP estimated lower SSB and abundance than the VPA for most of the time series (Figure 6.96). Around 2005, the VPA estimated SSB stabilized and abundance increased slightly, while ASAP showed declining trends in both.

ASAP also estimated a lower F for most of the time series, but starting in 2010, the VPA predicted a sharper decline in F and the 3-year average F than ASAP did (Figure 6.97). Note that the N-weighted average F over ages 8-10 are being compared between the VPA and ASAP, due to differences in how each model handles separability of F and selectivity patterns.

6.6 Additional Models Considered

6.6.1 Depletion Corrected Average Catch

The Depletion Corrected Average Catch (DCAC) method (MacCall 2009) was also considered for this assessment. DCAC provides an estimate of annual harvest that is likely sustainable but not overly cautious. If available data indicate that stock biomass has not been detrimentally impacted by harvest over time, then one estimate of a sustainable harvest would be the average harvest over the time series. However, unless annual harvest is very low, it is unlikely that the population is not affected by harvest. DCAC is an extension of the classical average catch method that incorporates information on the effect of harvest on population size. The number of years used in the average catch equation, and therefore the potential yield estimate, is “corrected” based on changes in the depletion level of the stock over the time series. A full description of the model is provided in MacCall (2009).

Although preliminary runs of the DCAC model were conducted, the TC elected not to pursue DCAC for this assessment. The estimates of potential yield from DCAC are *ad hoc* reference points. As the other models being investigated, which provide more rigorous reference points, appeared to be performing well at all regional scales, the need for DCAC was diminished.

6.6.2 Catch-MSY Method

The TC investigated the Catch-MSY Method described by Martell and Froese (2012). The simplest of production models require estimates of annual harvest and abundance in order to estimate population growth and carrying capacity (r and K parameters). However, with just a time series of harvest, Martell and Froese (2012) show there is only a small range of r and K combinations that produce valid ($0 < \text{biomass} < K$) trends. The Catch-MSY method is a data poor method to estimate r and K parameters, and thus MSY-based reference points, using only harvest, estimated change in relative population size, and assumptions about a species’ resilience. Preliminary runs of this model were conducted, as were investigations into Bayesian extensions of the model (similar to xDB-SRA methods of Dick et al, in prep.). The TC however, determined that use of the Catch-MSY method was not necessary because the Bayesian State Space Surplus Production Model, which is based on the same r and K parameters and is a much more rigorous model, was performing well at most regional levels.

6.7 Comparison of Models and Results

Comparisons of estimates of exploitation rates (μ) and total biomass for the ASAP, xDB-SRA, and BSSSPM models by region are shown in Figures 6.91 and 6.92, respectively. For the ASAP model runs, the annual exploitation rates were calculated as predicted catch divided by total biomass, to be comparable to the rates estimated by the surplus production-type models. In order to compare overfished status determinations across models, estimates of SSB were divided by the SSB threshold for ASAP runs, and estimates of total biomass were divided by estimates of the biomass threshold (75% BMSY) for the xDB-SRA and BSSSPM runs. Similarly, to compare overfishing status determinations, 3-year average estimates of F were divided by the F threshold for the ASAP model runs, and 3-year average estimates of μ were divided by the exploitation rate threshold for the xDB-SRA and BSSSPM runs.

For the southern New England region, all three models produced very similar estimates of total biomass and exploitation rate (Figure 6.91 and 6.92); this region had the most consistent estimates out of all three regions. Estimates of stock status (overfished and overfishing occurring in the terminal year) were also consistent across all three models, although ASAP suggested the stock started out much higher, relative to SSBMSY and became overfished later than the other two models. In addition, ASAP suggested that the level of overfishing at the beginning of the time-series was not as severe as the other two models estimated. It is important to note that although the MSY-based reference points are proposed for use in the SNE region, the results from ASAP are not directly comparable to the MSY-based estimates from the two other surplus production-type models, and the differing assumptions in how MSY-based reference points are calculated across models is what is driving the difference in relative trends despite estimates of B and μ being very consistent across models.

For the NY-NJ and DelMarVa regions, the trends in exploitation rates (Figure 6.91) were very similar; however, the magnitude of the estimates differed across the models, with ASAP estimates being the highest and the BSSSPM estimates being the lowest. ASAP and xDB-SRA suggested similar trends in overfishing status for both region. Both models indicated overfishing was not occurring in either region in the terminal year, although it had been occurring for most of the time-series, including the most recent years of 2007-2011 (and 2012, according to ASAP). In the most recent years, ASAP was more pessimistic about the level of overfishing. However, the BSSSPM suggested that overfishing had never occurred for either region, with the 3-year average μ being less than μMSY for all years.

For the NY-NJ region, ASAP and xDB-SRA produced similar trends in total biomass, although the xDB-SRA estimates were consistently higher than the ASAP estimates. These two models also produced similar trends in overfished status, with both models indicating the stock became overfished in the late 1990s and remained so until 2013, although the terminal year estimates are close to their respective SSB or B thresholds. The BSSSPM produced different results in terms of trends and absolute magnitude for both biomass and overfished status. The BSSSPM suggested that the stock has been undergoing fluctuations in abundance around a relatively steady mean that was greater than the estimates from xDB-SRA and ASAP, while both xDB-SRA and ASAP suggested the population had declined since the beginning of their respective time-series, with a slight increase at the end. In addition, the BSSSPM indicated that the NY-NJ stock had never been overfished, with B greater than Bthreshold in all years.

For the DelMarVa region, all three models showed similar trends in total biomass. However, while ASAP and xDB-SRA produced relatively similar estimates of the magnitude of B, the BSSSPM estimated B was twice as great as the estimates from ASAP and xDB-SRA. ASAP and xDB-SRA also produced similar estimates of overfished status. Both models indicated the stock became overfished in 1996 and remained at or below the SSB or B threshold for the rest of the time series. ASAP was slightly more pessimistic about the degree to which the stock was overfished, but both agreed that the stock has increased in recent years and is very near the threshold. However, the BSSSPM again indicated that the DelMarVa stock had never been overfished, with B greater than Bthreshold in all years.

Overall, the three models produced the most consistent estimates of biomass and exploitation rate in the southern New England region. This is most likely due to the fact that there are multiple indices with consistent signals that cover the entire time series and are consistent with trends in catch. The models produced slightly different estimates of potential productivity, in terms of trends in biomass relative to their respective reference points, but all three models resulted in consistent stock status determinations for this region: overfished and overfishing occurring in the terminal year.

ASAP and xDB-SRA produced similar trends in total biomass and exploitation rates in the other two regions and agreed on stock status in both regions: overfished (although close to the threshold), and overfishing not occurring in the terminal year.

The BSSSPM was not consistent with the other two models for these regions in terms of magnitude of estimates or, in the case of NY-NJ, even trends. It agreed with the overfishing status produced by ASAP and the xDB-SRA (not overfishing in the terminal year), but also indicated the stock had not experienced overfishing at any point in the time-series, which was not consistent with the other two models. It also did not produce the same overfished status as ASAP and DBSRA, indicating that the stock was not overfished in the terminal year, and had not been overfished at any point in the time-series.

The BSSSPM was not as stable as the other two models; in particular, in the NY-NJ region it was very sensitive to the inclusion or exclusion of indices. In addition, surplus production models can sometimes have problems establishing the magnitude of population size relative to reference points when the data follow the “one-way trip” pattern (i.e., landings and indices show only declines), and when data do not have strong contrast between population sizes, as appears to be the case in the DelMarVa region, which may explain why the BSSSPM showed similar trends in B and U, but not in stock status for that region.

Although the BSSSPM needs additional work to improve its stability and performance, the similarity of results in the southern New England region across models, and the similarity in results between ASAP and xDB-SRA, which are structurally very different models, is encouraging about the reliability of the assessment of stock status.

7.0 STOCK STATUS

7.1 Current Overfishing and Overfished Definitions

In April 2011, Addendum VI to the FMP established a new F_{target} of F = M = 0.15 for the coastwide stock. Btarg and Blim were established in Addendum 4 (2007) at 26,800 and 20,100 MT. Results from the 2011 assessment update were F=0.23 and SSB=10,663 MT, indicating the stock is overfished and overfishing is occurring.

7.2 New Proposed Definitions

The TC proposed an SSB target of SSB_{MSY} and an SSB threshold of 75% SSB_{MSY} for southern New England. The TC chose 75% SSB_{MSY} rather than the more commonly selected threshold of 50% SSB_{MSY}, due to concerns about tautog's slow growth and lower steepness. For this region, the TC proposed an F target of F_{MSY} and an F threshold of the F necessary to achieve 75%SSB_{MSY}, under equilibrium conditions.

Due to concerns about the reliability of the stock-recruitment relationships fit by the model for the NY-NJ and DelMarVa regions, the TC proposed an F target of $F_{40\%SPR}$ and an F threshold of $F_{30\%SPR}$. SSB targets and thresholds were estimated based on the long-term equilibrium biomass associated with those F targets and thresholds under conditions of observed average recruitment.

	SSB target		**SSB threshold**		**F target**		**F threshold**	
	Definition	Value	Definition	Value	Definition	Value	Definition	Value
SNE	SSB_{MSY}	3,883 MT	75%SSB_{MSY}	2,912 MT	F_{MSY}	0.15	F associated with 75%SSB_{MSY}	0.20
NY-NJ	SSB associated with $F_{40\%SPR}$	3,570 MT	SSB associated with $F_{30\%SPR}$	2,640 MT	$F_{40\%SPR}$	0.17	$F_{30\%SPR}$	0.26
DMV	SSB associated with $F_{40\%SPR}$	2,090 MT	SSB associated with $F_{30\%SPR}$	1,580 MT	$F_{40\%SPR}$	0.16	$F_{30\%SPR}$	0.24

7.3 Stock Status Determination

7.3.1 Overfishing Status

The ASAP model runs indicated overfishing was occurring in the Southern New England region in 2013. Both the point estimate of F_{2013}=0.59 and the 3 year average value of F=0.45 were above both F_{Target}=0.26 and $F_{threshold}$=0.44 (Table 7.1, Figure 7.1).

The results were consistent with the xDB-SRA and BSSSPM models, which both indicated exploitation rates were above U_{MSY} estimates in southern New England.

The ASAP model runs indicated overfishing was not occurring in the NY-NJ region in 2013. Both the point estimate of F_{2013}=0.21 and the 3 year average value of F=0.25 were below $F_{Threshold}$=0.26 but above F_{Target}=0.17 (Table 7.1, Figure 7.1).

The results were consistent with the xDB-SRA and BSSSPM models, which both indicated exploitation rates were below U_{MSY} estimates in the NY-NJ region.

The ASAP model runs indicated overfishing was not occurring in the DelMarVa region in 2013. Both the point estimate of F_{2013}=0.10 and the 3 year average value of F=0.17 were below both $F_{Threshold}$=0.24 and above F_{Target}=0.16 (Table 7.1, Figure 7.1).

The results were consistent with the xDB-SRA and BSSSPM models, which both indicated exploitation rates were below U_{MSY} estimates in the DelMarVa region.

7.3.2 Overfished Status

The ASAP model runs indicated the tautog stock was overfished in the southern New England region. SSB in 2013 was 1,839 MT, below both the SSB_{target}=3,090 MT and the $SSB_{threshold}$=2,310 MT (Table 7.1, Figure 7.2).

The results were consistent with the xDB-SRA and BSSSPM models, which both indicated biomass was below 75% B_{MSY} estimates in southern New England.

The ASAP model runs indicated the tautog stock was overfished in the NY-NJ region as well. SSB in 2013 was 2,078 MT, below both the SSB_{target}=3,570 MT and the $SSB_{threshold}$=2,640 MT (Table 7.1, Figure 7.2).

This was consistent with the results of the xDB-SRA, which indicated B was below 75% B_{MSY}, but not with the results of the BSSSPM, which indicated the stock was above B_{MSY}.

The ASAP model runs indicated the tautog stock was overfished in the DelMarVa region as well. SSB in 2013 was 1,459 MT, below both the SSB_{target}=2,090 MT and the $SSB_{threshold}$=1,580 MT (Table 7.1, Figure 7.2).

This was consistent with the xDB-SRA model, which indicated B was just below 75% B_{MSY}, but not with the results of the BSSSPM, which indicated the stock was above B_{MSY}.

8.0 RESEARCH RECOMMENDATIONS

The Technical Committee identified the following research recommendations to improve the stock assessment and our understanding of tautog population and fishery dynamics. Research recommendations are organized by topic and level of priority. Research recommendations that should be completed before the next benchmark assessment are underlined.

8.1 Fishery-Dependent Priorities

High

- Expand biological sampling of the commercial catch for each gear type over the entire range of the stock (including weight, lengths, age, sex, and discards).
- Continue collecting operculum from the tautog catch as the standard for biological sampling in addition to collecting paired sub-samples of otoliths and operculum.
- Increase catch and discard length sampling from the commercial and recreational fishery for all states from Massachusetts through Virginia.
- Increase collection of effort data for determining commercial and recreational CPUE.
- Increase MRIP sampling levels to improve recreational catch estimates by state and mode. Current sampling levels are high during times of the year when more abundant and popular species are abundant in catches, but much lower in early spring and late fall when tautog catches are more likely.

8.2 Fishery-Independent Priorities

High

- Conduct workshop and pilot studies to design a standardized, multi-state fishery independent survey for tautog along the lines of MARMAP and the lobster ventless trap survey.
- Establish standardized multi-state long-term fisheries-independent surveys to monitor tautog abundance and length-frequency distributions, and to develop YOY indices.
- Enhance collection of age information for smaller fish (<20 cm) to better fill in age-length keys.

8.3 Life History, Biological, and Habitat Priorities

Moderate

- Define local and regional movement patterns and site fidelity in the southern part of the species range. This information may provide insight into questions of aggregation versus recruitment to artificial reef locations, and to clarify the need for local and regional assessment.

- Assemble regional reference collections of paired operculum and otolith samples and schedule regular exchanges to maintain and improve the precision of age readings between states that will be pooled in the regional age-length keys.

- Calibrate age readings every year by re-reading a subset of samples from previous years before ageing new samples. States that do not currently assess the precision of their age readings over time should do so by re-ageing a subset of their historical samples.

Low

- Evaluate the potential impacts of climate change on tautog range, life history, and productivity.

- Conduct a tag retention study to improve return rates, particularly in the northern region.

- Define the status (condition and extent) of optimum or suitable juvenile habitats and trends in specific areas important to the species. It is critical to protect these habitats or to stimulate restoration or enhancement, if required.

- Define the specific spawning and pre-spawning aggregating areas and wintering areas of juveniles and adults used by all major local populations, as well as the migration routes used by tautog to get to and from spawning and wintering areas and the criteria or times of use. This information is required to protect these areas from damage and overuse or excessive exploitation.

- Define larval diets and prey availability requirements. This information can be used as determinants of recruitment success and habitat function status. Information can also be used to support aquaculture ventures with this species.

- Define the role of prey type and availability in local juvenile/adult population dynamics over the species range. This information can explain differences in local abundance, movements, growth, fecundity, etc. Conduct studies in areas where the availability of primary prey, such as blue mussels or crabs, is dependent on annual recruitment, the effect of prey recruitment variability as a factor in tautog movements (to find better prey fields), mortality (greater predation exposure when leaving shelter to forage open bottom), and relationship between reef prey availability/quality on tautog condition/fecundity.

- Define the susceptibility of juveniles to coastal/anthropogenic contamination and resulting effects. This information can explain differences in local abundance, movements, growth, fecundity, and serve to support continued or increased regulation of the inputs of these contaminants and to assess potential damage. Since oil spills seem to be a too frequent coastal impact problem where juvenile tautog live, it may be helpful to conduct specific studies on effects of various fuel oils and typical exposure concentrations, at various seasonal temperatures and salinities. Studies should also be conducted to evaluate the effect of common piling treatment leachates and common antifouling paints on YOY tautog. The synergistic effects of leaked fuel, bilge water, treated pilings, and antifouling paints on tautog health should also be studied.

- Define the source of offshore eggs and larvae (in situ or washed out coastal spawning).
- Confirm that tautog, like cunner, hibernate in the winter, and in what areas and temperature thresholds, for how long, and if there are special habitat requirements during these times that should be protected or conserved from damage or disturbance. This information will aid in understanding behavior variability and harvest availability.

8.4 Management, Law Enforcement, and Socioeconomic Priorities

Moderate

- Collect data to assess the magnitude of illegal harvest of tautog.

Low

- Collect basic sociocultural data on tautog user groups including demographics, location, and aspects of fishing practices such as seasonality.

8.5 Research Recommendations That Have Been Met

- ✓ Sample hard parts for annual ageing from the catches of recreational and commercial fisheries and fishery-independent surveys throughout the range of the stock. *Being conducted by all participating states.*
- ✓ Conduct hard part exchange and ageing workshop to standardize techniques and assess consistency across states. *Conducted May 2012, report available at http://www.asmfc.org//uploads/file/2012_Tautog_Ageing_Workshop_Report.pdf*

8.6 Future Stock Assessments

The TC recommends conducting an update in 2016 and a benchmark stock assessment in 2019.

9.0 LITERATURE CITED

Alverson, D. L., and M. J. Carney. 1975. A graphic review of the growth and decay of population cohorts. ICES Journal of Marine Science 36:133-143.

Atlantic States Marine Fisheries Commission. 1996. Fisheries Management Plan for Tautog. ASMFC, Washington, DC.

Atlantic States Marine Fisheries Commission. 2002. Addendum III to the Fisheries Management Plan for Tautog. ASMFC, Washington, DC.

Atlantic States Marine Fisheries Commission. 2006. Tautog stock assessment report for peer review. Report No. 06-02. Arlington, VA.

Atlantic States Marine Fisheries Commission. 2012. Proceedings of the Tautog Ageing Workshop. ASMFC, Arlington, VA. Access: http://www.asmfc.org/uploads/file/2012_Tautog_Ageing_Workshop_Report.pdf

Arendt, M., J. Lucy, and T. Munroe. 2001. Seasonal occurrence and site-utilization patterns of adult tautog, *Tautoga onitis* (Labridae), at manmade and natural structures in Chesapeake Bay. Fish Bull. 99:519-527.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Service, Fishery Bulletin 74: 223-230 p.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish & Wildlife Service Fishery Bulletin 77:1-576.

Briggs, P.T. 1969. The Sport Fisheries for Tautog in the Inshore Waters of Eastern Long Island. NY Fish & Game J. Vol. 16(2):238-254.

Briggs, P.T. 1975. An Evaluation of Artificial Reefs in New York's Marine Waters. NY Fish & Game J. Vol. 22(1):51-56.

Briggs, P.T. 1977. Status of Tautog Populations at Artificial Reefs in New York Waters and Effect of Fishing. NY Fish & Game J. Vol. 24(2):154-167.

Briggs, P.T. and J.S. O'Connor. 1971. Comparison of Shore-Zone Fishes Over Naturally Vegetated and Sand-Filled Bottoms in Great South Bay. NY Fish & Game J. Vol. 18(1):15-41.

Brodziak, J., Ianelli, J., Lorenzen, K. and R.D. Methot, Jr. 2011. Estimating natural mortality in stock assessment applications. NOAA Technical Memorandum NMFS-F/SPO, 119, 38p.

Brodziak, J. K. T., E. M. Holmes, K. A. Sosebee, R. K. Mayo. 2001. Assessment of the silver hake resource in the Northwest Atlantic in 2000. Northeast Fish. Scie. Cent. Ref. Doc. 01-03:

134p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

Brooks, SP. and Gelman, A. 1997. General methods for monitoring convergence of iterative simulations. Journal of Computational and Graphical Statistics. 7: 434-455p.

Capossela, K. 2014. Natural Mortality of Tautog. Maryland Department of Natural Resources. Personal communication.

Charnov, E. L., and D. Berrigan. 1990. Dimensionless numbers and life history evolution: age of maturity versus the adult lifespan. Evolutionary Ecology 4:273–275.

Chenoweth, S. 1963. Spawning and fecundity of the tautog, Tautoga onitis. M.S. thesis. University of Rhode Island. North Kingston, RI, 60 p.

Connecticut Department of Energy and Environmental Protection. 2013. A study of marine recreational fisheries in Connecticut – Marine finfish survey – Long Island Sound Trawl Survey Annual report. Federal Aid Project F-54-R-32.

Cooper, R.A. 1966. Migration and Population Estimation of the Tautog Tautoga onitis (Linnaeus), from Rhode Island. Trans. Am. Fish. Soc. 95(3):239-247.

Cooper, R.A. 1967. Age and growth of the tautog, Tautog onitis (Linnaeus), from Rhode Island. Transactions of the American Fisheries Society 96:134-142.

Dick, E.J., M. De Yoreo, and A. MacCall. In prep. A Bayesian approach to estimating sustainable yields for data-poor stocks. Draft report for NMFS Workshop on Assessment Methods for Data-Moderate Stocks. June 26-29, 2012, Seattle, WA.

Dixon, M.S. 1994. Habitat Selection in Juvenile Tautog, Tautoga onitis and Juvinile Cunner, Tautogolabrus adspersus. MS. Thesis. UCONN. 77 pp.

Dorf, B.A. and J.C. Powell. 1997. Distribution, Abundance and Habitat Characteristics of Juvenile Tautog (Tautoga onitis, Family Labridae) in Narragansett Bay, Rhode Island, 1988-1992. Estuaries. 20(3):589-600.

Ecklund, A.M. and T.E. Targett. 1990. Reproductive seasonality of fishes inhabiting hard bottom areas in the Middle Atlantic Bight. Copeia 1990:1180-1184.

Flint, R.F. 1971. Glacial and Quarternary Geology. John Wiley and Sons, Inc.

Gauthier, D.A., J.A. Lincoln, and J.T. Turner. 2008. Distribution, abundance, and growth of larval tautog, Tautoga onitis, in Buzzards Bay, Massachusetts. USA. Marine Ecology 29: 76-88.

Gelman, A and Rubin, DB (1992) Inference from iterative simulation using multiple sequences. Statistical Science. 7: 457-511p.

Gulland, J.A. 1983. Fish Stock Assessment. FAO/Wiley Series on Food and Agriculture. Vol. 1.

Hewitt, D.A. and J.M. Hoenig. 2005. Comparison of two approaches for estimating natural mortality based on longevity. Fishery Bulletin 103:433-437.

Hilborn, R. and C.J. Walters. eds. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics, and Uncertainty. Pg. 68.

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin, 82: 898–903.

Hoenig, J, J, Lucy, T. Tuckey and N. Yochum, 2005, Submission to the ASMFC Tautog Stock Assessment Sub-committee.

Hostetter, E.B. and T.A. Munroe 1993. Age, growth, and reproduction of tautog Tautoga onitis (Labridae: Perciformes) from coastal waters of Virginia. Fishery Bulletin 91:45-64.

Jaccard, Paul (1901), "Étude comparative de la distribution florale dans une portion des Alpes et des Jura", Bulletin de la Société Vaudoise des Sciences Naturelles 37: 547–579.

Jensen, A. L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53:820–822.

Kalman, R. E. 1960. A new approach to linear filtering and prediction problems. Journal of Basic Engineering, 82: 34-45.

Kenchington, T. 2013. Natural mortality estimators for information-limited fisheries. Fish and Fisheries. Online publication 6 Apr 2013.

Kimura, D. K., J. W. and D. H. Ito. 1996. Kalman filtering the delay difference equation practical approaches and simulations. Fisheries Bulletin, 94: 678-691.

LaPlante, L.H. and Eric Schultz. 2007. Annual Fecundity of Tautog in Long Island Sound: Size Effects and Long-Term Changes in a Harvested Population. American Fisheries Society 136: 1520-1533.

Lucy, J.A., C.M. Bain III, and M.D. Arendt. 1999. Virginia Game Fish Tagging Program Annual Report, 1998. Virginia Marine Resources Report Number 99-98.

Lynch, T.R. 1991. Marine Finfish Investigation, Sport Fish Population Survey in Rhode Island Marine Waters – Tautog Studies, January 1, 1990 – December 31, 1990. Rhode Island Division of Fish & Wildlife Performance report Project: F-54-R-1, Study: I-I.

Marine Recreational Information Program (MRIP), “Recreational Fisheries Statistics Queries,” April 28, 2013, http://www.st.nmfs.noaa.gov/recreational-fisheries/access-data/run-a-data-query/queries/index

Martell, S. And R. Froese. 2012. A simple method for estimating MSY from catch and resilience. Fish and Fisheries. 14:4. 504-514.

McAllister, M. K., and Ianelli, J. N. 1997. Bayesian stock assessment using catch-agedata and the Sampling/Importance Resampling Algorithm. Canadian Journal of Fisheries and Aquatic Sciences, 54: 284–300.

Meyer, R. and R. B. Millar. 1999a. BUGS in Bayesian stock assessments. Canadian Journal of Fisheries and Aquatic Sciences, 56: 1078-1086.

Meyer, R. and R. B. Millar. 1999b. Bayesian stock assessment using a state-space implementation of the delay difference model. Canadian Journal of Fisheries and Aquatic Sciences, 56: 37-52.

National Marine Fisheries Service (NMFS), “Annual Commercial Landing Statistics”, April 28, 2013. Access: http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index

New Jersey Department of Environmental Protection. 2013. Ocean Stock Assessment Program Annual Report.

NOAA Fisheries. 2013. Recreational Fisheries Statistics: 2013 MRIP Presentation. Access: http://www.st.nmfs.noaa.gov/recreational-fisheries/index

Northeast Fisheries Science Center (NEFSC). 2011. 51st Northeast Regional Stock Assessment Workshop (51st SAW) Assessment Report. US Dept Commerce, Northeast Fisheries Science Center Reference Document, 11-02; 856p.

Olla, B.L. A. J. Bejda, and A.D. Martin. 1974. Daily activity, movements, feeding and seasonal occurrence of the tautog, Tautoga onitis. Fishery Bulletin 72:27-35.

Olla, B.L., A.J. Bejde, and A.D. Martin. 1975. Activity, Movements and Feeding Behavior of the Cunner, Tautoglabrus adspersus, and Comparison of Food Habits with Young Tautog, Tautoga onitis, off Long Island, New York. Fishery Bulletin (U.S.) Vol. 73(4):895-900.

Olla, B.L., A.J. Bejde, and A.D. Martin. 1979. Seasonal Dispersal and Habitat Selection of the Cunner, Tautoglabrus adspersus and Young Tautog, Tautoga onitis, in Fire Island Inlet, Long Island, New York. Fishery Bulletin (U.S) Vol. 77(1):255-261.

Olla, B.L. and C. Samet. 1977. Courtship and spawning behavior of the tautog, Tautoga onitis (Pisces: Labridae), under laboratory conditions. Fishery Bulletin 75:585-599.

Olla, B.L.; Samet, C.; Studholme, A.L. 1981. Correlates between number of mates, shelter availability and reproductive behavior in the tautog, *Tautoga onitis*. Marine Biology (Berl.) 62:239-248.

Orbacz, E.A., and P. Gaffney. 2000, Genetic structure of tautog (Tautoga onitis) populations assayed by RFLP and DGGE analysis of mitochrondrial and nuclear genes. Fisheries Bulletin 98:336-344

Orth, R.J. and K.L. Heck Jr. 1980. Structural Components of Eelgrass (Zostera marina) Meadows in the Lower Chesapeake Bay-Fishes. Estuaries 3(4):278-288.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Reid, R.N., A.B. Frame and A.F. Draxler. 1979. Environmental baselines in Long Island Sound, 1972-73. NOAA Tech. Rpt. NMFS SSRF-738, 31 pp.

Richter, V. A., and V. N. Efanov. 1977. On one of the approaches for estimating natural mortality in fish populations (in Russian). Tr AtlantNIRO, via FAO 73:77-85.

Roff, D. A. 1986. Predicting body size with life history model. Bioscience 6:316-323.

Schnute, J. T. 1994. A general framework for developing sequential fisheries models. Canadian Journal of Fisheries and Aquatic Sciences, 51: 1676-1688.

Simpson, D.G. 1989. Population dynamics of the tautog, *Tautoga onitis*, in Long Island Sound. M.S. thesis. New Haven, CT: Southern Connecticut State Univ.; 65 p.

Simpson, D.G. and M. Gates, 1999. Studies in Conservation Engineering, Job 4. In: A Study of Marine Recreational Fisheries in Connecticut. Final Report. Pp 121 – 127. CT DEP Marine Fisheries Office, Old Lyme, CT.

Sissenwine, M.P. and L. Bowman. 1978. Factors affecting the catchability of fish by bottom trawls. ICNAF Research Bulletin No.13: 81-87.

Sogard, S.M., K.W. Able and M.P, Fahay. 1992. Early Life History of the Tautog Tautoga onitis in the Mid-Atlantic Bight. Fishery Bulletin, U.S. 90:529-539.

Steimle, F. W. and P. A. Shaheen. 1999. Tautog (*Tautoga onitis*) life history and habitat requirements. NOAA Technical Memorandum NMFS-NE-118.

Stephens, A. and A. McCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. Fisheries Research 70:299-310.

Stolgitis, J.A. 1970. Some aspects of the biology of tautog, Tautog onitis (Linnaeus), from the Weweantic River Estuary, Massachusetts, 1966. M.S. Thesis, University of Massachusetts, Amherst.

Sullivan, P. J. 1992. A Kalman filter approach to catch-at-length analysis. Biometrics, 48: 237-257.

Then, A., Hoenig, J., Hall, N. and D. Hewitt. In press. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on 201 fish species. ICES Journal of Marine Science.

Miller, T., 2014. University of Maryland Center for Environmental Science Chesapeake Biological Laboratory. Personal communications.

Wetzel, C.R. and A.E. Punt. 2011. Performance of a fisheries catch-at-age model (stock synthesis) in data-limited situations. Marine and Freshwater Research. 62: 927–936.

White, G.G. 1996. Reproductive Biology of Tautog, *Tautoga onitis*, in the Lower Chesapeake Bay and Coastal Waters of Virginia. M.S. Thesis. The College of William and Mary.

White, G.G., T.A. Munroe, and H.M. Austin. 2003. Reproductive seasonality, fecundity, and spawning frequency of tautog (Tautoga onitis) in the lower Chesapeake Bay and coastal waters of Virginia. Fisheries Bulletin 101: 424-442.

Wiedenmann, J., Michael J. Wilberg, and Thomas J. Miller. 2013. An Evaluation of Harvest Control Rules for Data-Poor Fisheries. North American Journal of Fisheries Management. 33:4, 845-860.

11.0 Tables

Table 1.1. Recreational regulations for tautog by state.

STATE	**SIZE LIMIT (inches)**	**POSSESSION LIMITS** (number of fish/ person/ day)	**OPEN SEASONS**
Massachusetts	16”	3	Jan 1 – Dec 31
Rhode Island	16”	3 3	Apr 15 – May 31 Aug 1 – Oct 15
		6 (up to 10 per vessel)	Oct 16- Dec 15 (private)
		6	Oct 20 – Dec 15 (party, charter)
Connecticut	16”	2 2 4	Apr 1-Apr 30 July 1 – Aug 31 Oct 10 – Dec 6
New York	16”	4	Oct 5 – Dec 14
New Jersey	15”	4 4 1 6	Jan 1 – Feb 28 Apr 1 – Apr 30 Jul 17 – Nov 15 Nov 16 – Dec 31
Delaware	15”	5 3 5 5	Jan 1 – Mar 31 Apr 1 – May 11 July 17 – Aug 31 Sept 29 – Dec 31
Maryland	16”	4 2 4	Jan 1- May 15 May 16 – Oct 3 Nov 1 – 26
Virginia	16"	3	Jan 1 - Apr 15
			Sept 24 - Dec 31
North Carolina	-	-	-

Table 1.2. Commercial regulations for tautog by state.

STATE	**SIZE LIMIT**	**POSSESSION LIMITS** (number of fish)	**OPEN SEASONS**	**QUOTA** (pounds)	**GEAR RESTRICTIONS***
Massachusetts	16”	40	April 14-May 16 Sept 1-Oct 31	61,180*	Mandatory pot requirements. Limited entry and area/time closures for specific gear types.
Rhode Island	16”	10	Apr 15 - May 30 Aug 1 - Sept 15 Oct 15 - Dec 31	51,348 (17,116 per period)	Harvest allowed by permitted gear types only.
Connecticut	16”	10	Apr 1- Apr 30 Jul 1 - Aug 31 Oct 8 - Dec 24	NA	Mandatory pot requirements.
New York	15”	25 (10 fish w/ lobster gear and when 6 lobsters are in possession)	Jan 1 - Feb 28 Apr 8 –Dec 31	-	Mandatory pot requirements. Gill or trammel net is prohibited.
New Jersey	15”	*> 100 lbs requires directed fishery permit*	Jan 1 - 15 June 11 - 30 Nov 1 - Dec 31	103,000	Mandatory pot requirements.
Delaware	15”	5 3 5 5	Jan 1 - Mar 31 Apr 1 - May 11 July 17 - Aug 31 Sept 29 - Dec 31	-	Mandatory pot requirements.
Maryland	16”	4 2 4	Jan 1- May 15 May 16 - Oct 31 Nov 1 - 26	-	Mandatory pot requirements.
Virginia	15”	-	Jan 1 – Jan 17 Mar 16 – Apr 30 Nov 13 – Dec 31	-	Mandatory pot requirements. Pots prohibited in tidal waters.
North Carolina	-	-	-	-	Mandatory pot requirements.

Table 2.1. Von Bertalanffy parameter estimates by region scenario.

Model	Parameter	Estimate	SE
3-Region	VA-MD-DE		
	L_{inf}	71.25	1.74
	K	0.09	0.01
	t_0	-4.84	0.24
	NJ&NY		
	L_{inf}	66.36	1.35
	K	0.09	0.00
	t_0	-3.69	0.21
	RI-CT-MA		
	L_{inf}	57.36	0.25
	K	0.186	0.003
	t_0	-0.51	0.05
2-Region	VA-MD-DE-NJ		
	L_{inf}	82.74	3.75
	K	0.051	0.005
	t_0	-7.52	0.37
	NY- RI-CT-MA		
	L_{inf}	57.58	0.25
	K	0.176	0.003
	t_0	-0.70	0.05
Coastwide	All States		
	L_{inf}	64.38	0.54
	K	0.101	0.003
	t_0	-3.84	0.10

Table 2.2. Von Bertalanffy parameter estimates by state.

Parameter	Estimate	SE
VA		
L_{inf}	74.67	3.34
K	0.065	0.01
t_0	-7.44	0.50
MD		
L_{inf}	78.23	2.86
K	0.085	0.01
t_0	-2.82	0.20
DE		
L_{inf}	76.03	6.57
K	0.060	0.01
t_0	-8.73	1.10
NJ		
L_{inf}	80.66	5.40
K	0.052	0.01
t_0	-5.98	0.50
NY		
L_{inf}	60.45	0.95
K	0.123	0.01
t_0	-2.21	0.18
RI		
L_{inf}	60.25	0.98
K	0.140	0.01
t_0	-1.93	0.20
CT		
L_{inf}	59.11	0.30
K	0.171	0.00
t_0	-0.02	0.05
MA		
L_{inf}	61.68	1.60
K	0.118	0.01
t_0	-3.88	0.46

Table 2.3. Mean length-at-age and mean weight-at-age by region.
Two-region and three-region scenarios are provided. In the three-region model, Mid-Atlantic states consist of New York and New Jersey.

Model	Region	Mean Length-at-Age (cm)	SD	Mean Weight-at-Age (kg)	SD
Three-Region	North	47.10	12.39	3.39	1.92
	Mid-Atlantic	46.97	13.37	2.23	1.61
	South	49.85	10.67	2.79	1.60
Two-Region	North	47.16	12.25	3.05	1.85
	South	48.92	12.01	2.67	1.71

Table 2.4. Estimators of natural mortality (M) examined for this assessment.
Accepted estimators are indicated in bold font.

Estimator Type		Estimates	M	Equation
Age Constant	Age -Based	Hoenig 1983 (rule-of-thumb) P = 0.05	0.10	$M = -\ln(P) / t_{max}$
		Hewitt and Hoenig 2005	**0.14**	**$M = 4.22 / t_{max}$**
		Updated T_{max} estimator (Then et al. 2013)	**0.16**	**$M = 5.075/t_{max}$**
		Hoenig 1983 (regression)	**0.15**	**$M = \exp[1.44 - 0.982*\ln(t_{max})]$**
		Updated Hoenig 1983 (Then et al. 2013)	**0.18**	**$M = \exp[1.682 - 0.998*\ln(t_{max})]$**
		Alverson and Carney 1975	0.13	$M = 3*K/(\exp[0.38*K*t_{max}) - 1]$
		Rikhter and Efanov 1977	0.53	$M = [1.521/(t_m^{0.720})] - 0.155$
		Roff's 1st 1984	0.86	$M = 3*K/[\exp(t_m*K) - 1]$
		Charnov & Berrigan 1990	0.73	$M = 2.2/t_m$
		Jensen's 1st 1996	0.55	$M = 1.65/t_m$
	Life History Based	**Jensen's 2nd 1996 (theoretical)**	**0.15**	**$M = 1.50*K$**
		Jensen's 2nd 1996 (derived from Pauly 1980)	**0.16**	**$M = 1.60*K$**
		Updated 1-parameter K (Then et al. 2013)	**0.17**	**$M = 1.686*K$**
		Ralston 1987 (linear regression)	0.23	$M = 0.0189 + 2.06*K$
		Ralston 1987 (geometric mean regression)	0.19	$M = -0.0666 + 2.52*K$
		Updated 2-parameter K (Then et al. 2013)	0.25	$M = 0.094 + 1.552*K$
		Cubillos 1999	**0.16**	**$M = 4.31*[t_0 - (\ln(0.05)/K)]^{-1.01}$**
		Pauly 1980	**0.22**	**$M = \exp[-0.0152 + 0.6543*\ln(K) - 0.279*\ln(L_{inf}/10) + 0.4634*\ln(Temp)]$**
		Pauly 1980 no temperature (Then et al. 2013)	0.07	$M = \exp[-0.0152 + 0.6543*\ln(K) - 0.279*\ln(L_{inf}/10)]$
		Updated nls Pauly (Then et al. 2013)	**0.15**	**$M = \exp(1.457)*K^{0.737}*L_{inf}^{-0.345}*Temp^{0.225}$**
		Updated nls Pauly no temperature (Then et al. 2013	0.09	$M = \exp(1.457)*K^{0.737}*L_{inf}^{-0.345}$
		Jensen's 3rd 2001	0.70	$M = \exp[0.66*\ln(K) + 0.45*\ln(Temp)]$

Table 2.5. Chosen natural mortality (M) estimators, parameter values used and results for coast-wide and regional M estimates.

Estimator Type		Area		Coastwide	North	South	S New England	NJ & NY	DelMarVa
		Parameters	L_inf (mm)	643.757	575.818	827.416	573.641	663.623	712.476
			K (year -1)	0.101	0.176	0.051	0.186	0.087	0.086
			t_0 (years)	-3.845	-0.701	-7.520	-0.507	-3.693	-4.842
			t_max (years)	31	31	29	31	29	25
			Temp ° C	12.5	12.5	12.5	12.5	12.5	12.5
		Method		M estimates by Area					
Age Constant	Age Based	**Hewitt and Hoenig 2005** $M = 4.22 / Tmax$		0.136	0.136	0.146	0.136	0.146	0.169
		Updated Tmax estimator (Then et al. 2013) $M = 5.075/Tmax$		0.164	0.164	0.175	0.164	0.175	0.203
		Hoenig 1983 (regression) $M = \exp[1.44 - 0.982*\ln(Tmax)]$		0.145	0.145	0.155	0.145	0.155	0.179
		Updated Hoenig 1983 (Then et al. 2013) $M = \exp[1.682 - 0.998*\ln(Tmax)]$		0.175	0.175	0.187	0.175	0.187	0.216
	Life History Based	**Jensen's 2nd 1996 (theoretical)** $M = 1.50*K$		0.152	0.264	0.077	0.279	0.130	0.129
		Jensen's 2nd 1996 (derived from Pauly 1980) $M = 1.60*K$		0.162	0.282	0.082	0.298	0.139	0.137
		Updated 1-parameter K (Then et al. 2013) $M = 1.686*K$		0.171	0.297	0.086	0.314	0.146	0.145
		Cubillos 1999 $M = 4.31*[t0 - (\ln(0.05)/K)]^{-1.01}$		0.162	0.257	0.081	0.269	0.135	0.139
		Pauly 1980 $M = \exp[-0.0152 + 0.6543*\ln(K) - 0.279*\ln(Linf/10) + 0.4634*\ln(Temp)]$		0.222	0.329	0.132	0.341	0.199	0.194
		Updated nls Pauly (Then et al. 2013) $M = \exp(1.457)*K^{0.737}*Linf^{-0.345}*Temp^{0.225}$		0.151	0.235	0.083	0.245	0.133	0.129
Range	Minimum 0.120	Average M estimate by Area	Maximum 0.237	0.164	0.228	0.120	0.237	0.154	0.164
Range of M estimates by Area			Minimum	0.136	0.136	0.077	0.136	0.130	0.129
			Maximum	0.222	0.329	0.187	0.341	0.199	0.216

Table 2.6. Proportion of VTR reported fishing trips (commercial and recreational) by NMFS statistical area and state. Values greater than 10% are shown in bold italics.

Stat Area	MA	RI	CT	NY	NJ	DE	MD	VA
514	***0.30***	0.00	0.00	0.00	0.00	0.00	0.00	0.00
537	0.04	0.06	0.00	0.00	0.00	0.00	0.00	0.00
538	***0.64***	0.05	0.00	0.00	0.00	0.00	0.00	0.00
539	0.01	***0.80***	0.02	0.01	0.00	0.00	0.00	0.00
611	0.00	0.09	***0.94***	***0.39***	0.00	0.00	0.00	0.00
612	0.00	0.00	0.01	***0.44***	***0.47***	0.00	0.00	0.01
613	0.00	0.00	0.03	***0.14***	0.01	0.00	0.00	0.00
614	0.00	0.00	0.00	0.00	***0.22***	0.00	0.03	0.00
615	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
621	0.00	0.00	0.00	0.00	***0.21***	***1.00***	***0.77***	0.07
625	0.00	0.00	0.00	0.00	0.00	0.00	0.04	***0.52***
626	0.00	0.00	0.00	0.00	0.00	0.00	***0.16***	0.05
631	0.00	0.00	0.00	0.00	0.00	0.00	0.00	***0.34***

Table 4.1. Commercial landings for tautog in metric tons (MT), by region, 1981-2012.
Source: NOAA Fisheries and ACCSP.

Year	Southern New England	Mid-Atlantic	DelMarVa + North Carolina	Total (Coastwide)
1981	87.6	61.6	1.3	150.5
1982	80.2	108.2	1.9	190.3
1983	106.0	85.7	1.3	193.0
1984	197.5	105.3	4.5	307.4
1985	234.3	95.3	3.5	333.1
1986	287.2	137.0	2.6	426.7
1987	376.3	145.3	3.2	524.9
1988	325.7	155.6	4.4	485.7
1989	302.4	153.0	5.7	461.0
1990	264.1	127.3	4.8	396.2
1991	353.8	144.9	4.9	503.5
1992	325.6	129.4	4.1	459.1
1993	203.2	110.2	3.4	316.8
1994	95.6	106.1	6.7	208.4
1995	68.4	85.7	16.3	170.4
1996	59.3	88.4	14.4	162.1
1997	53.7	58.0	15.7	127.4
1998	53.8	50.5	11.0	115.3
1999	52.0	29.6	13.1	94.7
2000	67.2	36.1	8.9	112.2
2001	73.8	55.8	9.0	138.6
2002	102.0	44.2	13.2	159.4
2003	83.3	63.1	9.0	155.4
2004	68.4	57.4	10.1	135.9
2005	75.4	51.6	5.6	132.5
2006	95.7	56.2	6.5	158.5
2007	85.8	62.0	6.8	154.6
2008	64.4	69.2	7.4	141.0
2009	57.1	46.2	6.8	110.1
2010	61.6	64.3	4.2	130.1
2011	54.2	56.5	8.2	118.9
2012	56.1	33.5	23.9	113.5

Table 4.2. Recreational harvest (A+B1) for tautog in number of fish, 1981-2012 (MRIP).

Year	MA	RI	CT	NY	NJ	DE	MD	VA	NC	Total
1981	228,736	233,508	100,308	721,062	132,271	3,457	4,670	236,768	3,072	1,663,852
1982	1,051,022	214,938	231,187	646,693	583,550	137,328	35,105	71,599	15,062	2,986,484
1983	670,508	245,796	200,676	612,163	344,580	4,350	2,126	579,795	36,549	2,696,543
1984	258,256	490,128	287,470	286,077	516,086	28,388	42,835	207,192	NA	2,116,432
1985	100,941	115,404	182,318	1,105,234	840,627	62,001	486	91,957	8,252	2,507,220
1986	1,980,719	671,592	333,396	1,183,114	2,369,852	141,290	5,476	322,905	12,660	7,021,004
1987	617,068	130,729	312,430	929,887	1,015,123	99,706	90,523	126,783	3,698	3,325,947
1988	621,679	207,799	234,198	828,183	564,286	94,491	107,570	368,320	4,462	3,030,988
1989	250,077	116,506	303,782	562,549	710,958	249,928	34,709	284,477	11,354	2,524,340
1990	233,444	153,433	75,871	953,622	841,770	61,526	45,467	111,998	3,428	2,480,559
1991	176,905	291,946	191,137	871,221	1,067,283	128,985	26,770	168,068	6,804	2,929,119
1992	357,949	193,786	319,221	413,236	1,018,205	68,769	106,255	100,952	5,249	2,583,622
1993	216,553	118,775	180,055	505,632	773,213	82,475	60,231	300,484	4,785	2,242,203
1994	78,483	82,304	150,109	196,937	208,003	65,837	157,260	231,740	2,271	1,172,944
1995	72,461	54,570	120,259	118,006	707,963	300,303	43,542	222,186	3,178	1,642,468
1996	79,798	55,528	72,558	82,826	470,431	57,751	9,695	224,447	6,605	1,059,639
1997	39,075	70,628	32,200	92,907	196,724	65,133	85,682	106,678	11,432	700,459
1998	25,034	56,084	66,797	68,887	11,667	62,584	6,512	50,923	9,487	357,975
1999	91,476	52,136	15,701	196,564	165,505	95,309	20,180	42,880	8,437	688,188
2000	87,552	38,687	10,648	79,245	462,371	113,686	20,129	34,725	5,555	852,598
2001	115,658	39,993	16,579	45,913	467,728	50,541	23,715	28,985	2,418	791,530
2002	102,662	62,423	100,240	629,772	347,831	185,684	42,038	25,987	4,514	1,501,151
2003	46,808	120,061	167,875	128,729	102,593	63,181	13,555	76,236	12,185	731,223
2004	21,816	124,419	16,464	278,749	90,214	70,608	8,690	150,703	9,137	770,800
2005	72,038	160,524	35,699	84,280	43,055	60,831	28,129	60,484	13,707	558,747
2006	79,639	81,611	200,708	246,882	200,725	111,028	14,894	105,137	1,234	1,041,858
2007	91,304	125,233	352,819	223,798	300,179	99,605	43,308	60,992	15,250	1,312,488
2008	34,237	103,760	167,179	318,899	172,518	101,735	19,128	56,384	734	974,574
2009	24,879	85,416	85,915	346,276	127,403	119,941	37,963	60,470	2,895	891,158
2010	45,743	197,062	116,058	145,663	374,599	56,505	57,338	127,221	3,720	1,123,909
2011	32,828	19,304	25,823	111,406	136,674	45,483	11,853	46,441	981	430,793
2012	24,796	104,425	194,101	58,127	30,705	44,807	5,216	13,918	9,936	486,031

Table 4.3. Recreational harvest (A + B1) for tautog in metric tons, by state, 1981-2012.
States are sorted from north to south. Source: MRIP.

Year	MA	RI	CT	NY	NJ	DE	MD	VA	NC	Total
1981	358.6	301.4	109.9	678.6	73.2	3.0	4.7	336.9	0.2	1,866.6
1982	1,463.7	352.9	277.0	759.7	563.0	194.2	41.1	123.3	7.2	3,782.0
1983	833.4	279.2	208.0	510.2	188.2	2.0	3.0	574.8	9.1	2,607.9
1984	332.9	820.9	332.8	245.8	325.3	43.4	35.9	303.8	na	2,440.9
1985	148.8	125.8	213.7	923.0	336.4	65.7	0.5	135.5	3.2	1,952.8
1986	3,566.4	926.5	380.3	1,285.1	967.3	120.1	4.6	416.5	1.9	7,668.6
1987	794.4	230.2	501.9	1,037.9	966.6	175.6	120.7	200.8	3.8	4,031.9
1988	1,023.3	277.7	276.8	1,079.7	604.1	113.3	202.7	639.6	2.1	4,219.2
1989	488.2	134.7	470.9	461.8	584.8	337.2	35.6	365.7	14.1	2,892.9
1990	406.1	176.7	90.7	898.2	569.9	64.7	27.1	104.1	1.2	2,338.8
1991	362.4	457.0	294.2	1,067.1	993.0	160.8	48.2	280.9	11.2	3,674.8
1992	756.8	297.9	475.7	544.1	1,127.5	83.4	72.5	116.1	5.7	3,479.6
1993	341.4	176.8	240.9	816.8	617.6	98.8	47.7	344.0	4.4	2,688.5
1994	169.3	149.1	189.3	265.4	149.9	69.0	80.4	499.5	1.2	1,573.1
1995	140.3	107.5	182.6	167.7	781.4	359.9	52.6	278.2	1.5	2,071.7
1996	180.2	112.9	111.5	87.6	509.5	72.0	12.0	353.0	6.0	1,444.6
1997	75.3	136.6	38.2	150.4	219.4	92.7	83.0	177.5	26.6	999.7
1998	43.9	143.5	105.1	94.7	18.8	116.7	12.5	124.1	12.0	671.2
1999	164.9	101.5	27.7	345.4	232.1	162.5	17.1	92.2	5.4	1,148.8
2000	200.9	92.4	26.5	117.1	822.3	169.5	25.5	85.4	2.0	1,541.5
2001	227.8	75.0	28.6	78.0	672.5	72.6	32.8	57.9	2.0	1,247.2
2002	236.6	120.3	202.8	968.5	537.3	295.7	47.3	53.0	2.0	2,463.5
2003	100.6	217.4	273.9	143.1	74.5	91.0	19.6	140.1	9.3	1,069.5
2004	48.9	316.9	35.0	438.2	128.4	109.0	9.8	237.8	14.2	1,338.3
2005	173.7	366.4	65.9	142.7	65.5	100.1	38.3	110.1	13.7	1,076.4
2006	133.7	172.4	382.0	360.2	329.6	184.4	21.5	212.4	1.5	1,797.6
2007	151.3	282.0	628.0	373.4	482.7	135.4	62.2	111.9	26.5	2,253.6
2008	49.9	223.1	326.8	490.6	235.9	172.7	31.4	100.9	0.7	1,632.2
2009	38.7	146.8	137.5	649.2	185.3	175.8	49.1	121.6	8.2	1,512.3
2010	73.7	419.0	187.2	227.9	484.2	66.2	91.5	217.5	4.3	1,771.5
2011	58.8	36.4	40.2	204.2	173.0	69.4	15.4	78.9	0.7	677.0
2012	43.0	242.5	446.5	109.1	49.0	74.7	7.7	22.7	5.3	1,000.4

Table 5.1. Available data sets and acceptance or rejection for use in stock assessment.

Data	Source	Years	State/Region	Category	Stock Assessment Use
Commercial Landings	ACCSP, NMFS	1950-2012	MA through VA	Fishery-dependent	Used in assessment. Commercial landings from 1983-2013 was used in the models. Landings from 1950-1982 was used to describe the fisheries in the report.
Commercial Landings by Gear	ACCSP, NMFS, VTR	1950-2012	MA through VA	Fishery-dependent	Generally, the data set is not very good. This data set was used to describe the fishery in the report. VTR data exists from 1994-2013.
Commercial Discard	NEFSC POP, VTR	1989-2012	MA through VA	Fishery-dependent	Used in the assessment.
Age	Commercial sampling by Individual States		MA through VA	Biological	Used in the assessment to calculate natural mortality.
Recreational Landings	MRFSS, MRIP	1981-2012	All states	Fishery-dependent	MRFSS data from 1981-2003 and MRIP data from 2004-2013 was used in the assessment.
Commercial CPUE	VTR	1994-2012	All states	Fishery-dependent	Used to inform species association.
Recreational CPUE	VTR	1994-2012	All states	Fishery-dependent	Used to inform species association and analysis of modes.
Recreational CPUE	MRFSS/MRIP	1981-2012	All states	Fishery-dependent	Used in the assessment. Charter boat data from MRFSS and MRIP was dropped when data was merged with VTR data to prevent double-counting.
Commercial Harvest	VA: State reports, Volunteer Angler Surveys (self-reporting, witnessed)	1993-2012	VA	Fishery-dependent	Not used in the assessment.
Biological data (size and weight)	Citations from fishing derbies, state records	VA: late 1950s - 2006	VA, DE, NY (small set), MD, NJ	Fishery-independent	Not used in the assessment.

Table 5.1. Available data sets and acceptance or rejection for use in stock assessment.

Data	**Source**	**Years**	**State/Region**	**Category**	**Stock Assessment Use**
Commercial Length Frequency	VA and other southern states	1998-2004	Southern states	Biological	Since the southern range (NJ through Virginia) is data-poor, commercial length frequency was incorporated into age-length keys.
Tagging Data	VA tagging study			Biological	Not used in the assessment.
Tagging Data	MD tag analysis (tagging by fishermen)	1983-2012	MD (south of Ocean City)	Biological	Used in analyses of migration and growth (life history section of report).
Abundance	MADMF	1978-2012	MA. Region = NE, Northern	Fishery-independent	Used in the stock assessment.
Abundance	RI Monthly Trawl	1990-2012	RI. Regions: NE, North	Fishery-independent	Used in the stock assessment. This data set was used in previous assessments.
Abundance	RI Spring trawl	1980-2012	RI. Regions: NE, North	Fishery-independent	Not used in the stock assessment.
Abundance	RI Seine (beach) Survey		RI. Regions: NE, North	Fishery-independent	Not used in the stock assessment. TC looked into using this survey to track cohorts.
Abundance	Fall Trawl	1979-2012	RI. Regions: NE, North	Fishery-independent	Used in the stock assessment.
Abundance	Long Island Sound Trawl		CT. Region: NE, North	Fishery-independent	Used to develop indices.
Abundance	Western Long Island Sound (striped bass) seine	1984-2012	NY. Region: Mid-Atl, North	Fishery-independent	Used to develop indices. Length data was used in age-length keys.
Abundance	Peconic Bay Trawl Survey	1987-2012	NY. Region: Mid-Atl, North	Fishery-independent	Used in the assessment.
Biological information from various sources	Lobster trap, thesis, etc.		NY	Fishery-independent	Did not use.
Abundance	Pot surveys (Tautog survey)	2007-2008, 2010-2012	NY	Fishery-independent	Did not use because the time series is too short.

Table 5.1. Available data sets and acceptance or rejection for use in stock assessment.

Data	Source	Years	State/Region	Category	Stock Assessment Use
Abundance	Ocean Trawl	1988-2012	NJ: Region: Mid-Atl, South	Fishery-independent	Used to develop indices.
Abundance, Juvenile	Coastal Bay Survey	1988-2012	MD. Regions: DelMarVa, South	Fishery-independent	Did not use in assessment. Survey may be useful for developing a juvenile recruitment index.
Abundance, Juvenile	Delaware Bay		DE	Fishery-independent	Did not use.
Abundance, Adult	Delaware Bay	1966-1971, 1979-1984, 1990-2012	DE. Regions: DelMarVa, South	Fishery-independent	Did not use in the assessment.
Abundance, Juvenile	Inland Bay Trawl	1986-2012	DE. Regions: DelMarVa, South	Fishery-independent	Did not use in the assessment.
Length-Frequency	MRFSS, MRIP	1982-2012	All states	Life History	Used in the assessment.
Length-Weight	States		All states	Life History	Used to develop age-length key.
Abundance, Juvenile	Rutgers Trawl	1997-2011	NJ. Region: Mid-Atl, South	Fishery-independent	Did not use in the assessment because study occurred in a small, isolated estuary in a pristine area of NJ and may not represent juvenile tog abundance in other areas.
Abundance, Juvenile	Rutgers Ichthyoplankton Survey	1989-2012	NJ, Great Bay Estuary	Fishery-independent	Not used in assessment.
Abundance, Juvenile	killipot	1990-2012	NJ	Fishery-independent	Not used in assessment because survey occurred in a very small area.

Table 5.2. Sample size by gear of observed commercial trips that caught tautog (1989-2012).

Gear	# Trips
Gillnet	710
Otter Trawl	604
Scallop Dredge	23
Fish pot/trap	19
Longline	6
Lobster pot/trap	4
Scottish Seine	1
Troll Line	1

Table 5.3. Sample size by state of observed commercial trips that caught tautog (1989-2012).

Region	State	# Trips
	ME	2
	NH	9
Southern New England	MA	456
	RI	620
	CT	7
NY-NJ	NY	59
	NJ	113
DelMarVa	DE	1
	MD	43
	VA	47
	NC	11

Table 5.4. Ratio of discarded to retained tautog observed commercially by regulatory period, region, and gear.

Regulatory Period	Region	Gear	# Observed Trips	Ratio	Variance
1989-1996	DMV	Gillnet	27	0.12	0.0040
1989-1996	DMV	Other	5	3.60	15.9684
1989-1996	DMV	Otter Trawl	6	0.01	0.00005
1989-1996	NY-NJ	Gillnet	15	0.04	0.0015
1989-1996	NY-NJ	Other	3	22.00	444.0000
1989-1996	NY-NJ	Otter Trawl	38	0.08	0.0002
1989-1996	SNE	Gillnet	269	0.02	0.0000
1989-1996	SNE	Other	5	0.01	0.0002
1989-1996	SNE	Otter Trawl	43	0.15	0.0062
1997-2007	DMV	Gillnet	18	0.18	0.0261
1997-2007	DMV	Other	3	0.28	0.1976
1997-2007	DMV	Otter Trawl	8	0.03	0.0013
1997-2007	NY-NJ	Gillnet	6	0.28	0.0643
1997-2007	NY-NJ	Other	5	Inf	NA
1997-2007	NY-NJ	Otter Trawl	48	0.08	0.0007
1997-2007	SNE	Gillnet	95	0.26	0.0073
1997-2007	SNE	Other	16	2.80	7.9330
1997-2007	SNE	Otter Trawl	203	1.88	0.2038
2008-2012	DMV	Gillnet	1	Inf	NA
2008-2012	DMV	Other	2	1.50	9.0000
2008-2012	DMV	Otter Trawl	3	0.01	0.0003
2008-2012	NY-NJ	Other	2	Inf	NA
2008-2012	NY-NJ	Otter Trawl	34	0.12	0.0009
2008-2012	SNE	Gillnet	30	0.71	0.0614
2008-2012	SNE	Other	12	Inf	NA
2008-2012	SNE	Otter Trawl	215	15.04	17.3780

Table 5.5. Species included in “logical” species guilds for development of fishery dependent indices using MRFSS/MRIP data.

		Rank by state							
Common name	**Scientific name**	**MA**	**RI**	**CT**	**NY**	**NJ**	**DE**	**MD**	**VA**
Atlantic croaker	*Micropogonias undulatus*						6		5
Black sea bass	*Centropristis striata*	6	6		5	3	2	2	2
Bluefish	*Pomatomus saltatrix*			6		6		4	4
Cunner	*Tautogolabrus adspersus*	~~4~~	~~2~~	~~3~~	~~2~~	~~2~~	~~4~~	~~5~~	
Gray triggerfish	*Balistes capriscus*						5	6	
Scup	*Stenotomus chrysops*	2	3	4	3	4			
Summer flounder	*Paralichthys dentatus*	5	5	5	6	5	3	3	3
Tautog	*Tautoga onitis*	1	1	1	1	1	1	1	1
Winter flounder	*Pseudopleuronectes americanus*	3	4	2	4				

Table 5.6. MRIP CPUE by region.

	SNE		NY-NJ		DMV	
	Mean	CV	Mean	CV	Mean	CV
1982	0.73	0.09	0.60	0.08	0.17	0.15
1983	1.71	0.09	0.41	0.09	0.16	0.09
1984	1.45	0.08	0.36	0.09	0.15	0.12
1985	0.77	0.11	0.46	0.09	0.05	0.09
1986	2.20	0.08	0.97	0.06	0.25	0.07
1987	1.00	0.09	0.84	0.08	0.10	0.11
1988	1.58	0.06	0.95	0.07	0.21	0.09
1989	1.62	0.06	1.11	0.05	0.24	0.07
1990	0.94	0.06	1.31	0.05	0.08	0.09
1991	1.08	0.06	1.25	0.04	0.12	0.08
1992	1.57	0.06	1.65	0.05	0.12	0.08
1993	1.28	0.06	0.92	0.05	0.23	0.08
1994	1.00	0.07	0.53	0.07	0.19	0.07
1995	0.70	0.08	0.98	0.08	0.17	0.07
1996	0.86	0.07	0.61	0.07	0.18	0.08
1997	0.45	0.07	0.52	0.07	0.11	0.07
1998	0.39	0.07	0.29	0.09	0.05	0.08
1999	0.34	0.07	0.52	0.07	0.08	0.08
2000	0.24	0.07	0.48	0.08	0.05	0.08
2001	0.28	0.07	0.67	0.06	0.07	0.07
2002	0.36	0.07	0.92	0.06	0.11	0.07
2003	0.54	0.06	0.28	0.06	0.09	0.07
2004	0.35	0.07	0.50	0.06	0.14	0.07
2005	0.55	0.08	0.31	0.07	0.11	0.07
2006	0.55	0.07	0.53	0.07	0.12	0.08
2007	0.42	0.08	0.59	0.07	0.08	0.07
2008	0.38	0.09	0.59	0.07	0.15	0.06
2009	0.84	0.10	0.89	0.07	0.10	0.07
2010	0.46	0.09	0.53	0.07	0.14	0.07
2011	0.62	0.10	0.51	0.08	0.08	0.08
2012	0.49	0.08	0.45	0.08	0.06	0.09

Table 5.7. Number of angler-trips intercepted by MRIP survey that caught tautog.

	SNE				NY-NJ				DMV			
	Positive Trips	Total Trips	Harvested Lengths	Released Lengths	Positive Trips	Total Trips	Harvested Lengths	Released Lengths	Positive Trips	Total Trips	Harvested Lengths	Released Lengths
1982	291	3,812	536	0	167	5,913	321	1	66	2,682	162	0
1983	341	5,102	621	0	138	4,271	273	31	46	9,915	91	0
1984	332	5,063	566	2	114	3,138	185	82	55	4,109	97	0
1985	128	3,049	131	9	177	4,287	294	95	65	12,672	112	0
1986	315	3,677	476	6	633	7,679	1,166	36	184	9,590	403	0
1987	223	4,548	329	7	274	5,061	372	48	102	5,213	186	0
1988	540	10,991	721	7	233	5,256	406	88	129	5,696	213	0
1989	556	11,325	853	38	800	12,366	1,485	111	401	10,448	694	0
1990	525	12,517	593	59	1,068	14,666	1,917	142	143	8,537	359	98
1991	495	12,654	595	79	997	16,896	1,605	180	252	9,597	554	37
1992	782	12,660	949	23	807	15,214	936	135	281	9,373	601	45
1993	625	13,282	993	16	512	12,677	510	96	334	8,255	650	45
1994	332	12,707	407	14	183	10,745	136	168	321	12,393	524	99
1995	200	12,137	212	34	135	6,612	160	112	370	9,726	544	60
1996	230	11,228	235	18	153	7,971	111	141	313	9,784	399	38
1997	173	12,623	145	9	136	7,680	83	60	195	12,164	250	54
1998	170	13,552	133	82	50	6,910	24	129	247	12,165	365	24
1999	199	12,980	125	39	137	6,879	79	192	252	10,831	346	98
2000	125	11,482	55	13	134	5,913	165	230	188	11,238	198	57
2001	178	13,480	176	18	218	11,503	335	374	169	13,872	218	102
2002	181	11,909	136	39	310	8,626	384	527	376	14,116	532	217
2003	403	14,851	470	38	201	12,405	183	75	328	14,541	421	204
2005	317	10,623	152	62	164	9,814	309	371	546	14,042	960	1,174
2006	236	10,061	346	158	283	8,952	157	211	634	12,096	933	1,312
2007	211	9,722	134	93	301	9,672	267	386	481	14,428	1,052	1,606
2008	171	8,327	93	206	395	9,861	308	298	707	14,708	871	1,566
2009	144	7,203	76	171	354	8,695	390	384	490	13,409	1,360	1,550
2010	212	7,773	169	95	257	8,839	390	302	498	13,595	878	773
2011	122	6,800	136	71	204	7,969	302	294	418	11,271	768	1,477
2012	170	7,563	122	61	163	6,826	181	209	274	9,122	895	770
2013	207	10,092	100	35	93	7,142	226	396	292	12,241	458	314
Min	122	3,049	55	2	50	3,138	24	1	46	2,682	91	24
Max	782	14,851	993	206	1,068	16,896	1,917	527	707	14,708	1,360	1,606
Avg	295	9,800	348	52	316	8,724	441	190	295	10,704	519	510

Table 5.8. MRFSS vs. MRIP estimates of proportional standard error (PSE) for recreational harvest in weight.

	Coastwide		S. New England		NY-NJ		DelMarVa	
Year	MRFSS	MRIP	MRFSS	MRIP	MRFSS	MRIP	MRFSS	MRIP
2004	11.5	21.7	24.4	48.9	19.4	34.7	15.4	26.2
2005	10.5	17.9	15.3	29.8	22.0	21.3	19.2	20.5
2006	9.8	14.1	14.7	24.1	17.7	25.4	16.9	17.5
2007	10.0	12.3	18.3	20.4	13.3	18.8	14.9	19.9
2008	9.9	10.2	18.4	19.0	15.8	15.4	11.5	14.4
2009	10.0	11.4	21.9	16.9	14.9	17.9	14.1	18.5
2010	11.9	16.0	15.6	22.7	24.2	31.6	15.0	21.3
2011	14.1	15.5	31.2	26.0	18.1	24.0	21.0	25.0
Calibration factor (ΣMRIP/ΣMRFSS)	1.36		1.30		1.30		1.27	

Table 5.9. Age-length key structure and sample sizes of tautog biological samples.

SNE			NY-NJ			DelMarVa		
Years	Sources	N's	Years	Sources	N's	Years	Sources	N's
1982-1986	CT	1236	1982-1986					
1987-1989	RI, CT	1208	1987-1989			1982-1989	VA	696
1990-1992	RI, CT	826	1990-1994					
1993-1995	MA, CT, + NY	768	1995	NY, NJ + CT	422	1990-1995	VA	940
1996	MA, CT, + NY	554	1996	NY, NJ + CT, DE	671	1996	VA,NJ,DE	738
1997	MA, CT, + NY	674	1997	NY, NJ + CT, DE	1461	1997	VA,NJ,DE	1309
1998	MA, CT, + NY	545	1998	NY, NJ + CT, DE	1010	1998	VA,NJ,DE	655
1999	MA, RI, CT, +NY	585	1999	NY, NJ + CT, DE	930	1999	VA,MD,NJ,DE	1075
2000	MA, RI, CT, +NY	733	2000	NY, NJ + CT, DE	1193	2000	VA,MD,NJ, DE	1055
2001	MA, RI, CT, +NY	1028	2001	NY, NJ + CT, DE	867	2001	VA,MD,NJ,DE	759
2002	MA, RI, CT	998	2002	NJ + CT, DE	816	2002	VA,MD,NJ,DE	1012
2003	MA, RI, CT	822	2003	NJ + CT, DE	490	2003	VA,MD,NJ,DE	1185
2004	MA, RI, CT, +NY	849	2004	NY, NJ + CT, DE	993	2004	VA,MD,NJ,DE	1465
2005	MA, RI, CT, +NY	765	2005	NY, NJ + CT, DE	981	2005	VA,MD,NJ,DE	1524
2006	MA, RI, CT, +NY	917	2006	NY, NJ + CT, DE	1005	2006	VA,MD,NJ,DE	1378
2007	MA, RI, CT, +NY	1026	2007	NY, NJ + CT, DE	1263	2007	VA,MD,NJ,DE	1315
2008	MA, RI, CT, +NY	1097	2008	NY, NJ + CT, DE	830	2008	VA,MD,NJ,DE	788
2009	MA, RI, CT, +NY	922	2009	NY, NJ + CT, DE	982	2009	VA,MD,NJ,DE	1017
2010	MA, RI, CT, +NY	710	2010	NY, NJ + CT, DE	1119	2010	VA,MD,NJ,DE	1366
2011	MA, RI, CT, +NY	728	2011	NY, NJ + CT, DE	998	2011	VA,MD,NJ,DE	1518
2012	MA, RI, CT, +NY	587	2012	NY, NJ + CT, DE	963	2012	VA,MD,NJ,DE	1209

Table 5.10. Index values for the Massachusetts Trawl Survey.

Year	Mean	SE	CV	LCI	UCI	Nominal
1978	0.428222	0.154621	0.361077	0.125164	0.73128	3.030769
1979	0.186194	0.07933	0.426062	0.030707	0.341682	3.850746
1980	0.215957	0.093654	0.433668	0.032396	0.399518	2.666667
1981	0.819135	0.312591	0.381611	0.206456	1.431814	3.265625
1982	0.811365	0.31997	0.39436	0.184224	1.438506	5.68254
1983	0.447002	0.176322	0.394453	0.101412	0.792592	3.741935
1984	0.972105	0.364693	0.375158	0.257307	1.686904	10.4
1985	0.715544	0.271267	0.379106	0.183861	1.247227	6.196721
1986	2.336993	0.835061	0.357323	0.700274	3.973713	10.96774
1987	0.85435	0.329977	0.386231	0.207596	1.501104	3.360656
1988	0.625482	0.24737	0.395487	0.140637	1.110328	3.25
1989	1.982111	0.80107	0.40415	0.412014	3.552208	2.783333
1990	0.233681	0.099319	0.42502	0.039016	0.428346	0.919355
1991	0.10088	0.045403	0.450071	0.01189	0.189871	1.580645
1992	0.549738	0.246368	0.448154	0.066858	1.032619	0.885246
1993	0.110273	0.049508	0.44896	0.013237	0.20731	0.824561
1994	0.400133	0.178734	0.446687	0.049814	0.750453	1.065574
1995	0.058175	0.029436	0.505986	0.000481	0.115868	0.296875
1996	0.1905	0.08064	0.423305	0.032446	0.348553	1.476923
1997	0.209076	0.088563	0.423592	0.035493	0.38266	1.4
1998	0.162369	0.073001	0.449602	0.019286	0.305451	1.034483
1999	0.041494	0.019311	0.465396	0.003644	0.079344	1.193548
2000	0.021391	0.011492	0.537252	-0.00113	0.043915	0.174603
2001	0.172308	0.073293	0.425361	0.028654	0.315962	1.4375
2002	0.176197	0.071538	0.406008	0.035984	0.316411	1.203125
2003	0.131957	0.061	0.462272	0.012397	0.251516	1.491803
2004	0.047675	0.023068	0.483856	0.002462	0.092889	0.5
2005	0.298017	0.126136	0.42325	0.050791	0.545242	2.016667
2006	0.302429	0.118588	0.392118	0.069997	0.534861	1.276923
2007	0.150048	0.063029	0.420061	0.026511	0.273585	1.234375
2008	0.211845	0.088414	0.417351	0.038554	0.385136	2.106061
2009	0.284062	0.112848	0.397266	0.062879	0.505245	1.787879
2010	0.024921	0.014101	0.565824	-0.00272	0.05256	1.181818
2011	0.145769	0.061062	0.418893	0.026088	0.265451	0.939394
2012	0.097676	0.041186	0.421658	0.016952	0.1784	1.846154
2013	0.045862	0.021453	0.467778	0.003814	0.087911	0.333333

Table 5.11. Variance Inflation Factors (VIF) for the final model for the Massachusetts Trawl Survey.

Parameter	VIF	Df
Year	1.488	35
Temp	1.633	1
Depth	1.070	1

Table 5.12. Index values for the Rhode Island Trawl Survey.

Year	Mean	SE	CV	LCI	UCI	Nominal
1979	1.0054	1.475102	1.467179	-1.8858	3.8966	1.241379
1980	0.153579	0.082978	0.540292	-0.00906	0.316215	0.5
1981	0.512474	0.192804	0.376222	0.134578	0.890371	0.71831
1982	0.274599	0.112575	0.40996	0.053953	0.495246	0.304348
1983	0.83048	0.304186	0.366278	0.234275	1.426684	0.838235
1984	1.674803	0.607049	0.36246	0.484986	2.864619	2.887097
1985	0.883917	0.355246	0.4019	0.187634	1.5802	1.354839
1986	2.700476	1.101962	0.408062	0.54063	4.860323	2.415094
1987	1.171754	0.583536	0.498002	0.028023	2.315486	2.392157
1988	0.054902	0.040715	0.741593	-0.0249	0.134702	0.333333
1989	0.465279	0.260996	0.560946	-0.04627	0.976831	0.833333
1990	0.26346	0.147105	0.558358	-0.02487	0.551787	0.555556
1991	0.191813	0.108361	0.564931	-0.02057	0.404201	0.230769
1992	0.133206	0.084352	0.633244	-0.03212	0.298536	0.314286
1993	0.043437	0.031027	0.714302	-0.01738	0.104251	0.147059
1994	0.099493	0.065251	0.655836	-0.0284	0.227386	0.095238
1995	0.103291	0.060536	0.586068	-0.01536	0.221941	0.166667
1996	0.588794	0.32684	0.555102	-0.05181	1.229401	0.666667
1997	0.041032	0.031034	0.756332	-0.01979	0.101859	0.071429
1998	0.070529	0.045923	0.651125	-0.01948	0.160539	0.119048
1999	0.121445	0.06679	0.54996	-0.00946	0.252353	0.317073
2000	0.53718	0.255497	0.475626	0.036407	1.037953	1
2001	0.150387	0.082171	0.546397	-0.01067	0.311443	0.214286
2002	0.432289	0.206359	0.477364	0.027825	0.836753	0.375
2003	0.234562	0.121564	0.51826	-0.0037	0.472828	0.285714
2004	0.53206	0.274192	0.51534	-0.00536	1.069475	0.380952
2005	0.145568	0.079764	0.54795	-0.01077	0.301906	0.325
2006	0.019688	0.02188	1.111331	-0.0232	0.062574	0.02381
2007	0.039319	0.028953	0.736362	-0.01743	0.096067	0.073171
2008	0.232809	0.114797	0.493097	0.007806	0.457812	0.47619
2009	0.141589	0.07419	0.523979	-0.00382	0.287	0.285714
2010	0.167229	0.088955	0.531934	-0.00712	0.341579	0.357143
2011	0.200231	0.102017	0.509496	0.000278	0.400183	0.325581
2012	0.085859	0.048322	0.562808	-0.00885	0.180571	0.295455
2013	0.203877	0.10171	0.498879	0.004526	0.403229	0.409091

Table 5.13. Variance Inflation Factors (VIF) for the final model for the RITS.

Parameter	VIF	Df
Year	1.865	34
Temp	2.448	1
Depth	1.711	1

Table 5.14. Index values for the Rhode Island Seine Survey (RISS).

Year	Mean	SE	CV	LCI	UCI	Nominal
1988	9.077	2.494	0.275	4.188	13.966	6.147
1989	14.957	4.540	0.304	6.058	23.855	6.405
1990	6.069	1.828	0.301	2.487	9.652	4.259
1991	7.961	2.115	0.266	3.816	12.105	7.139
1992	9.697	2.602	0.268	4.597	14.797	9.975
1993	3.763	1.044	0.278	1.716	5.809	5.190
1994	1.056	0.312	0.295	0.445	1.667	0.812
1995	0.945	0.275	0.291	0.406	1.484	0.843
1996	7.540	2.045	0.271	3.532	11.548	4.989
1997	2.916	0.794	0.272	1.361	4.472	4.478
1998	5.090	1.365	0.268	2.415	7.765	4.789
1999	5.973	1.558	0.261	2.919	9.027	7.878
2000	16.559	4.185	0.253	8.356	24.763	16.133
2001	9.538	2.493	0.261	4.651	14.424	12.187
2002	10.659	2.691	0.252	5.385	15.934	7.778
2003	17.950	4.669	0.260	8.798	27.102	15.889
2004	8.328	2.133	0.256	4.148	12.508	8.433
2005	15.086	4.106	0.272	7.039	23.133	19.211
2006	2.934	0.826	0.282	1.315	4.553	2.033
2007	9.596	2.410	0.251	4.872	14.320	11.433
2008	2.631	0.705	0.268	1.248	4.013	2.078
2009	2.593	0.726	0.280	1.171	4.016	2.000
2010	2.883	0.855	0.296	1.208	4.558	2.363
2011	1.498	0.492	0.328	0.534	2.462	1.156
2012	4.632	1.363	0.294	1.960	7.304	3.889
2013	4.672	1.432	0.306	1.865	7.478	3.267

Table 5.15. Variance Inflation Factors (VIF) for the final model for the RISS.

Parameter	VIF	Df
Year	2.445	25
Temp	4.034	1
Month	3.893	5
Station	2.176	17
Salinity	2.678	1

Table 5.16. Index values for the CT Long Island Sound Trawl Survey (LISTS).

Year	Mean	SE	CV	LCI	UCI	Nominal
1984	4.389	0.947	0.216	2.533	6.244	3.670
1985	3.689	0.762	0.206	2.197	5.182	3.142
1986	2.478	0.483	0.195	1.531	3.426	2.519
1987	2.317	0.452	0.195	1.431	3.203	1.950
1988	1.870	0.369	0.197	1.147	2.593	1.966
1989	2.403	0.469	0.195	1.483	3.322	2.472
1990	1.988	0.397	0.200	1.210	2.767	2.333
1991	2.314	0.505	0.218	1.324	3.304	2.505
1992	1.441	0.348	0.241	0.759	2.123	1.656
1993	0.729	0.173	0.237	0.391	1.067	0.683
1994	1.329	0.298	0.224	0.746	1.912	0.933
1995	0.383	0.101	0.263	0.186	0.581	0.305
1996	1.072	0.249	0.232	0.584	1.559	0.680
1997	0.692	0.168	0.243	0.362	1.021	0.950
1998	1.158	0.267	0.230	0.635	1.681	0.970
1999	1.359	0.309	0.227	0.753	1.964	1.085
2000	1.381	0.313	0.227	0.767	1.995	1.430
2001	1.332	0.303	0.228	0.738	1.926	1.595
2002	2.458	0.534	0.217	1.410	3.505	2.825
2003	1.098	0.252	0.230	0.603	1.592	1.125
2004	0.982	0.230	0.234	0.531	1.433	1.166
2005	1.023	0.239	0.233	0.556	1.491	0.890
2006	1.123	0.301	0.268	0.533	1.713	1.550
2007	0.916	0.216	0.236	0.493	1.339	1.395
2008	0.960	0.243	0.253	0.484	1.436	1.119
2009	0.714	0.173	0.242	0.375	1.053	0.815
2010	0.483	0.171	0.354	0.148	0.818	0.692
2011	0.496	0.132	0.267	0.237	0.755	0.616
2012	0.647	0.158	0.245	0.336	0.957	0.675
2013	0.891	0.211	0.236	0.479	1.304	0.805

Table 5.17. Variance Inflation Factors (VIF) for the final model for the Connecticut Long Island Sound Trawl Survey.

Parameter	VIF	Df
Year	1.777	29
Month	1.783	8
Stratum	1.029	11

Table 5.18. Index values for the New York Peconic Bay Trawl Survey.

Year	Mean	SE	CV	LCI	UCI	Nominal
1987	0.423129	0.108623	0.256714	0.210228	0.63603	0.265537
1988	0.337483	0.084516	0.25043	0.171832	0.503134	0.309859
1989	1.406774	0.326038	0.231763	0.767739	2.045809	1
1990	0.926185	0.217258	0.234573	0.500359	1.352011	0.744186
1991	0.687333	0.162677	0.236679	0.368485	1.006181	0.557789
1992	0.626856	0.15086	0.240662	0.33117	0.922542	0.613139
1993	0.468438	0.114331	0.24407	0.244348	0.692528	0.461353
1994	0.184177	0.047148	0.255992	0.091767	0.276586	0.212617
1995	0.245767	0.062774	0.255419	0.122731	0.368804	0.337766
1996	0.606568	0.145228	0.239425	0.321922	0.891214	0.471883
1997	0.332323	0.084548	0.254415	0.166609	0.498037	0.274406
1998	0.587707	0.142071	0.241737	0.309248	0.866166	0.453165
1999	0.351743	0.087362	0.24837	0.180513	0.522972	0.345
2000	0.714718	0.169461	0.237102	0.382574	1.046862	0.630952
2001	0.838024	0.199511	0.238073	0.446982	1.229065	0.76087
2002	1.263321	0.297883	0.235794	0.67947	1.847171	1.373494
2003	1.205115	0.284029	0.235686	0.648419	1.761811	0.938931
2004	0.485211	0.118147	0.243496	0.253643	0.716779	0.420147
2006	0.568051	0.147125	0.259	0.279685	0.856417	0.479167
2007	0.710605	0.16896	0.237769	0.379443	1.041767	0.582677
2008	1.97567	0.511575	0.258938	0.972982	2.978358	1.502924
2009	1.677125	0.387581	0.231099	0.917465	2.436785	1.347258
2010	0.631771	0.170606	0.270044	0.297383	0.966159	0.430464
2011	0.176949	0.048422	0.27365	0.082042	0.271857	0.1875
2012	0.573173	0.139187	0.242836	0.300367	0.84598	0.641026
2013	2.006728	0.572071	0.285076	0.885469	3.127986	1.162983

Table 5.19. Variance Inflation Factors (VIF) for the final model for the NY Peconic Bay Trawl Survey.

Parameter	VIF	Df
Year	9.860	25
Temp	1.416	1
Depth	4.281	1
Salinity	3.448	1
Station	3.236	76

Table 5.20. Index values for the New York Long Western Long Island Seine Survey (NYWLISS).

Year	Mean	SE	CV	LCI	UCI	Nominal
1984	0.559	0.264	0.473	0.041	1.076	0.303
1985	0.022	0.035	1.577	-0.047	0.092	0.036
1986	0.224	0.129	0.575	-0.028	0.476	0.202
1987	0.086	0.045	0.521	-0.002	0.174	0.104
1988	0.935	0.435	0.465	0.082	1.788	0.548
1989	0.592	0.265	0.448	0.072	1.112	0.224
1990	0.283	0.141	0.498	0.007	0.559	0.293
1991	1.756	0.764	0.435	0.258	3.254	4.339
1992	0.638	0.283	0.443	0.084	1.191	0.457
1993	0.015	0.013	0.870	-0.011	0.042	0.020
1994	0.047	0.029	0.608	-0.009	0.103	0.126
1995	0.181	0.113	0.623	-0.040	0.403	0.164
1996	0.091	0.056	0.620	-0.019	0.201	0.067
1997	0.153	0.087	0.571	-0.018	0.324	0.159
1998	0.096	0.054	0.559	-0.009	0.201	0.141
1999	0.938	0.428	0.456	0.100	1.776	1.392
2000	1.061	0.413	0.390	0.250	1.871	1.085
2001	0.249	0.114	0.457	0.026	0.472	0.344
2002	0.401	0.177	0.441	0.055	0.747	0.762
2003	0.497	0.196	0.394	0.113	0.880	0.590
2004	0.272	0.115	0.422	0.047	0.497	0.496
2005	0.721	0.301	0.418	0.130	1.312	1.833
2006	0.364	0.161	0.442	0.049	0.680	0.344
2007	0.247	0.105	0.425	0.041	0.453	0.657
2008	0.072	0.035	0.485	0.004	0.141	0.100
2009	0.015	0.011	0.759	-0.007	0.037	0.022
2010	0.006	0.007	1.072	-0.007	0.020	0.008
2011	0.133	0.061	0.461	0.013	0.254	0.387
2012	0.727	0.299	0.412	0.140	1.313	1.414
2013	0.456	0.182	0.399	0.099	0.813	0.217

Table 5.21. Variance Inflation Factors (VIF) for the final model for the NYWLISS.

Parameter	VIF	Df
Year	1.426	29
Temp	3.284	1
Month	3.680	5

Table 5.22. Index values for the New Jersey Ocean Trawl Survey (NJTS).

Year	Mean	SE	CV	LCI	UCI	Nominal
1989	1.211	0.405	0.334	0.418	2.004	1.212
1990	1.472	0.517	0.351	0.460	2.485	2.421
1991	0.980	0.337	0.344	0.320	1.641	1.159
1992	1.483	0.501	0.338	0.502	2.465	1.644
1993	0.639	0.220	0.345	0.207	1.071	0.781
1994	0.356	0.128	0.360	0.105	0.607	0.473
1995	0.539	0.186	0.345	0.175	0.902	0.856
1996	0.222	0.082	0.368	0.062	0.383	0.275
1997	0.106	0.042	0.394	0.024	0.188	0.134
1998	0.318	0.113	0.355	0.097	0.538	0.484
1999	0.572	0.197	0.345	0.185	0.959	0.763
2000	0.327	0.117	0.358	0.097	0.556	0.317
2001	0.278	0.101	0.363	0.080	0.476	0.371
2002	1.418	0.477	0.336	0.484	2.352	1.516
2003	0.636	0.219	0.344	0.207	1.066	0.702
2004	0.338	0.121	0.358	0.101	0.575	0.455
2005	0.533	0.190	0.357	0.160	0.905	0.500
2006	0.654	0.225	0.345	0.212	1.096	0.780
2007	0.364	0.129	0.354	0.112	0.617	0.390
2008	0.817	0.280	0.342	0.269	1.365	1.134
2009	0.478	0.167	0.350	0.150	0.805	0.468
2010	0.423	0.149	0.353	0.130	0.715	0.511
2011	0.141	0.056	0.395	0.032	0.250	0.177
2012	0.245	0.089	0.364	0.070	0.420	0.188
2013	0.445	0.156	0.351	0.139	0.752	0.435

Table 5.23. Variance Inflation Factors (VIF) for the final model for the NJTS.

Parameter	VIF	Df
Year	1.369	24
Temp	1.083	1
Depth	1.259	1
Salinity	1.446	1

Table 6.1. Goodness of fit for each region based on the ASAP model.

Southern New England

Total Likelihood	1933.9
Index RMSE	
MA Trawl	1.19
RI Trawl	1.18
RI Seine	1.15
CT Trawl	0.91
MRIP CPUE	1.10

N=30, 5%-95% RMSE values for N(0,1) = 0.79 - 1.21

New York-New Jersey

Total Likelihood	1090.2
Index RMSE	
NY Trawl (YOY)	1.14
NY Seine (YOY)	1.40
NJ Trawl	1.09
MRIP CPUE	0.82

N=30, 5%-95% RMSE values for N(0,1) = 0.79 - 1.21

DelMarVa

Total Likelihood	905.5
Index RMSE	
MRIP CPUE	1.09

Table 6.2. Index catchability coefficients from the ASAP model.

	Survey	**q**
SNE	MA Trawl	1.80E-04
	RI Trawl	1.56E-04
	RI Seine	7.80E-03
	CT Trawl	9.60E-04
	MRIP CPUE	2.84E-04
NY-NJ	NY Trawl (YOY)	4.10E-04
	NY Seine (YOY)	2.47E-04
	NJ Trawl	1.93E-04
	MRIP CPUE	2.27E-04
DMV	MRIP CPUE	9.81E-04

Table 6.3. Annual fishing mortality estimates from ASAP model.

	SNE		NY-NJ		DMV	
	Annual F	3-year Average	Annual F	3-year Average	Annual F	3-year Average
1982	0.17					
1983	0.13					
1984	0.13	0.14				
1985	0.09	0.12				
1986	0.34	0.18				
1987	0.25	0.23				
1988	0.25	0.28				
1989	0.25	0.25	0.23			
1990	0.18	0.23	0.28		0.24	
1991	0.29	0.24	0.41	0.31	0.29	
1992	0.46	0.31	0.43	0.37	0.17	0.23
1993	0.33	0.36	0.44	0.43	0.27	0.24
1994	0.27	0.36	0.19	0.35	0.28	0.24
1995	0.29	0.30	0.47	0.37	0.43	0.32
1996	0.29	0.29	0.35	0.34	0.31	0.34
1997	0.24	0.28	0.27	0.36	0.34	0.36
1998	0.22	0.25	0.12	0.25	0.27	0.31
1999	0.19	0.22	0.26	0.22	0.29	0.30
2000	0.19	0.20	0.32	0.24	0.30	0.29
2001	0.23	0.20	0.39	0.32	0.21	0.27
2002	0.32	0.24	0.54	0.42	0.41	0.31
2003	0.36	0.30	0.22	0.38	0.28	0.30
2004	0.22	0.30	0.29	0.35	0.36	0.35
2005	0.24	0.27	0.15	0.22	0.29	0.31
2006	0.31	0.26	0.32	0.25	0.44	0.36
2007	0.48	0.34	0.43	0.30	0.35	0.36
2008	0.47	0.42	0.49	0.41	0.34	0.38
2009	0.37	0.44	0.62	0.51	0.45	0.38
2010	0.50	0.44	0.63	0.58	0.51	0.44
2011	0.27	0.38	0.36	0.54	0.26	0.41
2012	0.54	0.44	0.17	0.39	0.14	0.30
2013	0.62	0.48	0.21	0.25	0.10	0.17

Table 6.4. Estimates of total abundance, spawning stock biomass, and recruitment from ASAP model.

	SNE			NY-NJ			DMV		
	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)
1982	14.20	11,377	2.34						
1983	13.01	11,376	1.66						
1984	11.82	11,447	1.29						
1985	10.62	11,367	1.10						
1986	10.04	10,242	1.38						
1987	8.55	8,369	1.30						
1988	7.67	7,180	1.20						
1989	6.84	6,289	0.98	8.58	5,504	1.49			
1990	6.18	5,738	0.90	8.13	5,270	1.39	3.53	2,197	0.85
1991	5.81	5,210	0.92	7.83	4,705	1.60	3.75	2,285	0.96
1992	5.28	4,266	0.86	7.10	3,995	1.36	3.66	2,406	0.74
1993	4.52	3,485	0.74	6.39	3,525	1.15	3.45	2,581	0.51
1994	4.22	3,153	0.79	5.57	3,408	0.85	2.98	2,555	0.32
1995	4.12	2,924	0.84	5.33	3,220	0.88	2.53	2,268	0.29
1996	3.96	2,730	0.76	4.60	2,746	0.81	2.00	1,881	0.26
1997	3.91	2,680	0.82	4.39	2,565	0.97	1.88	1,592	0.43
1998	4.12	2,743	0.96	4.76	2,613	1.29	1.93	1,355	0.56
1999	4.50	2,847	1.15	4.95	2,716	1.00	1.97	1,270	0.49
2000	4.63	3,003	0.94	4.89	2,759	0.94	2.09	1,278	0.56
2001	4.58	3,191	0.78	4.74	2,665	0.91	2.27	1,330	0.64
2002	4.49	3,260	0.78	4.56	2,395	0.92	2.42	1,364	0.60
2003	4.43	3,174	0.86	4.39	2,271	1.04	2.29	1,395	0.47
2004	4.26	3,137	0.77	4.64	2,343	1.09	2.36	1,446	0.57
2005	4.16	3,189	0.71	4.78	2,479	1.11	2.41	1,418	0.62
2006	3.92	3,127	0.58	4.86	2,604	0.92	2.33	1,383	0.46
2007	3.58	2,821	0.50	4.63	2,469	0.84	2.25	1,347	0.53
2008	3.53	2,402	0.89	4.37	2,168	0.96	2.20	1,294	0.51
2009	3.33	2,128	0.66	4.06	1,816	0.87	2.16	1,217	0.51
2010	3.25	1,996	0.65	4.26	1,521	1.37	2.14	1,097	0.57
2011	3.42	1,961	0.94	4.14	1,436	1.02	2.09	1,085	0.54
2012	3.10	1,931	0.33	3.64	1,758	0.38	1.99	1,247	0.35
2013	2.91	1,839	0.55	4.05	2,079	1.08	2.01	1,459	0.40

Table 6.5. Sensitivity Runs

SNE	Likelihood	Mohn's rho SSB	Mohn's rho F	2013 SSB	2013 F
Base Model	1728.24	-0.04	0.17	1814	0.62
Lorenzen M	1729.37	-0.06	0.19	1472	0.73
Indices Removed					
No MA Trawl	1738.23	-0.06	0.18	1946	0.57
No RI Trawl	1641.91	-0.01	0.14	1882	0.6
No RI Seine	1654.77	-0.09	0.23	1958	0.61
No CT Trawl	1271.77	-0.04	0.26	1750	0.64
No MRIP*	1486.77	-0.02	0.16	1653	0.67
MRIP only	Did not converge				
Ignore initial guesses	1731.92	-0.04	0.2	1749	0.64
2 Selectivity blocks	1729.15	-0.03	0.17	1857	0.68
Fixed steepness	1730	-0.001	0.12	1940	0.59
Truncated time-series	Did not converge				
NY-NJ					
Base	1193.8	0.20	0.13	2,278	0.24
Lorenzen M	1196.5	0.20	0.13	2,251	0.25
Commercial discards	1181.73	0.20	0.12	2143	0.26
Indices Removed					
No NY Trawl	1185.8	0.05	0.34	1,753	0.29
No NY Seine	1188.2	0.21	0.12	2,747	0.21
No NJ Trawl*	*878.5*	0.14	*0.24*	2,593	*0.2*
No MRIP	972.7	0.28	-0.1	2,089	0.23
MRIP only	Did not converge				
Ignore initial guesses	1193.2	0.180	0.14	2,187	0.24
2 Selectivity blocks	1197.9	0.200	0.08	2,369	0.27
Fixed steepness	1194.3	0.210	0.12	2,318	0.24
Full CAA	1490.2	0.350	-0.1	2511.11	0.25
DMV					
Base Model	905.481	0.26	-0.2	1458	0.1
Lorenzen M	911.435	0.26	-0.2	1520	0.1
Commercial discards	950.246	0.3	-0.03	1423	0.1
Indices Removed					
Catch upweighted	n/a	0.23	-0.19	1511	0.1
Index upweighted	n/a	0.23	-0.23	1321	0.1
Ignore initial guesses	908.091	0.25	-0.2	1128	0.13
2 Selectivity blocks	906.968	0.27	-0.17	1374	0.11
Fixed steepness	906.893	0.25	-0.2	1157	0.12

Table 6.6.A. ASAP reference points from base model run

	SNE	NY-NJ	DMV
F30%SPR	0.44	0.26	0.24
F40%SPR	0.26	0.17	0.16
FMSY	0.15	0.18	0.50
SSB30% (MT)	2,310	2,640	1,580
SSB40% (MT)	3,090	3,570	2,090
SSBMSY (MT)	3,883	3,823	867

Table 6.6.B. Sensitivity of ASAP reference points from base model run

	FSPR30%	FSPR40%	FMSY	SSB30%	SSB40%	SSBMSY
SNE						
Base Model	0.44	0.26	0.15	2,310	3,090	3,883
Lorenzen M	0.21	0.13	0.12	3,300	4,450	5,454
Indices Removed						
No MA Trawl	0.44	0.26	0.16	2,340	3,125	3,878
No RI Trawl	0.44	0.26	0.17	2,280	3,040	3,604
No RI Seine	0.44	0.26	0.17	2,350	3,130	3,604
No CT Trawl	0.46	0.27	0.14	2,230	2,900	3,683
No MRIP*	0.43	0.26	0.16	2,280	3,000	3,562
MRIP only	Did not converge					
Ignore initial guesses	0.44	0.26	0.15	2,310	3,090	3,883
2 Selectivity blocks	0.48	0.28	0.16	2,320	3,070	3,881
Fixed steepness	0.44	0.26	2.95	2,310	3,080	792
Truncated time-series	Did not converge					
NY-NJ						
Base Model	0.25	0.16	0.16	2,640	3,570	4,425
Lorenzen M	0.23	0.15	0.16	4,250	5,570	4,986
Commercial discards	0.25	0.16	0.16	2,740	3,790	4,532
Indices Removed						
No NY Trawl	0.27	0.18	0.16	3,230	4,135	4,361
No NY Seine	0.28	0.18	0.19	3,330	4,350	3,875
No NJ Trawl	0.27	0.18	0.10	3,380	4,420	47,910
No MRIP	0.27	0.17	0.15	3,210	4,200	4,658
MRIP only						
Ignore initial guesses	0.25	0.16	0.09	3,340	4,375	8.48E+25
2 Selectivity blocks	0.27	0.17	0.19	3,270	4,280	4,144
Fixed steepness	0.25	0.16	2.41	3,230	4,220	615
Truncated time-series	0.26	0.17	0.11	2,410	3,150	2.09E+04
DMV						
Base Model	0.24	0.16	0.5	1,580	2,090	867
Lorenzen M	0.24	0.16	0.65	1,620	2,120	748
Indices Removed						
Catch upweighted	0.24	0.16	0.5	1,620	2,150	885
Index upweighted	0.23	0.16	0.49	1,680	2,170	875
Ignore initial guesses	0.24	0.16	0.07	1,460	1,930	8.85E+25
2 Selectivity blocks	0.25	0.16	0.35	1,560	2,110	1,160
Fixed steepness	0.24	0.16	0.1	1,470	1,940	5,223

Table 6.7. Selection of indices used for each regional run (base runs) of the xDB-SRA model.

Region	**MA spring**	**RI fall**	**CT trawl**	**NY trawl**	**NJ trawl**	**MRIP**
SNE	X	X	X			MA-CT
NYNJ				X	X	NY-NJ
DMV						DE-VA
North	X	X	X	X		MA-NY
South					X	NJ-VA
Coast	X	X	X	X	X	MA-VA
MARI	X	X				MA-RI
CTNYNJ			X	X	X	CT-NJ

Table 6.8. Number of iterations and maximum likelihood weight values for each regional run (base runs and sensitivity runs) of the xDB-SRA model.

Region	Version	Iterations	Max weight	Run used
SNE	Base	150,000	0.0088	R2
	No MRIP	150,000	0.0081	R1
	MRIP only	150,000	0.0007	R1
	Schaeffer	150,000	0.0085	R1
	MARI	150,000	0.0039	R1
NYNJ	Base	150,000	0.0053	R2
	No MRIP	150,000	0.0009	R1
	MRIP only	150,000	0.0014	R1
	Schaeffer	150,000	0.0026	R1
	CTNYNJ	150,000	0.0127	R1
DMV	Base	150,000	0.0012	R1
	With VTR	150,000	0.0015	R1
	Schaeffer	150,000	0.0006	R1
North	Base	150,000	0.0081	R1
South	Base	150,000	0.0012	R1
Coast	Base	300,000	.0127	R1R2

Table 6.9. Summarized input parameter draws and estimated reference point values for base and sensitivity runs of SNE regional xDB-SRA model runs.

Region	Run	Parameter	Valid runs			Resampled runs		
			25th	50th	75th	25th	50th	75th
Inputs	Preferred	M	0.127	0.1502	0.1776	0.1134	0.1352	0.1563
		F_{MSY} : M	0.6387	0.9242	1.2092	0.5381	0.7305	0.9751
		B_{MSY} : K	0.4099	0.5001	0.5895	0.4131	0.5096	0.6033
		B_{1982} : K	0.6905	0.7585	0.8195	0.6974	0.7578	0.8209
		$B_{current}$: K	0.1613	0.2731	0.386	0.0958	0.1162	0.1441
	No MRIP	M	0.1268	0.15	0.1774	0.1195	0.1397	0.1647
		F_{MSY} : M	0.6426	0.9266	1.2117	0.7865	1.0006	1.2182
		B_{MSY} : K	0.4097	0.4995	0.5892	0.3661	0.4464	0.5196
		B_{1982} : K	0.691	0.7594	0.8196	0.7153	0.7746	0.8315
		$B_{current}$: K	0.1617	0.2732	0.3854	0.0732	0.0901	0.1136
	Only MRIP	M	0.1269	0.1501	0.1774	0.113	0.133	0.1573
		F_{MSY} : M	0.6387	0.9239	1.2112	0.4264	0.5494	0.7618
		B_{MSY} : K	0.4099	0.4996	0.5888	0.436	0.5588	0.6549
		B_{1982} : K	0.6904	0.7594	0.8203	0.6986	0.7648	0.8238
		$B_{current}$: K	0.161	0.2729	0.3857	0.1392	0.1889	0.2491
	Schaeffer	M						
		F_{MSY} : M						
		B_{MSY} : K						
		B_{1982} : K						
		$B_{current}$: K						
Outputs	Preferred	K	14,247.9	17,156.66	21,150.81	16,264.36	19,550.53	22,459.03
		B_{MSY}	6,737.582	8,278.154	10,409.79	7,921.276	9,295.404	10,691.37
		F_{MSY}	0.093	0.1347	0.1829	0.0738	0.0965	0.1272
		u_{MSY}	0.0827	0.1174	0.1548	0.0665	0.0863	0.1118
		MSY	797.0556	959.336	1,137.886	620.0094	816.5867	1,031.054
	No MRIP	K	14,231	17,120.69	21,090.68	14,723.4	17,074.17	19,497.25
		B_{MSY}	6,726.399	8250.75	1,0378.92	6,256.419	7,342.541	8,502.584
		F_{MSY}	0.0931	0.1352	0.183	0.1102	0.137	0.1669
		u_{MSY}	0.0829	0.1177	0.1549	0.0981	0.1193	0.1432
		MSY	797.1927	959.3693	1,138.868	699.032	867.8799	1,042.237
	Only MRIP	K	14,223.77	17,135.99	21,139.99	17,741.59	21,704.23	25,847.21
		B_{MSY}	6,734.234	8,272.19	1,0386.41	8,986.464	10,993.3	13,267.8
		F_{MSY}	0.0929	0.135	0.183	0.0569	0.075	0.1046
		u_{MSY}	0.0826	0.1176	0.155	0.052	0.0674	0.0924
		MSY	795.3171	959.8467	1,137.318	588.666	779.2552	997.5655
	Schaeffer	K						
		B_{MSY}						
		F_{MSY}						
		u_{MSY}						
		$B_{current}$: K						

Table 6.10. Summarized input parameter draws and estimated reference point values for base and sensitivity runs of NY-NJ regional xDB-SRA model runs.

Region	Run	Parameter	Valid runs			Resampled runs		
			25th	50th	75th	25th	50th	75th
Inputs	Preferred	M	0.1267	0.1501	0.1775	0.1176	0.1395	0.164
		F_{MSY} : M	0.6415	0.9276	1.2115	0.4946	0.6872	0.9668
		B_{MSY} : K	0.4102	0.5	0.5886	0.4672	0.5898	0.6777
		B_{1982} : K	0.6903	0.7587	0.8197	0.6284	0.7021	0.7678
		$B_{current}$: K	0.1608	0.2723	0.385	0.3648	0.4165	0.4585
	No MRIP	M	0.1268	0.1501	0.1778	0.1299	0.1531	0.181
		F_{MSY} : M	0.6403	0.9248	1.2127	0.7702	1.0421	1.274
		B_{MSY} : K	0.411	0.5003	0.5886	0.42	0.5026	0.5841
		B_{1982} : K	0.6902	0.7589	0.8198	0.6806	0.7491	0.8122
		$B_{current}$: K	0.1617	0.2732	0.3852	0.2821	0.3532	0.4206
	Only MRIP	M	0.1268	0.1501	0.1774	0.1153	0.1356	0.1596
		F_{MSY} : M	0.6396	0.9251	1.2105	0.441	0.5736	0.7858
		B_{MSY} : K	0.4094	0.4991	0.5883	0.4352	0.5647	0.6678
		B_{1982} : K	0.6897	0.7589	0.8196	0.6437	0.7151	0.7798
		$B_{current}$: K	0.1625	0.2736	0.3854	0.3506	0.4109	0.4567
	Schaeffer	M						
		F_{MSY} : M						
		B_{MSY} : K						
		B_{1982} : K						
		$B_{current}$: K						
Outputs	Preferred	K	12,975.84	16,010.47	20,225.31	15,342.14	20,502.85	26,569.1
		B_{MSY}	6,242.404	7,691.425	9,755.386	8,739.423	10,891.22	13,383.76
		F_{MSY}	0.0932	0.1352	0.1832	0.0696	0.095	0.1328
		u_{MSY}	0.0829	0.1177	0.1551	0.0629	0.0846	0.116
		MSY	771.4095	902.4616	1,031.749	796.6655	923.4917	1,098.191
	No MRIP	K	12,966.88	15,994.67	20,216.21	12,360.62	15,071.65	18,729.99
		B_{MSY}	6,243.044	7,706.845	9,758.595	6,097.538	7,302.678	8,985.696
		F_{MSY}	0.0932	0.1349	0.1835	0.1141	0.1531	0.1957
		u_{MSY}	0.0829	0.1175	0.1552	0.1007	0.1323	0.1643
		MSY	772.4589	902.6469	1,032.413	845.4772	948.9997	1,065.044
	Only MRIP	K	12,989.5	16,062.37	20,284.1	17,922.9	23,554.14	29,512.98
		B_{MSY}	6,241.631	7,698.666	9,757.581	9,605.208	11,863.89	14,646.35
		F_{MSY}	0.093	0.1349	0.1829	0.0598	0.079	0.1095
		u_{MSY}	0.0827	0.1175	0.1549	0.0542	0.071	0.0964
		MSY	770.8814	900.7412	1,030.987	737.1722	855.0145	1,020.931
	Schaeffer	K						
		B_{MSY}						
		F_{MSY}						
		u_{MSY}						
		MSY						

Table 6.11. Summarized input parameter draws and estimated reference point values for base and sensitivity runs of DMV regional xDB-SRA model runs.

Region	Run	Parameter	Valid runs			Resampled runs		
			25th	50th	75th	25th	50th	75th
Inputs	Preferred	M	0.1265	0.1497	0.177	0.1217	0.1429	0.1688
		F_{MSY} : M	0.6375	0.9237	1.2086	0.5209	0.7322	1.0313
		B_{MSY} : K	0.4085	0.4983	0.5878	0.4492	0.5617	0.6531
		B_{1982} : K	0.6895	0.7584	0.8194	0.6209	0.6925	0.7606
		$B_{current}$: K	0.1624	0.2745	0.3868	0.3636	0.419	0.4609
	With VTR	M	0.1266	0.1498	0.1773	0.1175	0.1388	0.1643
		F_{MSY} : M	0.6351	0.9213	1.2079	0.483	0.6645	0.964
		B_{MSY} : K	0.4091	0.4993	0.5891	0.4734	0.5983	0.6842
		B_{1982} : K	0.6898	0.759	0.8198	0.6445	0.7105	0.7778
		$B_{current}$: K	0.1627	0.2746	0.3867	0.3287	0.3905	0.4432
	Schaeffer	M						
		F_{MSY} : M						
		B_{MSY} : K						
		B_{1982} : K						
		$B_{current}$: K						
Outputs	Preferred	K	4,733.62	5,976.621	7,698.631	5,325.203	7,241.046	9,742.089
		B_{MSY}	2,299.478	2,851.887	3,650.375	2,981.664	3,756.523	4,797.167
		F_{MSY}	0.0927	0.1346	0.1823	0.074	0.105	0.1472
		u_{MSY}	0.0825	0.1173	0.1543	0.0665	0.0927	0.1269
		MSY	291.8306	335.4076	373.9474	308.9484	351.3031	395.994
	With VTR	K	4,724.376	5,972.674	7,711.871	5,408.663	7,458.311	9,894.503
		B_{MSY}	2,299.729	2,854.098	3,666.755	3,205.462	4,038.912	5,088.591
		F_{MSY}	0.0921	0.1346	0.1827	0.0678	0.0931	0.1339
		u_{MSY}	0.082	0.1172	0.1546	0.0612	0.083	0.1168
		MSY	291.7877	335.8153	374.0693	297.8919	343.8444	390.3407
	Schaeffer	K						
		B_{MSY}						
		F_{MSY}						
		u_{MSY}						
		MSY						

Table 6.12. Fishery indices used by regional configuration in the Bayesian State Space Surplus Production Model.

Regional Configuration	MA Spring Trawl Survey	RI Fall Trawl Survey	Ct Long Island Sound Trawl Survey	NY Peconic Bay Trawl Survey	New Jersey Ocean Trawl Survey	Regional MRIP Index
Southern New England - base	X	X	X			X
Southern New England – sensitivity 1		X	X			X
Southern New England – sensitivity 2	X		X			X
Southern New England – sensitivity 3	X	X				X
Southern New England – sensitivity 4	X	X	X			
New York – New Jersey - base				X	X	X
New York – New Jersey – sensitivity 1					X	X
New York – New Jersey – sensitivity 2				X		X
New York – New Jersey – sensitivity 3				X	X	
DelMarVa						X

Table 6.13. Biomass estimates for the Bayesian State Space Surplus Production Model with precision estimates for the Southern New England Region – base configuration.

Parameter	2.5% CI	Median	97.5% CI
B 1982	14.280	19.160	24.710
B 1983	12.460	17.360	22.980
B 1984	11.830	16.550	22.310
B 1985	10.950	15.420	20.970
B 1986	11.330	15.480	20.840
B 1987	7.294	10.940	15.880
B 1988	6.466	9.795	14.440
B 1989	5.619	8.686	13.150
B 1990	5.080	7.864	11.920
B 1991	4.932	7.483	11.150
B 1992	4.227	6.519	9.820
B 1993	3.025	5.092	8.043
B 1994	2.643	4.599	7.366
B 1995	2.487	4.347	6.896
B 1996	2.496	4.335	6.817
B 1997	2.480	4.277	6.656
B 1998	2.650	4.443	6.796
B 1999	2.792	4.584	6.899
B 2000	2.962	4.754	7.048
B 2001	3.146	4.932	7.248
B 2002	3.336	5.122	7.483
B 2003	3.216	4.940	7.217
B 2004	3.087	4.745	6.927
B 2005	3.202	4.811	6.956
B 2006	3.123	4.651	6.723
B 2007	2.932	4.377	6.377
B 2008	2.355	3.712	5.681
B 2009	2.169	3.479	5.427
B 2010	2.201	3.462	5.377
B 2011	1.911	3.150	5.110
B 2012	2.104	3.359	5.403
B 2013	1.717	2.992	5.156

Table 6.14. Biomass estimates for the Bayesian State Space Surplus Production Model with precision estimates for the New York – New Jersey Region – base configuration.

Parameter	2.5% CI	Median	97.5% CI
B 1982	6.166	14.580	37.251
B 1983	4.232	11.190	31.991
B 1984	3.922	10.600	31.240
B 1985	5.071	12.830	35.610
B 1986	7.850	18.120	47.210
B 1987	7.563	18.080	48.370
B 1988	8.113	19.630	52.910
B 1989	10.140	24.110	64.160
B 1990	11.470	26.850	70.930
B 1991	10.970	25.630	68.280
B 1992	11.180	26.840	71.950
B 1993	7.578	18.460	49.620
B 1994	5.155	13.100	36.830
B 1995	6.399	15.390	41.090
B 1996	4.980	12.250	33.120
B 1997	3.988	10.000	27.980
B 1998	3.452	9.192	26.740
B 1999	4.813	11.680	31.490
B 2000	4.948	12.270	33.480
B 2001	5.961	14.390	38.510
B 2002	7.540	17.750	47.130
B 2003	3.950	11.210	32.630
B 2004	4.559	11.350	31.640
B 2005	3.786	10.330	29.950
B 2006	5.273	12.940	35.100
B 2007	5.717	14.020	37.630
B 2008	6.500	16.040	43.120
B 2009	7.220	17.130	45.520
B 2010	5.231	12.920	35.350
B 2011	4.134	10.460	29.390
B 2012	4.453	11.200	31.250
B 2013	5.644	14.380	39.640

Table 6.15. Biomass estimates for the Bayesian State Space Surplus Production Model with precision estimates for the DelMarVa Region – base configuration.

Parameter	2.5% CI	Median	97.5% CI
B 1982	4.191	8.218	19.010
B 1983	3.808	7.854	18.790
B 1984	3.349	7.326	18.300
B 1985	3.197	7.090	18.020
B 1986	3.409	7.284	18.570
B 1987	3.189	7.017	18.270
B 1988	3.117	6.918	18.370
B 1989	2.563	6.296	17.880
B 1990	2.232	5.879	17.200
B 1991	2.473	6.115	17.500
B 1992	2.423	6.044	17.590
B 1993	2.595	6.230	17.960
B 1994	2.492	6.067	17.760
B 1995	2.215	5.695	17.180
B 1996	1.868	5.262	16.500
B 1997	1.743	5.039	15.930
B 1998	1.676	4.892	15.490
B 1999	1.745	4.939	15.430
B 2000	1.779	4.939	15.300
B 2001	1.836	5.013	15.440
B 2002	2.039	5.255	15.820
B 2003	1.991	5.221	15.810
B 2004	2.111	5.375	16.160
B 2005	2.082	5.353	16.190
B 2006	2.171	5.443	16.350
B 2007	2.102	5.349	16.190
B 2008	2.121	5.381	16.360
B 2009	2.128	5.373	16.240
B 2010	2.086	5.313	16.120
B 2011	1.992	5.193	15.900
B 2012	2.111	5.320	16.040
B 2013	2.314	5.570	16.490

Table 6.16. Exploitation estimates for the Bayesian State Space Surplus Production Model with precision estimates for the Southern New England Region – base configuration.

Parameter	2.5% CI	Median	97.5% CI
U 1982	0.083	0.113	0.157
U 1983	0.059	0.082	0.118
U 1984	0.072	0.102	0.147
U 1985	0.033	0.047	0.068
U 1986	0.238	0.328	0.444
U 1987	0.116	0.173	0.263
U 1988	0.127	0.193	0.295
U 1989	0.103	0.162	0.254
U 1990	0.077	0.120	0.190
U 1991	0.129	0.199	0.306
U 1992	0.189	0.292	0.455
U 1993	0.117	0.190	0.323
U 1994	0.081	0.134	0.238
U 1995	0.071	0.116	0.206
U 1996	0.067	0.109	0.193
U 1997	0.045	0.073	0.128
U 1998	0.050	0.079	0.136
U 1999	0.049	0.077	0.129
U 2000	0.053	0.082	0.135
U 2001	0.054	0.083	0.134
U 2002	0.088	0.133	0.210
U 2003	0.092	0.140	0.220
U 2004	0.065	0.098	0.155
U 2005	0.096	0.143	0.221
U 2006	0.115	0.171	0.260
U 2007	0.181	0.270	0.407
U 2008	0.114	0.180	0.288
U 2009	0.068	0.110	0.181
U 2010	0.135	0.215	0.343
U 2011	0.037	0.062	0.105
U 2012	0.144	0.237	0.384
U 2013	0.118	0.209	0.374

Table 6.17. Exploitation estimates for the Bayesian State Space Surplus Production Model with precision estimates for the New York – New Jersey Region – base configuration.

Parameter	2.5% CI	Median	97.5% CI
U 1982	0.038	0.098	0.237
U 1983	0.024	0.070	0.189
U 1984	0.021	0.064	0.174
U 1985	0.037	0.105	0.266
U 1986	0.050	0.131	0.306
U 1987	0.044	0.119	0.286
U 1988	0.034	0.093	0.228
U 1989	0.019	0.050	0.120
U 1990	0.022	0.060	0.141
U 1991	0.032	0.086	0.203
U 1992	0.025	0.067	0.165
U 1993	0.031	0.085	0.211
U 1994	0.014	0.040	0.104
U 1995	0.025	0.068	0.168
U 1996	0.021	0.057	0.142
U 1997	0.015	0.044	0.111
U 1998	0.007	0.020	0.053
U 1999	0.020	0.054	0.133
U 2000	0.029	0.081	0.203
U 2001	0.021	0.058	0.142
U 2002	0.034	0.090	0.218
U 2003	0.009	0.028	0.080
U 2004	0.020	0.056	0.143
U 2005	0.009	0.026	0.071
U 2006	0.021	0.059	0.146
U 2007	0.025	0.068	0.170
U 2008	0.019	0.051	0.129
U 2009	0.020	0.054	0.130
U 2010	0.022	0.062	0.154
U 2011	0.015	0.043	0.111
U 2012	0.008	0.021	0.054
U 2013	0.010	0.029	0.076

Table 6.18. Exploitation estimates for the Bayesian State Space Surplus Production Model with precision estimates for the DelMarVa Region – base configuration.

Parameter	2.5% CI	Median	97.5% CI
U 1982	0.019	0.044	0.088
U 1983	0.030	0.074	0.156
U 1984	0.021	0.053	0.117
U 1985	0.011	0.029	0.065
U 1986	0.029	0.074	0.161
U 1987	0.027	0.071	0.157
U 1988	0.051	0.138	0.305
U 1989	0.041	0.118	0.292
U 1990	0.012	0.034	0.091
U 1991	0.028	0.081	0.202
U 1992	0.016	0.046	0.116
U 1993	0.028	0.081	0.196
U 1994	0.037	0.109	0.268
U 1995	0.041	0.125	0.326
U 1996	0.027	0.086	0.247
U 1997	0.023	0.074	0.219
U 1998	0.017	0.054	0.161
U 1999	0.019	0.060	0.172
U 2000	0.019	0.060	0.170
U 2001	0.011	0.036	0.098
U 2002	0.027	0.081	0.210
U 2003	0.017	0.051	0.136
U 2004	0.024	0.072	0.187
U 2005	0.016	0.050	0.130
U 2006	0.026	0.078	0.197
U 2007	0.021	0.063	0.163
U 2008	0.019	0.059	0.152
U 2009	0.023	0.070	0.180
U 2010	0.024	0.075	0.194
U 2011	0.011	0.035	0.092
U 2012	0.007	0.023	0.058
U 2013	0.006	0.018	0.044

Table 6.19. Parameterization by region for the Bayesian State Space Surplus Production Model. Parameterization of τ^2 was kept consistent between surveys.

Region	**K**	**r**	σ^2	τ^2	**q**
Southern New England	Lognormal(2,3)	Uniform(0.1, 0.5)	Inverse gamma(4, 0.01)	Inverse gamma(2, 0.01)	Inverse gamma(0.001, 0.001)
New York – New Jersey	Lognormal(1.5, 3)	Uniform(0.1, 0.5)	Inverse gamma(4, 0.01)	Inverse gamma(2, 0.01)	Inverse gamma(0.001, 0.001)
DelMarVa	Lognormal(1.8, 3)	Uniform(0.1, 0.5)	Inverse gamma(4, 0.01)	Inverse gamma(2, 0.01)	Inverse gamma(0.001, 0.001)

Table 6.20. MCMC starting values for the two chains by region for the Bayesian State Space Surplus Production Model.

Region	K_{chain1}	K_{chain2}	r_{chain1}	r_{chain2}	inv σ^2_{chain1}	inv σ^2_{chain2}
Southern New England	15	5	0.5	0.2	900	1100
New York – New Jersey	10	5	0.5	0.2	900	1100
DelMarVa	10	5	0.5	0.2	900	1100

Table 6.21. Reference point estimates (median values) for the Bayesian State Space Surplus Production Model by region.

Region	**K**	**r**	**MSY**	**Umsy**	**Bmsy**
Southern New England	19.11	0.145	0.705	0.073	9.555
New York – New Jersey	17.650	0.269	1.165	0.135	8.826
DelMarVa	8.203	0.235	0.438	0.117	4.101

Table 6.22. Back-calculated partial recruitment of tautog.

	Age											
	1	2	3	4	5	6	7	8	9	10	11	12
1997	0.0002	0.0003	0.0156	0.0753	0.1891	0.5751	0.6151	0.9575	0.8604	1.0000	0.9393	0.9393
1998	0.0003	0.0047	0.0121	0.0793	0.1962	0.3313	0.4749	0.5238	0.4380	1.0000	0.6539	0.6539
1999	0.0013	0.0082	0.0563	0.1133	0.2358	0.4488	0.5731	1.0000	0.6820	0.8942	0.8588	0.8588
2000	0.0003	0.0036	0.1191	0.2260	0.4040	0.5082	1.0000	0.9229	0.8992	0.9451	0.9224	0.9224
2001	0.0002	0.0268	0.0908	0.2415	0.2213	0.1931	0.2130	0.3508	0.4988	1.0000	0.6165	0.6165
2002	0.0002	0.0572	0.1090	0.2737	0.6690	0.9416	1.0000	0.9488	0.9427	0.8361	0.9092	0.9092
2003	0.0004	0.0345	0.1088	0.2441	0.6058	0.8626	1.0000	0.9960	0.8162	0.8408	0.8843	0.8843
2004	0.0004	0.0180	0.1222	0.2655	0.4593	0.8564	0.7581	0.7664	1.0000	0.7469	0.8378	0.8378
2005	0.0024	0.0089	0.1022	0.2664	0.3911	0.6402	1.0000	0.7249	0.7252	0.9691	0.8064	0.8064
2006	0.0003	0.0331	0.0991	0.2240	0.4714	0.8321	0.7693	1.0000	0.7434	0.7535	0.8323	0.8323
2007	0.0002	0.0085	0.0894	0.1858	0.3112	0.5151	0.7148	0.8026	1.0000	0.8360	0.8795	0.8795
2008	0.0003	0.0062	0.0447	0.1750	0.3876	0.5719	0.6792	0.7245	0.7873	1.0000	0.8373	0.8373
2009	0.0002	0.0122	0.0737	0.2196	0.4060	0.5732	0.7875	0.9317	1.0000	0.6195	0.8504	0.8504
2010	0.0003	0.0202	0.1440	0.3907	0.6312	0.6898	0.7854	0.9624	0.7684	1.0000	0.9103	0.9103
2011	0.0011	0.0158	0.1366	0.3278	0.4883	0.7469	0.6885	0.8338	0.8411	1.0000	0.9206	0.9206

Table 6.23. Catchability estimates for tautog.

	NLLS Estimate	Bootstrap Mean	Bootstrap Std Error	C.V. for NLLS Soln.
Q 1	5.84E-06	6.05E-06	1.15E-06	0.1893
Q 2	1.70E-05	1.77E-05	3.90E-06	0.2198
Q 3	2.47E-05	2.54E-05	5.28E-06	0.2082
Q 4	5.60E-05	5.67E-05	1.01E-05	0.1780
Q 5	1.08E-04	1.09E-04	1.68E-05	0.1537
Q 6	1.82E-04	1.84E-04	2.41E-05	0.1314
Q 7	2.55E-04	2.56E-04	3.32E-05	0.1299
Q 8	3.38E-04	3.41E-04	3.90E-05	0.1142
Q 9	4.20E-04	4.21E-04	5.34E-05	0.1268
Q 10	5.41E-04	5.40E-04	7.34E-05	0.1361
Q 11	5.98E-04	5.92E-04	6.49E-05	0.1097
Q 12	7.68E-04	7.71E-04	7.41E-05	0.0961
Q 14	5.33E-06	5.58E-06	1.73E-06	0.3097
Q 15	2.17E-05	2.23E-05	4.43E-06	0.1987
Q 16	1.18E-05	1.19E-05	1.82E-06	0.1523
Q 17	1.76E-05	1.79E-05	2.39E-06	0.1335
Q 18	2.85E-05	2.87E-05	3.39E-06	0.1182
Q 19	4.88E-05	4.89E-05	6.37E-06	0.1303
Q 20	6.77E-05	6.84E-05	9.23E-06	0.1350
Q 21	8.95E-05	9.04E-05	1.33E-05	0.1476
Q 22	1.04E-04	1.05E-04	1.62E-05	0.1551
Q 23	1.14E-04	1.16E-04	1.76E-05	0.1511
Q 24	1.24E-04	1.26E-04	2.02E-05	0.1605
Q 25	1.26E-04	1.31E-04	2.61E-05	0.1996
Q 26	2.30E-06	2.51E-06	8.92E-07	0.3547
Q 27	2.03E-05	2.10E-05	4.41E-06	0.2101
Q 28	1.56E-05	1.58E-05	1.89E-06	0.1197
Q 29	2.23E-05	2.23E-05	2.52E-06	0.1129
Q 30	3.67E-05	3.67E-05	3.58E-06	0.0974
Q 31	6.39E-05	6.44E-05	7.36E-06	0.1141
Q 32	9.61E-05	9.70E-05	1.07E-05	0.1108
Q 33	1.47E-04	1.46E-04	1.50E-05	0.1027
Q 34	1.88E-04	1.89E-04	2.06E-05	0.1087
Q 35	2.07E-04	2.07E-04	2.78E-05	0.1343
Q 36	2.45E-04	2.47E-04	3.65E-05	0.1478
Q 37	2.77E-04	2.83E-04	4.07E-05	0.1440
Q 39	4.62E-05	4.74E-05	8.55E-06	0.1806

	NLLS Estimate	Bootstrap Mean	Bootstrap Std Error	C.V. for NLLS Soln.
Q 40	2.70E-06	3.16E-06	1.86E-06	0.5895
Q 41	9.85E-06	9.93E-06	2.27E-06	0.2290
Q 42	3.04E-05	3.06E-05	5.10E-06	0.1667
Q 43	2.91E-05	2.93E-05	3.69E-06	0.1262
Q 44	2.85E-05	2.92E-05	5.12E-06	0.1756
Q 45	2.69E-05	2.71E-05	4.39E-06	0.1623
Q 46	2.86E-05	2.89E-05	4.96E-06	0.1715
Q 47	2.93E-05	3.00E-05	5.21E-06	0.1737
Q 48	3.46E-05	3.52E-05	6.90E-06	0.1962
Q 49	2.69E-05	2.80E-05	6.70E-06	0.2395
Q 50	2.80E-05	2.93E-05	7.53E-06	0.2574
Q 51	3.22E-05	3.33E-05	8.19E-06	0.2464

Table 6.24. Maturity and partial recruitment inputs to continuity run of VPA.

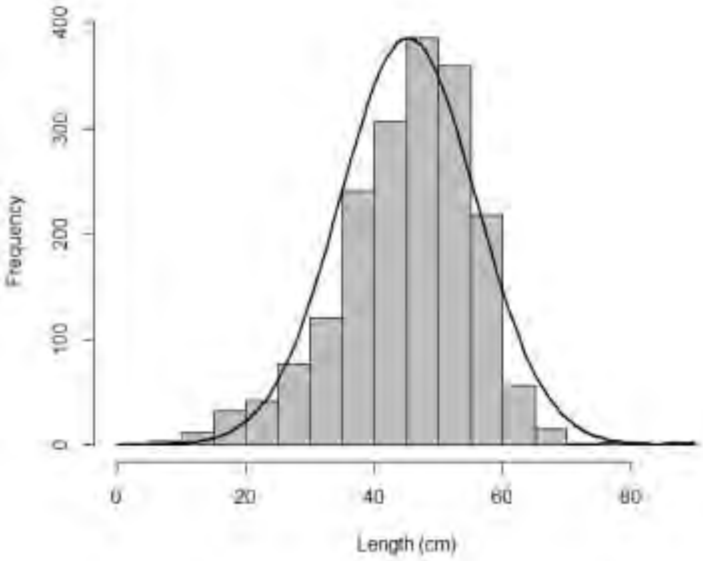
Age	Maturity	Partial recruitment
1	0.000	0.000
2	0.100	0.270
3	0.500	0.215
4	0.750	0.328
5	1.000	0.519
6	1.000	0.617
7	1.000	0.827
8	1.000	0.921
9	1.000	1.000
10	1.000	1.000
11	1.000	1.000
12+	1.000	1.000

Table 7.1. Reference points, terminal year estimates, and stock status by region.

	Southern New England	New York-New Jersey	DelMarVa
F_{TARGET}	0.15	0.17	0.16
$F_{THRESHOLD}$	0.20	0.26	0.24
3-YEAR AVG. F	0.48	0.25	0.17
SSB_{TARGET}	3,883	3,570	2,090
$SSB_{THRESHOLD}$	2,912	2,640	1,580
SSB_{2013}	1,839	2,079	1,532
STOCK STATUS	Overfishing, Overfished	Not overfishing, Overfished	Not overfishing, Overfished

12.0 FIGURES

Figure 2.1. Length-frequency histogram of mean length-at-age data overlayed with the normal probability distribution, and normal Q-Q plot for length-at-age by state.



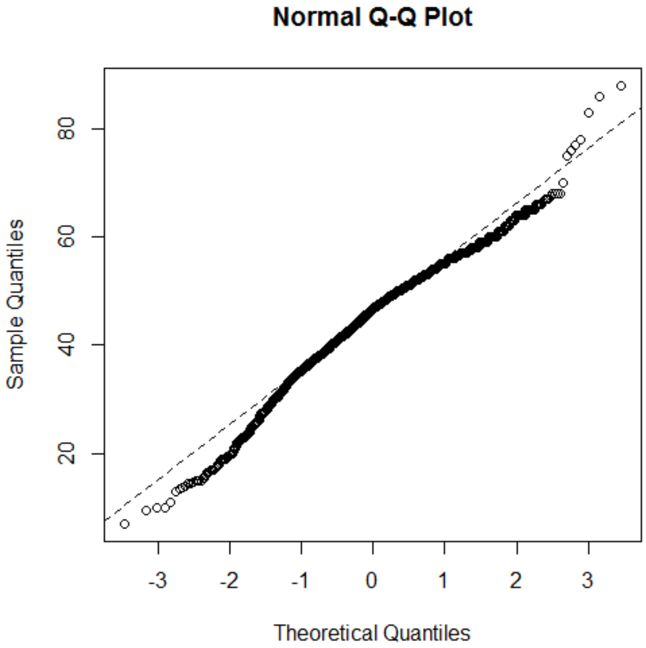


Figure 2.2. Von Bertalanffy growth curves by state.

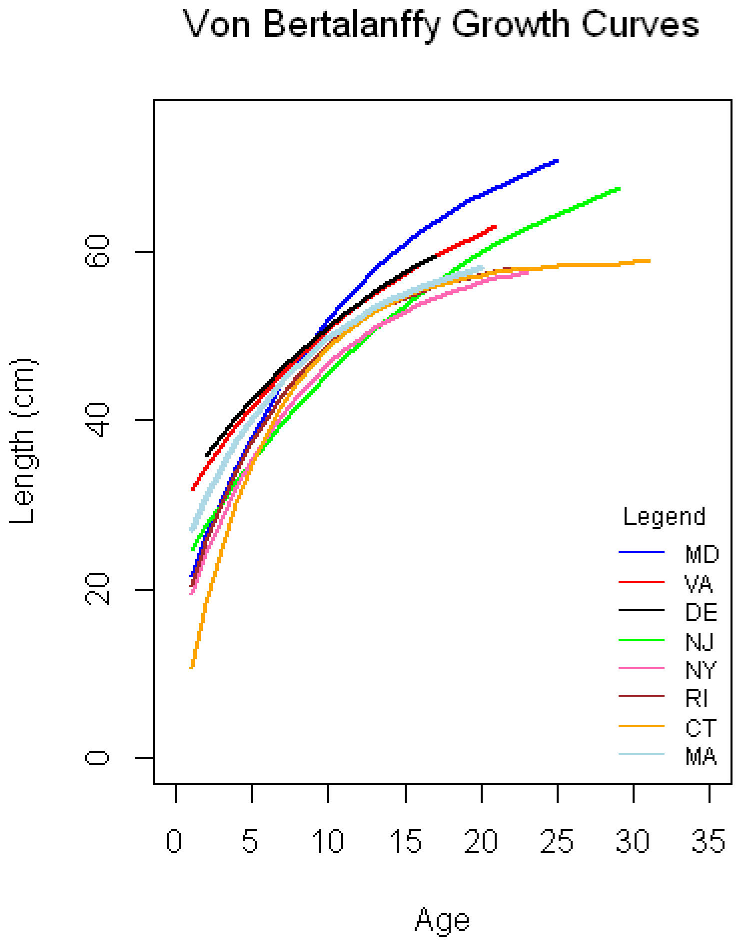
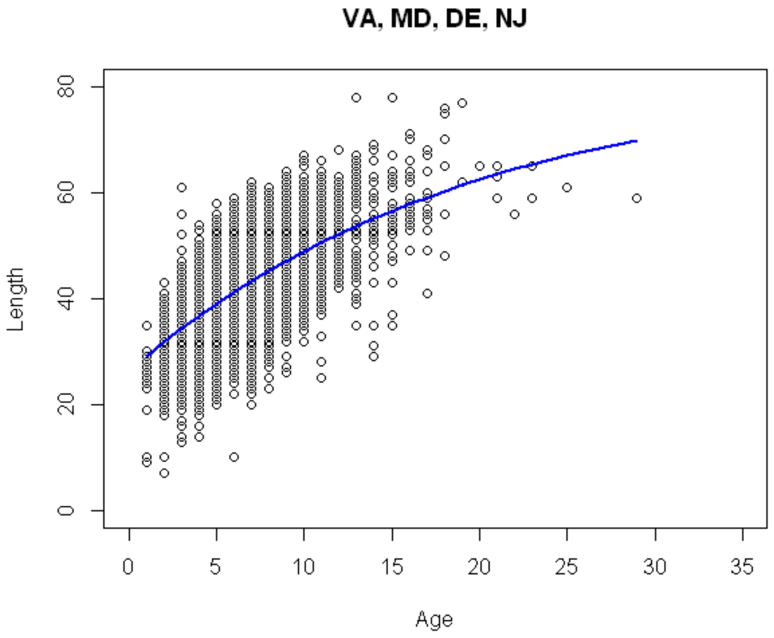


Figure 2.3. Von Bertalanffy data and growth curve for southern states and northern states (from 2-region scenario).



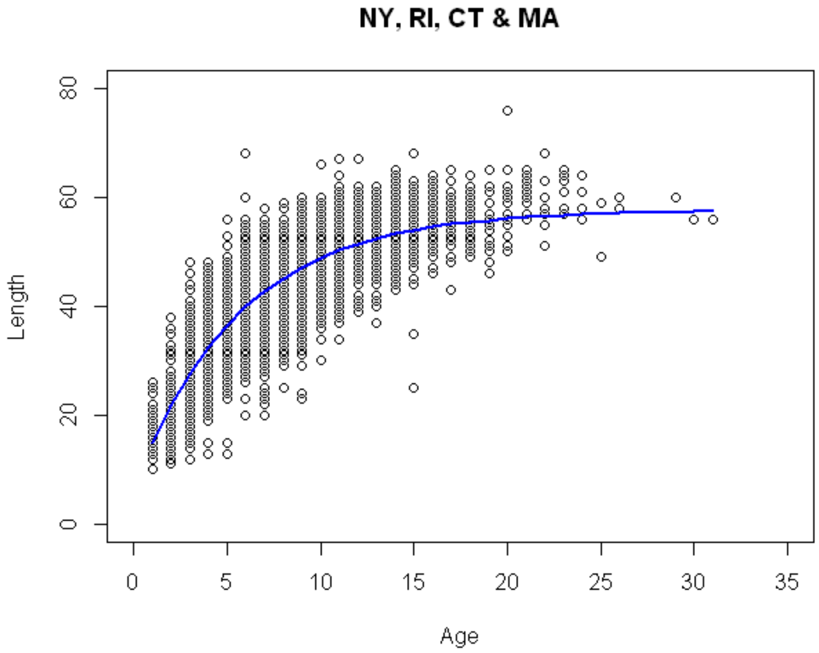


Figure 2.4. Mean (±SD) length-at-age for northern (MA, CT, RI, NY) and southern (NJ, DE, MD, VA) regions in Model 1. Error bars are 1 standard deviation.

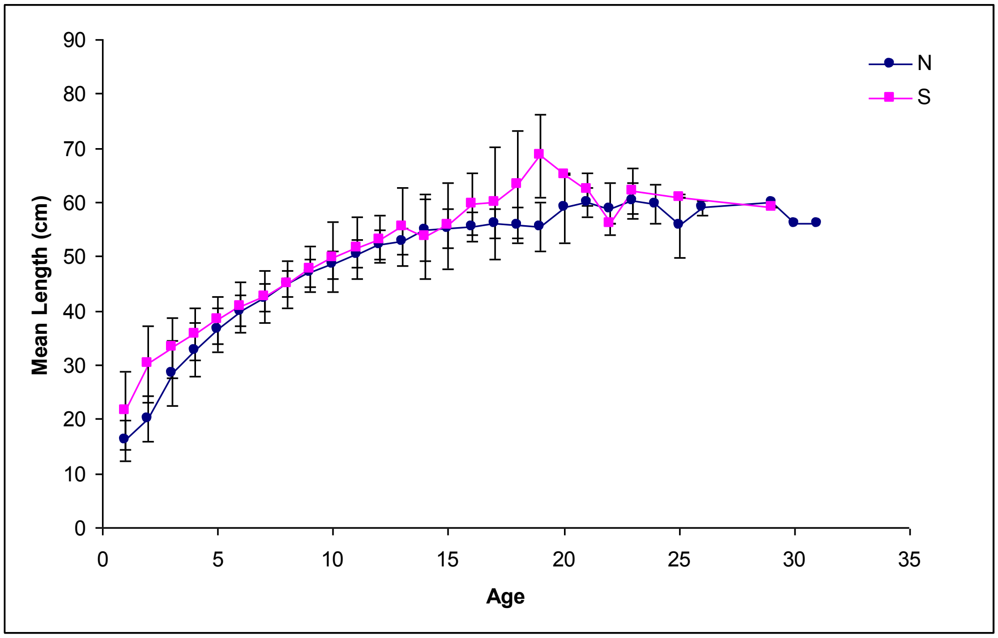


Figure 2.5. Mean (±SD) length-at-age for northern (MA, CT, RI), mid-Atlantic (NY, NJ), and southern (DE, MD, VA) regions in Model 2. Error bars are 1 standard deviation.

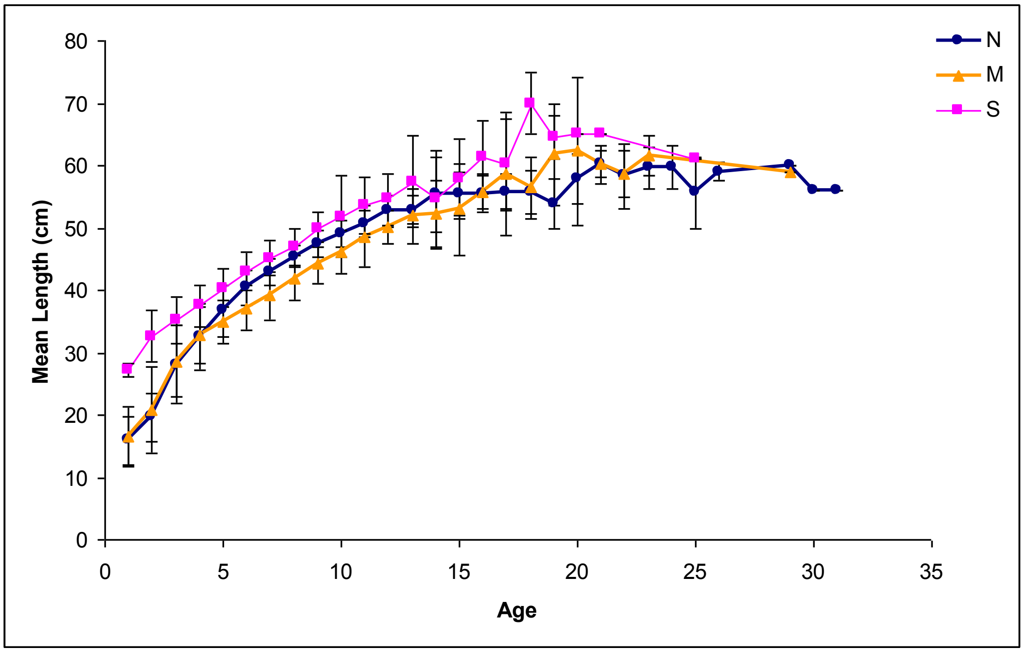


Figure 2.6. Mean length-at-age for all states in Model 3. To improve clarity, error bars were not included.

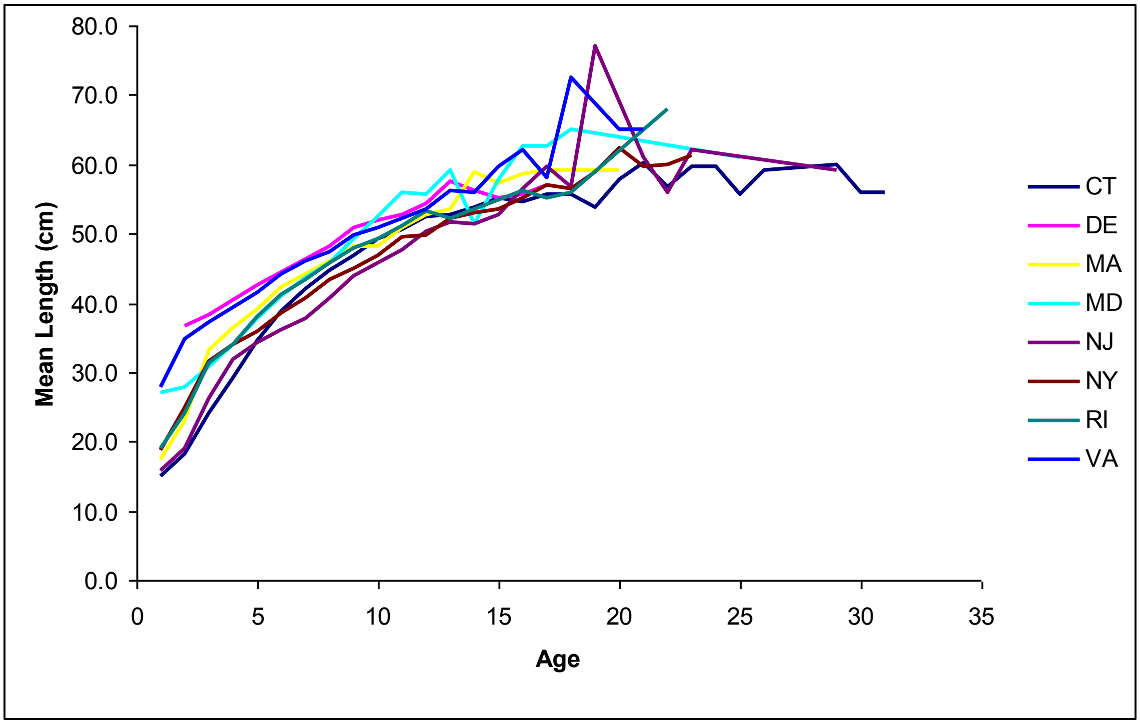


Figure 2.7. Length-weight relationships for tautog by state.

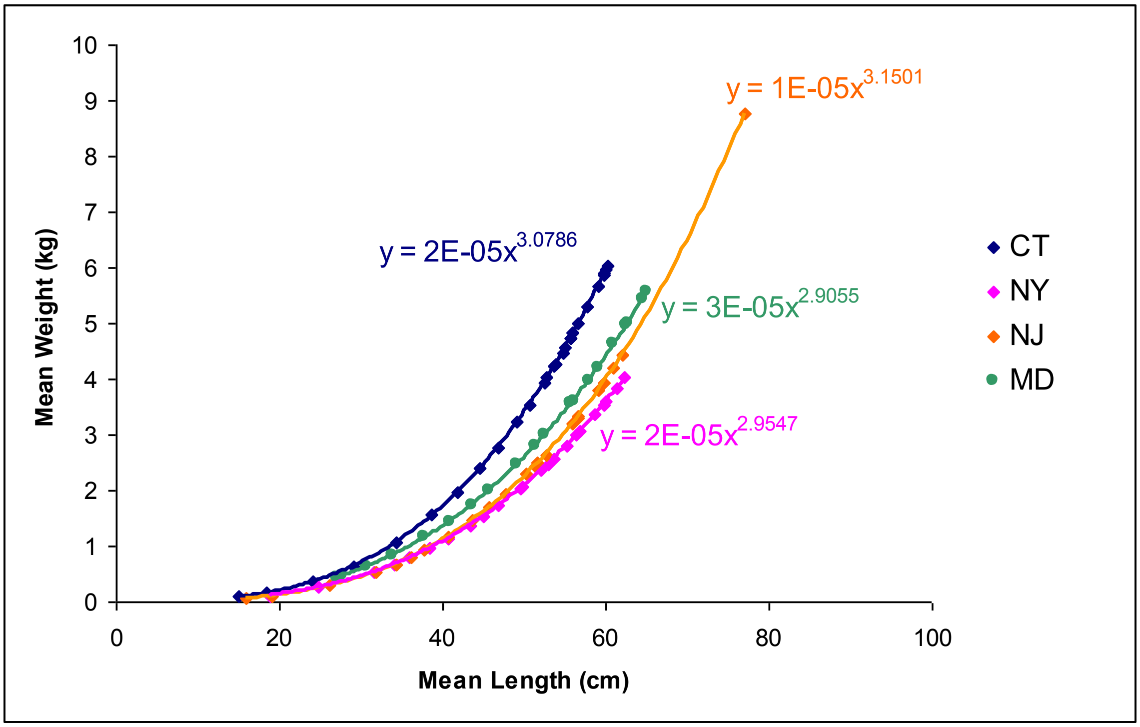


Figure 2.8. Mean weight-at-age by state. The length-weight relationship was used to get weight-at-age for states without weight data. Data from CT was applied to MA and RI. Data from NJ was applied to DE, and data from MD was applied to VA.

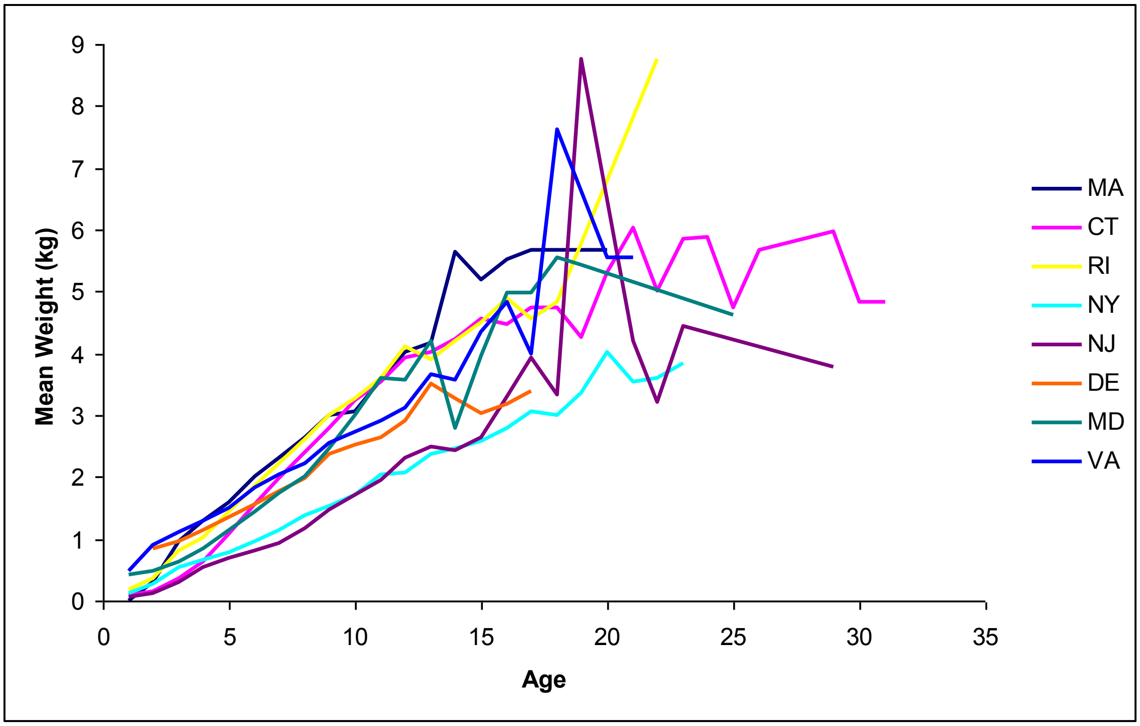


Figure 4.1. Coastwide commercial landings and values from 1950-2012. Source: NOAA Commercial Fisheries Database http://www.st.nmfs.noaa.gov/commercial-fisheries/index.

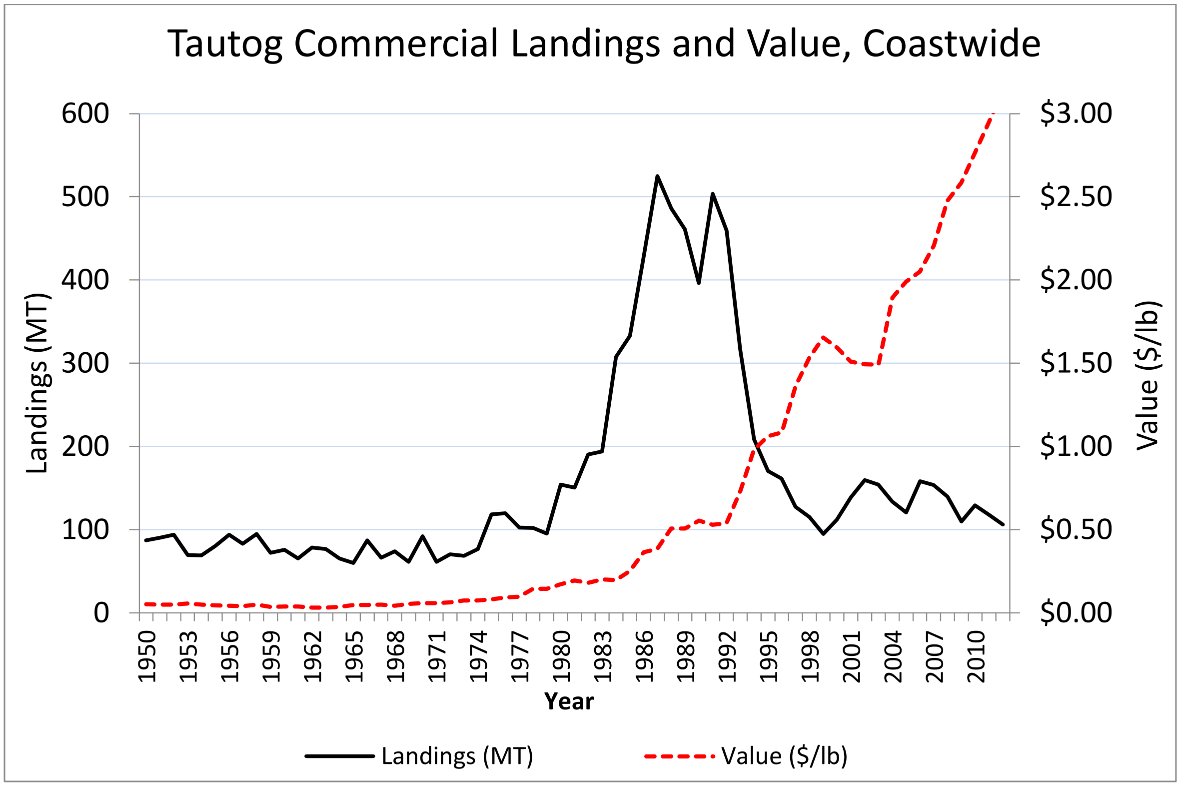


Figure 4.2. Relative activity of the commercial tautog fishery by month, based on commercial landings from 1990-2012.

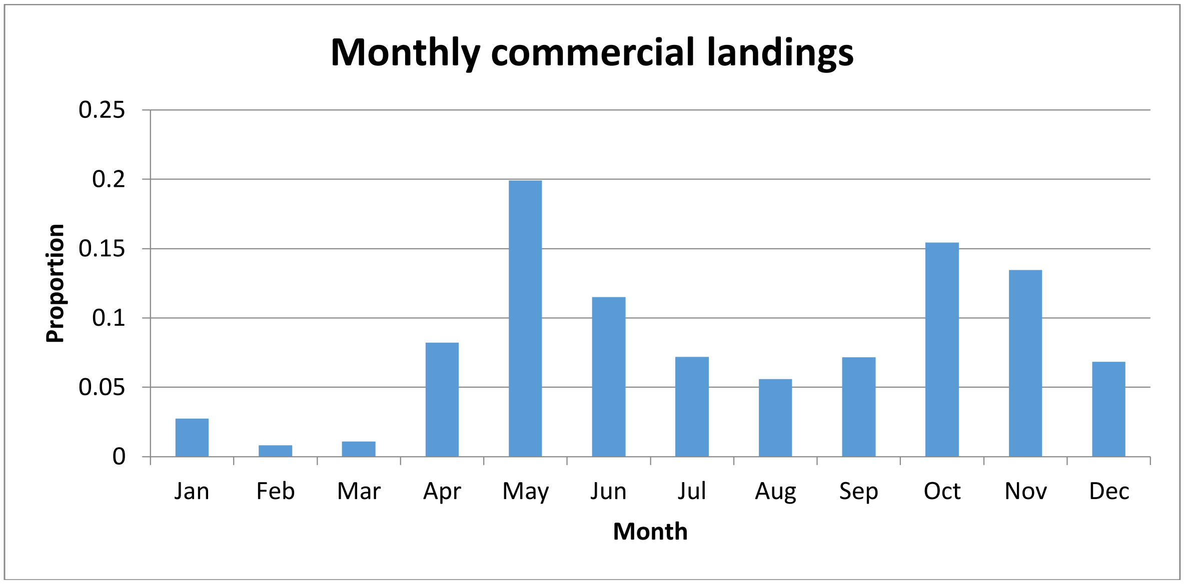


Figure 4.3. Relative activity of commercial tautog harvest by state, based on commercial landings from 1982-2012.

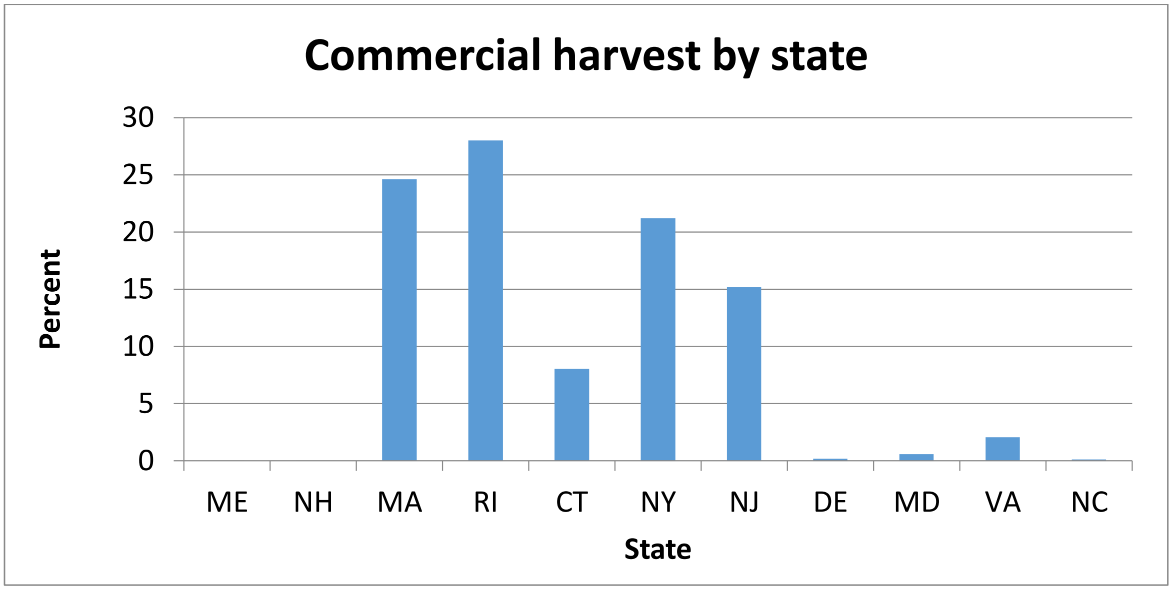


Figure 4.4. Relative commercial tautog landings by fishing gear, based on commercial landings from 1982-2012.

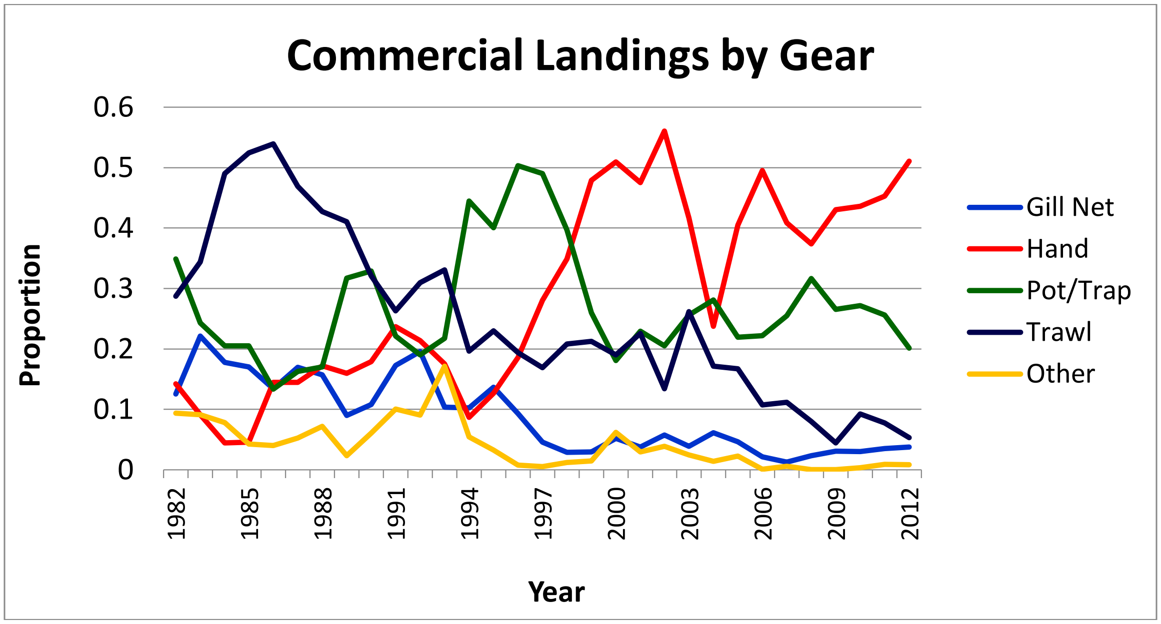


Figure 4.5. Total harvest of tautog (recreational and commercial landings) in metric tons. Source: NOAA Fisheries Commercial Fisheries Statistics Database, MRFSS, and MRIP.

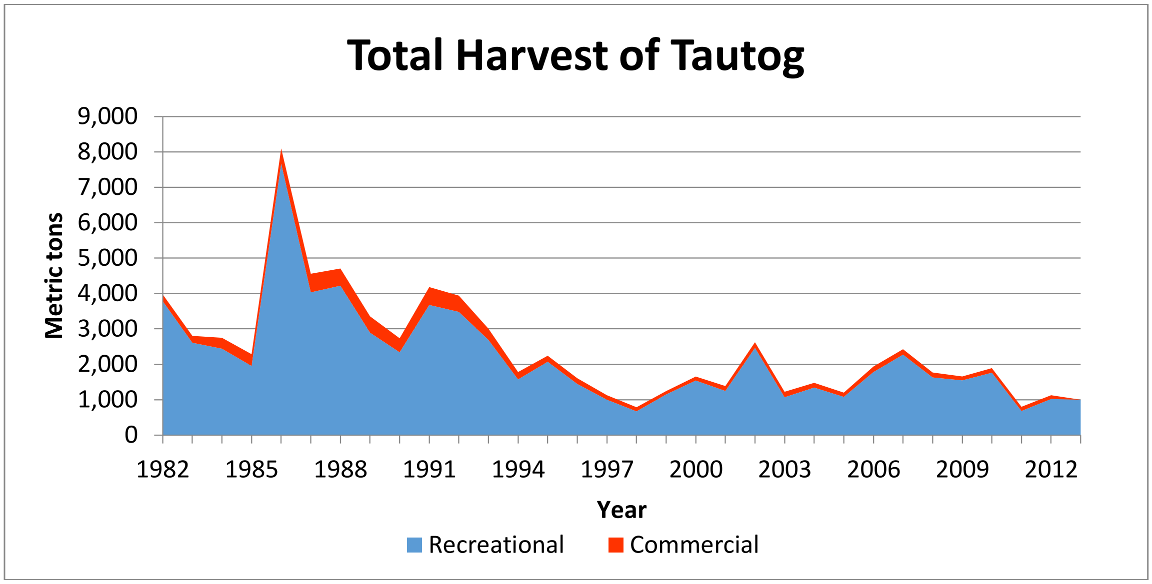


Figure 4.6. Coastwide recreational harvest by weight (pounds) and number of fish.

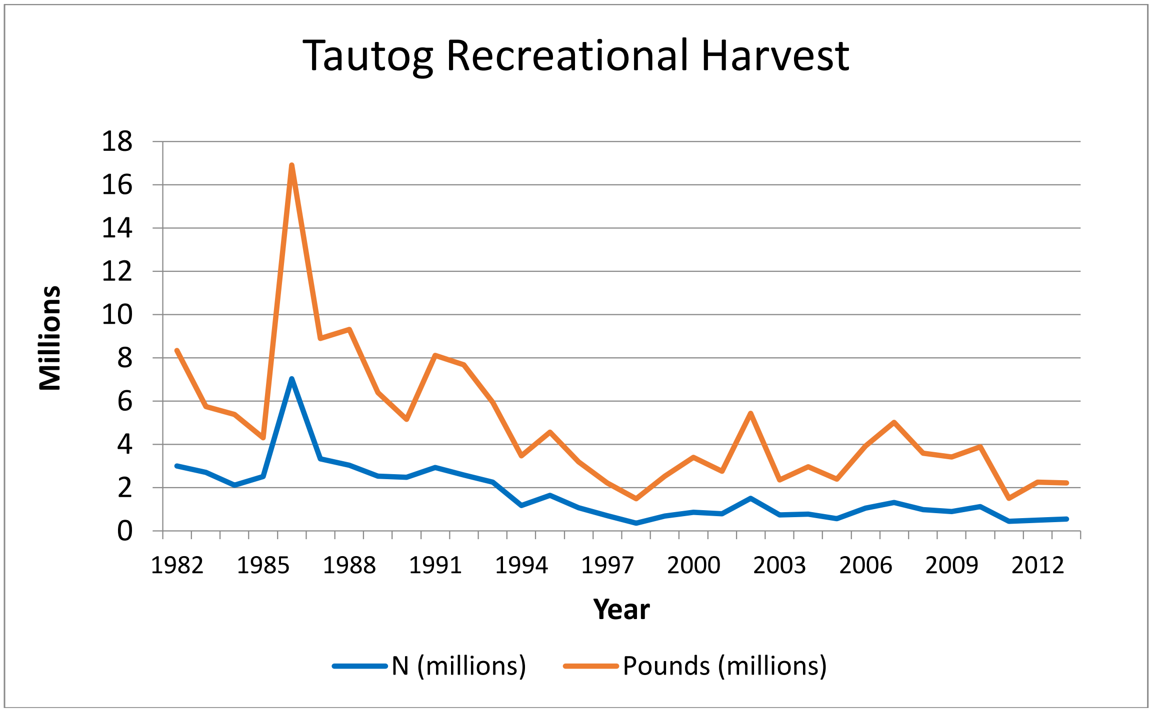


Figure 4.7. Coastwide recreational harvest by state. Source: MRIP.

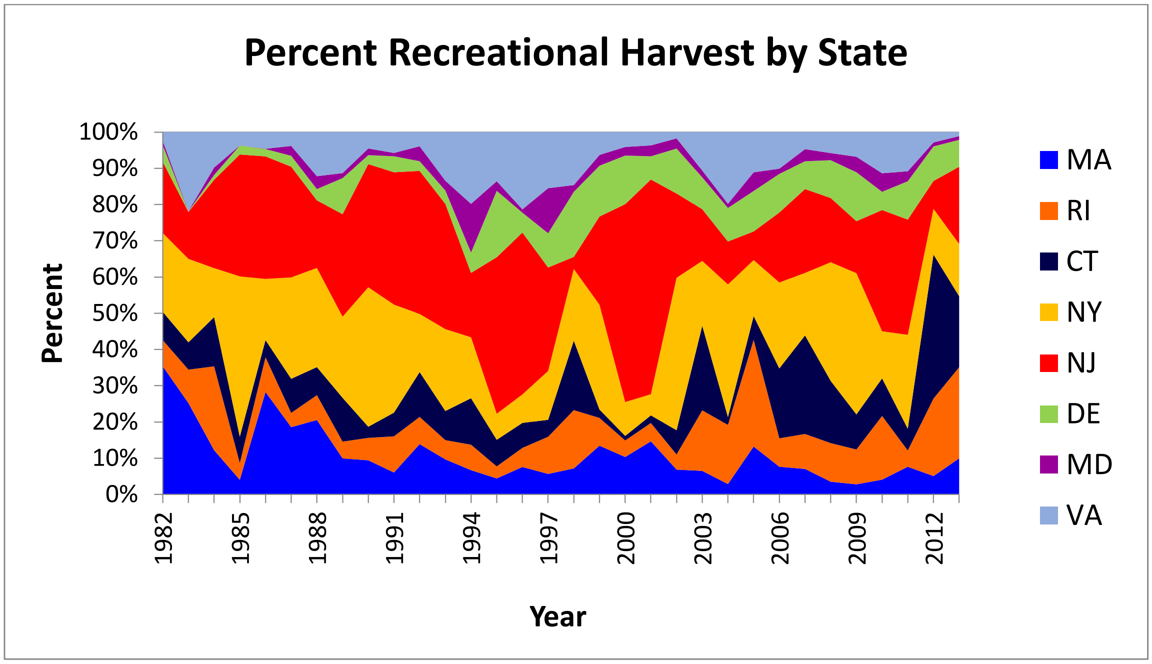


Figure 4.8. Coastwide recreational harvest by state. Source: MRIP

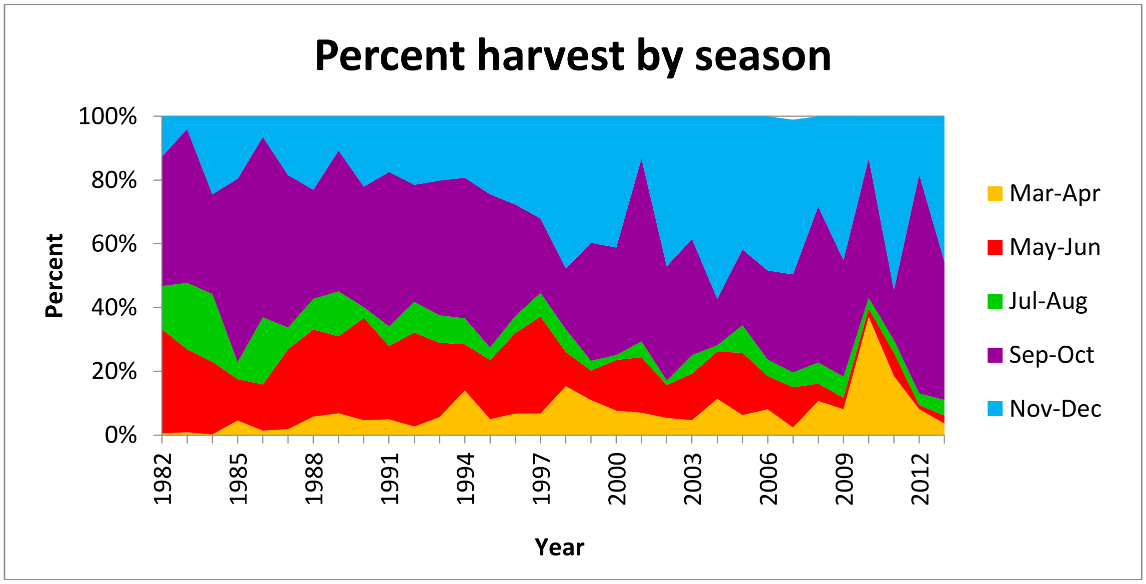


Figure 4.9. Coastwide recreational harvest by fishing mode. Source: MRIP

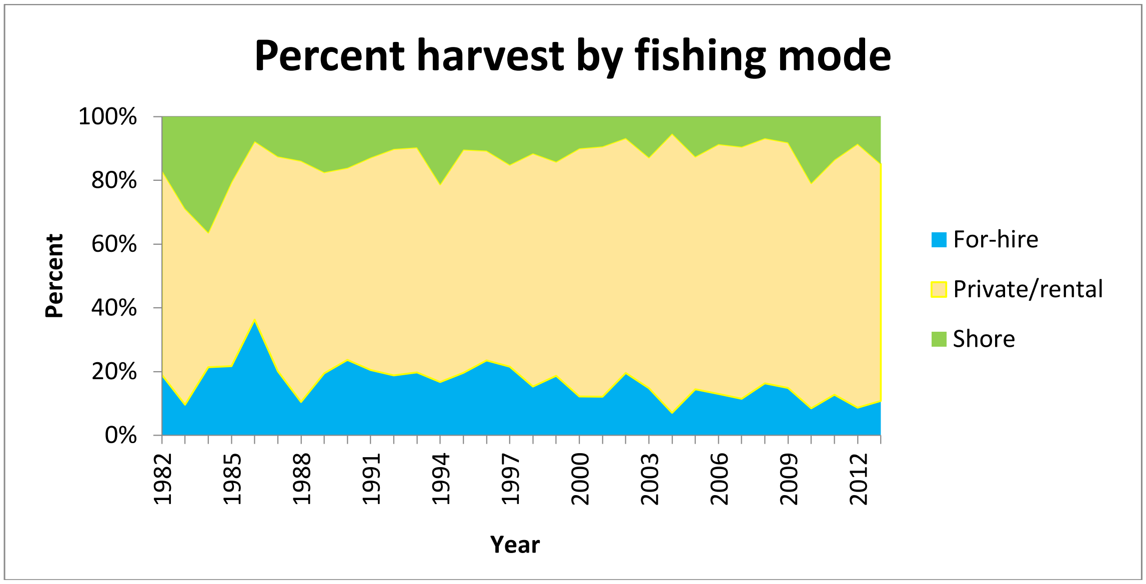


Figure 5.1. Number of observed commercial trips by year, region, and gear type that retained or discarded tautog.

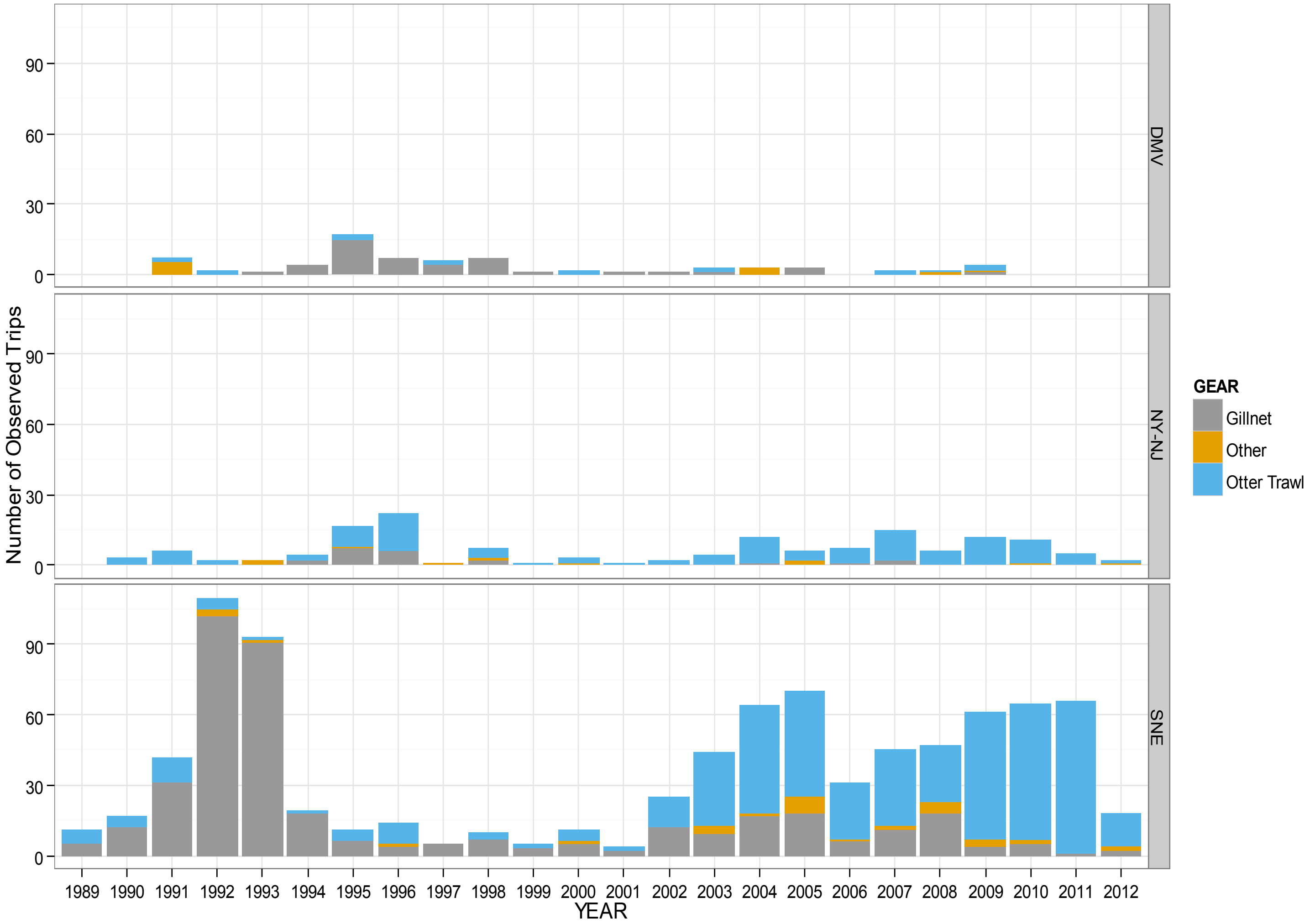


Figure 5.2. Length frequencies of commercially retained and discarded tautog by year from observer data.

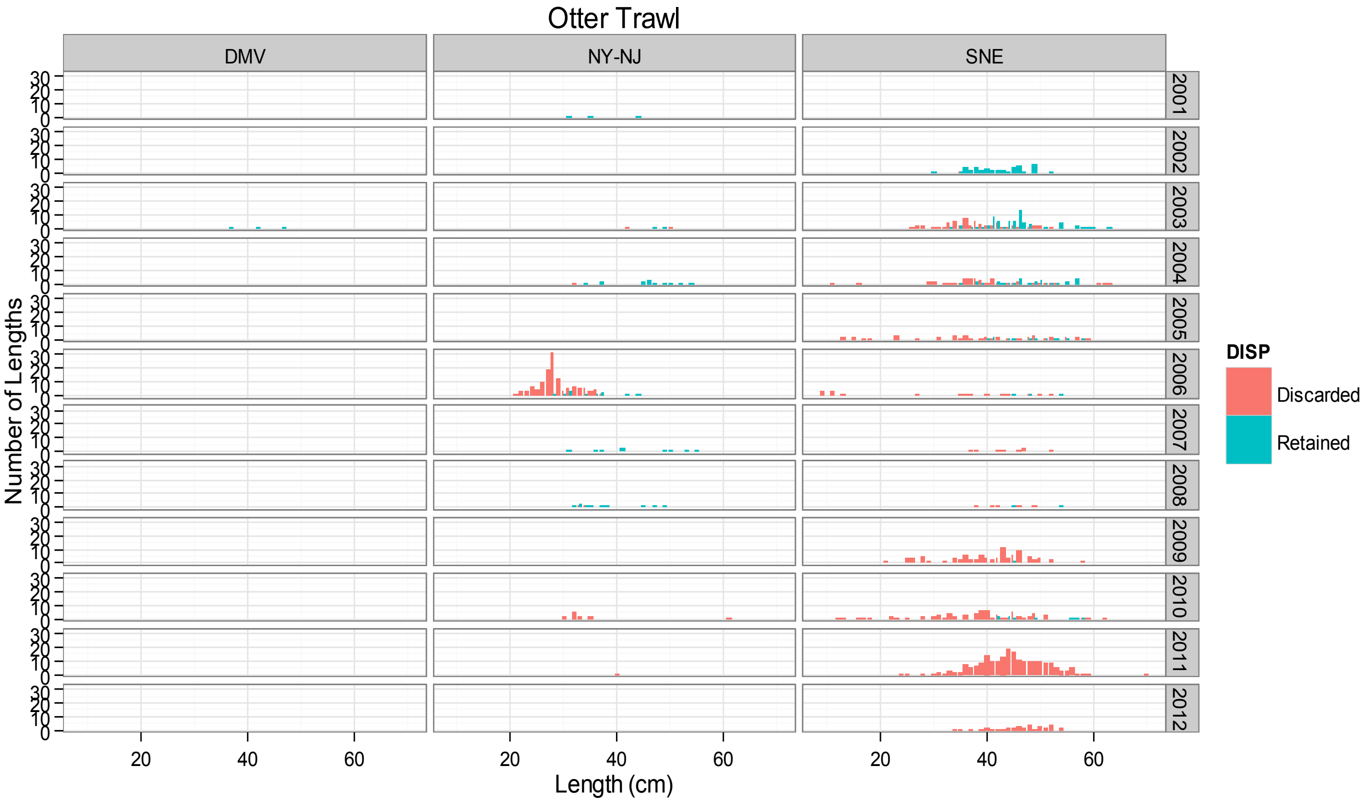
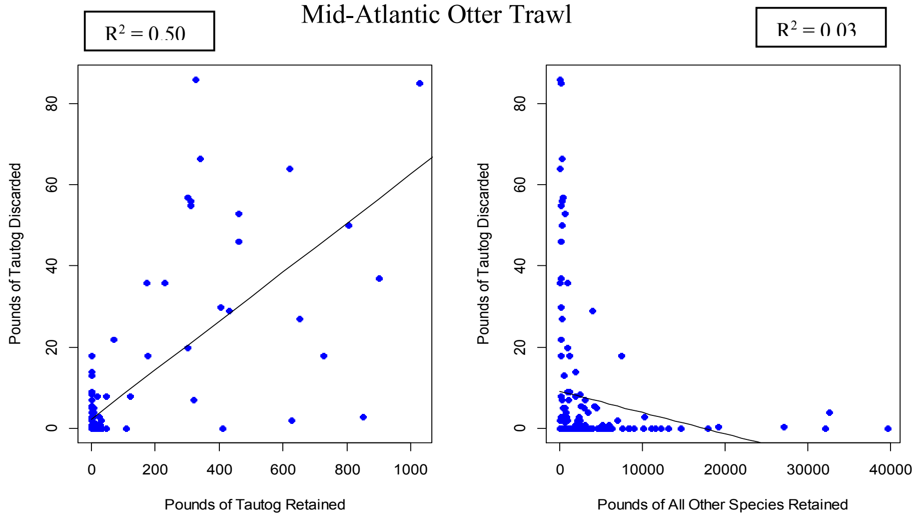
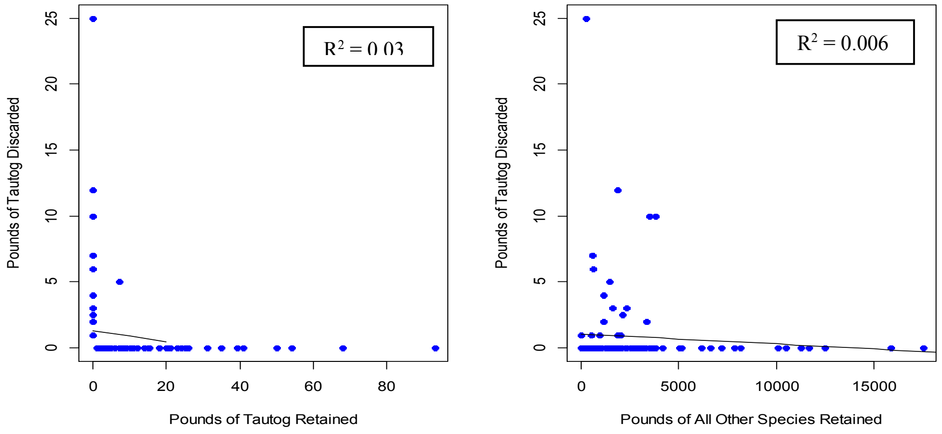


Figure 5.3.A. Relationship between pounds of tautog retained and pounds of tautog (left) or other species (right) retained on observed commercial trips in the Mid-Atlantic region.

Mid-Atlantic Otter Trawl



Mid-Atlantic Gillnet



Mid-Atlantic Other Gear

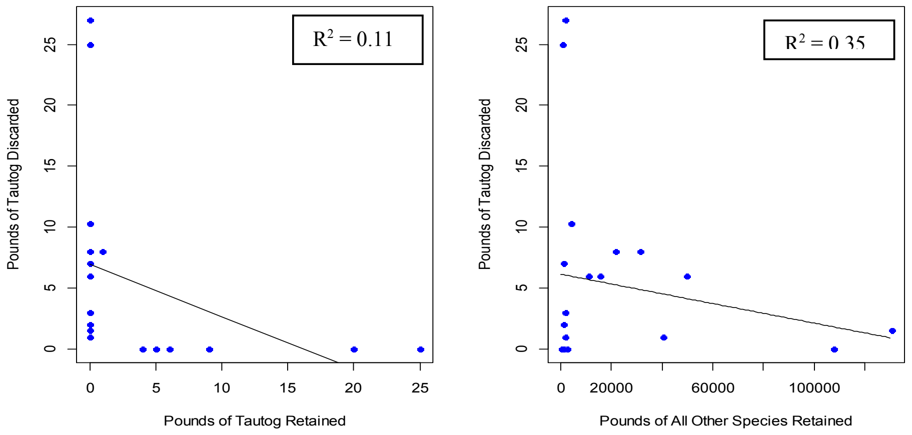
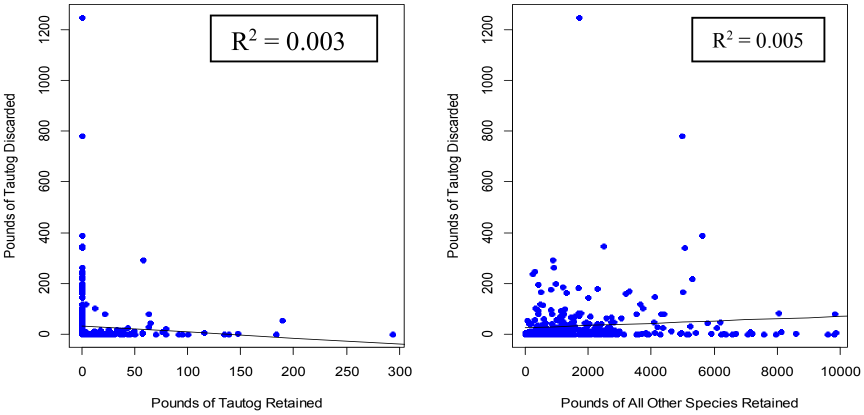
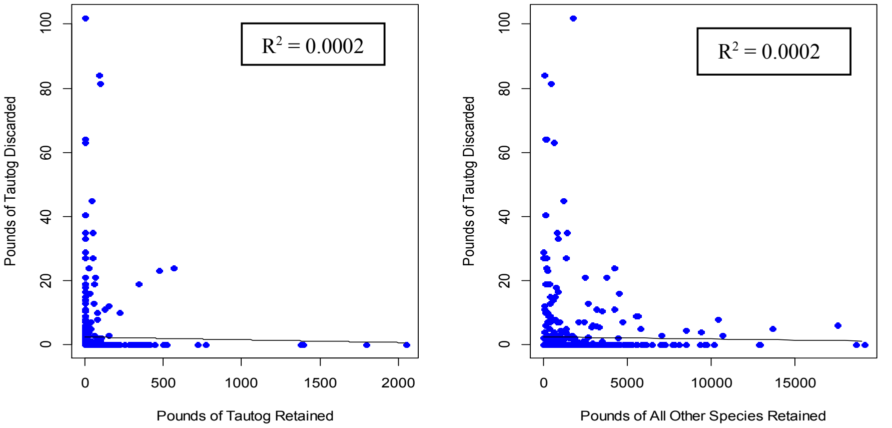


Figure 5.3.B. Relationship between pounds of tautog retained and pounds of tautog (left) or other species (right) retained on observed commercial trips in the New England region.

New England Otter Trawls



New England Gillnets



New England Other Gear

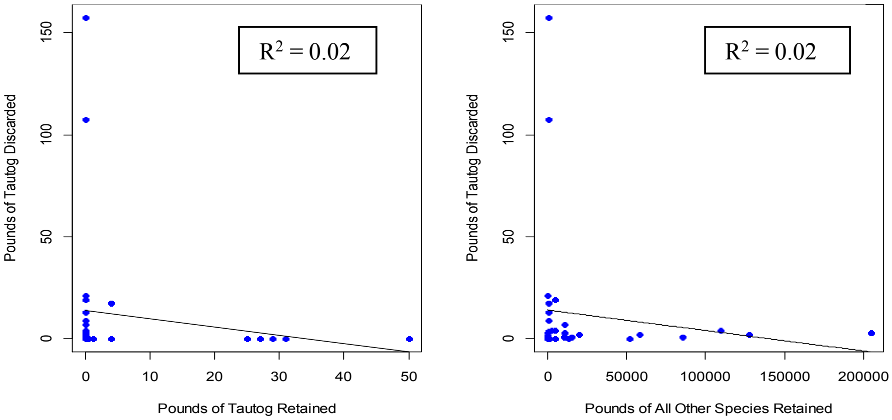


Figure 5.4. Total landings of tautog by source for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

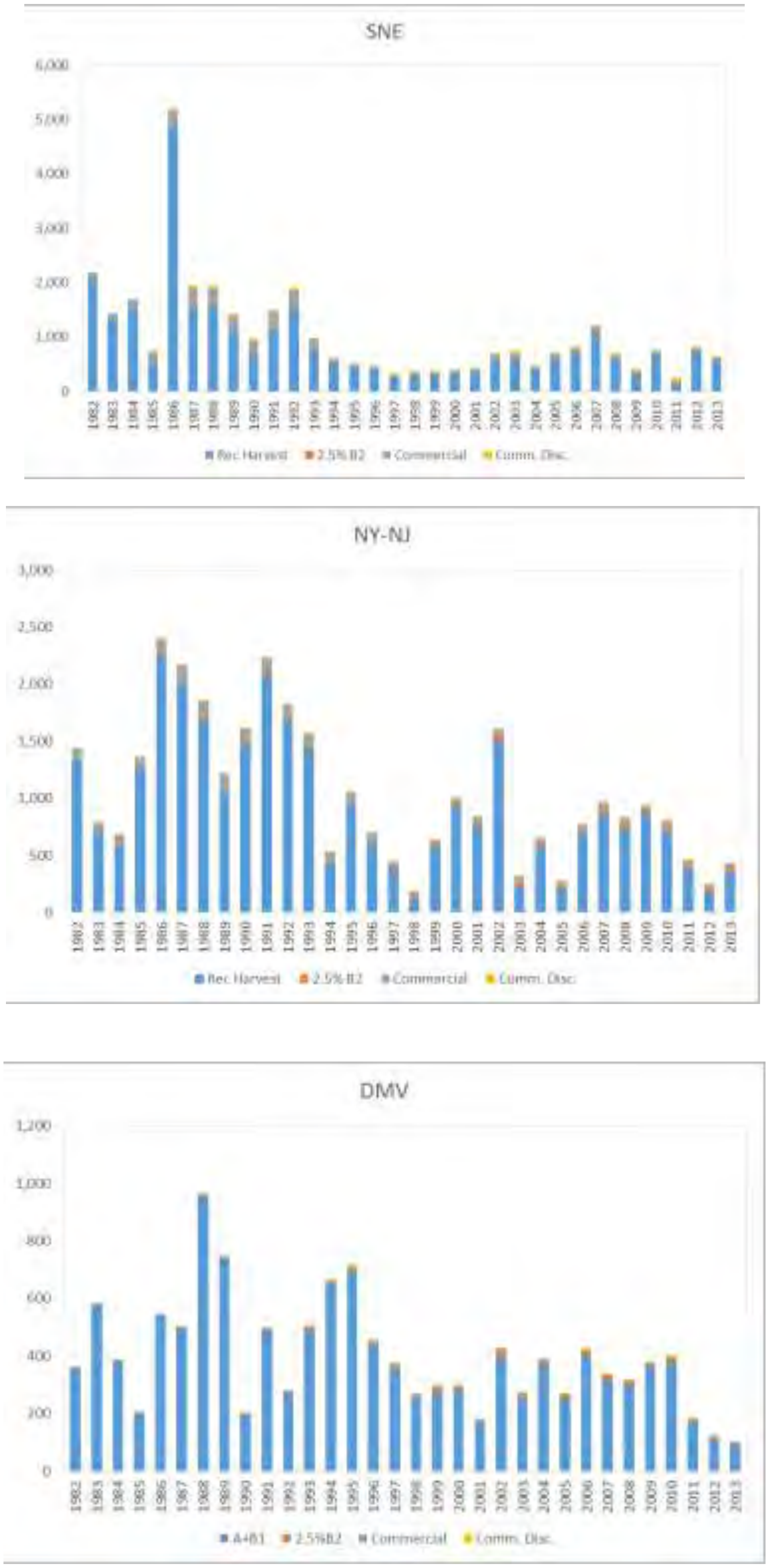
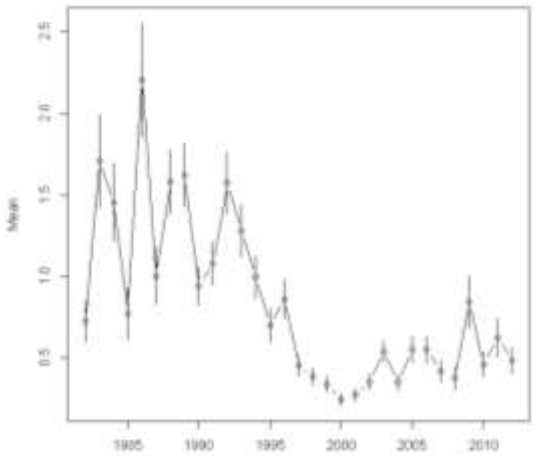
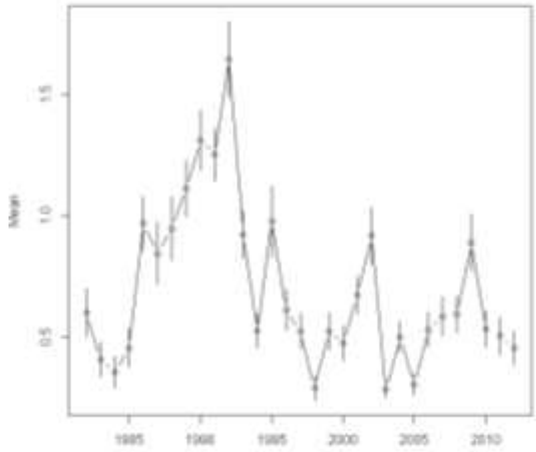


Figure 5.5. Standardized MRIP CPUE for the Southern New England (top), NY-NJ (middle), and DelMarVa region (bottom).

SNE



NY-NJ



DMV

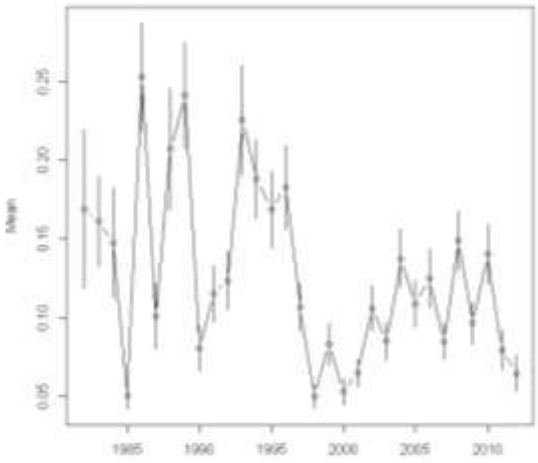


Figure 5.6. Recreational vs. commercial length frequencies for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions by regulatory period.

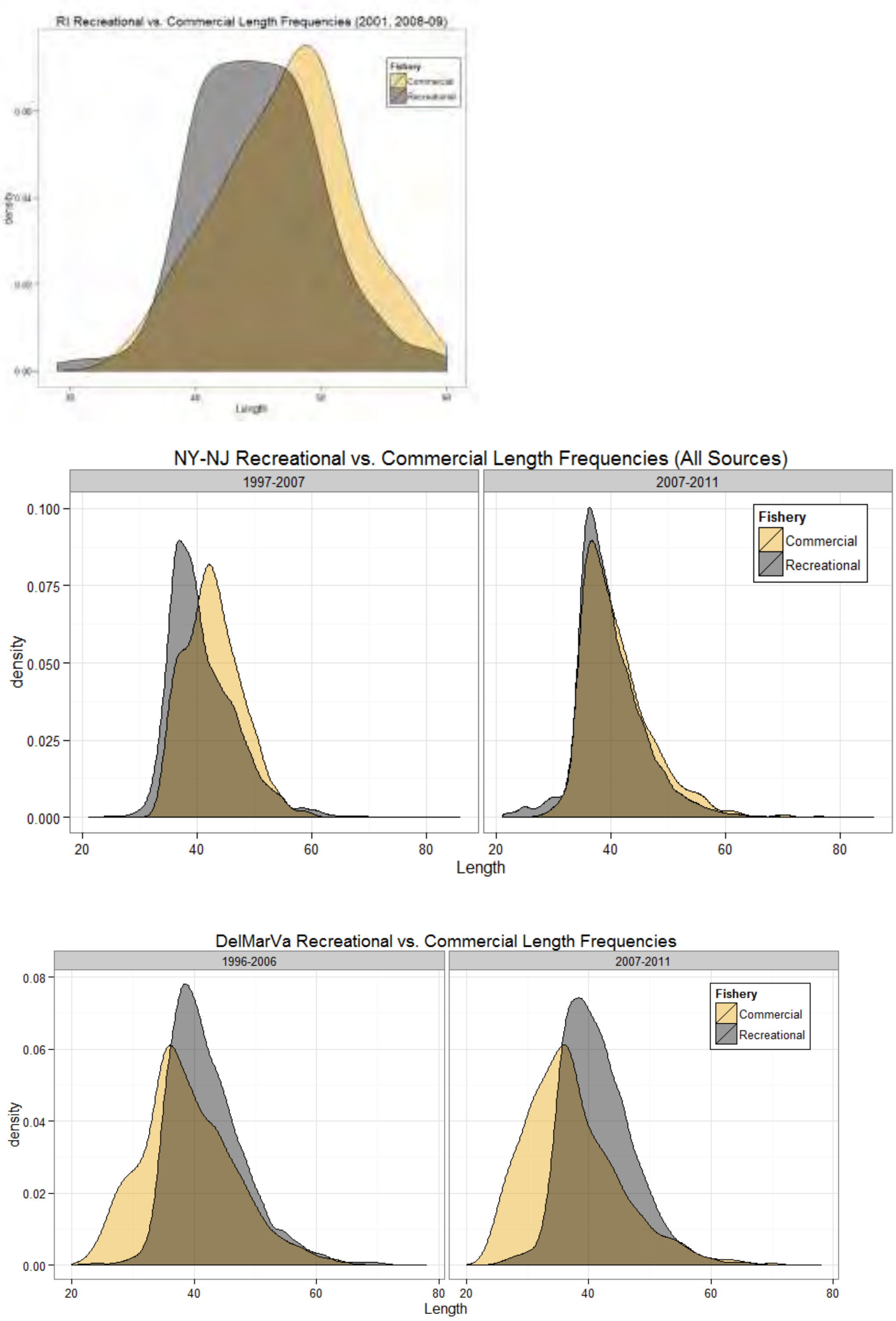
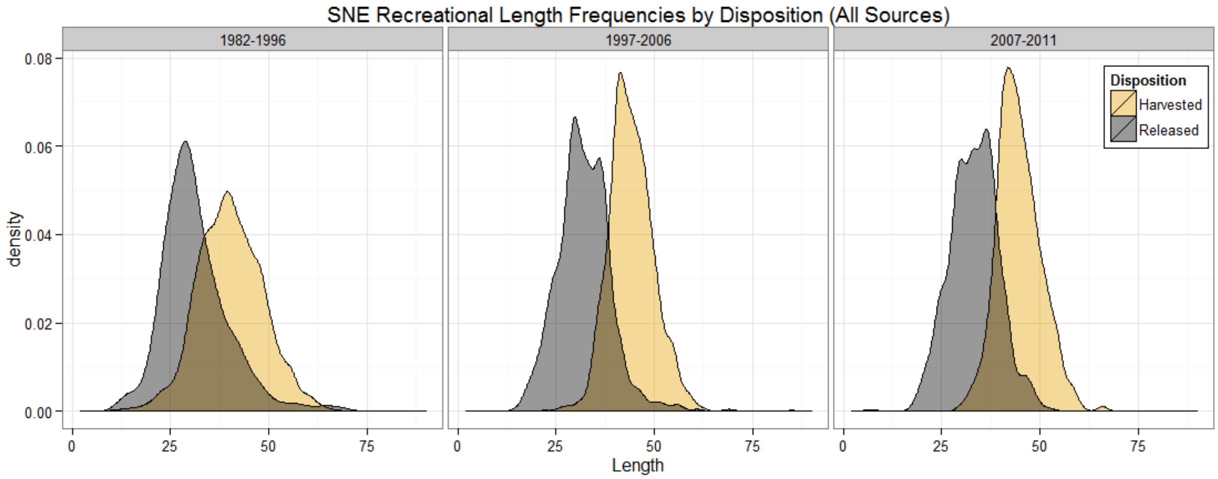
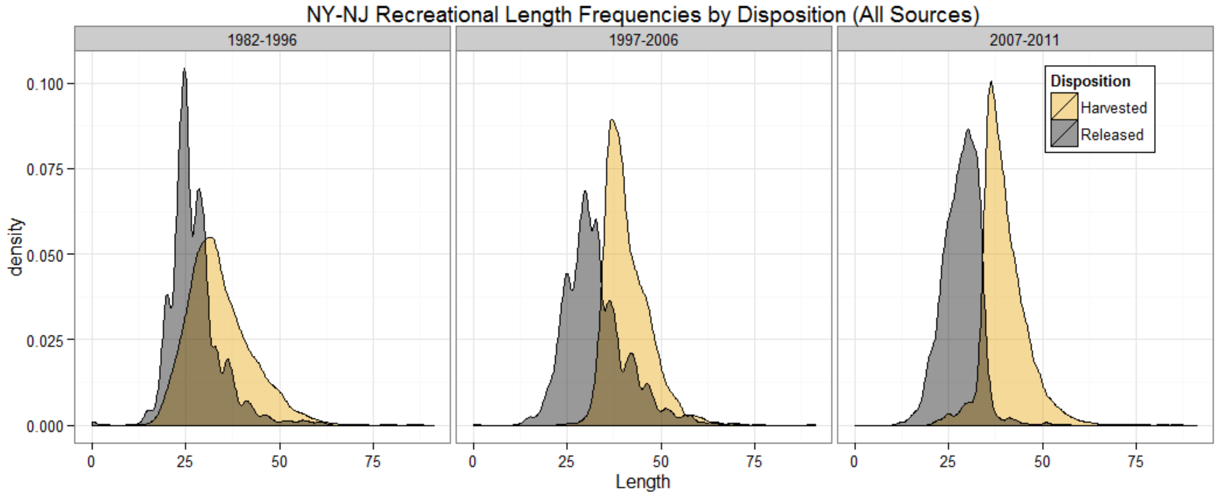


Figure 5.7. Recreational harvest vs. released alive length frequencies for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions by regulatory period.





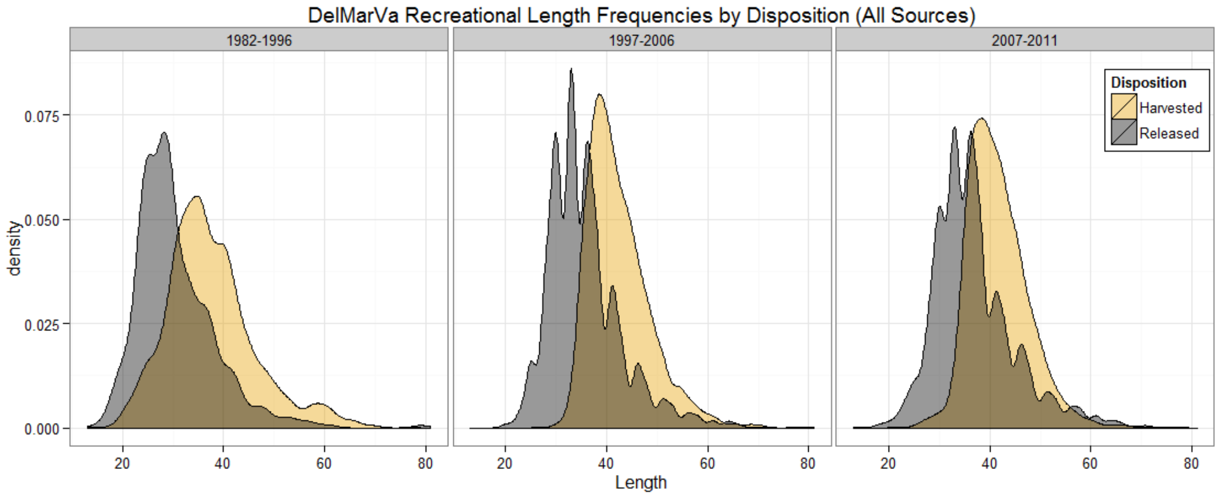


Figure 5.8. Recreational released alive length frequencies for the southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions by data source.

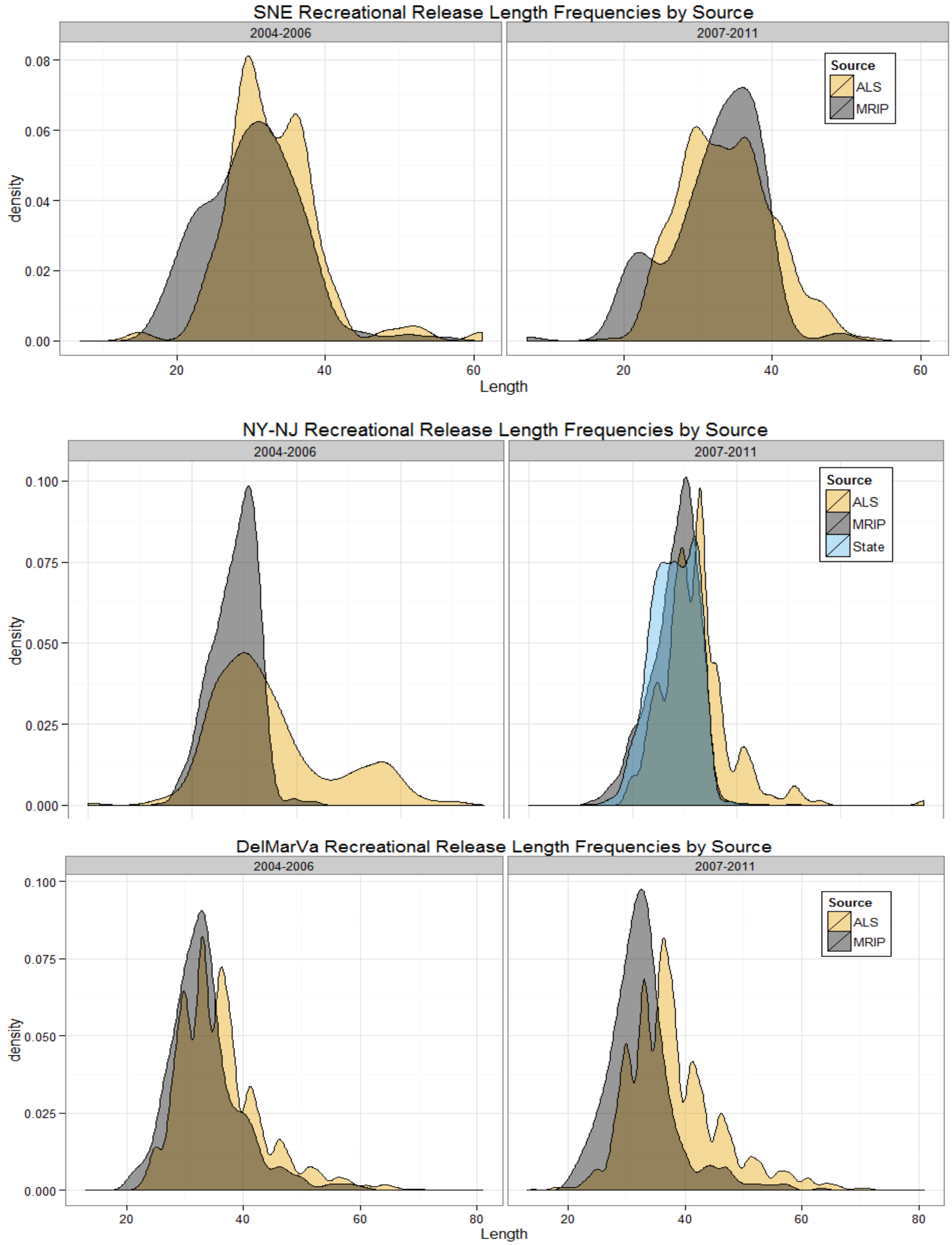


Figure 5.9. MRFSS vs. MRIP estimates of recreational harvest in weight by region, plotted with 95% confidence intervals calculated from MRIP estimate of PSE.

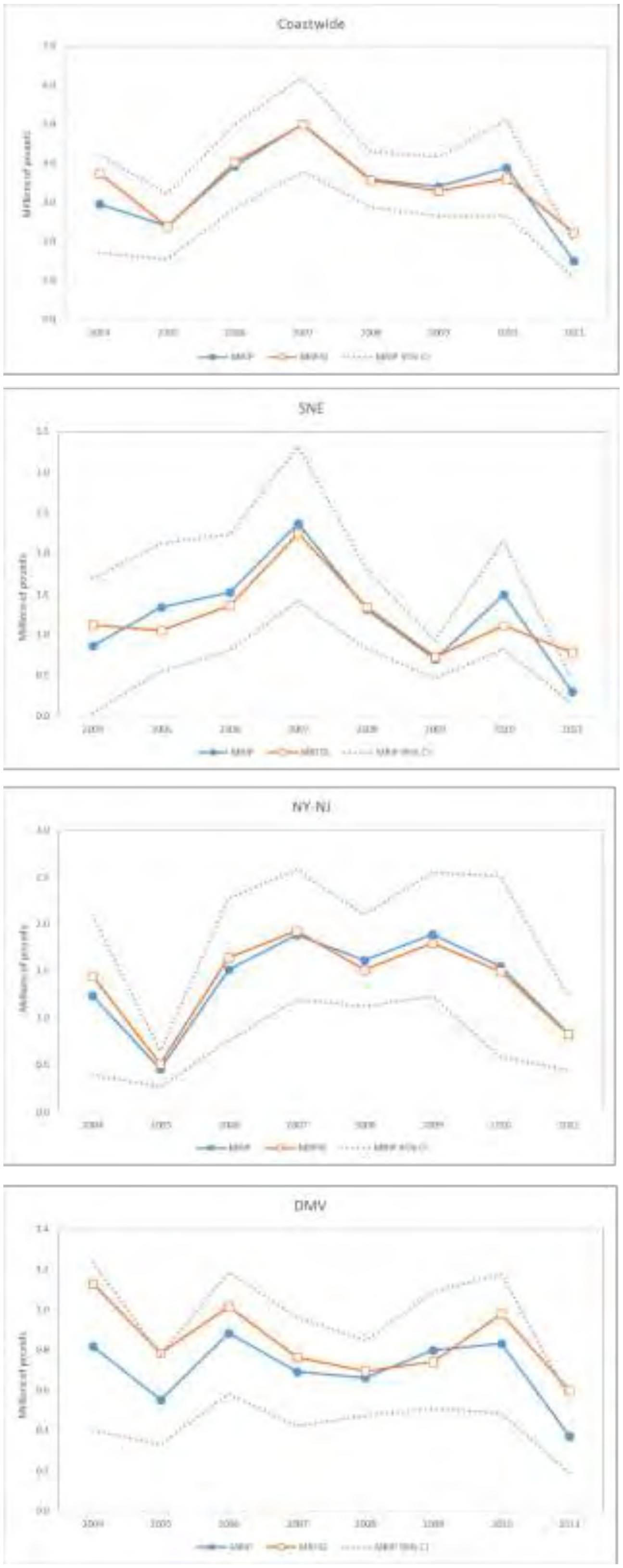


Figure 5.10. Histogram of catch data for the Massachusetts Trawl Survey (MATS) dataset**.**

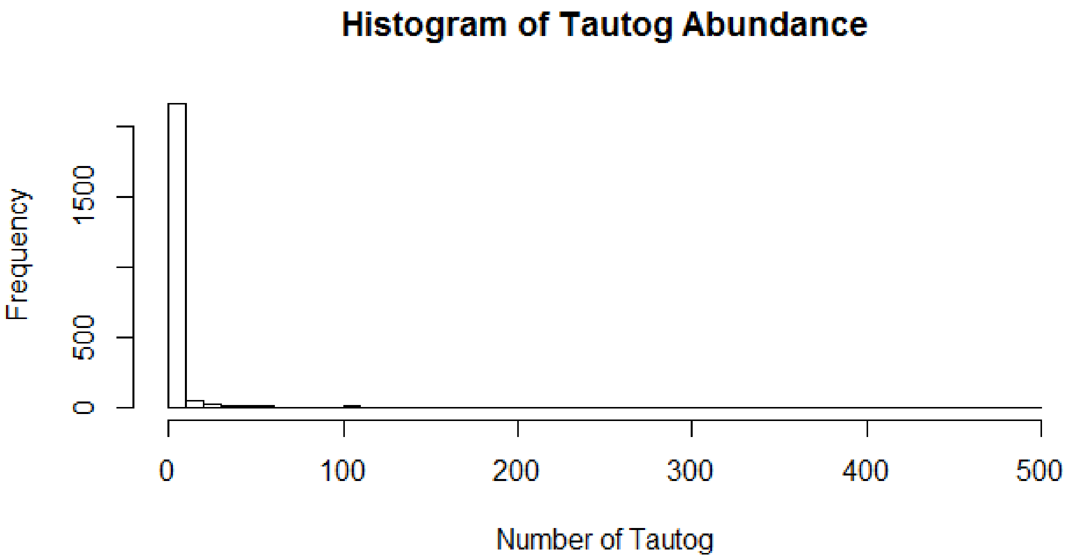


Figure 5.11. QQ Plot for negative binomial distribution for the final model used for the MATS.

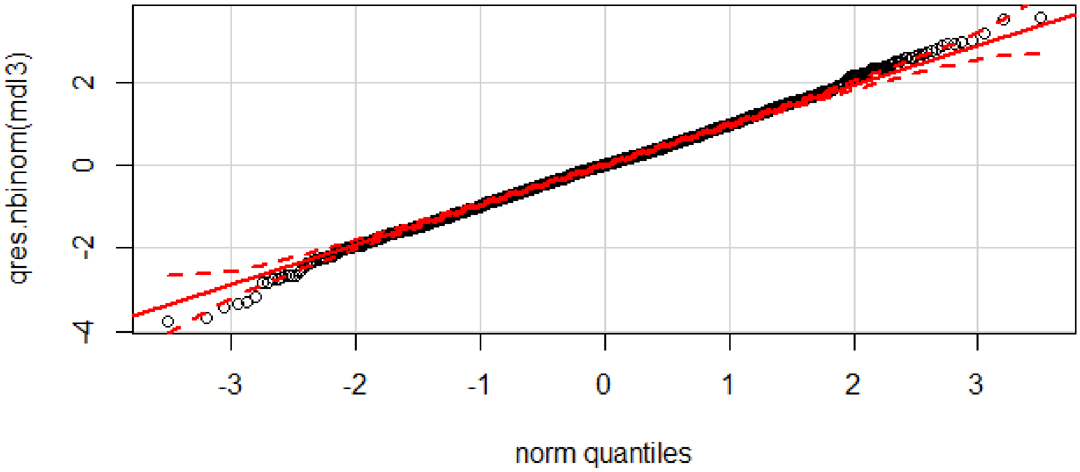


Figure 5.12. Cook's distance plot for the final model used for the MATS.

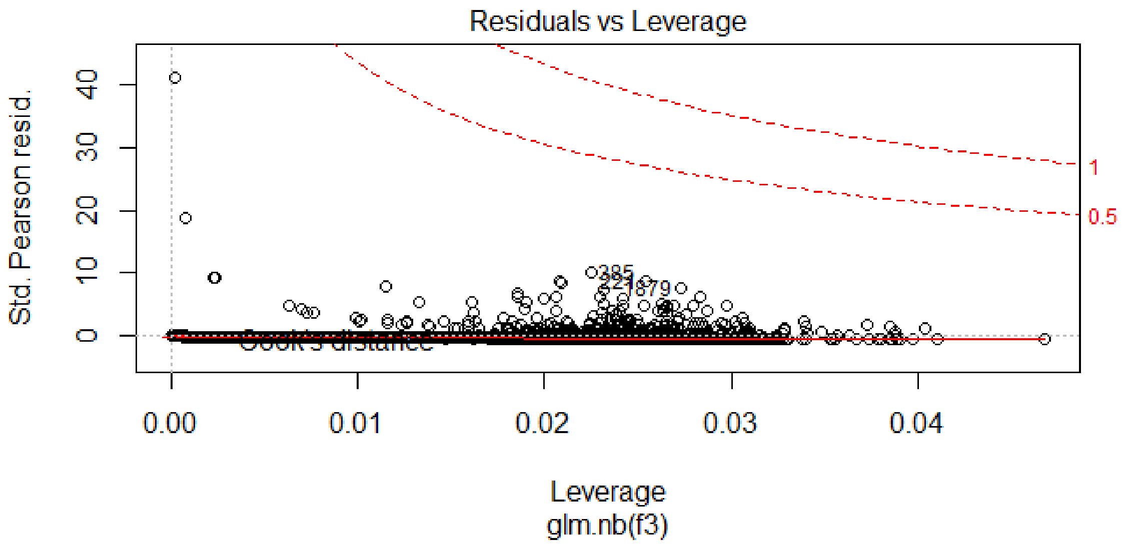


Figure 5.13. Standardized index versus the nominal index for the MATS.

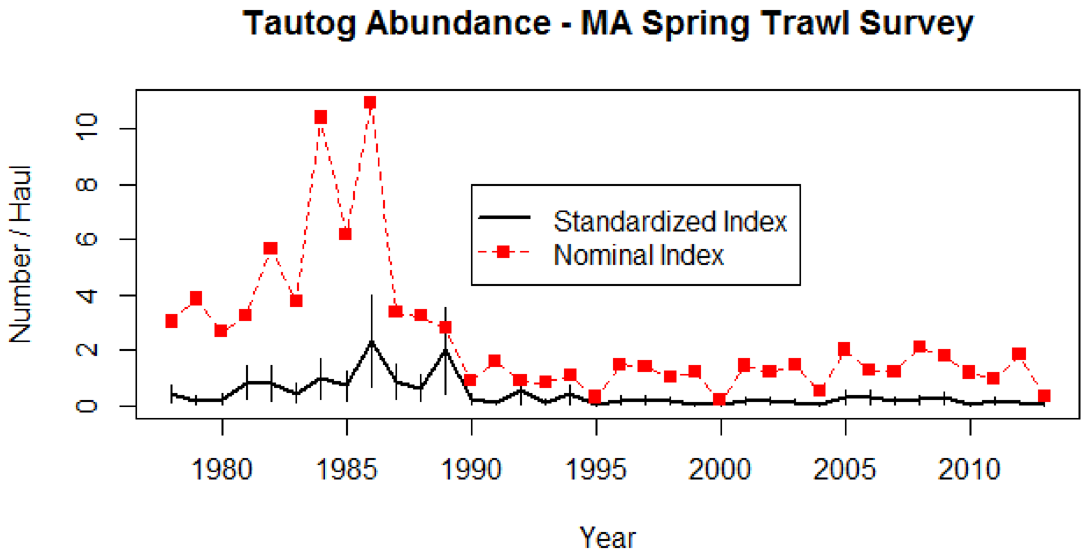


Figure 5.14. Histogram of catch data for the RITS dataset.

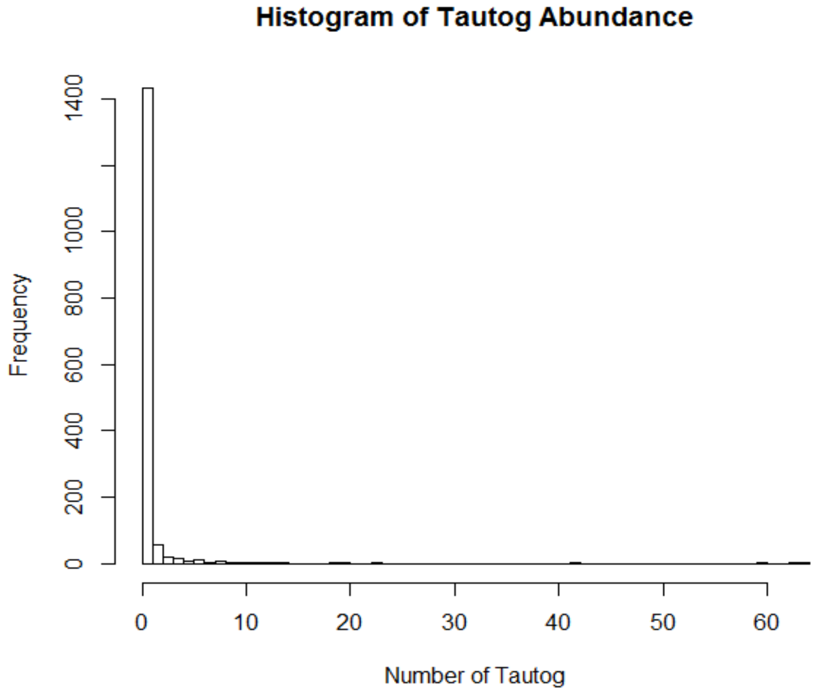


Figure 5.15. QQ Plot for negative binomial distribution for the final model used for the RITS.

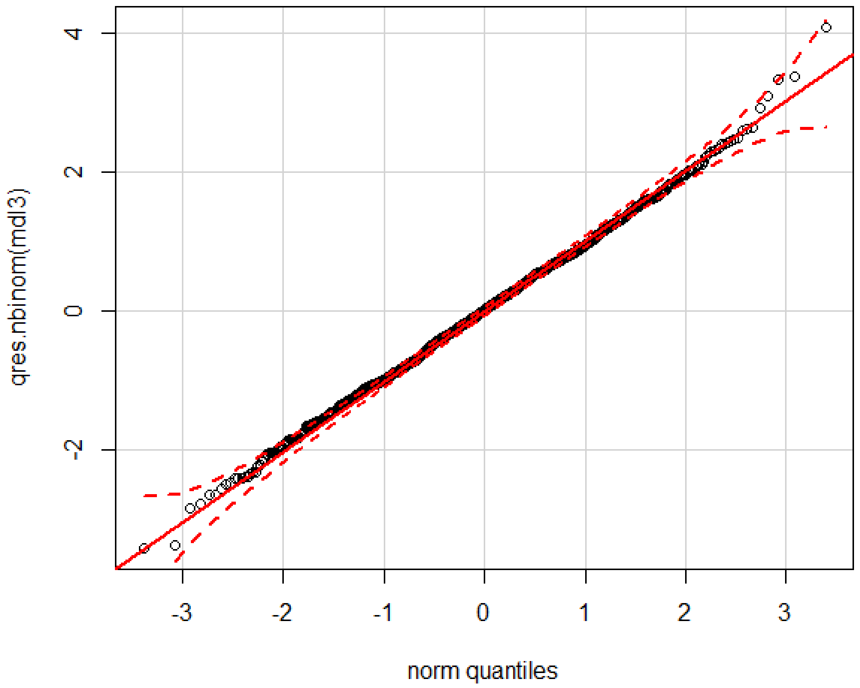


Figure 5.16. Cook's distance plot for the final model used for the RITS.

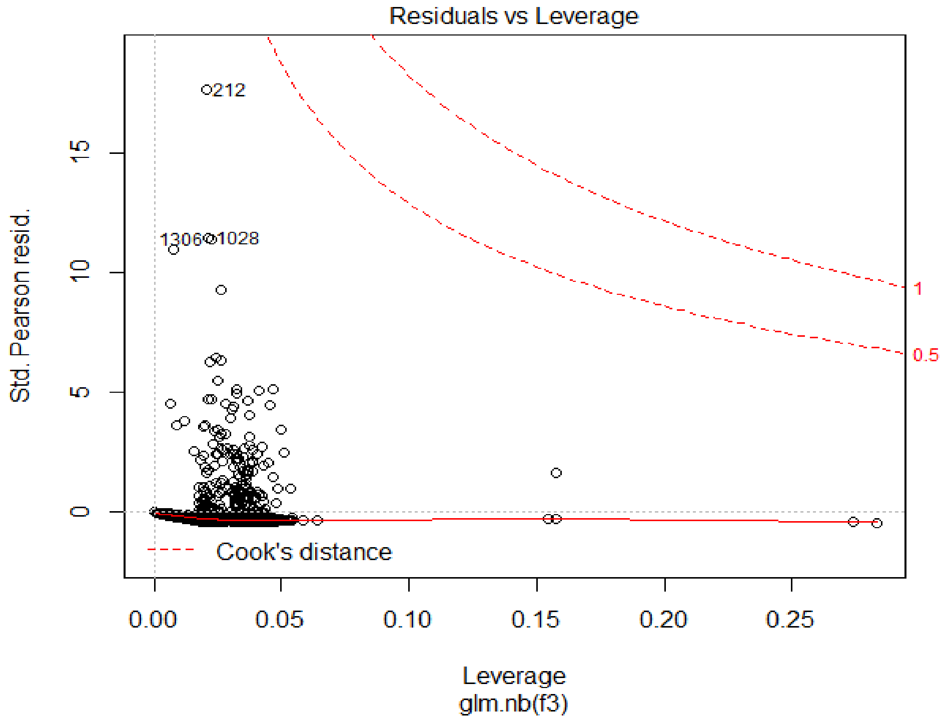


Figure 5.17. Standardized index versus the nominal index for the RITS.

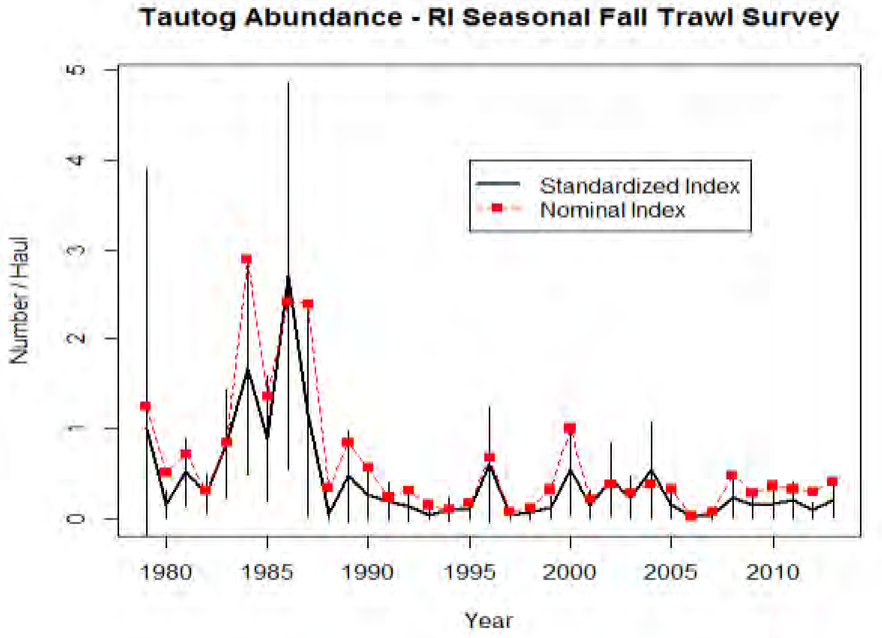


Figure 5.18. Histogram of catch data for the RISS dataset.

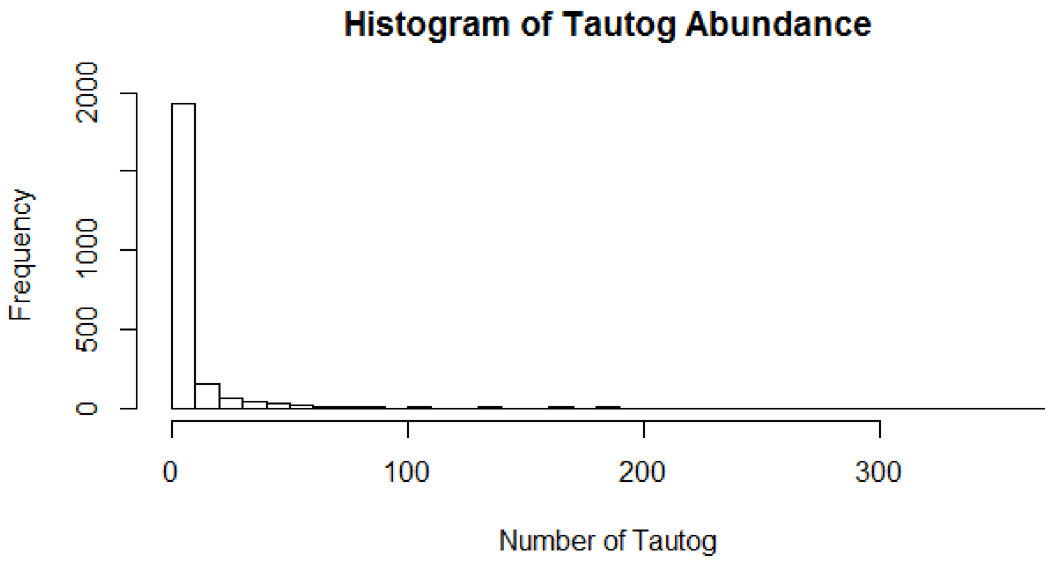


Figure 5.19. QQ Plot for negative binomial distribution for the final model used for the RISS.

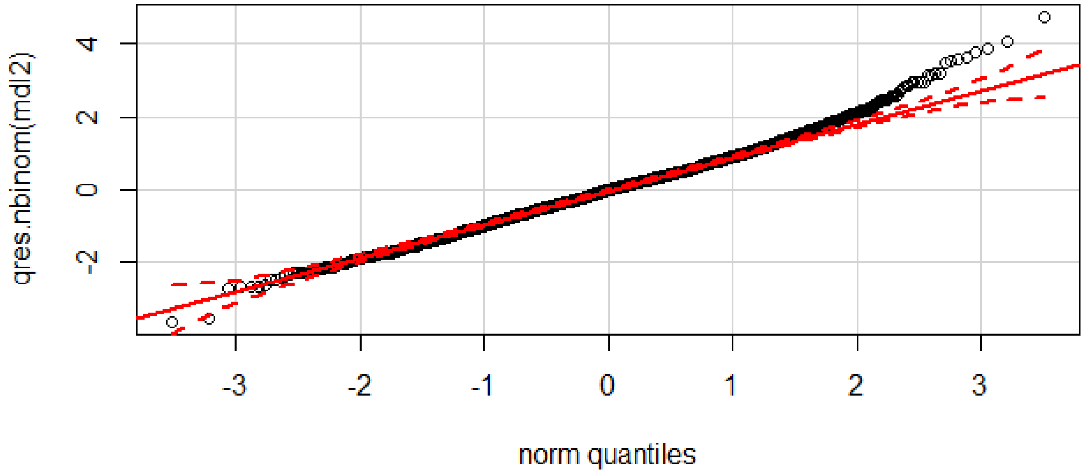


Figure 5.20. Cook's distance plot for the final model used for the RISS.

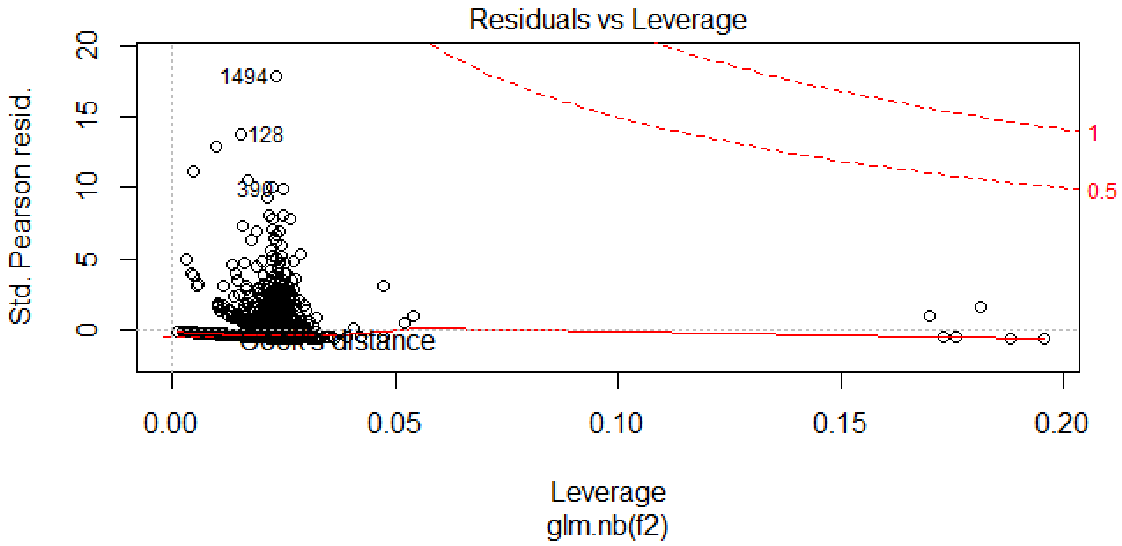


Figure 5.21. Standardized index versus the nominal index for the RISS.

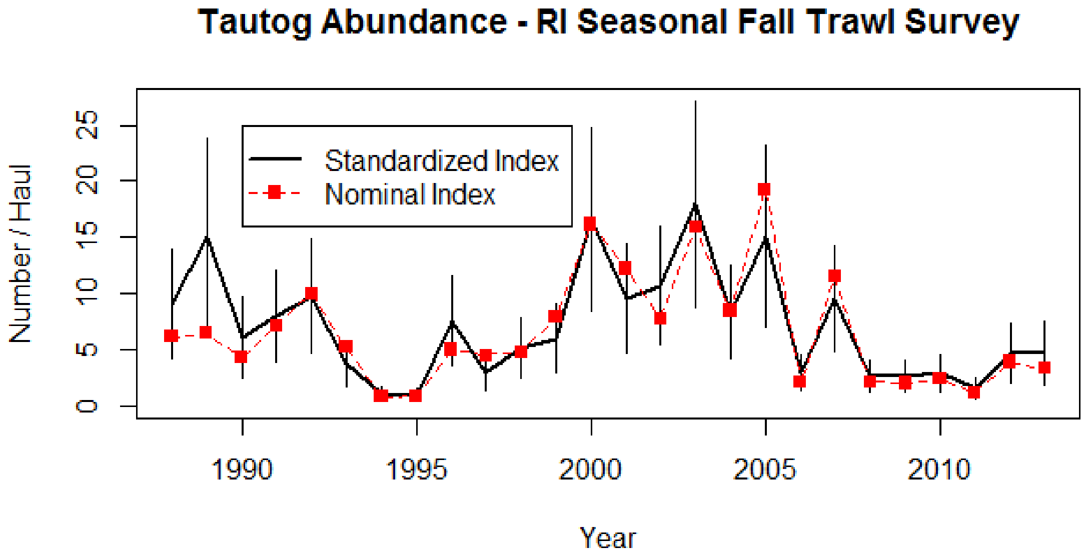


Figure 5.22. Histogram of catch data for the CT LISTS dataset.

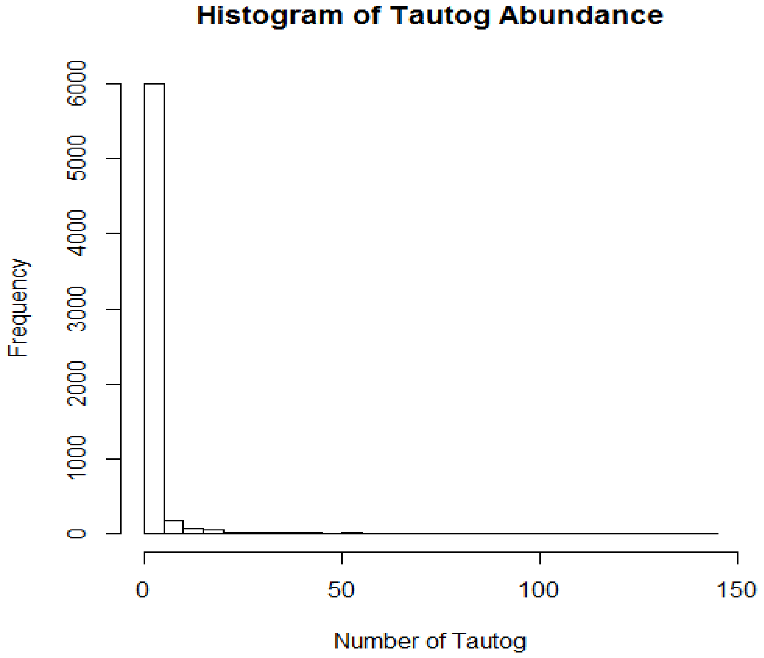


Figure 5.23. QQ Plot for negative binomial distribution for the final model used for the CT LISTS.

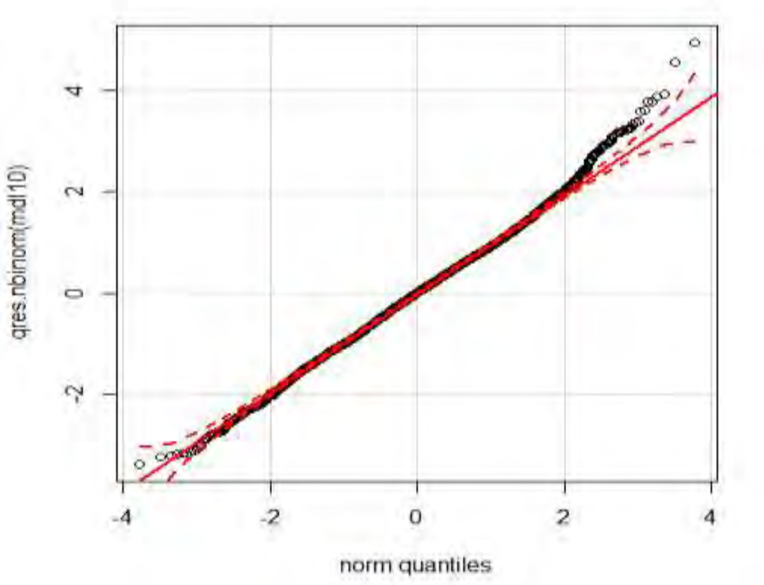


Figure 5.24. Cook's distance plot for the final model used for the CT LISTS.

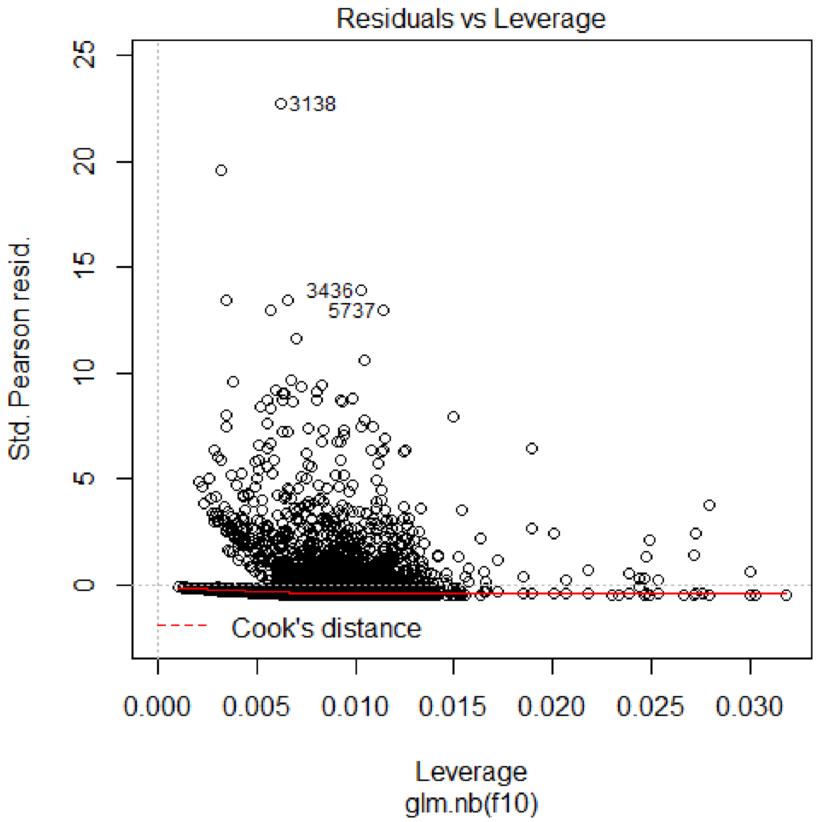


Figure 5.25. Standardized index versus the nominal index for the CT LISTS.

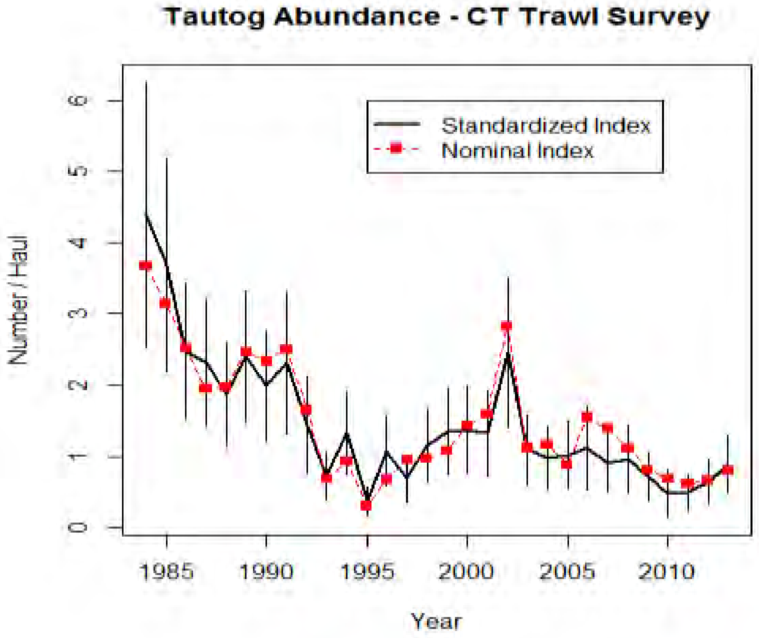


Figure 5.26. Histogram of catch data for the NYTS dataset.

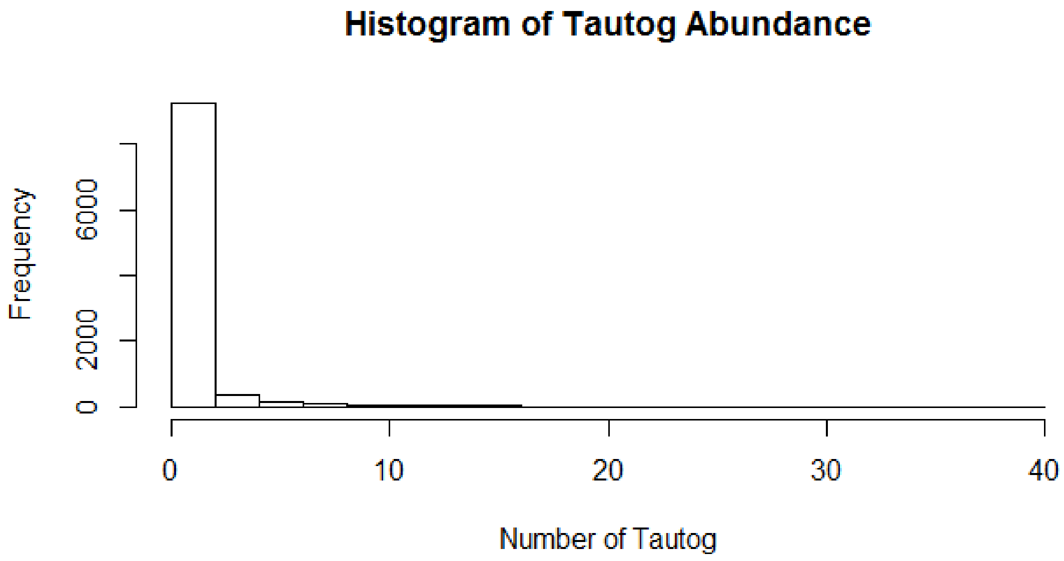


Figure 5.27. QQ Plot for negative binomial distribution for the final model used for the NYTS.

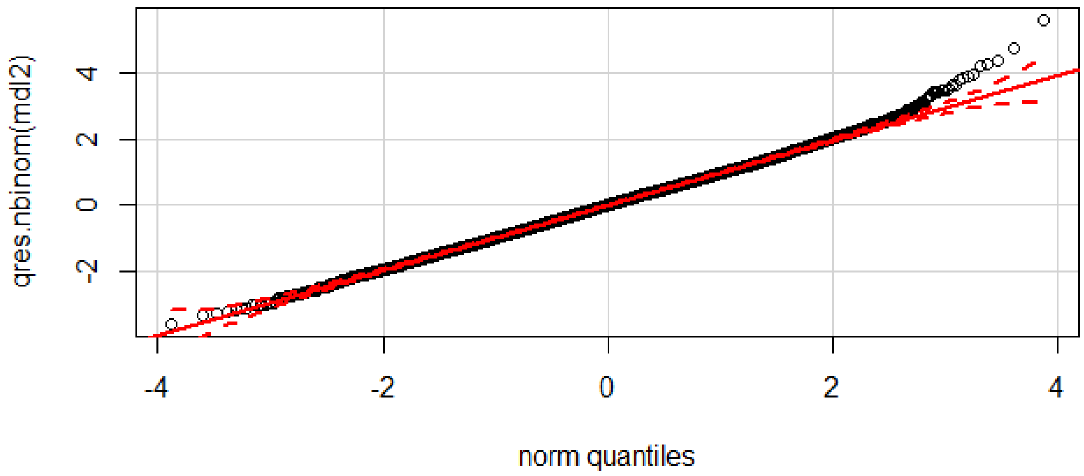


Figure 5.28. Cook's distance plot for the final model used for the NYTS.

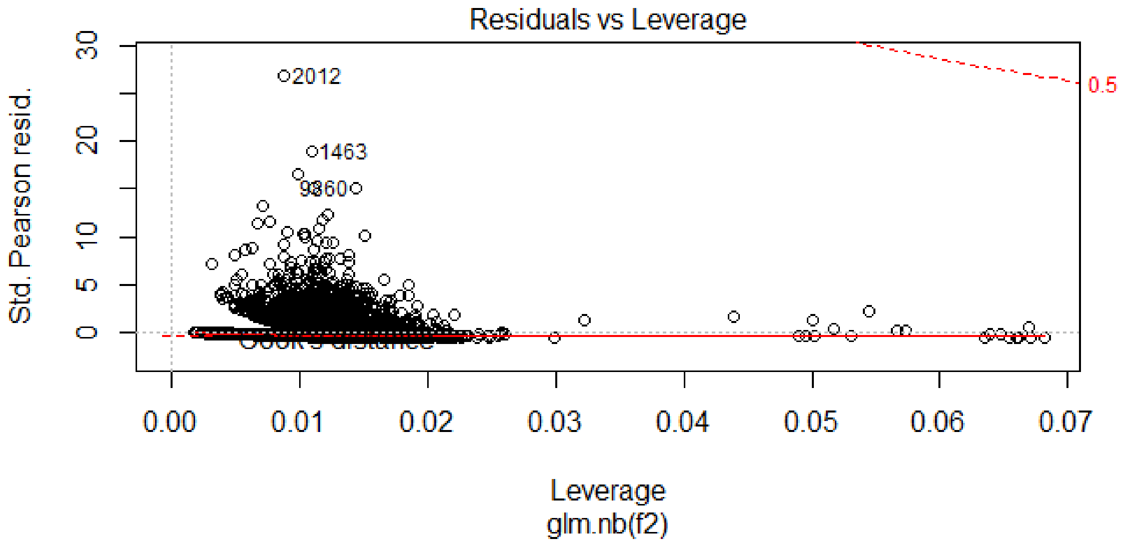


Figure 5.29. Standardized index versus the nominal index for the NYTS.

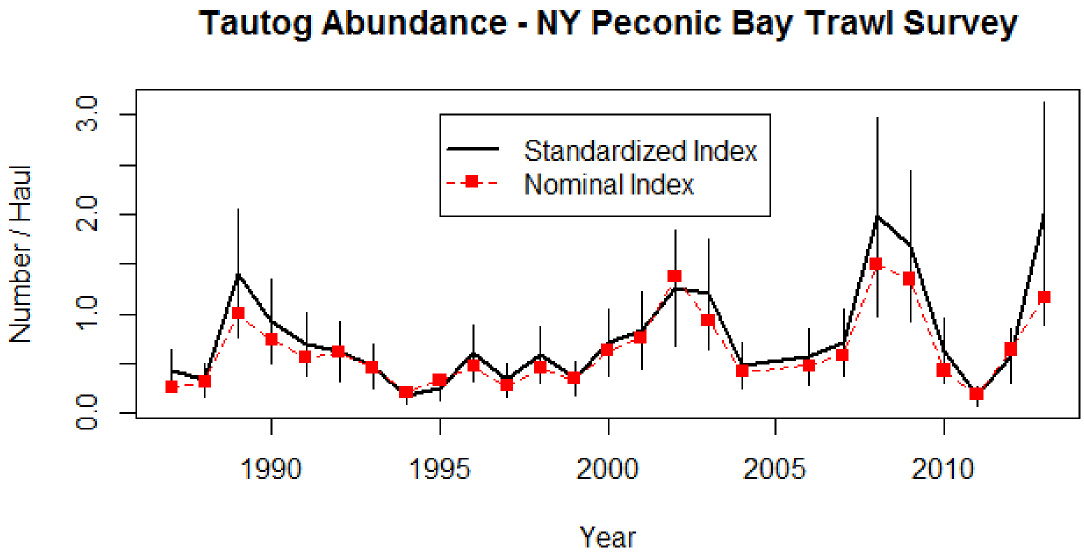


Figure 5.30. Histogram of catch data for the NYWLISS dataset.

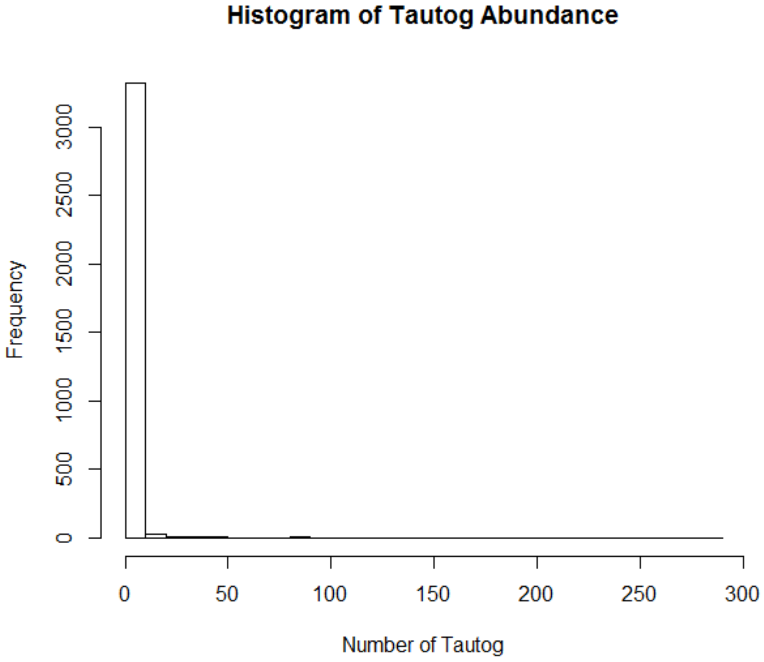


Figure 5.31. QQ Plot for negative binomial distribution for the final model used for the NYWLISS.

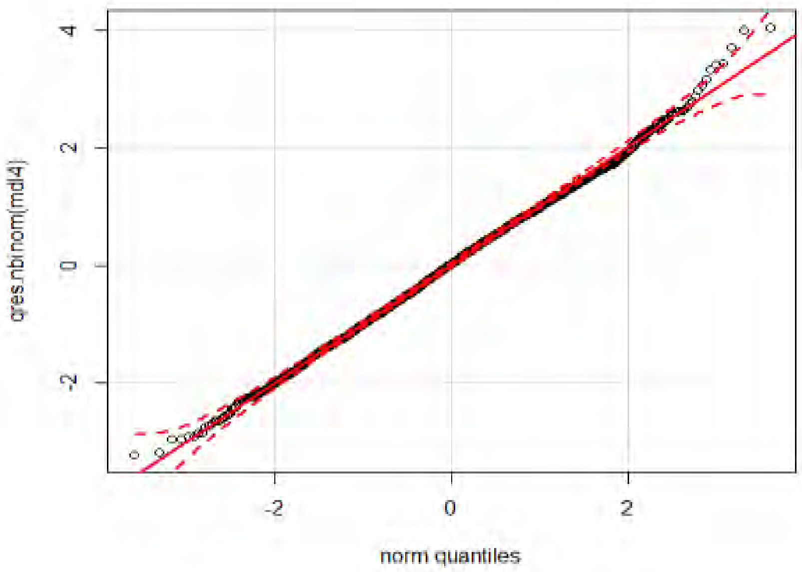


Figure 5.32. Cook's distance plot for the final model used for the NYWLISS.

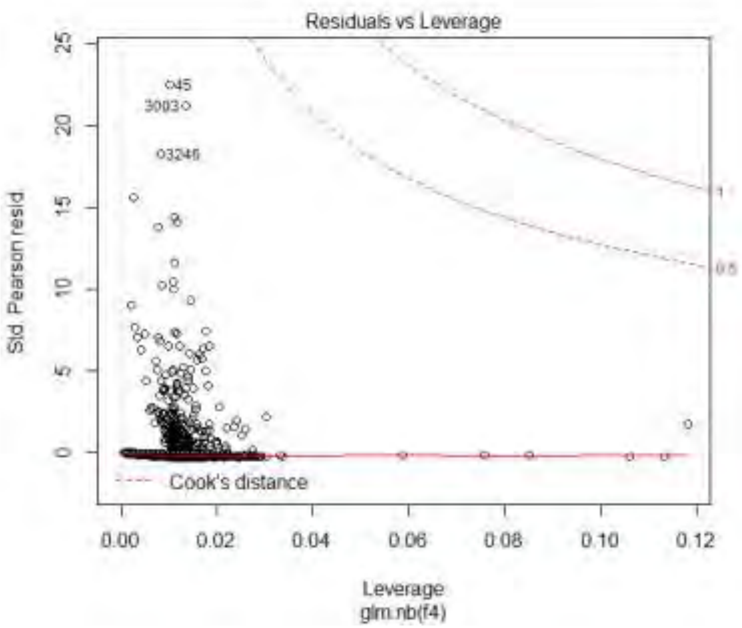


Figure 5.33. Standardized index versus the nominal index for the NYWLISS.

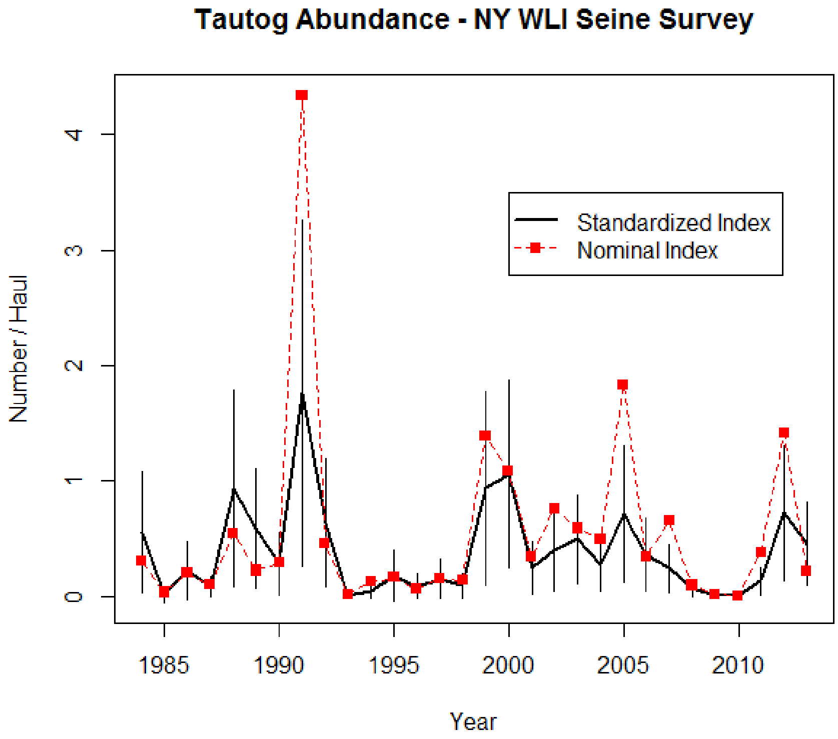


Figure 5.34. Histogram of catch data for the NJTS dataset.

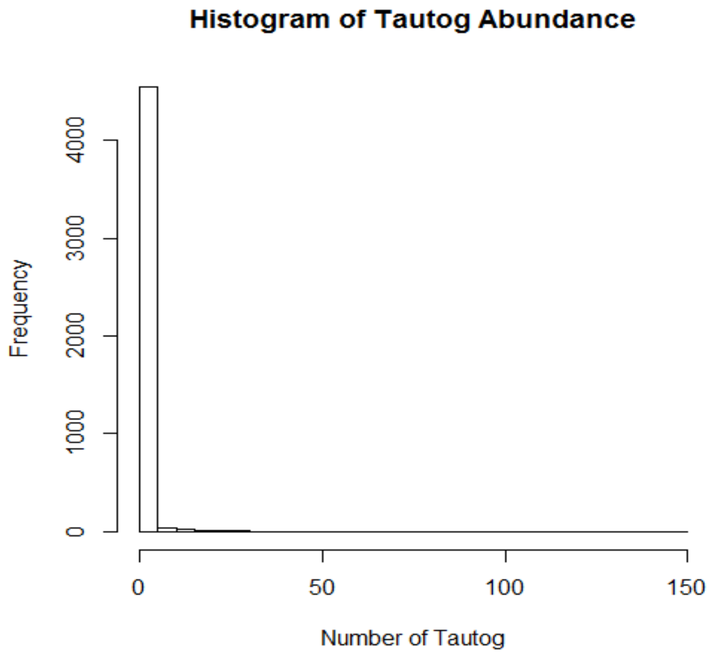


Figure 5.35. QQ Plot for negative binomial distribution for the final model used for the NJTS.

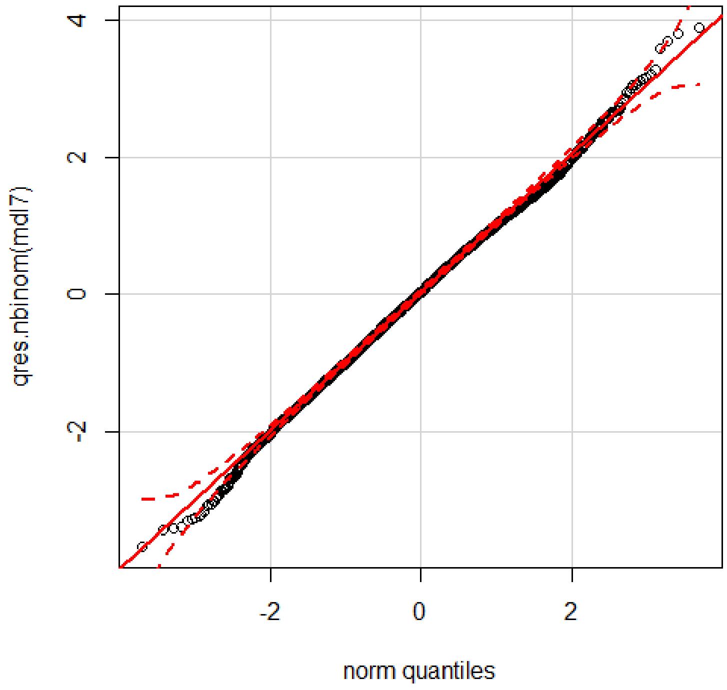


Figure 5.36. Cook's distance plot for the final model used for the NJTS.

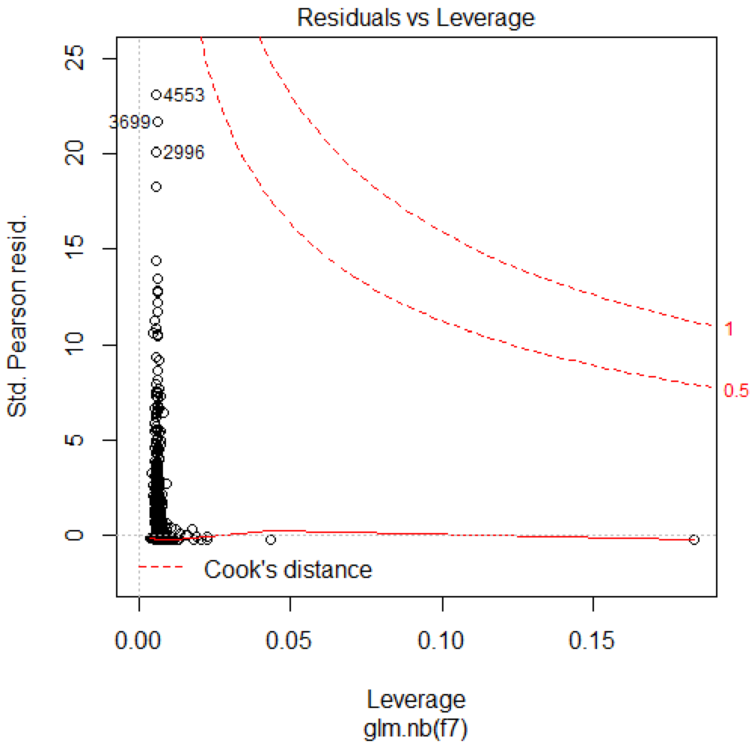


Figure 5.37. Standardized index versus the nominal index for the NJTS.

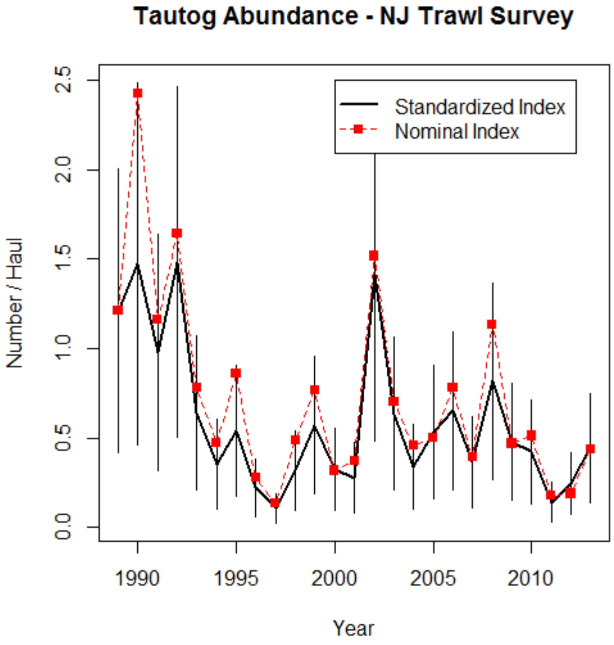


Figure 6.1. Observed and predicted total catch in weight (left) and standardized residuals (right) for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

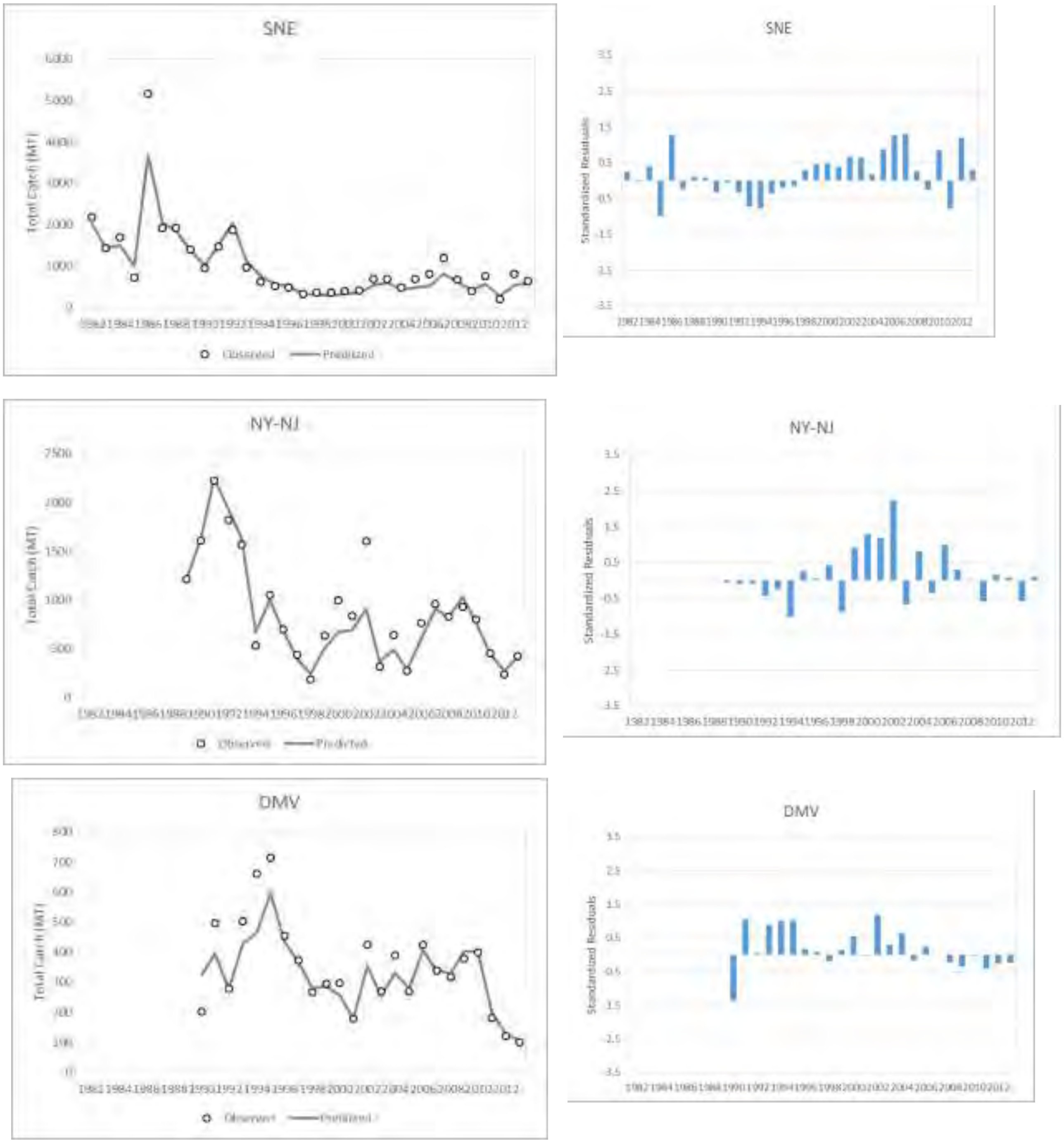


Figure 6.2.A. Observed and predicted fishery independent indices (left) and their standardized residuals (right) for the Southern New England region.

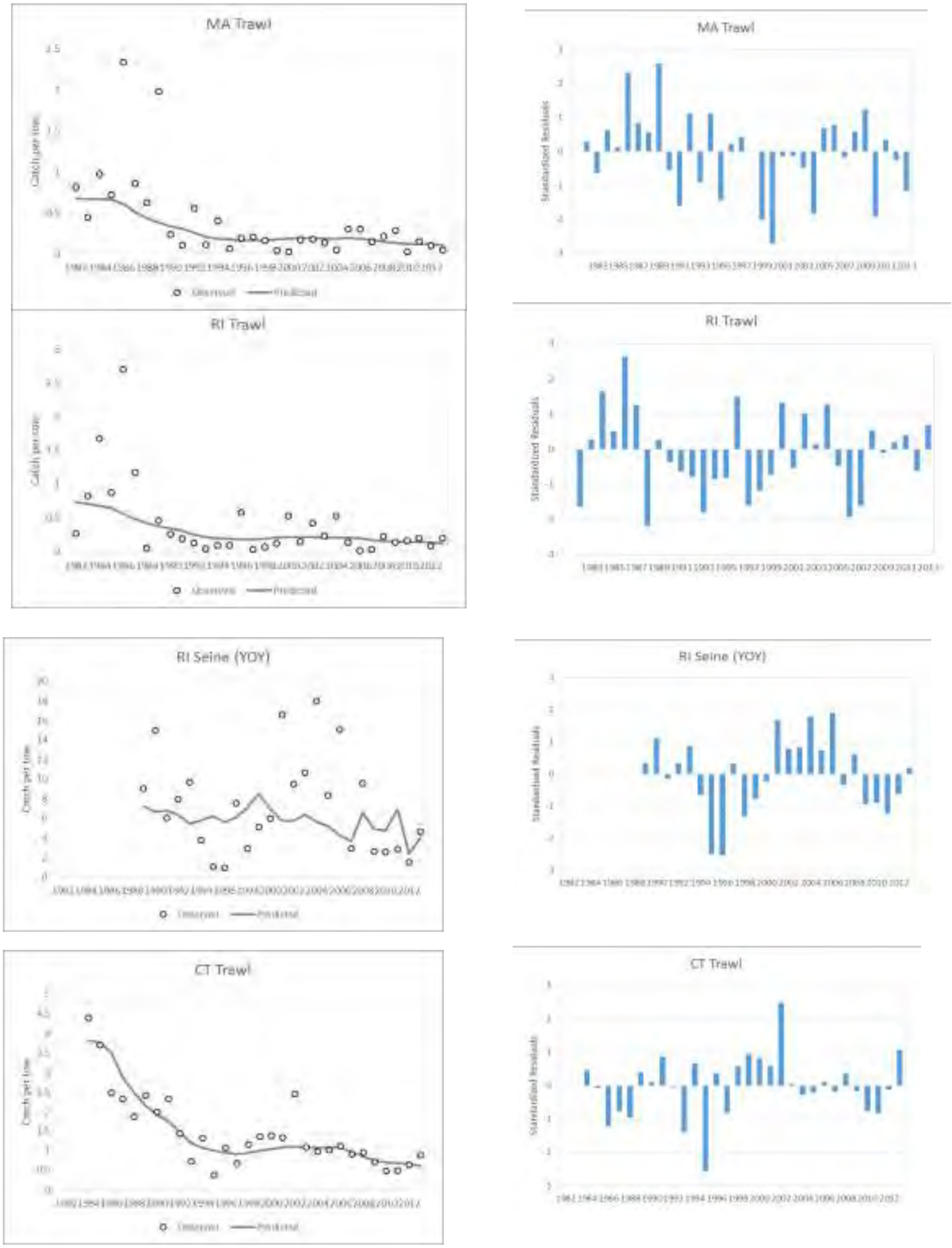


Figure 6.2.B. Observed and predicted fishery dependent index (left) and their standardized residuals (right) for the Southern New England region.

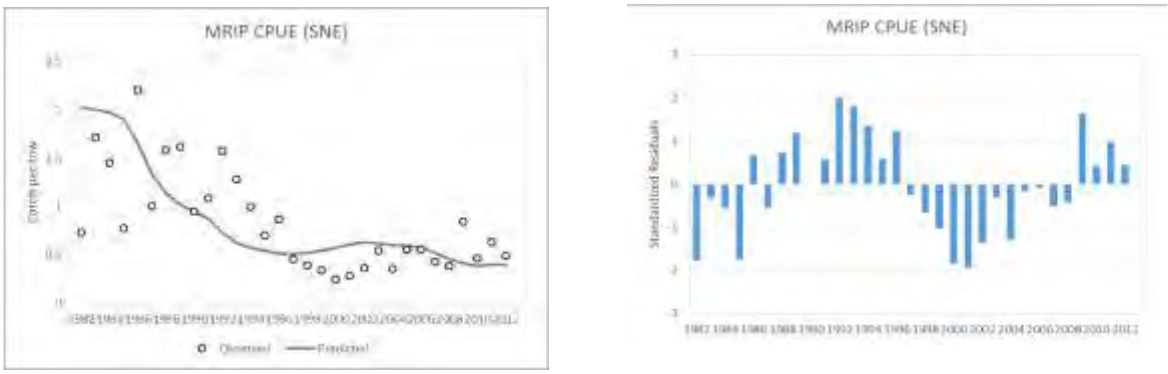


Figure 6.3. Observed and predicted indices (left) and their standardized residuals (right) for the NY-NJ region.

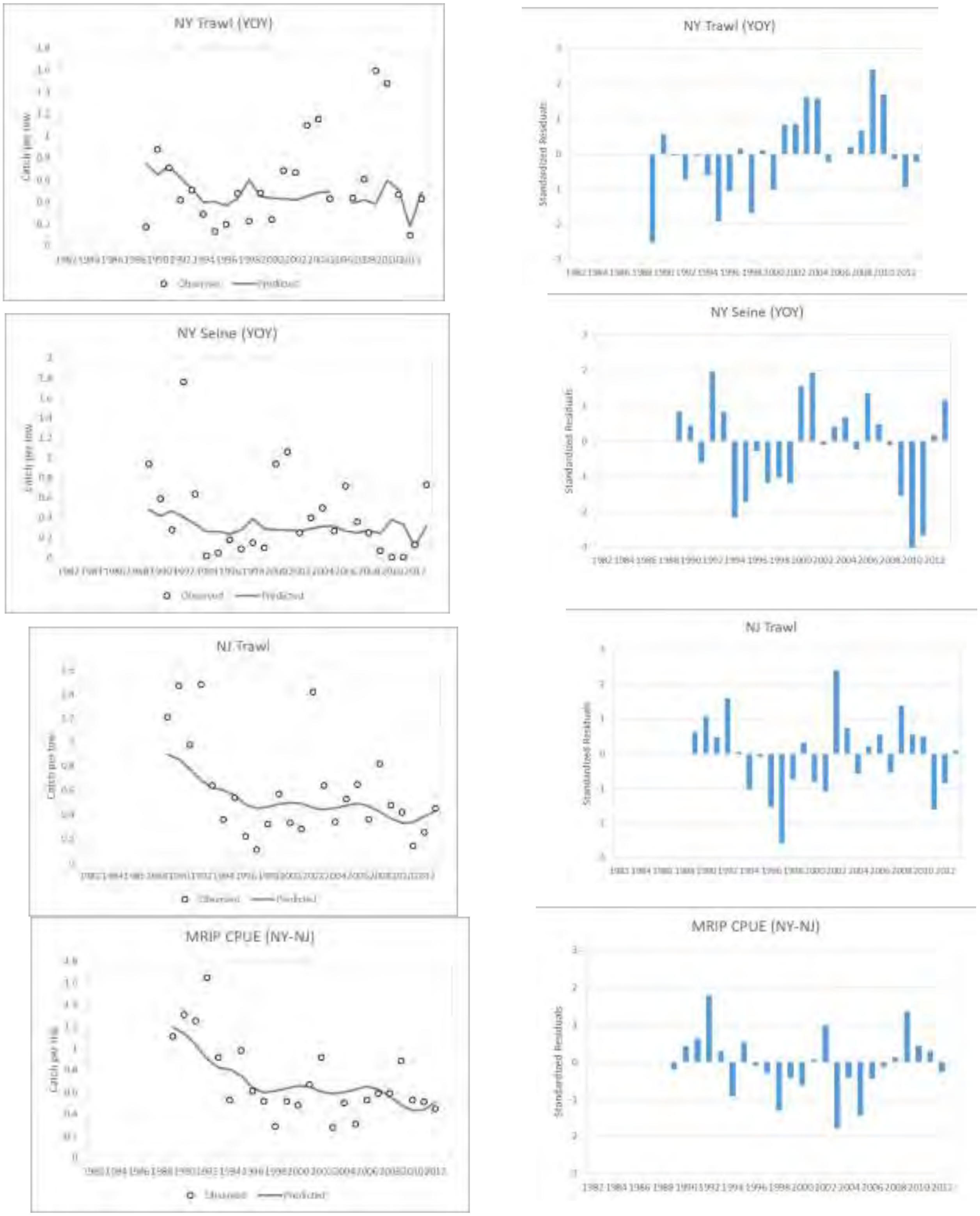
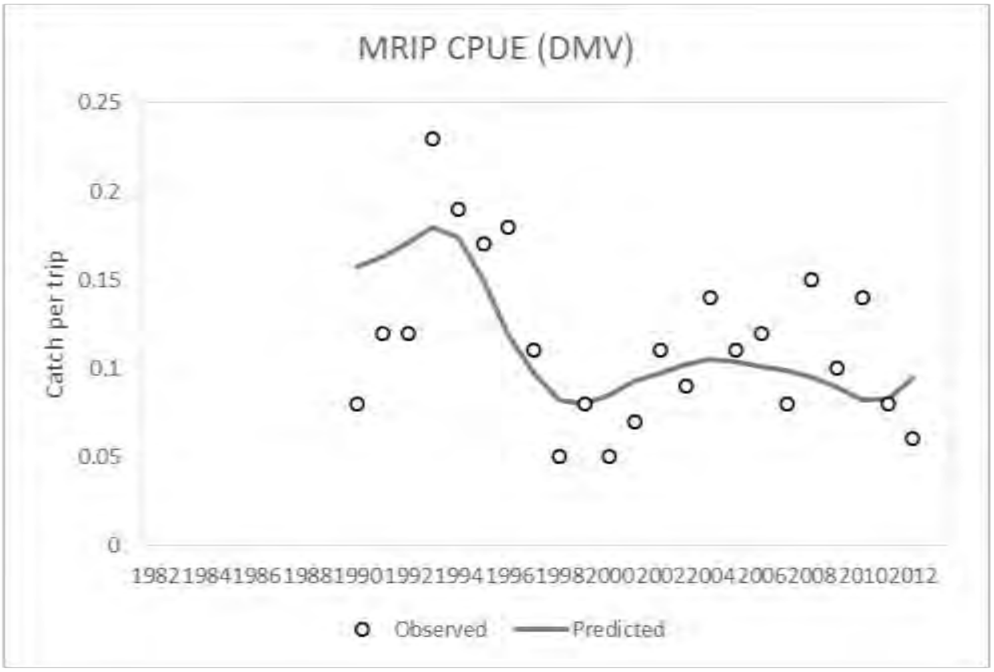


Figure 6.4. Observed and predicted index (top) and its standardized residuals (bottom) for the DelMarVa region.



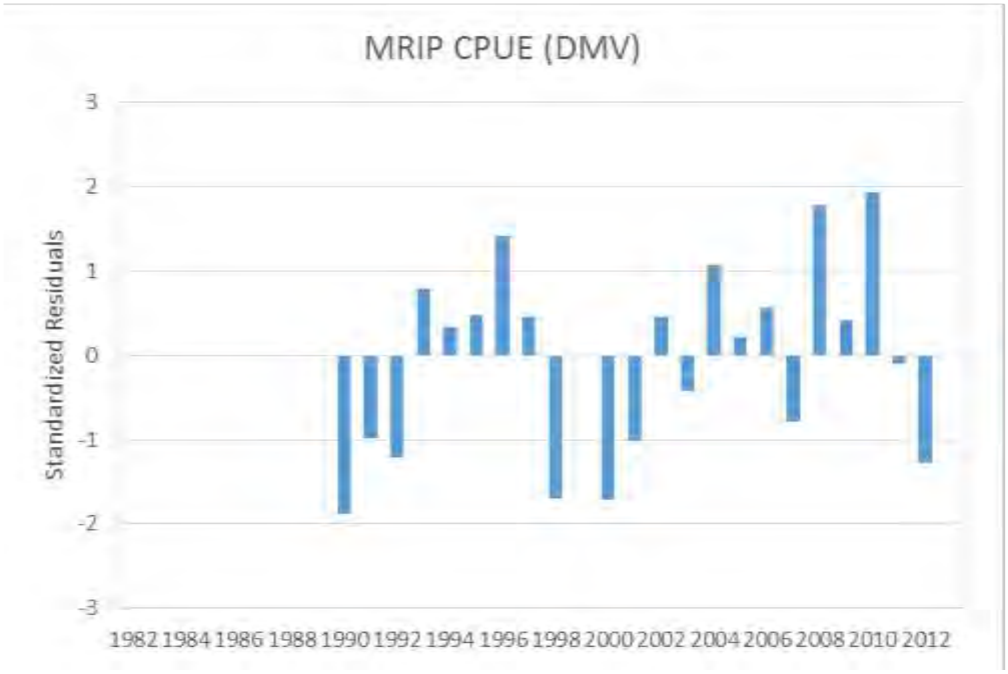


Figure 6.5. Total observed and predicted catch-at-age for the southern New England region (top), the NY-NJ region (middle), and the DelMarVa region (bottom).

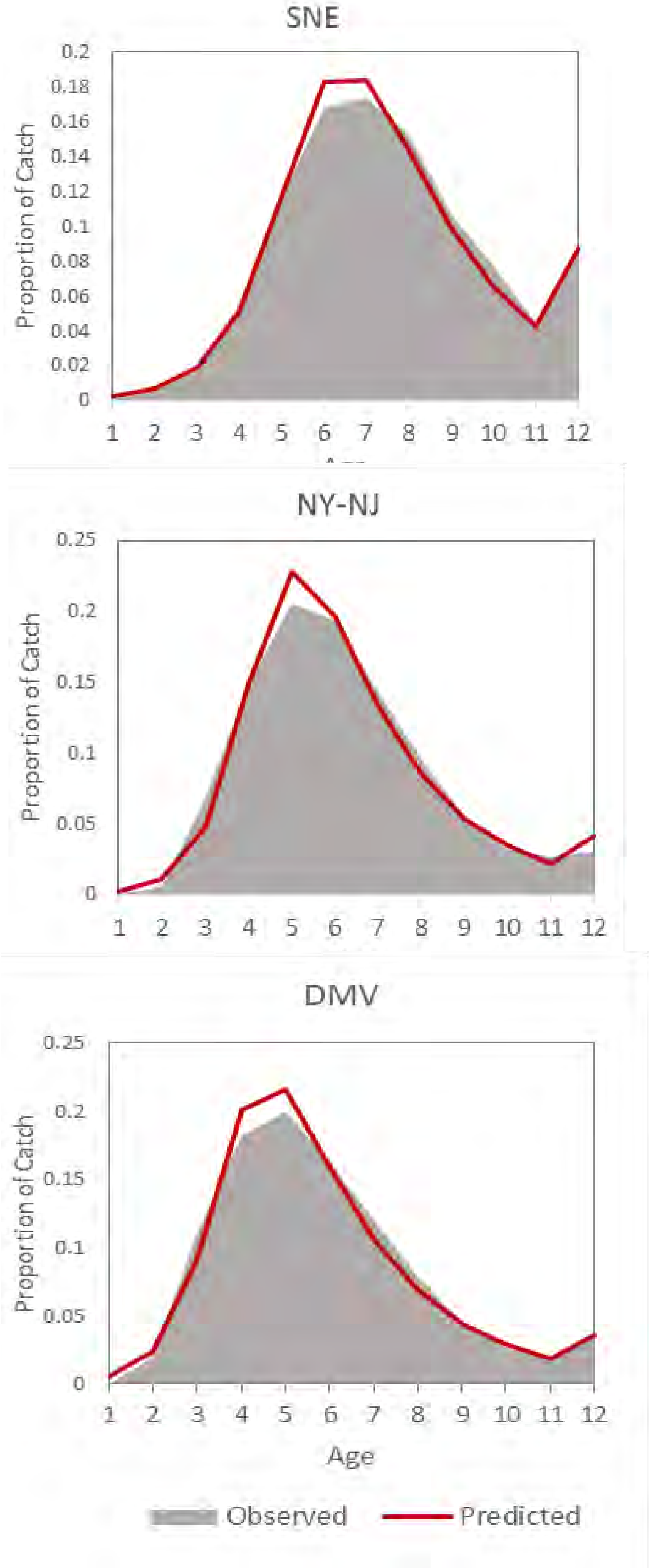


Figure 6.6. Annual observed and predicted total catch-at-age for the southern New England region.

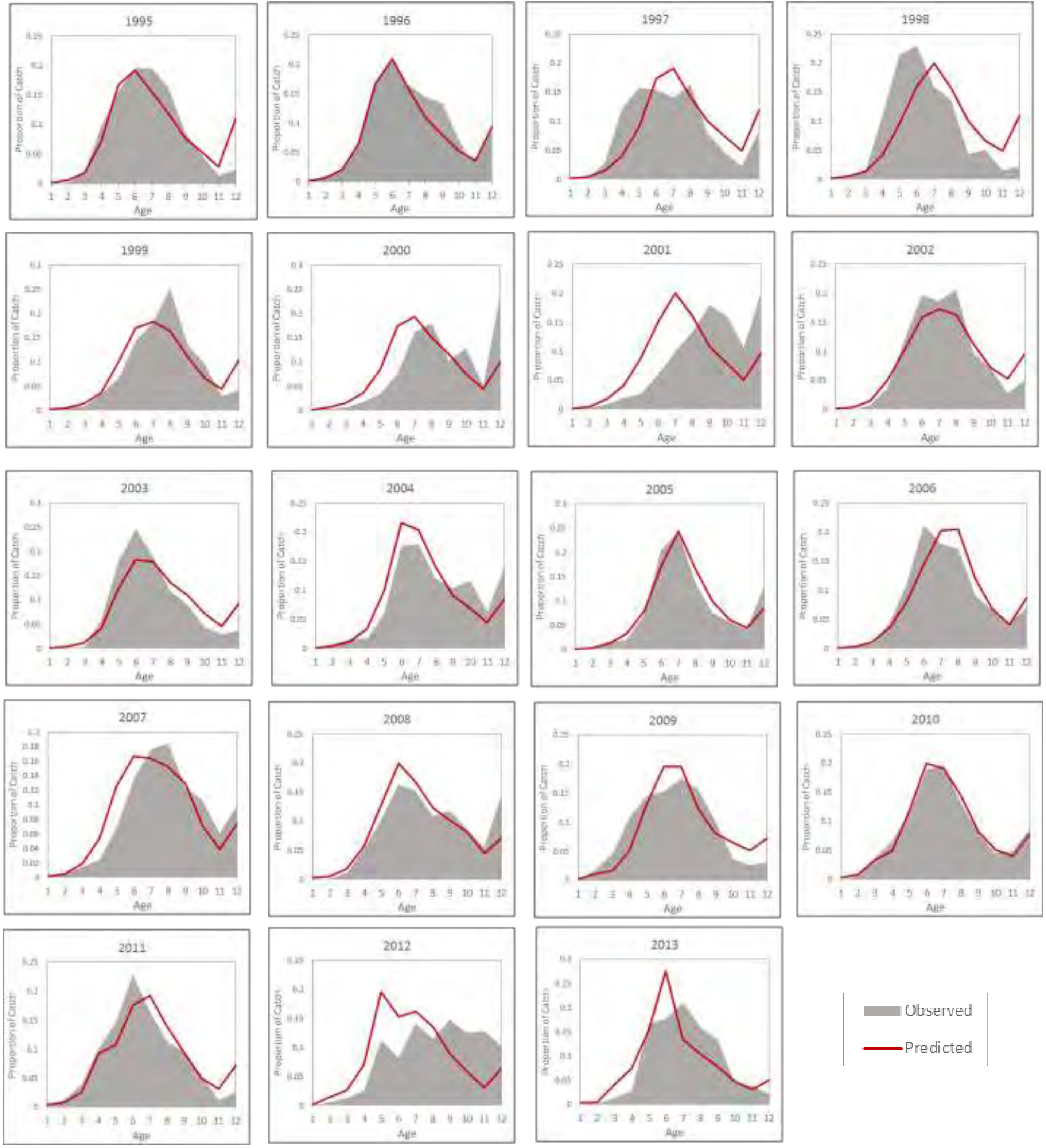


Figure 6.7. Annual observed and predicted total catch-at-age for the NY-NJ region.

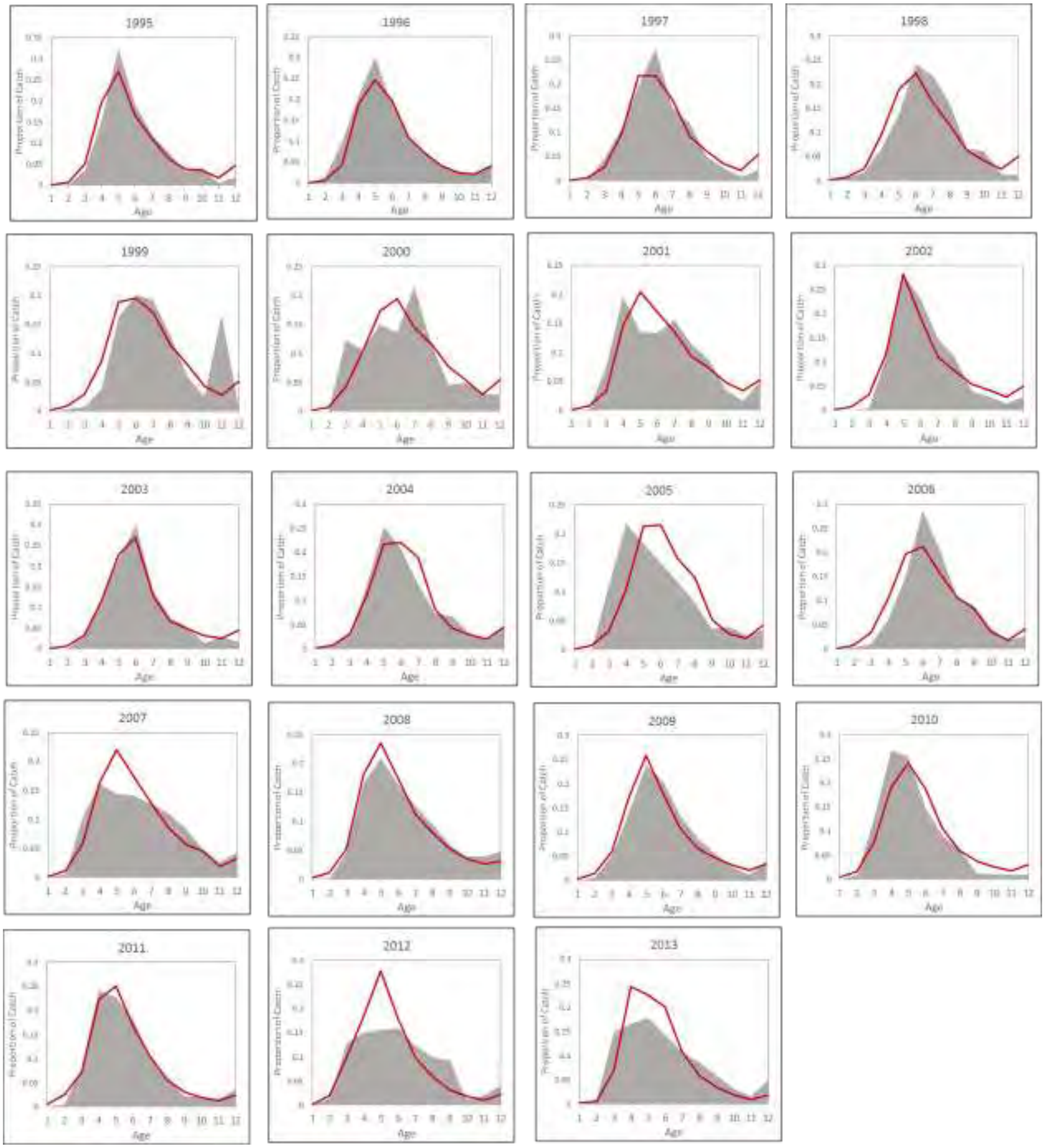


Figure 6.8. Annual observed and predicted total catch-at-age for the DelMarVa region.

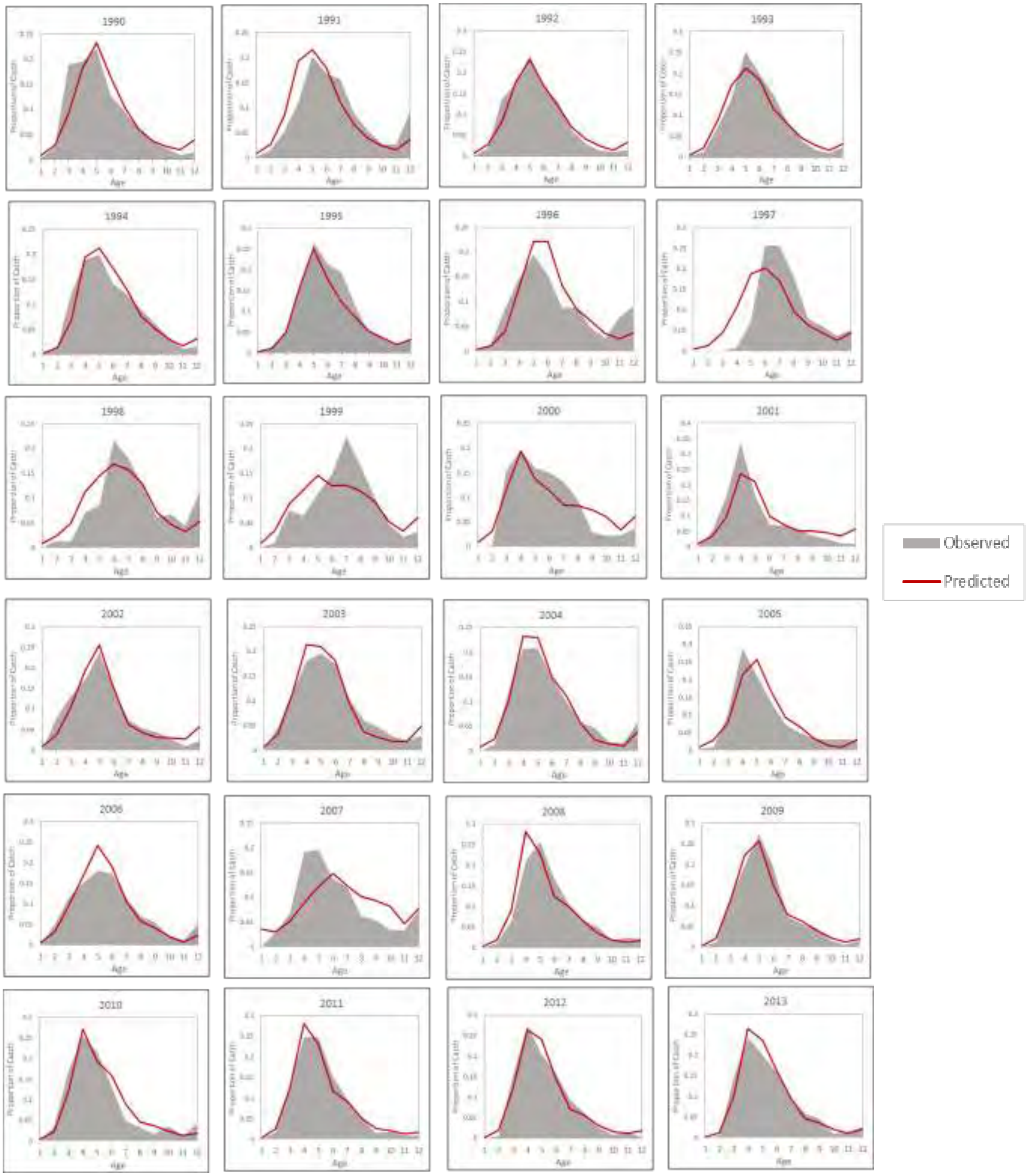


Figure 6.9. Total observed and predicted total index-at-age for the southern New England region.

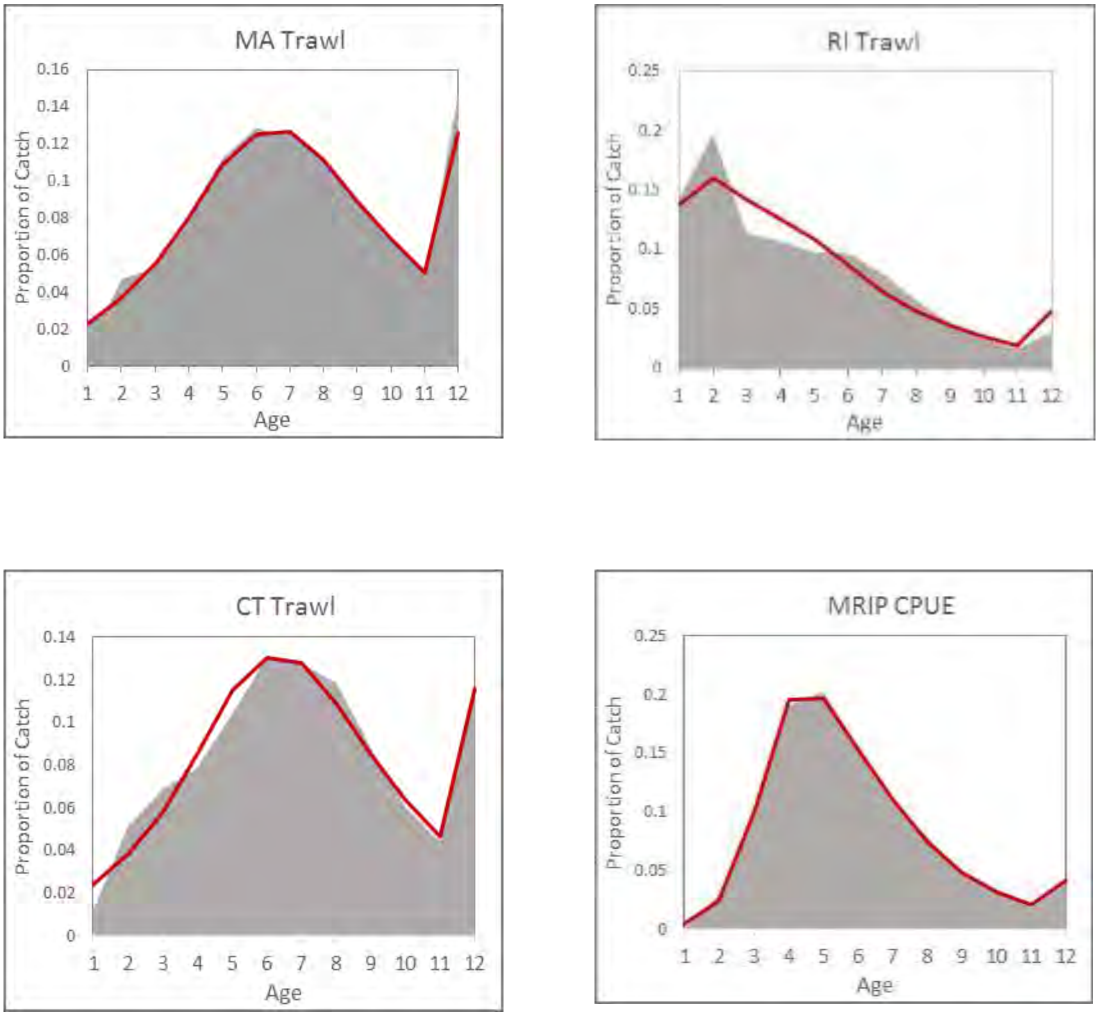


Figure 6.10. Total observed and predicted total index-at-age for the NY-NJ region.

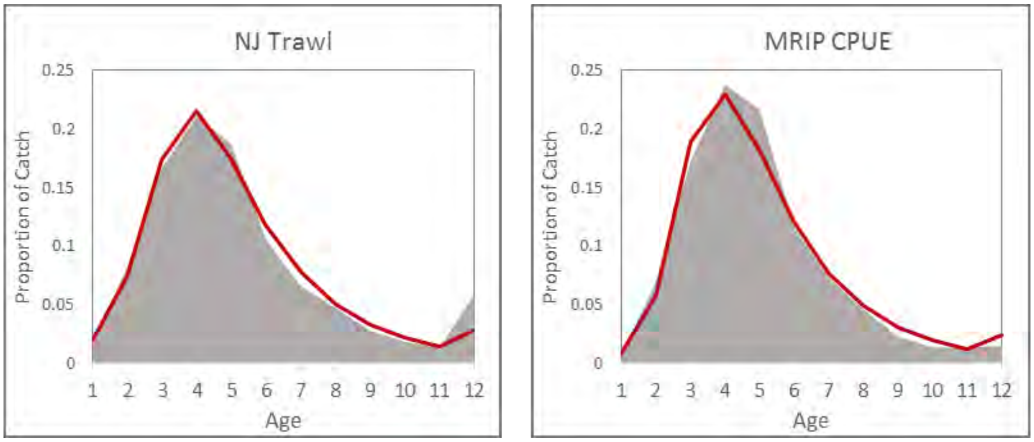


Figure 6.11. Total observed and predicted total index-at-age for the DelMarVa region.

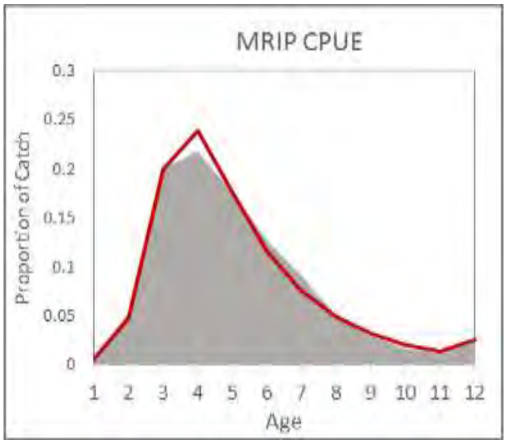


Figure 6.12. Selectivity by block for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

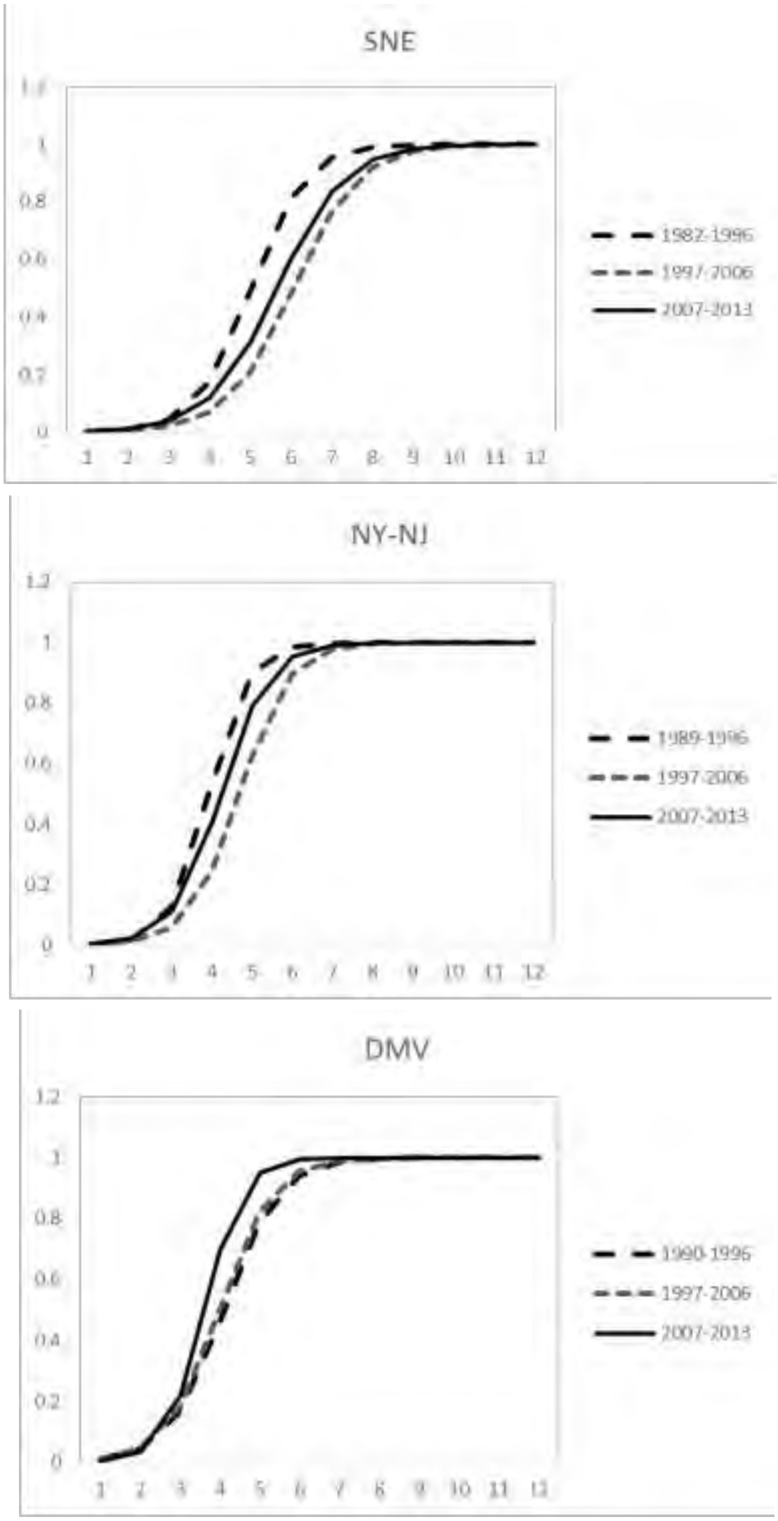


Figure 6.13. Observed and predicted stock-recruitment relationship for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

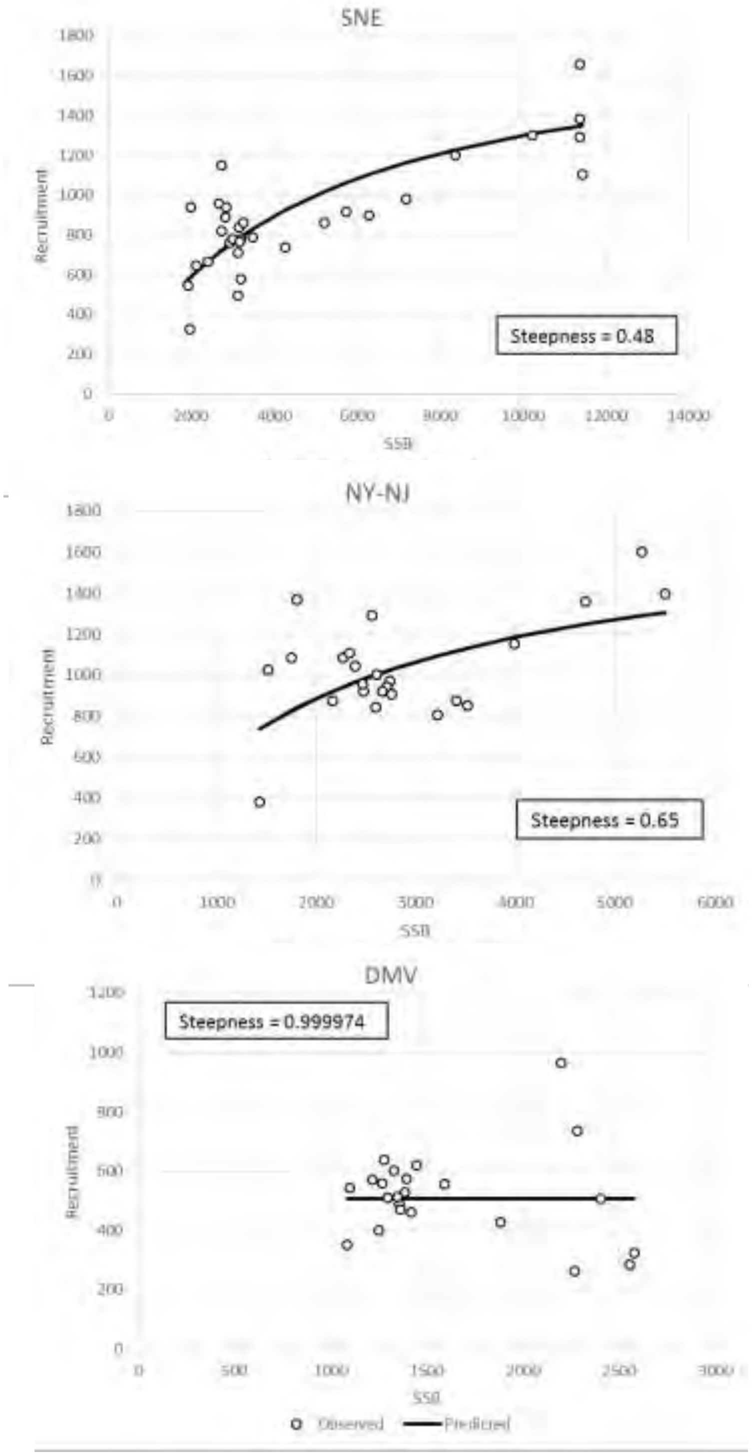


Figure 6.14. Annual and three-year average estimates of F for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

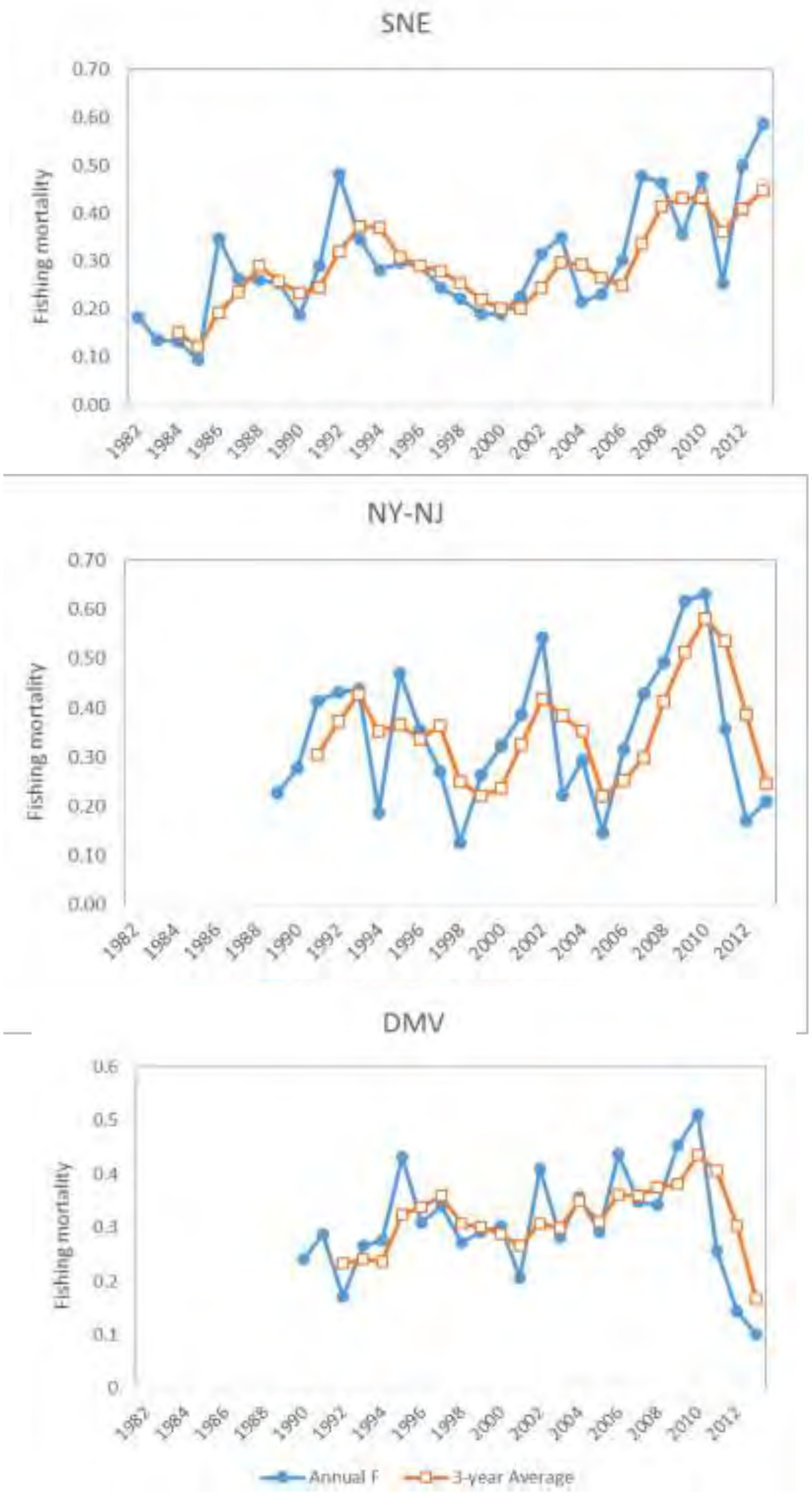


Figure 6.15. Median and 5th and 95th percentile MCMC estimates of F for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

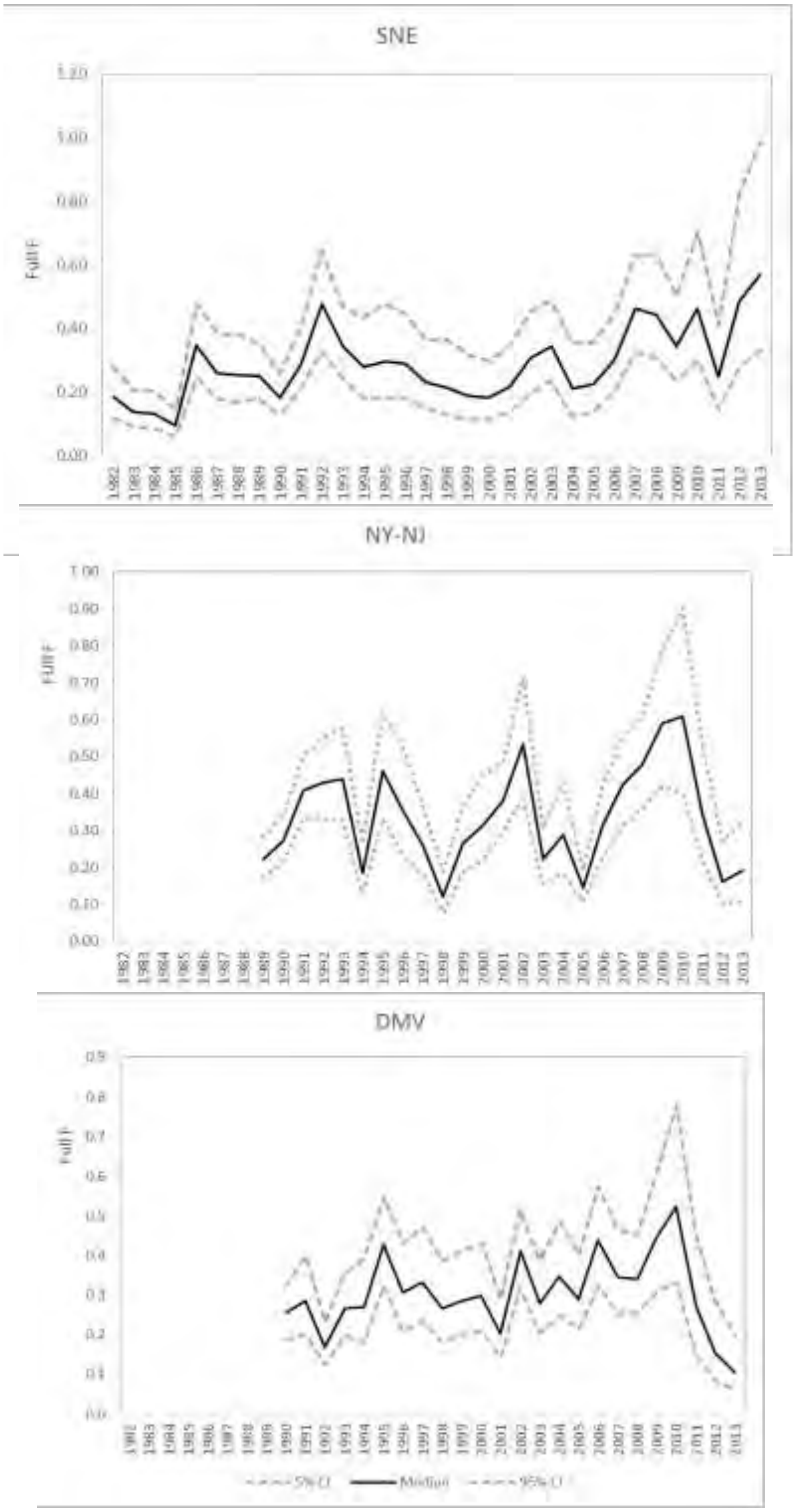


Figure 6.16. MCMC distributions on terminal F for southern New England (top left), NY-NJ (top right), and DelMarVa (bottom).

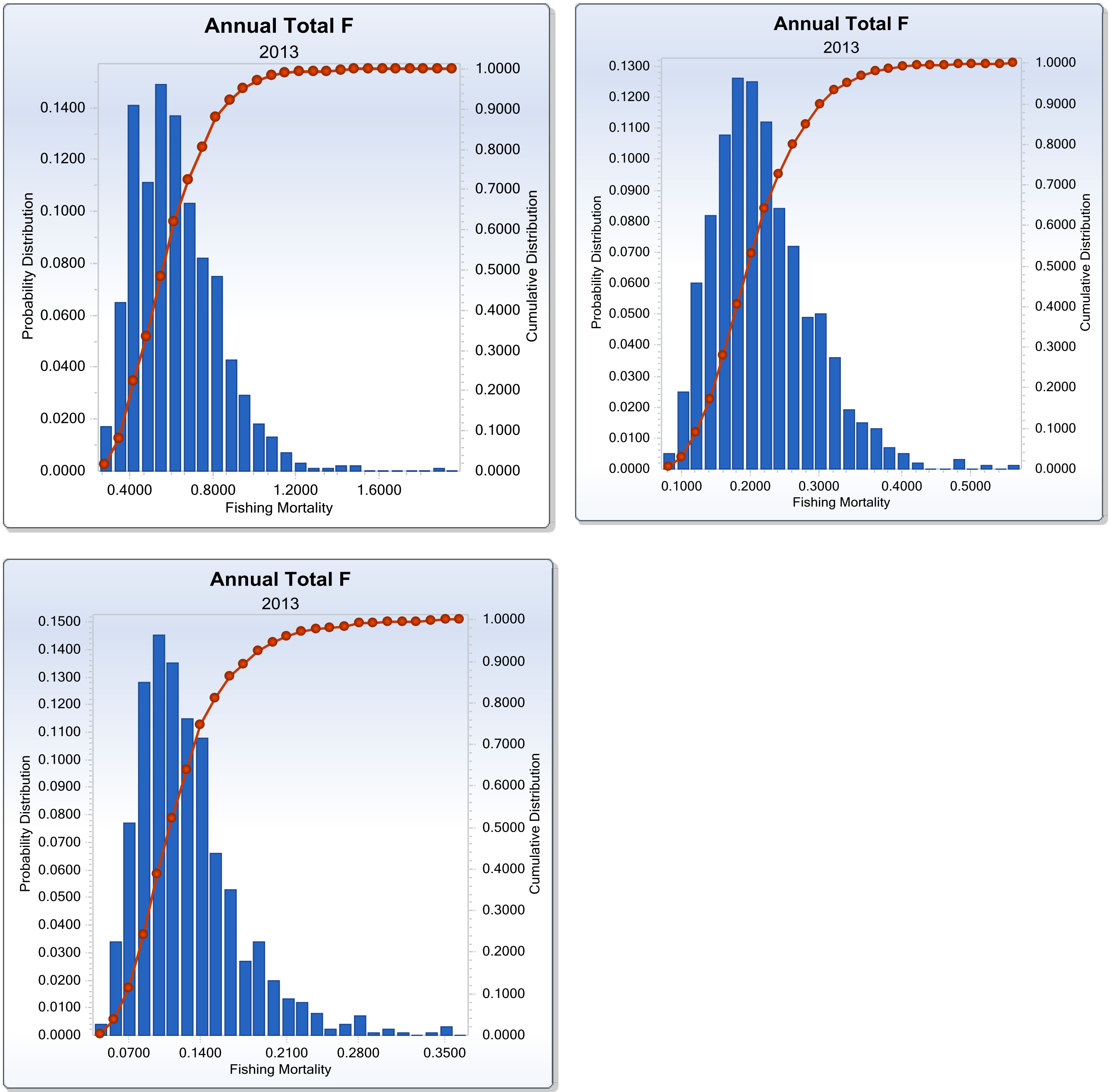


Figure 6.17. Median and 5th and 95th percentile MCMC estimates of SSB for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

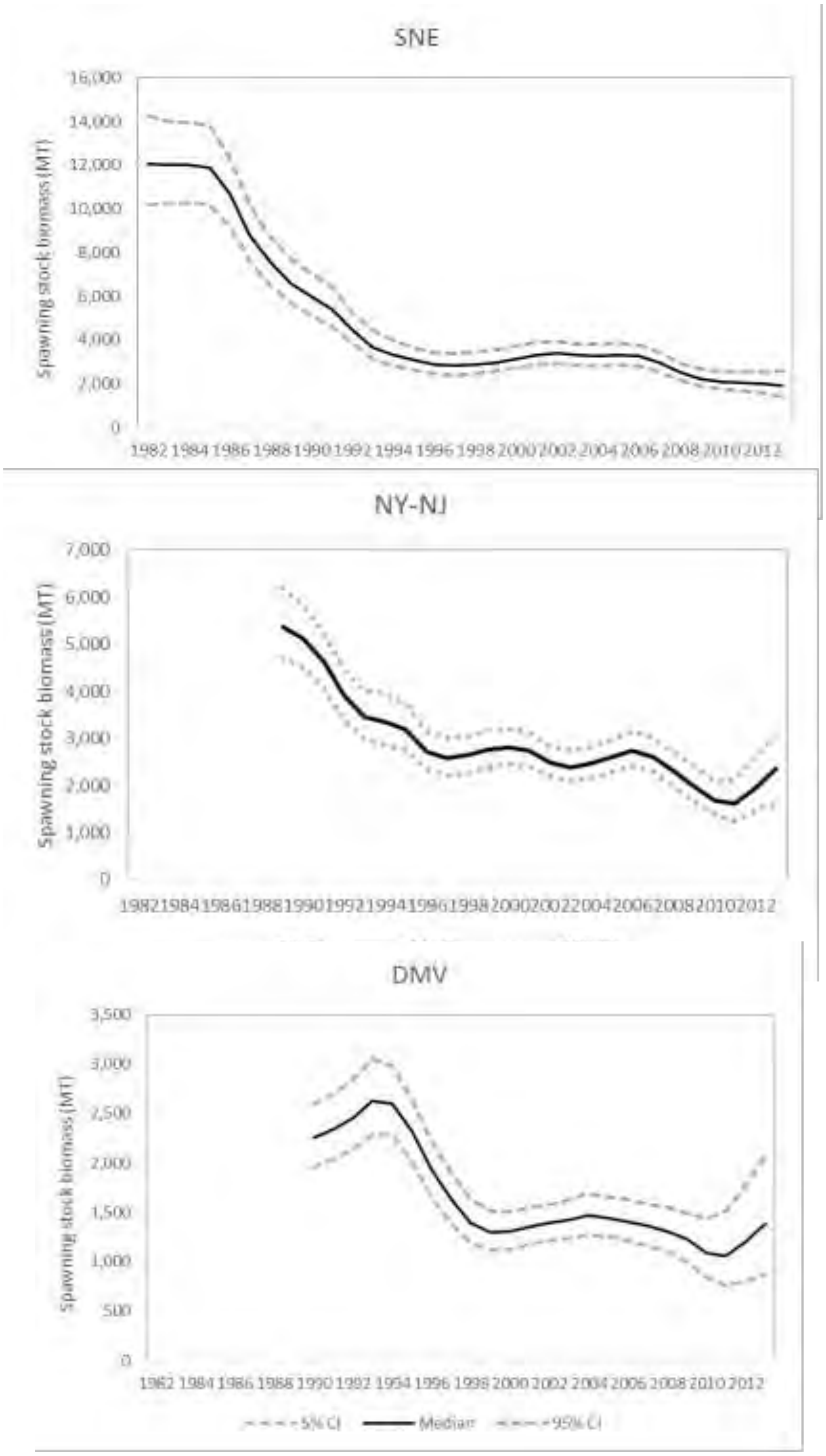


Figure 6.18. Distribution of MCMC estimates of SSB in the terminal year for southern New England (top left), NY-NJ (top right), and DelMarVa (bottom).

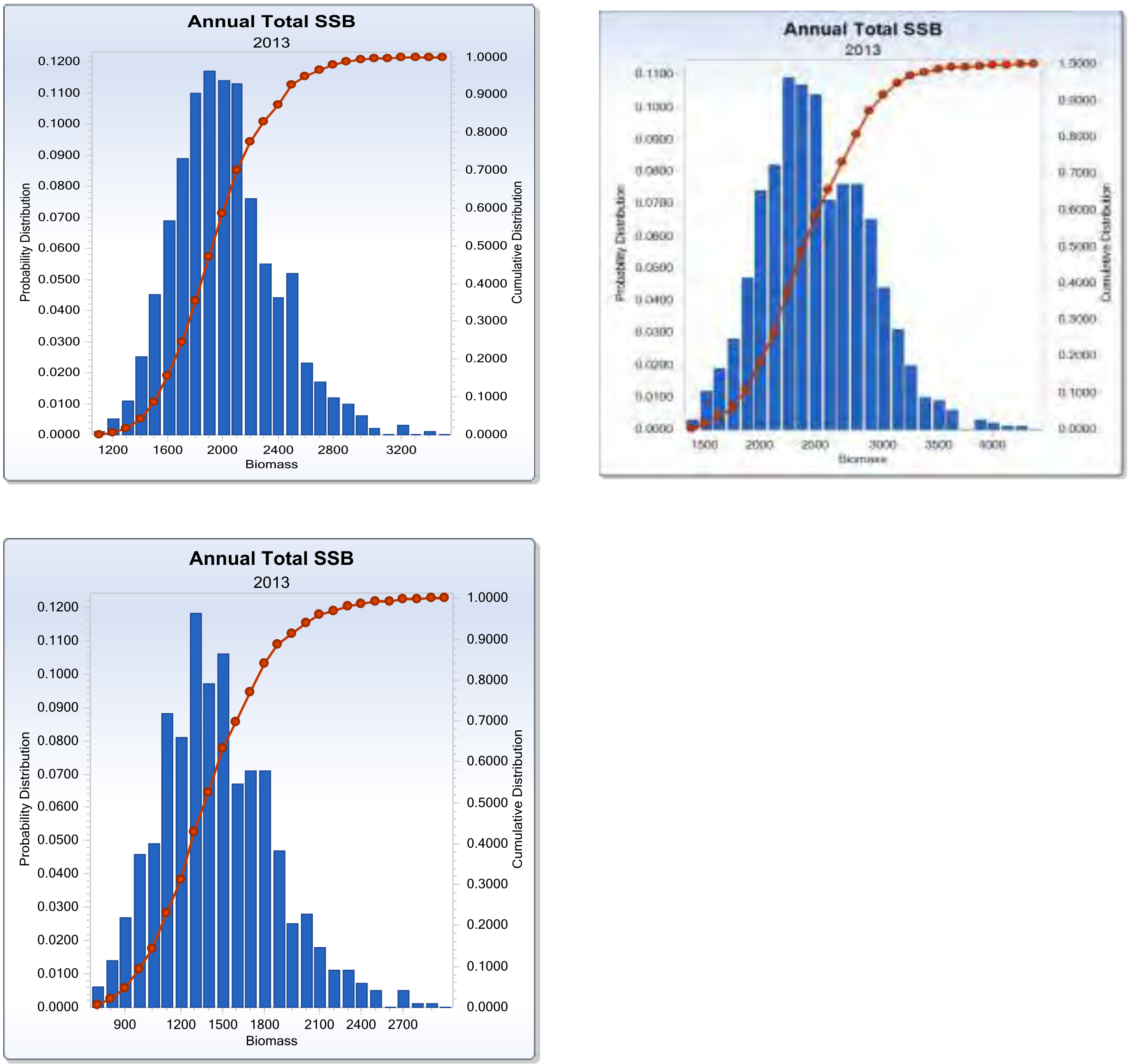


Figure 6.19. Estimates of recruitment and their standard deviations for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

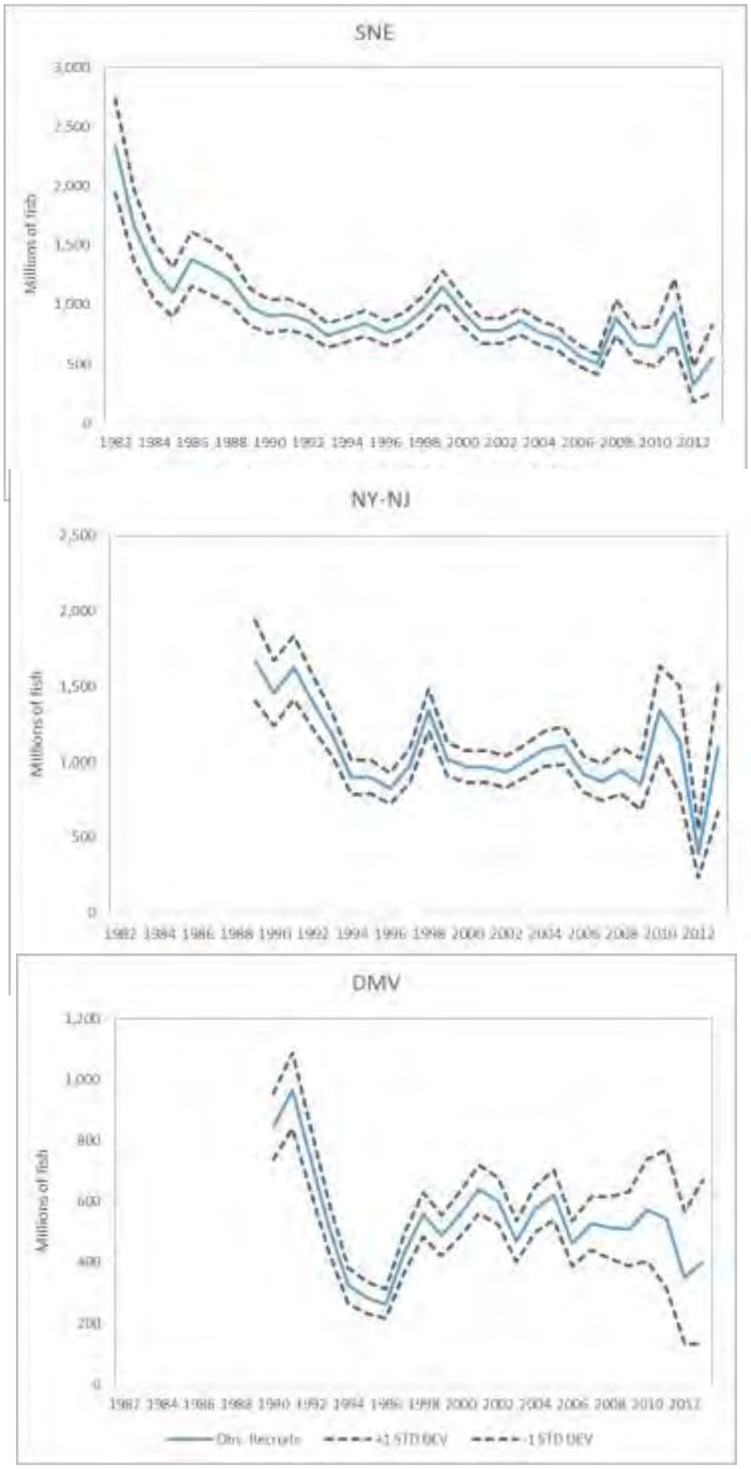


Figure 6.20. SSB trajectories for different sensitivity runs for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

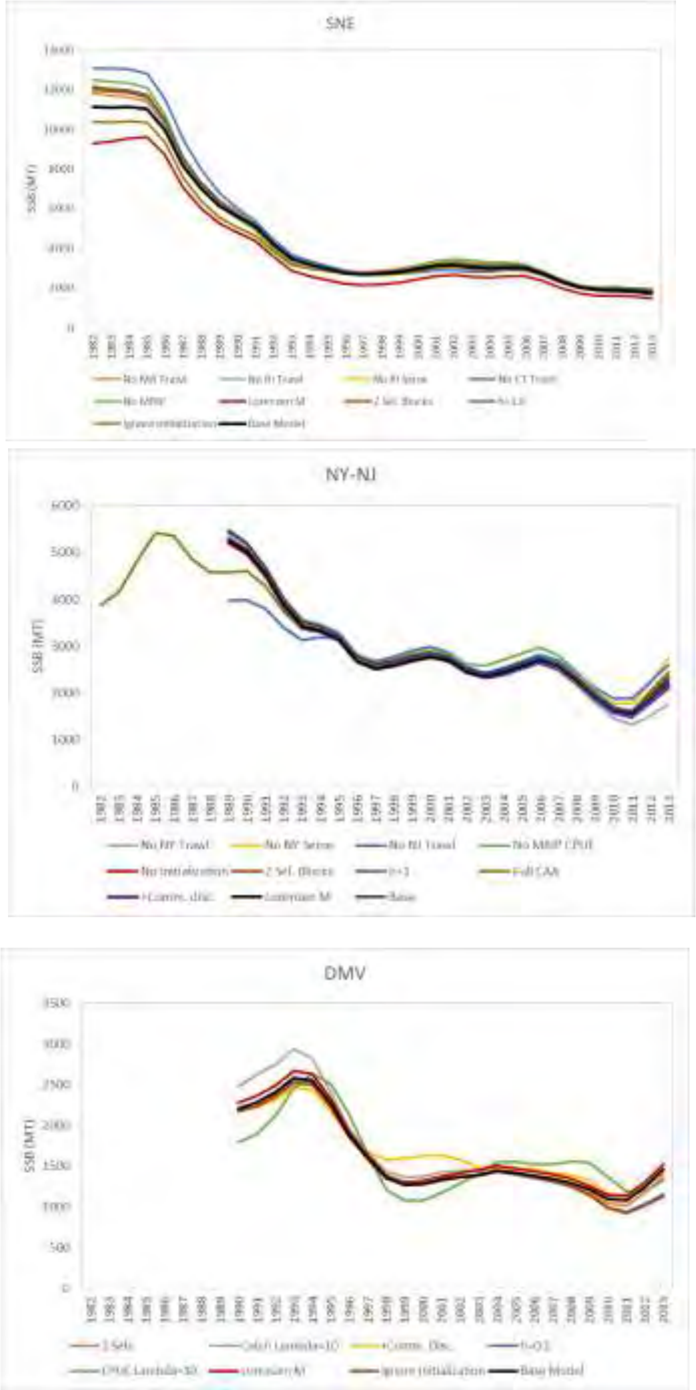


Figure 6.21. F trajectories for different sensitivity runs for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

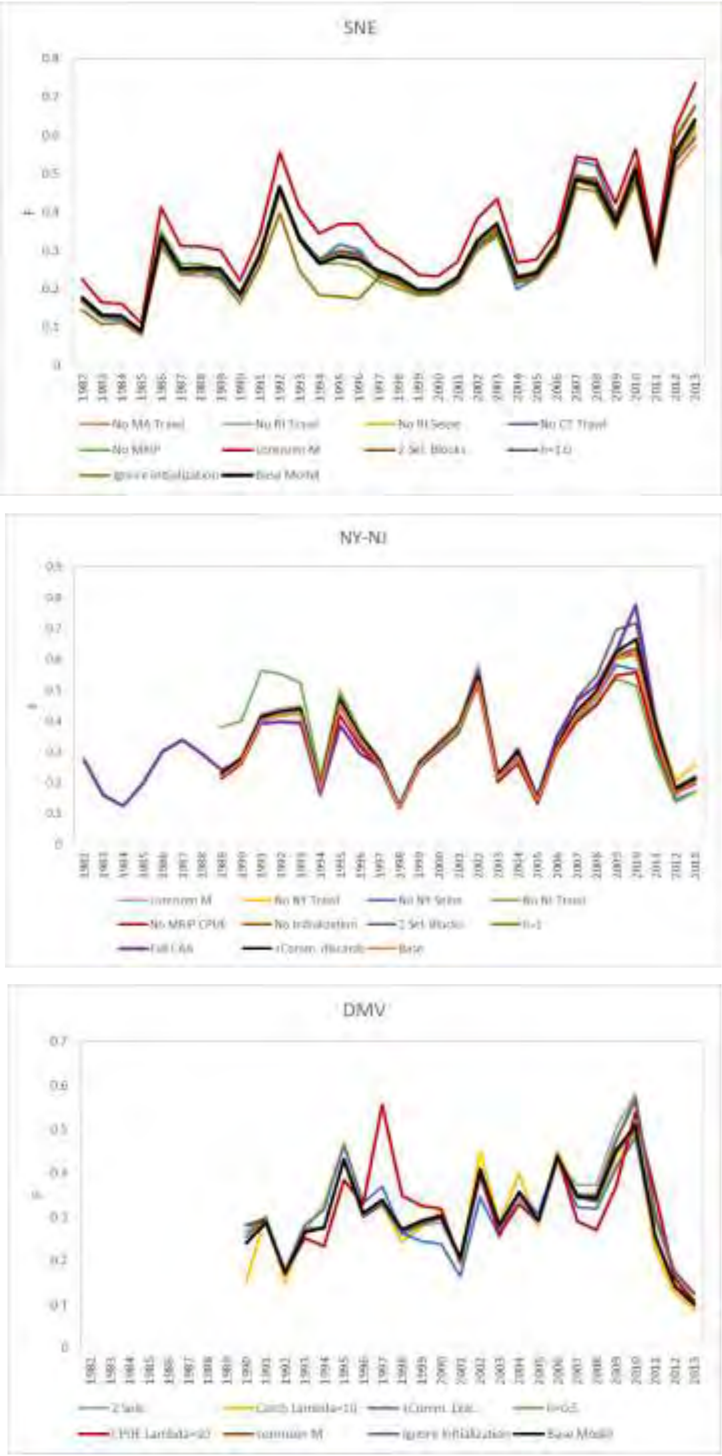


Figure 6.22A. Comparison of SSB trends between base model regions (MA-RI-CT/NY-NJ) and Long Island Sound regional split (MA-RI/CT-NY-NJ).

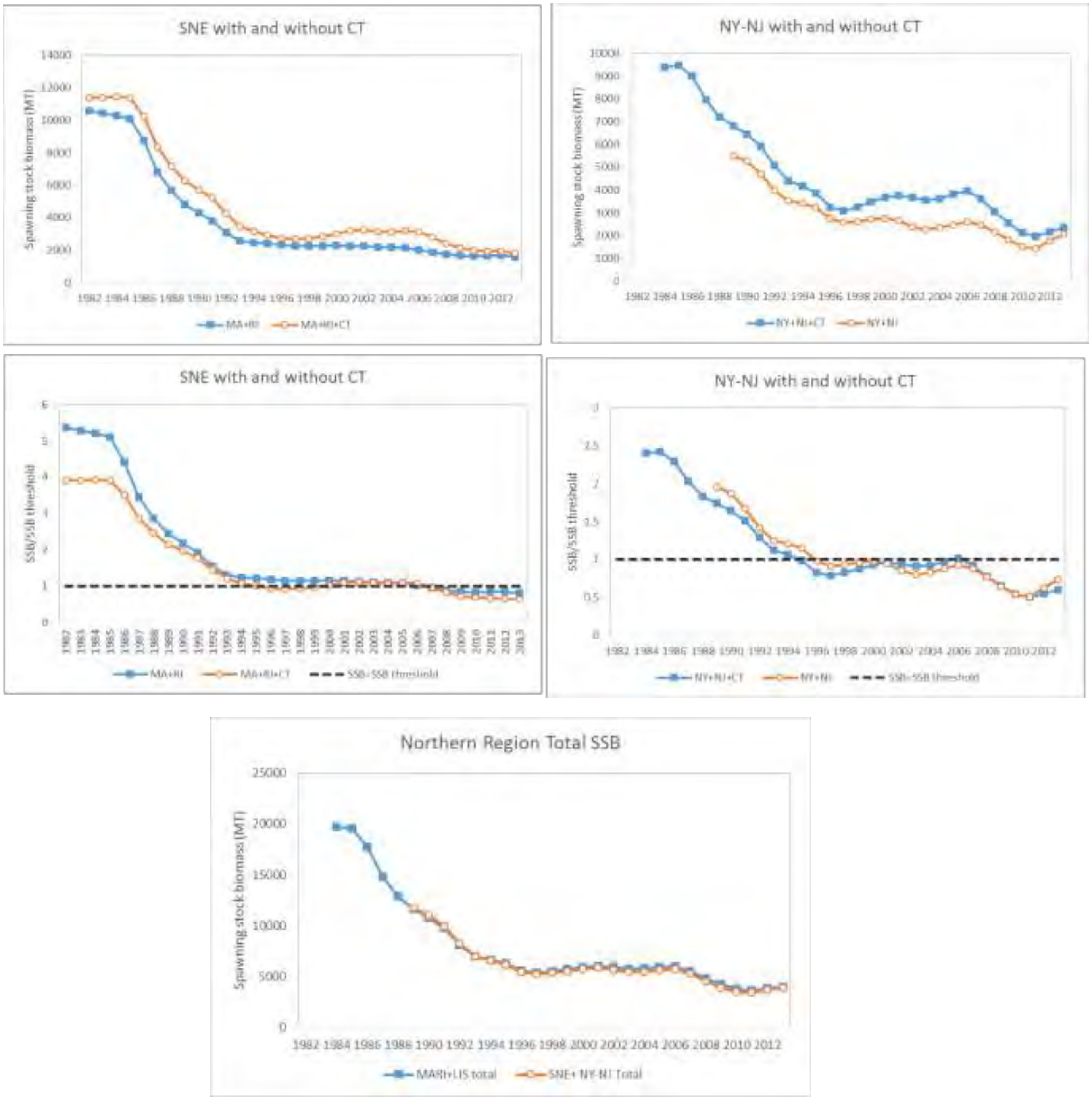


Figure 6.22B. Comparison of F trends between base model regions (MA-RI-CT/NY-NJ) and Long Island Sound regional split (MA-RI/CT-NY-NJ).

Figure 6.22C. Comparison of SSB trends between three-region model (SNE, NY-NJ, DMV) and North (MA-NY) – South (NJ-VA) split.

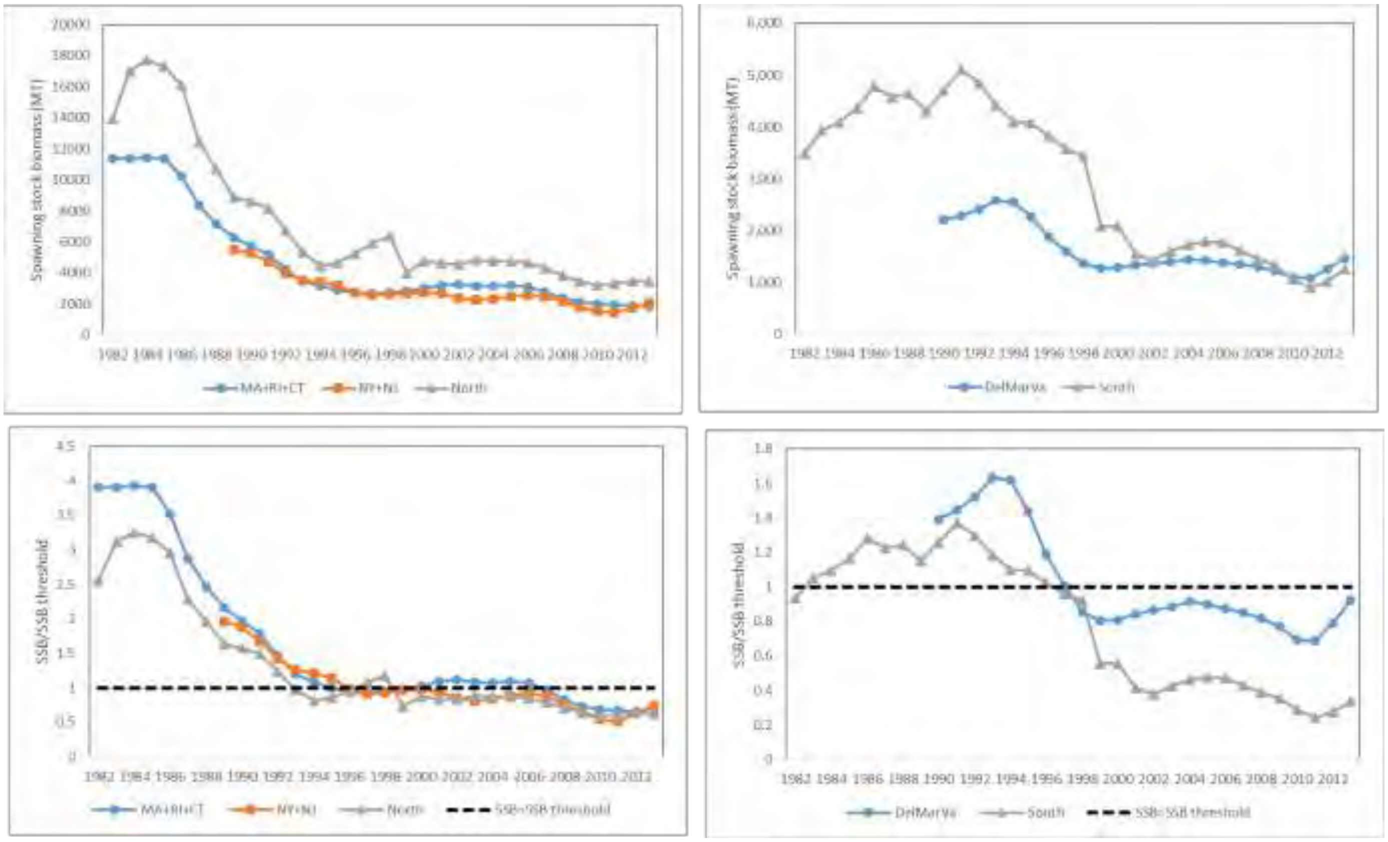


Figure 6.22D. Comparison of F trends between three-region model (SNE, NY-NJ, DMV) and North (MA-NY) – South (NJ-VA) split.

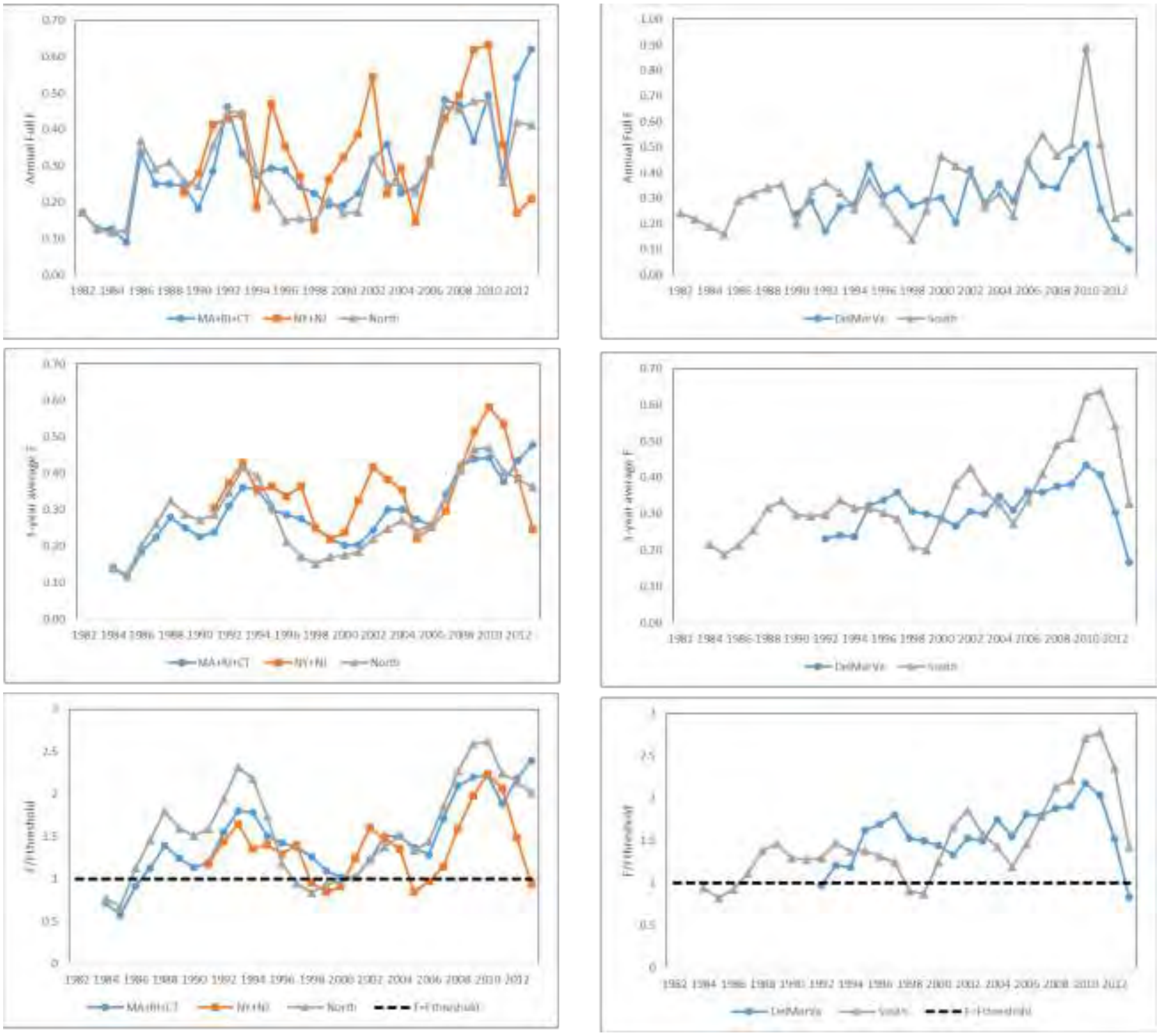
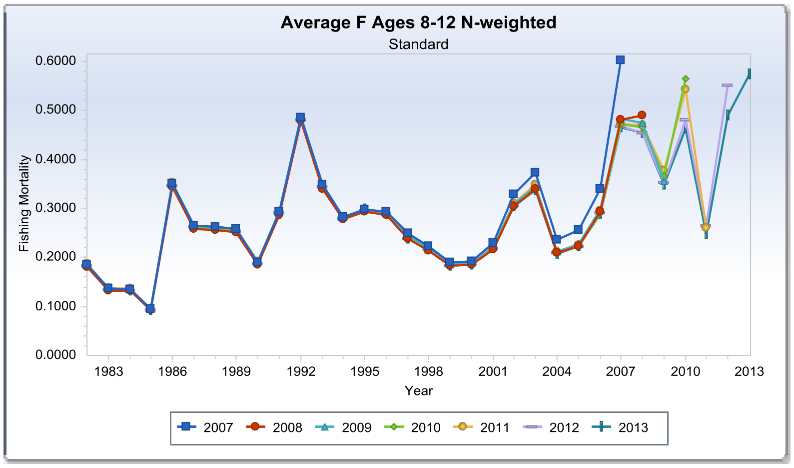
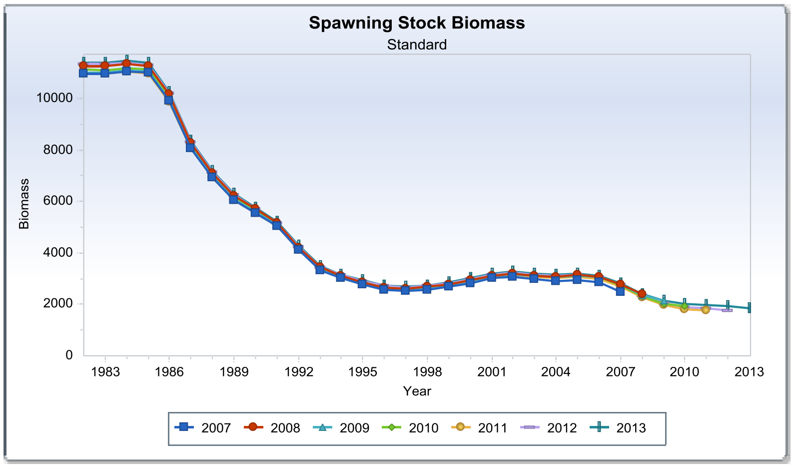


Figure 6.23. Retrospective patterns for average F (top), SSB (middle), and recruitment (bottom) for southern New England.





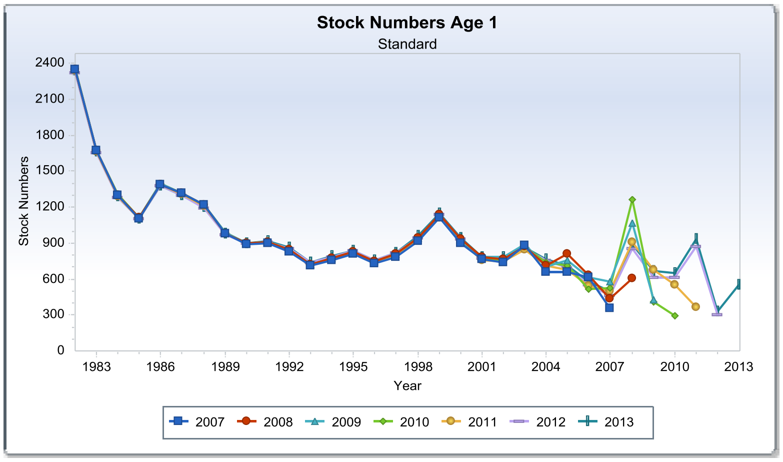


Figure 6.24. Retrospective patterns for average F (top), SSB (middle), and recruitment (bottom) for NY-NJ.

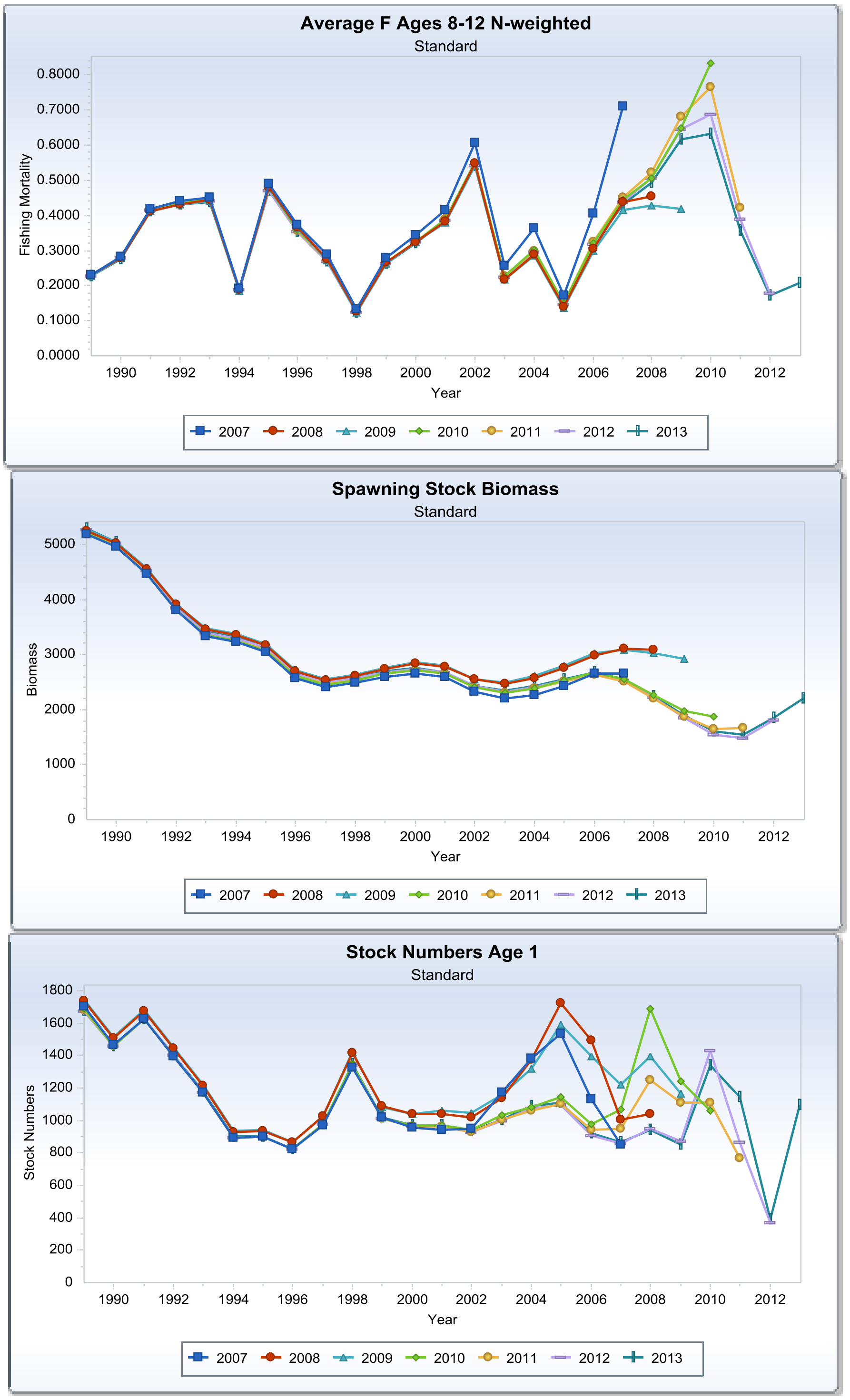
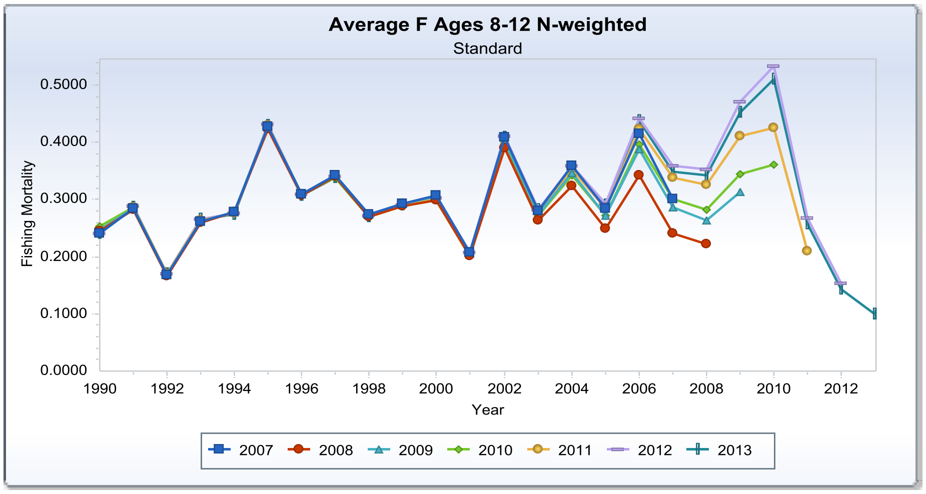
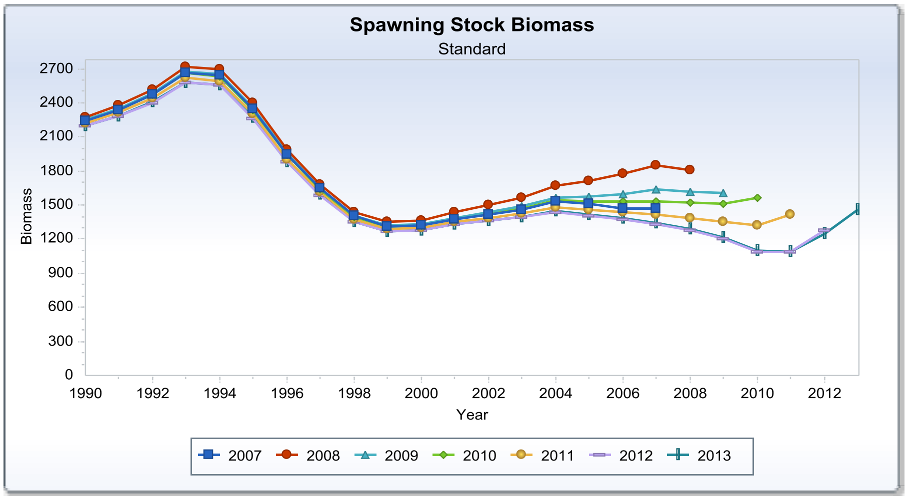


Figure 6.25. Retrospective patterns for average F (top), SSB (middle), and recruitment (bottom) for DelMarVa.





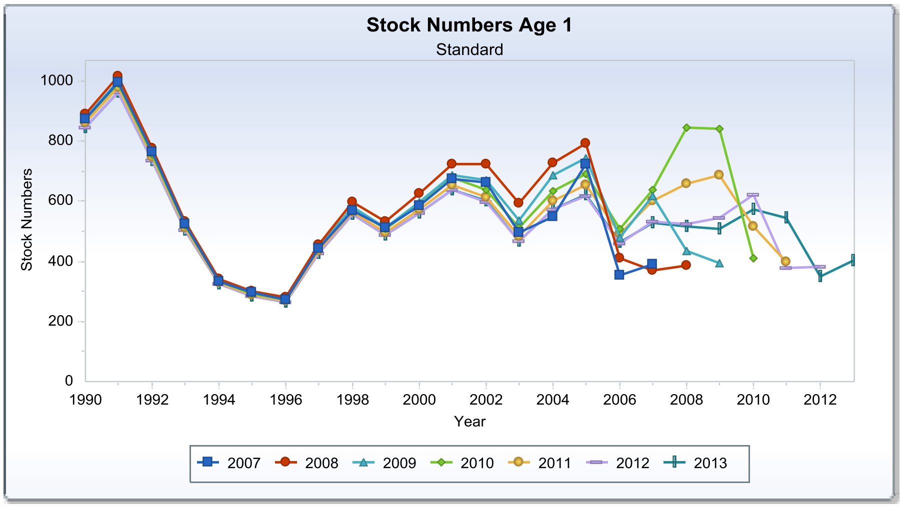


Figure 6.26. Valid and invalid draws of base model run of xDB-SRA for SNE region.

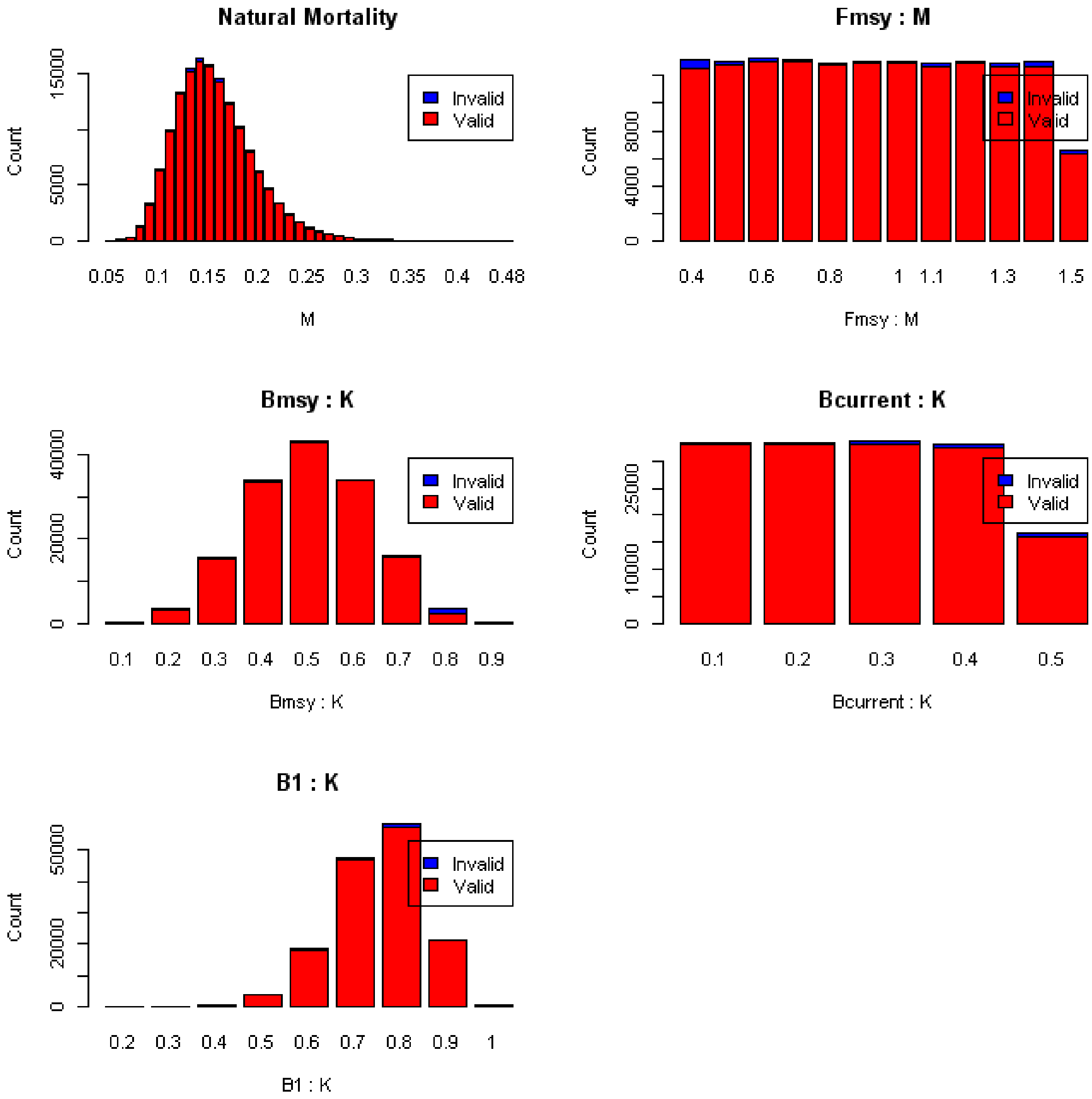


Figure 6.27. Distributions of valid and resampled parameter draws of the SNE base model run of xDB-SRA.

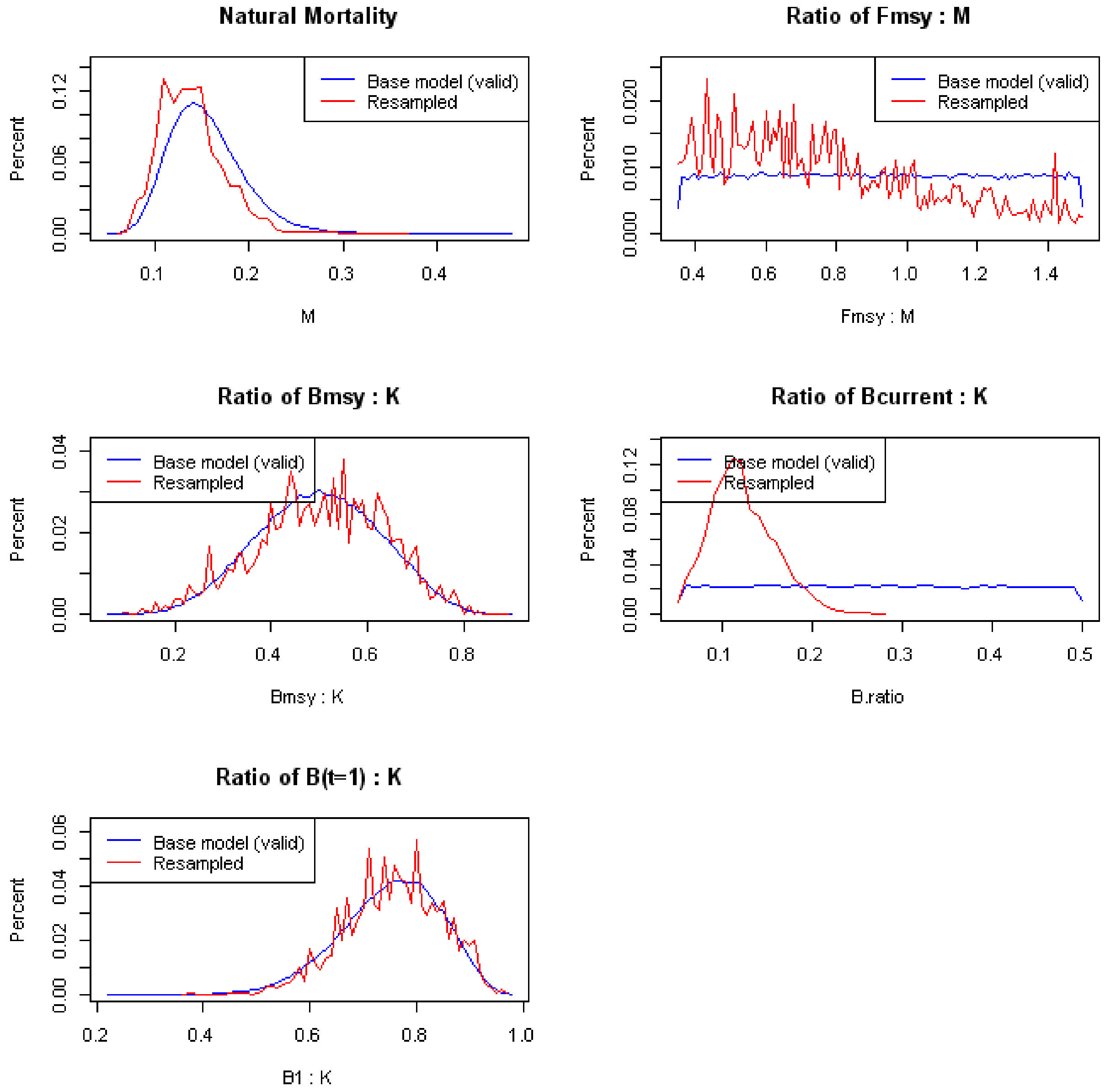
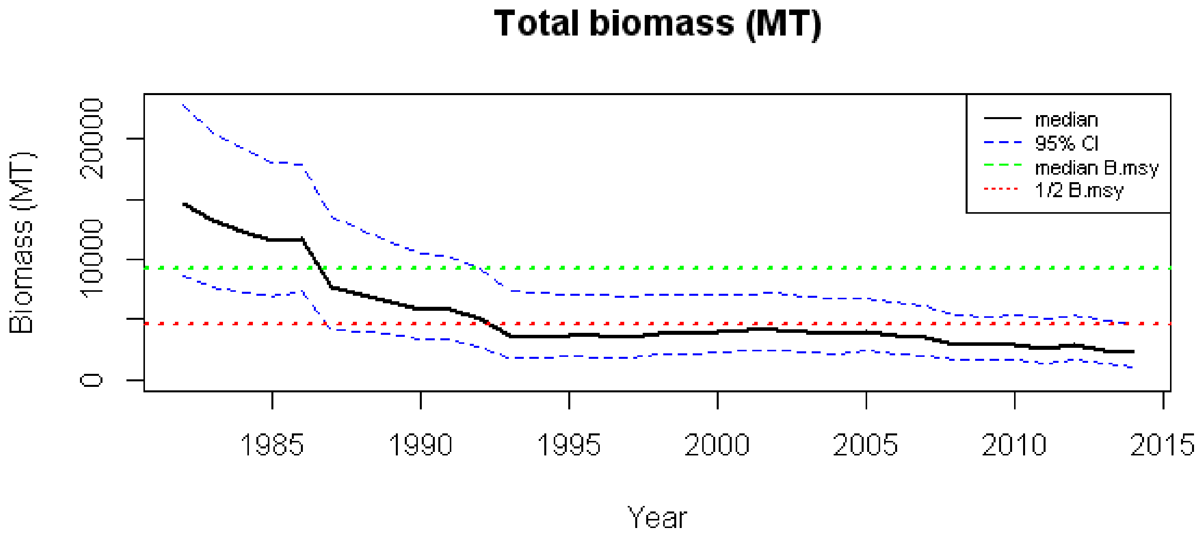


Figure 6.28. Biomass and exploitation trajectories for the SNE base model run of xDB-SRA.



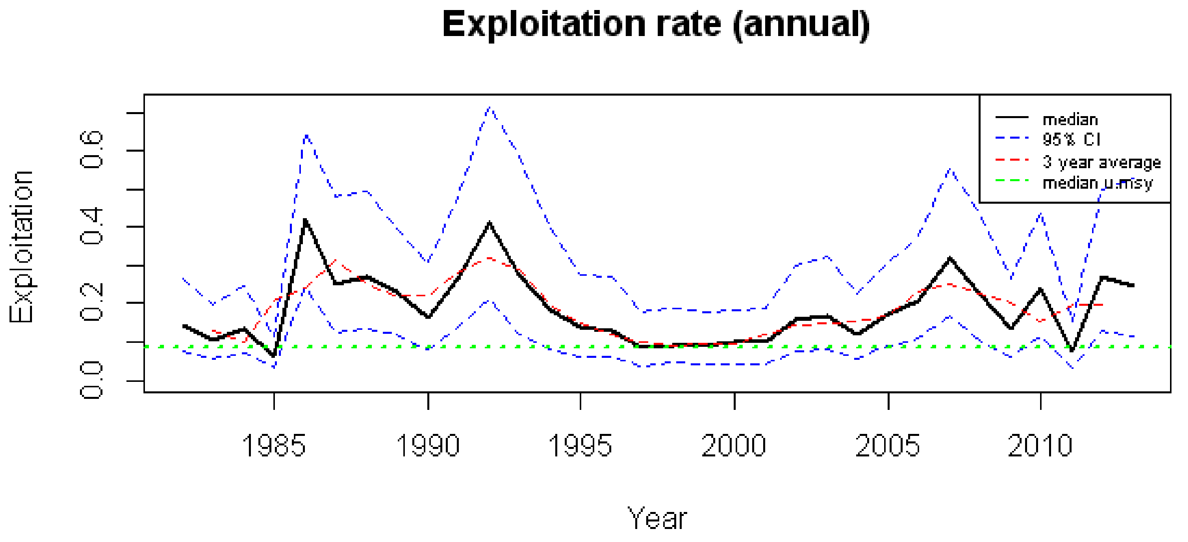


Figure 6.29. Distributions of valid and resampled reference point estimates for the SNE base model run of xDB-SRA.

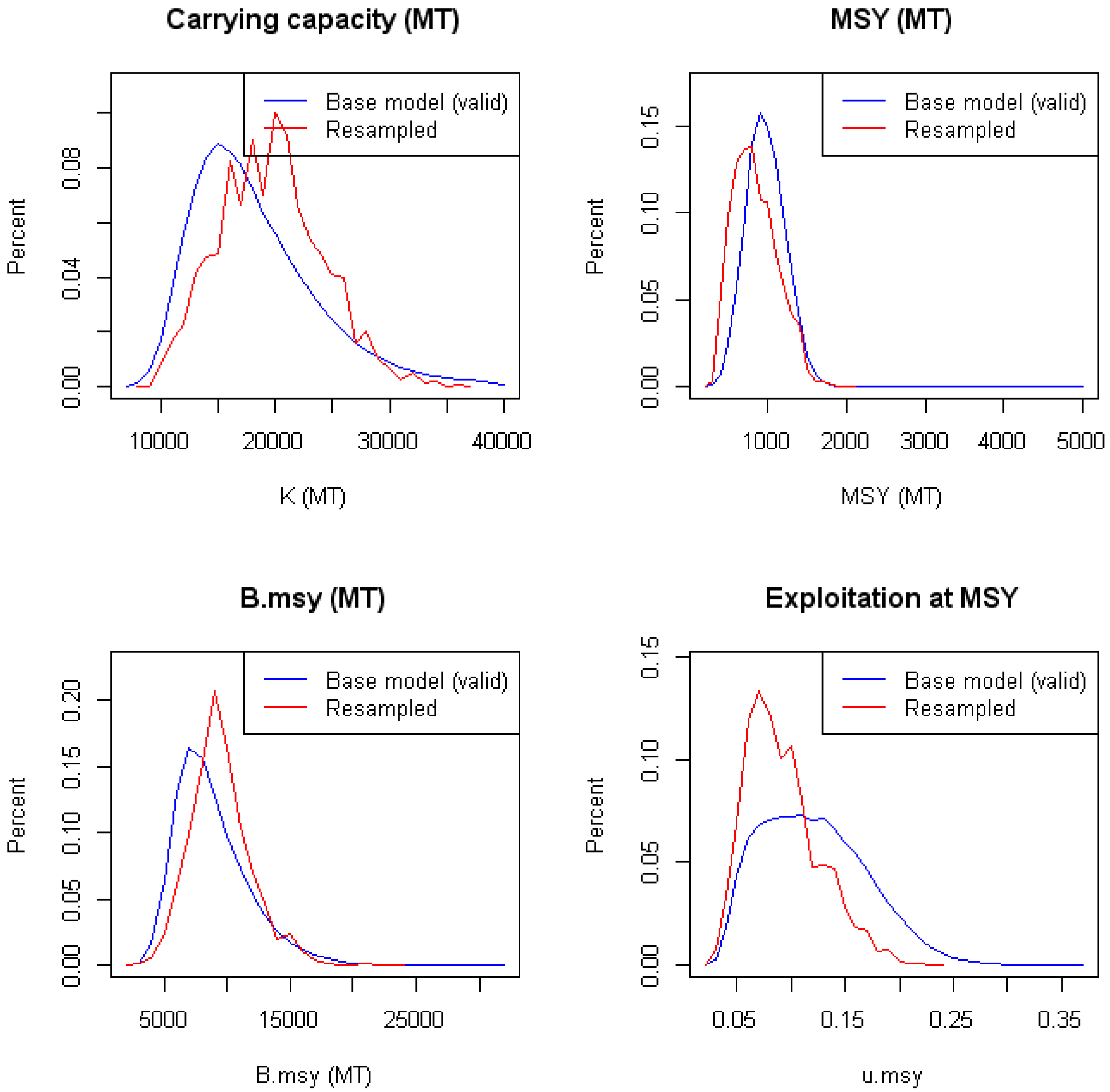


Figure 6.30. Results of survey index sensitivity runs for the SNE region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

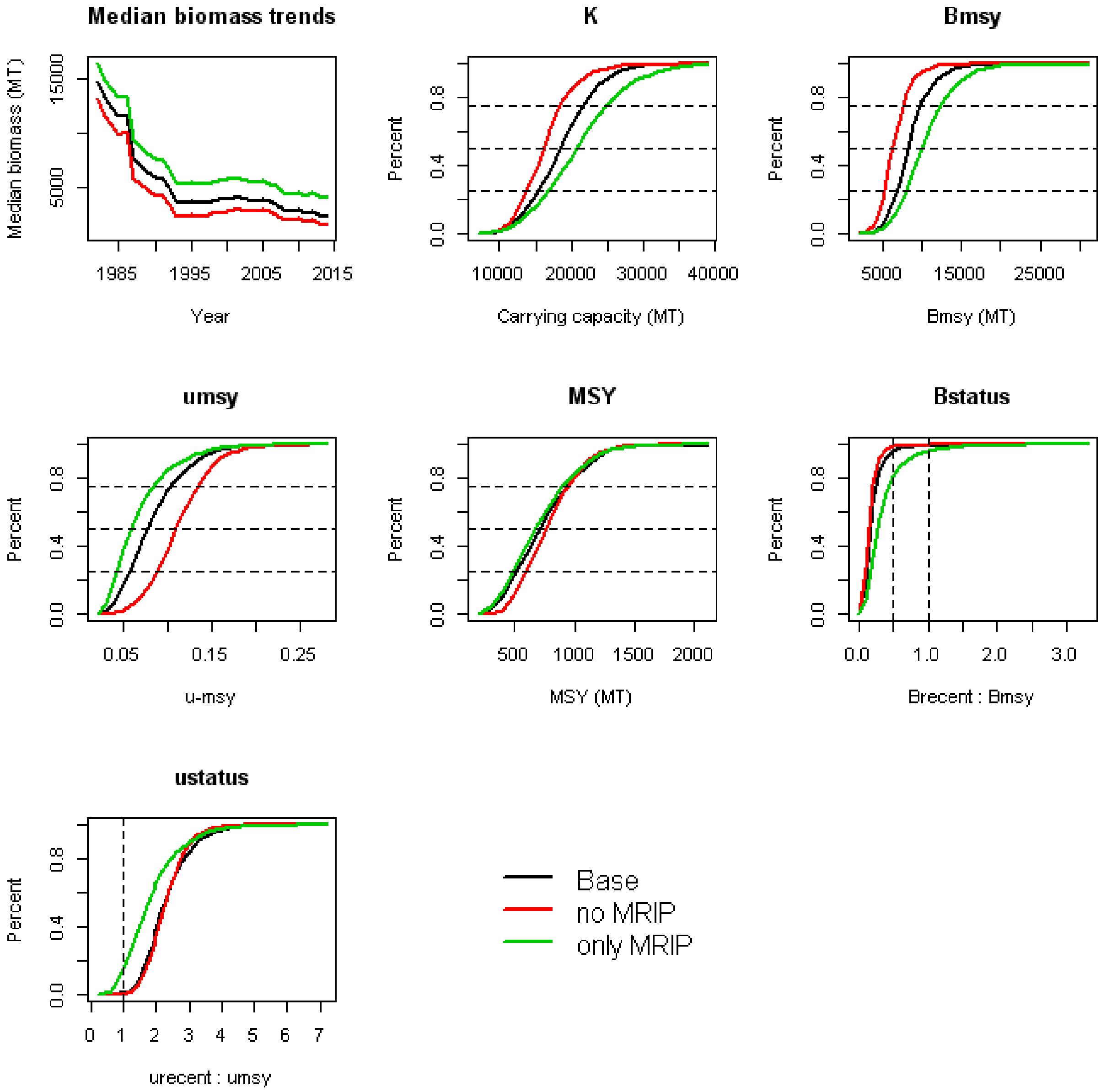


Figure 6.31. Results of model configuration sensitivity runs for the SNE region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

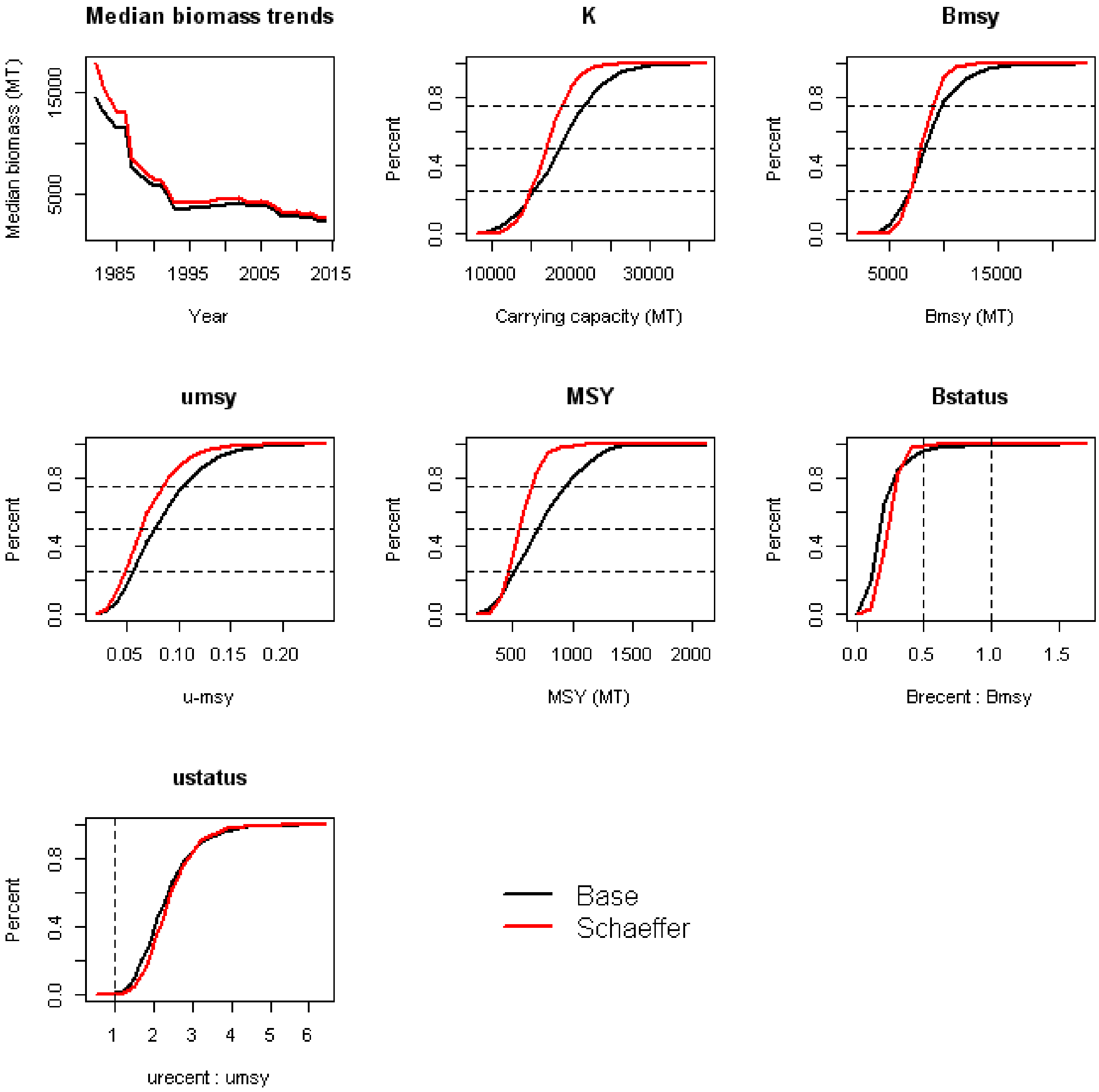


Figure 6.32. Results of regional configuration sensitivity runs for the SNE region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

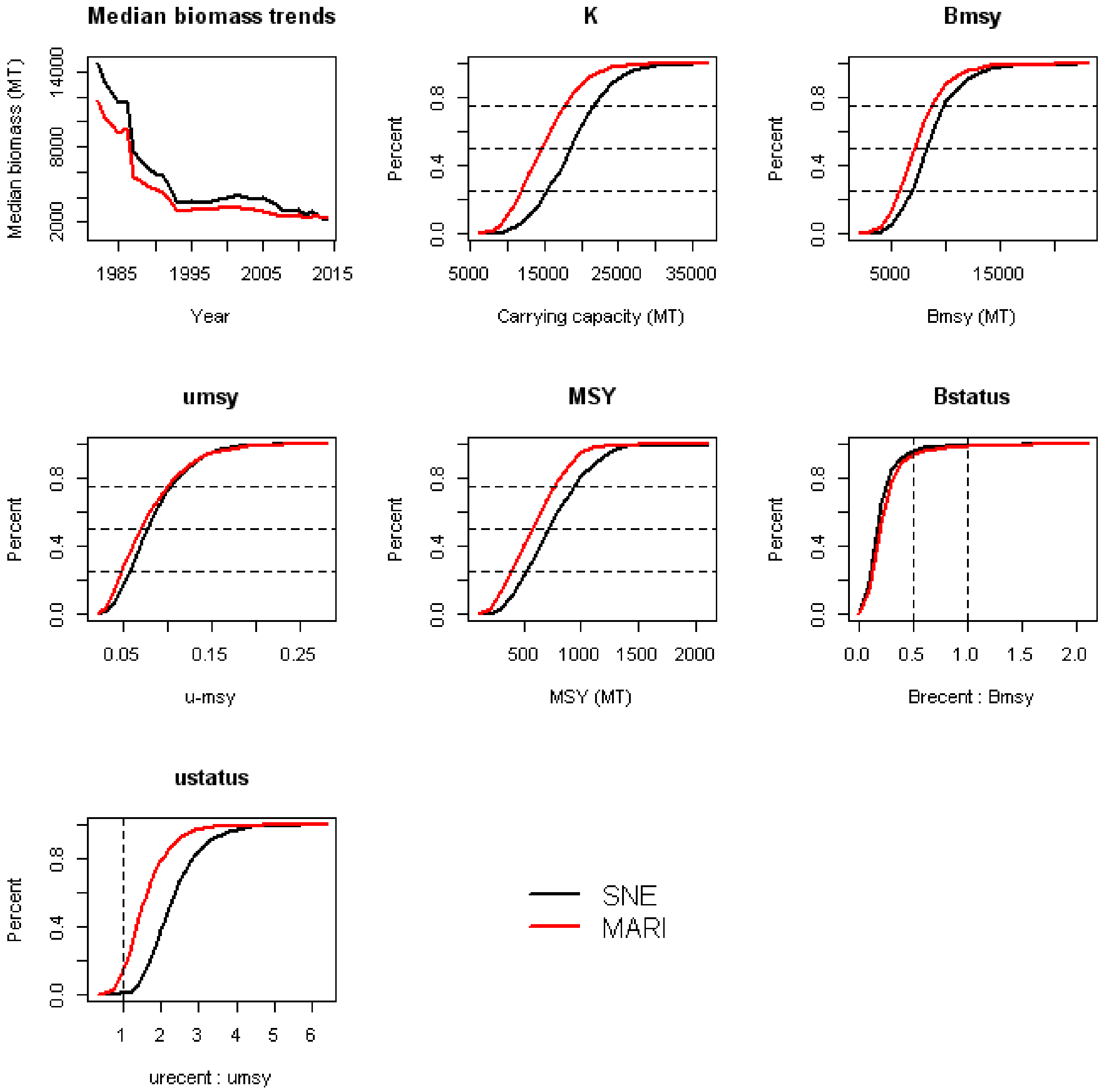


Figure 6.33. Valid and invalid draws of base model run of xDB-SRA for NY-NJ region.

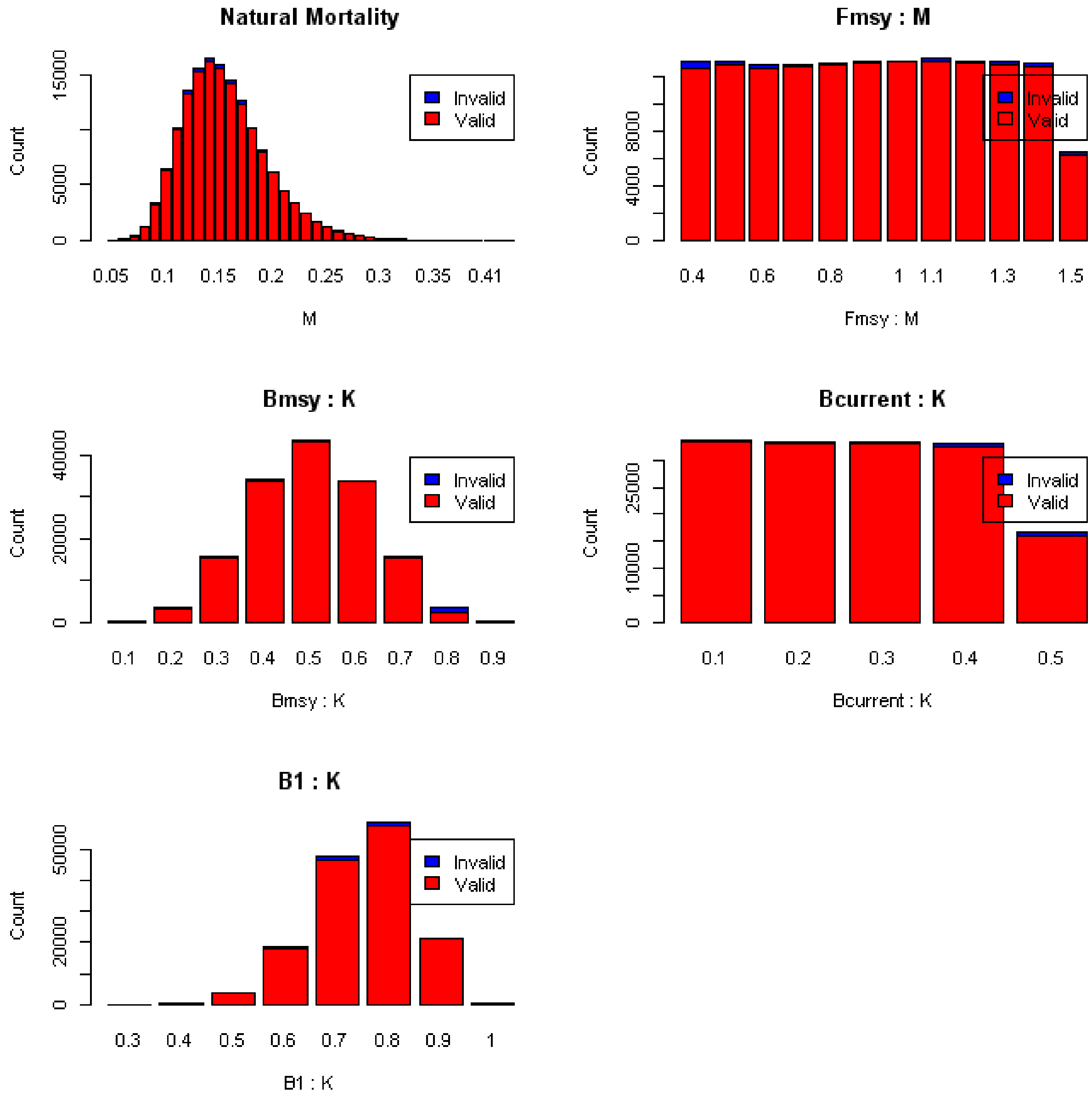


Figure 6.34. Distributions of valid and resampled parameter draws of the NY-NJ base model run of xDB-SRA.

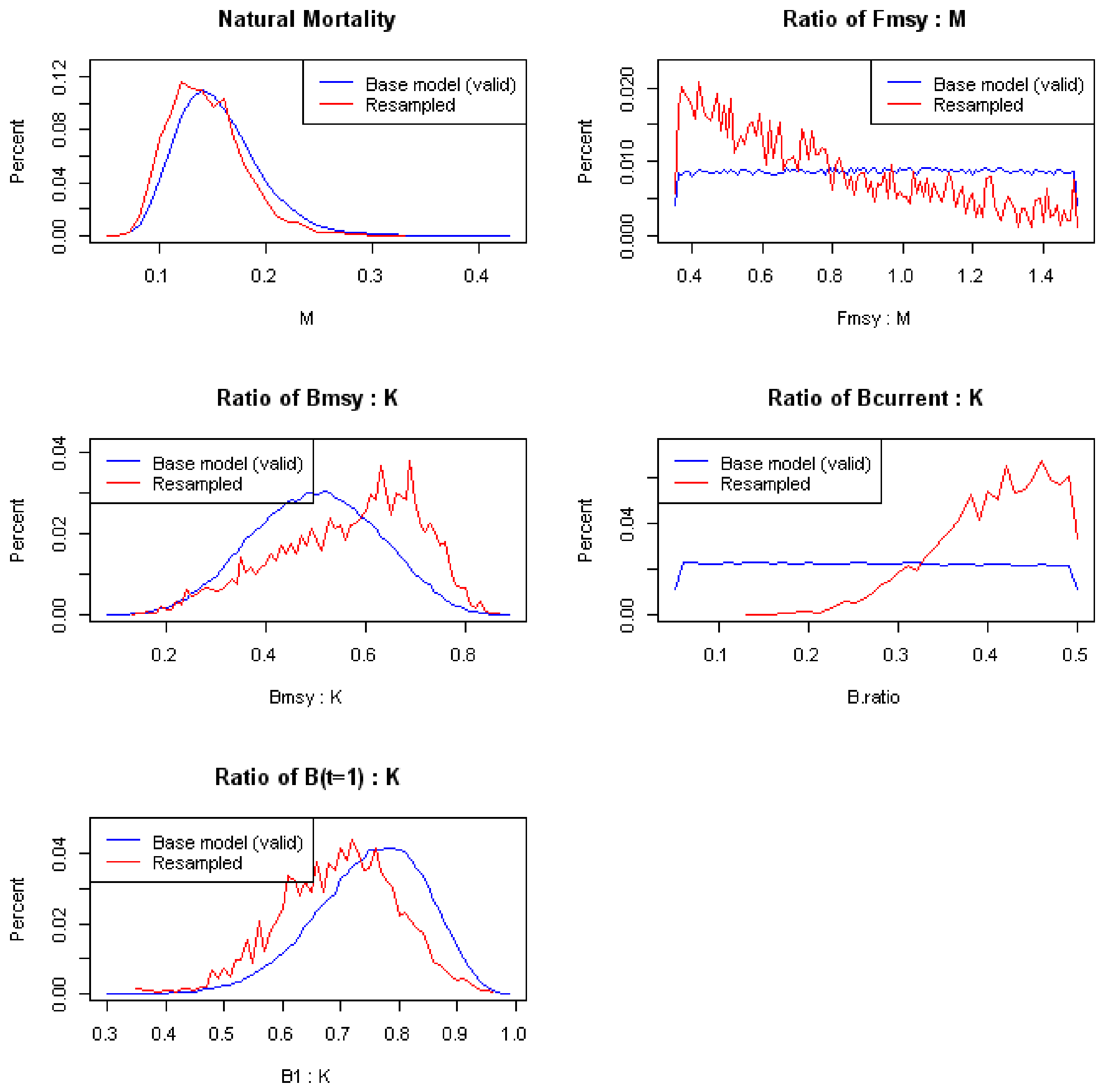


Figure 6.35. Biomass and exploitation trajectories for the NY-NJ base model run of xDB-SRA.

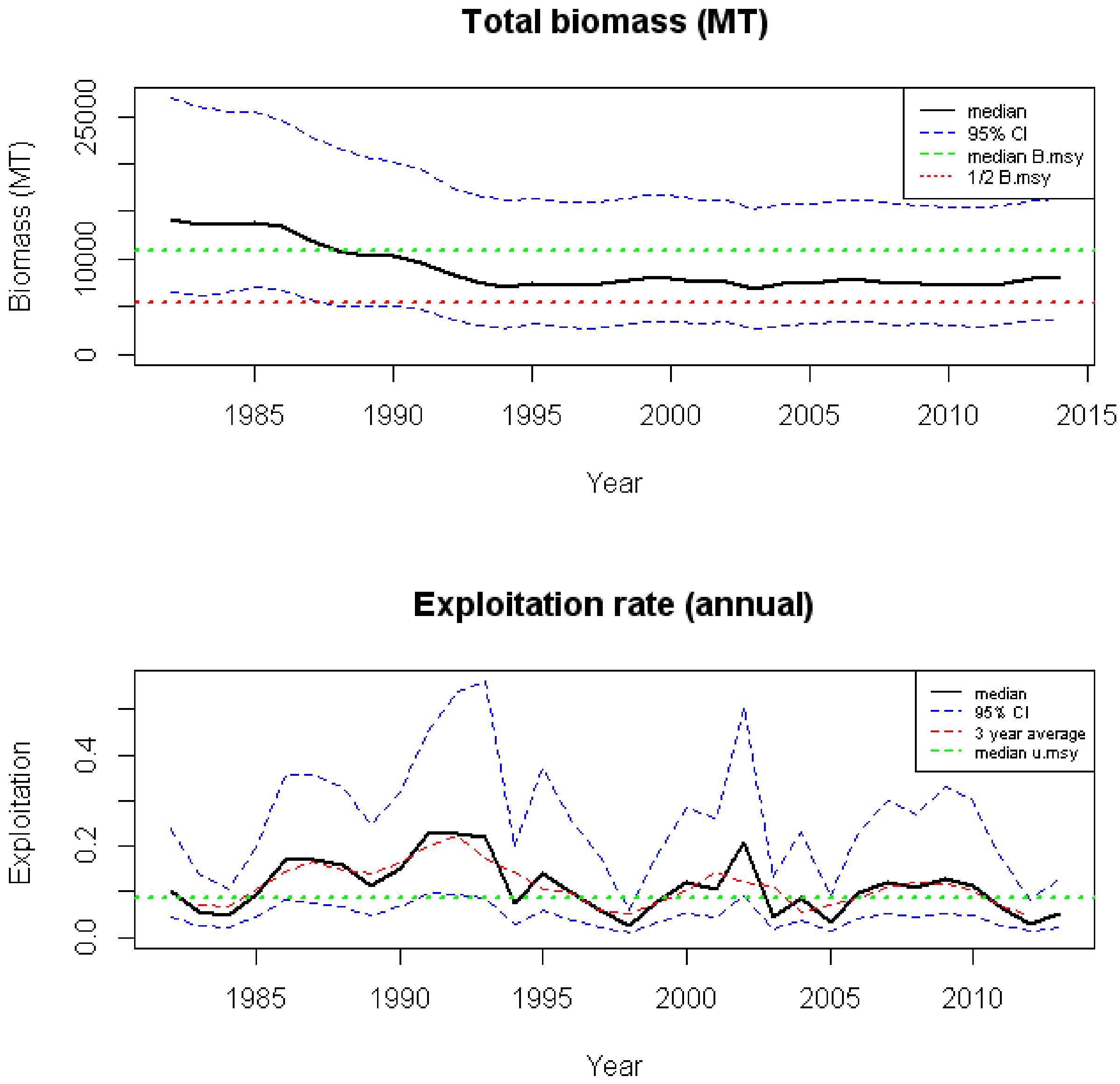


Figure 6.35. Distributions of valid and resampled reference point estimates for the NY-NJ base model run of xDB-SRA.

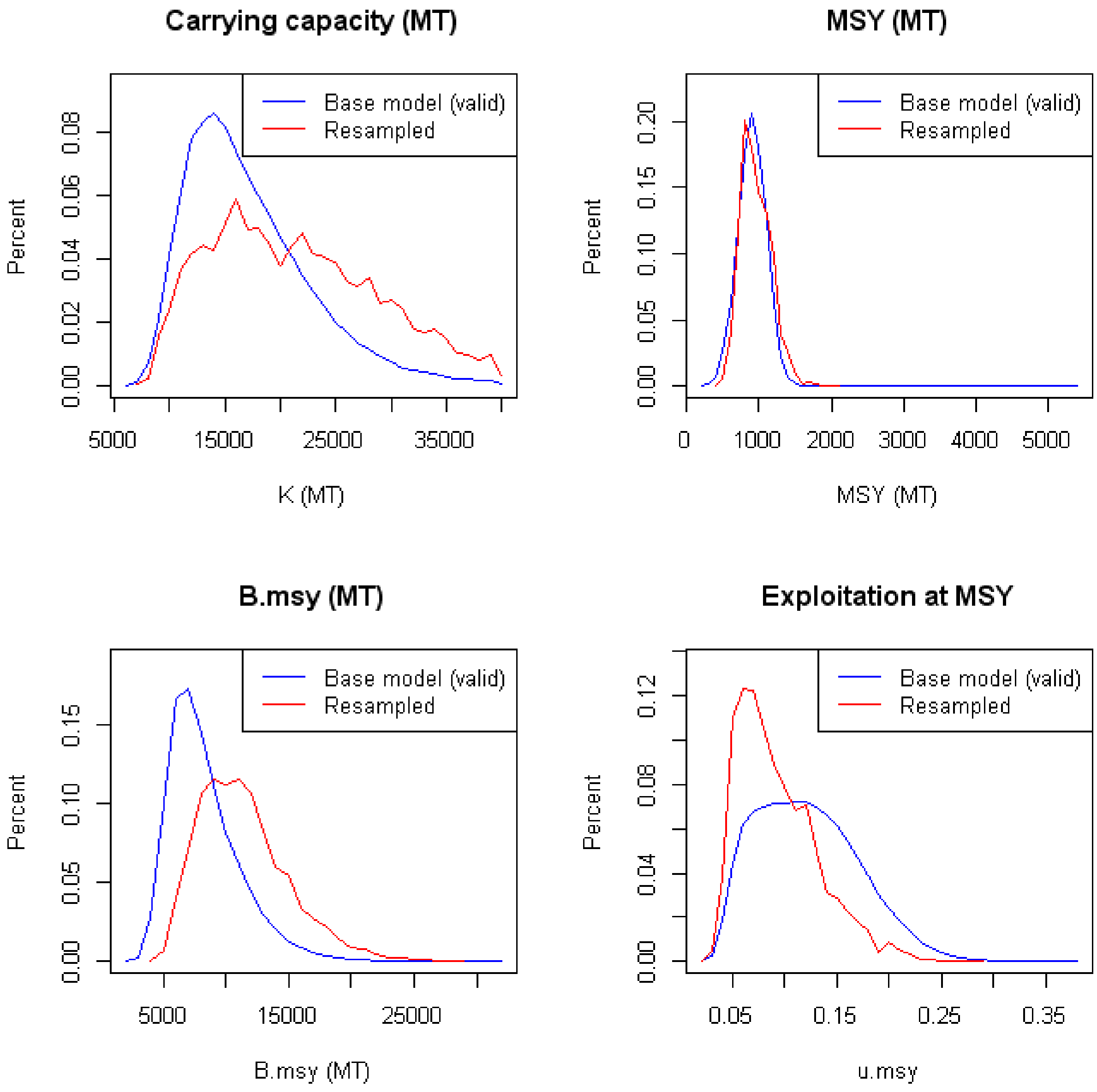


Figure 6.36. Results of survey index sensitivity runs for the NY-NJ region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

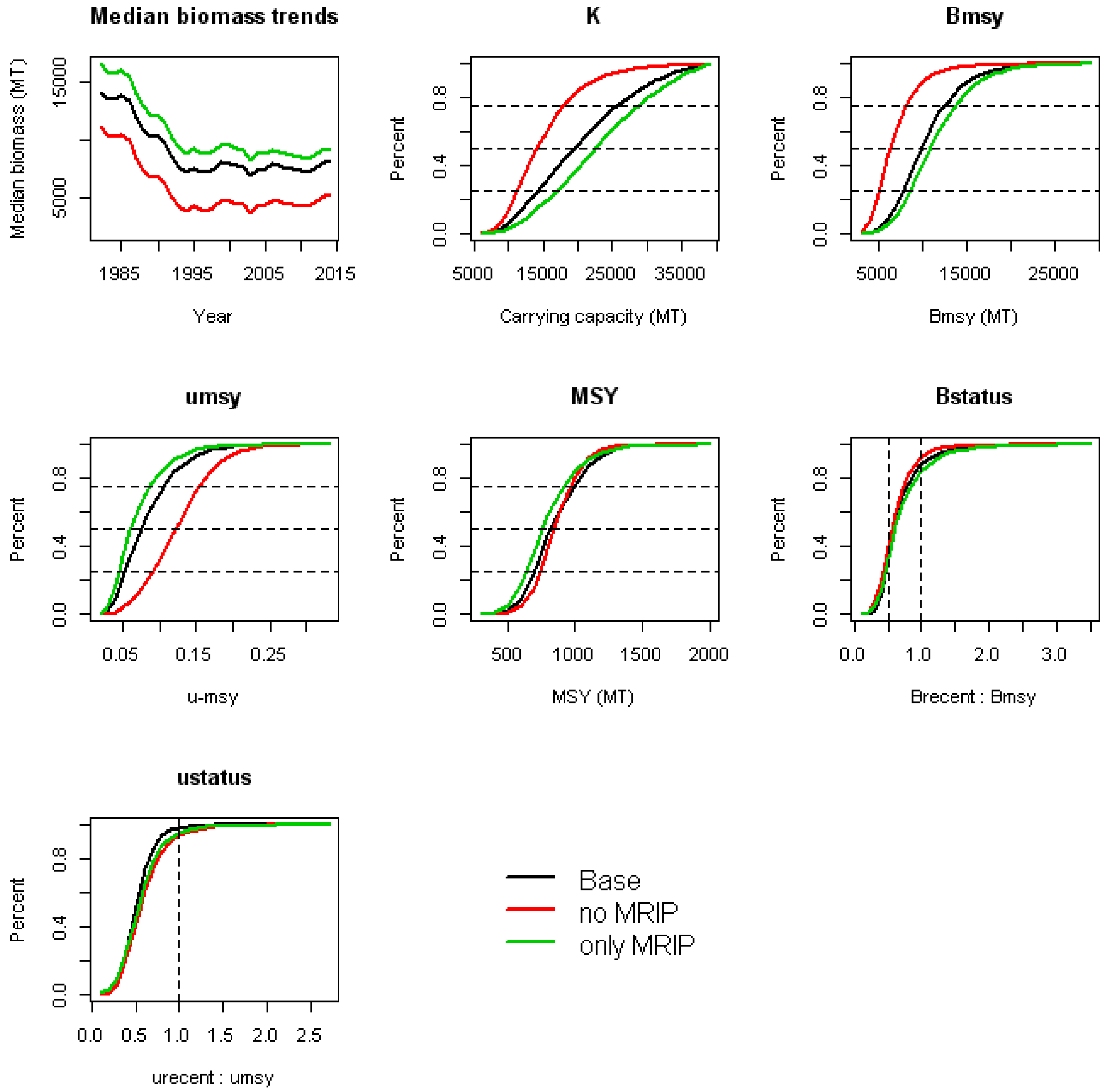


Figure 6.37. Results of model configuration sensitivity runs for the NY-NJ region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

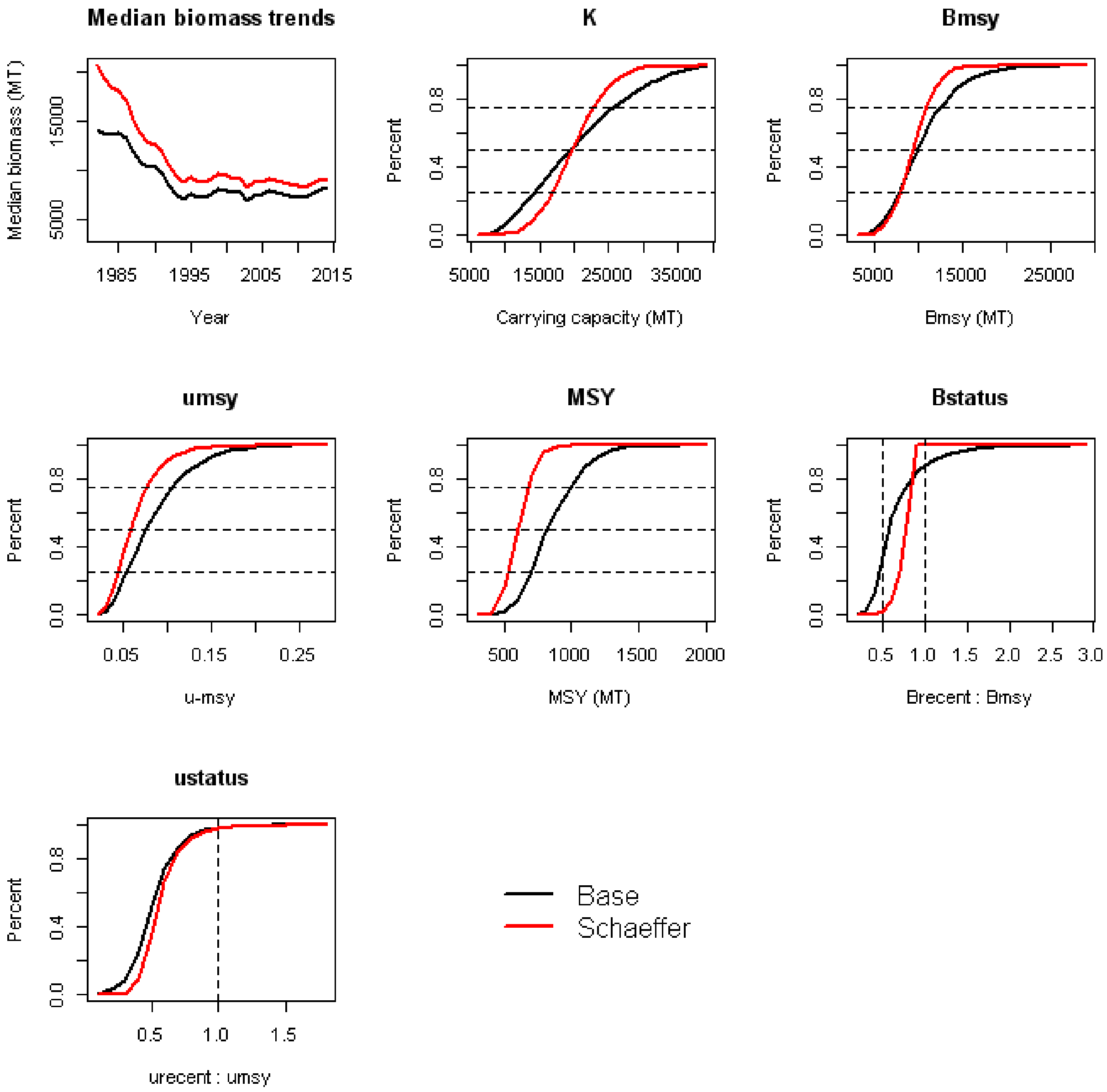


Figure 6.38. Results of regional configuration sensitivity runs for the NYNJ region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

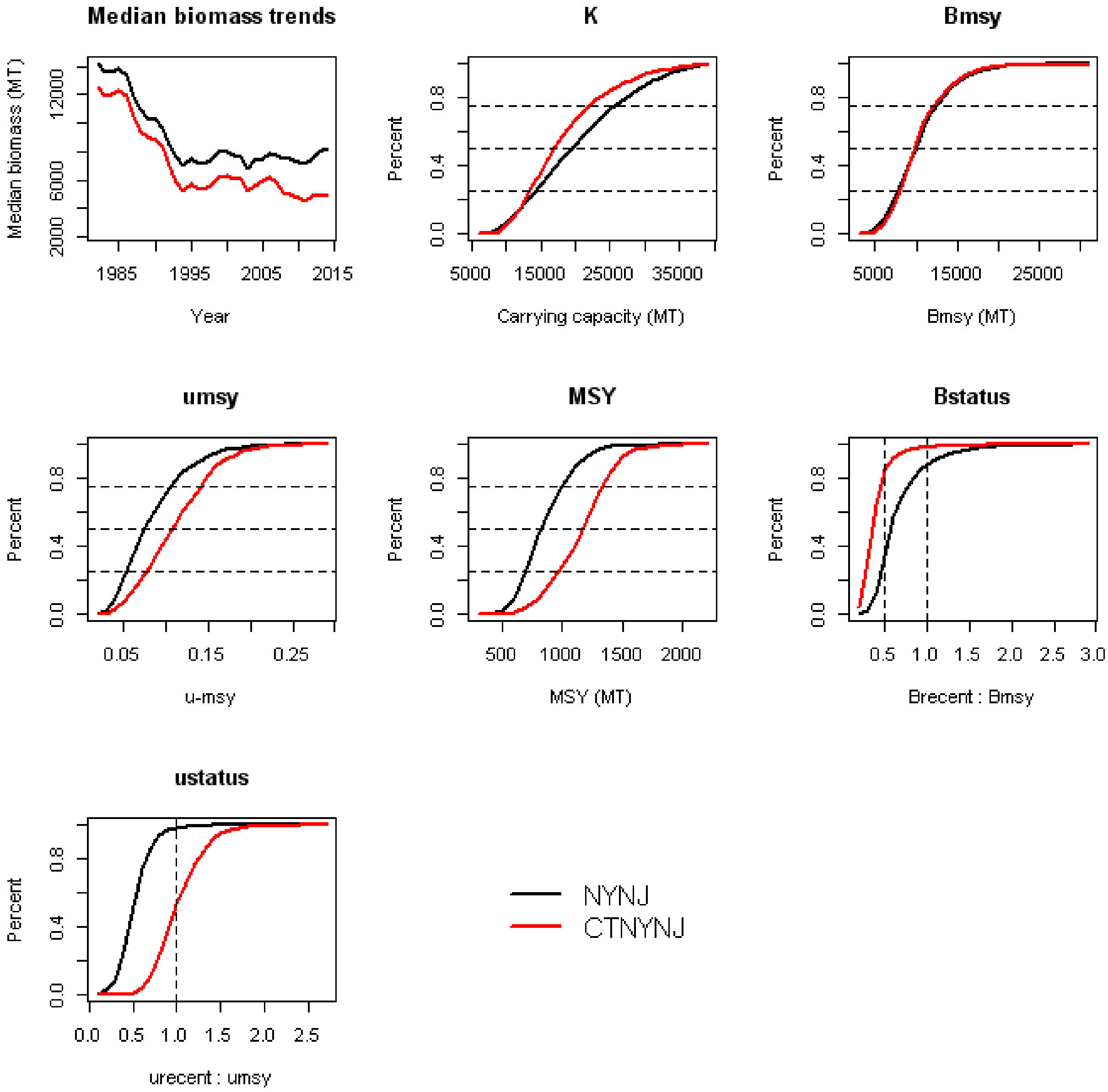


Figure 6.39. Valid and invalid draws of base model run of xDB-SRA for DMV region.

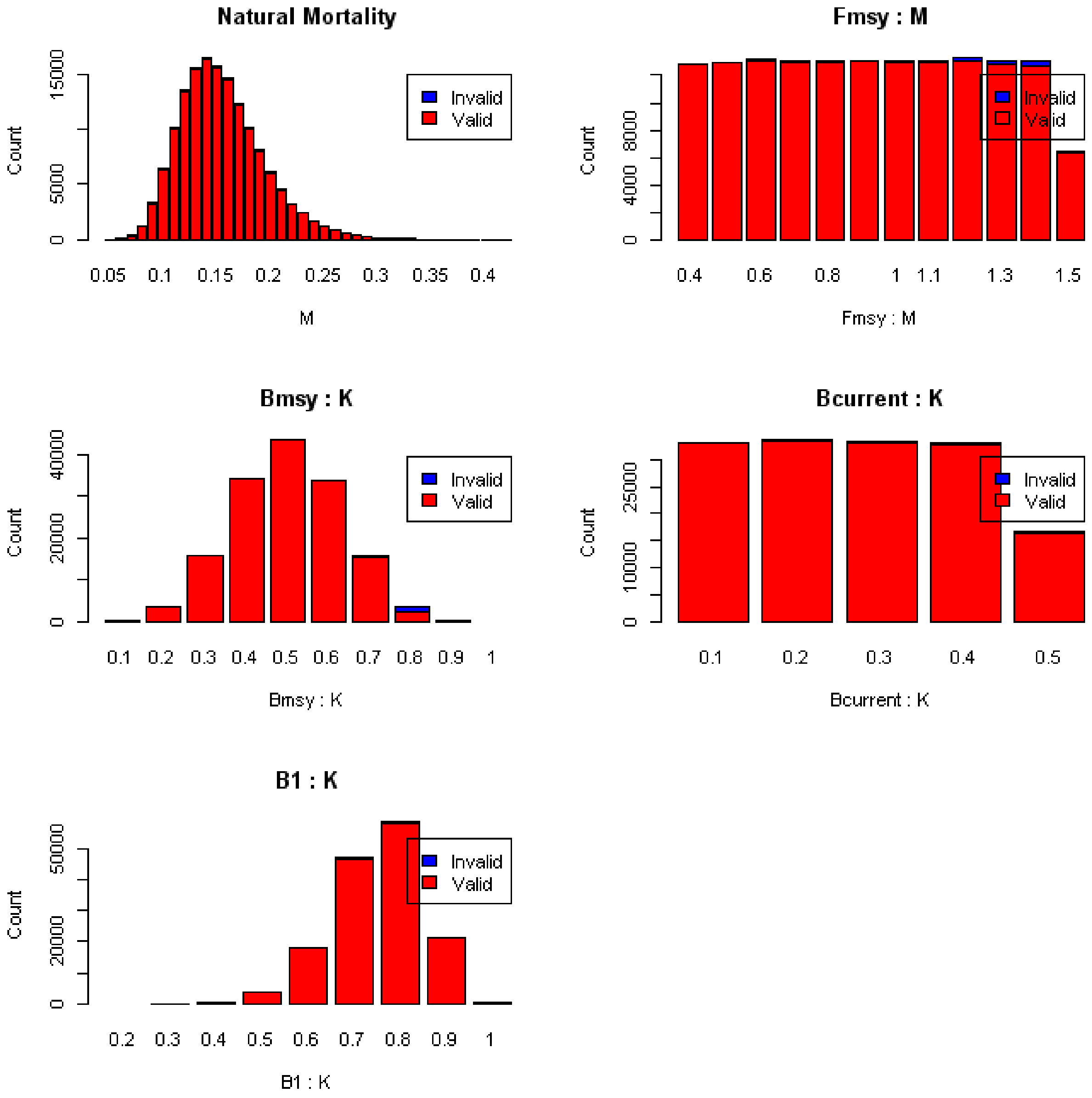


Figure 6.40. Distributions of valid and resampled parameter draws of the DMV base model run of xDB-SRA.

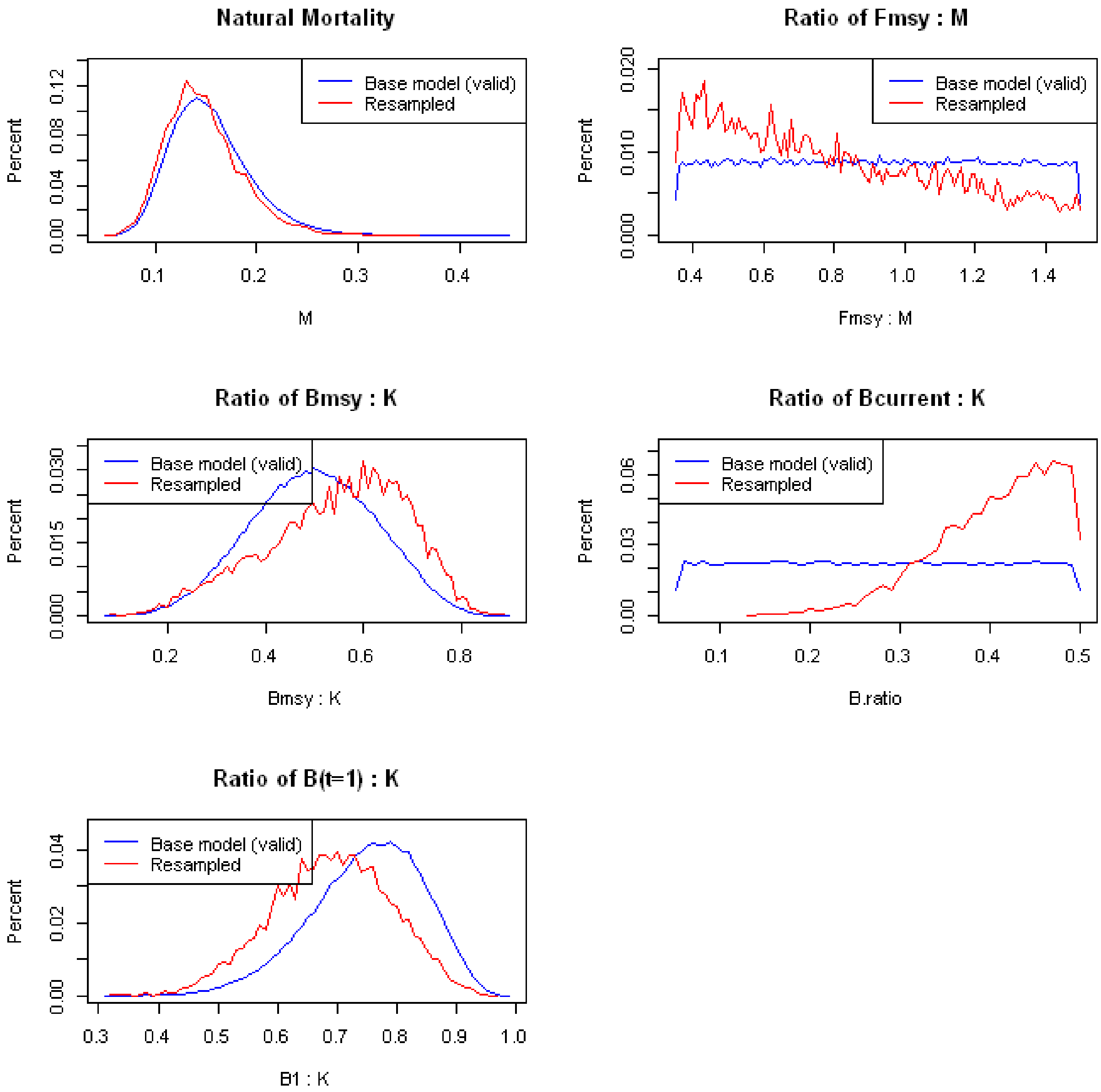


Figure 6.41. Biomass and exploitation trajectories for the DMV base model run of xDB-SRA.

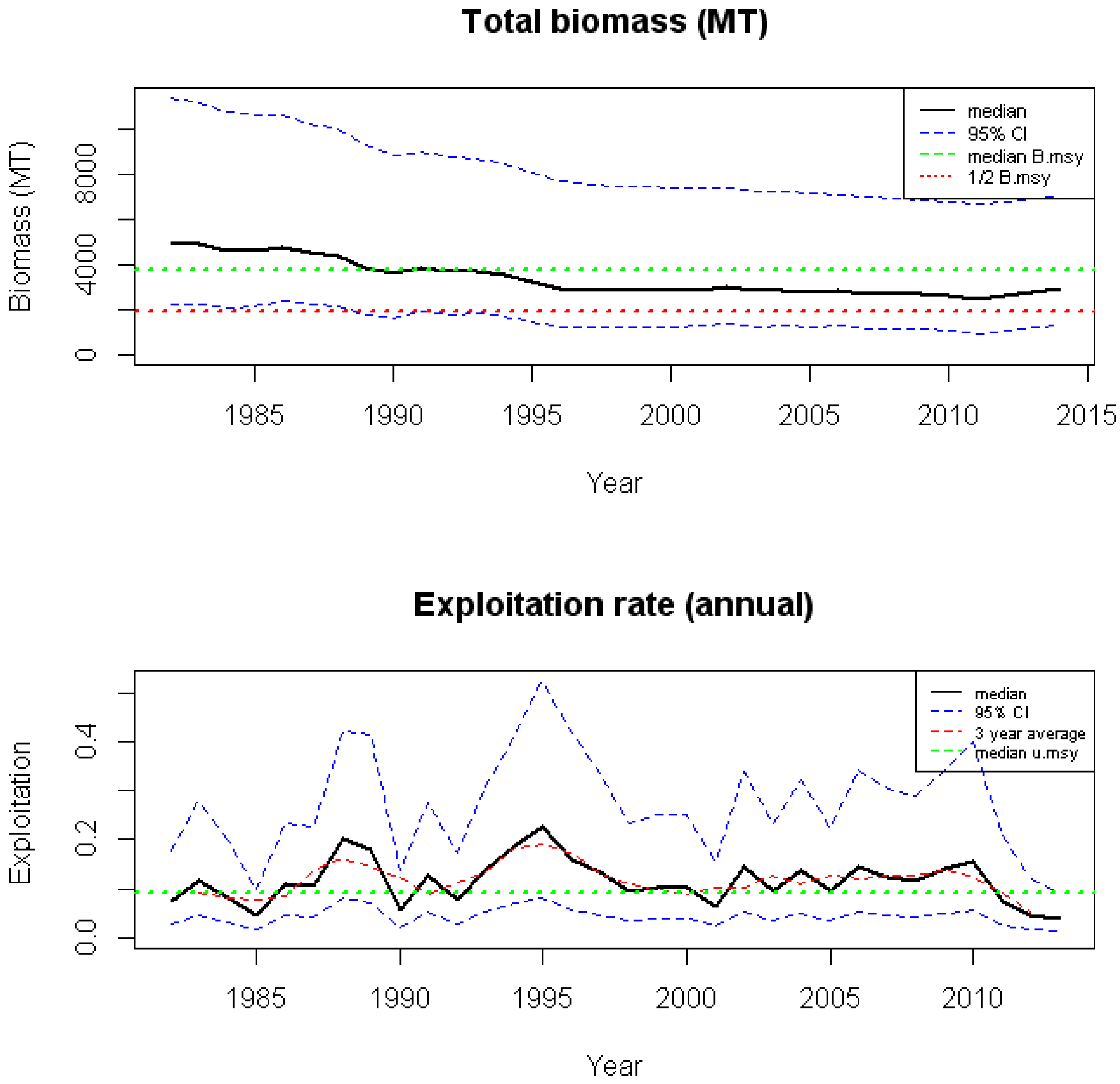
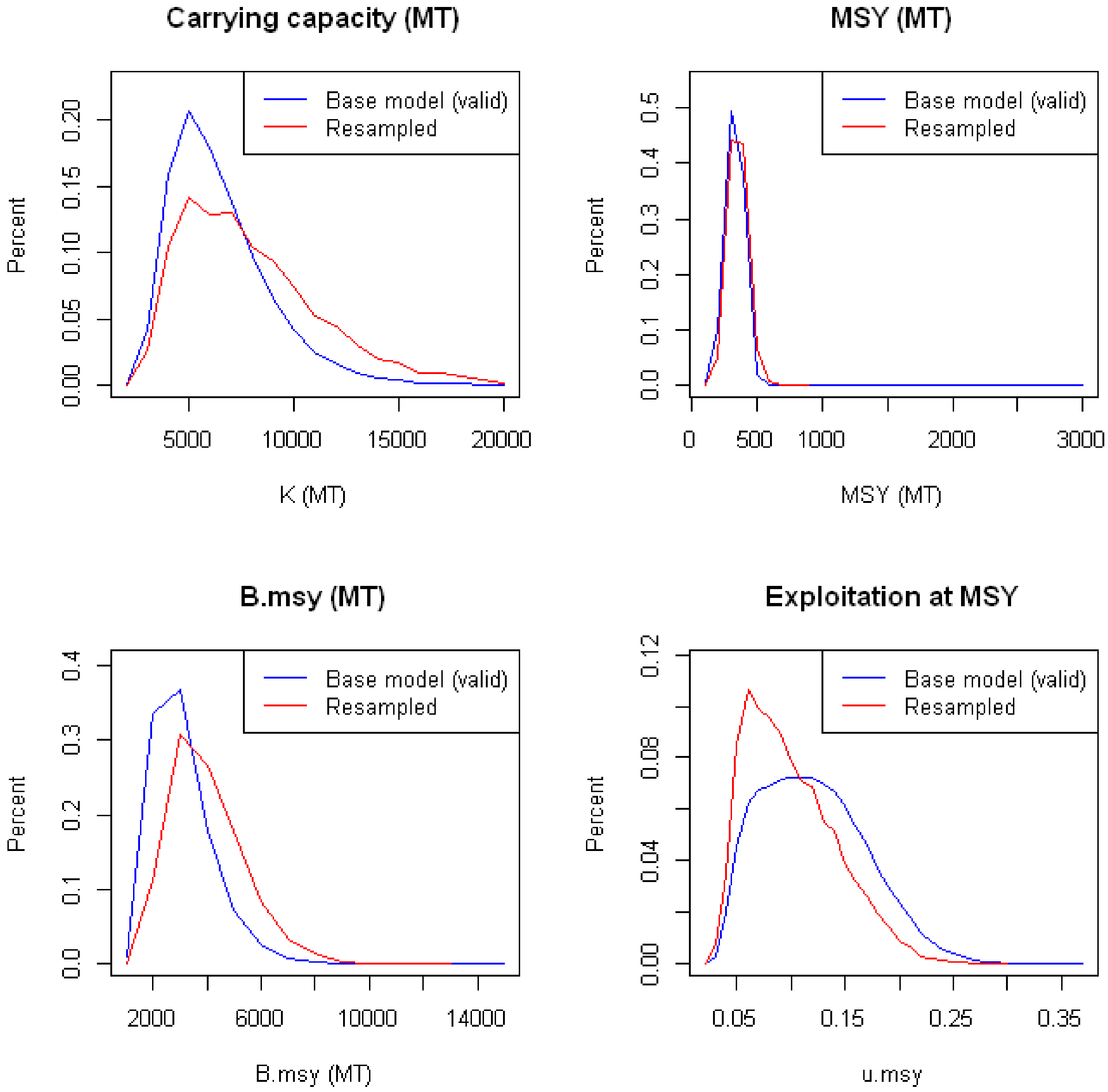


Figure 6.42. Distributions of valid and resampled reference point estimates for the DMV base model run of xDB-SRA.



Carrying capacity (MT)

MSY (MT)

B.msy (MT)

Exploitation at MSY

Figure 6.43. Results of survey index sensitivity runs for the DMV region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

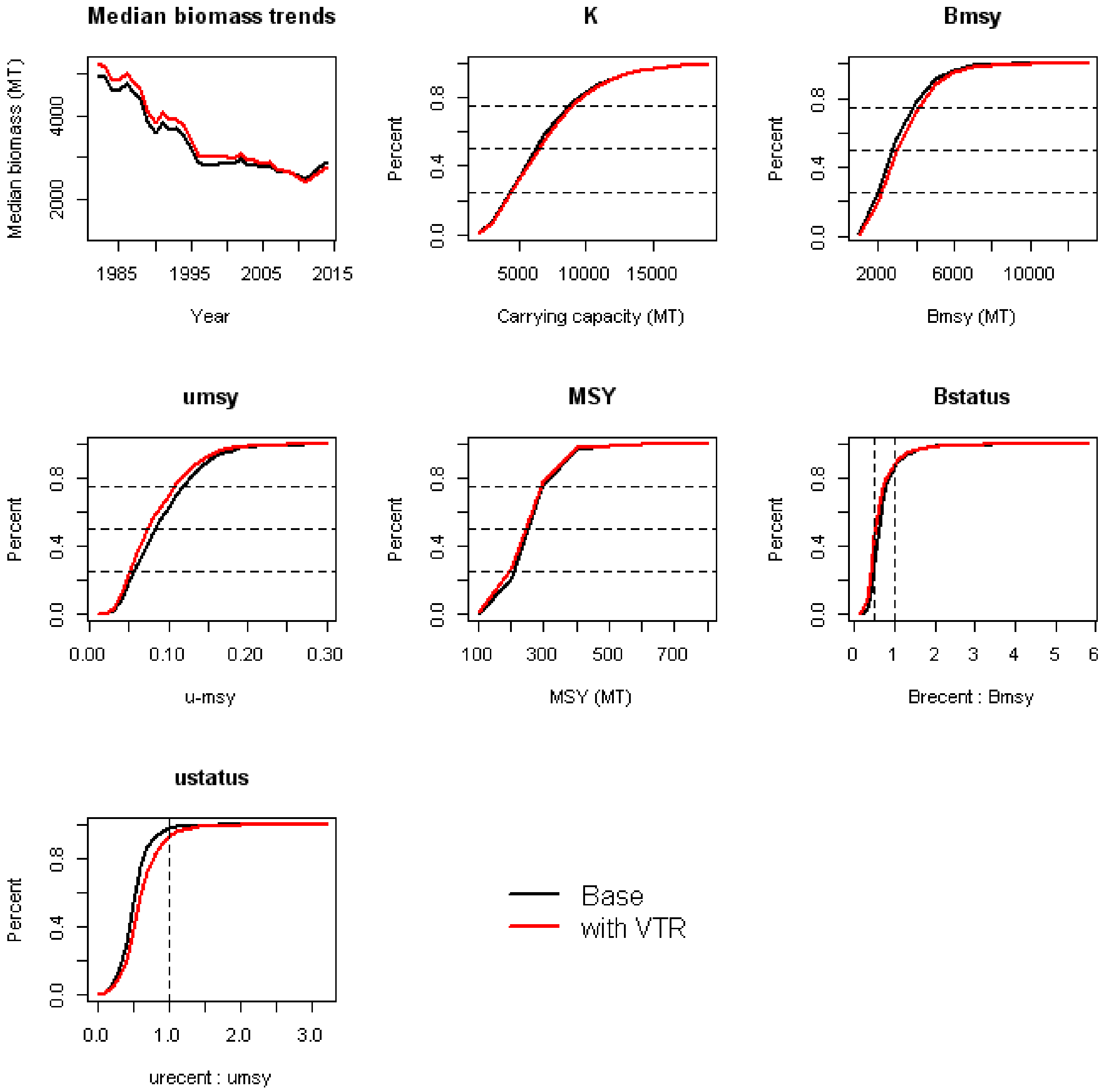


Figure 6.44. Results of model configuration sensitivity runs for the DMV region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

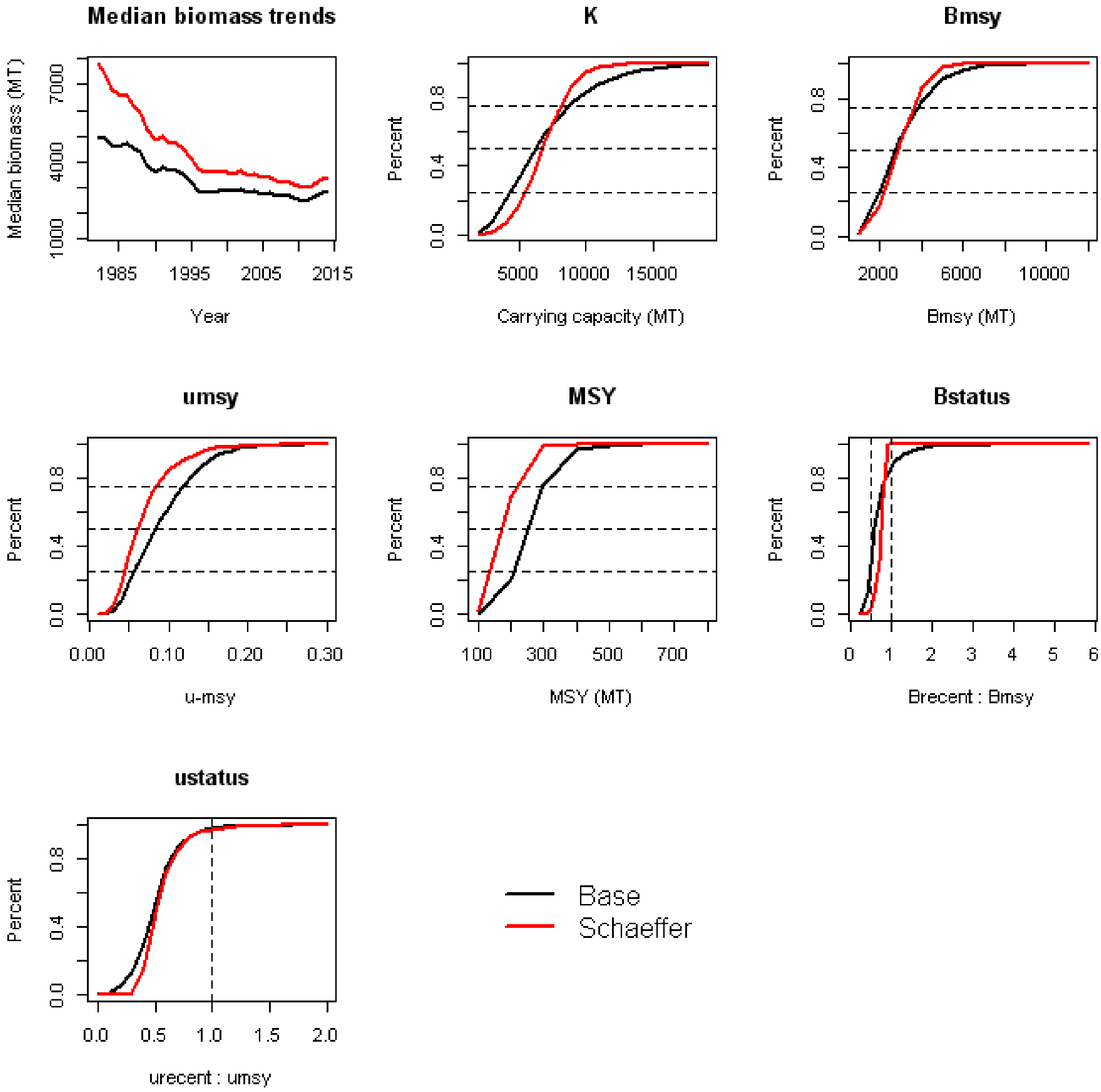


Figure 6.65. Biomass estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.

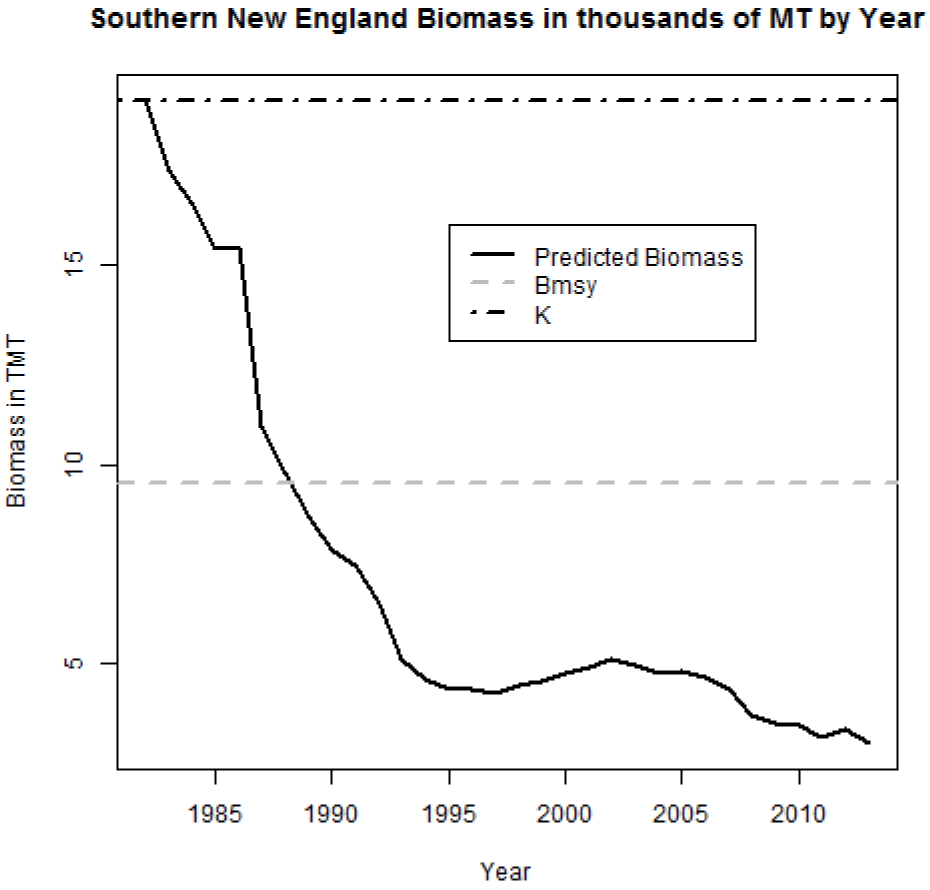


Figure 6.66. Predicted versus observed catch estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.

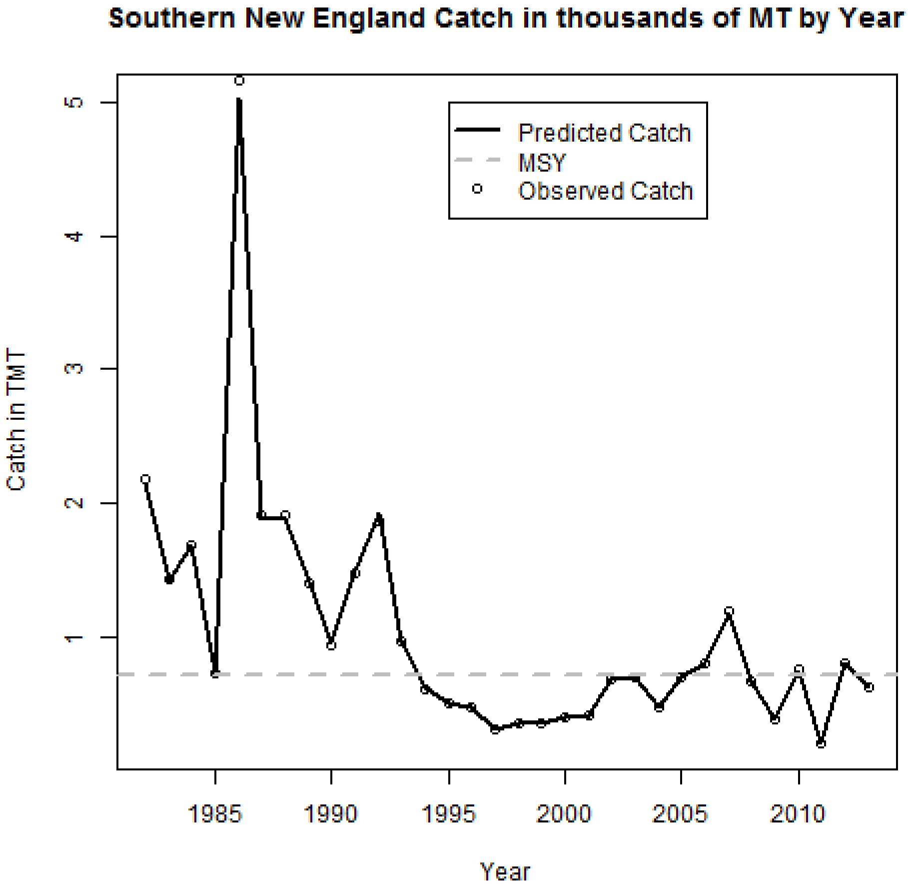
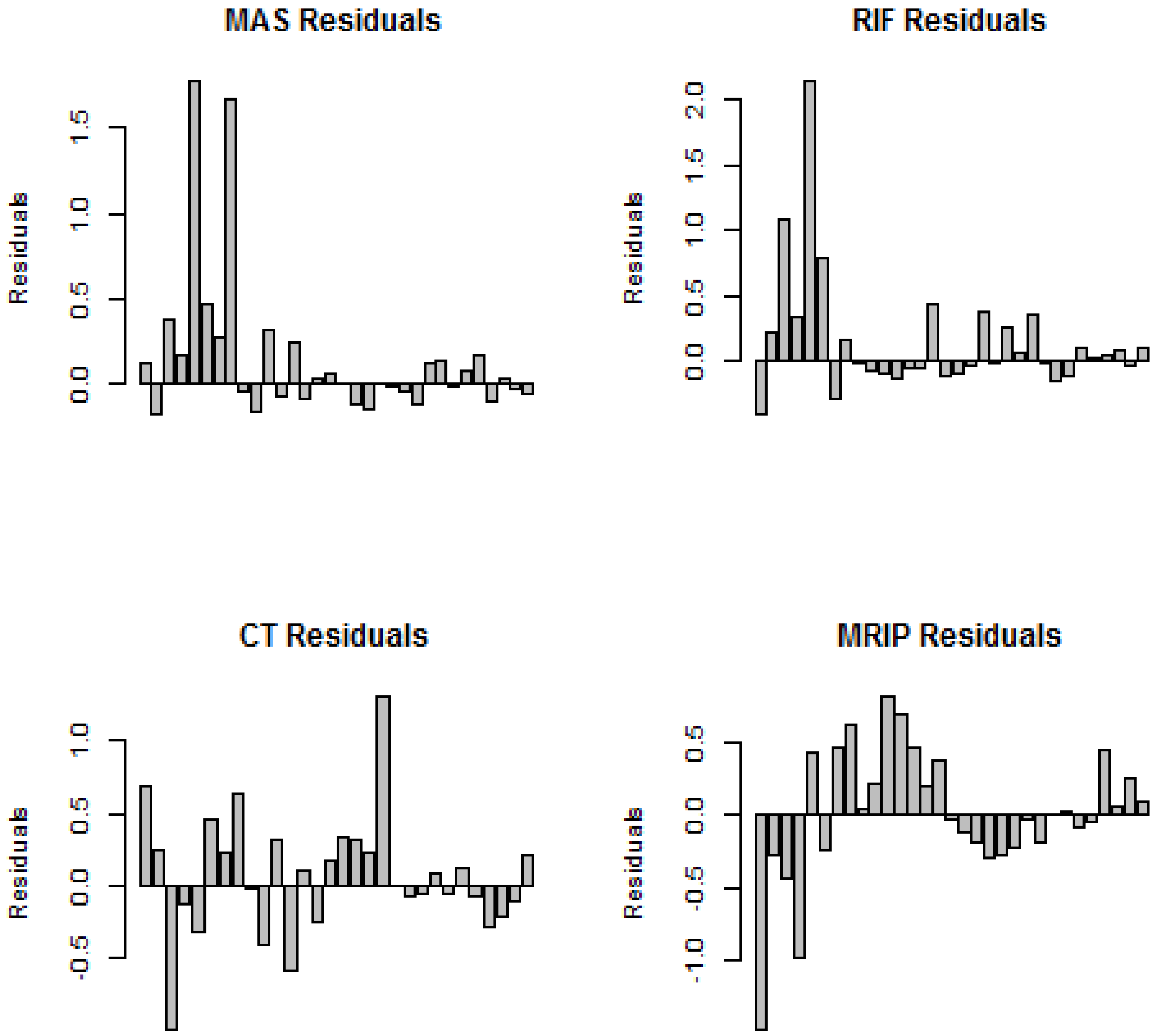


Figure 6.67. Index residual estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.



MAS Residuals

RIF Residuals

CT Residuals

MRIP Residuals

Figure 6.68. Exploitation rate estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.

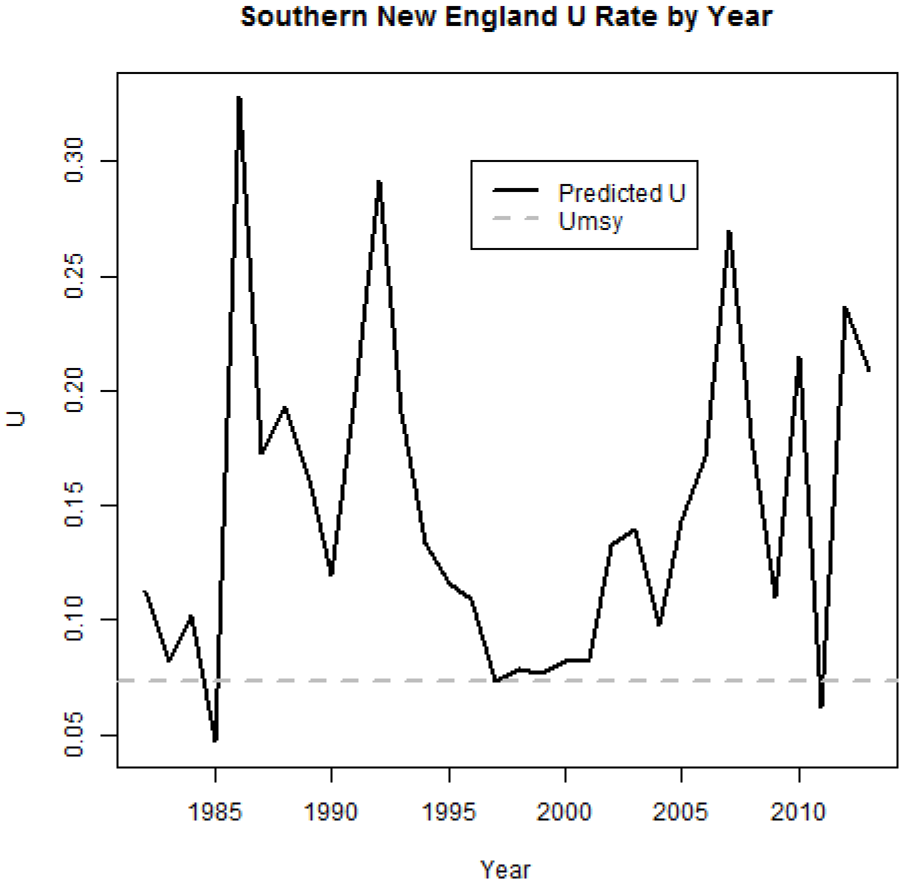


Figure 6.69. Biomass estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

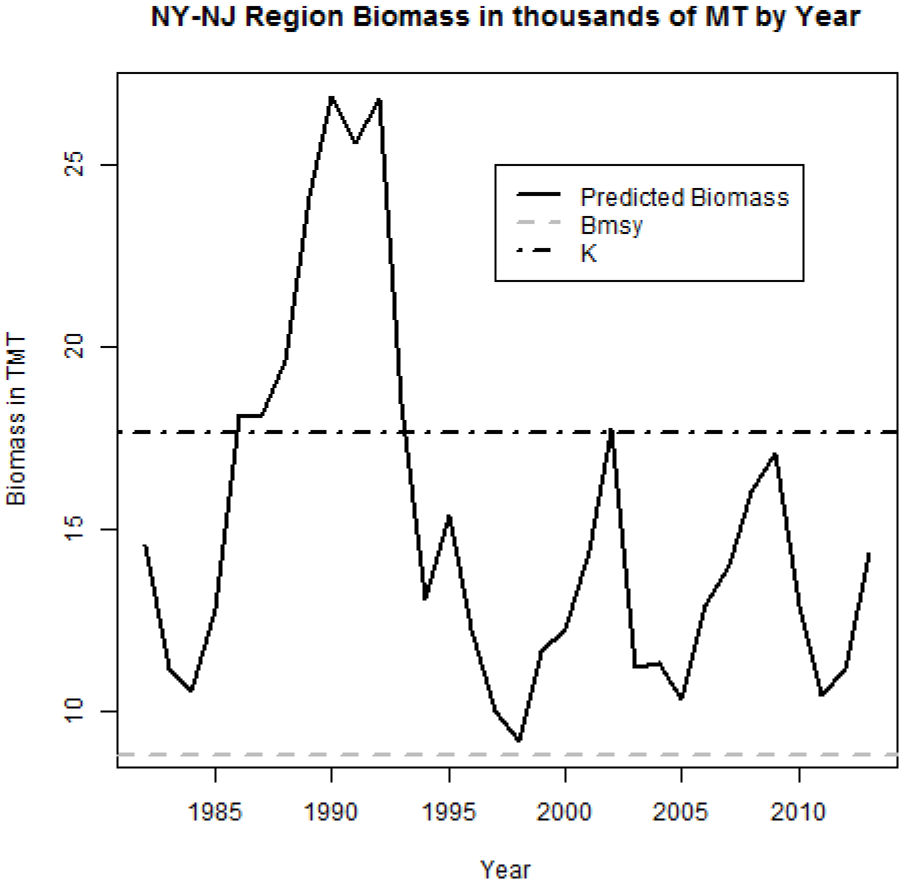


Figure 6.70. Predicted versus observed catch estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

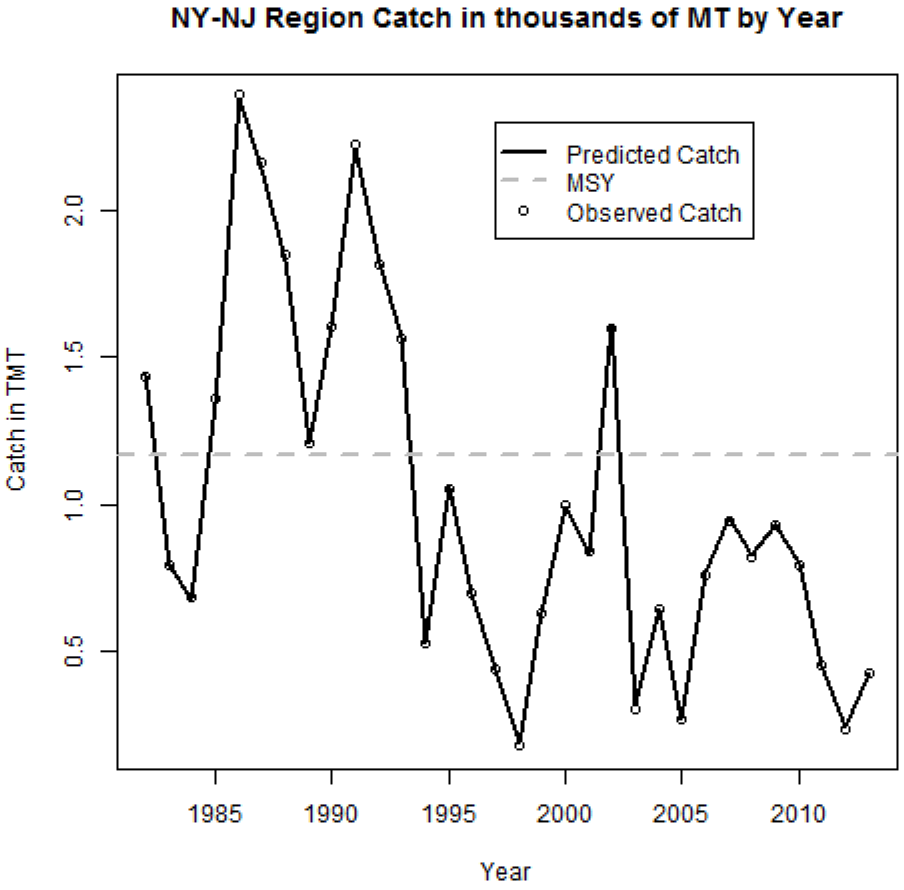


Figure 6.71. Index residual estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

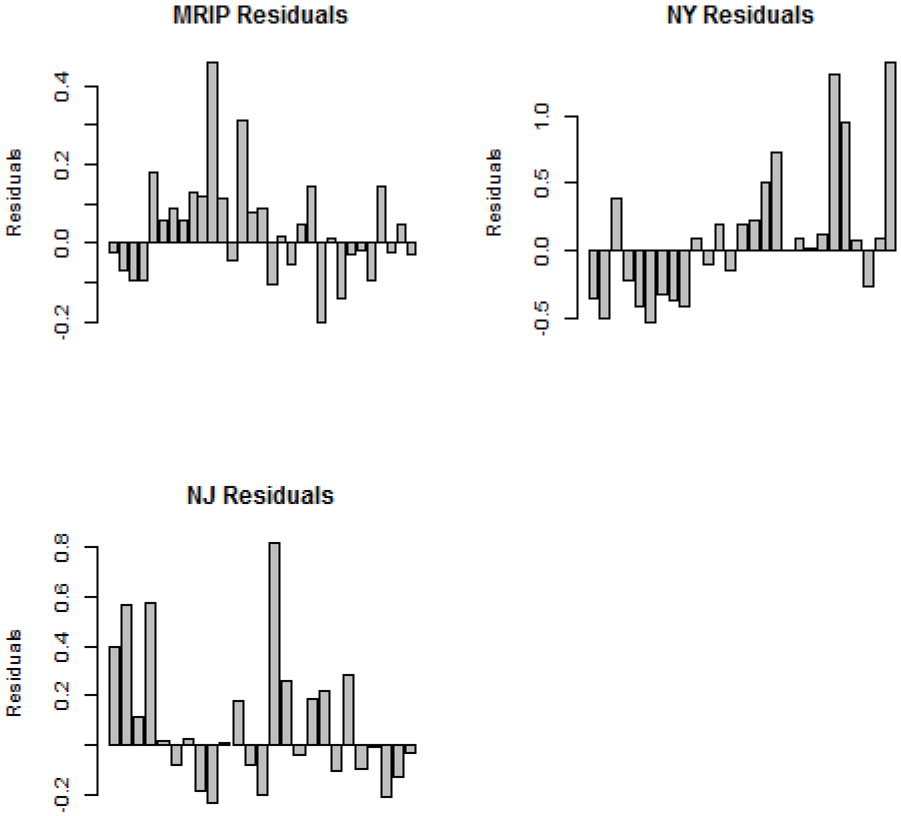


Figure 6.72. Exploitation rate estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

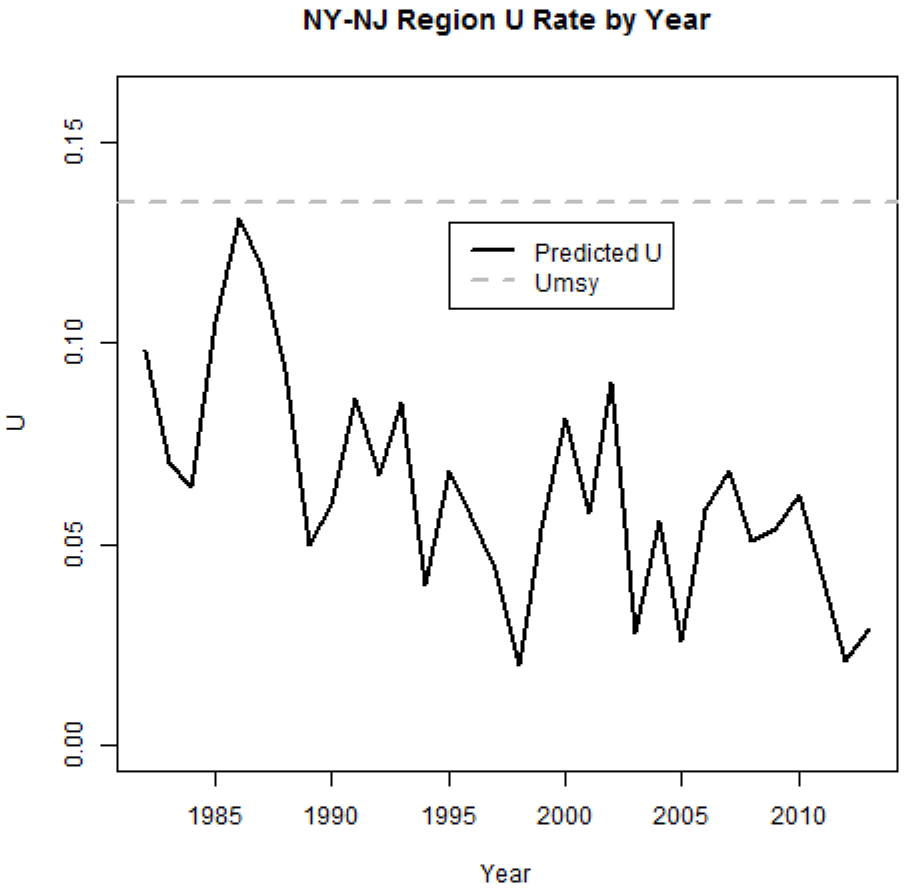


Figure 6.73. Biomass estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

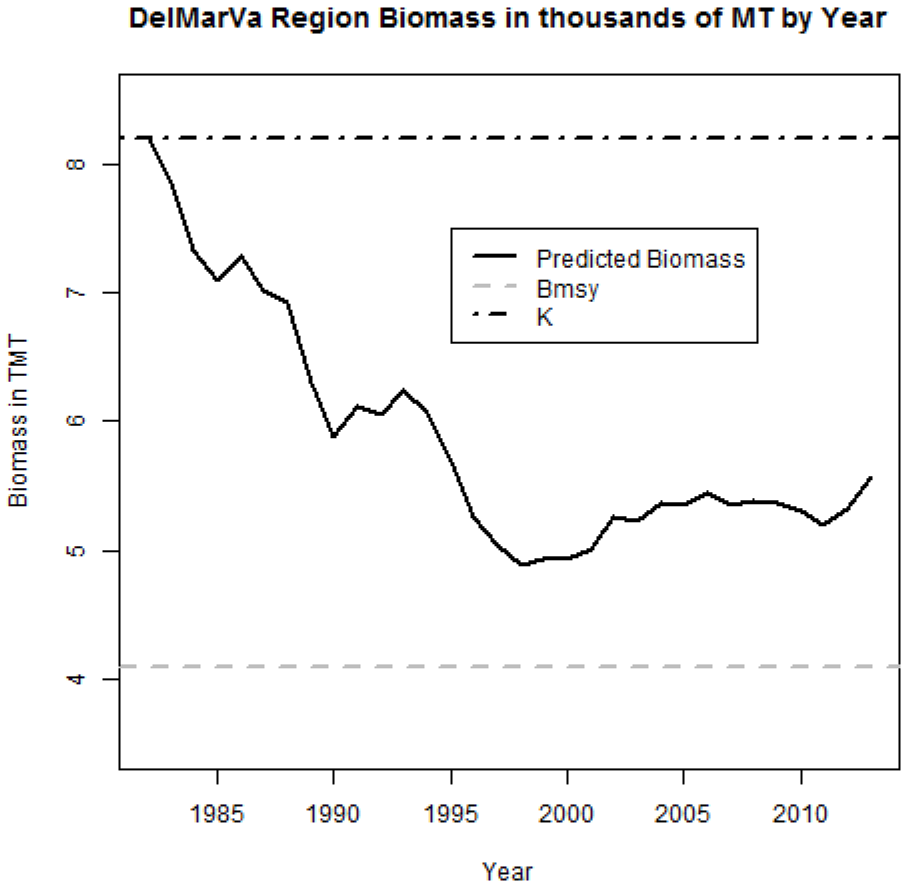


Figure 6.74. Predicted versus observed catch estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

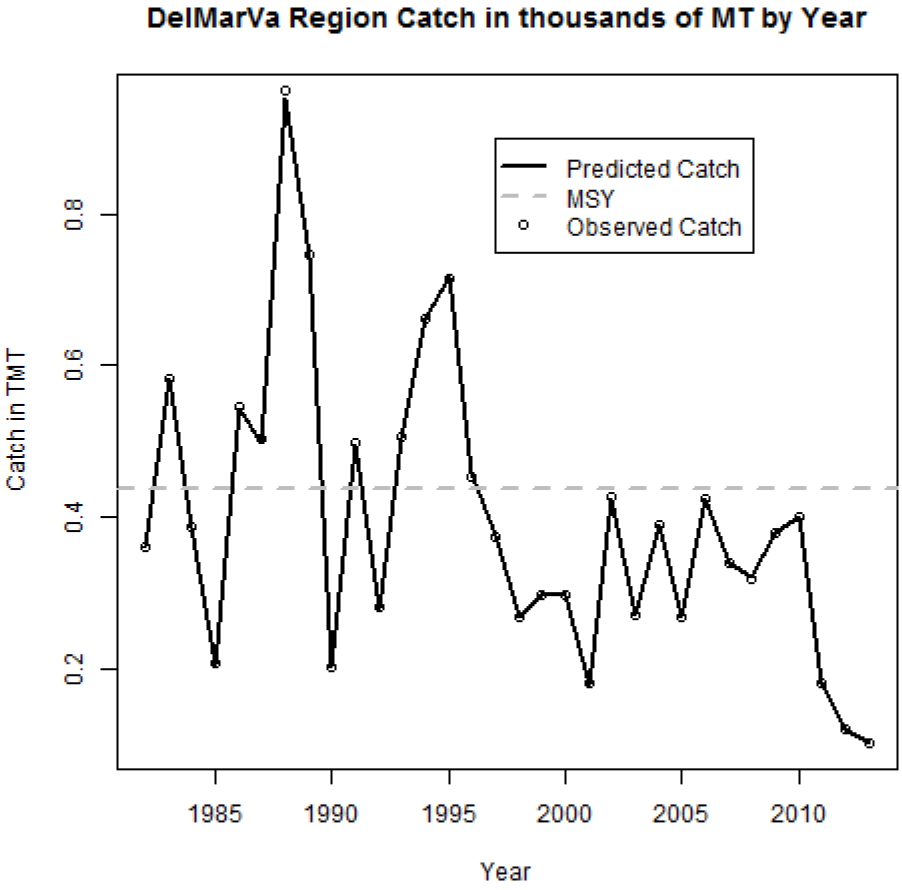


Figure 6.75. Index residual estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

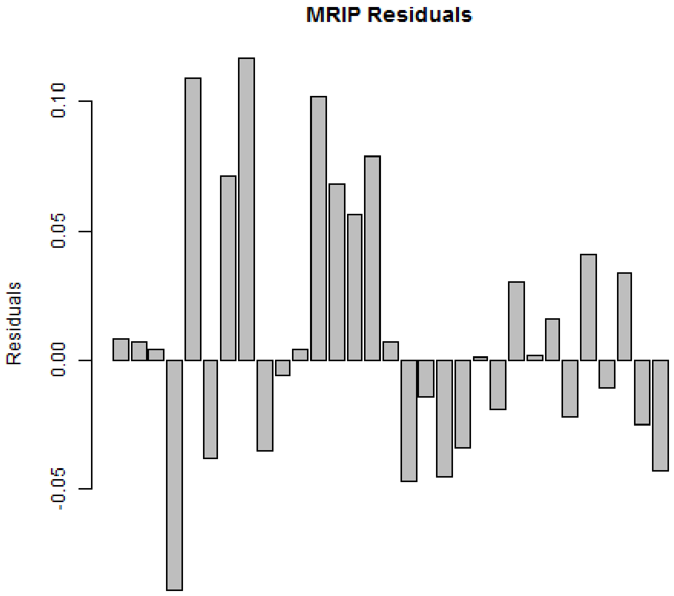


Figure 6.76. Exploitation rate estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

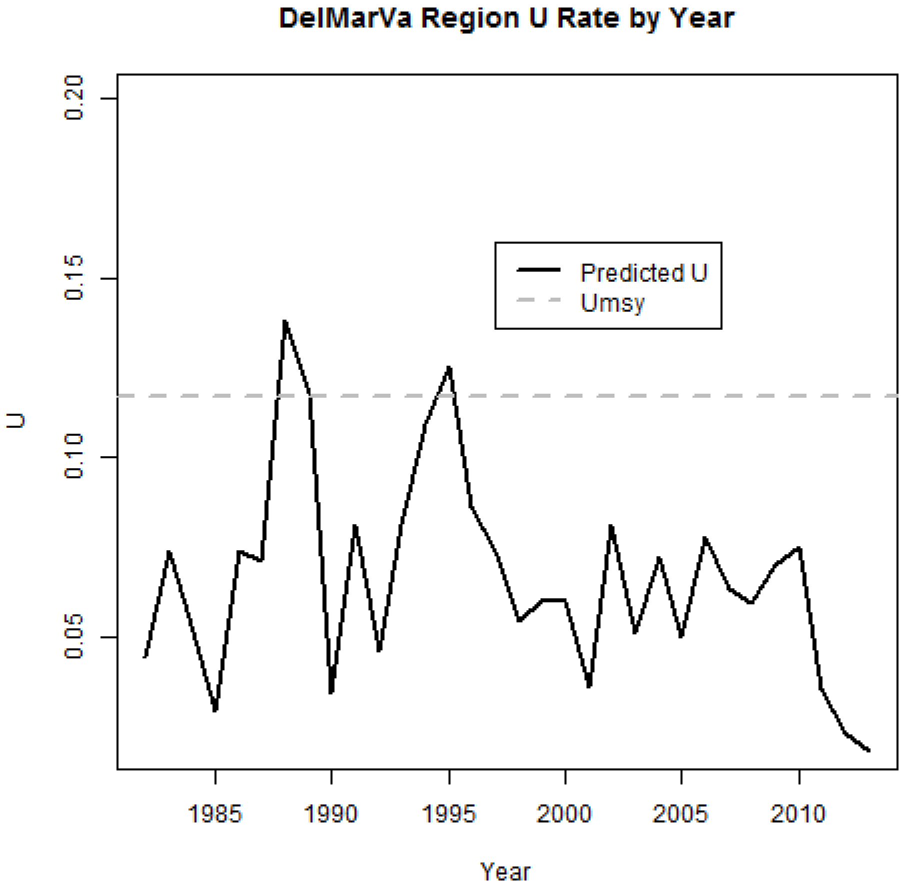


Figure 6.77. Biomass trends for different region configurations including a Coastwide region, two region split (Northern Region and Southern Region), and the base three region split (Southern New England, New York – New Jersey, and DelMarVa).

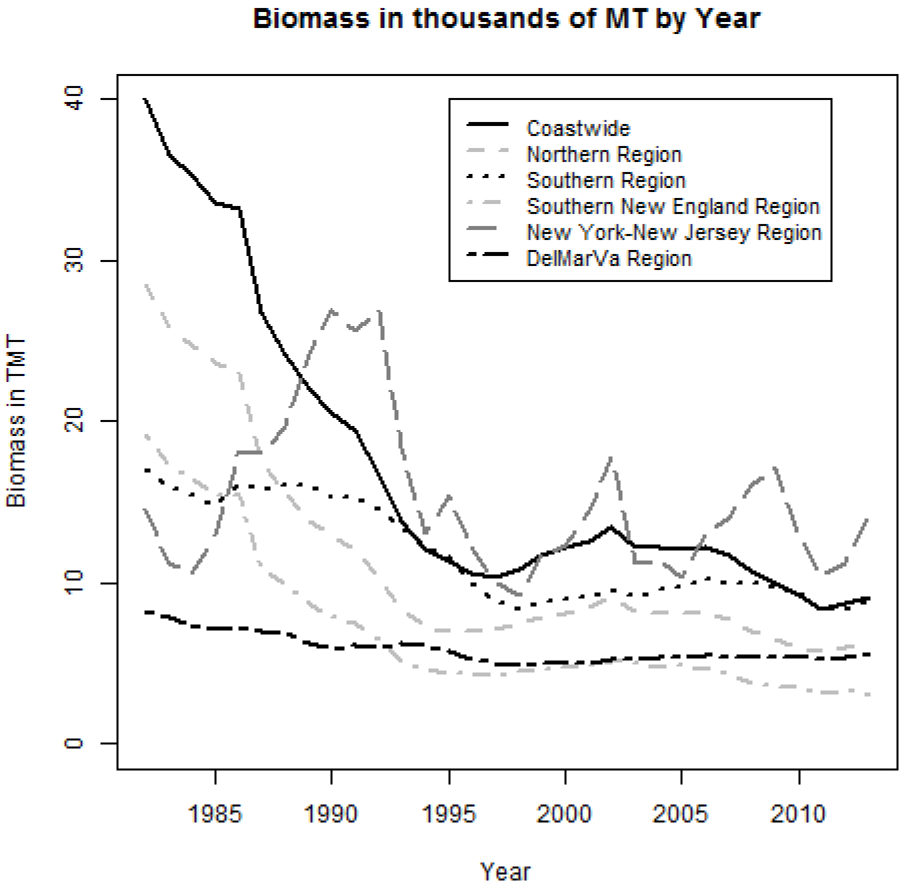


Figure 6.78. Exploitation rate trends for different region configurations including a Coastwide region, two region split (Northern Region and Southern Region), and the base three region split (Southern New England, New York – New Jersey, and DelMarVa).

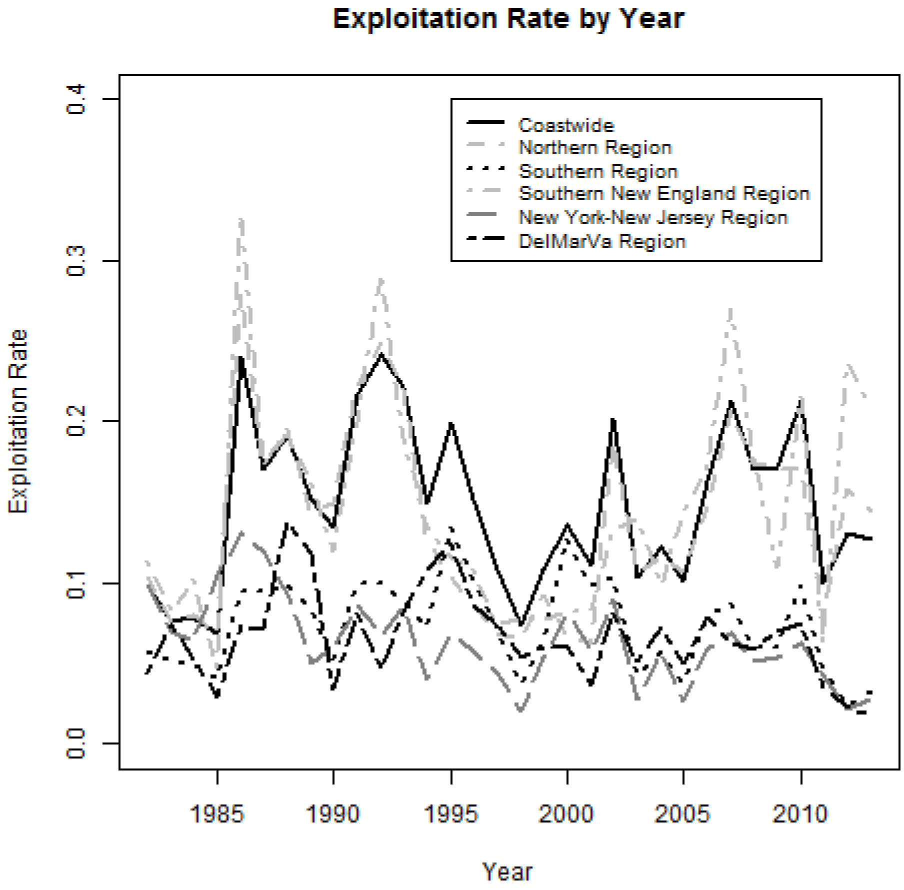


Figure 6.79. Biomass trend sensitivity to different index configurations within the New York – New Jersey region.

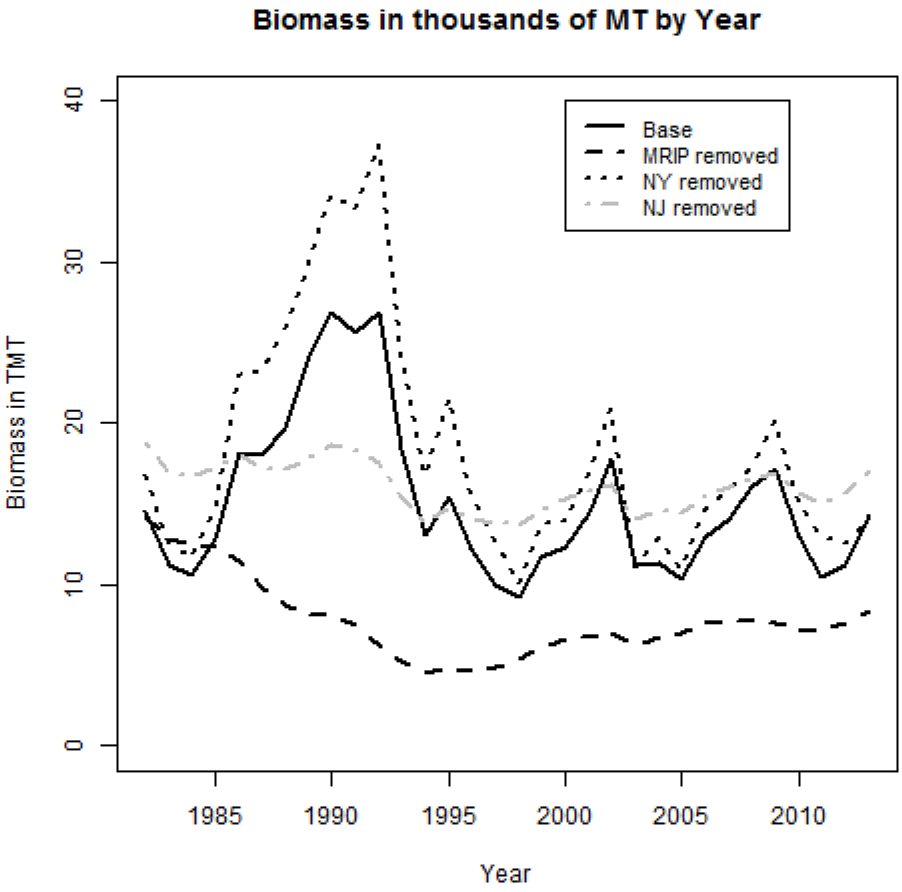


Figure 6.80. Exploitation rate trend sensitivity to different index configurations within the New York – New Jersey region.

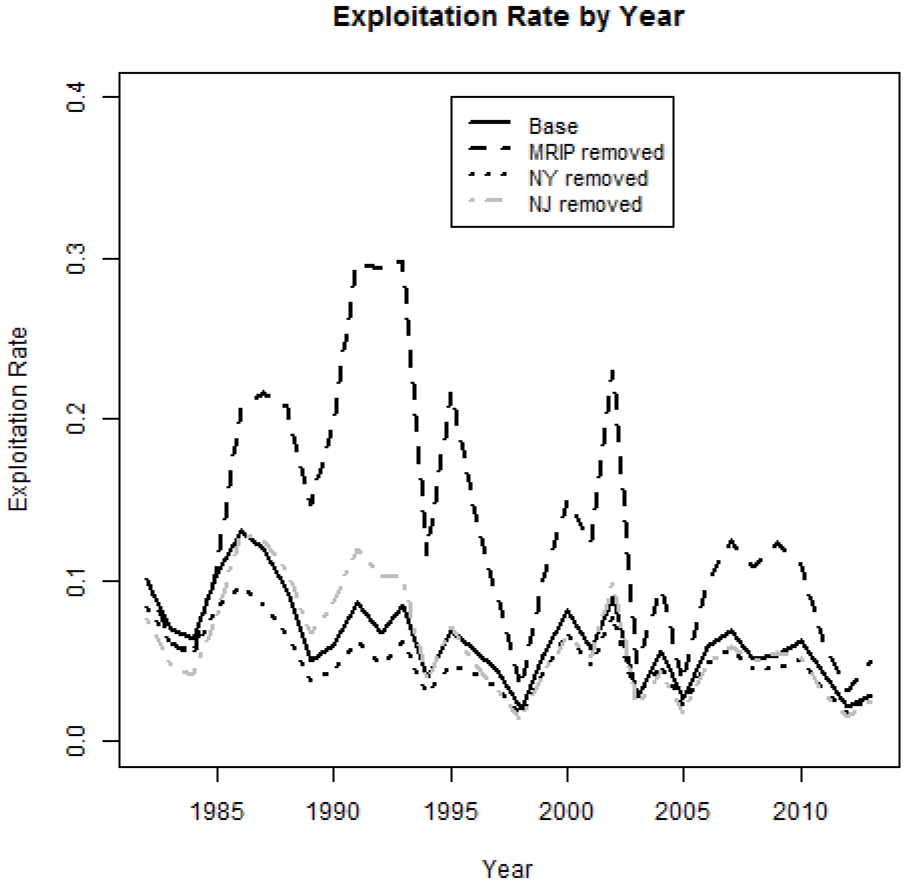


Figure 6.81. Biomass trend sensitivity to the alternate region configurations between the New York – New Jersey base configuration and the New York – New Jersey – Connecticut region configurations with calculated B_{MSY} values for each alternate region.

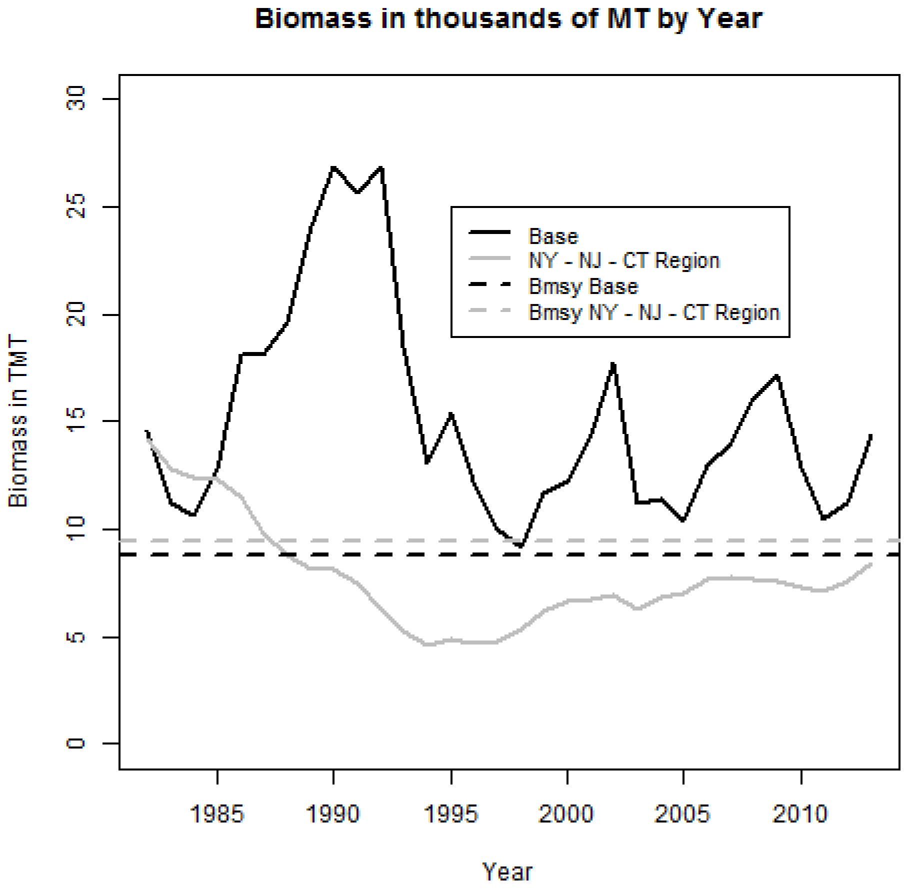


Figure 6.82. Exploitation rate sensitivity to the alternate region configurations between the New York – New Jersey base configuration and the New York – New Jersey – Connecticut region configurations with calculated U_{MSY} values for each alternate region.

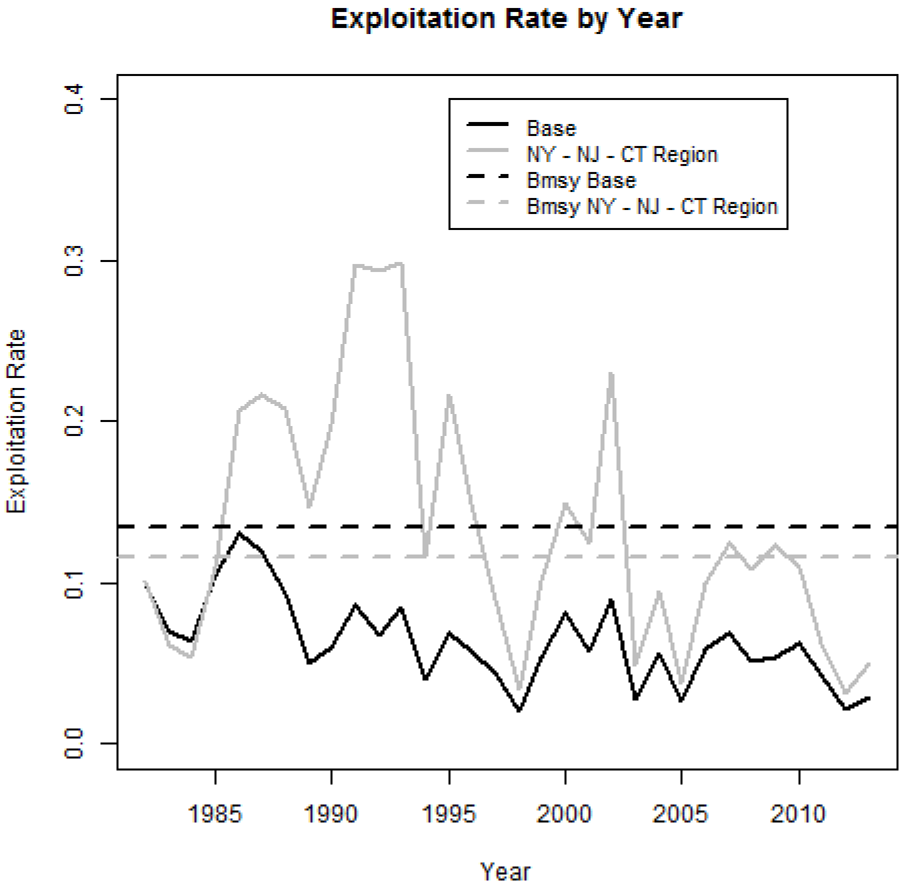


Figure 6.83. Biomass trend sensitivity to different index configurations within the Southern New England region.

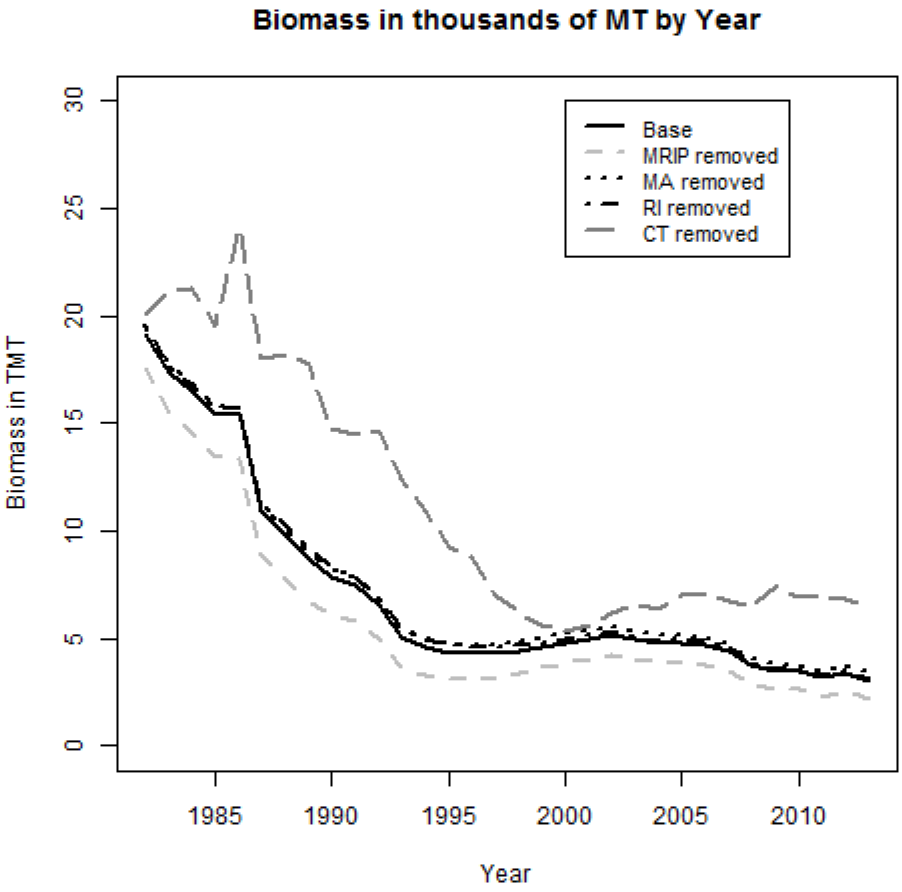


Figure 6.84. Exploitation rate trend sensitivity to different index configurations within the Southern New England region.

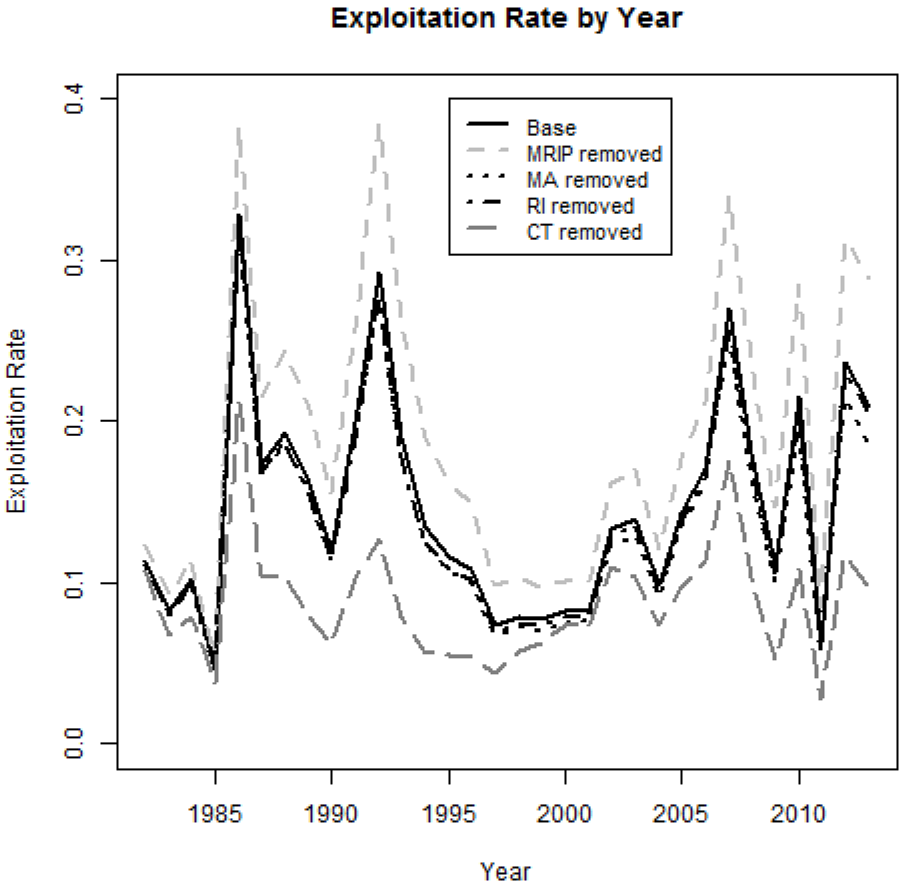


Figure 6.85. Biomass trend sensitivity to the alternate region configurations between the Southern New England base configuration and the Southern New England without Connecticut region configurations with calculated B_{MSY} values for each alternate region.

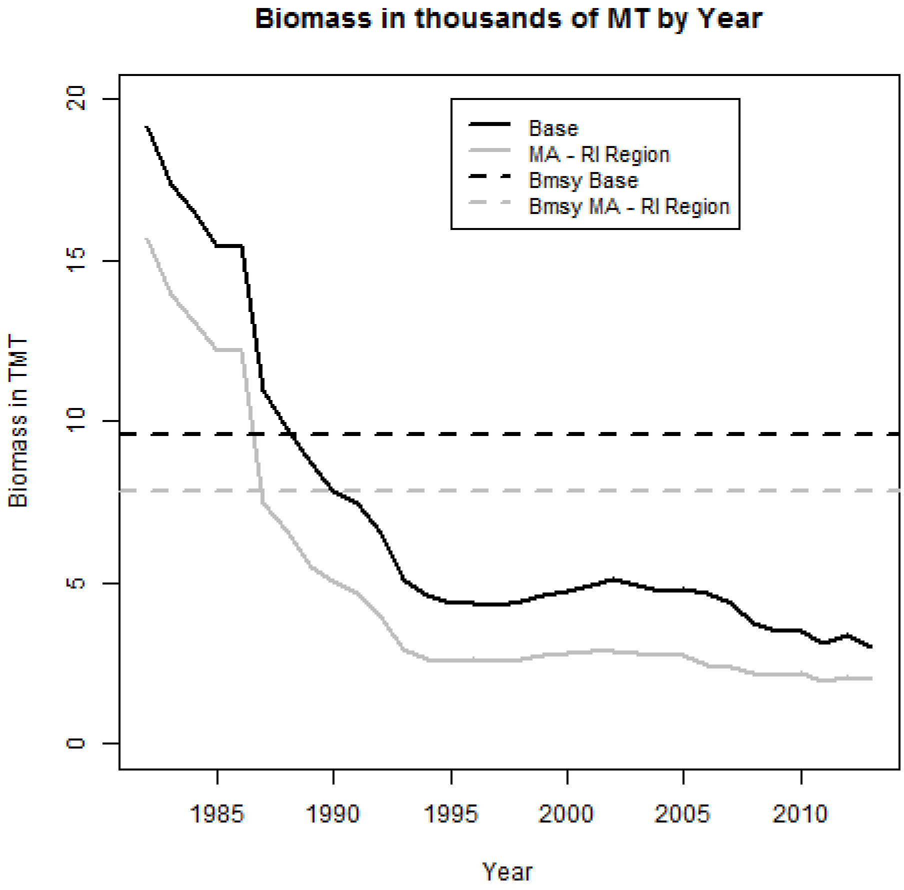


Figure 6.86. Exploitation rate sensitivity to the alternate region configurations between the Southern New England base configuration and the Southern New England without Connecticut region configurations with calculated U_{MSY} values for each alternate region.

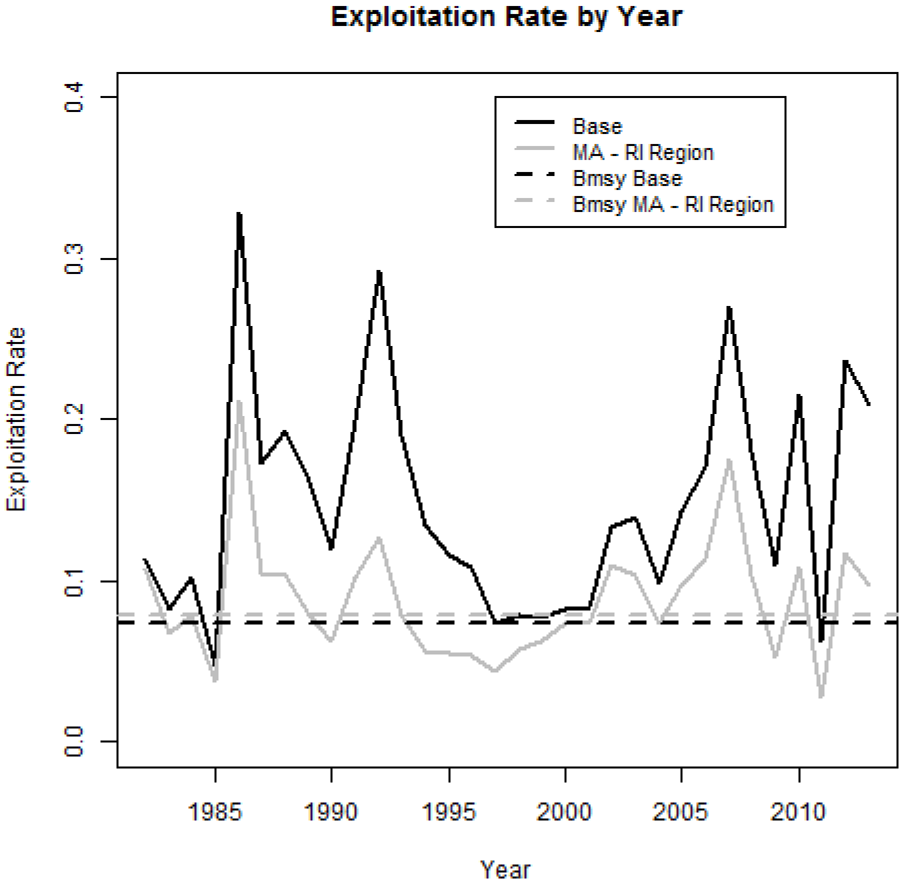


Figure 6.87 Three year average biomass trends and exploitation rates by region versus MSY reference points.

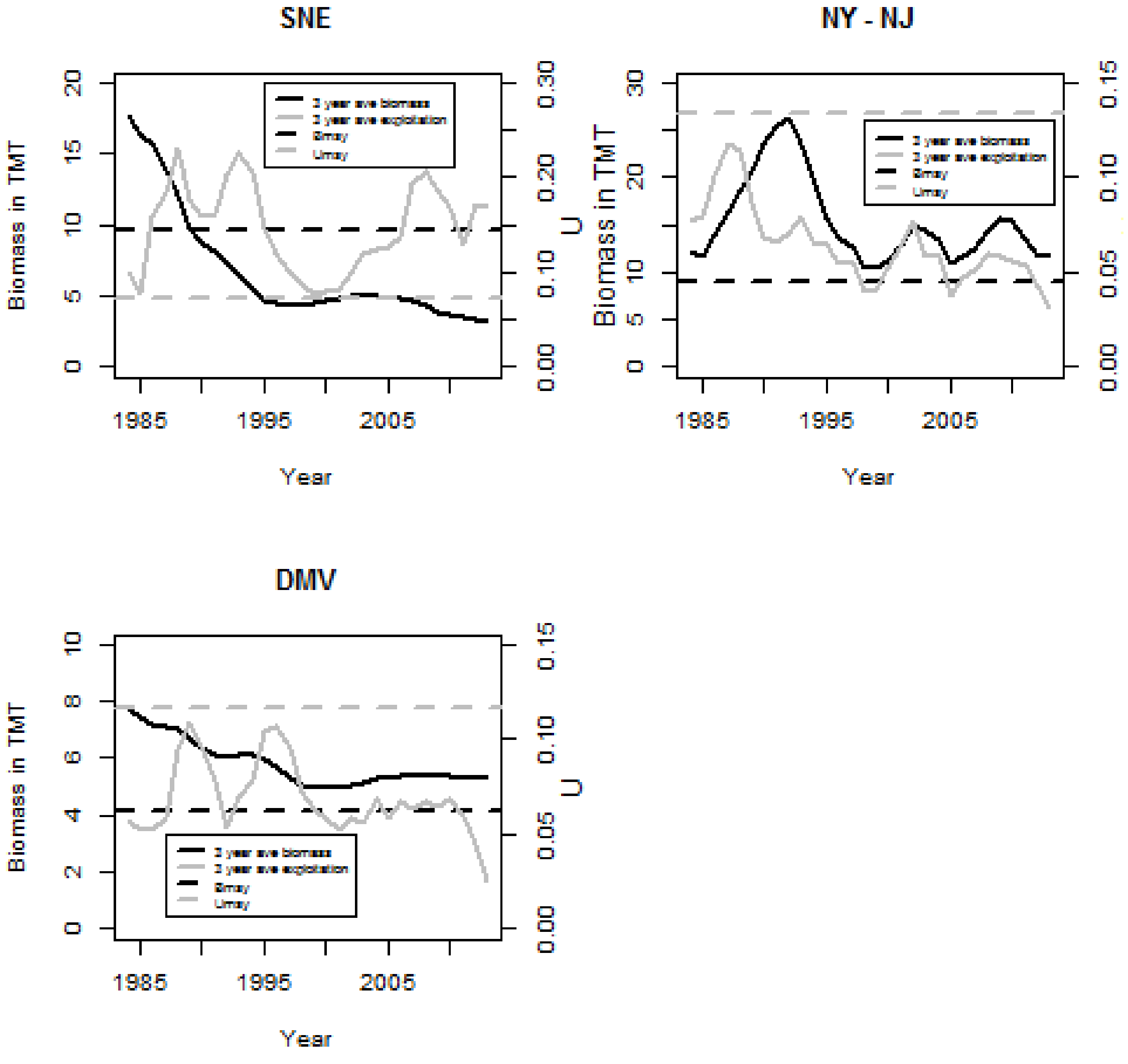


Figure 6.88. Index fits for the surveys used in the base configuration of the Southern New England Region.

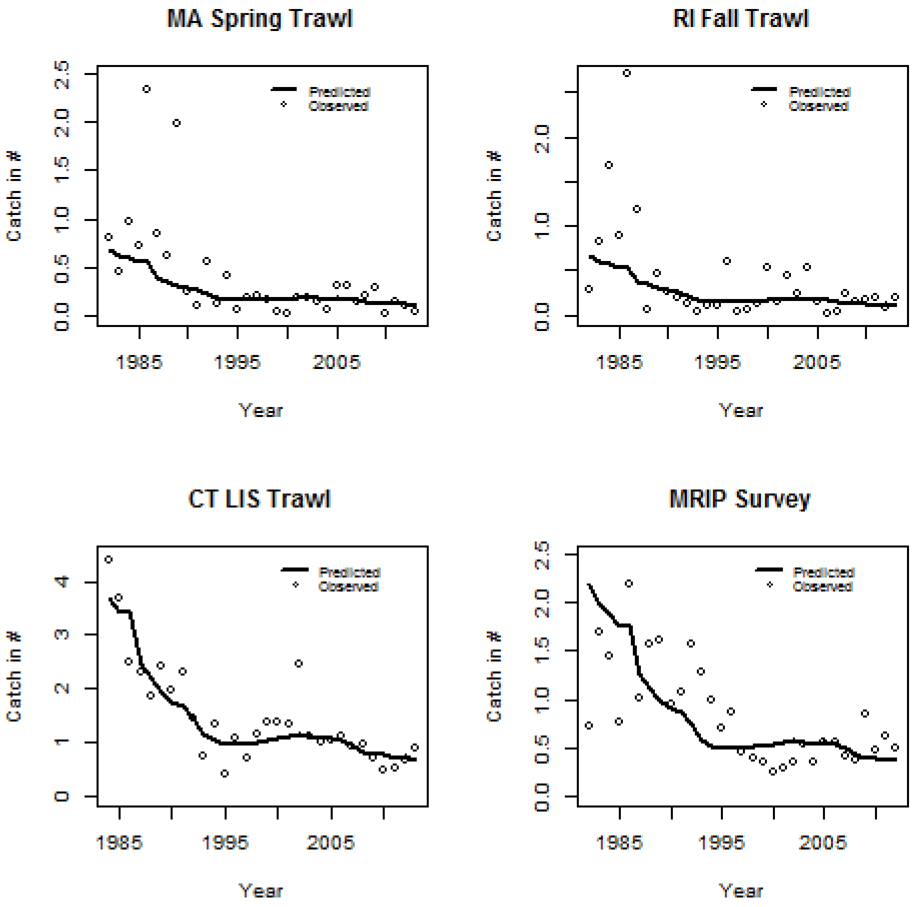


Figure 6.89. Index fits for the surveys used in the base configuration of the New York – New Jersey Region.

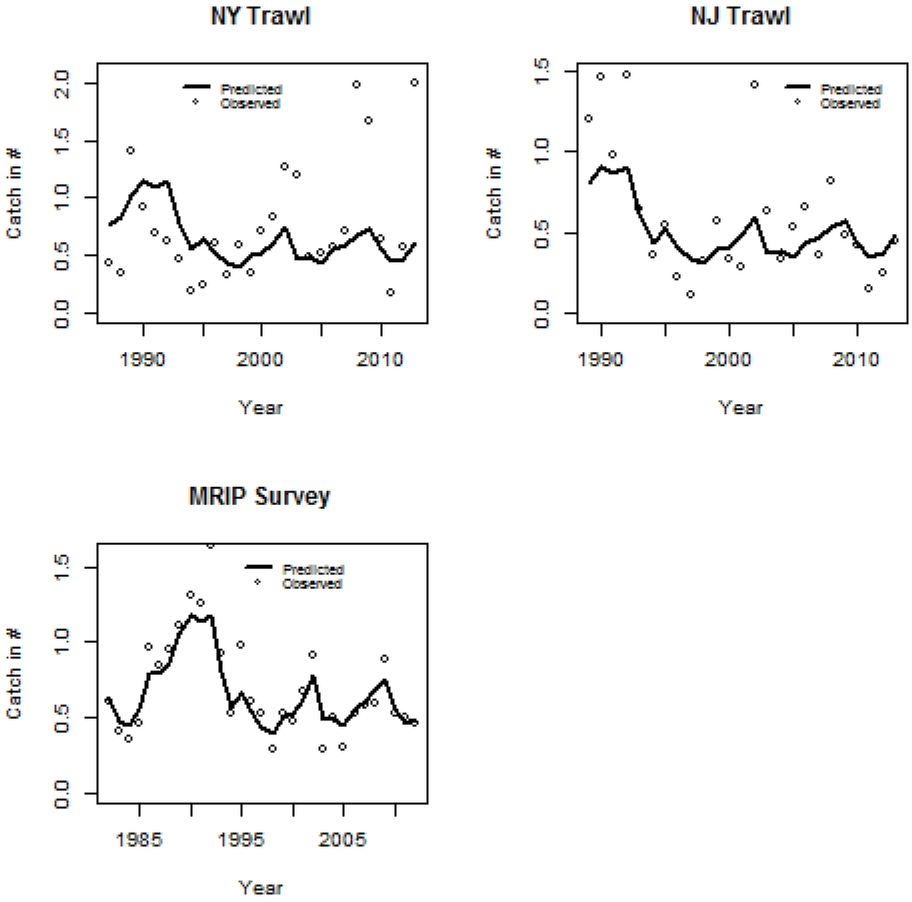


Figure 6.90. Index fit for the survey used in the base configuration of the DelMarVa Region.

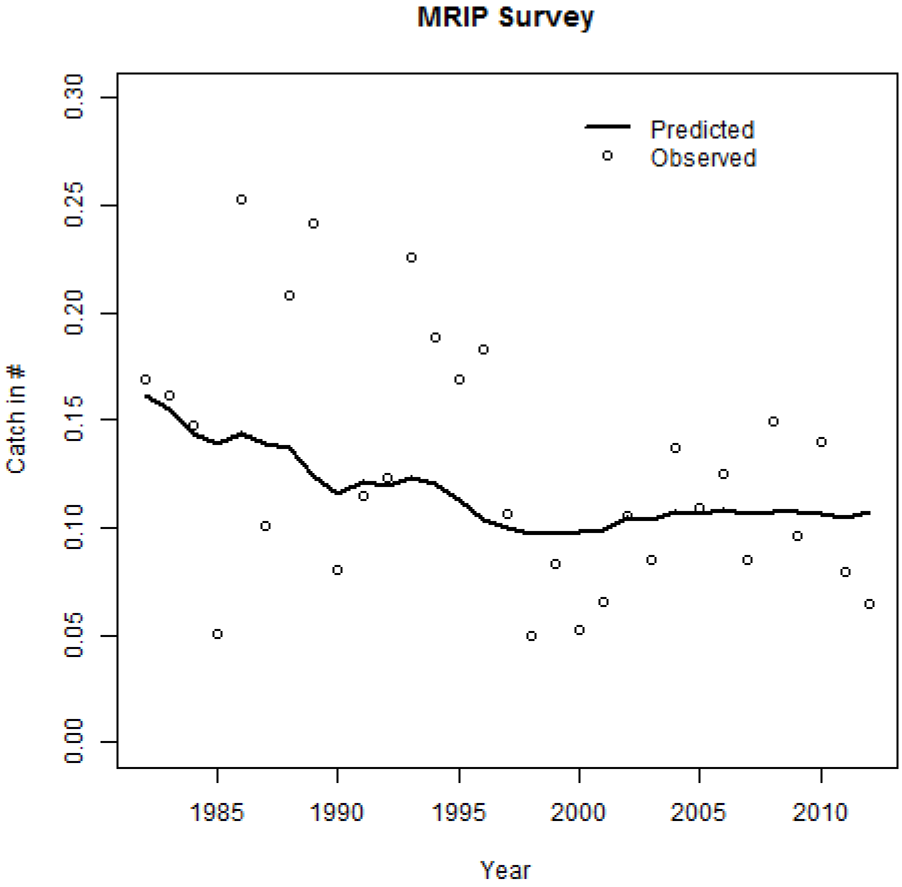
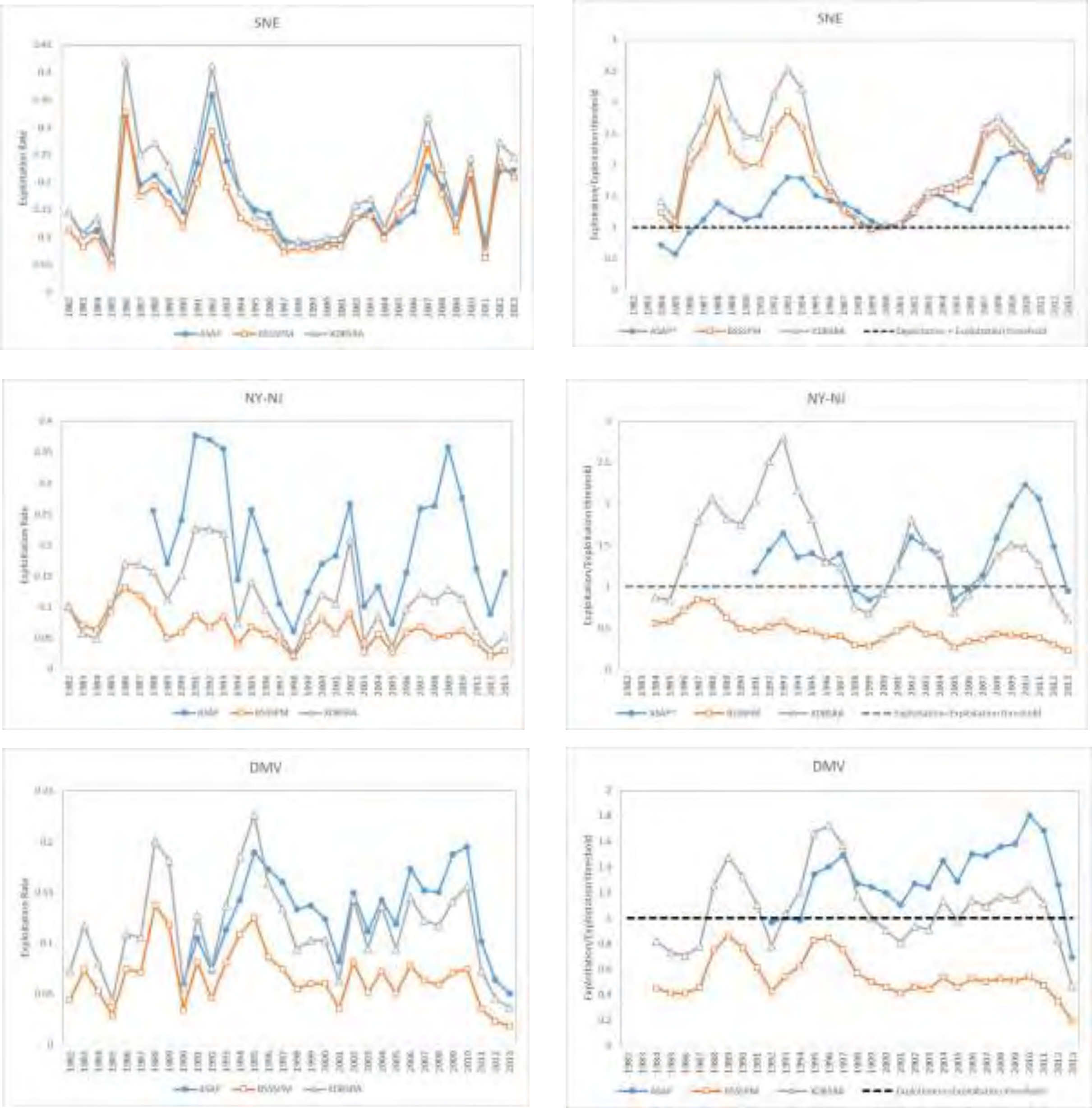
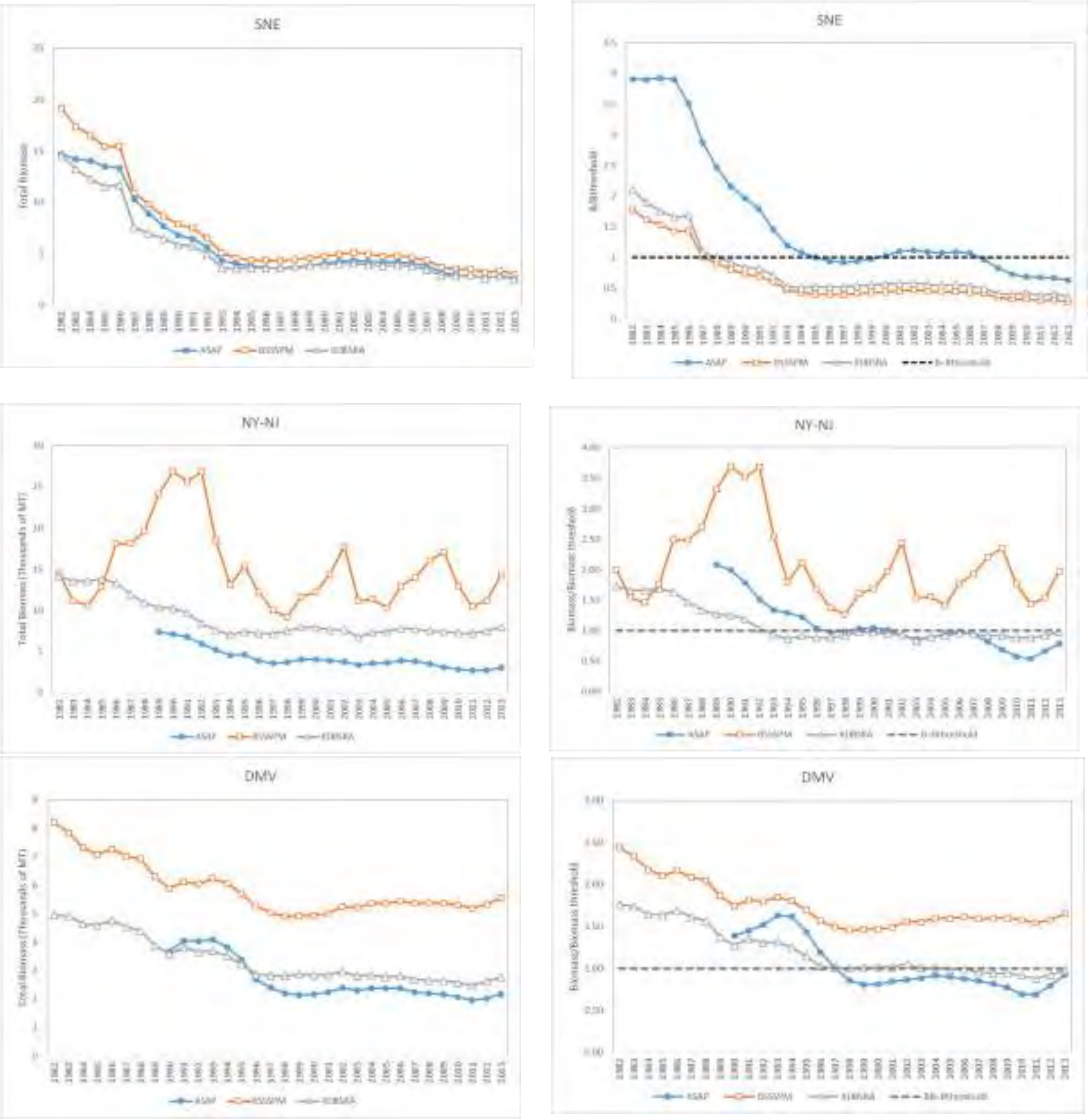


Figure 6.91. Annual exploitation rates (left) and 3-year average rates relative to the exploitation threshold (right) by region for the three models considered.



*Exploitation relative to the threshold is calculated as $F/F_{threshold}$ for ASAP, and $\mu/\mu_{threshold}$ for XDBSRA and BSSSPM for the figures on the right, in order to represent overfishing status consistently across models. $F_{threshold}$ was defined as F_{MSY} for ASAP in SNE and $F_{30\%SPR}$ for ASAP in NY-NJ and DMV. $\mu_{threshold}$ was defined as μ_{MSY} for all three regions for XDBSRA and BSSSPM.

Figure 6.92. Total biomass (right) and biomass relative to the biomass threshold (right) across all three models by region.



*Biomass relative to the threshold is calculated as SSB/$SSB_{thershold}$ for ASAP, and B/$B_{threshold}$ for XDBSRA and BSSSPM for the figures on the right, in order to represent overfished status consistently across models. $SSB_{threshold}$ was defined as 75%SSB_{MSY} in SNE and $SSB_{30\%SPR}$ in NY-NJ and DMV for ASAP. $B_{threshold}$ was defined as 75%B_{MSY} for all three regions for XDBSRA and BSSSPM.

Figure 6.93. VPA continuity run estimates of N-Weighted average F for ages 8-10.

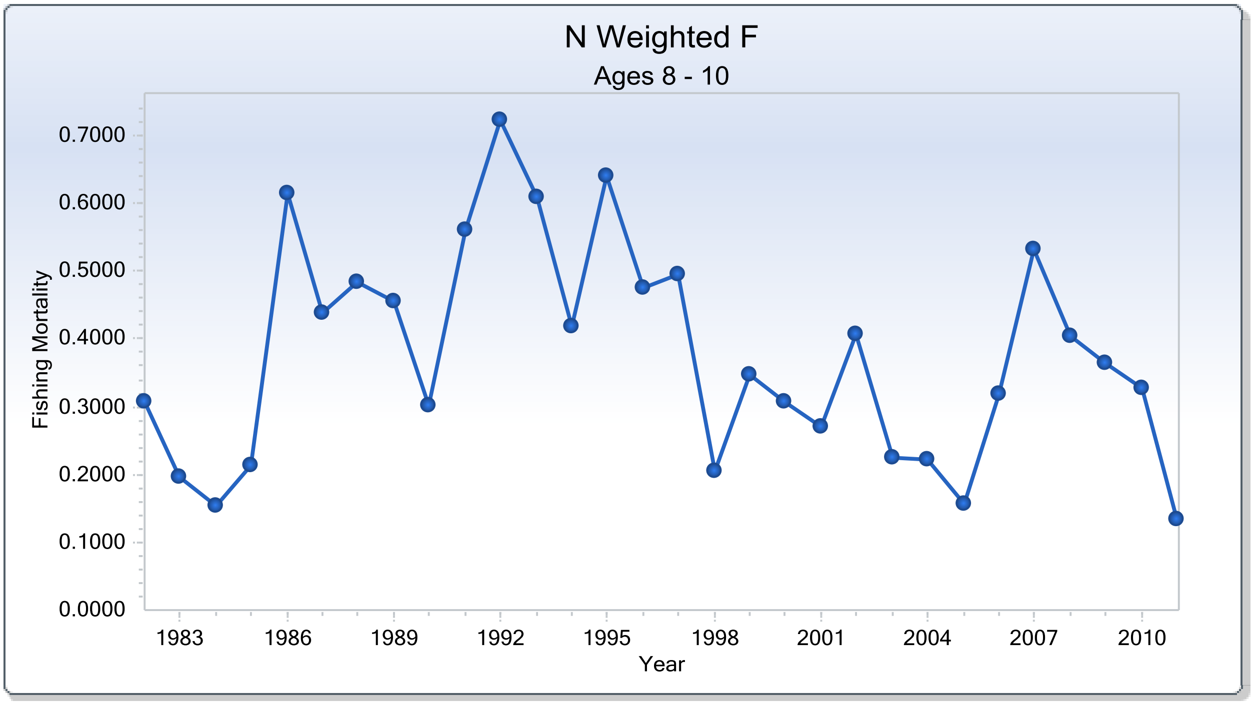
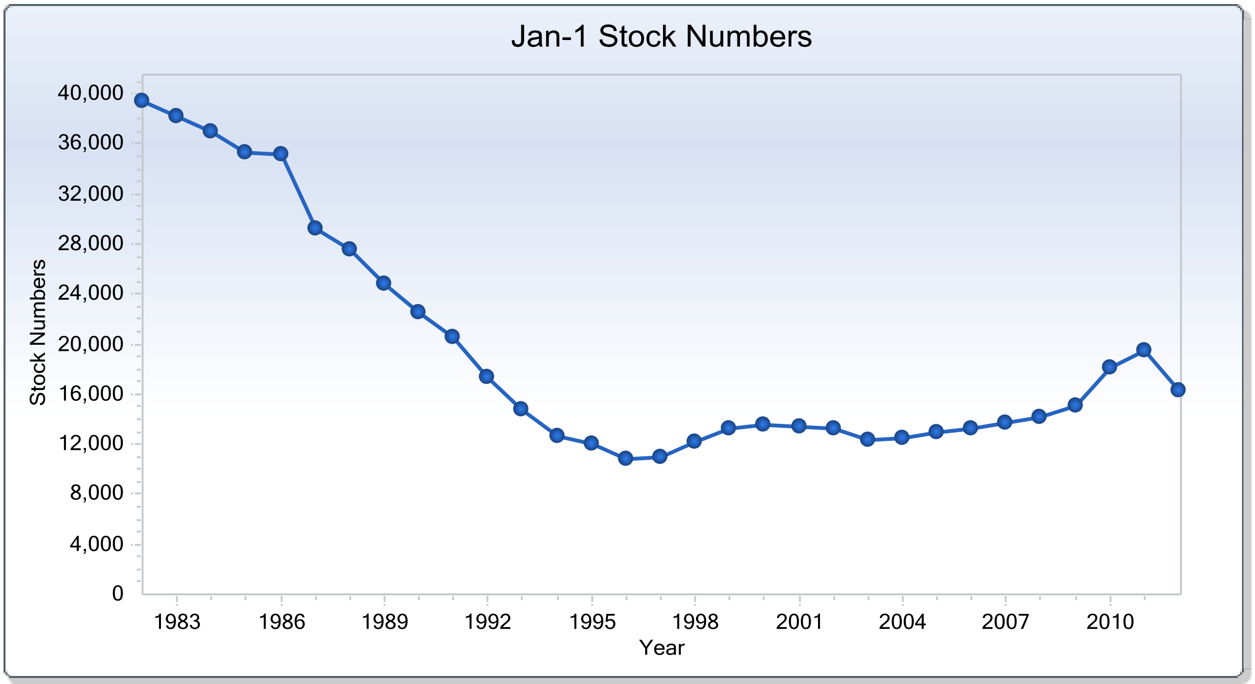


Figure 6.94. VPA continuity run estimates of abundance (thousands of fish) and spawning stock biomass (MT).



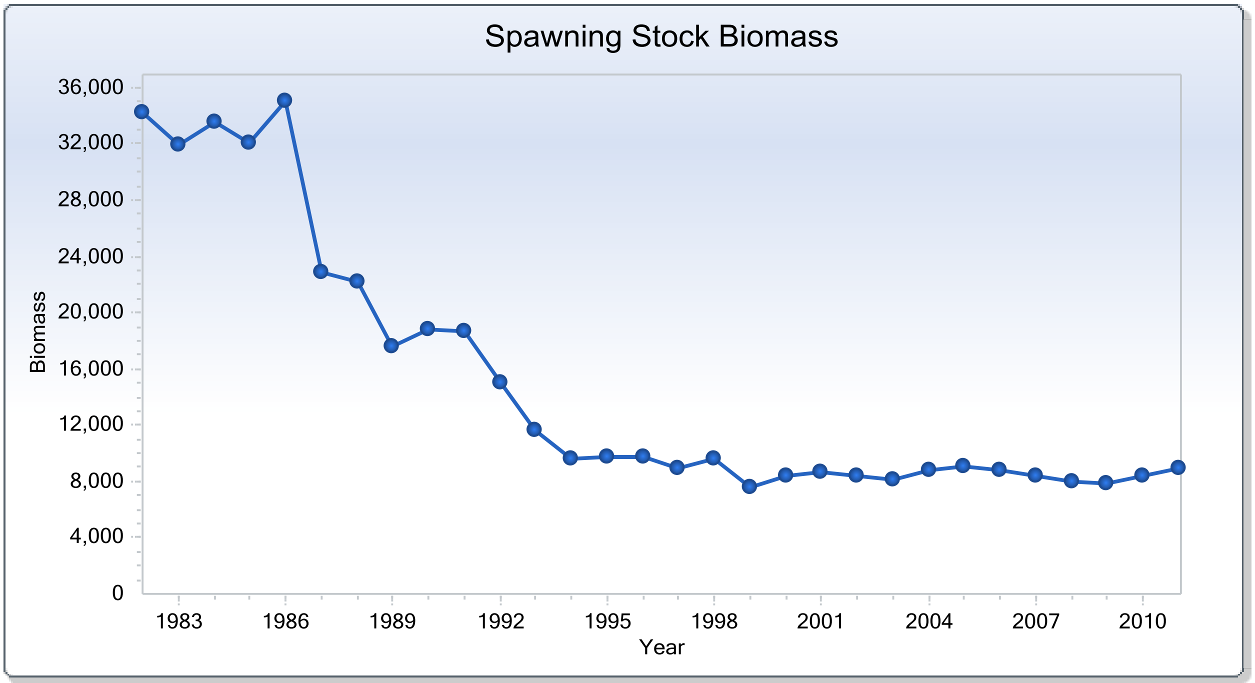
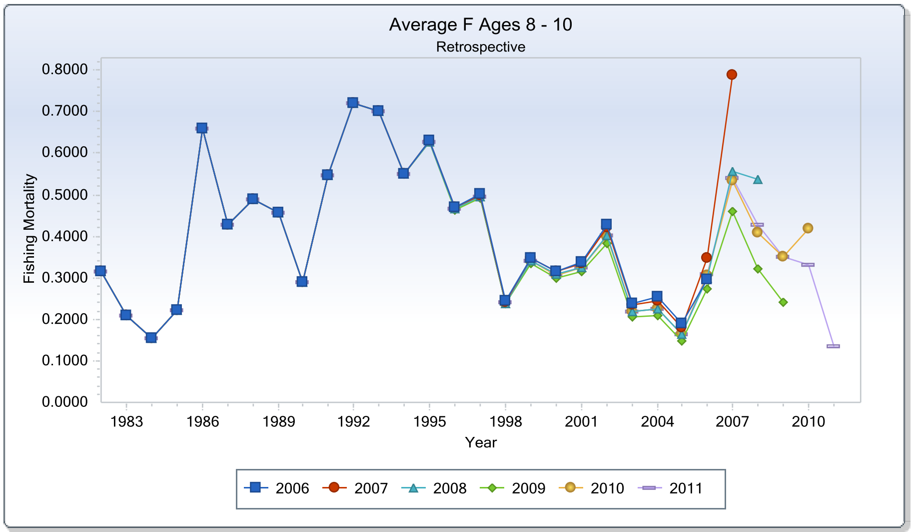
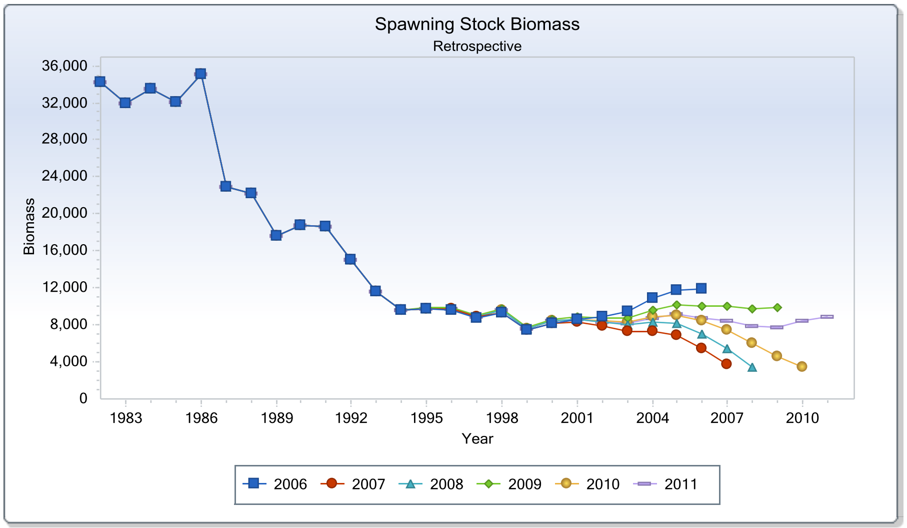


Figure 6.95. Retrospective patterns from the VPA continuity run.





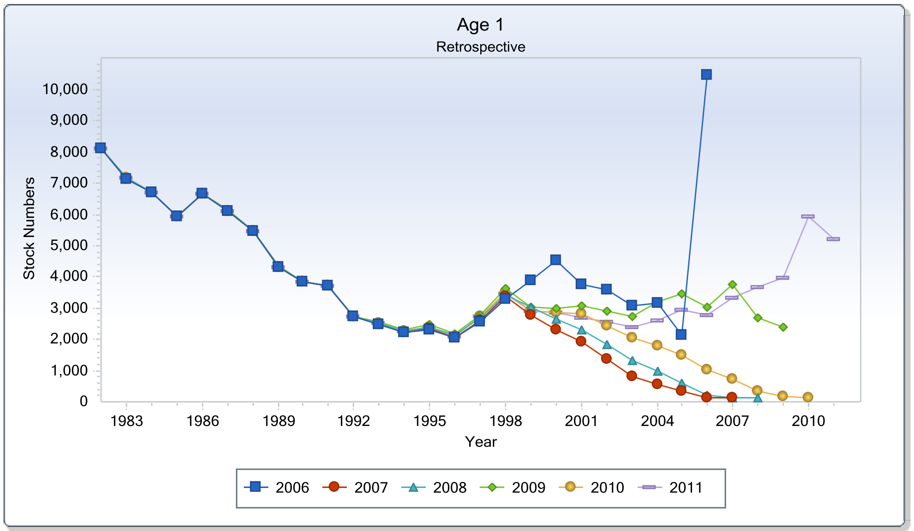
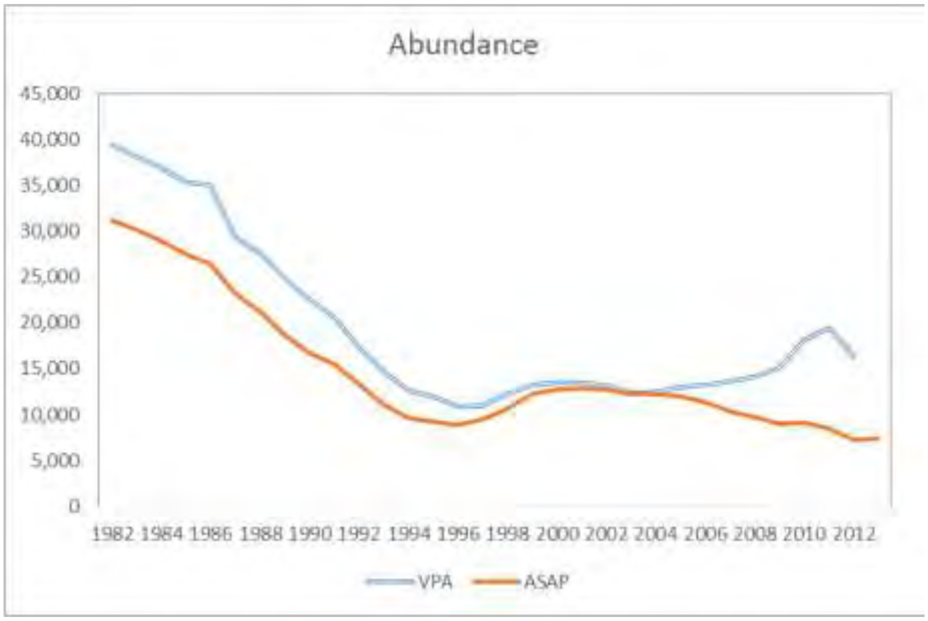


Figure 6.96. Comparison of ASAP and VPA estimates of abundance and SSB for the coastwide model.



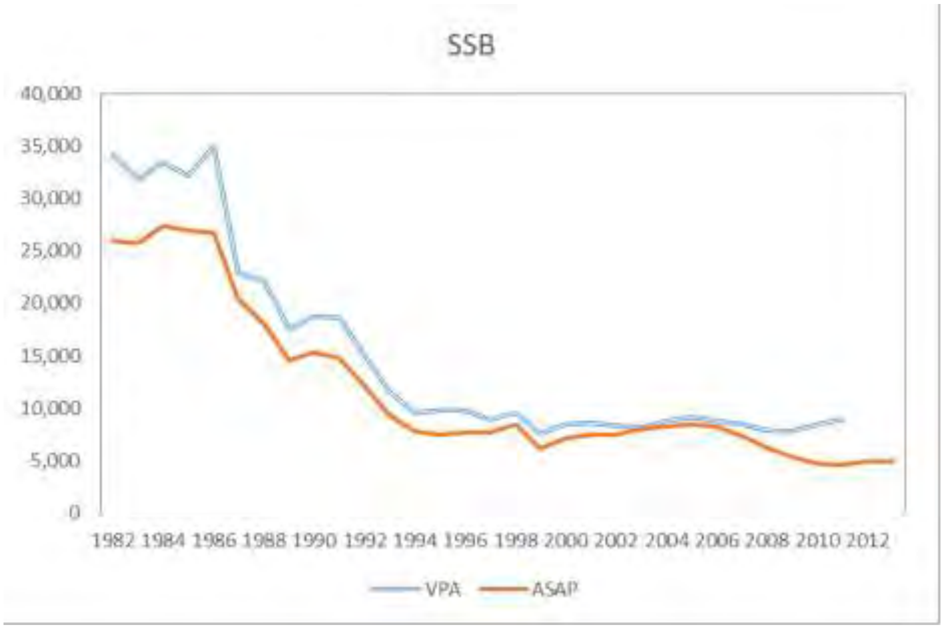
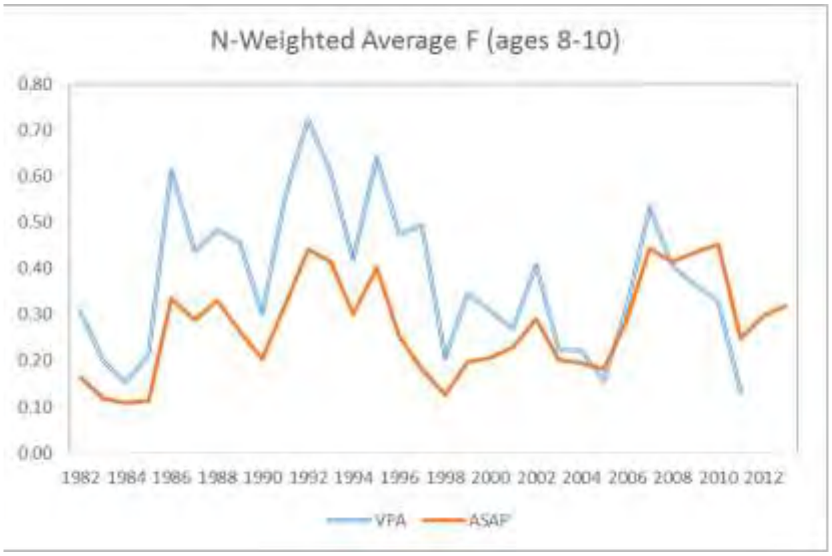


Figure 6.97. Comparison of ASAP and VPA estimates of annual N-weighted average F for ages 8-10 and the 3-year average of those values for the coastwide model.



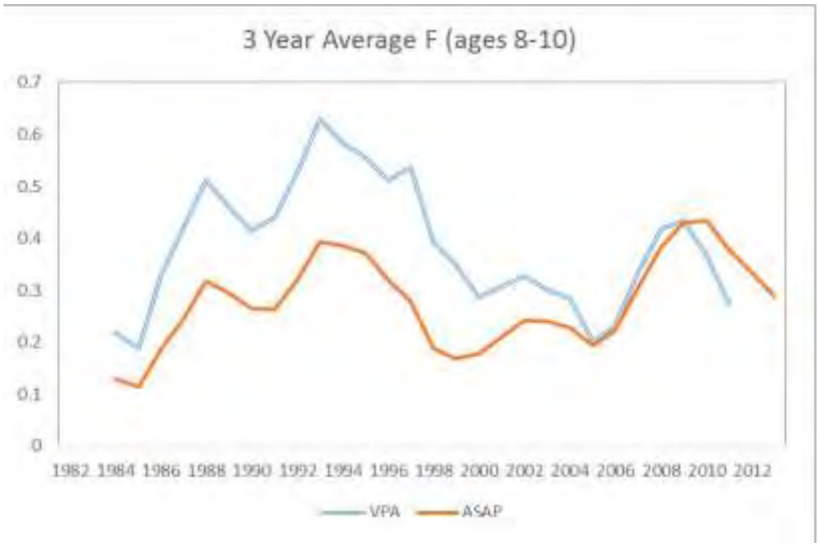


Figure 7.1. F estimates with MCMC confidence intervals and F target and threshold values for the southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

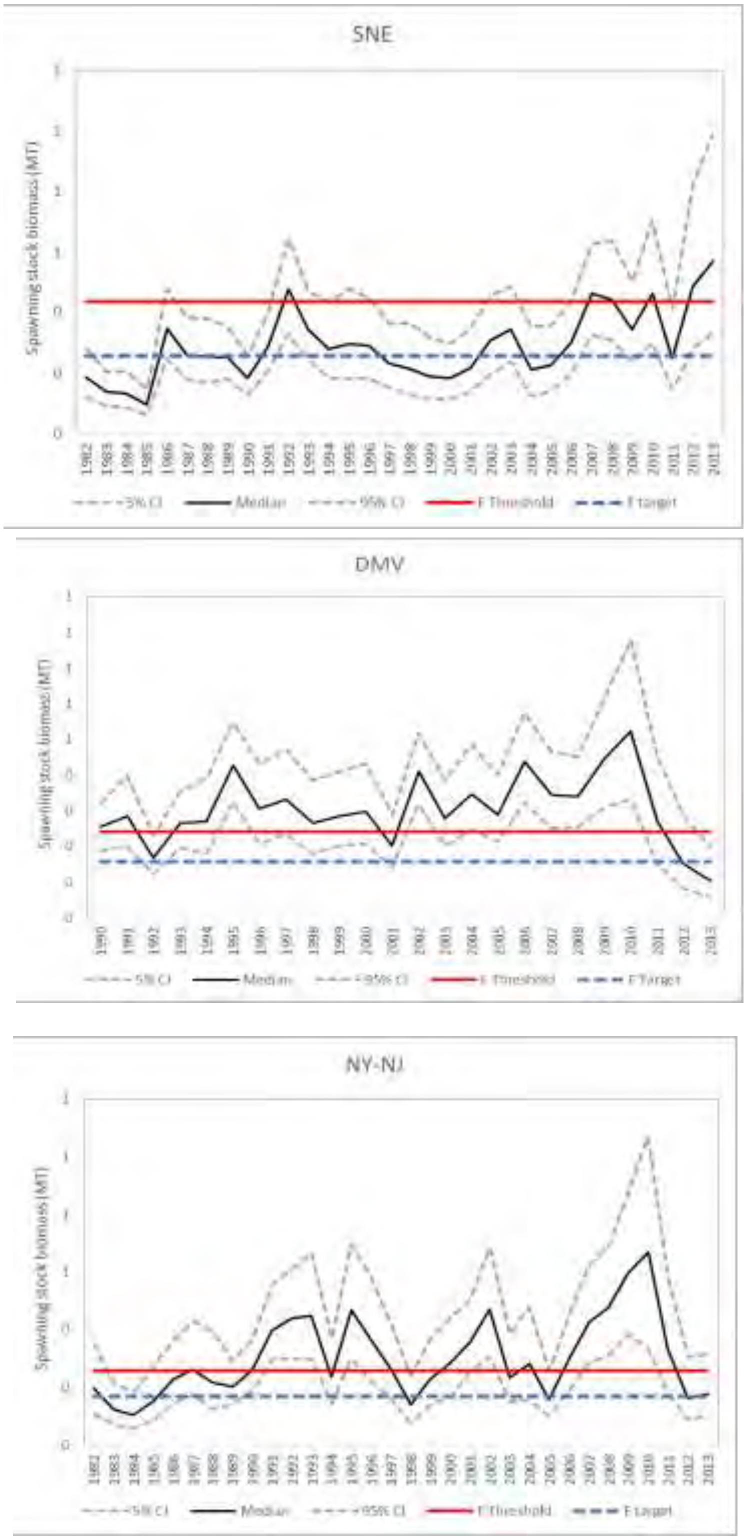
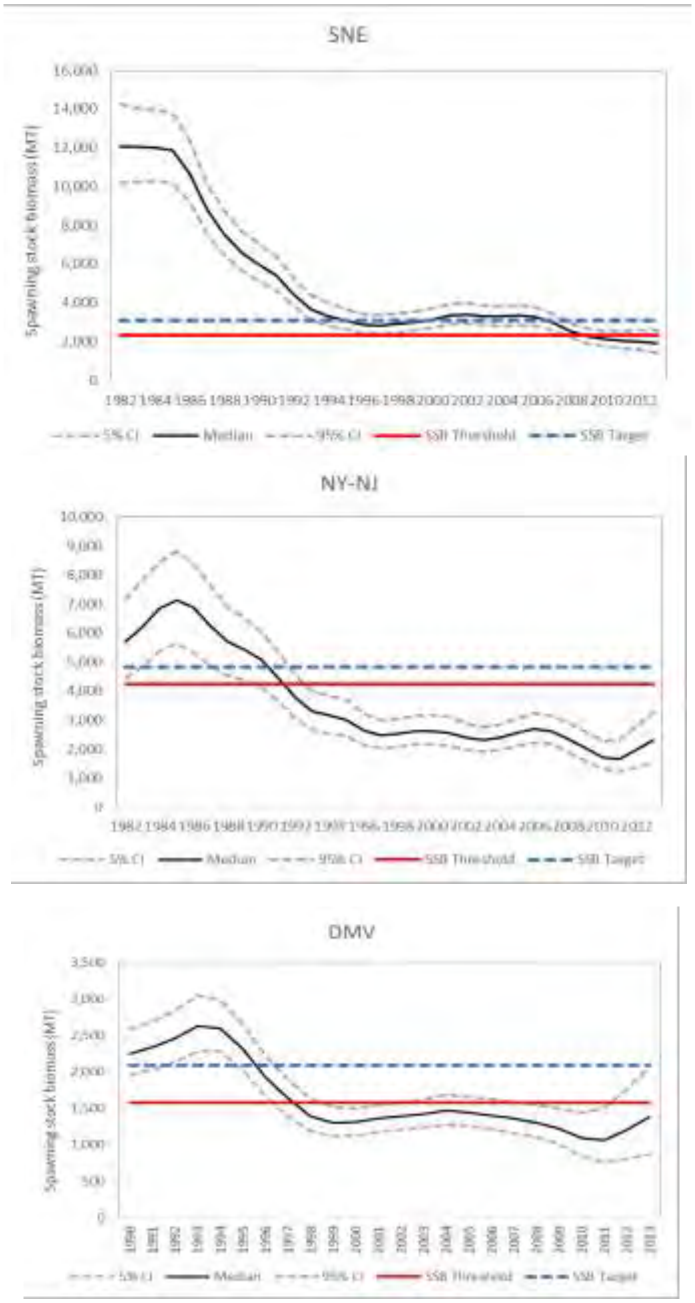


Figure 7.2. SSB estimates with MCMC confidence intervals and SSB target and threshold values for the southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.



Technical Documentation
for
ASAP Version 3.0

NOAA Fisheries Toolbox

September 2012

Table of Contents

Introduction

ASAP3 is an update to the program ASAP (Legault and Restrepo 1998), which was previously updated as ASAP2 in 2008. It contains a number of new features and options that are described in the ASAP3 User's Guide. This document provides the basic equations used in the program along with the approaches used to fit different components of the objective function. More importantly, it contains the actual ADMB code used to generate the executable, so that the exact calculations in the program can be followed. This document uses variable names in a number of places instead of symbols to facilitate understanding of the underlying code.

Basic Equations

The description of the model follows the steps in the code for ease of understanding. Calculation of the objective function is described in the next section.

Spawning Stock Biomass

The spawning stock biomass is calculated based on the population abundance at age (N), the fecundity (Φ), and the proportion of the total mortality (Z, see mortality section below) during the year prior to spawning (p_{SSB}) as

$$SSB_t = \sum_a N_{t,a} \Phi_{t,a} e^{-p_{SSB} Z_{t,a}} \qquad (1)$$

Where the fecundity matrix is either input by the user or else derived as the element by element product of the weight at age matrix and the maturity matrix.

Stock Recruitment Relationship

The Beverton and Holt stock recruitment relationship is used to calculate the expected recruitment in year t+1 from the spawning stock biomass in year t as

$$\hat{R}_{t+1} = \frac{\alpha SSB_t}{\beta + SSB_t} \qquad (2)$$

The equation is reparameterized following Mace and Doonan (ref) to use two parameters: the SR scaler and steepness (τ). The SR scaler can be either unexploited spawning stock biomass (SSB_0) or unexploited recruitment (R_0). These two values are related to each other based on the unexploited spawners per recruit (SPR_0) as $SPR_0 = SSB_0/R_0$. All three of these unexploited values are computed using the natural mortality, weights at age, and maturity (or fecundity) values in the terminal year of the assessment. The stock recruitment relationship is therefor fixed for all years using equation 2 with

$$\alpha = \frac{4\tau(SSB_0 / SPR_0)}{5\tau - 1} \quad and \quad \beta = \frac{SSB_0(1-\tau)}{5\tau - 1} \qquad (3)$$

However, the program also produces the values of unexploited SSB, R, spawners per recruit, and steepness associated with the natural mortality rate, weights at age, and maturity (or fecundity) for each year in the time series. This allows the user to see the influence of these values on the stock recruitment parameters SSB_0, R_0, SPR_0, and τ over time.

Steepness for the Beverton and Holt stock recruitment relationship is only defined between 0.2 and 1.0. Fixing steepness at 1.0 makes expected recruitment constant. The actual recruitment estimated by the model is formed by multiplying the expected recruitment by a recruitment deviation. The recruitment deviations are assumed to follow a lognormal distribution, making the parameters log_Rdev_t. The parameters are estimated as a bounded vector, meaning their sum is zero, so that they are centered on the expected stock recruitment relationship. The population numbers at age 1, recruitment is always assumed to occur at age 1, are

$$N_{t,1} = R_t e^{\log\_Rdev_t} \tag{4}$$

Selectivity

The approach used to estimate fleet selectivity in ASAP3 is quite different from that in ASAP, but the same as in ASAP2. As before, there are selectivity blocks, but now they are defined independently for each fleet. Within each selectivity block, there are three options for estimating selectivity:

1. estimate parameters for each age (one parameter for each age, similar to ASAP in concept, but now each age is bounded by zero and one and at least one age should be fixed at 1.0 instead of estimated)
2. logistic function (2 parameters: α_1, β_1)

   $$Sel_a = \frac{1}{1+e^{-(a-\alpha_1)/\beta_1}} \tag{5}$$

3. double logistic (4 parameters: α_1, β_1, α_2, β_2)

   $$Sel_a = \left(\frac{1}{1+e^{-(a-\alpha_1)/\beta_1}}\right)\left(1-\frac{1}{1+e^{-(a-\alpha_2)/\beta_2}}\right) \tag{6}$$

The selectivity at age is then assigned to all fleet and year combinations within that block. Note that for options 2 and 3, the selectivity at age is divided by the maximum value over all ages, creating the final selectivity vector with maximum of 1.0 for that block.

Mortality

Natural mortality (M) is entered as a year by age matrix, as it was in ASAP2, instead of just a vector by age as it was in ASAP.

Fishing mortality (F) is assumed to be separable, meaning it is the product of a year effect (*Fmult*) and selectivity at age (described above). The *Fmult* for a fleet and year is determined by two sets of parameters, log_Fmult1_{ifleet}, the parameter for first year for that fleet, and $log\_Fmultdev_{ifleet,t}$, where t=2 to the number of years, the deviation of the parameter from the value in the first year for that fleet. Both sets of parameters are estimated in log space and then exponentiated as

$$Fmult_{ifleet,1} = e^{\log\_Fmult1_{ifleet}}$$
$$Fmult_{ifleet,t} = Fmult_{ifleet,1} e^{\log\_Fmultdev_{ifleet,t}} \quad \forall t \geq 2 \tag{7}$$

Note that the *log_Fmultdev* parameters are not estimated as a dev_vector in the ADMB code, and so fishing intensity can increase continually, decrease continually, or fluctuate throughout the time series. The directed F for a fleet, year, and age, meaning that portion of the F that contributes to landings, is computed using the separable equation along with the proportion of catch released for that fleet, year, and age ($prop\_release_{ifleet,t,a}$) as

$$Fdir_{ifleet,t,a} = Fmult_{ifleet,t,a} Sel_{ifleet,t,a} (1 - prop\_release_{ifleet,t,a}) \tag{8}$$

The bycatch F contains an additional component, the proportion of released fish that die, which is fleet specific ($release\_mort_{ifleet}$)

$$Fbycatch_{ifleet,t,a} = Fmult_{ifleet,t,a} Sel_{ifleet,t,a} prop\_release_{ifleet,t,a} release\_mort_{ifleet} \tag{9}$$

The two parts are then added together to produce the fishing mortality for the fleet, year and age

$$F_{ifleet,t,a} = Fdir_{ifleet,t,a} + Fbycatch_{ifleet,t,a} \tag{10}$$

The total mortality (*Z*) is the sum of natural and fishing mortality at year and age over all fleets

$$Z_{t,a} = M_{t,a} + \sum_{ifleet} F_{ifleet,t,a} \tag{11}$$

Population Abundance

The population abundance in the first year for ages 2 through the maximum age are derived from either the initial guesses ($N1ini_a$) and the parameters $log\_Nyear1dev_a$ as

$$N_{1,a} = N1ini_a e^{\log\_Nyear1dev_a} \tag{12}$$

or as deviations from a population in equilibrium according to the total mortality at age vector in the first year. A partial spawning stock biomass for ages 2 through the maximum age is computed and used in the stock recruitment relationship (Eq. 2) to create an expected recruitment in the first year. The recruitment deviation for the first year is applied to form the population abundance at age 1 in the first year (Eq. 4). The full spawning stock biomass is computed for year 1 using all ages (Eq. 1) now that the first year is completely filled.

The population abundance for years 2 through the end year are then filled by first computing the expected recruitment (Eq. 2) and then applying the recruitment deviation to create the abundance at age 1 (Eq. 4). Ages 2 through the maximum age are filled using the following set of equations

$$\begin{aligned} N_{t,a} &= N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 2 \leq a < A \\ N_{t,A} &= N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}} \end{aligned} \tag{13}$$

Each year the spawning stock biomass is computed (Eq. 1) and the cycle continued until the end year is reached.

F Report

The original ASAP simply output the Fmult for each fleet and year as an indicator of fishing intensity, along with the full F matrix by fleet and combined over all fleets. This approach for comparing fishing intensity is sufficient if selectivity does not change over time, but can be problematic when selectivity changes. A feature of ASAP2 that is continued in ASAP3 is the use of Freport, which averages the total fishing mortality over an input range of ages (a_{repmin} to a_{repmax}). The averaging is done unweighted ($\omega_{t,a}$=1), weighted by population abundance at age ($\omega_{t,a}=N_{t,a}$), and weighted by population biomass at age ($\omega_{t,a}=N_{t,a}W_{t,a}$ where $W_{t,a}$ denotes the January 1 weight at year and age) as

$$Freport_t = \frac{\sum_{a=a_{rep\min}}^{a_{rep\max}} \omega_{t,a} F_{t,a}}{\sum_{a=a_{rep\min}}^{a_{rep\max}} \omega_{t,a}} \tag{14}$$

Predicted Catch

The predicted landings (*Lpred*) and discards (*Dpred*) in units of numbers of fish for each fleet, year, and age are derived from the Baranov catch equation

$$Lpred_{ifleet,t,a} = N_{ifleet,t,a} Fdir_{ifleet,t,a} (1-e^{-Z_{t,a}}) / Z_{t,a} \tag{15}$$

$$Dpred_{ifleet,t,a} = N_{ifleet,t,a} Fbycatch_{ifleet,t,a} (1-e^{-Z_{t,a}}) / Z_{t,a} \tag{16}$$

These predictions are used in two ways, one to form the predicted total weight of landings or discards for a fleet and year, and the other to form the proportions at age for a fleet and year. Both calculations are limited by the starting and ending ages for the fleet. The predicted total catch in weight calculations use the catch weight at year and age ($Wc_{t,a}$)

$$\hat{L}tot_{ifleet,t} = \sum_{a=fleetstart}^{fleetend} Lpred_{ifleet,t,a} Wc_{t,a} \tag{17}$$

$$\hat{D}tot_{ifleet,t} = \sum_{a=fleetstart}^{fleetend} Dpred_{ifleet,t,a} Wc_{t,a} \tag{18}$$

Note that since Fbycatch is derived using the proportion of fish that die after release, the total observed discards in weight (*Dtot*) should only include those fish that die after capture and release.

The predicted landings and discards proportions at age for each fleet and year are only computed for ages within the starting and ending range

$$\hat{L}p_{ifleet,t,a} = \frac{Lpred_{ifleet,t,a}}{\sum_{a=fleetstart}^{fleetend} Lpred_{ifleet,t,a}} \tag{19}$$

$$\hat{D}p_{ifleet,t,a} = \frac{Dpred_{ifleet,t,a}}{\sum_{a=fleetstart}^{fleetend} Dpred_{ifleet,t,a}} \tag{20}$$

Any predicted proportion less than 1e-15 is replaced by the value 1e-15 to avoid division by zero problems in the calculation of the likelihood function.

Catchability

Catchability for each index (*ind*) over time is computed similarly to the Fmult, with one parameter for the catchability in the first year (log_q1_{ind}) and a number of deviation parameters for each additional year of index observations ($log\_q\_dev_{ind,t}$). These parameters are combined and exponentiated to form the catchability value for the fleet and year as

$$q_{ind,t} = e^{\log\_q1_{ind} + \log\_q\_dev_{ind,t}} \tag{21}$$

where the parameter for the deviation in the first year ($log\_q\_dev_{ind,1}$) is defined as zero.

Predicted Indices

The observed indices have two characteristics that are matched when predicted values are computed, the time of year of the index and the units (numbers or biomass). The estimated population numbers at age are modified to the time of the index according to

$$N*_{ind,t,a} = N_{t,a} \frac{1-e^{-Z_{t,a}}}{Z_{t,a}} \tag{22}$$

if the index month is set to -1, corresponding to an average abundance, or

$$N*_{ind,t,a} = N_{t,a}(1-e^{-(ind\_month/12)Z_{t,a}}) \tag{23}$$

for index month between 0 and 12. Note that the index month refers to the end of the month, so *ind_month*=0 is January 1 and *ind_month*=12 is December 31. If the units for an index are biomass, then the N* values are multiplied by the user defined weights at age matrix. The selectivity associated with each index is either matched to a fleet or else input. If the selectivity for a fleet is input, it can be either fixed or estimated in the same way as the fleet selectivities (age based, logistic, or double logistic). The final predicted index (*Ipred*) is formed by summing the product of N* and selectivity values over the appropriate ages and multiplying by the catchability for the index

$$Ipred_{ind,t} = q_{ind,t} \sum_{a=indstart}^{indend} N*_{ind,t,a} \, Sel_{ind,t,a} \tag{24}$$

If the user selects to estimate the proportions at age for an index, then the proportions at age are computed in the same manner as the landings and discards at age (equations 19 and 20). Note that the units used for the aggregate index and proportions at age are set by the user separately, so all four combinations of numbers and biomass are possible.

Reference Points

The program computes a number of common reference points based on the estimated F and biological characteristics of the final year in the assessment. The reference points derive a directed and discard selectivity pattern from all the fleets that were assigned to be directed by summing the F at age and dividing by the maximum directed F. The nondirected F is summed over all fleets that were not assigned as directed, and these F values are fixed during the reference point calculations. The F reference points are computed through a bisection algorithm that is repeated 20 times (producing an accuracy of approximately 1E-05). The reference points computed are $F_{0.1}$, F_{MAX}, $F_{30\%SPR}$, $F_{40\%SPR}$, and F_{MSY}. The associated maximum sustainable yield and spawning stock biomass at F_{MSY} are also provided. The reference point values are averaged in the same manner as the Freport to allow direct comparison. Note, however, that if selectivity or biological characteristics change over time, these comparisons will not be accurate because the reference points are computed assuming the final year values. The program now computes the annual unexploited SSB, unexploited R, unexploited SSB per R, and steepness to demonstrate the potential for change in the F reference points.

Projections

The projections use the same basic calculations as the main assessment program, except that there is no fitting done. The recruitments for each projection year can either be entered by the user or else be derived from the stock recruitment curve (without deviations from the curve). The directed and discard selectivity as well as the bycatch F at age are the same as used in the reference point calculations. There are five options to define what is used to define the fishery in each projections year:

1. match an input directed catch in weight
2. fish at an input F%SPR
3. fish at F_{MSY}
4. fish at the current (terminal year) F
5. fish at an input F

Each year the bycatch F can be modified from the terminal year to examine either increases or decreases in this(these) fishery(ies).

Objective Function Calculation (Fitting the Model)

The objective function in ASAP3 is the sum of a number of model fits and two penalties. There are two types of error distributions in the calculation of the objective function: lognormal and multinomial. Both are converted to negative log likelihoods for use in the minimization conducted by ADMB. Both error distributions contain constant terms that do not change for any value of the parameters. These constants can be either included or excluded from the objective function. Note that since the weights for different components of the objective function multiply the constants, different solutions may result when the constants are included or not.

The lognormal model fits all contain a lambda value that allows emphasis of that particular part of the objective function along with an input coefficient of variation (CV) that is used to measure how strong a particular deviation is. The CV is converted to a variance (σ^2) and associated standard deviation (σ) using the equation

$$\sigma^2 = \ln(CV^2 + 1) \tag{25}$$

The lognormal distribution has a negative log likelihood, *-ln(L)*, defined by

$$-\ln(L) = 0.5\ln(2\pi) + \sum \ln(obs_i) + \ln(\sigma) + 0.5\sum \frac{(\ln(obs_i) - \ln(pred_i))^2}{\sigma^2} \qquad (26)$$

The first two terms on the right side of equation (26) are the constants that are optionally kept or set to zero. The objective function is calculated as

$$obj\ \ fxn = \lambda * (-\ln(L)) \qquad (27)$$

So that any component of the objective function can be turned off by setting λ for that component to zero. Standardized residuals for each component are calculated as

$$std\ \ resid_i = \frac{\ln(obs_i) - \ln(pred_i)}{\sigma} \qquad (28)$$

In a perfectly fit model, the standardized residuals would have mean zero and standard deviation one.

The multinomial distribution fits employ an input effective sample size to multiply the negative log likelihood when calculating the objective function. This distribution is made up of k bins each containing p_i proportion of the total (sum of p_i=1). The input effective sample size (*ESS*) is used to create the number of fish in each bin (n_i) as $n_i=ESS*p_i$. The multinomial distribution then has a negative log likelihood defined by

$$-\ln(L) = -\ln(ESS!) + \sum_{i=1}^{k} \ln(n_i!) - ESS\sum_{i=1}^{k} p_i \ln(predp_i) \qquad (29)$$

where p_i denotes an observed proportion and $predp_i$ denotes the associated predicted proportion. The first two terms on the right side of equation (29) are the constants that are optionally kept or set to zero. The objective function is simply the negative log likelihood for the multinomial distribution because the effective sample size is an integral part of the calculation of the likelihood.

The lognormal error distribution is assumed for

- Total catch in weight
- Total discards in weight
- Indices
- Stock recruitment relationship
- Selectivity parameters (relative to initial guesses)
- The two stock recruitment parameters (relative to their initial guesses)
- Fmult in year 1 by fleet (relative to initial guesses)
- Fmult deviations
- Catchability in year 1 by fleet (relative to initial guesses)
- Catchability deviations
- Numbers at age in year 1 (relative to either initial guesses or a population in equilibrium)

Multinomial distribution is assumed for

- Catch at age
- Discards at age
- Index proportions at age

The two penalties are formed from estimated total fishing mortality rates. The first is a penalty associated with any total F greater than an input maximum value, calculated as $1000*(F\text{-}Fmax)^2$ for F>Fmax. The second penalty is for F different than M in the early phases, calculated as $100*10^{-phase}$ $(\ln(avg(F)\text{-}\ln(M))^2$. The second penalty is always set to zero in the final estimation phase, regardless of the number of phases.

Appendix 1: Source Code for ASAP3

(Note the code sometimes wraps around to the next line in the presentation here.)

```
// ASAP3 (Age Structured Assessment Program Version 3: August 2012)
//   by Christopher Legault with major contributions from Liz Brooks
//   modified from ASAP2 by Christopher Legault
//   modified from original ASAP by Christopher Legault and Victor Restrepo 1998

// Major changes from ASAP2
// user defines SR curve using steepness and either R0 or S0
// allow user to mix and match biomass and numbers for aggreagate indices and indices proportions at age
// user enters a number of weight at age matrices then defines which are used for catch, discards, SSB, Jan-1 B,
and indices
// compute annual SR curve estimates of R0, S0, steepness, and spawners per recruit to show how changes in M,
fecundity, WAA impact these estimates over time
// expected population at age in year 1 can be either an exponential decline or user initial guesses for
optional deviation calculations
// compute Francis (2011) stage 2 multiplier for multinomial to adjust input Neff

// update April 2012
// fix bug with which inconsistent year for M and WAA used in calculation of unexploited SSB per recruit
// (was first year when all other calculations were last year, now everything last year)
// also added trap for division by zero in Freport calculation to avoid crashes when pop size gets small
// incorporated Liz Brook's make-Rfile.cxx for ADMB2R to optionally create rdat file automatically
// created new output file asap2RMSE.dat for use with R script

// update April 2008
// fixed bug in get_log_factorial function - variable could be i used in two places (thanks to Tim Miller for
finding this one)
//
// Major changes from original ASAP
//
// Enter all available indices and then select which ones to use for tuning
// Change in selectivity estimation to reduce parameter correlations
//   Added option to use logistic or double logistic selectivity patterns
//   Selectivity blocks now independent with own initial starting guesses
// Added CVs and lambdas for many parameters
// Multiple matrices for weights at age at different times of the year
// M matrix instead of vector
// Freport feature to allow easier comparison among years with different selectivity patterns
// Echo input read to file for improved debugging
// MCMC capability added
//   One file for Freport, SSB, and MSY related variables
//   One file for use in AgePro software (.bsn file)
// Full likelihood calculations, including (optionally) constants
// Output of standardized residuals
// Modified year 1 recruitment deviation calculations to reduce probability of extremely large residual

TOP_OF_MAIN_SECTION
// set buffer sizes
  arrmblsize=5000000;
  gradient_structure::set_GRADSTACK_BUFFER_SIZE(10000000);
  gradient_structure::set_MAX_NVAR_OFFSET(50000);
  gradient_structure::set_NUM_DEPENDENT_VARIABLES(10000);
  time(&start); //this is to see how long it takes to run
  cout << endl << "Start time : " << ctime(&start) << endl;

GLOBALS_SECTION
  #include <admodel.h>
  #include <time.h>
  #include <C:\ADMB\admb2r-1.15\admb2r\admb2r.cpp>
  time_t start,finish;
  long hour,minute,second;
  double elapsed_time;
  ofstream ageproMCMC("asap3.bsn");
  ofstream basicMCMC("asap3MCMC.dat");
  ofstream inputlog("asap3input.log");
  //--- preprocessor macro from Larry Jacobson NMFS-Woods Hole
```

```
  #define ICHECK(object) inputlog << "#" #object "\n " << object << endl;

DATA_SECTION
  int debug
  int iyear
  int iage
  int ia
  int ifleet
  int ind
  int i
  int j
  int k
  int iloop
  int io
  number pi
 !!  pi=3.14159265358979;
  number CVfill
 !! CVfill=100.0;
// basic dimensions
  init_int nyears
 !! ICHECK(nyears);
  init_int year1
 !! ICHECK(year1);
  init_int nages
 !! ICHECK(nages);
  init_int nfleets
 !! ICHECK(nfleets);
  init_int nselblocks;
 !! ICHECK(nselblocks);
  init_int navailindices
 !! ICHECK(navailindices);

// biology
  init_matrix M(1,nyears,1,nages)
 !! ICHECK(M);
  init_number isfecund
 !! ICHECK(isfecund);
  init_number fracyearSSB
 !! ICHECK(fracyearSSB);
  init_matrix mature(1,nyears,1,nages)
 !! ICHECK(mature);
  init_int nWAAmatrices
 !! ICHECK(nWAAmatrices);
  int nrowsWAAini
 !! nrowsWAAini=nyears*nWAAmatrices;
  init_matrix WAA_ini(1,nrowsWAAini,1,nages)
 !! ICHECK(WAA_ini);
  int nWAApointbio
 !! nWAApointbio=nfleets*2+2+2;
  init_ivector WAApointbio(1,nWAApointbio) // pointers to WAA matrix for fleet catch and discards, catch all fleets, discard all fleets, SSB, and Jan1B
 !! ICHECK(WAApointbio);
  matrix fecundity(1,nyears,1,nages)
  3darray WAAcatchfleet(1,nfleets,1,nyears,1,nages)
  3darray WAAdiscardfleet(1,nfleets,1,nyears,1,nages)
  matrix WAAcatchall(1,nyears,1,nages)
  matrix WAAdiscardall(1,nyears,1,nages)
  matrix WAAssb(1,nyears,1,nages)
  matrix WAAjan1b(1,nyears,1,nages)
 LOCAL_CALCS
  if ((max(WAApointbio) > nWAAmatrices) || (min(WAApointbio) < 1))
  {
     cout << "Problem with WAApointbio" << endl;
     ad_exit(1);
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     int ipointcatchfleet=(WAApointbio((ifleet*2)-1)-1)*nyears;
     int ipointdiscardfleet=(WAApointbio(ifleet*2)-1)*nyears;
     for (iyear=1;iyear<=nyears;iyear++)
     {
```

```
        WAAcatchfleet(ifleet,iyear)=WAA_ini((ipointcatchfleet+iyear));
        WAAdiscardfleet(ifleet,iyear)=WAA_ini((ipointdiscardfleet+iyear));
     }
  }
  int ipointcatchall=(WAApointbio((nfleets*2)+1)-1)*nyears;
  int ipointdiscardall=(WAApointbio((nfleets*2)+2)-1)*nyears;
  int ipointssb=(WAApointbio((nfleets*2)+3)-1)*nyears;
  int ipointjan1b=(WAApointbio((nfleets*2)+4)-1)*nyears;
  for (iyear=1;iyear<=nyears;iyear++)
  {
     WAAcatchall(iyear)=WAA_ini((ipointcatchall+iyear));
     WAAdiscardall(iyear)=WAA_ini((ipointdiscardall+iyear));
     WAAssb(iyear)=WAA_ini((ipointssb+iyear));
     WAAjan1b(iyear)=WAA_ini((ipointjan1b+iyear));
  }
  if (isfecund==1)
     fecundity=mature;
  else
     fecundity=elem_prod(WAAssb,mature);
 END_CALCS

// fleet names here with $ in front of label

// Selectivity ****************************************
// need to enter values for all options even though only one will be used for each block
  init_matrix sel_blocks(1,nfleets,1,nyears) // defines blocks for each fleet in successive order
 !! ICHECK(sel_blocks);
  int nsel_ini
 !! nsel_ini=nselblocks*(nages+6);
  init_ivector sel_option(1,nselblocks) // 1=by age, 2=logisitic, 3=double logistic
 !! ICHECK(sel_option);
  init_matrix sel_ini(1,nsel_ini,1,4) // 1st value is initial guess, 2nd is phase, 3rd is lambda, 4th is CV
 !! ICHECK(sel_ini);
  int nselparm
 LOCAL_CALCS
// first count number of selectivity parameters and replace CV=0 with CVfill
  nselparm=0;
  for (i=1;i<=nselblocks;i++)
  {
     if (sel_option(i)==1) nselparm+=nages;
     if (sel_option(i)==2) nselparm+=2;
     if (sel_option(i)==3) nselparm+=4;
  }
  for (i=1;i<=nsel_ini;i++)
  {
     if (sel_ini(i,4) <= 0.0)
         sel_ini(i,4) = CVfill;
  }
 END_CALCS
  vector sel_initial(1,nselparm)
  vector sel_lo(1,nselparm)
  vector sel_hi(1,nselparm)
  ivector sel_phase(1,nselparm)
  vector sel_lambda(1,nselparm)
  vector sel_CV(1,nselparm)
  vector sel_sigma2(1,nselparm)
  vector sel_sigma(1,nselparm)
  vector sel_like_const(1,nselparm)
 LOCAL_CALCS
// now assign bounds and phases for each selectivity parameter
  k=0;
  for (i=1;i<=nselblocks;i++){
     if (sel_option(i)==1) {
        for (iage=1;iage<=nages;iage++) {
           k+=1;
           j=(i-1)*(nages+6)+iage;
           sel_initial(k)=sel_ini(j,1);
           sel_lo(k)=0.0;
           sel_hi(k)=1.0;
           sel_phase(k)=sel_ini(j,2);
           sel_lambda(k)=sel_ini(j,3);
```

```
           sel_CV(k)=sel_ini(j,4);
           sel_sigma2(k)=log(sel_CV(k)*sel_CV(k)+1.0);
           sel_sigma(k)=sqrt(sel_sigma2(k));
        }
     }
     if (sel_option(i)==2) {
        for (ia=1;ia<=2;ia++) {
           k+=1;
           j=(i-1)*(nages+6)+nages+ia;
           sel_initial(k)=sel_ini(j,1);
           sel_lo(k)=0.0;
           sel_hi(k)=nages;
           sel_phase(k)=sel_ini(j,2);
           sel_lambda(k)=sel_ini(j,3);
           sel_CV(k)=sel_ini(j,4);
           sel_sigma2(k)=log(sel_CV(k)*sel_CV(k)+1.0);
           sel_sigma(k)=sqrt(sel_sigma2(k));
        }
     }
     if (sel_option(i)==3) {
        for (ia=1;ia<=4;ia++) {
           k+=1;
           j=(i-1)*(nages+6)+nages+2+ia;
           sel_initial(k)=sel_ini(j,1);
           sel_lo(k)=0.0;
           sel_hi(k)=nages;
           sel_phase(k)=sel_ini(j,2);
           sel_lambda(k)=sel_ini(j,3);
           sel_CV(k)=sel_ini(j,4);
           sel_sigma2(k)=log(sel_CV(k)*sel_CV(k)+1.0);
           sel_sigma(k)=sqrt(sel_sigma2(k));
        }
     }
  }
 END_CALCS
  init_ivector sel_start_age(1,nfleets)
 !! ICHECK(sel_start_age);
  init_ivector sel_end_age(1,nfleets)
 !! ICHECK(sel_end_age);

  init_int Freport_agemin
 !! ICHECK(Freport_agemin);
  init_int Freport_agemax
 !! ICHECK(Freport_agemax);
  init_int Freport_wtopt
 !! ICHECK(Freport_wtopt);

  init_int use_likelihood_constants
 !! ICHECK(use_likelihood_constants);
  init_vector release_mort(1,nfleets)
 !! ICHECK(release_mort);

// Catch ******************************************
// Includes both landed and discarded components
  init_matrix CAA_ini(1,nyears*nfleets,1,nages+1)
 !! ICHECK(CAA_ini);
  init_matrix Discard_ini(1,nyears*nfleets,1,nages+1)
 !! ICHECK(Discard_ini);
  init_matrix proportion_release_ini(1,nyears*nfleets,1,nages)
 !! ICHECK(proportion_release_ini);
  3darray CAA_obs(1,nfleets,1,nyears,1,nages)
  3darray Discard_obs(1,nfleets,1,nyears,1,nages)
  3darray proportion_release(1,nfleets,1,nyears,1,nages)
  3darray CAA_prop_obs(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  3darray Discard_prop_obs(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  number catch_prop_like_const
  number discard_prop_like_const
  matrix Catch_tot_fleet_obs(1,nfleets,1,nyears)
  matrix Discard_tot_fleet_obs(1,nfleets,1,nyears)
  matrix CAA_prop_obs_sum(1,nfleets,1,nyears)
  matrix Discard_prop_obs_sum(1,nfleets,1,nyears)
```

```
  vector catch_tot_like_const(1,nfleets)
  vector discard_tot_like_const(1,nfleets)
 LOCAL_CALCS
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     catch_tot_like_const(ifleet)=0.0;
     discard_tot_like_const(ifleet)=0.0;
     for (iyear=1;iyear<=nyears;iyear++)
     {
        CAA_obs(ifleet,iyear)(1,nages)=CAA_ini((ifleet-1)*nyears+iyear)(1,nages);
        Discard_obs(ifleet,iyear)(1,nages)=Discard_ini((ifleet-1)*nyears+iyear)(1,nages);
        proportion_release(ifleet,iyear)=proportion_release_ini((ifleet-1)*nyears+iyear)(1,nages);
        Catch_tot_fleet_obs(ifleet,iyear)=CAA_ini((ifleet-1)*nyears+iyear,nages+1);
        Discard_tot_fleet_obs(ifleet,iyear)=Discard_ini((ifleet-1)*nyears+iyear,nages+1);
        if (Catch_tot_fleet_obs(ifleet,iyear)>1.0e-15)
           catch_tot_like_const(ifleet)+=0.5*log(2.0*pi)+log(Catch_tot_fleet_obs(ifleet,iyear));
        if (Discard_tot_fleet_obs(ifleet,iyear)>1.0e-15)
           discard_tot_like_const(ifleet)=0.5*log(2.0*pi)+log(Discard_tot_fleet_obs(ifleet,iyear));
     }
  }
  if (use_likelihood_constants != 1)
  {
     catch_tot_like_const=0.0;
     discard_tot_like_const=0.0;
  }
  CAA_prop_obs=0.0;
  Discard_prop_obs=0.0;
  CAA_prop_obs_sum=0.0;
  Discard_prop_obs_sum=0.0;
  for (iyear=1;iyear<=nyears;iyear++)
  {
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
       if (Catch_tot_fleet_obs(ifleet,iyear)>0.0)
       {
          for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             CAA_prop_obs_sum(ifleet,iyear)+=CAA_obs(ifleet,iyear,iage);
          if (CAA_prop_obs_sum(ifleet,iyear)==0.0)
          {
             CAA_prop_obs(ifleet,iyear)=0.0;
          }
          else
          {

CAA_prop_obs(ifleet,iyear)=CAA_obs(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/CAA_prop_obs_sum(ifl
eet,iyear);
          }
       }
       if (Discard_tot_fleet_obs(ifleet,iyear)>0.0)
       {
          for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             Discard_prop_obs_sum(ifleet,iyear)+=Discard_obs(ifleet,iyear,iage);
          if (Discard_prop_obs_sum(ifleet,iyear)==0.0)
          {
             Discard_prop_obs(ifleet,iyear)=0.0;
          }
          else
          {

Discard_prop_obs(ifleet,iyear)=Discard_obs(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/Discard_prop
_obs_sum(ifleet,iyear);
          }
       }
    }
  }
 END_CALCS

// Indices ******************************
// Enter in all available indices and then pick the ones that are to be used in objective function
// navailindices is the number of indices entered
// nindices is the number of indices used (calculated by program)
```

```
  int indavail
// index names here with $ in front of label
  init_vector index_units_aggregate_ini(1,navailindices) // 1=biomass, 2=numbers
 !! ICHECK(index_units_aggregate_ini);
  init_vector index_units_proportions_ini(1,navailindices) // 1=biomass, 2=numbers
 !! ICHECK(index_units_proportions_ini);
  init_ivector index_WAApoint_ini(1,navailindices) // pointer for which WAA matrix to use for biomass
calculations for each index
 !! ICHECK(index_WAApoint_ini);
  init_vector index_month_ini(1,navailindices) // -1=average pop
 !! ICHECK(index_month_ini);
  init_ivector index_sel_choice_ini(1,navailindices) // -1=fixed
 !! ICHECK(index_sel_choice_ini);
  init_ivector index_sel_option_ini(1,navailindices) // 1=by age, 2=logisitic, 3=double logistic
 !! ICHECK(index_sel_option_ini);
  init_ivector index_start_age_ini(1,navailindices)
 !! ICHECK(index_start_age_ini);
  init_ivector index_end_age_ini(1,navailindices)
 !! ICHECK(index_end_age_ini);
  init_ivector index_estimate_proportions_ini(1,navailindices) // 1=yes
 !! ICHECK(index_estimate_proportions_ini);
  init_ivector use_index(1,navailindices) // 1=yes
 !! ICHECK(use_index);
  int nindexsel_ini
 !! nindexsel_ini=navailindices*(nages+6);
  init_matrix index_sel_ini(1,nindexsel_ini,1,4) // 1st value is initial guess, 2nd is phase, 3rd is lambda, 4th
is CV
 !! ICHECK(index_sel_ini);
  init_matrix index_ini(1,nyears*navailindices,1,3+nages+1) // year, index value, CV, proportions at age, input
effective sample size
 !! ICHECK(index_ini);
  int nindices
 !! nindices=sum(use_index);
  vector index_units_aggregate(1,nindices)
  vector index_units_proportions(1,nindices)
  ivector index_WAApoint(1,nindices)
  vector index_month(1,nindices)
  vector index_sel_option(1,nindices)
  vector index_start_age(1,nindices)
  vector index_end_age(1,nindices)
  vector index_sel_choice(1,nindices)
  ivector index_nobs(1,nindices)
  ivector index_estimate_proportions(1,nindices)
  int nindexselparms
 LOCAL_CALCS
  if ((max(index_WAApoint_ini) > nWAAmatrices) || (min(index_WAApoint_ini) < 1))
  {
     cout << "Problem with index_WAApoint_ini" << endl;
     ad_exit(1);
  }
  for (i=1;i<=nindexsel_ini;i++)
  {
     if (index_sel_ini(i,4) <= 0.0)
         index_sel_ini(i,4) = CVfill;
  }
  for (i=1;i<=nyears*navailindices;i++)
  {
     if (index_ini(i,3) <= 0.0)
         index_ini(i,3) = CVfill;
  }
  ind=0;
  nindexselparms=0;
  for (indavail=1;indavail<=navailindices;indavail++)
  {
     if (use_index(indavail)==1)
     {
       ind+=1;
       index_units_aggregate(ind)=index_units_aggregate_ini(indavail);
       index_units_proportions(ind)=index_units_proportions_ini(indavail);
       index_WAApoint(ind)=index_WAApoint_ini(indavail);
       index_month(ind)=index_month_ini(indavail);
```

```
       index_sel_option(ind)=index_sel_option_ini(indavail);
       if (index_sel_option(ind)==1) nindexselparms+=nages;
       if (index_sel_option(ind)==2) nindexselparms+=2;
       if (index_sel_option(ind)==3) nindexselparms+=4;
       index_start_age(ind)=index_start_age_ini(indavail);
       index_end_age(ind)=index_end_age_ini(indavail);
       index_sel_choice(ind)=index_sel_choice_ini(indavail);
       index_estimate_proportions(ind)=index_estimate_proportions_ini(indavail);
       j=0;
       for (iyear=1;iyear<=nyears;iyear++)
       {
         if (index_ini((indavail-1)*nyears+iyear,2)>0.0)  // zero or negative value for index means not included
             j+=1;
       }
       index_nobs(ind)=j;
     }
  }
 END_CALCS
  matrix index_time(1,nindices,1,index_nobs)
  matrix index_year(1,nindices,1,index_nobs)
  matrix index_obs(1,nindices,1,index_nobs)
  matrix index_cv(1,nindices,1,index_nobs)
  matrix index_sigma2(1,nindices,1,index_nobs)
  matrix index_sigma(1,nindices,1,index_nobs)
  matrix input_eff_samp_size_index(1,nindices,1,index_nobs)
  vector indexsel_initial(1,nindexselparms)
  vector indexsel_lo(1,nindexselparms)
  vector indexsel_hi(1,nindexselparms)
  ivector indexsel_phase(1,nindexselparms)
  vector indexsel_lambda(1,nindexselparms)
  vector indexsel_CV(1,nindexselparms)
  vector indexsel_sigma2(1,nindexselparms)
  vector indexsel_sigma(1,nindexselparms)
  vector indexsel_like_const(1,nindexselparms)
  number index_prop_like_const
  3darray index_sel_input(1,nindices,1,nyears,1,nages)
  3darray index_prop_obs(1,nindices,1,index_nobs,1,nages)
  3darray index_WAA(1,nindices,1,nyears,1,nages)
  vector index_like_const(1,nindices)
  number tempsum
 LOCAL_CALCS
  index_prop_obs=0.0;
  ind=0;
  k=0;
  for (indavail=1;indavail<=navailindices;indavail++)
  {
     if (use_index(indavail)==1)
     {
       ind+=1;
// get the index selectivity information
      if (index_sel_option(ind)==1)
      {
         for (iage=1;iage<=nages;iage++)
         {
            k+=1;
            j=(indavail-1)*(nages+6)+iage;
            indexsel_initial(k)=index_sel_ini(j,1);
            indexsel_lo(k)=0.0;
            indexsel_hi(k)=1.0;
            indexsel_phase(k)=index_sel_ini(j,2);
            indexsel_lambda(k)=index_sel_ini(j,3);
            indexsel_CV(k)=index_sel_ini(j,4);
            indexsel_sigma2(k)=log(indexsel_CV(k)*indexsel_CV(k)+1.0);
            indexsel_sigma(k)=sqrt(indexsel_sigma2(k));
         }
      }
      else if (index_sel_option(ind)==2)
      {
         for (ia=1;ia<=2;ia++)
         {
            k+=1;
```

```
            j=(indavail-1)*(nages+6)+nages+ia;
            indexsel_initial(k)=index_sel_ini(j,1);
            indexsel_lo(k)=0.0;
            indexsel_hi(k)=nages;
            indexsel_phase(k)=index_sel_ini(j,2);
            indexsel_lambda(k)=index_sel_ini(j,3);
            indexsel_CV(k)=index_sel_ini(j,4);
            indexsel_sigma2(k)=log(indexsel_CV(k)*indexsel_CV(k)+1.0);
            indexsel_sigma(k)=sqrt(indexsel_sigma2(k));
         }
      }
      else if (index_sel_option(ind)==3)
      {
         for (ia=1;ia<=4;ia++)
         {
            k+=1;
            j=(indavail-1)*(nages+6)+nages+2+ia;
            indexsel_initial(k)=index_sel_ini(j,1);
            indexsel_lo(k)=0.0;
            indexsel_hi(k)=nages;
            indexsel_phase(k)=index_sel_ini(j,2);
            indexsel_lambda(k)=index_sel_ini(j,3);
            indexsel_CV(k)=index_sel_ini(j,4);
            indexsel_sigma2(k)=log(indexsel_CV(k)*indexsel_CV(k)+1.0);
            indexsel_sigma(k)=sqrt(indexsel_sigma2(k));
         }
      }

// get the index and year specific information
       j=0;
       for (iyear=1;iyear<=nyears;iyear++)
       {
         i=(indavail-1)*nyears+iyear;
         index_sel_input(ind,iyear)=--(--(--index_ini(i)(4,3+nages)));
         if (index_ini(i,2)>0.0)
         {
             j+=1;
             index_time(ind,j)=index_ini(i,1)-year1+1;
             index_year(ind,j)=index_ini(i,1);
             index_obs(ind,j)=index_ini(i,2);
             index_cv(ind,j)=index_ini(i,3);
             index_sigma2(ind,j)=log(index_cv(ind,j)*index_cv(ind,j)+1.0);
             index_sigma(ind,j)=sqrt(index_sigma2(ind,j));
             input_eff_samp_size_index(ind,j)=index_ini(i,nages+4);
             tempsum=sum(index_sel_input(ind,iyear)(index_start_age(ind),index_end_age(ind)));
             if (tempsum > 0.0)
             {
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                     index_prop_obs(ind,j,iage)=index_sel_input(ind,iyear,iage)/tempsum;
                 }
             }
         }
       }
     }
  }
  index_like_const=0.0;
  if (use_likelihood_constants==1)
  {
     for (ind=1;ind<=nindices;ind++)
     {
        index_like_const(ind)=0.5*double(index_nobs(ind))*log(2.0*pi)+sum(log(index_obs(ind)));
     }
  }

// set up the index_WAA matrices (indices in numbers only will have WAA set to 0)
  index_WAA=0.0;
  for (ind=1;ind<=nindices;ind++)
  {
     if (index_units_aggregate(ind)==1 || index_units_proportions(ind)==1)
     {
```

```
        int ipointindex=(index_WAApoint(ind)-1)*nyears;
        for (iyear=1;iyear<=nyears;iyear++)
        {
           index_WAA(ind,iyear)=WAA_ini((ipointindex+iyear));
        }
     }
  }
 END_CALCS

// Phase Controls (other than selectivity)
  init_int phase_Fmult_year1
 !! ICHECK(phase_Fmult_year1);
  init_int phase_Fmult_devs
 !! ICHECK(phase_Fmult_devs);
  init_int phase_recruit_devs
 !! ICHECK(phase_recruit_devs);
  init_int phase_N_year1_devs
 !! ICHECK(phase_N_year1_devs);
  init_int phase_q_year1
 !! ICHECK(phase_q_year1);
  init_int phase_q_devs
 !! ICHECK(phase_q_devs);
  init_int phase_SR_scaler
 !! ICHECK(phase_SR_scaler);
  init_int phase_steepness
 !! ICHECK(phase_steepness);
  init_vector recruit_CV(1,nyears)
 !! ICHECK(recruit_CV);
  vector recruit_sigma2(1,nyears)
  vector recruit_sigma(1,nyears)
  number SR_like_const
 LOCAL_CALCS
  for (iyear=1;iyear<=nyears;iyear++)
  {
    if (recruit_CV(iyear) <= 0.0)
        recruit_CV(iyear) = CVfill;
    recruit_sigma2(iyear)=log(recruit_CV(iyear)*recruit_CV(iyear)+1.0);
    recruit_sigma(iyear)=sqrt(recruit_sigma2(iyear));
  }
  SR_like_const=0.0;
  if (use_likelihood_constants == 1)
     SR_like_const=0.5*double(nyears)*log(2.0*pi);
 END_CALCS
  init_vector lambda_ind_ini(1,navailindices)
 !! ICHECK(lambda_ind_ini);
  init_vector lambda_catch_tot(1,nfleets)
 !! ICHECK(lambda_catch_tot);
  init_vector lambda_Discard_tot(1,nfleets)
 !! ICHECK(lambda_Discard_tot);
  init_matrix catch_tot_CV(1,nyears,1,nfleets)
 !! ICHECK(catch_tot_CV);
  init_matrix discard_tot_CV(1,nyears,1,nfleets)
 !! ICHECK(discard_tot_CV);
  matrix catch_tot_sigma2(1,nfleets,1,nyears)
  matrix catch_tot_sigma(1,nfleets,1,nyears)
  matrix discard_tot_sigma2(1,nfleets,1,nyears)
  matrix discard_tot_sigma(1,nfleets,1,nyears)
  init_matrix input_eff_samp_size_catch_ini(1,nyears,1,nfleets)
 !! ICHECK(input_eff_samp_size_catch_ini);
  init_matrix input_eff_samp_size_discard_ini(1,nyears,1,nfleets)
 !! ICHECK(input_eff_samp_size_discard_ini);
  matrix input_eff_samp_size_catch(1,nfleets,1,nyears)
  matrix input_eff_samp_size_discard(1,nfleets,1,nyears)
  number nfact_in
  number nfact_out
 LOCAL_CALCS
  for(iyear=1;iyear<=nyears;iyear++)
  {
   for(ifleet=1;ifleet<=nfleets;ifleet++)
   {
     if (catch_tot_CV(iyear,ifleet) <= 0.0)
```

```
        catch_tot_CV(iyear,ifleet) = CVfill;
    if (discard_tot_CV(iyear,ifleet) <= 0.0)
        discard_tot_CV(iyear,ifleet) = CVfill;
    catch_tot_sigma2(ifleet,iyear)=log(catch_tot_CV(iyear,ifleet)*catch_tot_CV(iyear,ifleet)+1.0);
    catch_tot_sigma(ifleet,iyear)=sqrt(catch_tot_sigma2(ifleet,iyear));
    discard_tot_sigma2(ifleet,iyear)=log(discard_tot_CV(iyear,ifleet)*discard_tot_CV(iyear,ifleet)+1.0);
    discard_tot_sigma(ifleet,iyear)=sqrt(discard_tot_sigma2(ifleet,iyear));
    input_eff_samp_size_catch(ifleet,iyear)=input_eff_samp_size_catch_ini(iyear,ifleet);
    input_eff_samp_size_discard(ifleet,iyear)=input_eff_samp_size_discard_ini(iyear,ifleet);
  }
 }
END_CALCS
 init_vector lambda_Fmult_year1(1,nfleets)
!! ICHECK(lambda_Fmult_year1);
 init_vector Fmult_year1_CV(1,nfleets)
!! ICHECK(Fmult_year1_CV);
 init_vector lambda_Fmult_devs(1,nfleets)
!! ICHECK(lambda_Fmult_devs);
 init_vector Fmult_devs_CV(1,nfleets)
!! ICHECK(Fmult_devs_CV);
 init_number lambda_N_year1_devs
!! ICHECK(lambda_N_year1_devs);
 init_number N_year1_CV
!! ICHECK(N_year1_CV);
 init_number lambda_recruit_devs
!! ICHECK(lambda_recruit_devs);
 init_vector lambda_q_year1_ini(1,navailindices)
!! ICHECK(lambda_q_year1_ini);
 init_vector q_year1_CV_ini(1,navailindices)
!! ICHECK(q_year1_CV_ini);
 init_vector lambda_q_devs_ini(1,navailindices)
!! ICHECK(lambda_q_devs_ini);
 init_vector q_devs_CV_ini(1,navailindices)
!! ICHECK(q_devs_CV_ini);
 init_number lambda_steepness
!! ICHECK(lambda_steepness);
 init_number steepness_CV
!! ICHECK(steepness_CV);
 init_number lambda_SR_scaler
!! ICHECK(lambda_SR_scaler);
 init_number SR_scaler_CV
!! ICHECK(SR_scaler_CV);
LOCAL_CALCS
 for (i=1;i<=nfleets;i++)
 {
    if (Fmult_year1_CV(i) <= 0.0)
        Fmult_year1_CV(i) = CVfill;
    if (Fmult_devs_CV(i) <= 0.0)
        Fmult_devs_CV(i) = CVfill;
 }
 if (N_year1_CV <= 0.0)
     N_year1_CV = CVfill;
 for (i=1;i<=navailindices;i++)
 {
    if (q_year1_CV_ini(i) <= 0.0)
        q_year1_CV_ini(i) = CVfill;
    if (q_devs_CV_ini(i) <= 0.0)
        q_devs_CV_ini(i) = CVfill;
 }
 if (steepness_CV <= 0.0)
     steepness_CV = CVfill;
 if (SR_scaler_CV <= 0.0)
     SR_scaler_CV = CVfill;
END_CALCS
 vector Fmult_year1_sigma2(1,nfleets)
 vector Fmult_year1_sigma(1,nfleets)
 vector Fmult_year1_like_const(1,nfleets)
 vector Fmult_devs_sigma2(1,nfleets)
 vector Fmult_devs_sigma(1,nfleets)
 vector Fmult_devs_like_const(1,nfleets)
 number N_year1_sigma2
```

```
  number N_year1_sigma
  number N_year1_like_const
  vector lambda_ind(1,nindices)
  vector lambda_q_year1(1,nindices)
  vector q_year1_CV(1,nindices)
  vector q_year1_sigma2(1,nindices)
  vector q_year1_sigma(1,nindices)
  vector q_year1_like_const(1,nindices)
  vector lambda_q_devs(1,nindices)
  vector q_devs_CV(1,nindices)
  vector q_devs_sigma2(1,nindices)
  vector q_devs_sigma(1,nindices)
  vector q_devs_like_const(1,nindices)
  number steepness_sigma2
  number steepness_sigma
  number steepness_like_const
  number SR_scaler_sigma2
  number SR_scaler_sigma
  number SR_scaler_like_const

// starting guesses
  init_int NAA_year1_flag // 1 for devs from exponential decline, 2 for devs from initial guesses
 !! ICHECK(NAA_year1_flag);
  init_vector NAA_year1_ini(1,nages)
 !! ICHECK(NAA_year1_ini);
  init_vector Fmult_year1_ini(1,nfleets)
 !! ICHECK(Fmult_year1_ini);
  init_vector q_year1_iniavail(1,navailindices)
 !! ICHECK(q_year1_iniavail);
  vector q_year1_ini(1,nindices)
  init_number is_SR_scaler_R // 1 for R0, 0 for SSB0
 !! ICHECK(is_SR_scaler_R);
  init_number SR_scaler_ini
 !! ICHECK(SR_scaler_ini);
  init_number SR_steepness_ini
 !! ICHECK(SR_steepness_ini);
  init_number Fmult_max_value
 !! ICHECK(Fmult_max_value);

  init_number ignore_guesses
 !! ICHECK(ignore_guesses);
  number delta

// Projection Info*********************
  init_int do_projections
 !! ICHECK(do_projections);
  init_ivector directed_fleet(1,nfleets)
 !! ICHECK(directed_fleet);
  init_number nfinalyear
 !! ICHECK(nfinalyear);
  int nprojyears
 !! nprojyears=nfinalyear-year1-nyears+1;
  init_matrix project_ini(1,nprojyears,1,5)
 !! ICHECK(project_ini);
  vector proj_recruit(1,nprojyears)
  ivector proj_what(1,nprojyears)
  vector proj_target(1,nprojyears)
  vector proj_F_nondir_mult(1,nprojyears)
 LOCAL_CALCS
  for (iyear=1;iyear<=nprojyears;iyear++)
  {
    proj_recruit(iyear)=project_ini(iyear,2);
    proj_what(iyear)=project_ini(iyear,3);
    proj_target(iyear)=project_ini(iyear,4);
    proj_F_nondir_mult(iyear)=project_ini(iyear,5);
  }
 END_CALCS

// MCMC Info*******************************
  init_int doMCMC
 !! ICHECK(doMCMC);
```

```
 LOCAL_CALCS
  if (doMCMC == 1)
  {
     basicMCMC << " ";
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "F" << iyear+year1-1 << " ";
     }
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "SSB" << iyear+year1-1 << " ";
     }
     // Liz added Fmult_in lastyear and totBjan1
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "Fmult_" << iyear+year1-1 << " ";
          }
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "totBjan1_" << iyear+year1-1 << " ";
     }

     // end stuff Liz added
     basicMCMC << "MSY  SSBmsy  Fmsy  SSBmsy_ratio  Fmsy_ratio  ";
     basicMCMC << endl; // end of header line
  }
 END_CALCS
  init_int MCMCnyear_opt // 0=output nyear NAA, 1=output nyear+1 NAA
 !! ICHECK(MCMCnyear_opt)
  init_int MCMCnboot  // final number of values for agepro bootstrap file
 !! ICHECK(MCMCnboot);
  init_int MCMCnthin  // thinning rate (1=use every value, 2=use every other value, 3=use every third value,
etc)
 !! ICHECK(MCMCnthin);
  init_int MCMCseed   // large positive integer to seed random number generator
 !! ICHECK(MCMCseed);
// To run MCMC do the following two steps:
// 1st type "asap2 -mcmc N1 -mcsave MCMCnthin -mcseed MCMCseed"
//   where N1 = MCMCnboot * MCMCnthin
// 2nd type "asap2 -mceval"
  init_int fillR_opt // option for filling recruitment in terminal year+1 - used in agepro.bsn file only (1=SR,
2=geomean)
 !! ICHECK(fillR_opt);
  init_int Ravg_start
 !! ICHECK(Ravg_start);
  init_int Ravg_end
 !! ICHECK(Ravg_end);

  init_int make_Rfile // option to create rdat file of input and output values, set to 1 to create the file, 0
to skip this feature
 !! ICHECK(make_Rfile);

  init_int test_value
 !! ICHECK(test_value)
 !! cout << "test value = " << test_value << endl; //CHECK
 !! cout << "input complete" << endl;

  number ntemp0
  number SR_spawners_per_recruit
  vector s_per_r_vec(1,nyears)
 LOCAL_CALCS
  for (iyear=1;iyear<=nyears;iyear++)
  {
    ntemp0=1.0;
    s_per_r_vec(iyear)=0.0;
    for (iage=1;iage<nages;iage++)
    {
      s_per_r_vec(iyear)+=ntemp0*fecundity(iyear,iage)*mfexp(-1.0*fracyearSSB*M(iyear,iage));
      ntemp0*=mfexp(-M(iyear,iage));
    }
    ntemp0/=(1.0-mfexp(-M(iyear,nages)));
```

```
    s_per_r_vec(iyear)+=ntemp0*fecundity(iyear,nages)*mfexp(-1.0*fracyearSSB*M(iyear,nages));
  }
  SR_spawners_per_recruit=s_per_r_vec(nyears); // use last year calculations for SR curve
 END_CALCS

//***********************************************************************
PARAMETER_SECTION
  init_bounded_number_vector sel_params(1,nselparm,sel_lo,sel_hi,sel_phase)
  init_bounded_vector log_Fmult_year1(1,nfleets,-15.,2.,phase_Fmult_year1)
  init_bounded_matrix log_Fmult_devs(1,nfleets,2,nyears,-15.,15.,phase_Fmult_devs)
  init_bounded_dev_vector log_recruit_devs(1,nyears,-15.,15.,phase_recruit_devs)
  init_bounded_vector log_N_year1_devs(2,nages,-15.,15.,phase_N_year1_devs)
  init_bounded_vector log_q_year1(1,nindices,-30,5,phase_q_year1)
  init_bounded_matrix log_q_devs(1,nindices,2,index_nobs,-15.,15.,phase_q_devs)
  init_bounded_number_vector index_sel_params(1,nindexselparms,indexsel_lo,indexsel_hi,indexsel_phase)
  init_bounded_number log_SR_scaler(-1.0,200,phase_SR_scaler)
  init_bounded_number SR_steepness(0.20001,1.0,phase_steepness)
  vector sel_likely(1,nselparm)
  vector sel_stdresid(1,nselparm)
  number sel_rmse
  number sel_rmse_nobs
  number sum_sel_lambda
  number sum_sel_lambda_likely
  matrix indexsel(1,nindices,1,nages)
  vector indexsel_likely(1,nindexselparms)
  vector indexsel_stdresid(1,nindexselparms)
  number indexsel_rmse
  number indexsel_rmse_nobs
  number sum_indexsel_lambda
  number sum_indexsel_lambda_likely
  matrix log_Fmult(1,nfleets,1,nyears)
  matrix Fmult(1,nfleets,1,nyears)
  matrix NAA(1,nyears,1,nages)
  matrix temp_NAA(1,nyears,1,nages)
  matrix temp_BAA(1,nyears,1,nages)
  matrix temp_PAA(1,nyears,1,nages)
  matrix FAA_tot(1,nyears,1,nages)
  matrix Z(1,nyears,1,nages)
  matrix S(1,nyears,1,nages)
  matrix Catch_stdresid(1,nfleets,1,nyears)
  matrix Discard_stdresid(1,nfleets,1,nyears)
  matrix Catch_tot_fleet_pred(1,nfleets,1,nyears)
  matrix Discard_tot_fleet_pred(1,nfleets,1,nyears)
  3darray CAA_pred(1,nfleets,1,nyears,1,nages)
  3darray Discard_pred(1,nfleets,1,nyears,1,nages)
  3darray CAA_prop_pred(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  3darray Discard_prop_pred(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  3darray FAA_by_fleet_dir(1,nfleets,1,nyears,1,nages)
  3darray FAA_by_fleet_Discard(1,nfleets,1,nyears,1,nages)
  matrix sel_by_block(1,nselblocks,1,nages)
  3darray sel_by_fleet(1,nfleets,1,nyears,1,nages)
  vector temp_sel_over_time(1,nyears)
  number temp_sel_fix
  number temp_Fmult_max
  number Fmult_max_pen
  matrix q_by_index(1,nindices,1,index_nobs)
  matrix temp_sel(1,nyears,1,nages)
  vector temp_sel2(1,nages)
  matrix index_pred(1,nindices,1,index_nobs)
  3darray output_index_prop_obs(1,nindices,1,nyears,1,nages)
  3darray output_index_prop_pred(1,nindices,1,nyears,1,nages)
  matrix index_Neff_init(1,nindices,1,nyears)
  matrix index_Neff_est(1,nindices,1,nyears)
  3darray index_prop_pred(1,nindices,1,index_nobs,1,nages)
  number new_Neff_catch
  number new_Neff_discard
  number ntemp
  number SR_S0
  number SR_R0
  number SR_alpha
  number SR_beta
```

```
vector S0_vec(1,nyears)
vector R0_vec(1,nyears)
vector steepness_vec(1,nyears)
vector SR_pred_recruits(1,nyears+1)
number likely_SR_sigma
vector SR_stdresid(1,nyears)
number SR_rmse
number SR_rmse_nobs
vector RSS_sel_devs(1,nfleets)
vector RSS_catch_tot_fleet(1,nfleets)
vector RSS_Discard_tot_fleet(1,nfleets)
vector catch_tot_likely(1,nfleets)
vector discard_tot_likely(1,nfleets)
number likely_catch
number likely_Discard
vector RSS_ind(1,nindices)
vector RSS_ind_sigma(1,nindices)
vector likely_ind(1,nindices)
matrix index_stdresid(1,nindices,1,index_nobs)
number likely_index_age_comp
number fpenalty
number fpenalty_lambda
vector Fmult_year1_stdresid(1,nfleets)
number Fmult_year1_rmse
number Fmult_year1_rmse_nobs
vector Fmult_year1_likely(1,nfleets)
vector Fmult_devs_likely(1,nfleets)
matrix Fmult_devs_stdresid(1,nfleets,1,nyears)
vector Fmult_devs_fleet_rmse(1,nfleets)
vector Fmult_devs_fleet_rmse_nobs(1,nfleets)
number Fmult_devs_rmse
number Fmult_devs_rmse_nobs
number N_year1_likely
vector N_year1_stdresid(2,nages)
number N_year1_rmse
number N_year1_rmse_nobs
vector nyear1temp(1,nages)
vector q_year1_likely(1,nindices)
vector q_year1_stdresid(1,nindices)
number q_year1_rmse
number q_year1_rmse_nobs
vector q_devs_likely(1,nindices)
matrix q_devs_stdresid(1,nindices,1,index_nobs)
number q_devs_rmse
number q_devs_rmse_nobs
number steepness_likely
number steepness_stdresid
number steepness_rmse
number steepness_rmse_nobs
number SR_scaler_likely
number SR_scaler_stdresid
number SR_scaler_rmse
number SR_scaler_rmse_nobs
matrix effective_sample_size(1,nfleets,1,nyears)
matrix effective_Discard_sample_size(1,nfleets,1,nyears)
vector Neff_stage2_mult_catch(1,nfleets)
vector Neff_stage2_mult_discard(1,nfleets)
vector Neff_stage2_mult_index(1,nindices)
vector mean_age_obs(1,nyears)
vector mean_age_pred(1,nyears)
vector mean_age_pred2(1,nyears)
vector mean_age_resid(1,nyears)
vector mean_age_sigma(1,nyears)
number mean_age_x
number mean_age_n
number mean_age_delta
number mean_age_mean
number mean_age_m2
vector temp_Fmult(1,nfleets)
number tempU
number tempN
```

```
number tempB
number tempUd
number tempNd
number tempBd
number trefU
number trefN
number trefB
number trefUd
number trefNd
number trefBd
number Fref_report
number Fref
vector freftemp(1,nages)
vector nreftemp(1,nages)
vector Freport_U(1,nyears)
vector Freport_N(1,nyears)
vector Freport_B(1,nyears)
sdreport_vector Freport(1,nyears)
sdreport_vector TotJan1B(1,nyears)
sdreport_vector SSB(1,nyears)
sdreport_vector ExploitableB(1,nyears)
sdreport_vector recruits(1,nyears)
matrix SSBfracZ(1,nyears,1,nages)
vector final_year_total_sel(1,nages)
vector dir_F(1,nages)
vector Discard_F(1,nages)
vector proj_nondir_F(1,nages)
vector proj_dir_sel(1,nages)
vector proj_Discard_sel(1,nages)
matrix proj_NAA(1,nprojyears,1,nages)
vector proj_Fmult(1,nprojyears)
vector Ftemp(1,nages)
vector Ztemp(1,nages)
vector proj_TotJan1B(1,nprojyears)
vector proj_SSB(1,nprojyears)
number SSBtemp
number denom
matrix proj_F_dir(1,nprojyears,1,nages)
matrix proj_F_Discard(1,nprojyears,1,nages)
matrix proj_F_nondir(1,nprojyears,1,nages)
matrix proj_Z(1,nprojyears,1,nages)
matrix proj_SSBfracZ(1,nprojyears,1,nages)
matrix proj_catch(1,nprojyears,1,nages)
matrix proj_Discard(1,nprojyears,1,nages)
matrix proj_yield(1,nprojyears,1,nages)
vector proj_total_yield(1,nprojyears)
vector proj_total_Discard(1,nprojyears)
vector output_prop_obs(1,nages)
vector output_prop_pred(1,nages)
vector output_Discard_prop_obs(1,nages)
vector output_Discard_prop_pred(1,nages)
vector NAAbsn(1,nages)
number temp_sum
number temp_sum2
number A
number B
number C
number f
number z
number SPR_Fmult
number YPR_Fmult
number SPR
number SPRatio
number YPR
number S_F
number R_F
number slope_origin
number slope
number F30SPR
number F40SPR
number Fmsy
```

```
  number F01
  number Fmax
  number F30SPR_report
  number F40SPR_report
  number F01_report
  number Fmax_report
  number Fcurrent
  number F30SPR_slope
  number F40SPR_slope
  number Fmsy_slope
  number F01_slope
  number Fmax_slope
  number Fcurrent_slope
  number SSmsy
  number tempR
  vector tempFmult(1,nyears) // Liz added
  sdreport_number MSY
  sdreport_number SSBmsy_report
  sdreport_number Fmsy_report
  sdreport_number SSBmsy_ratio
  sdreport_number Fmsy_ratio
  objective_function_value obj_fun

PRELIMINARY_CALCS_SECTION
// subset only used index information
  ind=0;
  for (indavail=1;indavail<=navailindices;indavail++)
  {
     if (use_index(indavail)==1)
     {
       ind+=1;
       lambda_ind(ind)=lambda_ind_ini(indavail);
       lambda_q_year1(ind)=lambda_q_year1_ini(indavail);
       q_year1_CV(ind)=q_year1_CV_ini(indavail);
       lambda_q_devs(ind)=lambda_q_devs_ini(indavail);
       q_devs_CV(ind)=q_devs_CV_ini(indavail);
       q_year1_ini(ind)=q_year1_iniavail(indavail);
     }
  }

  if (ignore_guesses==0)
  {
     NAA(1)=NAA_year1_ini;
     log_Fmult_year1=log(Fmult_year1_ini);
     log_q_year1=log(q_year1_ini);
     log_SR_scaler=log(SR_scaler_ini);
     SR_steepness=SR_steepness_ini;
     for (k=1;k<=nselparm;k++)
     {
        sel_params(k)=sel_initial(k);
     }
     for (k=1;k<=nindexselparms;k++)
     {
        index_sel_params(k)=indexsel_initial(k);
     }
  }

  delta=0.00001;

// convert remaining CVs to variances
  Fmult_year1_sigma2=log(elem_prod(Fmult_year1_CV,Fmult_year1_CV)+1.0);
  Fmult_year1_sigma=sqrt(Fmult_year1_sigma2);
  Fmult_devs_sigma2=log(elem_prod(Fmult_devs_CV,Fmult_devs_CV)+1.0);
  Fmult_devs_sigma=sqrt(Fmult_devs_sigma2);
  N_year1_sigma2=log(N_year1_CV*N_year1_CV+1.0);
  N_year1_sigma=sqrt(N_year1_sigma2);
  q_year1_sigma2=log(elem_prod(q_year1_CV,q_year1_CV)+1.0);
  q_year1_sigma=sqrt(q_year1_sigma2);
  q_devs_sigma2=log(elem_prod(q_devs_CV,q_devs_CV)+1.0);
  q_devs_sigma=sqrt(q_devs_sigma2);
  steepness_sigma2=log(steepness_CV*steepness_CV+1.0);
```

```
  steepness_sigma=sqrt(steepness_sigma2);
  SR_scaler_sigma2=log(SR_scaler_CV*SR_scaler_CV+1.0);
  SR_scaler_sigma=sqrt(SR_scaler_sigma2);

// compute multinomial constants for catch and discards at age, if requested
  catch_prop_like_const=0.0;
  discard_prop_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        for (iyear=1;iyear<=nyears;iyear++)
        {
          if (input_eff_samp_size_catch(ifleet,iyear) > 0)
          {
             nfact_in=input_eff_samp_size_catch(ifleet,iyear);
             get_log_factorial();
             catch_prop_like_const+=-1.0*nfact_out;  // negative for the total
             for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             {
                nfact_in=double(input_eff_samp_size_catch(ifleet,iyear))*CAA_prop_obs(ifleet,iyear,iage)+0.5;
// +0.5 to round instead of truncate nfact_in
                get_log_factorial();
                catch_prop_like_const+=nfact_out;   // positive for the parts
             }
          }
          if (input_eff_samp_size_discard(ifleet,iyear) > 0)
          {
             nfact_in=input_eff_samp_size_discard(ifleet,iyear);
             get_log_factorial();
             discard_prop_like_const+=-1.0*nfact_out; // negative for the total
             for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             {

nfact_in=double(input_eff_samp_size_discard(ifleet,iyear))*Discard_prop_obs(ifleet,iyear,iage)+0.5;
                get_log_factorial();
                discard_prop_like_const+=nfact_out;   // positive for the parts
             }
          }
        }
     }
  }

// compute multinomial constants for index, if requested
  index_prop_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (ind=1;ind<=nindices;ind++)
     {
        if (index_estimate_proportions(ind)==1)
        {
           for (i=1;i<=index_nobs(ind);i++)
           {
              if (input_eff_samp_size_index(ind,i) > 0)
              {
                 nfact_in=input_eff_samp_size_index(ind,i);
                 get_log_factorial();
                 index_prop_like_const+=-1.0*nfact_out;    // negative for total
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                    nfact_in=double(input_eff_samp_size_index(ind,i))*index_prop_obs(ind,i,iage)+0.5;
                    get_log_factorial();
                    index_prop_like_const+=nfact_out;      // positive for the parts
                 }
              }
           }
        }
     }
  }

// selectivity likelihood constants
```

```
  sel_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (k=1;k<=nselparm;k++)
     {
        if (sel_phase(k) >= 1)
        {
           sel_like_const(k)=0.5*log(2.0*pi)+log(sel_initial(k));
        }
     }
  }

// index selectivity likelihood constants
  indexsel_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (k=1;k<=nindexselparms;k++)
     {
        if (indexsel_phase(k) >= 1)
        {
           indexsel_like_const(k)=0.5*log(2.0*pi)+log(indexsel_initial(k));
        }
     }
  }

// rest of likelihood constants
  if (use_likelihood_constants == 1)
  {
     Fmult_year1_like_const=0.5*log(2.0*pi)+log(Fmult_year1_ini);
     Fmult_devs_like_const=0.5*log(2.0*pi);
     N_year1_like_const=0.5*log(2.0*pi);
     q_year1_like_const=0.5*log(2.0*pi)+log(q_year1_ini);
     q_devs_like_const=0.5*log(2.0*pi);
     steepness_like_const=0.5*log(2.0*pi)+log(SR_steepness_ini);
     SR_scaler_like_const=0.5*log(2.0*pi)+log(SR_scaler_ini);
  }
  else
  {
     Fmult_year1_like_const=0.0;
     Fmult_devs_like_const=0.0;
     N_year1_like_const=0.0;
     q_year1_like_const=0.0;
     q_devs_like_const=0.0;
     steepness_like_const=0.0;
     SR_scaler_like_const=0.0;
  }

// set dev vectors to zero
  log_Fmult_devs.initialize();
  log_recruit_devs.initialize();
  log_N_year1_devs.initialize();
  log_q_devs.initialize();

// initialize MSY related sdreport variables
  MSY.initialize();
  SSBmsy_report.initialize();
  Fmsy_report.initialize();
  SSBmsy_ratio.initialize();
  Fmsy_ratio.initialize();

  debug=0; // debug checks commented out to speed calculations

//************************************************************************************************
PROCEDURE_SECTION
                                     //  if (debug==1) cout << "starting procedure section" << endl;
  get_SR();                         //  if (debug==1) cout << "got SR" << endl;
  get_selectivity();                 //  if (debug==1) cout << "got selectivity" << endl;
  get_mortality_rates();             //  if (debug==1) cout << "got mortality rates" << endl;
  get_numbers_at_age();              //  if (debug==1) cout << "got numbers at age" << endl;
  get_Freport();                     //  if (debug==1) cout << "got Freport" << endl;
  get_predicted_catch();             //  if (debug==1) cout << "got predicted catch" << endl;
```

```
  get_q();                            //  if (debug==1) cout << "got q" << endl;
  get_predicted_indices();            //  if (debug==1) cout << "got predicted indices" << endl;
  compute_the_objective_function();   //  if (debug==1) cout << "computed objective function" << endl;
  if (last_phase() || mceval_phase())
  {
     get_proj_sel();                  //  if (debug==1) cout <<"got proj sel" << endl;
     get_Fref();                      //  if (debug==1) cout <<"got Fref" << endl;
     get_multinomial_multiplier();    //  if (debug==1) cout <<"got multinomial multiplier" << endl;
  }
  if (mceval_phase())
  {
     write_MCMC();
  }                                   //  if (debug==1) cout << "  . . . end of procedure section" << endl;
//*************************************************************************************************

FUNCTION get_SR
// converts stock recruitment scaler and steepness to alpha and beta for Beverton-Holt SR
// note use of is_SR_scaler_R variable to allow user to enter guess for either R0 or SSB0
  if(is_SR_scaler_R==1)
  {
    SR_R0=mfexp(log_SR_scaler);
    SR_S0=SR_spawners_per_recruit*SR_R0;
  }
  else
  {
    SR_S0=mfexp(log_SR_scaler);
    SR_R0=SR_S0/SR_spawners_per_recruit;
  }
  SR_alpha=4.0*SR_steepness*SR_R0/(5.0*SR_steepness-1.0);
  SR_beta=SR_S0*(1.0-SR_steepness)/(5.0*SR_steepness-1.0);
  // now compute year specific vectors of R0, S0, and steepness
  for (iyear=1;iyear<=nyears;iyear++)
  {
    steepness_vec(iyear)=0.2*SR_alpha*s_per_r_vec(iyear)/(0.8*SR_beta+0.2*SR_alpha*s_per_r_vec(iyear));
    R0_vec(iyear)=(SR_alpha*s_per_r_vec(iyear)-SR_beta)/s_per_r_vec(iyear);
    S0_vec(iyear)=s_per_r_vec(iyear)*R0_vec(iyear);
  }

FUNCTION get_selectivity
  dvariable sel_alpha1;
  dvariable sel_beta1;
  dvariable sel_alpha2;
  dvariable sel_beta2;
  dvariable sel_temp;
  dvariable sel1;
  dvariable sel2;
// start by computing selectivity for each block
  k=0;
  for (i=1;i<=nselblocks;i++) {
     if (sel_option(i)==1) {
        for (iage=1;iage<=nages;iage++){
           k+=1;
           sel_by_block(i,iage)=sel_params(k);
        }
     }
     if (sel_option(i)==2) {
        sel_alpha1=sel_params(k+1);
        sel_beta1=sel_params(k+2);
        k+=2;
        for (iage=1;iage<=nages;iage++) {
           sel_by_block(i,iage)=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
        }
        sel_temp=max(sel_by_block(i));
        sel_by_block(i)/=sel_temp;
     }
     if (sel_option(i)==3) {
        sel_alpha1=sel_params(k+1);
        sel_beta1=sel_params(k+2);
        sel_alpha2=sel_params(k+3);
        sel_beta2=sel_params(k+4);
        k+=4;
```

```
        for (iage=1;iage<=nages;iage++) {
           sel1=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
           sel2=1.0-1.0/(1.0+mfexp((sel_alpha2-double(iage))/sel_beta2));
           sel_by_block(i,iage)=sel1*sel2;
        }
        sel_temp=max(sel_by_block(i));
        sel_by_block(i)/=sel_temp;
     }
  }
// now fill in selectivity for each fleet and year according to block
  for (ifleet=1;ifleet<=nfleets;ifleet++) {
     for (iyear=1;iyear<=nyears;iyear++) {
        sel_by_fleet(ifleet,iyear)=sel_by_block(sel_blocks(ifleet,iyear));
     }
  }

FUNCTION get_mortality_rates
// compute directed and discard F by fleet then sum to form total F at age matrix
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     log_Fmult(ifleet,1)=log_Fmult_year1(ifleet);
     if (active(log_Fmult_devs))
     {
         for (iyear=2;iyear<=nyears;iyear++)
             log_Fmult(ifleet,iyear)=log_Fmult(ifleet,iyear-1)+log_Fmult_devs(ifleet,iyear);
     }
     else
     {
         for (iyear=2;iyear<=nyears;iyear++)
             log_Fmult(ifleet,iyear)=log_Fmult_year1(ifleet);
     }
  }
  FAA_tot=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
       for (iage=1;iage<=nages;iage++)
       {

FAA_by_fleet_dir(ifleet,iyear,iage)=(mfexp(log_Fmult(ifleet,iyear))*sel_by_fleet(ifleet,iyear,iage))*(1.0-
proportion_release(ifleet,iyear,iage));

FAA_by_fleet_Discard(ifleet,iyear,iage)=(mfexp(log_Fmult(ifleet,iyear))*sel_by_fleet(ifleet,iyear,iage))*(propor
tion_release(ifleet,iyear,iage)*release_mort(ifleet));
       }
     }
     FAA_tot+=FAA_by_fleet_dir(ifleet)+FAA_by_fleet_Discard(ifleet);
  }
// add fishing and natural mortality to get total mortality
  for (iyear=1;iyear<=nyears;iyear++)
     Z(iyear)=FAA_tot(iyear)+M(iyear);
  S=mfexp(-1.0*Z);
  SSBfracZ=mfexp(-1.0*fracyearSSB*Z); // for use in SSB calcuations

FUNCTION get_numbers_at_age
// get N at age in year 1
  if (phase_N_year1_devs>0)
  {
     for (iage=2;iage<=nages;iage++)
     {
        NAA(1,iage)=NAA_year1_ini(iage)*mfexp(log_N_year1_devs(iage));
     }
  }
// compute initial SSB to derive R in first year
  SSB(1)=0.0;
  for (iage=2;iage<=nages;iage++)
  {
     SSB(1)+=NAA(1,iage)*SSBfracZ(1,iage)*fecundity(1,iage);  // note SSB in year 1 does not include age 1 to
estimate pred_R in year 1
  }
```

```
  SR_pred_recruits(1)=SR_alpha*SSB(1)/(SR_beta+SSB(1));
  NAA(1,1)=SR_pred_recruits(1)*mfexp(log_recruit_devs(1));
  SSB(1)+=NAA(1,1)*SSBfracZ(1,1)*fecundity(1,1);   // now SSB in year 1 is complete and can be used for pred_R
in year 2
// fill out rest of matrix
  for (iyear=2;iyear<=nyears;iyear++)
  {
     SR_pred_recruits(iyear)=SR_alpha*SSB(iyear-1)/(SR_beta+SSB(iyear-1));
     NAA(iyear,1)=SR_pred_recruits(iyear)*mfexp(log_recruit_devs(iyear));
     for (iage=2;iage<=nages;iage++)
         NAA(iyear,iage)=NAA(iyear-1,iage-1)*S(iyear-1,iage-1);
     NAA(iyear,nages)+=NAA(iyear-1,nages)*S(iyear-1,nages);
     SSB(iyear)=elem_prod(NAA(iyear),SSBfracZ(iyear))*fecundity(iyear);
  }
  SR_pred_recruits(nyears+1)=SR_alpha*SSB(nyears)/(SR_beta+SSB(nyears));
  for (iyear=1;iyear<=nyears;iyear++)
  {
     recruits(iyear)=NAA(iyear,1);
  }
// compute two other biomass time series
  for (iyear=1;iyear<=nyears;iyear++)
  {
     TotJan1B(iyear)=NAA(iyear)*WAAjan1b(iyear);
     ExploitableB(iyear)=elem_prod(NAA(iyear),FAA_tot(iyear))*WAAcatchall(iyear)/max(FAA_tot(iyear));
  }

FUNCTION get_Freport
// calculates an average F for a range of ages in each year under three weighting schemes
  for (iyear=1;iyear<=nyears;iyear++){
     tempU=0.0;
     tempN=0.0;
     tempB=0.0;
     tempUd=0.0;
     tempNd=0.0;
     tempBd=0.0;
     for (iage=Freport_agemin;iage<=Freport_agemax;iage++)
     {
       tempU+=FAA_tot(iyear,iage);
       tempN+=FAA_tot(iyear,iage)*NAA(iyear,iage);
       tempB+=FAA_tot(iyear,iage)*NAA(iyear,iage)*WAAjan1b(iyear,iage);
       tempUd+=1.0;
       tempNd+=NAA(iyear,iage);
       tempBd+=NAA(iyear,iage)*WAAjan1b(iyear,iage);
     }
     // April 2012 error trap addition
     if (tempUd <= 0.) Freport_U(iyear)=0.0;
     else Freport_U(iyear)=tempU/tempUd;
     if (tempNd <= 0.) Freport_N(iyear)=Freport_U(iyear);
     else Freport_N(iyear)=tempN/tempNd;
     if (tempBd <= 0.) Freport_B(iyear)=Freport_U(iyear);
     else Freport_B(iyear)=tempB/tempBd;
  }
  if (Freport_wtopt==1) Freport=Freport_U;
  if (Freport_wtopt==2) Freport=Freport_N;
  if (Freport_wtopt==3) Freport=Freport_B;

FUNCTION get_predicted_catch
// assumes continuous F using Baranov equation
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     CAA_pred(ifleet)=elem_prod(elem_div(FAA_by_fleet_dir(ifleet),Z),elem_prod(1.0-S,NAA));
     Discard_pred(ifleet)=elem_prod(elem_div(FAA_by_fleet_Discard(ifleet),Z),elem_prod(1.0-S,NAA));
  }
// now compute proportions at age and total weight of catch
  for (iyear=1;iyear<=nyears;iyear++)
  {
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
       CAA_prop_pred(ifleet,iyear)=0.0;
       Discard_prop_pred(ifleet,iyear)=0.0;
```

```
Catch_tot_fleet_pred(ifleet,iyear)=sum(CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet)));

Discard_tot_fleet_pred(ifleet,iyear)=sum(Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet)));
       if (Catch_tot_fleet_pred(ifleet,iyear)>0.0)

CAA_prop_pred(ifleet,iyear)=CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/Catch_tot_fleet_pr
ed(ifleet,iyear);
       if (Discard_tot_fleet_pred(ifleet,iyear)>0.0)

Discard_prop_pred(ifleet,iyear)=Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/Discard_to
t_fleet_pred(ifleet,iyear);

Catch_tot_fleet_pred(ifleet,iyear)=CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))*WAAcatchfle
et(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet));

Discard_tot_fleet_pred(ifleet,iyear)=Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))*WAAdi
scardfleet(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet));
       for (iage=1;iage<=nages;iage++)
       {
          if (CAA_prop_pred(ifleet,iyear,iage)<1.e-15)
             CAA_prop_pred(ifleet,iyear,iage)=1.0e-15;
          if (Discard_prop_pred(ifleet,iyear,iage)<1.e-15)
             Discard_prop_pred(ifleet,iyear,iage)=1.0e-15;
       }
    }
  }

FUNCTION get_q
// catchability for each index, can be a random walk if q_devs turned on
  for (ind=1;ind<=nindices;ind++)
  {
     q_by_index(ind,1)=mfexp(log_q_year1(ind));
     if (active(log_q_devs))
     {
         for (i=2;i<=index_nobs(ind);i++)
             q_by_index(ind,i)=q_by_index(ind,i-1)*mfexp(log_q_devs(ind,i));
     }
     else
     {
         for (i=2;i<=index_nobs(ind);i++)
             q_by_index(ind,i)=q_by_index(ind,1);
     }
  }

FUNCTION get_predicted_indices
  dvariable sel_alpha1;
  dvariable sel_beta1;
  dvariable sel_alpha2;
  dvariable sel_beta2;
  dvariable sel_temp;
  dvariable sel1;
  dvariable sel2;
// get selectivity for each index
  k=0;
  for (ind=1;ind<=nindices;ind++)
  {
     if (index_sel_choice(ind)>0)
     {
         temp_sel=sel_by_fleet(index_sel_choice(ind));
         if (index_sel_option(ind)==1) k+=nages;
         if (index_sel_option(ind)==2) k+=2;
         if (index_sel_option(ind)==3) k+=4;

     }
     else
     {
         if (index_sel_option(ind)==1)
         {
             for (iage=1;iage<=nages;iage++)
             {
```

```
                k+=1;
                temp_sel2(iage)=index_sel_params(k);
             }
         }
         if (index_sel_option(ind)==2)
         {
             sel_alpha1=index_sel_params(k+1);
             sel_beta1=index_sel_params(k+2);
             k+=2;
             for (iage=1;iage<=nages;iage++)
             {
                temp_sel2(iage)=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
             }
             sel_temp=max(temp_sel2);
             temp_sel2/=sel_temp;
         }
         if (index_sel_option(ind)==3)
         {
             sel_alpha1=index_sel_params(k+1);
             sel_beta1=index_sel_params(k+2);
             sel_alpha2=index_sel_params(k+3);
             sel_beta2=index_sel_params(k+4);
             k+=4;
             for (iage=1;iage<=nages;iage++)
             {
                sel1=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
                sel2=1.0-1.0/(1.0+mfexp((sel_alpha2-double(iage))/sel_beta2));
                temp_sel2(iage)=sel1*sel2;
             }
             sel_temp=max(temp_sel2);
             temp_sel2/=sel_temp;
         }
         for (iyear=1;iyear<=nyears;iyear++)
         {
             temp_sel(iyear)=temp_sel2;
         }
     }
     indexsel(ind)=temp_sel(1);
// determine when the index should be applied
     if (index_month(ind)==-1)
     {
         temp_NAA=elem_prod(NAA,elem_div(1.0-S,Z));
     }
     else
     {
         temp_NAA=elem_prod(NAA,mfexp(-1.0*((index_month(ind)-1.0)/12.0)*Z));
     }
     temp_BAA=elem_prod(temp_NAA,index_WAA(ind));
// compute the predicted index for each year where observed value > 0
     if (index_units_aggregate(ind)==1)
     {
         temp_PAA=temp_BAA;
     }
     else
     {
         temp_PAA=temp_NAA;
     }
     for (i=1;i<=index_nobs(ind);i++)
     {
         j=index_time(ind,i);
         index_pred(ind,i)=q_by_index(ind,i)*sum(elem_prod(
             temp_PAA(j)(index_start_age(ind),index_end_age(ind)) ,
             temp_sel(j)(index_start_age(ind),index_end_age(ind))));
     }
// compute index proportions at age if necessary
     if (index_units_proportions(ind)==1)
     {
         temp_PAA=temp_BAA;
     }
     else
     {
```

```
         temp_PAA=temp_NAA;
     }
     index_prop_pred(ind)=0.0;
     if (index_estimate_proportions(ind)==1)
     {
         for (i=1;i<=index_nobs(ind);i++)
         {
             j=index_time(ind,i);
             if (index_pred(ind,i)>0.0)
             {
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                     index_prop_pred(ind,i,iage)=q_by_index(ind,i)*temp_PAA(j,iage)*temp_sel(j,iage);
                 }
                 if (sum(index_prop_pred(ind,i)) > 0)
                     index_prop_pred(ind,i)/=sum(index_prop_pred(ind,i));
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                     if (index_prop_pred(ind,i,iage)<1.e-15)
                        index_prop_pred(ind,i,iage)=1.e-15;
                 }
             }
         }
     }
  }

FUNCTION get_proj_sel
// creates overall directed and discard selectivity patterns and sets bycatch F at age
  dir_F=0.0;
  Discard_F=0.0;
  proj_nondir_F=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if (directed_fleet(ifleet)==1)
     {
        dir_F+=FAA_by_fleet_dir(ifleet,nyears);
        Discard_F+=FAA_by_fleet_Discard(ifleet,nyears);
     }
     else
     {
        proj_nondir_F+=FAA_by_fleet_dir(ifleet,nyears);
     }
  }
  proj_dir_sel=dir_F/max(dir_F);
  proj_Discard_sel=Discard_F/max(dir_F);

FUNCTION get_Fref
// calculates a number of common F reference points using bisection algorithm
  A=0.0;
  B=5.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     SPR_Fmult=C;
     get_SPR();
     if (SPR/SR_spawners_per_recruit<0.30)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F30SPR=C;
  Fref=F30SPR;
  get_Freport_ref();
  F30SPR_report=Fref_report;
  F30SPR_slope=1.0/SPR;
  A=0.0;
  B=5.0;
```

```
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     SPR_Fmult=C;
     get_SPR();
     if (SPR/SR_spawners_per_recruit<0.40)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F40SPR=C;
  Fref=F40SPR;
  get_Freport_ref();
  F40SPR_report=Fref_report;
  F40SPR_slope=1.0/SPR;
  A=0.0;
  B=3.0;
  for (iloop=1;iloop<=20;iloop++)
  {
    C=(A+B)/2.0;
    SPR_Fmult=C+delta;
    get_SPR();
    S_F=SR_alpha*SPR-SR_beta;
    R_F=S_F/SPR;
    YPR_Fmult=C+delta;
    get_YPR();
    slope=R_F*YPR;
    SPR_Fmult=C;
    get_SPR();
    S_F=SR_alpha*SPR-SR_beta;
    R_F=S_F/SPR;
    YPR_Fmult=C;
    get_YPR();
    slope-=R_F*YPR;
//    slope/=delta; only care pos or neg
    if(slope>0.0)
    {
       A=C;
    }
    else
    {
       B=C;
    }
  }
  Fmsy=C;
  Fref=Fmsy;
  get_Freport_ref();
  Fmsy_report=Fref_report;
  SSmsy=S_F;
  SSBmsy_report=SSmsy;
  if (SSmsy>0.0)
    SSBmsy_ratio=SSB(nyears)/SSmsy;
  MSY=YPR*R_F;
  SPR_Fmult=Fmsy;
  get_SPR();
  Fmsy_slope=1.0/SPR;
  YPR_Fmult=delta;
  get_YPR();
  slope_origin=YPR/delta;
  A=0.0;
  B=5.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     YPR_Fmult=C+delta;
     get_YPR();
     slope=YPR;
```

```
      YPR_Fmult=C;
      get_YPR();
      slope-=YPR;
      slope/=delta;
      if (slope<0.10*slope_origin)
      {
         B=C;
      }
      else
      {
         A=C;
      }
   }
   F01=C;
   Fref=F01;
   get_Freport_ref();
   F01_report=Fref_report;
   SPR_Fmult=F01;
   get_SPR();
   F01_slope=1.0/SPR;
   A=0.0;
   B=10.0;
   for (iloop=1;iloop<=20;iloop++)
   {
      C=(A+B)/2.0;
      YPR_Fmult=C+delta;
      get_YPR();
      slope=YPR;
      YPR_Fmult=C;
      get_YPR();
      slope-=YPR;
      slope/=delta;
      if (slope<0.0)
      {
         B=C;
      }
      else
      {
         A=C;
      }
   }
   Fmax=C;
   Fref=Fmax;
   get_Freport_ref();
   Fmax_report=Fref_report;
   SPR_Fmult=Fmax;
   get_SPR();
   Fmax_slope=1.0/SPR;
   Fcurrent=max(FAA_tot(nyears)-proj_nondir_F-Discard_F);
   SPR_Fmult=Fcurrent;
   get_SPR();
   Fcurrent_slope=1.0/SPR;
   if (Fmsy>0.0)
     Fmsy_ratio=Fcurrent/Fmsy;

 FUNCTION get_Freport_ref
 // Freport calculations for each of the reference points
   trefU=0.0;
   trefN=0.0;
   trefB=0.0;
   trefUd=0.0;
   trefNd=0.0;
   trefBd=0.0;
   nreftemp(1)=1.0;
   for (iage=1;iage<nages;iage++)
   {
      freftemp(iage)=Fref*(proj_dir_sel(iage)+proj_Discard_sel(iage))+proj_nondir_F(iage);
      nreftemp(iage+1)=mfexp(-1.0*(M(nyears,iage)+freftemp(iage)));
   }
   freftemp(nages)=Fref*(proj_dir_sel(nages)+proj_Discard_sel(nages))+proj_nondir_F(nages);
   nreftemp(nages)/=(1.0-mfexp(-1.0*(M(nyears,nages)+freftemp(nages))));
```

```
  for (iage=Freport_agemin;iage<=Freport_agemax;iage++)
  {
     trefU+=freftemp(iage);
     trefN+=freftemp(iage)*nreftemp(iage);
     trefB+=freftemp(iage)*nreftemp(iage)*WAAjan1b(nyears,iage);
     trefUd+=1.0;
     trefNd+=nreftemp(iage);
     trefBd+=nreftemp(iage)*WAAjan1b(nyears,iage);
  }
  if (Freport_wtopt==1) Fref_report=trefU/trefUd;
  if (Freport_wtopt==2) Fref_report=trefN/trefNd;
  if (Freport_wtopt==3) Fref_report=trefB/trefBd;

FUNCTION get_YPR
// simple yield per recruit calculations
  YPR=0.0;
  ntemp=1.0;
  for (iage=1;iage<nages;iage++)
  {
    f=YPR_Fmult*proj_dir_sel(iage);
    z=M(nyears,iage)+f+proj_nondir_F(iage)+YPR_Fmult*proj_Discard_sel(iage);
    YPR+=ntemp*f*WAAcatchall(nyears,iage)*(1.0-mfexp(-1.0*z))/z;
    ntemp*=mfexp(-1.0*z);
  }
  f=YPR_Fmult*proj_dir_sel(nages);
  z=M(nyears,nages)+f+proj_nondir_F(nages)+YPR_Fmult*proj_Discard_sel(nages);
  ntemp/=(1.0-mfexp(-1.0*z));
  YPR+=ntemp*f*WAAcatchall(nyears,nages)*(1.0-mfexp(-1.0*z))/z;

FUNCTION project_into_future
// project population under five possible scenarios for each year
  for (iyear=1;iyear<=nprojyears;iyear++)
  {
    proj_F_nondir(iyear)=proj_nondir_F*proj_F_nondir_mult(iyear);
    if (proj_recruit(iyear)<0.0)  // use stock-recruit relationship
    {
       if (iyear==1)
       {
          proj_NAA(iyear,1)=SR_alpha*SSB(nyears)/(SR_beta+SSB(nyears));
       }
       else
       {
          proj_NAA(iyear,1)=SR_alpha*proj_SSB(iyear-1)/(SR_beta+proj_SSB(iyear-1));
       }
    }
    else
    {
       proj_NAA(iyear,1)=proj_recruit(iyear);
    }
    if (iyear==1)
    {
       for (iage=2;iage<=nages;iage++)
          proj_NAA(1,iage)=NAA(nyears,iage-1)*S(nyears,iage-1);
       proj_NAA(1,nages)+=NAA(nyears,nages)*S(nyears,nages);
    }
    else
    {
       for (iage=2;iage<=nages;iage++)
          proj_NAA(iyear,iage)=proj_NAA(iyear-1,iage-1)*mfexp(-1.0*proj_Z(iyear-1,iage-1));
       proj_NAA(iyear,nages)+=proj_NAA(iyear-1,nages)*mfexp(-1.0*proj_Z(iyear-1,nages));
    }
    if (proj_what(iyear)==1)           // match directed yield
    {
       proj_Fmult(iyear)=3.0;  // first see if catch possible
       proj_F_dir(iyear)=proj_Fmult(iyear)*proj_dir_sel;
       proj_F_Discard(iyear)=proj_Fmult(iyear)*proj_Discard_sel;
       proj_Z(iyear)=M(nyears)+proj_F_nondir(iyear)+proj_F_dir(iyear)+proj_F_Discard(iyear);
       proj_catch(iyear)=elem_prod(elem_div(proj_F_dir(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
       proj_Discard(iyear)=elem_prod(elem_div(proj_F_Discard(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
```

```
        proj_yield(iyear)=elem_prod(proj_catch(iyear),WAAcatchall(nyears));
        proj_total_yield(iyear)=sum(proj_yield(iyear));
        proj_total_Discard(iyear)=sum(elem_prod(proj_Discard(iyear),WAAdiscardall(nyears)));
        if (proj_total_yield(iyear)>proj_target(iyear))  // if catch possible, what F needed
        {
           proj_Fmult(iyear)=0.0;
           for (iloop=1;iloop<=20;iloop++)
           {
              Ftemp=proj_Fmult(iyear)*proj_dir_sel;
              denom=0.0;
              for (iage=1;iage<=nages;iage++)
              {

Ztemp(iage)=M(nyears,iage)+proj_F_nondir(iyear,iage)+proj_Fmult(iyear)*proj_Discard_sel(iage)+Ftemp(iage);
                 denom+=proj_NAA(iyear,iage)*WAAcatchall(nyears,iage)*proj_dir_sel(iage)*(1.0-mfexp(-
1.0*Ztemp(iage)))/Ztemp(iage);
              }
              proj_Fmult(iyear)=proj_target(iyear)/denom;
           }
        }
     }
     else if (proj_what(iyear)==2)      // match F%SPR
     {
        A=0.0;
        B=5.0;
        for (iloop=1;iloop<=20;iloop++)
        {
           C=(A+B)/2.0;
           SPR_Fmult=C;
           get_SPR();
           SPRatio=SPR/SR_spawners_per_recruit;
           if (SPRatio<proj_target(iyear))
           {
              B=C;
           }
           else
           {
              A=C;
           }
        }
        proj_Fmult(iyear)=C;
     }
     else if (proj_what(iyear)==3)      // project Fmsy
     {
        proj_Fmult=Fmsy;
     }
     else if (proj_what(iyear)==4)      // project Fcurrent
     {
        proj_Fmult=Fcurrent;
     }
     else if (proj_what(iyear)==5)      // project input F
     {
        proj_Fmult=proj_target(iyear);
     }
     proj_F_dir(iyear)=proj_Fmult(iyear)*proj_dir_sel;
     proj_F_Discard(iyear)=proj_Fmult(iyear)*proj_Discard_sel;
     proj_Z(iyear)=M(nyears)+proj_F_nondir(iyear)+proj_F_dir(iyear)+proj_F_Discard(iyear);
     proj_SSBfracZ(iyear)=mfexp(-1.0*fracyearSSB*proj_Z(iyear));
     proj_catch(iyear)=elem_prod(elem_div(proj_F_dir(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
     proj_Discard(iyear)=elem_prod(elem_div(proj_F_Discard(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
     proj_yield(iyear)=elem_prod(proj_catch(iyear),WAAcatchall(nyears));
     proj_total_yield(iyear)=sum(proj_yield(iyear));
     proj_total_Discard(iyear)=sum(elem_prod(proj_Discard(iyear),WAAdiscardall(nyears)));
     proj_TotJan1B(iyear)=sum(elem_prod(proj_NAA(iyear),WAAjan1b(nyears)));
     proj_SSB(iyear)=elem_prod(proj_NAA(iyear),proj_SSBfracZ(iyear))*fecundity(nyears);
   }

FUNCTION get_SPR
// simple spawners per recruit calculations
```

```
  ntemp=1.0;
  SPR=0.0;
  for (iage=1;iage<nages;iage++)
  {
    z=M(nyears,iage)+proj_nondir_F(iage)+SPR_Fmult*proj_dir_sel(iage)+SPR_Fmult*proj_Discard_sel(iage);
    SPR+=ntemp*fecundity(nyears,iage)*mfexp(-1.0*fracyearSSB*z);
    ntemp*=mfexp(-1.0*z);
  }
  z=M(nyears,nages)+proj_nondir_F(nages)+SPR_Fmult*proj_dir_sel(nages)+SPR_Fmult*proj_Discard_sel(nages);
  ntemp/=(1.0-mfexp(-1.0*z));
  SPR+=ntemp*fecundity(nyears,nages)*mfexp(-1.0*fracyearSSB*z);

FUNCTION get_multinomial_multiplier
// compute Francis (2011) stage 2 multiplier for multinomial to adjust input Neff
// Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. CJFAS 68: 1124-1138
  Neff_stage2_mult_catch=1;
  Neff_stage2_mult_discard=1;
  Neff_stage2_mult_index=1;
  // Catch
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    mean_age_obs=0.0;
    mean_age_pred=0.0;
    mean_age_pred2=0.0;
    mean_age_resid=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++){
        mean_age_obs(iyear) += CAA_prop_obs(ifleet,iyear,iage)*iage;
        mean_age_pred(iyear) += CAA_prop_pred(ifleet,iyear,iage)*iage;
        mean_age_pred2(iyear) += CAA_prop_pred(ifleet,iyear,iage)*iage*iage;
      }
    }
    mean_age_resid=mean_age_obs-mean_age_pred;
    mean_age_sigma=sqrt(mean_age_pred2-elem_prod(mean_age_pred,mean_age_pred));
    mean_age_n=0.0;
    mean_age_mean=0.0;
    mean_age_m2=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      if (input_eff_samp_size_catch(ifleet,iyear)>0){
        mean_age_x=mean_age_resid(iyear)*sqrt(input_eff_samp_size_catch(ifleet,iyear))/mean_age_sigma(iyear);
        mean_age_n += 1.0;
        mean_age_delta=mean_age_x-mean_age_mean;
        mean_age_mean += mean_age_delta/mean_age_n;
        mean_age_m2 += mean_age_delta*(mean_age_x-mean_age_mean);
      }
    }
    if ((mean_age_n > 0) && (mean_age_m2 > 0)) Neff_stage2_mult_catch(ifleet)=1.0/(mean_age_m2/(mean_age_n-
1.0));
  }

  // Discards
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    mean_age_obs=0.0;
    mean_age_pred=0.0;
    mean_age_pred2=0.0;
    mean_age_resid=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++){
        mean_age_obs(iyear) += Discard_prop_obs(ifleet,iyear,iage)*iage;
        mean_age_pred(iyear) += Discard_prop_pred(ifleet,iyear,iage)*iage;
        mean_age_pred2(iyear) += Discard_prop_pred(ifleet,iyear,iage)*iage*iage;
      }
    }
    mean_age_resid=mean_age_obs-mean_age_pred;
    mean_age_sigma=sqrt(mean_age_pred2-elem_prod(mean_age_pred,mean_age_pred));
    mean_age_n=0.0;
    mean_age_mean=0.0;
    mean_age_m2=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      if (input_eff_samp_size_discard(ifleet,iyear)>0){
        mean_age_x=mean_age_resid(iyear)*sqrt(input_eff_samp_size_discard(ifleet,iyear))/mean_age_sigma(iyear);
        mean_age_n += 1.0;
```

```
        mean_age_delta=mean_age_x-mean_age_mean;
        mean_age_mean += mean_age_delta/mean_age_n;
        mean_age_m2 += mean_age_delta*(mean_age_x-mean_age_mean);
      }
    }
    if ((mean_age_n > 0) && (mean_age_m2 > 0)) Neff_stage2_mult_discard(ifleet)=1.0/(mean_age_m2/(mean_age_n-
1.0));
  }
  // Indices
  for (ind=1;ind<=nindices;ind++){
    mean_age_obs=0.0;
    mean_age_pred=0.0;
    mean_age_pred2=0.0;
    mean_age_resid=0.0;
    for (i=1;i<=index_nobs(ind);i++){
      j=index_time(ind,i);
      for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++){
        mean_age_obs(j) += index_prop_obs(ind,i,iage)*iage;
        mean_age_pred(j) += index_prop_pred(ind,i,iage)*iage;
        mean_age_pred2(j) += index_prop_pred(ind,i,iage)*iage*iage;
      }
    }
    mean_age_resid=mean_age_obs-mean_age_pred;
    mean_age_sigma=sqrt(mean_age_pred2-elem_prod(mean_age_pred,mean_age_pred));
    mean_age_n=0.0;
    mean_age_mean=0.0;
    mean_age_m2=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      if (index_Neff_init(ind,iyear)>0){
        mean_age_x=mean_age_resid(iyear)*sqrt(index_Neff_init(ind,iyear))/mean_age_sigma(iyear);
        mean_age_n += 1.0;
        mean_age_delta=mean_age_x-mean_age_mean;
        mean_age_mean += mean_age_delta/mean_age_n;
        mean_age_m2 += mean_age_delta*(mean_age_x-mean_age_mean);
      }
    }
    if ((mean_age_n > 0) && (mean_age_m2 > 0)) Neff_stage2_mult_index(ind)=1.0/(mean_age_m2/(mean_age_n-1.0));
  }



FUNCTION get_log_factorial
// compute sum of log factorial, used in multinomial likelihood constant
  nfact_out=0.0;
  if (nfact_in >= 2)
  {
     for (int ilogfact=2;ilogfact<=nfact_in;ilogfact++)
     {
        nfact_out+=log(ilogfact);
     }
  }

FUNCTION compute_the_objective_function
  obj_fun=0.0;
  io=0; // io if statements commented out to speed up program

// indices (lognormal)
  for (ind=1;ind<=nindices;ind++)
  {
     likely_ind(ind)=index_like_const(ind);
     RSS_ind(ind)=norm2(log(index_obs(ind))-log(index_pred(ind)));
     for (i=1;i<=index_nobs(ind);i++)
     {
         likely_ind(ind)+=log(index_sigma(ind,i));
         likely_ind(ind)+=0.5*square(log(index_obs(ind,i))-log(index_pred(ind,i)))/index_sigma2(ind,i);
         index_stdresid(ind,i)=(log(index_obs(ind,i))-log(index_pred(ind,i)))/index_sigma(ind,i);
     }
     obj_fun+=lambda_ind(ind)*likely_ind(ind);
  }
  // if (io==1) cout << "likely_ind " << likely_ind << endl;
```

```
// indices age comp (multinomial)
  likely_index_age_comp=index_prop_like_const;
  for (ind=1;ind<=nindices;ind++)
  {
     if (index_estimate_proportions(ind)==1)
     {
       for (i=1;i<=index_nobs(ind);i++)
       {
         temp_sum=0.0;
         for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
         {
            temp_sum+=index_prop_obs(ind,i,iage)*log(index_prop_pred(ind,i,iage));
         }
         likely_index_age_comp+=-1.0*input_eff_samp_size_index(ind,i)*temp_sum;
       }
     }
  }
  obj_fun+=likely_index_age_comp;
  // if (io==1) cout << "likely_index_age_comp " << likely_index_age_comp << endl;

// total catch (lognormal)
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     catch_tot_likely(ifleet)=catch_tot_like_const(ifleet);
     discard_tot_likely(ifleet)=discard_tot_like_const(ifleet);
     RSS_catch_tot_fleet(ifleet)=norm2(log(Catch_tot_fleet_obs(ifleet)+0.00001)-
log(Catch_tot_fleet_pred(ifleet)+0.00001));
     RSS_Discard_tot_fleet(ifleet)=norm2(log(Discard_tot_fleet_obs(ifleet)+0.00001)-
log(Discard_tot_fleet_pred(ifleet)+0.00001));
     for (iyear=1;iyear<=nyears;iyear++)
     {
        catch_tot_likely(ifleet)+=log(catch_tot_sigma(ifleet,iyear));
        catch_tot_likely(ifleet)+=0.5*square(log(Catch_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Catch_tot_fleet_pred(ifleet,iyear)+0.00001))/catch_tot_sigma2(ifleet,iyear);
        discard_tot_likely(ifleet)+=log(discard_tot_sigma(ifleet,iyear));
        discard_tot_likely(ifleet)+=0.5*square(log(Discard_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Discard_tot_fleet_pred(ifleet,iyear)+0.00001))/discard_tot_sigma2(ifleet,iyear);
     }
     obj_fun+=lambda_catch_tot(ifleet)*catch_tot_likely(ifleet);
     obj_fun+=lambda_Discard_tot(ifleet)*discard_tot_likely(ifleet);
  }
  // if (io==1) cout << "catch_tot_likely " << catch_tot_likely << endl;

// catch age comp (multinomial)
  likely_catch=catch_prop_like_const;
  likely_Discard=discard_prop_like_const;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    for (iyear=1;iyear<=nyears;iyear++)
    {
       temp_sum=0.0;
       temp_sum2=0.0;
       for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
       {
          temp_sum+=CAA_prop_obs(ifleet,iyear,iage)*log(CAA_prop_pred(ifleet,iyear,iage));
          if(proportion_release(ifleet,iyear,iage)>0.0)
             temp_sum2+=Discard_prop_obs(ifleet,iyear,iage)*log(Discard_prop_pred(ifleet,iyear,iage));
       }
       likely_catch+=-1.0*input_eff_samp_size_catch(ifleet,iyear)*temp_sum;
       likely_Discard+=-1.0*input_eff_samp_size_discard(ifleet,iyear)*temp_sum2;
    }
  }
  obj_fun+=likely_catch;
  obj_fun+=likely_Discard;
  // if (io==1) cout << "likely_catch " << likely_catch << endl;

// stock-recruitment relationship (lognormal)
  likely_SR_sigma=SR_like_const;
  if (use_likelihood_constants==1)
  {
     likely_SR_sigma+=sum(log(SR_pred_recruits));
```

```
     likely_SR_sigma-=log(SR_pred_recruits(nyears+1));  // pred R in terminal year plus one does not have a
deviation
  }
  SR_stdresid=0.0;
  if (active(log_recruit_devs))
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
        likely_SR_sigma+=log(recruit_sigma(iyear));
        likely_SR_sigma+=0.5*square(log(recruits(iyear))-log(SR_pred_recruits(iyear)))/recruit_sigma2(iyear);
        SR_stdresid(iyear)=(log(recruits(iyear))-log(SR_pred_recruits(iyear)))/recruit_sigma(iyear);
     }
     obj_fun+=lambda_recruit_devs*likely_SR_sigma;
  }
  // if (io==1) cout << "likely_SR_sigma " << likely_SR_sigma << endl;

// selectivity parameters
  sel_likely=0.0;
  sel_stdresid=0.0;
  for (k=1;k<=nselparm;k++)
  {
     if (active(sel_params(k)))
     {
        sel_likely(k)+=sel_like_const(k);
        sel_likely(k)+=log(sel_sigma(k))+0.5*square(log(sel_initial(k))-log(sel_params(k)))/sel_sigma2(k);
        sel_stdresid(k)=(log(sel_initial(k))-log(sel_params(k)))/sel_sigma(k);
        obj_fun+=sel_lambda(k)*sel_likely(k);
     }
  }
  // if (io==1) cout << "sel_likely " << sel_likely << endl;

// index selectivity parameters
  indexsel_likely=0.0;
  indexsel_stdresid=0.0;
  for (k=1;k<=nindexselparms;k++)
  {
     if (active(index_sel_params(k)))
     {
        indexsel_likely(k)+=indexsel_like_const(k);
        indexsel_likely(k)+=log(indexsel_sigma(k))+0.5*square(log(indexsel_initial(k))-
log(index_sel_params(k)))/indexsel_sigma2(k);
        indexsel_stdresid(k)=(log(indexsel_initial(k))-log(index_sel_params(k)))/indexsel_sigma(k);
        obj_fun+=indexsel_lambda(k)*indexsel_likely(k);
     }
  }
  // if (io==1) cout << "indexsel_likely " << indexsel_likely << endl;

  steepness_likely=0.0;
  steepness_stdresid=0.0;
  if (active(SR_steepness))
  {
     steepness_likely=steepness_like_const;
     steepness_likely+=log(steepness_sigma)+0.5*square(log(SR_steepness_ini)-
log(SR_steepness))/steepness_sigma2;
     steepness_stdresid=(log(SR_steepness_ini)-log(SR_steepness))/steepness_sigma;
     obj_fun+=lambda_steepness*steepness_likely;
  }
  // if (io==1) cout << "steepness_likely " << steepness_likely << endl;

  SR_scaler_likely=0.0;
  SR_scaler_stdresid=0.0;
  if (active(log_SR_scaler))
  {
     SR_scaler_likely=SR_scaler_like_const;
     SR_scaler_likely+=log(SR_scaler_sigma)+0.5*(square(log(SR_scaler_ini)-log_SR_scaler))/SR_scaler_sigma2;
     SR_scaler_stdresid=(log(SR_scaler_ini)-log_SR_scaler)/SR_scaler_sigma;
     obj_fun+=lambda_SR_scaler*SR_scaler_likely;
  }
  // if (io==1) cout << "SR_scaler_likely " << SR_scaler_likely << endl;

  Fmult_year1_stdresid=0.0;
```

```
  if (active(log_Fmult_year1))
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        Fmult_year1_likely(ifleet)=Fmult_year1_like_const(ifleet);
        Fmult_year1_likely(ifleet)+=log(Fmult_year1_sigma(ifleet))+0.5*square(log_Fmult_year1(ifleet)-
log(Fmult_year1_ini(ifleet)))/Fmult_year1_sigma2(ifleet);
        Fmult_year1_stdresid(ifleet)=(log_Fmult_year1(ifleet)-
log(Fmult_year1_ini(ifleet)))/Fmult_year1_sigma(ifleet);
     }
     obj_fun+=lambda_Fmult_year1*Fmult_year1_likely;
  }
  // if (io==1) cout << "Fmult_year1_likely " << Fmult_year1_likely << endl;

  Fmult_devs_stdresid=0.0;
  if (active(log_Fmult_devs))
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        Fmult_devs_likely(ifleet)=Fmult_devs_like_const(ifleet);

Fmult_devs_likely(ifleet)+=log(Fmult_devs_sigma(ifleet))+0.5*norm2(log_Fmult_devs(ifleet))/Fmult_devs_sigma2(ifl
eet);
        for (iyear=2;iyear<=nyears;iyear++)
           Fmult_devs_stdresid(ifleet,iyear)=log_Fmult_devs(ifleet,iyear)/Fmult_devs_sigma(ifleet);
     }
     obj_fun+=lambda_Fmult_devs*Fmult_devs_likely;
  }
  // if (io==1) cout << "Fmult_devs_likely " << Fmult_devs_likely << endl;

  q_year1_stdresid=0.0;
  if (active(log_q_year1))
  {
     for (ind=1;ind<=nindices;ind++)
     {
        q_year1_likely(ind)=q_year1_like_const(ind);
        q_year1_likely(ind)+=log(q_year1_sigma(ind))+0.5*square(log_q_year1(ind)-
log(q_year1_ini(ind)))/q_year1_sigma2(ind);
        q_year1_stdresid(ind)=(log_q_year1(ind)-log(q_year1_ini(ind)))/q_year1_sigma(ind);
     }
     obj_fun+=lambda_q_year1*q_year1_likely;
  }
  // if (io==1) cout << "q_year1_likely " << q_year1_likely << endl;

  q_devs_stdresid=0.0;
  if (active(log_q_devs))
  {
     for (ind=1;ind<=nindices;ind++)
     {
       q_devs_likely(ind)=q_devs_like_const(ind);
       q_devs_likely(ind)+=log(q_devs_sigma(ind))+0.5*norm2(log_q_devs(ind))/q_devs_sigma2(ind);
       for (i=2;i<=index_nobs(ind);i++)
          q_devs_stdresid(ind,i)=log_q_devs(ind,i)/q_devs_sigma(ind);
     }
     obj_fun+=lambda_q_devs*q_devs_likely;
  }
  // if (io==1) cout << "q_devs_likely " << q_devs_likely << endl;

  if (NAA_year1_flag==1)
  {
     nyear1temp(1)=SR_pred_recruits(1);
     N_year1_stdresid=0.0;
     for (iage=2;iage<=nages;iage++)
     {
        nyear1temp(iage)=nyear1temp(iage-1)*S(1,iage-1);
     }
     nyear1temp(nages)/=(1.0-S(1,nages));
  }
  else if (NAA_year1_flag==2)
  {
     nyear1temp=NAA_year1_ini;
```

```
  }
  if (active(log_N_year1_devs))
  {
     if (N_year1_sigma>0.0)
     {
        for (iage=2;iage<=nages;iage++)
           N_year1_stdresid(iage)=(log(NAA(1,iage))-log(nyear1temp(iage)))/N_year1_sigma;
     }
     N_year1_likely=N_year1_like_const+sum(log(nyear1temp));
     N_year1_likely+=log(N_year1_sigma)+0.5*norm2(log(NAA(1))-log(nyear1temp))/N_year1_sigma2;
     obj_fun+=lambda_N_year1_devs*N_year1_likely;
  }
  // if (io==1) cout << "N_year1_likely " << N_year1_likely << endl;

  Fmult_max_pen=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    for (iyear=1;iyear<=nyears;iyear++)
    {
       temp_Fmult_max=mfexp(log_Fmult(ifleet,iyear))*max(sel_by_fleet(ifleet,iyear));
       if(temp_Fmult_max>Fmult_max_value)
          Fmult_max_pen+=1000.*(temp_Fmult_max-Fmult_max_value)*(temp_Fmult_max-Fmult_max_value);
    }
  }
  obj_fun+=Fmult_max_pen;
  // if (io==1) cout << "Fmult_max_pen " << Fmult_max_pen << endl;

  fpenalty_lambda=100.0*pow(10.0,(-1.0*current_phase())); // decrease emphasis on F near M as phases increase
  if (last_phase())                                         // no penalty in final solution
     fpenalty_lambda=0.0;
  fpenalty=fpenalty_lambda*square(log(mean(FAA_tot))-log(mean(M)));
  obj_fun+=fpenalty;
  // if (io==1) cout << "fpenalty " << fpenalty << endl;

FUNCTION write_MCMC
// first the output file for AgePro
  if (MCMCnyear_opt == 0)    // use final year
  {
     if (fillR_opt == 0)
     {
        NAAbsn(1)=NAA(nyears,1);
     }
     else if (fillR_opt == 1)
     {
        NAAbsn(1)=SR_pred_recruits(nyears);
     }
     else if (fillR_opt == 2)
     {
        tempR=0.0;
        for (i=Ravg_start;i<=Ravg_end;i++)
        {
           iyear=i-year1+1;
           tempR+=log(NAA(iyear,1));
        }
        NAAbsn(1)=mfexp(tempR/(Ravg_end-Ravg_start+1.0));
     }
     for (iage=2;iage<=nages;iage++)
     {
        NAAbsn(iage)=NAA(nyears,iage);
     }
  }
  else                       // use final year + 1
  {
     if (fillR_opt == 1)
     {
        NAAbsn(1)=SR_pred_recruits(nyears+1);
     }
     else if (fillR_opt == 2)
     {
        tempR=0.0;
        for (i=Ravg_start;i<=Ravg_end;i++)
```

```
        {
           iyear=i-year1+1;
           tempR+=log(NAA(iyear,1));
        }
        NAAbsn(1)=mfexp(tempR/(Ravg_end-Ravg_start+1.0));
     }
     for (iage=2;iage<=nages;iage++)
     {
        NAAbsn(iage)=NAA(nyears,iage-1)*S(nyears,iage-1);
     }
     NAAbsn(nages)+=NAA(nyears,nages)*S(nyears,nages);
  }

  // Liz added
       for (iyear=1;iyear<=nyears;iyear++)
     {
               tempFmult(iyear) = max(extract_row(FAA_tot,iyear));
               }
  // end stuff Liz added


// output the NAAbsn values
  ageproMCMC << NAAbsn << endl;

// now the standard MCMC output file
  basicMCMC << Freport << " " <<
               SSB << " " <<

                ///  Liz added

               tempFmult << " " <<

               rowsum(elem_prod(WAAjan1b, NAA)) << " " <<

               /// end stuff Liz added

               MSY << " " <<
               SSmsy << " " <<
               Fmsy << " " <<
               SSBmsy_ratio << " " <<
               Fmsy_ratio << " " <<
               endl;

REPORT_SECTION
  report << "Age Structured Assessment Program (ASAP) Version 3.0" << endl;
  report << "Start time for run: " << ctime(&start) << endl;
  report << "obj_fun        = " << obj_fun << endl << endl;
  report << "Component                Lambda          obj_fun" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
     report << "__Catch_Fleet_" << ifleet << "               " << lambda_catch_tot(ifleet) << "          " <<
lambda_catch_tot(ifleet)*catch_tot_likely(ifleet) << endl;
  report << "Catch_Fleet_Total             " << sum(lambda_catch_tot) << "          " <<
lambda_catch_tot*catch_tot_likely << endl;
  if (lambda_Discard_tot*discard_tot_likely > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << "__Discard_Fleet_" << ifleet << "             " << lambda_Discard_tot(ifleet) << "          "
<< lambda_Discard_tot(ifleet)*discard_tot_likely(ifleet) << endl;
  }
  report << "Discard_Fleet_Total          " << sum(lambda_Discard_tot) << "          " <<
lambda_Discard_tot*discard_tot_likely << endl;
  for (ind=1;ind<=nindices;ind++)
     report << "__Index_Fit_" << ind << "                 " << lambda_ind(ind) << "          " <<
lambda_ind(ind)*likely_ind(ind) << endl;
  report << "Index_Fit_Total               " << sum(lambda_ind) << "          " << lambda_ind*likely_ind <<
endl;
  report << "Catch_Age_Comps       see_below          " << likely_catch << endl;
  report << "Discard_Age_Comps     see_below          " << likely_Discard << endl;
  report << "Index_Age_Comps       see_below          " << likely_index_age_comp << endl;
  sum_sel_lambda=0;
  sum_sel_lambda_likely=0.0;
```

```
  for (k=1;k<=nselparm;k++)
  {
     if (sel_phase(k) >= 1)
     {
        if      (k < 10  ) report << "__Sel_Param_" << k << "                 " << sel_lambda(k) << "          "
<< sel_lambda(k)*sel_likely(k) << endl;
        else if (k < 100 ) report << "__Sel_Param_" << k << "                " << sel_lambda(k) << "          "
<< sel_lambda(k)*sel_likely(k) << endl;
        else if (k < 1000) report << "__Sel_Param_" << k << "               " << sel_lambda(k) << "          "
<< sel_lambda(k)*sel_likely(k) << endl;
        sum_sel_lambda+=sel_lambda(k);
        sum_sel_lambda_likely+=sel_lambda(k)*sel_likely(k);
     }
  }
  report << "Sel_Params_Total              " << sum_sel_lambda << "          " << sum_sel_lambda_likely << endl;
  sum_indexsel_lambda=0;
  sum_indexsel_lambda_likely=0.0;
  for (k=1;k<=nindexselparms;k++)
  {
     if (indexsel_phase(k) >= 1)
     {
        if      (k <10  ) report << "__Index_Sel_Param_" << k << "           " << indexsel_lambda(k) << "
" << indexsel_lambda(k)*indexsel_likely(k) << endl;
        else if (k <100 ) report << "__Index_Sel_Param_" << k << "          " << indexsel_lambda(k) << "
" << indexsel_lambda(k)*indexsel_likely(k) << endl;
        else if (k <1000) report << "__Index_Sel_Param_" << k << "         " << indexsel_lambda(k) << "
" << indexsel_lambda(k)*indexsel_likely(k) << endl;
        sum_indexsel_lambda+=indexsel_lambda(k);
        sum_indexsel_lambda_likely+=indexsel_lambda(k)*indexsel_likely(k);
     }
  }
  report << "Index_Sel_Params_Total        " << sum_indexsel_lambda << "          " <<
sum_indexsel_lambda_likely << endl;
  if (lambda_q_year1*q_year1_likely > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
        report << "__q_year1_index_" << ind << "             "  << lambda_q_year1(ind) << "          " <<
lambda_q_year1(ind)*q_year1_likely(ind) << endl;
  }
  report << "q_year1_Total                 " << sum(lambda_q_year1) << "          " <<
lambda_q_year1*q_year1_likely << endl;

  if (lambda_q_devs*q_devs_likely > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
        report << "__q_devs_index_" << ind << "              "  << lambda_q_devs(ind) << "          " <<
lambda_q_devs(ind)*q_devs_likely(ind) << endl;
  }
  report << "q_devs_Total                  " << sum(lambda_q_devs) << "          " <<
lambda_q_devs*q_devs_likely << endl;
  if (lambda_Fmult_year1*Fmult_year1_likely > 0.0);
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << "__Fmult_year1_fleet_" << ifleet << "         " << lambda_Fmult_year1(ifleet) << "          "
<< lambda_Fmult_year1(ifleet)*Fmult_year1_likely(ifleet) << endl;
  }
  report << "Fmult_year1_fleet_Total       " << sum(lambda_Fmult_year1) << "          " <<
lambda_Fmult_year1*Fmult_year1_likely << endl;
  if (lambda_Fmult_devs*Fmult_devs_likely > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << "__Fmult_devs_fleet_" << ifleet << "          " << lambda_Fmult_devs(ifleet) << "          "
<< lambda_Fmult_devs(ifleet)*Fmult_devs_likely(ifleet) << endl;
  }
  report << "Fmult_devs_fleet_Total        " << sum(lambda_Fmult_devs) << "          " <<
lambda_Fmult_devs*Fmult_devs_likely << endl;
  report << "N_year_1                      " << lambda_N_year1_devs << "          " <<
lambda_N_year1_devs*N_year1_likely << endl;
  report << "Recruit_devs                  " << lambda_recruit_devs << "          " <<
lambda_recruit_devs*likely_SR_sigma << endl;
```

```
  report << "SR_steepness                  " << lambda_steepness << "          " <<
lambda_steepness*steepness_likely << endl;
  report << "SR_scaler                     " << lambda_SR_scaler << "          " <<
lambda_SR_scaler*SR_scaler_likely << endl;
  report << "Fmult_Max_penalty          1000          " << Fmult_max_pen << endl;
  report << "F_penalty                     " << fpenalty_lambda << "           " << fpenalty << endl;
  report << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
       if (input_eff_samp_size_catch(ifleet,iyear)==0)
       {
         effective_sample_size(ifleet,iyear)=0;
       }
       else
       {
         effective_sample_size(ifleet,iyear)=CAA_prop_pred(ifleet,iyear)*(1.0-
CAA_prop_pred(ifleet,iyear))/norm2(CAA_prop_obs(ifleet,iyear)-CAA_prop_pred(ifleet,iyear));
       }
       if (input_eff_samp_size_discard(ifleet,iyear)==0)
       {
         effective_Discard_sample_size(ifleet,iyear)=0;
       }
       else
       {
         effective_Discard_sample_size(ifleet,iyear)=Discard_prop_pred(ifleet,iyear)*(1.0-
Discard_prop_pred(ifleet,iyear))/norm2(Discard_prop_obs(ifleet,iyear)-Discard_prop_pred(ifleet,iyear));
       }
     }
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " Input and Estimated effective sample sizes for fleet " << ifleet << endl;
     for (iyear=1;iyear<=nyears;iyear++)
        report << iyear+year1-1 << "  " << input_eff_samp_size_catch(ifleet,iyear) << "  " <<
effective_sample_size(ifleet,iyear) << endl;
     report << " Total  " << sum(input_eff_samp_size_catch(ifleet)) << "  " <<
sum(effective_sample_size(ifleet)) << endl;
  }
  report << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " Input and Estimated effective Discard sample sizes for fleet " << ifleet << endl;
     for (iyear=1;iyear<=nyears;iyear++)
        report << iyear+year1-1 << "  " << input_eff_samp_size_discard(ifleet,iyear) << "  " <<
effective_Discard_sample_size(ifleet,iyear) << endl;
     report << " Total  " << sum(input_eff_samp_size_discard(ifleet)) << "  " <<
sum(effective_Discard_sample_size(ifleet)) << endl;
  }
  report << endl;
  report << "Observed and predicted total fleet catch by year and standardized residual" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << " total catches" << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
      Catch_stdresid(ifleet,iyear)=(log(Catch_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Catch_tot_fleet_pred(ifleet,iyear)+0.00001))/catch_tot_sigma(ifleet,iyear);
      report << iyear+year1-1 << "  " << Catch_tot_fleet_obs(ifleet,iyear) << "  " <<
Catch_tot_fleet_pred(ifleet,iyear) << "  " << Catch_stdresid(ifleet,iyear) << endl;
    }
  }
  report << "Observed and predicted total fleet Discards by year and standardized residual" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << " total Discards" << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
      Discard_stdresid(ifleet,iyear)=(log(Discard_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Discard_tot_fleet_pred(ifleet,iyear)+0.00001))/discard_tot_sigma(ifleet,iyear);
```

```
      report << iyear+year1-1 << "  " << Discard_tot_fleet_obs(ifleet,iyear) << "  " <<
Discard_tot_fleet_pred(ifleet,iyear) << "  " << Discard_stdresid(ifleet,iyear) << endl;
    }
  }
  report << endl << "Index data" << endl;
  for (ind=1;ind<=nindices;ind++) {
     report << "index number " << ind << endl;
     report << "aggregate units = " << index_units_aggregate(ind) << endl;
     report << "proportions units = " << index_units_proportions(ind) << endl;
     report << "month = " << index_month(ind) << endl;
     report << "starting and ending ages for selectivity = " << index_start_age(ind) << "  " <<
index_end_age(ind) << endl;
     report << "selectivity choice = " << index_sel_choice(ind) << endl;
     report << " year, obs index, pred index, standardized residual" << endl;
     for (j=1;j<=index_nobs(ind);j++)
         report << index_year(ind,j) << "  " << index_obs(ind,j) << "  " << index_pred(ind,j) << "  " <<
index_stdresid(ind,j) << endl;
  }
  report << endl;
  index_Neff_init=0.0;
  index_Neff_est=0.0;
  for (ind=1;ind<=nindices;ind++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
         for (i=1;i<=index_nobs(ind);i++)
         {
             if (index_time(ind,i)==iyear)
             {
                 index_Neff_init(ind,iyear)=input_eff_samp_size_index(ind,i);
                 if (input_eff_samp_size_index(ind,i)==0)
                 {
                     index_Neff_est(ind,iyear)=0.0;
                 }
                 else
                 {
                     index_Neff_est(ind,iyear)=index_prop_pred(ind,i)*(1.0-
index_prop_pred(ind,i))/norm2(index_prop_obs(ind,i)-index_prop_pred(ind,i));
                 }
             }
         }
     }
  }
  report << "Input effective sample sizes by index (row=index, column=year)" << endl;
  report << index_Neff_init << endl;
  report << "Estimated effective sample sizes by index (row=index, column=year)" << endl;
  report << index_Neff_est << endl;
  report << endl;
  report << "Index proportions at age by index" << endl;
  for (ind=1;ind<=nindices;ind++)
  {
     output_index_prop_obs(ind)=0.0;
     output_index_prop_pred(ind)=0.0;
     if (index_estimate_proportions(ind)==1)
     {
        report << " Index number " << ind << endl;
        for (iyear=1;iyear<=nyears;iyear++)
        {
           for (i=1;i<=index_nobs(ind);i++)
           {
               if (index_time(ind,i)==iyear)
               {
                   for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                   {
                       output_index_prop_obs(ind,iyear,iage)=index_prop_obs(ind,i,iage);
                       output_index_prop_pred(ind,iyear,iage)=index_prop_pred(ind,i,iage);
                   }
               }
           }
           report << "Year " << iyear+year1-1 << " Obs  = " << output_index_prop_obs(ind,iyear) << endl;
           report << "Year " << iyear+year1-1 << " Pred = " << output_index_prop_pred(ind,iyear) << endl;
```

```
        }
     }
  }
  report << endl;
  report << "Index Selectivity at Age" << endl;
  report << indexsel << endl;
  report << endl;

  report << "Deviations section: only applicable if associated lambda > 0" << endl;
  report << "Nyear1 observed, expected, standardized residual" << endl;
  if (lambda_N_year1_devs > 0.0)
  {
     for (iage=2;iage<=nages;iage++)
     {
        report << iage << "  " << NAA(1,iage) << "  " << nyear1temp(iage) << "  " << N_year1_stdresid(iage) <<
endl;
     }
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Fleet Obs, Initial, and Stadardized Residual for Fmult" << endl;
  if (sum(lambda_Fmult_year1) > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << ifleet << "  " << mfexp(log_Fmult_year1(ifleet)) << "  " << Fmult_year1_ini(ifleet) << "  " <<
Fmult_year1_stdresid(ifleet) << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Standardized Residuals for Fmult_devs by fleet and year" << endl;
  if (sum(lambda_Fmult_devs) > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        report << " fleet " << ifleet << " Fmult_devs standardized residuals" << endl;
        for (iyear=2;iyear<=nyears;iyear++)
           report << iyear << "  " << Fmult_devs_stdresid(ifleet,iyear) << endl;
     }
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Index Obs, Initial, and Standardized Residual for q_year1" << endl;
  if (sum(lambda_q_year1) > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
        report << ind << "  " << mfexp(log_q_year1(ind)) << "  " << q_year1_ini(ind) << "  " <<
              (log_q_year1(ind)-log(q_year1_ini(ind)))/q_year1_sigma(ind) << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Standardized Residuals for catchability deviations by index and year" << endl;
  if (sum(lambda_q_devs) > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
     {
        report << " index " << ind << " q_devs standardized residuals" << endl;
        for (i=2;i<=index_nobs(ind);i++)
           report << index_year(ind,i) << "  " << log_q_devs(ind,i)/q_devs_sigma(ind) << endl;
     }
```

```
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Obs, Initial, and Stadardized Residual for SR steepness" << endl;
  if (lambda_steepness > 0.0)
  {
     report << SR_steepness << "  " << SR_steepness_ini << "  " << (log(SR_steepness)-
log(SR_steepness_ini))/steepness_sigma << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Obs, Initial, and Stadardized Residual for SR scaler" << endl;
  if (lambda_SR_scaler > 0.0)
  {
     report << mfexp(log_SR_scaler) << "  " << SR_scaler_ini << "  " << (log_SR_scaler-
log(SR_scaler_ini))/SR_scaler_sigma << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "End of Deviations Section" << endl << endl;

  report << "Selectivity by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++) {
     report << " fleet " << ifleet << " selectivity at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
       report << sel_by_fleet(ifleet,iyear) << endl;
  }
  report << endl;
  report << "Fmult by year for each fleet" << endl;
  Fmult=mfexp(log_Fmult);
  for (iyear=1;iyear<=nyears;iyear++) {
     for (ifleet=1;ifleet<=nfleets;ifleet++){
         temp_Fmult(ifleet)=Fmult(ifleet,iyear);
     }
     report << iyear+year1-1 << "  " << temp_Fmult << endl;
  }
  report << endl;
  report << "Directed F by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " fleet " << ifleet << " directed F at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
         report << FAA_by_fleet_dir(ifleet,iyear) << endl;
  }
  report << "Discard F by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " fleet " << ifleet << " Discard F at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
         report << FAA_by_fleet_Discard(ifleet,iyear) << endl;
  }
  report << "Total F" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
     report << FAA_tot(iyear) << endl;
  report << endl;
  report << "Average F for ages " << Freport_agemin << " to " << Freport_agemax << endl;
  if (Freport_wtopt==1) report << "Freport unweighted in .std and MCMC files" << endl;
  if (Freport_wtopt==2) report << "Freport N weighted in .std and MCMC files" << endl;
  if (Freport_wtopt==3) report << "Freport B weighted in .std and MCMC files" << endl;
  report << "year    unweighted   Nweighted    Bweighted" << endl;
  for (iyear=1;iyear<=nyears;iyear++){
```

```
     report << iyear+year1-1 << "  " << Freport_U(iyear) << "  " << Freport_N(iyear) << "  " << Freport_B(iyear)
<< endl;
  }
  report << endl;
  report << "Population Numbers at the Start of the Year" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
     report << NAA(iyear) << endl;
  report << endl;
  report << "Biomass Time Series" << endl;
  report << "Year, TotJan1B, SSB, ExploitableB" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
  {
     report << iyear+year1-1 << "  " << TotJan1B(iyear) << "  " << SSB(iyear) << "  " << ExploitableB(iyear) <<
endl;
  }
  report << endl;
  report << "q by index" << endl;
  for (ind=1;ind<=nindices;ind++)
  {
     report << " index " << ind << " q over time" << endl;
     for (i=1;i<=index_nobs(ind);i++)
     {
         report << index_year(ind,i) << "  " << q_by_index(ind,i) << endl;
     }
  }
  report << endl;
  report << "Proportions of catch at age by fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
       output_prop_obs=0.0;
       output_prop_pred=0.0;
       output_prop_obs(sel_start_age(ifleet),sel_end_age(ifleet))=CAA_prop_obs(ifleet,iyear);
       output_prop_pred(sel_start_age(ifleet),sel_end_age(ifleet))=CAA_prop_pred(ifleet,iyear);
       report << "Year " << iyear << " Obs  = " << output_prop_obs << endl;
       report << "Year " << iyear << " Pred = " << output_prop_pred << endl;
    }
  }
  report << endl;
  report << "Proportions of Discards at age by fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
       output_Discard_prop_obs=0.0;
       output_Discard_prop_pred=0.0;
       output_Discard_prop_obs(sel_start_age(ifleet),sel_end_age(ifleet))=Discard_prop_obs(ifleet,iyear);
       output_Discard_prop_pred(sel_start_age(ifleet),sel_end_age(ifleet))=Discard_prop_pred(ifleet,iyear);
       report << "Year " << iyear << " Obs  = " << output_Discard_prop_obs << endl;
       report << "Year " << iyear << " Pred = " << output_Discard_prop_pred << endl;
    }
  }
  report << endl;
  report << "F Reference Points Using Final Year Selectivity and Freport options" << endl;
  report << " refpt           F       slope to plot on SR" << endl;
  report << "  F0.1     " << F01_report << "     " << F01_slope << endl;
  report << "  Fmax     " << Fmax_report << "     " << Fmax_slope << endl;
  report << "  F30%SPR  " << F30SPR_report << "     " << F30SPR_slope << endl;
  report << "  F40%SPR  " << F40SPR_report << "     " << F40SPR_slope << endl;
  report << "  Fmsy     " << Fmsy_report << "     " << Fmsy_slope << "    SSBmsy    " << SSBmsy_report << "
MSY   " << MSY << endl;
  report << "  Fcurrent " << Freport(nyears) << "     " << Fcurrent_slope << endl;
  report << endl;
  report << "Stock-Recruitment Relationship Parameters" << endl;
  report << " alpha     = " << SR_alpha << endl;
  report << " beta      = " << SR_beta << endl;
  report << " R0        = " << SR_R0 << endl;
  report << " S0        = " << SR_S0 << endl;
```

```
  report << " steepness = " << SR_steepness << endl;
  report << "Spawning Stock, Obs Recruits(year+1), Pred Recruits(year+1), standardized residual" << endl;
  report << "init  xxxx  " << recruits(1) << "  " << SR_pred_recruits(1) << "  " <<
            (log(recruits(1))-log(SR_pred_recruits(1)))/recruit_sigma(1) << endl;
  for (iyear=1;iyear<nyears;iyear++)
    report << iyear+year1-1 << "  " << SSB(iyear) << "  " << recruits(iyear+1) << "  "  <<
SR_pred_recruits(iyear+1) << "  " <<
             (log(recruits(iyear+1))-log(SR_pred_recruits(iyear+1)))/recruit_sigma(iyear+1) << endl;
  report << nyears+year1-1 << "  " << SSB(nyears) << "       xxxx   " << SR_pred_recruits(nyears+1) << endl;
  report << endl;

  report << "Annual stock recruitment parameters" << endl;
  report << "Year, S0_vec, R0_vec, steepness_vec, s_per_r_vec" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
    report << iyear+year1-1 << "  " << S0_vec(iyear) << "  " << R0_vec(iyear) << "  " << steepness_vec(iyear) <<
"  " << s_per_r_vec(iyear) << endl;
  report << endl;

  report << "Root Mean Square Error computed from Standardized Residuals" << endl;
  report << "Component                 #resids         RMSE" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << "_Catch_Fleet_" << ifleet << "               " << nyears << "           " <<
sqrt(mean(square(Catch_stdresid(ifleet)))) << endl;
  }
  report << "Catch_Fleet_Total            " << nyears*nfleets << "           " <<
sqrt(mean(square(Catch_stdresid))) << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if (norm2(Discard_stdresid(ifleet)) > 0.0 )
     {
        report << "_Discard_Fleet_" << ifleet << "             " << nyears << "           " <<
sqrt(mean(square(Discard_stdresid(ifleet)))) << endl;
     }
     else
     {
        report << "_Discard_Fleet_" << ifleet << "             " << "0" << "            " << "0" << endl;
     }
  }
  if (norm2(Discard_stdresid) > 0.0)
  {
     report << "Discard_Fleet_Total          " << nyears*nfleets << "           " <<
sqrt(mean(square(Discard_stdresid))) << endl;
  }
  else
  {
     report << "Discard_Fleet_Total          " << "0" << "            " << "0" << endl;
  }
  for (ind=1;ind<=nindices;ind++)
  {
     report << "_Index_" << ind << "                     " << index_nobs(ind) << "           " <<
sqrt(mean(square(index_stdresid(ind)))) << endl;
  }
  report << "Index_Total                  " << sum(index_nobs) << "           " <<
sqrt(mean(square(index_stdresid))) << endl;
  N_year1_rmse=0.0;
  N_year1_rmse_nobs=0;
  if (lambda_N_year1_devs > 0.0 && norm2(N_year1_stdresid) > 0.0)
  {
     N_year1_rmse=sqrt(mean(square(N_year1_stdresid)));
     N_year1_rmse_nobs=nages-1;
  }
  report << "Nyear1                       " << N_year1_rmse_nobs << "           " << N_year1_rmse << endl;
  Fmult_year1_rmse=0.0;
  Fmult_year1_rmse_nobs=0;
  if (sum(lambda_Fmult_year1) > 0.0 && norm2(Fmult_year1_stdresid) > 0.0)
  {
     Fmult_year1_rmse=sqrt(mean(square(Fmult_year1_stdresid)));
     Fmult_year1_rmse_nobs=nfleets;
  }
```

```
  report << "Fmult_Year1                  " << Fmult_year1_rmse_nobs << "           " << Fmult_year1_rmse <<
endl;
  Fmult_devs_fleet_rmse=0.0;
  Fmult_devs_fleet_rmse_nobs=0;
  Fmult_devs_rmse=0.0;
  Fmult_devs_rmse_nobs=0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if (sum(lambda_Fmult_devs) > 0.0 && norm2(Fmult_devs_stdresid(ifleet)) > 0.0)
     {
        Fmult_devs_fleet_rmse(ifleet)=sqrt(mean(square(Fmult_devs_stdresid(ifleet))));
        Fmult_devs_fleet_rmse_nobs(ifleet)=nyears-1;
     }
     report << "_Fmult_devs_Fleet_" << ifleet << "          " << Fmult_devs_fleet_rmse_nobs(ifleet) << "
" << Fmult_devs_fleet_rmse(ifleet) << endl;
  }
  if (sum(lambda_Fmult_devs) > 0.0 && norm2(Fmult_devs_stdresid) > 0.0)
  {
     Fmult_devs_rmse=sqrt(mean(square(Fmult_devs_stdresid)));
     Fmult_devs_rmse_nobs=nfleets*(nyears-1);
  }
  report << "Fmult_devs_Total             " << Fmult_devs_rmse_nobs << "           " << Fmult_devs_rmse << endl;
  SR_rmse=0.0;
  SR_rmse_nobs=0;
  if (lambda_recruit_devs > 0.0 && norm2(SR_stdresid) > 0.0)
  {
     SR_rmse=sqrt(mean(square(SR_stdresid)));
     SR_rmse_nobs=nyears;
  }
  report << "Recruit_devs                 " << SR_rmse_nobs << "           " << SR_rmse << endl;
  sel_rmse=0.0;
  sel_rmse_nobs=0;
  if (sum(sel_lambda) > 0.0 && norm2(sel_stdresid) > 0.0)
  {
     sel_rmse=sqrt(mean(square(sel_stdresid)));
     for (k=1;k<=nselparm;k++)
     {
        if (sel_lambda(k) > 0.0)
           sel_rmse_nobs+=1;
     }
  }
  report << "Fleet_Sel_params             " << sel_rmse_nobs << "           " << sel_rmse << endl;
  indexsel_rmse=0.0;
  indexsel_rmse_nobs=0;
  if (sum(indexsel_lambda) > 0.0 && norm2(indexsel_stdresid) > 0.0)
  {
     indexsel_rmse=sqrt(mean(square(indexsel_stdresid)));
     for (k=1;k<=nindexselparms;k++)
     {
        if (indexsel_lambda(k) > 0.0)
           indexsel_rmse_nobs+=1;
     }
  }
  report << "Index_Sel_params             " << indexsel_rmse_nobs << "           " << indexsel_rmse << endl;
  q_year1_rmse=0.0;
  q_year1_rmse_nobs=0;
  if (sum(lambda_q_year1) > 0.0 && norm2(q_year1_stdresid) > 0.0)
  {
     q_year1_rmse=sqrt(mean(square(q_year1_stdresid)));
     for (ind=1;ind<=nindices;ind++)
     {
        if (lambda_q_year1(ind) > 0.0)
           q_year1_rmse_nobs+=1;
     }
  }
  report << "q_year1                      " << q_year1_rmse_nobs << "           " << q_year1_rmse << endl;
  q_devs_rmse=0.0;
  q_devs_rmse_nobs=0;
  if (sum(lambda_q_devs) > 0.0 && norm2(q_devs_stdresid) > 0.0)
  {
     q_devs_rmse=sqrt(mean(square(q_devs_stdresid)));
```

```
     for (ind=1;ind<=nindices;ind++)
     {
        if (lambda_q_year1(ind) > 0.0)
           q_devs_rmse_nobs+=index_nobs(ind)-1;
     }
  }
  report << "q_devs                       " << q_devs_rmse_nobs << "           " << q_devs_rmse << endl;
  steepness_rmse=0.0;
  steepness_rmse_nobs=0;
  if (lambda_steepness > 0.0)
  {
     steepness_rmse=sfabs(steepness_stdresid);
     steepness_rmse_nobs=1;
  }
  report << "SR_steepness                 " << steepness_rmse_nobs << "           " << steepness_rmse << endl;
  SR_scaler_rmse=0.0;
  SR_scaler_rmse_nobs=0;
  if (lambda_SR_scaler > 0.0)
  {
     SR_scaler_rmse=sfabs(SR_scaler_stdresid);
     SR_scaler_rmse_nobs=1;
  }
  report << "SR_scaler                    " << SR_scaler_rmse_nobs << "           " << SR_scaler_rmse << endl;
  report << endl;

  report << "Stage2 Multipliers for Multinomials (Francis 2011)" << endl;
  report << "Catch by Fleet" << endl;
  report << Neff_stage2_mult_catch << endl;
  report << "Discards by Fleet" << endl;
  report << Neff_stage2_mult_discard << endl;
  report << "Indices" << endl;
  report << Neff_stage2_mult_index << endl;
  report << endl;
  report << "New Input ESS based on applying stage2 multipliers" << endl;
  report << "Catch (rows are fleets, columns are years)" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    report << input_eff_samp_size_catch(ifleet) * Neff_stage2_mult_catch(ifleet) << endl;
  }
  report << "Discards (rows are fleets, columns are years)" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    report << input_eff_samp_size_discard(ifleet) * Neff_stage2_mult_discard(ifleet) << endl;
  }
  report << "Indices (rows are indices, columns are years)" << endl;
  for (ind=1;ind<=nindices;ind++){
    report << index_Neff_init(ind) * Neff_stage2_mult_index(ind) << endl;
  }
  report << endl;

  if (do_projections==1 && last_phase())
  {
     project_into_future();
     report << "Projection into Future" << endl;
     report << "Projected NAA" << endl;
     report << proj_NAA << endl;
     report << "Projected Directed FAA" << endl;
     report << proj_F_dir << endl;
     report << "Projected Discard FAA" << endl;
     report << proj_F_Discard << endl;
     report << "Projected Nondirected FAA" << endl;
     report << proj_F_nondir << endl;
     report << "Projected Catch at Age" << endl;
     report << proj_catch << endl;
     report << "Projected Discards at Age (in numbers)" << endl;
     report << proj_Discard << endl;
     report << "Projected Yield at Age" << endl;
     report << proj_yield << endl;
     report << "Year, Total Yield (in weight), Total Discards (in weight), TotJan1B, SSB, proj_what, SS/SSmsy"
<< endl;
     for (iyear=1;iyear<=nprojyears;iyear++)
```

```
       report << year1+nyears-1+iyear << "  " << proj_total_yield(iyear) << "  " << proj_total_Discard(iyear) <<
"  " << proj_TotJan1B(iyear) << "  " << proj_SSB(iyear) << "  " << proj_what(iyear) << "  " <<
proj_SSB(iyear)/SSmsy << endl;
     report << endl;
  }
  else
  {
     report << "Projections not requested" << endl;
     report << endl;
  }
  report << "that's all" << endl;

  if (make_Rfile==1 && last_phase())
  {
    #include "make-Rfile_asap3.cxx"  // ADMB2R code in this file
  }

RUNTIME_SECTION
  convergence_criteria 1.0e-4
  maximum_function_evaluations 1000,1600,10000

FINAL_SECTION
  //Calculates how long is taking to run
  // this code is based on the Widow Rockfish model (from Erik H. Williams, NMFS-Santa Cruz, now Beaufort)
  time(&finish);
  elapsed_time = difftime(finish,start);
  hour = long(elapsed_time)/3600;
  minute = long(elapsed_time)%3600/60;
  second = (long(elapsed_time)%3600)%60;
  cout<<endl<<endl<<"starting time: "<<ctime(&start);
  cout<<"finishing time: "<<ctime(&finish);
  cout<<"This run took: ";
  cout<<hour<<" hours, "<<minute<<" minutes, "<<second<<" seconds."<<endl<<endl<<endl;
```

Appendix 2: make-Rfile_asap3.cxx (to make rdat file)

```
// this is the file that creates the R data object

//=========================================================================
// Open the output file using the AD Model Builder template name, and
// specify 6 digits of precision
// use periods in R variable names instead of underscore

// variables used for naming fleets and indices
adstring ifleetchar;
adstring indchar;
adstring onenum(4);
adstring onednm(4);
adstring twodnm(4);

open_r_file(adprogram_name + ".rdat", 6, -99999);

  // metadata
  open_r_info_list("info", true);
      wrt_r_item("program", "ASAP3");
  close_r_info_list();


  // basic parameter values
  open_r_info_list("parms", false);
      wrt_r_item("styr", year1);
      wrt_r_item("endyr", (year1+nyears-1));
      wrt_r_item("nyears", nyears);
      wrt_r_item("nages", nages);
      wrt_r_item("nfleets", nfleets);
      wrt_r_item("nselblocks", nselblocks);
      wrt_r_item("navailindices", navailindices);
```

```
    wrt_r_item("nindices", nindices);
close_r_info_list();

// run options
open_r_info_list("options", false);
    wrt_r_item("isfecund", isfecund);
    wrt_r_item("frac.yr.spawn", fracyearSSB);
    wrt_r_item("do.projections", do_projections);
    wrt_r_item("ignore.guesses", ignore_guesses);
    wrt_r_item("Freport.agemin", Freport_agemin);
    wrt_r_item("Freport.agemax", Freport_agemax);
    wrt_r_item("Freport.wtopt", Freport_wtopt);
    wrt_r_item("use.likelihood.constants", use_likelihood_constants);
    wrt_r_item("Fmult.max.value", Fmult_max_value);
    wrt_r_item("N.year1.flag",NAA_year1_flag);
    wrt_r_item("do.mcmc",doMCMC);
close_r_info_list();

// Likelihood contributions
open_r_info_list("like", false);
    wrt_r_item("lk.total", obj_fun);
    wrt_r_item("lk.catch.total", (lambda_catch_tot*catch_tot_likely));
    wrt_r_item("lk.discard.total", (lambda_Discard_tot*discard_tot_likely));
    wrt_r_item("lk.index.fit.total", (lambda_ind*likely_ind));
    wrt_r_item("lk.catch.age.comp", likely_catch);
    wrt_r_item("lk.discards.age.comp", likely_Discard);
    wrt_r_item("lk.index.age.comp", likely_index_age_comp);
    wrt_r_item("lk.sel.param.total", sum_sel_lambda_likely);
    wrt_r_item("lk.index.sel.param.total", sum_indexsel_lambda_likely);
    wrt_r_item("lk.q.year1", (lambda_q_year1*q_year1_likely));
    wrt_r_item("lk.q.devs", (lambda_q_devs*q_devs_likely));
    wrt_r_item("lk.Fmult.year1.total", (lambda_Fmult_year1*Fmult_year1_likely));
    wrt_r_item("lk.Fmult.devs.total", (lambda_Fmult_devs*Fmult_devs_likely));
    wrt_r_item("lk.N.year1", (lambda_N_year1_devs*N_year1_likely));
    wrt_r_item("lk.Recruit.devs", (lambda_recruit_devs*likely_SR_sigma));
    wrt_r_item("lk.SR.steepness", (lambda_steepness*steepness_likely));
    wrt_r_item("lk.SR.scaler", (lambda_SR_scaler*SR_scaler_likely));
    wrt_r_item("lk.Fmult.Max.penalty", Fmult_max_pen);
    wrt_r_item("lk.F.penalty", fpenalty);
close_r_info_list();

// fleet, block, and index specific likelihood contributions
open_r_info_list("like.additional", false);
    wrt_r_item("nfleets",nfleets);
    wrt_r_item("nindices",nindices);
    wrt_r_item("nselparms",nselparm);
    wrt_r_item("nindexselparms",nindexselparms);
    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring lk_catch_fleet = adstring("lk.catch.") + ifleetchar;
            wrt_r_item(lk_catch_fleet,(lambda_catch_tot(ifleet)*catch_tot_likely(ifleet)));
        }

        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring lk_discard_fleet = adstring("lk.discard.") + ifleetchar;
            wrt_r_item(lk_discard_fleet,(lambda_Discard_tot(ifleet)*discard_tot_likely(ifleet)));
        }

        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
```

```
        ifleetchar = "fleet" + onenum;
        adstring lk_Fmult_year1_fleet = adstring("lk.Fmult.year1.") + ifleetchar;
        wrt_r_item(lk_Fmult_year1_fleet,(lambda_Fmult_year1(ifleet)*Fmult_year1_likely(ifleet)));
    }

    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring lk_Fmult_devs_fleet = adstring("lk.Fmult.devs.") + ifleetchar;
        wrt_r_item(lk_Fmult_devs_fleet,(lambda_Fmult_devs(ifleet)*Fmult_devs_likely(ifleet)));
    }
}

if (nindices>1)
{
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        adstring lk_index_fit_ind = adstring("lk.index.fit.") + indchar;
        wrt_r_item(lk_index_fit_ind,(lambda_ind(ind)*likely_ind(ind)));
    }

    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        adstring lk_q_year1_ind = adstring("lk.q.year1.") + indchar;
        wrt_r_item(lk_q_year1_ind,(lambda_q_year1(ind)*q_year1_likely(ind)));
    }

    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
```

```
            }
            indchar = "ind" + twodnm;
            adstring lk_q_devs_ind = adstring("lk.q.devs.") + indchar;
            wrt_r_item(lk_q_devs_ind,(lambda_q_devs(ind)*q_devs_likely(ind)));
        }
    }

    for (k=1;k<=nselparm;k++)
    {
        if (sel_phase(k) >=1)
        {
            if (k <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(k, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (k <=99)
            {
                itoa(k, twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            adstring lk_sel_param = adstring("lk.sel.param.") + twodnm;
            wrt_r_item(lk_sel_param,(sel_lambda(k)*sel_likely(k)));

        }
    }

    for (k=1;k<=nindexselparms;k++)
    {
        if (indexsel_phase(k) >=1)
        {
            if (k <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(k, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (k <=99)
            {
                itoa(k, twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            adstring lk_indexsel_param = adstring("lk.indexsel.param.") + twodnm;
            wrt_r_item(lk_indexsel_param,(indexsel_lambda(k)*indexsel_likely(k)));

        }
    }

close_r_info_list();

// initial guesses
open_r_list("initial.guesses");
    open_r_info_list("SR.inits", false);
        wrt_r_item("is.SR.scaler.R",is_SR_scaler_R);
        wrt_r_item("SR.scaler.init",SR_scaler_ini);
        wrt_r_item("SR_steepness.init",SR_steepness_ini);
    close_r_info_list();
    wrt_r_complete_vector("NAA.year1.init",NAA_year1_ini);
    wrt_r_complete_vector("Fmult.year1.init",Fmult_year1_ini);
    wrt_r_complete_vector("q.year1.init",q_year1_ini);
    wrt_r_complete_vector("release.mort", release_mort);
    wrt_r_complete_vector("index.use.flag",use_index);
close_r_list();

// control parameters
open_r_list("control.parms");
```

```
      open_r_info_list("phases", false);
          wrt_r_item("phase.Fmult.year1", phase_Fmult_year1);
          wrt_r_item("phase.Fmult.devs", phase_Fmult_devs);
          wrt_r_item("phase.recruit.devs", phase_recruit_devs);
          wrt_r_item("phase.N.year1.devs", phase_N_year1_devs);
          wrt_r_item("phase.q.year1", phase_q_year1);
          wrt_r_item("phase.q.devs", phase_q_devs);
          wrt_r_item("phase.SR.scaler", phase_SR_scaler);
          wrt_r_item("phase.steepness", phase_steepness);
      close_r_info_list();
      open_r_info_list("singles", false);
          wrt_r_item("lambda.N.year1.devs",lambda_N_year1_devs);
          wrt_r_item("N.year1.cv",N_year1_CV);
          wrt_r_item("lambda.recruit.devs",lambda_recruit_devs);
          wrt_r_item("lambda.steepness",lambda_steepness);
          wrt_r_item("steepness.cv",steepness_CV);
          wrt_r_item("lambda.SR.scaler",lambda_SR_scaler);
          wrt_r_item("SR.scaler.cv", SR_scaler_CV);
      close_r_info_list();
      open_r_info_list("mcmc", false);
          wrt_r_item("mcmc.nyear.opt",MCMCnyear_opt);
          wrt_r_item("mcmc.n.boot",MCMCnboot);
          wrt_r_item("mcmc.n.thin",MCMCnthin);
          wrt_r_item("mcmc.seed",MCMCseed);
          wrt_r_item("fillR.opt",fillR_opt);
          wrt_r_item("Ravg.start",Ravg_start);
          wrt_r_item("Ravg.end",Ravg_end);
      close_r_info_list();
      wrt_r_complete_vector("recruit.cv",recruit_CV);
      wrt_r_complete_vector("lambda.ind",lambda_ind);
      wrt_r_complete_vector("lambda.catch.tot",lambda_catch_tot);
      open_r_matrix("catch.tot.cv");
          wrt_r_matrix(catch_tot_CV, 2, 2);
          wrt_r_namevector(year1, (year1+nyears-1));
          wrt_r_namevector(1, nfleets);
      close_r_matrix();
      wrt_r_complete_vector("lambda.Discard.tot",lambda_Discard_tot);
      open_r_matrix("discard.tot.cv");
          wrt_r_matrix(discard_tot_CV, 2, 2);
          wrt_r_namevector(year1, (year1+nyears-1));
          wrt_r_namevector(1, nfleets);
      close_r_matrix();
      wrt_r_complete_vector("lambda.Fmult.year1",lambda_Fmult_year1);
      wrt_r_complete_vector("Fmult.year1.cv",Fmult_year1_CV);
      wrt_r_complete_vector("lambda.Fmult.devs",lambda_Fmult_devs);
      wrt_r_complete_vector("Fmult.devs.cv",Fmult_devs_CV);
      wrt_r_complete_vector("lambda.q.year1",lambda_q_year1);
      wrt_r_complete_vector("q.year1.cv",q_year1_CV);
      wrt_r_complete_vector("lambda.q.devs",lambda_q_devs);
      wrt_r_complete_vector("q.devs.cv",q_devs_CV);
      wrt_r_complete_vector("directed.fleet",directed_fleet);
      wrt_r_complete_vector("WAA.point.bio",WAApointbio);
      wrt_r_complete_vector("index.units.aggregate", index_units_aggregate);
      wrt_r_complete_vector("index.units.proportions", index_units_proportions);
      wrt_r_complete_vector("index.WAA.point", index_WAApoint);
      wrt_r_complete_vector("index.month", index_month);
      wrt_r_complete_vector("index.sel.start.age",index_start_age);
      wrt_r_complete_vector("index.sel.end.age",index_end_age);
      wrt_r_complete_vector("index.sel.choice",index_sel_choice);
      wrt_r_complete_vector("index.age.comp.flag",index_estimate_proportions);
  close_r_list();

  // selectivity input matrices for fleets and indices
  open_r_list("sel.input.mats");
      // input selectivity matrix, contains combinations of values not used, see fleet_sel_option to determine
which choice was made for each block
      open_r_matrix("fleet.sel.ini");
          wrt_r_matrix(sel_ini, 2, 2);
          wrt_r_namevector(1, (nselblocks*(nages+6)));
          wrt_r_namevector(1, 4);
      close_r_matrix();
```

```
    open_r_matrix("index.sel.ini");
        wrt_r_matrix(index_sel_ini, 2, 2);
        wrt_r_namevector(1, (navailindices*(nages+6)));
        wrt_r_namevector(1, 4);
    close_r_matrix();
close_r_list();

// Weight at Age matrices
open_r_list("WAA.mats");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring WAA_c_fleet = adstring("WAA.catch.") + ifleetchar;
        open_r_matrix(WAA_c_fleet);
            wrt_r_matrix(WAAcatchfleet(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
        adstring WAA_d_fleet = adstring("WAA.discard.") + ifleetchar;
        open_r_matrix(WAA_d_fleet);
            wrt_r_matrix(WAAdiscardfleet(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
    }
    open_r_matrix("WAA.catch.all");
        wrt_r_matrix(WAAcatchall, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    open_r_matrix("WAA.discard.all");
        wrt_r_matrix(WAAdiscardall, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    open_r_matrix("WAA.ssb");
        wrt_r_matrix(WAAssb, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    open_r_matrix("WAA.jan1");
        wrt_r_matrix(WAAjan1b, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    for (ind=1;ind<=nindices;ind++)
    {
        if (index_units_aggregate(ind)==1 || index_units_proportions(ind)==1)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            adstring index_WAA_name = adstring("index.WAA.") + indchar;
```

```
            open_r_matrix(index_WAA_name);
                wrt_r_matrix(index_WAA(ind), 2, 2);
                wrt_r_namevector(year1, (year1+nyears-1));
                wrt_r_namevector(1,nages);
            close_r_matrix();
        }
    }

  close_r_list();

  // Year by Age Matrices (not fleet specific): M, maturity, fecundity, N, Z, F,
  open_r_matrix("M.age");
      wrt_r_matrix(M, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("maturity");
      wrt_r_matrix(mature, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("fecundity");
      wrt_r_matrix(fecundity, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("N.age");
      wrt_r_matrix(NAA, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("Z.age");
      wrt_r_matrix(Z, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("F.age");
      wrt_r_matrix(FAA_tot, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  // Fleet by Year Matrices: Catch.tot.obs, Catch.tot.pred, Catch.tot.resid), Discard.tot.obs, Discard.tot.pred,
Discard.tot.resid
  open_r_matrix("catch.obs");
      wrt_r_matrix(Catch_tot_fleet_obs, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  open_r_matrix("catch.pred");
      wrt_r_matrix(Catch_tot_fleet_pred, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  open_r_matrix("catch.std.resid");
      wrt_r_matrix(Catch_stdresid, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  open_r_matrix("discard.obs");
      wrt_r_matrix(Discard_tot_fleet_obs, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
```

```
close_r_matrix();

open_r_matrix("discard.pred");
    wrt_r_matrix(Discard_tot_fleet_pred, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("discard.std.resid");
    wrt_r_matrix(Discard_stdresid, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();


// Age Compositions: Catch and Discards observed and predicted by fleet
open_r_list("catch.comp.mats");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring ccomp_ob = adstring("catch.") + ifleetchar + adstring(".ob");
        open_r_matrix(ccomp_ob);
            wrt_r_matrix(CAA_prop_obs(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();

        adstring ccomp_pr = adstring("catch.") + ifleetchar + adstring(".pr");
        open_r_matrix(ccomp_pr);
            wrt_r_matrix(CAA_prop_pred(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();

        adstring dcomp_ob = adstring("discard.") + ifleetchar + adstring(".ob");
        open_r_matrix(dcomp_ob);
            wrt_r_matrix(Discard_prop_obs(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();

        adstring dcomp_pr = adstring("discard.") + ifleetchar + adstring(".pr");
        open_r_matrix(dcomp_pr);
            wrt_r_matrix(Discard_prop_pred(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();
    }
close_r_list();


// fleet selectivity blocks
open_r_matrix("fleet.sel.blocks");
    wrt_r_matrix(sel_blocks, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

// vectors of fleet selectivity options
wrt_r_complete_vector("fleet.sel.start.age",sel_start_age);
wrt_r_complete_vector("fleet.sel.end.age",sel_end_age);
wrt_r_complete_vector("fleet.sel.option",sel_option);

// selecivity matrices for each fleet
open_r_list("fleet.sel.mats");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
```

```
        ifleetchar = "fleet" + onenum;
        adstring sel_fleet_char = adstring("sel.m.") + ifleetchar;
        open_r_matrix(sel_fleet_char);
            wrt_r_matrix(sel_by_fleet(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1, nages);
        close_r_matrix();
    }
close_r_list();

// Fmults by fleet
open_r_matrix("fleet.Fmult");
    wrt_r_matrix(Fmult, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

// FAA by fleet directed and discarded
open_r_list("fleet.FAA");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;

        adstring fleet_FAA_dir = adstring("FAA.directed.") + ifleetchar;
        open_r_matrix(fleet_FAA_dir);
            wrt_r_matrix(FAA_by_fleet_dir(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();

        adstring fleet_FAA_discard = adstring("FAA.discarded.") + ifleetchar;
        open_r_matrix(fleet_FAA_discard);
            wrt_r_matrix(FAA_by_fleet_Discard(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
    }
close_r_list();

// proportion release year by age matrices by fleet
open_r_list("fleet.prop.release");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring fleet_prop_release = adstring("prop.release.") + ifleetchar;
        open_r_matrix(fleet_prop_release);
            wrt_r_matrix(proportion_release(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
    }
close_r_list();

// fleet specific annual effective sample sizes input and estimated for catch and discards
open_r_matrix("fleet.catch.Neff.init");
    wrt_r_matrix(input_eff_samp_size_catch, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("fleet.catch.Neff.est");
    wrt_r_matrix(effective_sample_size, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("fleet.discard.Neff.init");
```

```
    wrt_r_matrix(input_eff_samp_size_discard, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("fleet.discard.Neff.est");
    wrt_r_matrix(effective_Discard_sample_size, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

// vector of q for each index if qdevs turned off, otherwise a list with vectors for each index
if (phase_q_devs <= 0)
{
    wrt_r_complete_vector("q.indices",  column(q_by_index,1));
}
else
{
    open_r_list("q.random.walk");
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            adstring q_ind = adstring("q.") + indchar;
            wrt_r_complete_vector(q_ind,q_by_index(ind));
        }
    close_r_list();
}

// vectors for Freport and Biomasses (TotJan1B, SSB, ExploitableB)
wrt_r_complete_vector("F.report",Freport);
wrt_r_complete_vector("tot.jan1.B",TotJan1B);
wrt_r_complete_vector("SSB",SSB);
wrt_r_complete_vector("exploitable.B",ExploitableB);


// F reference values
open_r_info_list("Fref", false);
    wrt_r_item("Fmax", Fmax_report);
    wrt_r_item("F01", F01_report);
    wrt_r_item("F30", F30SPR_report);
    wrt_r_item("F40", F40SPR_report);
    wrt_r_item("Fcurrent", Freport(nyears));
close_r_info_list();

// SR curve parameters
open_r_info_list("SR.parms", false);
    wrt_r_item("SR.alpha", SR_alpha);
    wrt_r_item("SR.beta", SR_beta);
    wrt_r_item("SR.SPR0", SR_spawners_per_recruit);
    wrt_r_item("SR.S0", SR_S0);
    wrt_r_item("SR.R0", SR_R0);
    wrt_r_item("SR.steepness", SR_steepness);
close_r_info_list();

// SR obs, pred, devs, and standardized resids
// note year coresponds to age-1 recruitment, when plot SR curve have to offset SSB and R by one year
open_r_df("SR.resids", year1, (year1+nyears-1), 2);
    wrt_r_namevector(year1, (year1+nyears-1));
```

```
        wrt_r_df_col("year", year1, (year1+nyears-1));
        wrt_r_df_col("recruits", recruits, year1);
        wrt_r_df_col("R.no.devs", SR_pred_recruits, year1);
        wrt_r_df_col("logR.dev", log_recruit_devs, year1);
        wrt_r_df_col("SR.std.resid", SR_stdresid, year1);
    close_r_df();

    // annual values for S0_vec, R0_vec, steepness_vec, s_per_r_vec (last year values should match SR.parms
  values)
    open_r_df("SR.annual.parms", year1, (year1+nyears-1), 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_df_col("year", year1, (year1+nyears-1));
        wrt_r_df_col("S0.vec", S0_vec, year1);
        wrt_r_df_col("R0.vec", R0_vec, year1);
        wrt_r_df_col("steepness.vec", steepness_vec, year1);
        wrt_r_df_col("s.per.r.vec",s_per_r_vec, year1);
    close_r_df();



    // index stuff starts here

    // selectivity by index
    open_r_matrix("index.sel");
        wrt_r_matrix(indexsel, 2, 2);
        wrt_r_namevector(1, nindices);
        wrt_r_namevector(1, nages);
    close_r_matrix();

    wrt_r_complete_vector("index.nobs",index_nobs);

    // index year counter (sequential numbers starting at 1 for first year)
    open_r_list("index.year.counter");
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            wrt_r_complete_vector(indchar,index_time(ind));
        }
    close_r_list();

    // index years
    open_r_list("index.year");
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
```

```
        wrt_r_complete_vector(indchar,index_year(ind));
    }
close_r_list();

// index CV
open_r_list("index.cv");
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        wrt_r_complete_vector(indchar,index_cv(ind));
    }
close_r_list();

// index sigmas (derived from input CV)
open_r_list("index.sigma");
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        wrt_r_complete_vector(indchar,index_sigma(ind));
    }
close_r_list();

// index observations
open_r_list("index.obs");
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        wrt_r_complete_vector(indchar,index_obs(ind));
    }
close_r_list();

// predicted indices
```

```
  open_r_list("index.pred");
      for (ind=1;ind<=nindices;ind++)
      {
          if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
          {
              itoa(ind, onednm, 10);
              twodnm = "0" + onednm;
          }
          else if (ind <=99)
          {
              itoa(ind,twodnm, 10);
          }
          else
          {
              twodnm = "00";
          }
          indchar = "ind" + twodnm;
          wrt_r_complete_vector(indchar,index_pred(ind));
      }
  close_r_list();

  // index standardized residuals
  open_r_list("index.std.resid");
      for (ind=1;ind<=nindices;ind++)
      {
          if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
          {
              itoa(ind, onednm, 10);
              twodnm = "0" + onednm;
          }
          else if (ind <=99)
          {
              itoa(ind,twodnm, 10);
          }
          else
          {
              twodnm = "00";
          }
          indchar = "ind" + twodnm;
          wrt_r_complete_vector(indchar,index_stdresid(ind));
      }
  close_r_list();

  // index proportions at age related output
  if (max(index_estimate_proportions)>0)  // check to see if any West Coast style indices, skip this section if
all are East Coast style
  {
      // Index Age Comp
      open_r_list("index.comp.mats");
          for (ind=1;ind<=nindices;ind++)
          {
              if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
              {
                  itoa(ind, onednm, 10);
                  twodnm = "0" + onednm;
              }
              else if (ind <=99)
              {
                  itoa(ind,twodnm, 10);
              }
              else
              {
                  twodnm = "00";
              }
              indchar = "ind" + twodnm;

              adstring acomp_ob = indchar + adstring(".ob");
              open_r_matrix(acomp_ob);
                  wrt_r_matrix(output_index_prop_obs(ind), 2, 2);
                  wrt_r_namevector(year1, (year1+nyears-1));
                  wrt_r_namevector(1,nages);
```

```
            close_r_matrix();

            adstring acomp_pr = indchar + adstring(".pr");
            open_r_matrix(acomp_pr);
                wrt_r_matrix(output_index_prop_pred(ind), 2, 2);
                wrt_r_namevector(year1, (year1+nyears-1));
                wrt_r_namevector(1, nages);
            close_r_matrix();
        }
    close_r_list();

  // Neff for indices initial guess
  open_r_matrix("index.Neff.init");
      wrt_r_matrix(index_Neff_init, 2, 2);
      wrt_r_namevector(1, nindices);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  // Neff for indices estimated
  open_r_matrix("index.Neff.est");
      wrt_r_matrix(index_Neff_est, 2, 2);
      wrt_r_namevector(1, nindices);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

}  // end if-statement to test for any index age comp


// deviations section: only reported if associated with lambda > 0
if (lambda_N_year1_devs > 0)
{
    // note: obs and pred include age 1 while std.resid does not - do not use age 1 when plotting
    open_r_list("deviations.N.year1");
        wrt_r_complete_vector("N.year1.obs",NAA(1));
        wrt_r_complete_vector("N.year1.pred",nyear1temp);
        wrt_r_complete_vector("N.year1.std.resid",N_year1_stdresid);
    close_r_list();
}


// RMSE number of observations section
open_r_info_list("RMSE.n", false);
    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring rmse_n_catch_fleet = adstring("rmse.n.catch.") + ifleetchar;
            wrt_r_item(rmse_n_catch_fleet,nyears);
        }
    }
    wrt_r_item("rmse.n.catch.tot",(nyears*nfleets));

    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring rmse_n_discard_fleet = adstring("rmse.n.discard.") + ifleetchar;
            if (sum(Discard_tot_fleet_obs(ifleet)) > 0)
            {
                wrt_r_item(rmse_n_discard_fleet,nyears);
            }
            else
            {
                wrt_r_item(rmse_n_discard_fleet,0);
            }
```

```
        }
    }
    if (sum(Discard_tot_fleet_obs) > 0)
    {
        wrt_r_item("rmse.n.discard.tot",(nyears*nfleets));
    }
    else
    {
        wrt_r_item("rmse.n.discard.tot",0);
    }

    if (nindices>1)
    {
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            adstring rmse_n_ind = adstring("rmse.n.") + indchar;
            wrt_r_item(rmse_n_ind,index_nobs(ind));
        }
    }
    wrt_r_item("rmse.n.ind.total",sum(index_nobs));

    wrt_r_item("rmse.n.N.year1",N_year1_rmse_nobs);

    wrt_r_item("rmse.n.Fmult.year1",Fmult_year1_rmse_nobs);

    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring rmse_n_Fmult_devs_fleet = adstring("rmse.n.Fmult.devs.") + ifleetchar;
            wrt_r_item(rmse_n_Fmult_devs_fleet,Fmult_devs_fleet_rmse_nobs(ifleet));
        }
    }
    wrt_r_item("rmse.n.Fmult.devs.total",Fmult_devs_rmse_nobs);

    wrt_r_item("rmse.n.recruit.devs",SR_rmse_nobs);

    wrt_r_item("rmse.n.fleet.sel.params",sel_rmse_nobs);

    wrt_r_item("rmse.n.index.sel.params",indexsel_rmse_nobs);

    wrt_r_item("rmse.n.q.year1",q_year1_rmse_nobs);

    wrt_r_item("rmse.n.q.devs",q_devs_rmse_nobs);

    wrt_r_item("rmse.n.SR.steepness",steepness_rmse_nobs);

    wrt_r_item("rmse.n.SR.scaler",SR_scaler_rmse_nobs);

close_r_info_list();

// RMSE section
open_r_info_list("RMSE", false);
    if (nfleets>1)
```

```
{
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring rmse_catch_fleet = adstring("rmse.catch.") + ifleetchar;
        wrt_r_item(rmse_catch_fleet,sqrt(mean(square(Catch_stdresid(ifleet)))));
    }
}
wrt_r_item("rmse.catch.tot",sqrt(mean(square(Catch_stdresid))));

if (nfleets>1)
{
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring rmse_discard_fleet = adstring("rmse.discard.") + ifleetchar;
        if (sum(Discard_tot_fleet_obs(ifleet)) > 0)
        {
            wrt_r_item(rmse_discard_fleet,sqrt(mean(square(Discard_stdresid(ifleet)))));
        }
        else
        {
            wrt_r_item(rmse_discard_fleet,0);
        }
    }
}
if (sum(Discard_tot_fleet_obs) > 0)
{
    wrt_r_item("rmse.discard.tot",sqrt(mean(square(Discard_stdresid))));
}
else
{
    wrt_r_item("rmse.discard.tot",0);
}

if (nindices>1)
{
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        adstring rmse_ind = adstring("rmse.") + indchar;
        wrt_r_item(rmse_ind,sqrt(mean(square(index_stdresid(ind)))));
    }
}
wrt_r_item("rmse.ind.total",sqrt(mean(square(index_stdresid))));

wrt_r_item("rmse.N.year1",N_year1_rmse);

wrt_r_item("rmse.Fmult.year1",Fmult_year1_rmse);

if (nfleets>1)
{
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
```

```
             if (nfleets < 10) itoa(ifleet, onenum, 10);
             else onenum="0";
             ifleetchar = "fleet" + onenum;
             adstring rmse_Fmult_devs_fleet = adstring("rmse.Fmult.devs.") + ifleetchar;
             wrt_r_item(rmse_Fmult_devs_fleet,Fmult_devs_fleet_rmse(ifleet));
         }
     }
     wrt_r_item("rmse.Fmult.devs.total",Fmult_devs_rmse);

     wrt_r_item("rmse.recruit.devs",SR_rmse);

     wrt_r_item("rmse.fleet.sel.params",sel_rmse);

     wrt_r_item("rmse.index.sel.params",indexsel_rmse);

     wrt_r_item("rmse.q.year1",q_year1_rmse);

     wrt_r_item("rmse.q.devs",q_devs_rmse);

     wrt_r_item("rmse.SR.steepness",steepness_rmse);

     wrt_r_item("rmse.SR.scaler",SR_scaler_rmse);

 close_r_info_list();

 open_r_list("Neff.stage2.mult");
     wrt_r_complete_vector("Neff.stage2.mult.catch", Neff_stage2_mult_catch);
     wrt_r_complete_vector("Neff.stage2.mult.discard", Neff_stage2_mult_discard);
     wrt_r_complete_vector("Neff.stage2.mult.index", Neff_stage2_mult_index);
 close_r_list();

// close file
close_r_file();
```

AGEPRO User Guide

Jon Brodziak
NOAA Fisheries
Pacific Islands Fisheries Science Center
2570 Dole Street
Honolulu, HI 96822
Tel: 808-983-2964
Fax: 808-983-2902
Email: Jon.Brodziak@NOAA.GOV

Version 3.4
1 April 2011

Abstract

This User Guide describes the AGEPRO version 3.4 model and software to perform stochastic projections for an exploited age-structured fish stock. This new version allows for multiple recruitment models to account for alternative hypotheses about recruitment dynamics and applies model-averaging to predict the distribution of realized recruitment given estimates of recruitment model probabilities. The AGEPRO model can be used to quantify the probable effects of a harvest scenario on an age-structured population over a given time horizon. Primary outputs include the projected distribution of spawning biomass, fishing mortality, recruitment, and landings by time period. This guide describes the numerical algorithms as well as the theoretical basis of the projection model. Program inputs, outputs, structure and general usage are also described in detail. The AGEPRO model is distributed in the hope that it will be useful, but includes no warranty. If you have problems with the software, please consult the User Guide and if the problem persists, please contact Alan.Seaver@NOAA.GOV or Jon.Brodziak@NOAA.GOV.

Table of Contents

Table of Contents

Introduction

The AGEPRO program can be used to perform stochastic projections of the abundance of an exploited age-structured population over a given time horizon. The primary purpose of the AGEPRO model is to produce management strategy projections that characterize the sampling distribution of key fishery system outputs such as landings, spawning stock biomass, population age structure, and fishing mortality accounting for uncertainty in initial population estimates, future recruitment, and natural mortality. The acronym “AGEPRO” derives from **age**-structured **pro**jections, in contrast to size- or biomass-based projection models. The user can evaluate alternative harvest scenarios by setting quotas or fishing mortality rates in each year of the time horizon.

Three elements of uncertainty can be included in an AGEPRO projection: **recruitment**, **initial population size**, and **natural mortality**. Recruitment is the primary stochastic element in the population model, where recruitment is defined as the number of fish entering the modeled population at the beginning of each year in the time horizon. There are a total of fifteen stochastic recruitment models that can be used for population projection. It is also possible to simulate a deterministic recruitment trajectory (see recruitment model 9 below).

Initial population size is the second potential element of uncertainty for population projection. To include this element, a distribution of initial population sizes at age must be calculated a priori. This is typically done using bootstrapping, Markov chain Monte carlo simulation, or other techniques in most age-structured assessments. If recruitment occurs at an age greater than age-1, then additional distributions of population size at age and fishing mortality at age prior to the projection time horizon are needed. Alternatively, projections can be based on the best point estimate of initial population size.

The third potential element of uncertainty is natural mortality. The user can choose to simulate natural mortality as a constant or a stochastic process at age. In the stochastic case, the instantaneous natural mortality rate is simulated as an autocorrelated lognormal process. Annual natural mortality rates at age are random samples from age-specific uniform distributions with means equal to the age-specific vulnerabilities of each age class to the full natural mortality rate and with age-specific coefficients of variation.

The AGEPRO model was initially developed in 1994 to determine optimal strategies to rebuild a depleted fish stock. The model was reviewed at the May 1994 meeting of the Northeast Fisheries Science Center Methods Working Group (Brodziak and Rago, 1994; Brodziak et al. 1998). Subsequently, the model was applied to groundfish stocks at the 18th SARC (NEFSC 1994) to evaluate Amendment 5 harvest scenarios (NEFMC 1994) and was applied again in 1995 to assist with Amendment 7 (NEFMC 1996). The User Guide was prepared in 1997 to provide documentation and has been updated since then to describe modifications to the model and software. The current program is written in Fortran 95 to allow for dynamic array allocation and to achieve rapid processing speeds.

Age-Structured Population Model

A simple age-structured population model is the basis for the AGEPRO model and software. This model represents an iteroparous fish population whose abundance changes due to fluctuations in recruitment, natural mortality, and fishing mortality. Population size at age changes continuously throughout the year due to the concurrent forces of natural and fishing mortality. Recruitment (R) to the population occurs at the beginning of each year (January 1^{st}) and is the first element in the population size at age vector (Table 1).

Population Abundance, Survival, and Spawning Biomass

The AGEPRO model calculates the number of fish alive within each age class of the population through time. Let Y denote the number of years in a projection where t indexes time for t=1,2, ..., Y. The maximum number of years (Y) in the projection is a dynamic variable specified by the user and constrained by the amount of computer memory. The youngest age class comprises the recruits and the age of recruitment (r) is specified by the user. The oldest age class is a plus-group which consists of all fish that are at least as old as a cutoff age (A). The maximum number of age classes is 100. For each age class, the number of fish alive at the beginning of a each calendar year (January 1st) is $N_j(t)$ where “j” indexes age class and “t” indexes year. Note that $N_A(t)$ is the number of fish that are age-A or older at the beginning of year t. Given this, the population abundance at the beginning of year t is the vector $\underline{N}(t)$ with R(t) used as an alternate notation to emphasize that a recruitment submodel is needed to stochastically generate recruitment through time horizon

$$(1) \qquad \underline{N}(t) = \begin{bmatrix} N_r(t) \\ N_{r+1}(t) \\ N_{r+2}(t) \\ \vdots \\ N_A(t) \end{bmatrix} = \begin{bmatrix} R(t) \\ N_{r+1}(t) \\ N_{r+2}(t) \\ \vdots \\ N_A(t) \end{bmatrix}$$

When the age of recruitment is greater than age-1, the modeled age classes are age-r through the plus-group. In this case, the dynamics of age classes younger than age-r are not explicitly modeled.

Population survival at age from year t-1 to year t is calculated using instantaneous fishing and mortality rates at age. To describe annual survival through mortality, let $M_a(t)$ denote the instantaneous natural mortality rate on age group a and let $F_j(t)$ denote the instantaneous fishing mortality rate for age-j fish in year t. Population size at age in year t for the age classes indexed by a= r +1 to A-1 is given by

$$(2) \qquad N_a(t) = N_{a-1}(t-1) \cdot e^{-M_{a\text{-}1}(t-1) - F_{a\text{-}1}(t-1)}$$

Similarly, population size at age in year t for the plus group of fish age-A and older is given by

(3) $$N_A(t) = N_A(t-1)\cdot e^{-M_A(t-1)-F_A(t-1)} + N_{A-1}(t-1)\cdot e^{-M_{A-1}(t-1)-F_{A-1}(t-1)}$$

where survival for the plus-group involves an age-A and an age-(A-1) component. Incoming recruitment is determined through a stochastic process that is either dependent or independent of spawning biomass in year t-r (see **Stock-Recruitment Relationship** below).

Annual spawning biomass ($B_S(t)$) is calculated from the population size vector $\underline{N}(t)$ and total mortality rates as well as information on sexual maturity and weight at age. To describe natural mortality at age in year t, let M(t) denote the instantaneous natural mortality rate and let $P_{M,a}(t)$ be the fraction of the natural mortality rate experienced by age group a . The age-specific natural mortality rate ($M_a(t)$) is then the product of M and the vulnerability at age-a, i.e., $M_a(t) = M(t)PM_a(t)$. To describe annual survival, let $F_j(t)$ be the instantaneous fishing mortality rate for age-j fish in year t. Further, let $P_{S,j}(t)$ denote the average fraction of age-j fish that are sexually mature in year t and let $W_{S,j}(t)$ denote the average spawning weight of an age-j fish in year t. Last, let $P_Z(t)$ denote the proportion of total mortality that occurs from January 1st to the mid-point of the spawning season. Given this, population size at the midpoint of the spawning season in year t ($\underline{N}_s(t)$) is obtained by applying instantaneous natural and fishing mortality rates that occur prior to the spawning season to the population vector at the beginning of the year, $\underline{N}(t)$.

(4) $$\underline{N}_S(t) = \begin{bmatrix} N_r(t)\cdot e^{-P_Z(t)[M_R(t)+F_R(t)]} \\ N_{r+1}(t)\cdot e^{-P_Z(t)[M_{R+1}(t)+F_{R+1}(t)]} \\ N_{r+2}(t)\cdot e^{-P_Z(t)[M_{R+2}(t)+F_{R+2}(t)]} \\ \vdots \\ N_A(t)\cdot e^{-P_Z(t)[M_A(t)+F_A(t)]} \end{bmatrix}$$

The amount of spawning biomass in year t, $B_S(t)$, is the sum of the weight of mature fish at the midpoint of the spawning season

(5) $$B_S(t) = \sum_{a=r}^{A} W_{S,a}(t)\cdot P_{S,a}(t)\cdot N_a(t)\cdot e^{-P_Z(t)[M_a(t)+F_a(t)]}$$

Catch, Landings, and Discards

The fishery catch depends on the fraction of the population that is vulnerable to harvest or the exploitable stock size. Catch by age class is determined by the Baranov catch equation (see, for example, Quinn and Deriso 1999), and the catch of age-a fish in year t ($C_a(t)$) is

(6) $$C_a(t) = \frac{F_a(t)}{M_a(t) + F_a(t)}\left[1 - e^{-M_a(t) - F_a(t)}\right]\cdot N_a(t)$$

To account for age-specific discarding of fish, let $P_{D,a}(t)$ be the proportion of age-a fish that are discarded and die in year t, and let $W_{L,a}(t)$ and $W_{D,a}(t)$ be the average weight at age-a in year t for landed and discarded fish, respectively. Then, if discarding is included in the projections (discflag=true), the total landed weight in year t, denoted by L(t), is

(7) $$L(t) = \sum_{a=r}^{A} C_a(t)\cdot\left[1 - P_{D,a}(t)\right]\cdot W_{L,a}(t)$$

Similarly, the total weight of discarded fish in year t, denoted by D(t), is

(8) $$D(t) = \sum_{a=r}^{A} C_a(t)\cdot P_{D,a}(t)\cdot W_{D,a}(t)$$

Population Harvest

There are two options for determining the level of population harvest in each year of the time horizon. The first option is a user-input fishing mortality rate (effort-based management, quotaflag=false & mixflag=false). The second option is a user-input landings quota (quota-based management, quotaflag=true & mixflag=false). These two harvest options can be mixed in any order within a given projection run where effort-based management is applied in some years and quota-based management in the other years (mixflag=true). In this case, the user sets a binary index I(t) to determine the harvest option for each year in the projection time horizon. If I(t) =1, a quota-based management is applied in year t; else if I(t)=0, effort-based management is applied in year t. A mixture of quotas and effort-based harvest can be useful when projecting forward from a previous assessment when only catch is available for intervening years.

When effort-based management is applied, catch at age is determined by setting $F_a(t)$ for each age class. In this case, the fishing mortality rate on age-a fish in year t is the product of the fully-selected fishing mortality rate, denoted by F(t), and the age-specific fishery selectivity (or partial recruitment) of age-a fish, denoted by $P_{F,a}(t)$

(9) $$F_a(t) = F(t)\cdot P_{F,a}(t)$$

Landings and discards, if applicable, are then determined from $F_a(t)$. When quota-based management is applied, however, the F(t) that would yield the landings quota must be determined numerically.

Under quota-based management, the landings quota in year t, denoted by Q(t), will translate into a variety of effective fishing mortality rates depending on population size, fishery selectivity, and discarding, if applicable. Ignoring the time dimension for a moment, a landings quota Q can be expressed as a function of F, Q= L(F), where F is the fully-recruited F and L is the landings as a function of F. To see this result, observe that the catch of age-a fish can be expressed as a function of F

$$(10) \qquad C_a(F) = \frac{F \cdot P_{F,a}(t)}{M_a(t) + F \cdot P_{F,a}(t)} \left[1 - e^{-M_a(t) - F \cdot P_{F,a}(t)}\right] \cdot N_a(t)$$

As a result, landings can also be expressed as a function of F

$$(11) \qquad L(F) = \sum_{a=r}^{A} C_a(F) \cdot \left[1 - P_{D,a}(t)\right] \cdot W_{L,a}(t)$$

The fully-recruited fishing mortality which satisfies the equation Q=L(F) can be found using Newton's method. Details of this numerical approach are provided below (see Appendix). Quotas which exceed the exploitable biomass of the population are infeasible; conditions defining infeasible quotas are also specified below (Appendix).

Stock-Recruitment Relationship

In general, the relationship between spawning stock B_S and recruitment R is highly variable owing to intrinsic variability in factors governing early life history survival and to measurement error in the estimates of recruitment and the spawning biomass that generated it. The stock-recruitment relationship ultimately defines the sustainable yield curve and its expected variability assuming that the stochastic processes of growth, maturation, and natural mortality are density-independent and stationary throughout the time horizon. Quinn and Deriso (1999) provide a useful general discussion of stock-recruitment models, renewal processes, and sustainable yield. Note that the assumed stock-recruitment relationship does not affect the initial population abundance at the beginning of the time horizon (see **Initial Population Abundance**).

A total of nineteen stochastic recruitment models are available for population projection in the AGEPRO software. Twelve of the recruitment models are functionally dependent on B_S while seven do not depend on B_S. Five of the recruitment models have time-dependent parameters, ten are time-invariant, and four may include time as a predictor, or not. The user is responsible for the choice and parameterization of the recruitment models. In what follows, the age of recruitment to the population is denoted as “r”; the recruitment age is either age-1 or age-r for r>1. A description of each of the recruitment models follows. Also note that the absolute units for recruitment are numbers of age-r fish, while for B_S, the absolute units are kilograms of spawning biomass in each of the recruitment models below.

Model 1. Markov Matrix

A Markov matrix approach to modeling recruitment may be useful when there is uncertainty about the functional form of the stock-recruitment relationship. A Markov matrix contains transition probabilities that define the probability of obtaining a given level of recruitment given that B_S was within a defined interval range. In particular, the distribution of recruitment is assumed to follow a multinomial distribution conditioned on the spawning biomass interval (state). <u>The Markov matrix model depends on spawning biomass and is time-invariant.</u>

An empirical approach to estimate a Markov matrix uses stock-recruitment data to determine the parameters of a multinomial distribution for each spawning biomass state. In this case, matrix elements can be empirically determined by counting the number of times that a recruitment observation interval lies within a given spawning biomass state, defined by an interval of spawning biomass, and normalizing over all spawning states. To do this, assume that there are m recruitment states and n spawning biomass states defined by disjoint intervals on the recruitment and spawning biomass axes

$$I_j = \left[B_{S,j}, B_{S,j+1}\right] \text{ and } O_k = \left[R_k, R_{k+1}\right] \tag{12}$$

where $B_{S,j}$ and R_k are endpoints of the disjoint intervals of spawning biomass and recruitment. Note that $B_{S,1}=0$ and that the spawning biomass intervals are defined by the cut points $B_{S,2}$, $B_{S,3}$, ..., $B_{S,J}$.

The conditional probability of realizing the k^{th} recruitment state given that spawning biomass ($P_{j,k}$) is in the j^{th} state is the element in the j^{th} row and k^{th} column of the Markov matrix where

$$P_{j,k} = \Pr\left(N_r \in O_k \mid B_S \in I_j\right) \tag{13}$$

This conditional probability can be approximated by the computing the number of points in the stock recruitment data set that fall within the I_j x O_k cell and normalizing within each spawning biomass interval I_j. If x_{jk} represents the number of stock-recruitment observations in cell I_j x O_k and there is at least one observation in spawning state j, then an empirical estimate of $P_{j,k}$ is

$$\Pr\left(R \in O_k \mid B_S \in I_j\right) = \frac{x_{j,k}}{\sum_k x_{j,k}} \tag{14}$$

Note that the $P_{j,k}$ are nonnegative and the sum of $P_{j,k}$ over k is unity.

If there are few stock-recruitment observations, then an empirical approach will produce imprecise estimates of the $P_{j,k}$. In this case, elements of the Markov matrix might be estimated using either a frequentist bootstrapping or a Bayesian parametric approach.

Up to 25 recruitment states and up to 10 B_S states can be used in the Markov matrix model. The simulated recruitments ($N_{r,k}$) are defined to be the midpoints of the recruitment intervals O_k. That is, $R = N_{r,k} = (R_k + R_{k+1})/2$. For each spawning biomass interval, the user also needs to specify the conditional probabilities of realizing the expected recruitment level, e.g., the $P_{j,k}$.

Model 2. Empirical Recruits Per Spawning Biomass Distribution

For some stocks, the distribution of recruits per spawner may be independent of the number of spawners over the range of observed data. The recruitment per spawning biomass (R/B_S) model randomly generates recruitment under the assumption that the distribution of the R/B_S ratio is stationary and independent of stock size. The empirical recruits per spawning biomass distribution model depends on spawning biomass and is time-invariant.

To describe this nonparametric approach, let S_t be the R/B_S ratio for the tth stock recruitment data point

(15) $$S_t = \frac{N_r(t)}{B_S(t-r)}$$

and let R_S represent the s$_{th}$ element in the ordered set of S_t. The empirical probability density function for R_S, denoted as $g(R_S)$, is 1/T for all values of R/B_S where T = the number of stock-recruitment data points. Let $G(R_S)$ denote the cumulative distribution function (cdf). Let $G(R_{MIN}) = 0$ and $G(R_{MAX}) = 1$ so that the cdf of R_s can be written as

(16) $$G(R_S) = \frac{s-1}{T-1}$$

Random values of $S=R/B_S$ can be generated by applying the probability integral transform to the empirically derived cdf. To do this, let U be a uniformly distributed random variable on the interval [0,1]. The value of R/B_S corresponding to U is determined by applying the inverse function of the cdf $G(R_s)$. In particular, when U is an integer multiple of 1/(T-1) so that U=s/(T-1) then $R/B_S = G^{-1}(U) = R_S$. Otherwise R/B_S can be obtained by linear interpolation when U is not a multiple of 1/(T-1).

In particular, if (s-1)/(T-1) < U < s/(T-1), then

(17) $$U = \left(\frac{\frac{s}{T-1} - \frac{s-1}{T-1}}{R_{S+1} - R_S} \right) \left(\frac{R}{B_S} - R_S \right) + \frac{s-1}{T-1}$$

Solving for R/B_S as a function of U yields

(18) $$\frac{R}{B_S} = (T-1)(R_{S+1} - R_S)\left(U - \frac{s-1}{T-1} \right) + R_S$$

where the interpolation index s is determined as the greatest integer in 1+U(T-1). Given a random value of R/B_S, recruitment is generated as

(19)
$$R(t) = N_r(t) = B_S(t-r) \cdot \frac{R}{B_S}$$

The AGEPRO program can generate stochastic recruitments using model 2 with up to 100 stock-recruitment data points.

Model 3. Empirical Recruitment Distribution

Another simple model for generating recruitment is to draw randomly from the observed set of recruitments { $N_r(1)$, $N_r(2)$, ..., $N_r(T)$}. This may be a useful approach when the recruitment has randomly fluctuated about its mean and appears to be independent of spawning biomass for the observed range of data. In this case, the recruitment distribution may be modeled as a multinomial random variable where the probability of randomly choosing a particular recruitment is 1/T given T observed recruitments. The empirical recruitment distribution model does not depend on spawning biomass and is time-invariant.

In this model, realized recruitment N_r is simulated using

(20)
$$\Pr\left(R = N_r(t)\right) = \frac{1}{T} \ , \quad for\ t \in \{1, 2, ..., T\}$$

The empirical recruitment distribution approach is nonparametric and assumes that future recruitment is totally independent of spawning stock biomass. When current levels of B_S are near the midrange of historical values this assumption is acceptable. However, if contemporary B_S values are near the bottom of the range, then this approach could be overly optimistic, for it assumes that all historically observed recruitment levels are possible, regardless of B_S. The AGEPRO program allows up to 100 observed recruitments for random sampling. Note that the empirical recruitment distribution model can be used to make deterministic projections by specifying a single observed recruitment.

Model 4. Two-Stage Empirical Recruits Per Spawning Biomass Distribution

The two-stage recruits per spawning biomass model is a direct generalization of the R/B_S model where the spawning stock of the population is categorized into “low” and “high” states. The two-stage empirical recruits per spawning biomass distribution model depends on spawning biomass and is time-invariant.

In this model, there is an R/B_S distribution for the low spawning biomass state and an R/B_S distribution for the high spawning biomass state. Let G_{LOW} be the cdf and let T_{LOW} be the number of R/B_S values for the low B_S state. Similarly, let G_{HIGH} be the cdf and let T_{HIGH} be the number of R/B_S values for the high B_S state. Further, let $B_S{*}$ denote the cutoff level of B_S such that, if $B_S > B_S{*}$, then B_S falls in the high state. Conversely if $B_S < B_S{*}$ then B_S falls in the low state. Recruitment is stochastically generated from G_{LOW} or G_{HIGH} using equations (18) and (19) dependent on the B_S state. The AGEPRO program can generate stochastic recruitments using the two-stage model with up to 100 stock-recruitment data points per B_S state.

Model 5. Beverton-Holt Curve with Lognormal Error

The Beverton-Holt curve (Beverton and Holt 1957) with lognormal errors is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. The Beverton-Holt curve with lognormal error model depends on spawning biomass and is time-invariant.

The Beverton-Holt curve with lognormal error generates recruitment as

(21)

$$n_r(t) = \frac{\alpha \cdot b_S(t-r)}{\beta + b_S(t-r)} \cdot e^w$$

$$where \;\; w \sim N\left(0, \sigma_w^2\right), \; R(t) = c_R \cdot n_r(t), \; and \;\; B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters “α”, “β”, and the error variance“ σ_w^2 ” and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Beverton-Holt curve have been estimated in relative units determined (e.g., $n_r(t)$ and $b_S(t-r)$) which can be converted to absolute values with the conversion coefficients. Note that the absolute value for recruitment is numbers of fish, while for B_S, the absolute value is kilograms of B_S. For example, if the stock-recruitment curve was estimated with stock-recruitment data that were measured in millions of fish and thousands of metric tons of B_S, then $c_R = 10^6$ and $c_B = 10^6$. It may be important to estimate the parameters of the stock-recruitment curve in relative units to reduce the potential effects of roundoff error on parameter estimates. It is important to note that the expected value of the lognormal error term is not unity but is $\exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $\exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Beverton-Holt curve has a log-scale error term w with zero mean.

The Beverton-Holt curve is often reparameterized in a modified form with steepness (h), virgin recruitment (R_0), and virgin spawning biomass ($B_{S,0}$) parameters. The modified Beverton-Holt curve produces $h \cdot R_0$ recruits when $B_S = 0.2 \cdot B_{S,0}$ and has the form

(22)

$$R = \frac{4hR_0B_S}{B_{S,0}(1-h) + B_S(5h-1)}$$

The parameters α and β can be expressed as functions of the parameters of the modified Beverton-Holt curve as

(23) $$\alpha = \frac{4hR_0}{5h-1} = 4B_{S,0}\frac{h}{\left(\frac{B_{S,0}}{R_0}\right)(5h-1)}$$

and

(24) $$\beta = \frac{B_{S,0}(1-h)}{(5h-1)} = \frac{\alpha\left(\frac{B_{S,0}}{R_0}\right)(h^{-1}-1)}{4}$$

Thus, parameter estimates for the modified curve can be used to determine the Beverton-Holt parameters for the AGEPRO program.

Model 6. Ricker Curve with Lognormal Error

The Ricker curve (Ricker 1954) with lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. The Ricker curve with lognormal error model depends on spawning biomass and is time invariant.

The Ricker curve with lognormal error generates recruitment as

(25) $$n_r(t) = \alpha \cdot b_S(t-r) \cdot e^{-\beta \cdot b_S(t-r)} \cdot e^{w}$$
$$\text{where } w \sim N\left(0,\sigma_w^2\right),\ R(t) = c_R \cdot n_r(t),\ \text{and } B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters "α", "β", and the error variance "σ_w^2" and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Ricker curve have been estimated in relative units determined by the user (e.g., $n_r(t)$ and $b_S(t-r)$) and then converted to absolute values with the conversion coefficients. It is important to note that the expected value of the lognormal error term is not unity but is $\exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $\exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Ricker curve has a log-scale error term w with zero mean.

Model 7. Shepherd Curve with Lognormal Error

The Shepherd curve (Shepherd 1982) with lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. The Shepherd curve with lognormal error model depends on spawning biomass and is time-invariant.

The Shepherd curve with lognormal error generates recruitment as

$$n_r(t) = \frac{\alpha \cdot b_S(t-r)}{1+\left(\frac{b_S(t-r)}{k}\right)^{\beta}} \cdot e^w$$

(26)

$$where\ \ w \sim N\left(0,\sigma_w^2\right),\ R(t) = c_R \cdot n_r(t),\ and\ \ B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters "α", "β", "k" and the error variance "σ_w^2" and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Shepherd curve have been estimated in relative units determined by the user (e.g., $n_r(t)$ and $b_S(t-r)$) and then converted to absolute values with the conversion coefficients. It is important to note that the expected value of the lognormal error term is not unity but is $\exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $\exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Shepherd curve has a log-scale error term w with zero mean.

Model 8. Lognormal Distribution

The lognormal distribution provides a parametric model for stochastic recruitment generation. The lognormal distribution model does not depend on spawning biomass and is time-invariant.

The lognormal distribution generates recruitment as

$$n_r(t) = e^w$$

(27)

$$where\ \ w \sim N\left(\mu_{\log(r)},\ \sigma_{\log(r)}^2\right)\ \ and\ \ R(t) = c_R \cdot n_r(t)$$

The lognormal distribution parameters "$\mu_{\log(r)}$" and the log-scale variance "$\sigma_{\log(r)}^2$" as well as the conversion coefficient for recruitment c_R are specified by the user. It is assumed that the parameters of the lognormal distribution have been estimated in relative units (e.g., $n_r(t)$) and then converted to absolute values with the conversion coefficients.

Model 9. Time-Varying Empirical Recruitment Distribution

The time-varying empirical recruitment distribution model is a time-dependent extension of model 3. The time-varying empirical recruitment distribution model does not depend on spawning biomass and is time-dependent.

In this approach, the empirical model for the estimation of recruitment draws randomly from a set of T recruitments levels for year t of the time horizon { $N_r(t,1)$, $N_r(t,2)$, ..., $N_r(t,T)$ }. Here the recruitment distribution for each year of the time horizon is a time-dependent multinomial random variable where the probability of randomly choosing a particular recruitment level is 1/T given T levels of recruitment. In particular, realized recruitment in year t is simulated using

$$\Pr\left(R(t) = N_r\left(t,k\right)\right) = \frac{1}{T} \ , \quad for\ k \in \{1,2,...,T\} \tag{28}$$

This approach is nonparametric and assumes that future recruitment is totally independent of spawning stock biomass. Further, it is the responsibility of the USER to determine an appropriate set of recruitment levels for each year of the time horizon. The AGEPRO software permits up to 100 observed recruitments for the recruitment distribution in each year of the time horizon. The user must input T potential recruitment levels in each year for a total of TY recruitment inputs. As in recruitment model 3, the time-varying empirical recruitment distribution model can be used to make deterministic projections by specifying a single recruitment level for each year of the time horizon. In this case, recruitment will be constant time series over the time horizon.

Model 10. Beverton-Holt Curve with Autocorrelated Lognormal Error

The Beverton-Holt curve with autocorrelated lognormal errors is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially-correlated stochastic variation. The Beverton-Holt curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.

The Beverton-Holt curve with autocorrelated lognormal error generates recruitment as

$$n_r\left(t\right) = \frac{\alpha \cdot b_S\left(t-r\right)}{\beta + b_S(t-r)} \cdot e^{\varepsilon_t}$$

$$\begin{aligned} &where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t \ \ where\ Var\left(\varepsilon\right) = \sigma^2, \\ &\sigma_w^2 = \left(1-\phi^2\right)\sigma^2,\ \ w_t \sim N\left(0,\sigma_w^2\right), \\ &R\left(t\right) = c_R \cdot n_r\left(t\right),\ and\ \ B_S\left(t\right) = c_B \cdot b_S\left(t\right) \end{aligned} \tag{29}$$

The stock-recruitment parameters "α", "β", "ε_0", "φ" and error variance "σ^2" and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If this value is not known, set ε_0=0.

Model 11. Ricker Curve with Autocorrelated Lognormal Error

The Ricker curve with autocorrelated lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially correlated stochastic variation. The Ricker curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.

The Ricker curve with autocorrelated lognormal error generates recruitment as

$$n_r(t) = \alpha \cdot b_S(t-r) \cdot e^{-\beta \cdot b_S(t-r)} \cdot e^{\varepsilon_t}$$

(30)

$$\begin{aligned} &where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t \ \ where\ Var(\varepsilon) = \sigma^2, \\ &\sigma_w^2 = \left(1-\phi^2\right)\sigma^2,\ \ w_t \sim N\left(0, \sigma_w^2\right), \\ &R(t) = c_R \cdot n_r(t),\ and\ \ B_S(t) = c_B \cdot b_S(t) \end{aligned}$$

The stock-recruitment parameters “α”, “β”, “ε0”, “φ” and error variance “σ^2” and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If the log-scale residual value is not known, set ε_0=0.

Model 12. Shepherd Curve with Autocorrelated Lognormal Error

The Shepherd curve with autocorrelated lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially-correlated stochastic variation. The Shepherd curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.

The Shepherd curve with autocorrelated lognormal error generates recruitment as

$$n_r(t) = \frac{\alpha \cdot b_S(t-r)}{1 + \left(\dfrac{b_S(t-r)}{k}\right)^{\beta}} \cdot e^{\varepsilon_t}$$

(31)

$$\begin{aligned} &where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t \ \ where\ Var(\varepsilon) = \sigma^2, \\ &\sigma_w^2 = \left(1-\phi^2\right)\sigma^2,\ \ w_t \sim N\left(0, \sigma_w^2\right), \\ &R(t) = c_R \cdot n_r(t),\ and\ \ B_S(t) = c_B \cdot b_S(t) \end{aligned}$$

The stock-recruitment parameters ““α”, “β”, “k”, “ε0”, “φ” and error variance “σ^2” and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If this value is not known, set $\varepsilon_0=0$.

Model 13. Autocorrelated Lognormal Distribution
The autocorrelated lognormal distribution provides a parametric model for stochastic recruitment generation with serial correlation. The autocorrelated lognormal distribution model does not depend on spawning biomass and is time-dependent.

The autocorrelated lognormal distribution is

$$n_r(t) = e^{\mu_{\log(r)}} \cdot e^{\varepsilon_t}$$

(32)

$$\begin{aligned}&where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t\ \ where\ Var(\varepsilon) = \sigma^2_{\log(r)},\\ &\sigma^2_w = \left(1-\phi^2\right)\sigma^2_{\log(r)},\ \ w_t \sim N\left(0,\sigma^2_w\right),\\ &and\ \ R(t) = c_R \cdot n_r(t)\end{aligned}$$

The lognormal distribution parameters “$\mu_{\log(r)}$”, “$\sigma^2_{\log(r)}$”, “ε_0”, “φ” and the conversion coefficient for recruitment c_R are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If this value is not known, set $\varepsilon_0=0$.

Model 14. Empirical Cumulative Distribution Function of Recruitment
The empirical cumulative distribution function of recruitment can be used to randomly generates recruitment under the assumption that the distribution of the R is stationary and independent of stock size. The empirical cumulative distribution function of recruitment model does not depend on spawning biomass and is time-invariant.

To describe this nonparametric approach, let R_S represent the S^{th} element in the ordered set of observed recruitment values. The empirical probability density function for R_S, denoted as $g(R_S)$, is 1/T for all observed values of R where T is the number of stock-recruitment data points. Let $G(R_S)$ denote the cumulative distribution function of observed recruitment.

Random values of R can be generated by applying the probability integral transform to the empirically derived cdf. Let U be a uniformly distributed random variable on the interval [0,1]. The value of R corresponding to U is determined by applying the inverse of the cdf $G(R_S)$. In particular, when U is an integer multiple of 1/(T-1) so that U=s/(T-1) then $R = G^{-1}(U) = R_S$. Otherwise R can be obtained by linear interpolation when U is not a multiple of 1/(t-1). In particular, if $(s-1)/(T-1) < U < s/(T-1)$, then

(33) $$U = \left(\frac{\frac{s}{T-1} - \frac{s-1}{T-1}}{R_{S+1} - R_S} \right) \left(R - R_S \right) + \frac{s-1}{T-1}$$

Solving for R as a function of U yields

(34) $$R = \left(T-1 \right) \left(R_{S+1} - R_S \right) \left(U - \frac{s-1}{T-1} \right) + R_S$$

where the interpolation index s is determined as the greatest integer in 1+U(T-1). The AGEPRO program can generate stochastic recruitments using model 14 with up to 100 recruitment data points.

Model 15. Two-Stage Empirical Cumulative Distribution Function of Recruitment

The two-stage empirical cumulative distribution function of recruitment model is an extension of Model 14 where the spawning stock of the population is categorized into “low” and “high” states. The two-stage empirical cumulative distribution function of recruitment model depends on spawning biomass and is time-invariant.

In particular, there is a cdf for R when the population is in the low B_S state and a cdf for R when the population is in the high B_S state. Let G_{LOW} be the cdf and let T_{LOW} be the number of R values for the low B_S state. Similarly, let G_{HIGH} be the cdf and let T_{HIGH} be the number of R values for the high B_S state. Further, let B_S* denote the cutoff level of B_S such that, if $B_S > B_S$*, then B_S falls in the high state, while if $B_S < B_S$* then B_S falls in the low state. Recruitment is stochastically generated from G_{LOW} or G_{HIGH} using equations (33) and (34) dependent on the B_S state. The AGEPRO program can generate stochastic recruitments using model 15 with up to 100 stock-recruitment data points.

Model 16. Linear Recruits Per Spawning Biomass Predictor with Normal Error

The linear recruits per spawning biomass predictor with normal error is a parametric model to simulate random values of recruits per spawning biomass R/B_S and associated random recruitments. The predictors in the linear model ($X_p(t)$) can be any continuous variable and may typically be survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. Similarly, if this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of R/B_S is generated using the linear model

(35) $$\frac{R}{B_S} = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient of the p^{th} predictor and ε is a normal distribution with zero mean and constant variance σ^2. It is possible negative values of R/B_S to be generated using this formulation; such values are excluded from the set of simulated values of R/B_S from equation (35) by testing if R/B_S repeating the random sampling until an acceptable positive value of R/B_S is obtained. This model randomly generates R/B_S values under the assumption that the linear predictor of the R/B_S ratio is stationary and independent of stock size. Random values of R/B_S are multiplied by realized spawning biomass to generate recruitment in each time period. <u>The linear recruits per spawning biomass predictor with normal error depends on spawning biomass and is time-invariant unless time is used as a predictor.</u>

<u>Model 17. Loglinear Recruits Per Spawning Biomass Predictor with Lognormal Error</u>

The loglinear recruits per spawning biomass predictor with lognormal error is a parametric model to simulate random values of recruits per spawning biomass R/B_S and associated random recruitments. Predictors for the loglinear model ($X_p(t)$) can be any continuous variable and could include survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. If this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of the natural logarithm of R/B_S is generated using the loglinear model

(36) $$\log\left(\frac{R}{B_S}\right) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient for the pth predictor and ε is a normal distribution with constant variance σ^2 and mean equal to $-\frac{1}{2}\sigma^2$. In this case, the mean of ε implies that the expected value of the lognormal error term is unity. This model generates positive random values of R/B_S under the assumption that the linear predictor of the R/B_S ratio is stationary and independent of stock size. Random values of R/B_S are multiplied by realized spawning biomass to generate recruitment in each time period. <u>The loglinear recruits per spawning biomass predictor with lognormal error depends on spawning biomass and is time-invariant unless time is used as a predictor.</u>

<u>Model 18. Linear Recruitment Predictor with Normal Error</u>

The linear recruitment predictor with normal error is a parametric model to simulate random values of recruitment R. The predictors in the linear model ($X_p(t)$) can be any continuous variable and could represent survey indices of cohort abundance or environmental covariates correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. Similarly, if this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of R is generated using the linear model

(37)
$$\begin{gathered} n_r(t) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon \\ with\ R(t) = c_R \cdot n_r(t) \end{gathered}$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient for the pth predictor, ε is a normal distribution with zero mean and constant variance σ^2, and the conversion coefficients for recruitment is c_R. It is possible that negative values of R can be generated using this formulation; such values are excluded from the set of simulated values of R from equation (37) by testing if R repeating the random sampling until an acceptable positive value of R is obtained. This model randomly generates R values under the assumption that the linear predictor of R is stationary and independent of stock size. The linear recruitment predictor with normal error does not depend on spawning biomass and is time-invariant unless time is used as a predictor.

Model 19. Loglinear Recruitment Predictor with Lognormal Error

The loglinear recruitment predictor with lognormal error is a parametric model to simulate random values of recruitment R. Predictors for the loglinear model ($X_p(t)$) can be any continuous variable such as survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. If this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of the natural logarithm of R is generated using the loglinear model

(38)
$$\begin{gathered} \log\left(n_r(t)\right) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon \\ with\ \ R(t) = c_R \cdot n_r(t) \end{gathered}$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient for the pth predictor, ε is a normal distribution with constant variance σ^2 and mean equal to $-\frac{1}{2}\sigma^2$, and the conversion coefficients for recruitment is c_R. In this case, the mean of ε implies that the expected value of the lognormal error term is unity. This model generates positive random values of R under the assumption that the linear predictor of the R is stationary and independent of stock size. The loglinear recruitment predictor with lognormal error does not depend on spawning biomass and is time-invariant unless time is used as a predictor.

Constrained Recruits Per Spawning Biomass For Lognormal Error Models

The lognormal error terms for the six parametric recruitment models and the two lognormal distribution models can produce outliers of R/B_S in a projection analysis because lognormal distributions are highly skewed and generally have a wide tail. The impact of recruitment outliers on a projection analysis can be substantial. To address this issue, realized R/B_S values can be constrained for the eight stock-recruitment models that use the lognormal distribution by setting the bounded recruitment flag to be true (bdrecflag=true). Two constraints can be applied based on the level of B_S within the stock. Let $B_{S,CUT}$ denote a cutoff of B_S, where one R/B_S constraint operates below $B_{S,CUT}$ and another constraint operates above $B_{S,CUT}$. Let $[\ L_{Low}, U_{Low}\ ]$ and $[\ L_{High}, U_{High}\ ]$ denote the lower and upper R/B_S constraint intervals. If $B_S(t) < B_{S,CUT}$ in year t, then the realized R/B_S value generated from a lognormal recruitment model must lie within the interval $[\ L_{Low}, U_{Low}\ ]$

$$(39)\qquad B_S(t) < B_{S,CUT} \;\Rightarrow\; \Pr\left(\frac{N_r(t)}{B_S(t)} \in \left[L_{Low}, U_{Low}\right]\right) = 1$$

If the realized R/B_S falls outside the interval $[\ L_{Low}, U_{Low}\ ]$, additional recruitments are simulated until one falls within the constraining interval. Similarly, if $B_S(t) > B_{S,CUT}$ in year t then the realized R/B_S value generated from the recruitment model must lie within the interval $[\ L_{High}, U_{High}\ ]$

$$(40)\qquad B_S(t) > B_{S,CUT} \;\Rightarrow\; \Pr\left(\frac{N_r(t)}{B_S(t)} \in \left[L_{High}, U_{High}\right]\right) = 1$$

If R/B_S values are expected to be more variable when B_S is above $B_{S,CUT}$ then it is natural to choose to have the interval $[\ L_{Low}, U_{Low}\ ]$ to be within the interval $[\ L_{High}, U_{High}\ ]$. In this case, the endpoints of the intervals are ordered as $L_{High} < L_{Low} < U_{Low} < U_{High}$.

The use of R/B_S constraints may be appropriate when the stock is near an historic low value of B_S. In this case, it would be natural to set $B_{S,CUT}$ to be the historic minimum value of B_S. Extrapolating R/B_S values that would result if $B_S(t)$ falls below $B_{S,CUT}$ could have substantial influence on estimating a rebuilding strategy for the stock. For example, one might constrain the realized R/B_S values when $B_S(t)$ falls below $B_{S,CUT}$ to be between the 10th and 90th percentiles of the empirical R/B_S distribution taken from the assessment. When $B_S(t)$ is above $B_{S,CUT}$, one might consider other bounds on the R/B_S values such as 1/100 of the minimum observed R/SB value or 100 times the maximum observed R/B_S value. Similar comments apply for a population that is near its historic maximum value of B_S. While the AGEPRO program requires the user to set two bounding intervals for R/B_S

values when the R/B_S constraint option is selected, one can create a single interval by either (i) setting the intervals to be equal or (ii) setting $B_{S,CUT}$ to be 0.

Recruitment Model Probabilities

Model uncertainty about the appropriate stock-recruitment model can be directly incorporated into AGEPRO projections. Multiple recruitment models may be appropriate when each model provides a similar statistical fit to a set of stock-recruitment data, where similarity can be measured using Akaike's, Bayesian, or deviance information criterion. Given a measure of a model's relative likelihood compared to a set of alternative models, one can use information criteria to calculate an individual model's probability of best representing the true state of nature. Alternatively, one can assign model probabilities based on judgment of other measures of goodness of fit or use this principle of indifference to assign equal probabilities in the absence of compelling information.

Regardless of the approach used to develop model probabilities, such probabilities can be used in AGEPRO to drive the stochastic recruitment dynamics in a straightforward manner. Suppose there are a total of N_M probable recruitment models, as determined by the user. The probability that recruitment model m is realized in year t is denoted by $P_{R,m}(t)\geq 0$. The conservation of probability implies that the sum of model probabilities over the set of probable models in each year is unity

$$\sum_{m=1}^{N_M} P_{R,m}(t) = 1 \tag{41}$$

This gives a conditional probability distribution for randomly sampling recruitment models in each year of the projection time horizon. As in previous versions of AGEPRO, a single recruitment model can be chosen for the entire projection time horizon by setting $N_M=1$. One advantage of including multiple recruitment models with possibly time-varying probabilities is that one can use auxiliary information on recruitment strength, such as survey indices of relative cohort abundance or environmental covariates, to make short-term recruitment predictions (1-2 years) and then change to a different recruitment model or set of models for medium-term recruitment predictions (3-5 years). Another advantage of including multiple recruitment models is to account for model selection uncertainty, which can be a substantial source of uncertainty.

Initial Population Abundance

There are two ways to set the initial population abundance, defined as the vector of the absolute number of fish alive on January 1st of the first year of the projection time horizon ($\underline{N}(1)$). The primary option is to use a set of samples from the distribution of the estimator of $\underline{N}(1)$. This option explicitly incorporates uncertainty in the estimate of initial population abundance into the projections and occurs when the logical variable bootflag=true. In this case, either frequentist methods such as bootstrapping or Bayesian methods such as Markov Chain Monte Carlo simulation could be used to determine the sampling distribution of $\underline{N}(1)$. The secondary option is to ignore uncertainty in the estimator of initial population abundance and use a single best estimate for the value of

$\underline{N}(1)$. In this case, only a point estimate of $\underline{N}(1)$ is required for the projections (bootflag=false).

The primary option uses a set of B initial population vectors, denoted by $\{ \underline{N}_{(1)}(1), \underline{N}_{(2)}(1), ..., \underline{N}_{(B)}(1) \}$, for stochastic projections. In this case, the set of B values are random samples from the distribution of the estimator of $\underline{N}(1)$ generated by the assessment model or other means. Given this, stochastic projection can be used to characterize the sampling distribution of key fishery outputs accounting for the uncertainty in the estimate of the initial population size. The age of recruitment determines the amount of information needed to use the primary option. If the age of recruitment is age-1 (age1recflag=true), then the primary option only requires the set of initial population vectors, $\underline{\mathbf{N}} = \{ \underline{N}_{(1)}(1), \underline{N}_{(2)}(1), ..., \underline{N}_{(B)}(1) \}$ to do the projections. For each initial condition $\underline{N}_{(j)}(1)$, a set of simulations will be performed using the specified harvest strategy. Since dynamic array allocation is used to dimension the set of initial population vectors, the user may choose to input a large number of initial population vectors (B>1000) within the practical constraint of available computer memory.

If the age of recruitment is age-r for r>1 (age1recflag=false), then the primary option requires additional information to do the projections. In particular, a set of B population vectors for each of the previous (R-1) years are needed: $\underline{\mathbf{N}}(0)$, $\underline{\mathbf{N}}(-1)$, ..., $\underline{\mathbf{N}}(2-R)$, where $\underline{\mathbf{N}}(j) = \{ \underline{N}_{(1)}(j), \underline{N}_{(2)}(j), ..., \underline{N}_{(B)}(j) \}$ for year j and the ordering of the population vectors within each $\underline{\mathbf{N}}(j)$ is identical for all prior time periods j. That is, the sequence of vectors$\{ \underline{N}_{(b)}(2-R), ..., \underline{N}_{(b)}(-1), \underline{N}_{(b)}(0), \underline{N}_{(b)}(1) \}$ represents the b^{th} distinct estimate of the trajectory of population numbers at age from time=2-R to time=1 as calculated from the assessment model. Similarly, a set of B fishing mortality at age vectors for each of the previous (R-1) years are needed: $\underline{\mathbf{F}}(0)$, $\underline{\mathbf{F}}(-1)$, ..., $\underline{\mathbf{F}}(2-R)$, where $\underline{\mathbf{F}}(j) = \{ \underline{F}_{(1)}(j), \underline{F}_{(2)}(j), ..., \underline{F}_{(B)}(j) \}$. Here $\underline{F}_{(b)}(j)$ is the vector of fishing mortalities at age in time j for the b^{th} initial population trajectory $\underline{F}_{(b)}(j) = \{ F_{r,(b)}(j) , F_{r+1,(b)}(j), ..., F_{A,(b)}(j)\}$. As with the $\underline{\mathbf{N}}(j)$, the ordering of the fishing mortality at age vectors within each $\underline{\mathbf{F}}(j)$ must be the same for all prior time periods. That is, each initial population and fishing mortality vector represents a single trajectory from the assessment model.

The secondary option is to use a single point estimate of $\underline{N}(1)$ for projection. In this case, one estimate of population abundance is assumed to characterize the initial state of the population. Since there is no uncertainty in the initial state of the population this option allows one to characterize the sampling distribution of key fishery outputs due to uncertainty in recruitment or natural mortality. Note that it is not possible to use an age of recruitment r>1 along with a single initial population vector which is entered directly in the input file (i.e., one cannot set both bootflag=false and age1recflag=false, see Table 1). It is possible, however, to use a single population vector with age of recruitment r>1 input from a file using the bootstrap input file option with the number of bootstraps B=1 (i.e., set bootflag=true and age1recflag=false).

Regardless of which initial population abundance option is used, the user must also specify the units of the initial population size vector taken from the assessment model. In particular, the initial population abundance vector can be input in relative units ($\underline{n}(1)$)

along with a conversion coefficient (k_N) to compute absolute numbers where absolute initial population abundance is the conversion coefficient times the relative abundance estimate, i.e., $\underline{N}(1) = k_{N^*}\underline{n}(1)$.

Retrospective Adjustment

One can adjust the initial population numbers at age vector $\underline{N}(1)$ to reflect a retrospective pattern in calculating these estimates (retroflag=true). In this case, the user must determine an appropriate vector of retrospective bias-correction coefficients, denoted by $\underline{C}$, to apply to the vector $\underline{N}(1)$. These multiplicative bias-correction coefficients may be age-specific or constant across age classes. The bias-corrected initial population vector $\underline{N}^*(1)$ is calculated from the element-wise product of $\underline{N}(1)$ and $\underline{C}$ as

$$\underline{N}^*\left(1\right) = \left(C_r \cdot N_r(1),\ldots,C_a \cdot N_a(1),\ldots,C_A \cdot N_A(1)\right)^T \tag{42}$$

Note that the bias-correction coefficients are applied to all initial population vectors. If the bias-correction coefficients are determined to be constant across age classes then $\underline{C} = (C, C, \ldots, C)^T$ and the bias-corrected initial population vector is

$$\underline{N}^*\left(1\right) = \left(C \cdot N_1(1),\ldots,C \cdot N_a(1),\ldots,C \cdot N_A(1)\right)^T = C \cdot \underline{N}\left(1\right) \tag{43}$$

The bias-correction coefficients are only applied in the first time period of the projection time horizon to reflect uncertainty in the estimated population size at age. Mohn (1999) provides a useful discussion of the retrospective problem in sequential population analysis.

Stochastic Natural Mortality

Natural mortality is often assumed to be constant over recruited age classes and equal to its long-term average for assessment purposes. The effects of constant age-specific natural mortality can be investigated using AGEPRO (set varmflag=false). The potential effects of variation in the age-specific instantaneous natural mortality rates can also be assessed when performing stochastic projections. To do this, the natural mortality rate at age can be modeled as a random variable in the AGEPRO program (set varmflag=true). In this case, the natural mortality rate can be modeled as a autocorrelated, or uncorrelated lognormal process where the natural mortality rate at age a in year t would be simulated as

$$\begin{aligned} &M_a\left(t\right) = M\left(t\right)\cdot P_{M,a}(t) \;\; where \\ &M\left(t\right) = M \cdot \exp\left(\varepsilon_t - 0.5\sigma_M^2\right) \;\; and \\ &\varepsilon_t = \rho_M \cdot \varepsilon_{t-1} + \sqrt{1-\rho_M^2} \cdot \upsilon_t \;\; and \\ &\upsilon_t \sim N\left(0, \sigma_M^2\right) \end{aligned} \tag{44}$$

Here the simulated natural mortality rate M(t) in year t depends on a the input mean value M which is adjusted annually with an autocorrelated random error ε_t which has a lognormal distribution. Autocorrelation in the random errors ε_t can be turned off by setting ρ_M=0. The multiplicative lognormal error has a mean value of unity due to the application of the bias-adjustment factor ($-0.5\sigma_M^2$). The simulated natural mortality rate at age a in year t is M(t) times the vulnerability of age class a to the full natural mortality rate, denoted by $P_{M,a}(t)$, in year t. The vulnerabilities at age are simulated as uniform distributions with means equal to the input vulnerability values at age $P_{M,a}$ and the input coefficients of variation CV_a. In particular, the probability density function for $P_{M,a}$ is $f(P_{M,a}(t))$ which is given by

(45)
$$f\left(P_{M,a}(t)\right) = \frac{1}{U_a - L_a} \; where \;\; L_a \le P_{M,a}(t) \le U_a$$
$$and \;\; L_a = P_{M,a}\left(1-\sqrt{3}\cdot CV_a\right) \; and \;\; U_a = P_{M,a}\left(1+\sqrt{3}\cdot CV_a\right)$$

Note that the input coefficient of variation cannot be greater than $\sqrt{3}$ for any age class otherwise the lower bound of the uniform distribution (L_a) is not feasible.

Total Stock Biomass

Total stock biomass (B_T) is the sum over the recruitment age (r) to the plus-group age (A) of stock biomasses at age on January 1_{st}. The computational formula for B_T in year

(46)
$$B_T\left(t\right) = \sum_{a=r}^{A} W_{P,a}\left(t\right)\cdot N_a\left(t\right)$$

where $W_{P,a}$(t) is the population mean weight of age-a fish on January 1^{st} in year t.

Mean Biomass

Mean stock biomass (B_M) is the average biomass of the stock over a given year. In particular, mean stock biomass depends on the total mortality rate experienced by the stock in each year. In the AGEPRO model, the user selects the range of ages to be used for calculating mean biomass. One can choose the full range of ages in the model (age-r through age-A) or alternatively choose a smaller range if desired. The upper age (A_U) for mean biomass calculations must be less than or equal to A; similarly the lower age (A_L) must be greater than or equal to r. Let $W_{M,a}$(t) denote the mean weight of age-a fish at the mid-point of year t. The computational formula for B_M in year t is

(47)
$$B_M\left(t\right) = \sum_{j=A_L}^{A_U} W_{M,j}\left(t\right)\cdot N_j\left(t\right)\cdot\frac{\left(1-\exp\left(-M_j\left(t\right)-F_j\left(t\right)\right)\right)}{\left(M_j\left(t\right)+F_j\left(t\right)\right)}$$

Fishing Mortality Weighted by Mean Biomass

Fishing mortality weighted by mean biomass (F_B(t)) in year t is the mean-biomass weighted sum of fishing mortality at age over the age range of A_L to A_U (see Mean Biomass above). This quantity may be useful for equilibrium comparisons with fishing mortality reference points developed from surplus production models. The computational formula for fishing mortality weighted by mean biomass is

(48)
$$F_B(t) = \frac{\sum_{j=A_L}^{A_U} B_{M,j}(t)\cdot F_j(t)}{B_M(t)}$$
$$where \;\; B_{M,j}(t) = W_{M,j}(t)\,N_j(t)\frac{\left(1-\exp\left(-M_j(t)-F_j(t)\right)\right)}{\left(M_j(t)+F_j(t)\right)}$$

Feasible Simulations
A feasible simulation is defined as one where the input landings quota can be harvested in each year of the projection time horizon. An infeasible simulation is one where the exploitable biomass is less than the landings quota in at least one year of the time horizon. All simulations are feasible for projections where population harvest is based solely on fishing mortality values. For projections that specify a landings quota in one or more years, the feasibility of harvesting the landings quota is evaluated using an upper bound on F that defines infeasible quotas relative to the exploitable biomass (Appendix). For purposes of summarizing projection results, the total number of simulations is denoted as K_{TOTAL} and the total number of feasible simulations is denoted as $K_{FEASIBLE}$.

Biomass Thresholds
The user can specify biomass thresholds for spawning biomass ($B_{S,THRESHOLD}$), mean biomass ($B_{M,THRESHOLD}$), and total stock biomass ($B_{T,THRESHOLD}$) for Sustainable Fisheries Act policy evaluation. This is the SFA-threshold option (sfaflag=true). If the SFA-threshold option is chosen, projected biomass values are compared to the input thresholds through time. Probabilities that biomasses meet or exceed threshold values are computed for each year. In addition, the probability that biomass thresholds were exceeded in at least one year within a single simulated population trajectory is computed. If the user specifies fishing mortality-based harvesting with no landings quotas, then the SFA-threshold probabilities are computed over the entire set of simulations. Let $K_B(t)$ be the number of times that projected biomass B(t) meets or exceeds the threshold biomass $B_{THRESHOLD}$ in year t. The counter $K_B(t)$ is evaluated for each year and biomass series (spawning, mean, or total stock). Given that K_{TOTAL} is the total number of feasible simulation runs, the estimate of the annual probability that $B_{THRESHOLD}$ would be met or exceeded in year t is

(49)
$$\Pr\left(B(t) \geq B_{THRESHOLD}\right) = \frac{K_B(t)}{K_{TOTAL}}$$

Note that this also provides an estimate of the probability of the complementary event that biomass does not exceed the threshold via

(50) $$\Pr\left(B(t) < B_{THRESHOLD}\right) = 1 - \Pr\left(B(t) \geq B_{THRESHOLD}\right) = 1 - \frac{K_B(t)}{K_{TOTAL}}$$

Next, if $K_{THRESHOLD}$ denotes the number of simulations where biomass exceeded its threshold at least once, then the probability that $B_{THRESHOLD}$ would be met or exceeded at least

(51) $$\Pr\left(\exists t \in \left[1, 2, \ldots, Y\right] \text{ such that } B\left(t\right) \geq B_{THRESHOLD}\right) = \frac{K_{THRESHOLD}}{K_{TOTAL}}$$

If the user specifies landings quota-based harvesting in one or more years, then the SFA-threshold probabilities can be computed over the set of feasible simulations. In this case, the year-specific conditional probability that $B_{THRESHOLD}$ would be met or exceeded for feasible simulations is

(52) $$\Pr\left(B\left(t\right) \geq B_{THRESHOLD}\right) = \frac{K_B\left(t\right)}{K_{FEASIBLE}}$$

Note that the counter KB(t) can only be incremented in a feasible simulation. In contrast, the joint probability that $B_{THRESHOLD}$ would be met or exceeded for the entire set of simulations is given by Equation 42 and the probability that $B_{THRESHOLD}$ would be met or exceeded at least once during the projection time horizon is given by Equation 43.

Fishing Mortality Thresholds

The user can specify fishing mortality rate thresholds for annual fishing mortality ($F_{THRESHOLD}$) and fishing mortality weighted by mean biomass ($F_{B,THRESHOLD}$) under the SFA-threshold option. If the SFA-threshold option is chosen (sfaflag=true), projected F and F_B values are compared to the thresholds through time. Probabilities that fishing mortalities exceed threshold values are computed for each year in the same manner as for biomass thresholds (see Biomass Thresholds above). In particular,
if K_F(t) is the number of times that fishing mortality F(t) exceeds the threshold fishing mortality $F_{THRESHOLD}$ in year t, then the annual probability that the fishing mortality threshold is exceeded is

(53) $$\Pr\left(F\left(t\right) > F_{THRESHOLD}\right) = \frac{K_F\left(t\right)}{K_{TOTAL}}$$

and the complementary probability that the fishing mortality threshold is not exceeded is

(54) $$\Pr\left(F(t) \leq F_{THRESHOLD}\right) = 1 - \frac{K_F(t)}{K_{TOTAL}}$$

Target Fishing Mortality

In some projections, it may be necessary to change the fishing mortality rate when a spawning biomass threshold is met or exceeded. This can occur, for example, if the $B_{S,THRESHOLD}$ is the spawning biomass to produce maximum sustainable yield (B_{MSY}). In this case, the fishing mortality rate can be increased from a rebuilding value to F_{MSY}. The AGEPRO software includes an option to specify a target F (F_{TARGET}) that will be applied in the year subsequent to the year in which the $B_{S,THRESHOLD}$ is met or exceeded. This is the F-target option (ftarflag=true). Note that the F-target option requires that the SFA-threshold option is selected (sfaflag=true).

The F-target option depends on the spawning biomass realized in each year of the time horizon. In a given simulated population trajectory, F_{TARGET} is applied in the year following a year in which the $B_{S,THRESHOLD}$ is met or exceeded. In addition to specifying a target F, a calendar year within the projection time horizon when the F-target option may occur must also be specified; denote this initial year as $Y_{FTARGET}$. For example, if the projection time horizon is the interval [2002, 2007] , then $Y_{FTARGET}$ might be chosen to be 2005. Given this, the F in year 2005 would be set to F_{TARGET} if the spawning biomass threshold was achieved in 2004. In general, the F-target option sets F(t+1)= F_{TARGET} in year t+1 provided that

$$(55) \qquad F\left(t+1\right) = F_{TARGET} \quad \Leftrightarrow \quad t \geq Y_{TARGET} \;\; and \;\; B_S\left(t\right) \geq B_{S,THRESHOLD}$$

Fishing Mortality Bounds

In some projections, it may be necessary to specify bounds on fishing mortality under a quota-based harvest strategy. In this case one can input an upper bound on realized fishing mortality (F_{UPPER}). If a harvest quota generates a realized F that exceeds F_{UPPER}, then the realized F is set equal to F_{UPPER} and the catch biomass generated by applying F_{UPPER} is the realized catch, not the user-specified quota. Similarly, one can set a lower bound on fishing mortality (F_{LOWER}). Fishing mortality bounds can be applied by setting the bounded F flag to be true (bdFflag=true)). When the bounded F flag is true and the harvest strategy is composed of a mixture of catch quotas and fishing mortality rates, the upper and lower bounds on F apply to both quotas and fishing mortality rates. In particular, F(t) is bounded above and below for all years t when the bounded F flag is true.

$$(56) \qquad Bounded\,F\;\; flag = true \;\Rightarrow\; F_{LOWER} \;\leq\; F(t) \;\leq\; F_{UPPER} \;\; for\,all\,t$$

Landings by Market Category

It may be necessary to partition projected landings into market categories for economic analyses. In particular, evaluating the expected benefits of a harvest policy can depend on whether fish price differs by fish size or market category. By setting the market category flag to be true (mcflag=1 for standard output or mcflag=2 for full distribution output), one can partition landings at age into up to three market categories. Both the number of landed fish and total weight of landed fish can be partitioned into market categories based on fish age. To apply this option, one must specify the proportion of each age class within each market category. Let $q_{a,j}$ denote the proportion of age-a fish in the j^{th} market category. These proportions must be nonnegative and less than one, $0 < q_{a,j} < 1$. Further the proportions must sum to unity across market categories for each age a.

(57) $$\sum_j q_{a,j} = 1$$

Given the proportions $q_{a,j}$ for each age class, the total number of landed fish ($L_{N,j}(t)$) in the j^{th} market category is

(58) $$L_{N,j}(t) = \sum_{a=r}^{A} q_{a,j} \cdot C_a(t) \cdot \left(1 - P_{D,a}(t)\right)$$

Similarly, the total weight of fish ($L_{W,j}(t)$) in the j_{th} market category is

(59) $$L_{W,j}(t) = \sum_{a=r}^{A} q_{a,j} \cdot C_a(t) \cdot W_{L,a}(t) \cdot \left(1 - P_{D,a}(t)\right)$$

Time-Varying Weights and Fraction Mature at Age

It may be necessary to investigate the effects of trends in mean weights and fraction mature at age through time. In particular, if average fish weights have decreased as population size has been increasing, it may be important to characterize what would happen if the trends continue in the future. The time-varying weight and fraction mature option allows one to specify a time series of average fish weights at age and fraction mature at age during the projection time horizon. If the time-varying weight option is true (varwtflag=true), the user must input a time series of Y vectors for average population ($W_a(t)$), landed ($W_{L,a}(t)$), spawning ($W_{S,a}(t)$), and mid-year ($W_{M,a}(t)$) weights at age along with a time series of Y vectors for the fraction mature at age ($P_{S,a}(t)$). In addition, if the discard option is selected, then the user must also input a time series of vectors for average discard weights at age ($W_{D,a}(t)$).

Time-Varying Fishery Selectivity at Age

It may also be necessary to assess the effects of trends in fishery selectivity at age or in the amount of total mortality occurring prior to spawning through time. If the time-varying fishery selectivity flag is set to be true (prflag=true), then the user can input a sequence of Y vectors for fishery selectivity at age ($P_{F,a}(t)$) and a set of Y values for the fraction of total mortality occurring prior to spawning ($P_Z(t)$). Of course, constant values of $P_Z(t) = P_Z$ can be input if only the effect of time-varying selectivity is of interest.

Time-Varying Discard Fraction at Age

It may also be useful to quantify the potential effects of changes in discard fraction at age through time. If the constant fishery discard flag is set to be false (constdiscflag=flag), then the user can input a sequence of Y vectors for fishery discard fraction at age ($P_{D,a}(t)$) to quantify the effects of trends in discarding practices.

Age-Specific Summaries of Spawning Biomass and Population Size

The user may select the age summary option (agesumflag=true) to produce summaries of the distribution of spawning biomass at age and population size at age by year in the standard output file. Otherwise, age-specific summaries will not be output.

Auxiliary Output Files

The user may select the outfile option (outfileflag=true) to create auxiliary output files to record simulated trajectories of spawning biomass, mean biomass, fishing mortality, and landings. This option can be useful if one wants to depict the variability of one or more simulated trajectories in a graph. One file is created for each output ($B_S(t)$, $B_M(t)$, F(t), L(t)). The four output files have the same structure. In each output file, a single row represents a single simulated time trajectory with Y entries ordered from time t=1 to time t=Y. Within the file, trajectories are ordered by initial population vector (bootstrap) and then simulation for that initial vector. For example, if $B_{S,\,(b),k}(t)$ denotes the spawning biomass realized from the b^{th} initial population vector and the k^{th} simulation for that vector, then the output file for spawning biomass with B initial vectors and N simulations would have $B \cdot N$ rows that were ordered as

$$(60) \qquad \begin{bmatrix} B_{S,(1),1}(1) & B_{S,(1),1}(2) & \dots & B_{S,(1),1}(Y) \\ B_{S,(1),2}(1) & B_{S,(1),2}(2) & \dots & B_{S,(1),2}(Y) \\ \vdots & \vdots & \vdots & \vdots \\ B_{S,(B),N}(1) & B_{S,(B),N}(2) & \dots & B_{S,(B),N}(Y) \end{bmatrix}$$

The output units of spawning biomass, mean biomass, and landings are kilograms. The units of F are instantaneous fishing mortality rate per year.

Age-Structured Projection Software

Software to implement the current age-structured projection model has been revised several times since 1996 to reflect requests and technical improvements. As a result, input files for previous versions of the code will need some revision to be compatible with version 3.4. The required modifications, however, are relatively minor. Input files for more recent versions (i.e., versions 3.0x and higher) can be converted to the new format using the PC graphical user interface, with the caveat that the user must still input missing data not present in the older file format.

This part of the User Guide provides operational details for the AGEPRO software and is organized into four sections. First, input data requirements and projection options are covered and the structure of an input file is described. Second, model outputs are described in relation to logical flags in the input file and the structure of an output file is described. Third, a section on program structure describes the flow of data and calculations. Fourth, a set of examples are provided to identify some general features of the software.

Input Data

There are four categories of input data for an AGEPRO projection run: *system*, *simulation*, *biological*, and *fishery* (Figure 1). The *system* data are read from standard input (e.g., from a terminal or via input redirection) while the *simulation*, *biological* and *fishery* data are read from an input file. A description of each data category follows.

System Data

The *system* data are the file names for the input and output files for the projection run. The input and output filenames are stored in the text file that must be named "agepro34.ctl"; this is the control file for the AGEPRO application. To manually change the names of input and output files for a projection at the DOS command line prompt, first delete the existing control file "agepro34.ctl" and then move a new control file to be named "agepro34.ctl". This approach can be used to set up batch runs consisting of many projection runs with different model configurations with input and output file names. *It is recommended that the USER run the AGEPRO GUI to set up an initial set of control and input files before running the program in a batch mode.*

To run the AGEPRO program from the DOS command line, enter "agepro34.exe". You will see the following output in the command line screen:

```
>agepro34.exe
>
>Projection analysis is running ...
>
> Simulation completed for bootstrap: 1
> Simulation completed for bootstrap: 2
...
>Bootstrap loop completed. Summarizing results ...
>
>Projection analysis has been completed.
>
>Results are in the file: my_output_filename
```

The software checks whether the input file exists and prompts the user for another filename if the input file does not exist. Similarly, the software checks whether the output file already exists and prompts the user for another filename if the output file already exists. Running several large projections concurrently in batch mode can cause system crashes.

To run the AGEPRO program from the GUI, use the pull down menus to select the command "run model".

Simulation Data

The *simulation* data are the inputs needed to setup and define the simulation run. These data are required to run the AGEPRO software and are read from the input file (Tables 2 and 3, Figure 1).

Here is a description of the simulation data inputs:

1. Character tag that identified the AGEPRO version.
2. Character string that identifies the projection run (64 characters).
3. First year of the time horizon.
4. Length of time horizon.
5. Number of simulations to perform for each initial population vector.
6. Number of probable recruitment models for the projection
7. Number of replications to initialize the random number generator.
8. Age-1 recruitment flag (age1recflag). If true, recruitment occurs at age-1; else it occurs at an older age r.
9. Harvest mixture flag (mixflag). If true, the harvest scenario is a mixture of quotas and fishing mortality rates; else it is either all quotas or all fishing mortality rates.
10. Discard flag (discflag). If true, discards at age are included in the projection; else no discards are included.
11. Quota flag (quotaflag). If true, the harvest scenario is all quota-based; else it is all F-based.
12. Age summary flag (agesumflag). If true, age-specific summaries of the distribution of spawning biomass and population size at age by year are produced; else not.
13. Target F flag (ftarflag). If true, then a target value of F is applied in the year after any year when the SB threshold is achieved; otherwise no change occurs.
14. Retrospective adjustment flag (retroflag). If true, an age-specific retrospective adjustment coefficient is applied to each initial population vector; else not.
15. SFA biomass and fishing mortality threshold flag (sfaflag). If true, realized spawning biomass, mean stock biomass, total stock biomass, fully-recruited fishing mortality, and biomass-weighted fishing mortality are compared to a threshold level; otherwise no comparisons are made.
16. Market category flag (mcflag). If true, landings are summarized by market category and output to file; otherwise no market category summaries are made.
17. Time-varying weight and fraction mature at age flag (varwtflag). If true, fish weights and fraction mature at age can vary from year to year; otherwise there is no annual variation.
18. Time-varying fishery selectivity flag (prflag). If true, both the partial recruitment at age and the fraction of total mortality that occurs prior to spawning can vary from year to year; otherwise there is no annual variation.
19. Constant discard at age flag (constdiscflag). If true, the fraction discarded at age is constant; otherwise the fraction discarded at age can vary from year to year.
20. Bounded recruitment flag (bdrecflag). If true, then realized recruitments generated with the lognormal, Beverton-Holt, Ricker, and Shepherd stock-recruitment models will be bounded based on realized R/B_S ratios; otherwise no bounds are applied.
21. Bounded fishing mortality flag (bdFflag). If true realized fishing mortality is constrained within user-specified upper and lower bounds.
22. Stochastic natural mortality flag (varmflag). If true, natural mortality at age varies according to a lognormal process that may be serially correlated and the vulnerability at age to natural mortality varies according to a uniform distribution.

23. Bootstrap flag (bootflag). If true, a file of initial population vectors is used in the projection analysis; otherwise a single initial population vector is used.
24. Output file flag (outfileflag). If true, auxiliary output files for spawning biomass, mean biomass, fishing mortality, and landings are created; else not.

Biological Data

The *biological* data are the values of a set of biological inputs needed to describe the dynamics of the age-structured population. Most of these data are required to run the AGEPRO software although some data are optional and dependent upon the simulation settings (Table 3). The biological data are read from the input file. By convention, optional inputs will be enumerated sequentially along with required inputs. Note that, if recruitment age is age-R, there is no accounting of fish younger than age-R in the model.

Here is a description of the biological data inputs

25. This input is the number of age classes in the population model (A), where A < 100 along with lower and upper bound on range of ages for computing mean biomass, Lowerage and Upperage, and the age of recruitment (r) if this age is not equal to 1.
26. This input is the instantaneous natural mortality rate (M) and the vulnerability to M at age vector ($P_{M,a}$). If natural mortality at age is stochastic, then the log-variance σ_M^2 , correlation parameter ρ_M, initial error ε_0 (set to 0 if unknown), and coefficient of variation of the uniform distribution for vulnerability to M, CV_a.
27. This input is the vector of mean stock weights at age on January 1 ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
28. This input is the vector of mean landed weights at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
29. This input is the vector of mean spawning weights at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
30. This input is the vector of mean mid-year weights at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
31. If discards at age are included in the projection, this input is the vector of mean weights at age of discarded fish ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
32. This input is the vector of fraction mature at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight and fraction mature option is selected.
33. This input is the fraction of total mortality that occurs prior to spawning (P_Z). If the partial recruitment flag is true, then a set of Y values of P_Z must be input.
34. This input is the recruitment flag which is a number from 1 to 19 that identifies the choice of stochastic stock-recruitment model to be used. These models are

numbered 1 to 19 in exact correspondence with their descriptions (see **Stock-Recruitment Relationship**).

35. This input is the set of parameters needed for the probable stock-recruitment models. The set of parameters depends on the set of probable models; these parameters are specified in Table 3 for each of the nineteen stock-recruitment models.
36. This input is the set of parameters to constrain recruitment for stock-recruitment models with lognormal error terms. These parameters are input only if the bounded recruitment flag is true. If this flag is true, then the endpoints of the constraining intervals are input on one line as L_{HIGH}, L_{LOW}, U_{LOW}, U_{HIGH}, while $B_{S,CUT}$ is input on the next line.
37. This input is the set of parameters to define the initial population sizes for projection. The set of parameters depends on the value of the age-1 recruitment flag and the bootstrap flag (see Table 3).
38. This input is the set of coefficients for the retrospective bias adjustment. These parameters are input only if the retrospective adjustment flag is true.
39. This input is the set of SFA status determination parameters. These thresholds are input only if the SFA threshold flag is true.
40. This input is the set of parameters to apply the F target option. These parameters are input only if the target F flag is true and are listed in Table 3.
41. This input is the set of parameters to apply the bounded F option. These parameters are input only if the bounded F flag is true and are listed in Table 3.

Fishery Data

The *fishery* data are the values of a set of inputs needed to describe fishery impacts on the population and yields.

Here is a description of the fishery data inputs

42. This input is the set of parameters to define fishery selectivity through time. These parameters depend upon the time-varying fishery selectivity flag (Table 3).
43. This input is the set of parameters to define age-specific discarding through time. These parameters depend upon the discard and constant discard flags (Table 3).
44. This input is the set of parameters to define the harvest strategy. These parameters depend upon the harvest mixture, quota-based, and constant harvest strategy flags (Table 3).
45. This input is the set of parameters to define the market category summarization. These parameters depend upon the market category flag (Table 3).
46. This input is the set of auxiliary output file names for spawning biomass, mean biomass, fishing mortality, and landings.

Model Outputs

The AGEPRO program creates a standard output file that summarizes the projection analysis results. The program may also create an output file for market category summaries and auxiliary files storing simulated trajectories of spawning biomass, mean biomass, fishing mortality, and landings, if applicable (Figure 1).

There are twelve general categories of output in the standard output file. The first output describes the AGEPRO projection run and lists the input and output file names and the recruitment models and associated model probabilities. The second output shows the user-input harvest scenario in terms of quotas or fishing mortality rates. The third output characterizes the distribution of projected spawning biomass through time including the probability that spawning biomass exceeds a threshold if applicable. The fourth output characterizes the distribution of the projected trajectory of mean biomass. The fifth output describes the distribution of the fishing mortality weighted by mean biomass trajectory. The sixth output characterizes the distribution of the projected trajectory of total stock biomass. The seventh output characterizes the distribution of projected recruitment through time. The eighth output characterizes the distribution of the projected landings through time. The ninth output characterizes the distribution of the population numbers at age (on January 1st) through time, if applicable. The tenth output characterizes the distribution of projected landings by market category through time, if applicable. The eleventh output characterizes the distribution of projected discards and catch biomass through time, if applicable. The twelfth output characterizes the distribution of the realized fishing mortality rates through time including the probability that fishing mortality exceeds a threshold, if applicable.

There are six categories of output in the market category summary file which will be created if the market category option is selected (mcflag=1 or 2). The first output describes the AGEPRO projection run and lists the input and output file names. The second output characterizes the distribution of the projected trajectory of landed weight by market category. The third output describes the distribution of numbers of landed fish by year and market category. The fourth output shows the average total weight and numbers of fish landed weight by market category. The fifth output gives the median total weight and numbers of fish landed weight by market category. The sixth output lists the entire set of simulated trajectories of landings and weight by market category; this output occurs only if full market category output is selected (mcflag=2). In this case, each row represents market category information from a single trajectory. The output variables in a row (in order): year, total landings (kg), market category 1 landings (kg), market category 2 landings (kg), and market category 3 landings (kg). The rows are ordered by year (time), initial population vector (bootstrap), and simulation (sim). The full output option can create a large market category summary file; a 5-year projection with 1000 initial population vectors and 100 simulations per vector will produce a market category file with over 500,000 lines.

There is one category of output in the auxiliary files for spawning biomass, mean biomass, fishing mortality, and landings. These files are created if the output file option is selected (outfileflag=true). Each row in an auxiliary output file gives the trajectory of the output variable through time, ordered from the 1st to the last year in the projection time horizon.

Examples

The following two examples show some general features of the AGEPRO program. These projections are hypothetical and for the purposes of illustration only.

Example 1: This example is a projection for Acadian redfish from 2004 through 2009 using recruitment model 14. This projection illustrates the mixed harvest, SFA threshold, and stochastic natural mortality options. Fishing mortality in 2004 is assumed to be equal to the 2003 estimate. Catch biomass of redfish in 2005 is estimated from the first half-year landings in 2005. Fishing mortality in 2006-2009 is assumed to be constant with F_{2006}=0.01. This harvest scenario represents an increase in F over 2003. Mean vulnerability to natural mortality (M=0.05) is constant across age classes ($P_{M,a}$=1 for each age class a) but the coefficient of variation of vulnerability is CV_a=0.2 for ages 1-9 and CV_a=0.1 for ages 10 and older. Natural mortality has a log-variance of $\sigma_M^2 = 0.2$ with an autocorrelation parameter of ρ_M=0.5 and an initial random shock of ε_0=0. Three hypothetical questions are posed. Does this scenario reduce the spawning potential of the redfish stock ? Is there any chance that the stock would be at B_{MSY} in 2009 under this scenario? What are the potential redfish landings in 2009 under this scenario ?

These hypothetical questions can be readily answered using the output and graphing capabilities of the AGEPRO GUI. First, graphing the spawning biomass variable with 5% to 95% confidence limits shows that spawning biomass is likely to increase under this harvest scenario (Figure 3.1). Based on this graph it appears that there is a chance that the spawning biomass threshold B_{MSY} will be exceeded in 2009 and also a small chance that spawning biomass will not increase beyond 2008. In the Output Report File, one can see that the annual probabilities of exceeding BMSY are:

```
ANNUAL PROBABILITY THAT SSB EXCEEDS THRESHOLD:   236.700 THOUSAND MT
 YEAR    Pr(SSB >= Threshold Value) FOR FEASIBLE SIMULATIONS
 2004          0.000
 2005          0.000
 2006          0.000
 2007          0.019
 2008          0.154
 2009          0.289
```

This output indicates that there is a 29% probability that BMSY would be exceeded in 2009, a moderate chance. This can also be shown by graphing of the probability of achieving this threshold (Figure 3.3). Last, graphing the landings variable with 5% to 95% confidence limits shows that landings would be very likely to increase under this harvest scenario (Figure 3.3). By 2009 the probable range of redfish landings indexed by the 5th and 90th percentiles would be (1.898, 2.496) thousand mt, a substantial increase over the 2005 catch estimate.

Example 2: This example is a projection for Georges Bank haddock from 2005 through 2014 using recruitment model 15. This projection illustrates the discard, age summary and market category options. Fishing mortality in 2005 is based on an expected catch of about 22.5 thousand mt. Fishing mortality in 2006-2014 is assumed to be constant with F_{2006}=0.26. Hypothetical discard fractions of age-1 to age-3 fish are 20%, 10%, and 5%

while discard fraction of fish ages 4 and older is 1%. Three hypothetical questions are posed. What is the likely trend in discard biomass through time ? What is the likely contribution of the 2003 year class to spawning biomass in 2009? What are the likely trends of landings by market category under this scenario ?

These hypothetical questions can be generally addressed using graphical output from the projection run while quantitative answers can be gathered from the Output Report File. First, plotting the time trend in discard biomass indicates it would increase to about 1500 mt in 2006 and then decline to about 600 mt in 2014 (Figure 4.1). Second, the contribution of the 2003 year class to spawning biomass in 2009 is substantial but uncertain (Figure 4.2). The median contribution of this exceptional year class would be about 300 kt but with a probable range of roughly 100-600 kt. Third, the projected landings of large haddock would increase sharply to a peak of about 50 kt during 2008-2010 and then gradually decline to about 30 kt in 2014 (Figure 4.3). In comparison, landings of scrod haddock were projected to increase to about 70 kt in 2007-2008 and then decline to about 20 kt in 2014 (Figure 4.4). The growth and eventual decline in landings from both market categories have relatively large probable ranges. This reflects uncertainty in the size of the 2003 year class which dominates the projected landings and spawning biomass in 2007-2012.

Example 3: This example is a model-averaged projection for Georges Bank haddock that compares the results of using recruitment model 15 versus using a model-averaged combination of alternative models 18 and 19 to predict recruitment during 2005-2007. The existing (status quo) recruitment prediction model for haddock was taken from the recommendations of the 2005 Groundfish Assessment Review Meeting (Mayo and Terceiro 2006). This status quo model was a two-stage cumulative distribution function for observed recruitments above and below the productivity threshold of 75,000 mt of spawning biomass (NEFSC 2002).

The first alternative model ($M_{HAD,R1}$) was a linear model with no intercept fit to log-scale R during 1985-2004 from Brodziak et al. (2006) as a function of sea surface temperature on Georges Bank during February-May. The fitted model was

$$\log(R) = 0.3588 \cdot ST2.spr.mm + \varepsilon \quad \text{where } \varepsilon \sim N(-1.209,\ 2.418) \tag{61}$$

The fitted model was highly significant (P<0.001) and explained a good amount of variation in the R data relative to the model log(R) = 0 + ε (multiple $R^2 = 0.72$).

The second alternative model to predict haddock recruitment ($M_{HAD,R2}$) also used sea surface temperature during February-May and the haddock age-0 survey index but was fitted to untransformed haddock R. The estimated model was

$$R = 1.1362 \cdot ST2.spr.mm + 1.5567 \cdot age0.had + \varepsilon \quad \text{where } \varepsilon \sim N(0, 386.5) \tag{62}$$

This model was also highly significant (P<0.001) and explained much of the variation in haddock R relative to the model R = 0 + ε (multiple $R^2 = 0.99$).

The model-averaged combination of the two alternative models to predict haddock recruitment ($M_{HAD,MA}$) was a weighted average of models $M_{HAD,R1}$ and $M_{HAD,R2}$. In the absence of a preference, the two model probabilities were equal to 0.5 and each model was randomly sampled with probability one-half to simulate recruitment in each year of the stochastic projections.

To compare the status quo and alternative model-averaged prediction model, estimates of recruitment for Georges Bank haddock during 2005-2007 were gathered from the recently completed 2008 stock assessment (NEFSC 2008a, NEFSC 2008b). Observed values of sea surface temperatures were not available in 2007 and SST in 2007 was imputed using the average sea surface temperature during 1985-2006. Observed catch biomasses of Georges Bank haddock during 2005 to 2007 were input to the AGEPRO model to compute annual fishing mortality during 2005-2007 for each projection. For haddock, the catch biomasses in 2005-2007 were 21814, 15989, and 16815 mt.

Because the 2008 stock assessment for Georges Bank haddock was a bench mark assessment, and not a simple assessment update, estimates of recruitment, spawning biomass, and other variables were expected to have a somewhat different scale than those from the 2005 assessments. In this case, comparing the projected recruitments during 2005-2007 with the observed values from the assessment could be misleading. To address this concern, the best-fitting linear model to predict observed from the 2008 assessment as a function of the 2005 assessment value during 1985-2004 was used to rescale predicted recruitments during 2005-2007 to be comparable to the values in the 2008 assessments of haddock. Regression analyses and associated Akaike information criteria values indicated that the best fitting linear model relating the new 2008 VPA estimates of Georges Bank haddock recruitment to the old estimates from the 2005 assessment was $R_{NEW} = 6.076 + 0.6247 \cdot R_{OLD}$. This model was used to rescale the predicted recruitment values from the projections using both the status quo models and the model-averaged alternative using the environmental covariates.

Results of the projections indicated that the model-averaged combination of two predictive models, one that used sea surface temperature and the haddock age-0 index and one that used only sea surface temperature, provided more accurate predictions of haddock recruitment during 2005-2007 (Figure 5). This model-averaged combination had a root mean-square prediction error that was roughly 5-fold lower than the status quo model. This example illustrates that the use of multiple predictive models may be able to improve predictive accuracy in some cases.

Acknowledgments

I extend a special thanks to Paul Rago for his help in developing this modeling framework and software. I also thank Alan Seaver for programming the graphical user interface, Laurel Col for assistance with the figures, and Laura Shulman for historic programming support.

References

Beverton, R.J.H., and Holt, S.J. 1957. On the dynamics of exploited fish populations. Chapman and Hall, London. Fascimile reprint, 1993.

Brodziak, J. and P. Rago. Manuscript 1994. A general approach for short-term stochastic projections in age-structured fisheries assessment models. Methods working group, Population dynamics branch. Northeast Fisheries Science Center. Woods Hole, Massachusetts, 02543.

Brodziak, J., P. Rago, and R. Conser. 1998. A general approach for making short-term stochastic projections from an age-structured fisheries assessment model. In F. Funk, T. Quinn II, J. Heifetz, J. Ianelli, J. Powers, J. Schweigert, P. Sullivan, and C.-I. Zhang (Eds.), *Proceedings of the International Symposium on Fishery Stock Assessment Models for the 21st Century*. Alaska Sea Grant College Program, Univ. of Alaska, Fairbanks.

Brodziak, J., Traver, M., Col, L., and Sutherland, S. 2006. Stock assessment of Georges Bank haddock, 1931-2004. NEFSC Ref. Doc. 06-11. Available at: http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0611/

Mayo, R.K. and Terceiro, M., editors. 2005. Assessment of 19 Northeast groundfish stocks through 2004. 2005 Groundfish Assessment Review Meeting (2005 GARM), Northeast Fisheries Science Center, Woods Hole, Massachusetts, 15-19 August 2005. U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref. Doc. 05-13; 499 p.

Metcalf, M. 1985. Effective Fortran 77. Oxford University Press, Oxford, U.K., 231 p.

Metcalf, M., and J. Reid. 1998. Fortran 90/95 Explained. Oxford University Press, Oxford, U.K., 333 p.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56,473–488.

New England Fishery Management Council [NEFMC]. 1994. Amendment 5 to the Northeast Multispecies Fishery Management Plan. NEFMC, Newburyport, MA.

NEFMC. 1996. Amendment 7 to the Northeast Multispecies Fishery Management Plan. NEFMC, Newburyport, MA.

Northeast Fisheries Science Center [NEFSC]. 1994. Report of the 18th Northeast Regional Stock Assessment Workshop: Stock Assessment Review Committee Consensus Summary of Assessments. NEFSC Ref. Doc. 94-22, Woods Hole, MA 02543, 199 p.

NEFSC. 2002. Final Report of the Working Group on Re Evaluation of Biological Reference Points for New England Groundfish. NEFSC Ref. Doc. 02 04, p. 254. Available at: http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0204/

NEFSC. 2008a. Assessment of 19 Northeast Groundfish Stocks through 2007: Report of the 3rd Groundfish Assessment Review Meeting (GARM III), Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 08-15; 884 p + xvii.

NEFSC. 2008b. Appendix to the Report of the 3rd Groundfish Assessment Review Meeting (GARM III): Assessment of 19 Northeast Groundfish Stocks through 2007, Northeast Fisheries Science Center, Woods Hole, Massachusetts, August 4-8, 2008. US Dep Commer, NOAA Fisheries, Northeast Fish Sci Cent Ref Doc. 08-16; 1056 p.

Quinn, T.J., II, and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, New York, 542 p.

Ricker, W.E. 1954. Stock and recruitment. J. Fish. Res. Board. Can. 11:559-623.

Shepherd, J.G. 1982. A versatile new stock-recruitment relationship for fisheries and the construction of sustainable yield curves. J. Cons. Int. Explor. Mer 40:67-75.

Table 1. Notation for variables used in the AGEPRO model.

Variable	Description
A	Age of plus-group (fish age-A and older) and last index value for <u>N</u>.
$B_S(t)$	Spawning biomass in year t.
$B_M(t)$	Mean stock biomass in year t.
$B_T(t)$	Total stock biomass on January 1st of year t.
B	Number of input initial population vectors N(1).
$C_a(t)$	Number of age-a fish that are captured and die in year t.
D(t)	Total weight of discarded fish in year t.
$F_a(t)$	Instantaneous fishing mortality rate for age-a fish in year t.
F(t)	Instantaneous fully-recruited fishing mortality rate in year t.
$F_B(t)$	Instantaneous fishing mortality weighted by mean biomass in year t.
I(t)	Harvest index for year t. If I(t) = 1, then harvest is based on a landings quota Q(t). If I(t) = 0, then harvest is based on a fishing mortality rate F(t).
L(t)	Total weight of landed fish in year t.
M(t)	Instantaneous fully-vulnerable natural mortality rate in year t.
$M_a(t)$	Instantaneous natural mortality rate for age-a fish in year t.
$N_a(t)$	Number of age-a fish alive on January 1st of year t.
N_M	Number of probable recruitment models used in the projection.
$P_{D,a}(t)$	Proportion of age-a fish discarded in year t.
$P_{F,a}(t)$	Selectivity to F(t) for age-a fish (age-specific fishery selectivity).
$P_{M,a}(t)$	Selectivity to M(t) for age-a fish (age-specific natural mortality multiplier).
$P_{R,m}(t)$	Probability that the mth recruitment model is randomly sampled in year t.
$P_{S,a}(t)$	Proportion of age-a fish that are sexually mature in year t.
$P_Z(t)$	Proportion of total mortality occurring prior to spawning in year t.
Q(t)	Landings quota in year t.
r	Age of recruitment and age of first element in population vector <u>N</u>.
R(t)	Recruitment (absolute number of age-r fish on January 1st) in year t.
$W_{P,a}(t)$	Average population weight of an age-a fish on January 1st in year t.
$W_{L,a}(t)$	Average landed weight of an age-a fish in year t.
$W_{S,a}(t)$	Average spawning weight of an age-a fish in year t.
$W_{M,a}(t)$	Average mid-year weight of an age-a fish in year t.
$W_{D,a}(t)$	Average weight of an age-a fish that is discarded in year t.
Y	Number of years (t) in projection time horizon where t = 1, 2, ..., Y.

Table 2. Summary of logical flags used in AGEPRO version 3.4.

Flag	Name	Description
1	Age-1 Recruitment	If true, recruitment age is age-1. Otherwise recruitment age is age-2 or older.
2	Harvest Mixture	If true, a mixture of F-based and quota-based harvest can be specified in the projection. Otherwise, harvest is either F-based or it is quota-based.
3	Discard	If true, discards at age are incorporated in the projection. Otherwise, there are no discards included in the projection.
4	Quota-Based	If true, catches are determined as quotas. Otherwise, catches are determined from fishing mortality rates.
5	Age Summary	If true, age-specific summaries of spawning biomass and population size are output. Otherwise, no summaries are output.
6	Target F	If true, a target value of F is applied if the current year is greater than or equal to the F-target year and the B_S threshold was achieved in the previous year. Otherwise, no target F is applied.
7	Retrospective	If true, retrospective adjustment coefficients are applied to each initial population vector. Otherwise no adjustments are made.
8	SFA Threshold	If true, realized B_S, B_M, B_T, F, and F_B are compared to thresholds. Otherwise, no comparisons are made.
9	Market Category	If true, landings by market category are output. Otherwise, no market category summaries are made.
10	Time-Varying Weights	If true, stock, landed, and discard weights at age and fraction mature at age can vary through time. Otherwise, they do not.
11	Time-Varying Selectivity	If true, fishery selectivity at age vector and the fraction of total mortality that occurs prior to spawning can vary through time. Otherwise, they do not.
12	Constant Discard	If true, discard proportions at age are constant. Otherwise, discard proportion at age can vary through time.
13	Bounded Recruitment	If true, realized recruitments from models with lognormal errors are constrained based on R/B_S ratios. Otherwise, no constraints are applied.
14	Bounded F	If true, realized fishing mortality is bounded below by F_{LOWER} and above by F_{UPPER}. Otherwise, no constraints are applied to F.
15	Stochastic M	If true, natural mortality at age varies stochastically through time. Otherwise, natural mortality at age is constant.
16	Bootstrap	If true, a file of initial population vectors is used for the projection analysis. Otherwise, a single initial population vector in the standard input file is used.
17	Outfile	If true, trajectories of spawning biomasses, mean biomasses, fishing mortalities, and landings are output to auxiliary files. Otherwise, no auxiliary files are created.

Table 3. Structure of an AGEPRO version 3.4 input file. Inputs can be delimited by a comma or a space.

Input #	Is input required?	Input description
1	Yes	AGEPRO version tag
2	Yes	Name of projection run, input: up to 64 character string
3	Yes	First year of projection run, input: 4-digit year (Positive integer)
4	Yes	Length of planning horizon, input: Y (Positive integer)
5	Yes	Number of simulations per initial population vector, input: Positive integer
6	Yes	Number of recruitment models (nmodel), input: Positive integer $\leq$ 19
7	Yes	Number of "warmups" for random number generator, input: Positive integer
8	Yes	Age-1 recruitment flag, input: Integer (1=true; 0=false)
9	Yes	Harvest mixture flag, input: Integer (1=true; 0=false)
10	Yes	Discard flag, input: Integer (1=true; 0=false)
11	Yes	Quota-based flag, input: Integer (1=true; 0=false)
12	Yes	Age summary flag, input: Integer (1=true; 0=false)
13	Yes	F target flag, input: Integer (1=true; 0=false)
14	Yes	Retrospective adjustment flag, input: Integer (1=true; 0=false)
15	Yes	SFA threshold flag, input: Integer (1=true; 0=false)
16	Yes	Market category flag, input: Integer (1=standard output; 2=standard and full output; 0=false)
17	Yes	Time-varying weights flag, input: Integer (1=true; 0=false)
18	Yes	Time-varying selectivity flag, input: Integer (1=true; 0=false)
19	Yes	Constant discard flag, input: Integer (1=true; 0=false)
20	Yes	Bounded recruitment flag, input: Integer (1=true; 0=false)
21	Yes	Bounded F flag, input: Integer (1=true; 0=false)
22	Yes	Stochastic natural mortality flag, input: Integer (1=true; 0=false)
23	Yes	Bootstrap flag, input: Integer (1=true; 0=false)
24	Yes	Outfile flag, input: Integer (1=true; 0=false)
25	Yes; depends on flag 1	If flag 1= true, then input number of age classes, lower and upper bound on range. If flag 1= false, then input number of age classes, lower & upper bound on range of ages for computing mean biomass, and recruitment age: A, A_L, A_U, r
26	Yes; depends on flag 15	Natural mortality rate. Input: M. Input: $P_{M,r}$, $P_{M,r+1}$, ..., $P_{M,A}$. If flag 15=true, then input: σ_M^2 and input: ρ_M, ε_0 and input: CV_r , CV_{r+1}, ..., CV_A
27	Yes; depends on flag 10	If flag 10=true, input mean population weights at age: $W_r(t)$, $W_{r+1}(t)$,... , $W_A(t)$, for t=1..Y. Else input W_r, W_{r+1} ,... , W_A

Table 3. Continued.

Input #	Is input required?	Input description
28	Yes; depends on flag 10	If flag 10=true, input mean landed weights at age: $W_{L,r}(t)$, $W_{L,r+1}(t)$,... , $W_{L,A}(t)$, for t=1..Y. Else input $W_{L,r}$, $W_{L,r+1}$,... , $W_{L,A}$
29	Yes; depends on flag 10	If flag 10=true, input mean spawning weights at age: $W_{S,r}(t)$, $W_{S,r+1}(t)$,... , $W_{S,A}(t)$, for t=1..Y. Else input $W_{S,r}$, $W_{S,r+1}$,... , $W_{S,A}$
30	Yes; depends on flag 10	If flag 10=true, input mean mid-year weights at age: $W_{M,r}(t)$, $W_{M,r+1}(t)$,... , $W_{M,A}(t)$, for t=1..Y. Else input $W_{M,r}$, $W_{M,r+1}$,... , $W_{M,A}$
31	No; required if flag 3=true	If flags 3 and 10=true, input mean discarded weights at age: $W_{D,r}(t)$, $W_{D,r+1}(t)$,... , $W_{D,A}(t)$, for t=1..Y. Else input $W_{D,r}$, $W_{D,r+1}$,... , $W_{D,A}$
32	Yes; depends on flag 10	If flag 10=true, input fraction mature at age: $P_{S,r}(t)$, $P_{S,r+1}(t)$,... , $P_{S,A}(t)$, for t=1..Y. Else input $P_{S,r}$, $P_{S,r+1}$,... , $P_{S,A}$
33	Yes; depends on flag 11	If flag 11=false, then input: P_Z If flag 11=true, input: $P_Z(1)$, $P_Z(2)$, ..., $P_Z(Y)$
34	Yes	Recruitment model vector, input: integer vector of length nmodel with elements between 1 and 19. Input only one copy of each model.
35	Yes; depends on input #34	If input #34 includes 1, input number of recruitment states: K and on the next line input: $N_{r,1}$, $N_{r,2}$, $N_{r,3}$, ..., $N_{r,K}$ and on the next line input number of spawning biomass states: J and on the next line input J-1 cut points: $B_{S,2}$, $B_{S,3}$, $B_{S,4}$, ..., $B_{S,J}$ and on the next J lines input: $p_{1,1}$, $p_{1,2}$, $p_{1,3}$, ..., $p_{1,K}$ $p_{2,1}$, $p_{2,2}$, $p_{2,3}$, ..., $p_{2,K}$ ... $p_{J,1}$, $p_{J,2}$, $p_{J,3}$, ..., $p_{J,K}$ If input #34 includes 2, input: T and on the next line input: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T)$ and on the next line input: $B_S(1\text{-}r)$, $B_S(2\text{-}r)$, $B_S(3\text{-}r)$, ..., $B_S(T\text{-}r)$ If input #34 includes 3, input: T and on the next line input: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T)$ If input #34 includes 4, input: T_{LOW} , T_{HIGH} and on the next line input: B_S* and on the next line the low-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{LOW})$ and on the next line the low-B_S state spawning biomass series: $B_S(1\text{-}r)$, $B_S(2\text{-}r)$, $B_S(3\text{-}r)$, ..., $B_S(T_{LOW}\text{-}r)$ and on the next line the high-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{HIGH})$ and on the next line the high-B_S state spawning biomass series: $B_S(1\text{-}r)$, $B_S(2\text{-}r)$, $B_S(3\text{-}r)$, ..., $B_S(T_{HIGH}\text{-}r)$ If input #34 includes 5, input: α, β, σ_W^2 and on the next line input: c_B , c_R

Table 3. Continued.

Input #	Is input required?	Input description
35	Yes; depends on input #34	If input #34 includes 6, input: α, β, σ_W^2 and on the next line input: c_B , c_R If input #34 includes 7, input: α, β, k, σ_W^2 and on the next line input: c_B , c_R If input #34 includes 8, input: $\mu_{\log(r)}$, $\sigma_{\log(r)}^2$ and on the next line input: c_R If input #34 includes 9, input: T and on the next line input: $N_r(1,1)$, $N_r(1,2)$, $N_r(1,3)$, ..., $N_r(1,T)$ and on the next line input: $N_r(2,1)$, $N_r(2,2)$, $N_r(2,3)$, ..., $N_r(2,T)$ ... and on the next line input: $N_r(Y,1)$, $N_r(Y,2)$, $N_r(Y,3)$, ..., $N_r(Y,T)$ If input #34 includes 10, input: α, β, σ^2 and on the next line input: φ , ε_0 and on the next line input: c_B , c_R If input #34 includes 11, input: α, β, σ^2 and on the next line input: φ , ε_0 and on the next line input: c_B , c_R If input #34 includes 12, input: α, β, k, σ^2 and on the next line input: φ , ε_0 and on the next line input: c_B , c_R If input #34 includes 13, input: $\mu_{\log(r)}$, $\sigma_{\log(r)}^2$ and on the next line input: φ , ε_0 and on the next line input: c_R If input #34 includes 14, input: T and on the next line input: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T)$

Table 3. Continued.

Input #	Is input required?	Input description
35	Yes; depends on input #34	If input #34 includes 15, input: T_{LOW} , T_{HIGH} and on the next line input: B_S* and on the next line the low-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{LOW}$) and on the next line the high-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{HIGH}$) If input #34 includes 16, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1)$, $X_1(2)$,..., $X_1(Y)$ $X1_2(1)$, $X_2(2)$,..., $X_2(Y)$ ... $X_p(1)$, $X_p(2)$,..., $X_p(Y)$ If input #34 includes 17, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1)$, $X_1(2)$,..., $X_1(Y)$ $X1_2(1)$, $X_2(2)$,..., $X_2(Y)$ ... $X_p(1)$, $X_p(2)$,..., $X_p(Y)$ If input #34 includes 18, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1)$, $X_1(2)$,..., $X_1(Y)$ $X1_2(1)$, $X_2(2)$,..., $X_2(Y)$ ... $X_p(1)$, $X_p(2)$,..., $X_p(Y)$ and on the next line input: c_R If input #34 includes 19, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1)$, $X_1(2)$,..., $X_1(Y)$ $X1_2(1)$, $X_2(2)$,..., $X_2(Y)$ ... $X_p(1)$, $X_p(2)$,..., $X_p(Y)$ and on the next line input: c_R

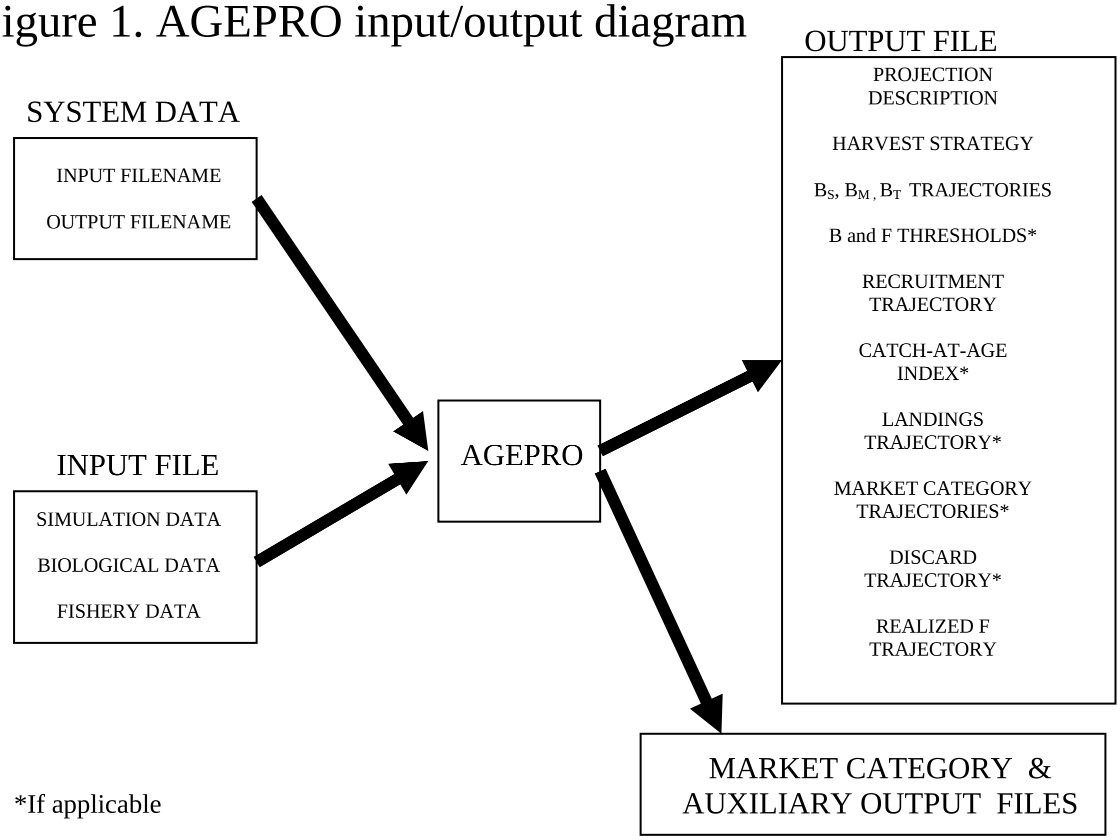
Table 3. Continued.

Input #	Is input required?	Input description
36	Yes	Input recruitment model probabilities for each year t=1,2, ..., Y Input: $P_{R,1}(1)$, $P_{R,2}(1)$, ..., $P_{R,Nm}(1)$ and on the next line input: $P_{R,1}(2)$, $P_{R,2}(2)$, ..., $P_{R,Nm}(2)$ ... and on the next line input: $P_{R,1}(Y)$, $P_{R,2}(Y)$, ..., $P_{R,Nm}(Y)$
37	No; required if flag 13=true	R/B_S constraints, input: L_{High} , L_{Low} , U_{Low} , U_{High} and on the next line input: $B_{S,CUT}$
38	Yes; depends on flags 16 and 1	Initial population abundance parameters. If flag 16=true and flag 1=true, input: B and on the next line input: name of the file (bfile1) containing B initial population vectors $\underline{n}(1)$ in relative units (one vector per row) and on the next line input the conversion coefficient: k_N If flag 16=true and flag 1=false, input: B and on the next line input: name of the file (bfile1) containing B initial population vectors $\underline{n}(1)$ in relative units (one vector per row) and B prior population vectors at time t=0 in relative units, and so on to time t=2-r. Note that in bfile1, the bootstrap data are grouped by time in blocks of B rows and where the first time block corresponds to the first year (t=1) in the time horizon, the second time block corresponds to the year prior to the first year (t=0), the third time block corresponds to the next previous year (t=-1) and so on... and on the next line input the conversion coefficient: k_N and on the next line, input: name of the file (bfile2) containing B fishing mortality at age vectors $\underline{F}(0)$ (one vector per row) and B fishing mortality at age vectors $\underline{F}(-1)$ at time t=-1, and so on to time t=2-r where the bootstrap data are grouped by time in blocks of size nboot with the first time block corresponds to the year prior to the first year (t=0), the second time block corresponds to the next prior year (t=-1) and so on... where the order of the population vectors matches the order of the fishing mortality at age vectors. If flag 16=false, input: c_N and on the next line input: $n_r(1)$, $n_{r+1}(1)$, ..., $n_A(1)$
39	No; required if flag 7=true	Retrospective adjustment coefficients, input: C_r, C_{r+1}, ..., C_A
40	No; required if flag 8=true	SFA thresholds, input: $B_{S,THRESHOLD}$,$B_{T,THRESHOLD}$, $F_{THRESHOLD}$, $B_{M,THRESHOLD}$, $F_{B,THRESHOLD}$
41	No; required if flag 6=true	F target parameters, input: F_{TARGET} and on the next line input: Y_{TARGET}
42	No; required if flag 14=true	Bounded F parameters, input: F_{LOWER} , F_{UPPER}

Table 3. Continued.

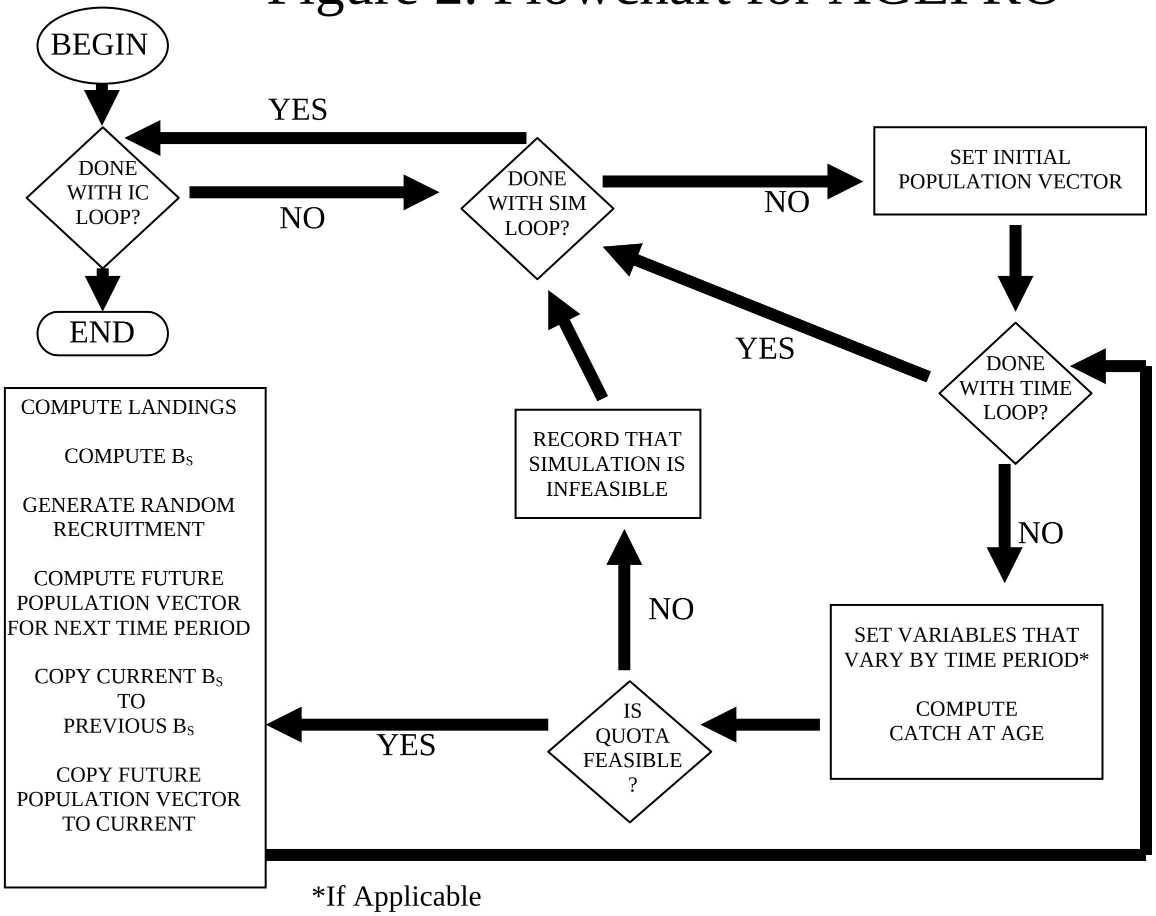
Input #	Is input required?	Input description
43	Yes; depends on flag 11	Fishery selectivity parameters. If flag 11=true, input: $P_{F,r}(1)$, $P_{F,r+1}(1)$, ... , $P_{F,A}(1)$ and on the next Y-1 lines input: $P_{F,r}(2)$, $P_{F,r+1}(2)$, ... , $P_{F,A}(2)$ $P_{F,r}(3)$, $P_{F,r+1}(3)$, ... , $P_{F,A}(3)$ ... $P_{F,r}(Y)$, $P_{F,r+1}(Y)$, ... , $P_{F,A}(Y)$ If flag 11=false, input: $P_{F,r}$, $P_{F,r+1}$, ... , $P_{F,A}$
44	No; required if flag 3=true and depends on flag 12	Discard parameters. If flag 3=true and flag 12=true, input: $P_{D,r}$, $P_{D,r+1}$, ... , $P_{D,A}$ If flag 3=true and flag 12=false, on the next Y lines input: $P_{D,r}$ (1) , $P_{D,r+1}$ (1) , ... , $P_{D,A}$ (1) $P_{D,r}$ (2) , $P_{D,r+1}$ (2) , ... , $P_{D,A}$ (2) ... $P_{D,r}$ (Y) , $P_{D,r+1}$ (Y) , ... , $P_{D,A}$ (Y)
45	Yes; depends on flags 2 and 4	Harvest strategy parameters. If flag 2=false and flag 4=true, input: Q(1) , Q(2) , Q(3) , ... , Q(Y) If flag 2=false and flag 4=false, input: F(1) , F(2) , F(3) , ... , F(Y) If flag 2=true, input: I(1) , I(2) , I(3) , ... , I(Y) where I(year)=1 indicates a quota-based harvest and I(year)=0 indicates an F-based harvest in a given year and on the next line input: Q(1) , Q(2) , Q(3) , ... , Q(Y) with placeholder values (-1) for F-based years and on the next line input: F(1) , F(2) , F(3) , ... , F(Y) with placeholder values (-1) for quota-based years
46	No; required if flag 9=true	Market category parameters, input number of market categories: MC (integer between 1 and 3) and on the next 2*MC lines input: Market category 1 label (character string) $q_{r,1}$, $q_{r+1,1}$, ..., $q_{A,1}$ Market category 2 label (character string) $q_{r,2}$, $q_{r+1,2}$, ..., $q_{A,2}$ Market category 3 label (character string) $q_{r,3}$, $q_{r+1,3}$, ..., $q_{A,3}$ and on the next line input: Market category file name (character string)
47	No; required if flag 17=true	Auxiliary output file names (4), input on four successive lines. Input: Spawning biomass output file name (character string) Input: Mean biomass output file name (character string) Input: Fishing mortality output file name (character string) Input: Landings output file name (character string)

Figure 1. AGEPRO input/output diagram



*If applicable

Figure 2. Flowchart for AGEPRO



*If Applicable

Figure 3.1. Projected median spawning biomass of redfish with 90% confidence intervals.

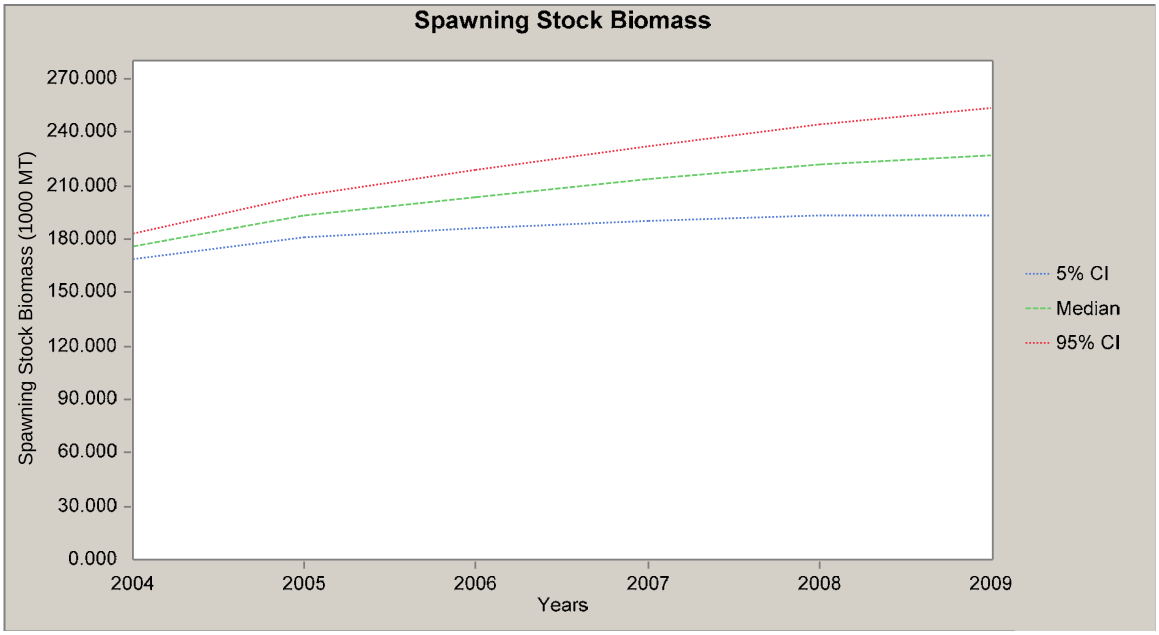


Figure 3.2. Projected annual probability of exceeding redfish spawning biomass threshold B_{MSY}.

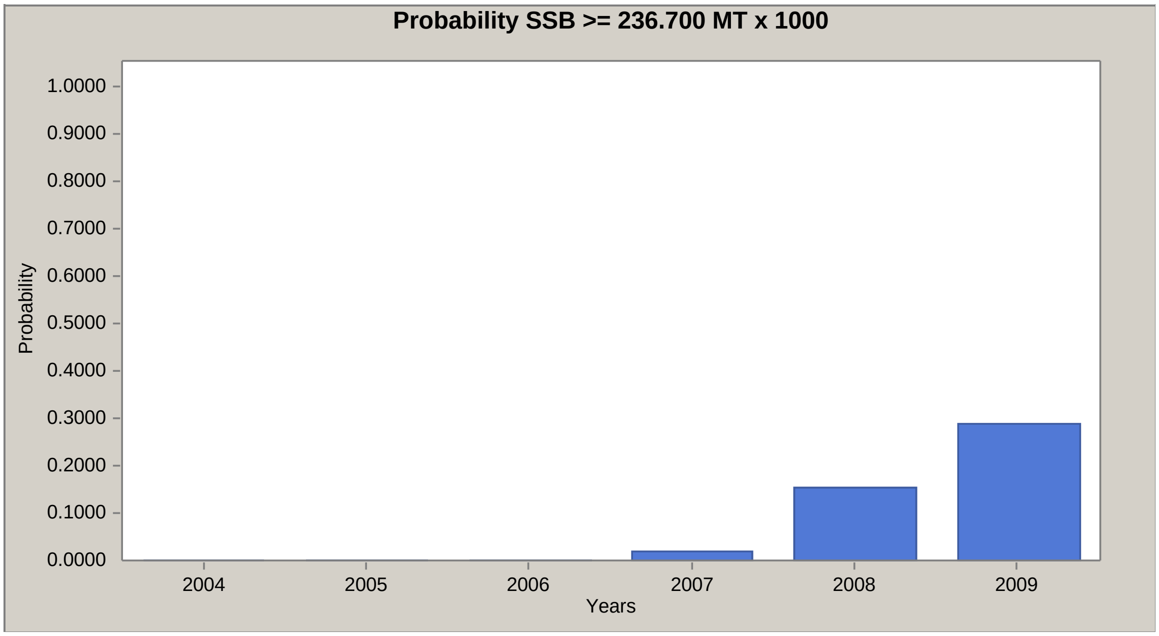


Figure 3.3. Projected median landings of redfish with 90% confidence intervals.

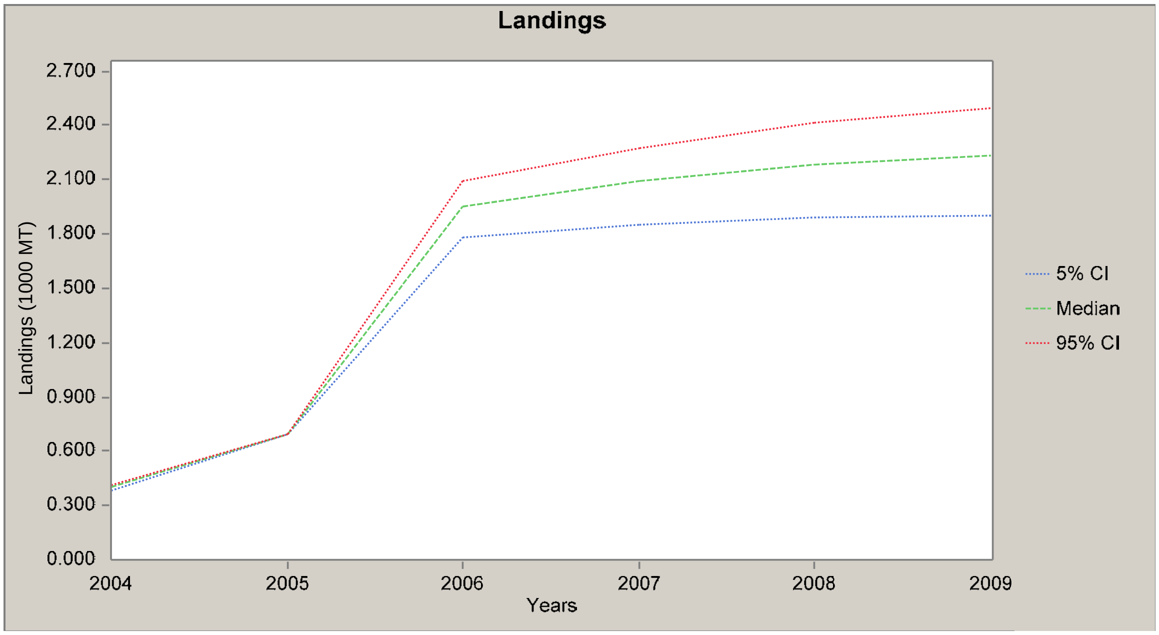


Figure 4.1. Projected median discard biomass of Georges Bank haddock with 90% confidence intervals.

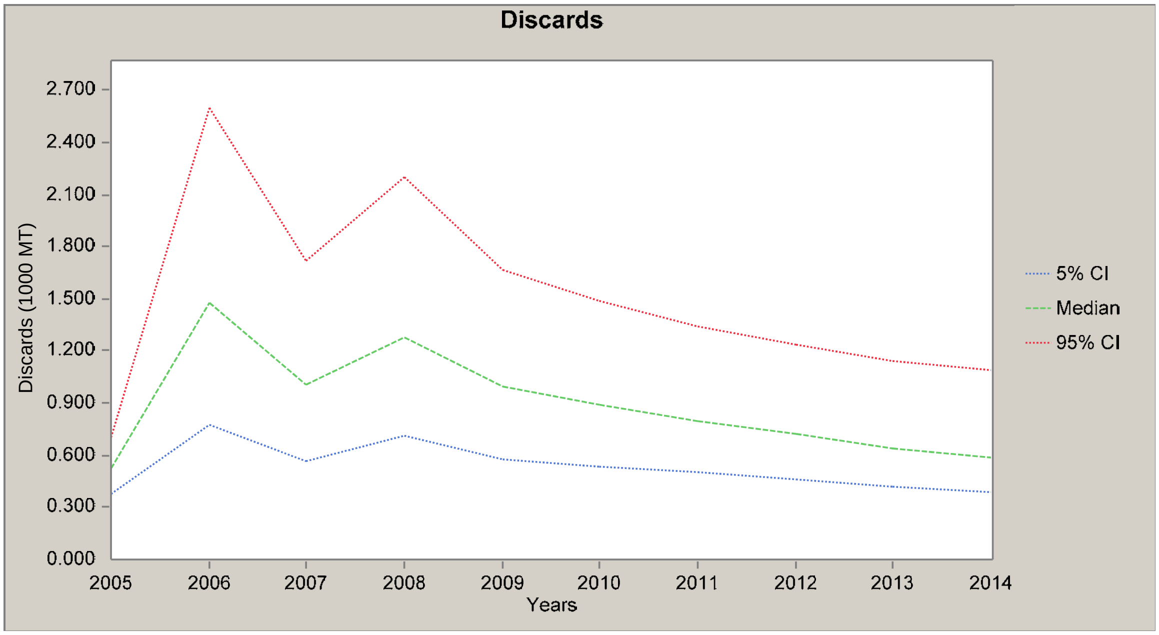


Figure 4.2. Projected median contribution of age-6 Georges Bank haddock to spawning biomass through time with 90% confidence intervals. The 2003 year class would be age 6 in 2009.

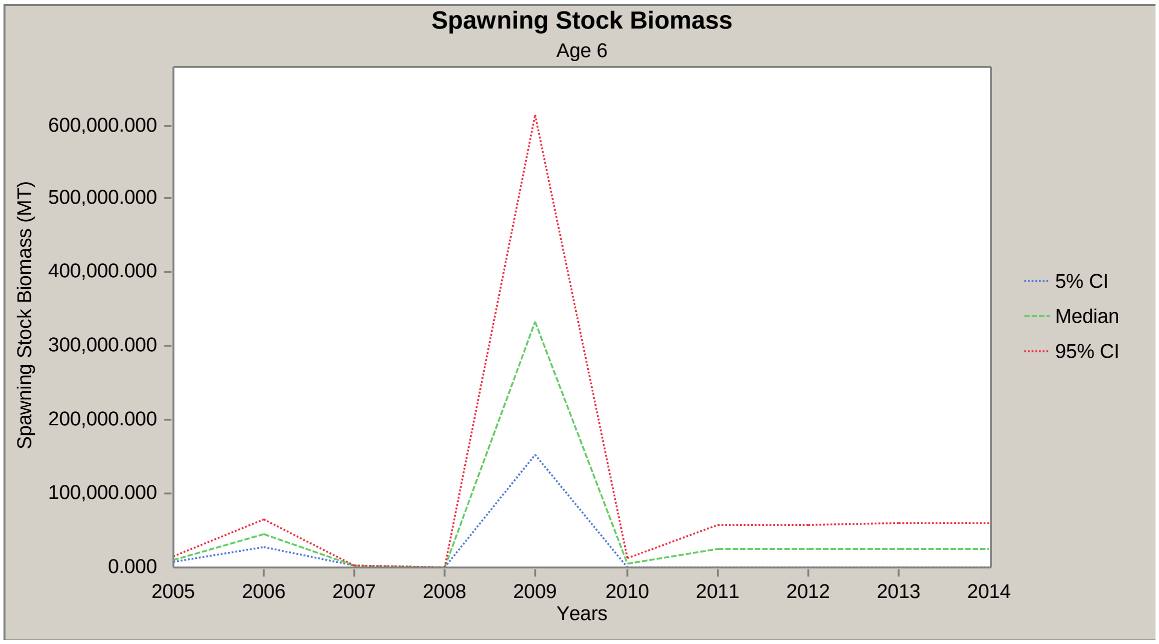


Figure 4.3. Projected median landings of large market category Georges Bank haddock with 90% confidence intervals.

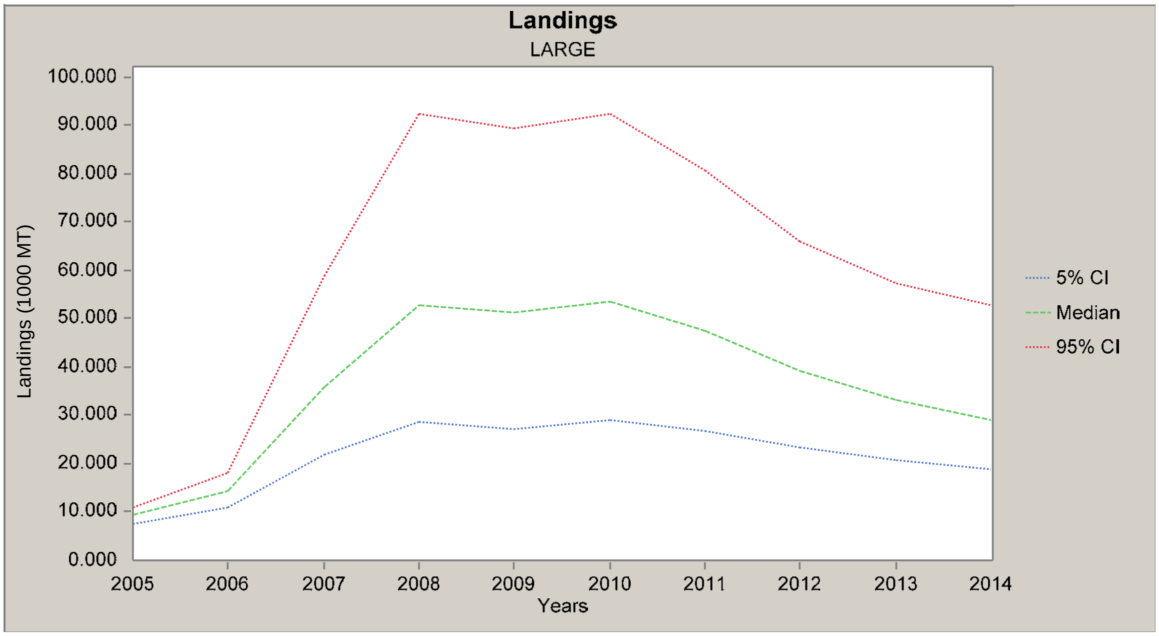


Figure 4.4. Projected median landings of scrod market category Georges Bank haddock with 90% confidence intervals.

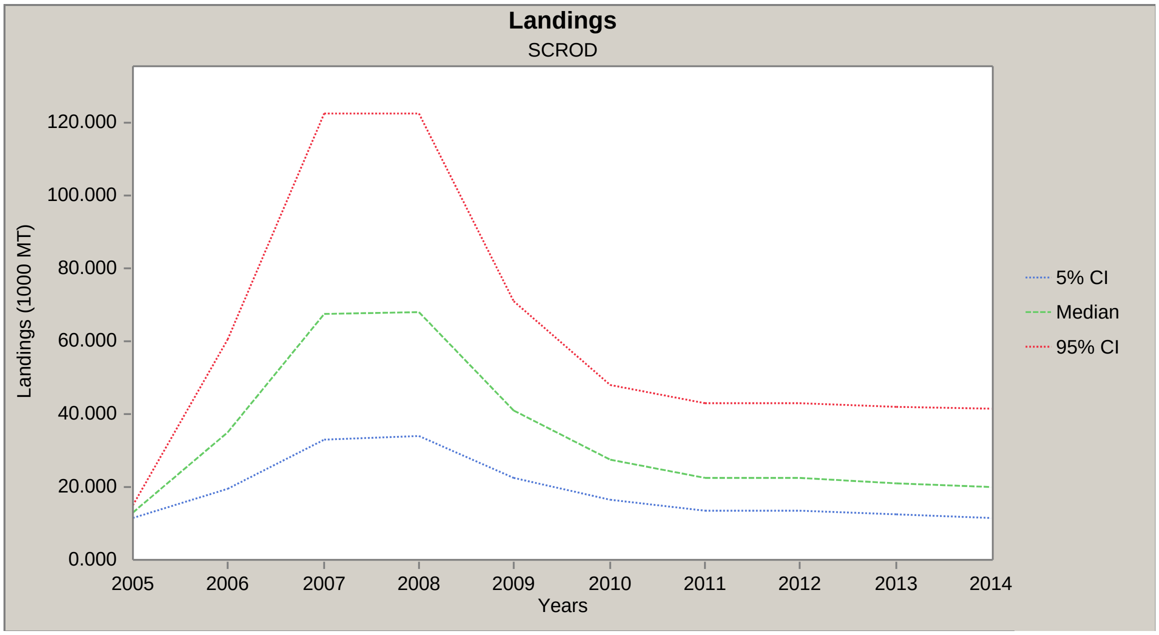
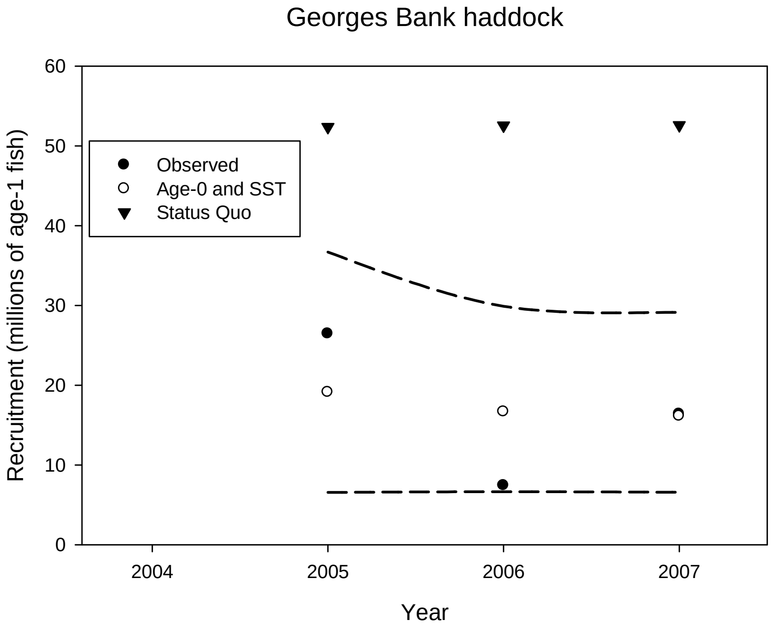


Figure 5. Comparison of Georges Bank haddock observed recruitment (solid circle) during 2005-2007 (NEFSC 2008a) and rescaled recruitment predictions from the best predictive model (open circle), a model-averaged combination of predictors using the haddock age-0 survey index and average sea surface temperature (SST) during February-May, and the status quo model (solid triangle) from Mayo and Terceiro (2006) along with 80% confidence intervals for the Age-0 index and SST-based prediction.



Appendix

Application of Newton's Method

To solve for the fishing mortality F that would yield the landings quota Q, we define a function g() and find its root. Let g(F) = L(F) - Q where L(F) is defined in Equation 11. The first order Taylor series expansion of g(F) about an arbitrary positive real number x is

(63)
$$g(F) = g(x) + g'(x)\cdot(F-x)$$

Solving for the value of F that implies g(F) = 0, one obtains

(64)
$$F = x - \frac{g(x)}{g'(x)}$$

One can numerically solve g(F)=0 by successively substituting iterates of $x=F^{(n)}$

(65)
$$F^{(n+1)} = F^{(n)} - \frac{g\left(F^{(n)}\right)}{g'\left(F^{(n)}\right)}$$

The function g'(F) is the first derivative of L(F) - Q with respect to F. Since Q is a constant, this derivative is g'(F) = L'(F) where

(66)
$$L'(F) = \sum_{a=r}^{A}\left(1-P_{D,a}\right)\cdot W_{L,a}\cdot C_a'(F)$$

The derivative of catch with respect to F can be derived by taking the derivative of F with respect to C. After some algebra the derivative g'(F) reduces to

(67)
$$g'(F) = \sum_{a=r}^{A}\left(1-P_{D,a}\right)\cdot W_{L,a}\cdot\frac{P_{F,a}N_a}{\left(M_a+P_{F,a}F\right)^2}\cdot\left(M_a+\left(M_aP_{F,a}F-M_a+P_{F,a}^2F^2\right)\cdot e^{-M_a-P_{F,a}F}\right)$$

Therefore, the iterative solution for F that results in catch of the quota Q can be found from

(68)
$$F^{(n+1)} = F^{(n)} - \frac{L\left(F^{(n)}\right)-Q}{g'\left(F^{(n)}\right)}$$

The iterates $F^{(n)}$ are constrained to remain within a bounded interval to ensure that the iterates $F^{(n)}$ converge to the solution of g(F)=0. In this case, the bounded interval of feasible iterates $F^{(n)}$ for g(F)=0 is set to be [0, 25] and the iteration has numerically converged when $| F^{(n+1)} - F^{(n)} | < 0.0005$.

Definition of Infeasible Quotas

An infeasible quota occurs when the landings quota cannot be removed from the exploitable biomass for some maximum feasible fishing mortality, denoted by F*. In this case, it is assumed that the maximum feasible F is F*=25.0 . Given this choice of F*and a constant M=0.2, it follows that the survival probability of average recruit would be exp(-Z) = exp(-25.2) ≈ $1.137 \cdot 10^{-11}$, or roughly 1 chance in 100 billion. This survival probability was small enough to characterize the maximum fishing mortality rate on a stock. Given F*, the maximum landings in time period t, denoted by L*, are

(69)

$$L^*\left(F^*\right) = \sum_{a=r}^{A}\left(1-P_{D,a}\left(t\right)\right)\cdot W_{L,a}\left(t\right)\cdot N_a\left(t\right)\cdot\frac{P_{F,a}\left(t\right)F^*}{M_a\left(t\right)+P_{F,a}\left(t\right)F^*}\cdot\left(1-e^{-M_a(t)-P_{F,a}(t)F^*}\right)$$

```
# ASAP VERSION 3.0
# SNE
#
# ASAP GUI 15 AUG 2012
#
# Number of Years
32
# First Year
1982
# Number of Ages
12
# Number of Fleets
1
# Number of Sensitivity Blocks
3
# Number of Available Survey Indices
8
# Natural Mortality
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
```

```
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
# Fecundity Option
0
# Fraction of year that elapses prior to SSB calculation (0=Jan-1)
0.42
# Maturity
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
```

```
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
0          0          0.8        1.0        1          1
1          1          1          1          1          1
# Number of Weights at Age Matrices
3
# Weight Matrix - 1
0.147           0.249           0.518           1.219
1.638           1.983           2.3             2.594
2.916           3.267           3.476           4.558
0.143           0.291           0.544           1.168
1.518           1.918           2.311           2.561
2.785           2.984           3.229           4.119
0.143           0.369           0.666           0.964
```

1.364	1.897	2.287	2.612
3.007	3.307	3.95	4.448
0.141	0.377	0.722	0.992
1.353	1.829	2.126	2.41
2.689	3.028	3.329	3.956
0.141	0.342	0.682	0.974
1.444	1.956	2.334	2.621
2.835	3.165	3.367	4.532
0.302	0.494	0.754	1.029
1.463	1.77	1.939	2.079
2.421	2.974	3.273	3.895
0.259	0.432	0.718	1.04
1.464	1.763	1.938	2.141
2.546	3.174	3.608	4.502
0.312	0.502	0.722	0.992
1.313	1.577	1.712	1.918
2.19	3.044	3.312	4.133
0.309	0.308	0.864	1.156
1.461	1.778	2.171	2.334
2.401	3.238	3.409	4.303
0.309	0.303	0.897	1.161
1.553	1.968	2.326	2.449
2.603	3.246	3.428	4.313
0.309	0.29	0.979	1.199
1.478	1.832	2.216	2.431
2.548	3.345	3.537	4.395
0.309	0.212	0.905	1.13
1.318	1.836	2.121	2.391
2.791	3.049	3.906	4.518
0.309	0.263	0.877	1.199
1.365	1.747	2.054	2.396
2.62	2.993	3.452	4.21
0.133	0.312	0.894	1.035
1.069	1.378	1.685	1.987
1.972	2.251	2.256	3.321
0.133	0.237	0.889	0.965
1.19	1.425	1.713	1.843
2.309	2.174	2.244	2.852
0.133	0.312	0.927	1.16
1.244	1.392	1.663	1.753
2.027	2.14	2.179	3.19
0.125	0.631	0.974	1.027
1.196	1.436	1.659	1.852
2.139	2.753	2.758	2.892
0.113	0.284	0.911	1.221
1.522	1.67	1.865	2.003
2.091	2.298	2.452	2.441
0.133	0.312	0.85	1.221
1.392	1.572	1.84	2.081
2.344	2.341	2.468	3.234
0.133	0.341	0.706	1.054
1.128	1.5	1.773	1.784
2.018	2.237	2.282	2.443
0.133	0.312	0.467	0.981

```
1.35            1.499           1.656           1.961
2.088           2.325           2.308           3.219
0.133           0.312           1.098           0.918
1.253           1.552           1.788           1.875
2.305           2.305           2.996           3.193
0.133           0.631           0.653           1.195
1.494           1.752           1.889           2.152
2.469           2.486           2.586           3.225
0.138           0.237           0.237           1.341
1.318           1.752           1.89            2.151
2.601           2.719           2.9             3.312
0.133           0.19            0.758           0.973
1.248           1.403           1.67            1.84
1.965           2.166           2.504           3.143
0.133           0.117           1.297           1.085
1.294           1.442           1.865           1.931
2.071           2.156           2.199           2.521
0.133           0.113           0.82            1.154
1.165           1.459           1.515           1.702
2.022           2.365           2.16            2.66
0.133           0.574           0.692           1.022
1.269           1.408           1.501           1.714
1.78            2.096           2.178           2.409
0.156           0.156           0.91            1.145
1.53            1.693           1.768           1.888
1.988           2.102           2.335           3.235
0.133           0.336           1.012           1.262
1.365           1.531           1.535           1.741
1.712           1.992           2.513           3.766
0.133           0.202           1.205           1.265
1.359           1.65            1.82            1.907
2.279           2.564           2.935           3.158
0.133           0.202           1.205           1.265
1.359           1.65            1.82            1.907
2.279           2.564           2.935           3.158
# Weight Matrix - 2
0.147           0.249           0.518           1.219
1.638           1.983           2.3             2.594
2.916           3.267           3.476           4.558
0.147           0.291           0.544           1.168
1.518           1.918           2.311           2.561
2.785           2.984           3.229           4.119
0.147           0.369           0.666           0.964
1.364           1.897           2.287           2.612
3.007           3.307           3.95            4.448
0.147           0.377           0.722           0.992
1.353           1.829           2.126           2.41
2.689           3.028           3.329           3.956
0.147           0.342           0.682           0.974
1.444           1.956           2.334           2.621
2.835           3.165           3.367           4.532
0.147           0.494           0.754           1.029
1.463           1.77            1.939           2.079
2.421           2.974           3.273           3.895
```

0.147	0.432	0.718	1.04
1.464	1.763	1.938	2.141
2.546	3.174	3.608	4.502
0.147	0.502	0.722	0.992
1.313	1.577	1.712	1.918
2.19	3.044	3.312	4.133
0.147	0.308	0.864	1.156
1.461	1.778	2.171	2.334
2.401	3.238	3.409	4.303
0.147	0.303	0.897	1.161
1.553	1.968	2.326	2.449
2.603	3.246	3.428	4.313
0.147	0.29	0.979	1.199
1.478	1.832	2.216	2.431
2.548	3.345	3.537	4.395
0.147	0.212	0.905	1.13
1.318	1.836	2.121	2.391
2.791	3.049	3.906	4.518
0.147	0.263	0.877	1.199
1.365	1.747	2.054	2.396
2.62	2.993	3.452	4.21
0.147	0.263	1.1552	1.35
1.487	1.897	2.122	2.41
2.792	3.068	3.508	4.192
0.147	0.646	1.337	1.526
1.813	2.077	2.207	2.596
2.826	3.501	3.544	4.357
0.147	0.898	1.371	1.516
1.725	1.945	2.018	2.425
2.67	3.323	3.341	4.325
0.147	0.544	1.398	1.612
1.891	2.119	2.041	2.387
2.58	3.249	3.302	4.285
0.147	0.59	0.881	0.947
1.214	1.383	1.667	1.889
2.038	2.182	2.252	2.547
0.147	0.877	1.014	1.001
1.215	1.339	1.724	1.903
2.009	2.374	2.258	3.466
0.147	0.373	0.771	1.089
1.331	1.445	1.629	1.932
2.114	2.262	2.316	2.943
0.147	0.364	0.686	1.002
1.232	1.357	1.599	1.861
2.174	2.408	2.45	3.4
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316

```
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
# Weight Matrix - 3
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
```

2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049
2.307	2.535	2.733	3.349
0.067	0.236	0.49	0.796
1.124	1.451	1.763	2.049

```
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
0.067           0.236           0.49            0.796
1.124           1.451           1.763           2.049
2.307           2.535           2.733           3.349
# Weights at Age Pointers
1
1
1
1
3
3
# Selectivity Block Assignment
# Fleet 1 Selectivity Block Assignment
1
1
1
1
1
1
1
1
1
1
1
1
1
1
1
2
2
2
2
2
2
2
2
2
2
3
3
3
3
3
3
3
```

```
# Selectivity Options for each block 1=by age, 2=logisitic, 3
=double logistic
2  2  2
# Selectivity Block #1 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               3               0               0
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #2 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               3               0               0
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #3 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
5               3               0               0
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Fleet Start Age
1
# Fleet End Age
12
# Age Range for Average F
8  12
# Average F report option (1=unweighted, 2=Nweighted, 3
=Bweighted)
2
# Use Likelihood constants? (1=yes)
1
# Release Mortality by Fleet
0.025
# Catch Data
# Fleet-1 Catch Data
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
2174.64
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1430.89
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1690.14
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
724.78
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
5167.35
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1909.43
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1908.62
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1399.65
-999            -999            -999            -999
```

```
-999            -999            -999            -999
-999            -999            -999            -999
940.57
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1473.51
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1866.94
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
965.19
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
612.36
0.090723214     0.343875        5.515971439     28.3175603
44.9553527      56.4360455      56.29293502     46.96618972
24.79221977     13.72654087     4.017941246     6.702241702
505.82
0.074830357     2.508342852     3.229647906     16.29756577
38.6129811      39.60875345     39.8299646      34.73515161
32.38742259     17.55561512     3.964060914     12.16916808
471.37
0               0.155242424     4.916811391     21.04042095
27.17986562     26.77273517     24.46138439     28.18005247
13.77740648     8.034430216     3.92126586      14.64114302
311.53
0.134580357     0.605042987     2.337609392     19.75344541
38.47092874     41.35106136     28.67737226     24.5921362
7.81467946      9.127576121     2.729793898     4.155529289
353.01
0.101232143     1.49775         1.560220379     6.699950943
12.82631978     27.50637501     34.74865393     48.44380059
26.2312517      18.53543941     5.580279217     8.06044155
352.11
0               0.491352973     1.095762387     2.900157268
5.712056063     12.53319908     26.89293818     29.94104223
17.0250782      21.3535555      8.532573966     39.87507489
391.48
0.013660714     0.610362119     1.743668103     4.286395374
5.650236865     12.81054855     21.1501448      28.30048119
38.21421882     34.00380999     22.58653857     42.77360444
410.6
0               0.06161         2.423846838     11.68508853
38.68805544     63.25762996     59.88346289     66.05092526
31.20746713     22.62780001     9.144186425     15.93886739
682.75
0               0.1758          0.871735956     23.05129558
70.68319287     96.27955267     73.8444275      46.46521004
35.51142601     17.37692369     11.47931016     14.41304238
```

```
689.77
0.182           14.905          31.404          33.025
118.961         344.286         348.908         233.512
202.789         227.278         123.189         272.668
467
0.957           8.625           50.908          59.989
221.228         634.741         754.949         427.995
235.037         177.059         131.254         402.355
691.99
0               15.48           33.507          180.807
465.886         888.77          757.523         717.649
387.208         271.79          178.009         295.912
799.14
0               31.543          93.343          156.699
442.96          871.816         1132.407        1188.54
797.539         683.291         391.425         638.547
1193.84
4.03            5.524           40.085          181.746
356.561         564.242         525.223         375.937
408.575         297.349         191.201         498.837
669.88
0.133           42.03           110.09          253.883
341.53          360.459         411.7           366.476
239.139         87.987          62.092          72.139
382.75
0               25.85           145.683         268.881
452.338         756.49          783.581         523.348
319.106         183.525         193.493         344.591
748.71
3.303           14.229          42.15           109.674
158.641         248.268         179.242         123.222
104.312         60.136          13.687          29.567
196.87
0               2.21            4.82            9.7
41.9            30.65           52.62           42.66
54.73           46.43           47.72           38.03
802.15
0               0.87            4.75            10.17
59.26           62.75           74.46           56.38
47.54           15.95           13.99           7.38
627.29
# Discards
# Fleet-1 Discards Data
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
0          0          0          0
0          0          0          0
0
0          0          0          0
```

```
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
0
0                 0                 0                 0
0                 0                 0                 0
0                 0                 0                 0
```

```
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
# Release Proportion
# Fleet-1 Release Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Survey Index Data
```

```
# Aggregate Index Units
2  2  2  2  2  2  2  2
# Age Proportion Index Units
2  2  2  2  2  2  2  2
# Weight at Age Matrix
3  3  3  3  3  3  3  3
# Index Month
5  9  5  5  5  5  6  6
# Index Selectivity Link to Fleet
-1  -1  -1  -1  -1  -1  -1  -1
# Index Selectivity Options 1=by age, 2=logisitic, 3=double
logistic
2  2  1  2  1  1  2  2
# Index Start Age
1  1  1  1  1  1  1  1
# Index End Age
12  12  1  12  1  1  12  12
# Estimate Proportion (Yes=1)
1  1  0  1  0  0  0  1
# Use Index (Yes=1)
1  1  1  1  0  0  0  1
# Index-1 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               3               0               0
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-2 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               3               0               0
```

```
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-3 Selectivity Data
1               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-4 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               3               0               0
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-5 Selectivity Data
1               -1              0               1
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
```

```
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-6 Selectivity Data
1               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-7 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               3               0               0
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-8 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               3               0               0
0.6             3               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-1 Data
1982  0.811           0.69            0.139           0.0888
0.1972          0.4152          0.502           0.8566
0.971           0.8253          0.7492          0.6518
0.4036          0.9287          14
1983  0.447           0.69            0.0354          0.1942
0.234           0.3118          0.4437          0.5172
0.6555          0.5957          0.5747          0.5219
0.3023          0.7622          14
1984  0.972           0.66            0.0921          0.1533
0.4127          1.1074          1.6842          2.0778
1.7991          1.3029          1.1779          0.9851
0.5629          1.4763          14
1985  0.716           0.66            0.0342          0.0663
0.1051          0.218           0.4845          0.8902
1.1289          1.0115          0.864           0.7232
0.448           0.9691          14
1986  2.337           0.63            0.0809          0.046
0.0663          0.2567          0.8403          1.5286
1.7289          1.4221          1.3422          1.1543
0.7443          3.0189          14
1987  0.854           0.68            0.0319          0.0064
0.0353          0.0838          0.2405          0.5086
0.5731          0.5748          0.4791          0.3279
0.2378          0.8495          14
1988  0.625           0.69            0.0045          0.0133
0.0388          0.0897          0.1514          0.3014
0.4408          0.5195          0.5087          0.3754
0.278           1.0322          14
1989  1.982           0.71            0.0316          0.0857
0.0325          0.1408          0.2823          0.4479
0.4628          0.4734          0.3579          0.2745
0.2006          0.7343          14
1990  0.234           0.74            0               0.0219
0.0278          0.0623          0.1138          0.1076
0.0774          0.0934          0.0731          0.0714
0.0779          0.3369          14
1991  0.101           0.79            0.0244          0.024
0.0751          0.1557          0.2057          0.251
0.2361          0.2544          0.1853          0.1626
0.1359          0.4785          14
1992  0.55            0.78            0.0391          0.0736
0.0728          0.0658          0.0545          0.0728
```

```
0.0842          0.091           0.077           0.0947
0.0735          0.3035          14
1993  0.11            0.79            0               0
0.0126          0.0314          0.0421          0.0815
0.0962          0.1054          0.0948          0.0643
0.0617          0.2795          14
1994  0.4             0.78            0               0.0116
0.0405          0.219           0.178           0.1705
0.1676          0.1013          0.0699          0.0619
0.0347          0.2034          14
1995  0.058           0.89            0               0
0.0014          0.0163          0.0383          0.0772
0.0529          0.0422          0.0186          0.0275
0.0076          0.1125          14
1996  0.19            0.74            0               0.0798
0.0676          0.1757          0.3187          0.3023
0.225           0.2124          0.1709          0.1269
0.0402          0.1172          14
1997  0.209           0.74            0               0.0383
0.1325          0.2606          0.2787          0.2443
0.2009          0.1532          0.1007          0.0902
0.0388          0.1256          14
1998  0.162           0.79            0               0.0286
0.0169          0.1028          0.17            0.1871
0.1519          0.1415          0.0763          0.0544
0.0532          0.0866          14
1999  0.041           0.81            0.046           0.057
0.06            0.1204          0.2643          0.2238
0.1613          0.1891          0.1334          0.1191
0.045           0.1632          14
2000  0.021           0.94            0               0.0081
0.0265          0.0047          0.0179          0.0267
0.0346          0.0281          0.0162          0.012
0.0085          0.0365          14
2001  0.172           0.74            0.02            0.0881
0.0843          0.1026          0.1353          0.1307
0.1703          0.1734          0.1829          0.1404
0.104           0.2764          14
2002  0.176           0.71            0               0.0718
0.0641          0.0898          0.1348          0.2071
0.178           0.1924          0.1179          0.0824
0.0519          0.1194          0
2003  0.132           0.81            0.0385          0
0.0132          0.2182          0.2018          0.1963
0.1118          0.0836          0.0815          0.0477
0.0392          0.0807          20
2004  0.048           0.85            0               0.1477
0.0552          0.0356          0.0386          0.0667
0.0596          0.0403          0.0326          0.0274
0.0114          0.0692          20
2005  0.298           0.74            0               0.1444
0.0515          0.1524          0.4465          0.5458
0.4903          0.3927          0.2246          0.1116
0.0819          0.1208          20
```

```
2006  0.302           0.69            0               0.149
0.0445          0.14            0.1813          0.176
0.2152          0.2087          0.1207          0.0971
0.0711          0.0862          20
2007  0.15            0.74            0               0.1072
0.1575          0.1835          0.1698          0.235
0.1877          0.2004          0.1792          0.1329
0.0717          0.1659          20
2008  0.212           0.73            0               0.0769
0.1716          0.4914          0.5026          0.3535
0.3099          0.1599          0.139           0.0882
0.0859          0.1857          20
2009  0.284           0.7             0.0562          0.3977
0.287           0.2065          0.1614          0.1242
0.125           0.0643          0.0439          0.0433
0.0229          0.0838          20
2010  0.025           0.99            0               0.0128
0.3216          0.1769          0.1685          0.2162
0.2096          0.1213          0.0595          0.0376
0.0329          0.0714          20
2011  0.146           0.73            0               0.0756
0.1768          0.1028          0.1301          0.1804
0.0989          0.0729          0.0662          0.058
0.0819          0.1096          20
2012  0.098           0.74            0               0.3528
0.1141          0.2757          0.5181          0.1933
0.2344          0.1776          0.2101          0.0867
0.078           0.0788          20
2013  0.046           0.82            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-2 Data
1982  0.275           0.66            7.2             4.08
2.2             2.54            1.46            1.15
0.85            0.41            0.33            0.34
0.23            0.22            4
1983  0.83            0.59            3.2             5.96
6.39            6.61            6.12            7.59
5.35            3.62            3.48            2.78
1.87            4.02            4
1984  1.675           0.58            9.6             30.52
33.72           29.59           24.79           19.39
13.09           7.72            5.17            2.24
1.13            2.03            4
1985  0.884           0.64            3.2             7.14
12.34           11.8            11.43           12.21
10.01           6.19            4.34            2.73
1.47            1.14            4
1986  2.7             0.65            6.4             8.07
11.06           23.01           26.36           19.98
11.44           5.89            5.77            4.53
2.22            3.28            4
1987  1.172           0.8             16.27           22.09
```

```
12.93           16.13           5.71            9.06
11.4            9.93            8.19            4
1.85            4.45            4
1988  0.055           1.19            3.55            3.26
1.78            1.43            0.4             0.96
1.03            0.76            0.53            0.11
0.17            0.02            4
1989  0.465           0.9             12.31           8.95
6.77            3.77            0.24            0.49
0.5             0.55            0.45            0.35
0.26            0.37            4
1990  0.263           0.89            6               10.5
4.17            1.63            0.47            0.38
0.34            0.29            0.12            0.09
0.28            0.75            4
1991  0.192           0.9             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1992  0.133           1.01            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1993  0.043           1.14            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1994  0.099           1.05            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1995  0.103           0.94            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1996  0.589           0.89            1.49            8.04
2.75            3.51            1.98            1.19
1.12            0.98            0.47            0.32
0.09            0.06            4
1997  0.041           1.21            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1998  0.071           1.04            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1999  0.121           0.88            2.53            5.22
2.19            0.33            0.27            0.89
0.8             0.37            0.28            0.06
0.04            0.02            4
2000  0.537           0.76            4.35            10.69
5.91            2.34            3.05            3.81
3.56            2.43            1.69            0.99
```

```
0.43            0.76            4
2001  0.15            0.87            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2002  0.432           0.76            0               1
0.27            2.03            3.68            2.84
2.27            1.35            0.37            0.36
0.32            0.51            4
2003  0.235           0.83            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2004  0.532           0.82            4               0
0.07            0.85            2.63            2.66
1.97            1.62            0.95            0.42
0.07            0.77            4
2005  0.146           0.88            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2006  0.02            1.78            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2007  0.039           1.18            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2008  0.233           0.79            0.02            3
0.08            0.83            2.03            2.2
2.22            2.57            1.52            1.44
1.25            2.85            4
2009  0.142           0.84            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2010  0.167           0.85            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2011  0.2             0.82            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2012  0.086           0.9             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
2013  0.204           0.8             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-3 Data
```

```
1982  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1983  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1984  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1985  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1986  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1987  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1988  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1989  9.08            0.76            0               0
0               0               0               0
0               0               0               0
0               0               0
1990  14.96           0.83            0               0
0               0               0               0
0               0               0               0
0               0               0
1991  6.07            0.83            0               0
0               0               0               0
0               0               0               0
0               0               0
1992  7.96            0.73            0               0
0               0               0               0
0               0               0               0
0               0               0
1993  9.7             0.74            0               0
0               0               0               0
0               0               0               0
0               0               0
1994  3.76            0.76            0               0
0               0               0               0
0               0               0               0
0               0               0
1995  1.06            0.81            0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
1996  0.95            0.8             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  7.54            0.75            0               0
0               0               0               0
0               0               0               0
0               0               0
1998  2.92            0.75            0               0
0               0               0               0
0               0               0               0
0               0               0
1999  5.09            0.74            0               0
0               0               0               0
0               0               0               0
0               0               0
2000  5.97            0.72            0               0
0               0               0               0
0               0               0               0
0               0               0
2001  16.56           0.7             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  9.54            0.72            0               0
0               0               0               0
0               0               0               0
0               0               0
2003  10.66           0.69            0               0
0               0               0               0
0               0               0               0
0               0               0
2004  17.95           0.72            0               0
0               0               0               0
0               0               0               0
0               0               0
2005  8.33            0.7             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  15.09           0.75            0               0
0               0               0               0
0               0               0               0
0               0               0
2007  2.93            0.77            0               0
0               0               0               0
0               0               0               0
0               0               0
2008  9.6             0.69            0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
2009  2.63            0.74            0               0
0               0               0               0
0               0               0               0
0               0               0
2010  2.59            0.77            0               0
0               0               0               0
0               0               0               0
0               0               0
2011  2.88            0.82            0               0
0               0               0               0
0               0               0               0
0               0               0
2012  1.5             0.9             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  4.63            0.81            0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-4 Data
1982  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1983  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1984  4.389           0.32            0.0109          0.0816
0.1898          0.303           0.459           0.4955
0.2892          0.2851          0.3105          0.3532
0.1261          0.5654          28
1985  3.689           0.31            0               0.0189
0.0938          0.1922          0.1667          0.1279
0.1836          0.3005          0.2021          0.0902
0.1595          0.2614          28
1986  2.478           0.29            0.0015          0.0273
0.0933          0.0495          0.1037          0.2019
0.2409          0.2452          0.2864          0.1017
0.1423          0.2263          28
1987  2.317           0.29            0.0242          0.0799
0.0592          0.0602          0.1003          0.1341
0.1908          0.1349          0.0957          0.0523
0.0607          0.2206          28
1988  1.87            0.3             0.0031          0.0327
0.0466          0.0721          0.0447          0.0401
0.0755          0.1008          0.1641          0.079
0.0469          0.195           28
1989  2.403           0.29            0               0.0425
0.0683          0.137           0.0893          0.1154
0.1495          0.16            0.1046          0.0817
0.0569          0.2537          28
1990  1.988           0.3             0.0113          0.084
```

```
0.1546          0.1122          0.1142          0.0493
0.05            0.1247          0.0875          0.0622
0.0979          0.2136          28
1991  2.314           0.33            0.0057          0.0235
0.0582          0.1189          0.1241          0.1487
0.0931          0.1253          0.1071          0.1067
0.061           0.1745          28
1992  1.441           0.36            0.0197          0.049
0.0709          0.0412          0.0491          0.1229
0.1323          0.0849          0.0632          0.0636
0.0599          0.2687          28
1993  0.729           0.36            0.0034          0.0211
0.0505          0.0313          0.0166          0.0605
0.0595          0.0423          0.0489          0.0522
0.0368          0.1463          28
1994  1.329           0.34            0.0093          0.0362
0.0322          0.0684          0.0558          0.0551
0.0555          0.0799          0.0516          0.0312
0.0234          0.0853          28
1995  0.383           0.39            0.0034          0.009
0.0092          0.0297          0.0602          0.0269
0.0212          0.0346          0.015           0.0219
0.0036          0.0181          28
1996  1.072           0.35            0.0073          0.0518
0.0305          0.0086          0.0762          0.0452
0.0654          0.0712          0.0667          0.0608
0.023           0.056           28
1997  0.692           0.36            0               0.039
0.0675          0.0568          0.0574          0.0639
0.0491          0.0556          0.0486          0.0101
0.0072          0.0527          28
1998  1.158           0.35            0               0.0425
0.0281          0.0701          0.0821          0.0876
0.0875          0.0848          0.0465          0.0575
0.0192          0.0383          28
1999  1.359           0.34            0.0498          0.0792
0.0583          0.0666          0.1015          0.1379
0.0748          0.0843          0.0431          0.0203
0.0191          0.0265          28
2000  1.381           0.34            0.0012          0.0466
0.0578          0.0829          0.074           0.1402
0.1376          0.0897          0.0392          0.0467
0.0213          0.0632          28
2001  1.332           0.34            0.0062          0.0303
0.0864          0.083           0.1294          0.1197
0.1193          0.1058          0.0715          0.0454
0.0407          0.0569          28
2002  2.458           0.33            0.0101          0.0247
0.0585          0.1012          0.1748          0.1972
0.1895          0.2091          0.0739          0.0419
0.0257          0.06            28
2003  1.098           0.34            0.0033          0.0124
0.0083          0.0598          0.1485          0.2385
0.1596          0.0893          0.0778          0.0185
```

```
0.0274          0.0544          28
2004  0.982           0.35            0.0075          0.0205
0.015           0.0361          0.071           0.193
0.1096          0.0494          0.0812          0.044
0.0204          0.0457          28
2005  1.023           0.35            0.01            0.0367
0.0618          0.0261          0.0922          0.1437
0.1576          0.1064          0.0303          0.0268
0.0347          0.0333          28
2006  1.123           0.4             0               0.0334
0.0345          0.1039          0.1274          0.114
0.1196          0.1521          0.062           0.0479
0.0183          0.0274          28
2007  0.916           0.35            0.0038          0.0126
0.0167          0.046           0.0478          0.0608
0.0919          0.0936          0.0966          0.0532
0.0294          0.0612          28
2008  0.96            0.38            0.0066          0.0279
0.0428          0.062           0.0848          0.1164
0.0708          0.0649          0.0831          0.064
0.0322          0.0714          28
2009  0.714           0.36            0.015           0.0355
0.0074          0.0026          0.0394          0.0681
0.1013          0.0658          0.0319          0.0324
0.0343          0.0485          28
2010  0.483           0.53            0               0.0053
0.0455          0.0093          0.0053          0.0315
0.0503          0.0294          0.0096          0.0093
0.0192          0.0325          28
2011  0.496           0.4             0.018           0.0401
0.0532          0.0303          0.0301          0.0612
0.063           0.0415          0.0267          0.0167
0.0167          0.0481          28
2012  0.647           0.37            0.027           0.1148
0.0919          0.0808          0.0635          0.0389
0.0397          0.0461          0.0502          0.0115
0               0.0166          28
2013  0.891           0.35            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-5 Data
1982  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1983  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1984  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
1985  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1986  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1987  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1988  0.185           0.9             0               0
0               0               0               0
0               0               0               0
0               0               0
1989  0.174           0.88            0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.878           0.81            0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.708           0.82            0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.421           0.83            0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.507           0.84            0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.286           0.85            0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.131           0.9             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.197           0.89            0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.476           0.84            0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.224           0.89            0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
1999  0.479           0.85            0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.242           0.87            0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.682           0.83            0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.67            0.83            0               0
0               0               0               0
0               0               0               0
0               0               0
2003  1.097           0.83            0               0
0               0               0               0
0               0               0               0
0               0               0
2004  1.156           0.82            0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.431           0.85            0               0
0               0               0               0
0               0               0               0
0               0               0
2006  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.436           0.91            0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.605           0.83            0               0
0               0               0               0
0               0               0               0
0               0               0
2009  1.59            0.91            0               0
0               0               0               0
0               0               0               0
0               0               0
2010  1.479           0.81            0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.467           0.95            0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
2012  0.098           0.96            0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0.429           0.85            0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-6 Data
1982  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1983  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1984  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1985  0.74            0.559           0               0
0               0               0               0
0               0               0               0
0               0               0
1986  0.03            0.022           0               0
0               0               0               0
0               0               0               0
0               0               0
1987  0.26            0.224           0               0
0               0               0               0
0               0               0               0
0               0               0
1988  0.1             0.086           0               0
0               0               0               0
0               0               0               0
0               0               0
1989  1.06            0.935           0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.81            0.592           0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.32            0.283           0               0
0               0               0               0
0               0               0               0
0               0               0
1992  2.01            1.756           0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.76            0.638           0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
1994  0.02            0.015           0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.06            0.047           0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.22            0.181           0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.1             0.091           0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.17            0.153           0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.11            0.096           0               0
0               0               0               0
0               0               0               0
0               0               0
2000  1.14            0.938           0               0
0               0               0               0
0               0               0               0
0               0               0
2001  1.26            1.061           0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.3             0.249           0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.47            0.401           0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.56            0.497           0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.32            0.272           0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.87            0.721           0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
2007  0.44            0.364           0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.29            0.247           0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.08            0.072           0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.02            0.015           0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.01            0.006           0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.16            0.133           0               0
0               0               0               0
0               0               0               0
0               0               0
2013  -999            0.727           0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-7 Data
1982  -999            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1983  -999            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1984  -999            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1985  -999            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1986  -999            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1987  -999            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
1988  3.76            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1989  1.2             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1990  1.48            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.99            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  1.47            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.64            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.35            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.54            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.22            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.31            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.57            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.32            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.28            0.3             0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
2002  1.45            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.62            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.34            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.53            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.66            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.36            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.84            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.49            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.43            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.14            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.25            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0.445           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-8 Data
1982  0.726           0.63            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
```

```
-999            -999            0
1983  1.707           0.53            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1984  1.453           0.59            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1985  0.771           0.55            0.0726          0.0306
0.0397          0.148           0.1439          0.1355
0.1366          0.0949          0.0638          0.046
0.026           0.0624          26
1986  2.203           0.45            0               0.013
0.0519          0.1242          0.1325          0.1077
0.109           0.1005          0.0953          0.068
0.0418          0.1562          26
1987  1.003           0.56            0.0158          0.0194
0.0555          0.1105          0.14            0.1716
0.1395          0.1036          0.0745          0.0373
0.0269          0.1055          26
1988  1.577           0.47            0.0288          0.0225
0.0573          0.1248          0.1247          0.1489
0.1367          0.1012          0.0731          0.0394
0.0336          0.109           26
1989  1.62            0.41            0.0079          0.0173
0.0397          0.1159          0.1336          0.1452
0.123           0.1065          0.0923          0.0587
0.0397          0.1203          26
1990  0.94            0.41            0               0
0.0783          0.18            0.1923          0.1183
0.102           0.1207          0.0542          0.0172
0.0405          0.0967          26
1991  1.078           0.39            0               0.0164
0.0538          0.1952          0.2049          0.1352
0.0844          0.0967          0.0686          0.0586
0.0235          0.0627          26
1992  1.572           0.4             0               0.0004
0.0248          0.1007          0.1911          0.2197
0.1278          0.0806          0.0512          0.0389
0.0272          0.1377          26
1993  1.279           0.42            0               0.0217
0.0811          0.2743          0.1134          0.1922
0.1099          0.0394          0.0373          0.047
0.0192          0.0646          26
1994  0.996           0.43            0               0
0.0405          0.3136          0.1654          0.0866
0.12            0.1284          0.0786          0.0218
0.0144          0.0307          26
1995  0.7             0.46            0               0
0.0909          0.169           0.3151          0.1278
0.0985          0.0868          0.0623          0.0318
0.0077          0.0102          26
1996  0.861           0.45            0               0.0356
```

```
0.0547          0.1235          0.3193          0.1355
0.1093          0.0883          0.0675          0.0365
0.0107          0.019           26
1997  0.454           0.45            0               0
0.0953          0.2062          0.1733          0.1427
0.0813          0.1164          0.0318          0.0412
0.0109          0.1009          26
1998  0.388           0.46            0.0031          0.0231
0.0614          0.3064          0.2935          0.1282
0.0901          0.0512          0.0158          0.0152
0.0056          0.0065          26
1999  0.339           0.47            0.0103          0.0719
0.0567          0.3602          0.0809          0.1308
0.0904          0.0853          0.0581          0.0321
0.0094          0.0139          26
2000  0.244           0.48            0               0
0.0369          0.2071          0.1818          0.1407
0.1228          0.0895          0.0492          0.0547
0.022           0.0953          26
2001  0.276           0.42            0               0.0789
0.1533          0.1498          0.1144          0.1256
0.0706          0.0686          0.0688          0.0601
0.0397          0.0701          26
2002  0.355           0.43            0               0
0.0175          0.0966          0.2019          0.2461
0.1605          0.1357          0.048           0.0402
0.0142          0.0393          26
2003  0.539           0.41            0               0
0.0103          0.248           0.3346          0.194
0.0888          0.0556          0.0311          0.0154
0.01            0.0121          26
2004  0.352           0.42            0               0.0444
0.1558          0.1532          0.1819          0.1797
0.0901          0.0455          0.0383          0.0406
0.0237          0.0468          26
2005  0.55            0.45            0.0036          0.0349
0.1892          0.1386          0.1992          0.1517
0.1161          0.0664          0.0255          0.0186
0.0138          0.0423          26
2006  0.551           0.46            0               0.0103
0.0217          0.208           0.2343          0.1905
0.1192          0.0792          0.0454          0.0359
0.0184          0.0373          26
2007  0.42            0.44            0               0.0055
0.0906          0.1276          0.1986          0.175
0.1128          0.1049          0.0695          0.051
0.027           0.0375          26
2008  0.378           0.44            0.0004          0.0024
0.074           0.2729          0.1612          0.1252
0.1208          0.0721          0.0579          0.0357
0.0215          0.056           26
2009  0.844           0.47            0               0.0347
0.0966          0.1794          0.2231          0.184
0.1359          0.0713          0.0408          0.0138
```

```
0.0097          0.0106          26
2010  0.462           0.46            0               0.0259
0.2419          0.1551          0.1204          0.1407
0.1295          0.0706          0.0338          0.0208
0.023           0.0383          26
2011  0.624           0.51            0               0.0439
0.1972          0.2095          0.1866          0.1768
0.0861          0.0515          0.0233          0.0106
0.0022          0.0123          26
2012  0.486           0.51            0               0.1044
0.098           0.1362          0.2124          0.0779
0.0967          0.0874          0.0744          0.0417
0.0406          0.0303          26
2013  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Phase Control
# Phase for F mult in 1st Year
1
# Phase for F mult Deviations
2
# Phase for Recruitment Deviations
4
# Phase for N in 1st Year
1
# Phase for Catchability in 1st Year
2
# Phase for Catchability Deviations
-1
# Phase for Stock Recruitment Relationship
5
# Phase for Steepness
5
# Recruitment CV by Year
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
```

```
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
# Lambdas by Index
1  1  1  1  1  1  1  1
# Lambda for Total Catch in Weight by Fleet
1
# Lambda for Total Discards at Age by Fleet
1
# Catch Total CV by Year and Fleet
0.2
0.18
0.21
0.21
0.18
0.22
0.24
0.15
0.14
0.15
0.18
0.13
0.19
0.23
0.21
0.19
0.32
0.31
0.27
0.26
0.25
0.15
0.49
0.3
0.24
0.21
0.19
0.17
0.23
0.26
0.23
0.25
# Discard Total CV by Year and Fleet
0
```

```
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Catch Effective Sample Size by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
38
44
33
33
38
24
34
35
77
```

```
69
61
45
40
33
28
41
23
33
40
# Discard Effective Sample Size by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Lambda for F Mult in First year by Fleet
0
# CV for F Mult in First year by Fleet
0.5
# Lambda for F Mult Deviations by Fleet
0.5
# CV for F Mult Deviations by Fleet
0.5
# Lambda for N in 1st Year Deviations
0
# CV for N in 1st Year Deviations
```

```
0.85
# Lambda for Recruitment Deviations
0.5
# Lambda for Catchability in First year by Index
0  0  0  0  0  0  0  0
# CV for Catchability in First year by Index
1  1  1  1  1  1  1  1
# Lambda for Catchability Deviations by Index
0  0  0  0  0  0  0  0
# CV for Catchability Deviations by Index
1  1  1  1  1  1  1  1
# Lambda for Deviation from Initial Steepness
0
# CV for Deviation from Initial Steepness
0.5
# Lambda for Deviation from Unexploited Stock Size
0
# CV for Deviation from Unexploited Stock Size
0.5
# NAA Deviations Flag
1
# Initial Numbers at Age in 1st Year
5588  3873  2269  1983  1203  728  746  431  242  136  77  99
# Initial F Mult in 1st Year by Fleet
1.0
# Initial Catchabilty by Index
0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
# Stock Recruitment Flag
0
# Initial Unexploited Stock
10000
# Initial Steepness
0.7
# Maximum F
5
# Ignore Guesses (Yes=1)
0
# Projection Control
# Do Projections (Yes=1)
0
# Fleet Directed Flag
1
# Final Year in Projection
2014
# Projection Data by Year
2014     -1         3     -99        1
# Do MCMC (Yes=1)
1
# MCMC Year Option
1
# MCMC Iterations
1000
# MCMC Thinning Factor
200
```

```
# MCMC Random Seed
314156
# Agepro R Option
1
# Agepro R Option Start Year
1982
# Agepro R Option End Year
2013
# Export R Flag
0
# Test Value
-23456
######
###### FINIS ######
# Fleet Names
#$Rec + Comm
# Survey Names
#$MA Trawl
#$RI Fall Trawl
#$RI Seine
#$CT Trawl
#$NY Trawl
#$NY Seine
#$NJ Trawl
#$MRIP CPUE
#
```

```
# ASAP VERSION 3.0
# NY-NJ Base Model
#
# ASAP GUI 15 AUG 2012
#
# Number of Years
25
# First Year
1989
# Number of Ages
12
# Number of Fleets
1
# Number of Sensitivity Blocks
3
# Number of Available Survey Indices
8
# Natural Mortality
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
```

```
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
# Fecundity Option
0
# Fraction of year that elapses prior to SSB calculation (0=Jan-
1)
0.42
# Maturity
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
```

```
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
0          0          0.80       1          1          1
1          1          1          1          1          1
# Number of Weights at Age Matrices
3
# Weight Matrix - 1
0.312           0.502           0.722           0.992
1.313           1.577           1.712           1.918
2.19            3.044           3.312           4.133
0.309           0.308           0.864           1.156
1.461           1.778           2.171           2.334
2.401           3.238           3.409           4.303
0.309           0.303           0.897           1.161
1.553           1.968           2.326           2.449
2.603           3.246           3.428           4.313
0.309           0.29            0.979           1.199
1.478           1.832           2.216           2.431
2.548           3.345           3.537           4.395
0.309           0.212           0.905           1.13
1.318           1.836           2.121           2.391
2.791           3.049           3.906           4.518
0.309           0.263           0.877           1.199
1.365           1.747           2.054           2.396
2.62            2.993           3.452           4.21
0.11            0.53            0.71            0.78
0.78            0.9             1.19            1.47
1.67            1.92            2.51            3.28
0.11            0.67            0.82            0.87
0.87            1.05            0.98            1.53
1.42            2.42            2.57            3.12
0.11            0.33            0.73            0.87
0.85            0.99            1.18            1.41
1.72            1.65            1.33            2.66
0.11            0.14            0.95            1.04
1.3             1.46            1.58            1.68
1.73            2.1             2.19            2.41
0.09            0.22            0.89            1.05
1.1             1.25            1.48            1.58
1.77            1.59            4.03            1.86
0.11            0.21            1.01            1.1
1.26            1.4             1.75            1.83
```

```
2.05            2.1             2.43            2.89
0.15            0.25            0.99            1.22
1.26            1.21            1.25            1.54
1.75            1.97            2.23            3
0.11            0.2             0.67            1.06
1.18            1.25            1.52            1.71
1.96            2.1             2.14            3.36
0.11            0.17            0.96            1.02
1.14            1.19            1.48            1.82
2.01            2.89            2.89            3.1
0.11            0.61            0.95            1.09
1.18            1.27            1.38            1.61
1.73            1.78            2.06            3.16
0.11            0.88            0.9             1.22
1.32            1.34            1.64            1.8
1.93            2.01            2.15            3.3
0.11            1.04            1.15            1.24
1.23            1.21            1.35            1.56
1.8             2.21            2.04            3.06
0.11            0.99            1.16            1.24
1.4             1.43            1.46            1.64
1.75            1.87            1.93            2.27
0.11            0.23            1.11            1.09
1.21            1.29            1.32            1.43
1.61            1.77            2.03            2.44
0.11            1.27            1.35            1.32
1.38            1.39            1.53            1.88
2.02            2.14            2.38            3.27
0.11            0.97            1.09            1.17
1.27            1.35            1.35            1.43
1.87            2.05            2.22            2.37
0.11            0.26            1.02            1.14
1.29            1.53            1.7             1.83
1.98            2.35            2.82            3
0.11            0.51            1.18            1.35
1.5             1.64            1.78            1.99
2.31            2.08            2.55            2.76
0.11            0.51            1.18            1.35
1.5             1.64            1.78            1.99
2.31            2.08            2.55            2.76
# Weight Matrix - 2
0.147           0.502           0.722           0.992
1.313           1.577           1.712           1.918
2.19            3.044           3.312           4.133
0.147           0.308           0.864           1.156
1.461           1.778           2.171           2.334
2.401           3.238           3.409           4.303
0.147           0.303           0.897           1.161
1.553           1.968           2.326           2.449
2.603           3.246           3.428           4.313
0.147           0.29            0.979           1.199
1.478           1.832           2.216           2.431
2.548           3.345           3.537           4.395
0.147           0.212           0.905           1.13
```

1.318	1.836	2.121	2.391
2.791	3.049	3.906	4.518
0.147	0.263	0.877	1.199
1.365	1.747	2.054	2.396
2.62	2.993	3.452	4.21
0.147	0.263	1.1552	1.35
1.487	1.897	2.122	2.41
2.792	3.068	3.508	4.192
0.147	0.646	1.337	1.526
1.813	2.077	2.207	2.596
2.826	3.501	3.544	4.357
0.147	0.898	1.371	1.516
1.725	1.945	2.018	2.425
2.67	3.323	3.341	4.325
0.147	0.544	1.398	1.612
1.891	2.119	2.041	2.387
2.58	3.249	3.302	4.285
0.147	0.59	0.881	0.947
1.214	1.383	1.667	1.889
2.038	2.182	2.252	2.547
0.147	0.877	1.014	1.001
1.215	1.339	1.724	1.903
2.009	2.374	2.258	3.466
0.147	0.373	0.771	1.089
1.331	1.445	1.629	1.932
2.114	2.262	2.316	2.943
0.147	0.364	0.686	1.002
1.232	1.357	1.599	1.861
2.174	2.408	2.45	3.4
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.147	0.35	0.781	1.005

```
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
# Weight Matrix - 3
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
```

```
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
# Weights at Age Pointers
1
1
1
1
3
3
# Selectivity Block Assignment
# Fleet 1 Selectivity Block Assignment
1
1
1
1
1
1
1
1
2
2
2
2
2
2
2
```

```
2
2
2
3
3
3
3
3
3
3
# Selectivity Options for each block 1=by age, 2=logisitic, 3
=double logistic
2  2  2
# Selectivity Block #1 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #2 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #3 Data
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Fleet Start Age
1
# Fleet End Age
12
# Age Range for Average F
8  12
# Average F report option (1=unweighted, 2=Nweighted, 3
=Bweighted)
2
# Use Likelihood constants? (1=yes)
1
# Release Mortality by Fleet
0.025
# Catch Data
# Fleet-1 Catch Data
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1210
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1607.1
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
2227.1
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1815.8
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1562.2
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
```

```
528.1
0.37125         0               31.64036519     139.8397605
299.6954378     176.8181056     110.5111928     71.64208973
29.39585201     38.18280588     3.993126471     17.75993443
1053.5
0               8.602412506     61.9076098      132.7223213
193.2352388     116.5498592     61.71724653     29.98767782
12.59224076     7.355607432     6.550999992     6.204996008
695
0               0.736051541     15.15698159     36.17692285
66.61907236     93.44035746     51.81442125     40.78312121
17.16399282     9.061928641     2.911157895     7.738067834
438.3
0               0.791333333     2.31427606      8.543157087
17.52166233     31.15196439     27.92723799     20.53563987
8.536675622     7.963822502     1.812340795     1.426580431
181.7
0               1.659666667     3.3486148       16.22863817
67.45733283     82.95174242     79.6774037      54.49808468
25.16051124     10.77464074     68.80261224     3.168102684
630
0               0.045657895     73.10988702     63.10341249
89.19843423     80.67766758     128.3126666     68.55234142
27.2557479      29.44223085     18.14726487     17.29292729
996.1
0.3735          1.141269231     42.87375739     115.0669524
79.40646808     78.6502424      91.59934469     66.76642837
51.41135617     20.49052009     9.842639232     29.29759375
838.3
0               0.244666667     5.149528106     117.4682367
293.6430838     241.7164914     156.2225639     114.0575858
41.58950783     30.59151881     15.51979822     29.69339099
1605.2
0               0.067           10.12086489     36.01399586
65.99310818     91.22539993     42.84238402     22.61582115
16.27212146     4.185526043     9.01104308      5.283590644
310.9
0               3.443478811     13.06771755     55.86251118
107.8889967     87.97878955     57.00367224     31.44031199
28.6516206      13.04615952     9.214422689     18.33860461
642.6
0               0.11771785      18.08042932     35.54243904
30.0193326      24.61899147     19.28261875     13.31284313
5.964855096     6.533329935     4.068723228     5.702712959
268
0               17.965          53.028          315.642
765.577         1466.423        1060.397        548.853
459.707         214.833         91.725          138.316
763.5
0               37.972          615.664         964.014
861.001         844.657         762.319         664.75
507.391         300.101         154.992         257.638
959.7
2.47            11.801          271.187         954.302
```

```
1191.114        933.903         724.052         547.214
340.217         227.298         228.053         274.001
827
0               35.753          273.915         752.318
1276.396        1084.149        713.126         467.988
304.654         148.621         65.969          210.217
927.4
0               56.897          755.749         1600.268
1520.828        889.437         542.901         360.813
79.498          66.03           60.339          62.339
796.2
2.73            19.577          248.341         754.419
712.148         571.269         319.338         193.046
70.721          67.816          52.888          115.516
452.1
0.405           17.397          164.938         194.15
200.459         206.067         159.589         128.362
120.904         16.681          24.762          53.636
237.6
0               2675.04         37246.86        41633.76
44745.39        35794.32        26726.15        21738.05
14837.39        8048.86         4028.22         12355.09
421
# Discards
# Fleet-1 Discards Data
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
```

```
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
0
0                   0                   0                   0
0                   0                   0                   0
0                   0                   0                   0
```

```
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
# Release Proportion
# Fleet-1 Release Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Survey Index Data
# Aggregate Index Units
2  2  2  2  2  2  2  2
# Age Proportion Index Units
2  2  2  2  2  2  2  2
# Weight at Age Matrix
3  3  3  3  3  3  3  3
# Index Month
5  9  5  5  5  5  6  6
# Index Selectivity Link to Fleet
-1  -1  -1  -1  -1  -1  -1  -1
# Index Selectivity Options 1=by age, 2=logisitic, 3=double logistic
2  2  1  2  1  1  2  2
```

```
# Index Start Age
1  1  1  1  1  1  1  1
# Index End Age
12  12  1  12  1  1  12  12
# Estimate Proportion (Yes=1)
0  0  0  0  0  0  1  1
# Use Index (Yes=1)
0  0  0  0  1  1  1  1
# Index-1 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-2 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-3 Selectivity Data
1               -1              0               1
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
```

```
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-4 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-5 Selectivity Data
1               -1              0               1
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-6 Selectivity Data
1               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
```

```
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-7 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
2               1               0               0
0.6             2               0               0
5               1               0               0
0.6             2               0               0
# Index-8 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-1 Data
1989  1.98            0.3             0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
1990  0.23            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.55            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.11            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.4             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.06            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.19            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.16            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.02            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.17            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.18            0.3             0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
2003  0.13            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.05            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.3             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.3             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.28            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.02            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-2 Data
1989  0.46            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.26            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
1991  0.19            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.13            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.58            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.07            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.12            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.54            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.43            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.23            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.53            0.3             0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
2005  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.02            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.24            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.14            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.17            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.2             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.09            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-3 Data
1989  9.08            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1990  14.96           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  6.07            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  7.96            0.3             0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
1993  9.7             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  3.76            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  1.06            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.95            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  7.54            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  2.92            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  5.09            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  5.97            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  16.56           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  9.54            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  10.66           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  17.95           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  8.33            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  15.09           0.3             0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
2007  2.93            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  9.6             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  2.63            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  2.59            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  2.88            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  1.5             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-4 Data
1989  0.83            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.8             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  1.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.53            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.28            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.34            0.3             0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
1995  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.24            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.33            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.42            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.59            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.55            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.59            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  1.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.44            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.41            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.33            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.43            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.43            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
2008  0.42            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.3             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.32            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-5 Data
1989  0.174           0.63            0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.878           0.58            0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.708           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.421           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.507           0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.286           0.61            0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.131           0.64            0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.197           0.64            0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
1997  0.476           0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.224           0.64            0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.479           0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.242           0.62            0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.682           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.67            0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  1.097           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
2004  1.156           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.431           0.61            0               0
0               0               0               0
0               0               0               0
0               0               0
2006  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.436           0.65            0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.605           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
2009  1.59            0.65            0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
2010  1.479           0.58            0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.467           0.68            0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.098           0.68            0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0.429           0.61            0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-6 Data
1989  0.94            0.93            0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.59            0.9             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.28            1               0               0
0               0               0               0
0               0               0               0
0               0               0
1992  1.76            0.87            0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.64            0.89            0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.02            1.74            0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.05            1.22            0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.18            1.25            0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.09            1.24            0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
1998  0.15            1.14            0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.1             1.12            0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.94            0.91            0               0
0               0               0               0
0               0               0               0
0               0               0
2001  1.06            0.78            0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.25            0.91            0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.4             0.88            0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.5             0.79            0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.27            0.84            0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.72            0.84            0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.36            0.88            0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.25            0.85            0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.07            0.97            0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.01            1.52            0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.01            2.14            0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
2012  0.13            0.92            0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0.73            0.82            0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-7 Data
1989  1.21            0.5             0.0292          0.0648
0.1284          0.2144          0.1295          0.1178
0.0948          0.0737          0.0549          0.0276
0.0169          0.048           20
1990  1.47            0.53            0.002           0.0259
0.1675          0.2212          0.196           0.1202
0.0705          0.0674          0.0391          0.021
0.0222          0.0468          20
1991  0.98            0.52            0.0093          0.0311
0.1614          0.2516          0.2364          0.1279
0.0569          0.0465          0.0332          0.0145
0.0087          0.0224          20
1992  1.48            0.51            0               0.014
0.151           0.2032          0.2164          0.1261
0.0675          0.0653          0.0425          0.0273
0.0219          0.0647          20
1993  0.64            0.52            0.0425          0.0904
0.1696          0.2768          0.1693          0.079
0.0539          0.0356          0.0207          0.0164
0.0108          0.035           20
1994  0.36            0.54            0.0095          0.055
0.1761          0.292           0.1673          0.0974
0.0641          0.0394          0.0239          0.0137
0.0156          0.0459          20
1995  0.54            0.52            0               0
0.0988          0.133           0.3459          0.081
0.0698          0.0573          0.0333          0.0392
0.0063          0.1355          20
1996  0.22            0.55            0               0.1605
0.1291          0.2192          0.2286          0.0698
0.046           0.0295          0.0325          0.0292
0.0104          0.0452          20
1997  0.11            0.59            0               0.0347
0.0745          0.1022          0.0795          0.0595
0.0568          0.0432          0.0218          0.0102
0.0032          0.5143          20
1998  0.32            0.53            0               0.0541
0.1201          0.2086          0.15            0.1324
0.111           0.0738          0.0424          0.0402
0.0245          0.0429          20
1999  0.57            0.52            0.0543          0.087
0.1553          0.1223          0.1739          0.1692
0.1108          0.0699          0.0313          0.0091
```

```
0.0164          0.0005          20
2000  0.33            0.54            0               0.1554
0.143           0.1821          0.1507          0.1055
0.1053          0.0799          0.022           0.0151
0.0181          0.0231          20
2001  0.28            0.55            0.0745          0.0897
0.2163          0.1994          0.2262          0.0754
0.0342          0.0294          0.0094          0.0137
0.002           0.0298          20
2002  1.42            0.5             0.0131          0.0284
0.1333          0.2525          0.2533          0.1238
0.0609          0.0452          0.0235          0.0144
0.0065          0.045           20
2003  0.64            0.52            0               0.0032
0.0174          0.2987          0.2098          0.2151
0.0877          0.0716          0.034           0.0138
0.0205          0.0281          20
2004  0.34            0.54            0               0.1347
0.2629          0.179           0.1823          0.1375
0.0489          0.0191          0.0096          0.0032
0.0013          0.0215          20
2005  0.53            0.54            0.0369          0.1139
0.2073          0.1625          0.1713          0.0877
0.0591          0.0411          0.027           0.0315
0.0253          0.0364          20
2006  0.65            0.52            0               0.1421
0.0327          0.2213          0.1741          0.1275
0.0999          0.0545          0.0555          0.0384
0.0194          0.0347          20
2007  0.36            0.53            0               0.0804
0.1974          0.3798          0.126           0.0604
0.0436          0.0357          0.0274          0.0177
0.0097          0.022           20
2008  0.82            0.51            0.0003          0.0623
0.1498          0.2272          0.1817          0.0989
0.0701          0.0468          0.0346          0.0257
0.0295          0.0731          20
2009  0.48            0.52            0.0052          0.1794
0.1765          0.1609          0.2149          0.0848
0.0597          0.0471          0.0248          0.0103
0.0076          0.0289          20
2010  0.42            0.53            0.0051          0.0961
0.313           0.1701          0.1491          0.0914
0.045           0.0373          0.016           0.0089
0.0217          0.0463          20
2011  0.14            0.59            0.0743          0.1665
0.1952          0.2027          0.2095          0.0898
0.0357          0.0159          0.0054          0.0032
0.0009          0.0009          20
2012  0.25            0.55            0.0234          0.1146
0.4316          0.1926          0.1326          0.0572
0.0324          0.0149          0.0001          0.0006
0               0               20
2013  0.45            0.53            -999            -999
```

```
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-8 Data
1989  1.11            0.38            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1990  1.31            0.34            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1991  1.25            0.31            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1992  1.65            0.34            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1993  0.92            0.38            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1994  0.53            0.48            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1995  0.98            0.53            17511.56282
11674.37522     162113.3398     295310.9443     1101625.199
226869.3927     135411.0189     87859.02377     31317.64969
41272.86621     6200.068909     16333.68418     22
1996  0.61            0.5             7201.645441
88714.20977     101098.9053     389739.1818     341552.8218
149850.1878     72286.77279     36083.19356     14685.37882
9244.729522     8335.558087     11419.71775     22
1997  0.52            0.49            0
25386.99001     105885.7912     161013.1832     189539.9976
181977.1426     109756.1287     55479.76705     21407.61526
11961.8707      6096.952092     7334.486366     22
1998  0.29            0.62            0
66015.47361     52300.42347     200079.4051     162958.554
129965.5551     96229.43749     41645.68205     36431.06457
18899.36857     10305.23819     7781.953738     22
1999  0.52            0.52            17080.80926
212561.1819     67767.90828     343027.0721     341769.6092
321704.9341     175219.283      196477.9183     36005.96717
24017.85069     79644.61282     4354.042919     22
2000  0.48            0.54            0
82308.42563     361408.5098     278543.8379     237399.7127
169195.4944     205250.2477     104375.1059     40693.02839
38674.46258     27616.8119      24196.69832     22
2001  0.67            0.41            14120.63038
47928.67812     253448.1943     424551.0505     312446.4605
```

```
240999.664      185292.931      145869.6821     87279.34198
46403.43699     19304.37221     56275.51687     22
2002  0.92            0.45            0               14717.9246
108762.6376     417818.0766     883836.3998     545860.8187
327143.4758     228823.4386     83915.20212     59531.23589
31966.08696     65153.67583     22
2003  0.28            0.43            0
18430.52502     7544.612417     323966.7356     180503.6275
132476.7608     63581.40582     47399.86921     41561.39772
14235.13618     68731.0315      24034.68088     22
2004  0.5             0.45            0
139061.8736     339400.7668     205680.0088     273097.2667
181901.1718     71448.80941     39025.0274      37567.89483
14558.7273      11026.67158     83084.31787     22
2005  0.31            0.52            950.5994317
14259.98001     135848.9356     104348.1672     125799.5838
46054.09117     32546.31367     28578.51201     11739.43306
9646.598546     6218.958814     12497.12281     22
2006  0.53            0.49            0
117961.9484     217450.301      649033.0753     452251.8111
185080.0451     110656.9363     53518.45605     44601.76984
22142.10143     9307.71211      13173.2167      22
2007  0.59            0.48            0
276201.5962     406672.3783     794209.7299     327525.7691
121921.5421     83322.67992     69163.11764     50991.34661
31373.53602     16455.22974     22563.42098     22
2008  0.59            0.46            249.7922008     191816.41
528693.9963     646056.158      371475.7654     135360.293
89197.94074     54524.83345     33525.52708     21640.33396
21600.89034     26835.41629     22
2009  0.89            0.47            0               205137.18
334901.4724     465120.7179     505587.2714     158124.2613
203043.863      47979.80597     29876.46695     14070.91936
6708.893659     23735.34052     22
2010  0.53            0.5             38821.97345
322793.5717     897021.0008     385995.7275     225510.1152
143785.3473     61002.82884     37052.7623      9269.456842
6946.886364     8981.652621     13604.34463     22
2011  0.51            0.54            48807.13459
161275.7491     451230.5154     438558.8365     287550.998
112909.9007     32417.99295     18249.01137     6930.43865
6093.847646     4695.519514     9885.048649     22
2012  0.45            0.53            4051.007968
84716.00639     364153.5089     243895.141      123079.5303
73714.41528     26936.50885     36105.94066     9977.807182
1360.856526     1900.97186      4245.473914     22
2013  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Phase Control
# Phase for F mult in 1st Year
1
# Phase for F mult Deviations
```

```
2
# Phase for Recruitment Deviations
2
# Phase for N in 1st Year
2
# Phase for Catchability in 1st Year
3
# Phase for Catchability Deviations
-1
# Phase for Stock Recruitment Relationship
3
# Phase for Steepness
3
# Recruitment CV by Year
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
# Lambdas by Index
1  1  1  1  1  1  1  1
# Lambda for Total Catch in Weight by Fleet
1
# Lambda for Total Discards at Age by Fleet
1
# Catch Total CV by Year and Fleet
0.13
0.12
0.1
0.15
0.18
0.23
0.22
0.33
```

```
0.26
0.34
0.26
0.32
0.17
0.26
0.24
0.34
0.21
0.25
0.19
0.15
0.18
0.32
0.24
0.25
0.25
# Discard Total CV by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Catch Effective Sample Size by Year and Fleet
0
0
0
0
0
0
51
58
52
19
```

```
52
51
83
118
76
69
62
107
114
150
134
98
77
62
35
# Discard Effective Sample Size by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Lambda for F Mult in First year by Fleet
0
# CV for F Mult in First year by Fleet
0.5
# Lambda for F Mult Deviations by Fleet
0.5
# CV for F Mult Deviations by Fleet
0.5
# Lambda for N in 1st Year Deviations
0
# CV for N in 1st Year Deviations
0.5
# Lambda for Recruitment Deviations
```

```
0.5
# Lambda for Catchability in First year by Index
0  0  0  0  0  0  0  0
# CV for Catchability in First year by Index
1  1  1  1  1  1  1  1
# Lambda for Catchability Deviations by Index
0  0  0  0  0  0  0  0
# CV for Catchability Deviations by Index
1  1  1  1  1  1  1  1
# Lambda for Deviation from Initial Steepness
0
# CV for Deviation from Initial Steepness
0.5
# Lambda for Deviation from Unexploited Stock Size
0
# CV for Deviation from Unexploited Stock Size
0.5
# NAA Deviations Flag
2
# Initial Numbers at Age in 1st Year
2487  2103  1762  1385  1067  767  557  426  268  191  127  279
# Initial F Mult in 1st Year by Fleet
1.0
# Initial Catchabilty by Index
0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
# Stock Recruitment Flag
0
# Initial Unexploited Stock
10000
# Initial Steepness
0.7
# Maximum F
5
# Ignore Guesses (Yes=1)
0
# Projection Control
# Do Projections (Yes=1)
0
# Fleet Directed Flag
1
# Final Year in Projection
2014
# Projection Data by Year
2014     -1         3     -99        1
# Do MCMC (Yes=1)
1
# MCMC Year Option
0
# MCMC Iterations
1000
# MCMC Thinning Factor
200
# MCMC Random Seed
314156
```

```
# Agepro R Option
2
# Agepro R Option Start Year
1989
# Agepro R Option End Year
2013
# Export R Flag
0
# Test Value
-23456
######
###### FINIS ######
# Fleet Names
#$Rec + Comm
# Survey Names
#$MA Trawl
#$RI Fall Trawl
#$RI Seine
#$CT Trawl
#$NY Trawl
#$NY Seine
#$NJ Trawl
#$MRIP CPUE
#
```

```
# ASAP VERSION 3.0
# DMV
#
# ASAP GUI 15 AUG 2012
#
# Number of Years
24
# First Year
1990
# Number of Ages
12
# Number of Fleets
1
# Number of Sensitivity Blocks
3
# Number of Available Survey Indices
8
# Natural Mortality
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
```

```
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
# Fecundity Option
0
# Fraction of year that elapses prior to SSB calculation (0=Jan-1)
0.42
# Maturity
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
```

```
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
0          0          0.78       0.97       1          1
1          1          1          1          1          1
# Number of Weights at Age Matrices
3
# Weight Matrix - 1
0.394           0.726           0.964           1.015
1.143           1.19            1.484           1.824
2.012           2.89            2.893           3.101
0.394           0.612           0.953           1.086
1.184           1.27            1.376           1.607
1.728           1.781           2.057           3.162
0.516           0.883           0.898           1.218
1.32            1.34            1.642           1.799
1.934           2.011           2.153           3.297
0.394           1.038           1.155           1.244
1.227           1.207           1.346           1.557
1.799           2.213           2.042           3.064
0.495           0.988           1.158           1.24
1.398           1.431           1.464           1.638
1.753           1.865           1.931           2.268
0.165           0.56            1.107           1.093
1.213           1.288           1.322           1.431
1.611           1.774           2.029           2.44
0.394           1.273           1.346           1.319
1.378           1.387           1.532           1.879
2.018           2.145           2.378           3.265
0.394           0.969           1.088           1.174
1.267           1.348           1.352           1.432
1.869           2.046           2.222           2.374
0.401           0.441           1.024           1.138
1.285           1.528           1.698           1.826
1.976           2.352           2.819           3.002
0.394           0.512           1.185           1.354
1.505           1.643           1.777           1.987
2.305           2.077           2.546           2.763
0.124           0.877           1.014           1.001
1.215           1.339           1.724           1.903
2.009           2.374           2.258           3.466
0.115           0.373           0.771           1.089
1.331           1.445           1.629           1.932
2.114           2.262           2.316           2.943
0.115           0.364           0.686           1.002
1.232           1.357           1.599           1.861
2.174           2.408           2.45            3.4
```

```
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
# Weight Matrix - 2
0.147           0.308           0.864           1.156
1.461           1.778           2.171           2.334
2.401           3.238           3.409           4.303
0.147           0.303           0.897           1.161
1.553           1.968           2.326           2.449
2.603           3.246           3.428           4.313
0.147           0.29            0.979           1.199
1.478           1.832           2.216           2.431
2.548           3.345           3.537           4.395
0.147           0.212           0.905           1.13
1.318           1.836           2.121           2.391
2.791           3.049           3.906           4.518
0.147           0.263           0.877           1.199
1.365           1.747           2.054           2.396
2.62            2.993           3.452           4.21
0.147           0.263           1.1552          1.35
1.487           1.897           2.122           2.41
2.792           3.068           3.508           4.192
0.147           0.646           1.337           1.526
1.813           2.077           2.207           2.596
```

```
2.826           3.501           3.544           4.357
0.147           0.898           1.371           1.516
1.725           1.945           2.018           2.425
2.67            3.323           3.341           4.325
0.147           0.544           1.398           1.612
1.891           2.119           2.041           2.387
2.58            3.249           3.302           4.285
0.147           0.59            0.881           0.947
1.214           1.383           1.667           1.889
2.038           2.182           2.252           2.547
0.147           0.877           1.014           1.001
1.215           1.339           1.724           1.903
2.009           2.374           2.258           3.466
0.147           0.373           0.771           1.089
1.331           1.445           1.629           1.932
2.114           2.262           2.316           2.943
0.147           0.364           0.686           1.002
1.232           1.357           1.599           1.861
2.174           2.408           2.45            3.4
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.147           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
# Weight Matrix - 3
0.453           0.638           0.846           1.074
```

1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074
1.317	1.571	1.832	2.097
2.362	2.625	2.884	4.206
0.453	0.638	0.846	1.074

```
1.317           1.571           1.832           2.097
2.362           2.625           2.884           4.206
0.453           0.638           0.846           1.074
1.317           1.571           1.832           2.097
2.362           2.625           2.884           4.206
0.453           0.638           0.846           1.074
1.317           1.571           1.832           2.097
2.362           2.625           2.884           4.206
0.453           0.638           0.846           1.074
1.317           1.571           1.832           2.097
2.362           2.625           2.884           4.206
0.453           0.638           0.846           1.074
1.317           1.571           1.832           2.097
2.362           2.625           2.884           4.206
0.453           0.638           0.846           1.074
1.317           1.571           1.832           2.097
2.362           2.625           2.884           4.206
# Weights at Age Pointers
1
1
1
1
3
3
# Selectivity Block Assignment
# Fleet 1 Selectivity Block Assignment
1
1
1
1
1
1
1
2
2
2
2
2
2
2
2
2
2
3
3
3
3
3
3
3
# Selectivity Options for each block 1=by age, 2=logisitic, 3
=double logistic
2  2  2
# Selectivity Block #1 Data
```

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #2 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #3 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
# Fleet Start Age
1
# Fleet End Age
12
# Age Range for Average F
8  12
# Average F report option (1=unweighted, 2=Nweighted, 3
=Bweighted)
2
# Use Likelihood constants? (1=yes)
1
# Release Mortality by Fleet
0.025
# Catch Data
# Fleet-1 Catch Data
562.1609149     5633.983972     43075.35731     44484.32688
50261.02377     29202.71591     21918.69187     13814.77241
8012.335799     5130.983534     2023.07818      3332.688474
203.22
975.2599764     5040.685278     17658.80737     37150.24495
67445.51828     55807.3341      52053.62729     29403.17993
17598.07153     8935.64943      8901.055302     30900.92676
496.72
126.3911427     5444.893643     38983.43748     49816.64463
68614.84739     47415.20811     37441.63289     17977.41018
8583.378206     3968.121024     2783.947766     4170.672065
279.54
882.2639359     5820.860233     32105.50634     64259.95461
115691.1248     91028.28266     68403.15141     38462.85542
18341.80169     7943.551049     4281.991452     11022.00493
504.14
451.2769421     6959.99319      57139.38409     89517.01397
93964.52597     66881.66925     56408.71281     42782.03509
29337.52586     16115.91961     5549.996751     7491.568488
661.86
0               321.5765234     23831.91727     43043.92508
157683.0795     126742.2511     115104.2824     67232.81904
26614.25172     16743.06635     1942.007194     12936.64976
713.27
0               3245.484035     25968.96545     44901.76025
59531.5681      47095.56965     26615.4554      27208.7105
14496.47959     7865.118636     20819.84975     27671.87048
454.06
0               0               171.0752322     2234.069594
19583.97937     70187.74186     69767.27777     49510.92802
21450.13534     16564.10198     10064.58698     14221.51526
373.76
0               1859.577532     1637.610257     9298.780228
11447.14087     28719.52713     23955.74117     16846.88901
8216.856819     8850.577207     5859.81381      15193.44998
267.38
0               1892.596907     13485.15233     11276.97275
```

```
19300.95662     26191.72186     39511.80258     29199.46083
17696.19169     8155.161808     3862.785878     5709.567338
295.93
0               412.3589805     28594.68124     36278.42008
29443.11828     27818.69598     24490.35976     17428.61458
5449.540928     4147.409401     4301.493511     6994.407718
297.84
0               5718.253194     19247.06749     39648.46344
19690.17861     8604.901387     8054.288826     7069.706871
4243.959843     3077.94237      1441.760214     1218.107748
179.5
0               22102.02475     37076.64662     47973.8856
66820.95419     40963.92096     20985.60092     14915.11817
12321.53962     7925.259156     2688.696261     6625.797878
425.53
0               7838.260408     19115.09859     30099.89323
32535.6187      28946.00426     17091.50159     9966.745482
7831.321062     4703.152346     3301.396111     4808.253068
269.78
0               3346.584153     30387.05862     50826.86535
51004.47615     36281.26517     24614.28368     14097.58589
11597.78277     4481.987919     3964.378315     14462.90814
389.76
692.5752276     1495.829655     16845.85374     47433.17857
34942.64642     22461.61479     11992.41715     8164.790854
5517.407697     5008.887694     5168.010141     4545.389381
268.61
0               12721.27346     28953.10777     37994.30938
45136.20704     43288.27006     28473.71146     17563.69136
13850.70854     5629.680421     3209.048965     12738.49791
424.27
6.182894726     3714.601721     43020.63648     52949.15375
40257.57235     32717.29054     24346.9028      11505.74431
6691.775983     2443.60007      1832.276048     2113.841122
338.36
2.251681866     2036.630037     12425.80686     39942.1228
49129.21152     31823.06105     20390.20196     12706.85937
9713.118859     3390.109666     4674.662709     4212.760207
318.63
0               2647.345635     26271.95437     46175.40959
63696.1178      44665.35006     17002.97592     12932.60046
10494.46483     3606.616793     1266.318311     3517.291766
378.66
0               8988.490089     44042.29528     66566.95516
56782.46037     34932.55424     12780.6251      8655.760319
4352.987929     9398.803518     2866.396687     11483.31965
399.23
9.383895128     2009.102102     14987.35343     28279.60895
28214.09451     17237.99168     11166.6675      6090.37556
1790.534492     2080.784648     1046.148111     949.3170457
180.83
0               464.125639      11633.18721     20778.82586
15639.74868     11989.67625     7055.692856     4677.826089
1961.427        667.8957181     1142.555622     230.0584696
```

```
120.56
5.298333333     340.6483037     9570.701754     15780.0815
13092.99517     10279.33871     6046.238152     3797.212661
2960.157482     581.7381683     993.9714158     1614.908423
101.31
# Discards
# Fleet-1 Discards Data
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
0       0       0       0
0       0       0       0
0       0       0       0
0
# Release Proportion
# Fleet-1 Release Data
0       0       0       0
0       0       0       0
0       0       0       0
```

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Survey Index Data
# Aggregate Index Units
2  2  2  2  2  2  2  2
# Age Proportion Index Units
2  2  2  2  2  2  2  2
# Weight at Age Matrix
3  3  3  3  3  3  3  3
# Index Month
5  9  5  5  5  5  6  6
# Index Selectivity Link to Fleet
-1  -1  -1  -1  -1  -1  -1  -1
# Index Selectivity Options 1=by age, 2=logisitic, 3=double
logistic
2  2  1  2  1  1  2  2
# Index Start Age
1  1  1  1  1  1  1  1
# Index End Age
12  12  1  12  1  1  12  12
# Estimate Proportion (Yes=1)
0  0  0  0  0  0  0  1
# Use Index (Yes=1)
0  0  0  0  0  0  0  1
# Index-1 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
# Index-2 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-3 Selectivity Data
1               -1              1               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-4 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
```

```
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-5 Selectivity Data
1               -1              1               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-6 Selectivity Data
1               -1              1               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-7 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-8 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-1 Data
1990  0.23            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.55            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.11            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.4             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.06            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.19            0.3             0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
1997  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.16            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.02            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.17            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.18            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.13            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.05            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.3             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.3             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.28            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
2010  0.02            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-2 Data
1990  0.26            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.19            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.13            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.58            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.07            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.12            0.3             0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
2000  0.54            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.43            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.23            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.53            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.02            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.04            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.24            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.14            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.17            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.2             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.09            0.3             0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-3 Data
1990  14.96           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  6.07            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  7.96            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  9.7             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  3.76            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  1.06            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.95            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  7.54            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  2.92            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  5.09            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  5.97            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  16.56           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
2002  9.54            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  10.66           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  17.95           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  8.33            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  15.09           0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  2.93            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  9.6             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  2.63            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  2.59            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  2.88            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  1.5             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-4 Data
1990  0.8             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  1.21            0.3             0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
1992  0.53            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.28            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.34            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.24            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.33            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.42            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.59            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.55            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.59            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  1.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.44            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.41            0.3             0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
2005  0.33            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.43            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.43            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.42            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.3             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.32            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-5 Data
1990  1.48            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.86            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.66            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.58            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
1994  0.42            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.16            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.21            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.58            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.31            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.59            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.33            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.68            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.8             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  1.15            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  1.19            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.46            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  -999            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.57            0.3             0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
2008  0.67            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  1.9             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  1.67            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.79            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.17            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-6 Data
1990  0.81            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.32            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  2.01            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.76            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.02            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.06            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.22            0.3             0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
1997  0.1             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.17            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.11            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  1.14            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2001  1.26            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.3             0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.47            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.56            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.32            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.87            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.44            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.29            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.08            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.02            0.3             0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
2011  0.01            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.16            0.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-7 Data
1990  1.48            0.3             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            20
1991  0.99            0.3             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            20
1992  1.47            0.3             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            20
1993  0.64            0.3             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            20
1994  0.35            0.3             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            20
1995  0.54            0.3             0               0
0.02806         0.03777         0.09822         0.02299
0.01983         0.01626         0.00944         0.01113
0.00178         0.03848         20
1996  0.22            0.3             0               0.0288
0.02316         0.03932         0.041           0.01253
0.00826         0.00529         0.00583         0.00523
0.00187         0.00811         20
1997  0.1             0.3             0               0.00314
0.00676         0.00927         0.00721         0.0054
0.00516         0.00392         0.00198         0.00092
0.00029         0.04666         20
1998  0.31            0.3             0               0.00794
0.01761         0.0306          0.02201         0.01943
0.01628         0.01083         0.00623         0.00589
0.00359         0.0063          20
1999  0.57            0.3             0.02024         0.03245
0.05794         0.04563         0.06486         0.0631
```

```
0.04131         0.02608         0.01166         0.00339
0.0061          0.0002          20
2000  0.32            0.3             0               0.0227
0.02089         0.02661         0.02202         0.01541
0.01538         0.01167         0.00322         0.0022
0.00264         0.00338         20
2001  0.28            0.3             0.01374         0.01655
0.03988         0.03676         0.04171         0.01391
0.0063          0.00542         0.00173         0.00253
0.00037         0.0055          20
2002  1.45            0.3             0.01056         0.02298
0.10777         0.20405         0.20474         0.10006
0.04921         0.03657         0.01903         0.0116
0.00523         0.03638         20
2003  0.62            0.3             0               0.00079
0.00427         0.07311         0.05137         0.05264
0.02147         0.01753         0.00833         0.00338
0.00503         0.00688         20
2004  0.34            0.3             0               0.02036
0.03974         0.02707         0.02757         0.02079
0.00739         0.00288         0.00146         0.00048
0.0002          0.00325         20
2005  0.53            0.3             0.00944         0.0291
0.05297         0.04152         0.04376         0.02241
0.01511         0.01049         0.0069          0.00804
0.00646         0.00931         20
2006  0.66            0.3             0               0.03752
0.00863         0.05842         0.04595         0.03365
0.02636         0.01438         0.01464         0.01013
0.00511         0.00917         20
2007  0.36            0.3             0               0.0103
0.02529         0.04868         0.01615         0.00774
0.00558         0.00457         0.00351         0.00227
0.00125         0.00281         20
2008  0.84            0.3             0.00014         0.02705
0.065           0.09863         0.07886         0.04292
0.03042         0.0203          0.01504         0.01117
0.01281         0.03171         20
2009  0.49            0.3             0.00139         0.0477
0.04694         0.04278         0.05715         0.02256
0.01589         0.01252         0.0066          0.00275
0.00203         0.00767         20
2010  0.43            0.3             0.001           0.01884
0.06133         0.03334         0.02922         0.0179
0.00882         0.0073          0.00314         0.00174
0.00424         0.00908         20
2011  0.14            0.3             0.011           0.02465
0.02891         0.03002         0.03103         0.01331
0.00529         0.00235         0.00081         0.00048
0.00013         0.00013         20
2012  0.25            0.3             0.00316         0.01548
0.0583          0.02602         0.0179          0.00773
0.00438         0.00201         2E-05           9E-05
0               0               20
```

```
2013  0               0               0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-8 Data
1990  0.08            0.37            1639.545243
10232.86229     58703.71674     73349.6927      72271.16947
46225.75453     42036.57107     23750.85825     12755.55332
6447.770925     2419.327267     4453.456164     20
1991  0.12            0.32            4676.95013
27450.13595     74582.05257     104128.7944     85847.89285
63094.57321     59936.53353     33256.34056     19846.82157
10036.57883     10409.1252      31675.65674     20
1992  0.12            0.3             5055.645709
29117.01705     81705.21317     101177.8372     97783.26787
61769.39886     44646.60908     22916.93848     13321.57436
6797.105047     4630.251474     11023.79711     20
1993  0.23            0.32            1840.097735
10601.09375     116165.0724     161518.3295     237119.8295
168200.3683     100566.9667     65305.1581      40317.6436
12458.35509     6129.823311     12011.9027      20
1994  0.19            0.27            2104.496959
30024.76902     149386.0903     250072.13       191509.1289
110931.1348     80860.77572     52112.47438     31554.05834
16957.43916     6885.848265     8333.861663     20
1995  0.17            0.29            0
12863.06093     96427.07635     142680.2076     321509.9289
169505.9752     137037.4915     69899.70351     25931.19956
18565.87421     1892.16577      19925.31221     20
1996  0.18            0.3             0
3431.030617     35188.6389      68876.7317      121476.7729
84208.41276     30287.6114      28428.85041     14324.06168
7852.720055     22416.9202      32856.37532     20
1997  0.11            0.29            0               0
6843.009289     11226.50019     38912.55761     128229.1708
178382.1119     58408.97281     25563.11858     22007.5302
14311.2097      19956.90715     20
1998  0.05            0.3             0
47467.53824     29061.78407     72783.57654     44652.40659
68601.34189     53437.95521     18280.92561     31171.93579
9550.615189     5977.490149     14940.07513     20
1999  0.08            0.33            0
21917.02158     83658.71466     88376.68972     100291.1038
113486.8435     82964.91762     68110.20436     24797.33766
14474.50615     5666.538769     5479.735427     20
2000  0.05            0.32            0
1657.588695     174166.1264     237451.5985     70758.9931
47461.26513     46099.51529     27481.73558     9364.998272
4368.418252     7952.563911     7034.45151      20
2001  0.07            0.28            0
42991.72022     199399.4132     142149.6522     48429.52294
12806.20828     9946.000579     8589.741106     4852.40433
5604.265914     1369.819647     1157.326933     20
2002  0.11            0.28            0
```

```
167544.2853     359238.0078     124459.3435     132828.929
102534.2591     43153.8621      24103.34041     19284.80946
12150.81051     3062.047894     9619.846476     20
2003  0.09            0.29            0               39940.8156
118269.5282     86655.86608     66601.31686     58631.72584
36946.52903     20459.09614     15873.16522     7781.714879
7817.708352     12833.49362     20
2004  0.14            0.27            0
8634.757278     113106.6635     180094.7439     103623.7702
59442.81639     38446.38078     22811.97196     15684.73692
5953.707544     4491.576554     23252.14251     20
2005  0.11            0.28            24536.07182     28367.1893
134546.7679     186578.005      94835.03906     51970.11791
23501.22906     15689.26773     11666.96161     9144.473224
10679.29328     15014.28326     20
2006  0.12            0.31            0
57254.26222     169993.484      141972.2817     150820.3733
107182.105      67033.19874     38119.49336     29615.61577
11024.83082     9688.498858     27819.98395     20
2007  0.08            0.27            216.3682128
20568.84361     183528.8257     179358.2342     113531.1821
76321.79461     63581.6662      28559.71831     16111.13249
20659.91572     6227.276615     20422.99967     20
2008  0.15            0.26            90.06727465
16864.95236     68014.19323     135734.9593     117189.9899
63544.87624     42066.89893     30308.23553     21239.94278
8321.586421     11190.67677     11691.22965     20
2009  0.1             0.28            0
33404.53874     162671.0932     139755.4679     117982.8731
85547.93572     25655.55711     17103.46616     14019.81141
4779.808673     1988.229995     6001.110643     20
2010  0.14            0.28            0
109456.5223     277175.8268     223189.6624     136052.5227
80301.32621     30001.90449     17374.08165     6256.930596
12815.14111     7763.639515     27067.84791     20
2011  0.08            0.33            375.3558051
25917.35367     72769.56537     84859.43615     58503.99252
26666.8047      19204.51062     7627.621242     2376.241514
2800.789095     1103.006025     1666.005472     20
2012  0.06            0.36            0
17157.89227     98918.68869     85756.16086     49226.21034
25414.17566     11564.90695     6741.072531     3237.596833
920.088079      1186.066528     252.6514483     20
2013  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Phase Control
# Phase for F mult in 1st Year
1
# Phase for F mult Deviations
2
# Phase for Recruitment Deviations
2
```

```
# Phase for N in 1st Year
2
# Phase for Catchability in 1st Year
3
# Phase for Catchability Deviations
-1
# Phase for Stock Recruitment Relationship
3
# Phase for Steepness
3
# Recruitment CV by Year
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
# Lambdas by Index
1  1  1  1  1  1  1  1
# Lambda for Total Catch in Weight by Fleet
1
# Lambda for Total Discards at Age by Fleet
1
# Catch Total CV by Year and Fleet
0.36
0.22
0.19
0.18
0.36
0.17
0.27
0.24
0.27
0.25
0.26
0.24
```

```
0.15
0.22
0.25
0.21
0.18
0.2
0.14
0.19
0.21
0.25
0.28
0.28
# Discard Total CV by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Catch Effective Sample Size by Year and Fleet
93
93
100
79
45
38
37
27
25
31
24
30
46
50
50
55
```

```
62
53
68
53
52
40
32
32
# Discard Effective Sample Size by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Lambda for F Mult in First year by Fleet
0
# CV for F Mult in First year by Fleet
0.5
# Lambda for F Mult Deviations by Fleet
0.5
# CV for F Mult Deviations by Fleet
0.5
# Lambda for N in 1st Year Deviations
0
# CV for N in 1st Year Deviations
0.5
# Lambda for Recruitment Deviations
0.5
# Lambda for Catchability in First year by Index
0  0  0  0  0  0  0  0
# CV for Catchability in First year by Index
1  1  1  1  1  1  1  1
# Lambda for Catchability Deviations by Index
0  0  0  0  0  0  0  0
# CV for Catchability Deviations by Index
```

```
1  1  1  1  1  1  1  1
# Lambda for Deviation from Initial Steepness
0
# CV for Deviation from Initial Steepness
0.5
# Lambda for Deviation from Unexploited Stock Size
0
# CV for Deviation from Unexploited Stock Size
0.5
# NAA Deviations Flag
1
# Initial Numbers at Age in 1st Year
5588  3873  2269  1983  1203  728  746  431  242  136  77  99
# Initial F Mult in 1st Year by Fleet
1.0
# Initial Catchabilty by Index
0.001  0.001  0.001  0.001  0.001  0.001  0.001  0.001
# Stock Recruitment Flag
0
# Initial Unexploited Stock
10000
# Initial Steepness
0.7
# Maximum F
5
# Ignore Guesses (Yes=1)
0
# Projection Control
# Do Projections (Yes=1)
0
# Fleet Directed Flag
1
# Final Year in Projection
2014
# Projection Data by Year
2014     -1        3     -99        1
# Do MCMC (Yes=1)
1
# MCMC Year Option
1
# MCMC Iterations
0
# MCMC Thinning Factor
0
# MCMC Random Seed
0
# Agepro R Option
-1
# Agepro R Option Start Year
0
# Agepro R Option End Year
0
# Export R Flag
0
```

```
# Test Value
-23456
######
###### FINIS ######
# Fleet Names
#$Rec + Comm
# Survey Names
#$MA Trawl
#$RI Fall Trawl
#$RI Seine
#$CT Trawl
#$NY Trawl
#$NY Seine
#$NJ Trawl
#$MRIP CPUE
#
```

```
# ASAP VERSION 3.0
# Coastwide - VPA inputs
#
# ASAP GUI 15 AUG 2012
#
# Number of Years
32
# First Year
1982
# Number of Ages
12
# Number of Fleets
1
# Number of Sensitivity Blocks
3
# Number of Available Survey Indices
7
# Natural Mortality
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
```

```
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
0.16       0.16       0.16       0.16       0.16       0.16
# Fecundity Option
0
# Fraction of year that elapses prior to SSB calculation (0=Jan-
1)
0.42
# Maturity
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
```

```
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
0          0.1        0.5        0.75       1          1
1          1          1          1          1          1
# Number of Weights at Age Matrices
3
# Weight Matrix - 1
0.147           0.249           0.518           1.219
1.638           1.983           2.3             2.594
2.916           3.267           3.476           4.558
0.143           0.291           0.544           1.168
1.518           1.918           2.311           2.561
2.785           2.984           3.229           4.119
0.143           0.369           0.666           0.964
```

1.364	1.897	2.287	2.612
3.007	3.307	3.95	4.448
0.141	0.377	0.722	0.992
1.353	1.829	2.126	2.41
2.689	3.028	3.329	3.956
0.141	0.342	0.682	0.974
1.444	1.956	2.334	2.621
2.835	3.165	3.367	4.532
0.302	0.494	0.754	1.029
1.463	1.77	1.939	2.079
2.421	2.974	3.273	3.895
0.259	0.432	0.718	1.04
1.464	1.763	1.938	2.141
2.546	3.174	3.608	4.502
0.312	0.502	0.722	0.992
1.313	1.577	1.712	1.918
2.19	3.044	3.312	4.133
0.309	0.308	0.864	1.156
1.461	1.778	2.171	2.334
2.401	3.238	3.409	4.303
0.309	0.303	0.897	1.161
1.553	1.968	2.326	2.449
2.603	3.246	3.428	4.313
0.309	0.29	0.979	1.199
1.478	1.832	2.216	2.431
2.548	3.345	3.537	4.395
0.309	0.212	0.905	1.13
1.318	1.836	2.121	2.391
2.791	3.049	3.906	4.518
0.309	0.263	0.877	1.199
1.365	1.747	2.054	2.396
2.62	2.993	3.452	4.21
0.309	0.263	1.1552	1.35
1.487	1.897	2.122	2.41
2.792	3.068	3.508	4.192
0.276	0.646	1.337	1.526
1.813	2.077	2.207	2.596
2.826	3.501	3.544	4.357
0.274	0.898	1.371	1.516
1.725	1.945	2.018	2.425
2.67	3.323	3.341	4.325
0.283	0.544	1.398	1.612
1.891	2.119	2.041	2.387
2.58	3.249	3.302	4.285
0.204	0.59	0.881	0.947
1.214	1.383	1.667	1.889
2.038	2.182	2.252	2.547
0.124	0.877	1.014	1.001
1.215	1.339	1.724	1.903
2.009	2.374	2.258	3.466
0.115	0.373	0.771	1.089
1.331	1.445	1.629	1.932
2.114	2.262	2.316	2.943
0.115	0.364	0.686	1.002

```
1.232           1.357           1.599           1.861
2.174           2.408           2.45            3.4
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
# Weight Matrix - 2
0.147           0.249           0.518           1.219
1.638           1.983           2.3             2.594
2.916           3.267           3.476           4.558
0.143           0.291           0.544           1.168
1.518           1.918           2.311           2.561
2.785           2.984           3.229           4.119
0.143           0.369           0.666           0.964
1.364           1.897           2.287           2.612
3.007           3.307           3.95            4.448
0.141           0.377           0.722           0.992
1.353           1.829           2.126           2.41
2.689           3.028           3.329           3.956
0.141           0.342           0.682           0.974
1.444           1.956           2.334           2.621
2.835           3.165           3.367           4.532
0.302           0.494           0.754           1.029
1.463           1.77            1.939           2.079
2.421           2.974           3.273           3.895
```

0.259	0.432	0.718	1.04
1.464	1.763	1.938	2.141
2.546	3.174	3.608	4.502
0.312	0.502	0.722	0.992
1.313	1.577	1.712	1.918
2.19	3.044	3.312	4.133
0.309	0.308	0.864	1.156
1.461	1.778	2.171	2.334
2.401	3.238	3.409	4.303
0.309	0.303	0.897	1.161
1.553	1.968	2.326	2.449
2.603	3.246	3.428	4.313
0.309	0.29	0.979	1.199
1.478	1.832	2.216	2.431
2.548	3.345	3.537	4.395
0.309	0.212	0.905	1.13
1.318	1.836	2.121	2.391
2.791	3.049	3.906	4.518
0.309	0.263	0.877	1.199
1.365	1.747	2.054	2.396
2.62	2.993	3.452	4.21
0.309	0.263	1.1552	1.35
1.487	1.897	2.122	2.41
2.792	3.068	3.508	4.192
0.276	0.646	1.337	1.526
1.813	2.077	2.207	2.596
2.826	3.501	3.544	4.357
0.274	0.898	1.371	1.516
1.725	1.945	2.018	2.425
2.67	3.323	3.341	4.325
0.283	0.544	1.398	1.612
1.891	2.119	2.041	2.387
2.58	3.249	3.302	4.285
0.204	0.59	0.881	0.947
1.214	1.383	1.667	1.889
2.038	2.182	2.252	2.547
0.124	0.877	1.014	1.001
1.215	1.339	1.724	1.903
2.009	2.374	2.258	3.466
0.115	0.373	0.771	1.089
1.331	1.445	1.629	1.932
2.114	2.262	2.316	2.943
0.115	0.364	0.686	1.002
1.232	1.357	1.599	1.861
2.174	2.408	2.45	3.4
0.115	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.115	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316
0.115	0.35	0.781	1.005
1.226	1.435	1.698	1.904
2.369	2.82	3.1	3.316

```
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
0.115           0.35            0.781           1.005
1.226           1.435           1.698           1.904
2.369           2.82            3.1             3.316
# Weight Matrix - 3
0.104           0.187           0.4             0.793
0.98            1.199           1.585           1.871
2.13            2.316           2.503           4.558
0.089           0.207           0.368           0.778
1.36            1.772           2.141           2.427
2.688           2.95            3.248           4.119
0.088           0.23            0.44            0.724
1.262           1.697           2.094           2.457
2.775           3.035           3.433           4.448
0.091           0.232           0.516           0.813
1.142           1.579           2.008           2.348
2.65            3.017           3.318           3.956
0.075           0.22            0.507           0.839
1.197           1.627           2.066           2.361
2.614           2.917           3.193           4.532
0.253           0.264           0.508           0.838
1.194           1.599           1.947           2.203
2.519           2.904           3.219           3.895
0.186           0.361           0.596           0.886
1.227           1.606           1.852           2.037
2.301           2.772           3.276           4.502
0.314           0.361           0.558           0.844
1.169           1.519           1.737           1.928
2.165           2.784           3.242           4.133
0.312           0.31            0.659           0.914
1.204           1.528           1.85            1.999
2.146           2.663           3.221           4.303
0.319           0.306           0.526           1.002
1.34            1.696           2.034           2.306
```

2.465	2.792	3.332	4.313
0.373	0.299	0.545	1.037
1.31	1.687	2.088	2.378
2.498	2.951	3.388	4.395
0.335	0.256	0.512	1.052
1.257	1.647	1.971	2.302
2.605	2.787	3.615	4.518
0.335	0.285	0.431	1.042
1.242	1.517	1.942	2.254
2.503	2.89	3.244	4.21
0.214	0.285	0.55	1.335
1.335	1.609	1.925	2.225
2.586	2.835	3.24	4.192
0.153	0.447	0.593	1.564
1.564	1.757	2.046	2.347
2.61	3.126	3.297	4.357
0.194	0.498	0.941	1.622
1.622	1.878	2.047	2.313
2.633	3.064	3.42	4.325
0.207	0.386	1.12	1.693
1.693	1.912	1.992	2.195
2.501	2.945	3.312	4.285
0.091	0.204	0.59	0.881
0.947	1.214	1.383	1.667
1.889	2.038	2.182	2.252
0.091	0.124	0.877	1.014
1.001	1.215	1.339	1.724
1.903	2.009	2.374	2.258
0.091	0.115	0.373	0.771
1.089	1.331	1.445	1.629
1.932	2.114	2.262	2.316
0.091	0.115	0.364	0.686
1.002	1.232	1.357	1.599
1.861	2.174	2.408	2.45
0.091	0.115	0.35	0.781
1.005	1.226	1.435	1.698
1.904	2.369	2.82	3.1
0.115	0.115	0.35	0.781
1.005	1.226	1.435	1.698
1.904	2.369	2.82	3.1
0.115	0.115	0.35	0.781
1.005	1.226	1.435	1.698
1.904	2.369	2.82	3.1
0.115	0.115	0.35	0.781
1.005	1.226	1.435	1.698
1.904	2.369	2.82	3.1
0.115	0.115	0.35	0.781
1.005	1.226	1.435	1.698
1.904	2.369	2.82	3.1
0.115	0.115	0.35	0.781
1.005	1.226	1.435	1.698
1.904	2.369	2.82	3.1
0.115	0.115	0.35	0.781
1.005	1.226	1.435	1.698

```
1.904           2.369           2.82            3.1
0.115           0.115           0.35            0.781
1.005           1.226           1.435           1.698
1.904           2.369           2.82            3.1
0.115           0.115           0.35            0.781
1.005           1.226           1.435           1.698
1.904           2.369           2.82            3.1
0.115           0.115           0.35            0.781
1.005           1.226           1.435           1.698
1.904           2.369           2.82            3.1
0.115           0.115           0.35            0.781
1.005           1.226           1.435           1.698
1.904           2.369           2.82            3.1
# Weights at Age Pointers
1
1
1
1
2
3
# Selectivity Block Assignment
# Fleet 1 Selectivity Block Assignment
1
1
1
1
1
1
1
1
1
1
1
1
1
2
2
2
2
2
2
2
2
2
2
2
2
3
3
3
3
3
3
3
```

```
# Selectivity Options for each block 1=by age, 2=logisitic, 3
=double logistic
2  2  2
# Selectivity Block #1 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               1               0               1
0.6             1               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #2 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               1               0               1
0.6             1               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #3 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
5               1               0               1
0.6             1               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Fleet Start Age
1
# Fleet End Age
12
# Age Range for Average F
8  10
# Average F report option (1=unweighted, 2=Nweighted, 3
=Bweighted)
1
# Use Likelihood constants? (1=yes)
1
# Release Mortality by Fleet
0.025
# Catch Data
# Fleet-1 Catch Data
33.5            142             190             340.7
430.2           393.6           382.7           296.7
264.9           179             113.1           304
3968.64
85.6            240.7           371.9           467
404.2           311             279.8           189.8
168.6           117.3           73              160.9
2800.2
58.3            172.3           310.5           365.5
349.4           300.4           245.7           172.5
137.3           80.5            54.2            139.6
2754.48
92.3            280             258.1           376.3
388.8           360.1           337.7           237.8
213.1           140.6           83.6            164.1
2291.63
179.5           449.2           785.7           951.1
945.1           852.6           847.5           594.2
512.1           344.7           227.8           734.2
8107.08
81.6            200.5           313.4           467.6
486.4           552.5           521.9           405.8
312.1           137.1           82.6            233
4573.7
89              177.6           224.1           344.1
421.2           453.8           429.5           365.2
279.9           156.5           108.3           354.7
4721.02
61.2            163.7           325.4           439.6
381.2           356             326.9           273.3
236             111.2           81.1            203.3
3354.91
5.4             59.1            376.2           603.6
```

```
691.5           427.2           254.1           189.5
112.6           63.3            45.9            119.1
2751.24
3.2             35.6            272.1           505.6
673.1           541.7           403.5           296.6
180.1           110.5           81.7            255.9
4199.7
1.5             23.6            240.1           428
637.2           485.4           337.3           251.5
161             100.8           81.5            223.1
3956.65
10.2            73.8            236.5           415.7
508.4           402.8           327.5           213.7
108.4           76.7            41.5            129
3028.4
0.7             23.9            120.2           256.8
271.6           201.4           174.7           119.6
69.9            46.4            22.3            48.6
1799.65
0.2             1.4             49.7            166.8
473.5           378.6           308.7           185.9
96.1            78.6            11.7            36.4
2271.22
0.1             14.4            104.7           156.3
251.6           212.5           152.1           104.4
61              30.3            36              44.4
1618.36
0               0.3             13.4            48.3
103.5           195.5           157.1           123.4
51.1            37.2            18.1            36.1
1121.42
0.3             3.7             6.4             40
71.3            97.2            75.8            61.6
23.9            23.5            9.8             20.5
800.58
1.4             9               41.3            54.7
104.5           134.6           132.1           112.8
59.5            35.4            13.2            82.8
1283.45
0               2.8             92.8            114.1
129             142.9           168.6           117.9
51.5            44.5            18.9            52.9
1686.22
0               32.1            93.3            235.9
138.2           74.5            70.7            61.8
65.1            52.1            28.7            52.6
1426.22
0               53.4            91.1            186.2
382.8           327.8           214.2           175.7
89.3            57.5            21.3            46.7
2704.32
0               17.5            48.1            93.9
175             185.4           120.6           72.9
53.4            28.1            21.9            24.7
```

```
1262.77
0.1             9.3             56.8            104.4
149.9           189.8           122.4           68.1
52.4            36.9            20.9            53
1496.63
1.3             3.2             32.5            75.9
92              120.1           116.8           64.2
35.4            26.3            21.8            48.6
1229.06
0               28.9            65.5            110.8
190.3           255             183.8           137.4
83.5            46.4            27.4            51.2
1991.1
0.1             11.5            106.4           161.8
191.8           234.5           218.1           188.8
122.5           91.5            52.1            80.4
2493.3
0.6             8.3             42.9            138.9
206.7           197.6           157.3           104
83.4            49.2            40.6            73.4
1826.5
0.1             14.6            68.9            138.7
197.2           172.1           140.6           105.6
68.6            33              19              41.7
1695.55
0               23.1            127.1           251.9
256.5           206.2           137.5           92.7
47              35.1            27.4            52
1950.29
0.8             11.5            56.2            100.4
103.1           93.2            62.6            43.2
23.2            17.9            8.9             15.3
836.67
0               5.3             25.9            43.2
73              58.9            78              62.5
71.8            53.3            54.7            43.6
1154.57
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
1153.29
# Discards
# Fleet-1 Discards Data
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
0                  0                  0                  0
0                  0                  0                  0
0
0                  0                  0                  0
```

```
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
0
0           0           0           0
0           0           0           0
0           0           0           0
```

```
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
# Release Proportion
# Fleet-1 Release Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Survey Index Data
```

```
# Aggregate Index Units
2  2  2  2  2  2  2
# Age Proportion Index Units
2  2  2  2  2  2  2
# Weight at Age Matrix
3  3  3  3  3  3  3
# Index Month
5  9  5  5  5  5  6
# Index Selectivity Link to Fleet
-1  -1  -1  -1  -1  -1  -1
# Index Selectivity Options 1=by age, 2=logisitic, 3=double
logistic
2  2  1  2  1  2  2
# Index Start Age
1  1  1  1  1  1  1
# Index End Age
12  12  1  12  1  12  12
# Estimate Proportion (Yes=1)
1  1  0  1  0  1  1
# Use Index (Yes=1)
1  1  0  1  1  1  1
# Index-1 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
3               2               0               1
0.6             2               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-2 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
3               2               0               1
```

```
0.6             2               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-3 Selectivity Data
1               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-4 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
3               2               0               1
0.6             2               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-5 Selectivity Data
1               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
```

```
0               -1              0               1
0               -1              0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-6 Selectivity Data
1               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
0               -1              0               1
3               2               0               1
0.6             2               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-7 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
3               2               0               1
0.6             2               0               1
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-1 Data
1982  0.811           0.59            0.139           0.0888
0.1972          0.4152          0.502           0.8566
0.971           0.8253          0.7492          0.6518
0.4036          0.9287          40
1983  0.447           0.59            0.0354          0.1942
0.234           0.3118          0.4437          0.5172
0.6555          0.5957          0.5747          0.5219
```

```
0.3023          0.7622          40
1984  0.972           0.56            0.0921          0.1533
0.4127          1.1074          1.6842          2.0778
1.7991          1.3029          1.1779          0.9851
0.5629          1.4763          40
1985  0.716           0.57            0.0342          0.0663
0.1051          0.218           0.4845          0.8902
1.1289          1.0115          0.864           0.7232
0.448           0.9691          40
1986  2.337           0.54            0.0809          0.046
0.0663          0.2567          0.8403          1.5286
1.7289          1.4221          1.3422          1.1543
0.7443          3.0189          40
1987  0.854           0.58            0.0319          0.0064
0.0353          0.0838          0.2405          0.5086
0.5731          0.5748          0.4791          0.3279
0.2378          0.8495          40
1988  0.625           0.59            0.0045          0.0133
0.0388          0.0897          0.1514          0.3014
0.4408          0.5195          0.5087          0.3754
0.278           1.0322          40
1989  1.982           0.61            0.0316          0.0857
0.0325          0.1408          0.2823          0.4479
0.4628          0.4734          0.3579          0.2745
0.2006          0.7343          40
1990  0.234           0.64            0               0.0219
0.0278          0.0623          0.1138          0.1076
0.0774          0.0934          0.0731          0.0714
0.0779          0.3369          40
1991  0.101           0.68            0.0244          0.024
0.0751          0.1557          0.2057          0.251
0.2361          0.2544          0.1853          0.1626
0.1359          0.4785          40
1992  0.55            0.67            0.0391          0.0736
0.0728          0.0658          0.0545          0.0728
0.0842          0.091           0.077           0.0947
0.0735          0.3035          40
1993  0.11            0.67            0               0
0.0126          0.0314          0.0421          0.0815
0.0962          0.1054          0.0948          0.0643
0.0617          0.2795          40
1994  0.4             0.67            0               0.0116
0.0405          0.219           0.178           0.1705
0.1676          0.1013          0.0699          0.0619
0.0347          0.2034          40
1995  0.058           0.76            0               0
0.0014          0.0163          0.0383          0.0772
0.0529          0.0422          0.0186          0.0275
0.0076          0.1125          40
1996  0.19            0.63            0.0126          0.0611
0.0737          0.1757          0.3187          0.3023
0.225           0.2124          0.1709          0.1269
0.0402          0.1172          40
1997  0.209           0.64            0.0227          0.0907
```

```
0.113           0.2606          0.2787          0.2443
0.2009          0.1532          0.1007          0.0902
0.0388          0.1256          40
1998  0.162           0.67            0.0066          0.017
0.0218          0.1028          0.17            0.1871
0.1519          0.1415          0.0763          0.0544
0.0532          0.0866          40
1999  0.041           0.7             0.0307          0.0608
0.06            0.1204          0.2643          0.2238
0.1613          0.1891          0.1334          0.1191
0.045           0.1632          40
2000  0.021           0.81            0               0.0081
0.0265          0.0047          0.0179          0.0267
0.0346          0.0281          0.0162          0.012
0.0085          0.0365          40
2001  0.172           0.64            0.0265          0.0941
0.0718          0.1026          0.1353          0.1307
0.1703          0.1734          0.1829          0.1404
0.104           0.2764          40
2002  0.176           0.61            0               0.0438
0.0921          0.0898          0.1348          0.2071
0.178           0.1924          0.1179          0.0824
0.0519          0.1194          40
2003  0.132           0.69            0               0.0385
0.0132          0.2182          0.2018          0.1963
0.1118          0.0836          0.0815          0.0477
0.0392          0.0807          40
2004  0.048           0.73            0               0.1118
0.0911          0.0356          0.0386          0.0667
0.0596          0.0403          0.0326          0.0274
0.0114          0.0692          40
2005  0.298           0.63            0.008           0.1044
0.0836          0.1524          0.4465          0.5458
0.4903          0.3927          0.2246          0.1116
0.0819          0.1208          40
2006  0.302           0.59            0               0.1151
0.0785          0.14            0.1813          0.176
0.2152          0.2087          0.1207          0.0971
0.0711          0.0862          40
2007  0.15            0.63            0               0.0683
0.1965          0.1835          0.1698          0.235
0.1877          0.2004          0.1792          0.1329
0.0717          0.1659          40
2008  0.212           0.63            0.0064          0.0769
0.1652          0.4914          0.5026          0.3535
0.3099          0.1599          0.139           0.0882
0.0859          0.1857          40
2009  0.284           0.6             0.0224          0.3802
0.3383          0.2065          0.1614          0.1242
0.125           0.0643          0.0439          0.0433
0.0229          0.0838          40
2010  0.025           0.85            0               0.0788
0.2555          0.1769          0.1685          0.2162
0.2096          0.1213          0.0595          0.0376
```

```
0.0329          0.0714          40
2011  0.146           0.63            0               0.0726
0.1799          0.1028          0.1301          0.1804
0.0989          0.0729          0.0662          0.058
0.0819          0.1096          40
2012  0.098           0.63            0               0.2506
0.2162          0.2757          0.5181          0.1933
0.2344          0.1776          0.2101          0.0867
0.078           0.0788          40
2013  0.046           0.7             -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-2 Data
1982  0.275           0.51            0.0701          0.0254
0.0159          0.0182          0.0109          0.0106
0.0078          0.0049          0.0028          0.0027
0.0017          0.0016          40
1983  0.83            0.46            0.027           0.0419
0.0544          0.0589          0.0751          0.0961
0.0749          0.0548          0.047           0.0411
0.028           0.0842          40
1984  1.675           0.45            0.125           0.2444
0.2811          0.2464          0.2222          0.1925
0.1334          0.0859          0.0644          0.0392
0.0309          0.0695          40
1985  0.884           0.5             0.0142          0.0574
0.1171          0.1054          0.097           0.107
0.0929          0.0612          0.0422          0.027
0.0153          0.0194          40
1986  2.7             0.51            0.0347          0.0775
0.1163          0.241           0.2862          0.2268
0.1394          0.0822          0.0757          0.0617
0.0323          0.0707          40
1987  1.172           0.62            0.207           0.2143
0.0995          0.1445          0.0581          0.0915
0.112           0.0968          0.08            0.0388
0.0184          0.0626          40
1988  0.055           0.93            0.1031          0.0606
0.0158          0.0176          0.0274          0.0741
0.0868          0.0865          0.0584          0.0407
0.031           0.0922          40
1989  0.465           0.7             0.0864          0.0257
0.0807          0.0201          0.0185          0.0266
0.0305          0.0315          0.0233          0.0183
0.0091          0.0221          40
1990  0.263           0.7             0.0306          0.0735
0.0764          0.0719          0.066           0.0416
0.0336          0.0341          0.0231          0.0142
0.016           0.0292          40
1991  0.192           0.71            0.0135          0.0203
0.0189          0.0379          0.0815          0.0968
0.0869          0.0801          0.057           0.0458
0.0375          0.1266          40
```

```
1992  0.133           0.79            0.0055          0.0246
0.0124          0.0249          0.0467          0.0442
0.0351          0.034           0.0246          0.0131
0.015           0.0423          40
1993  0.043           0.89            0.0391          0.0595
0.0066          0.0313          0.028           0.0374
0.0446          0.0331          0.0136          0.0123
0.0077          0.0406          40
1994  0.099           0.82            0.0138          0.0415
0.0091          0.0227          0.0155          0.0264
0.0244          0.023           0.0163          0.0083
0.0066          0.0136          40
1995  0.103           0.73            0.014           0.0445
0.0163          0.0261          0.0372          0.0336
0.0269          0.0245          0.0088          0.0097
0.0027          0.0058          40
1996  0.589           0.69            0.0409          0.1158
0.0164          0.0302          0.0264          0.0159
0.0146          0.0117          0.0244          0.0094
0.0015          0.0103          40
1997  0.041           0.95            0.0249          0.0771
0.0064          0.0367          0.0434          0.0295
0.0279          0.0219          0.0197          0.0109
0.0065          0.033           40
1998  0.071           0.81            0.0208          0.0603
0.0213          0.0149          0.0125          0.0095
0.008           0.0152          0.0084          0.0039
0.0025          0.0036          40
1999  0.121           0.69            0.153           0.0029
0.0157          0.0077          0.0212          0.0341
0.0235          0.0211          0.0193          0.0162
0.0088          0.0215          40
2000  0.537           0.59            0               0.1325
0.0715          0.0125          0.0301          0.0468
0.0726          0.0481          0.027           0.0196
0.0143          0.0415          40
2001  0.15            0.68            0.0367          0.1226
0.0349          0.0491          0.0627          0.0687
0.059           0.0607          0.0589          0.0366
0.0204          0.0665          40
2002  0.432           0.6             0               0.1795
0.0763          0.0264          0.0398          0.0301
0.0295          0.0226          0.0115          0.0058
0.0063          0.0111          40
2003  0.235           0.65            0.0009          0.1597
0.0092          0.0358          0.0481          0.0862
0.0739          0.0542          0.0426          0.0239
0.0224          0.0272          40
2004  0.532           0.64            0.001           0.1059
0.0117          0.0111          0.0628          0.1594
0.1361          0.0856          0.0657          0.0523
0.0363          0.0309          40
2005  0.146           0.68            0.0026          0.1886
0.0293          0.0259          0.05            0.0949
```

```
0.0985          0.0613          0.0388          0.0211
0.0152          0.0315          40
2006  0.02            1.39            0               0.0408
0.0299          0.0579          0.0639          0.1108
0.1148          0.1253          0.0736          0.0567
0.0297          0.0479          40
2007  0.039           0.92            0               0.0288
0.015           0.0157          0.0183          0.032
0.0448          0.0467          0.0398          0.036
0.0247          0.0536          40
2008  0.233           0.62            0.0009          0.0724
0.0113          0.0503          0.0458          0.0518
0.0504          0.0508          0.0407          0.0344
0.0339          0.076           40
2009  0.142           0.65            0.0024          0.1197
0.046           0.0415          0.0634          0.0642
0.0626          0.0552          0.0508          0.0396
0.0371          0.097           40
2010  0.167           0.66            0               0.0581
0.0604          0.0422          0.0354          0.0524
0.0565          0.0339          0.0227          0.0106
0.0136          0.0312          40
2011  0.2             0.64            0               0.123
0.0503          0.036           0.049           0.0543
0.0424          0.0338          0.0176          0.01
0.0047          0.016           40
2012  0.086           0.7             0               0.0549
0.0272          0.0343          0.0464          0.0352
0.055           0.053           0.0517          0.0203
0.0254          0.0472          40
2013  0.204           0.62            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-3 Data
1982  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1983  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1984  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1985  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1986  -999            -999            0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
1987  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1988  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1989  9.08            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1990  14.96           0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1991  6.07            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1992  7.96            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1993  9.7             0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  3.76            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1995  1.06            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.95            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1997  7.54            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  2.92            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1999  5.09            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  5.97            0.5             0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
2001  16.56           0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2002  9.54            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  10.66           0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  17.95           0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2005  8.33            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  15.09           0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  2.93            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2008  9.6             0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2009  2.63            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2010  2.59            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  2.88            0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2012  1.5             0.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2013  4.63            0.5             0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
# Index-4 Data
1982  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1983  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1984  4.389           0.32            0.0109          0.0816
0.1898          0.303           0.4594          0.4954
0.2869          0.2883          0.3093          0.3528
0.1259          0.5663          40
1985  3.689           0.31            0               0.0157
0.085           0.1857          0.1694          0.1328
0.1924          0.3175          0.2118          0.0928
0.1725          0.2544          40
1986  2.478           0.29            0.001           0.0277
0.0916          0.0497          0.1064          0.1877
0.2085          0.2295          0.3452          0.1073
0.1481          0.2172          40
1987  2.317           0.29            0.0231          0.0813
0.059           0.0602          0.1             0.133
0.1911          0.1373          0.0958          0.0521
0.0603          0.2195          40
1988  1.87            0.3             0.0038          0.0312
0.0462          0.0727          0.0453          0.0403
0.0756          0.1007          0.1641          0.079
0.0469          0.1949          40
1989  2.403           0.29            0               0.0425
0.0667          0.138           0.09            0.1154
0.1495          0.16            0.1046          0.0817
0.0569          0.2537          40
1990  1.988           0.3             0.0055          0.0893
0.1554          0.1118          0.1139          0.049
0.0501          0.1247          0.0874          0.062
0.0979          0.2141          40
1991  2.314           0.33            0.0049          0.022
0.0598          0.1194          0.1242          0.1487
0.093           0.1254          0.1071          0.1067
0.0608          0.1745          40
1992  1.441           0.36            0.0206          0.0484
0.0691          0.0423          0.0492          0.1229
0.1324          0.0849          0.0632          0.0636
0.0599          0.2687          40
1993  0.729           0.36            0.0033          0.021
0.0488          0.0327          0.017           0.0605
0.0596          0.0423          0.0489          0.0522
0.0368          0.1463          40
1994  1.329           0.34            0.0084          0.0371
0.0313          0.0691          0.0559          0.0551
0.0555          0.0799          0.0516          0.0312
0.0234          0.0853          40
```

```
1995  0.383           0.39            0.014           0.0445
0.0163          0.0261          0.0372          0.0336
0.0269          0.0245          0.0088          0.0097
0.0027          0.0058          40
1996  1.072           0.35            0.0409          0.1158
0.0164          0.0302          0.0264          0.0159
0.0146          0.0117          0.0244          0.0094
0.0015          0.0103          40
1997  0.692           0.36            0.0249          0.0771
0.0064          0.0367          0.0434          0.0295
0.0279          0.0219          0.0197          0.0109
0.0065          0.033           40
1998  1.158           0.35            0.0208          0.0603
0.0213          0.0149          0.0125          0.0095
0.008           0.0152          0.0084          0.0039
0.0025          0.0036          40
1999  1.359           0.34            0.153           0.0029
0.0157          0.0077          0.0212          0.0341
0.0235          0.0211          0.0193          0.0162
0.0088          0.0215          40
2000  1.381           0.34            0               0.1325
0.0715          0.0125          0.0301          0.0468
0.0726          0.0481          0.027           0.0196
0.0143          0.0415          40
2001  1.332           0.34            0.0367          0.1226
0.0349          0.0491          0.0627          0.0687
0.059           0.0607          0.0589          0.0366
0.0204          0.0665          40
2002  2.458           0.33            0               0.1795
0.0763          0.0264          0.0398          0.0301
0.0295          0.0226          0.0115          0.0058
0.0063          0.0111          40
2003  1.098           0.34            0.0009          0.1597
0.0092          0.0358          0.0481          0.0862
0.0739          0.0542          0.0426          0.0239
0.0224          0.0272          40
2004  0.982           0.35            0.001           0.1059
0.0117          0.0111          0.0628          0.1594
0.1361          0.0856          0.0657          0.0523
0.0363          0.0309          40
2005  1.023           0.35            0.0026          0.1886
0.0293          0.0259          0.05            0.0949
0.0985          0.0613          0.0388          0.0211
0.0152          0.0315          40
2006  1.123           0.4             0               0.0408
0.0299          0.0579          0.0639          0.1108
0.1148          0.1253          0.0736          0.0567
0.0297          0.0479          40
2007  0.916           0.35            0               0.0288
0.015           0.0157          0.0183          0.032
0.0448          0.0467          0.0398          0.036
0.0247          0.0536          40
2008  0.96            0.38            0.0009          0.0724
0.0113          0.0503          0.0458          0.0518
```

```
0.0504          0.0508          0.0407          0.0344
0.0339          0.076           40
2009  0.714           0.36            0.0024          0.1197
0.046           0.0415          0.0634          0.0642
0.0626          0.0552          0.0508          0.0396
0.0371          0.097           40
2010  0.483           0.53            0               0.0581
0.0604          0.0422          0.0354          0.0524
0.0565          0.0339          0.0227          0.0106
0.0136          0.0312          40
2011  0.496           0.4             0               0.123
0.0503          0.036           0.049           0.0543
0.0424          0.0338          0.0176          0.01
0.0047          0.016           40
2012  0.647           0.37            0               0.0549
0.0272          0.0343          0.0464          0.0352
0.055           0.053           0.0517          0.0203
0.0254          0.0472          40
2013  0.891           0.35            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-5 Data
1982  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1983  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1984  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1985  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1986  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1987  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1988  0.185           0.64            0               0
0               0               0               0
0               0               0               0
0               0               0
1989  0.174           0.63            0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
1990  0.878           0.58            0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.708           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.421           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.507           0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.286           0.61            0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.131           0.64            0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.197           0.64            0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.476           0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.224           0.64            0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.479           0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.242           0.62            0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.682           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.67            0.6             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  1.097           0.59            0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
2004  1.156           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.431           0.61            0               0
0               0               0               0
0               0               0               0
0               0               0
2006  -999            0               0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.436           0.65            0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.605           0.59            0               0
0               0               0               0
0               0               0               0
0               0               0
2009  1.59            0.65            0               0
0               0               0               0
0               0               0               0
0               0               0
2010  1.479           0.58            0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.467           0.68            0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.098           0.68            0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0.429           0.61            0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-6 Data
1982  0.78            0.44            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1983  1.04            0.37            137287.1827
354575.3521     420632.2076     480493.5356     504844.3543
408527.8935     304580.9203     214476.6489     183284.8779
124658.5024     64806.68422     138158.3694     11
1984  1.03            0.41            123186.9148
248235.6827     417489.9276     513254.6476     382375.2693
```

```
298983.913      216168.6691     146601.3574     118304.1198
70718.05077     58969.66415     170108.3124     11
1985  0.43            0.38            214711.803
333048.2555     469715.8842     655808.6596     463806.2503
323267.4707     245535.0696     164150.0099     130489.9272
71930.59412     44500.9276      98740.96442     8
1986  1.26            0.32            348240.7899     524019.755
1229932.923     1215354.713     1092235.61      825798.839
698841.7837     532257.115      475645.5495     310288.8925
197097.3958     661251.9443     24
1987  0.75            0.39            236518.0271
419699.7816     498927.6266     676241.8897     500142.8186
579204.8927     540988.5296     434773.2844     310561.3891
146526.0787     84545.89788     299894.4804     13
1988  1.12            0.33            215537.564
308838.7949     423941.8979     653845.5761     447076.6389
439342.0294     442480.425      379953.0748     282666.2342
147407.3805     104031.5152     422100.7857     19
1989  1.33            0.29            155661.2708
373105.8835     449771.4854     573693.0353     439790.4811
377173.9926     351015.1188     279226.876      220612.3613
97377.93007     72240.8385      188028.6289     38
1990  0.94            0.29            18361.19694
106737.1594     636229.7165     917182.6833     763577.4449
382204.6942     307465.6624     260336.8954     122214.0669
35822.25848     51065.00189     113486.3333     37
1991  1.01            0.27            12726.70938
213983.9221     564764.6182     1469309.252     1081402.5
598193.6883     400149.441      292895.7702     189883.3553
133118.2799     62439.7497      160079.1383     37
1992  1.34            0.28            15974.61144
196816.2912     408613.2622     1004575.224     889518.2386
533287.0585     330085.2063     234342.0294     179463.8314
135495.5305     75134.05227     182494.4176     40
1993  1.13            0.3             8872.449798
111747.5762     657036.4054     1158028.927     674782.8505
588736.3487     358444.1027     178266.0487     105710.4574
109660.5094     49020.68638     208219.7126     31
1994  0.84            0.3             12248.08735
73033.89489     331971.0216     974039.6486     477528.8901
224774.4112     202397.9753     154053.8323     90676.27183
44058.52799     21388.27141     44078.17361     18
1995  0.82            0.32            7841.417718
64453.24278     427483.3271     636316.0513     1282830.334
484549.5279     365925.7941     207760.2768     110977.6555
95199.64507     12339.49577     46196.82497     15
1996  0.83            0.32            3938.764212
91179.67978     159920.4865     373141.072      727251.0567
366047.0319     173982.2405     114896.6328     64185.36944
34506.28293     42115.65427     59565.01265     15
1997  0.54            0.31            0
10374.98629     126040.9252     171697.6864     232439.9531
401284.1953     436344.8309     175577.9033     65897.86322
67302.04778     27543.55278     54099.55562     11
```

```
1998  0.41            0.32            12706.40791
115866.7177     115210.3198     456941.0589     400420.3623
236903.7888     187269.5602     79864.03356     69566.30831
33658.86416     13194.78036     25373.89061     10
1999  0.44            0.33            12576.0673
247051.2292     313183.8831     739672.1839     391423.9289
496018.0101     277840.01       233701.7395     94001.79341
53002.43037     24421.07371     79382.52458     13
2000  0.3             0.33            0               55700.0271
534759.3071     714334.9066     341934.1231     288090.0229
274114.295      167546.9852     75438.78394     48044.26723
28615.49888     44361.53521     10
2001  0.42            0.3             1049.03155
319500.3698     840238.2178     626018.825      299426.8058
186702.8239     136951.5555     132282.6812     92969.13405
75302.47045     40052.79214     70889.99019     12
2002  0.6             0.3             0
369017.3337     856472.6562     645551.2962     944319.1747
717045.9219     453926.4189     306561.4352     157114.9126
100044.4906     41406.87648     77207.79211     19
2003  0.45            0.29            0
103313.4397     293719.583      574934.6728     553955.8772
350816.0279     183421.5827     110615.1329     75931.75745
36555.11283     34979.76884     79738.80063     20
2004  0.56            0.3             12720.53504
112316.0714     477258.0606     622881.4333     453833.4832
348589.4924     176981.3894     86556.78472     66644.00954
38954.95568     24947.83313     77429.57291     21
2005  0.52            0.32            41114.98709
73477.49895     378489.5473     432821.3586     385747.4424
262514.5442     168253.0638     91773.31483     43509.58602
30569.93706     28333.14219     60710.8547      22
2006  0.6             0.32            0
223479.0646     553167.2505     954870.4403     731506.01
448927.9775     291763.5601     179616.591      116903.8173
61312.79917     39762.86608     84518.59383     25
2007  0.48            0.31            1839.404458
204496.9212     898608.7964     1017489.968     867579.3701
605320.3643     437484.1561     305210.4824     190830.55
173241.891      76526.59121     145422.4692     21
2008  0.61            0.31            5405.190868
118555.9154     475595.1744     1009422.616     659556.0637
371753.6426     293944.8234     188586.8749     128326.0904
64324.77667     58651.76436     92148.42393     27
2009  0.61            0.33            1277.44091      254833.448
737285.1052     687114.3697     557760.136      410379.7911
237920.4824     123417.3306     78962.4349      35072.28169
20655.92385     50155.62215     21
2010  0.55            0.32            0
311586.0698     1298620.531     917440.1373     537883.5088
354891.1849     227745.9473     124239.1049     52036.10195
43689.7027      39141.26208     91333.21766     21
2011  0.42            0.36            2090.361906
244370.9741     683916.4785     518527.9644     406765.4184
```

```
229643.9296     133905.8341     58636.14015     26118.58906
19873.67631     8073.202775     13329.96477     16
2012  0.35            0.36            0
153553.8502     464815.8361     542932.0523     540530.7055
162254.5909     190289.136      118660.0212     169007.6339
49593.87457     75185.25443     40116.18249     13
2013  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Index-7 Data
1982  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1983  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1984  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1985  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1986  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1987  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1988  -999            -999            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
1989  1.211           0.5             0.0506          0.0958
0.0847          0.0628          0.0445          0.0317
0.0296          0.0291          0.025           0.0123
0.0055          0.0116          40
1990  1.472           0.53            0.0123          0.0713
0.2404          0.2154          0.1767          0.1104
0.0956          0.0581          0.0397          0.0204
0.015           0.0393          40
1991  0.98            0.52            0.0058          0.0309
0.1074          0.1538          0.1355          0.0872
0.0739          0.0408          0.0225          0.0087
0.0019          0.0029          40
1992  1.483           0.51            0.0016          0.0144
0.0722          0.0747          0.0751          0.0453
0.036           0.0293          0.025           0.0151
```

```
0.0083          0.0119          40
1993  0.639           0.52            0.0122          0.0576
0.0562          0.0599          0.0542          0.0278
0.0155          0.0103          0.0084          0.0053
0.0021          0.0032          40
1994  0.356           0.54            0.0042          0.0269
0.0757          0.0776          0.0594          0.0312
0.024           0.0146          0.0072          0.0036
0.0019          0.0038          40
1995  0.539           0.52            0               0
0.0280575       0.037770312     0.098215686     0.022991901
0.019831609     0.016257304     0.009442133     0.011133044
0.001776667     0.038477092     40
1996  0.222           0.55            0
0.028797119     0.023157223     0.039315591     0.041000263
0.012527234     0.00825897      0.005285366     0.005831921
0.005234031     0.001868898     0.008107256     40
1997  0.106           0.59            0
0.003144211     0.006755429     0.009270686     0.007211987
0.005397549     0.005157043     0.00392287      0.001981301
0.000924922     0.000293054     0.046655377     40
1998  0.318           0.53            0
0.007942728     0.017614486     0.030596145     0.022009656
0.019426292     0.01627726      0.010829682     0.006226048
0.005893751     0.003591631     0.006300363     40
1999  0.572           0.52            0.020237433
0.032445167     0.057936767     0.045626762     0.064863641
0.063097211     0.041311996     0.026082344     0.0116575
0.00339256      0.006100795     0.000202296     40
2000  0.327           0.54            0               0.02270445
0.020890896     0.026612376     0.022016409     0.01541
0.015383718     0.011673256     0.003215989     0.002202085
0.002644886     0.003375282     40
2001  0.278           0.55            0.013738095
0.016548236     0.039883926     0.036762804     0.041713346
0.013906305     0.00630342      0.005415923     0.001726332
0.00252682      0.000366993     0.005502068     40
2002  1.418           0.5             0.010556634
0.022975171     0.107767529     0.204054532     0.204743815
0.10005948      0.049205712     0.036568229     0.019027824
0.011603243     0.005233505     0.036384636     40
2003  0.636           0.52            0
0.000785714     0.004265256     0.073109034     0.051365987
0.052642715     0.021470544     0.017526691     0.008325453
0.003379354     0.005027631     0.006881785     40
2004  0.338           0.54            0
0.020360266     0.039738813     0.027069109     0.027565621
0.020789854     0.007394016     0.002883183     0.001457394
0.000481306     0.000196476     0.003247511     40
2005  0.533           0.54            0.009435714
0.029102708     0.052973417     0.041522431     0.043761937
0.022413439     0.015113638     0.010490332     0.00689816
0.008039468     0.006458856     0.009308637     40
2006  0.654           0.52            0               0.0375166
```

```
0.008628873     0.05842224      0.045945488     0.033647246
0.026361585     0.014379663     0.014637634     0.010134862
0.005112546     0.009166411     40
2007  0.364           0.53            0
0.010303429     0.025291876     0.048678524     0.016152996
0.00774122      0.005583593     0.004571472     0.003505538
0.002266342     0.001247549     0.002813175     40
2008  0.817           0.51            0.000136933
0.027045156     0.065000745     0.098628893     0.078858565
0.042918416     0.030423748     0.02030037      0.015036145
0.01116722      0.012807782     0.03171218      40
2009  0.478           0.52            0.001385714
0.047701899     0.046936622     0.042780296     0.057146965
0.022562303     0.015885416     0.012518202     0.006595192
0.002745543     0.002027539     0.007674628     40
2010  0.423           0.53            0.001
0.018836724     0.06132749      0.03334         0.029224806
0.017902743     0.008821834     0.007301616     0.003139669
0.001739162     0.004242656     0.009075179     40
2011  0.141           0.59            0.011
0.024652747     0.028905304     0.030019725     0.03103264
0.01330693      0.005293346     0.002352259     0.000806594
0.00047551      0.000128571     0.000128571     40
2012  0.245           0.55            0.003157143     0.01547571
0.058296508     0.026016908     0.017904476     0.007725466
0.004381749     0.002008047     1.88679E-05     8.65546E-05
0               0               40
2013  0.445           0.53            -999            -999
-999            -999            -999            -999
-999            -999            -999            -999
-999            -999            0
# Phase Control
# Phase for F mult in 1st Year
1
# Phase for F mult Deviations
2
# Phase for Recruitment Deviations
2
# Phase for N in 1st Year
1
# Phase for Catchability in 1st Year
1
# Phase for Catchability Deviations
-1
# Phase for Stock Recruitment Relationship
3
# Phase for Steepness
3
# Recruitment CV by Year
0.5
0.5
0.5
0.5
0.5
```

```
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
# Lambdas by Index
1  1  1  1  1  1  1
# Lambda for Total Catch in Weight by Fleet
1
# Lambda for Total Discards at Age by Fleet
1
# Catch Total CV by Year and Fleet
0.17
0.2
0.21
0.23
0.17
0.17
0.21
0.12
0.12
0.1
0.14
0.14
0.23
0.16
0.22
0.18
0.24
0.22
0.27
0.16
```

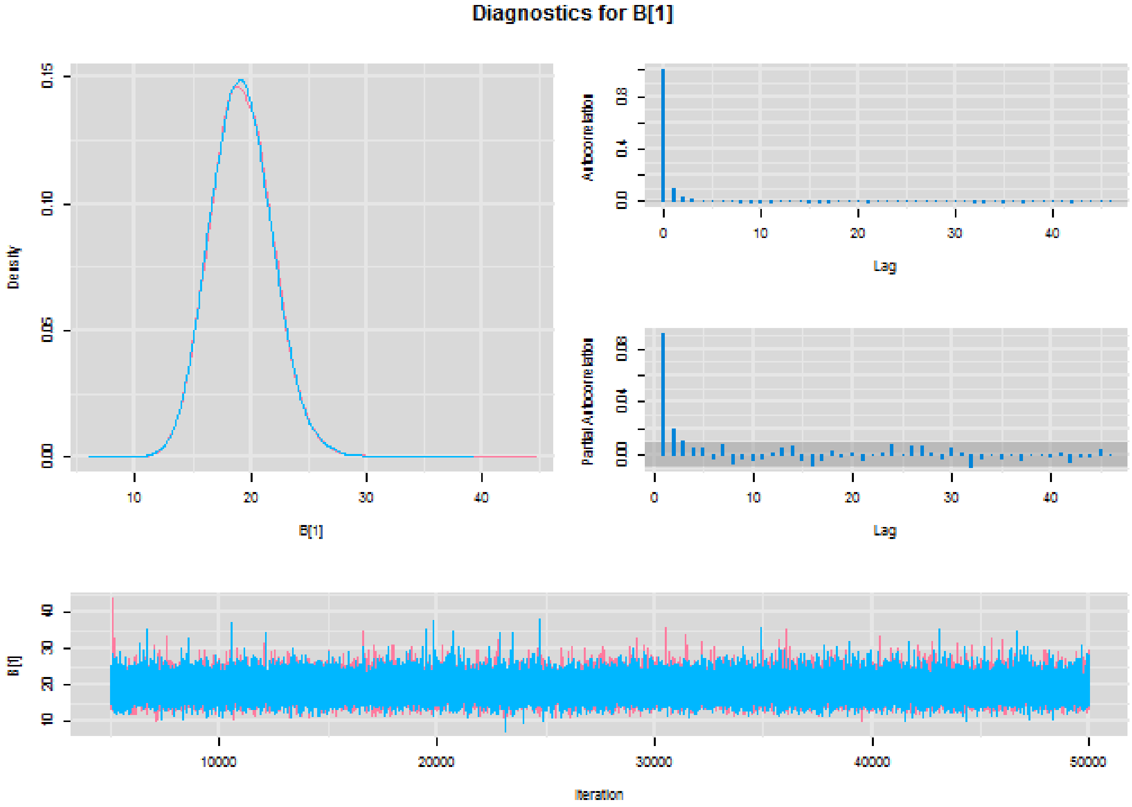
```
0.23
0.15
0.27
0.22
0.18
0.15
0.13
0.14
0.2
0.19
0.22
0.21
# Discard Total CV by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Catch Effective Sample Size by Year and Fleet
42
42
40
30
91
48
72
141
```

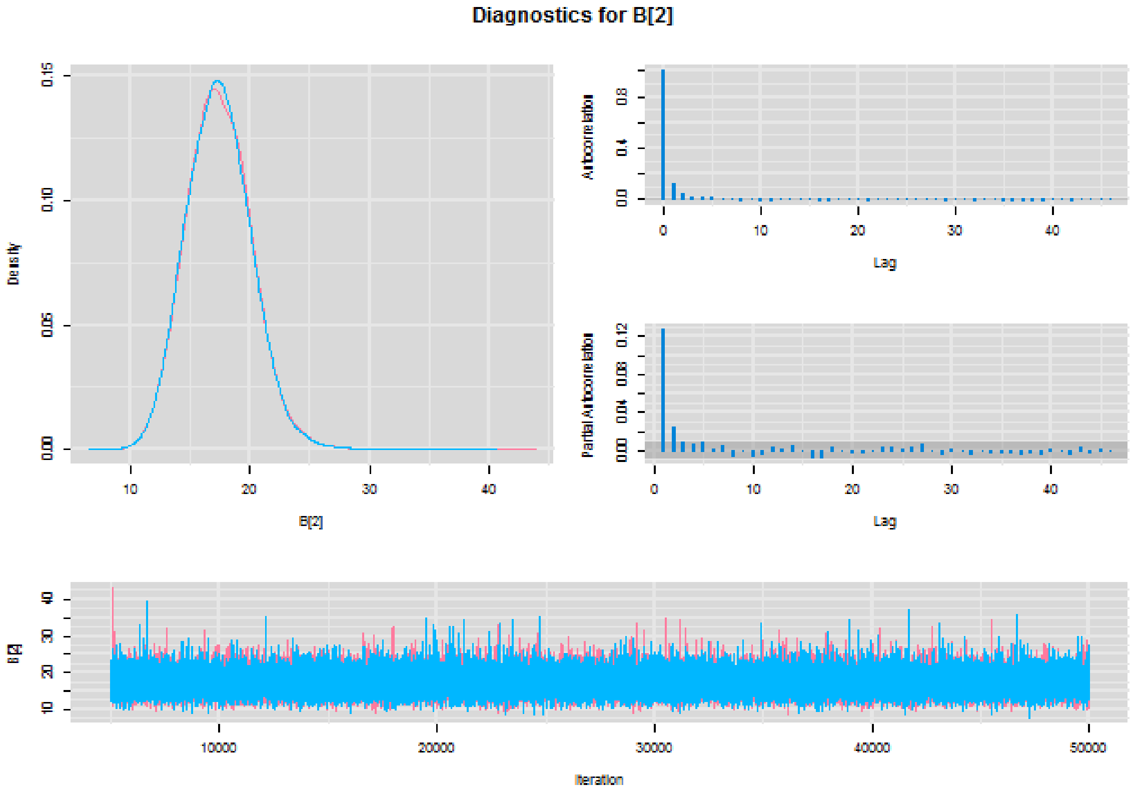
```
139
140
150
118
67
57
56
40
37
47
36
45
70
75
79
82
92
80
102
79
78
60
49
0
# Discard Effective Sample Size by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
```

```
0
0
0
# Lambda for F Mult in First year by Fleet
0
# CV for F Mult in First year by Fleet
1
# Lambda for F Mult Deviations by Fleet
0.5
# CV for F Mult Deviations by Fleet
0.5
# Lambda for N in 1st Year Deviations
0
# CV for N in 1st Year Deviations
1
# Lambda for Recruitment Deviations
0.5
# Lambda for Catchability in First year by Index
0  0  0  0  0  0  0
# CV for Catchability in First year by Index
1  1  1  1  1  1  1
# Lambda for Catchability Deviations by Index
0  0  0  0  0  0  0
# CV for Catchability Deviations by Index
1  1  1  1  1  1  1
# Lambda for Deviation from Initial Steepness
0
# CV for Deviation from Initial Steepness
1
# Lambda for Deviation from Unexploited Stock Size
0
# CV for Deviation from Unexploited Stock Size
1
# NAA Deviations Flag
1
# Initial Numbers at Age in 1st Year
8111  7364  6202  4831  3652  2590  2004  1351  983  677  450
1209
# Initial F Mult in 1st Year by Fleet
0.5
# Initial Catchabilty by Index
0.00001  0.00001  0.00001  0.00001  0.00001  0.00001  0.00001
# Stock Recruitment Flag
0
# Initial Unexploited Stock
1000
# Initial Steepness
0.75
# Maximum F
5.0
# Ignore Guesses (Yes=1)
0
# Projection Control
# Do Projections (Yes=1)
```

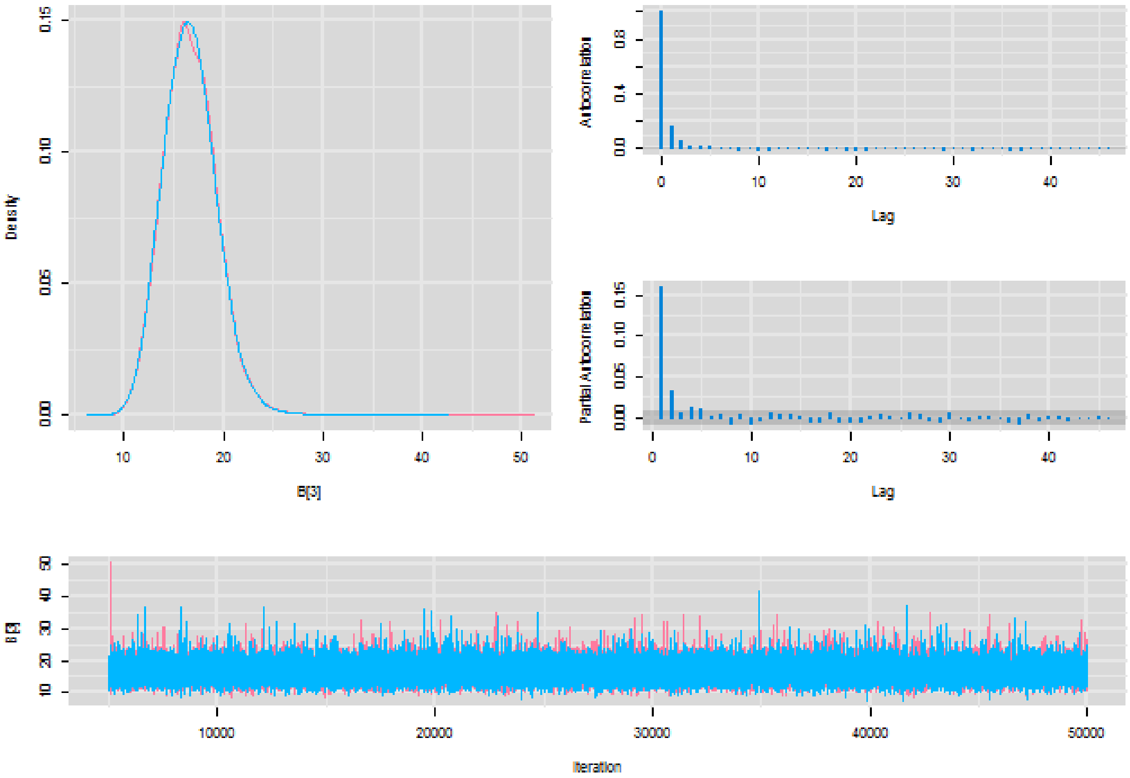
```
0
# Fleet Directed Flag
1
# Final Year in Projection
2014
# Projection Data by Year
2014     -1         3     -99        1
# Do MCMC (Yes=1)
1
# MCMC Year Option
1
# MCMC Iterations
1000
# MCMC Thinning Factor
200
# MCMC Random Seed
31415
# Agepro R Option
0
# Agepro R Option Start Year
0
# Agepro R Option End Year
0
# Export R Flag
0
# Test Value
-23456
######
###### FINIS ######
# Fleet Names
#$Comm + Rec
# Survey Names
#$MA Spring Trawl
#$RI Fall Trawl
#$RI Seine
#$CT Trawl
#$NY Trawl
#$MRIP CPUE
#$NJ Trawl
#
```

Appendix 1.1 – Diagnostic plots for the Southern New England base run of the Bayesian State Space Surplus Production Model

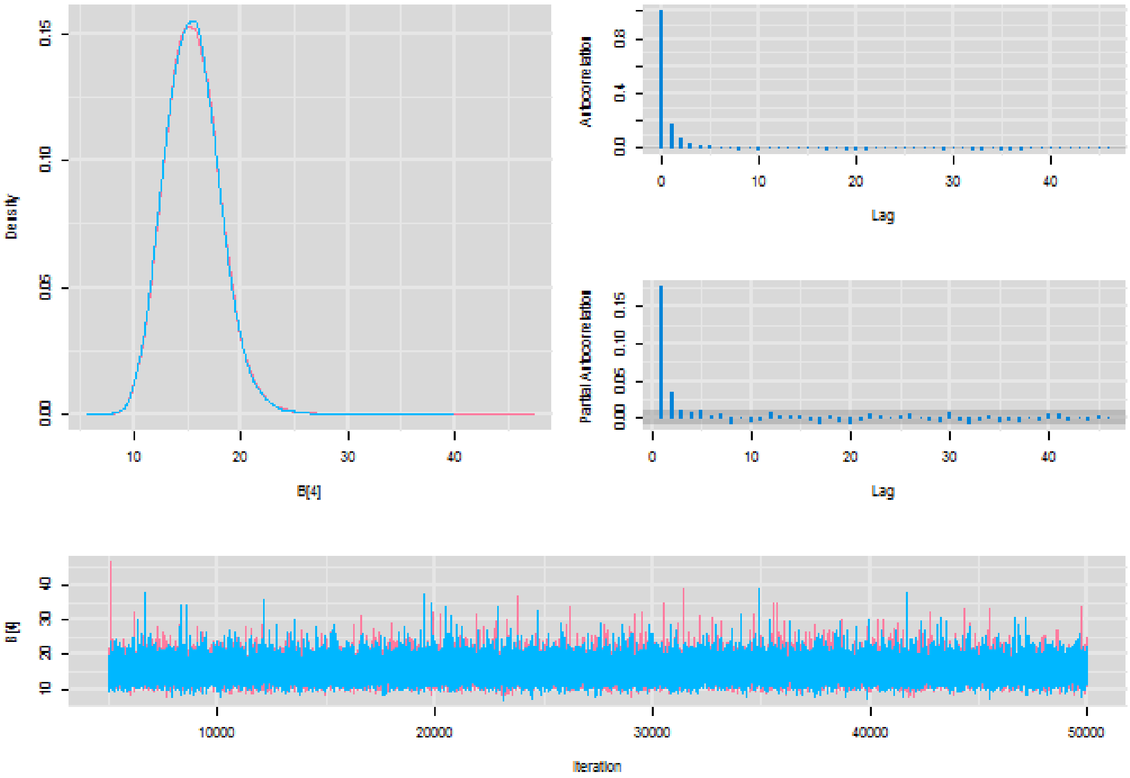

Diagnostics for B[1]


Diagnostics for B[2]

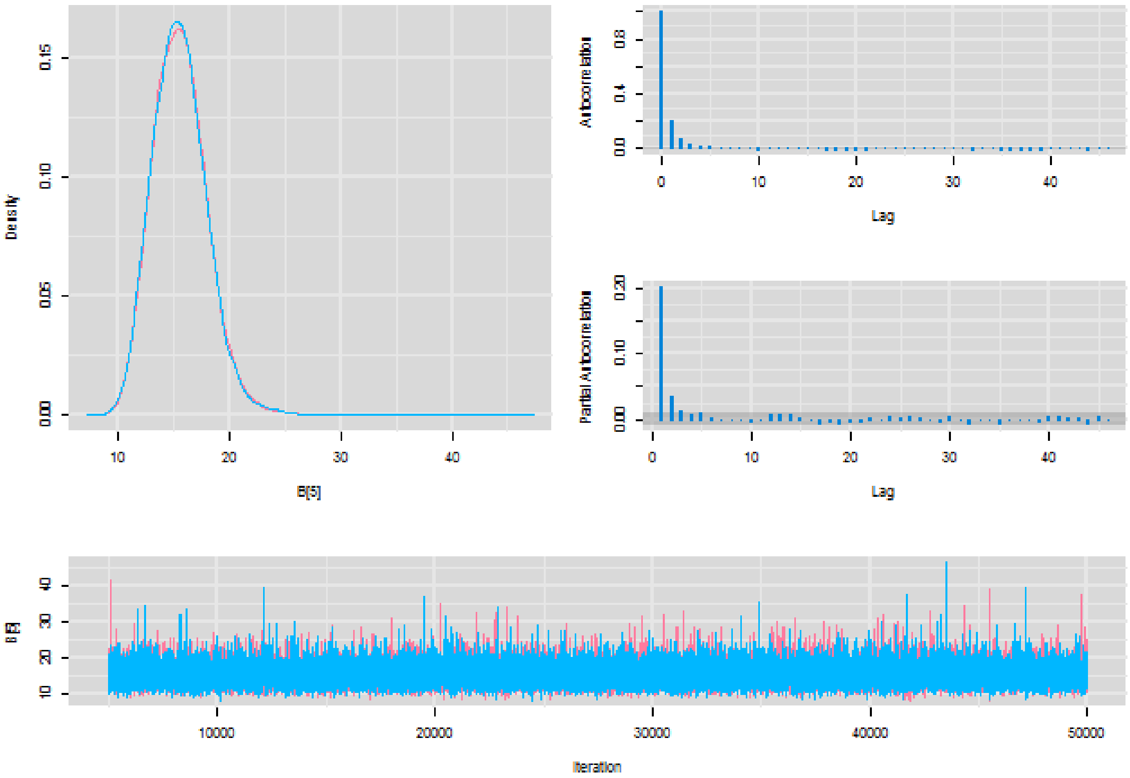
Diagnostics for B[3]



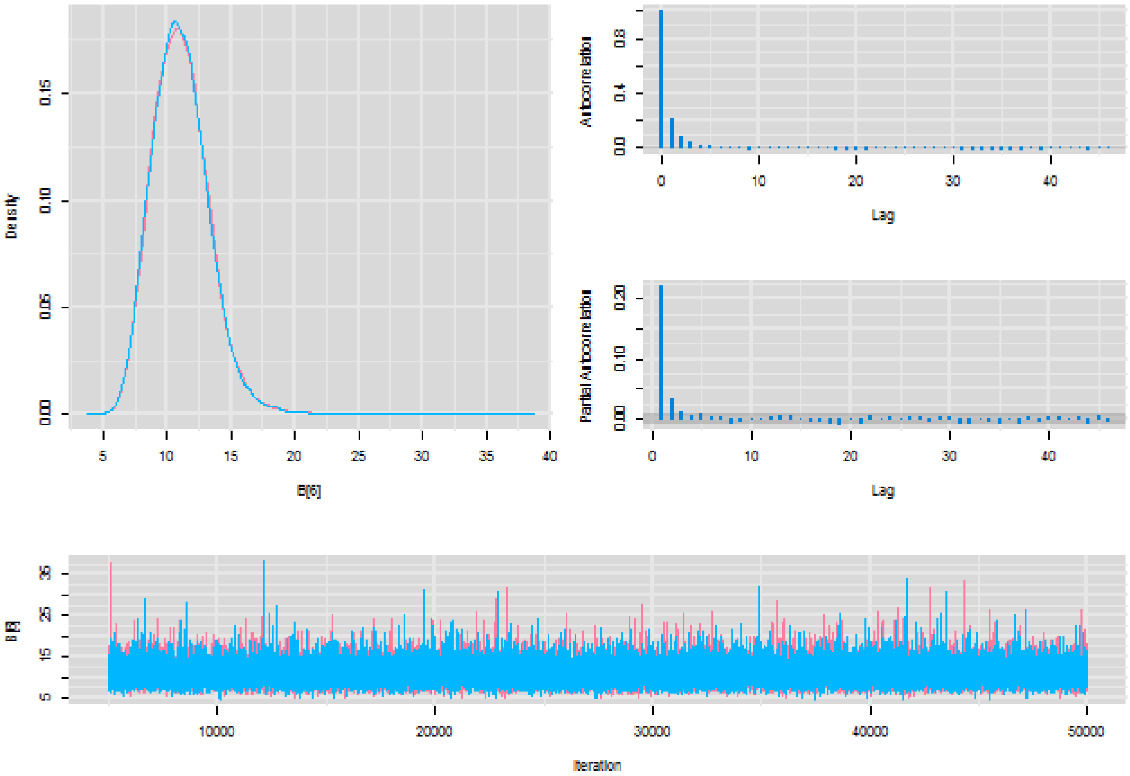
Diagnostics for B[4]



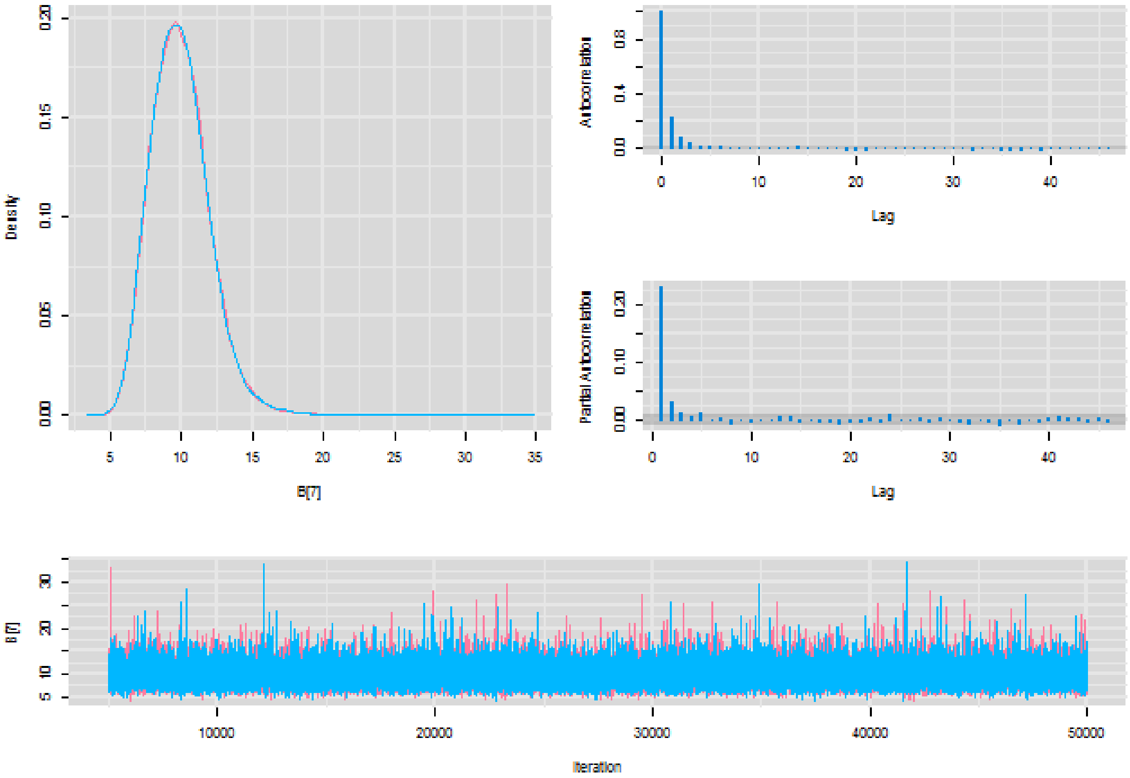
Diagnostics for B[5]



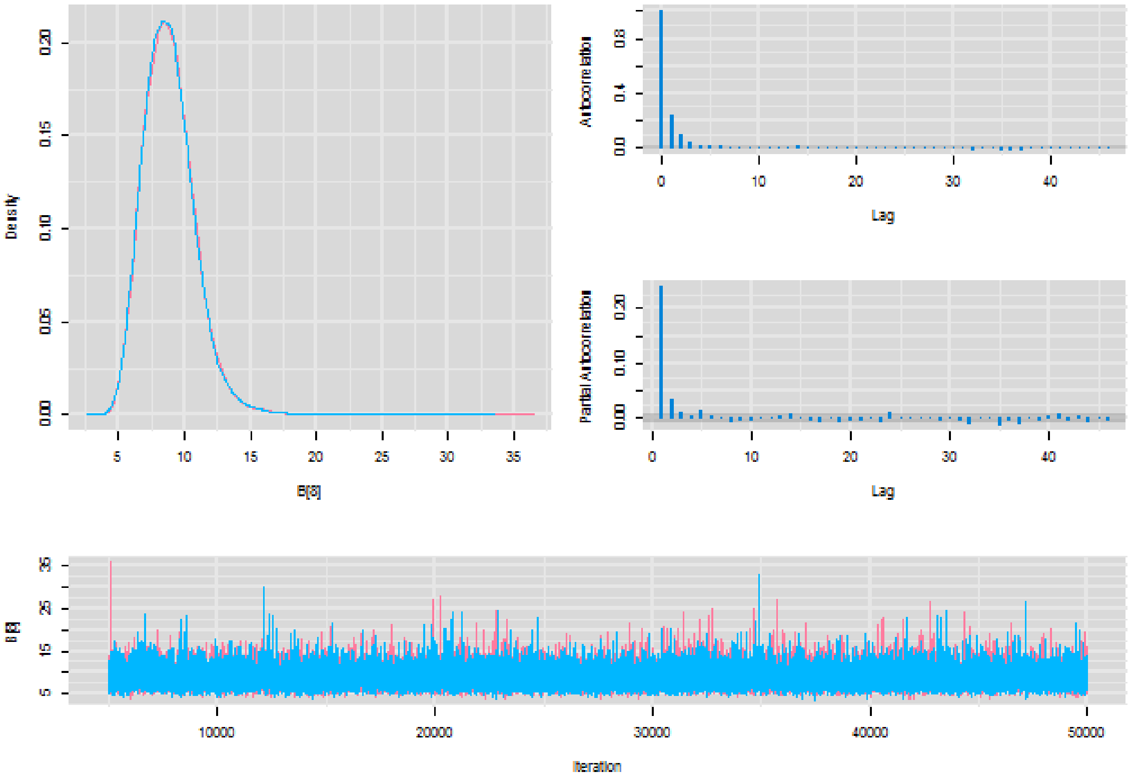
Diagnostics for B[6]



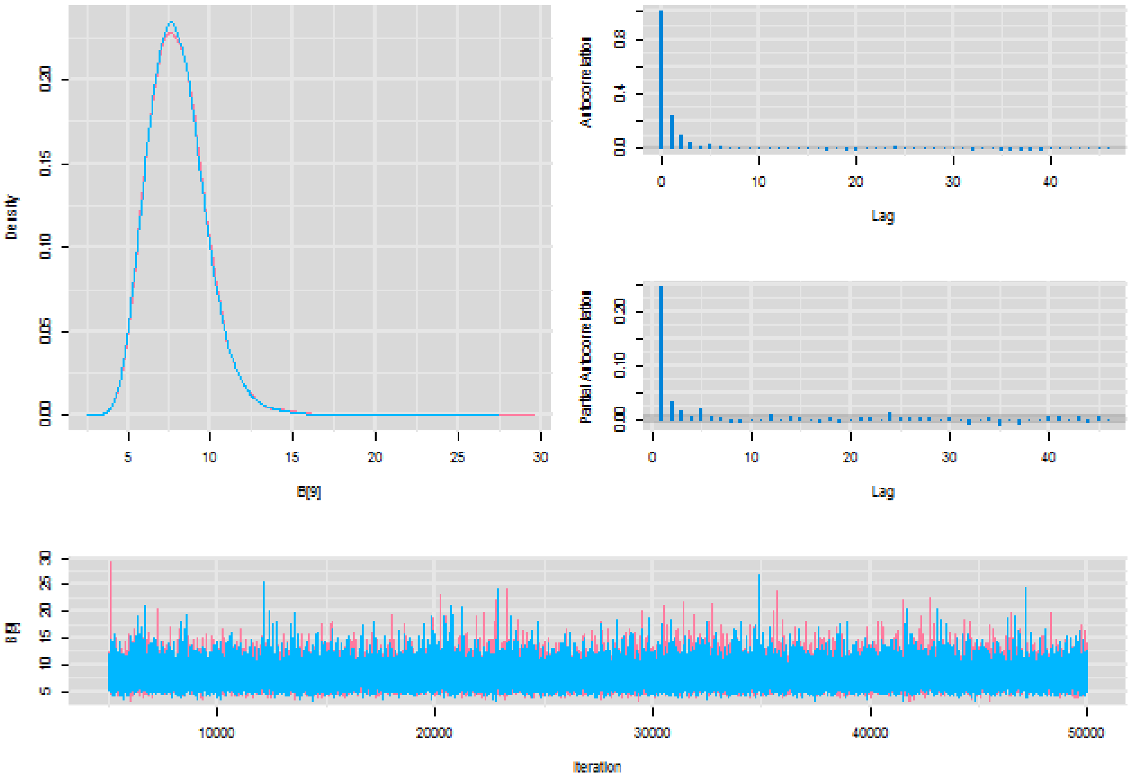
Diagnostics for B[7]



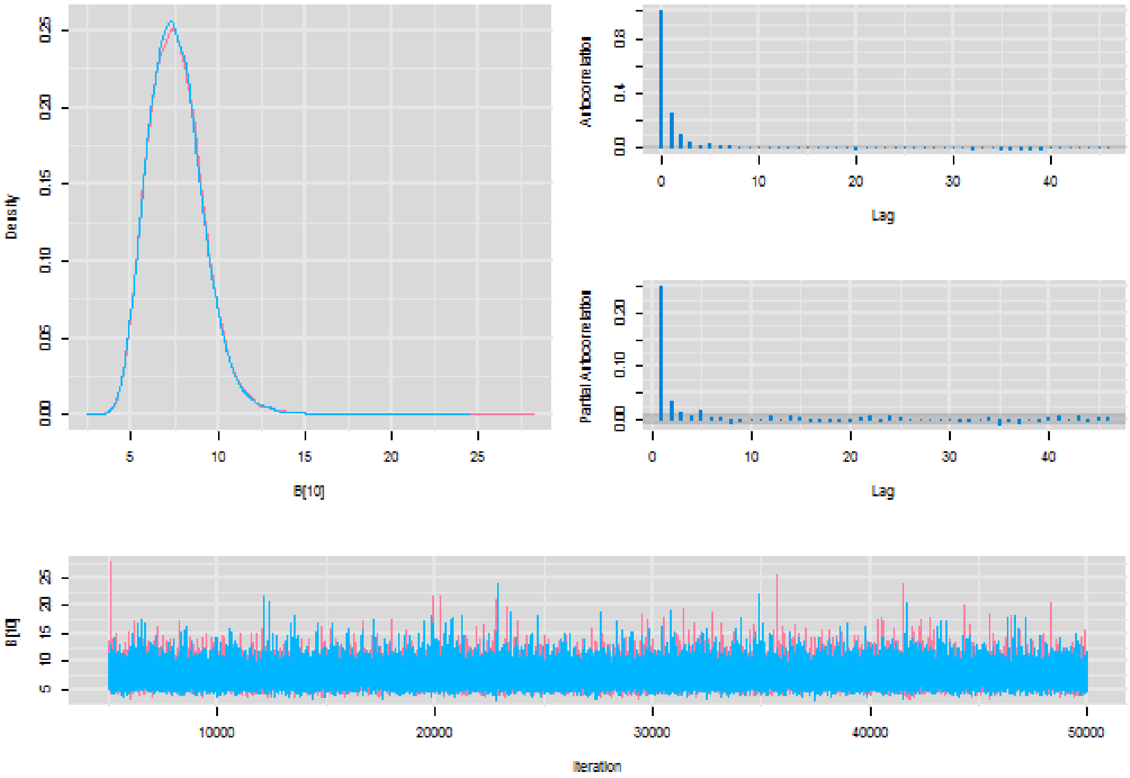
Diagnostics for B[8]



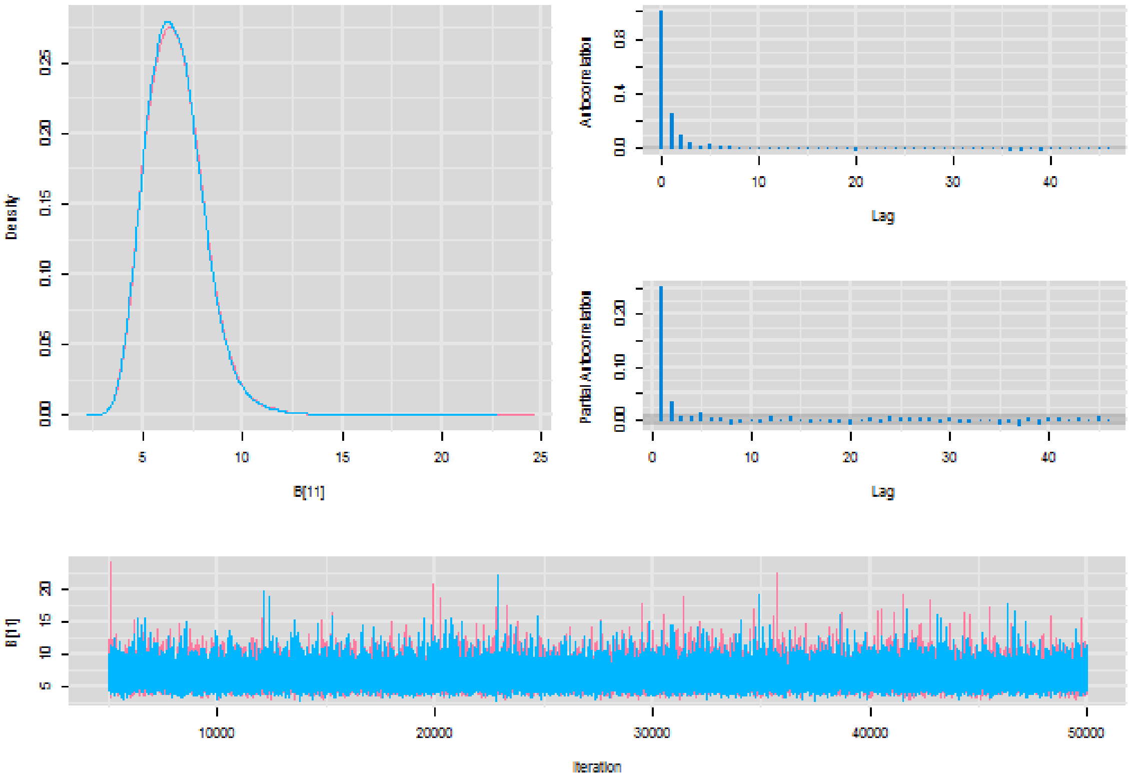
Diagnostics for B[9]



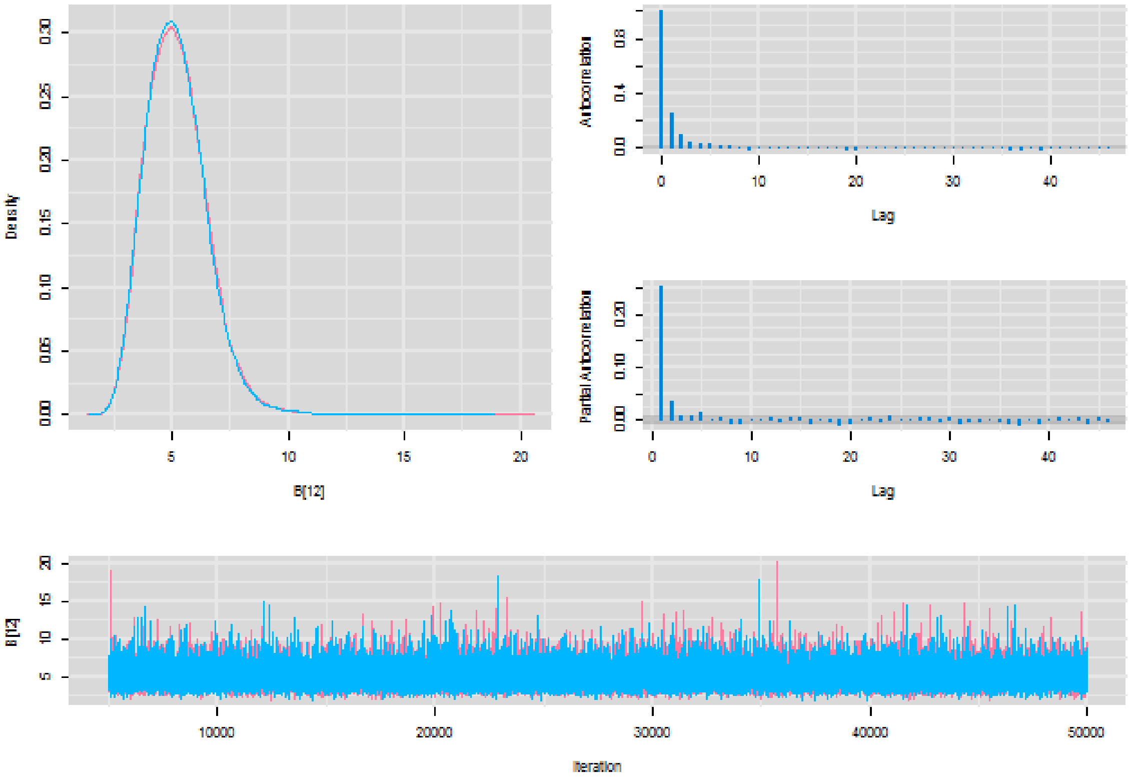
Diagnostics for B[10]



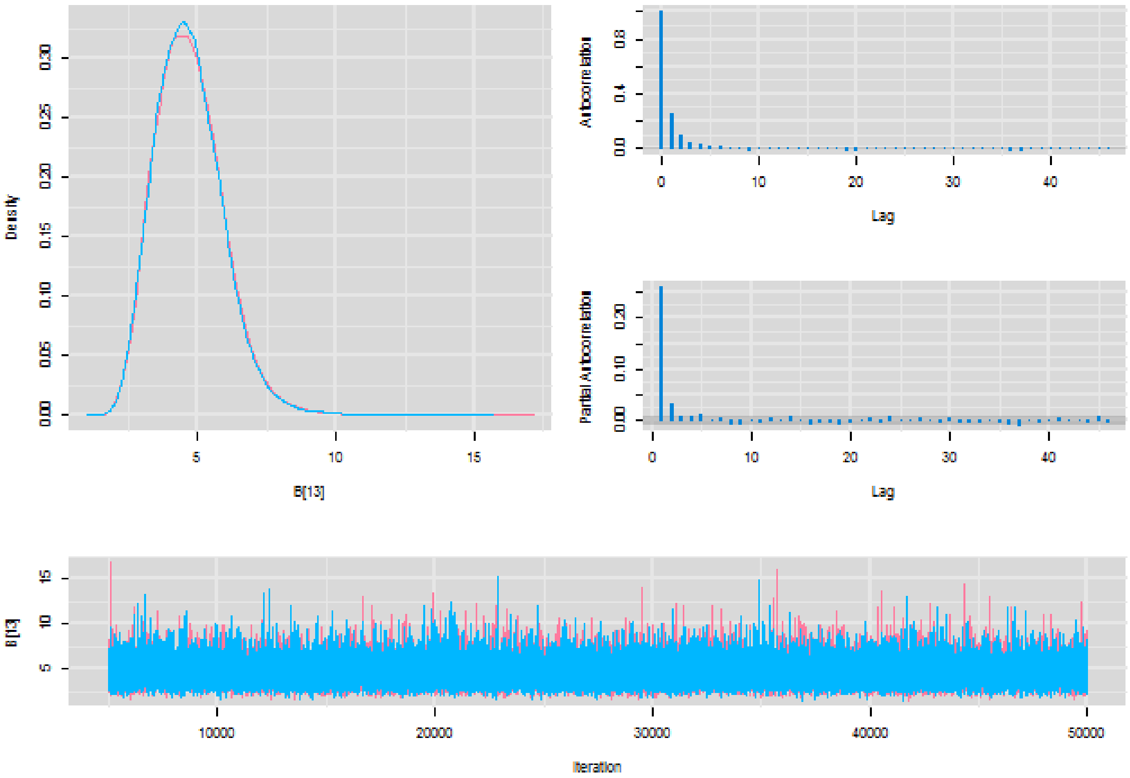
Diagnostics for B[11]



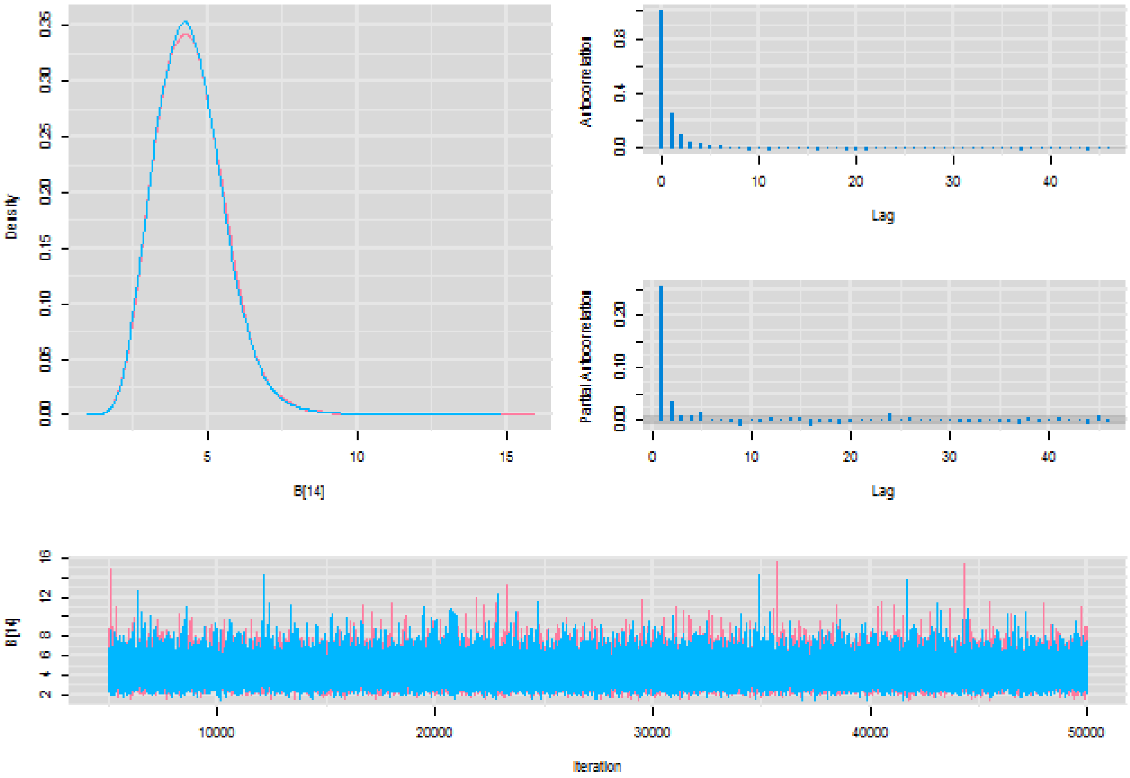
Diagnostics for B[12]



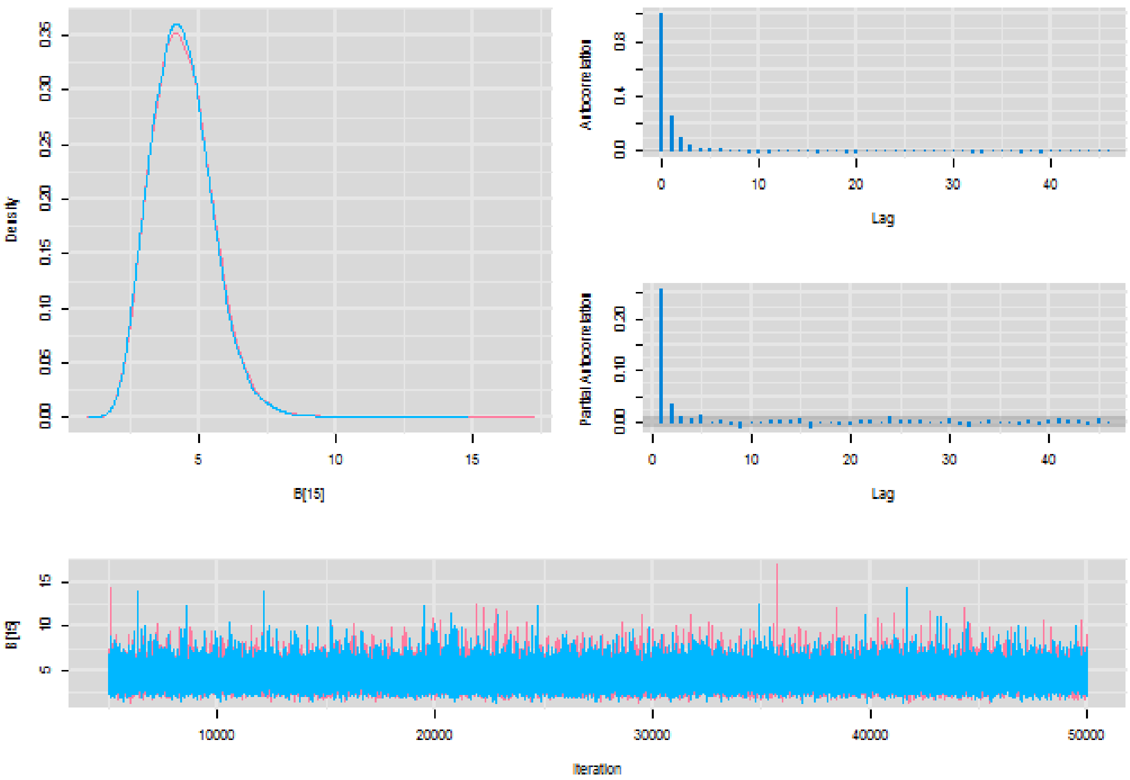
Diagnostics for B[13]



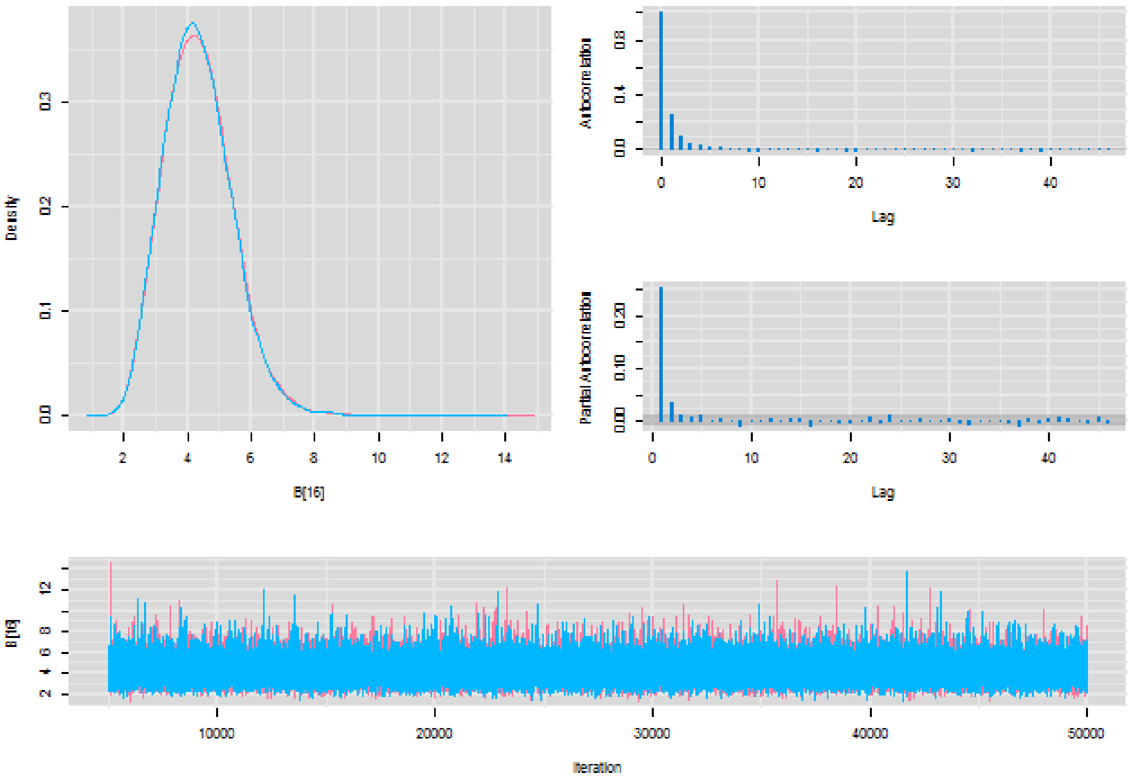
Diagnostics for B[14]



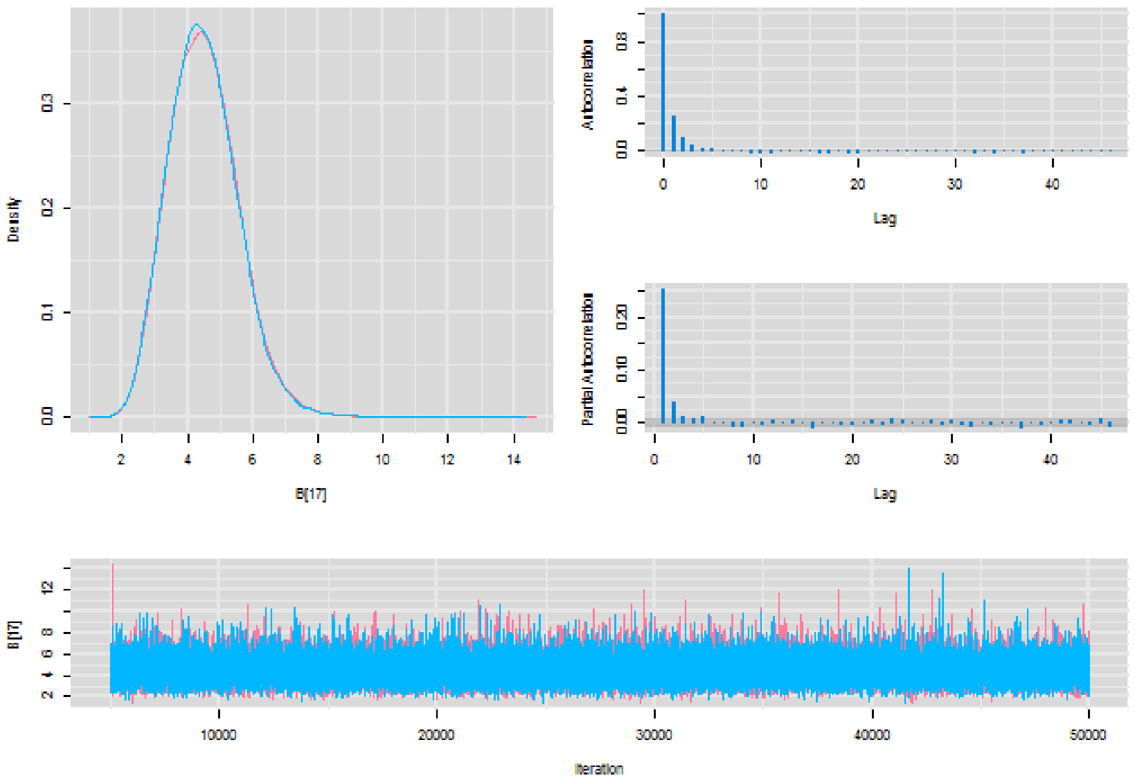
Diagnostics for B[15]



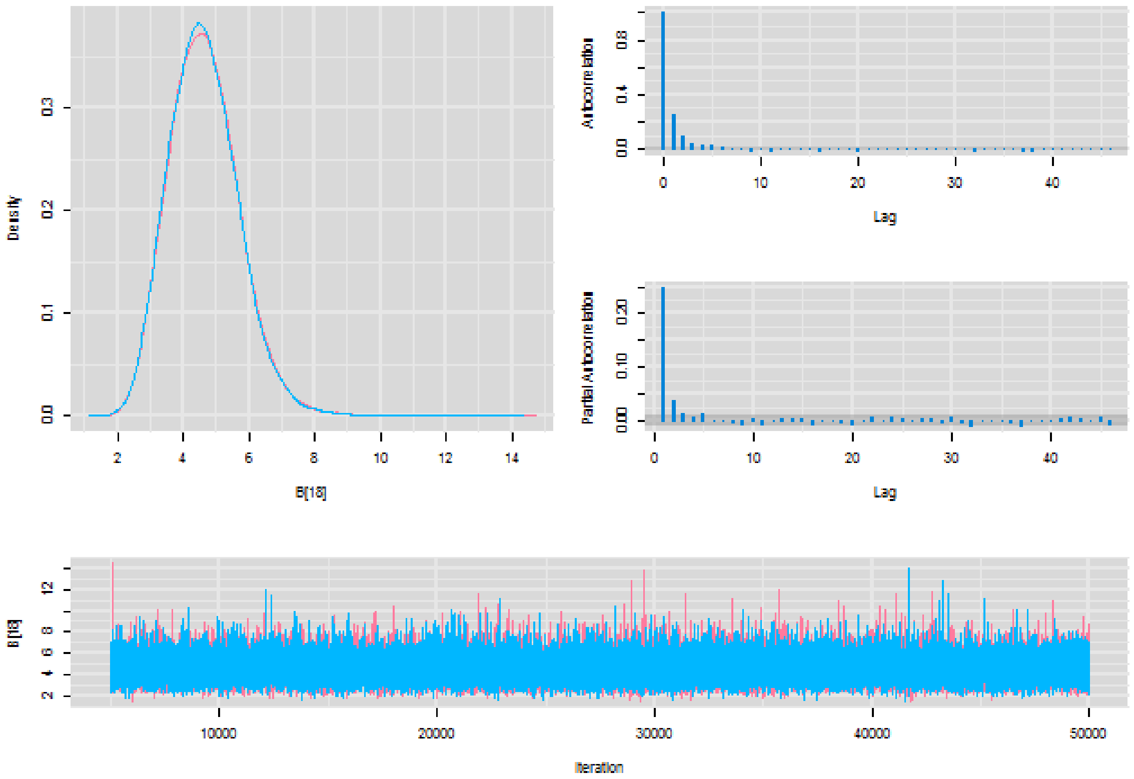
Diagnostics for B[16]



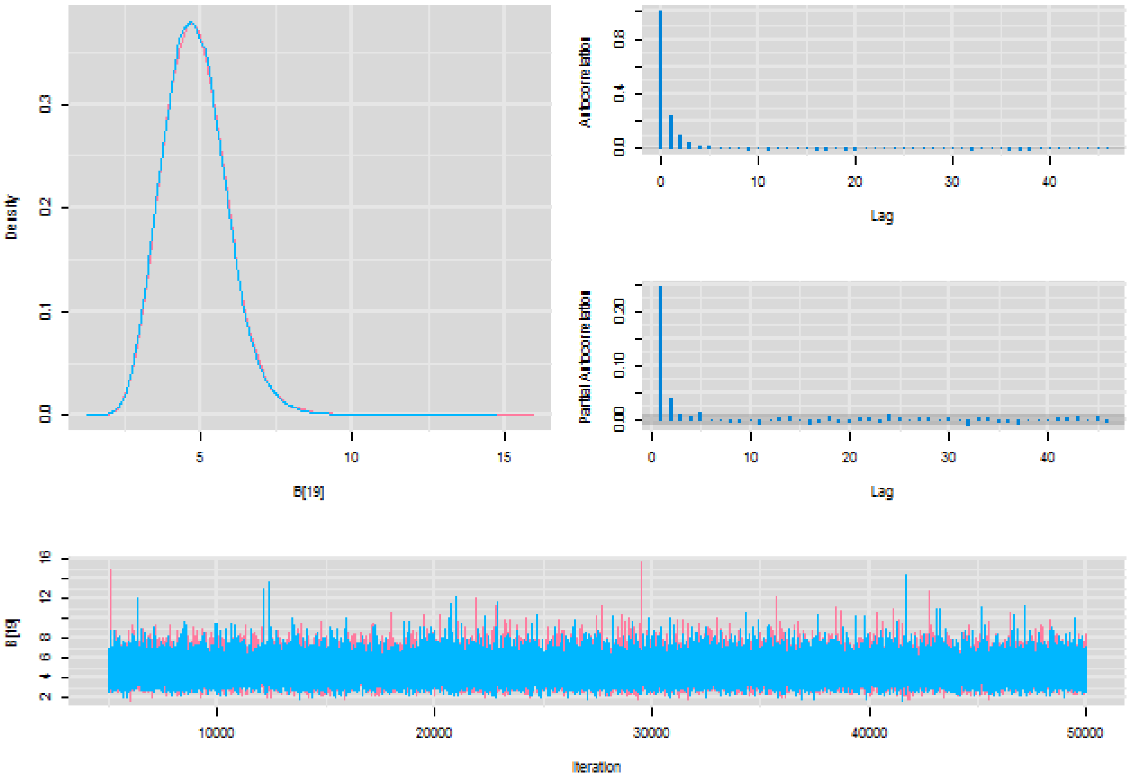
Diagnostics for B[17]



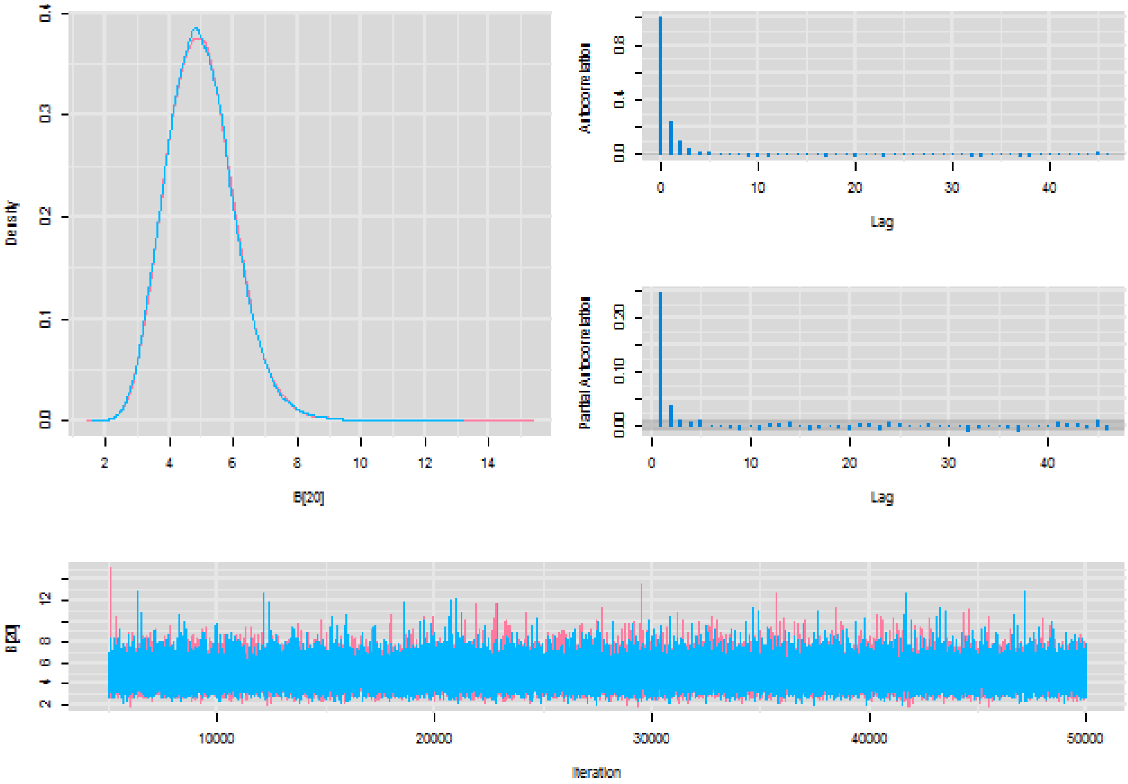
Diagnostics for B[18]



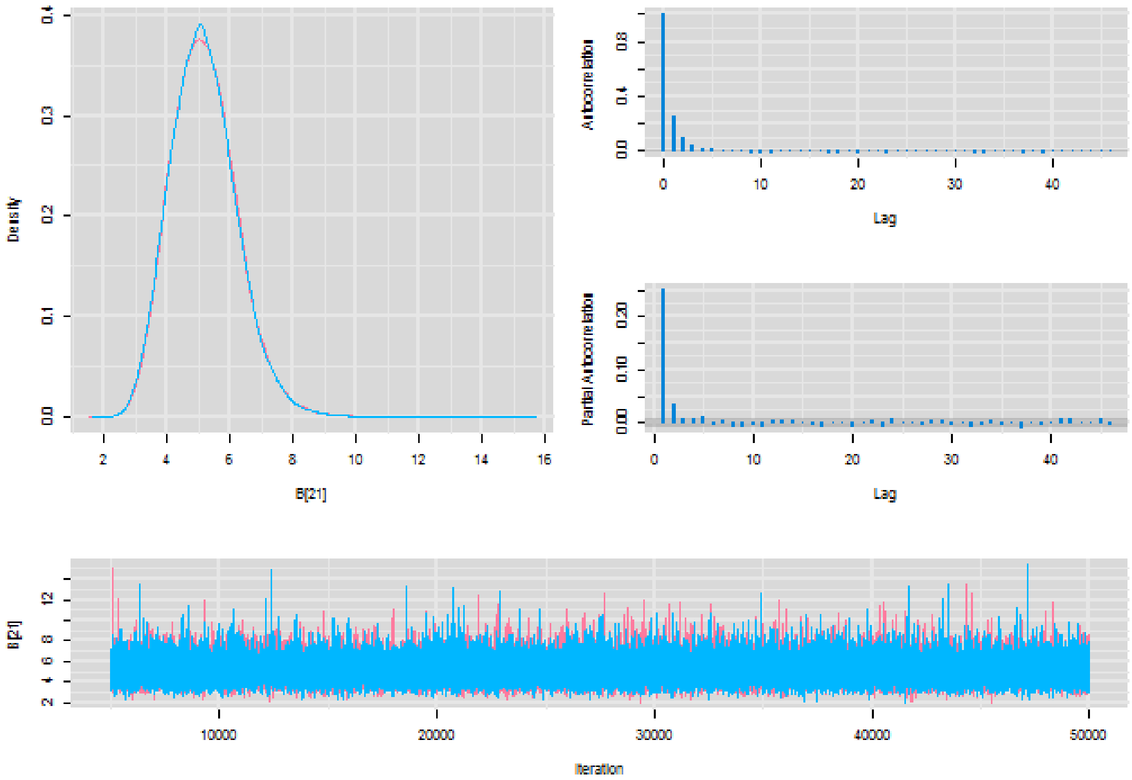
Diagnostics for B[19]



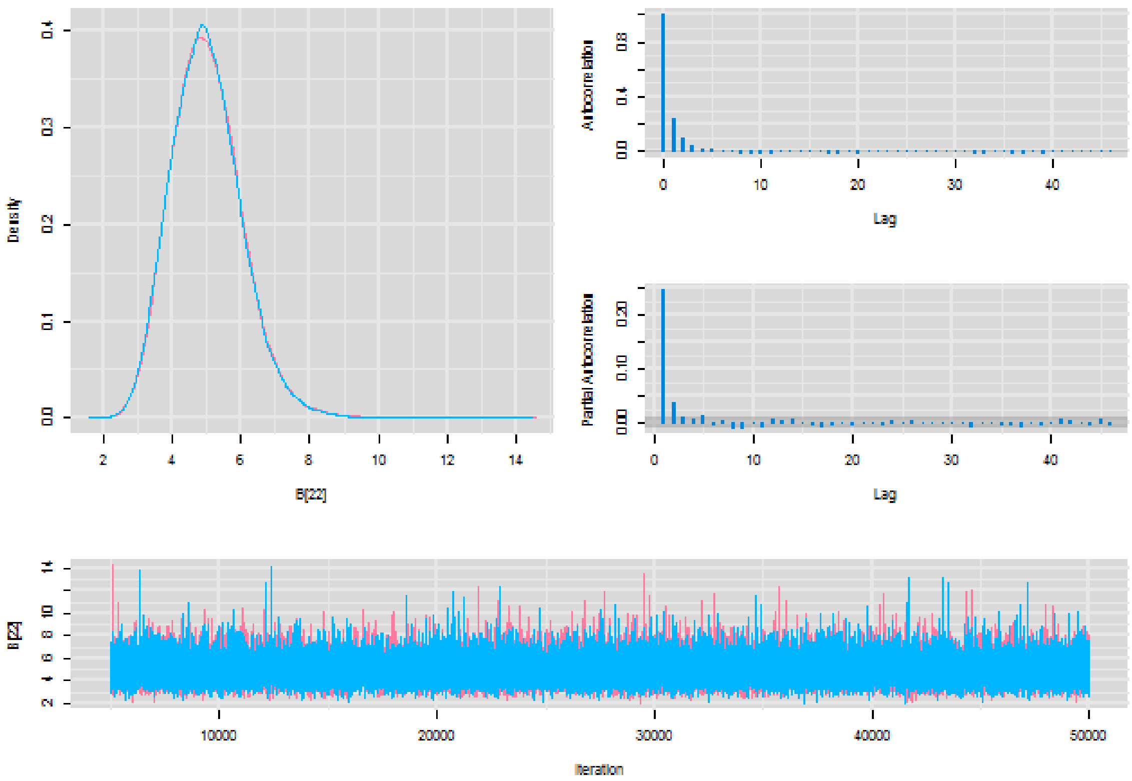
Diagnostics for B[20]



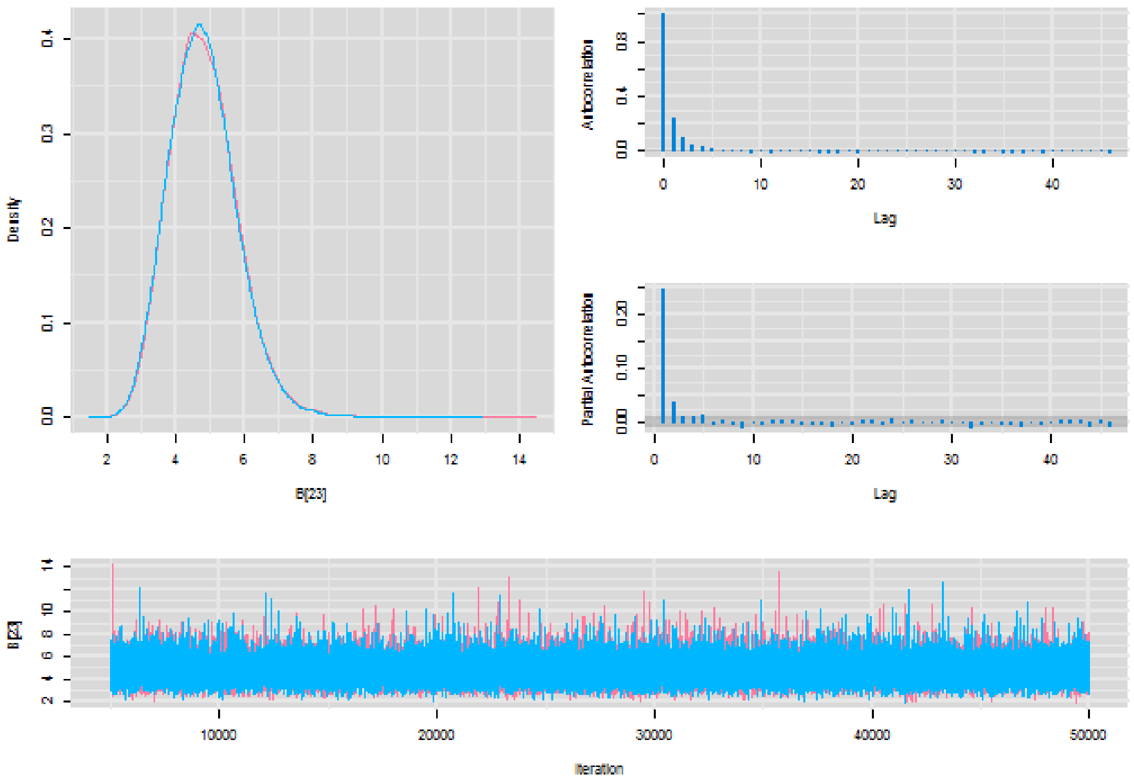
Diagnostics for B[21]



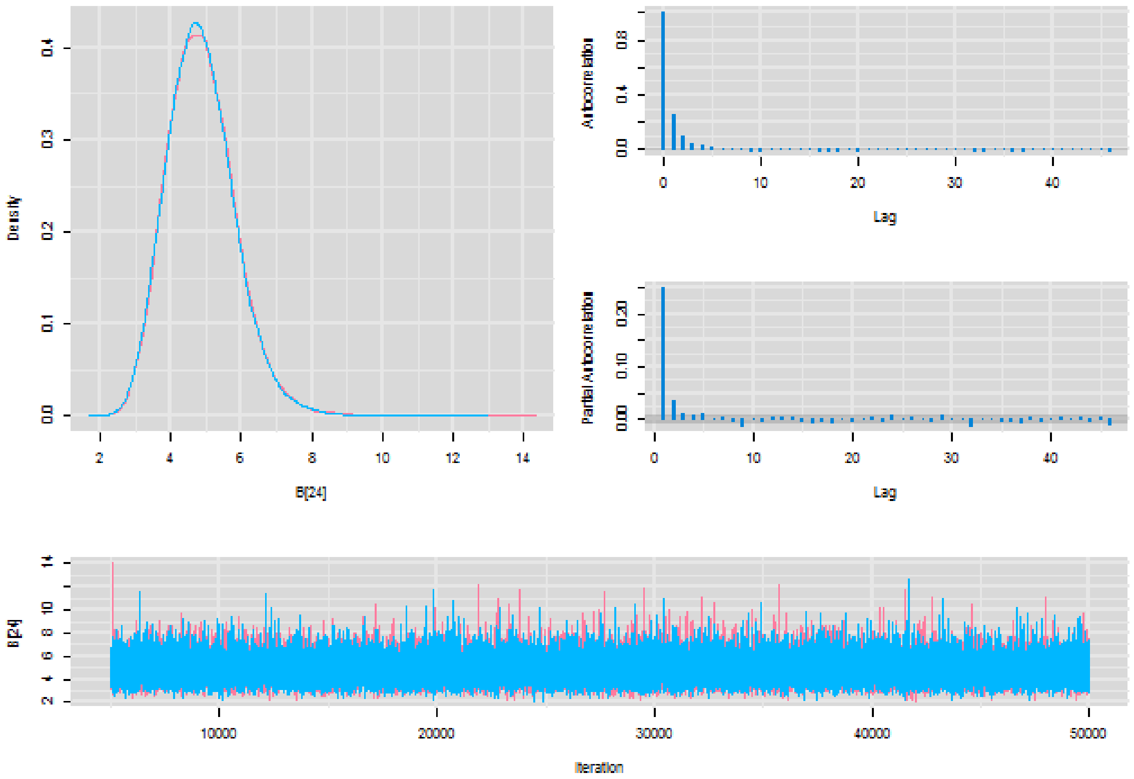
Diagnostics for B[22]



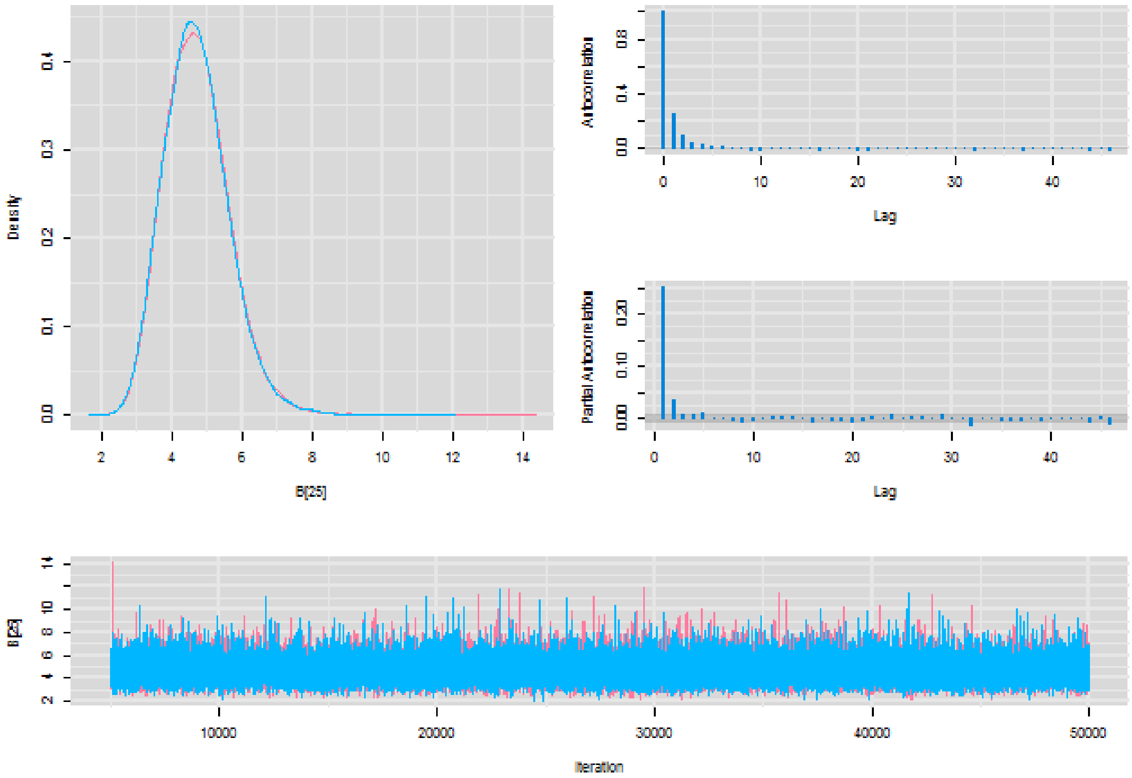
Diagnostics for B[23]



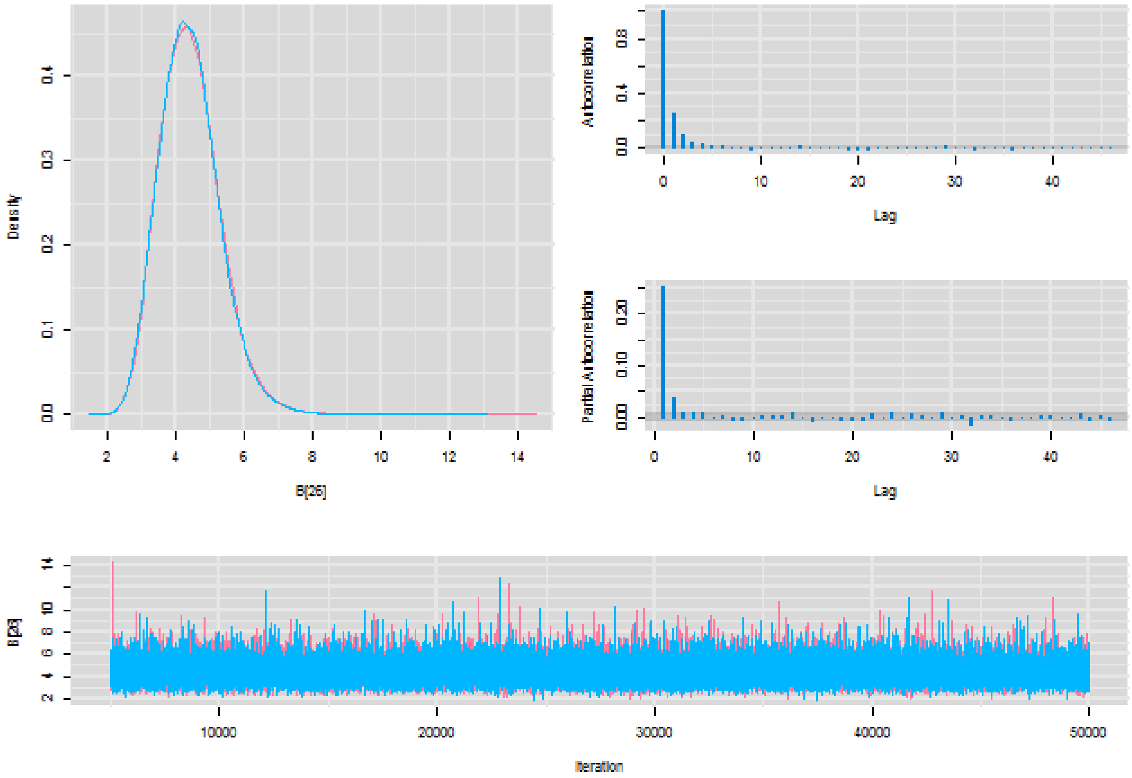
Diagnostics for B[24]



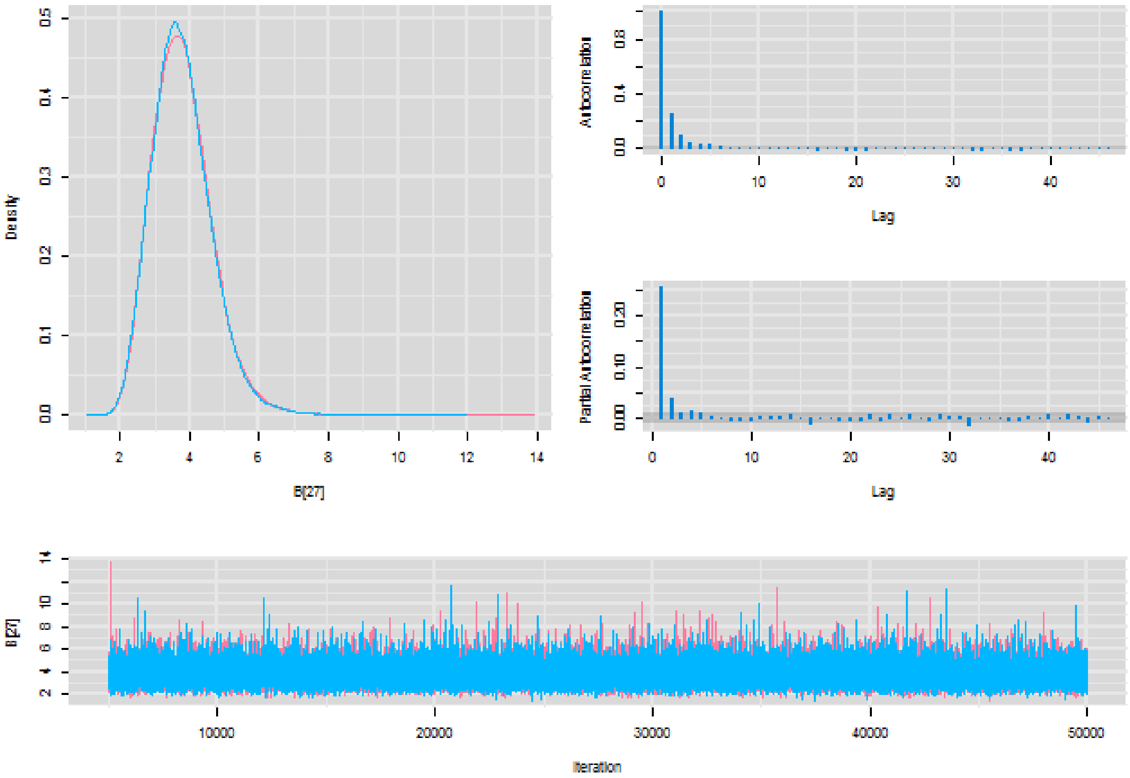
Diagnostics for B[25]



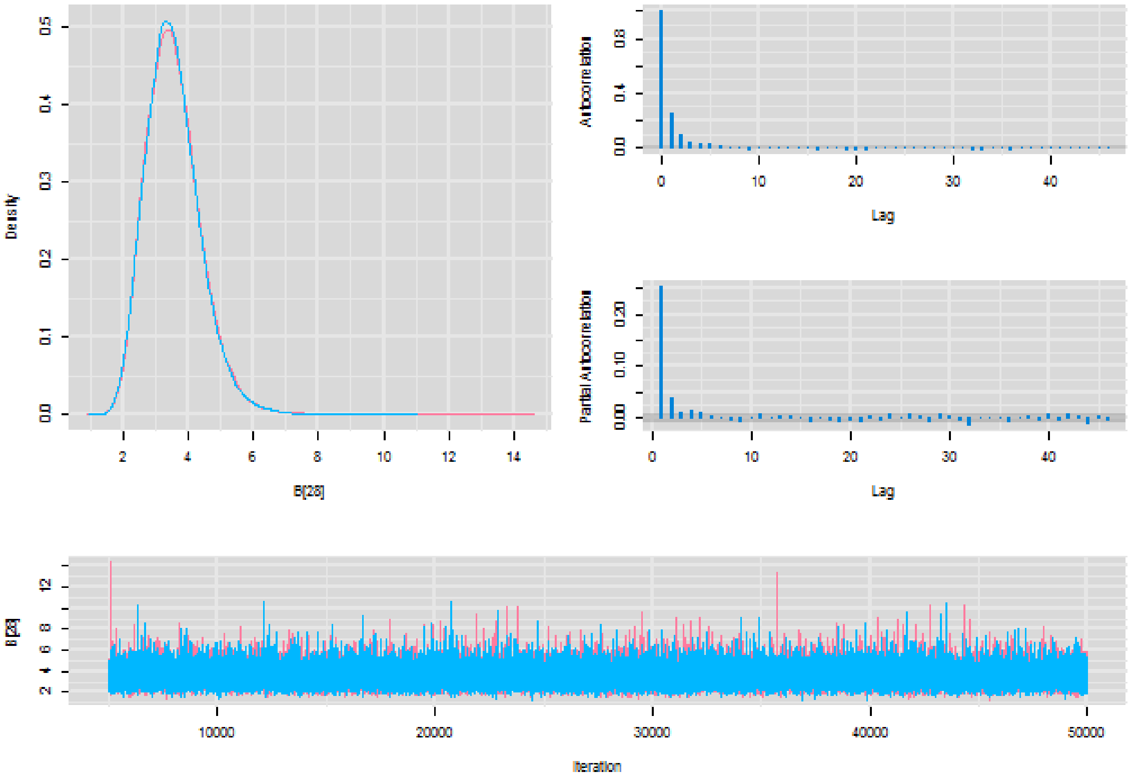
Diagnostics for B[26]



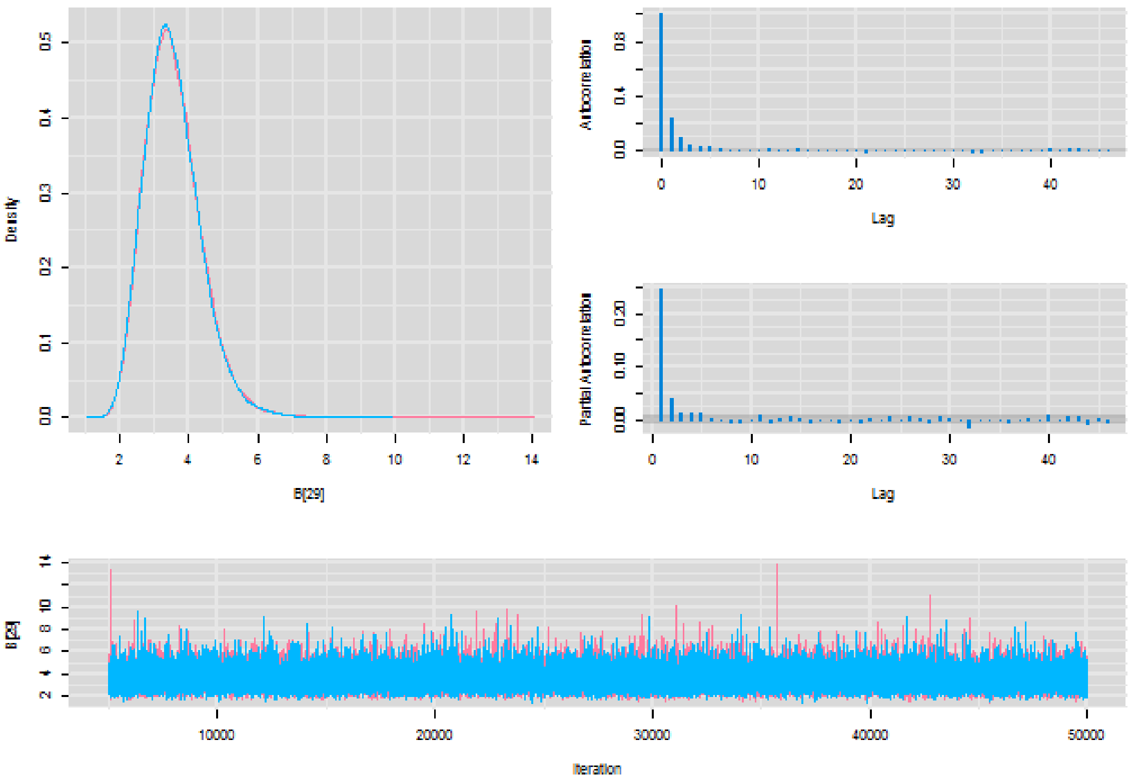
Diagnostics for B[27]



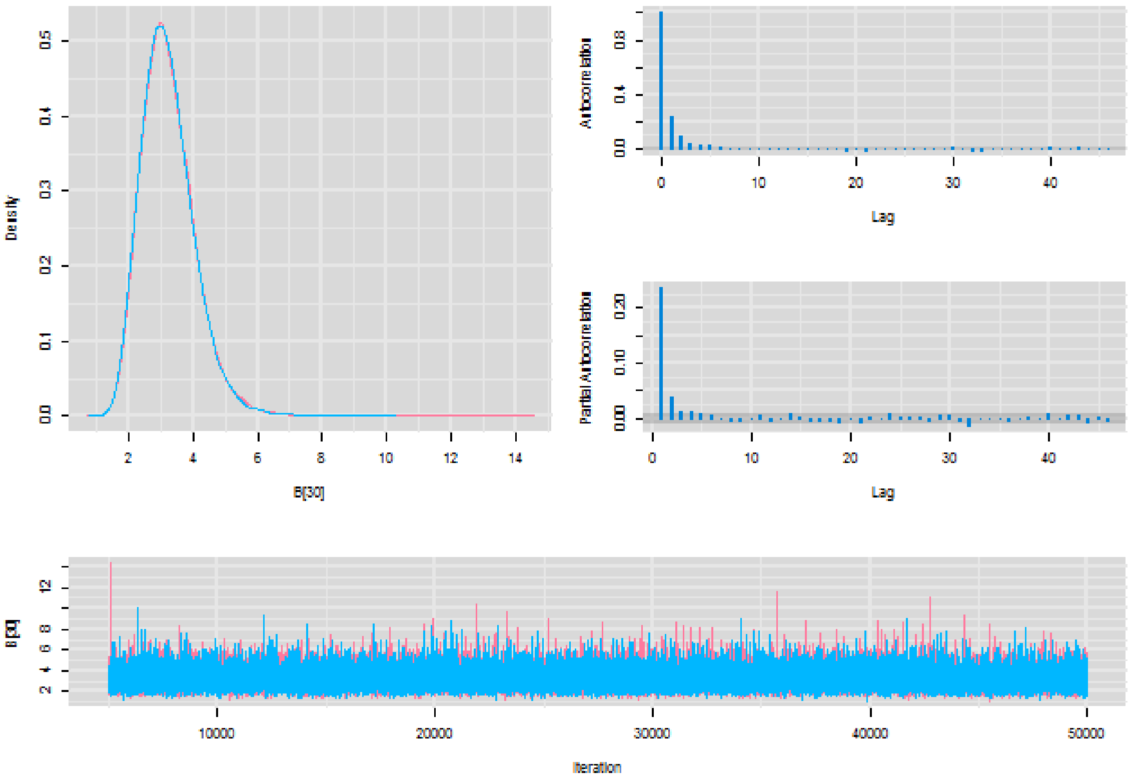
Diagnostics for B[28]



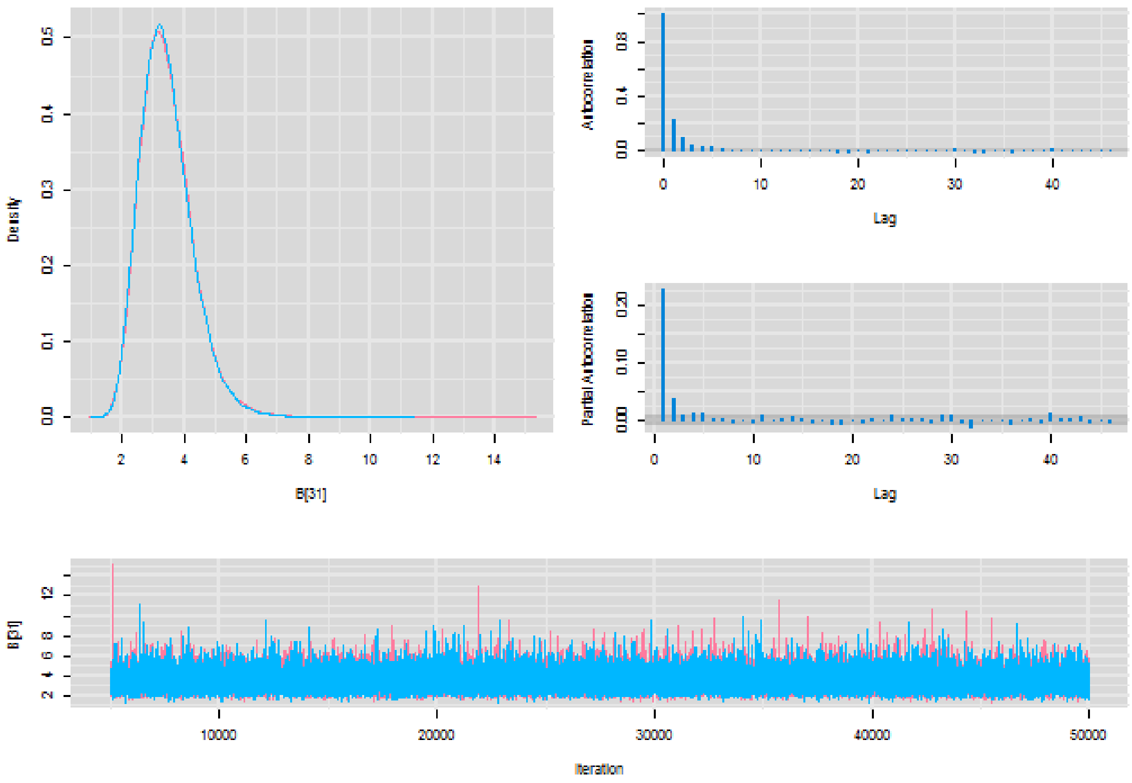
Diagnostics for B[29]



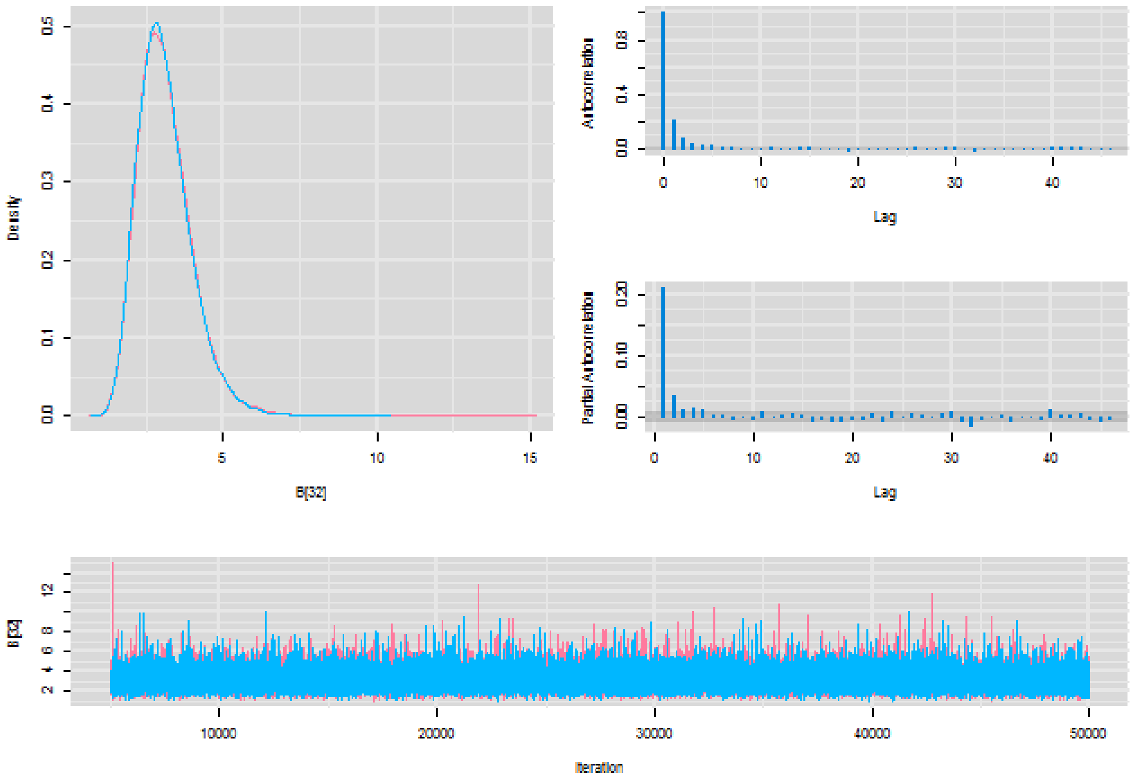
Diagnostics for B[30]



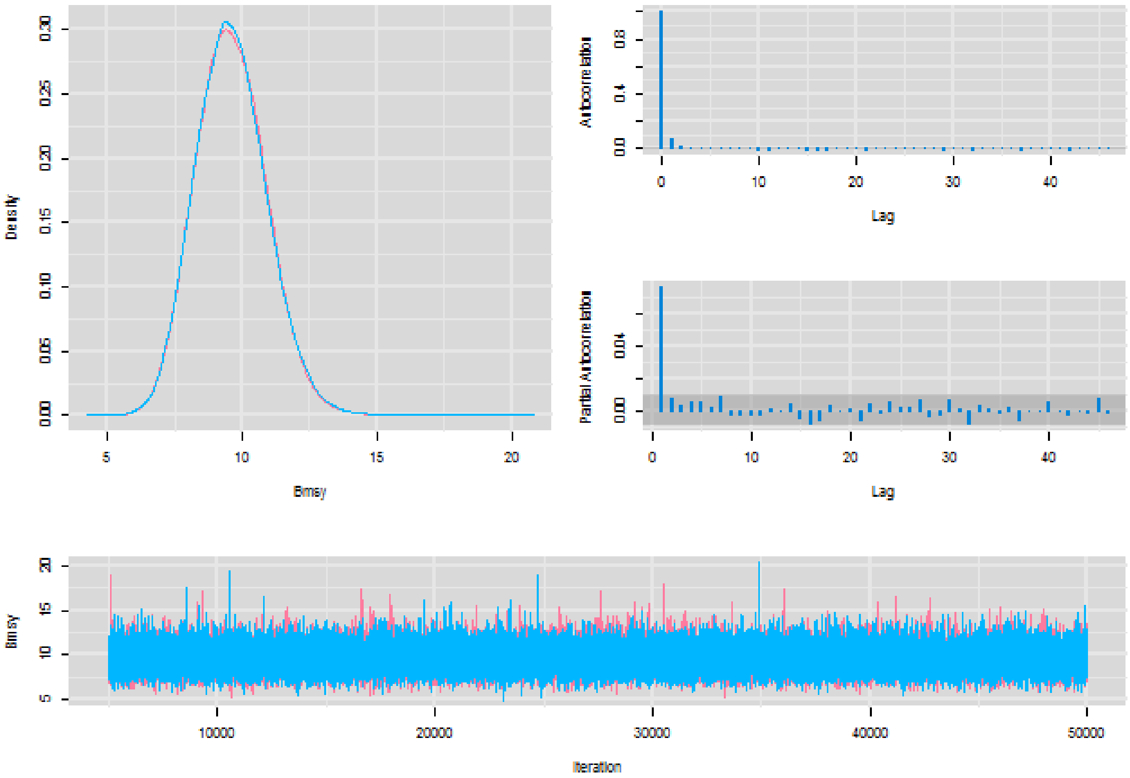
Diagnostics for B[31]



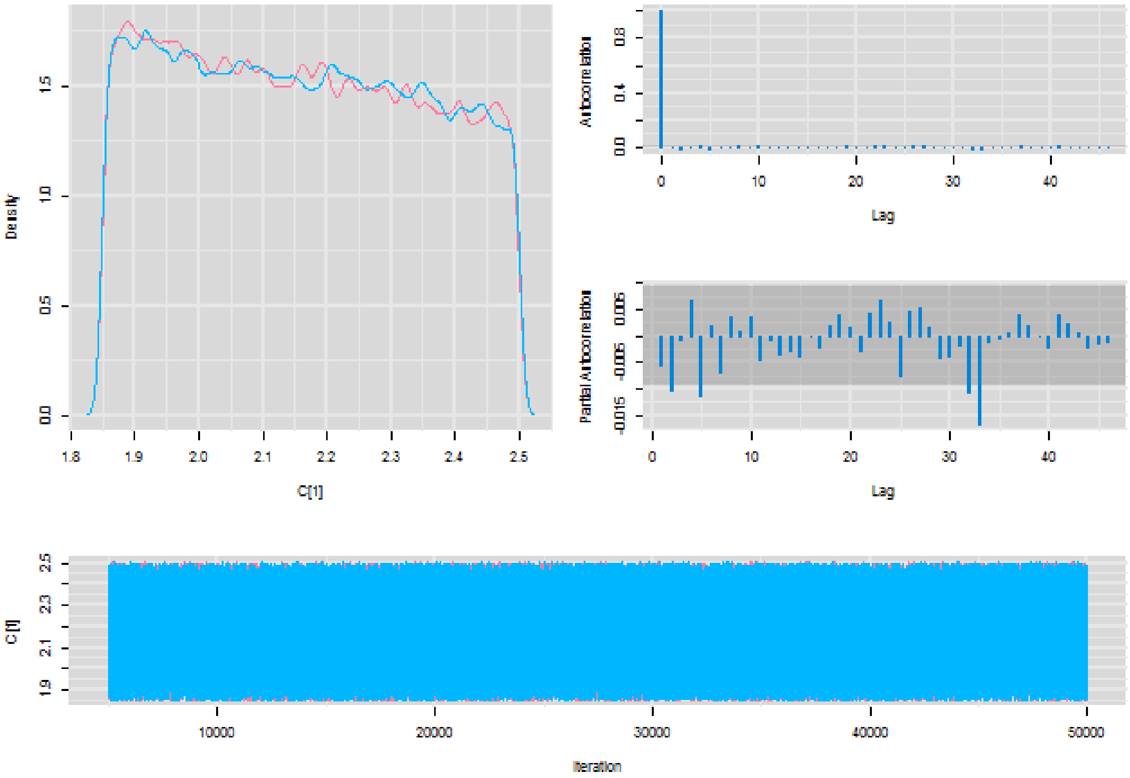
Diagnostics for B[32]



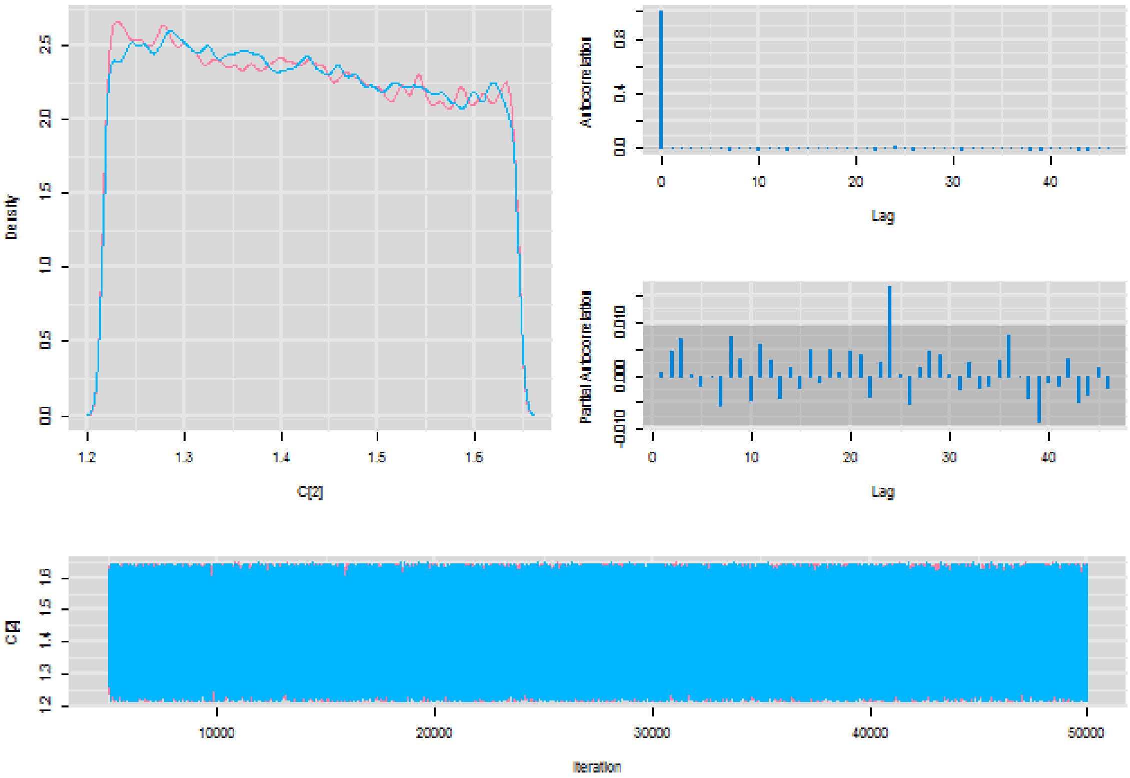
Diagnostics for Bmsy



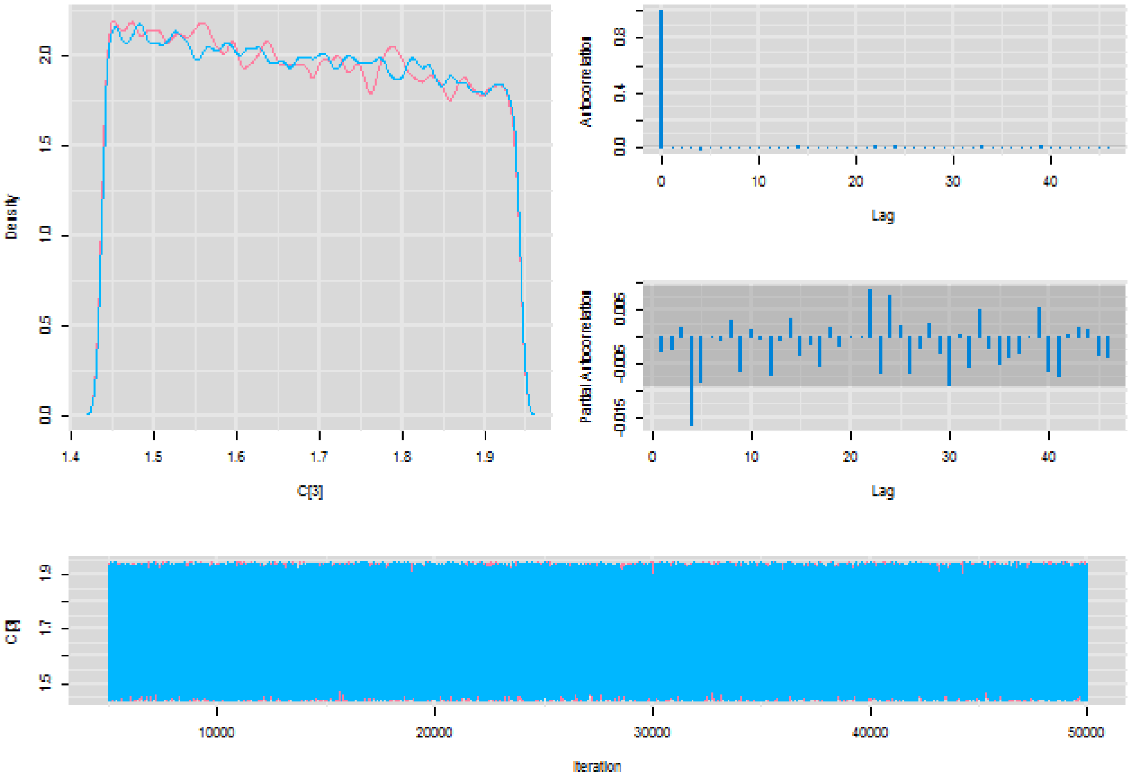
Diagnostics for C[1]



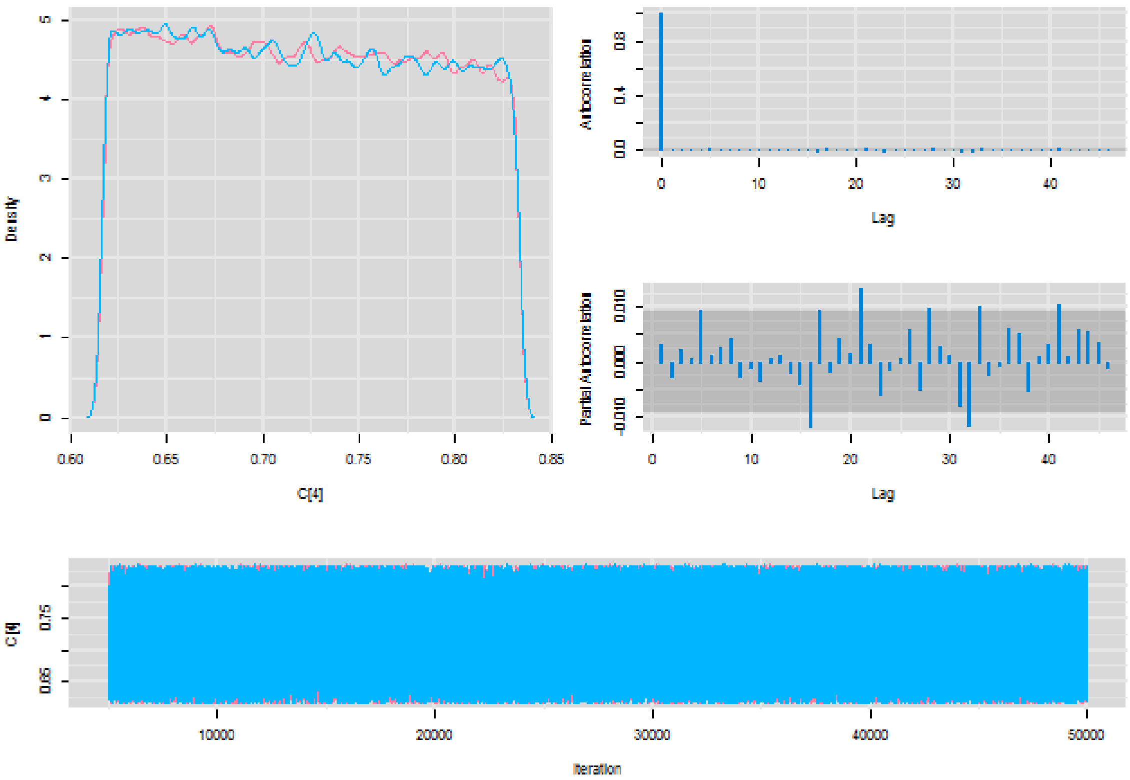
Diagnostics for C[2]



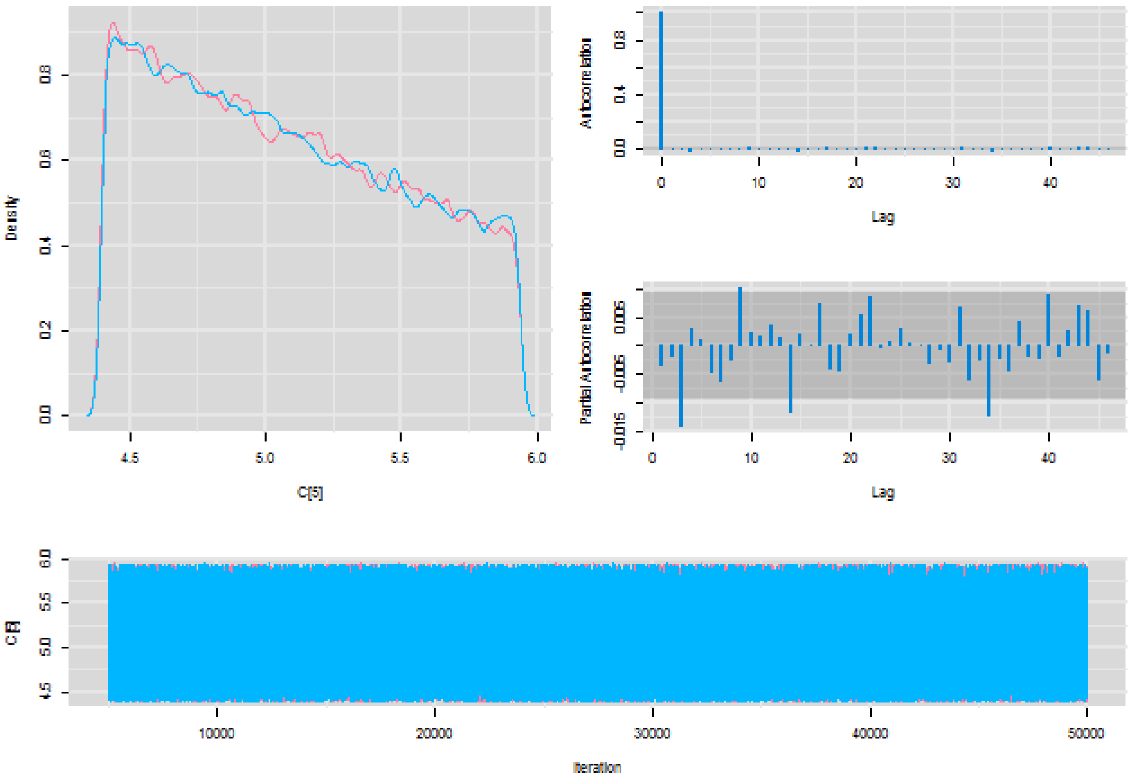
Diagnostics for C[3]



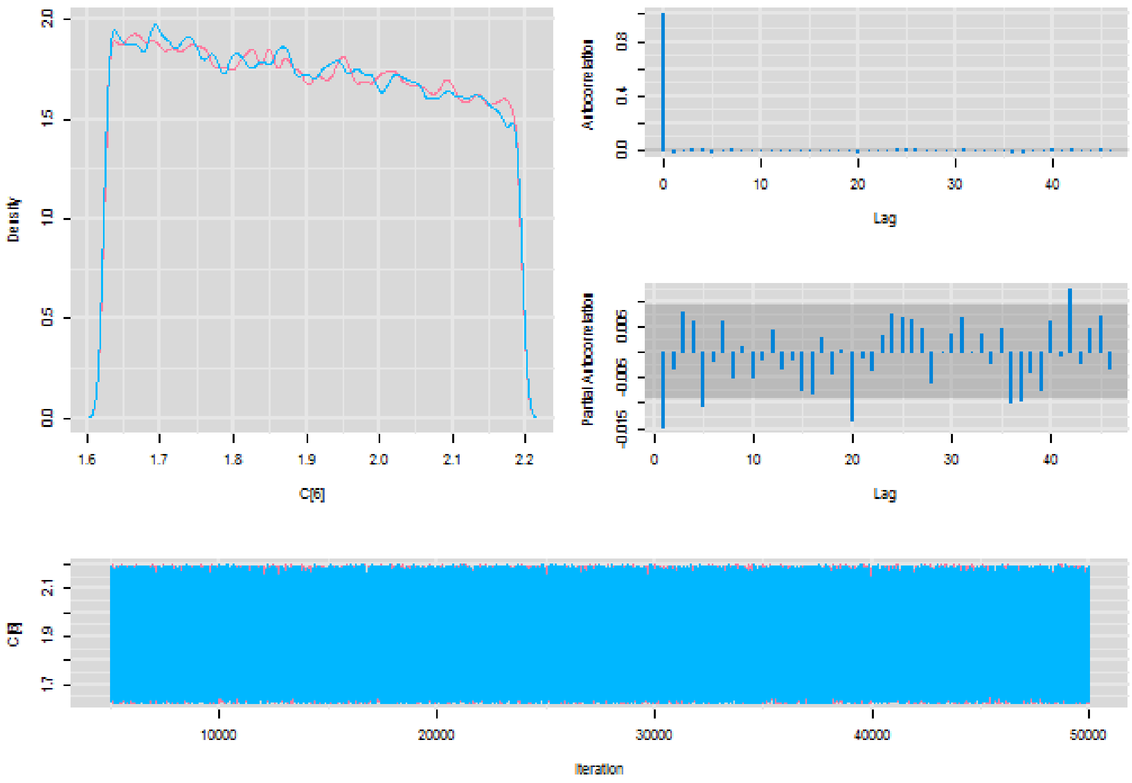
Diagnostics for C[4]



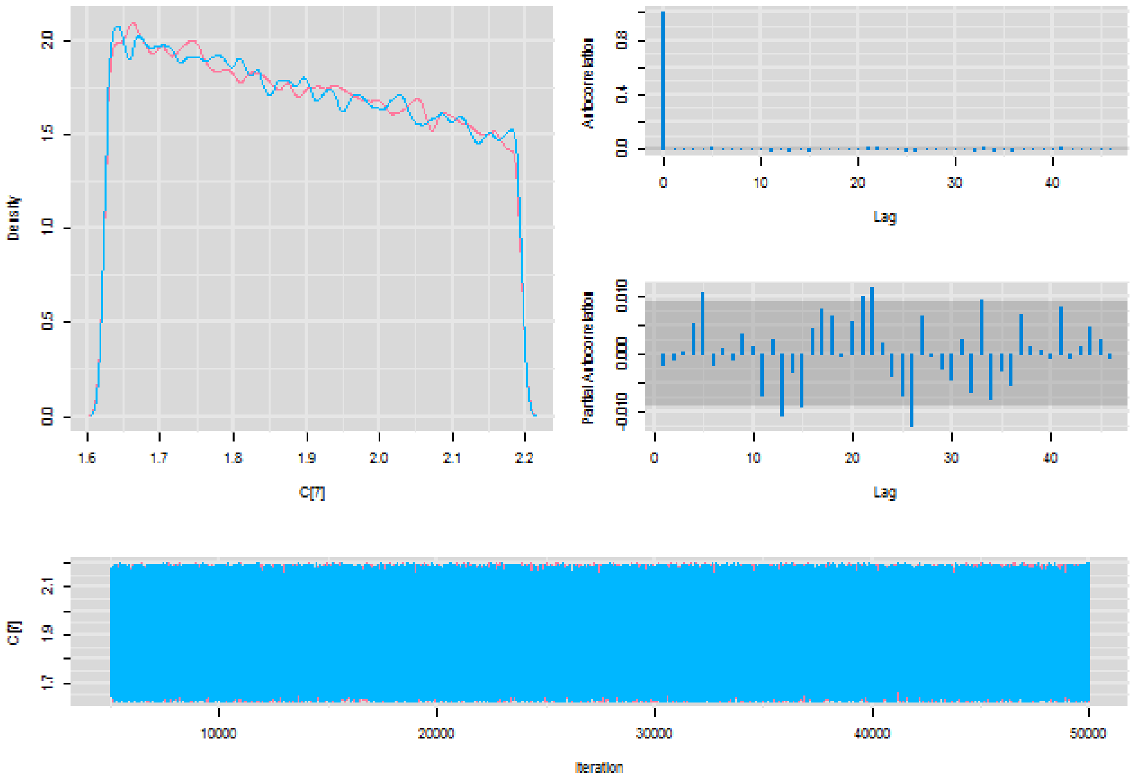
Diagnostics for C[5]



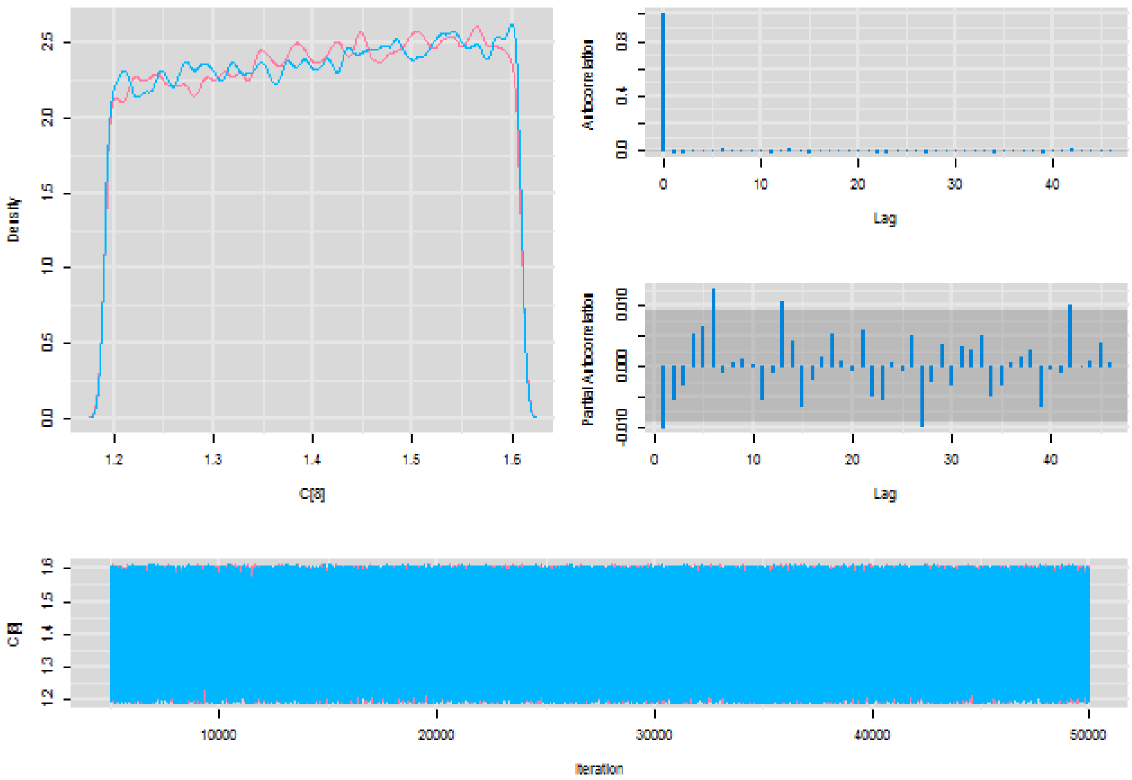
Diagnostics for C[6]



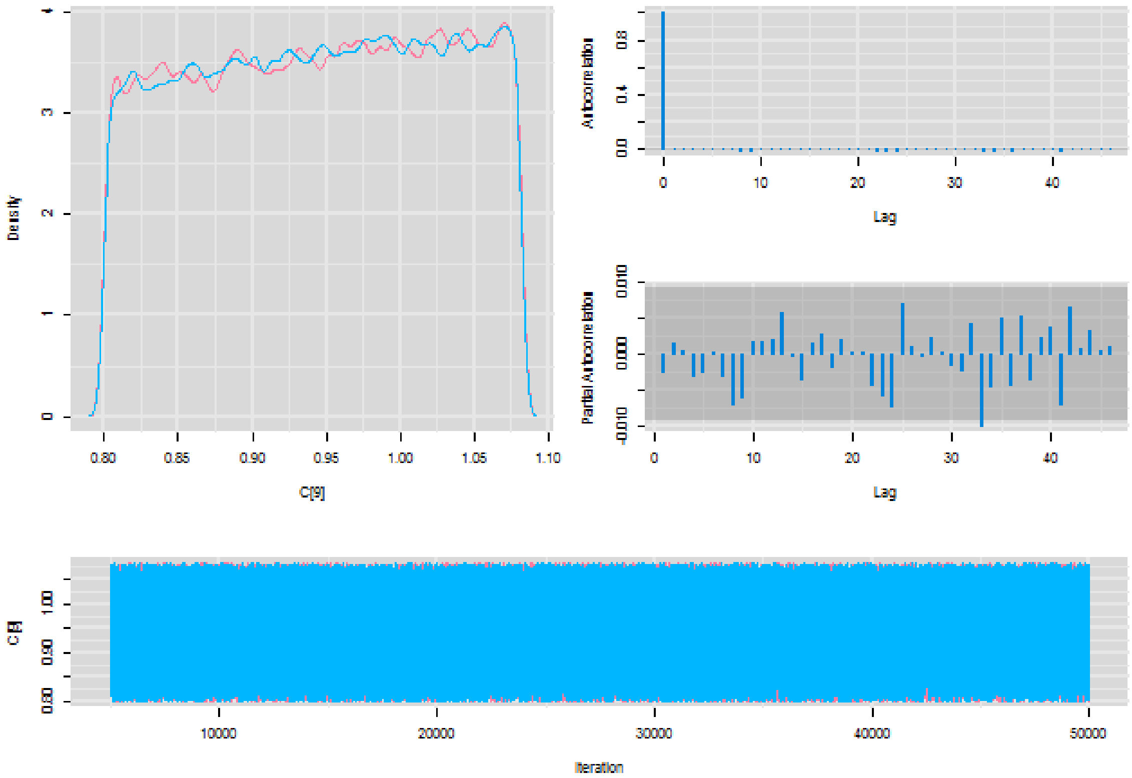
Diagnostics for C[7]



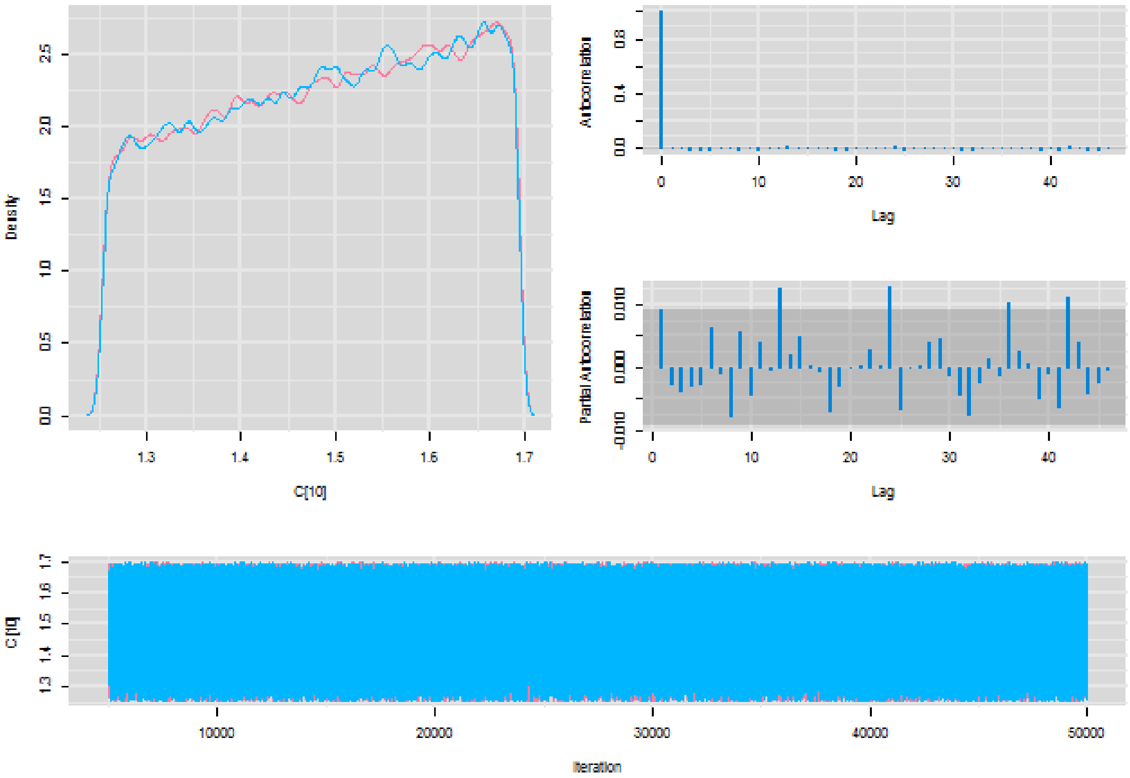
Diagnostics for C[8]



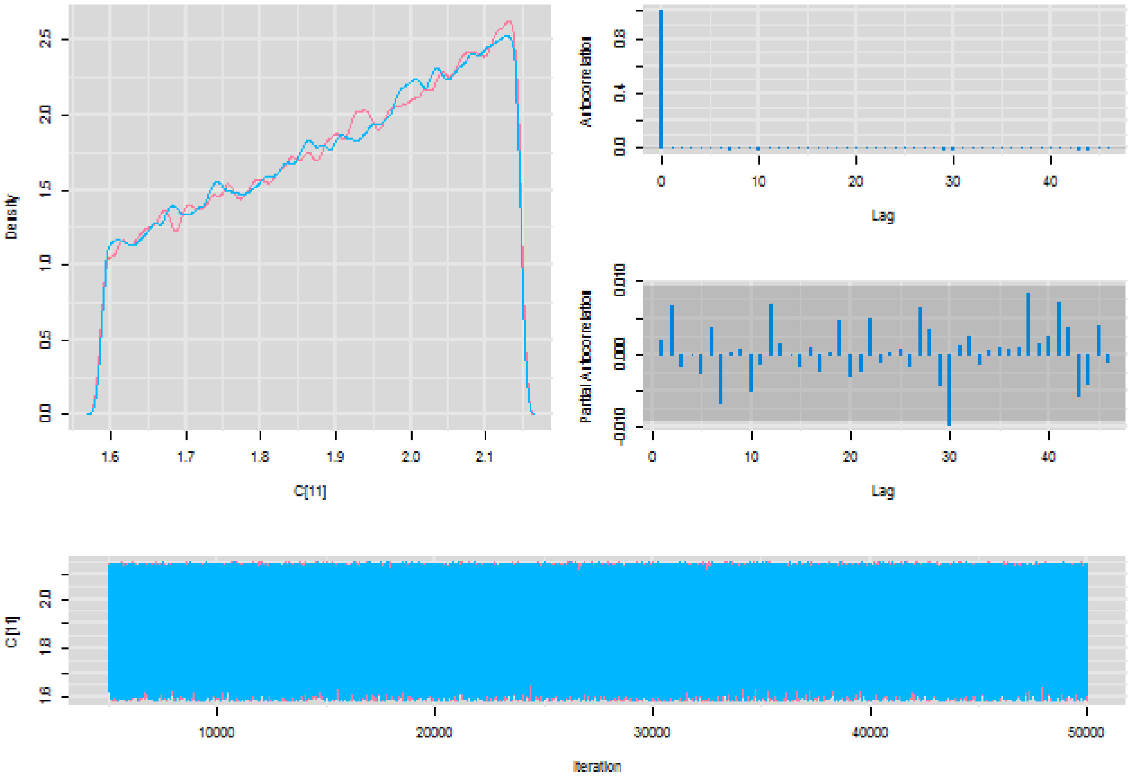
Diagnostics for C[9]



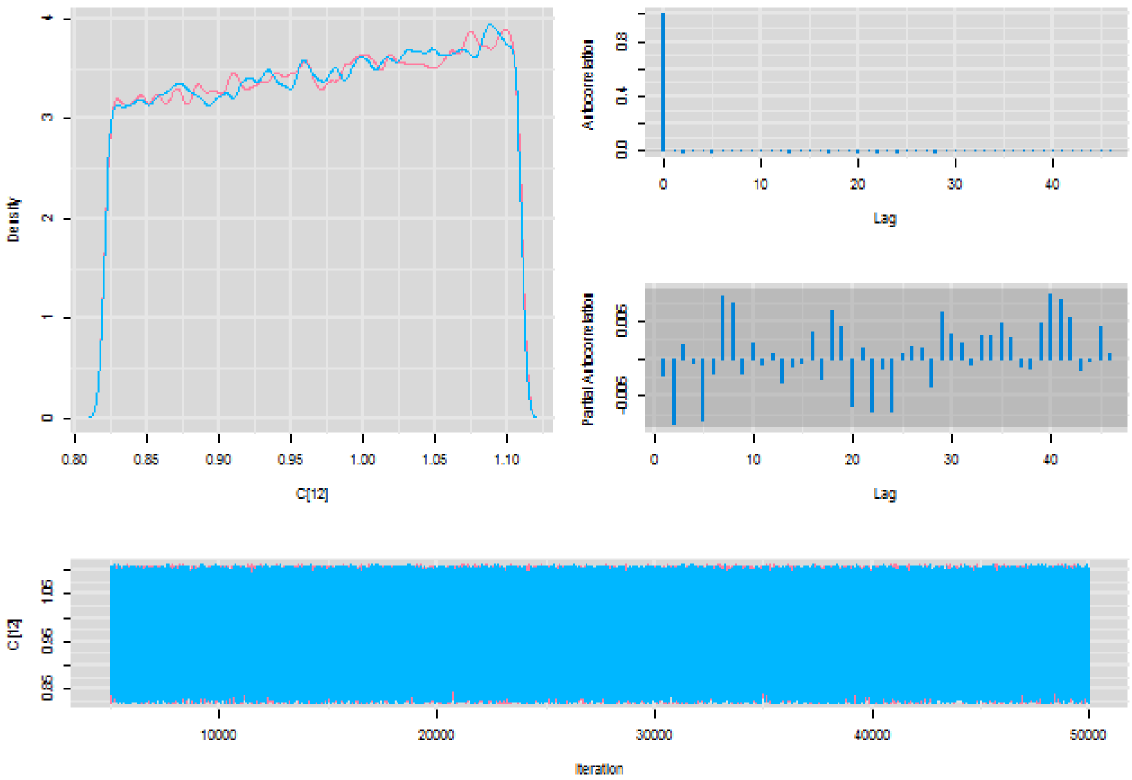
Diagnostics for C[10]



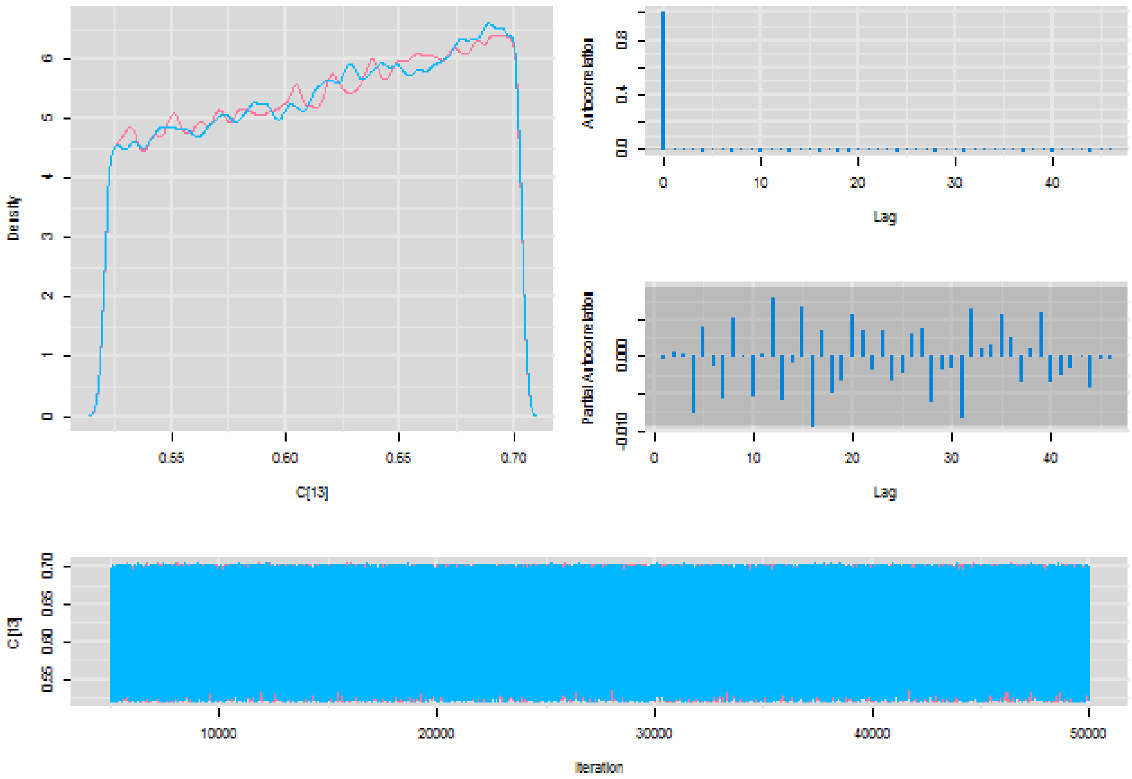
Diagnostics for C[11]



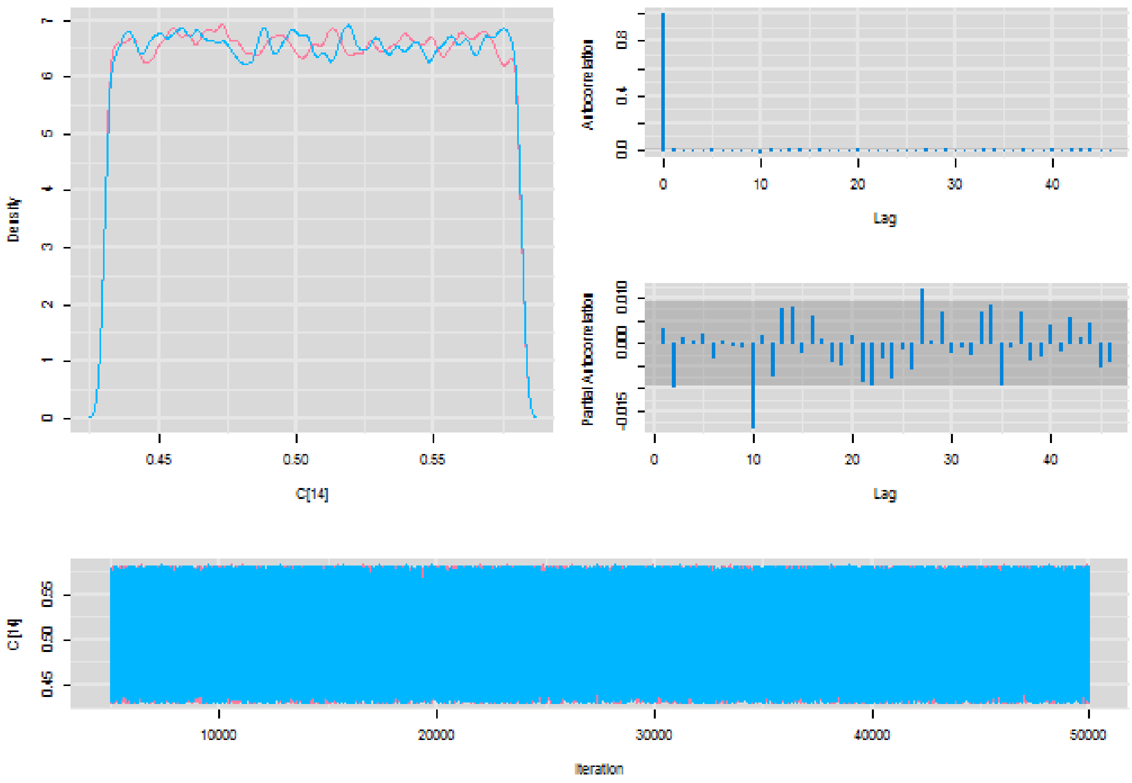
Diagnostics for C[12]



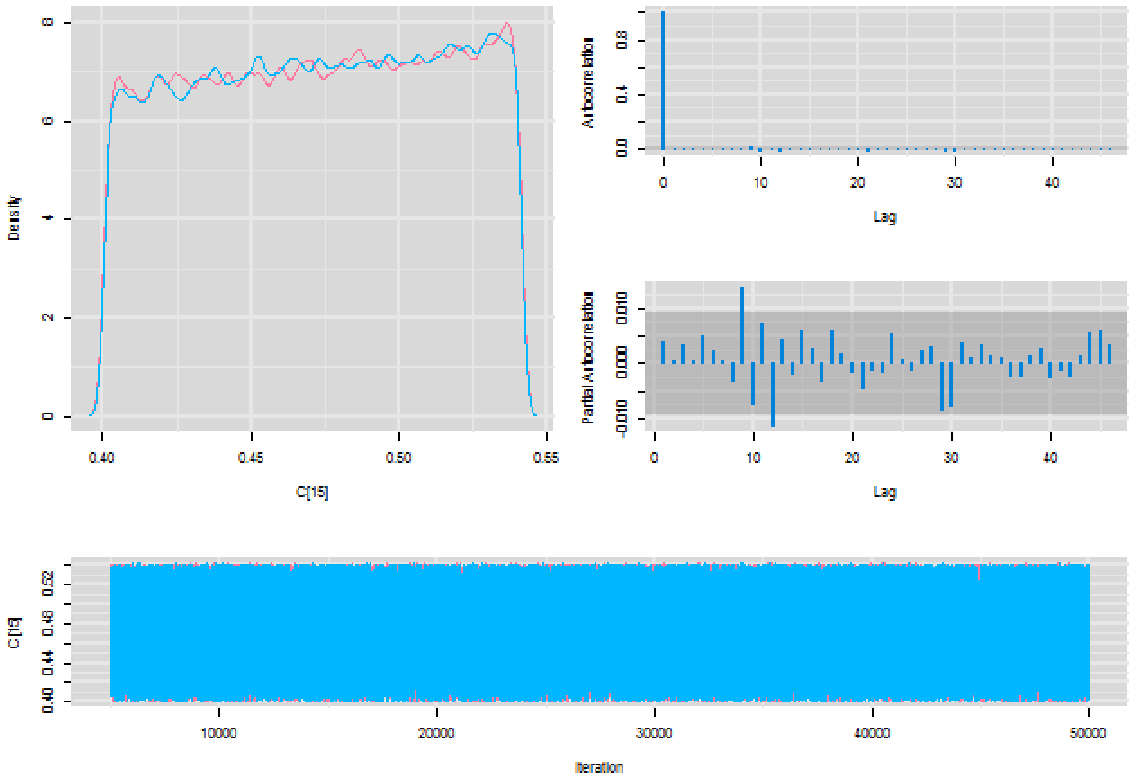
Diagnostics for C[13]



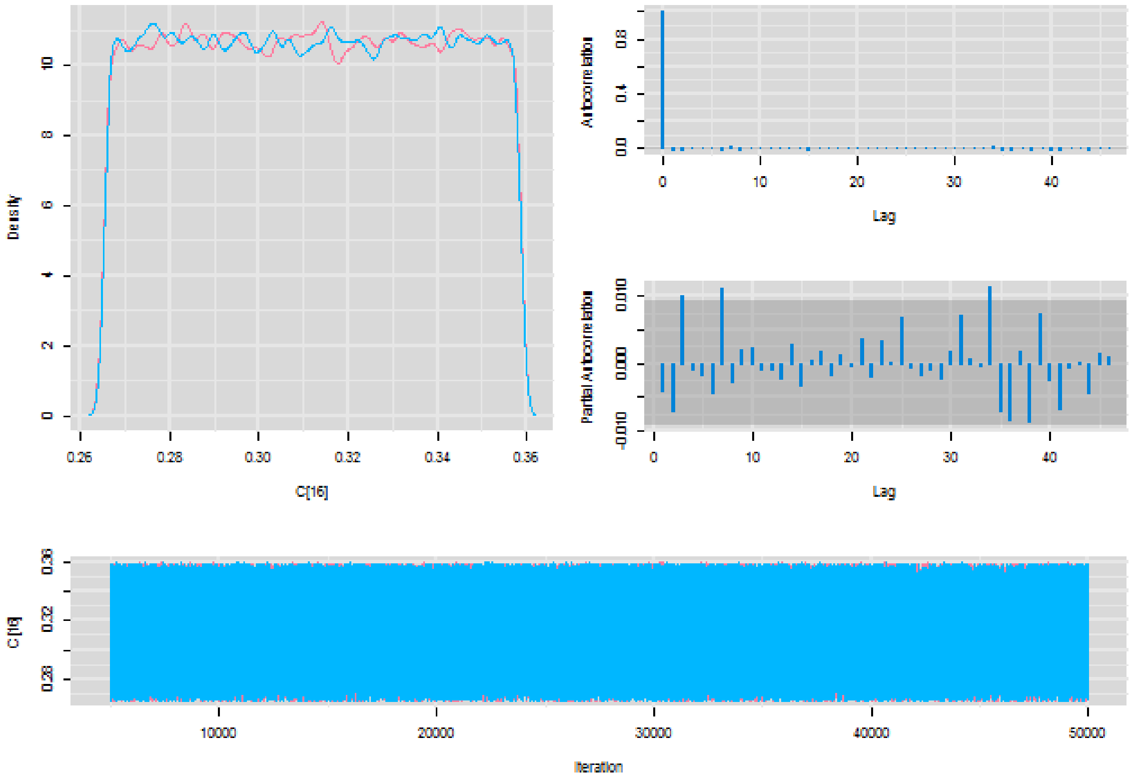
Diagnostics for C[14]



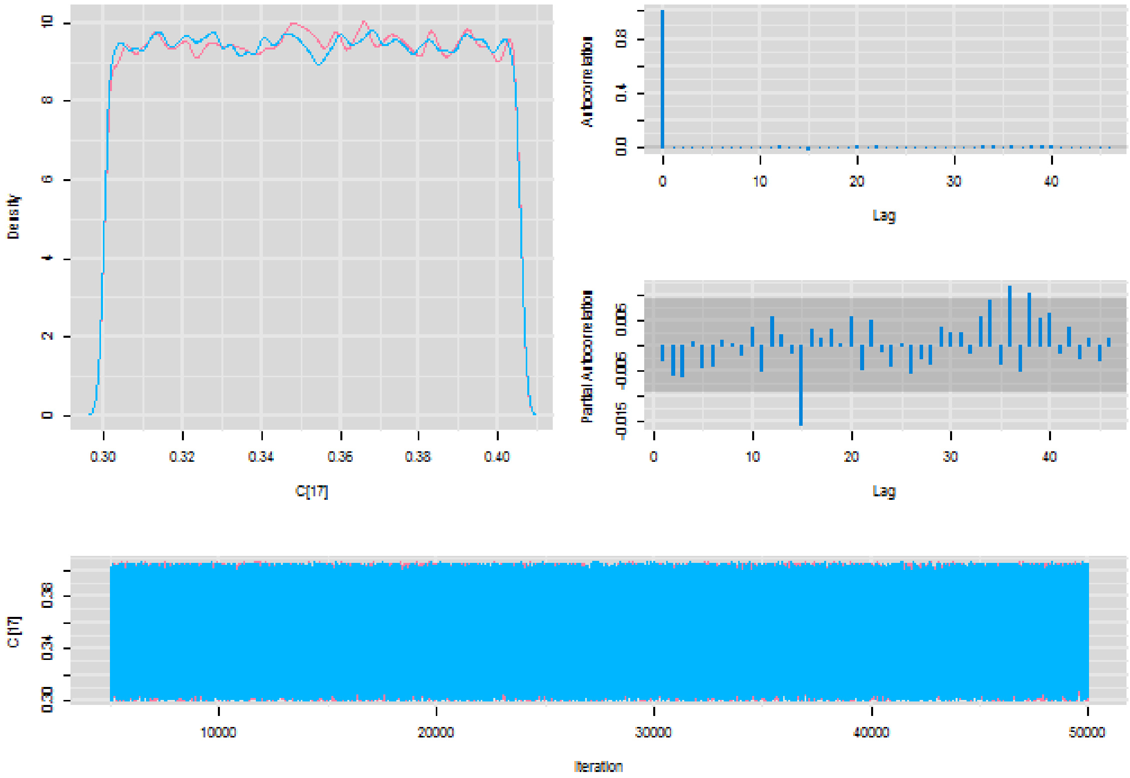
Diagnostics for C[15]



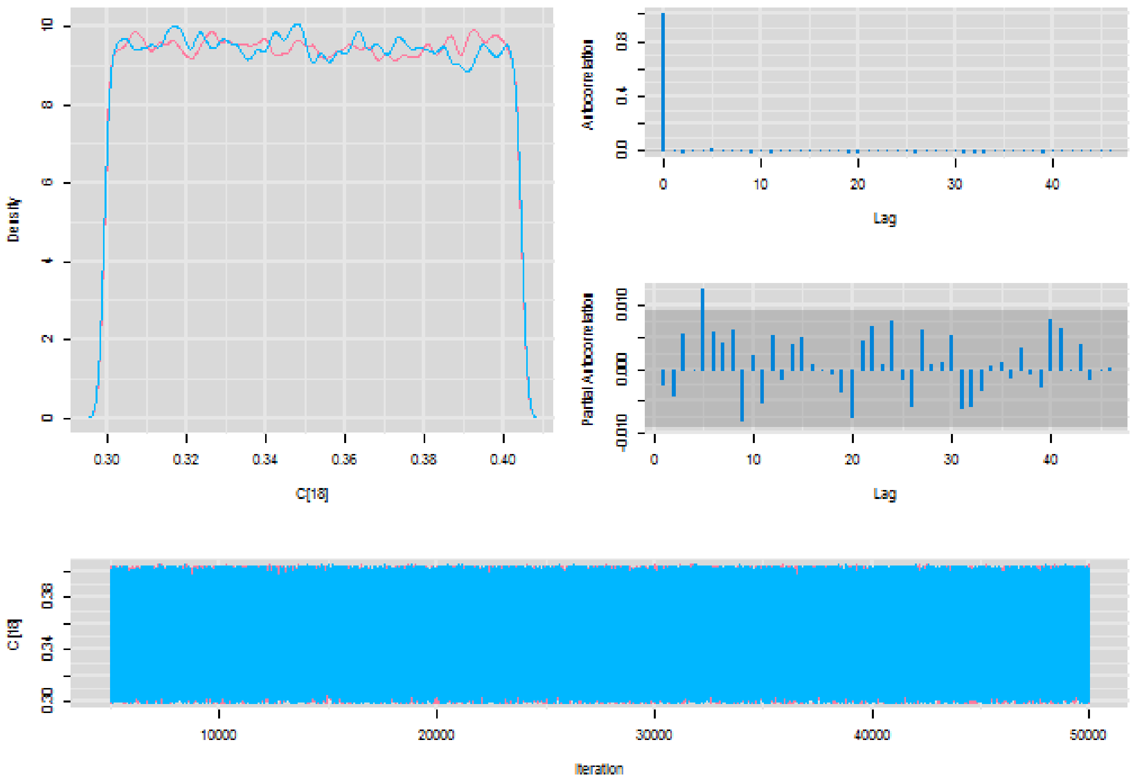
Diagnostics for C[16]



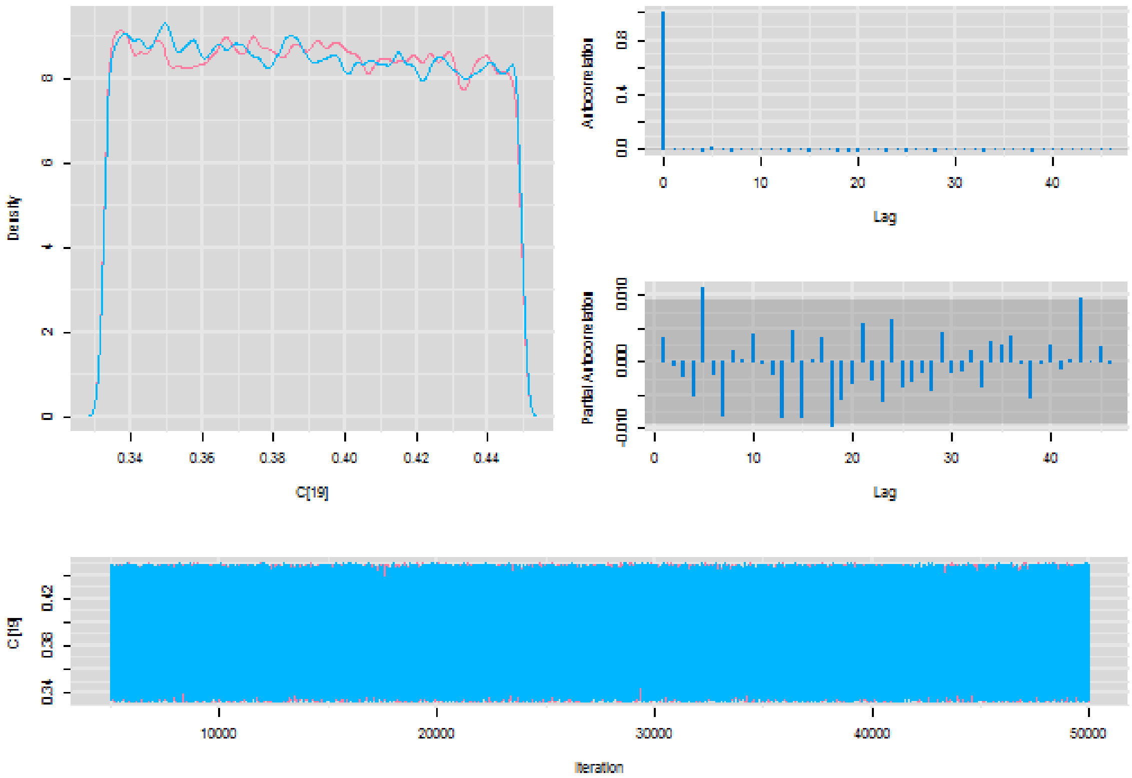
Diagnostics for C[17]



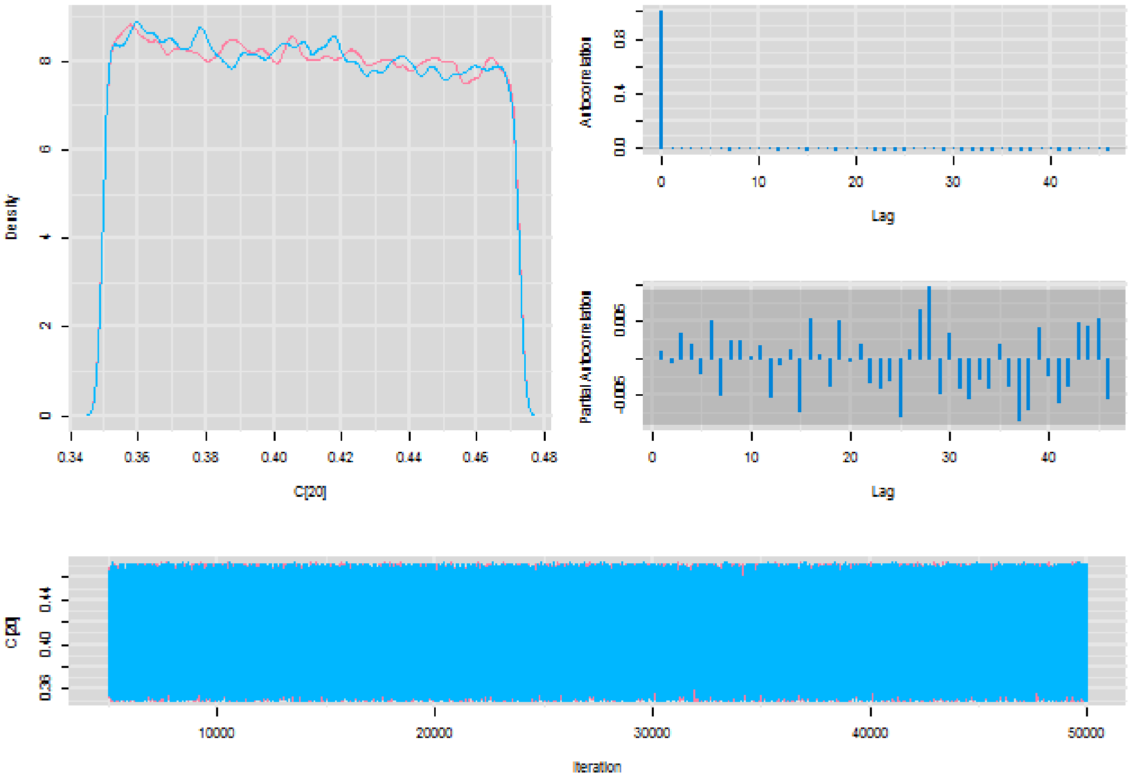
Diagnostics for C[18]



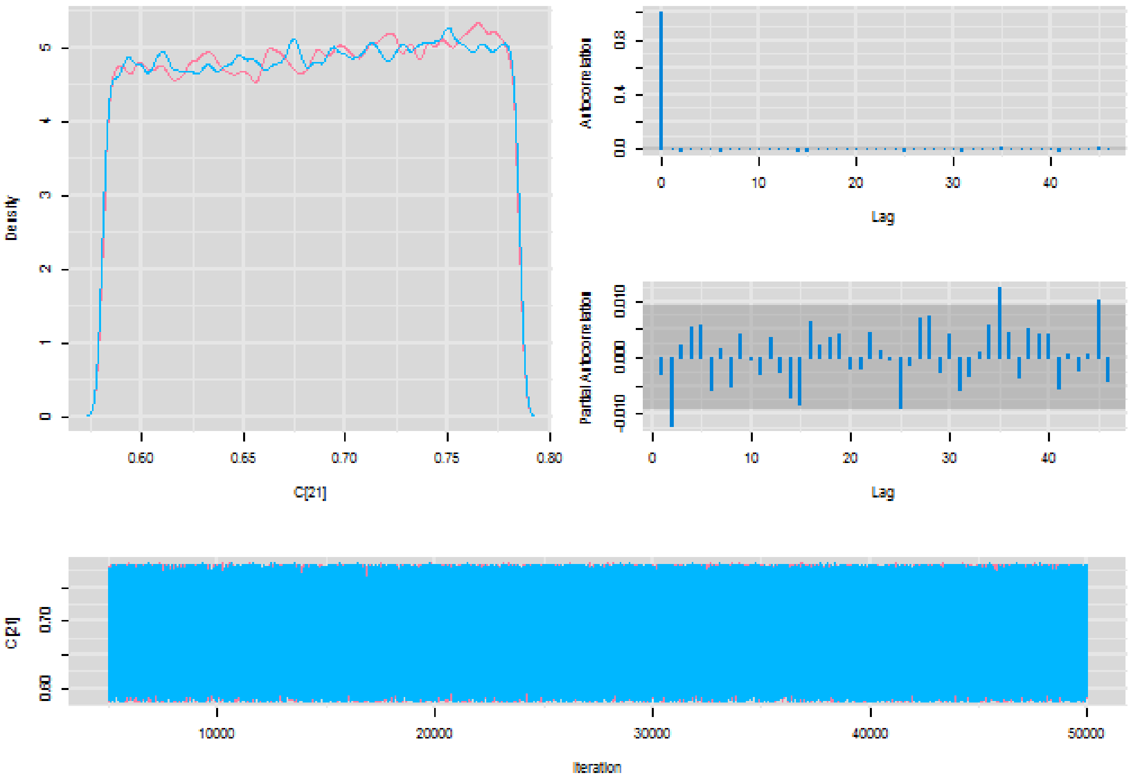
Diagnostics for C[19]



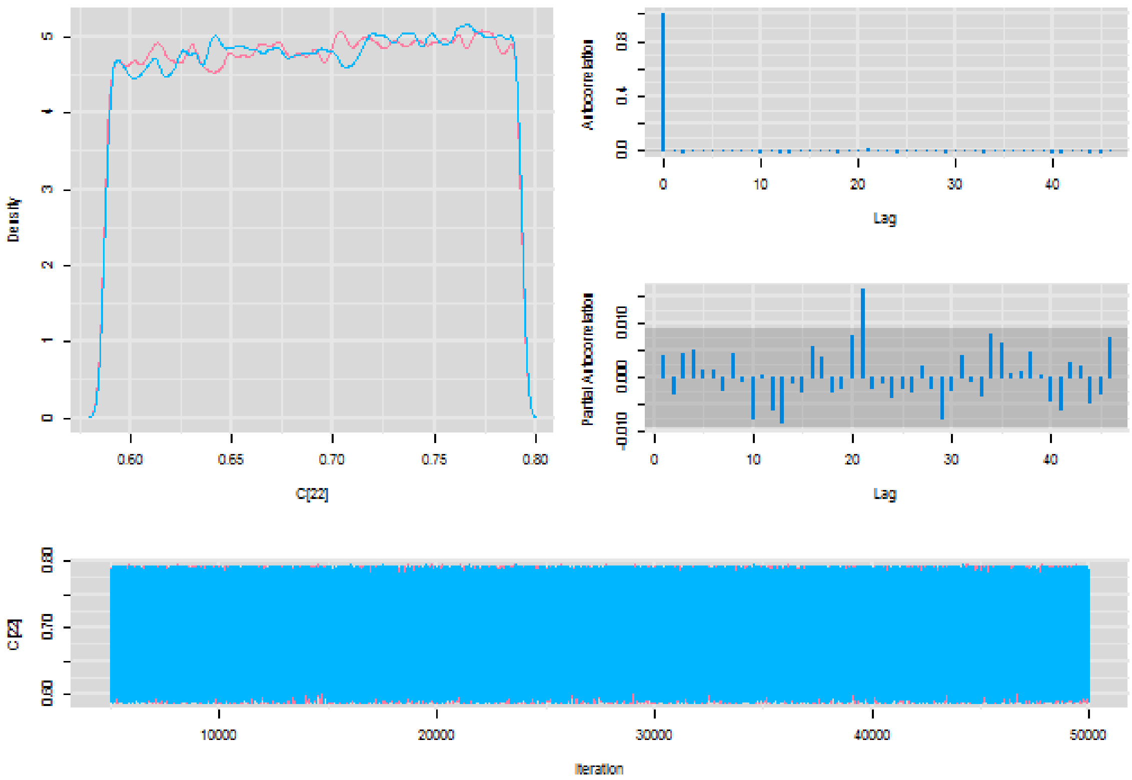
Diagnostics for C[20]



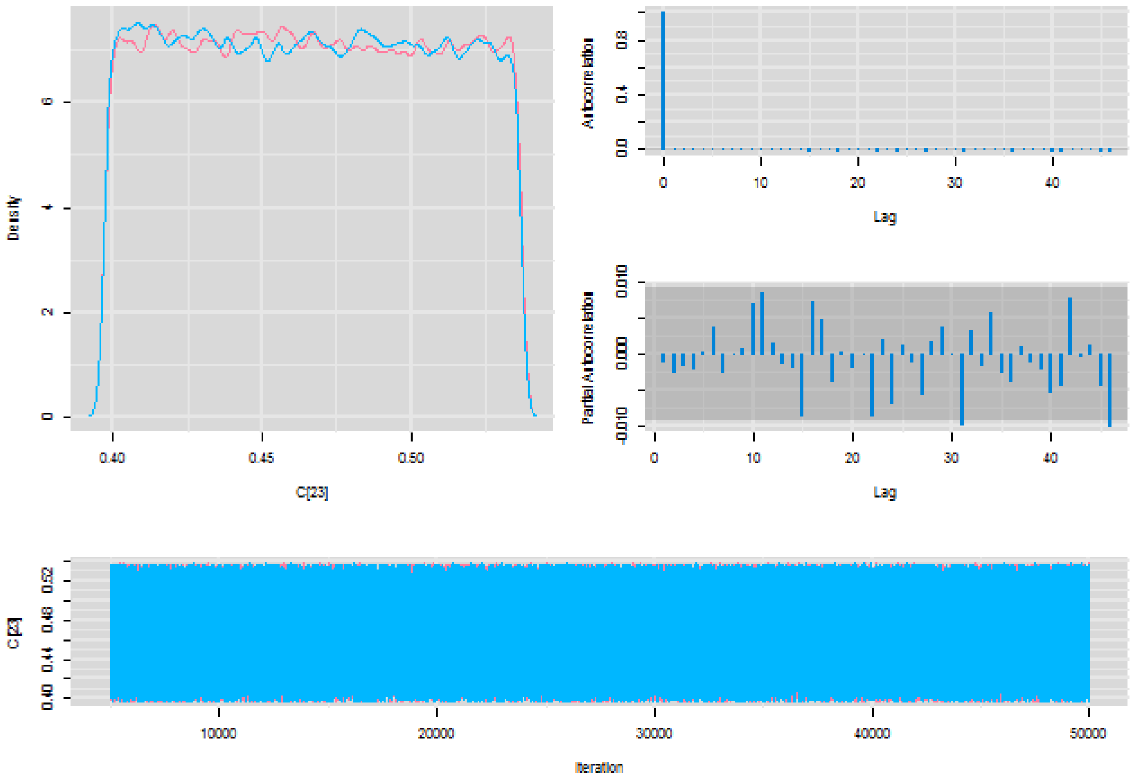
Diagnostics for C[21]



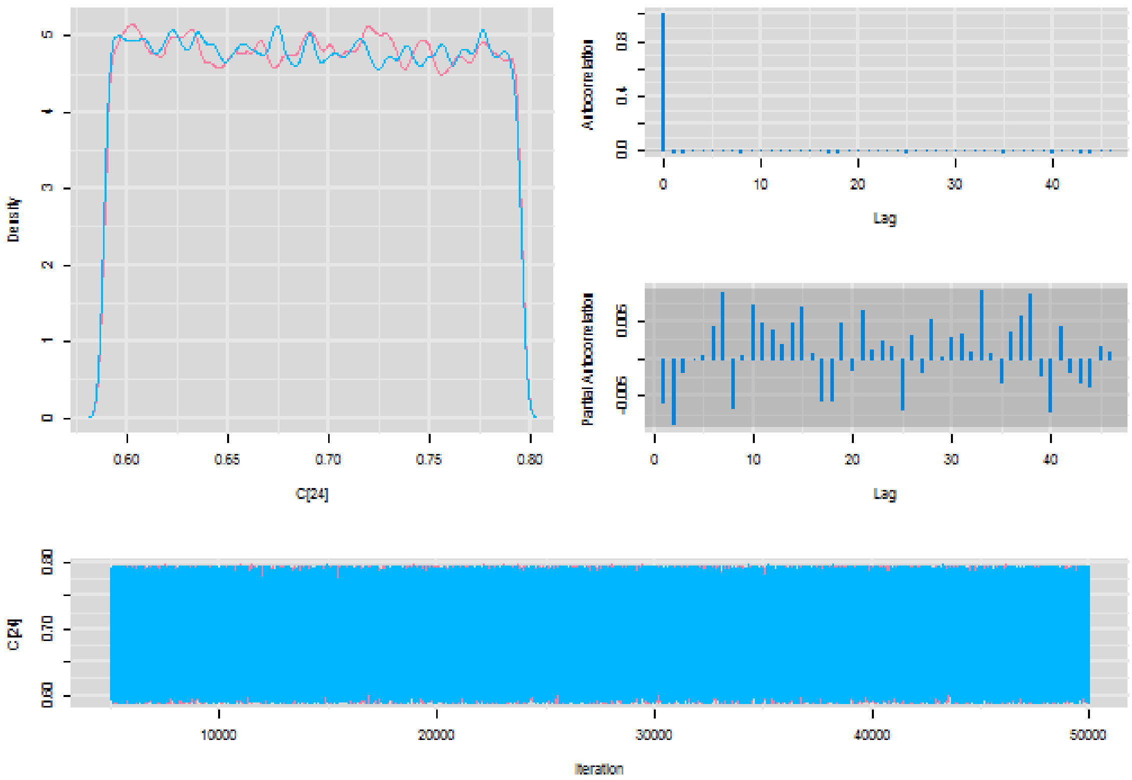
Diagnostics for C[22]



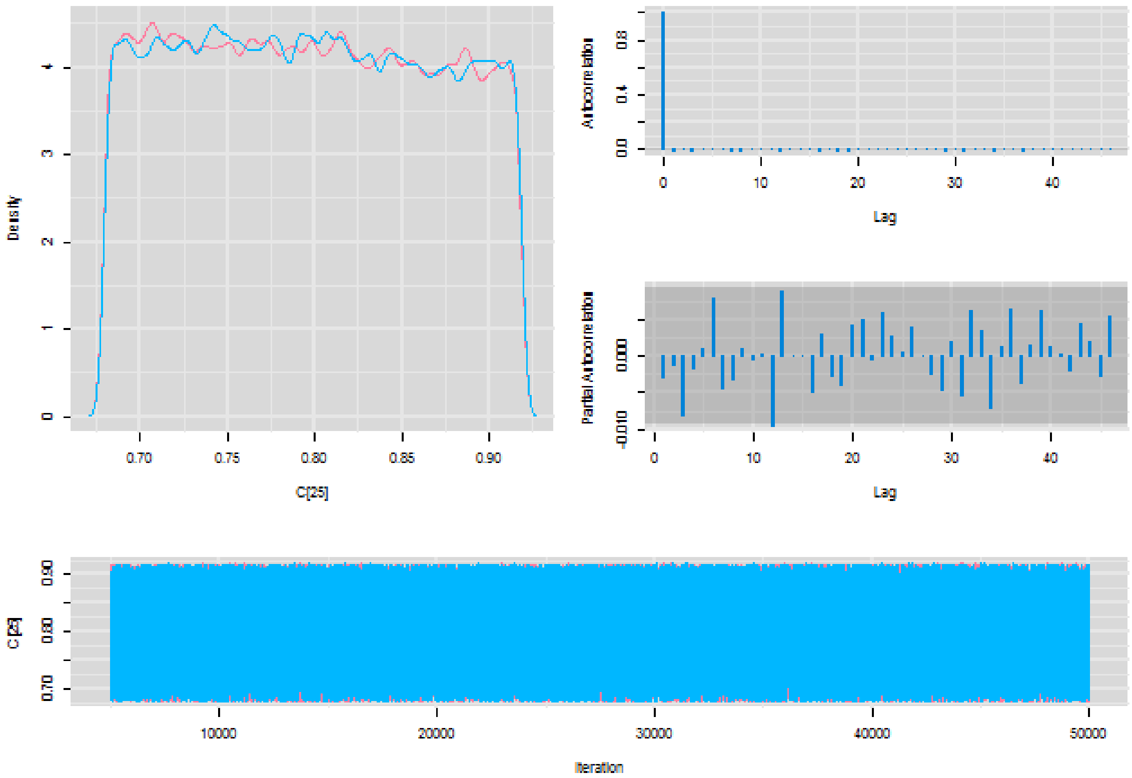
Diagnostics for C[23]



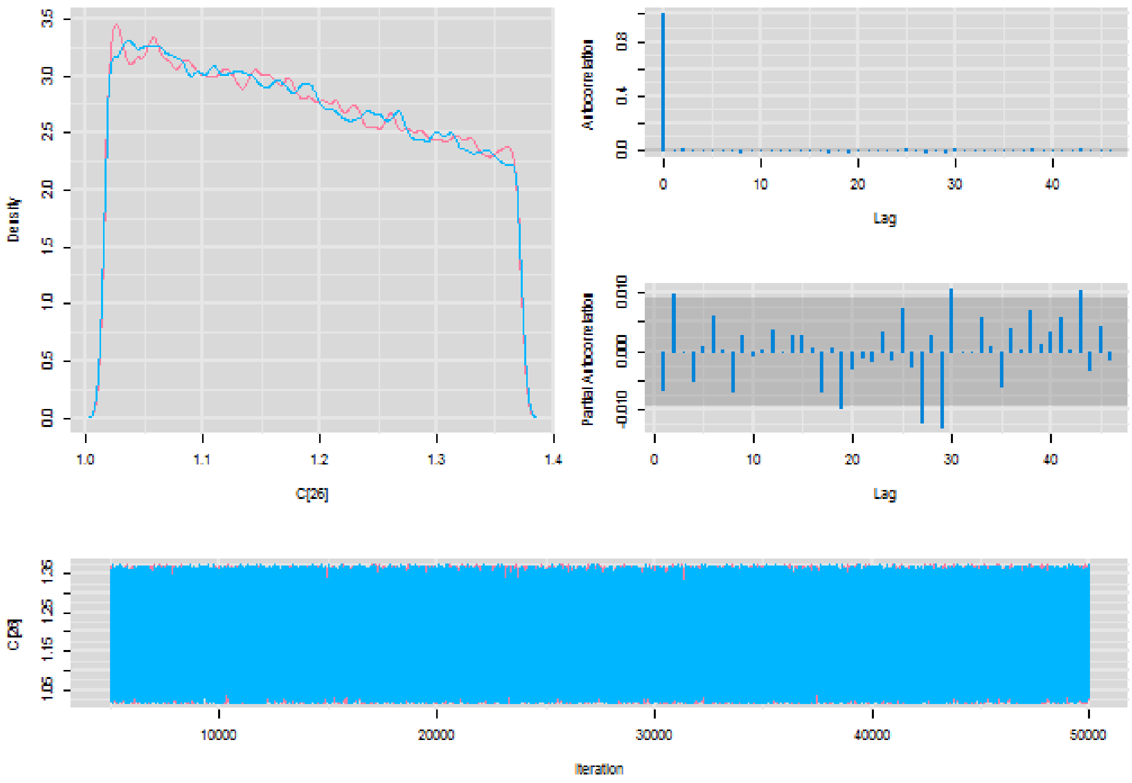
Diagnostics for C[24]



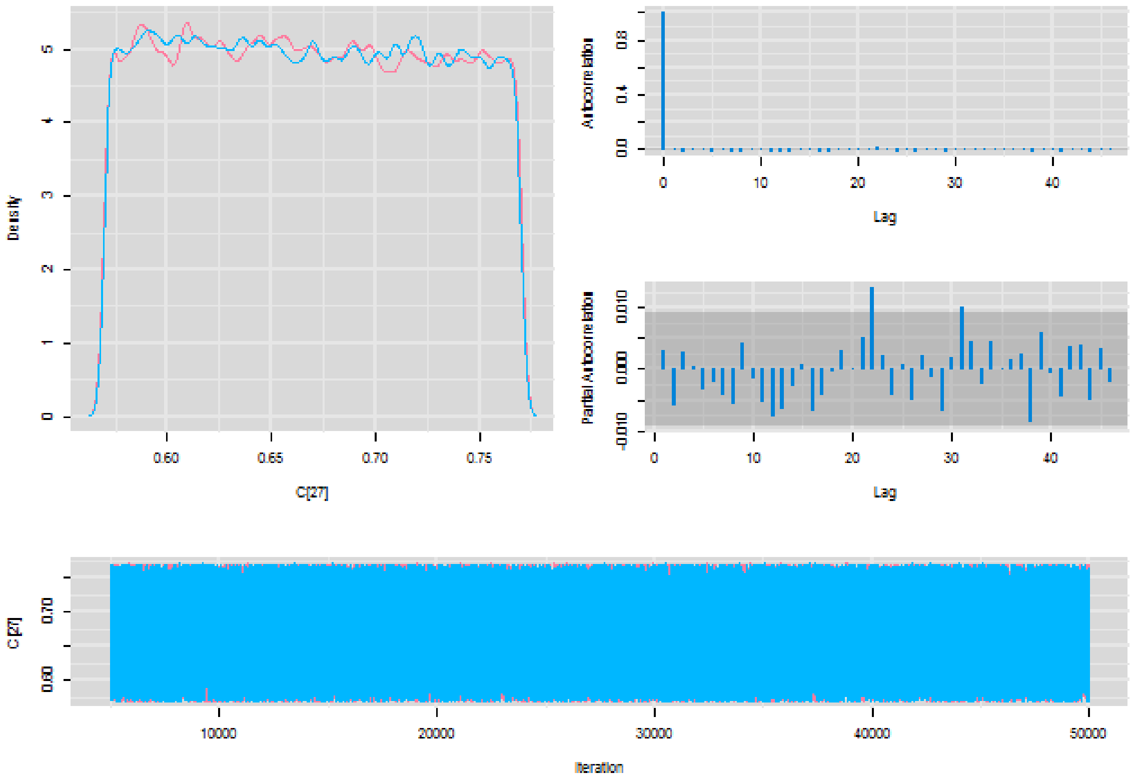
Diagnostics for C[25]



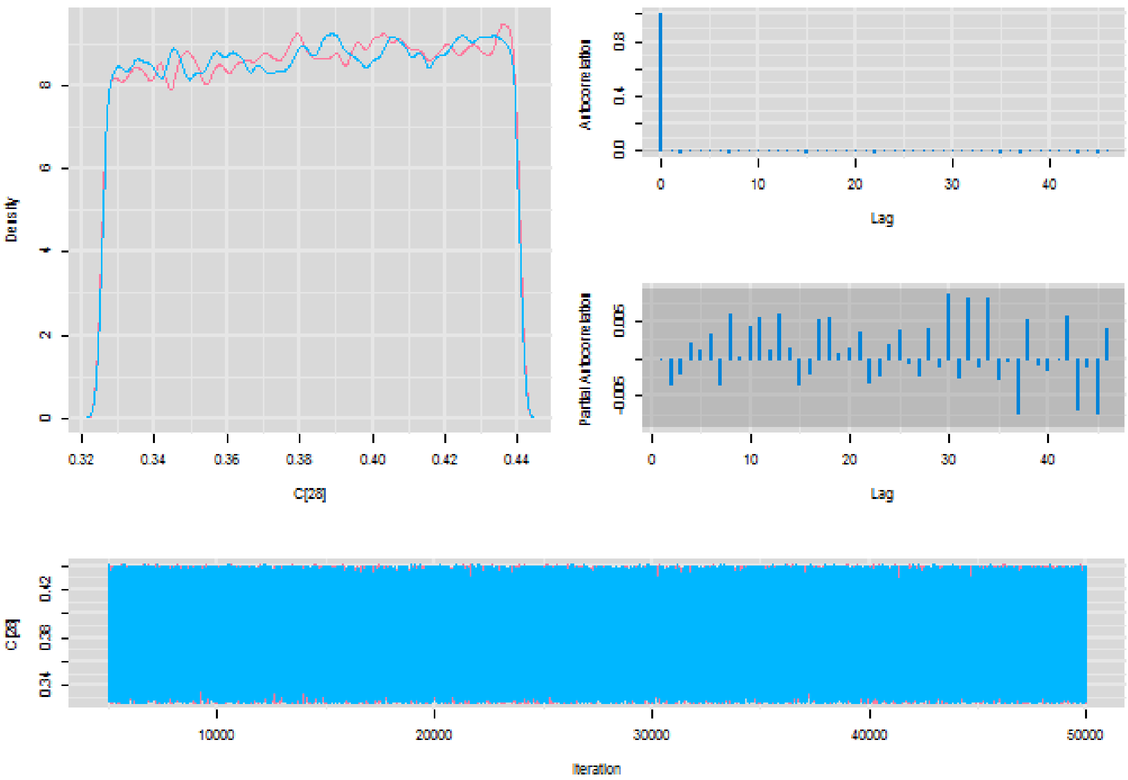
Diagnostics for C[26]



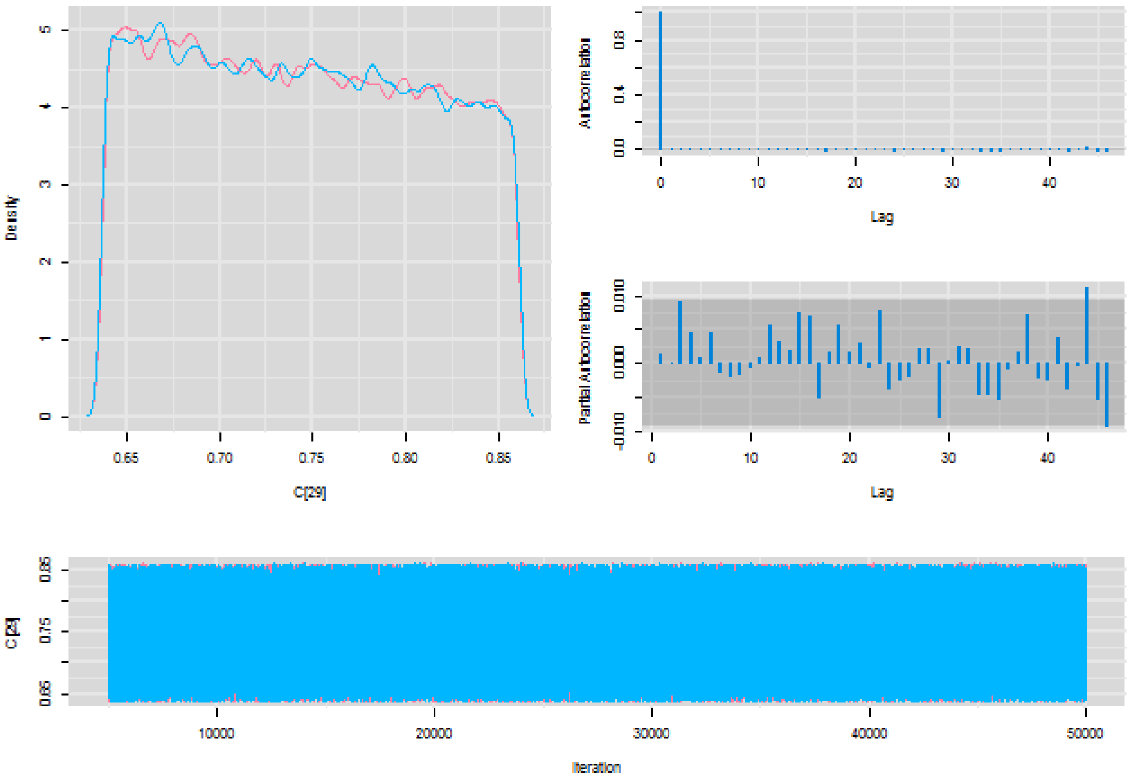
Diagnostics for C[27]



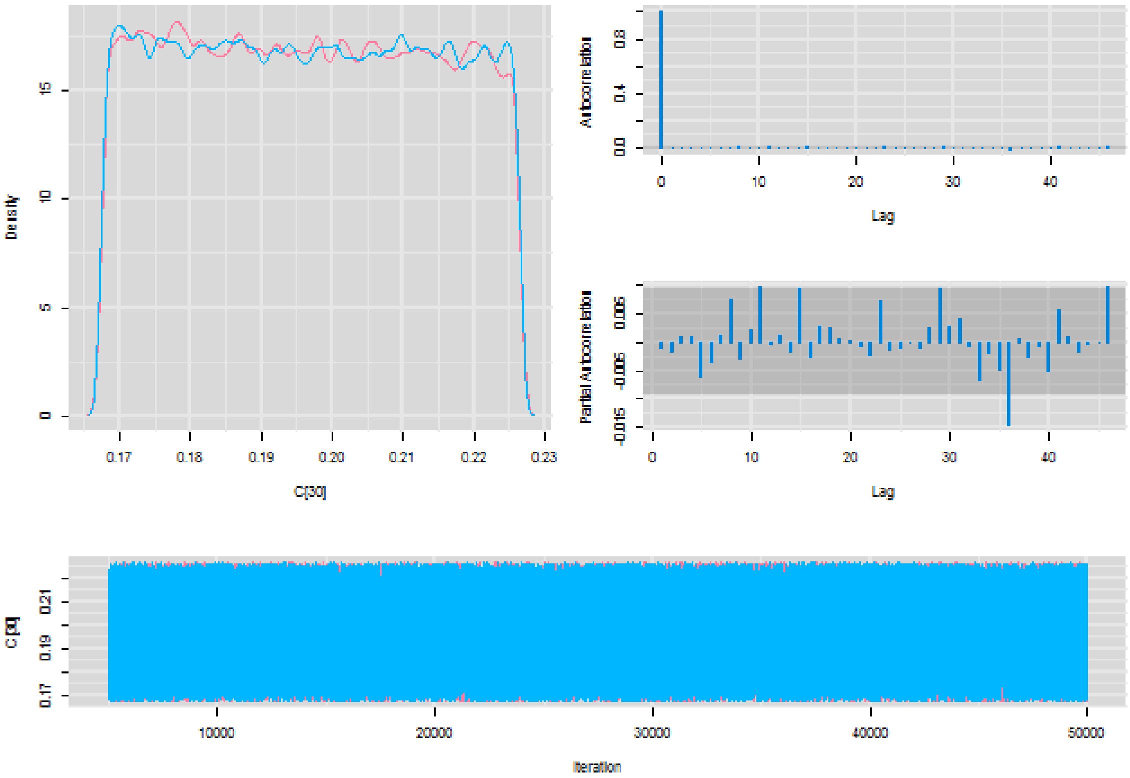
Diagnostics for C[28]



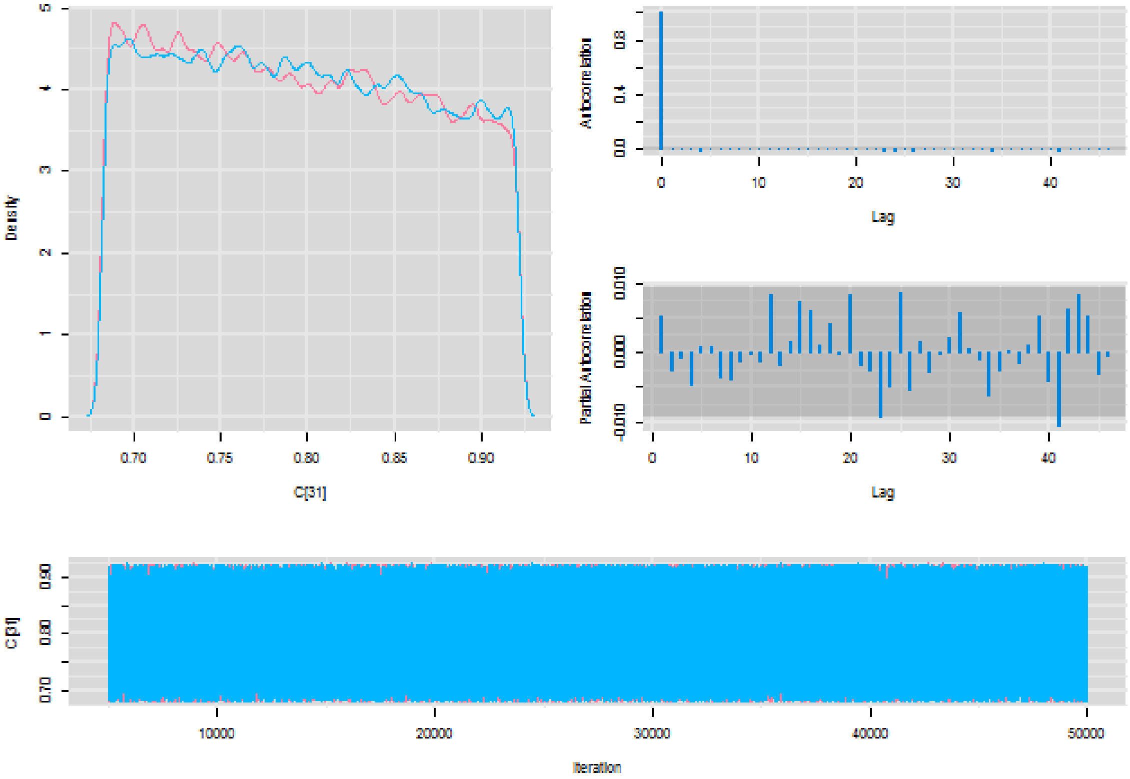
Diagnostics for C[29]



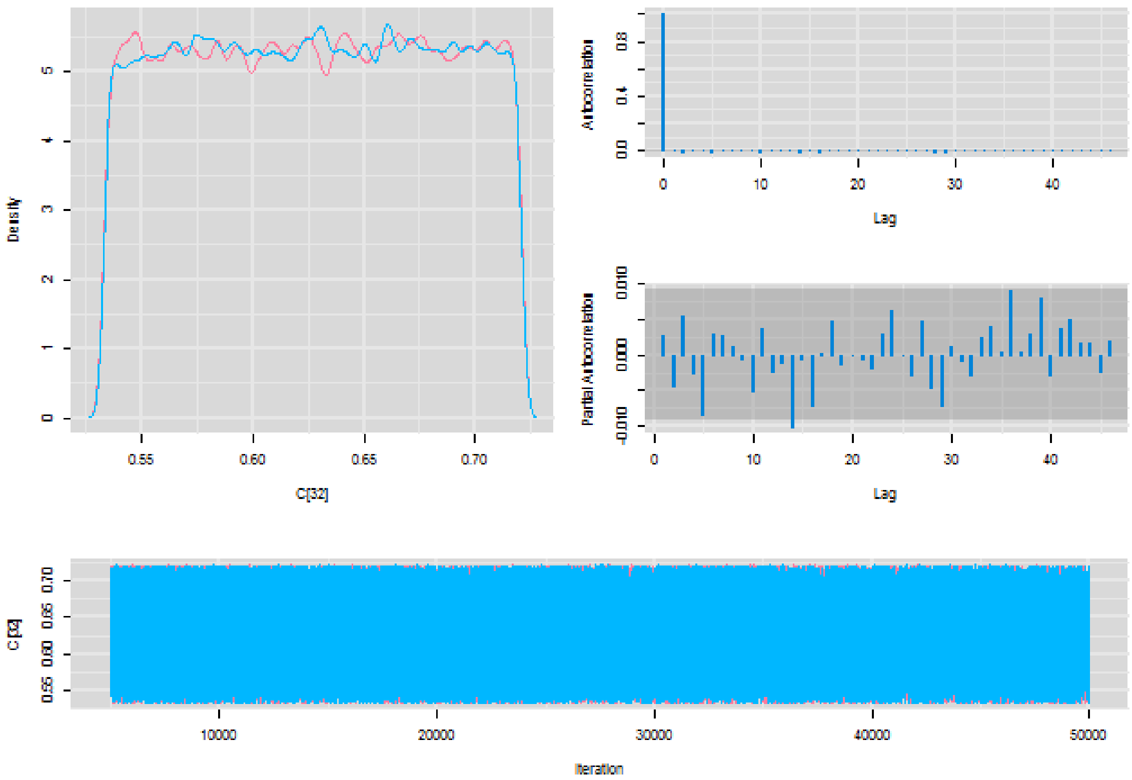
Diagnostics for C[30]



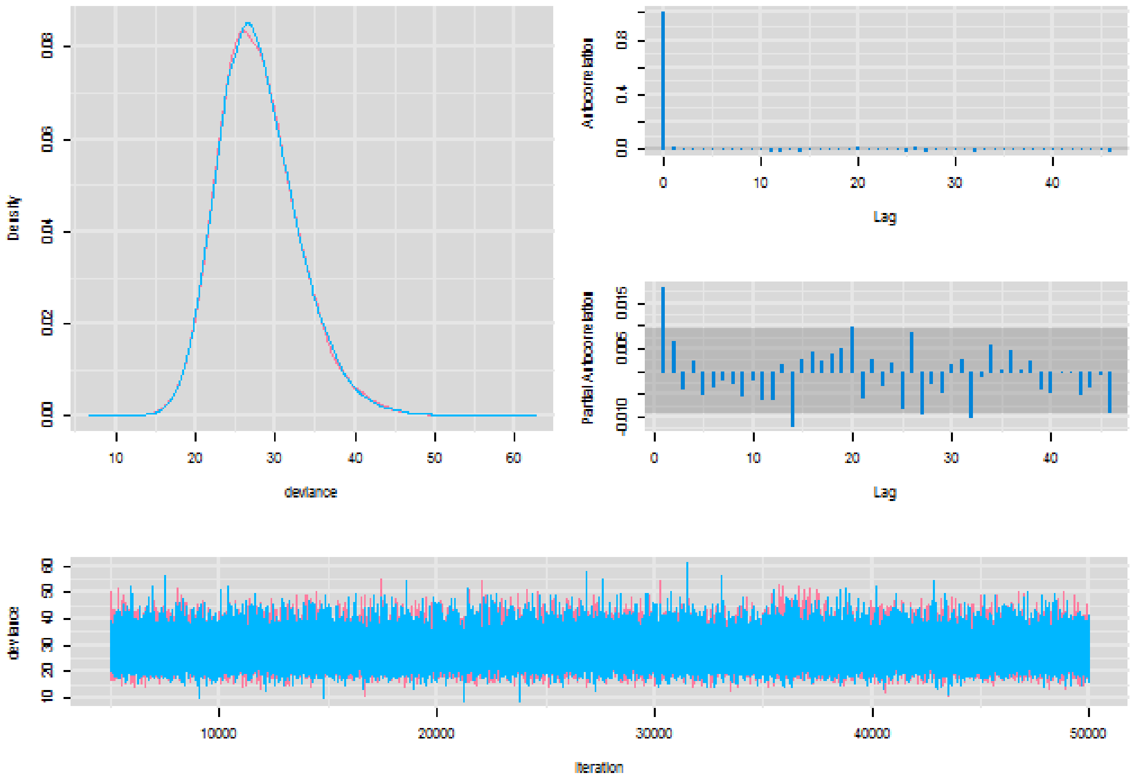
Diagnostics for C[31]



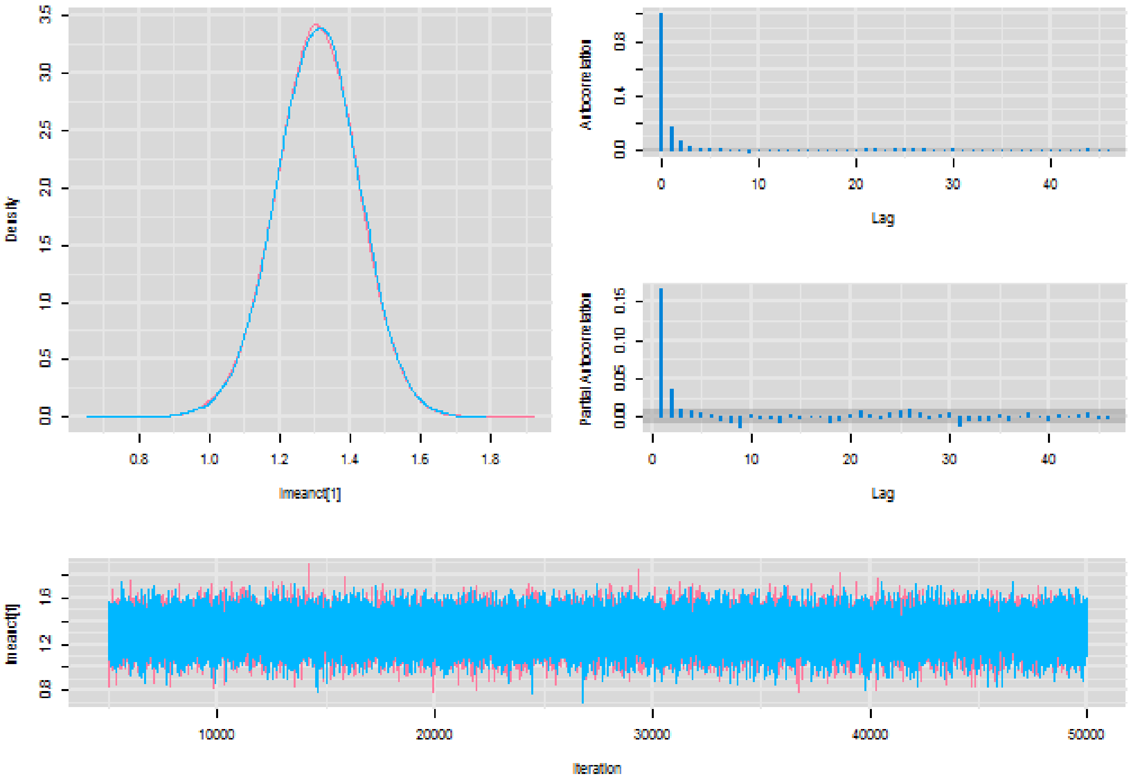
Diagnostics for C[32]



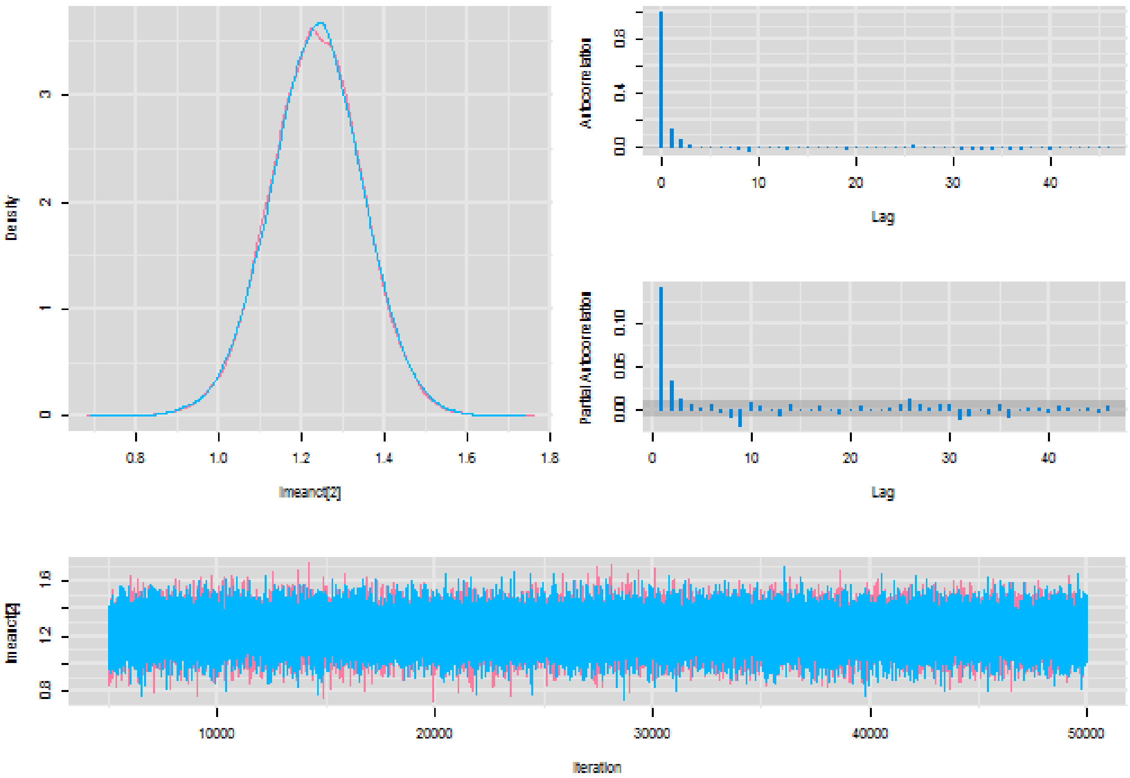
Diagnostics for deviance



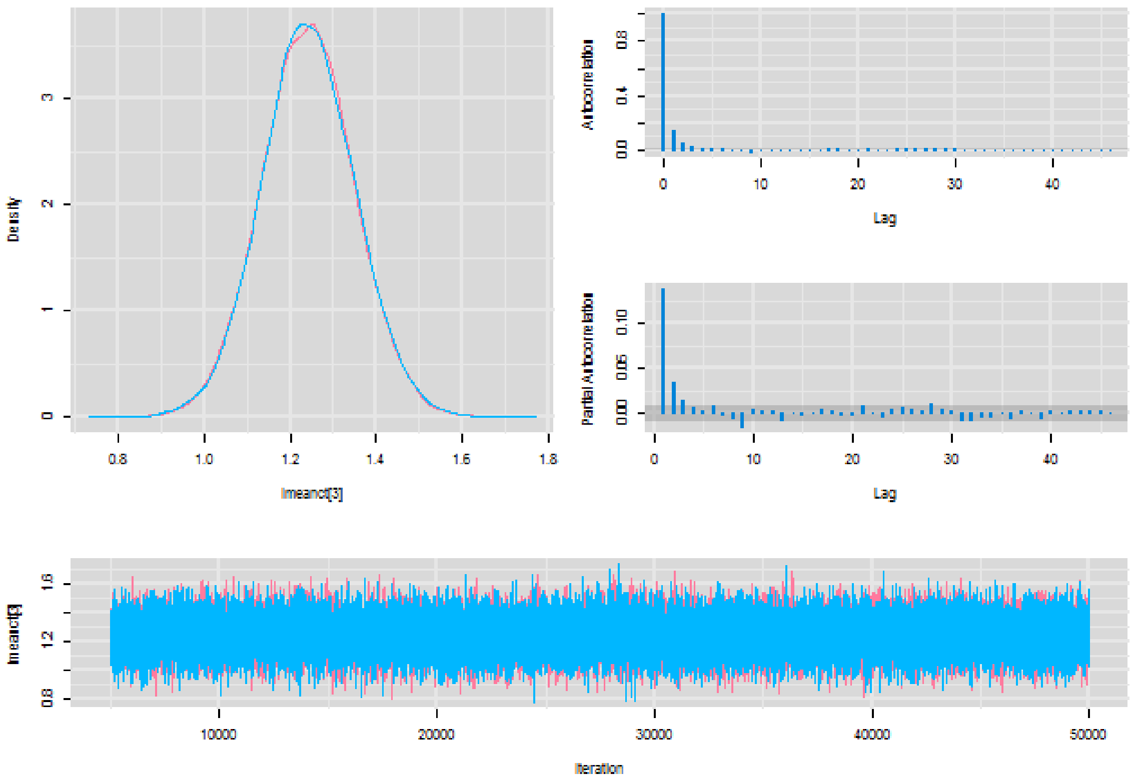
Diagnostics for lmeanct[1]



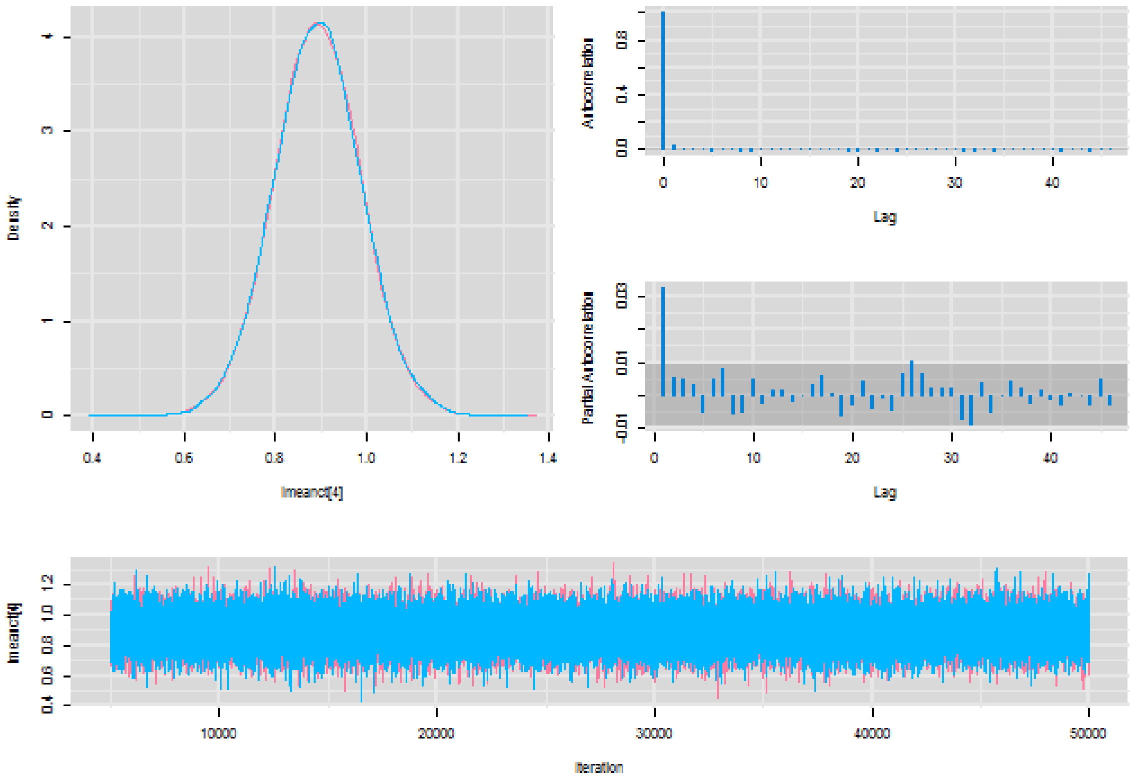
Diagnostics for lmeanct[2]



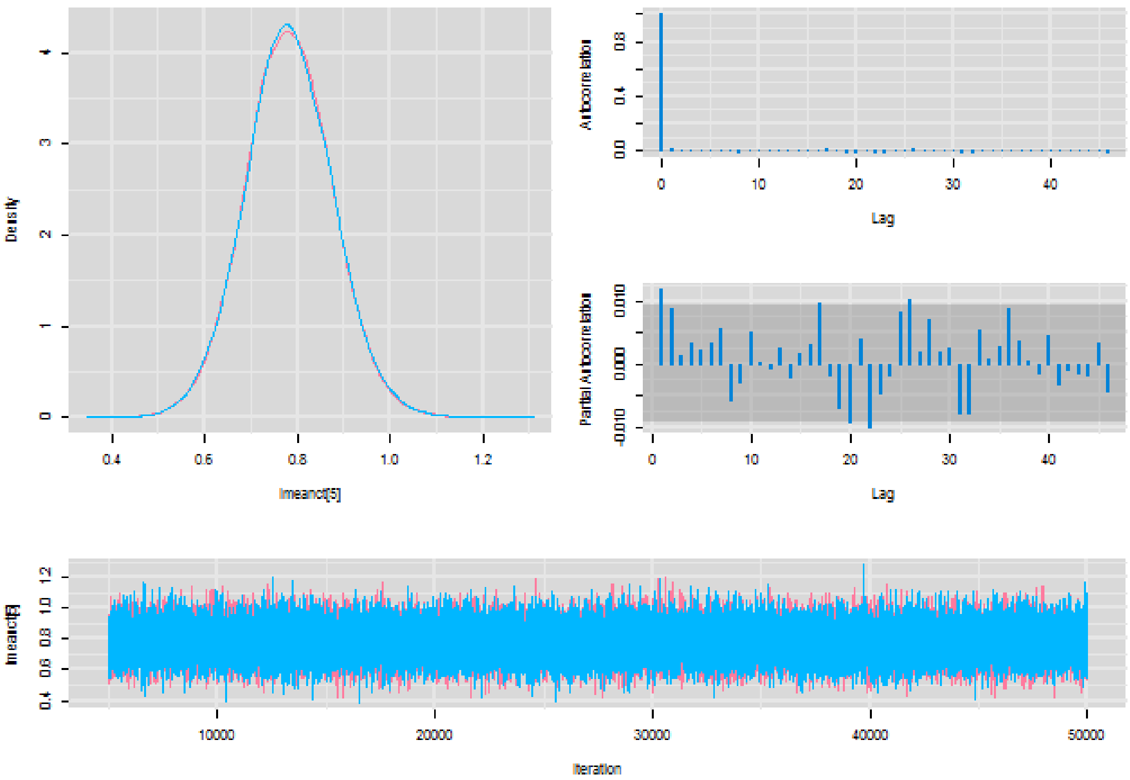
Diagnostics for lmeanct[3]



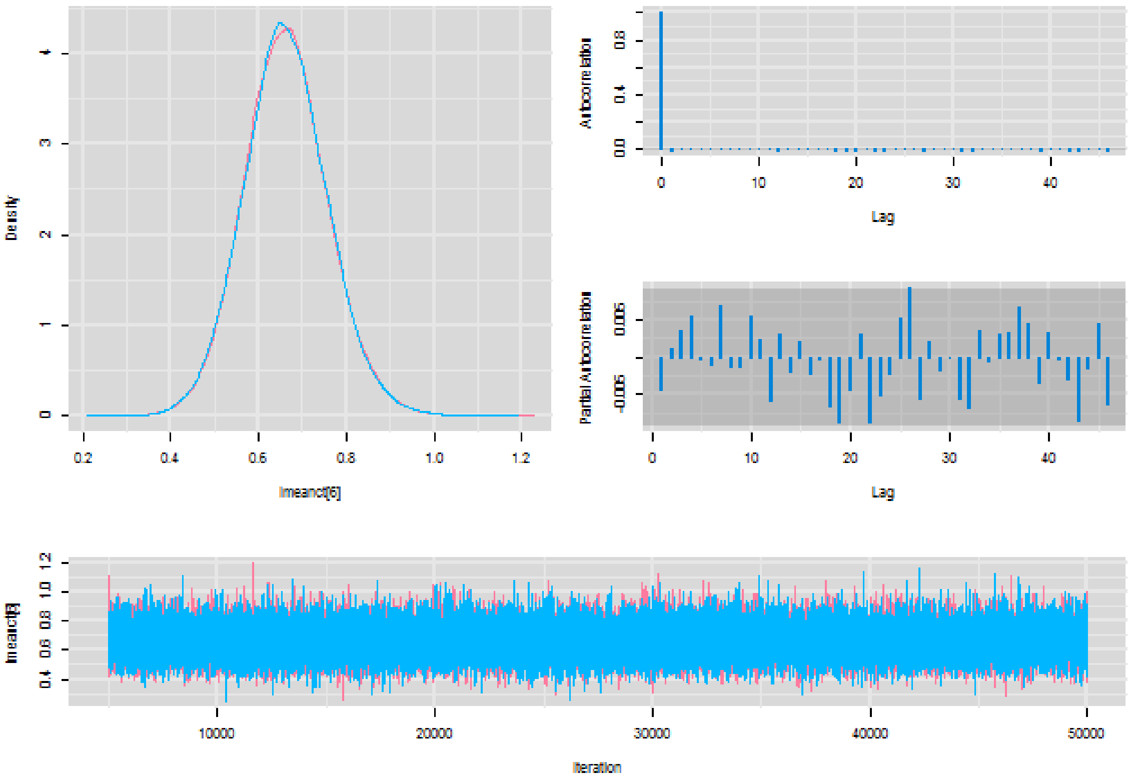
Diagnostics for lmeanct[4]



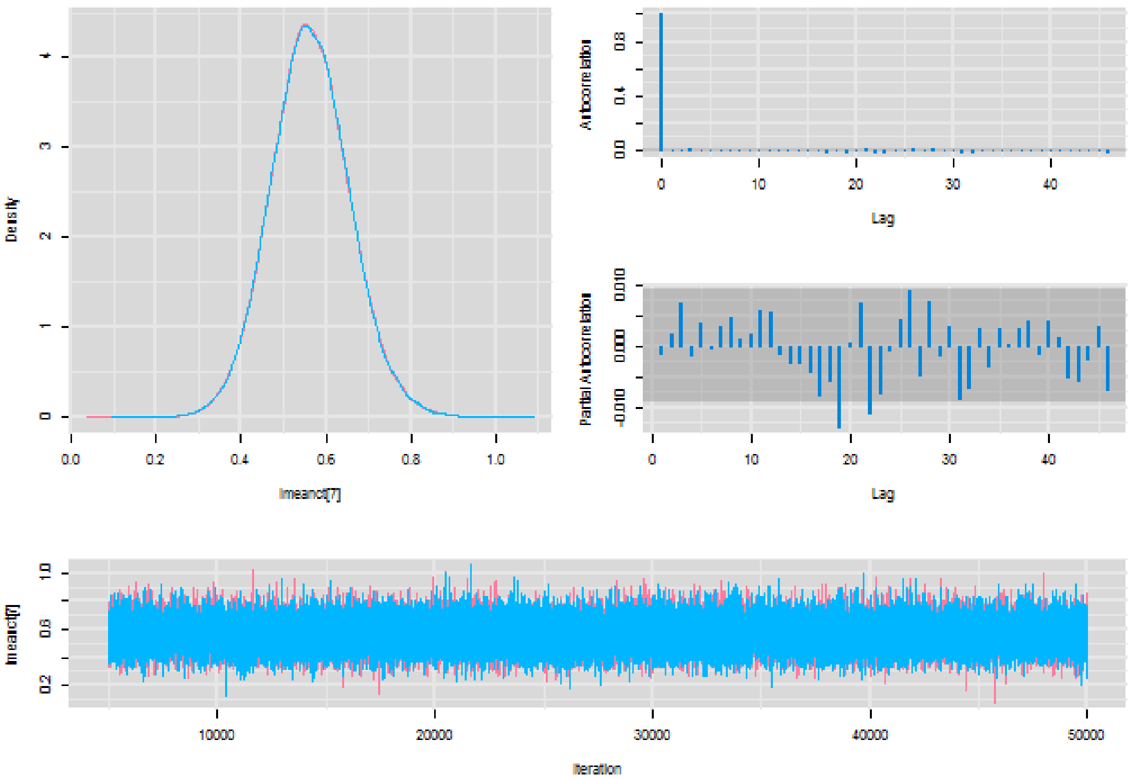
Diagnostics for lmeanct[5]



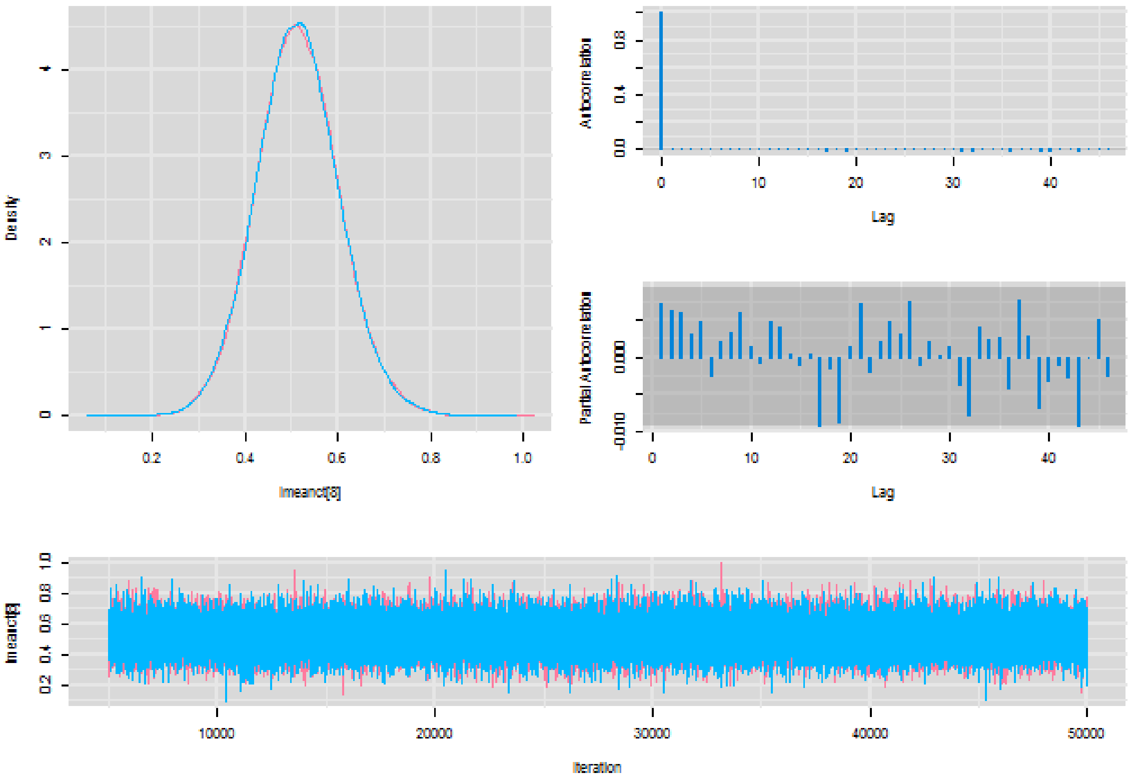
Diagnostics for lmeanct[6]



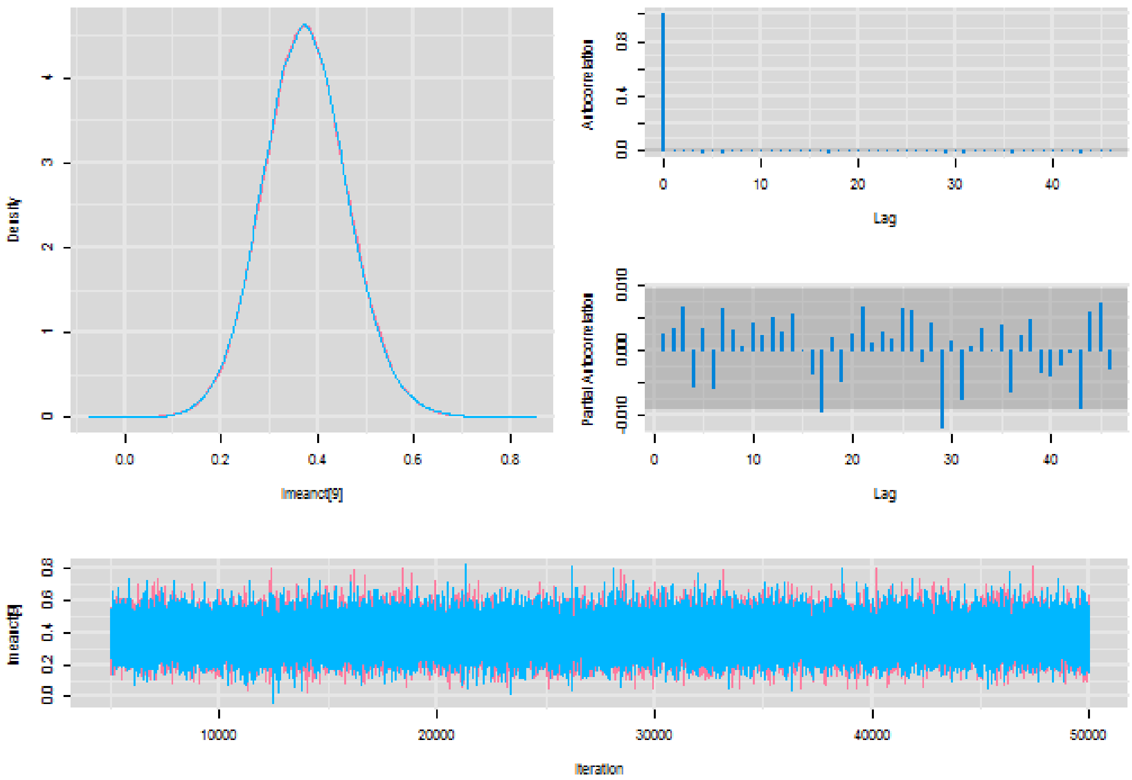
Diagnostics for lmeanct[7]



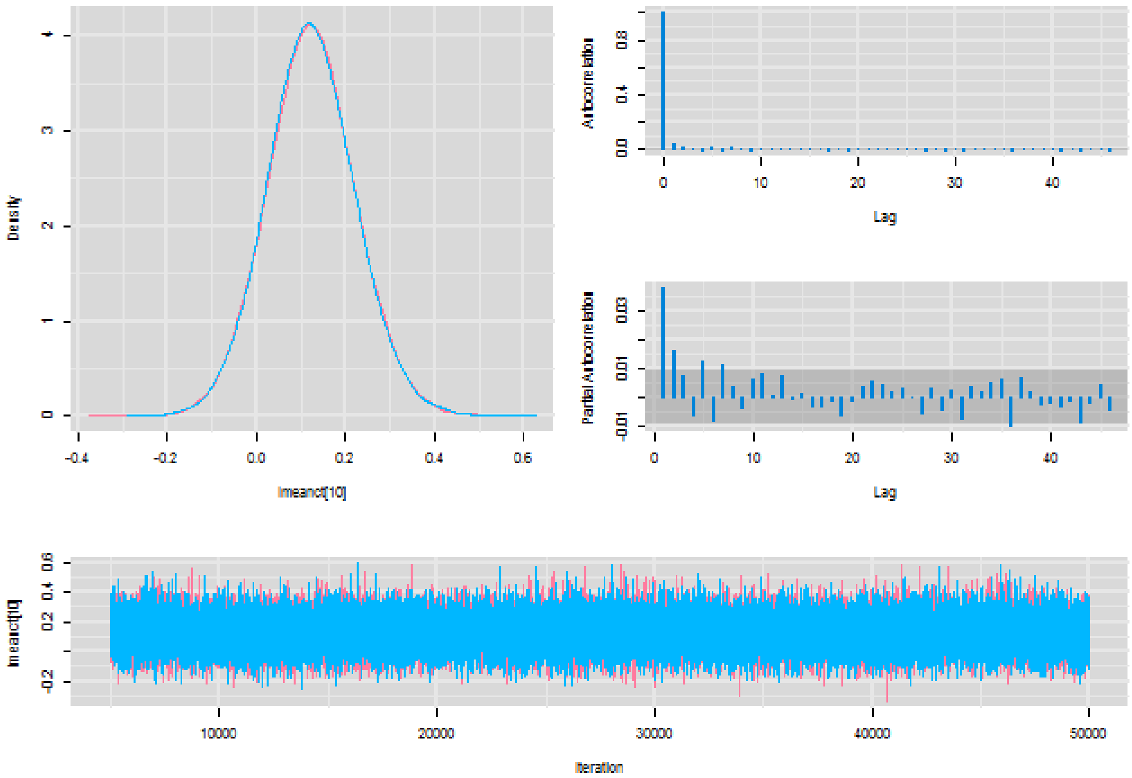
Diagnostics for lmeanct[8]



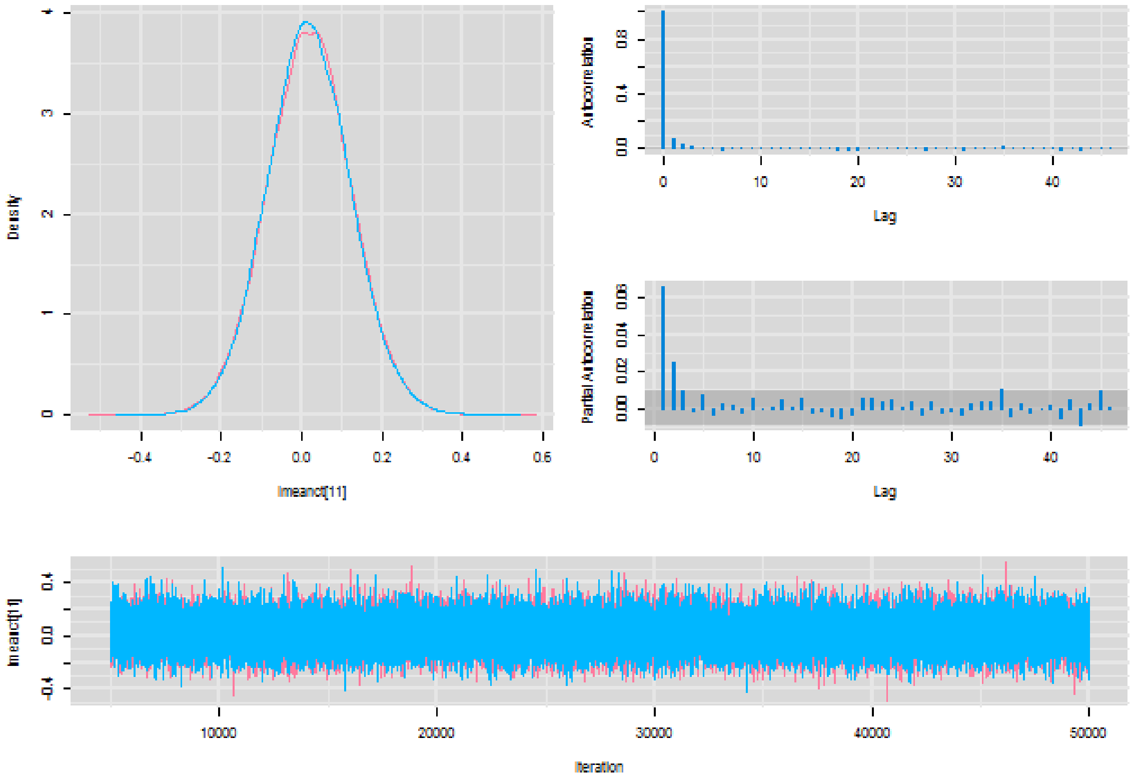
Diagnostics for lmeanct[9]



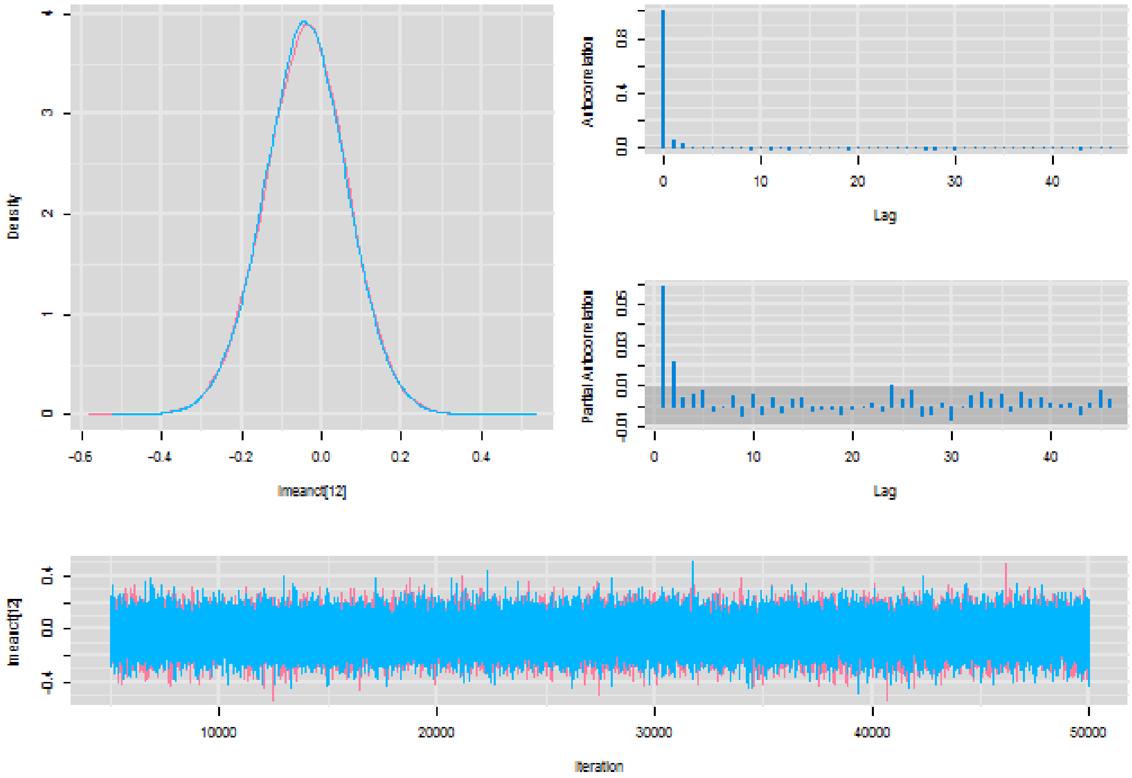
Diagnostics for lmeanct[10]



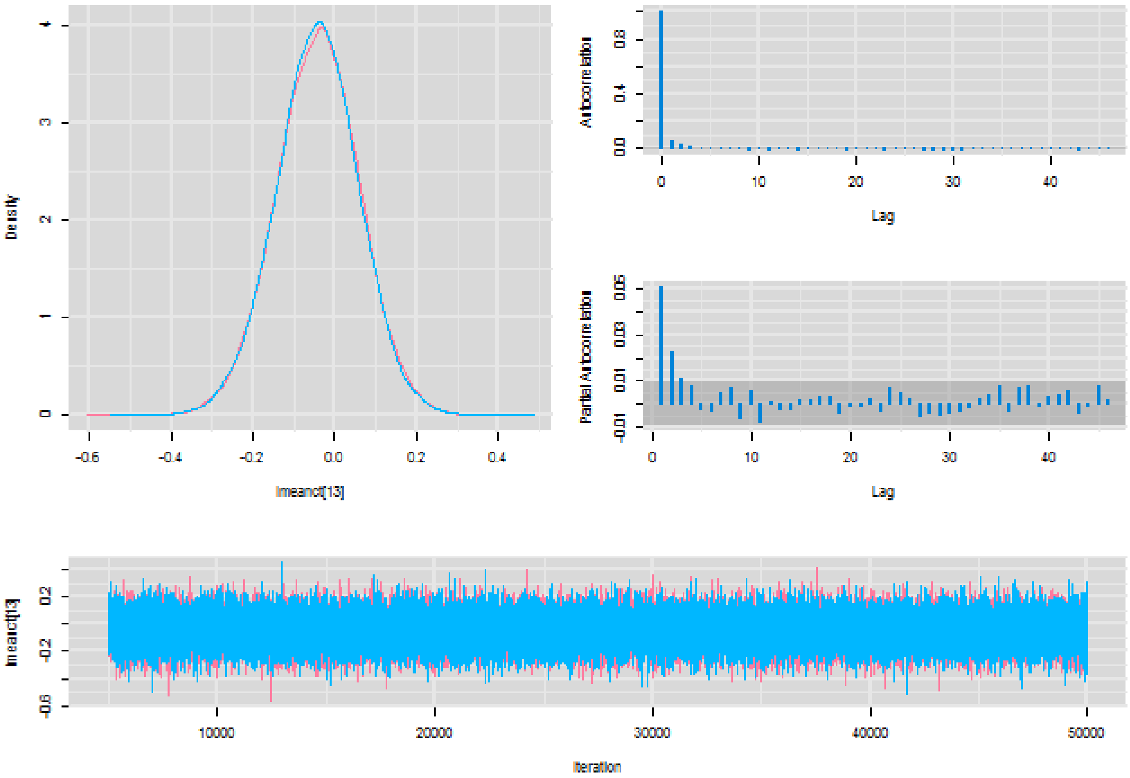
Diagnostics for lmeanct[11]



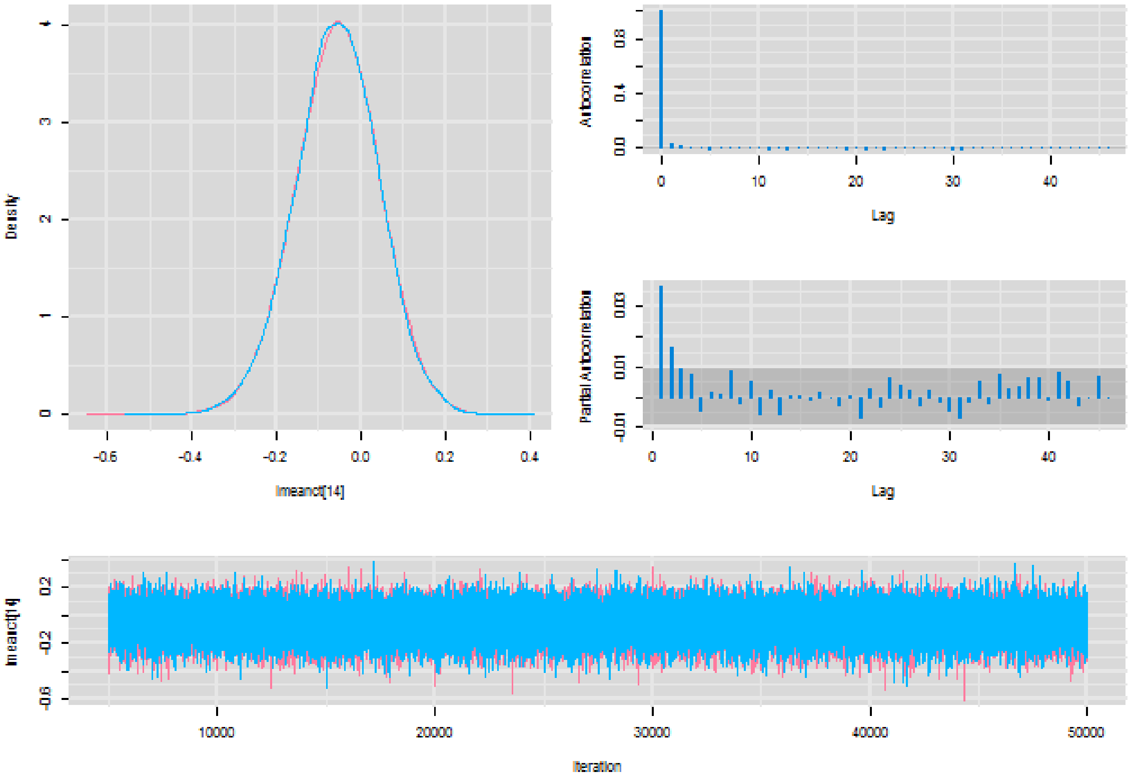
Diagnostics for lmeanct[12]



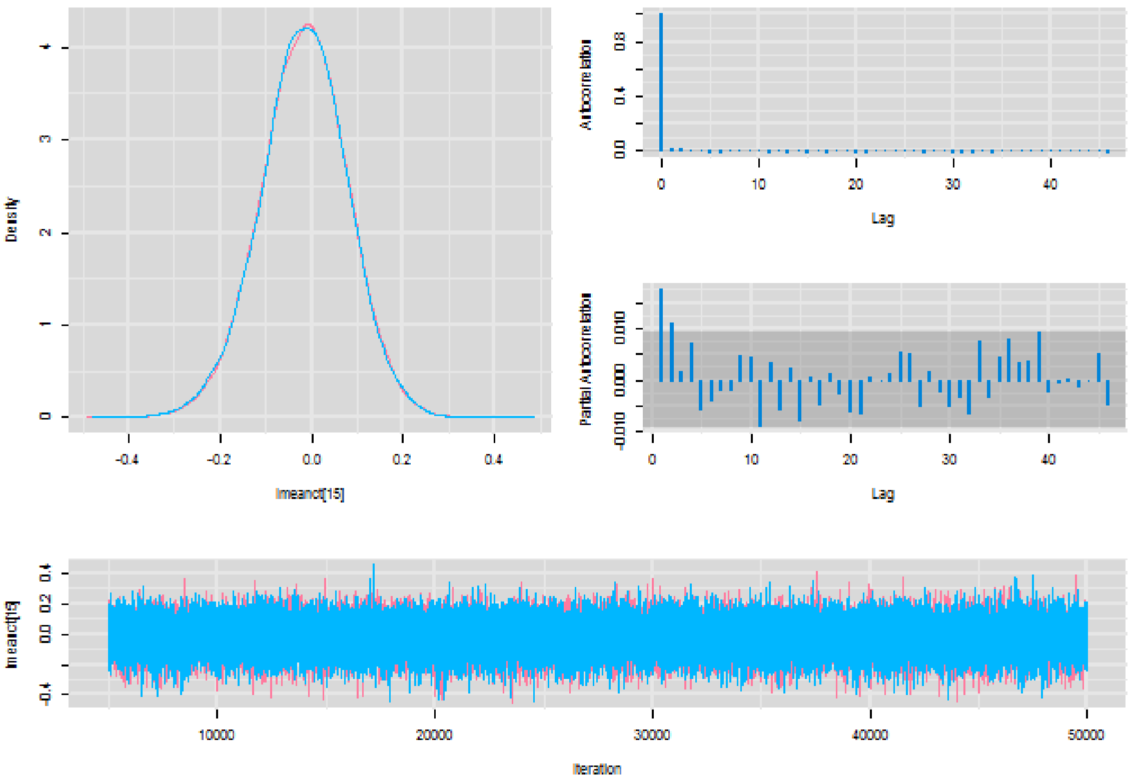
Diagnostics for lmeanct[13]



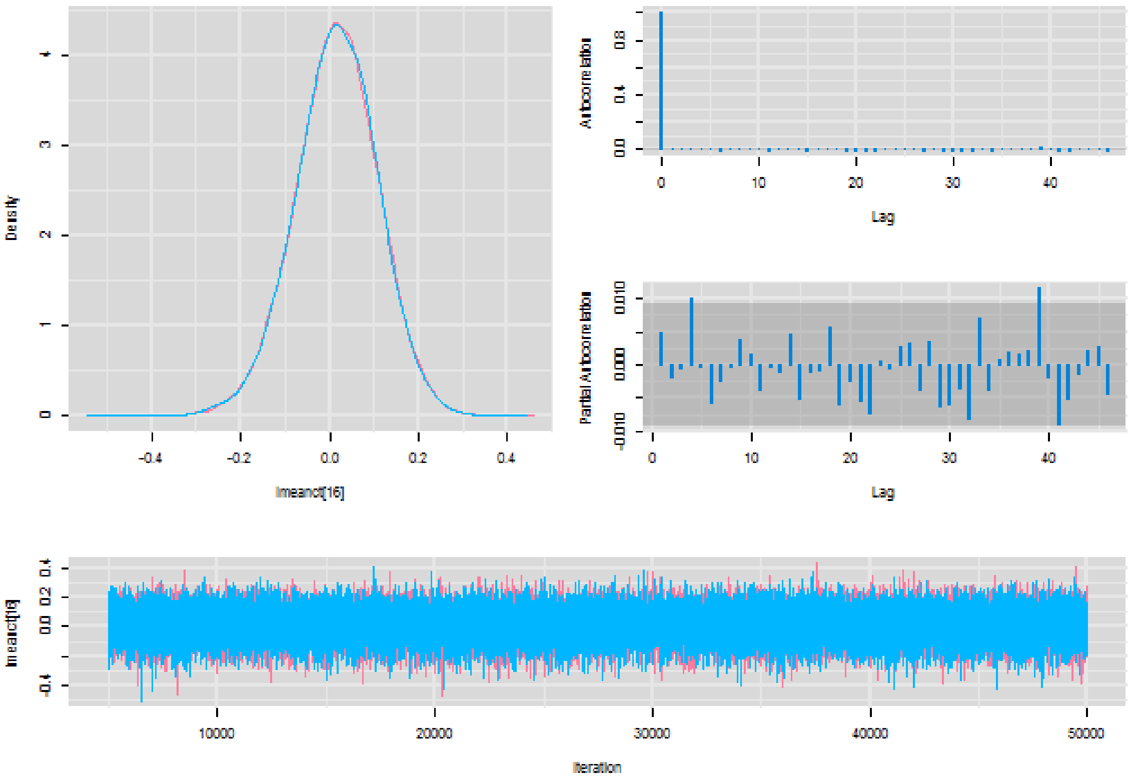
Diagnostics for lmeanct[14]



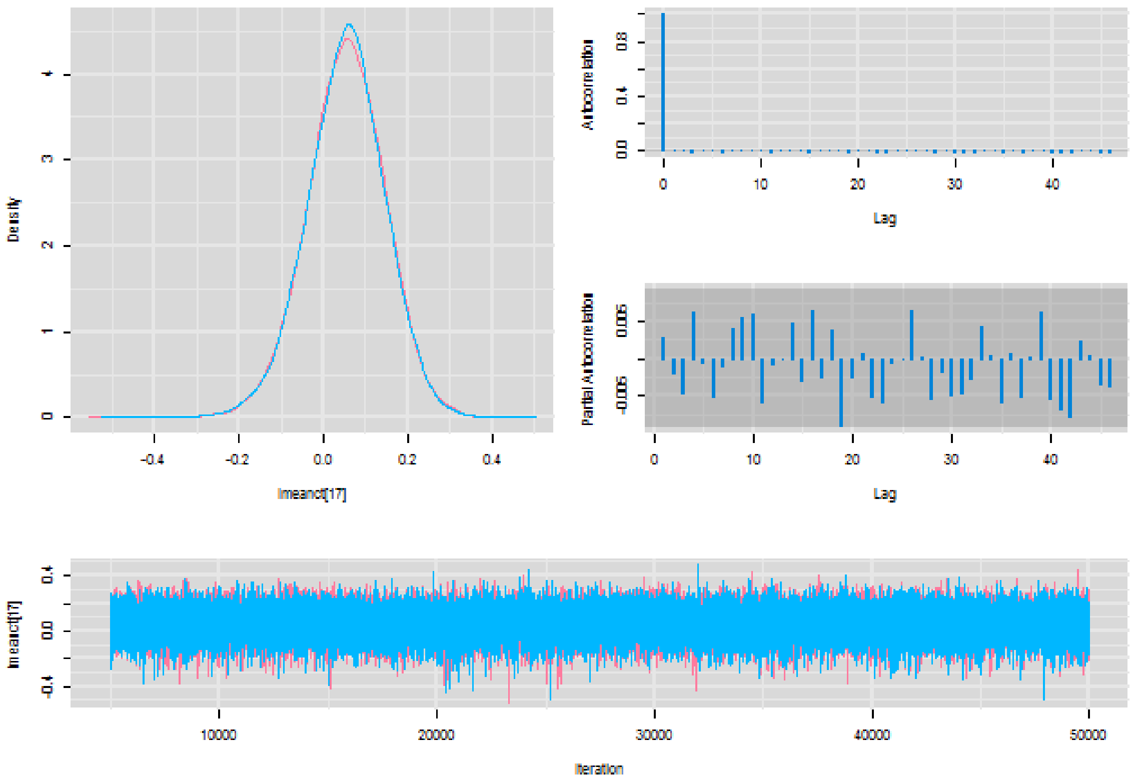
Diagnostics for lmeanct[15]



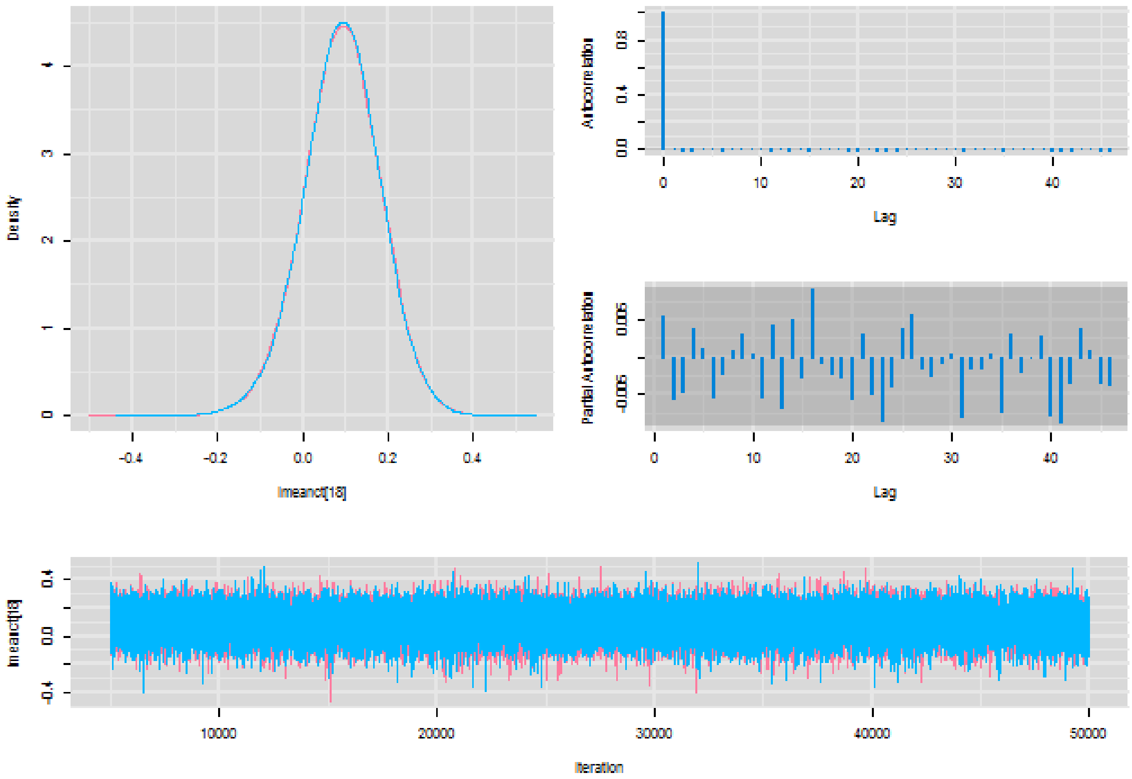
Diagnostics for lmeanct[16]



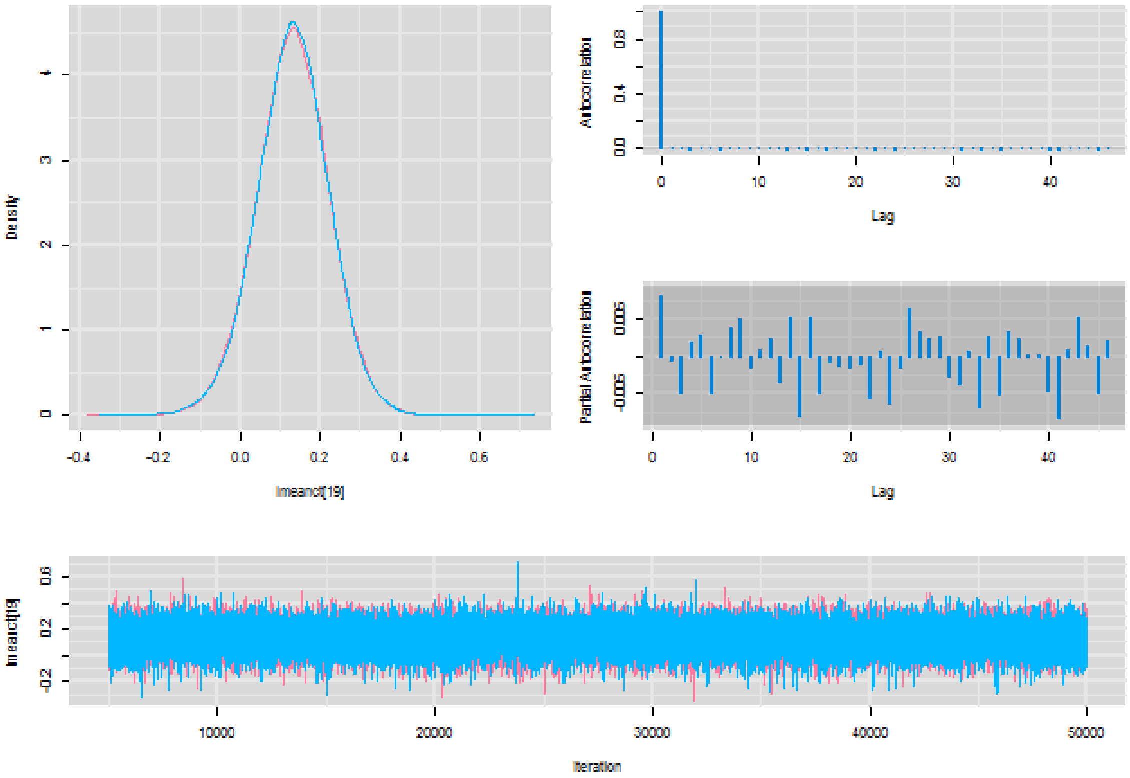
Diagnostics for lmeanct[17]



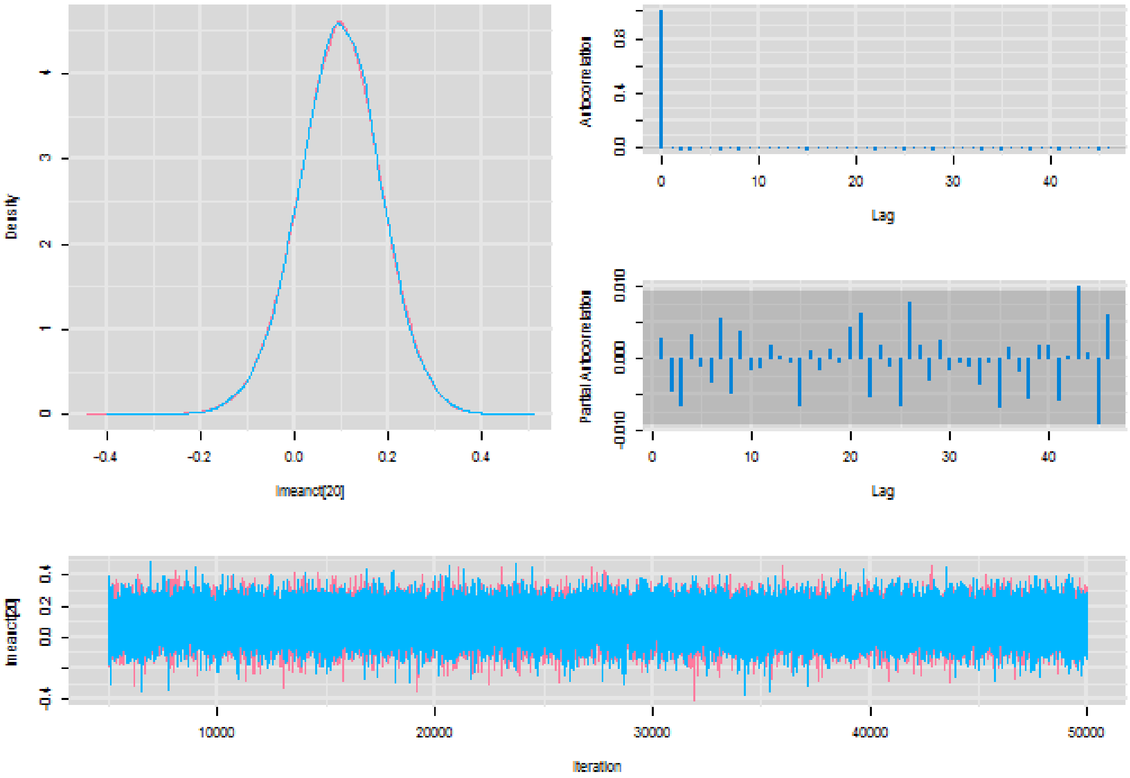
Diagnostics for lmeanct[18]



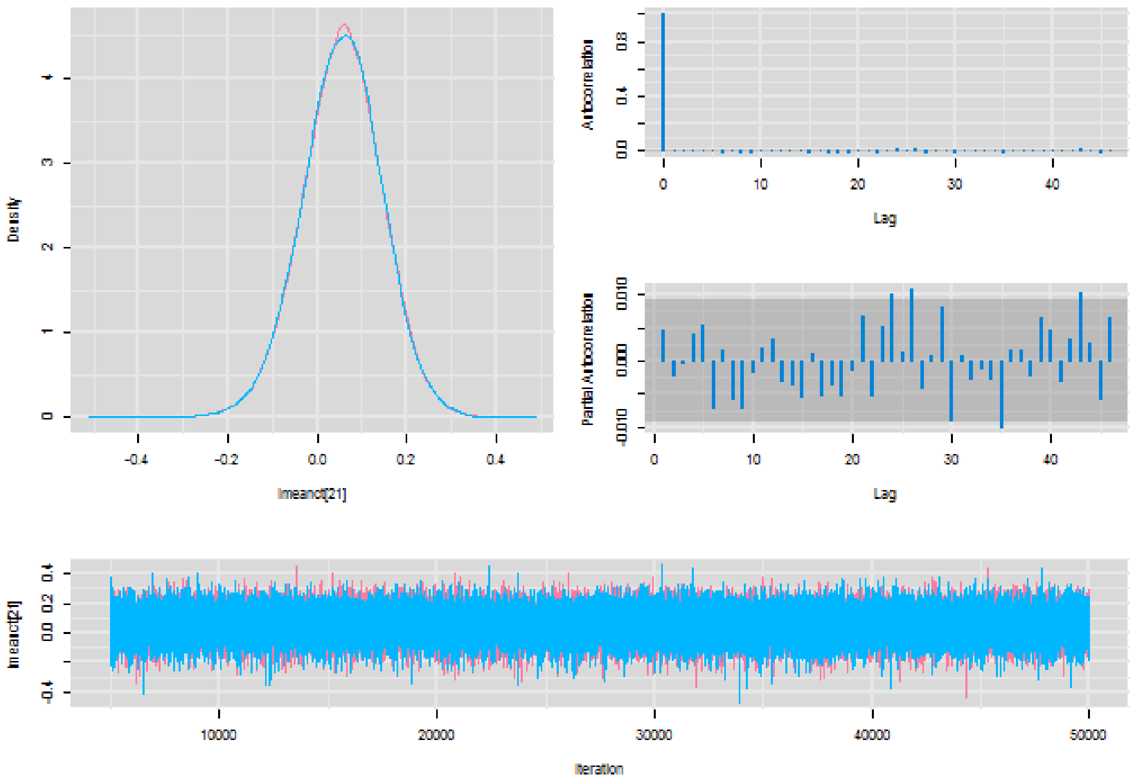
Diagnostics for lmeanct[19]



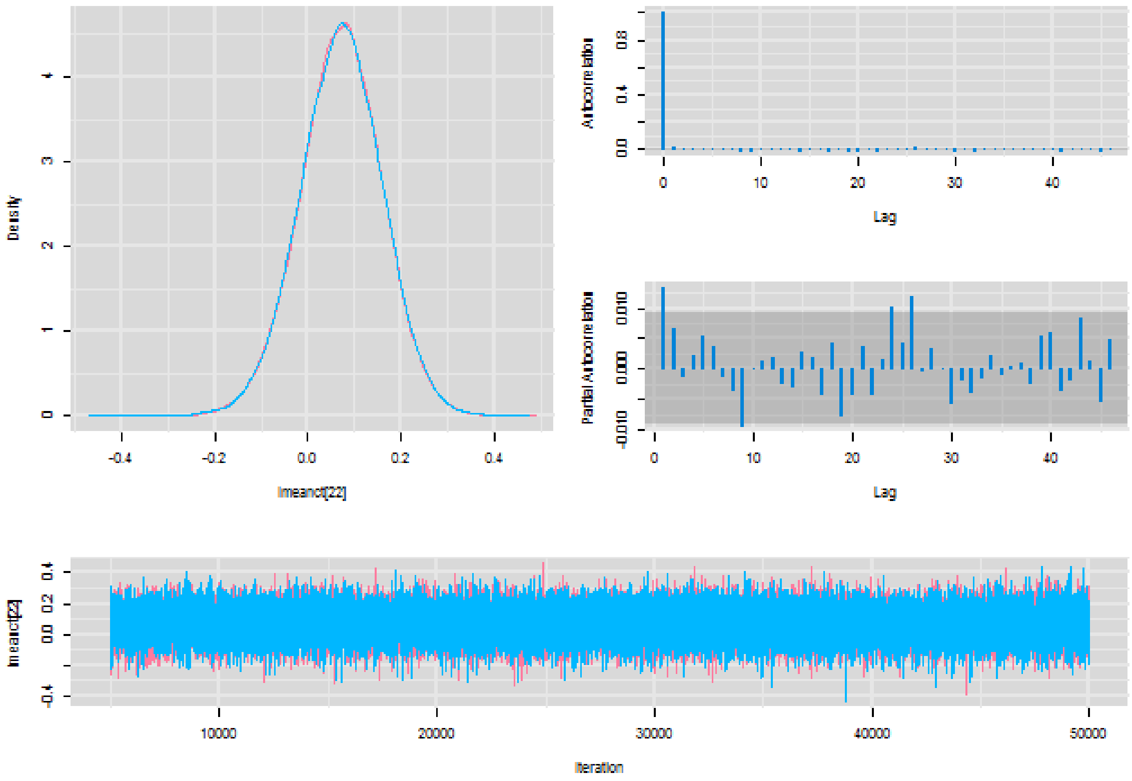
Diagnostics for lmeanct[20]



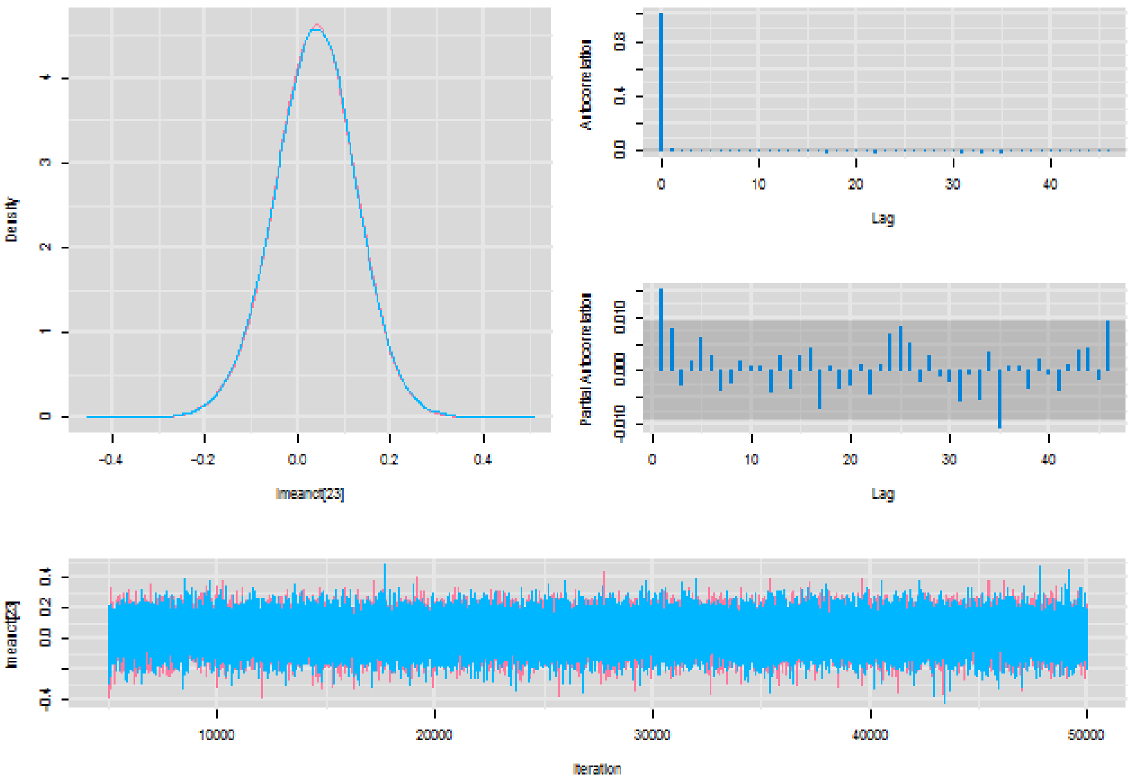
Diagnostics for lmeanct[21]



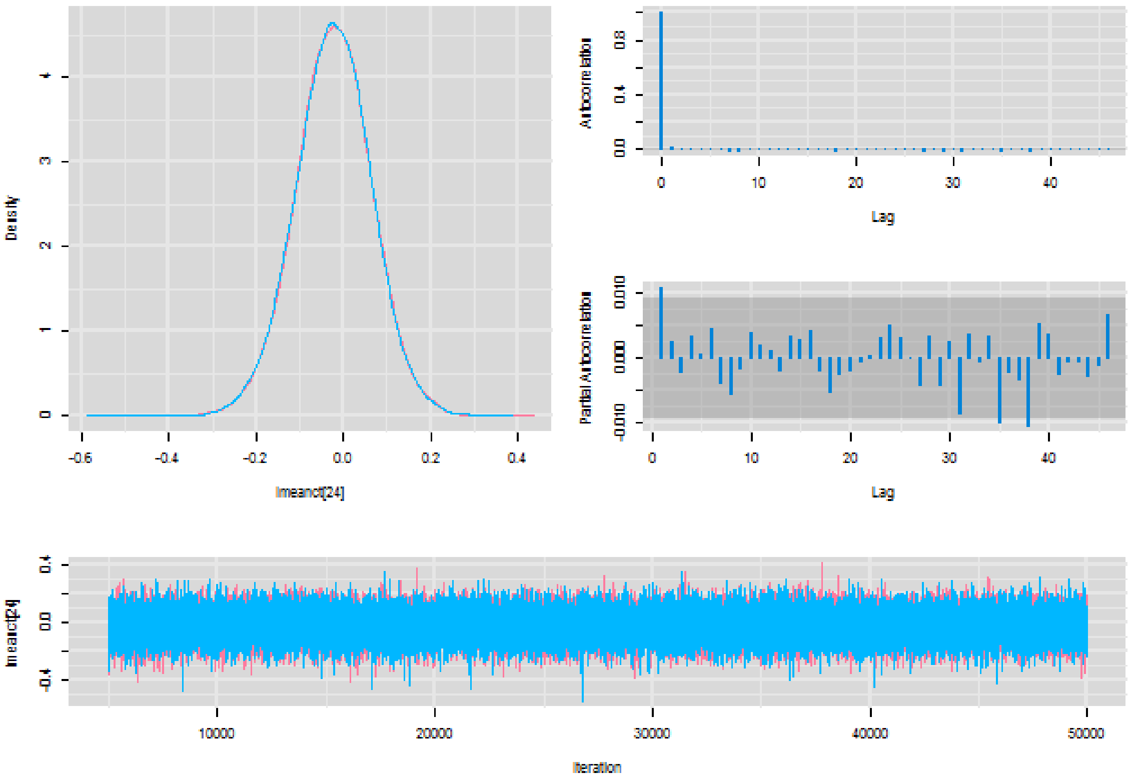
Diagnostics for lmeanct[22]



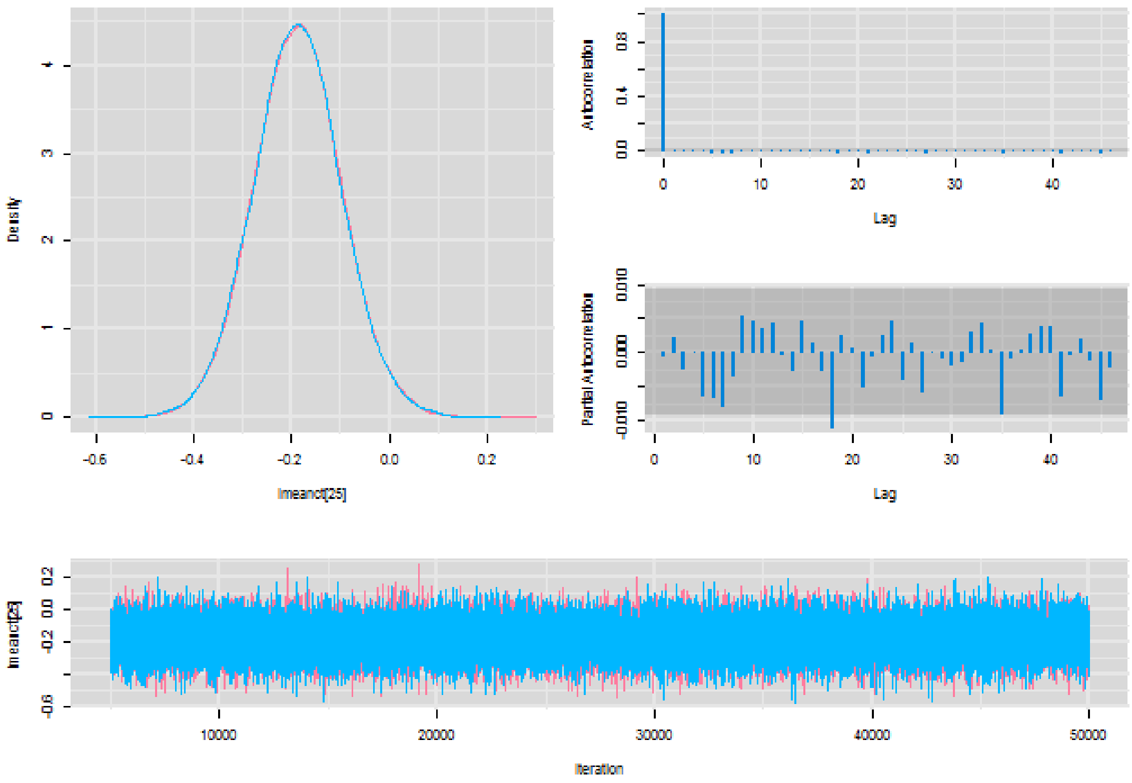
Diagnostics for lmeanct[23]



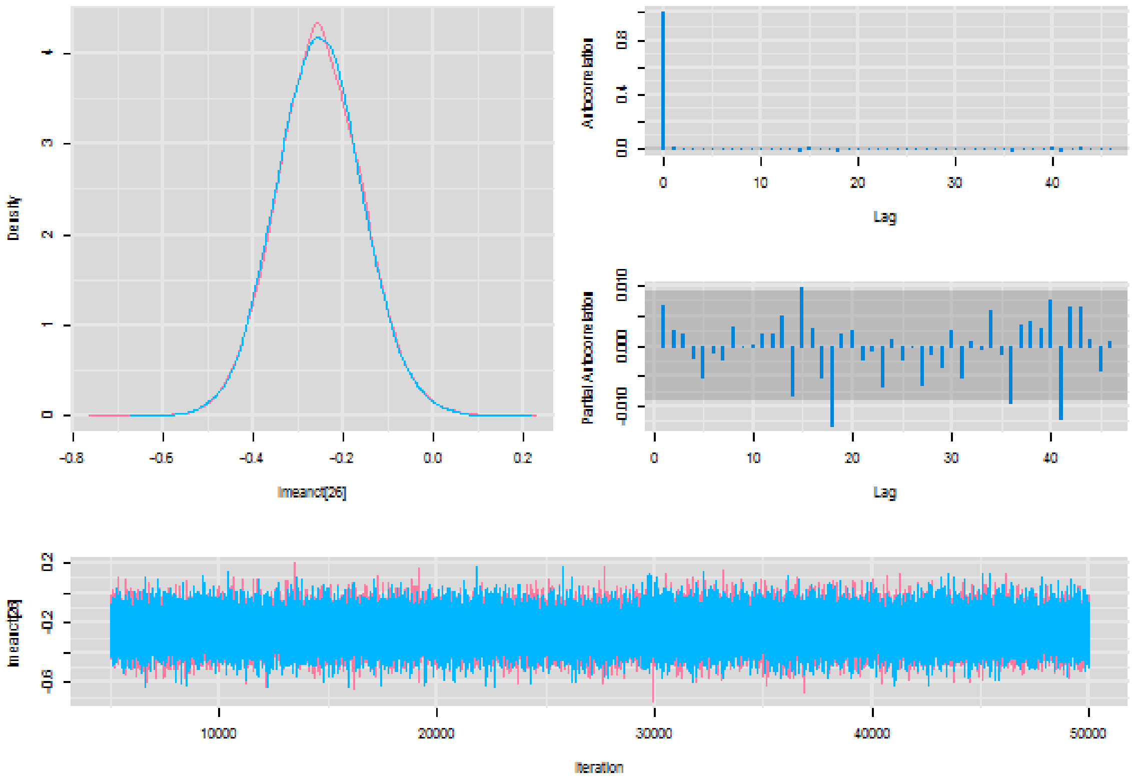
Diagnostics for lmeanct[24]



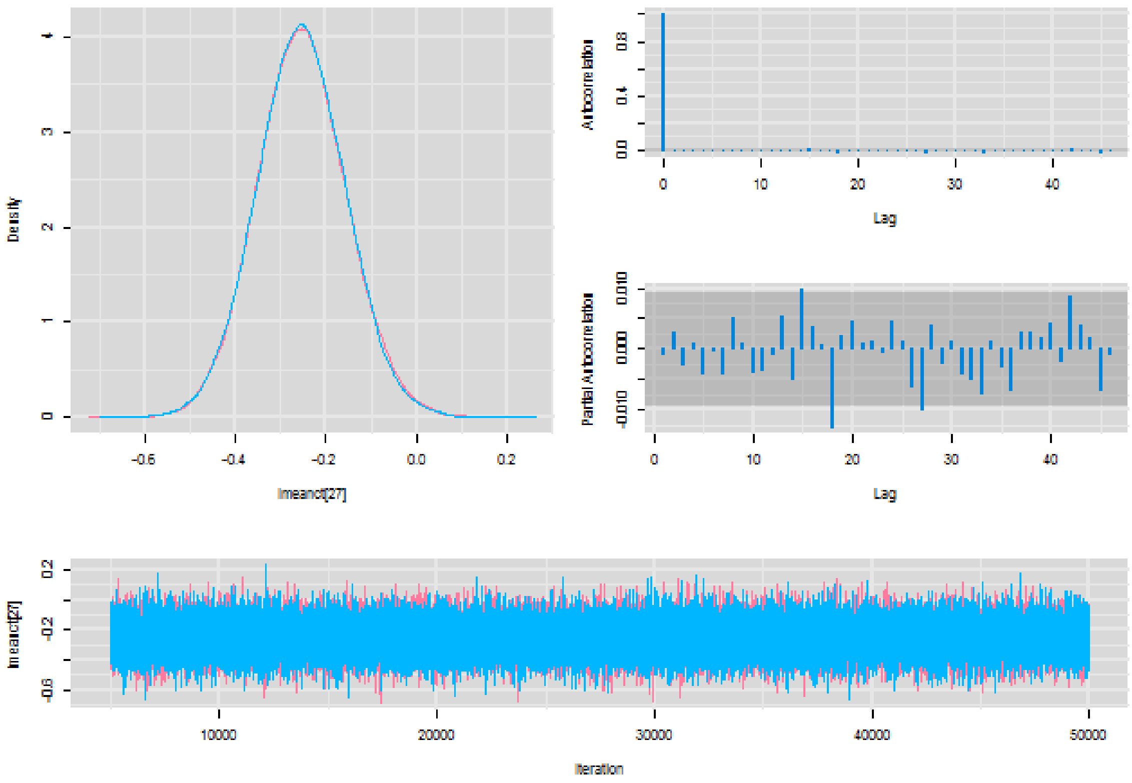
Diagnostics for lmeanct[25]



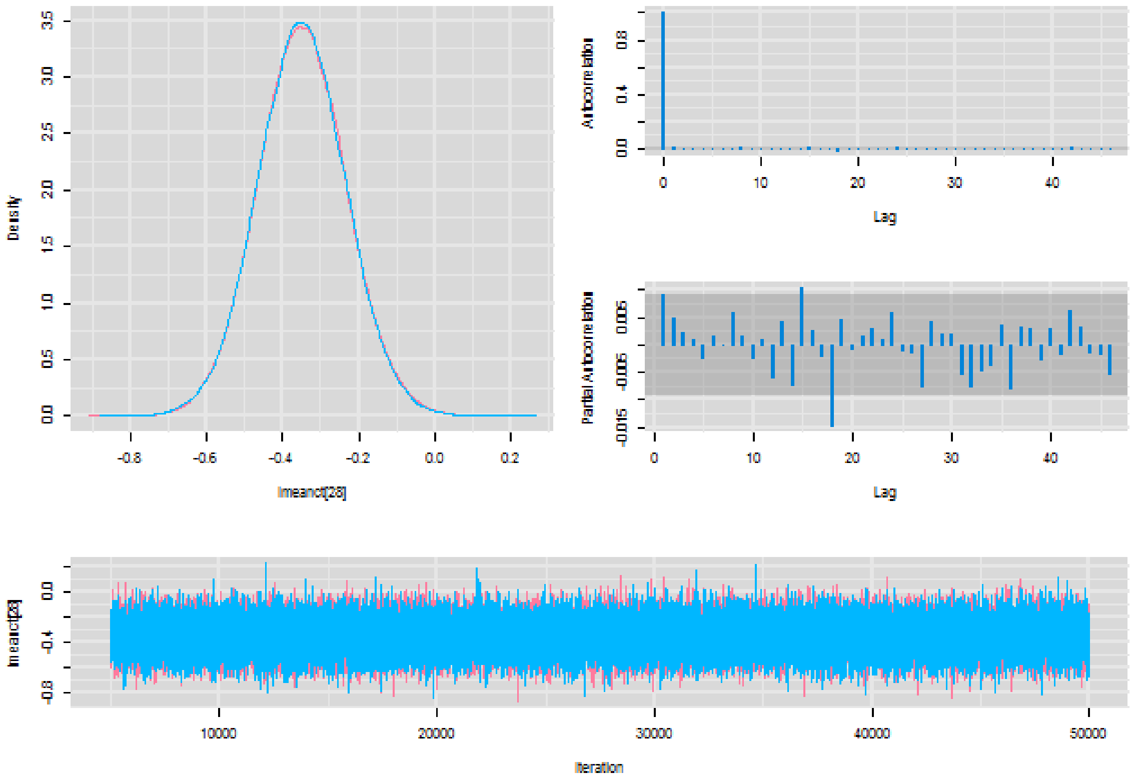
Diagnostics for lmeanct[26]



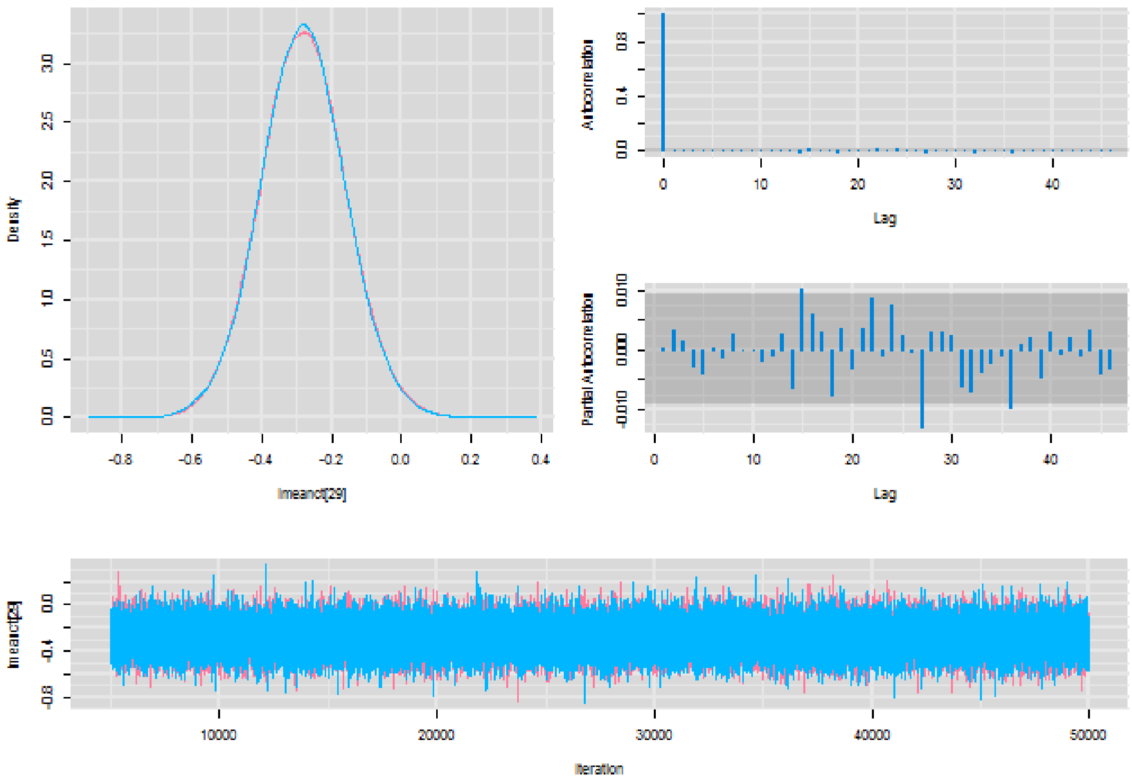
Diagnostics for lmeanct[27]



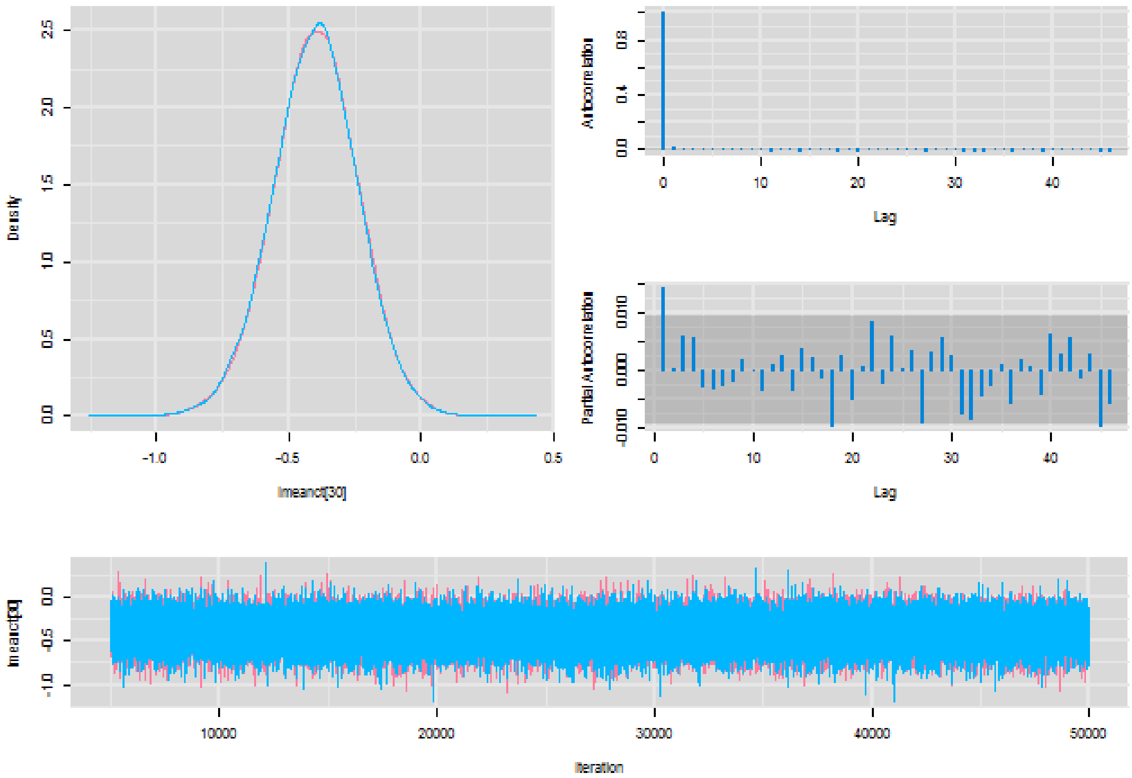
Diagnostics for lmeanct[28]



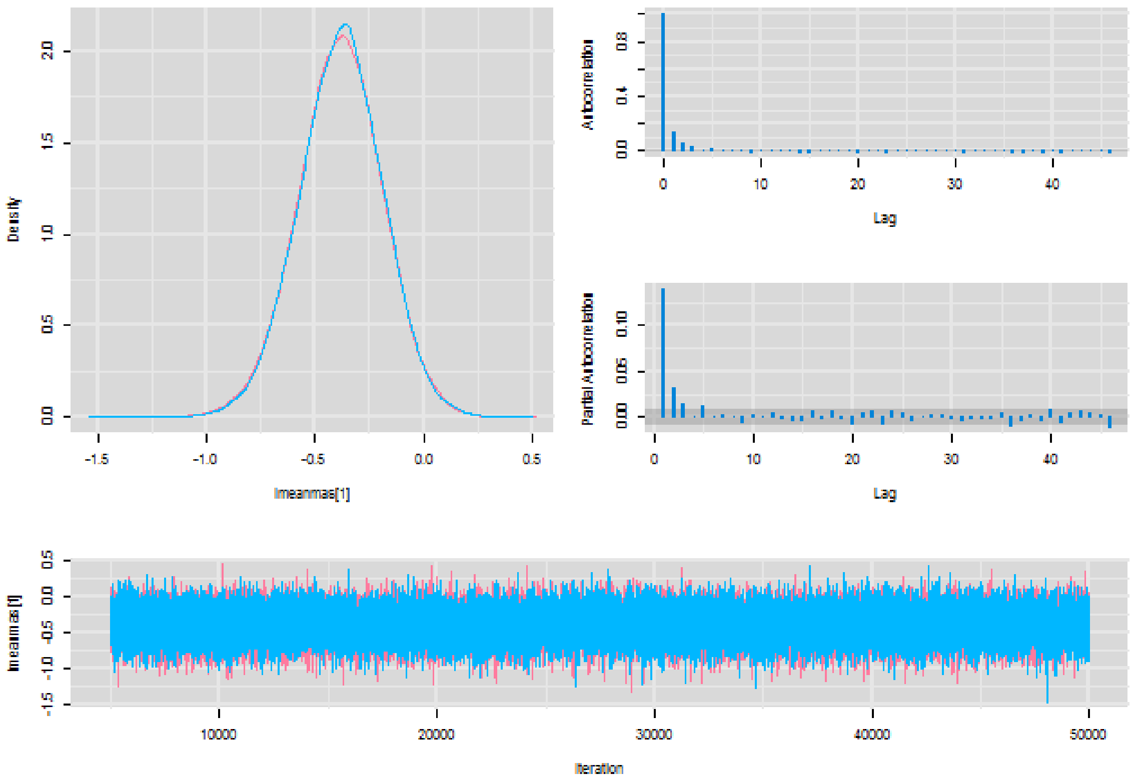
Diagnostics for lmeanct[29]



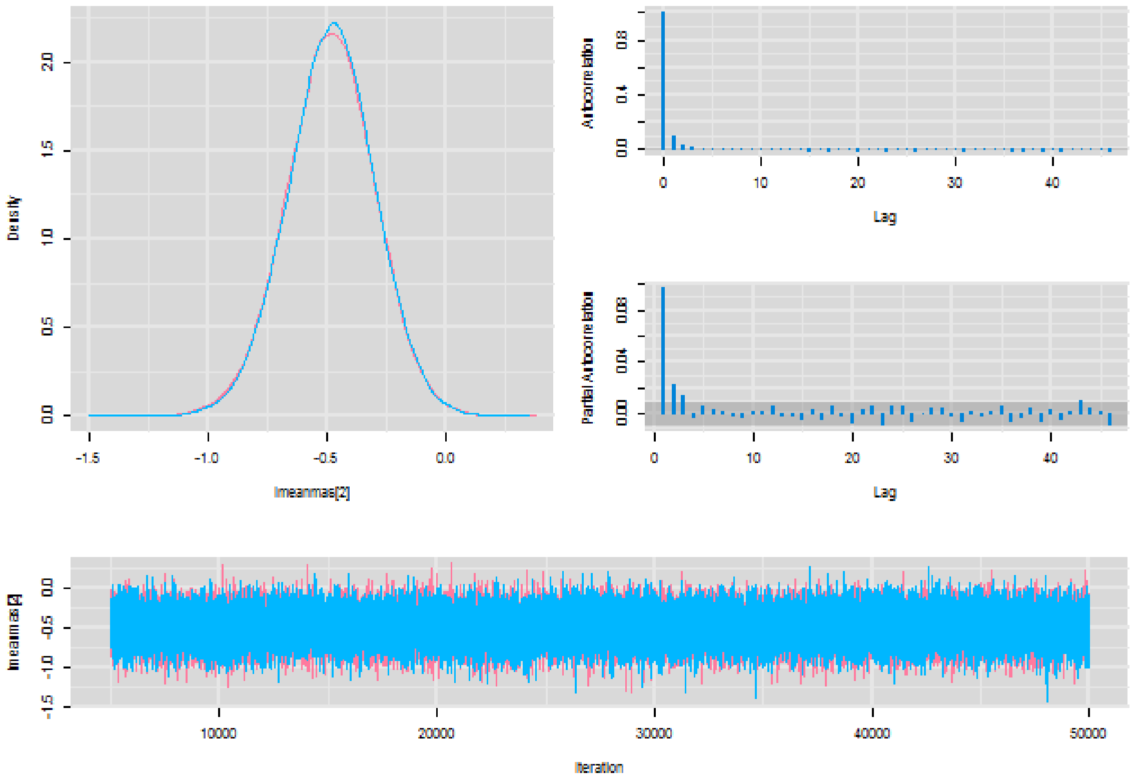
Diagnostics for lmeanct[30]



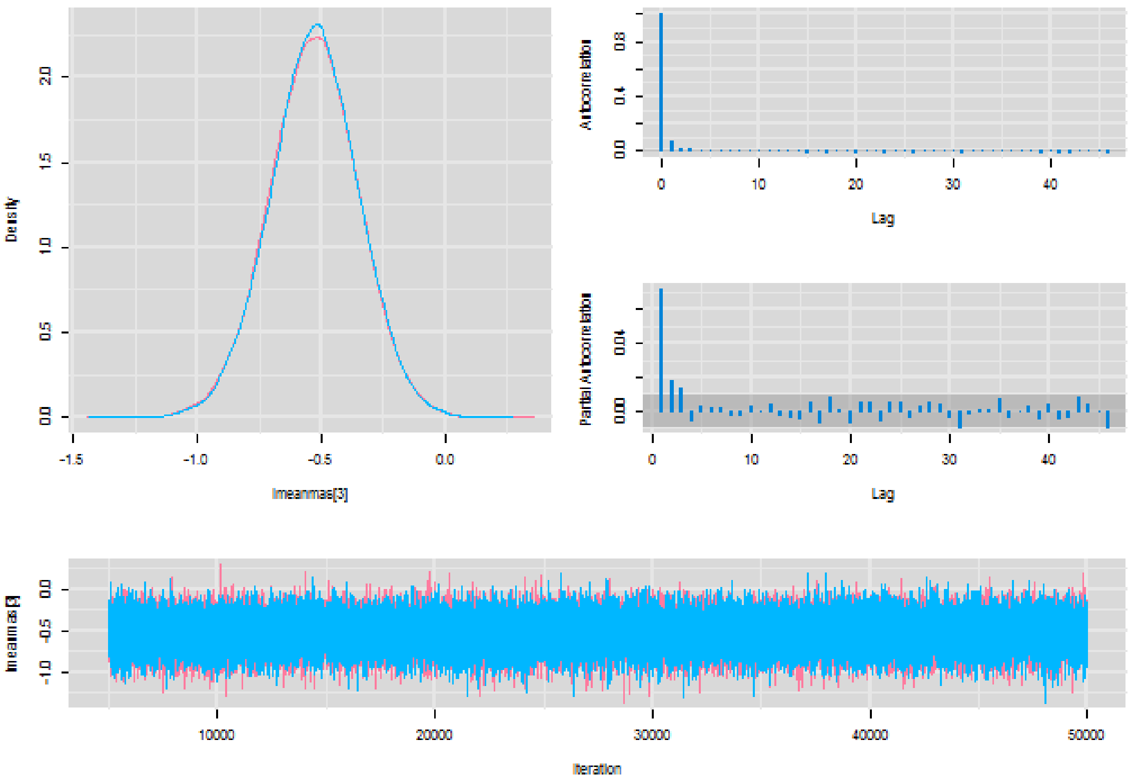
Diagnostics for lmeanmas[1]



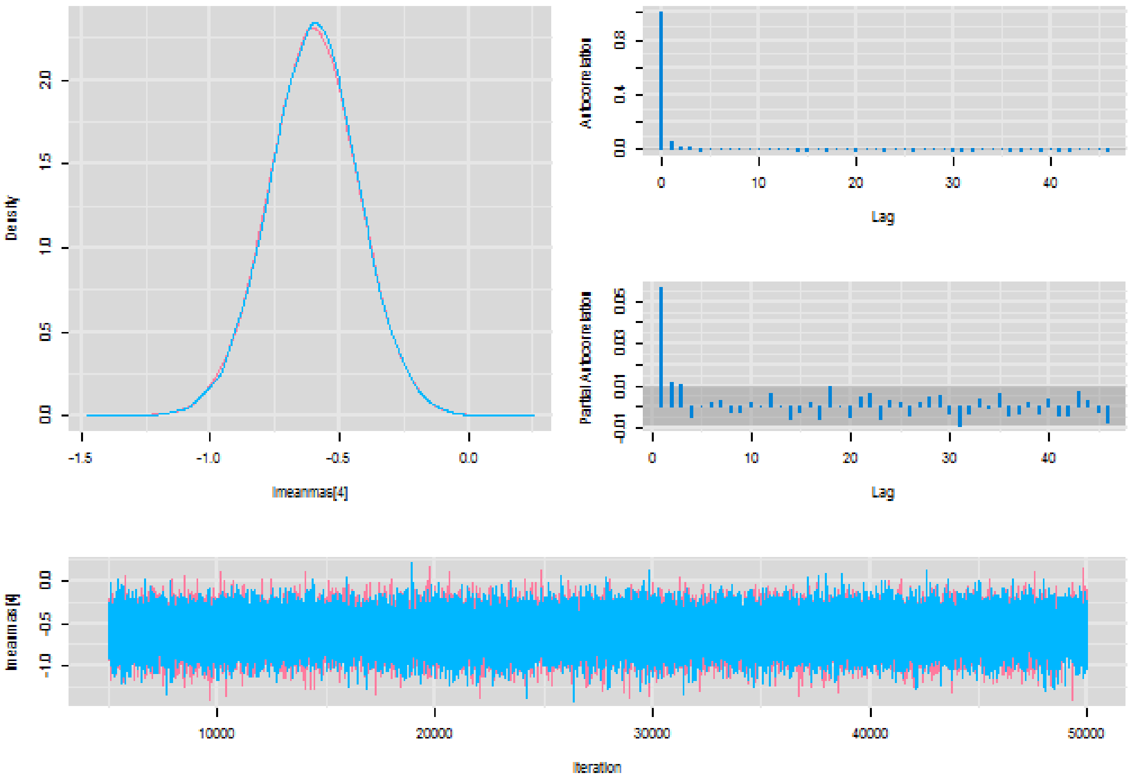
Diagnostics for lmeanmas[2]



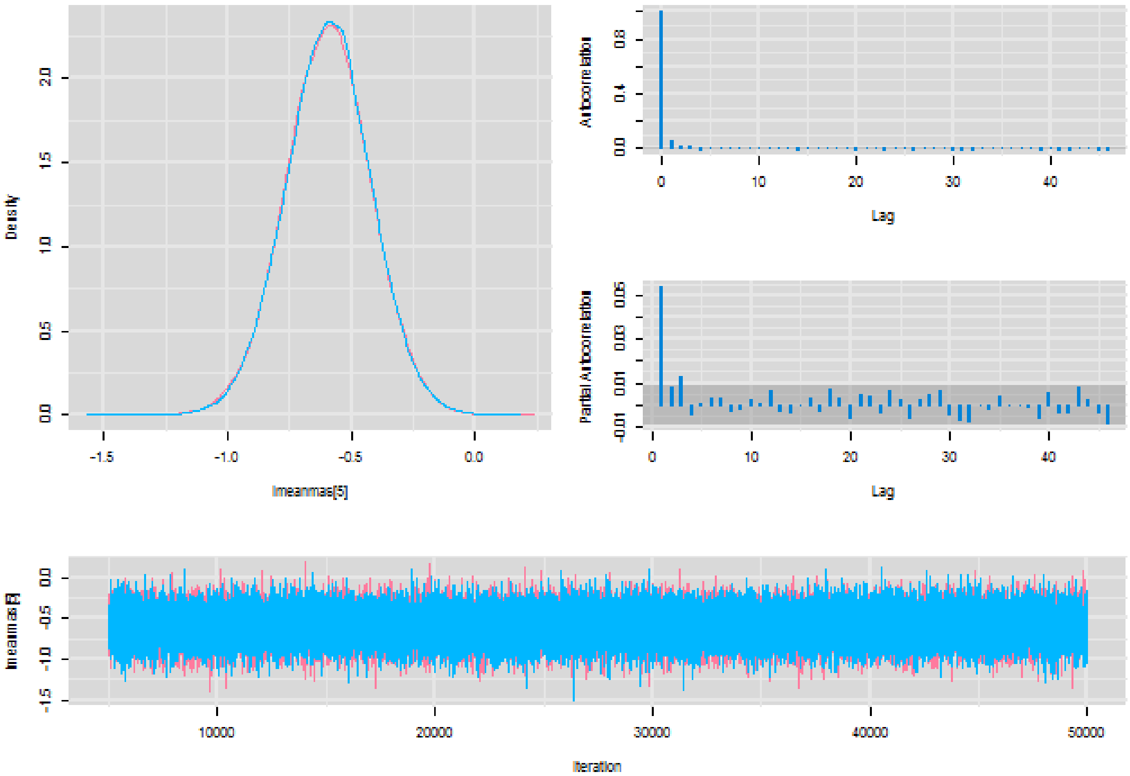
Diagnostics for lmeanmas[3]



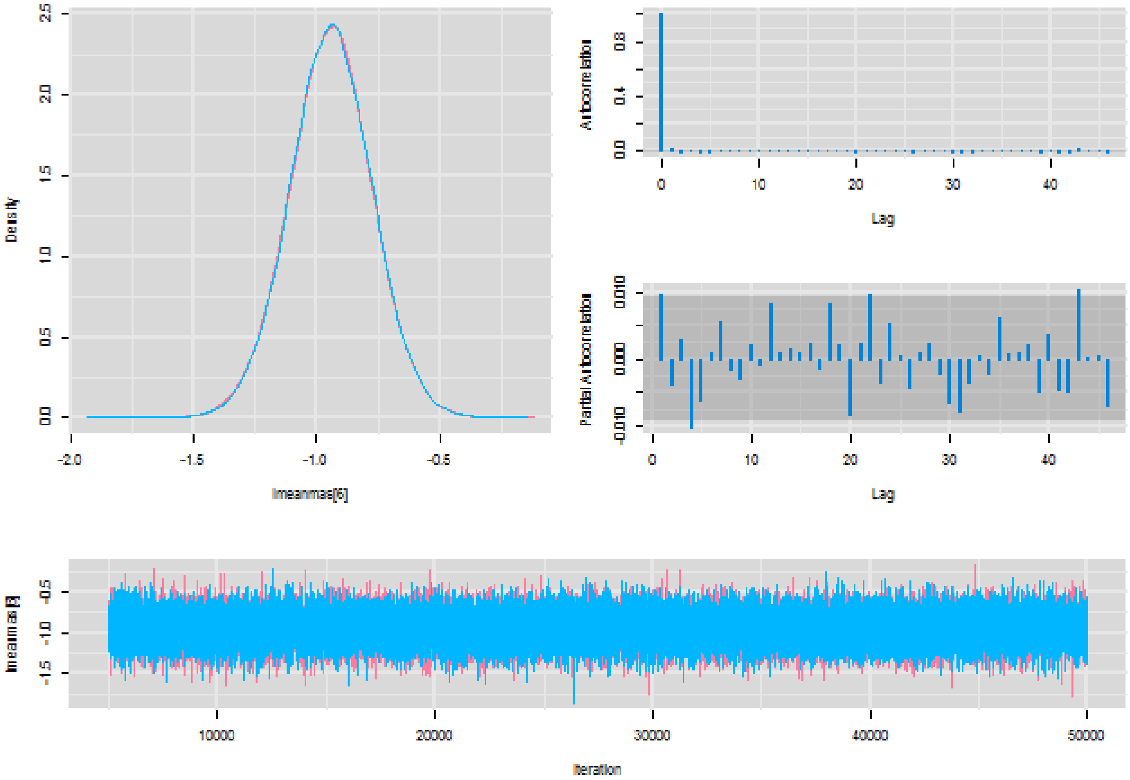
Diagnostics for lmeanmas[4]

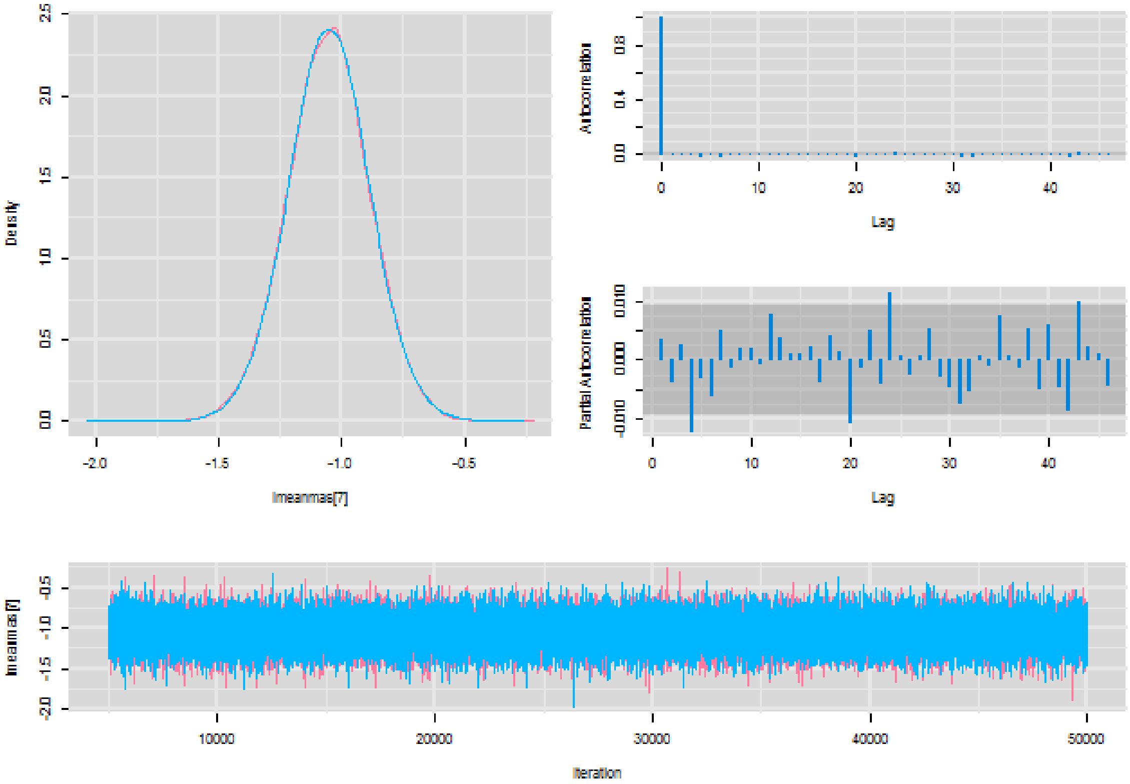


Diagnostics for lmeanmas[5]

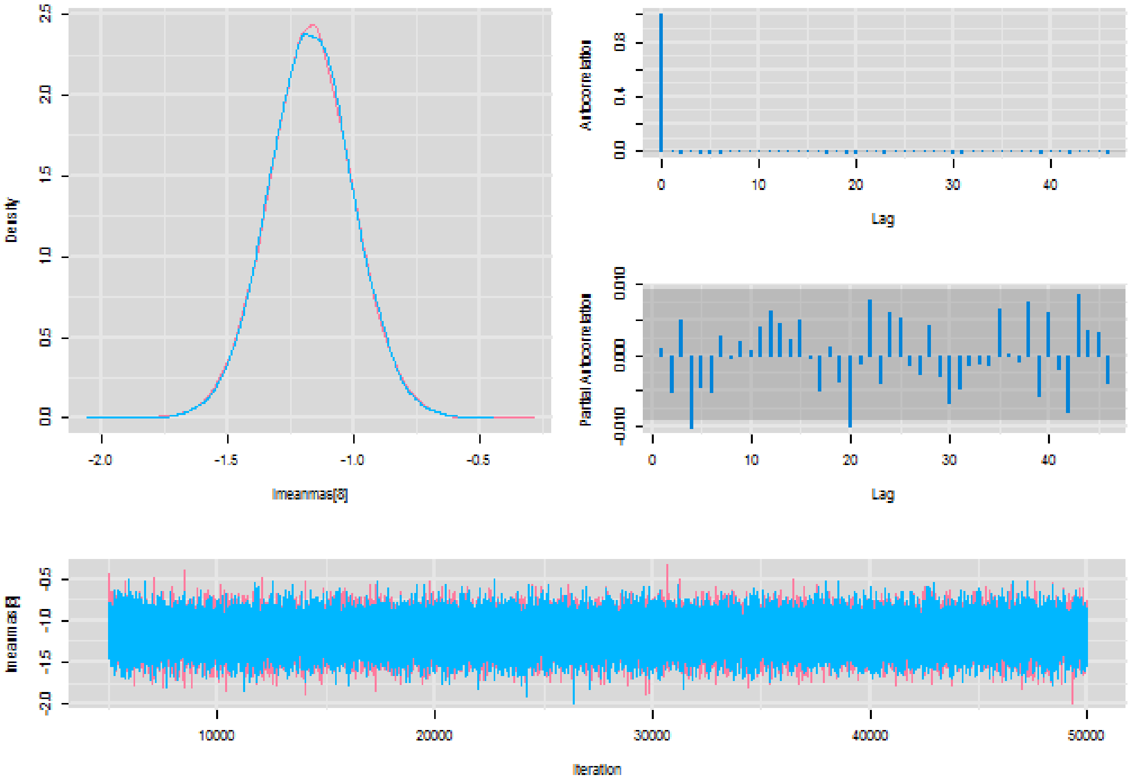


Diagnostics for lmeanmas[6]



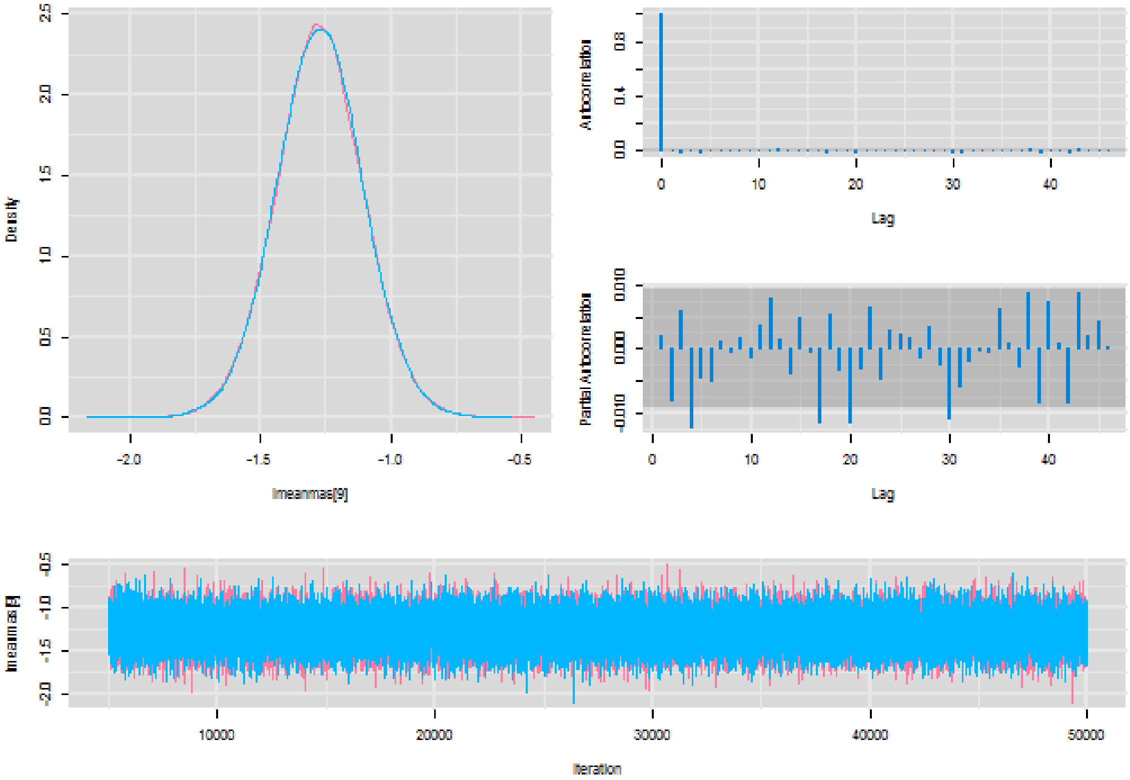


Diagnostics for lmeanmas[7]

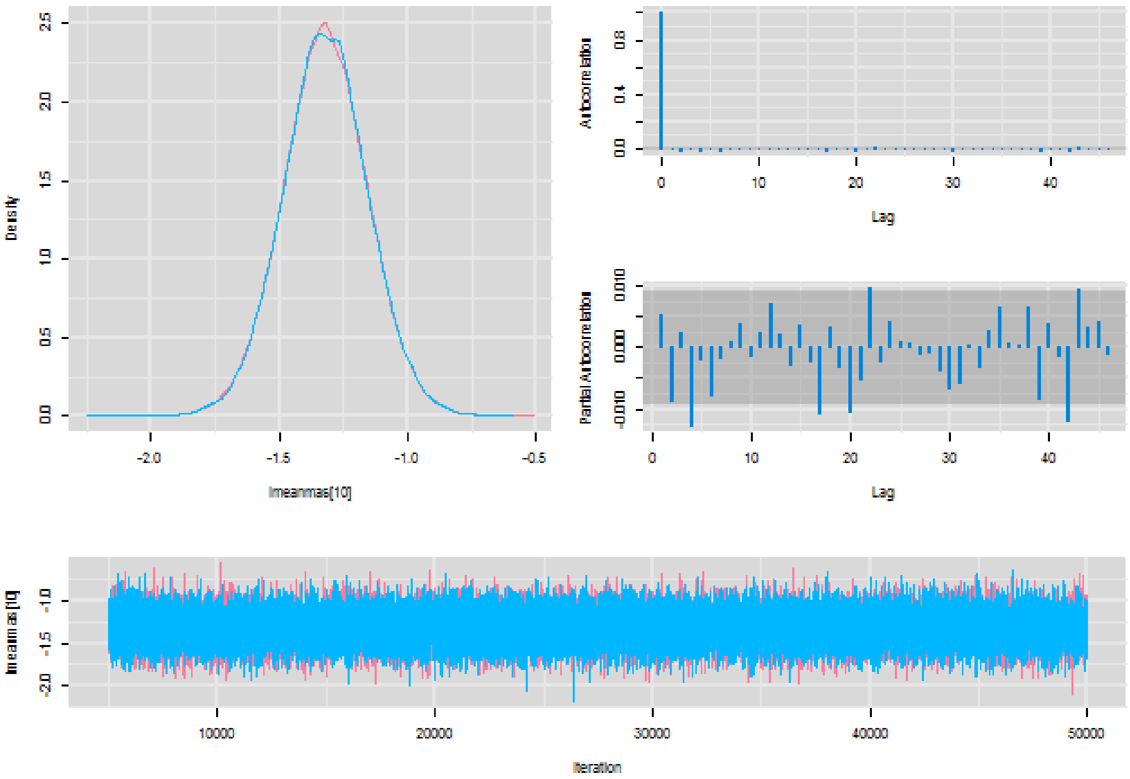


Diagnostics for lmeanmas[8]

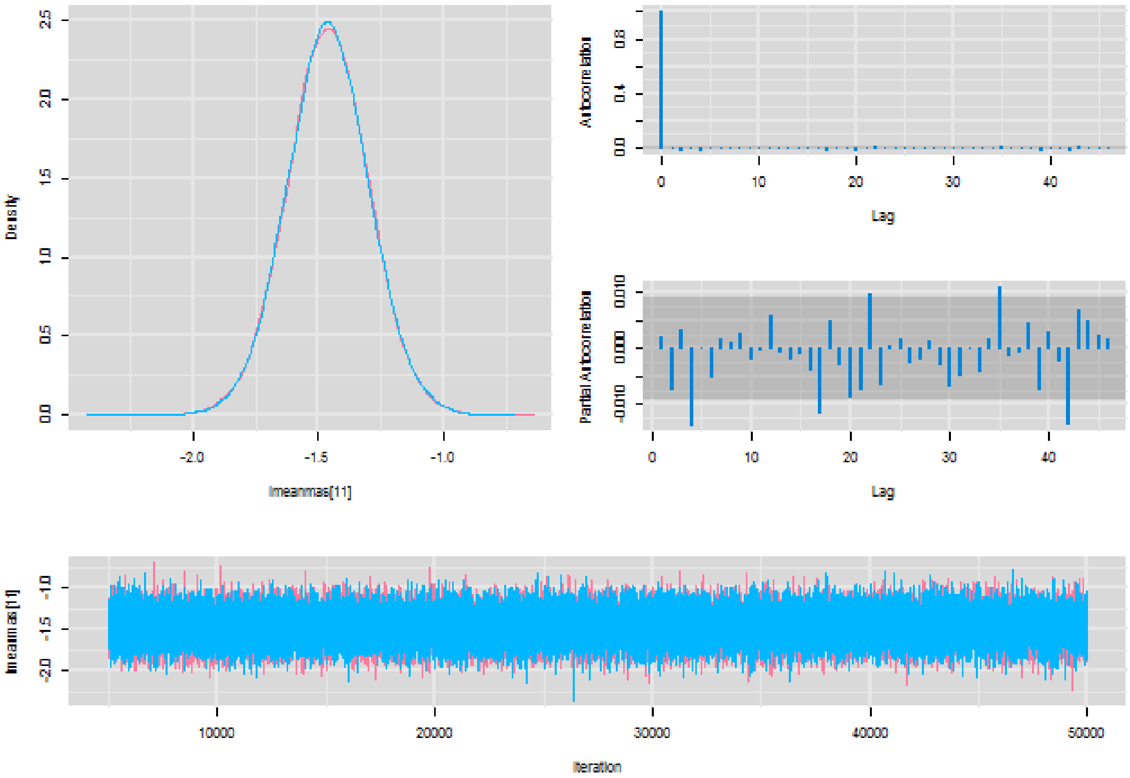
Diagnostics for lmeanmas[9]



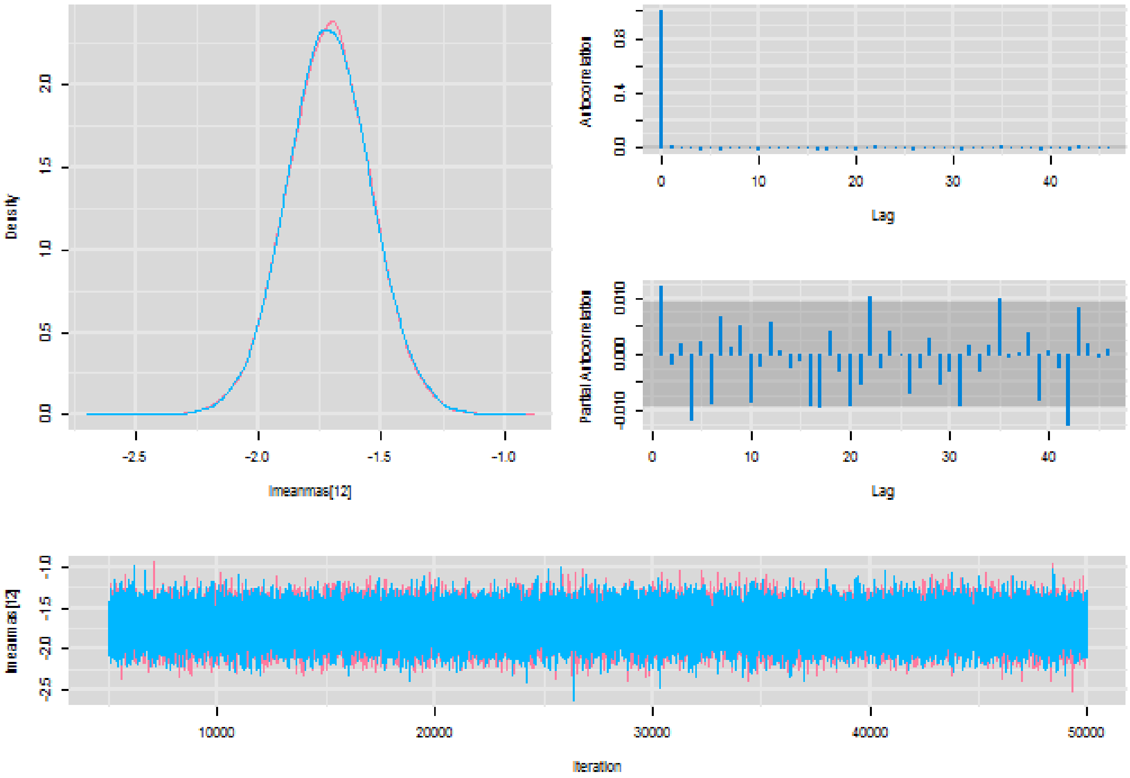
Diagnostics for lmeanmas[10]



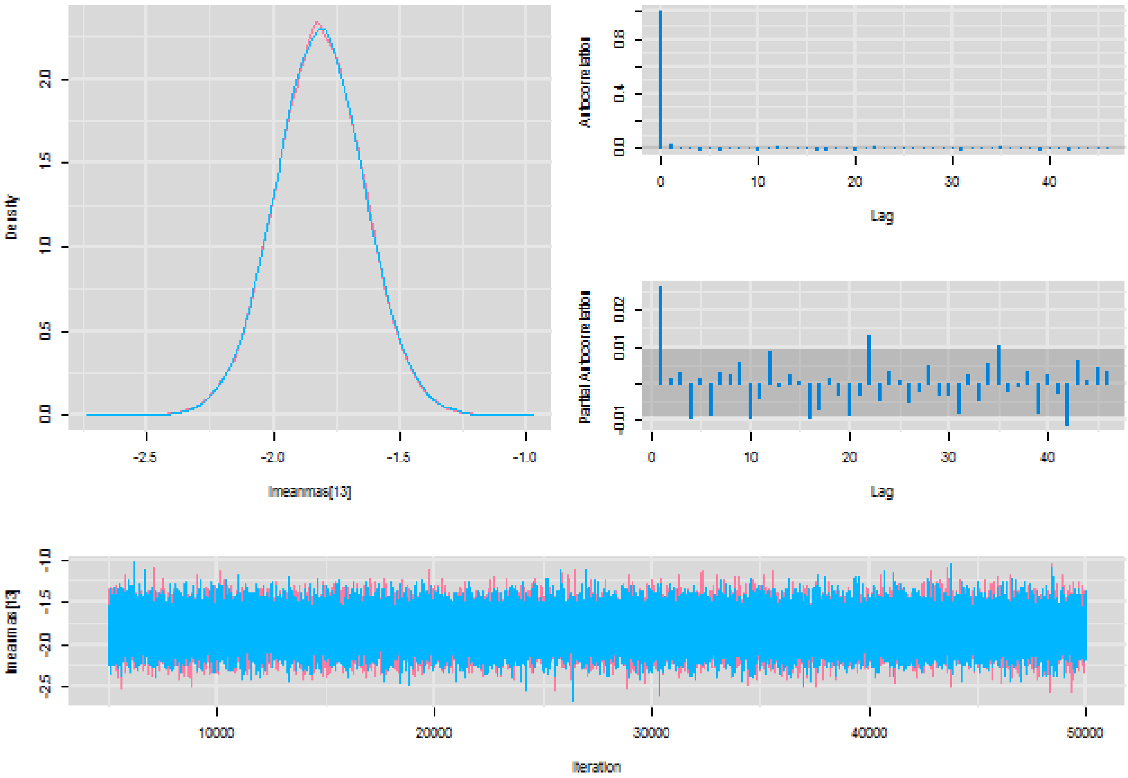
Diagnostics for lmeanmas[11]



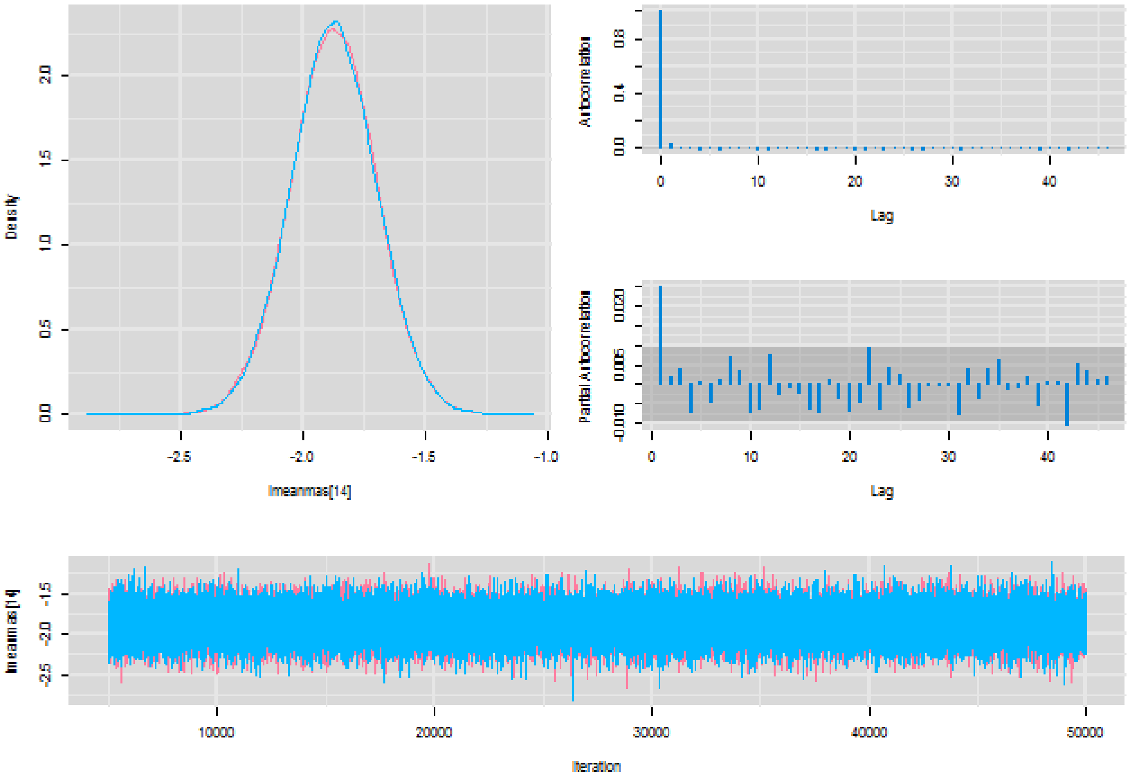
Diagnostics for lmeanmas[12]



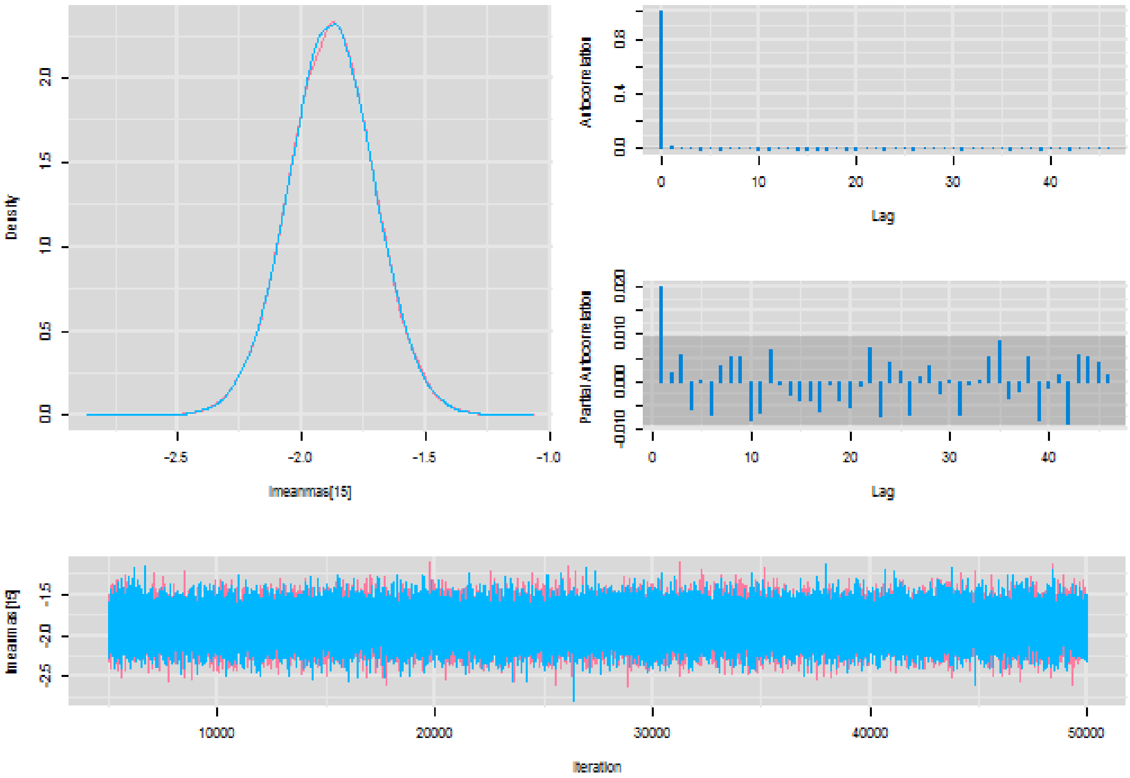
Diagnostics for lmeanmas[13]



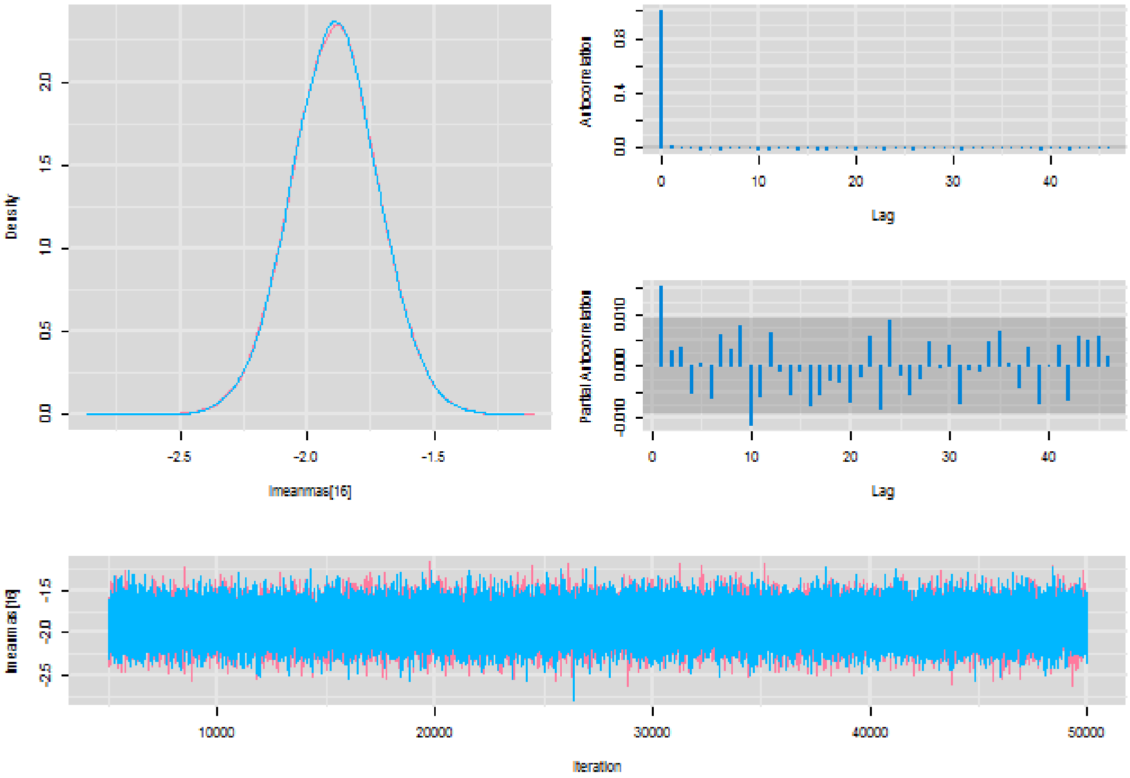
Diagnostics for lmeanmas[14]



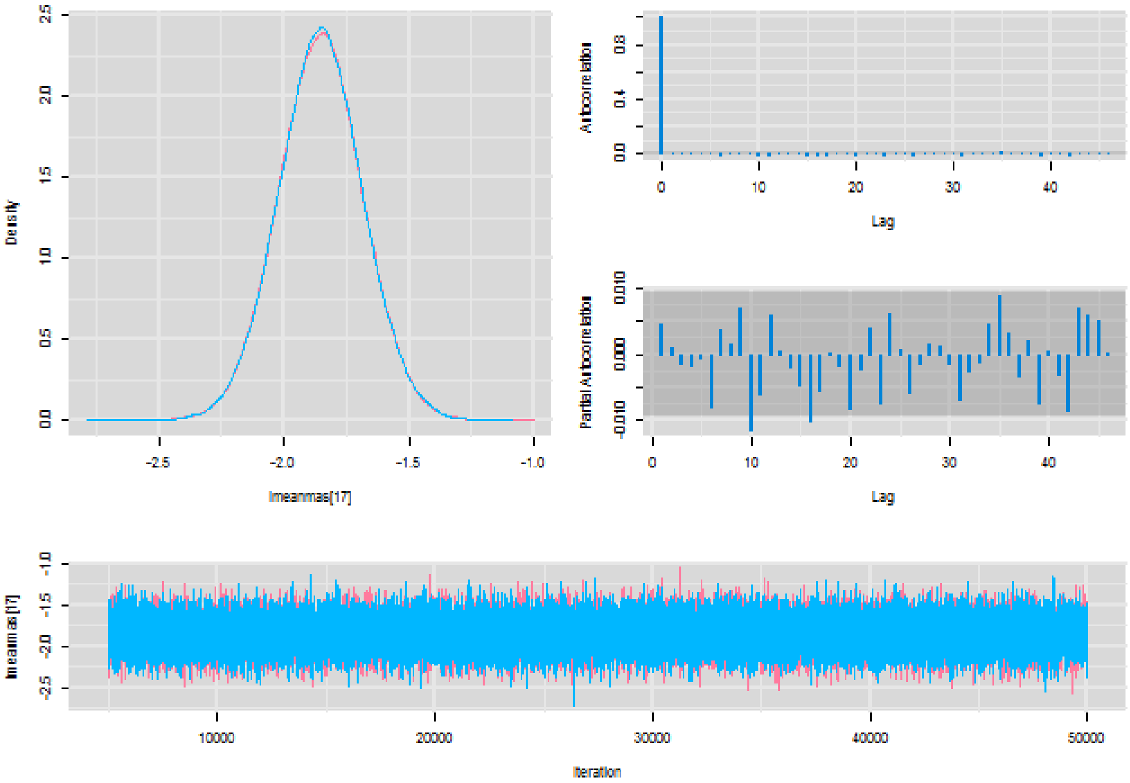
Diagnostics for lmeanmas[15]



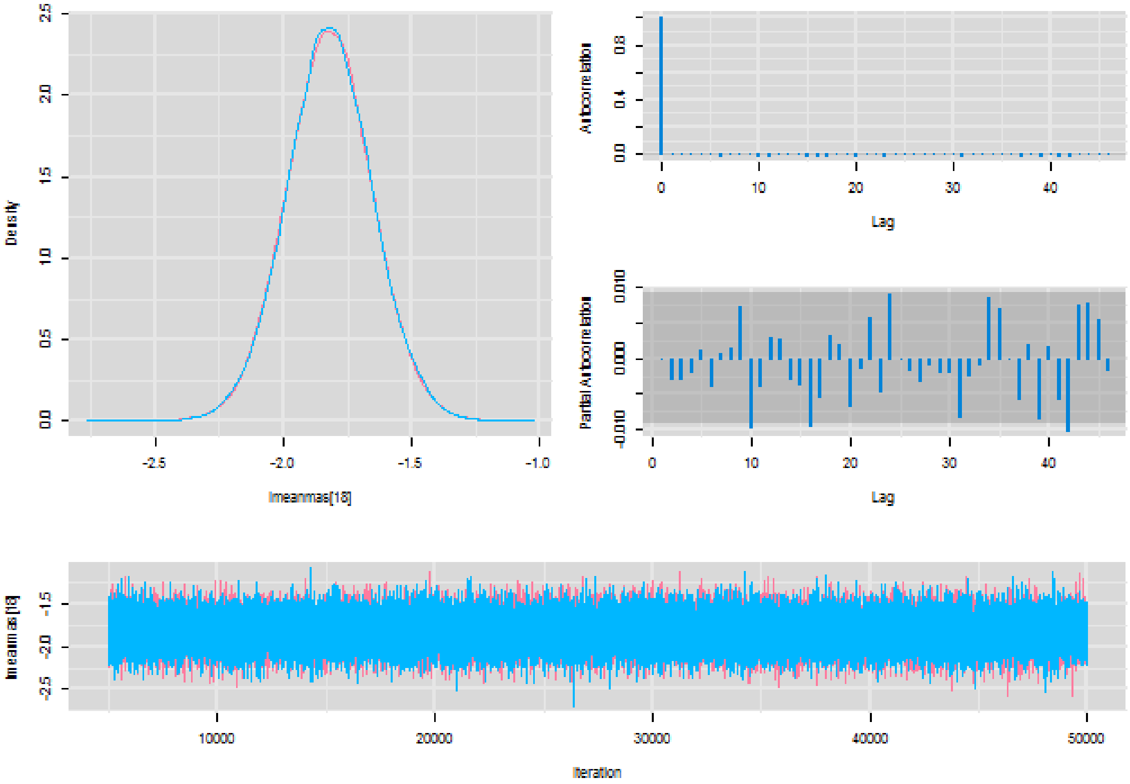
Diagnostics for lmeanmas[16]



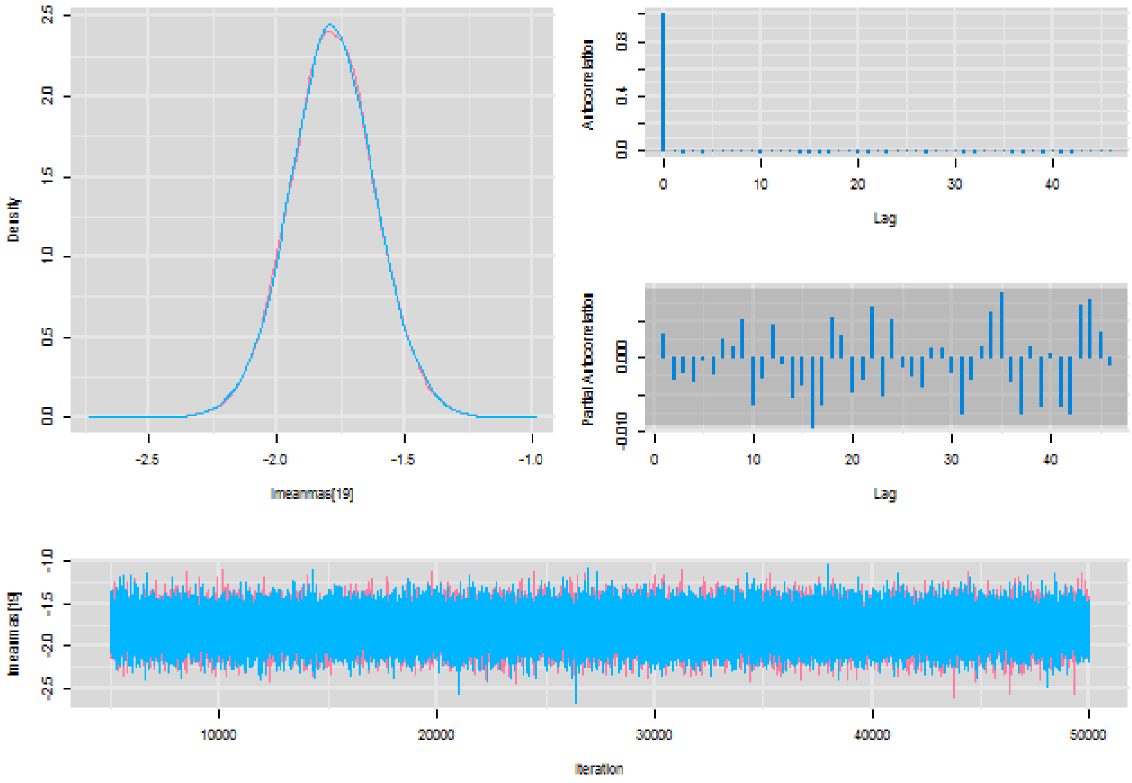
Diagnostics for lmeanmas[17]



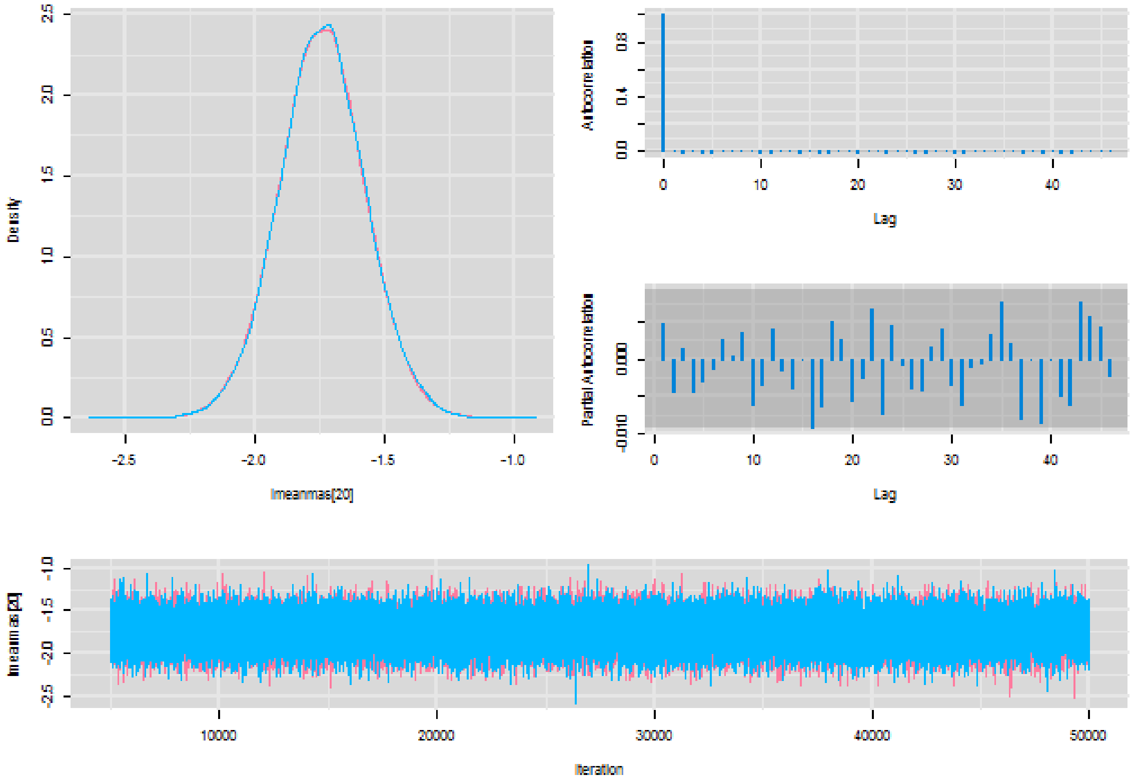
Diagnostics for lmeanmas[18]



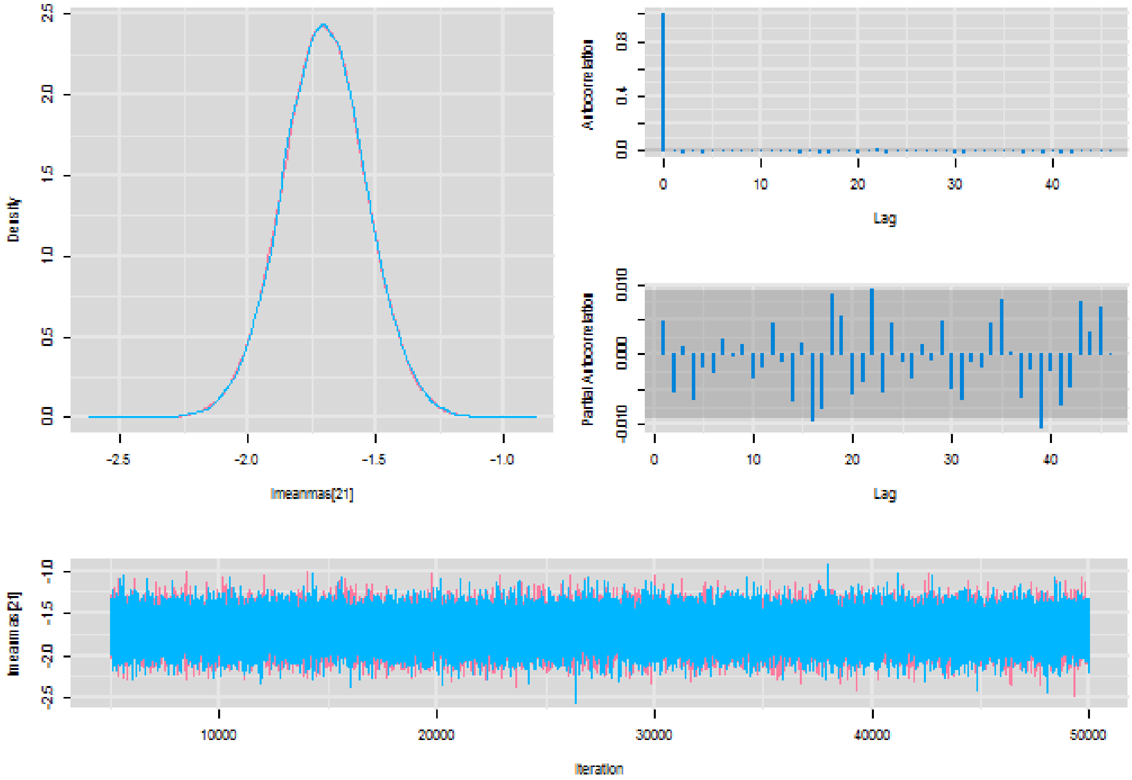
Diagnostics for lmeanmas[19]



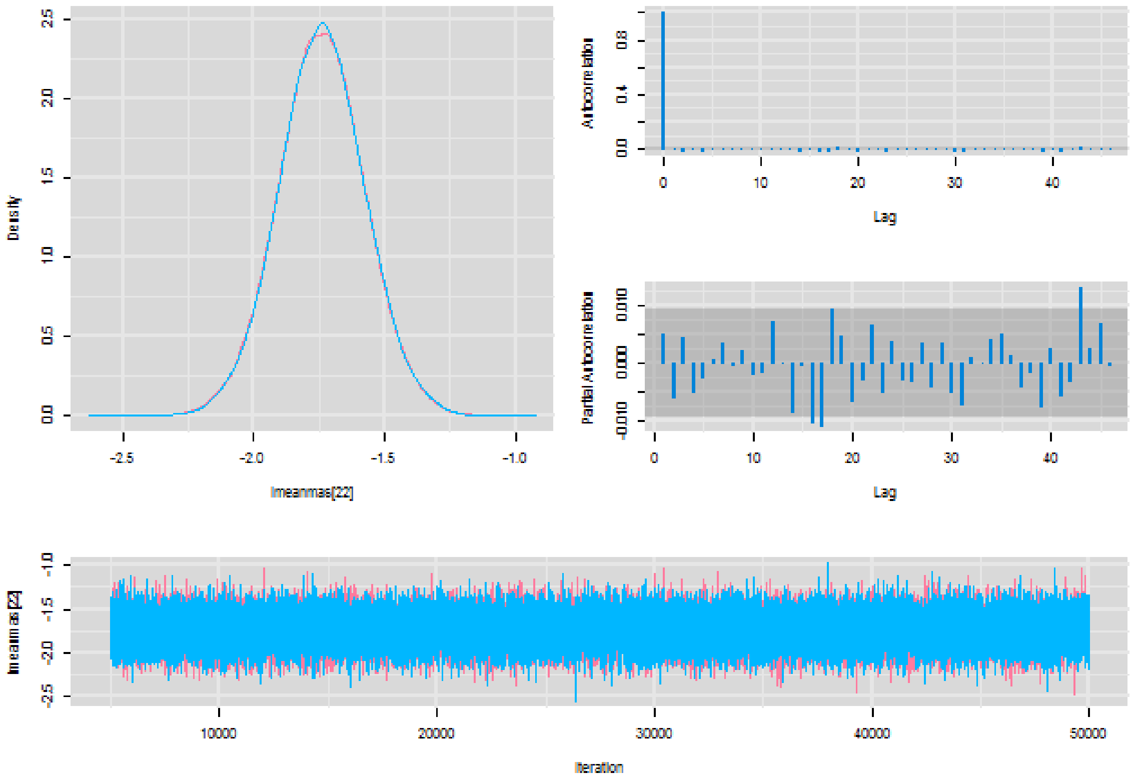
Diagnostics for lmeanmas[20]



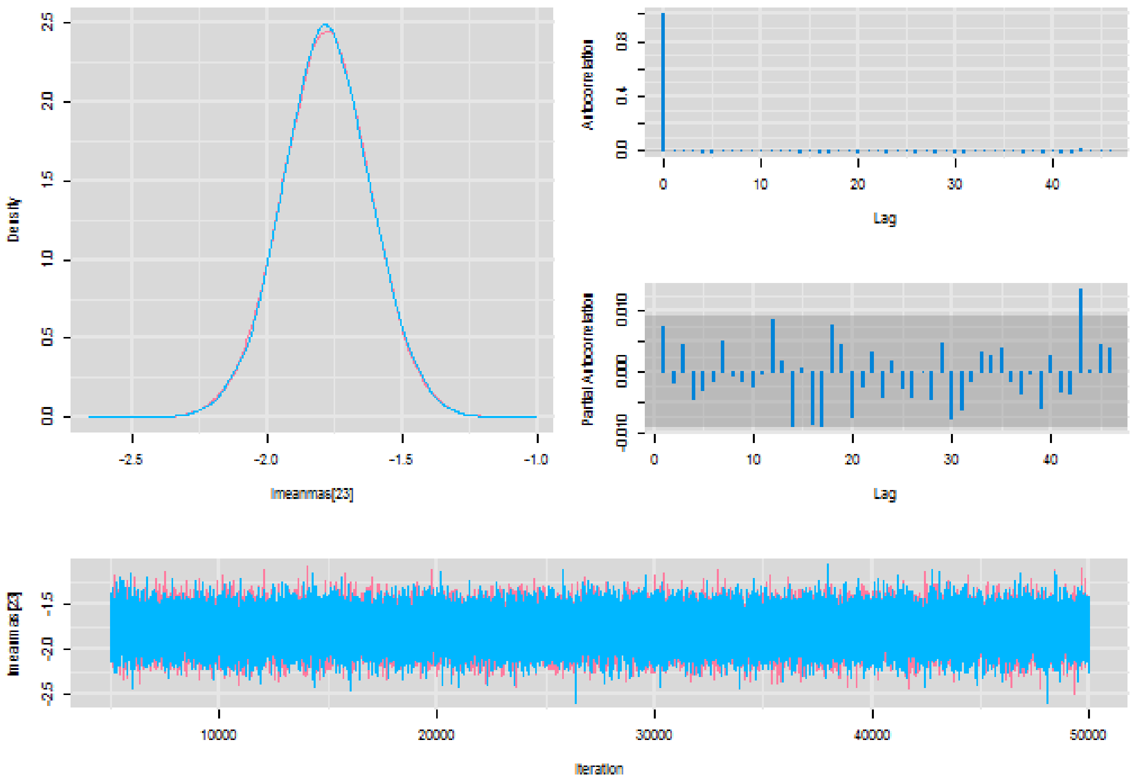
Diagnostics for lmeanmas[21]



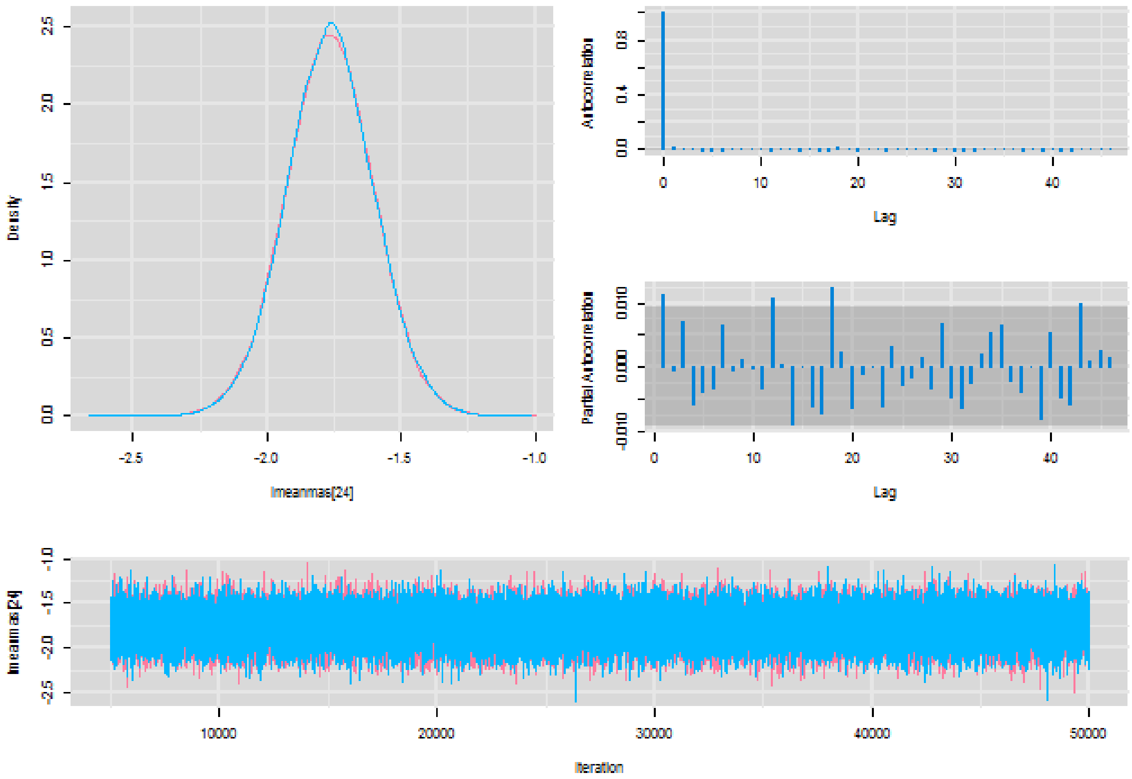
Diagnostics for lmeanmas[22]



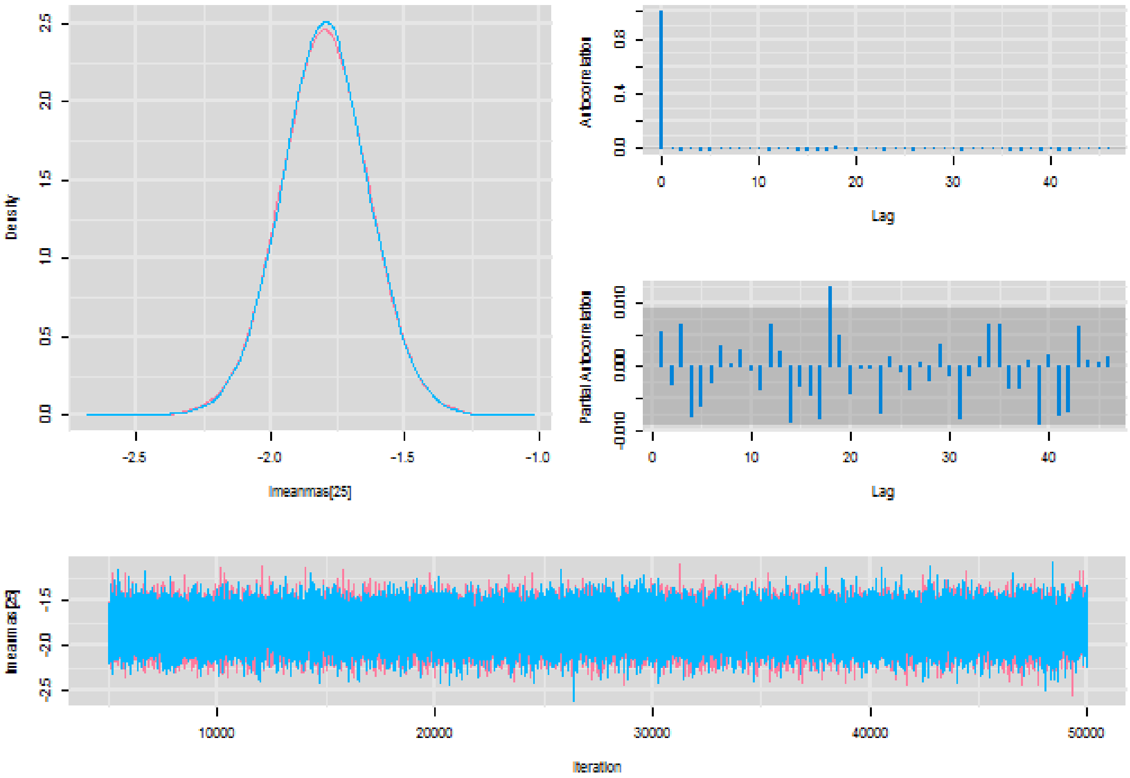
Diagnostics for lmeanmas[23]



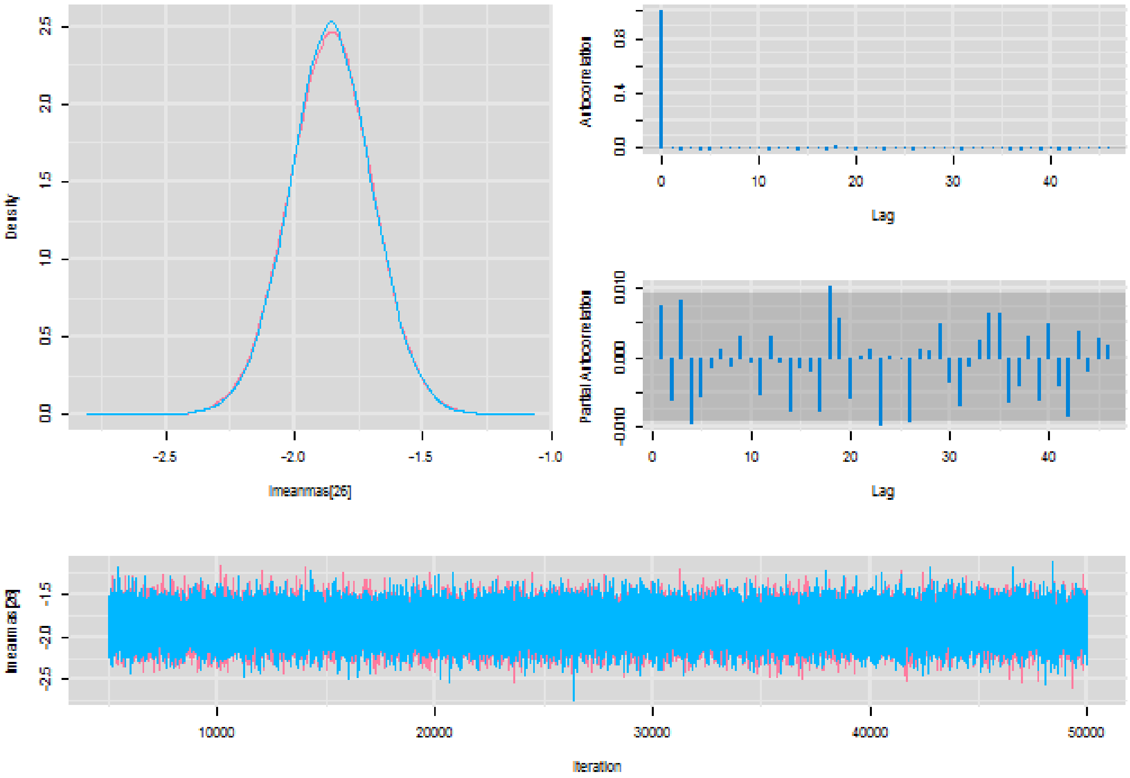
Diagnostics for lmeanmas[24]



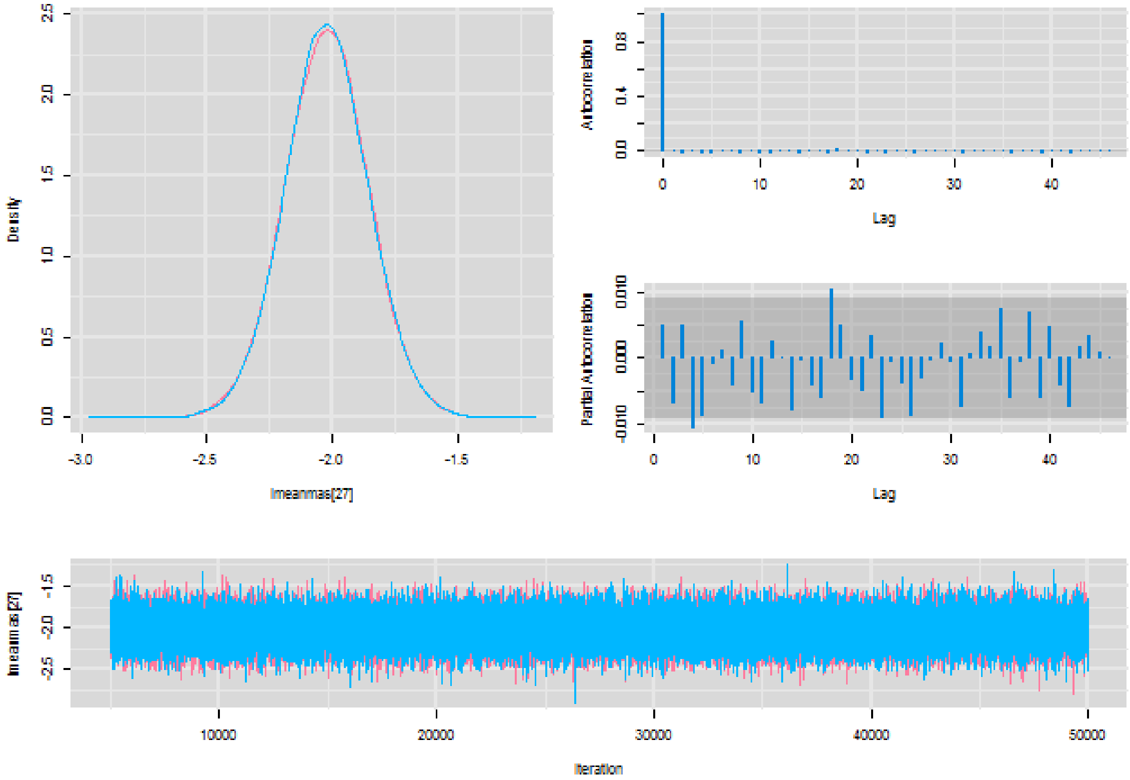
Diagnostics for lmeanmas[25]



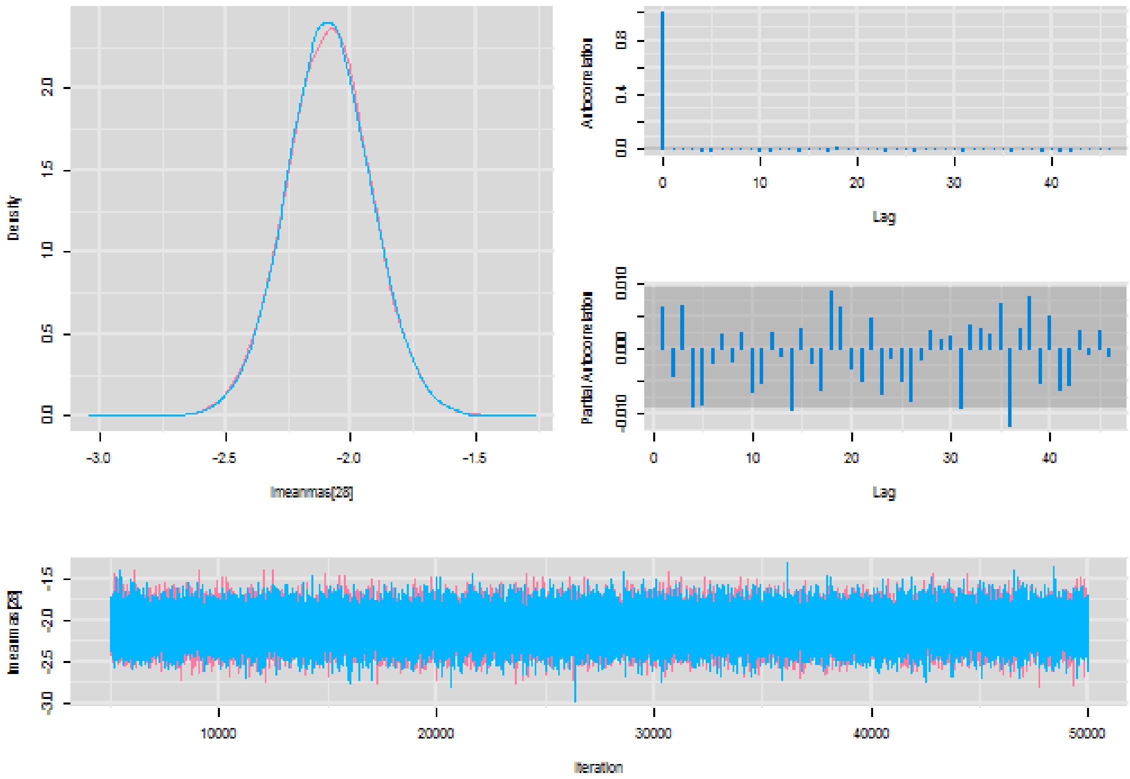
Diagnostics for lmeanmas[26]



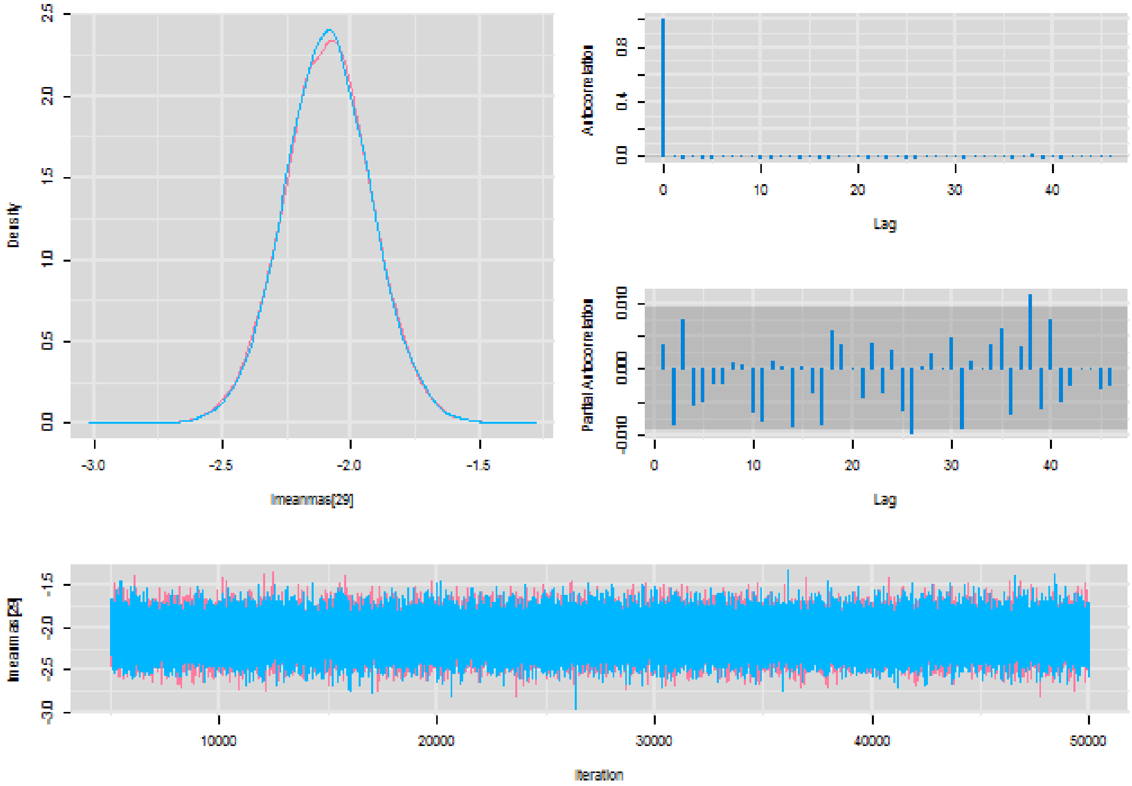
Diagnostics for lmeanmas[27]



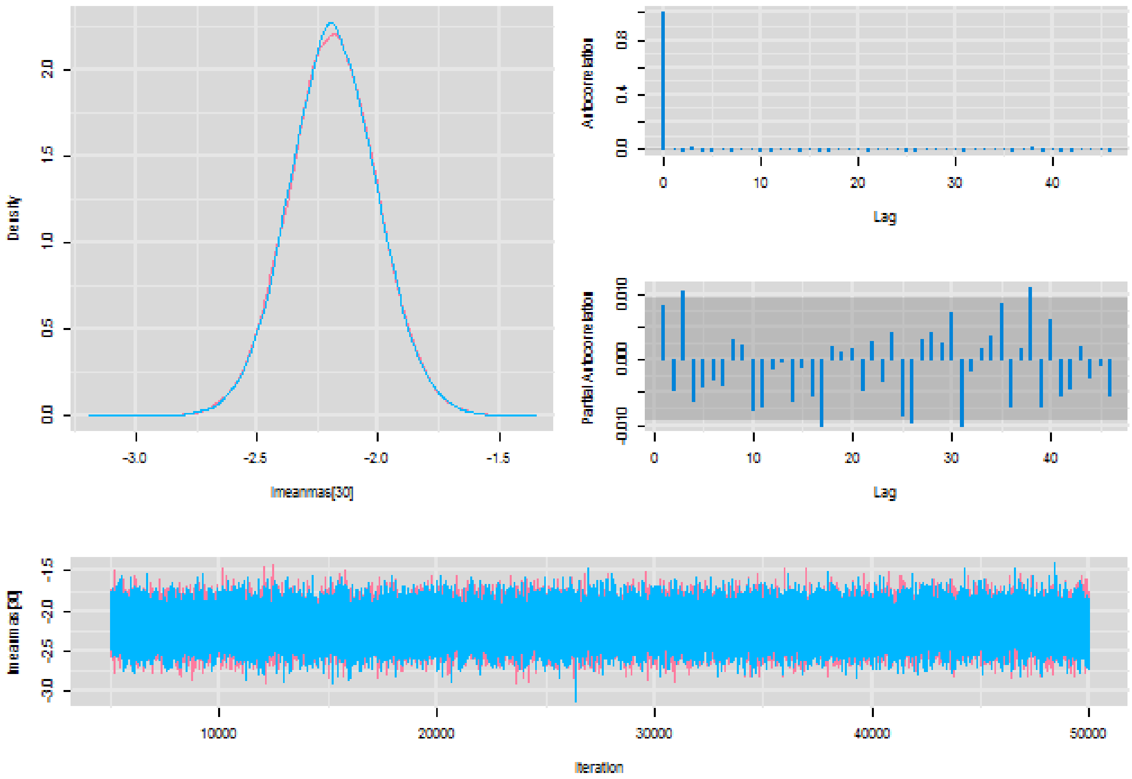
Diagnostics for lmeanmas[28]



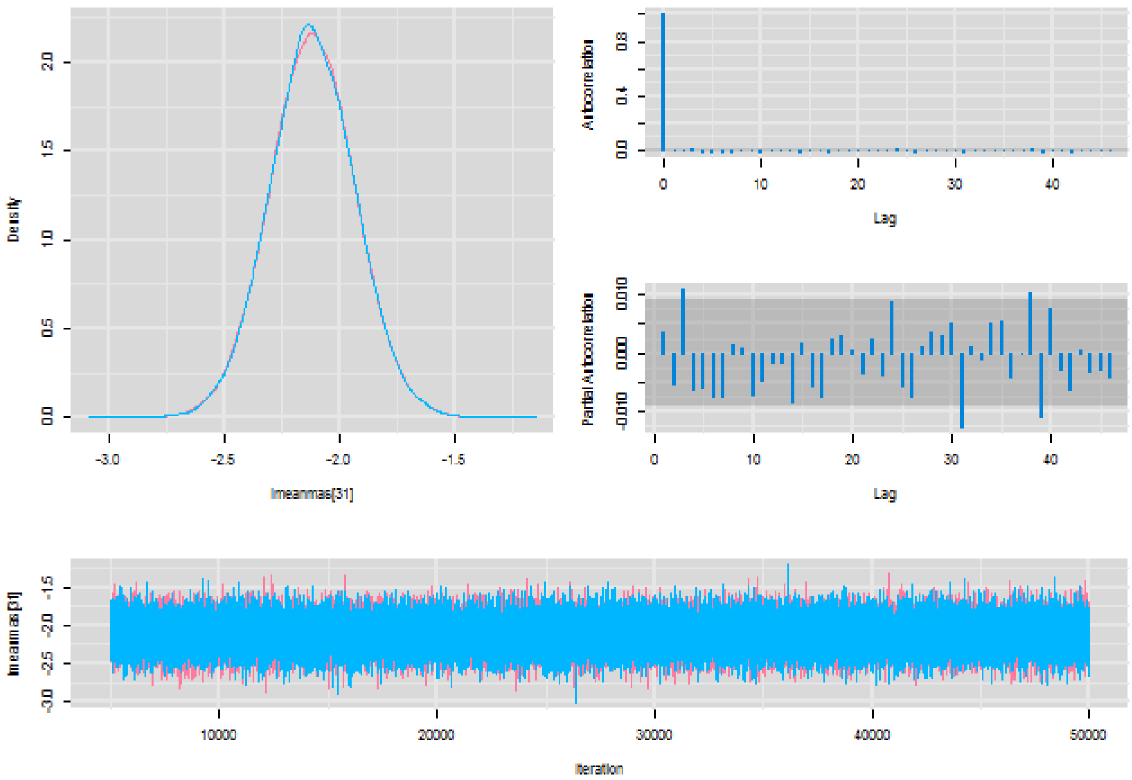
Diagnostics for lmeanmas[29]



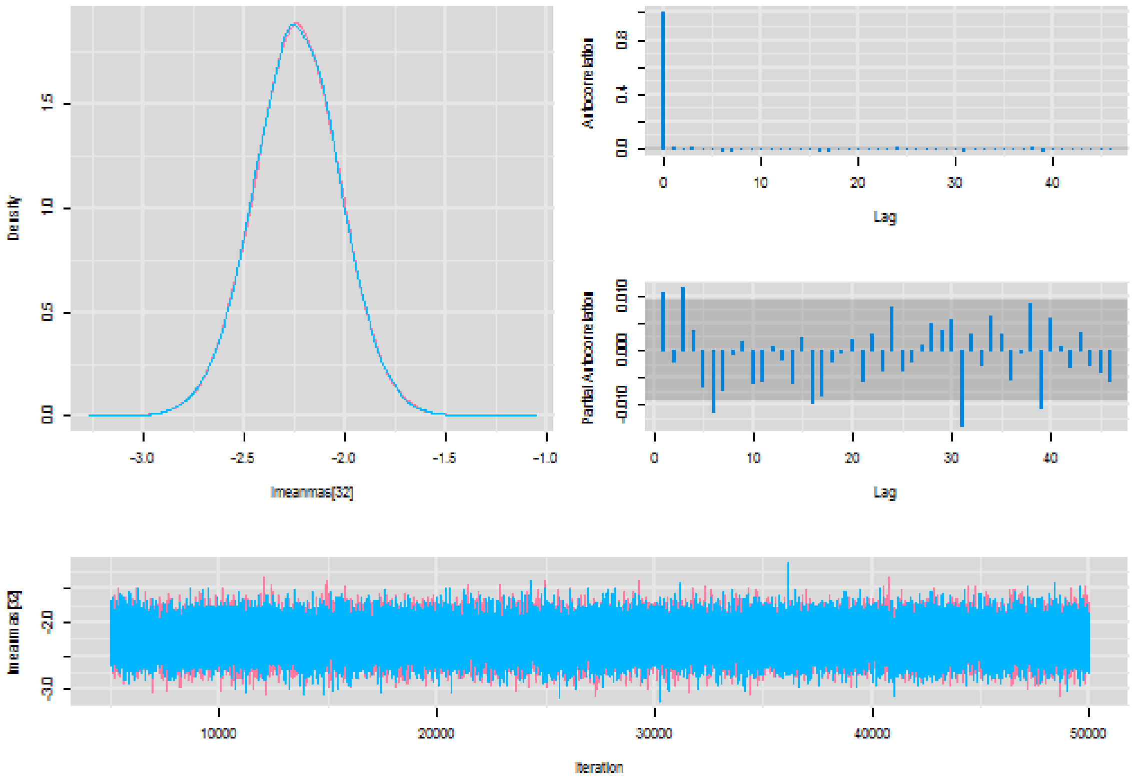
Diagnostics for lmeanmas[30]



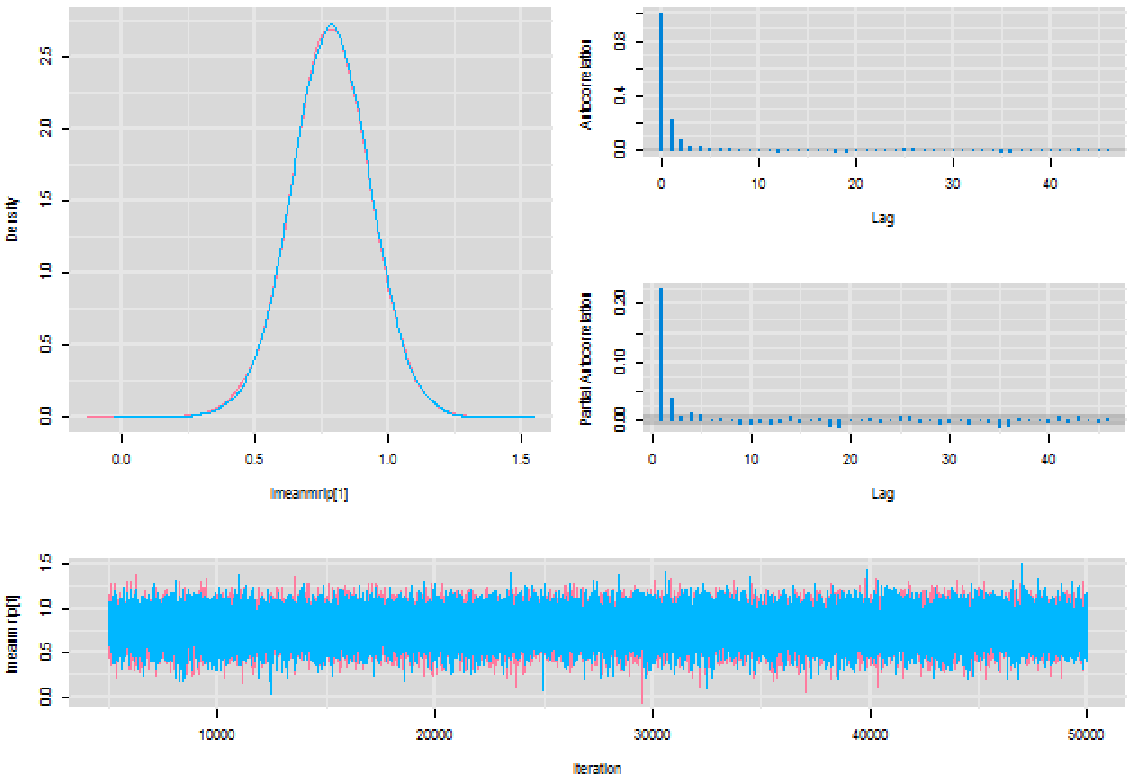
Diagnostics for lmeanmas[31]



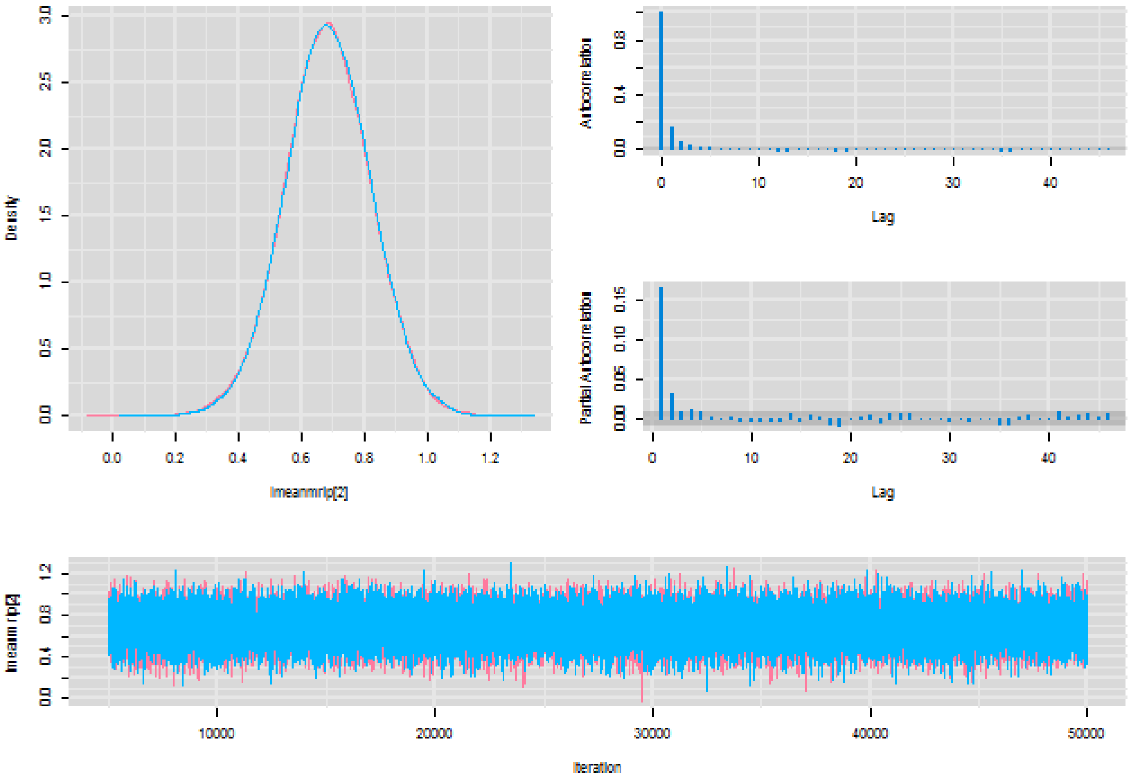
Diagnostics for lmeanmas[32]



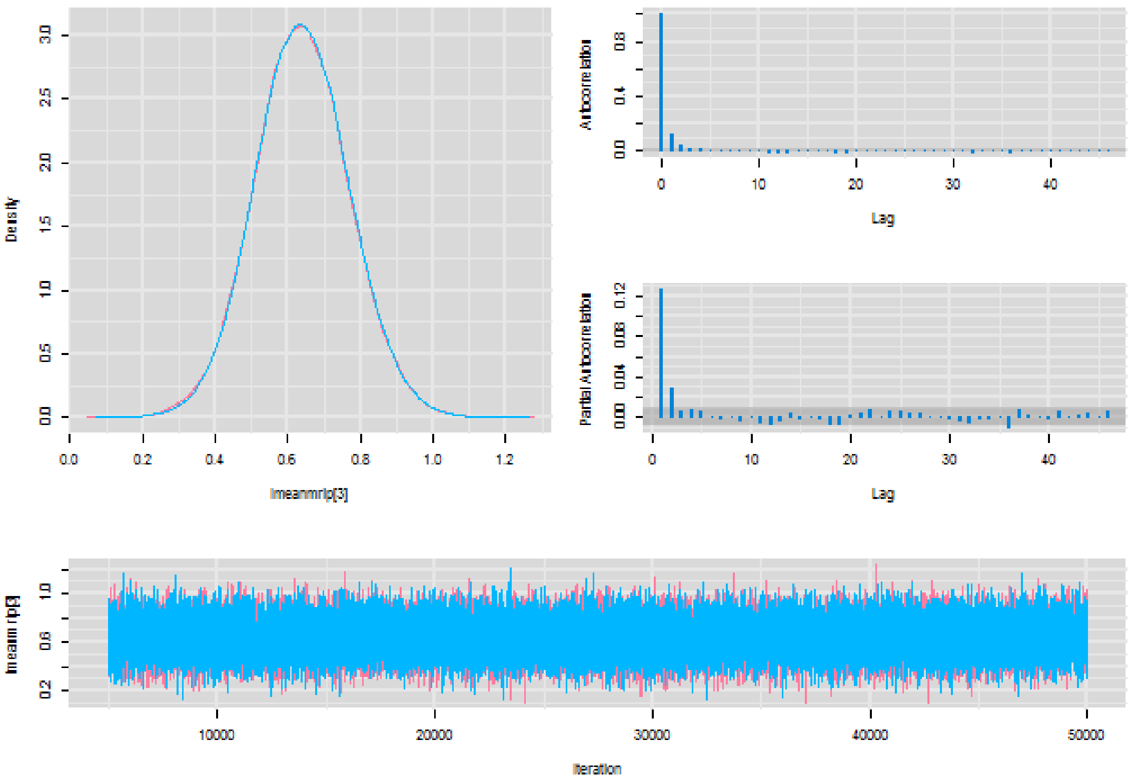
Diagnostics for lmeanmrip[1]



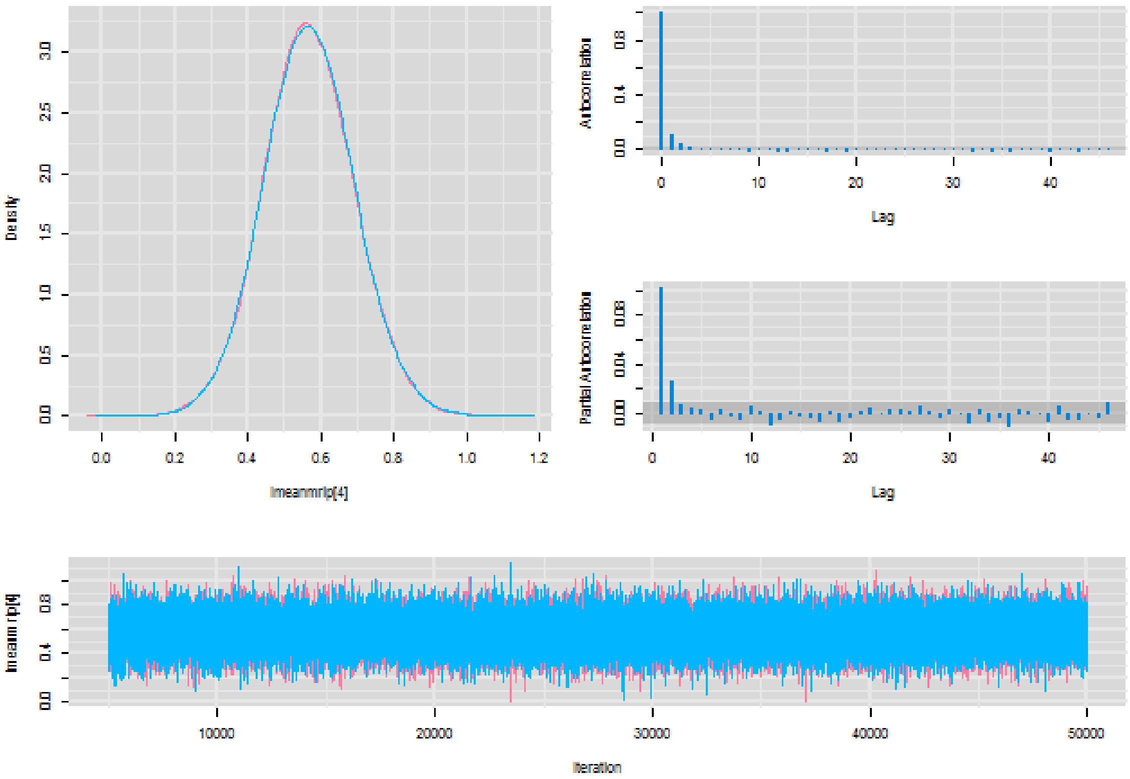
Diagnostics for lmeanmrip[2]



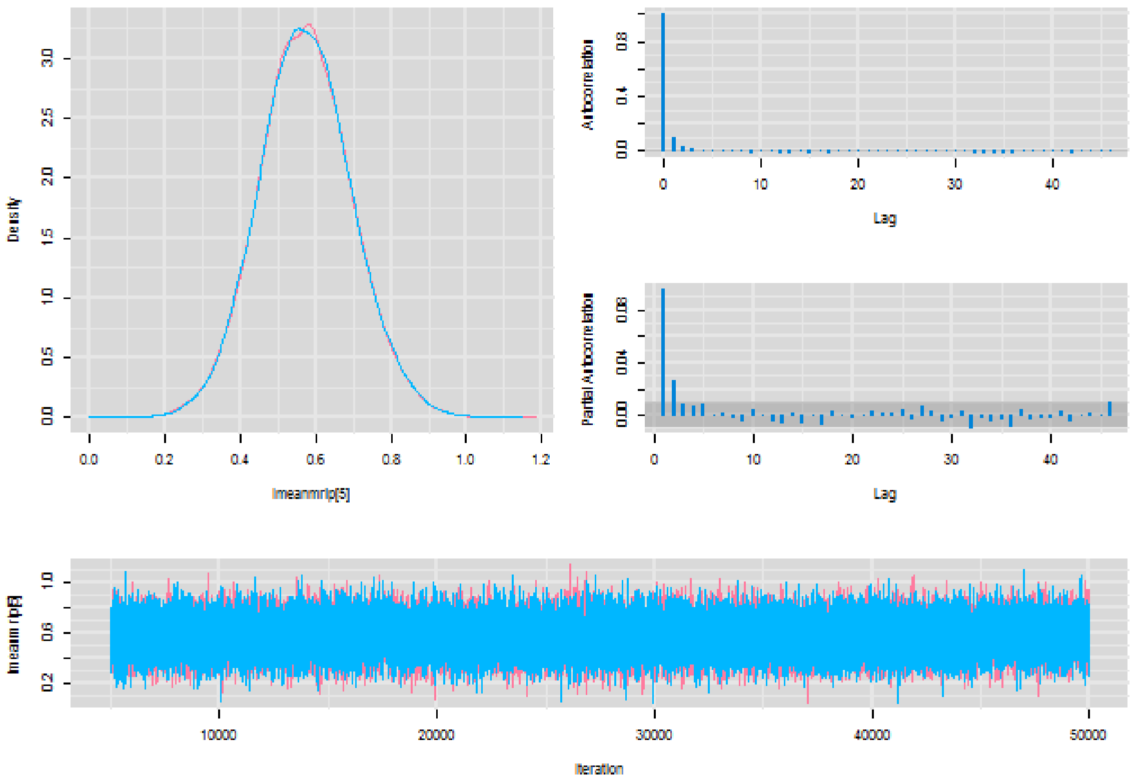
Diagnostics for lmeanmrip[3]



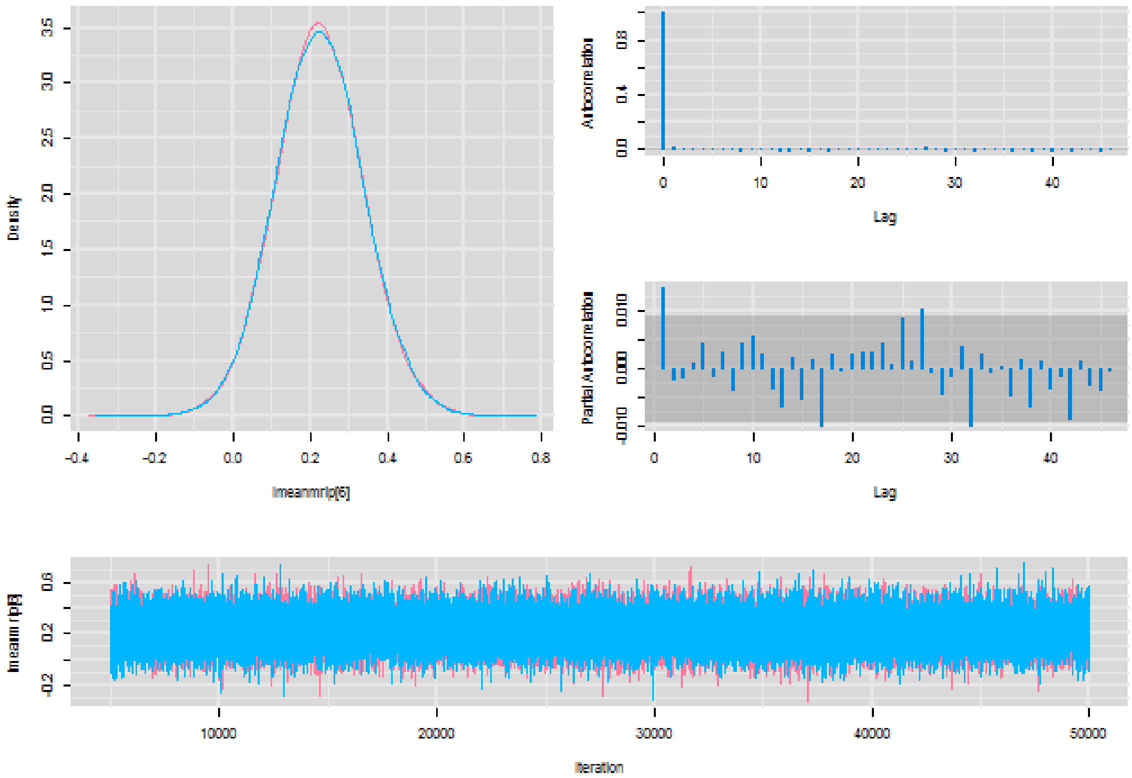
Diagnostics for lmeanmrip[4]



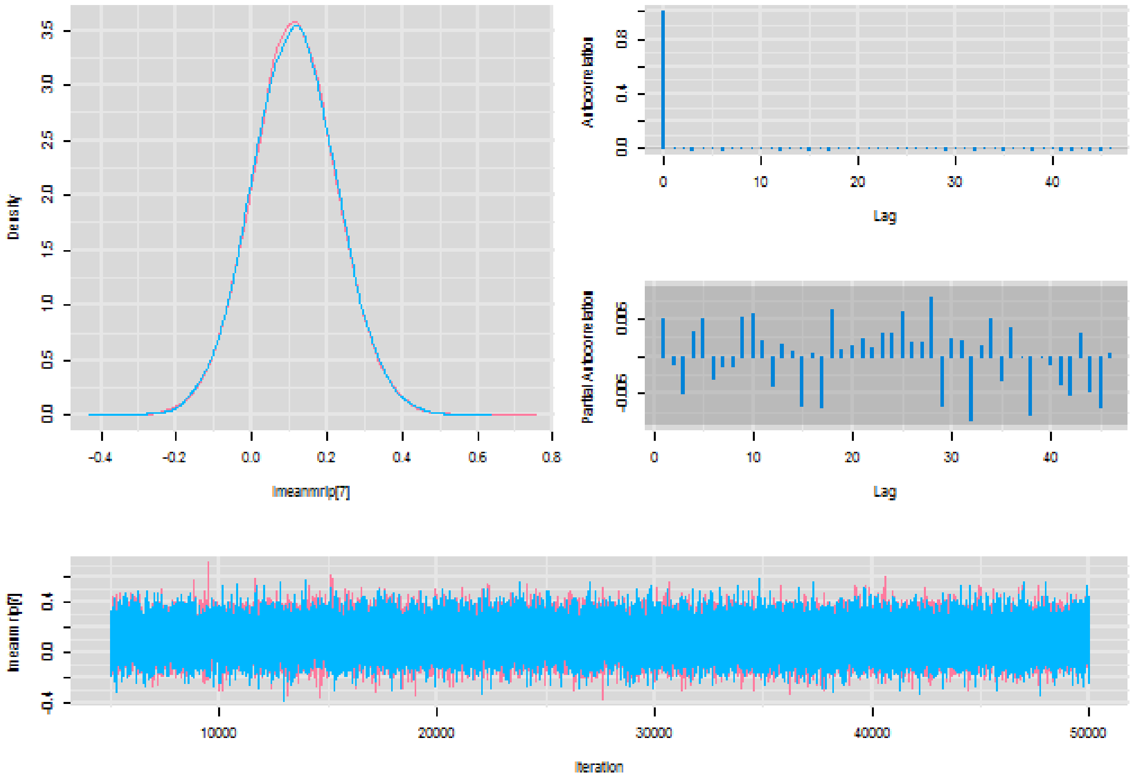
Diagnostics for lmeanmrip[5]



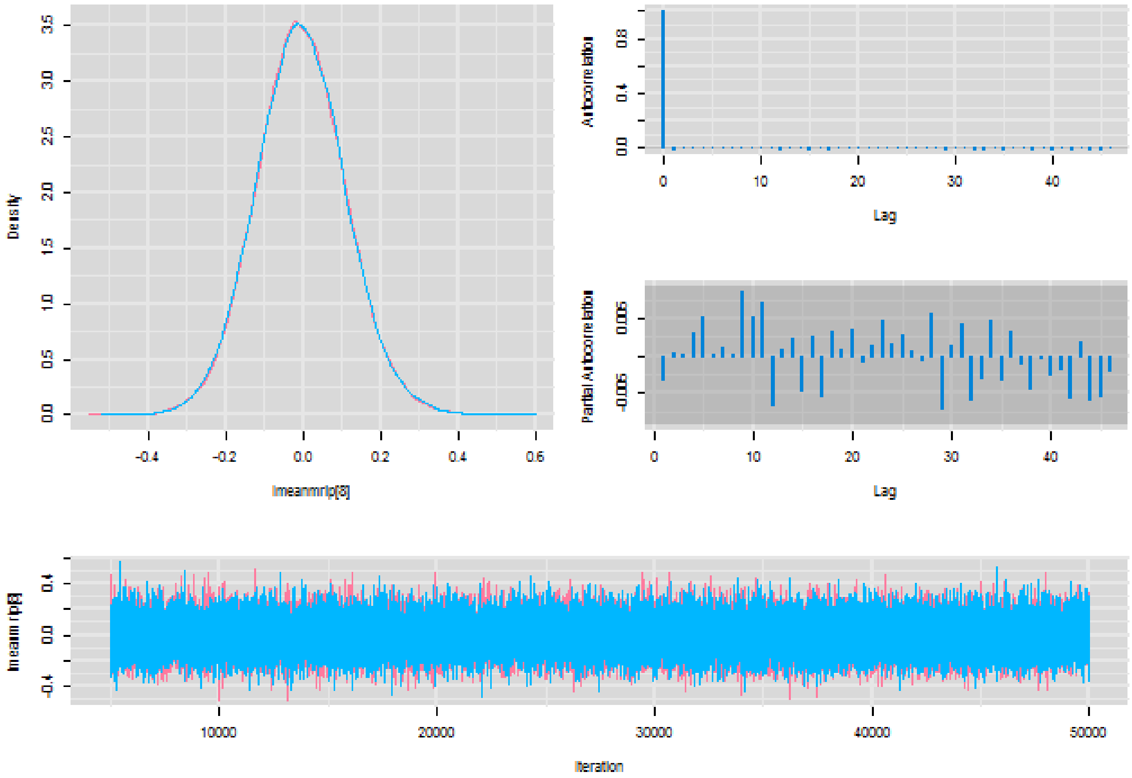
Diagnostics for lmeanmrip[6]



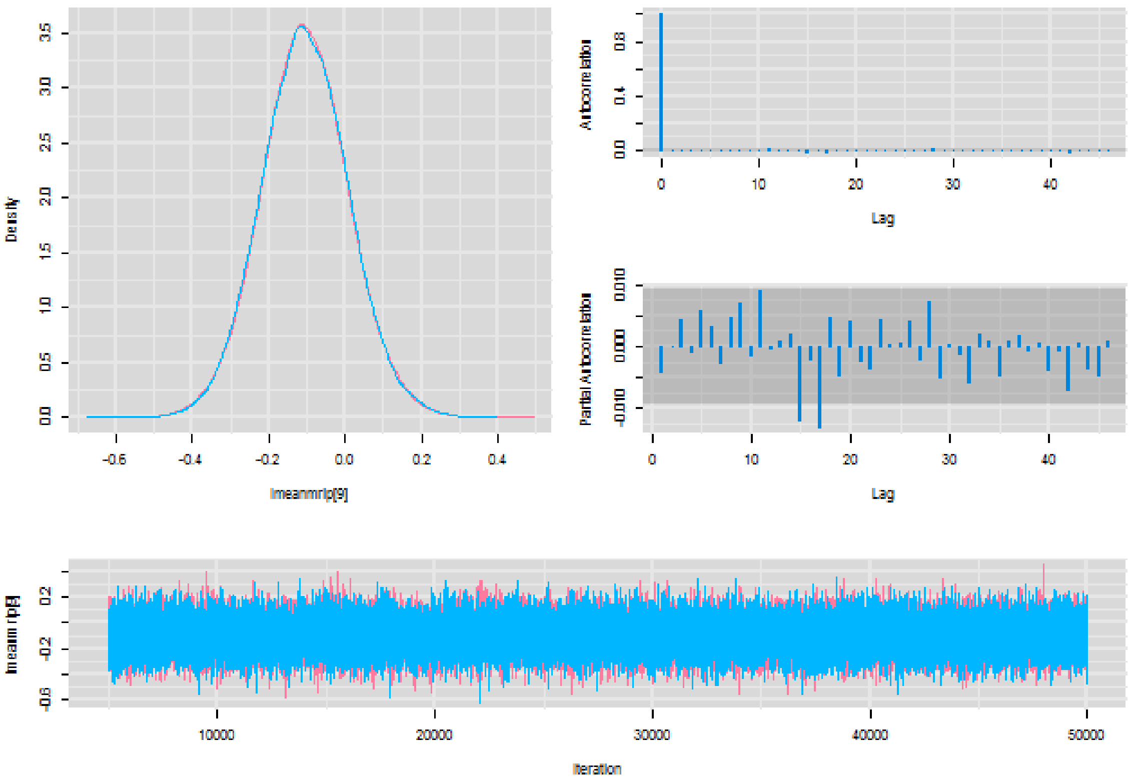
Diagnostics for lmeanmrip[7]



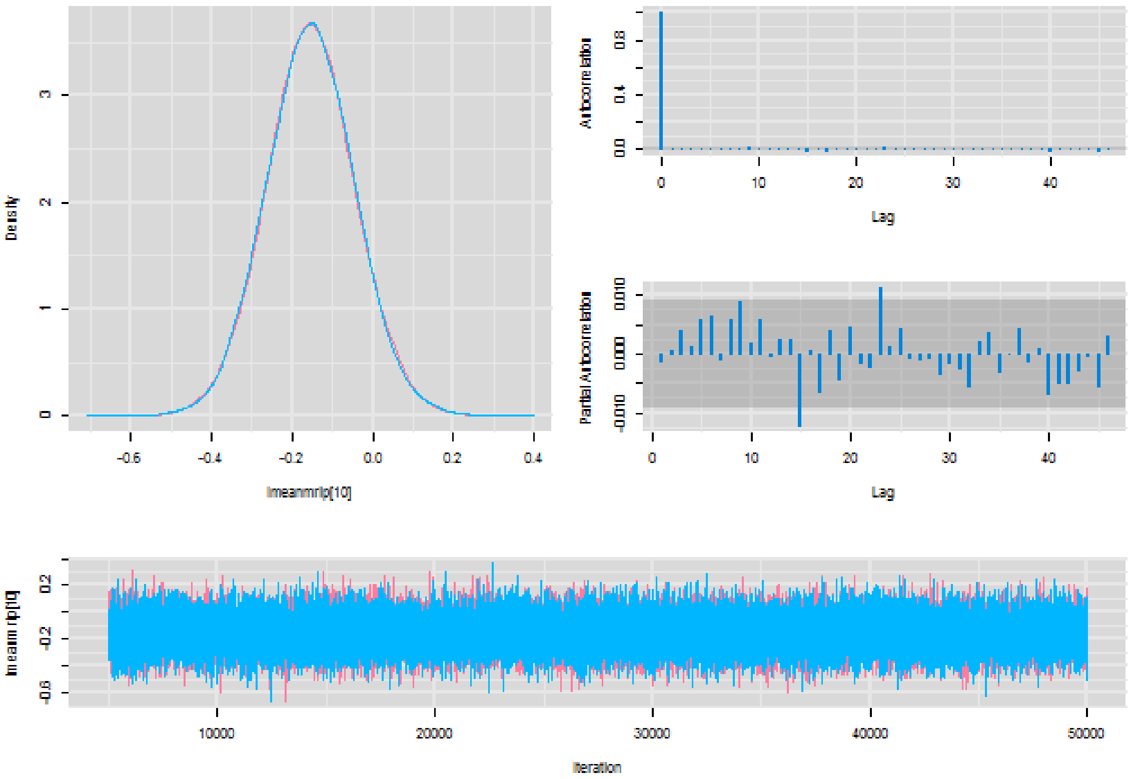
Diagnostics for lmeanmrip[8]



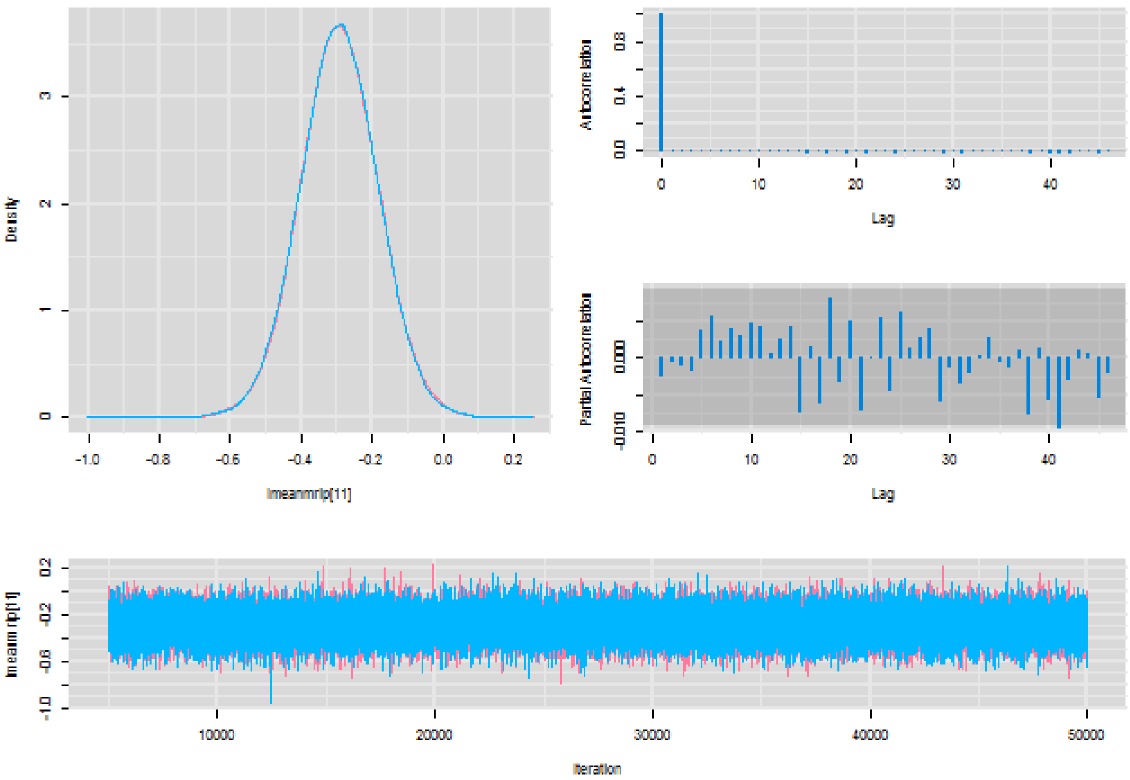
Diagnostics for lmeanmrip[9]



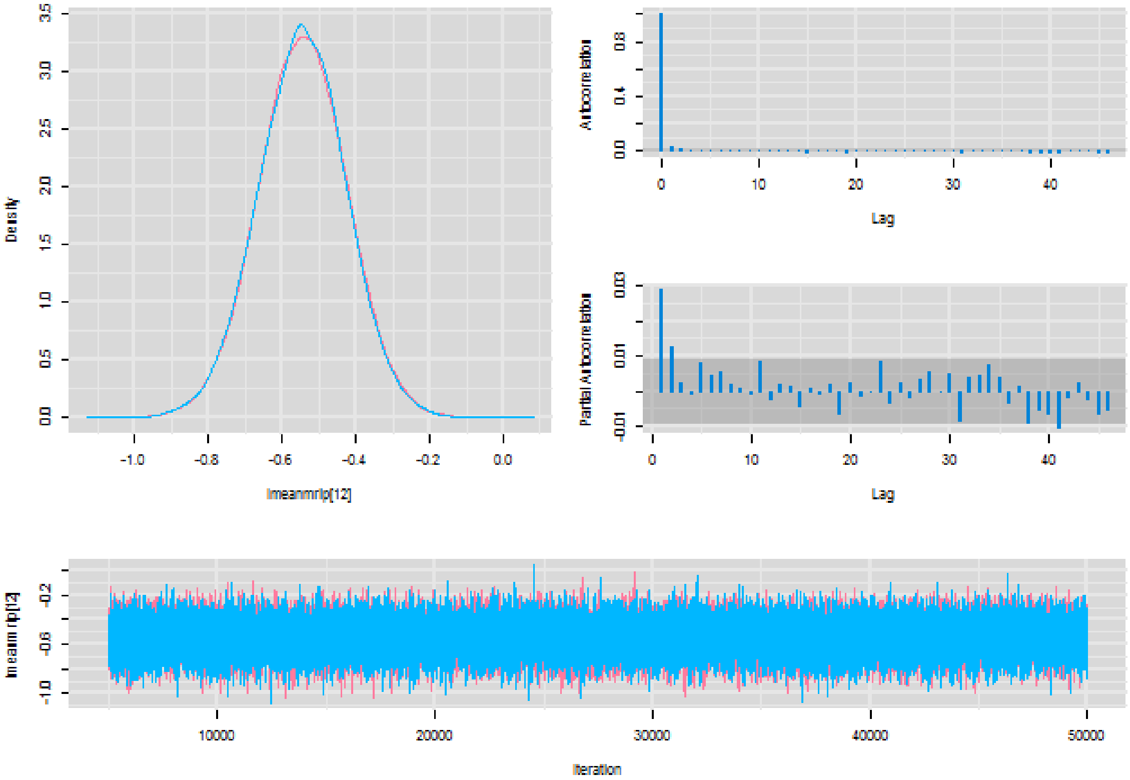
Diagnostics for lmeanmrip[10]



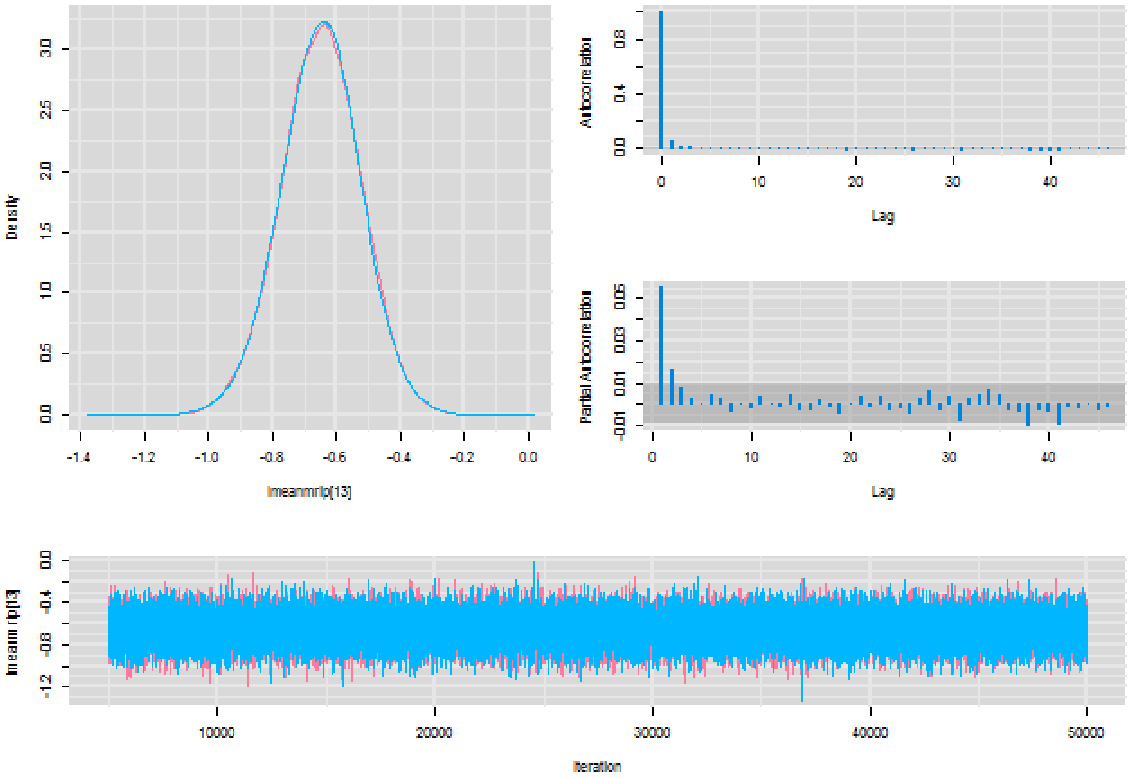
Diagnostics for lmeanmrip[11]



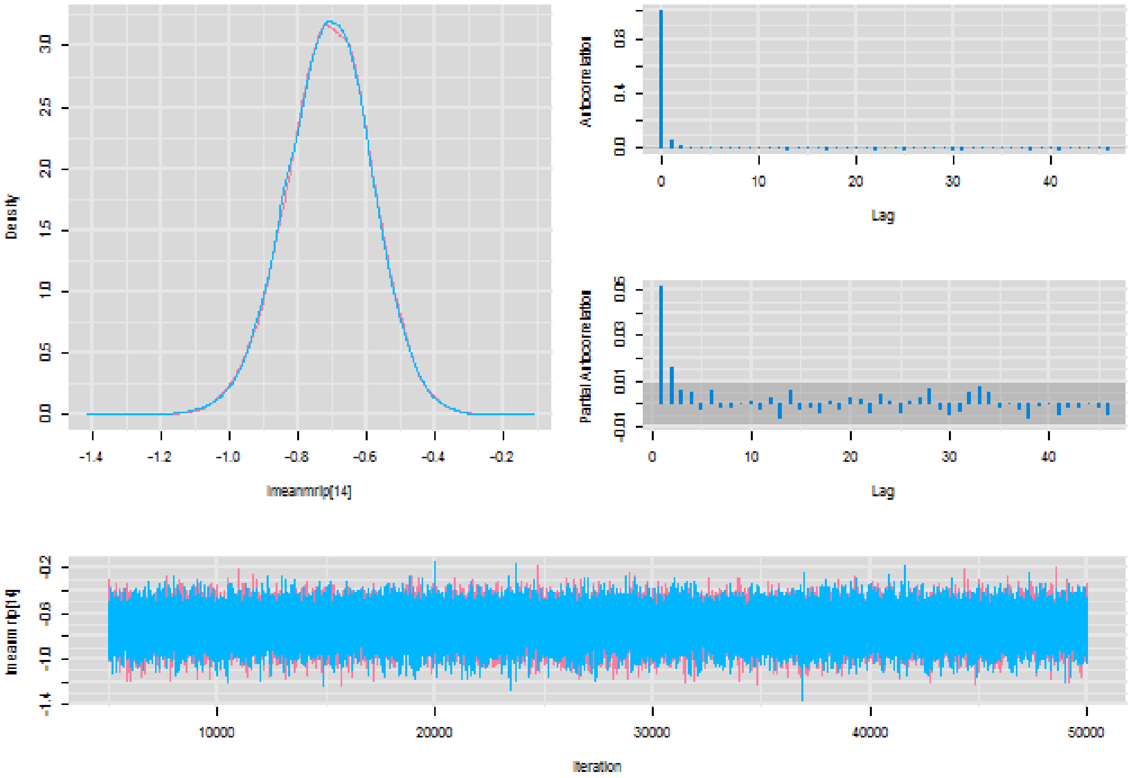
Diagnostics for lmeanmrip[12]



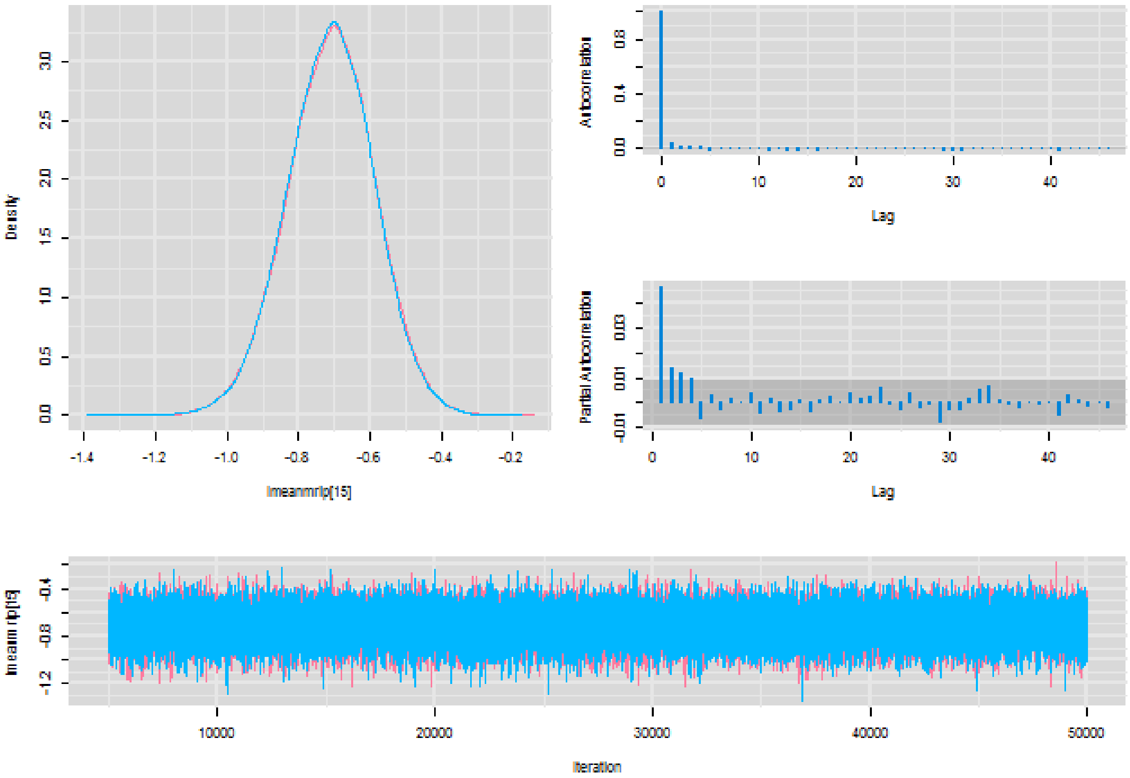
Diagnostics for lmeanmrip[13]



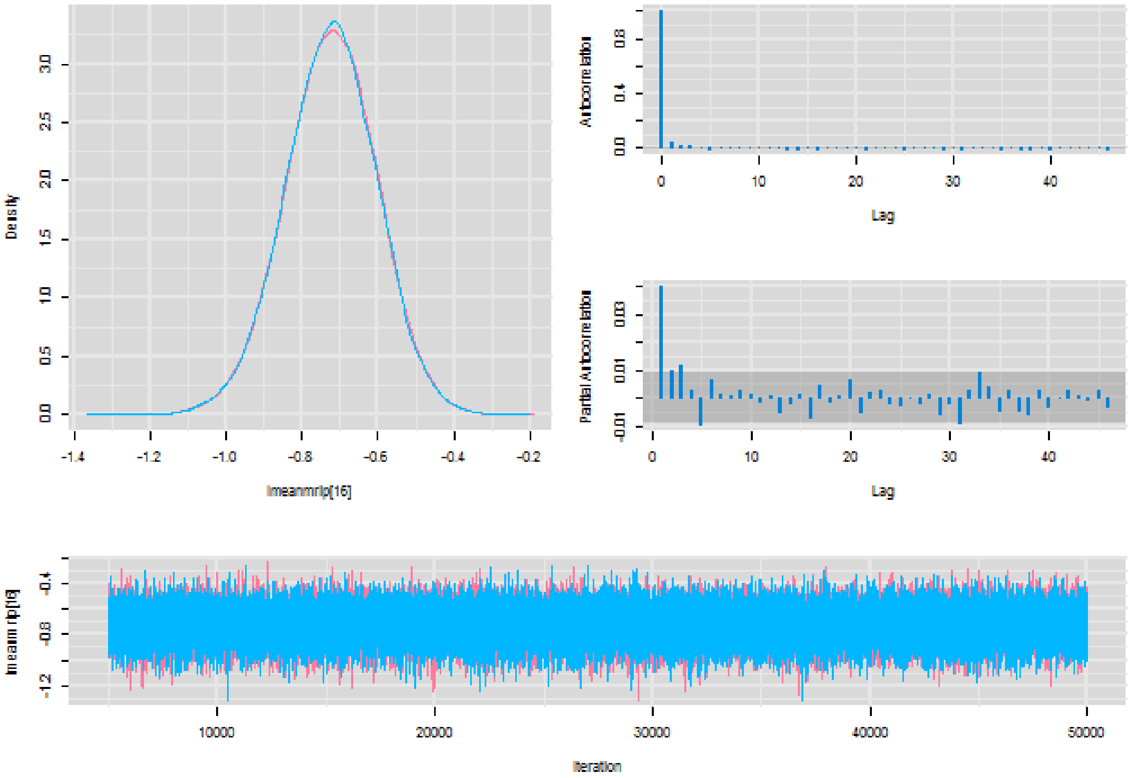
Diagnostics for lmeanmrip[14]



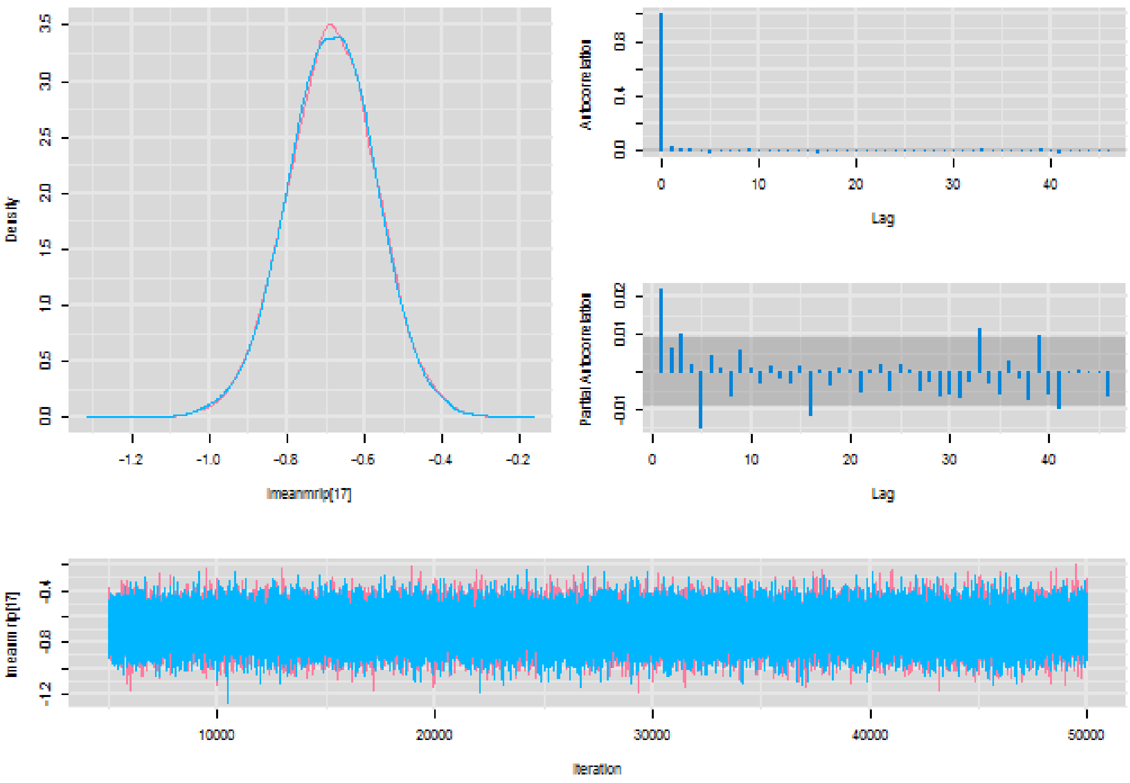
Diagnostics for lmeanmrip[15]



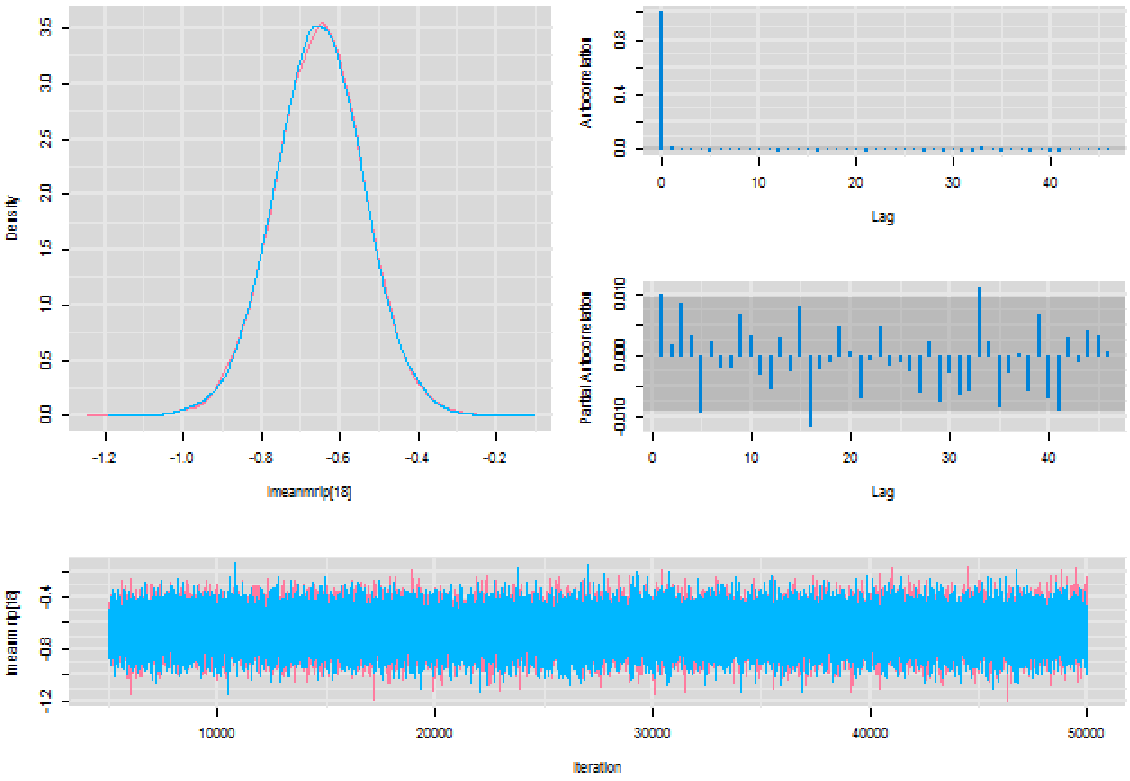
Diagnostics for lmeanmrip[16]



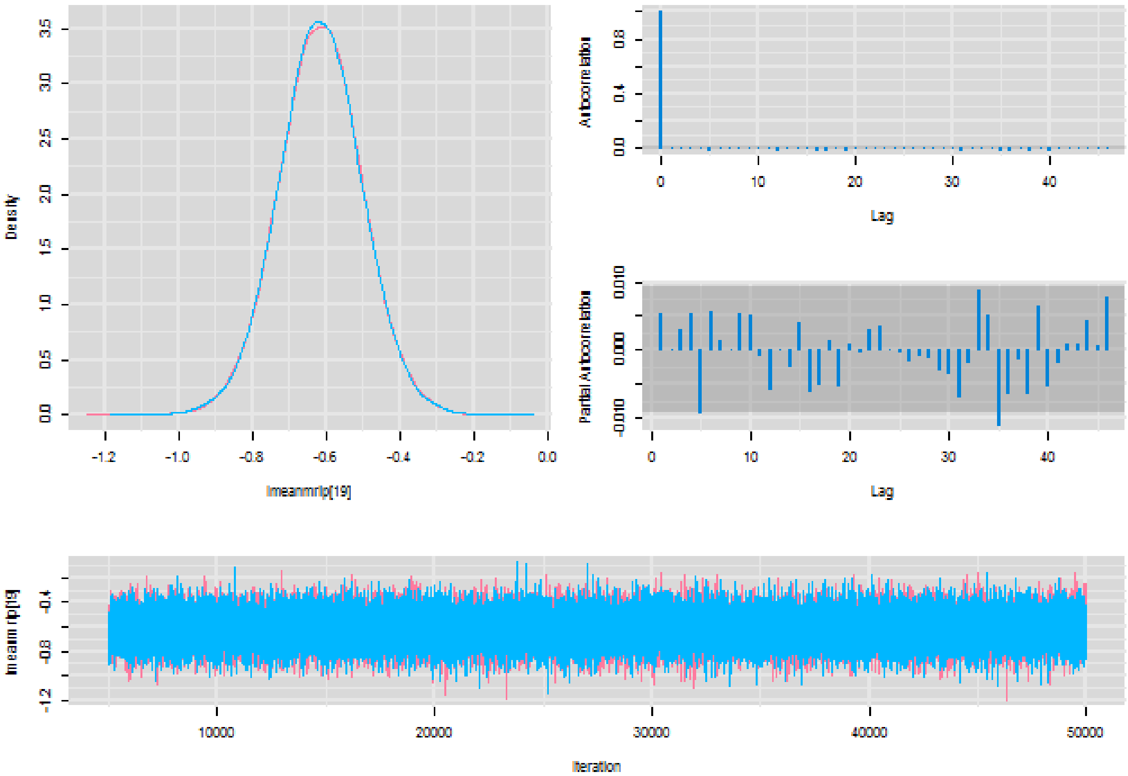
Diagnostics for lmeanmrip[17]



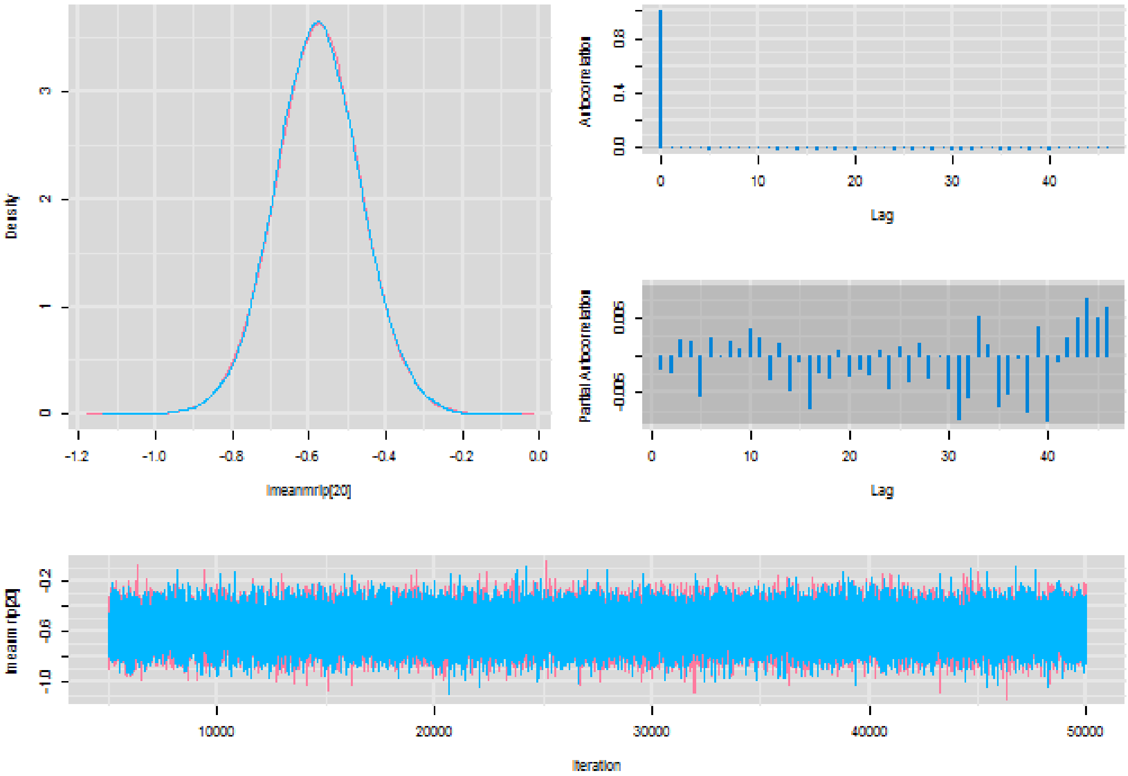
Diagnostics for lmeanmrip[18]



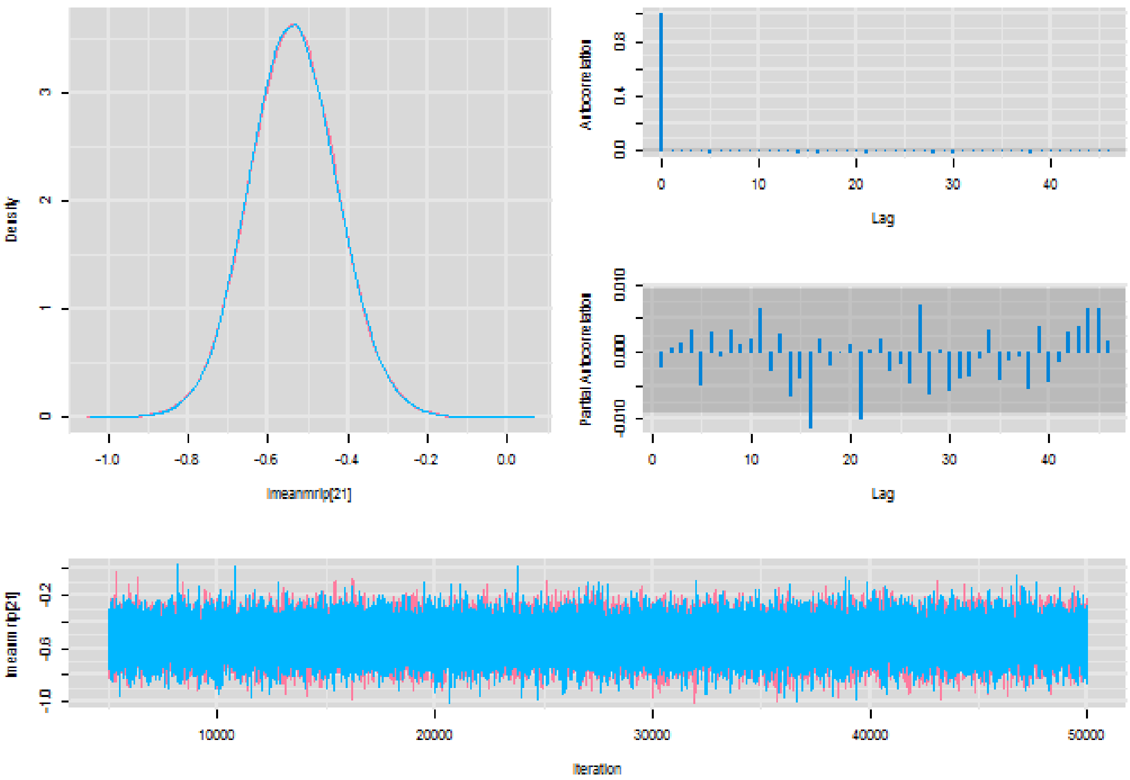
Diagnostics for lmeanmrip[19]



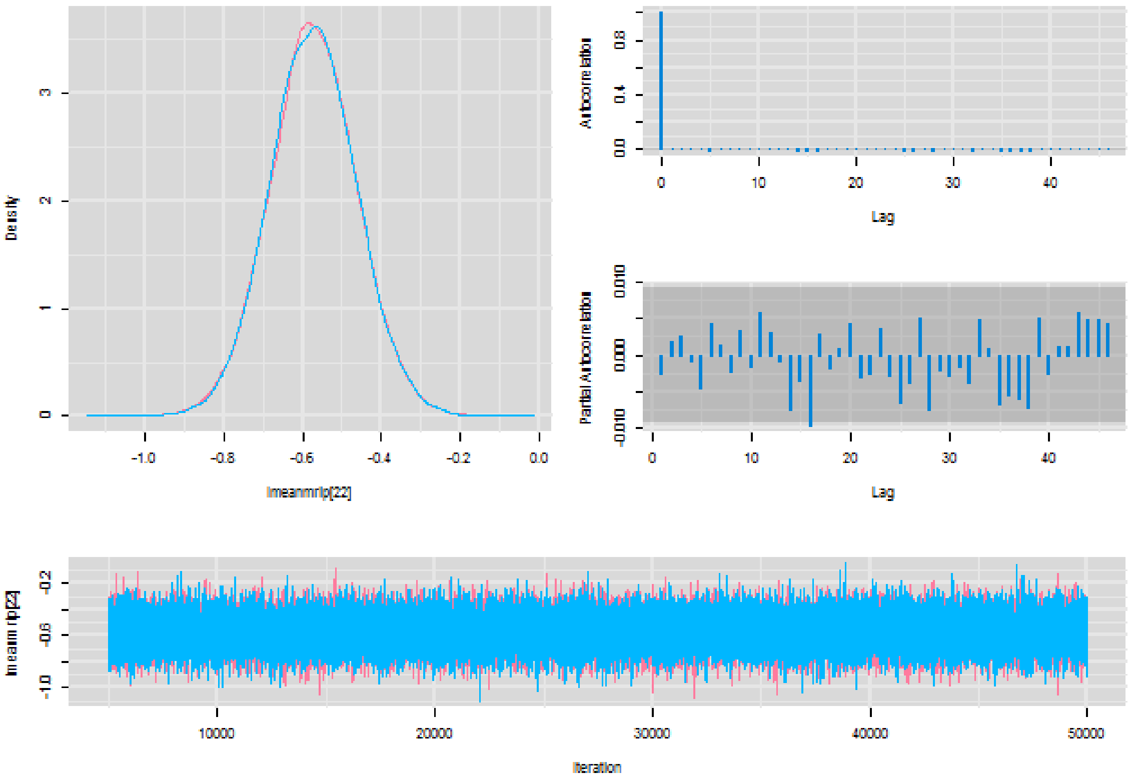
Diagnostics for lmeanmrip[20]



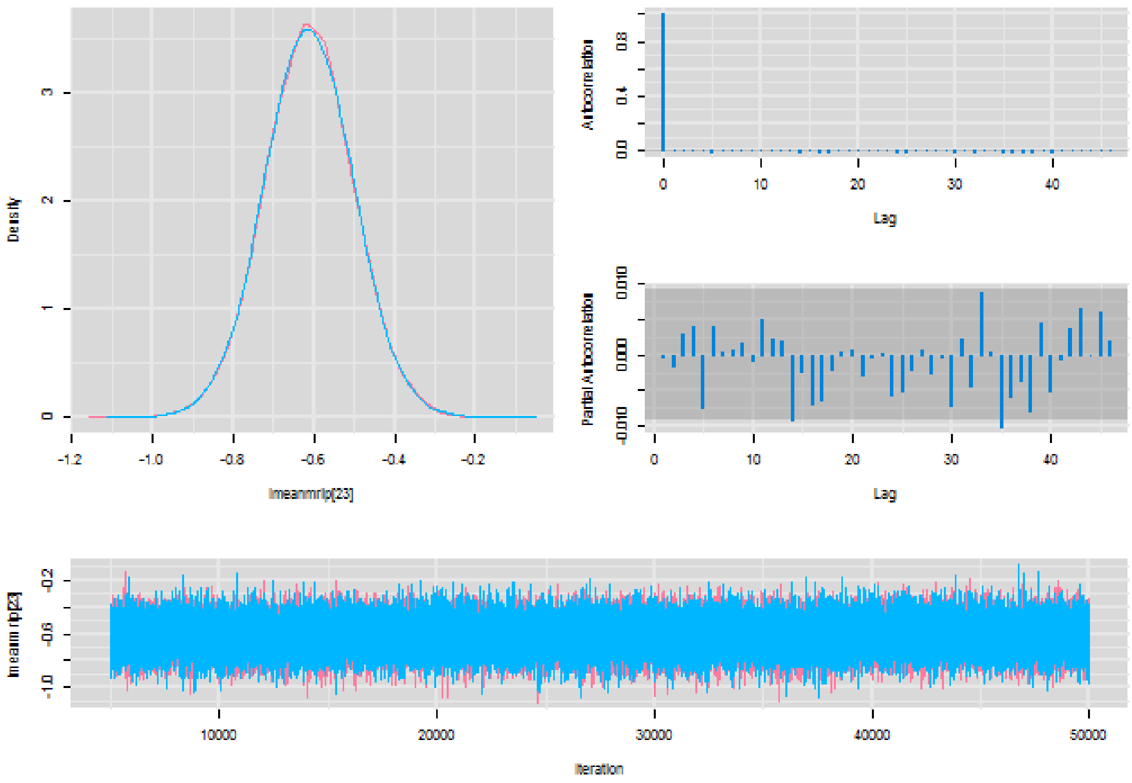
Diagnostics for lmeanmrip[21]



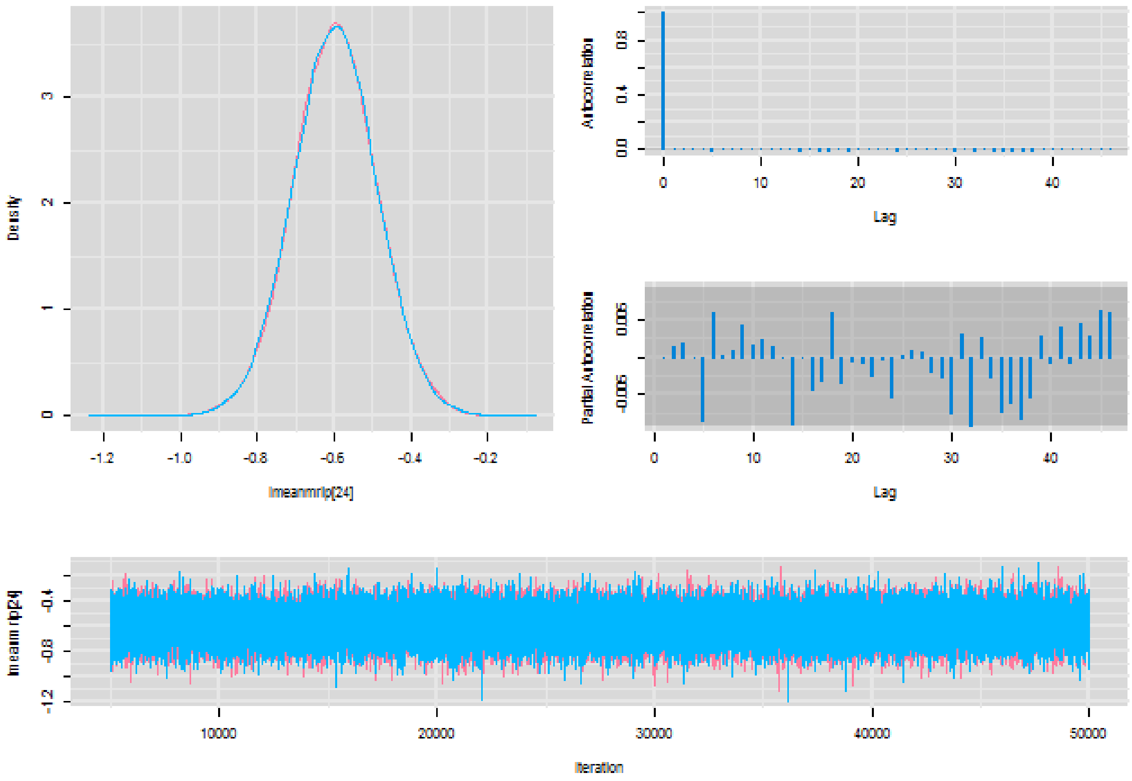
Diagnostics for lmeanmrip[22]



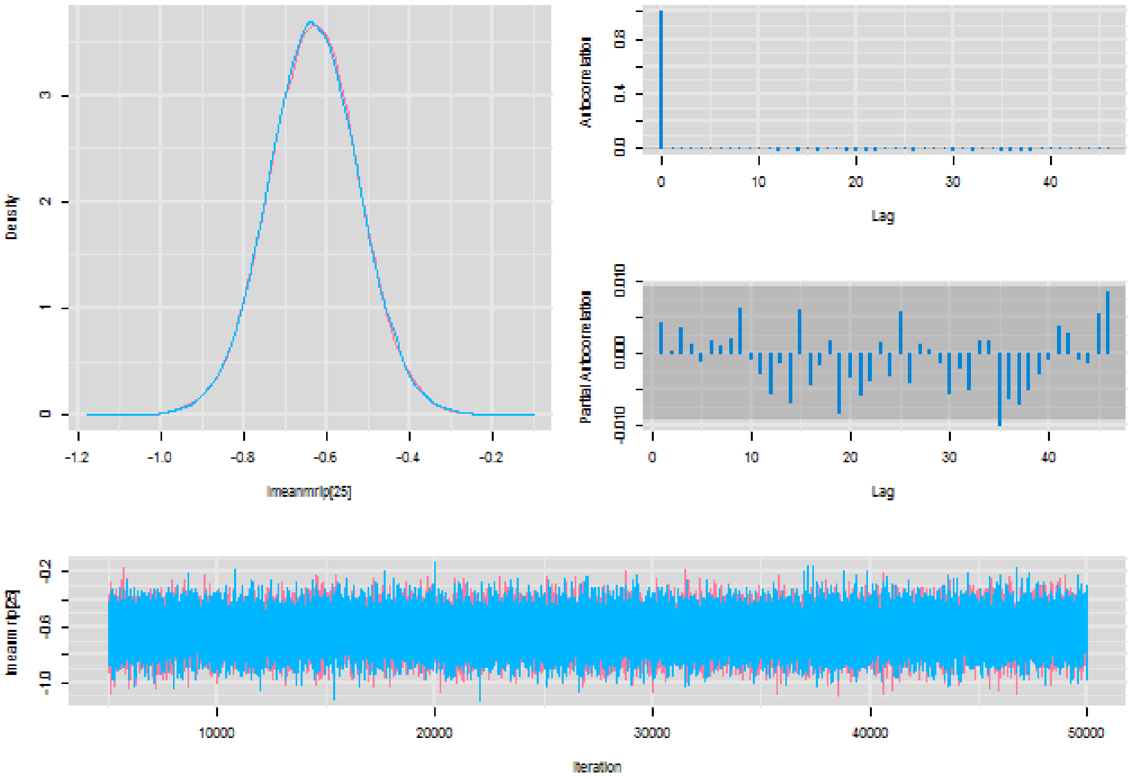
Diagnostics for lmeanmrip[23]



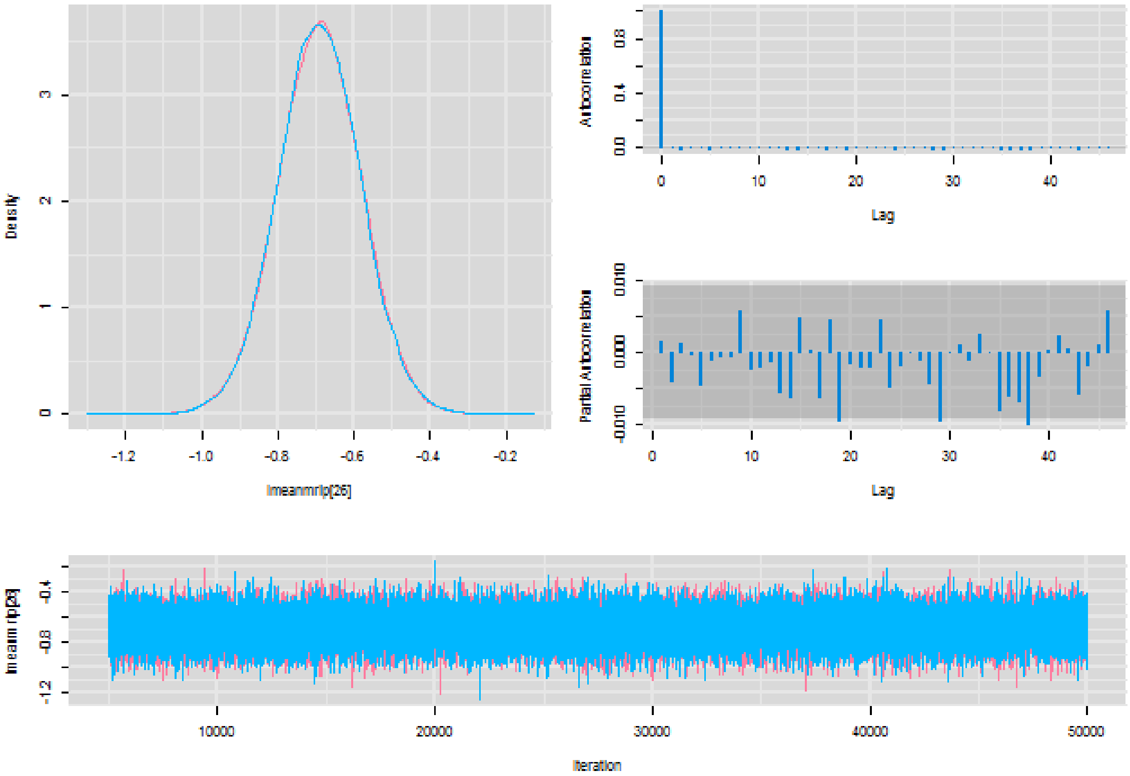
Diagnostics for lmeanmrip[24]



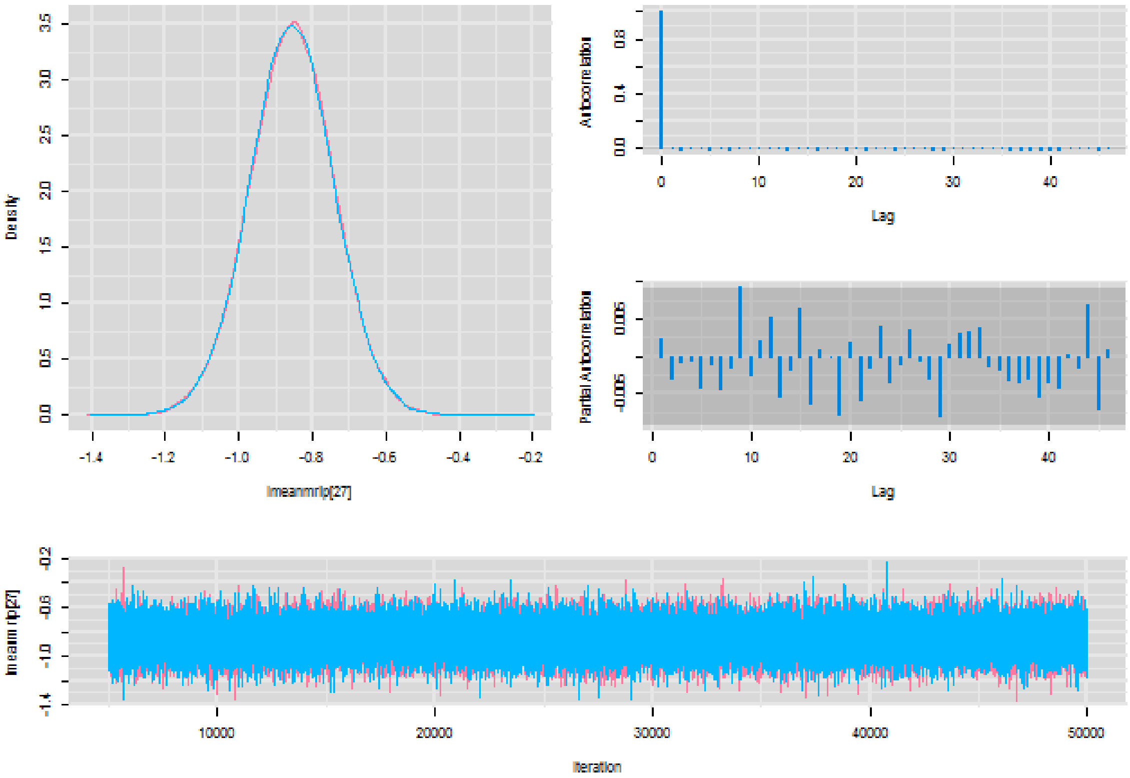
Diagnostics for lmeanmrip[25]



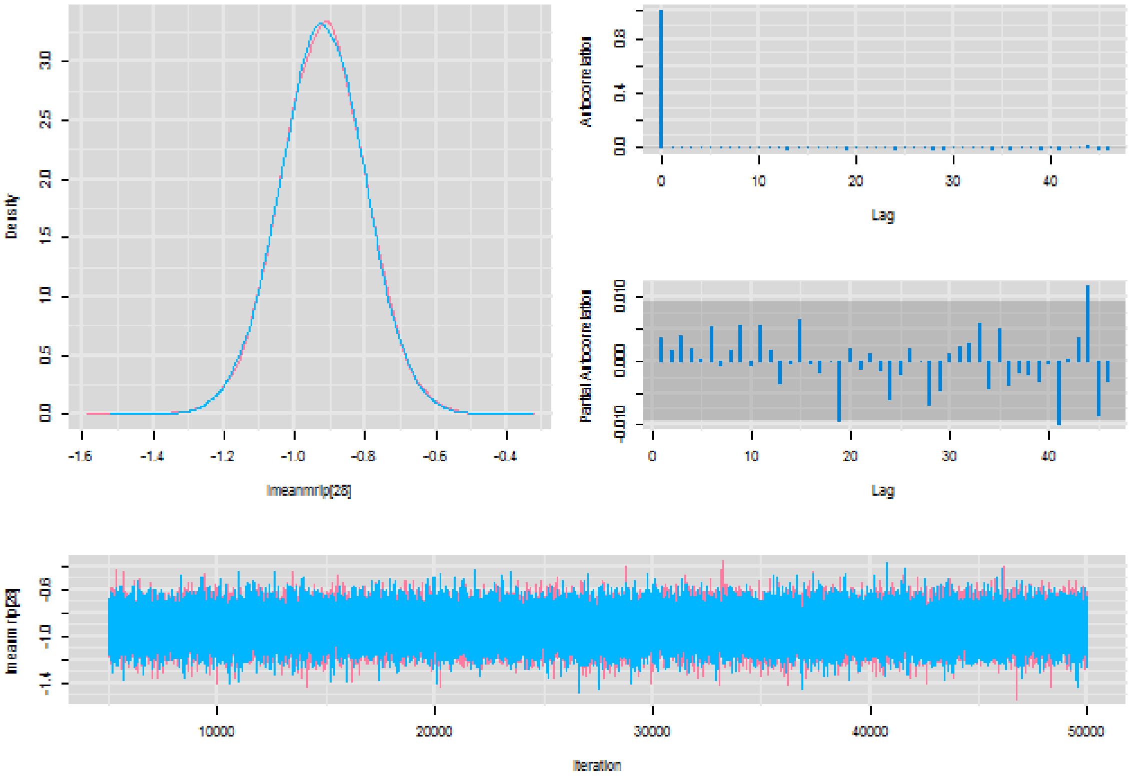
Diagnostics for lmeanmrip[26]



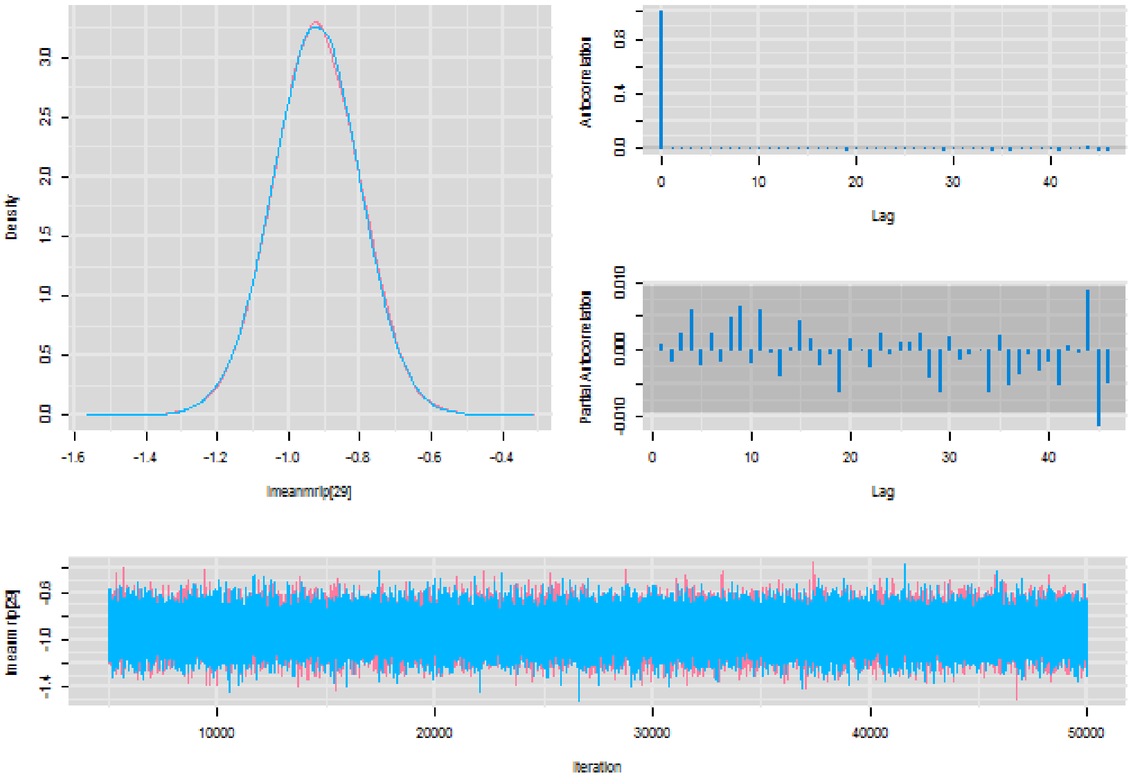
Diagnostics for lmeanmrip[27]



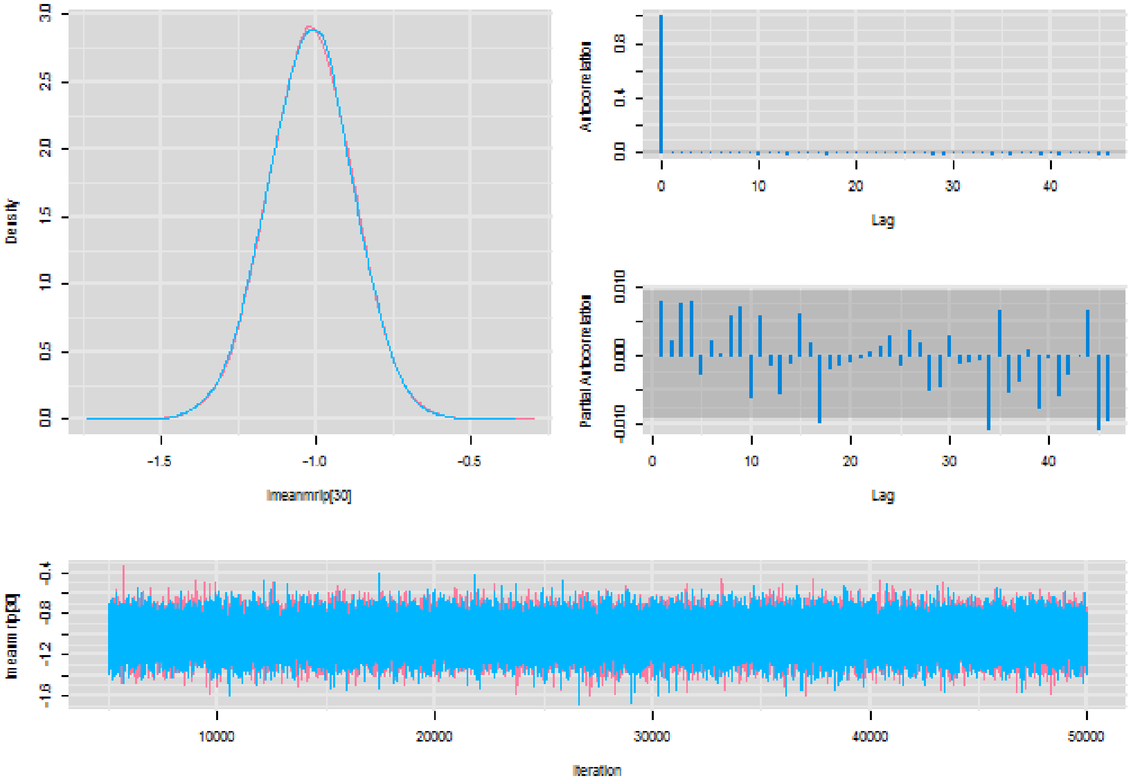
Diagnostics for lmeanmrip[28]



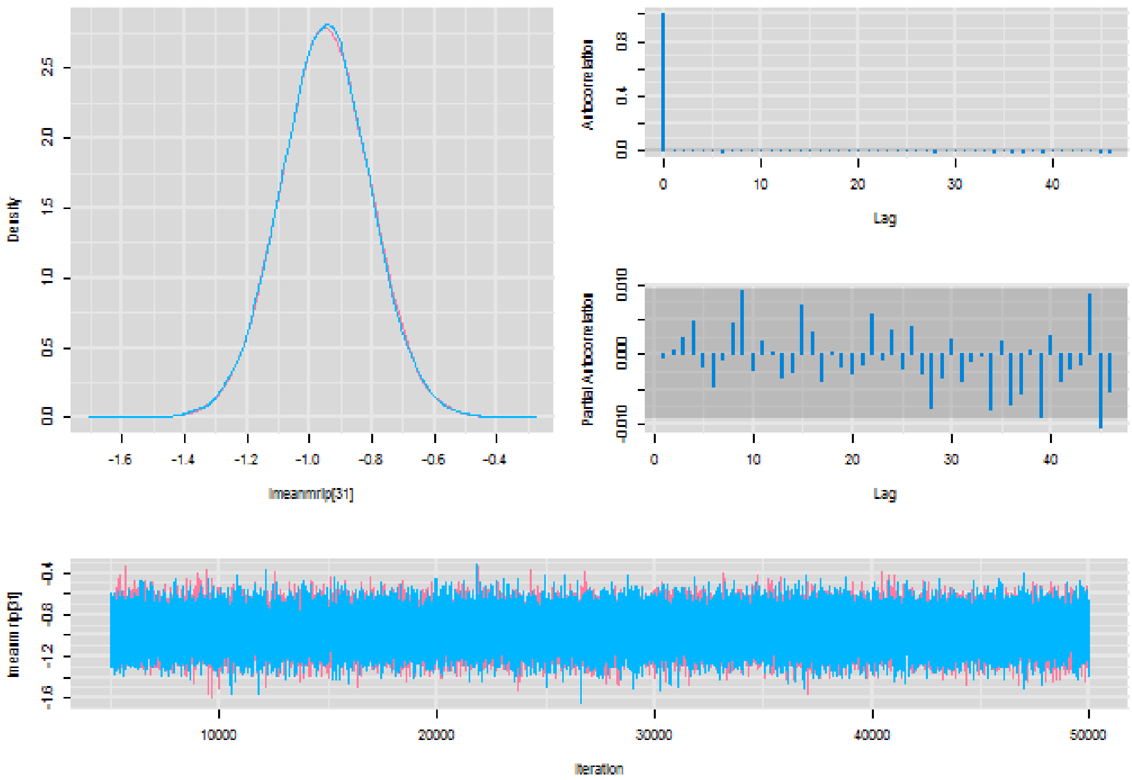
Diagnostics for lmeanmrip[29]



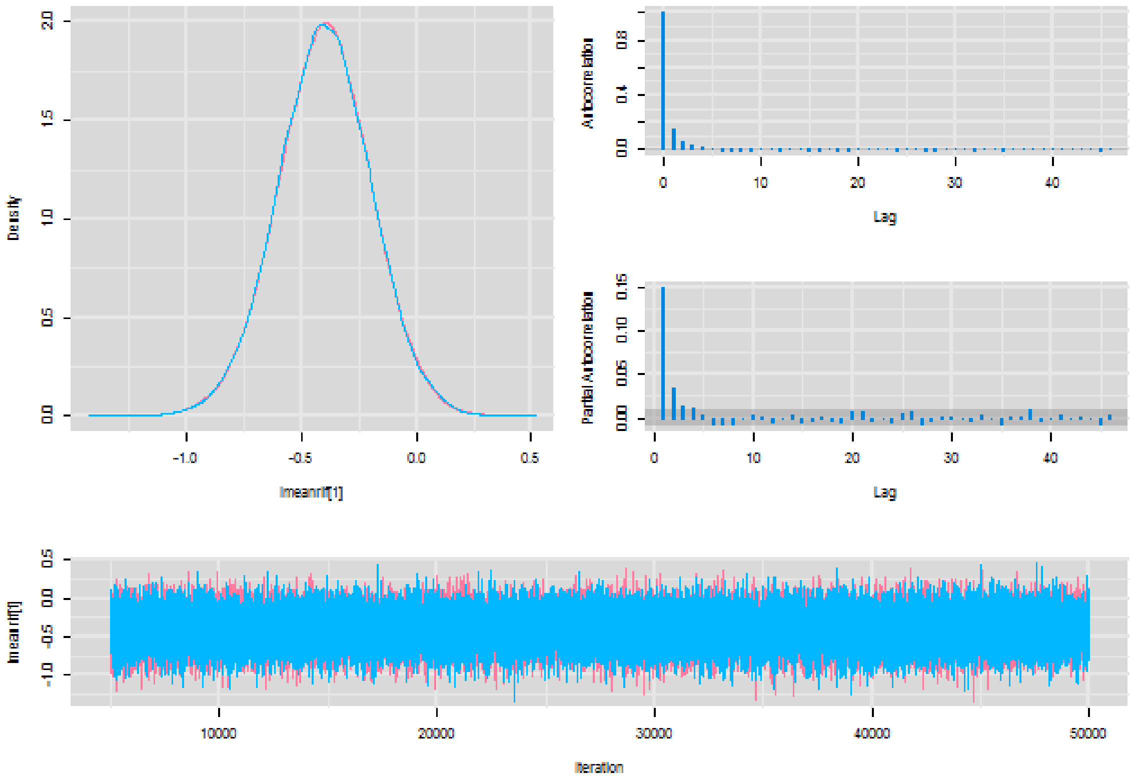
Diagnostics for lmeanmrip[30]



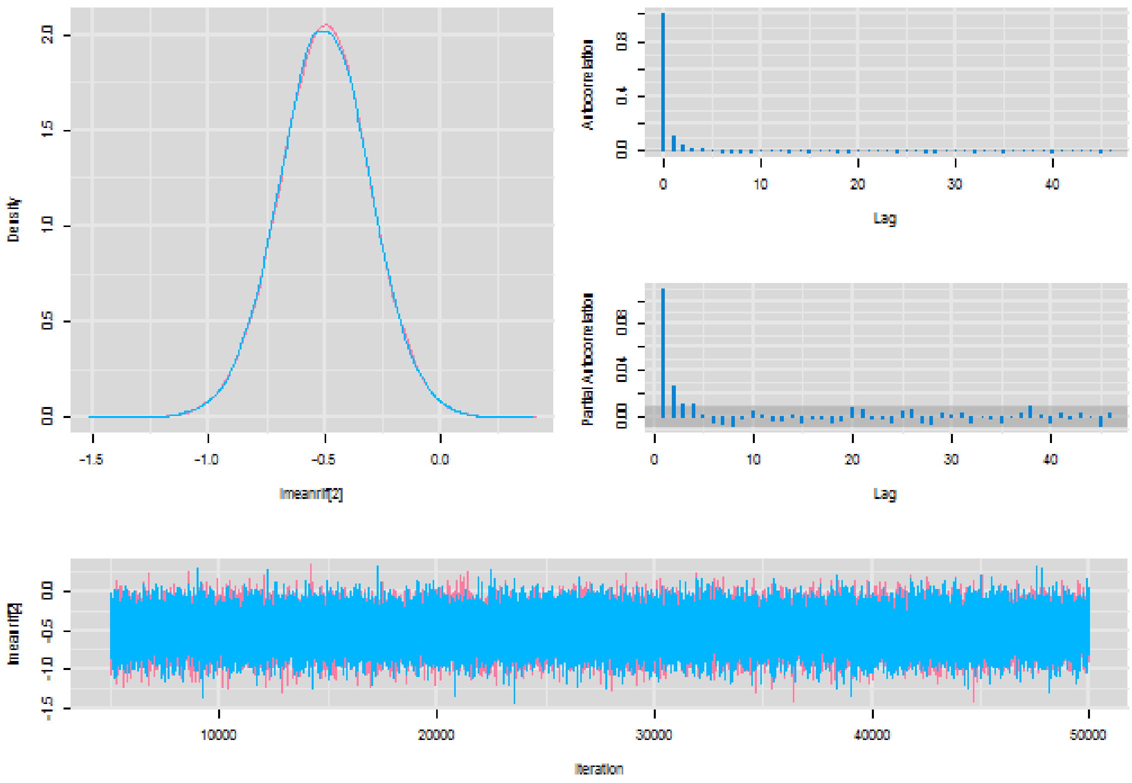
Diagnostics for lmeanmrip[31]



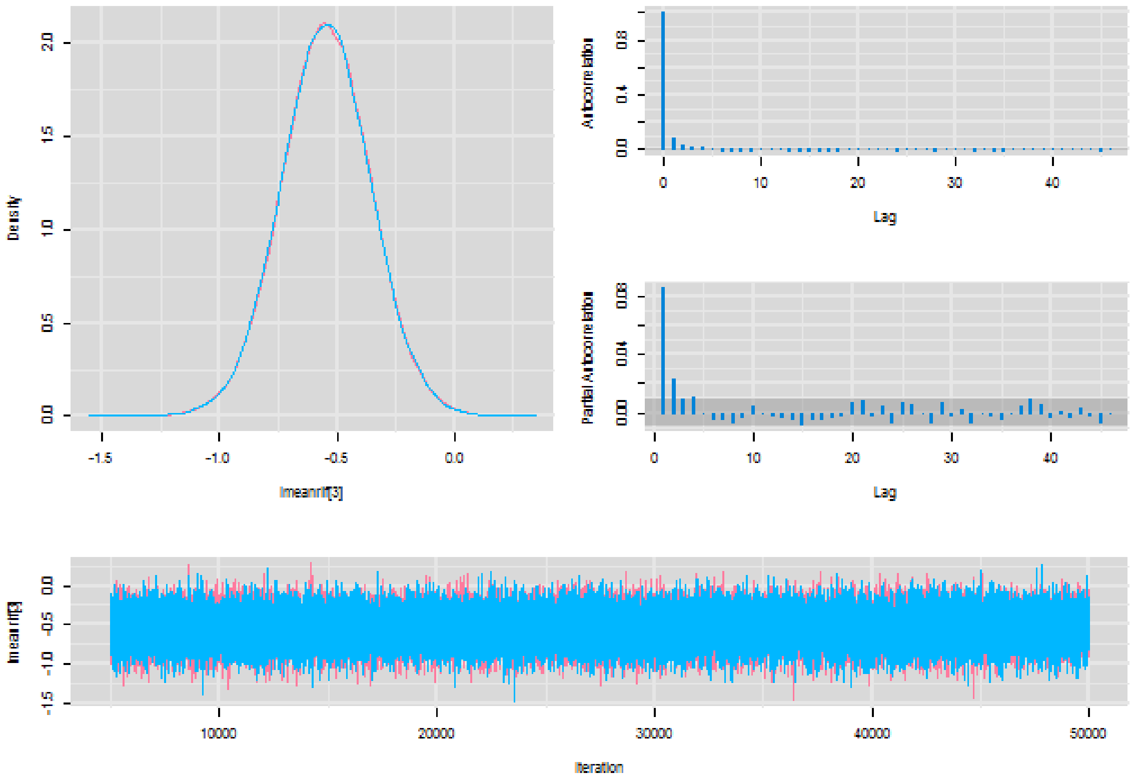
Diagnostics for lmeanrif[1]



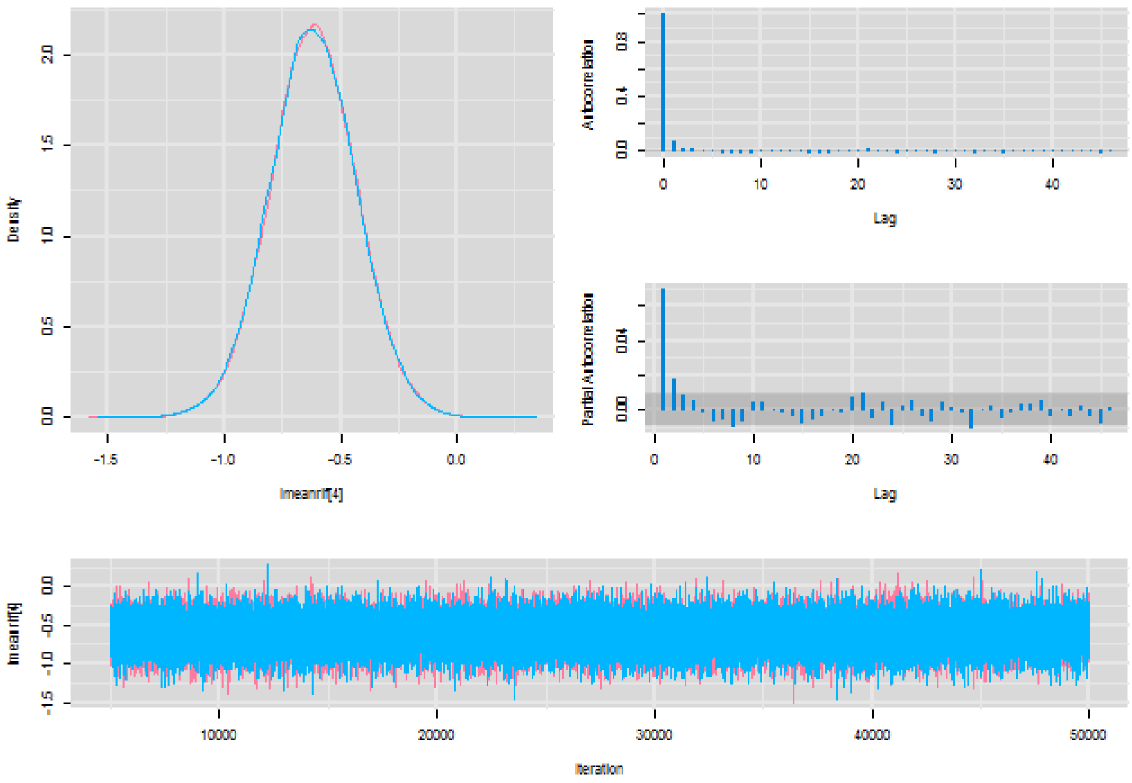
Diagnostics for lmeanrif[2]



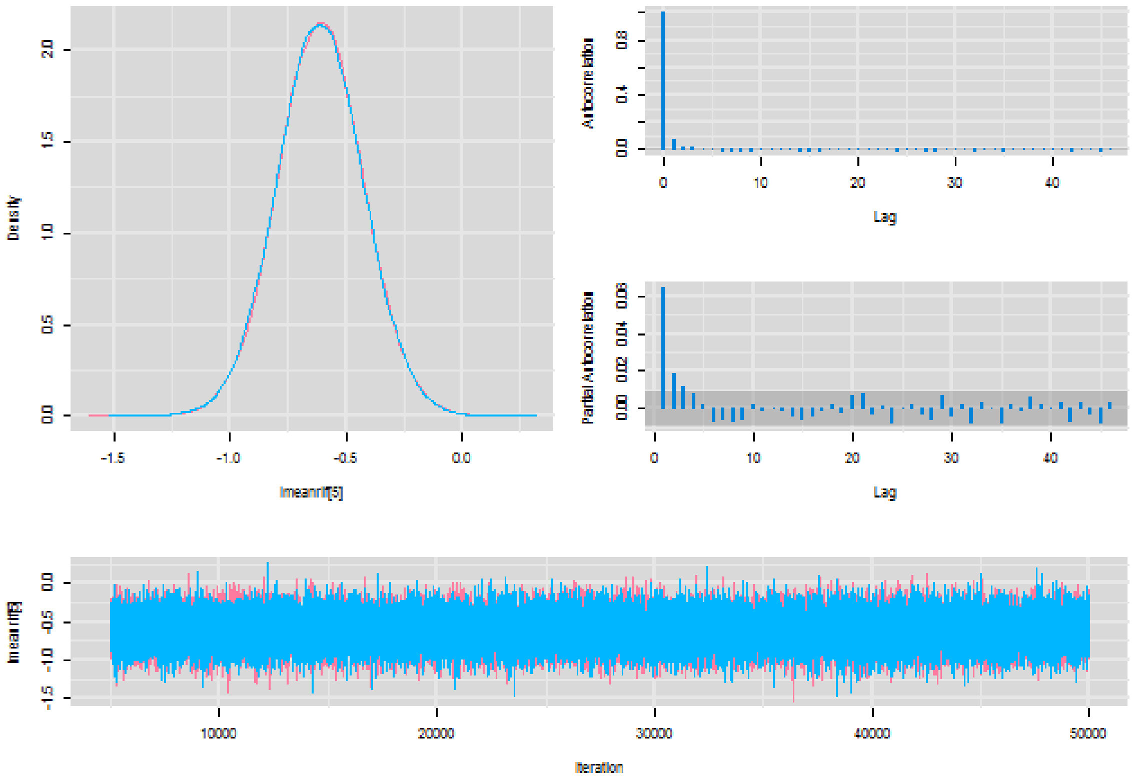
Diagnostics for lmeanrif[3]



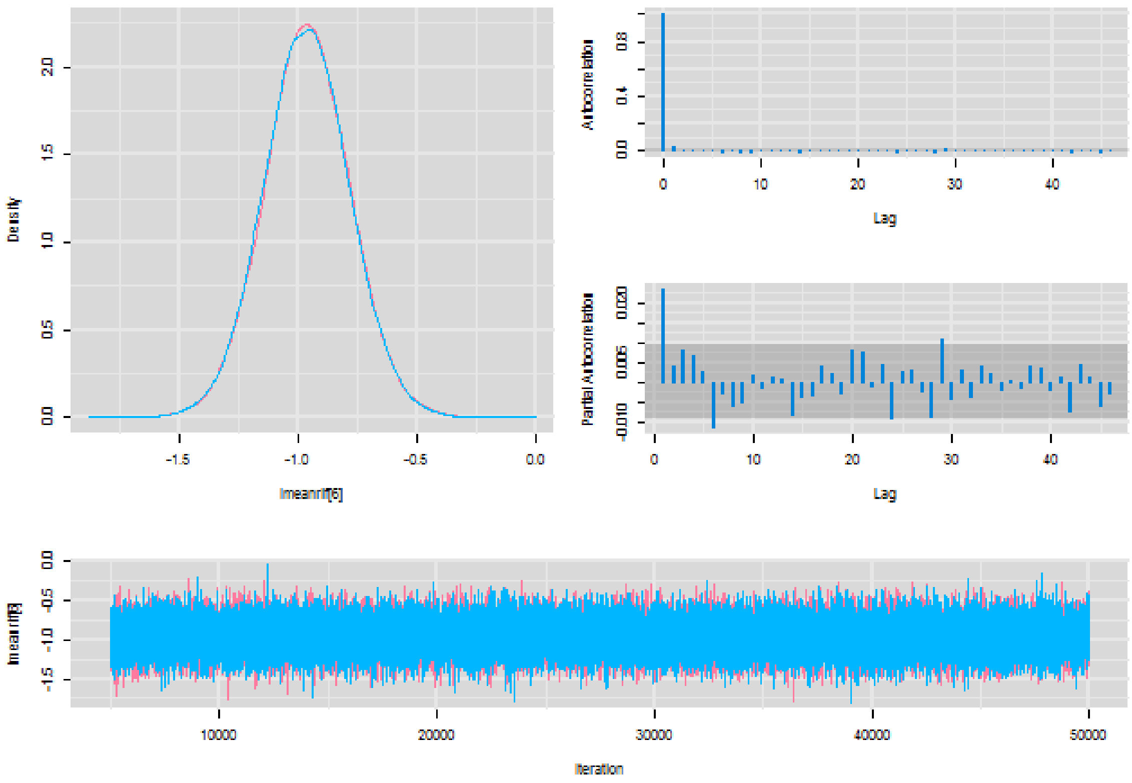
Diagnostics for lmeanrif[4]



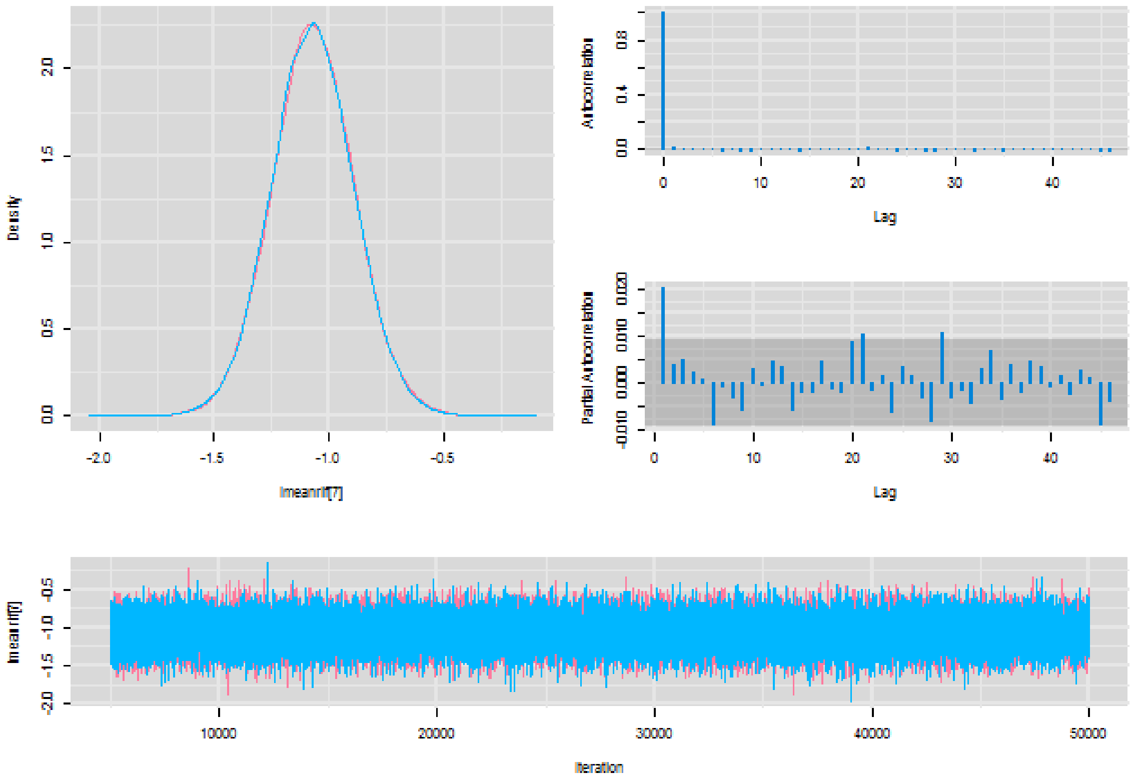
Diagnostics for lmeanrif[5]



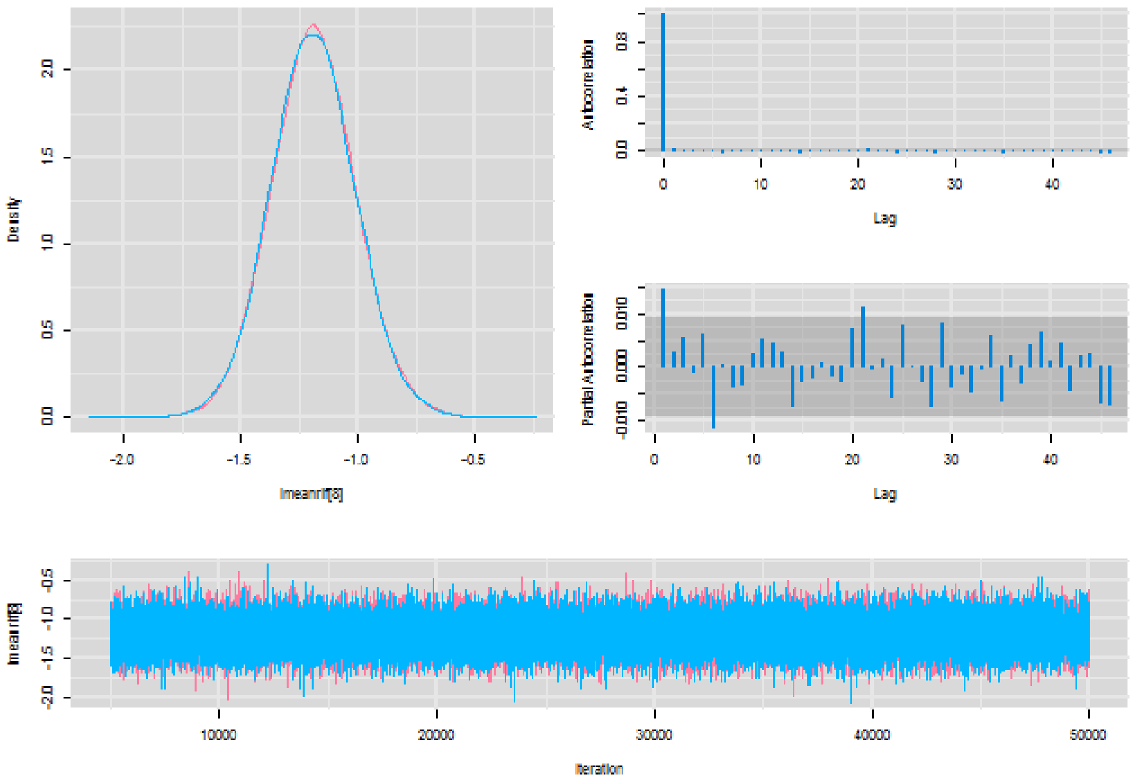
Diagnostics for lmeanrif[6]



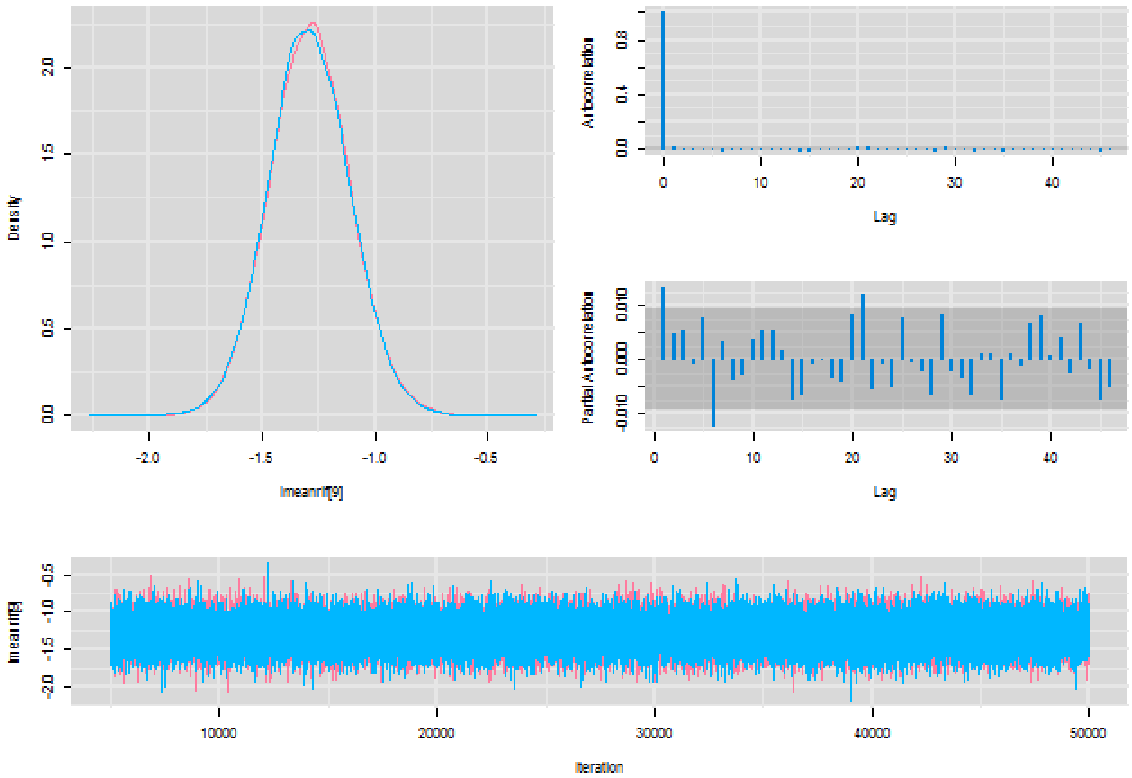
Diagnostics for lmeanrif[7]



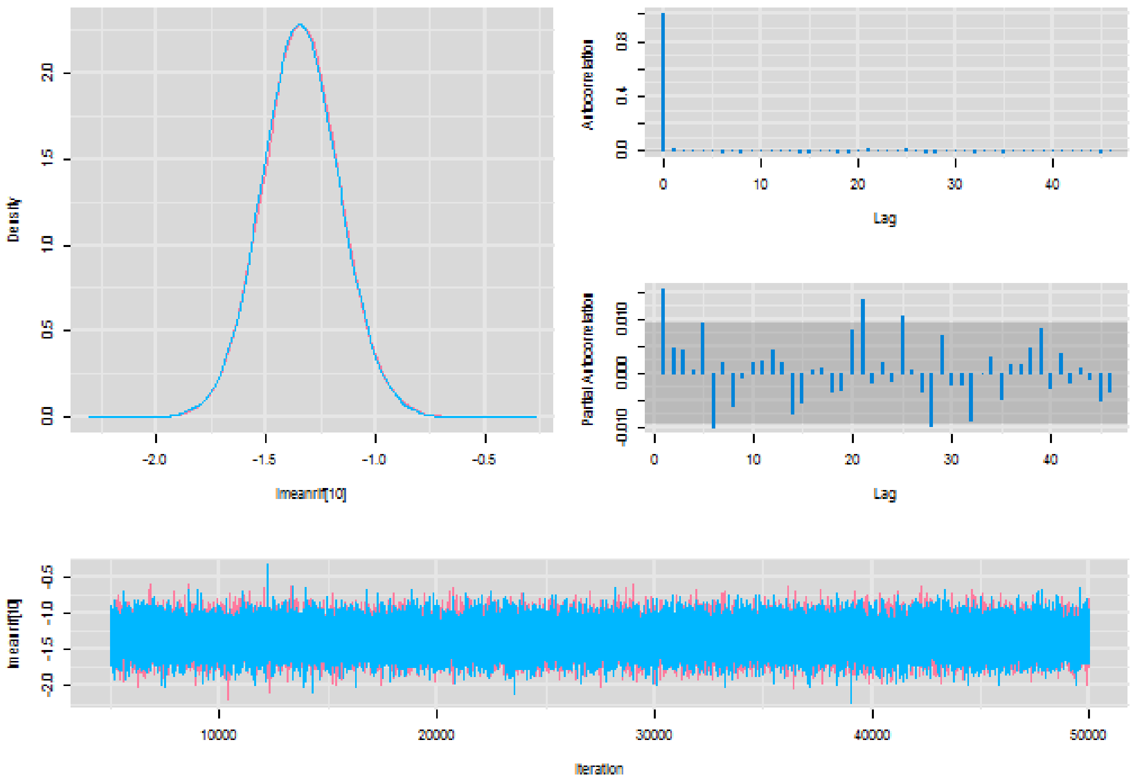
Diagnostics for lmeanrif[8]



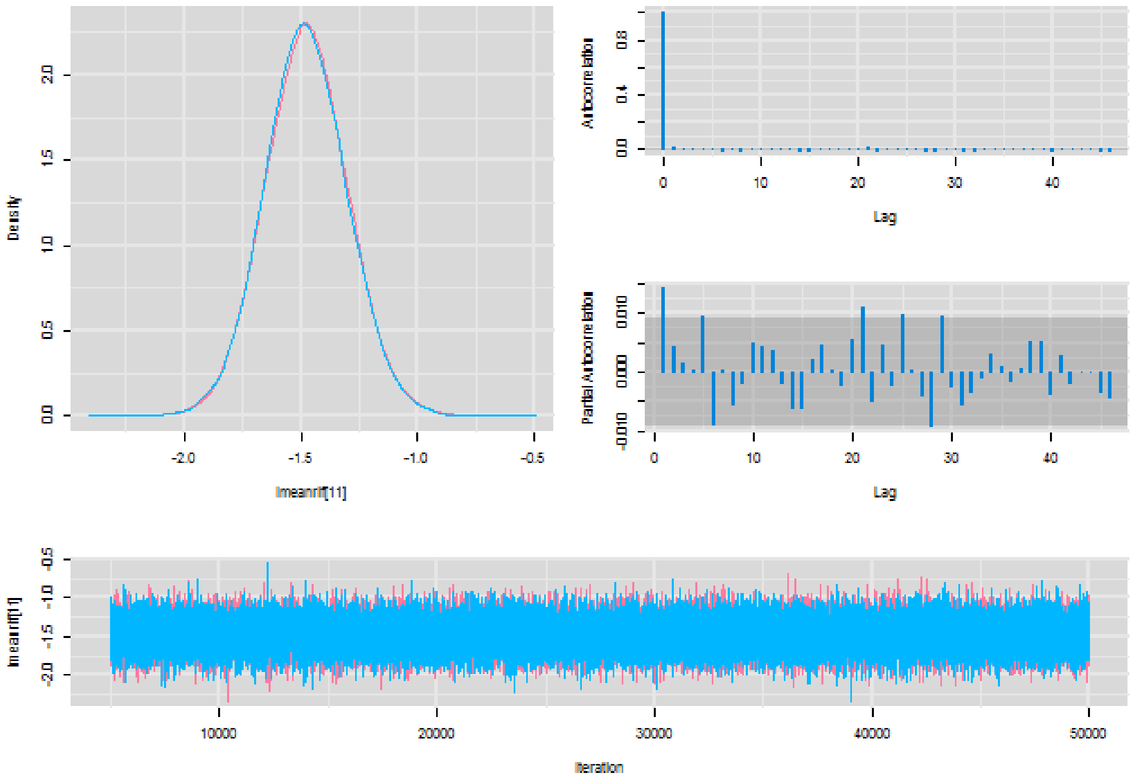
Diagnostics for lmeanrif[9]



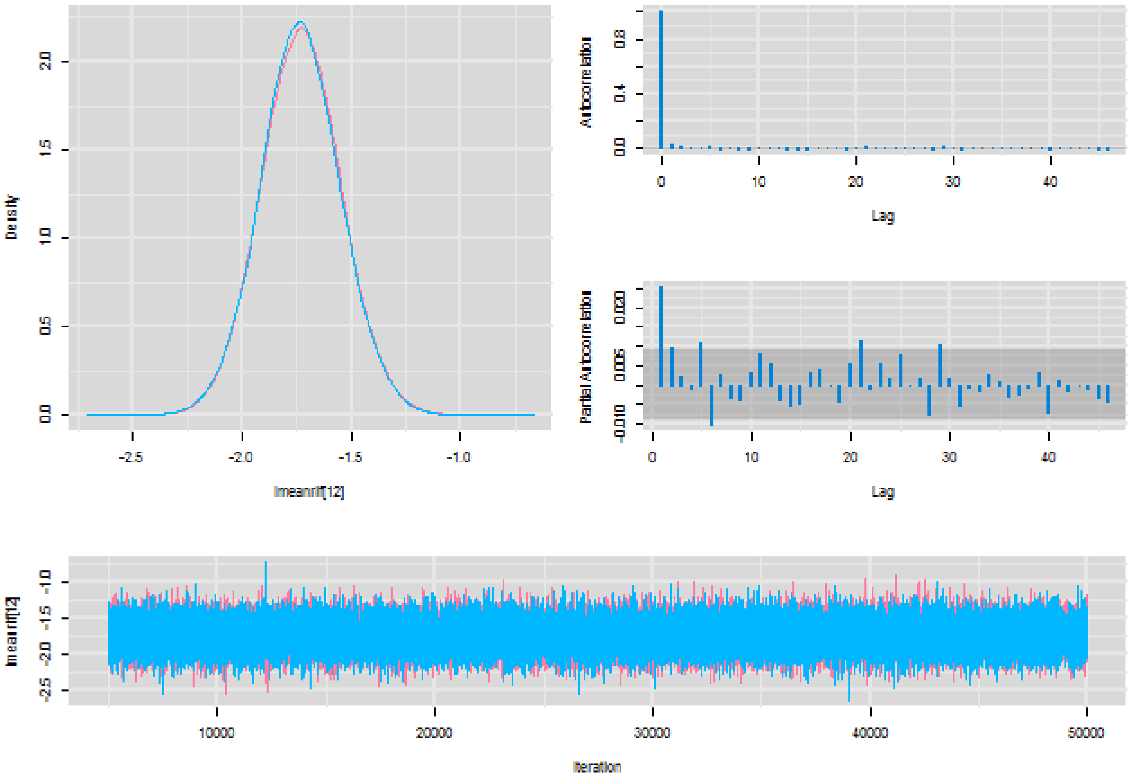
Diagnostics for lmeanrif[10]



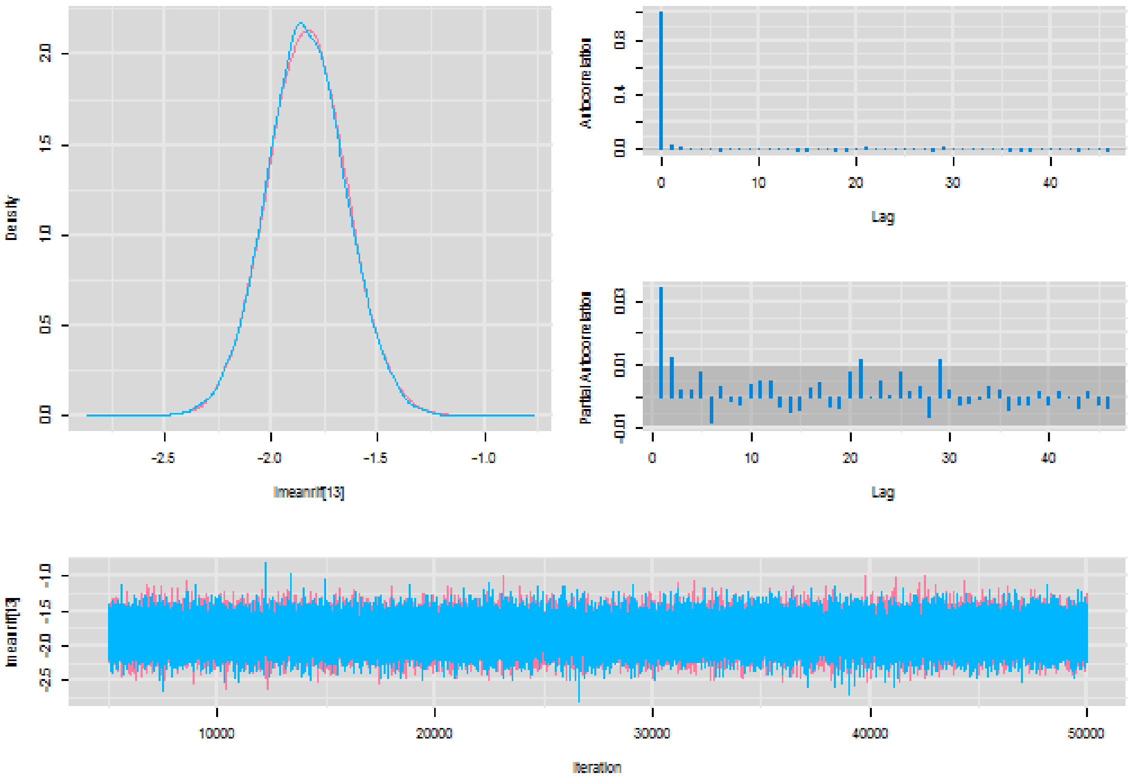
Diagnostics for lmeanrif[11]



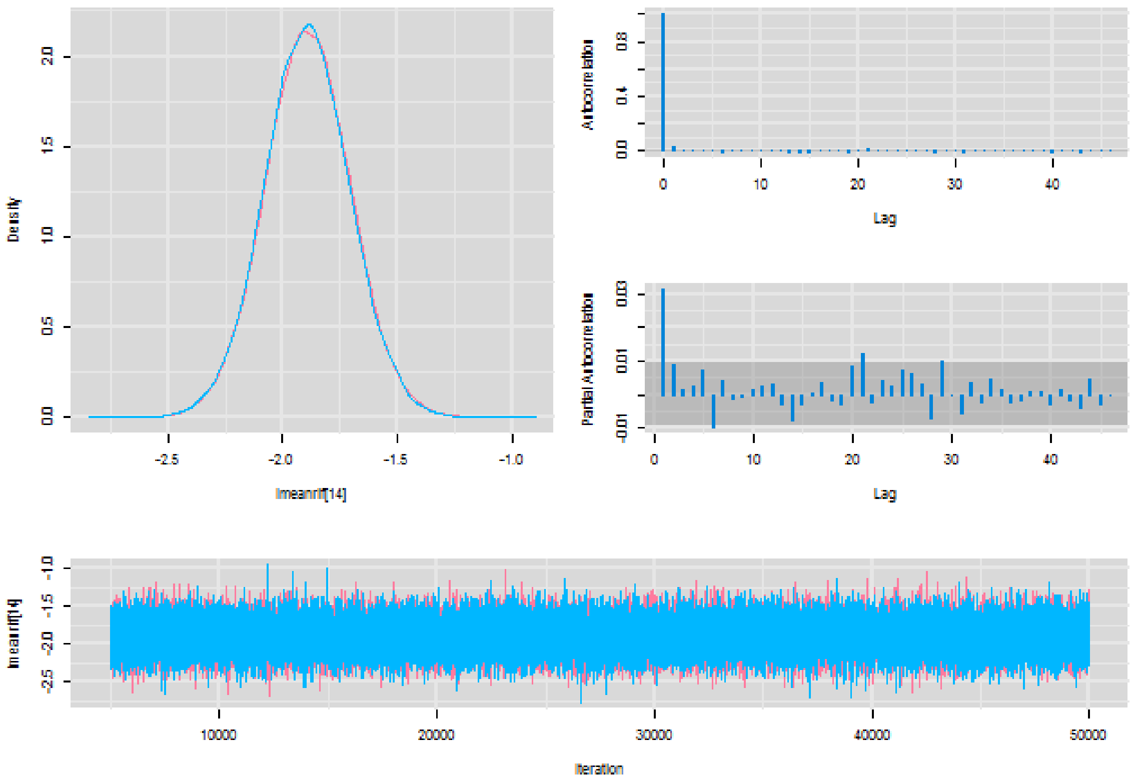
Diagnostics for lmeanrif[12]



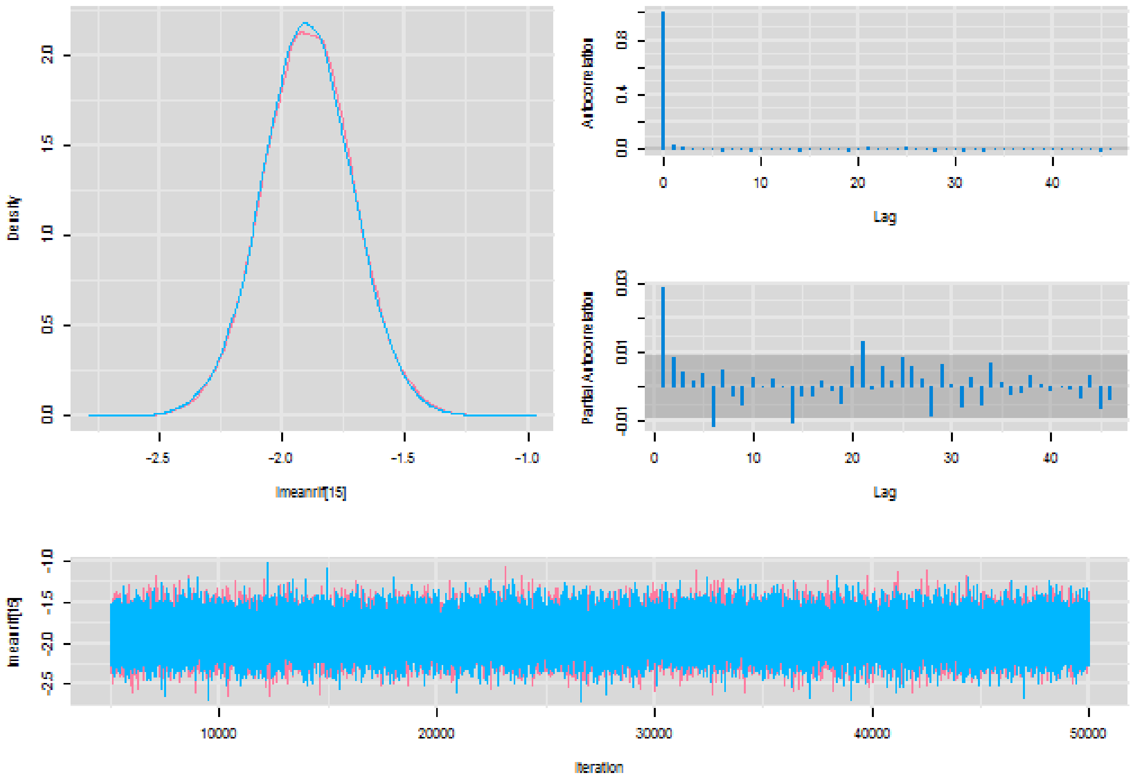
Diagnostics for lmeanrif[13]



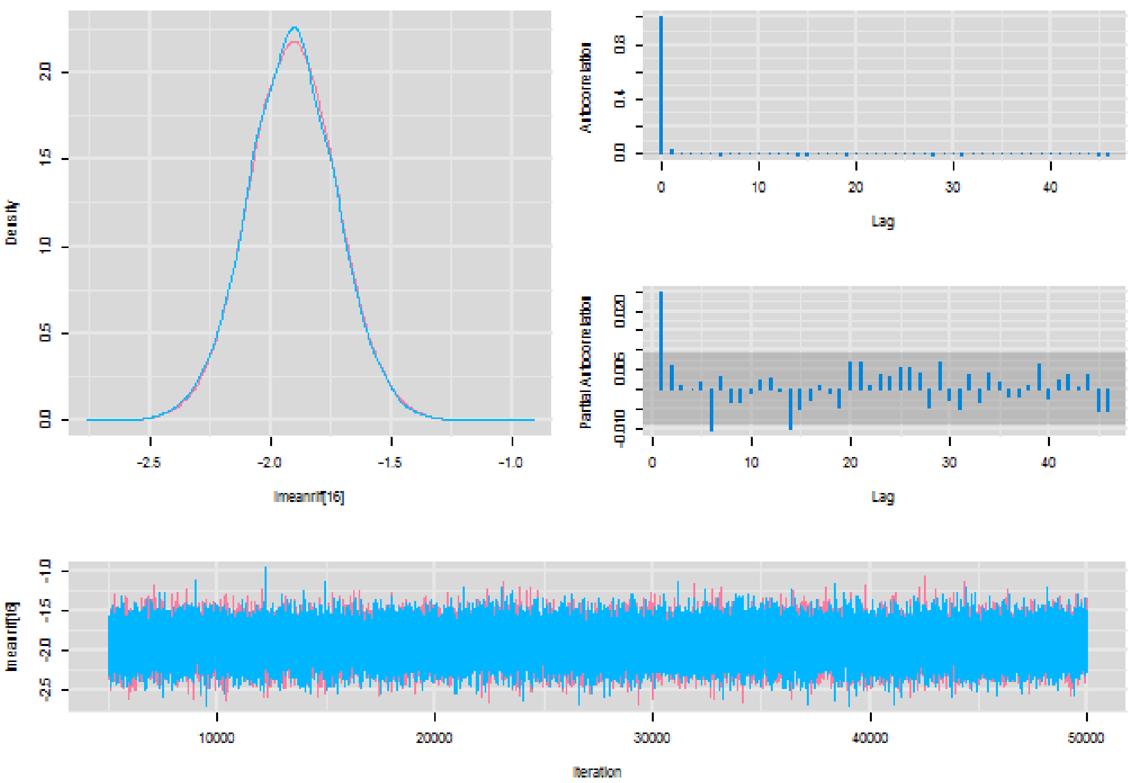
Diagnostics for lmeanrif[14]



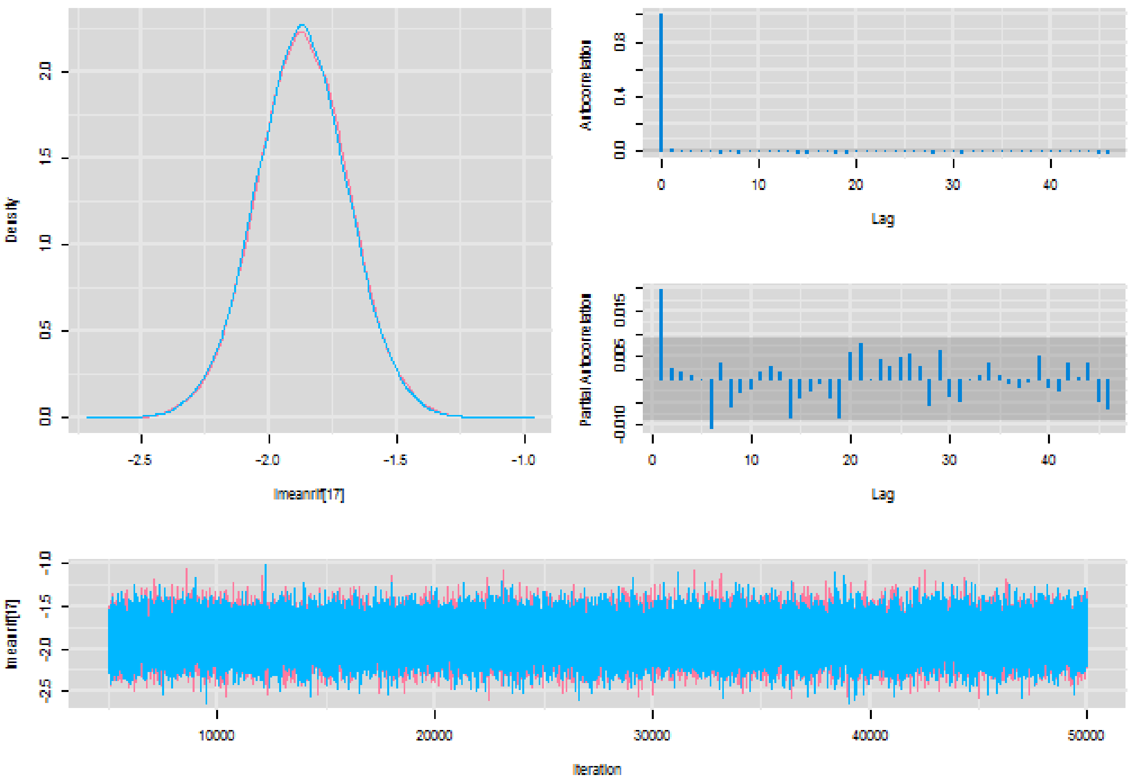
Diagnostics for lmeanrif[15]



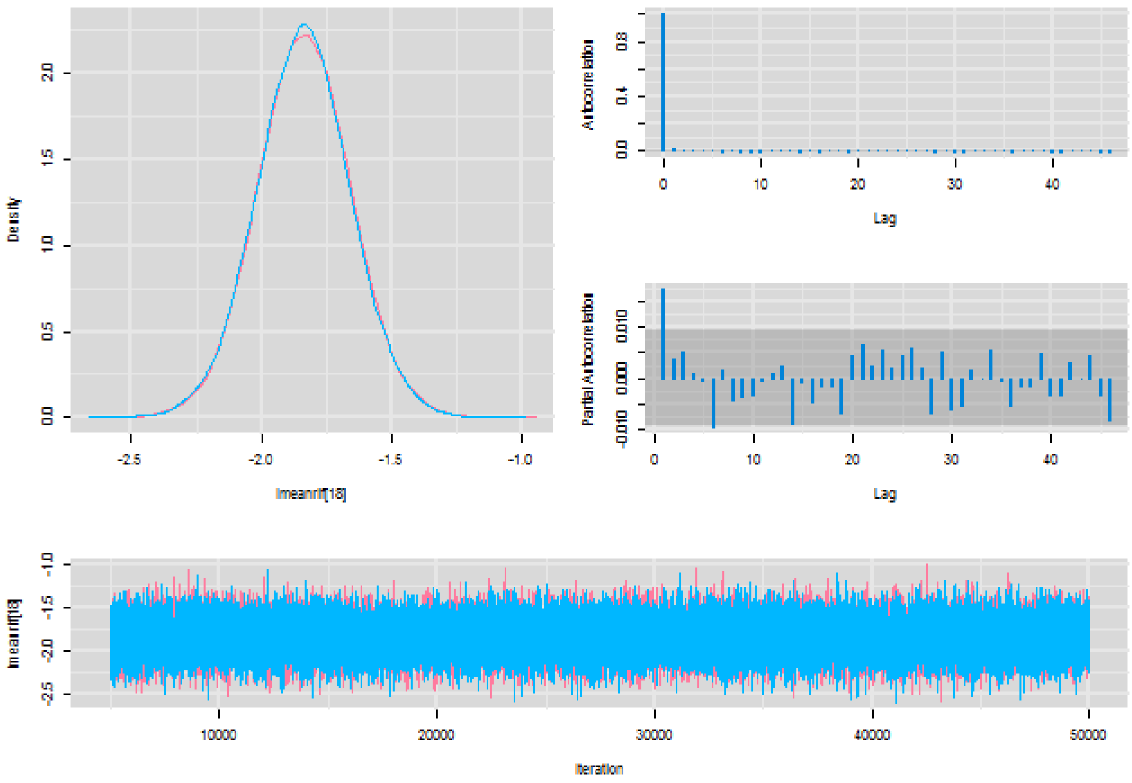
Diagnostics for lmeanrif[16]



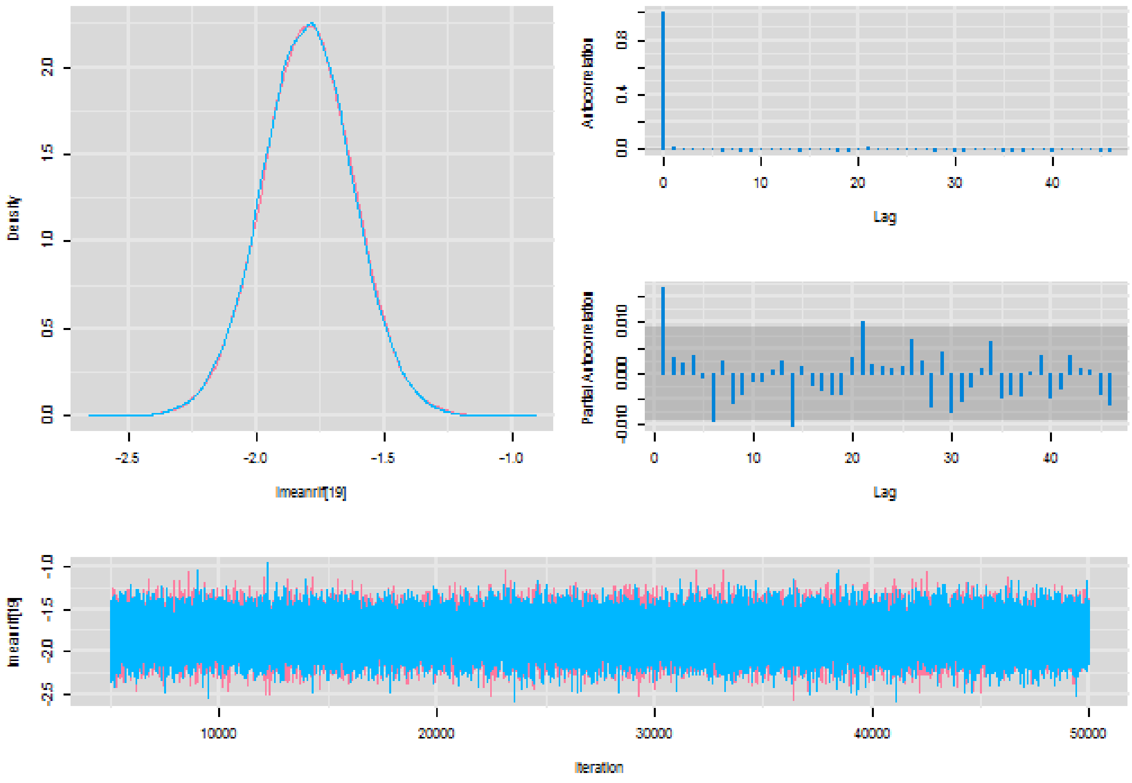
Diagnostics for lmeanrif[17]



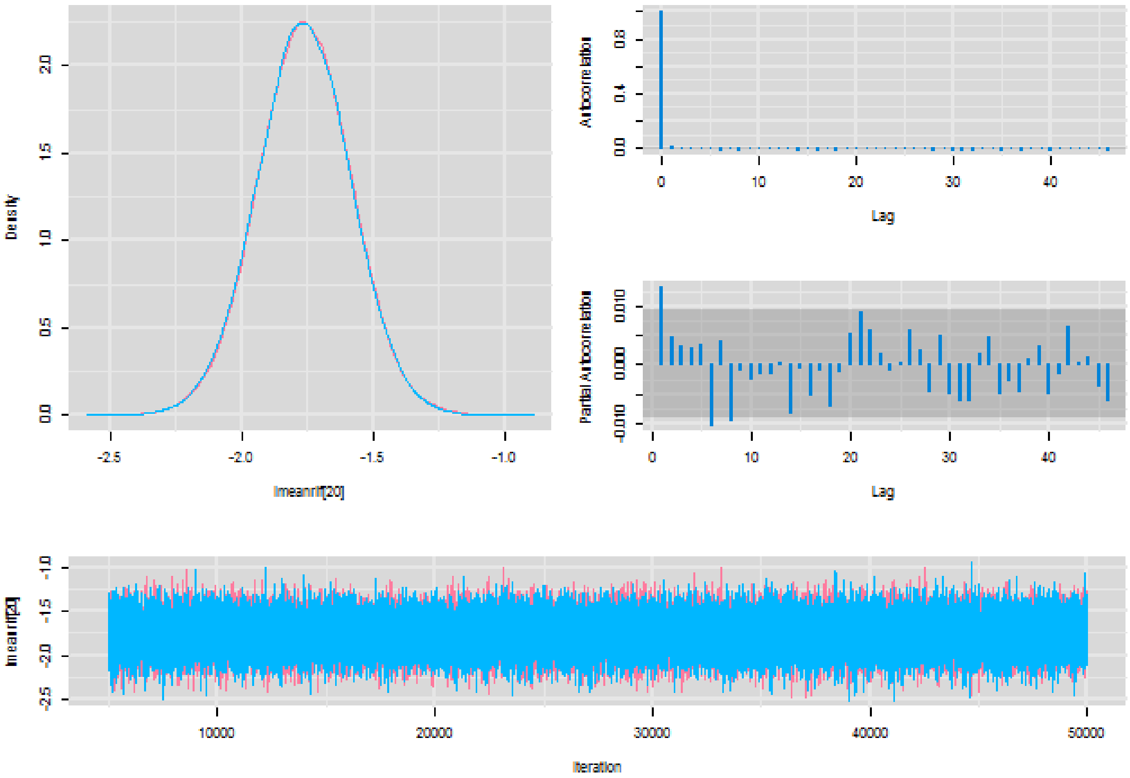
Diagnostics for lmeanrif[18]



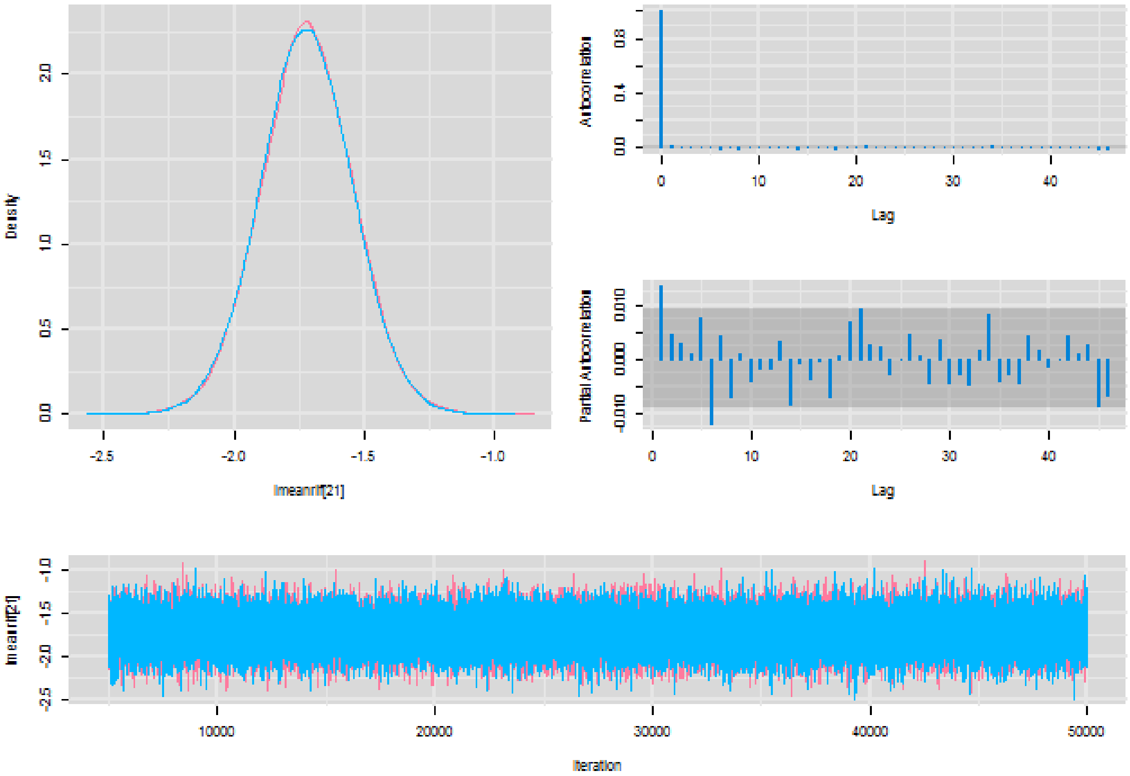
Diagnostics for lmeanrif[19]



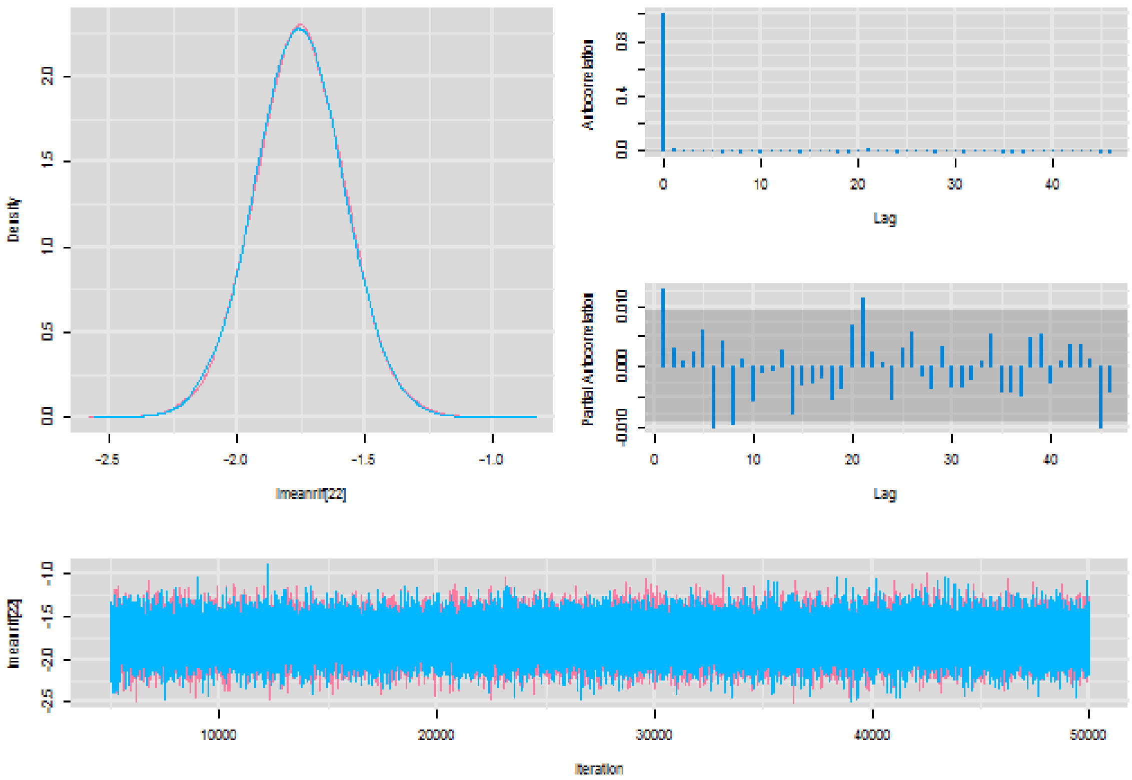
Diagnostics for lmeanrif[20]



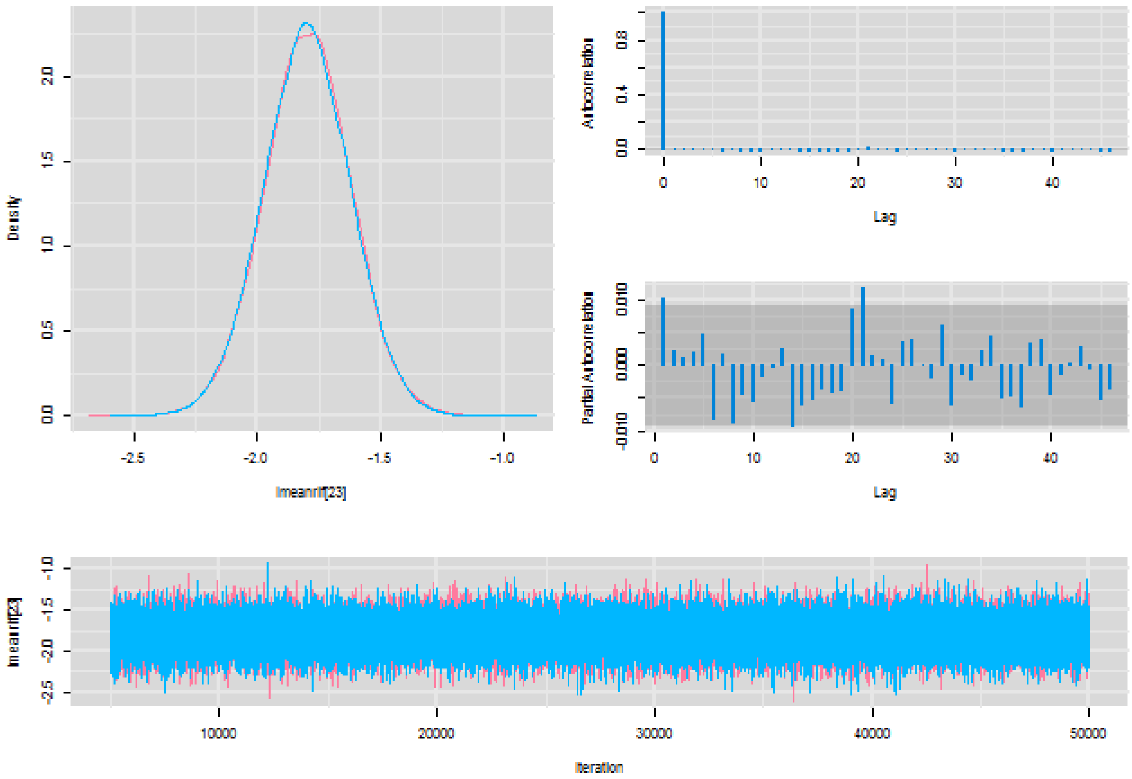
Diagnostics for lmeanrif[21]



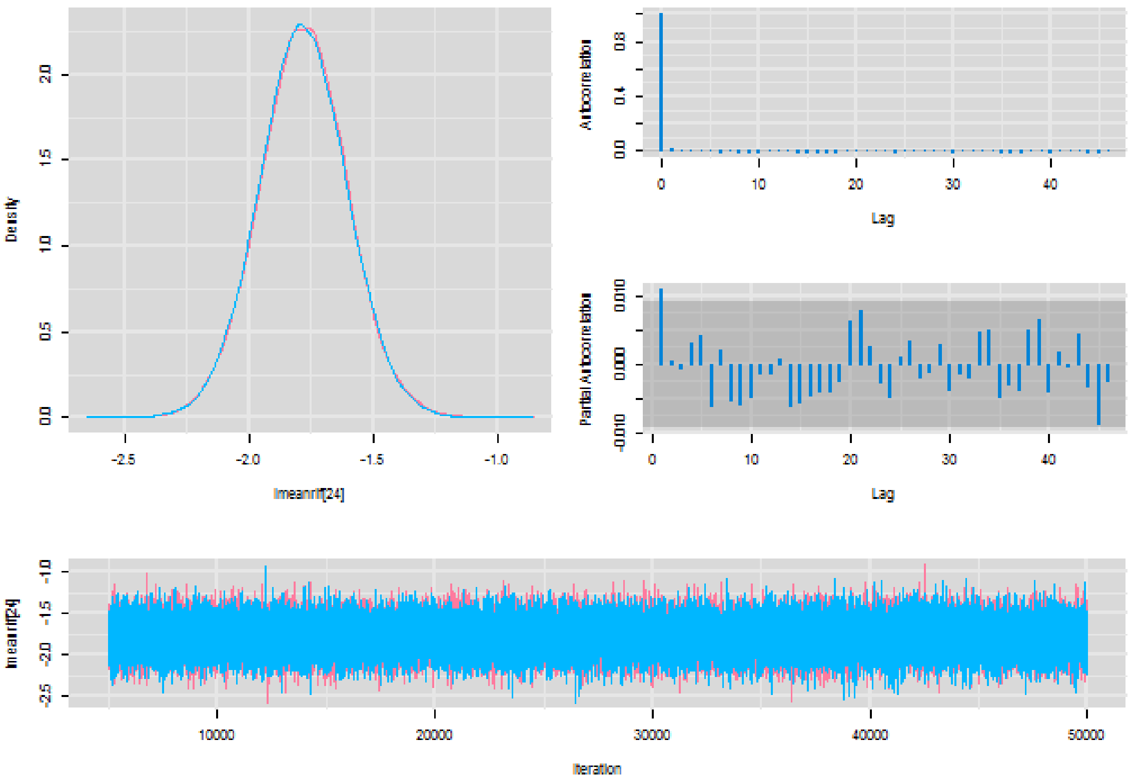
Diagnostics for lmeanrif[22]



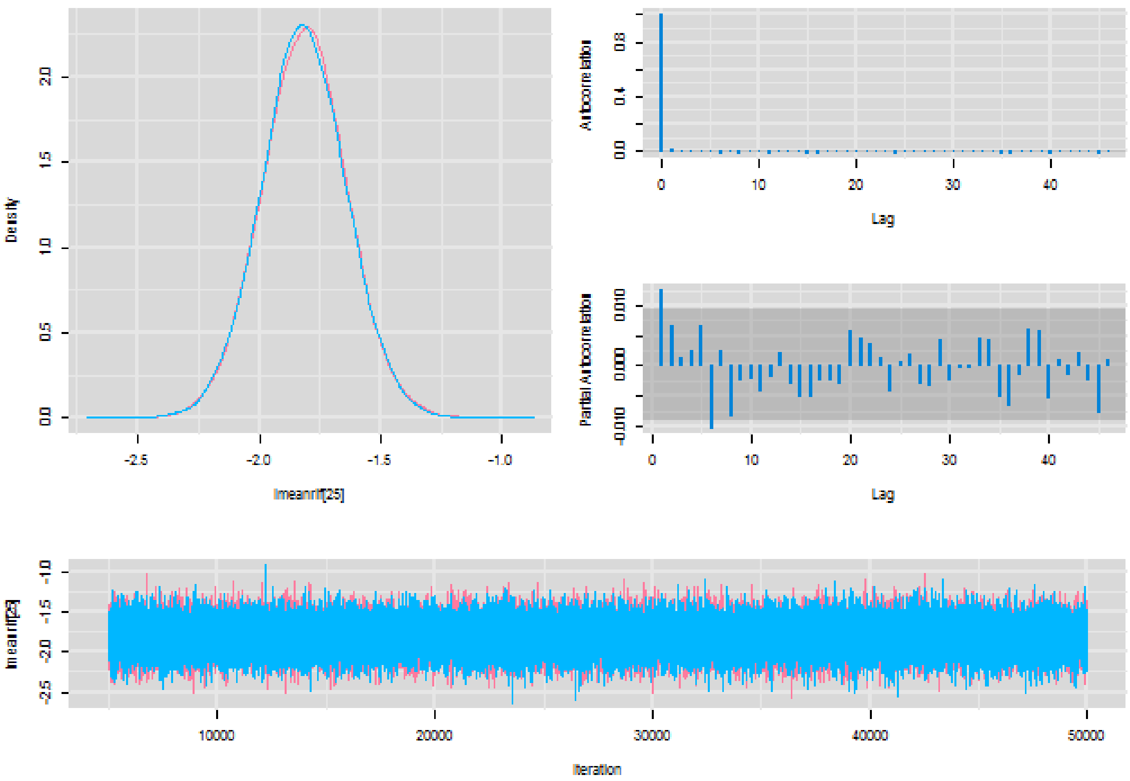
Diagnostics for lmeanrif[23]



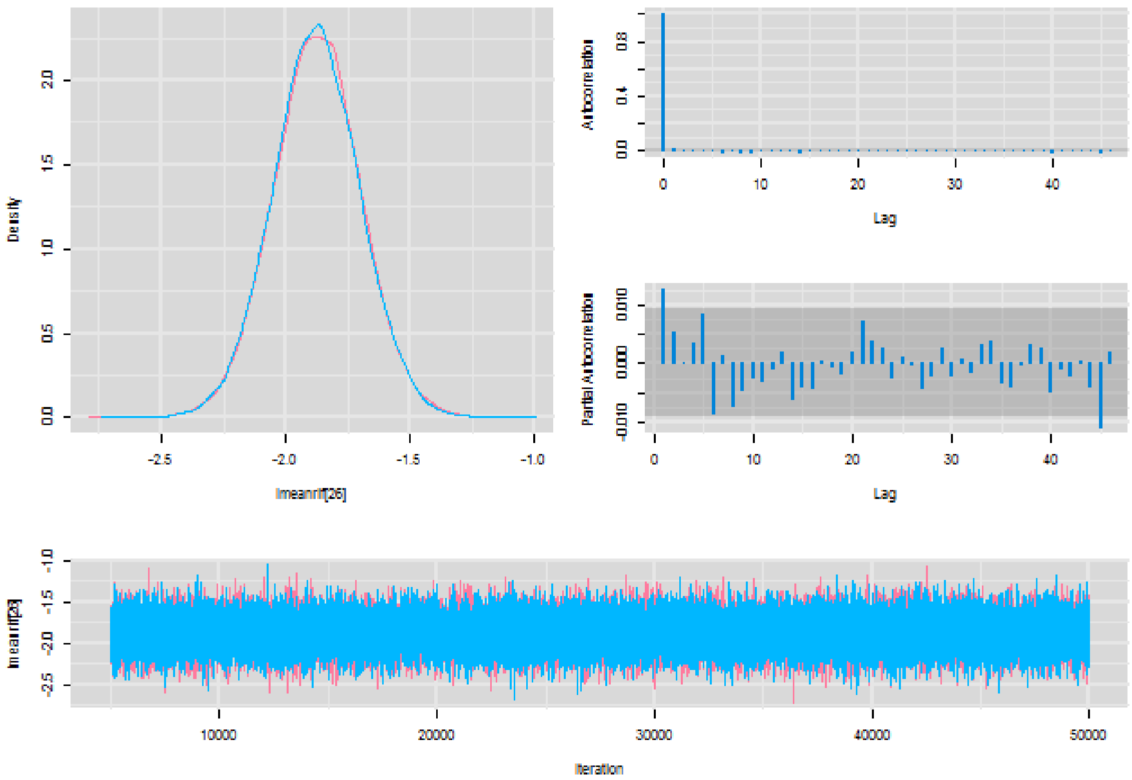
Diagnostics for lmeanrif[24]



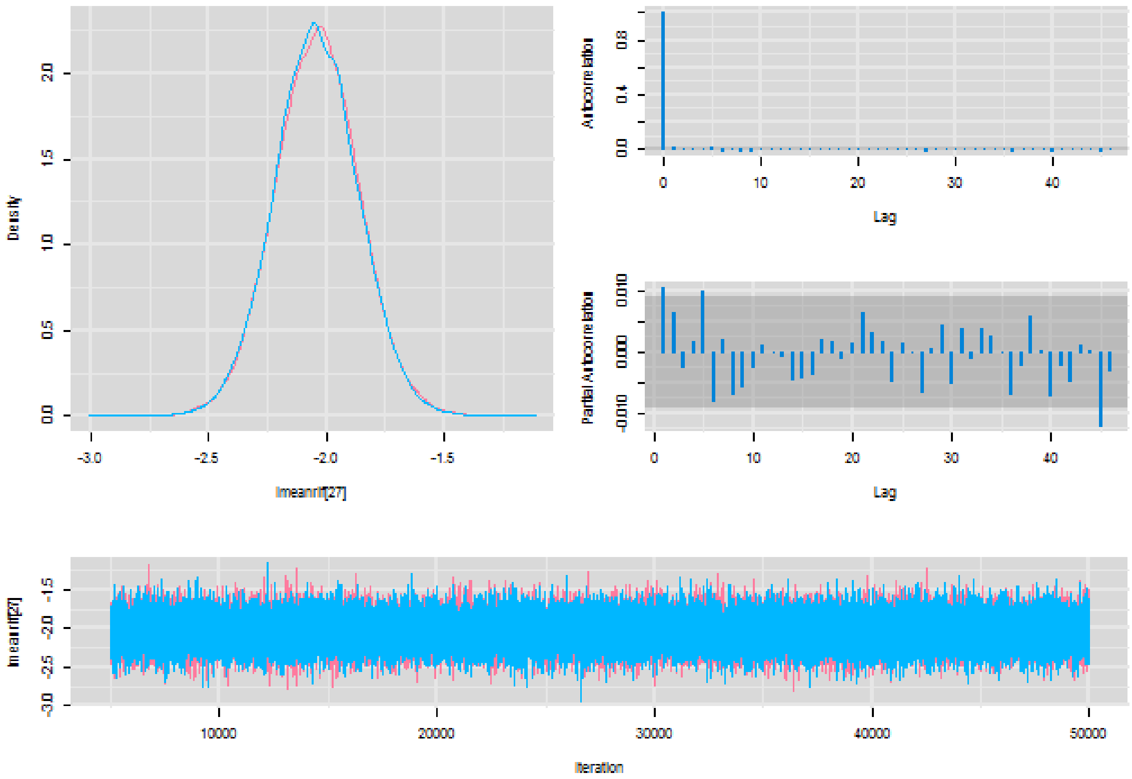
Diagnostics for lmeanrif[25]



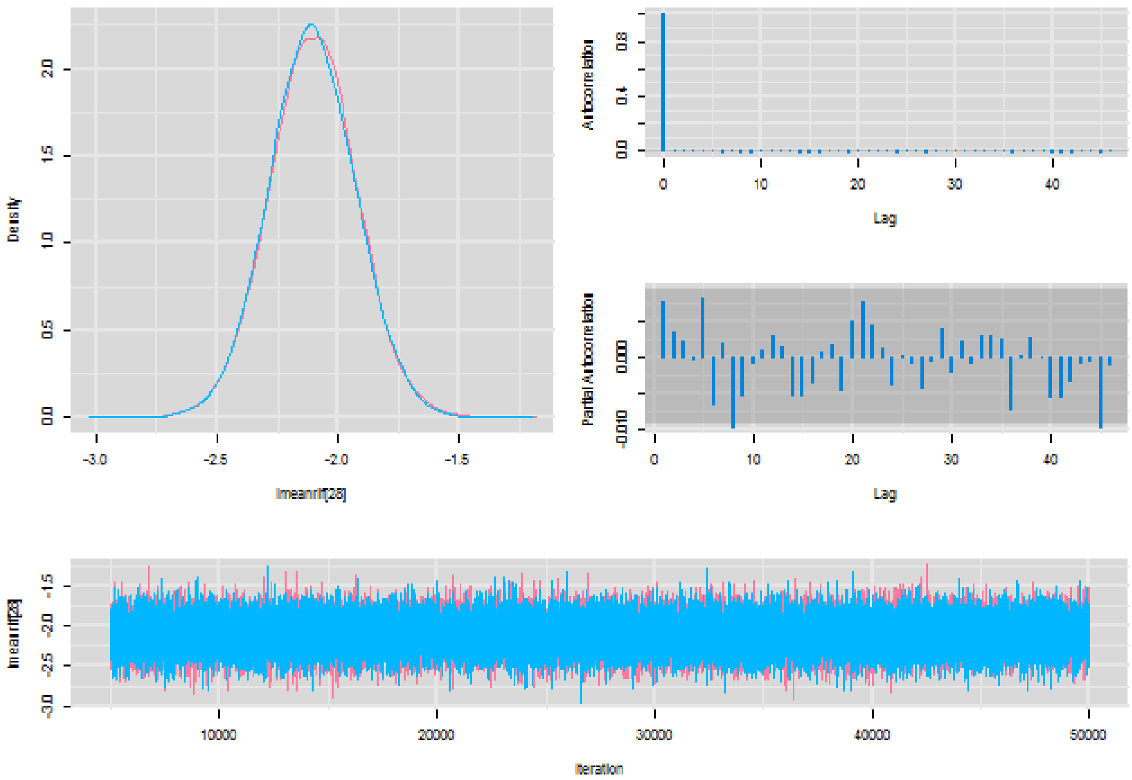
Diagnostics for lmeanrif[26]



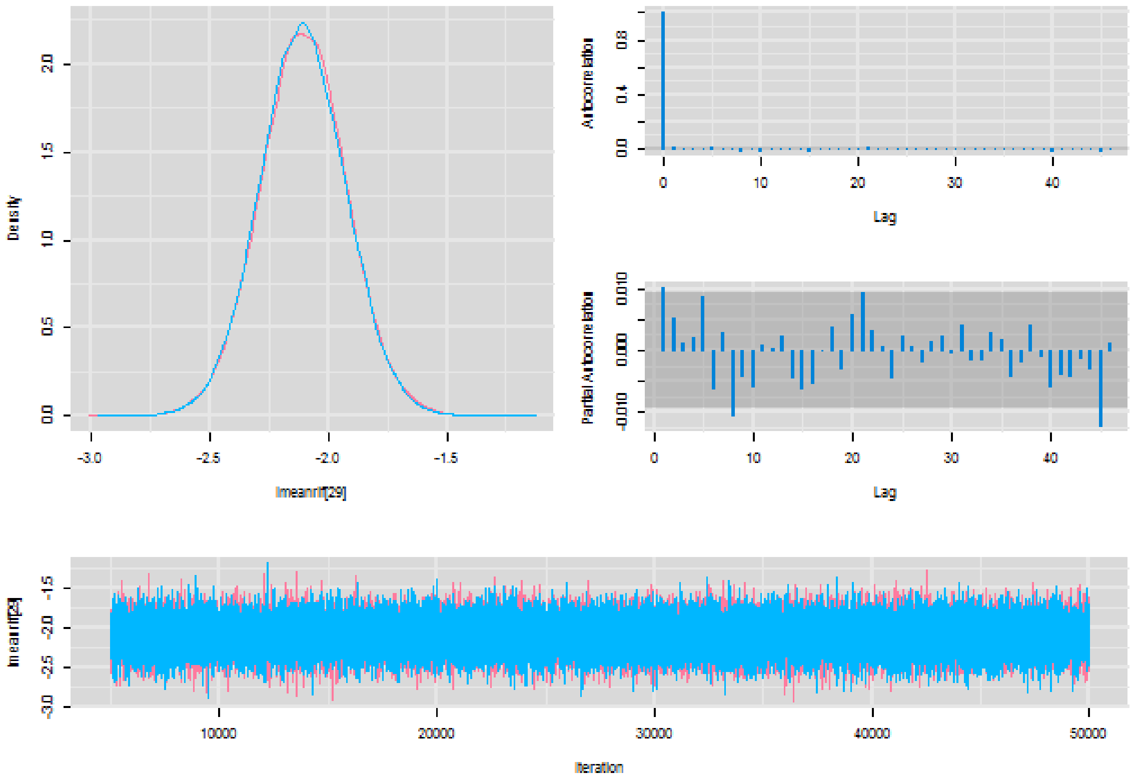
Diagnostics for lmeanrif[27]



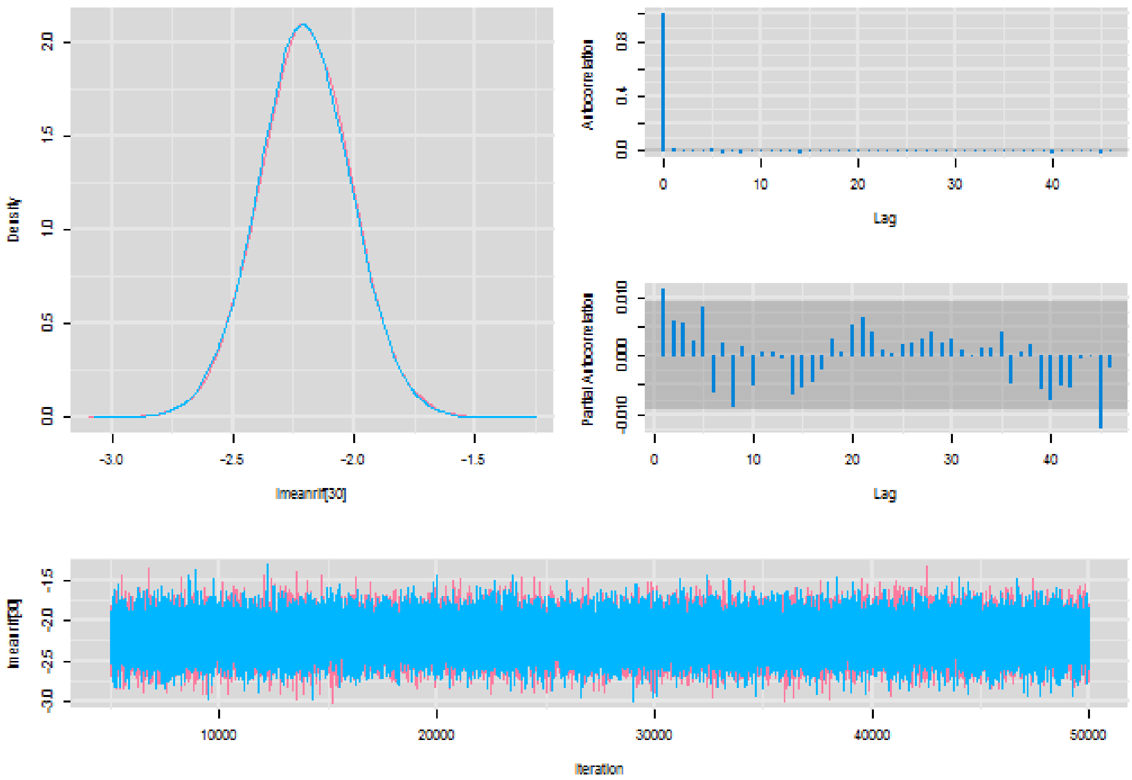
Diagnostics for lmeanrif[28]



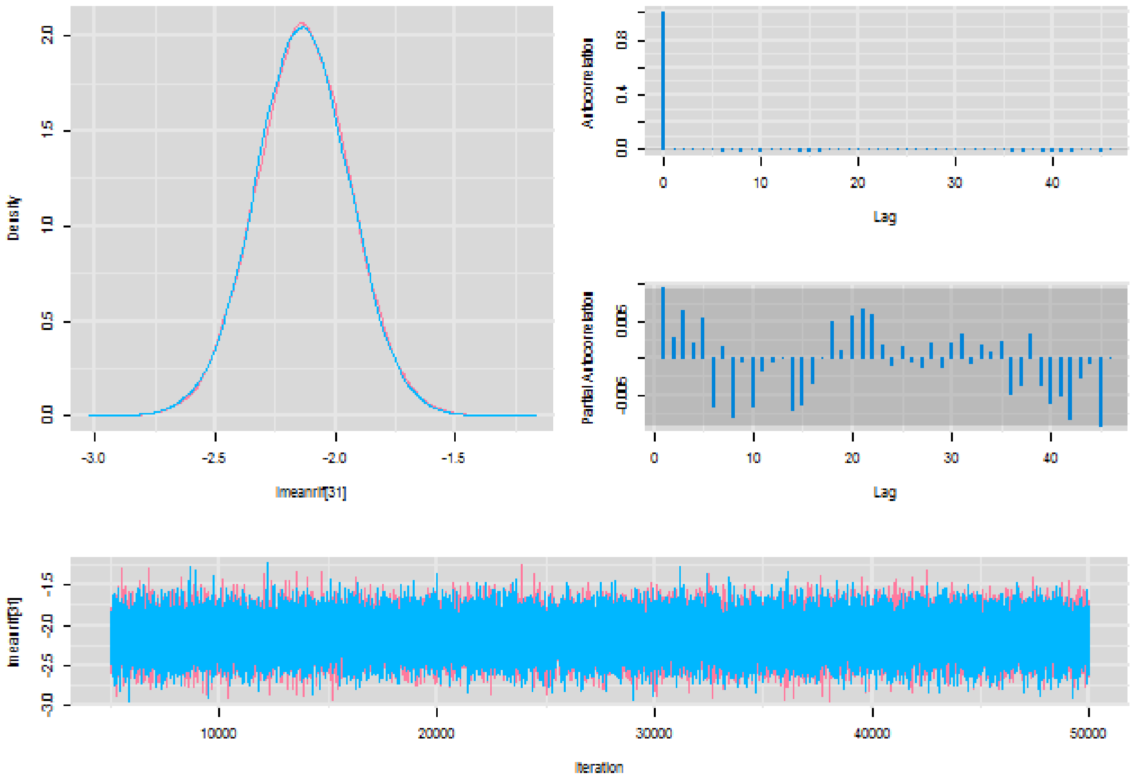
Diagnostics for lmeanrif[29]



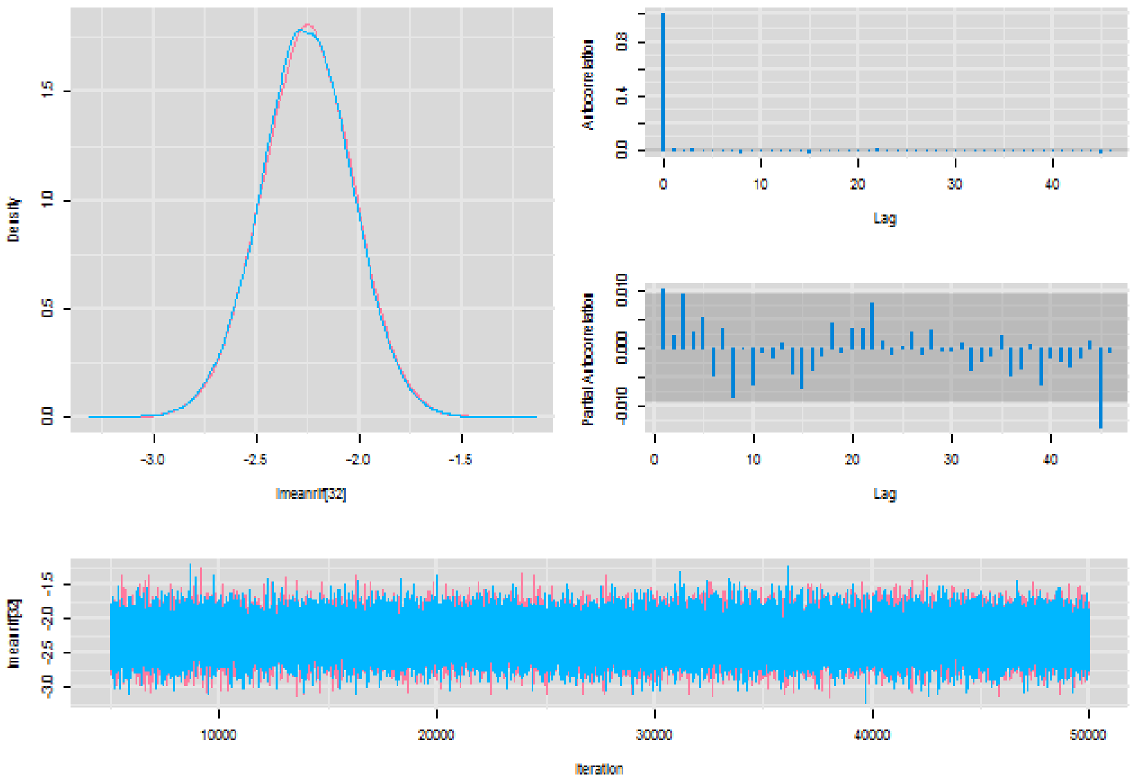
Diagnostics for lmeanrif[30]



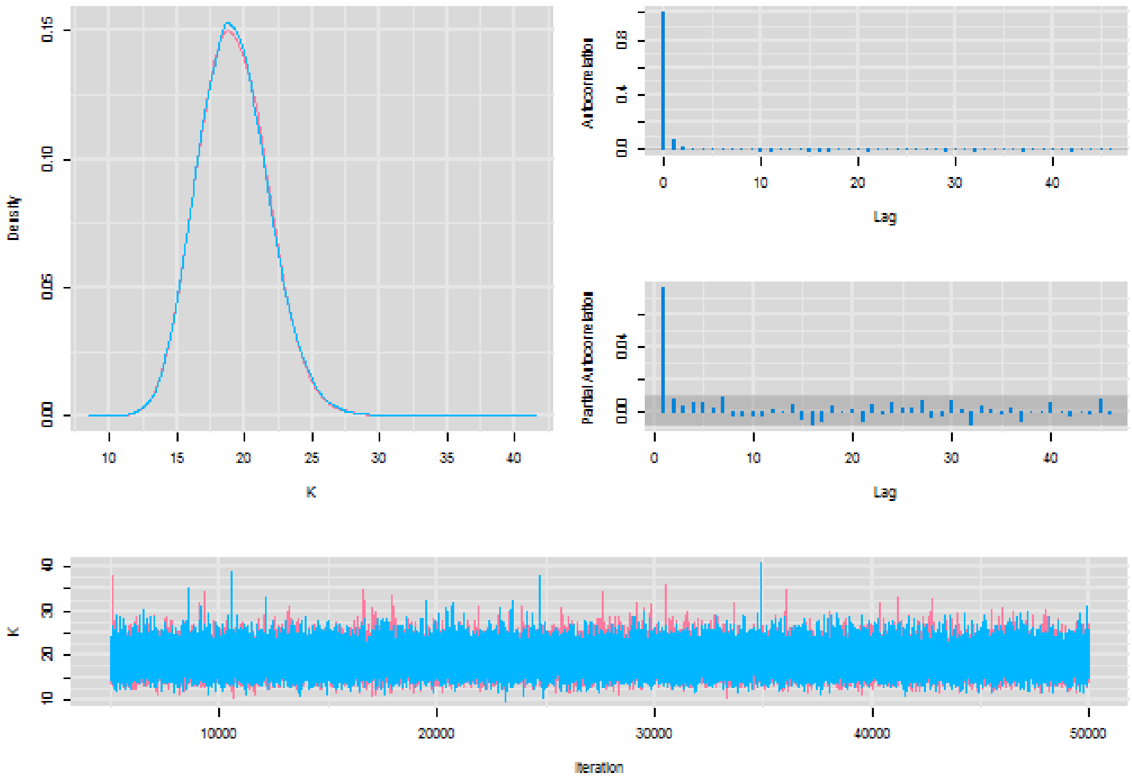
Diagnostics for lmeanrif[31]



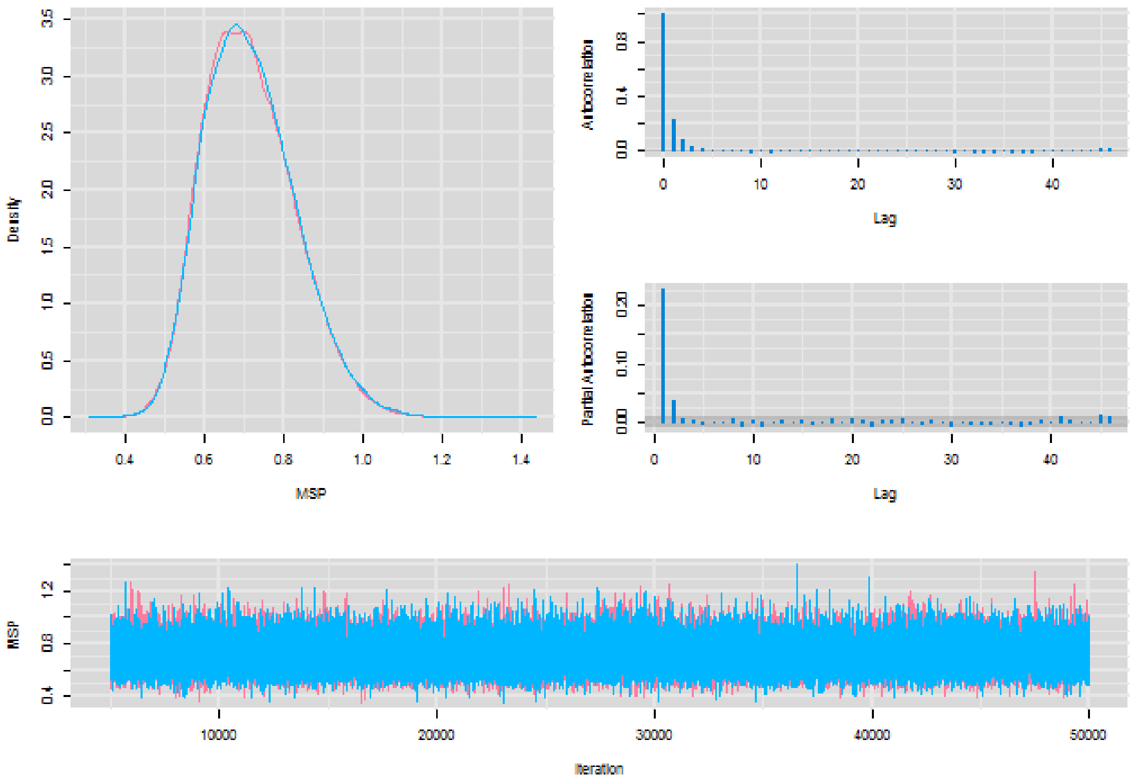
Diagnostics for lmeanrif[32]



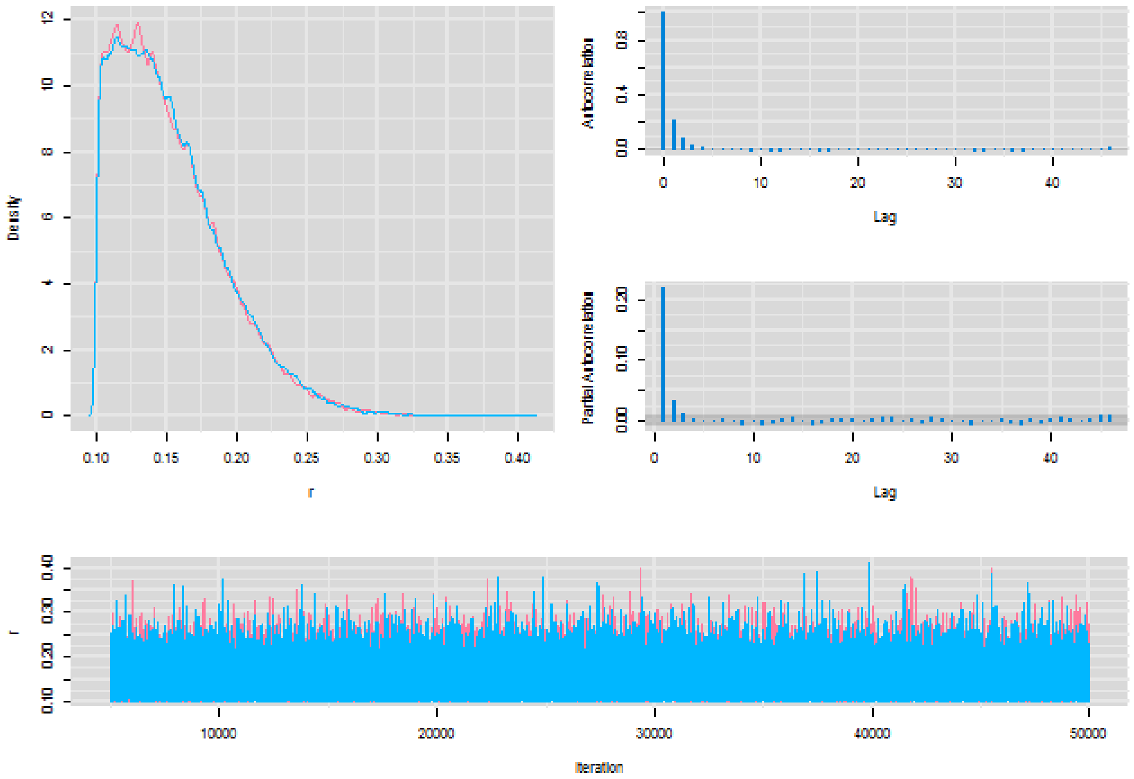
Diagnostics for K



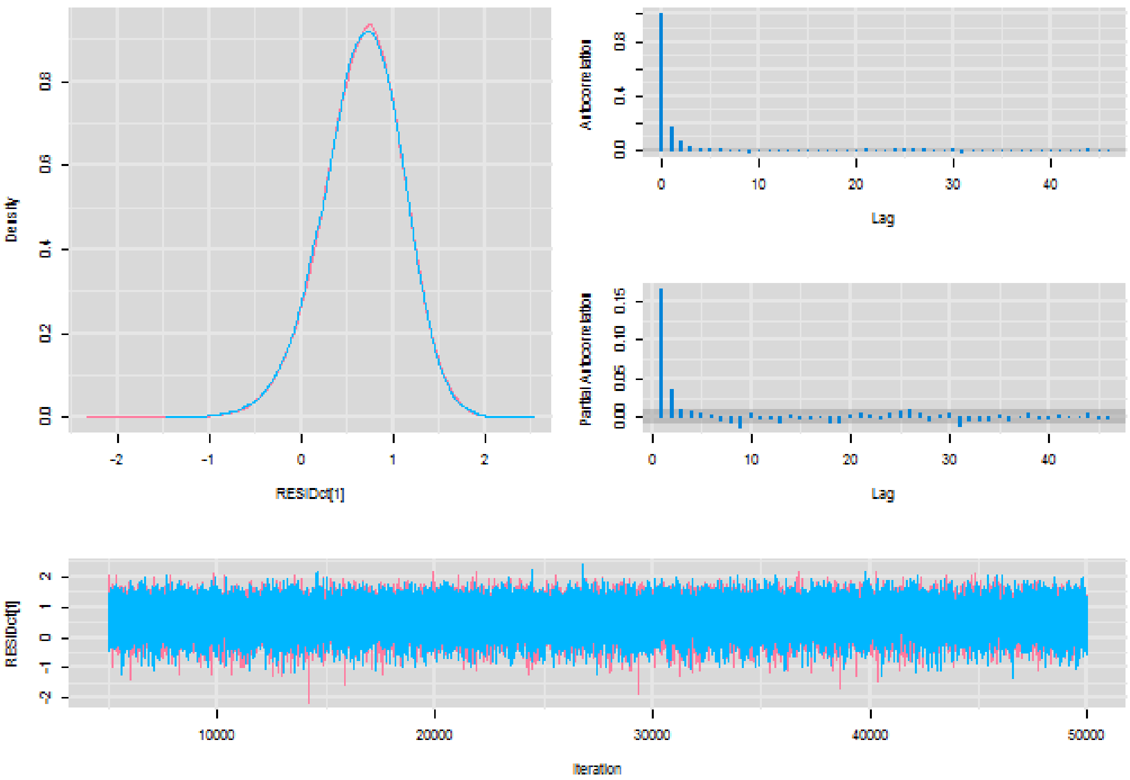
Diagnostics for MSP



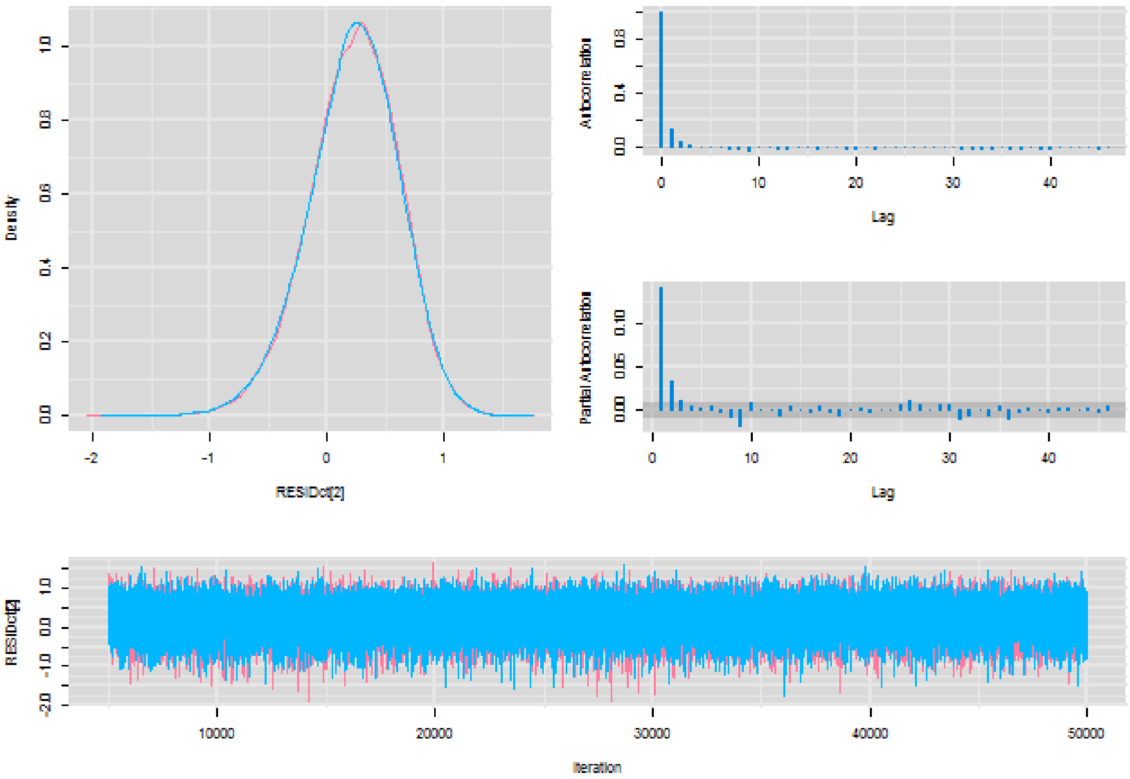
Diagnostics for r

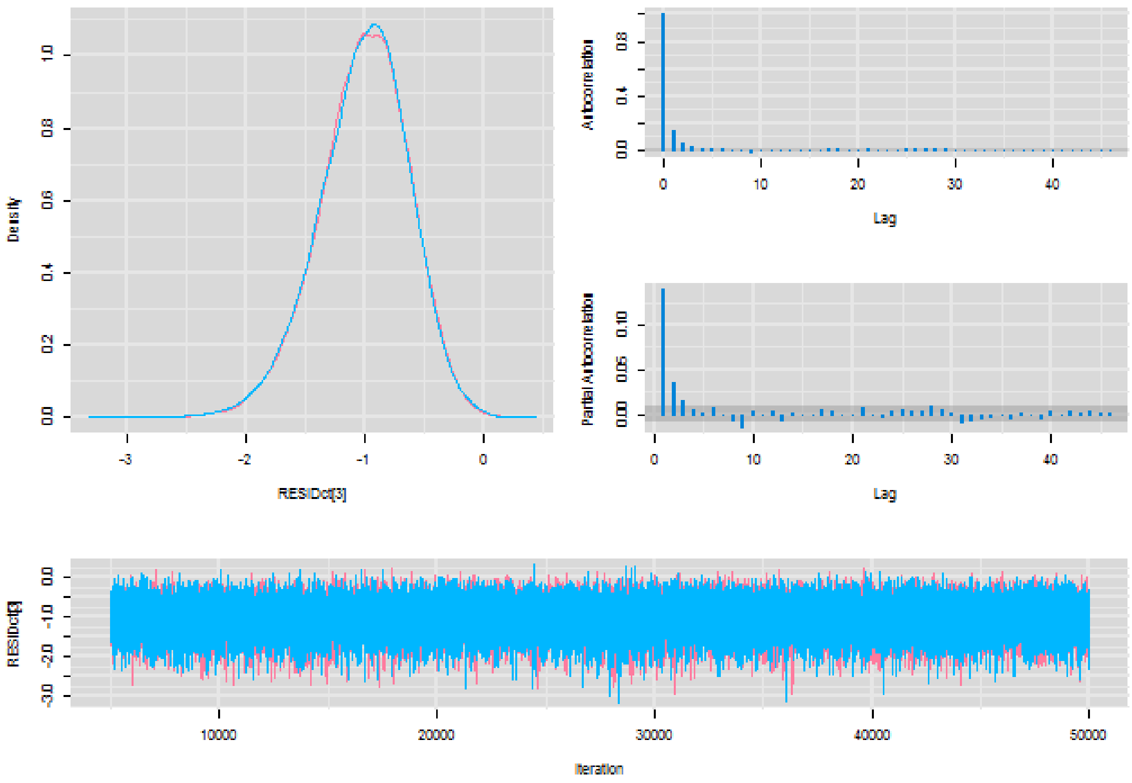


Diagnostics for RESIDct[1]

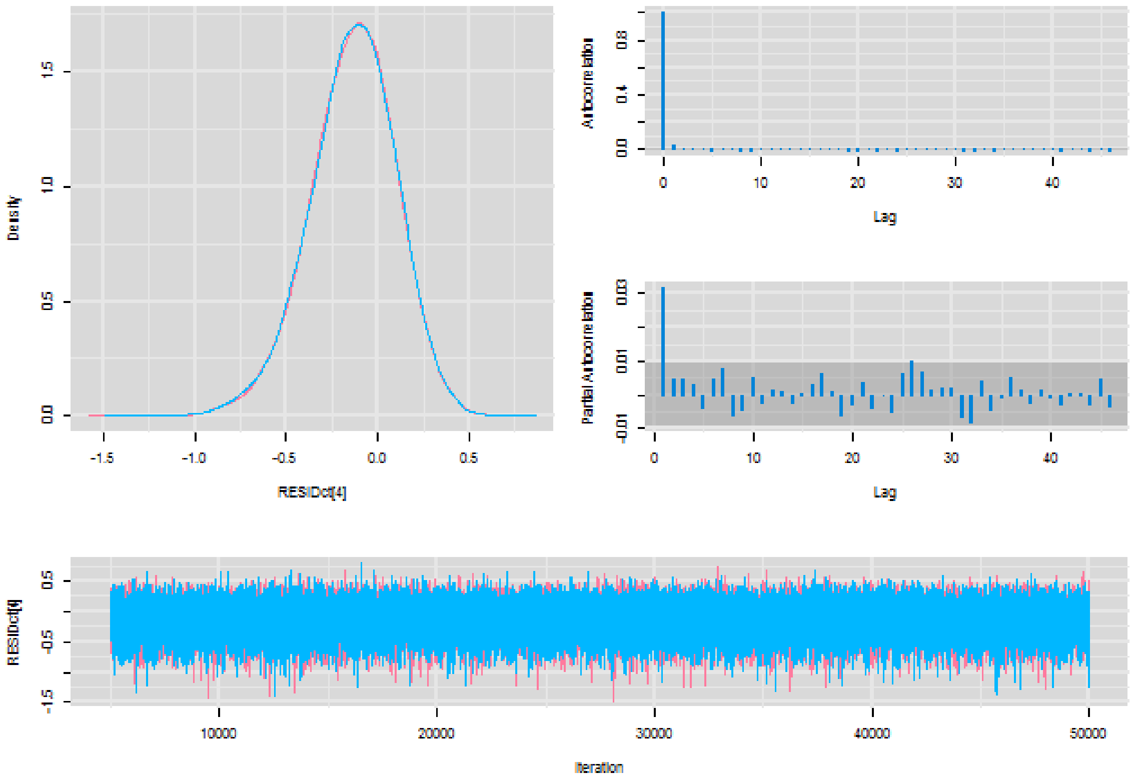


Diagnostics for RESIDct[2]



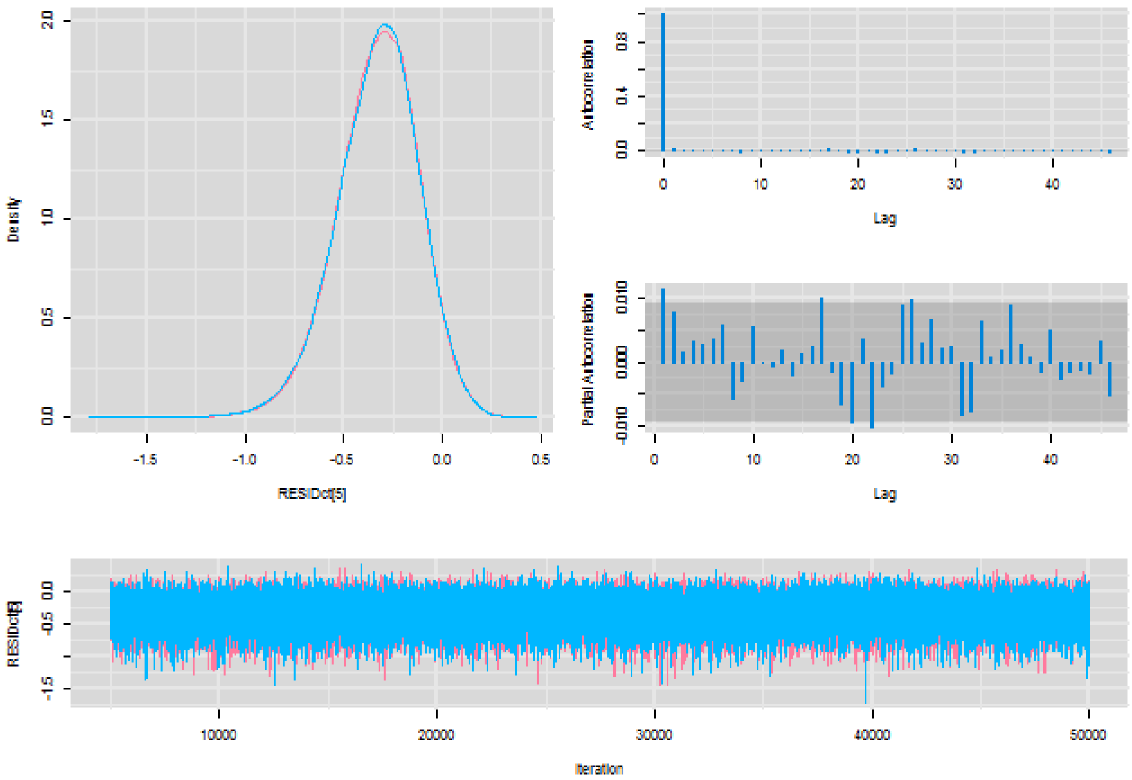


Diagnostics for RESIDct[3]

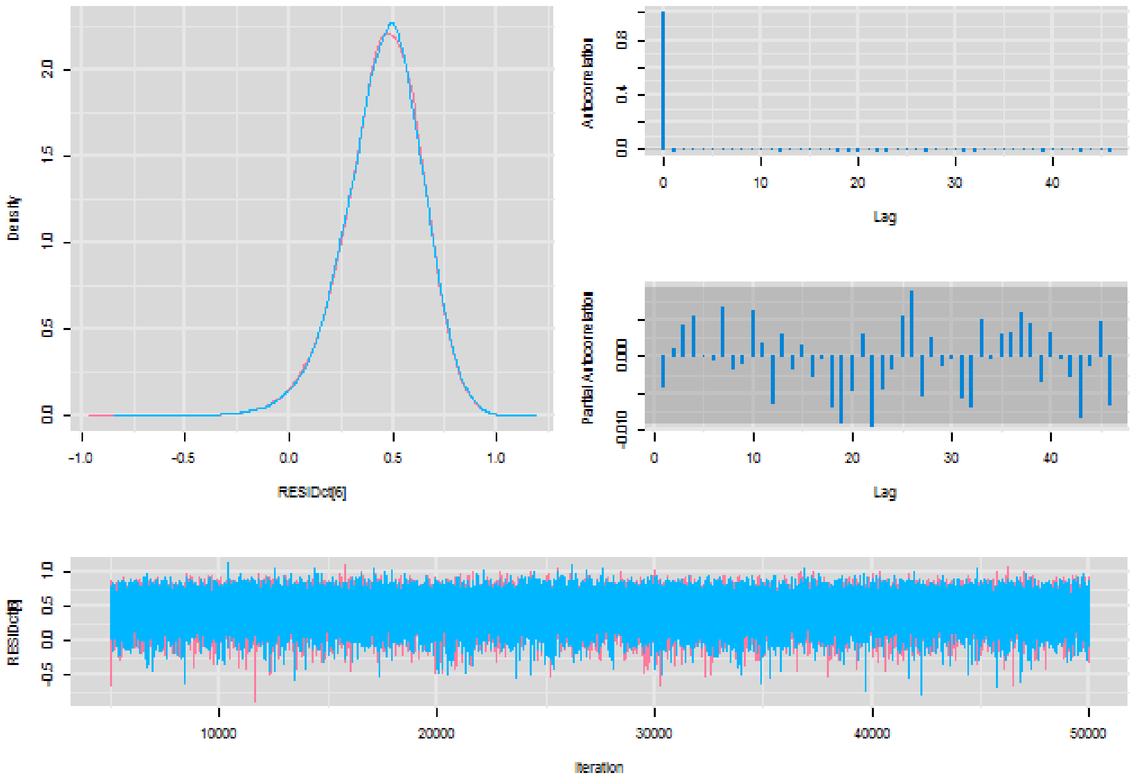


Diagnostics for RESIDct[4]

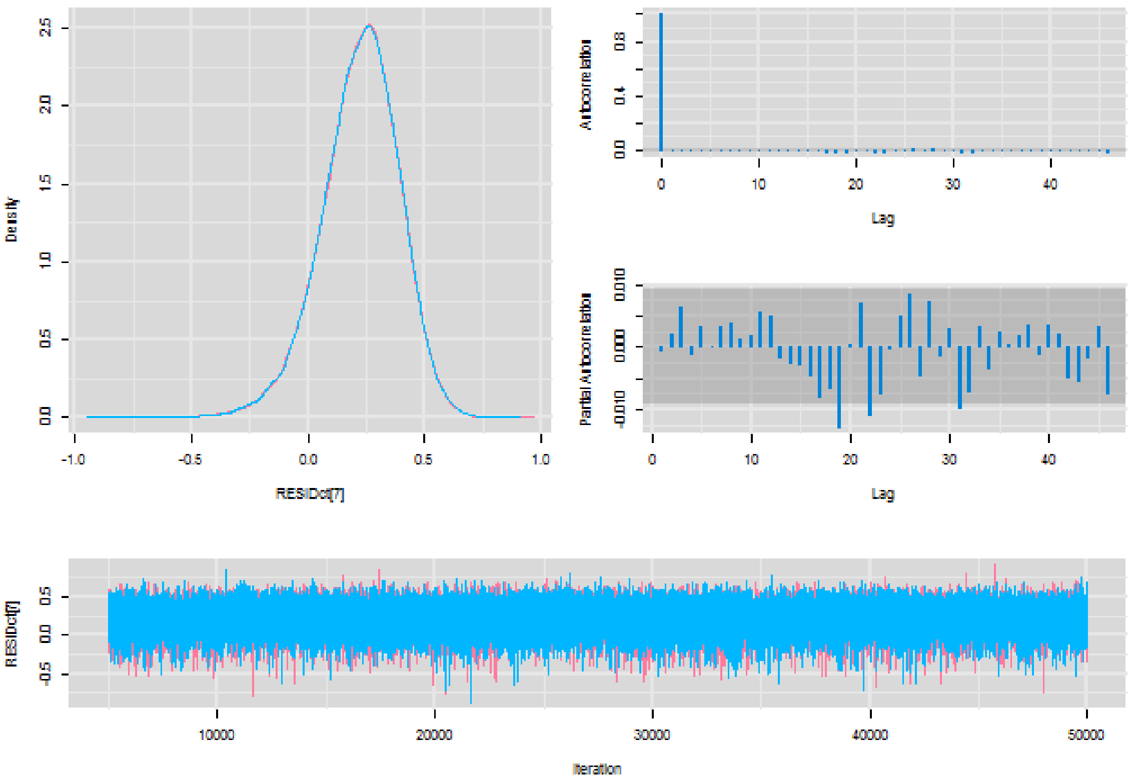
Diagnostics for RESIDct[5]



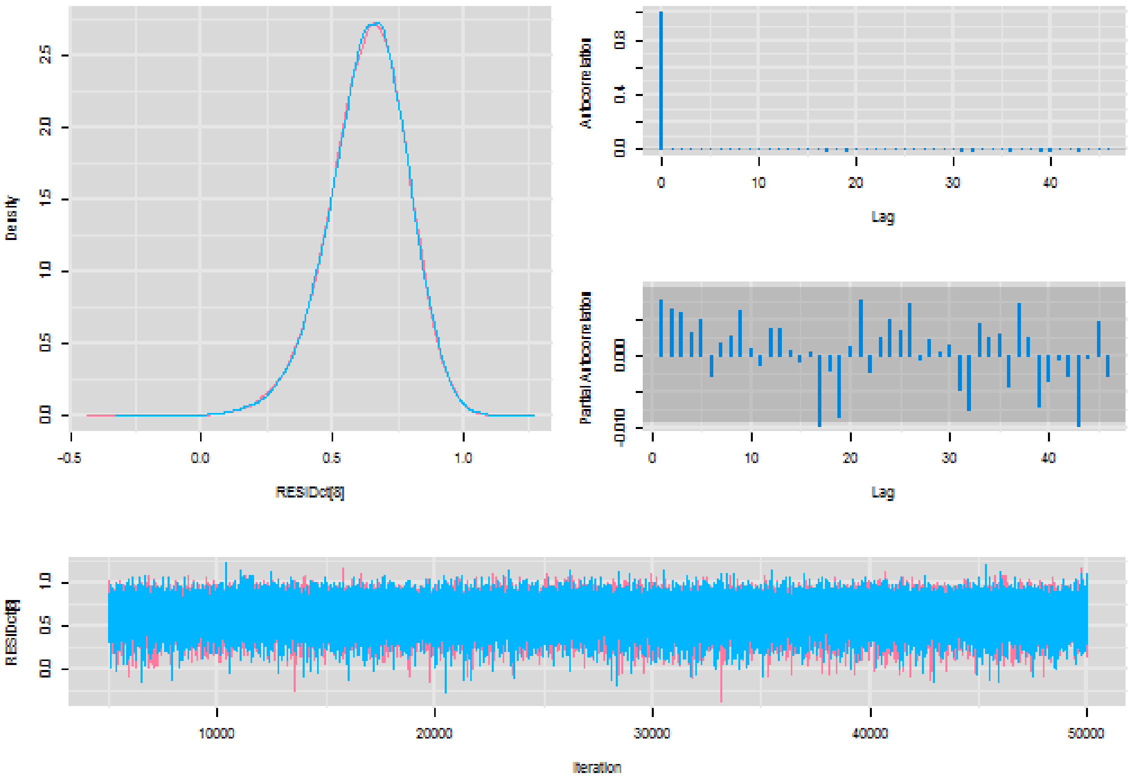
Diagnostics for RESIDct[6]

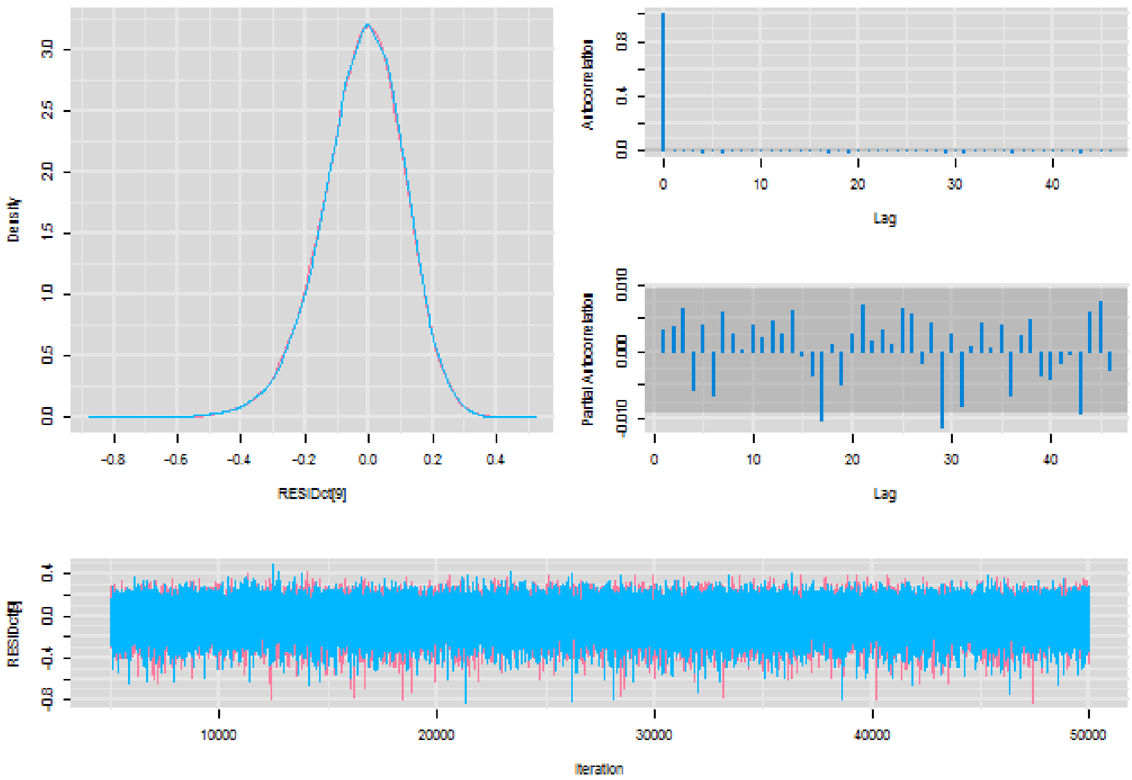


Diagnostics for RESIDct[7]

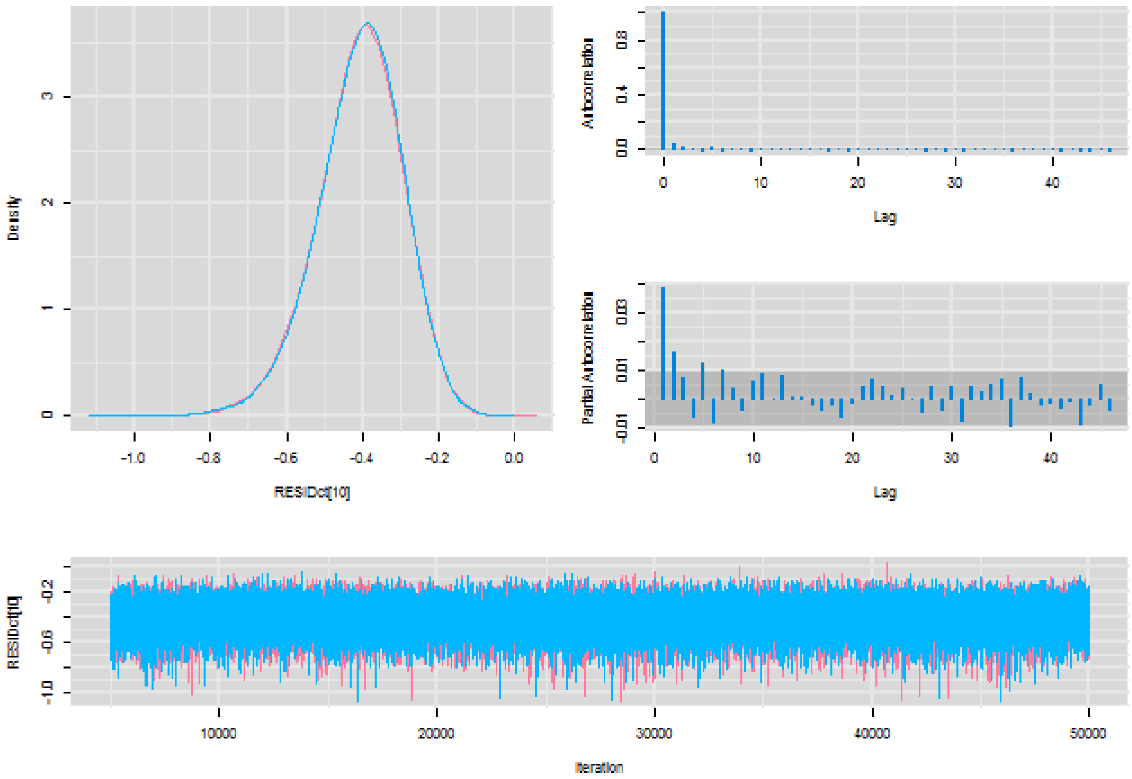


Diagnostics for RESIDct[8]



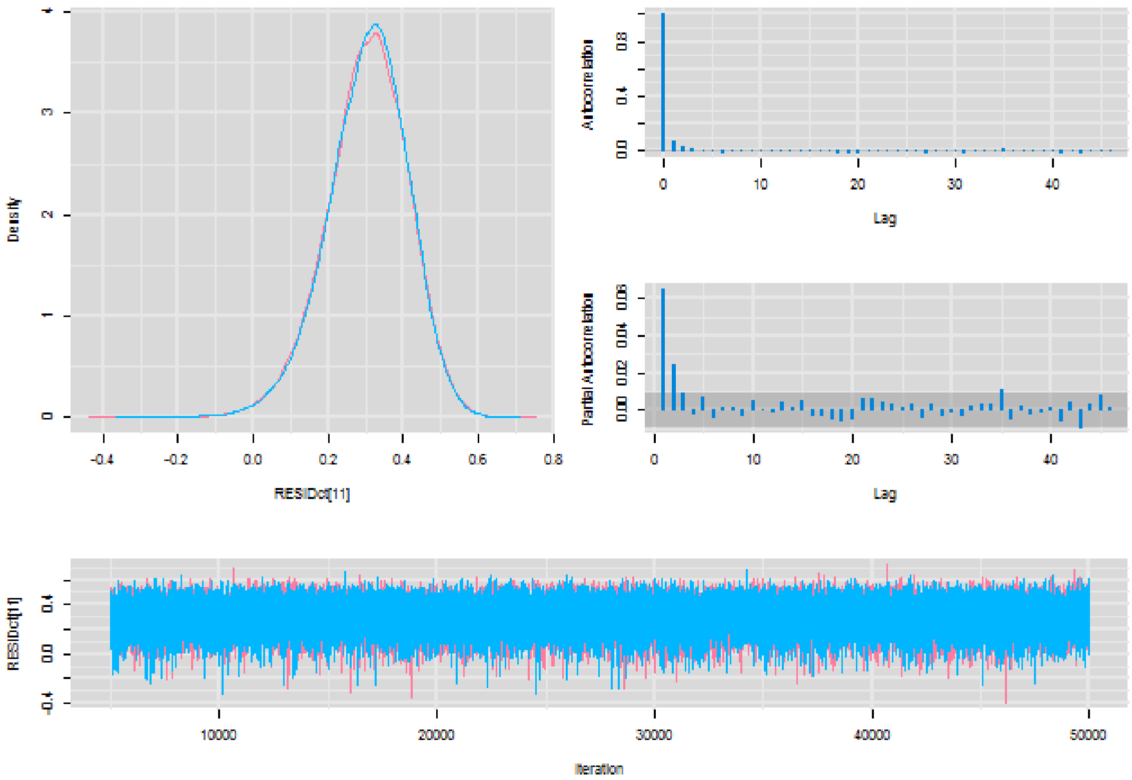


Diagnostics for RESIDct[9]

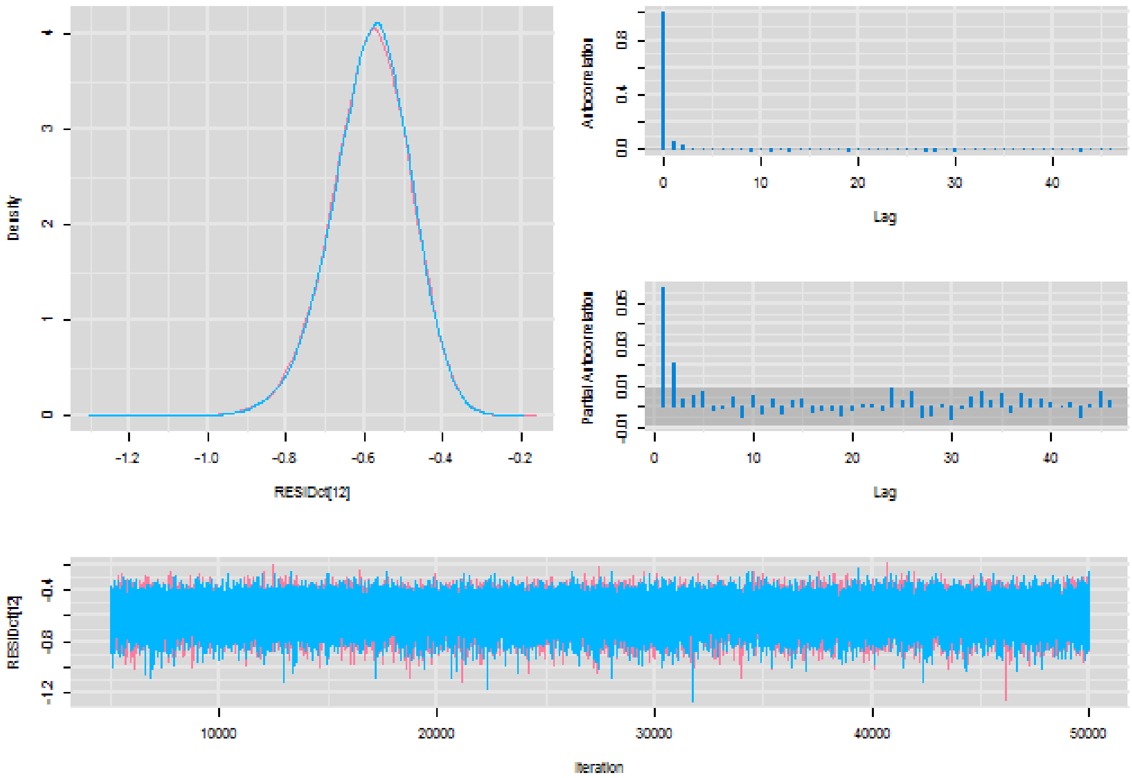


Diagnostics for RESIDct[10]

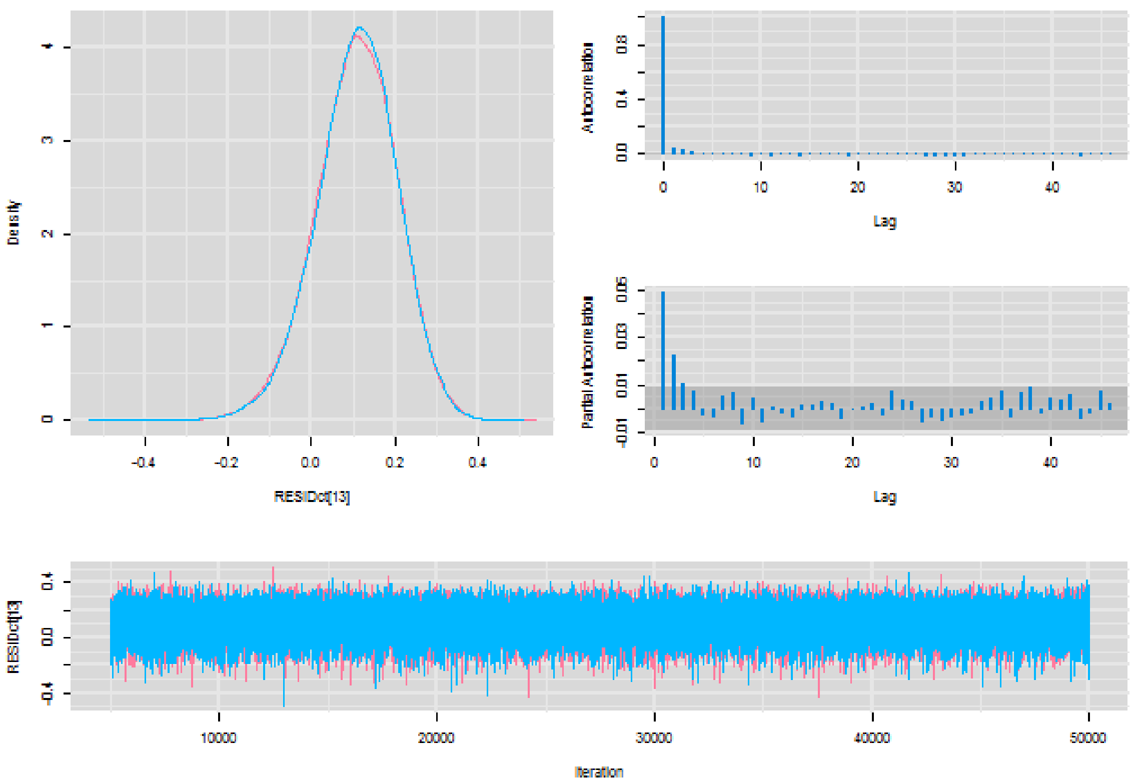
Diagnostics for RESIDct[11]



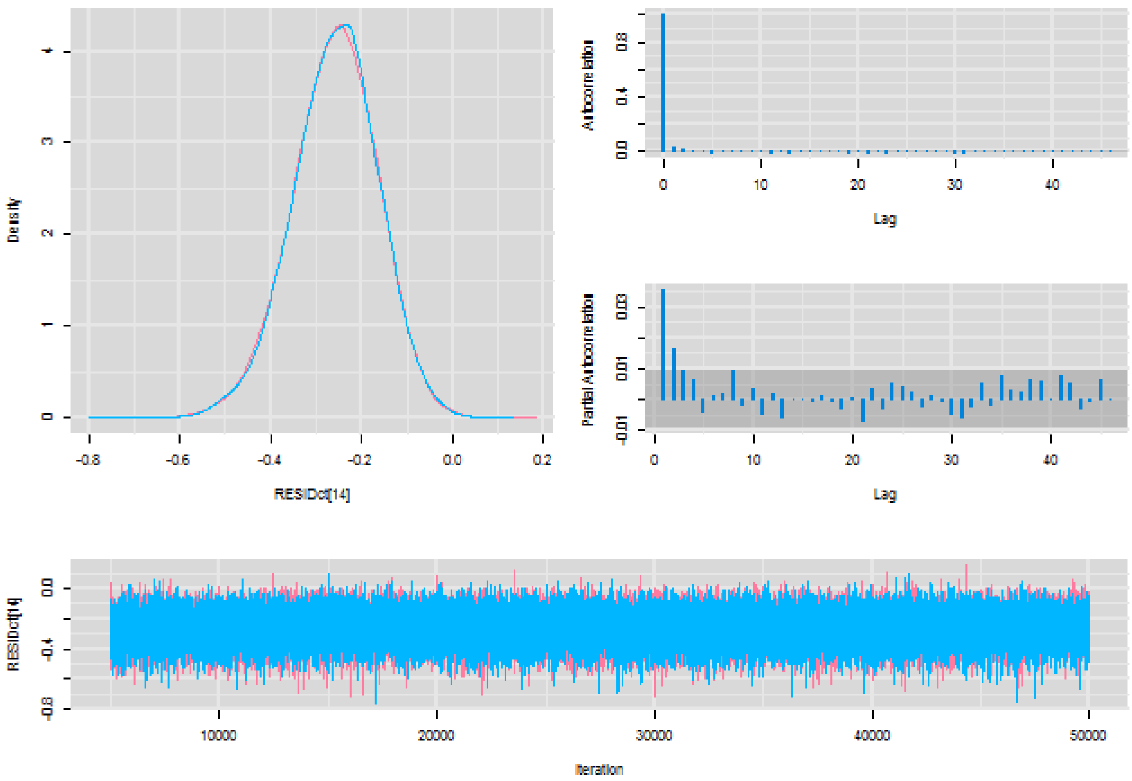
Diagnostics for RESIDct[12]



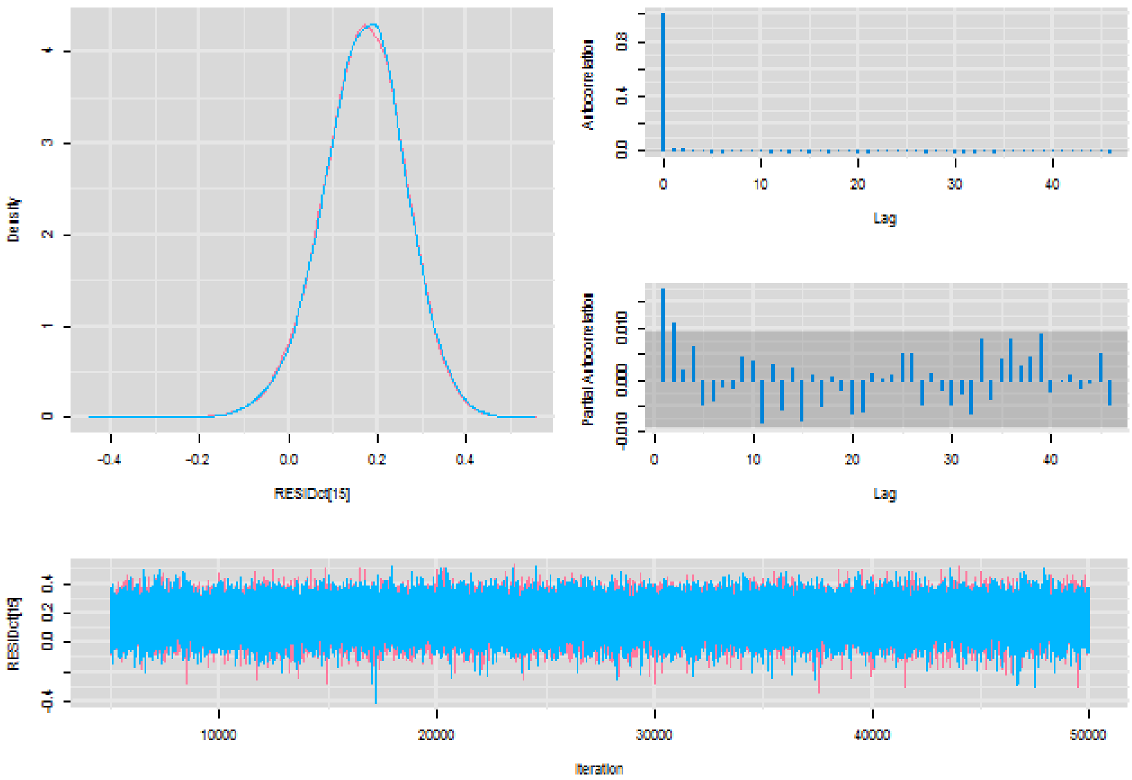
Diagnostics for RESIDct[13]



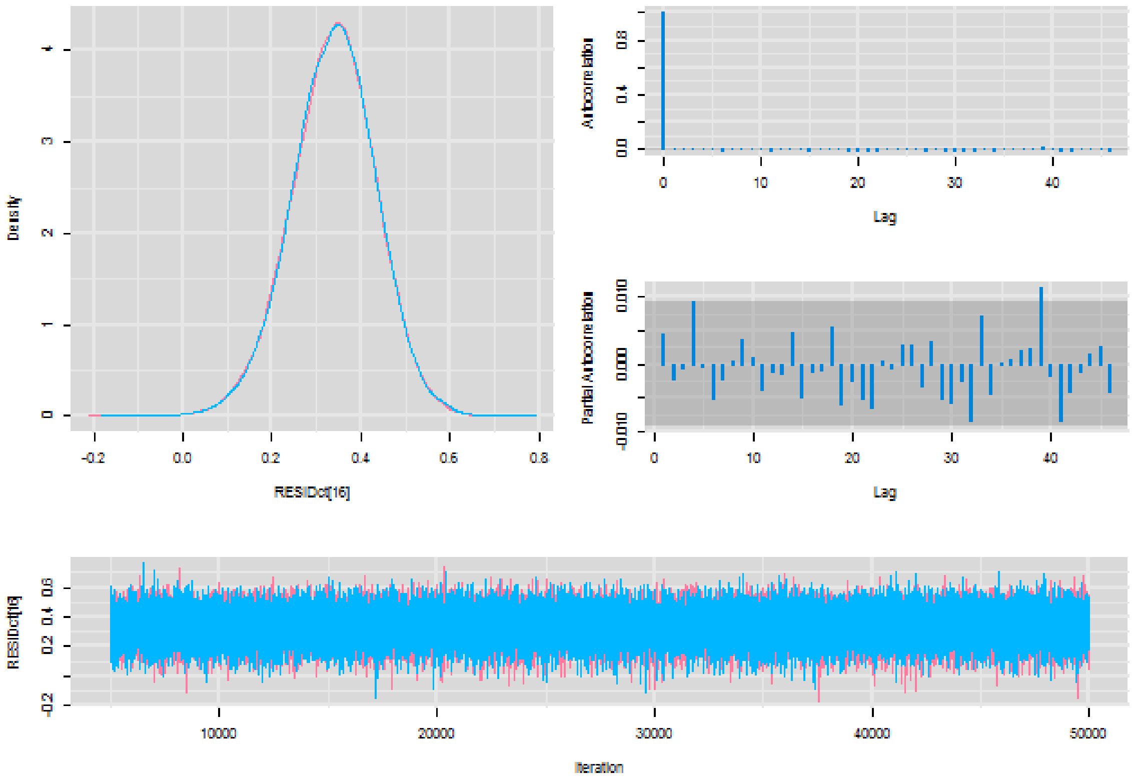
Diagnostics for RESIDct[14]



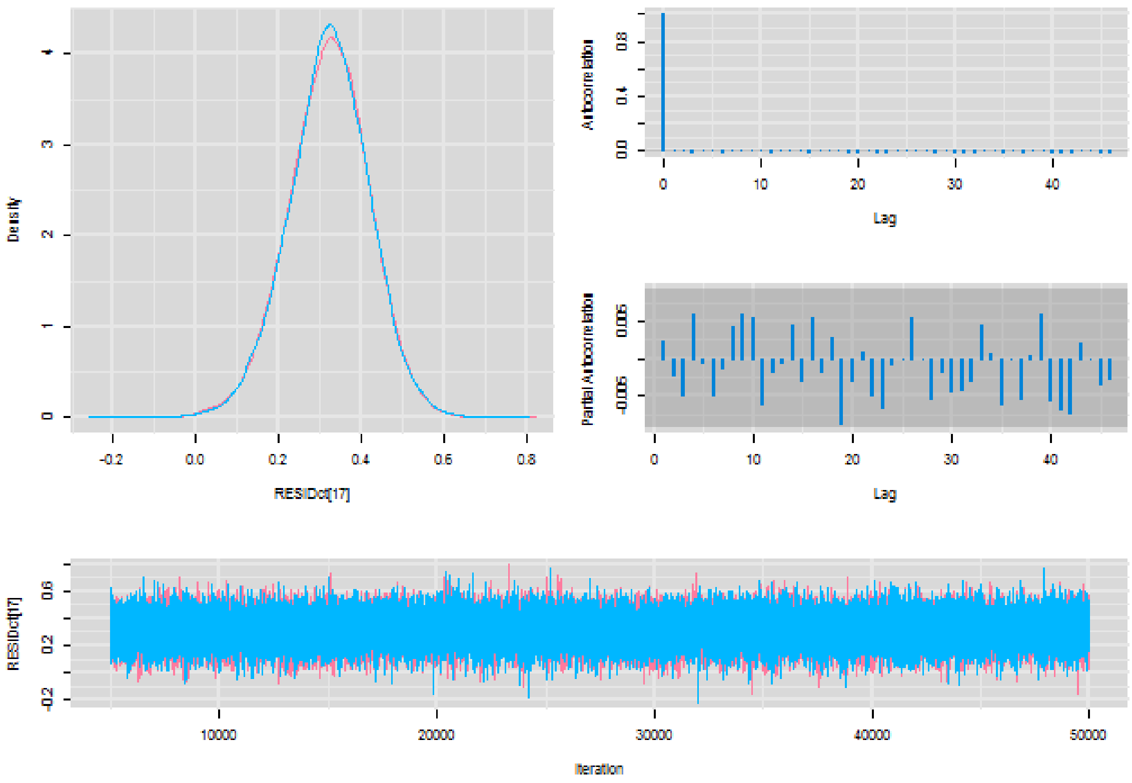
Diagnostics for RESIDct[15]



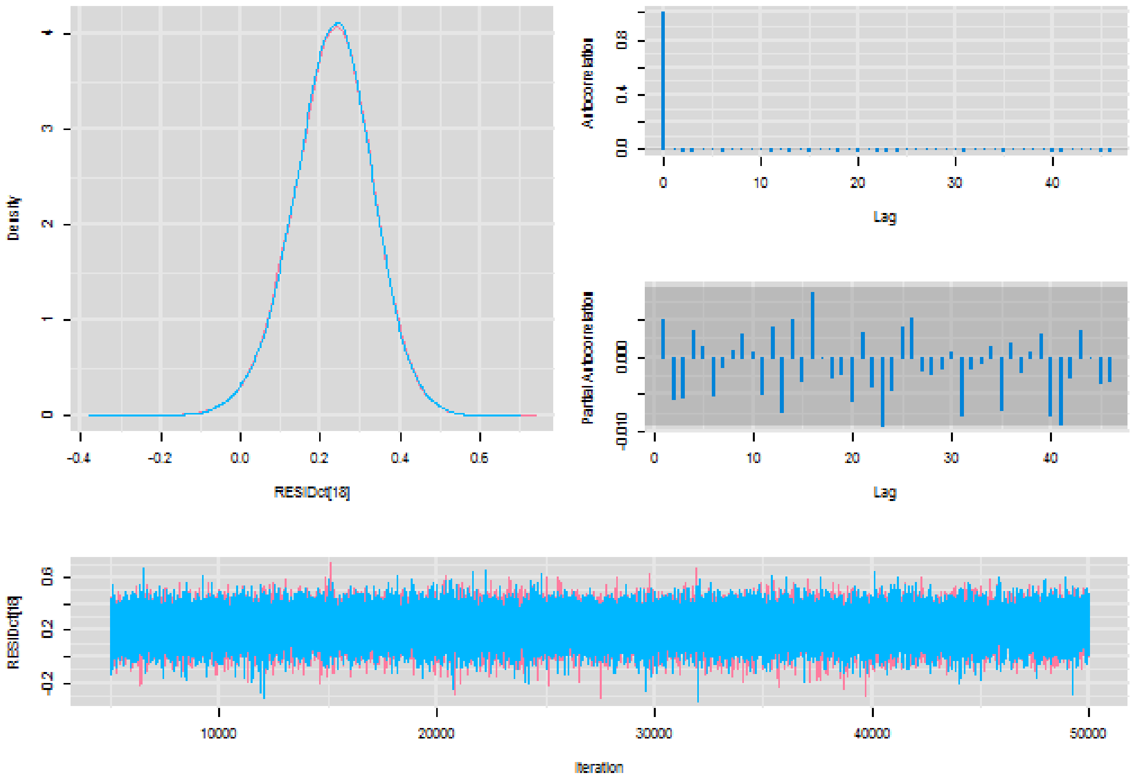
Diagnostics for RESIDct[16]



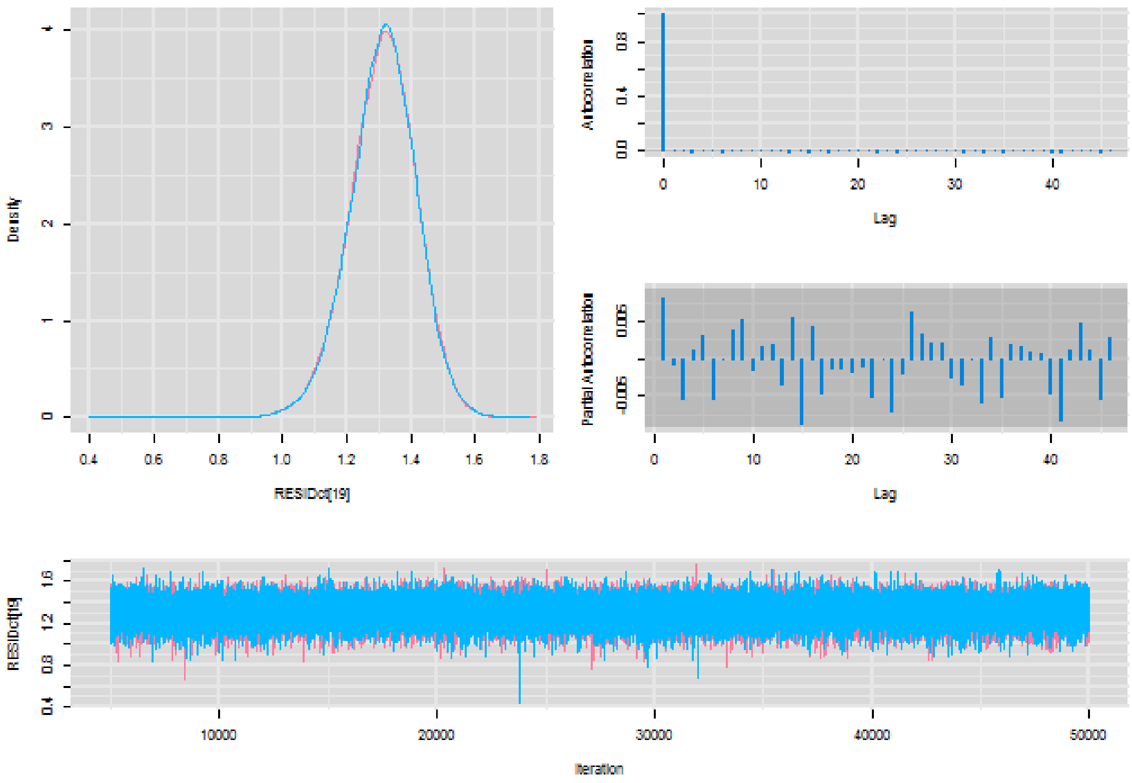
Diagnostics for RESIDct[17]



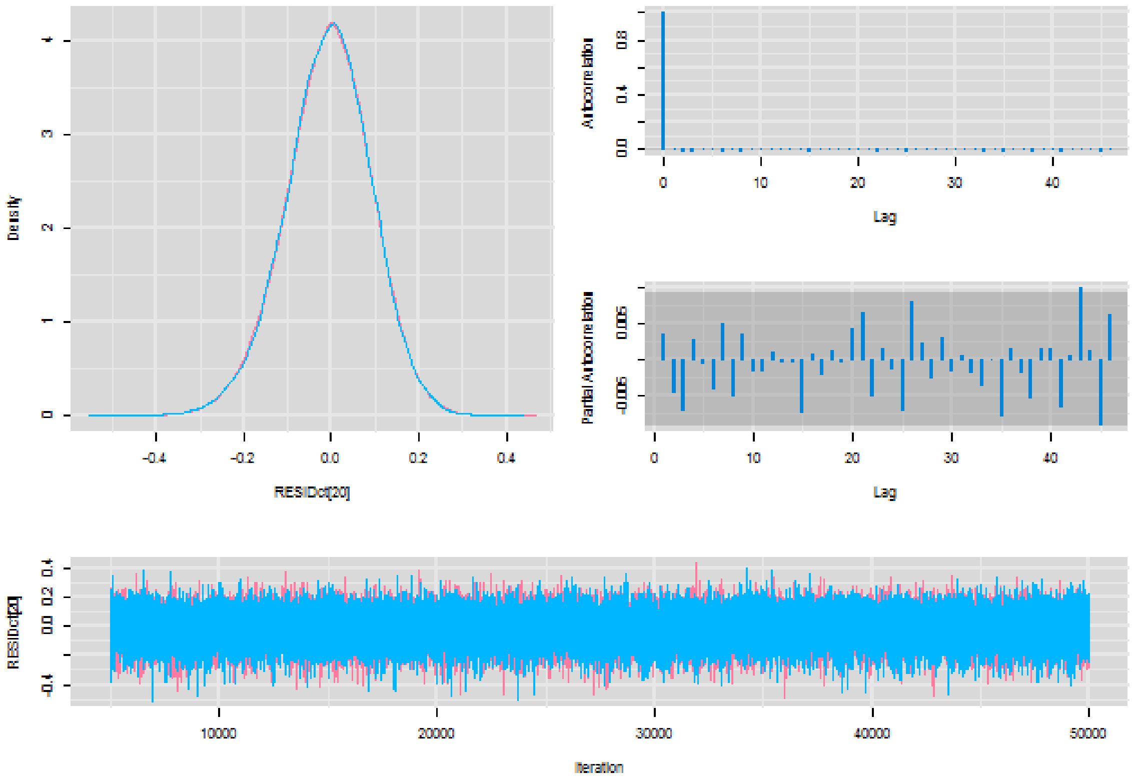
Diagnostics for RESIDct[18]



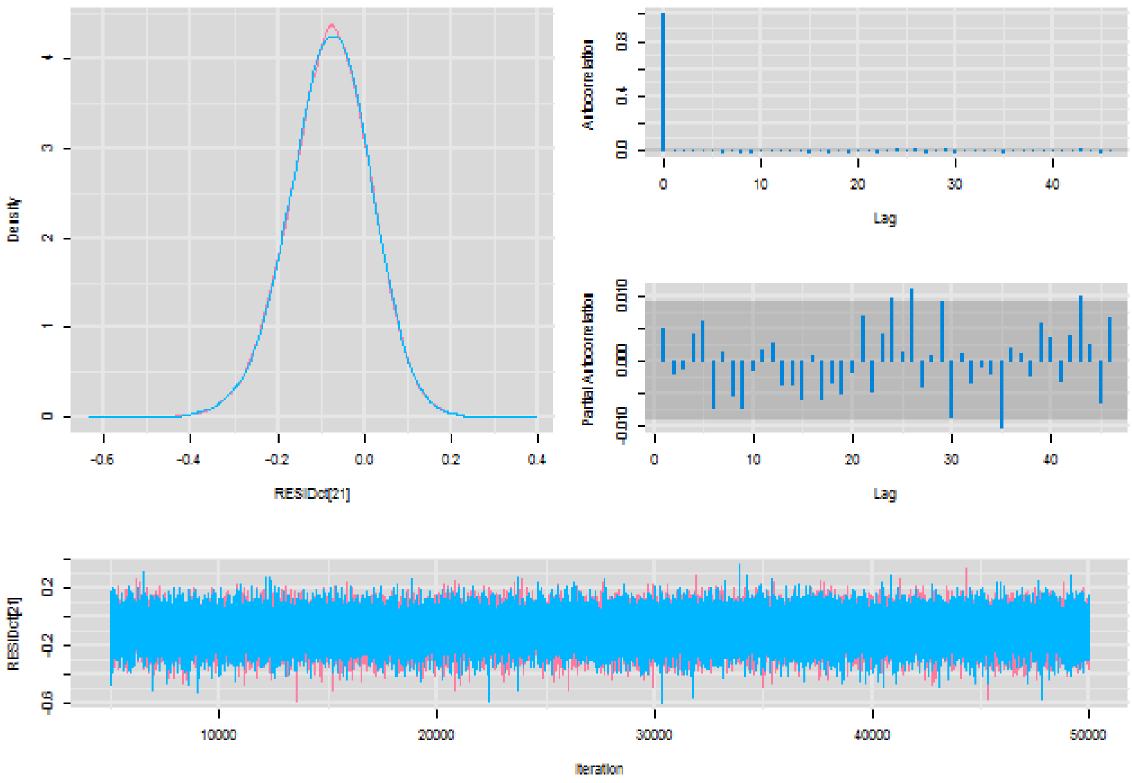
Diagnostics for RESIDct[19]



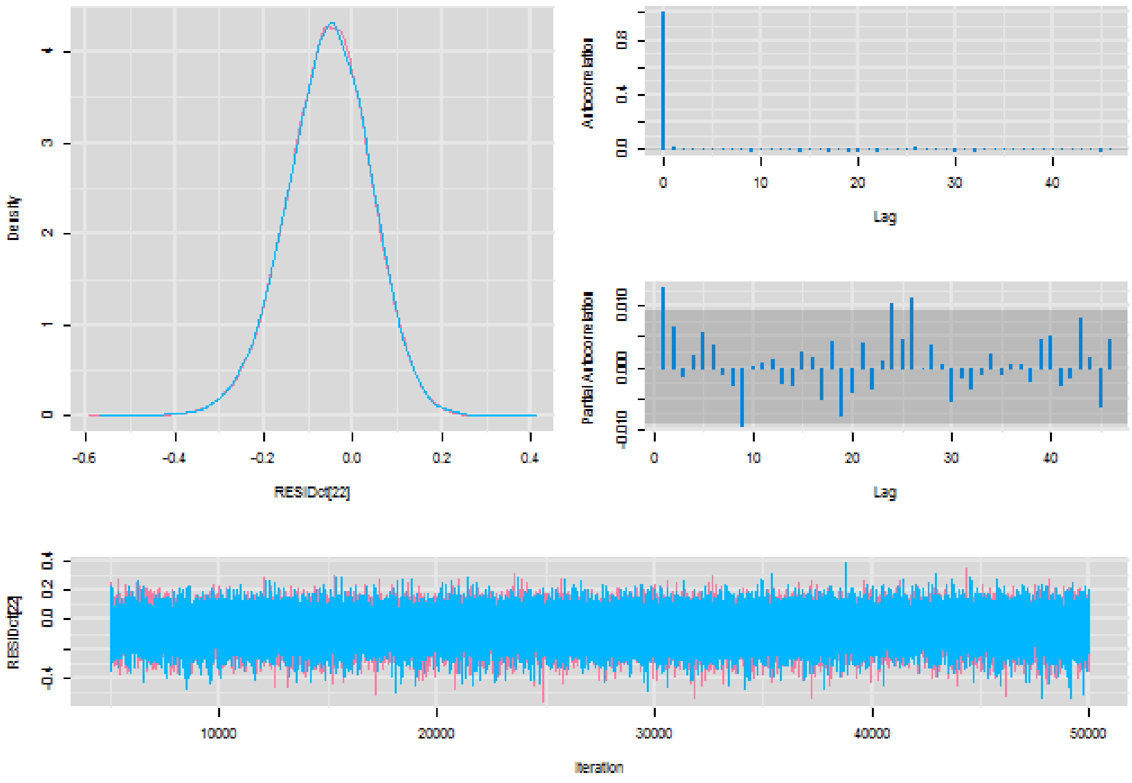
Diagnostics for RESIDct[20]



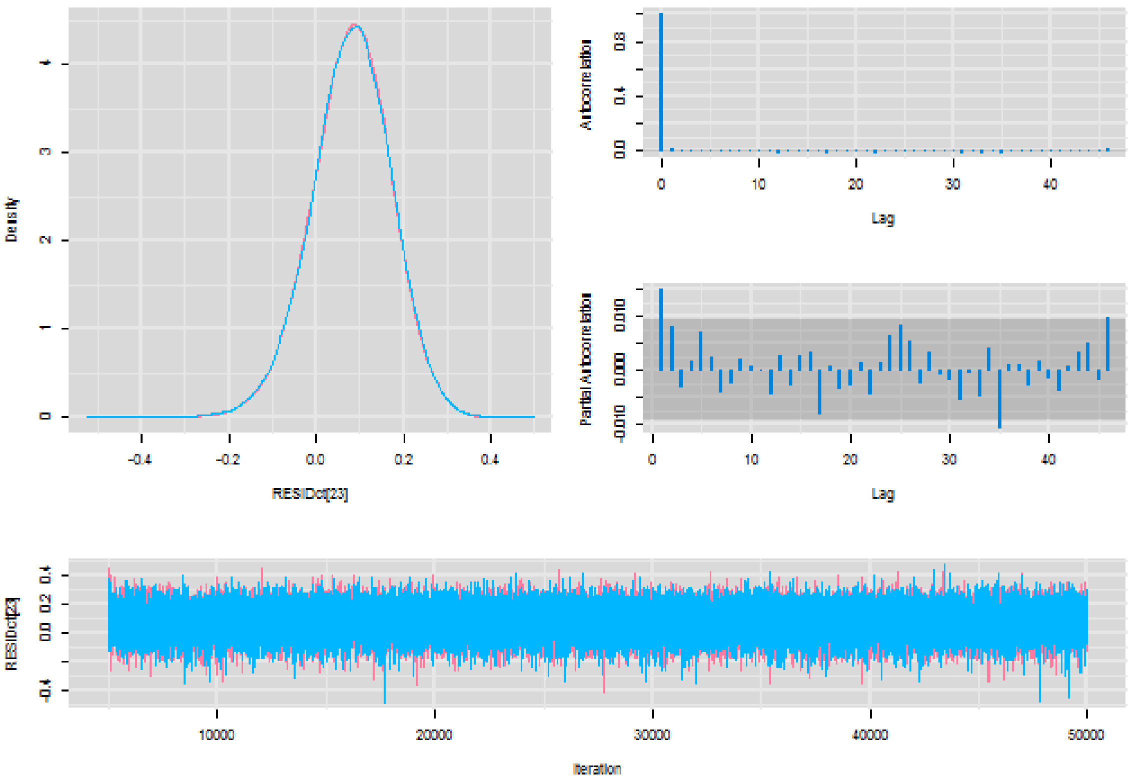
Diagnostics for RESIDct[21]



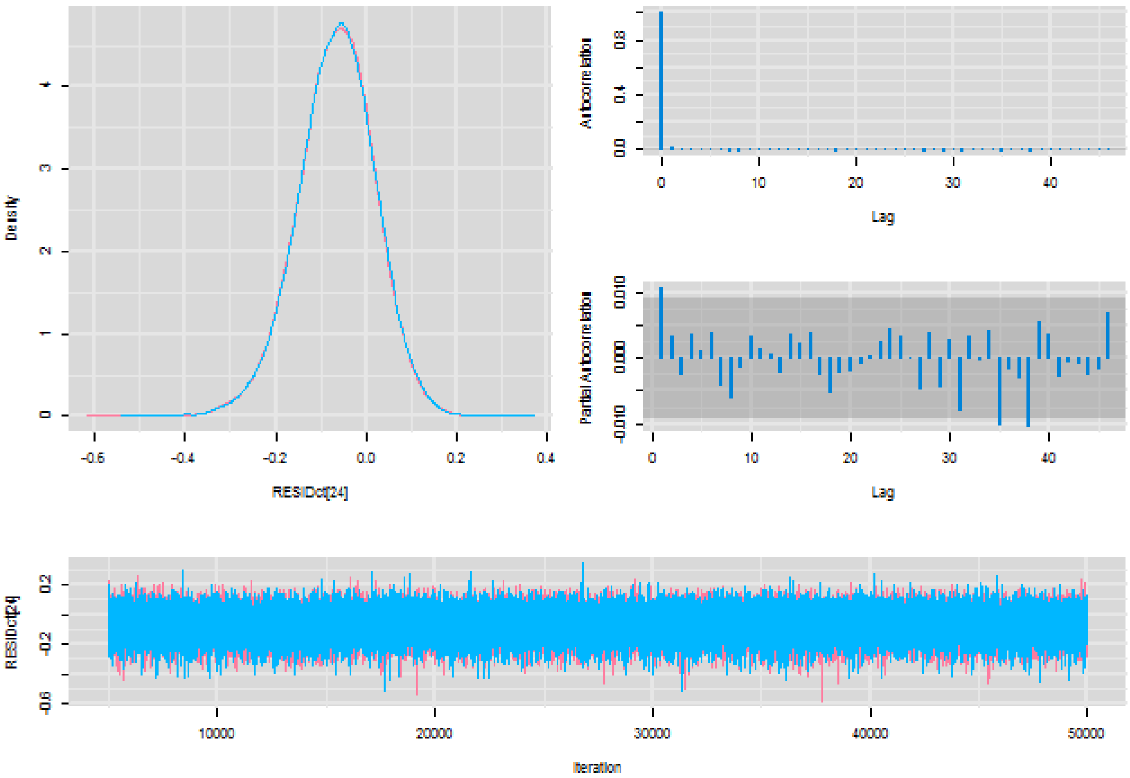
Diagnostics for RESIDct[22]



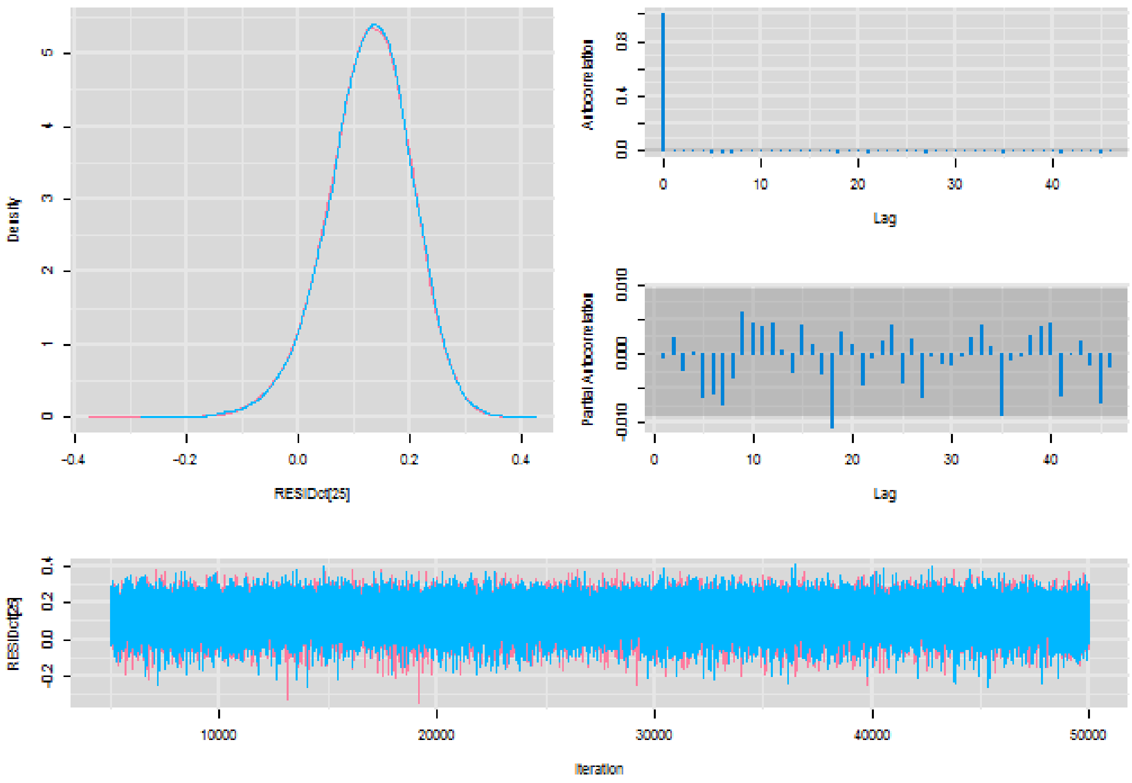
Diagnostics for RESIDct[23]



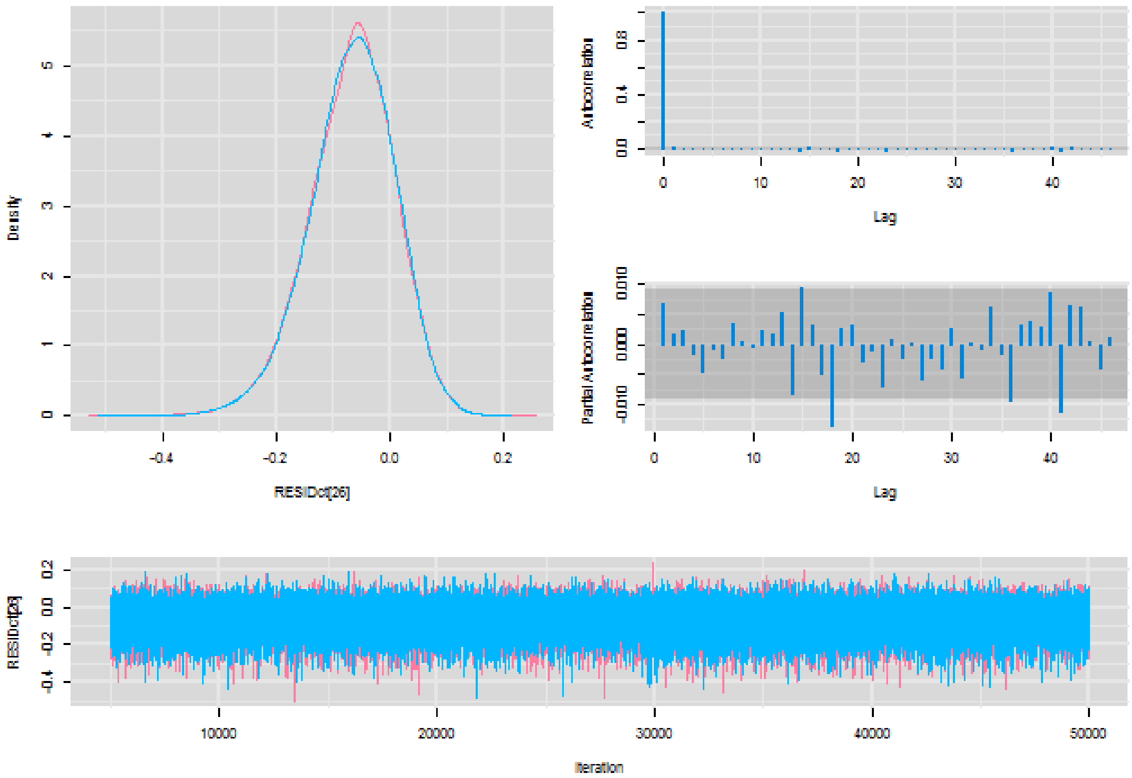
Diagnostics for RESIDct[24]



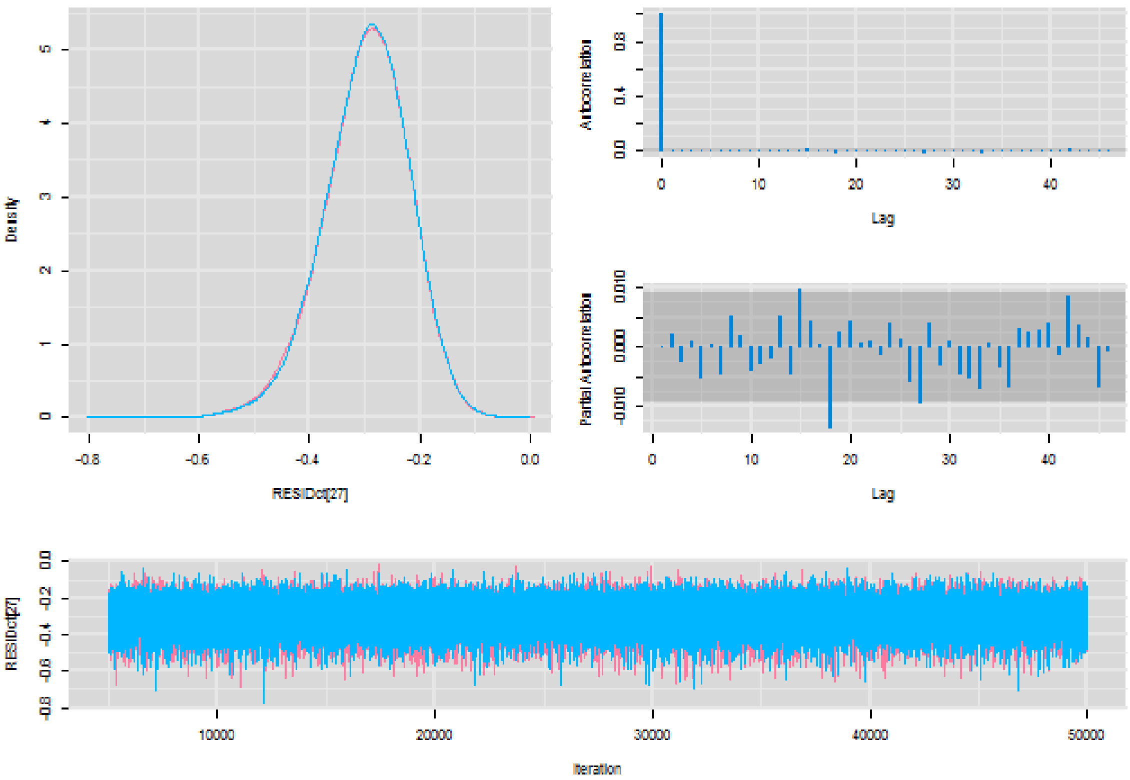
Diagnostics for RESIDct[25]



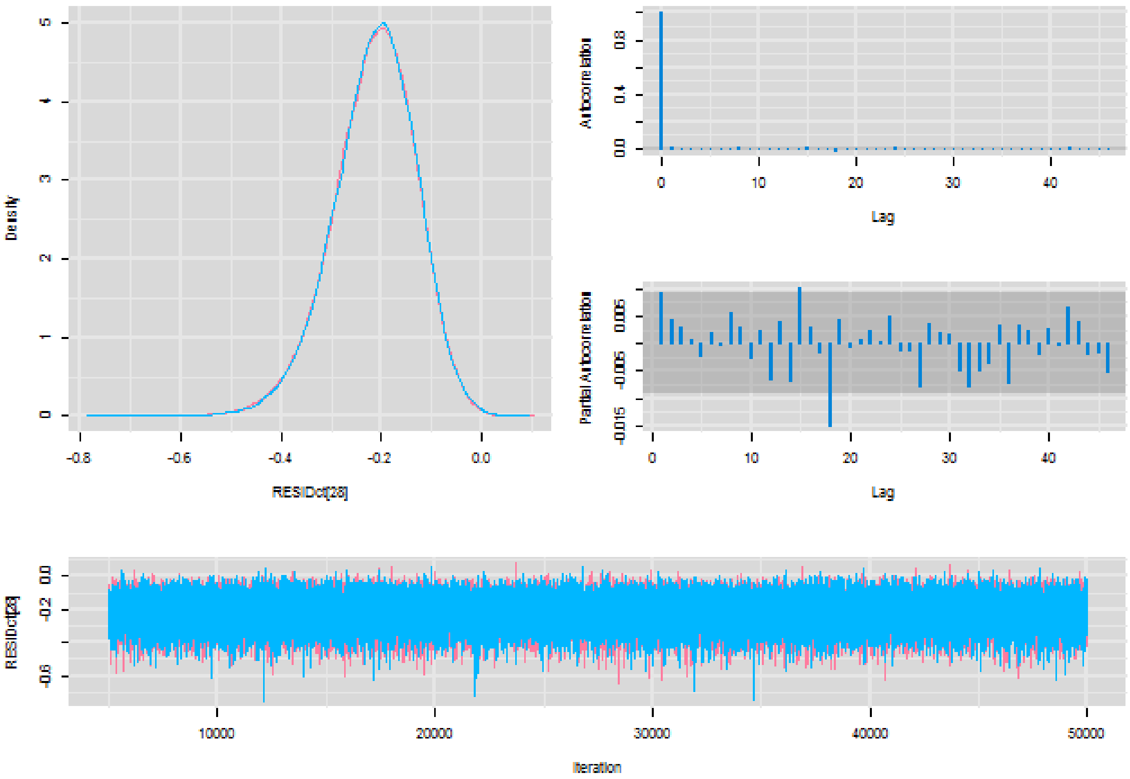
Diagnostics for RESIDct[26]



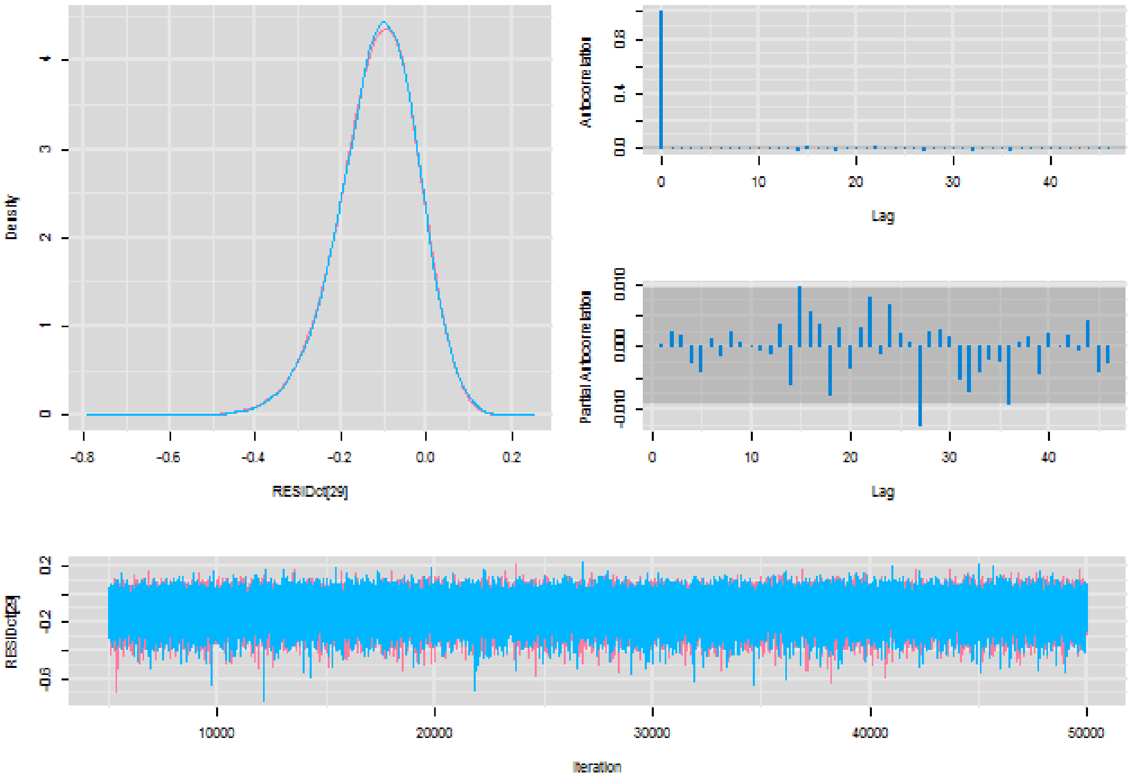
Diagnostics for RESIDct[27]



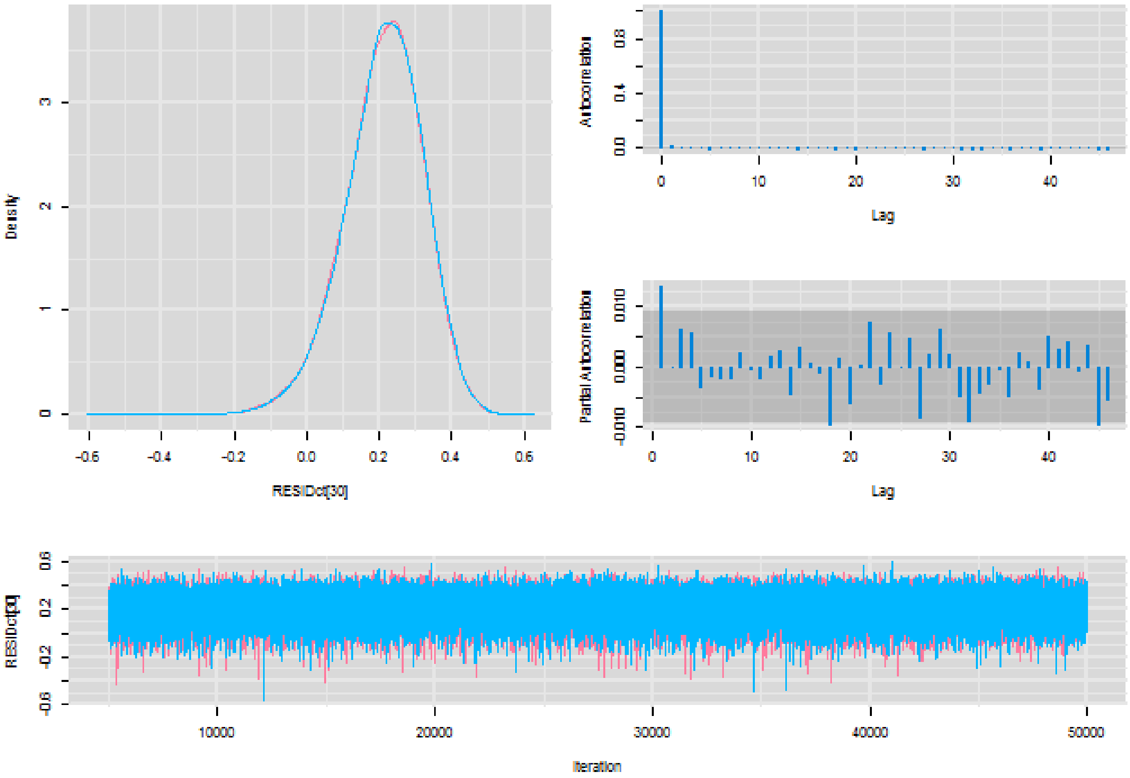
Diagnostics for RESIDct[28]



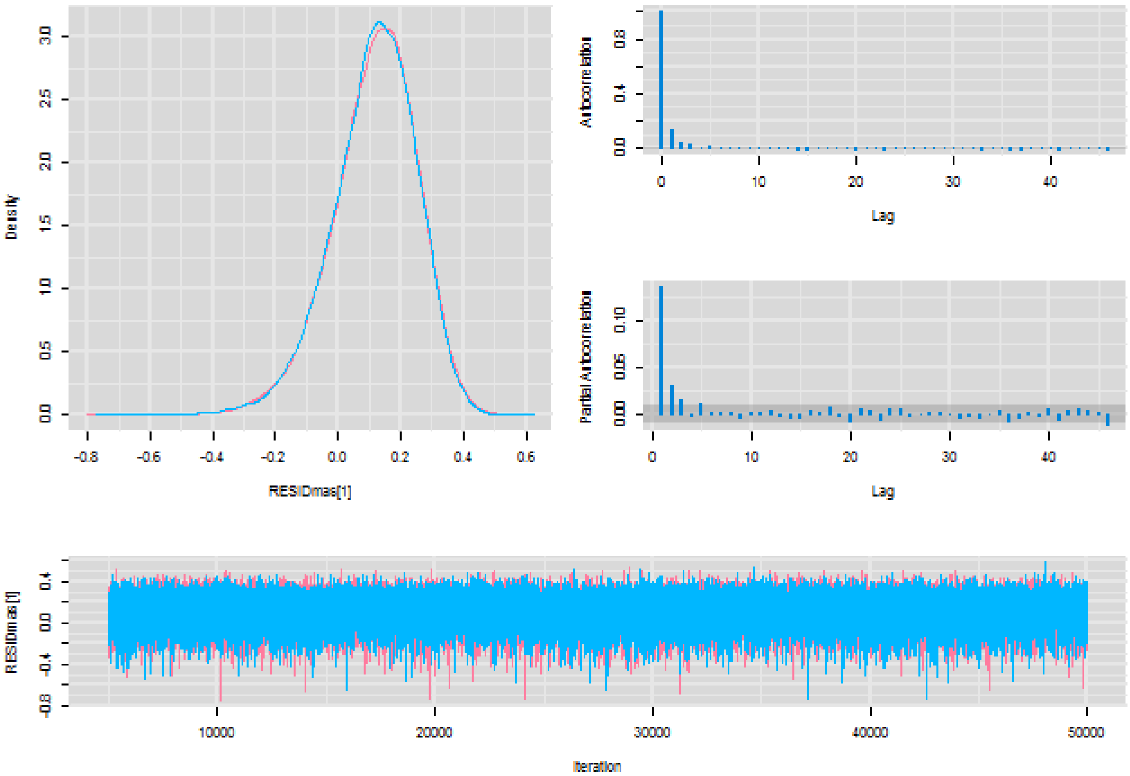
Diagnostics for RESIDct[29]



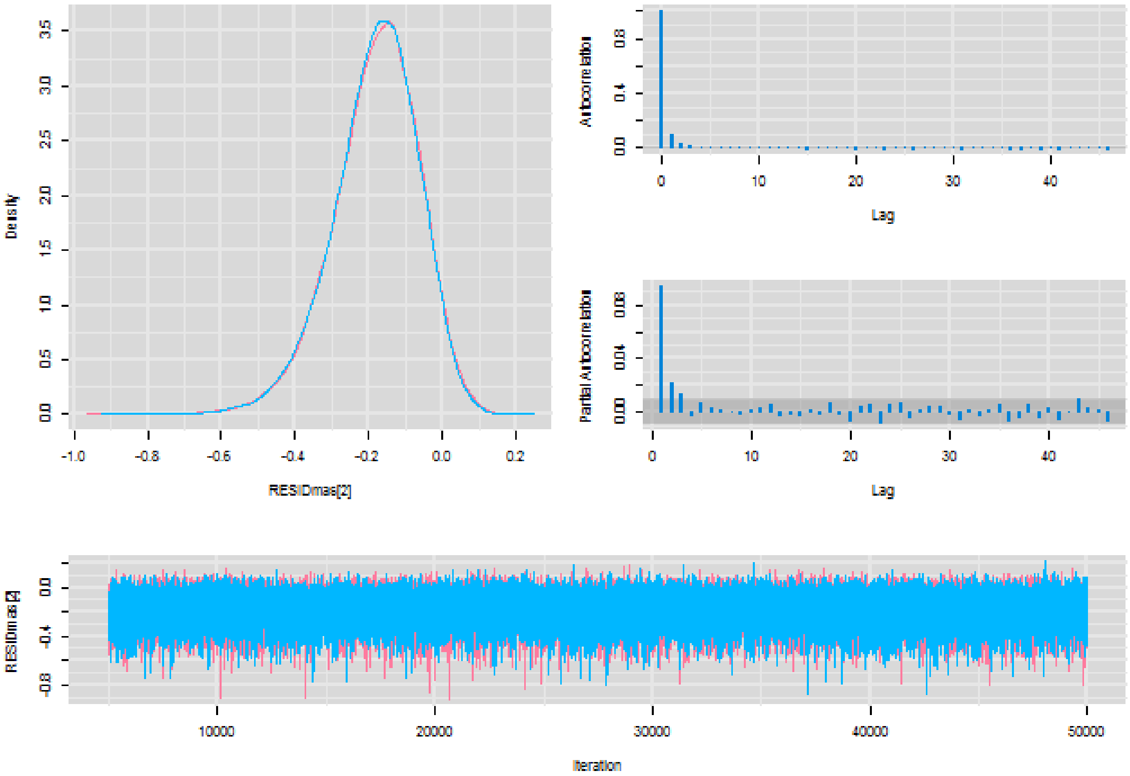
Diagnostics for RESIDct[30]



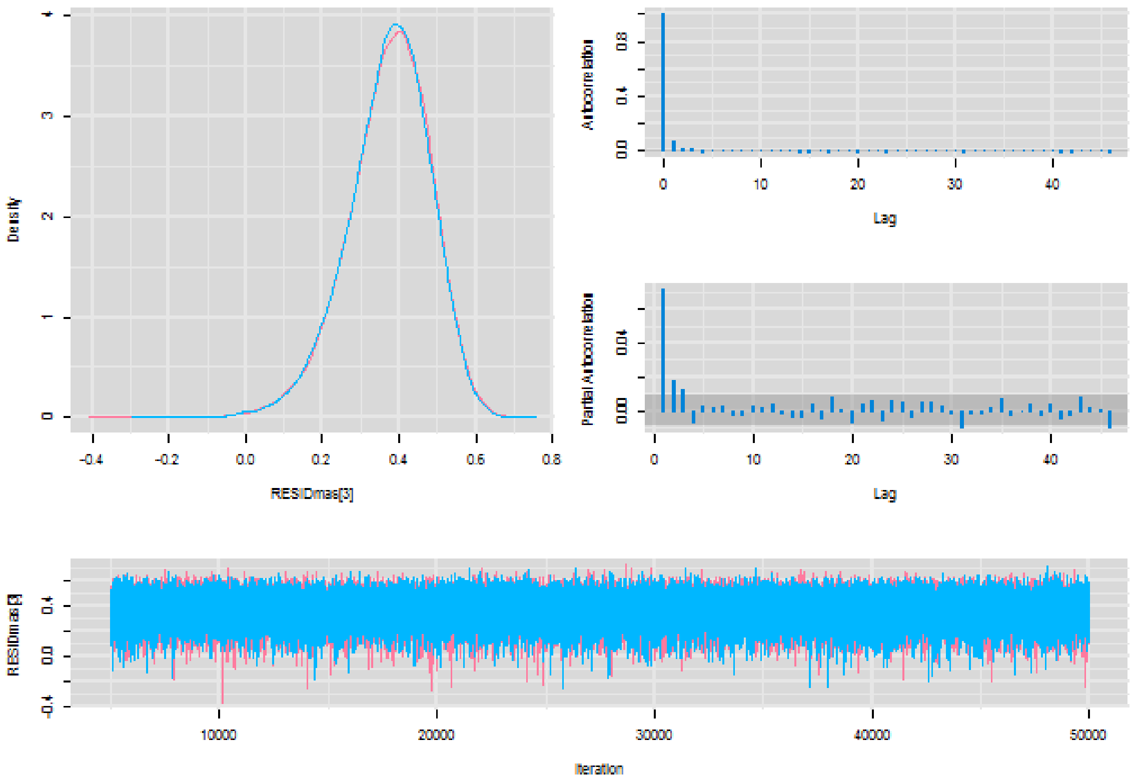
Diagnostics for RESIDmas[1]



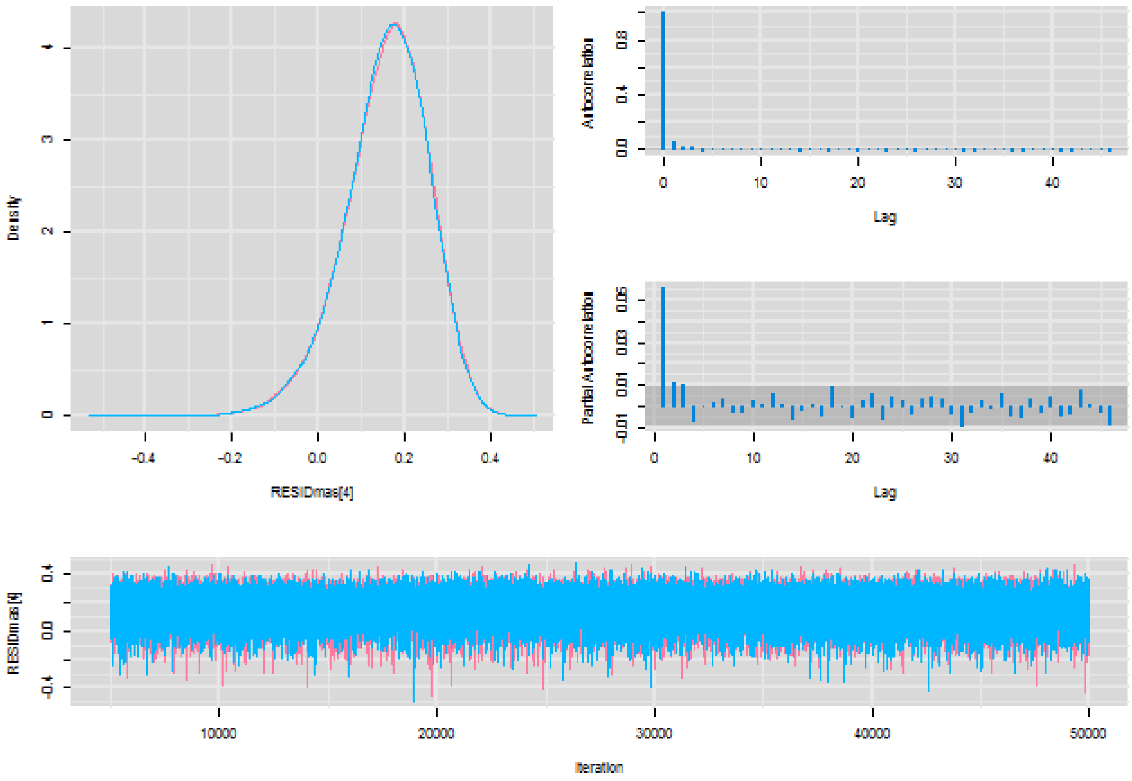
Diagnostics for RESIDmas[2]



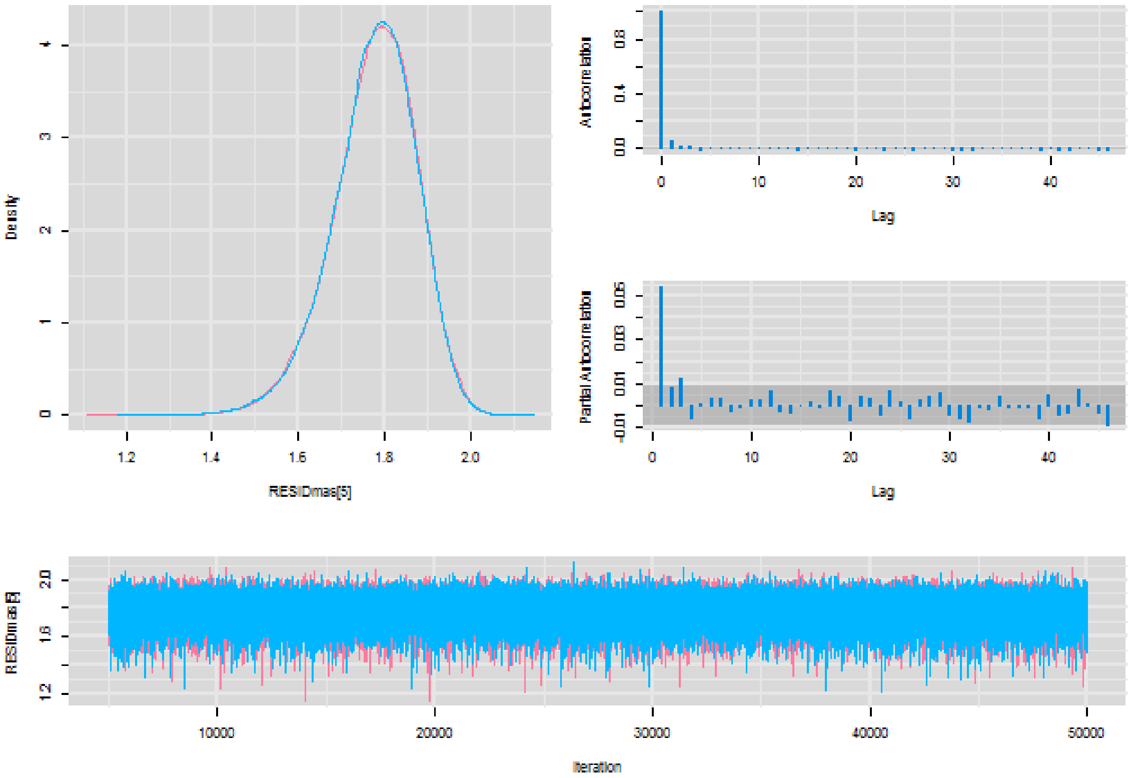
Diagnostics for RESIDmas[3]



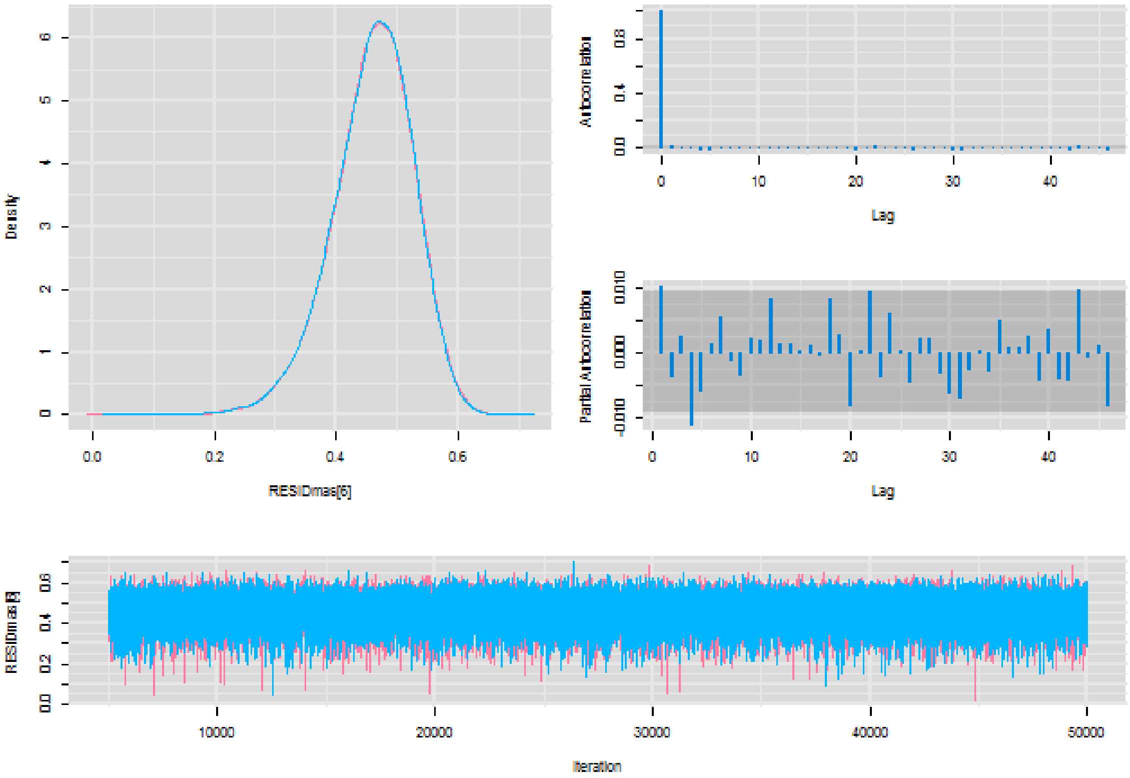
Diagnostics for RESIDmas[4]



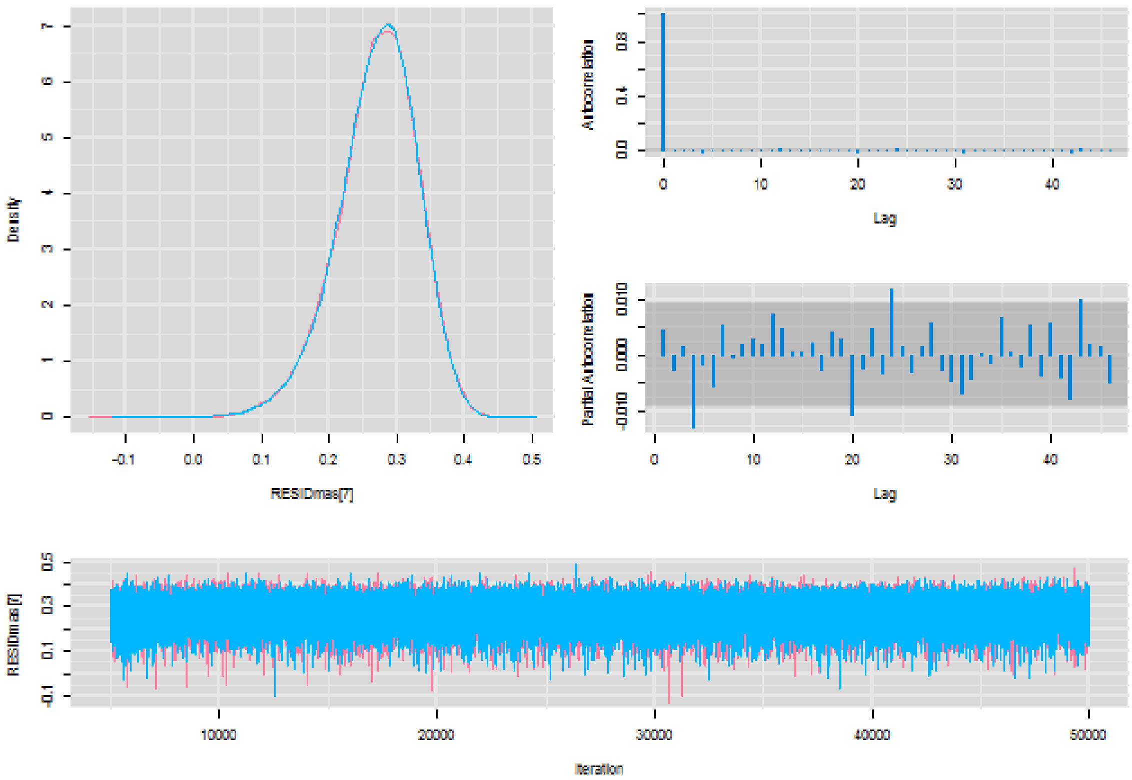
Diagnostics for RESIDmas[5]



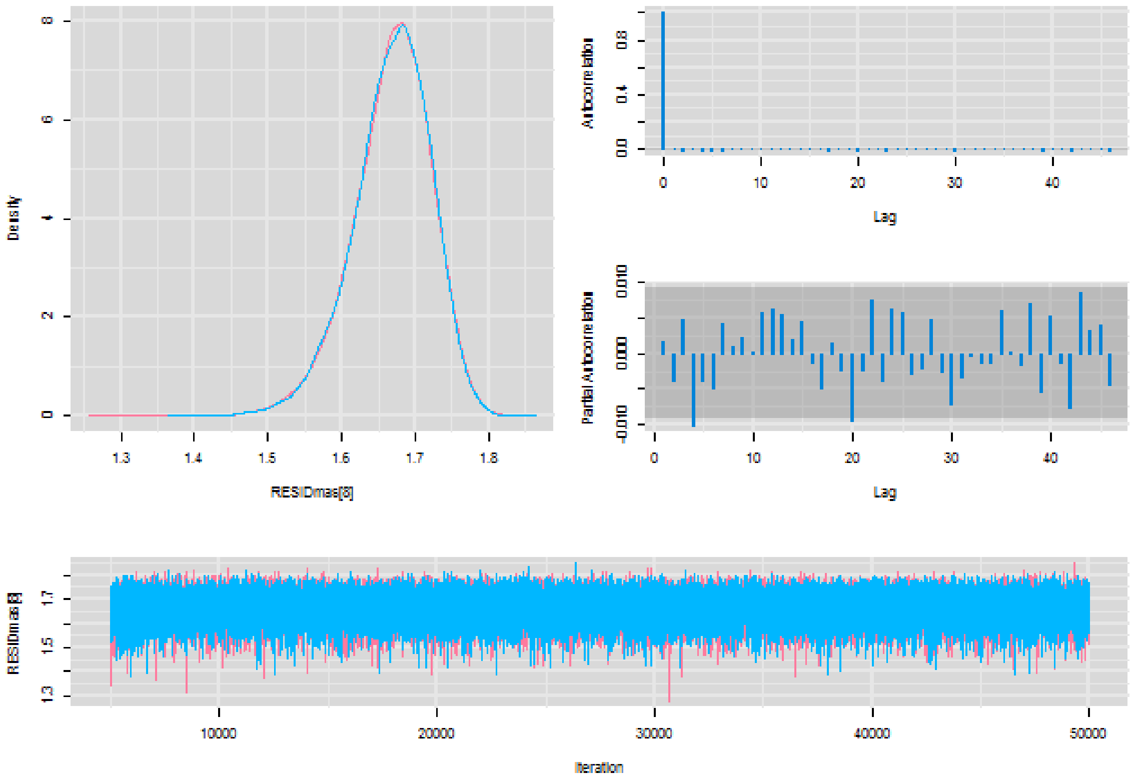
Diagnostics for RESIDmas[6]



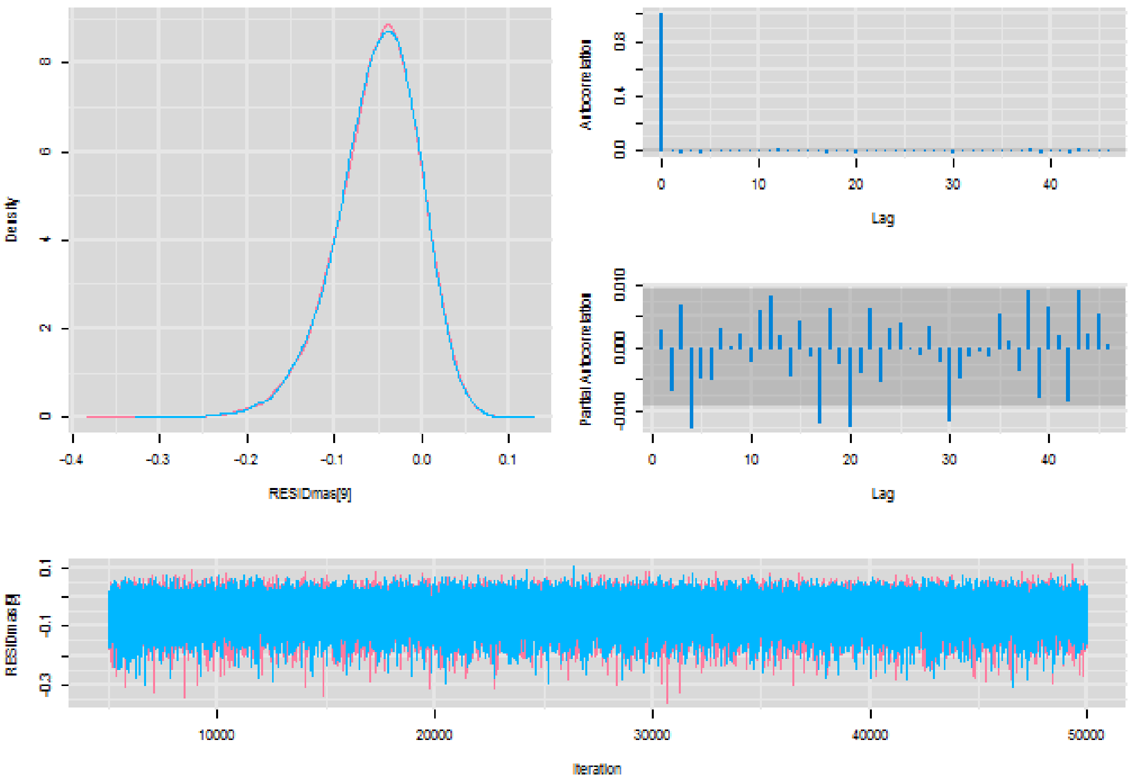
Diagnostics for RESIDmas[7]



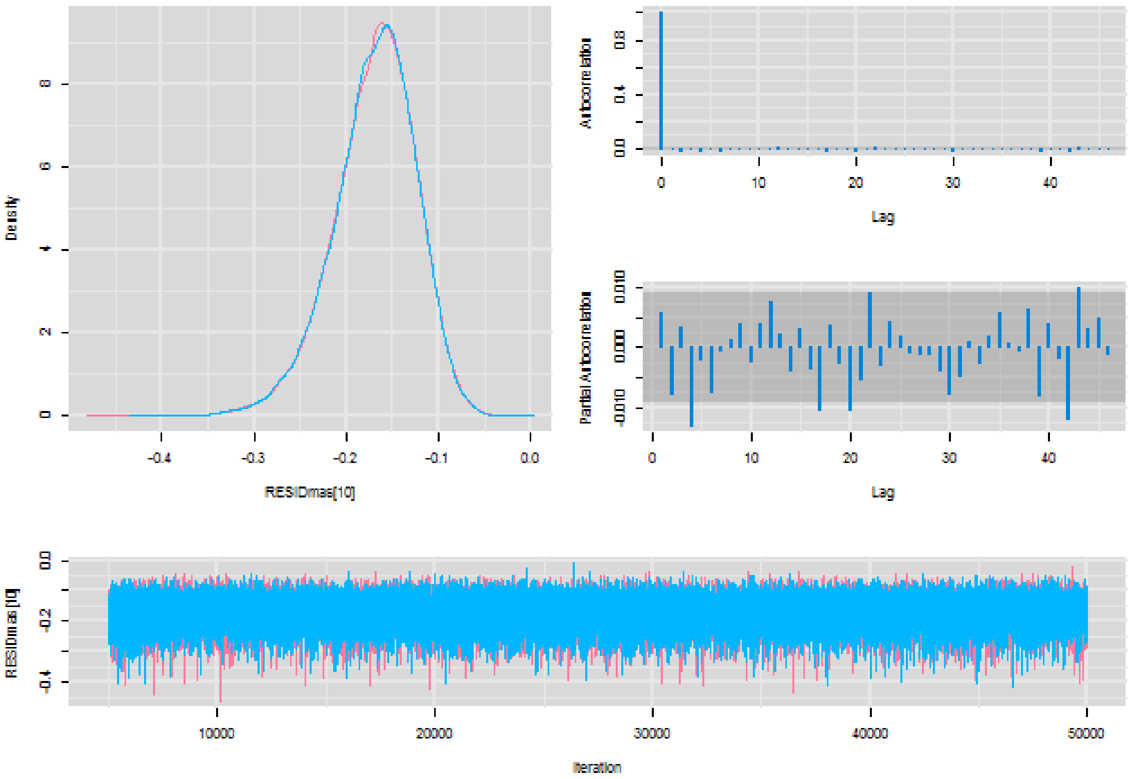
Diagnostics for RESIDmas[8]



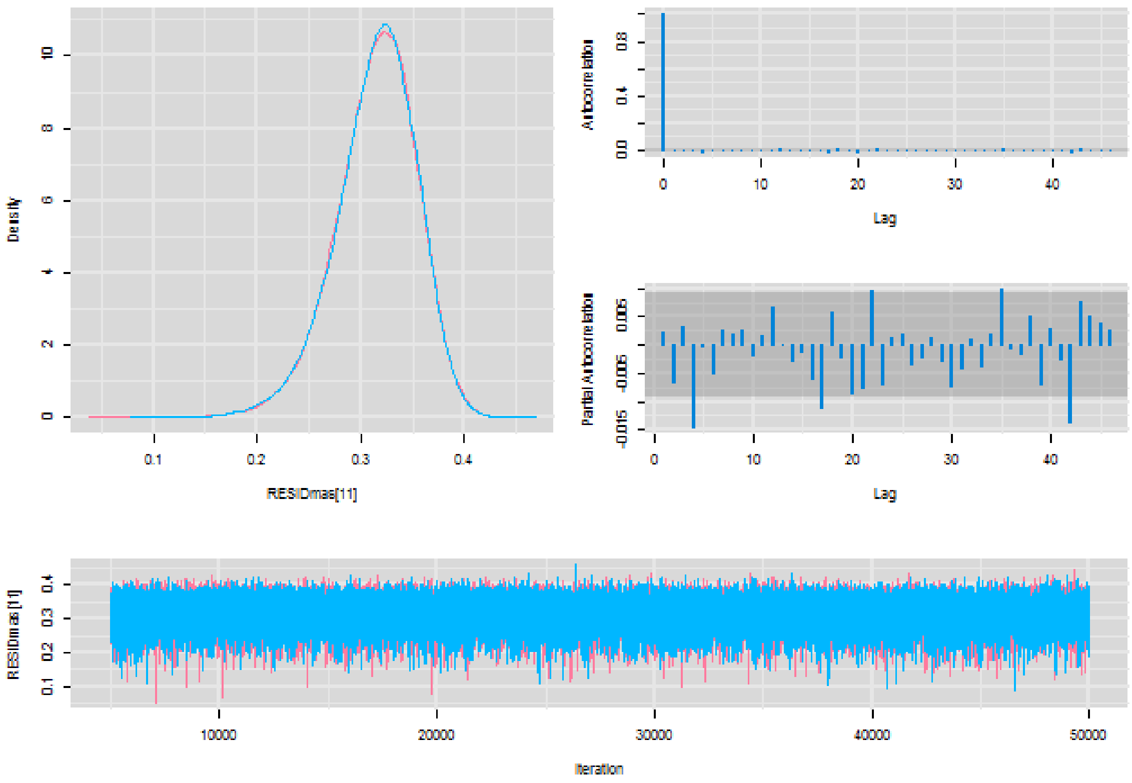
Diagnostics for RESIDmas[9]



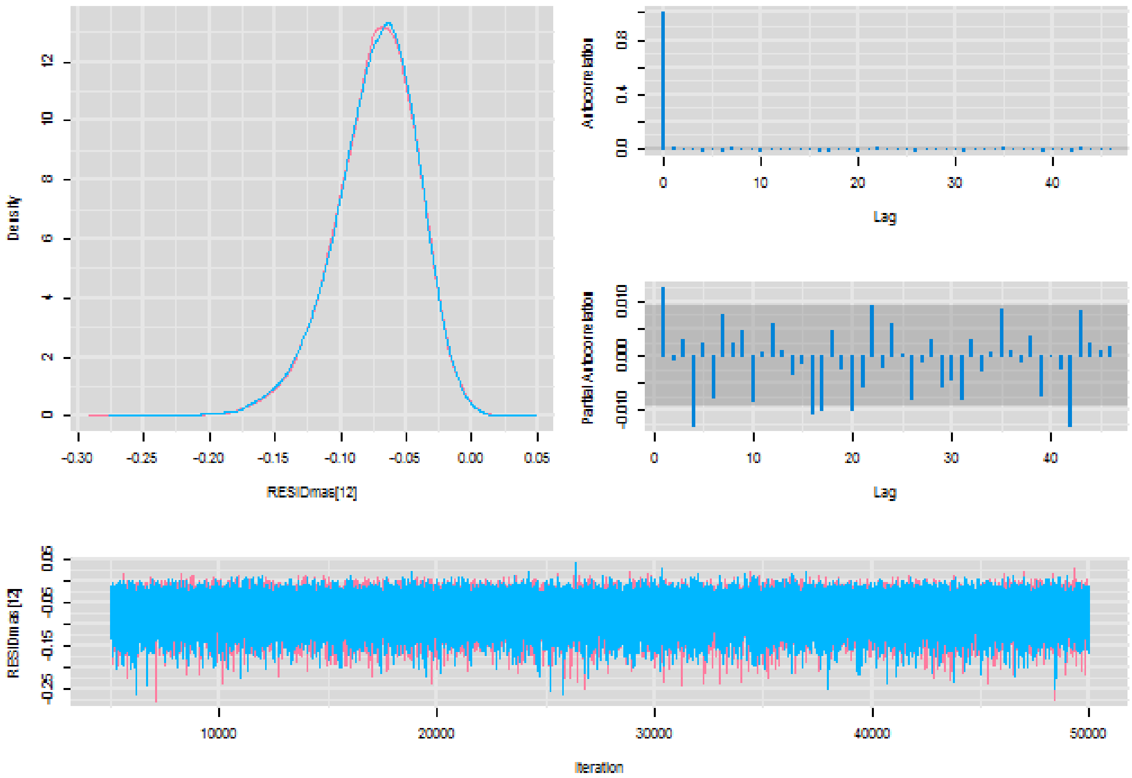
Diagnostics for RESIDmas[10]



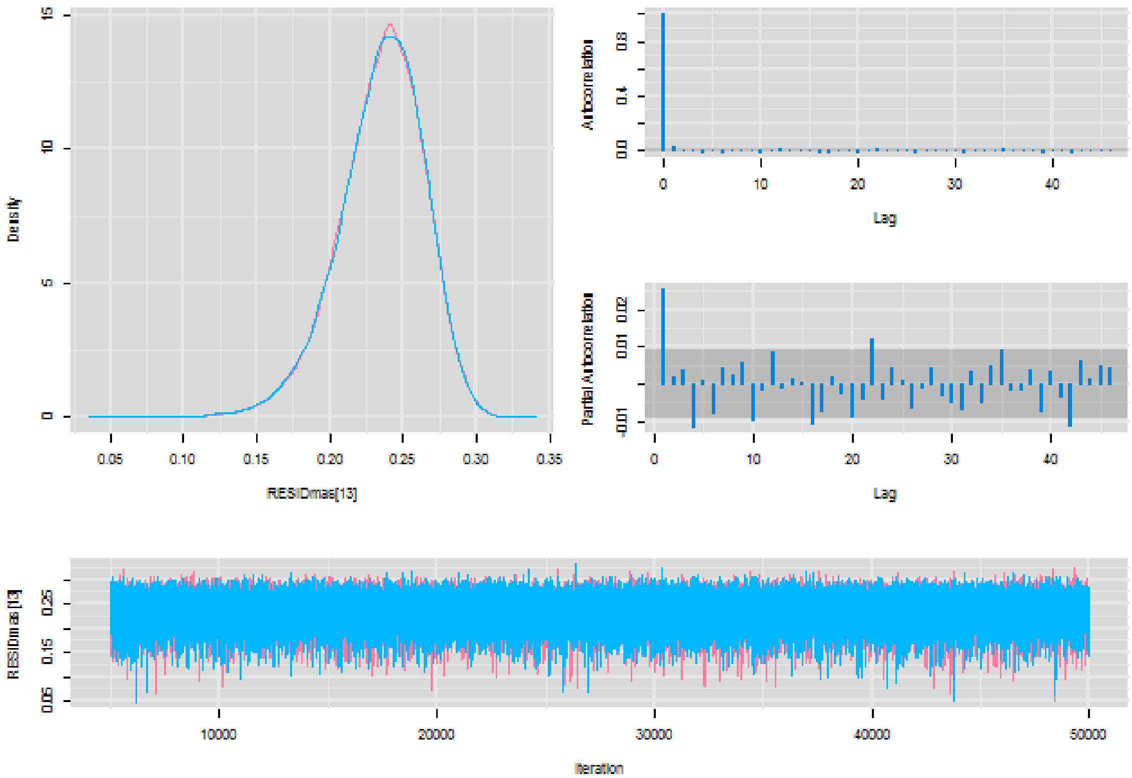
Diagnostics for RESIDmas[11]



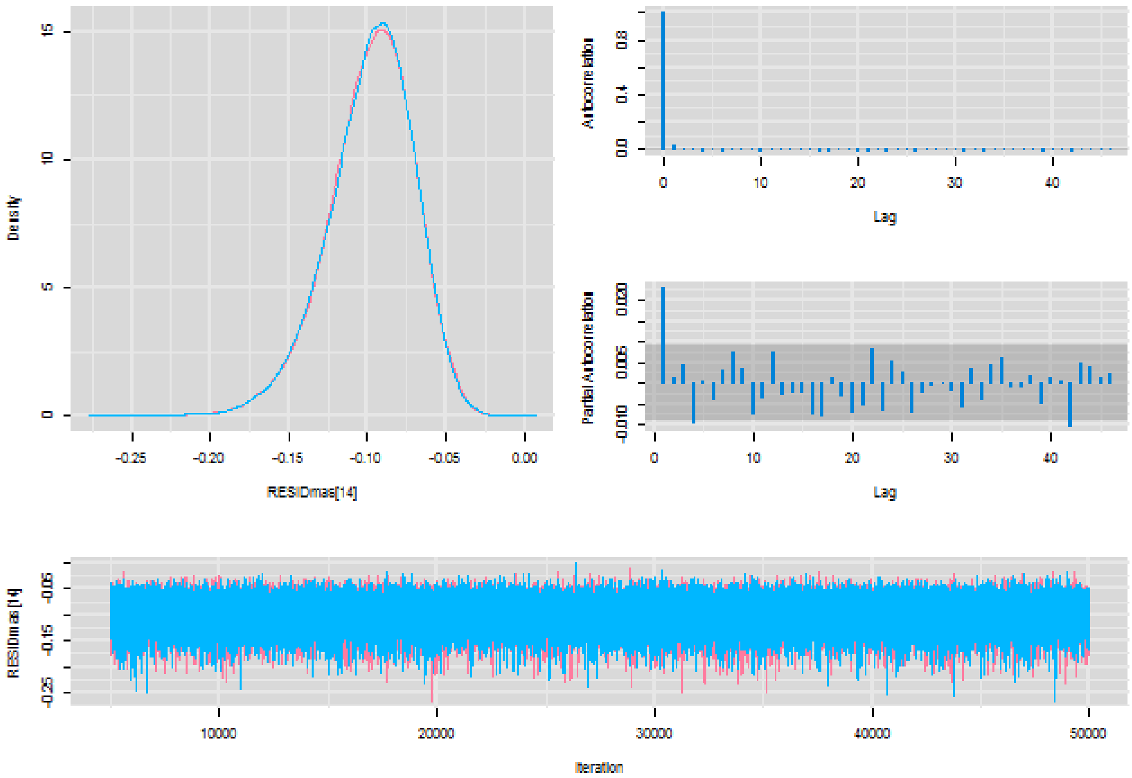
Diagnostics for RESIDmas[12]



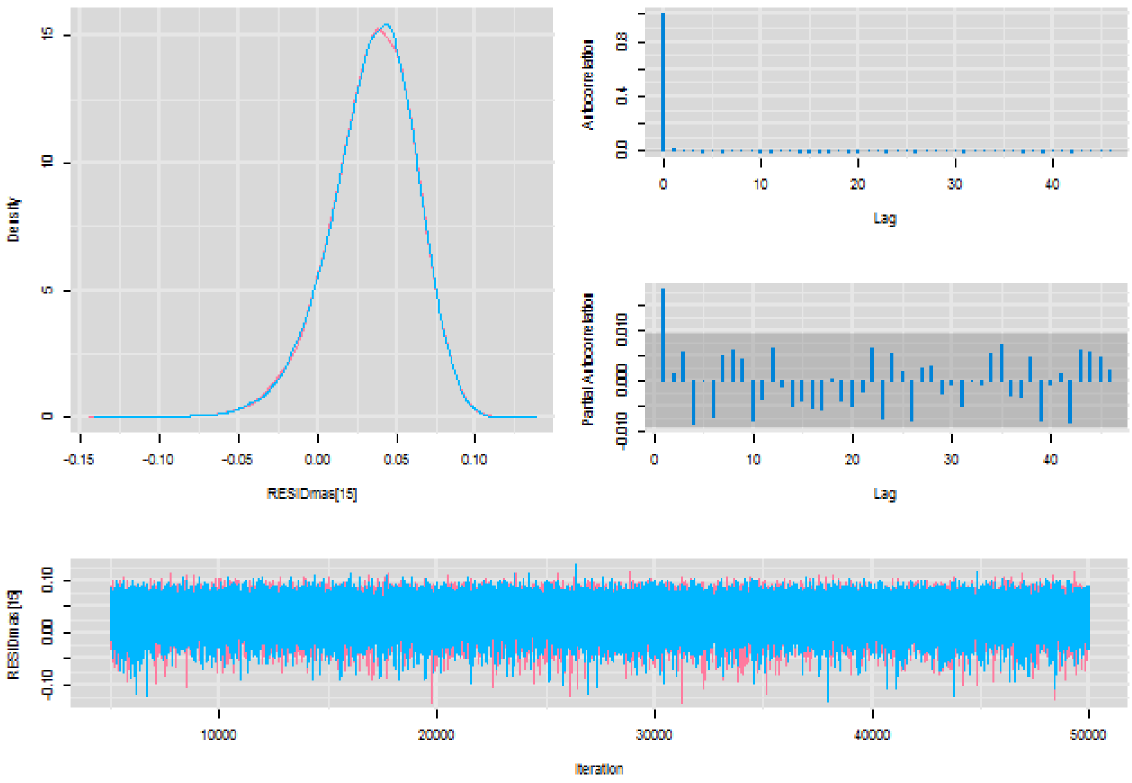
Diagnostics for RESIDmas[13]



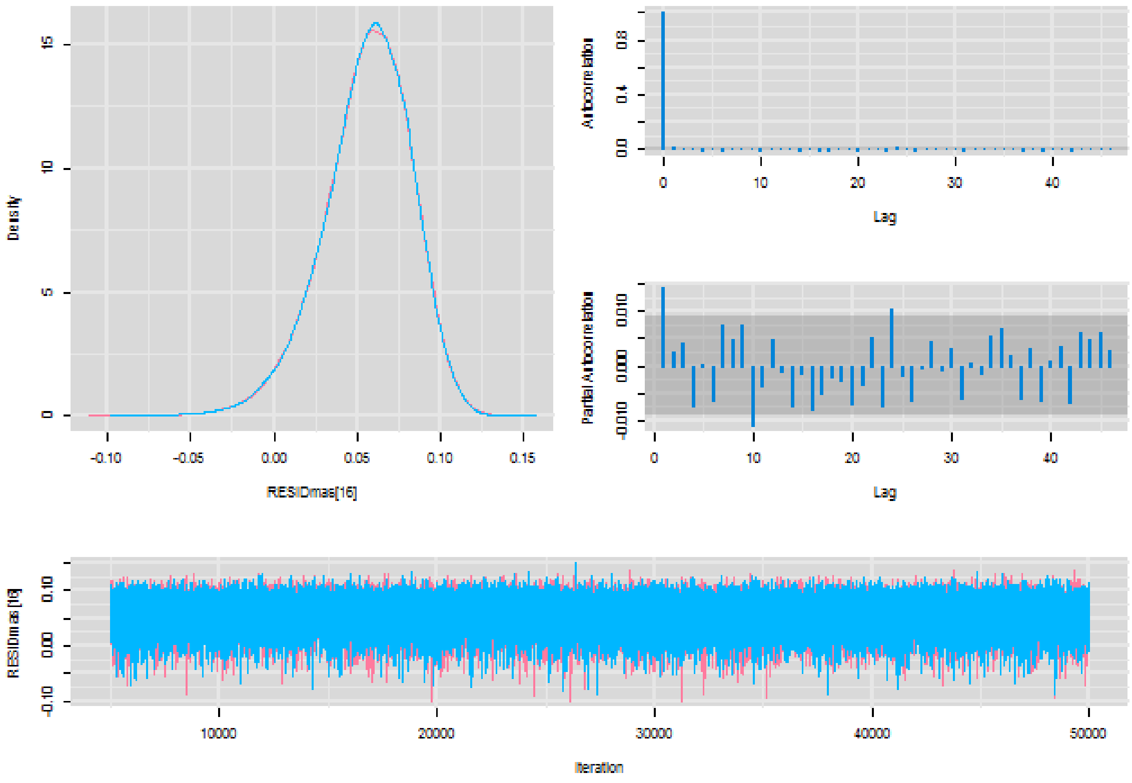
Diagnostics for RESIDmas[14]



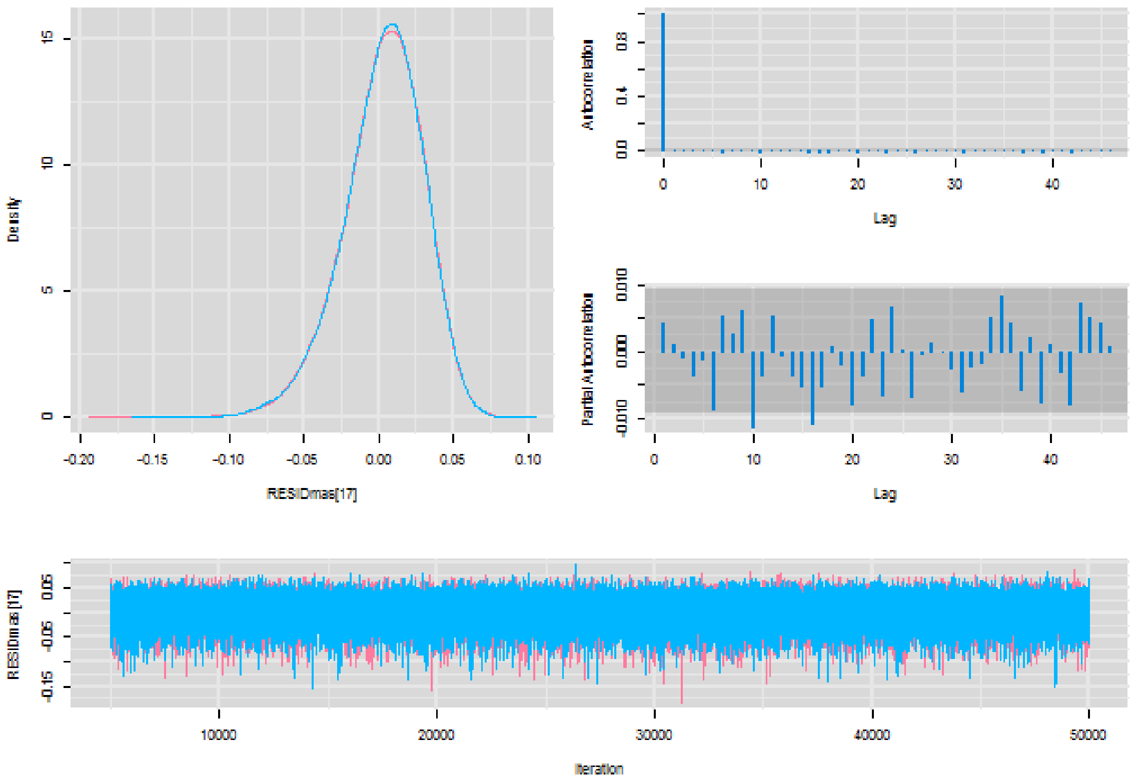
Diagnostics for RESIDmas[15]



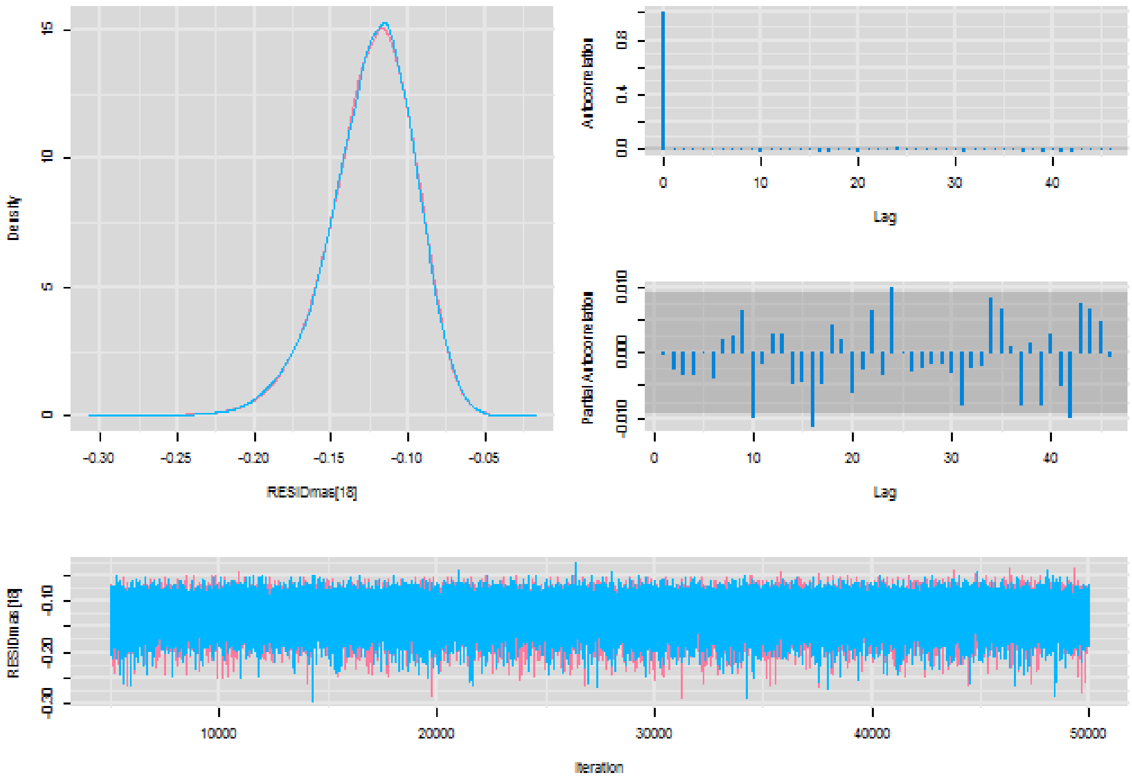
Diagnostics for RESIDmas[16]



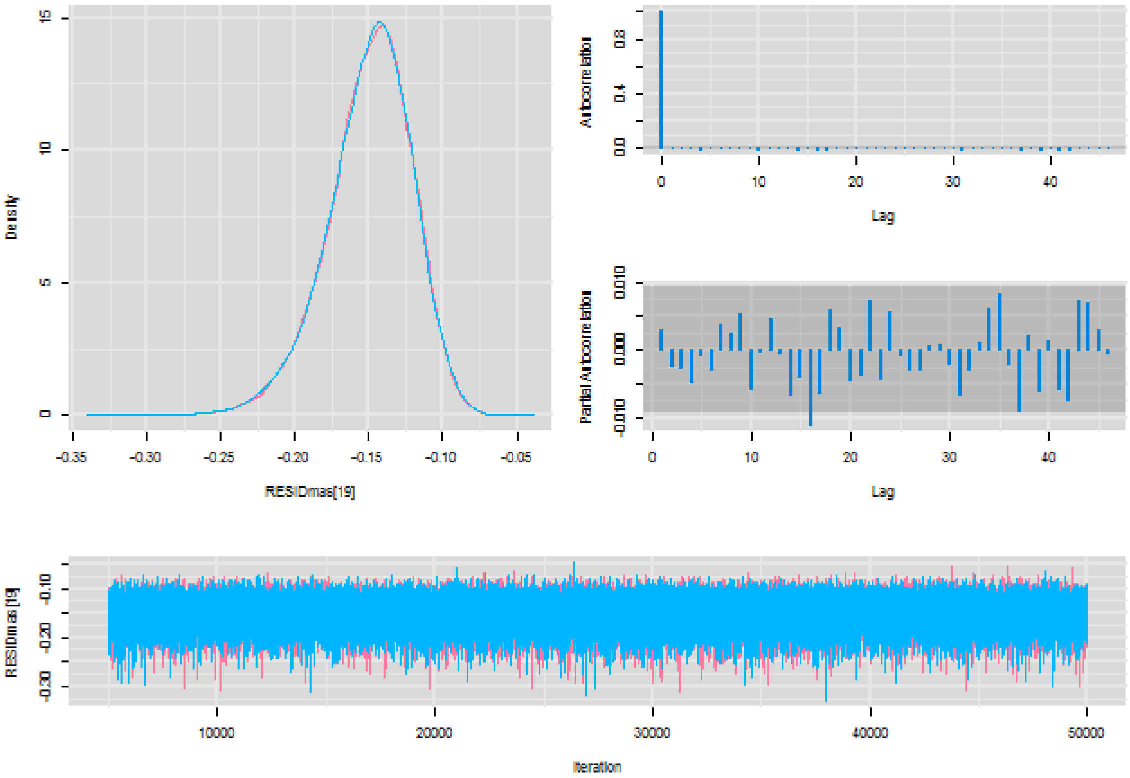
Diagnostics for RESIDmas[17]



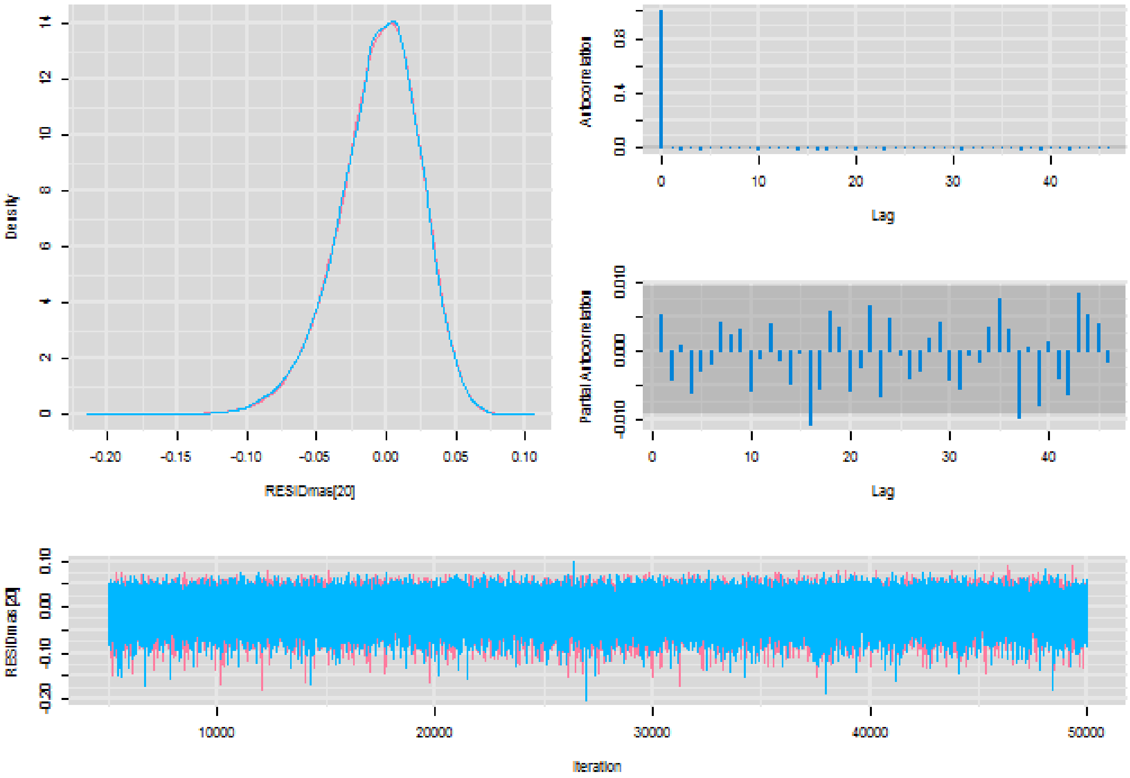
Diagnostics for RESIDmas[18]



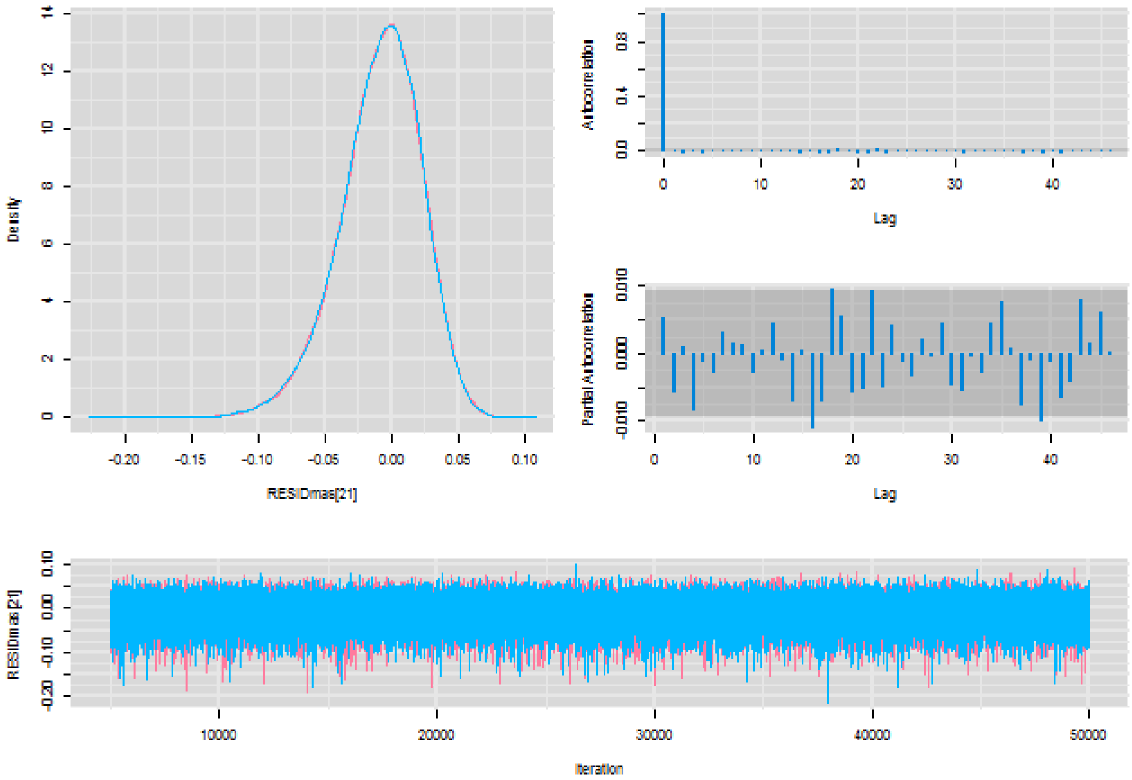
Diagnostics for RESIDmas[19]



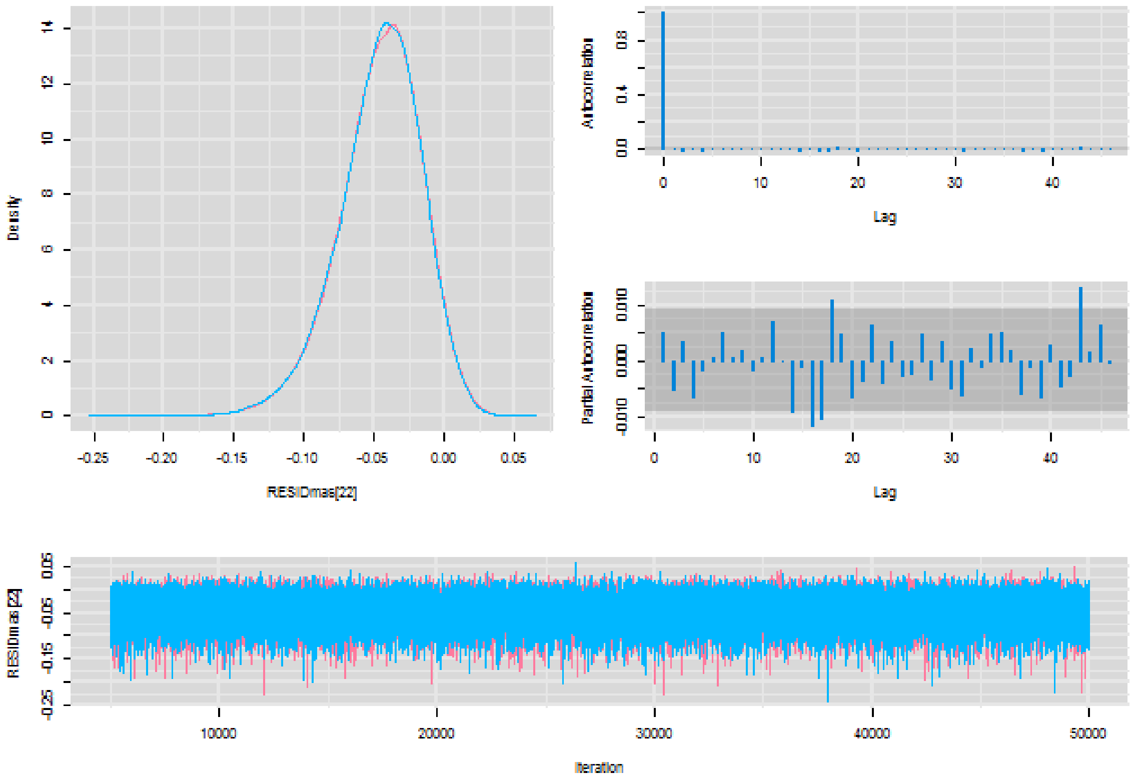
Diagnostics for RESIDmas[20]



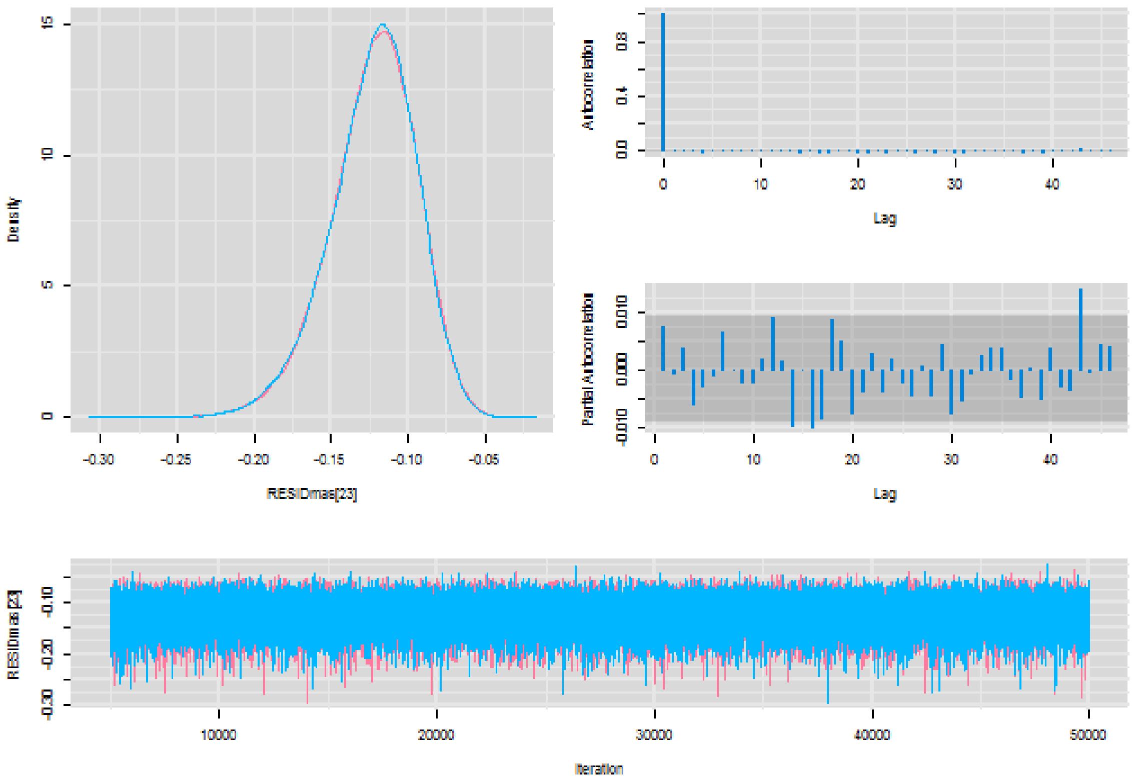
Diagnostics for RESIDmas[21]



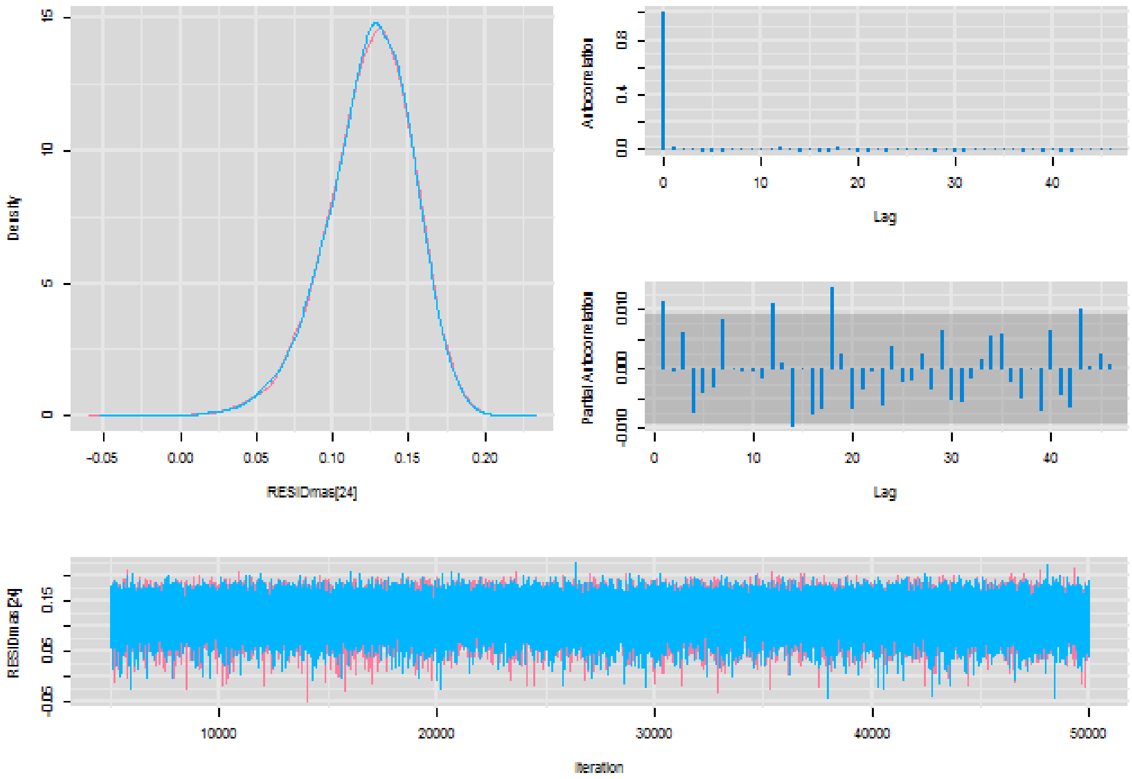
Diagnostics for RESIDmas[22]



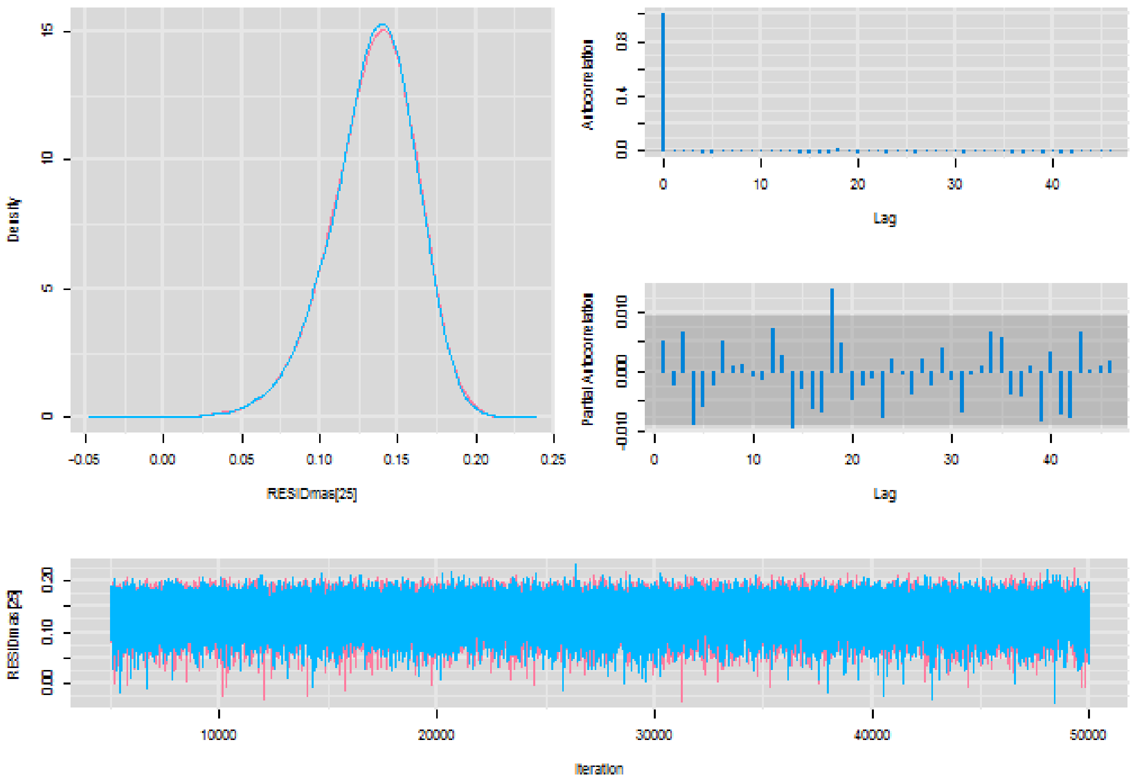
Diagnostics for RESIDmas[23]



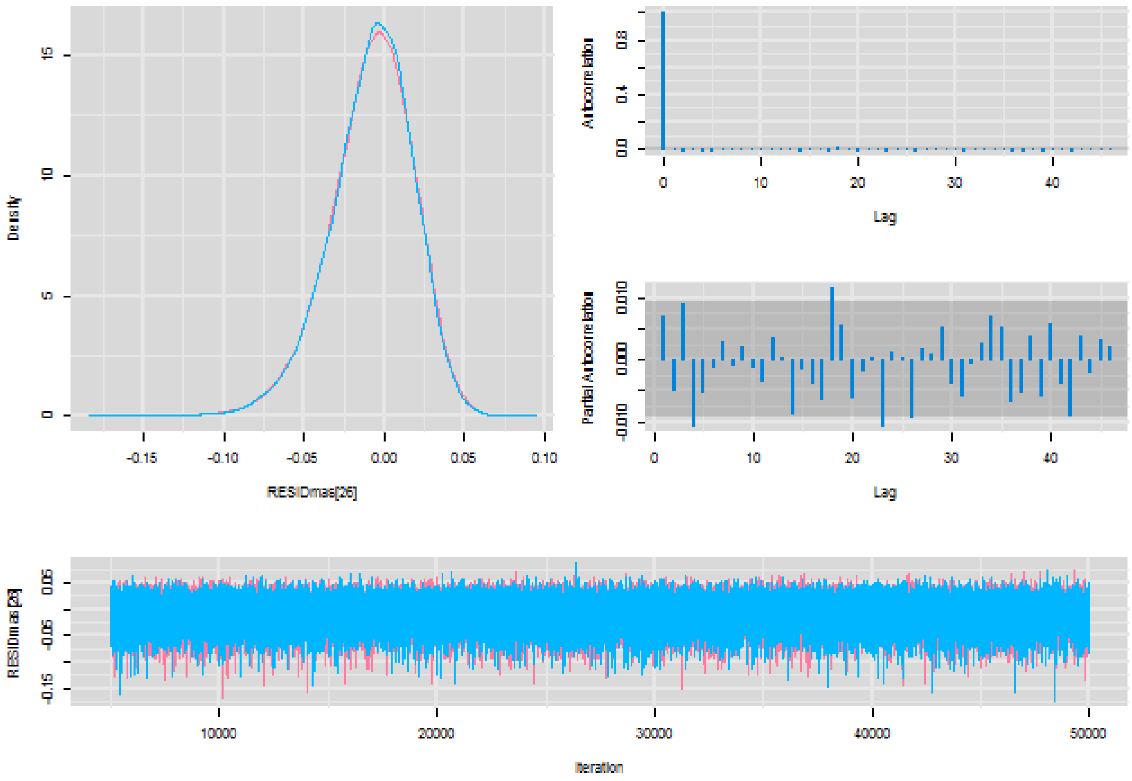
Diagnostics for RESIDmas[24]



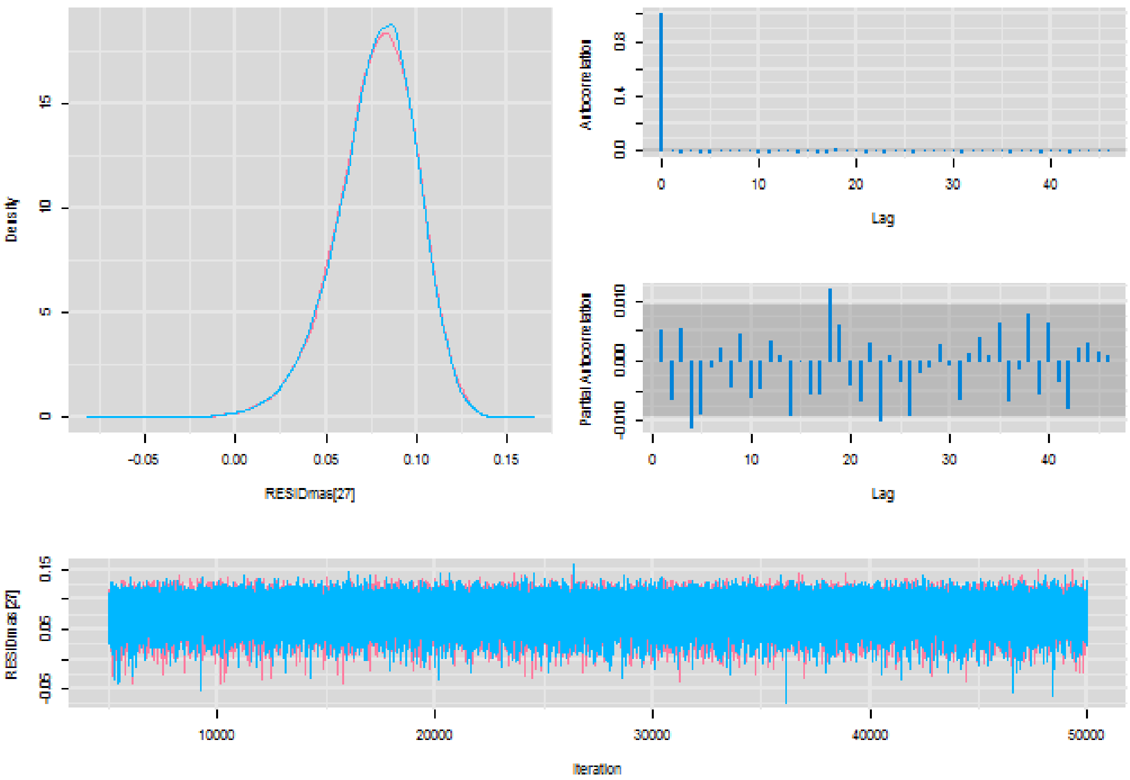
Diagnostics for RESIDmas[25]



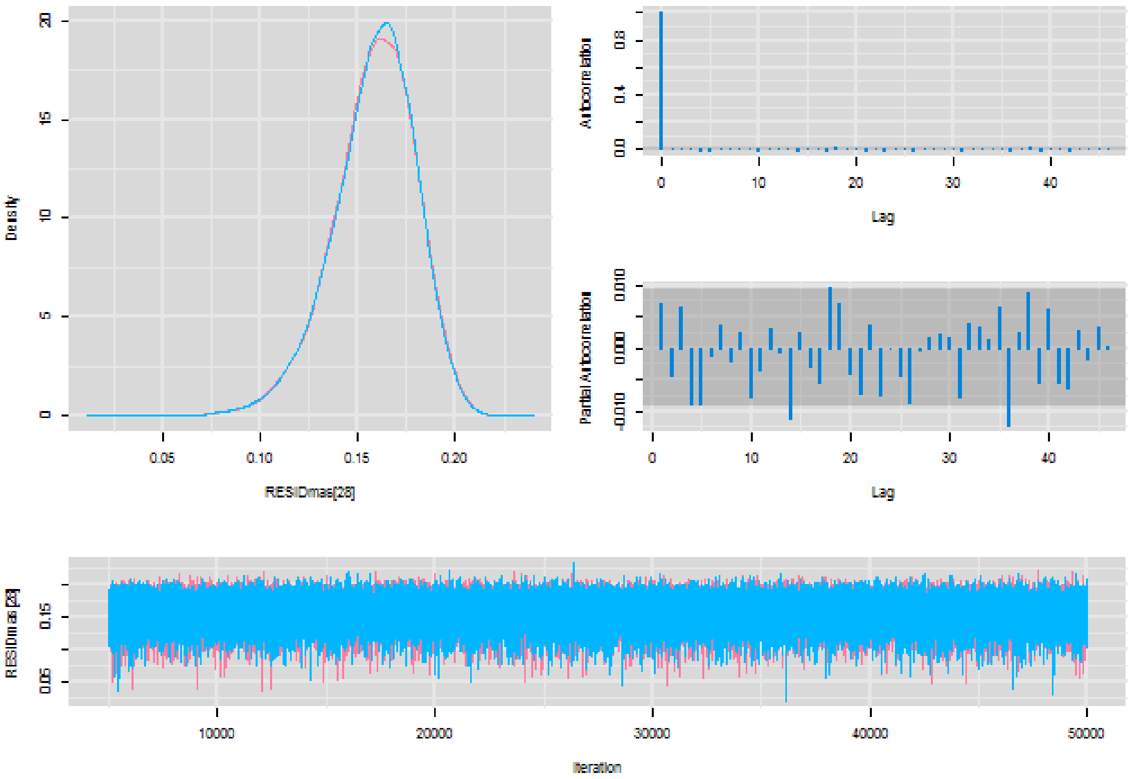
Diagnostics for RESIDmas[26]



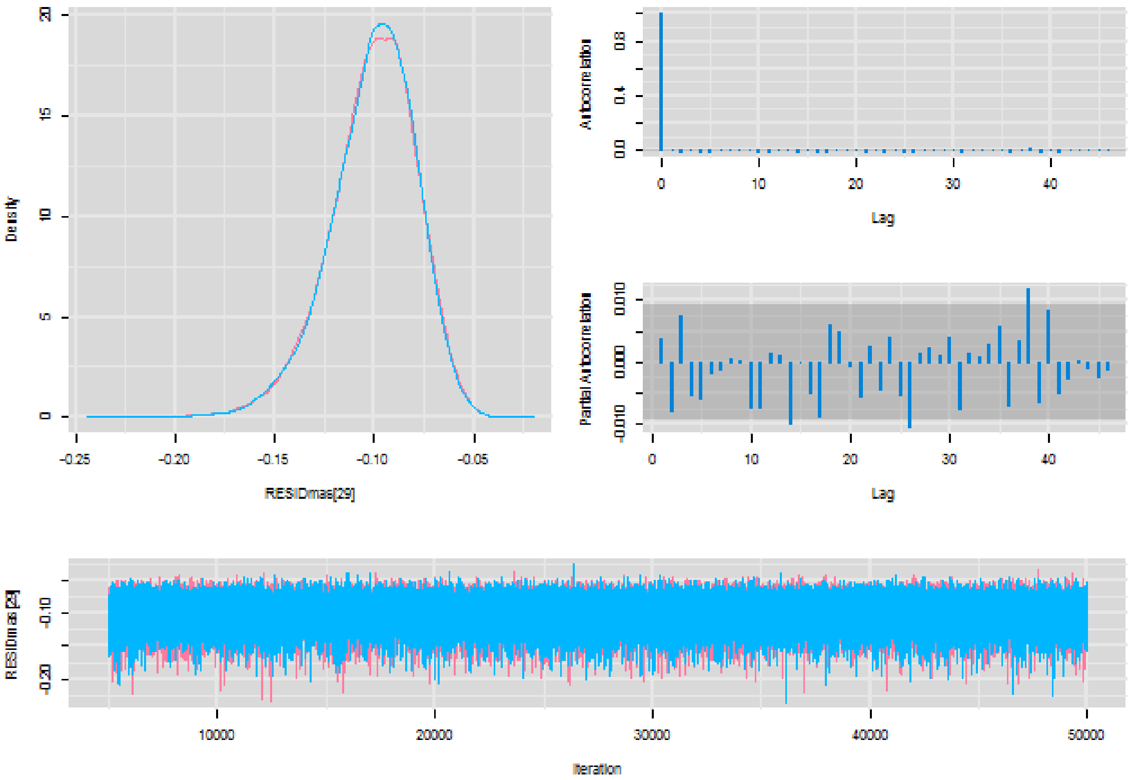
Diagnostics for RESIDmas[27]



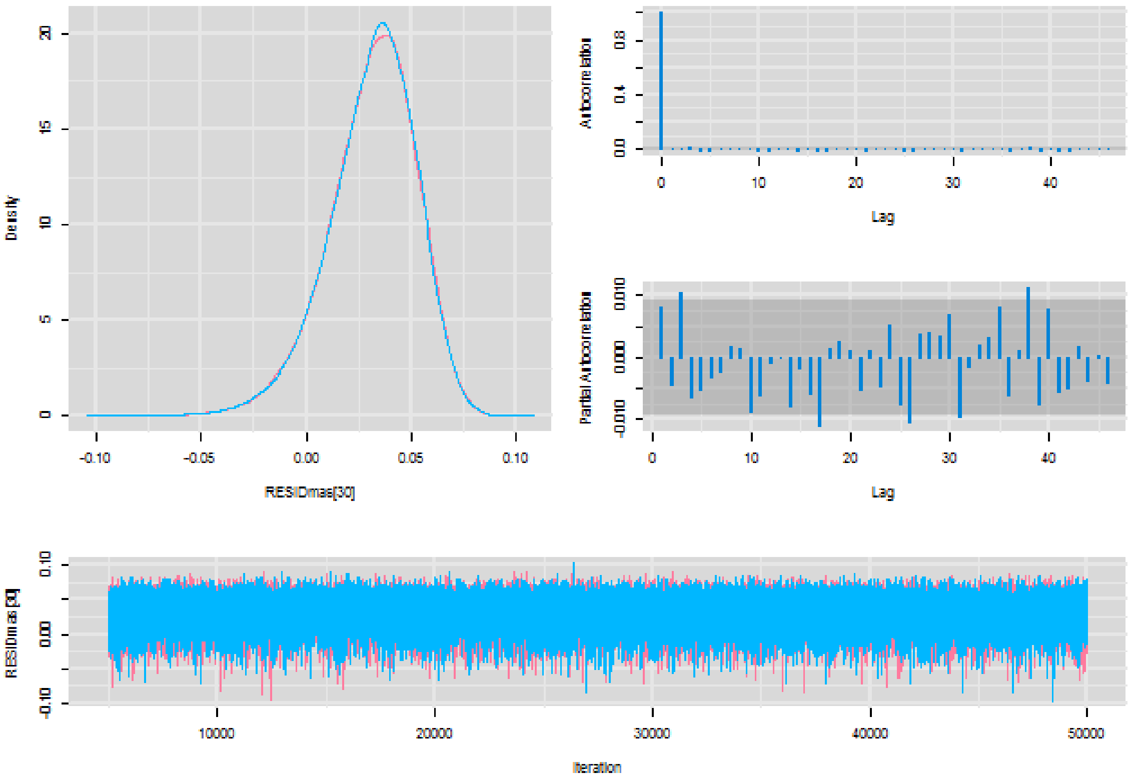
Diagnostics for RESIDmas[28]



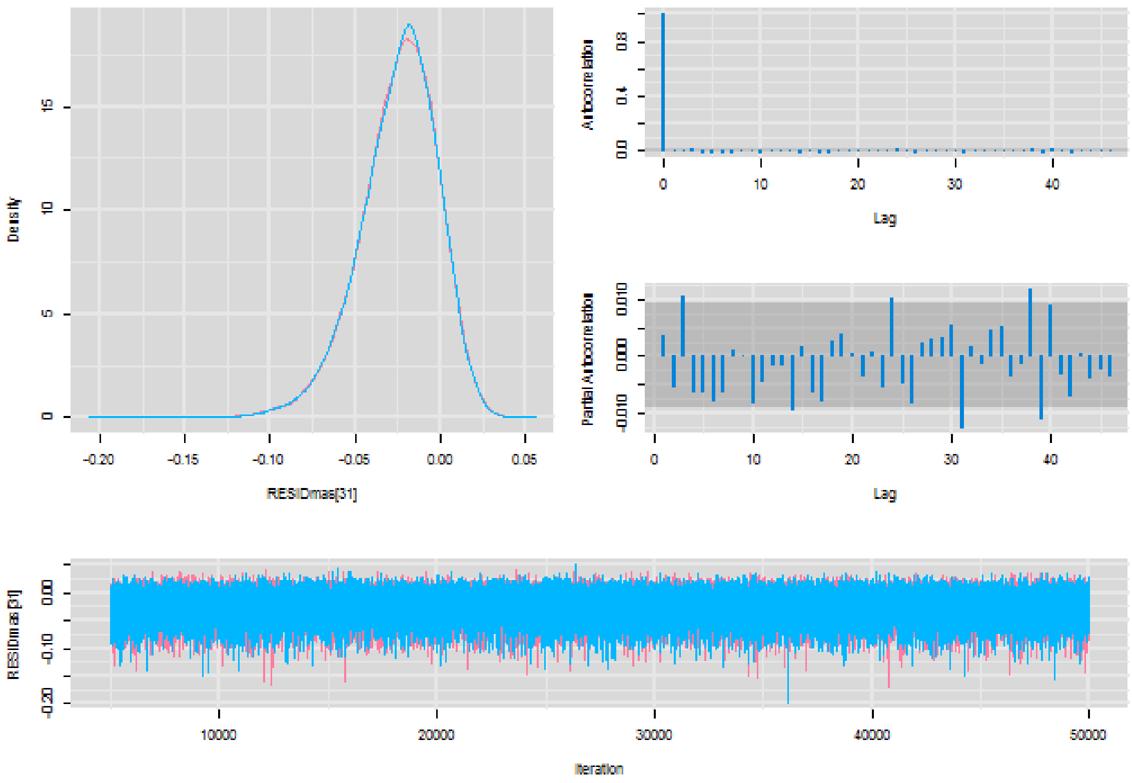
Diagnostics for RESIDmas[29]



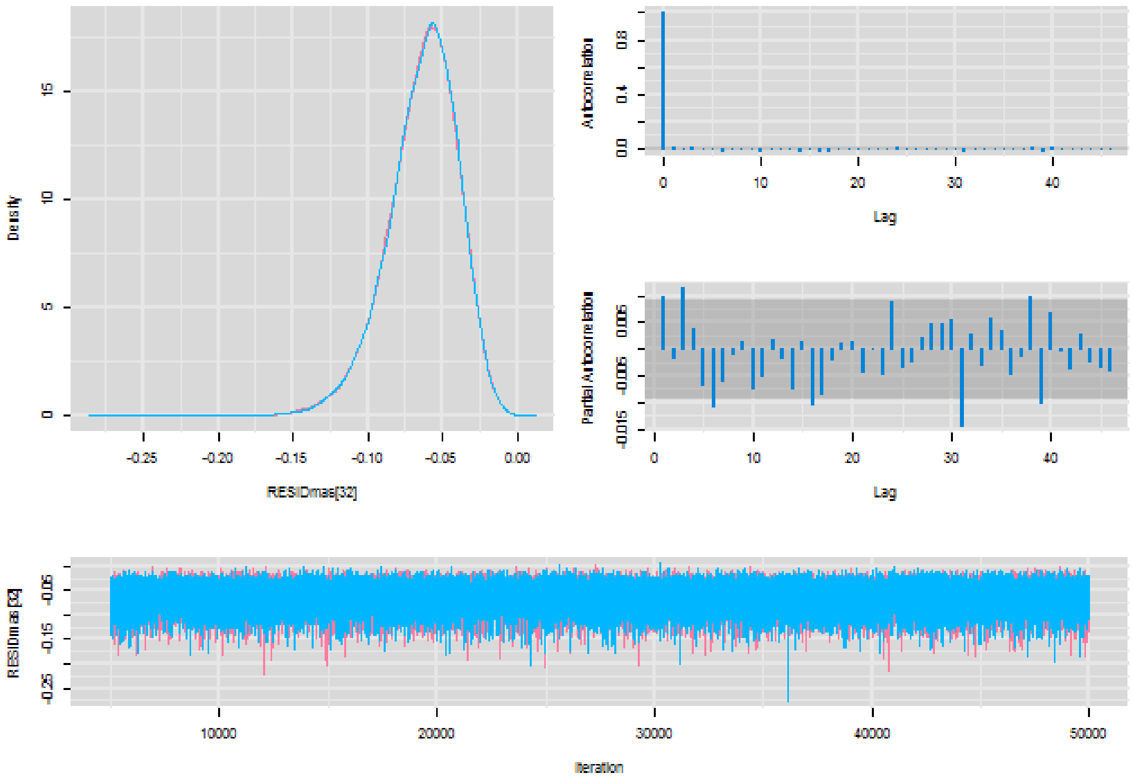
Diagnostics for RESIDmas[30]



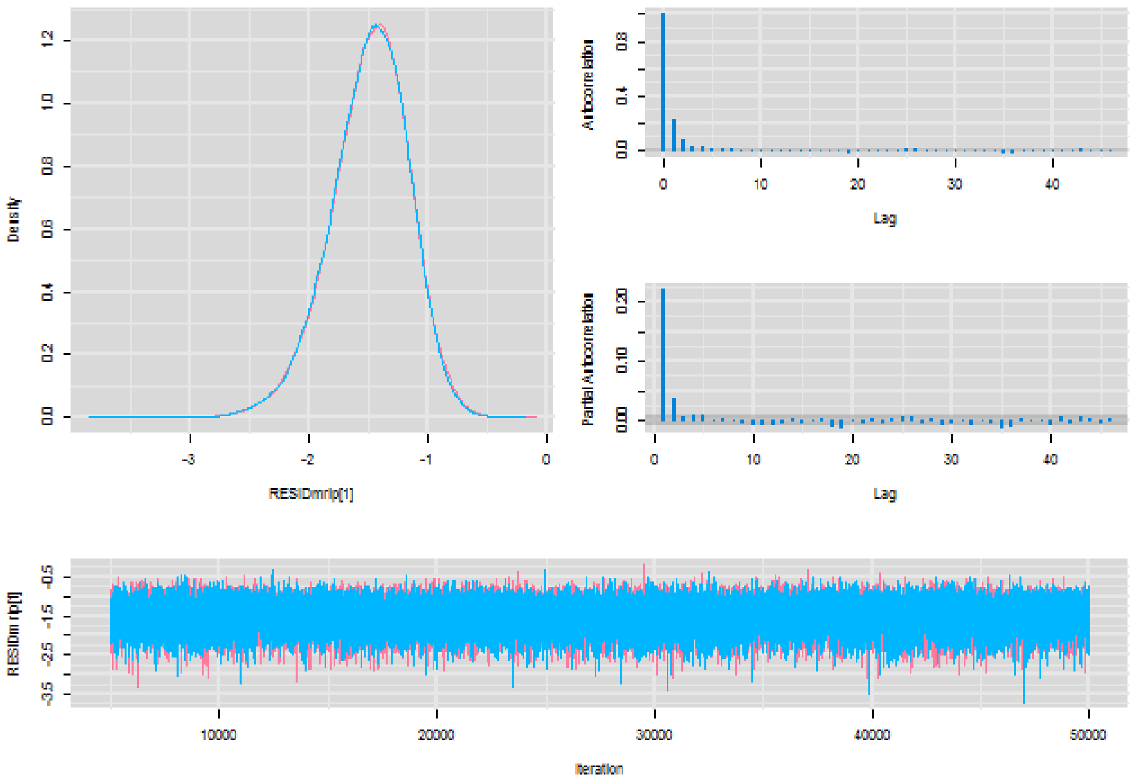
Diagnostics for RESIDmas[31]



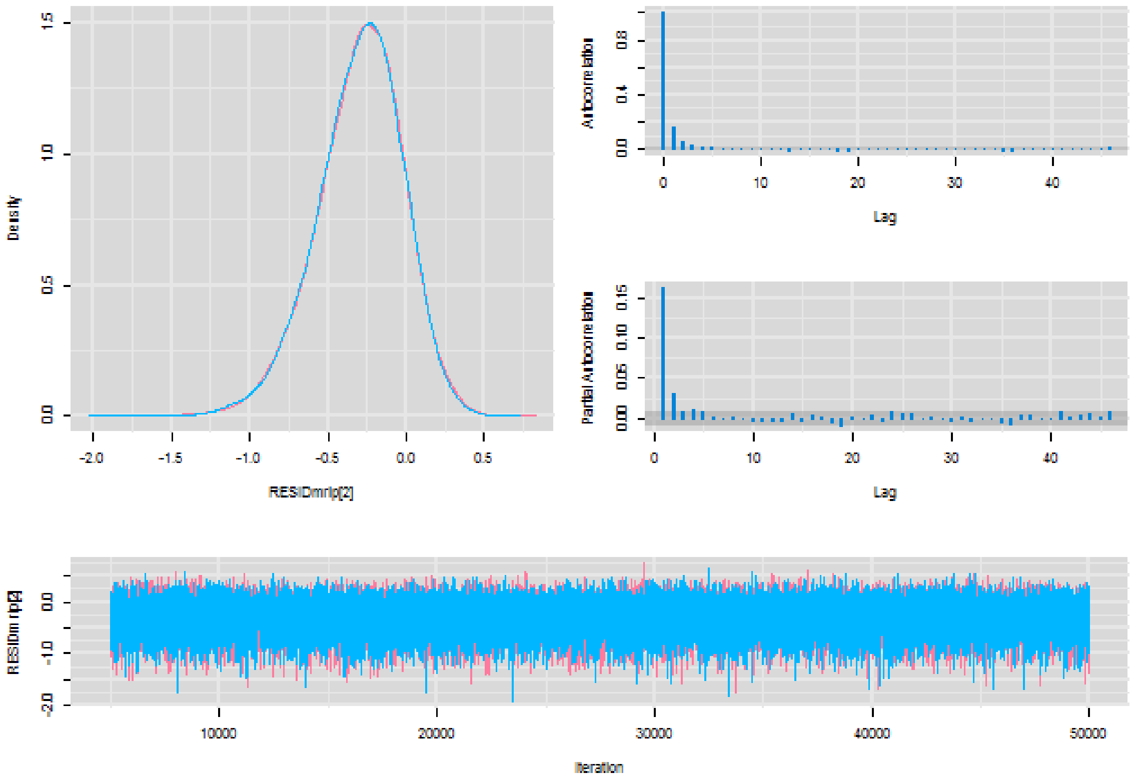
Diagnostics for RESIDmas[32]



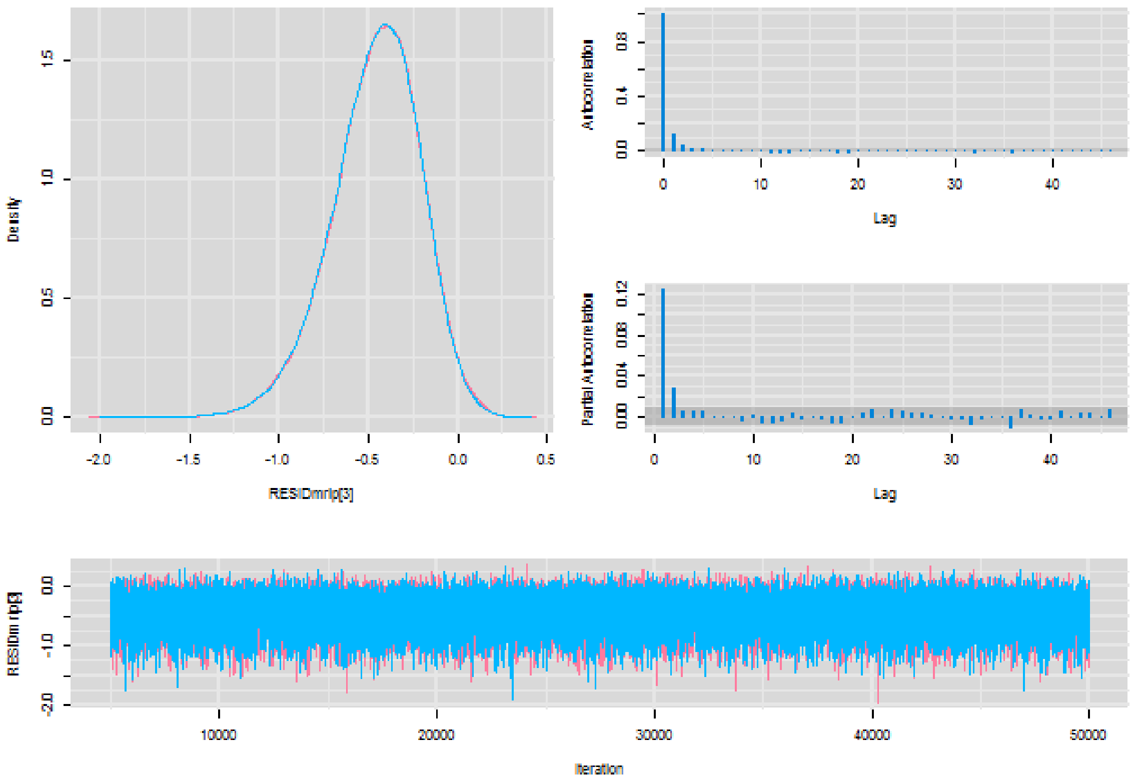
Diagnostics for RESIDmrip[1]



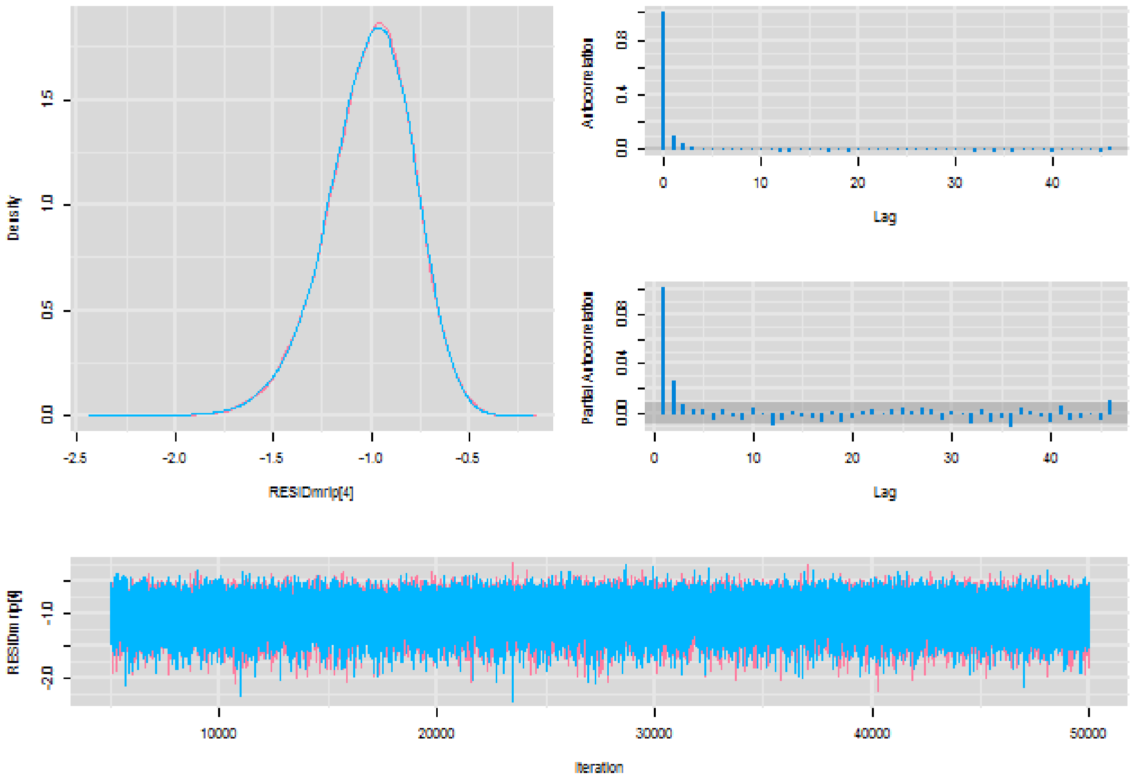
Diagnostics for RESIDmrip[2]



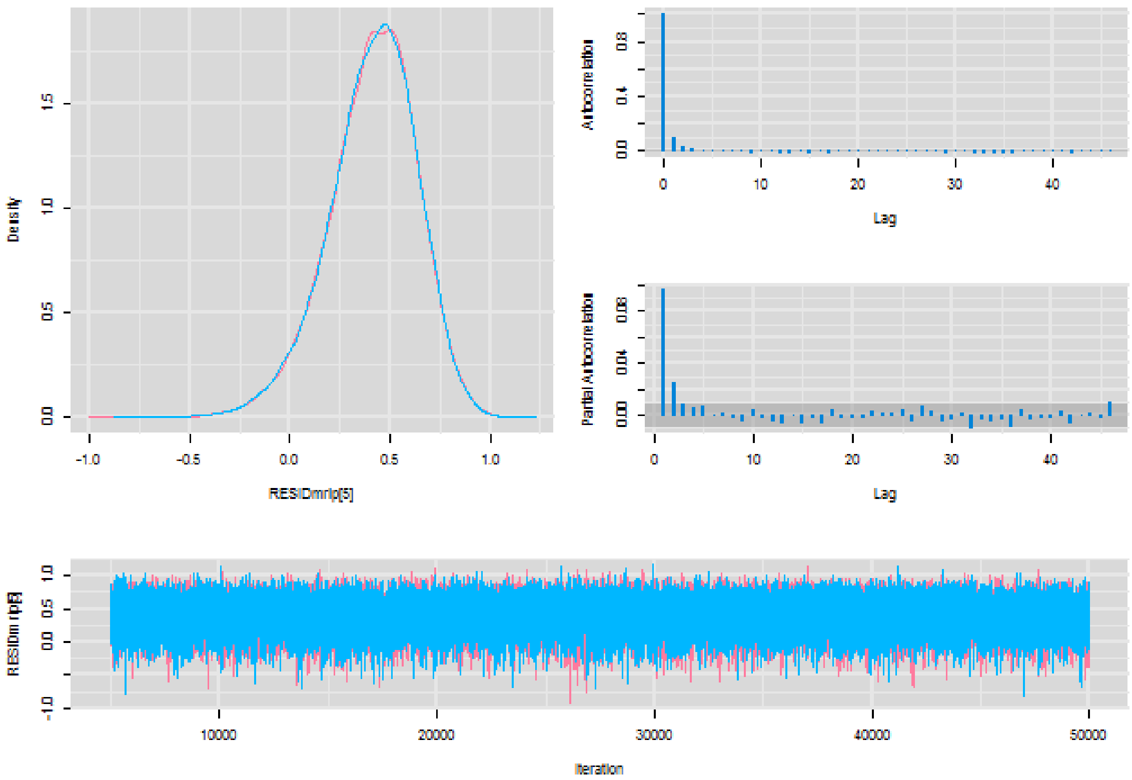
Diagnostics for RESIDmrip[3]



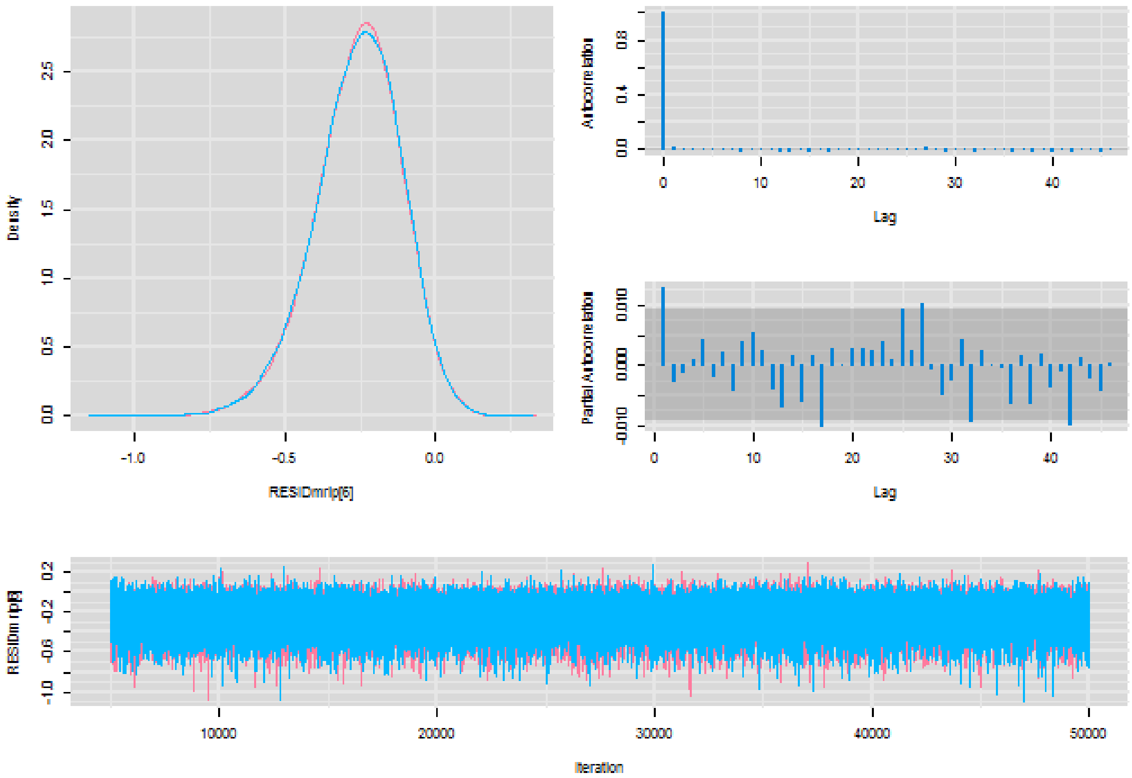
Diagnostics for RESIDmrip[4]



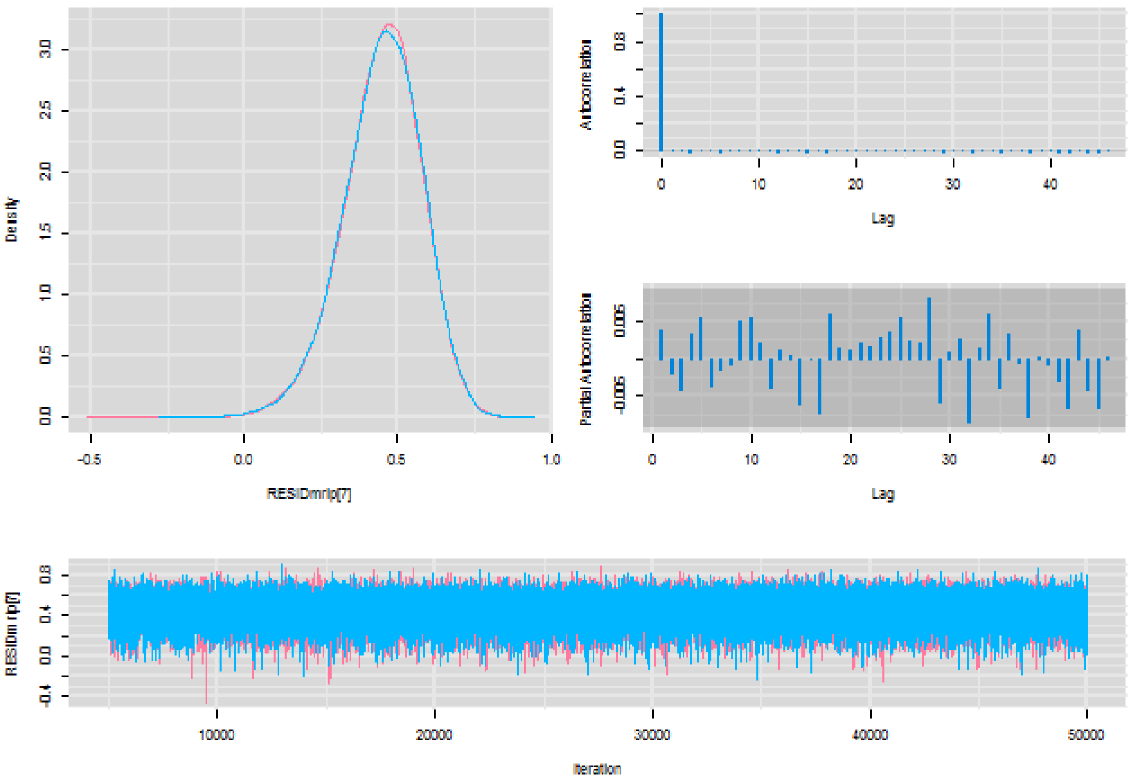
Diagnostics for RESIDmrip[5]



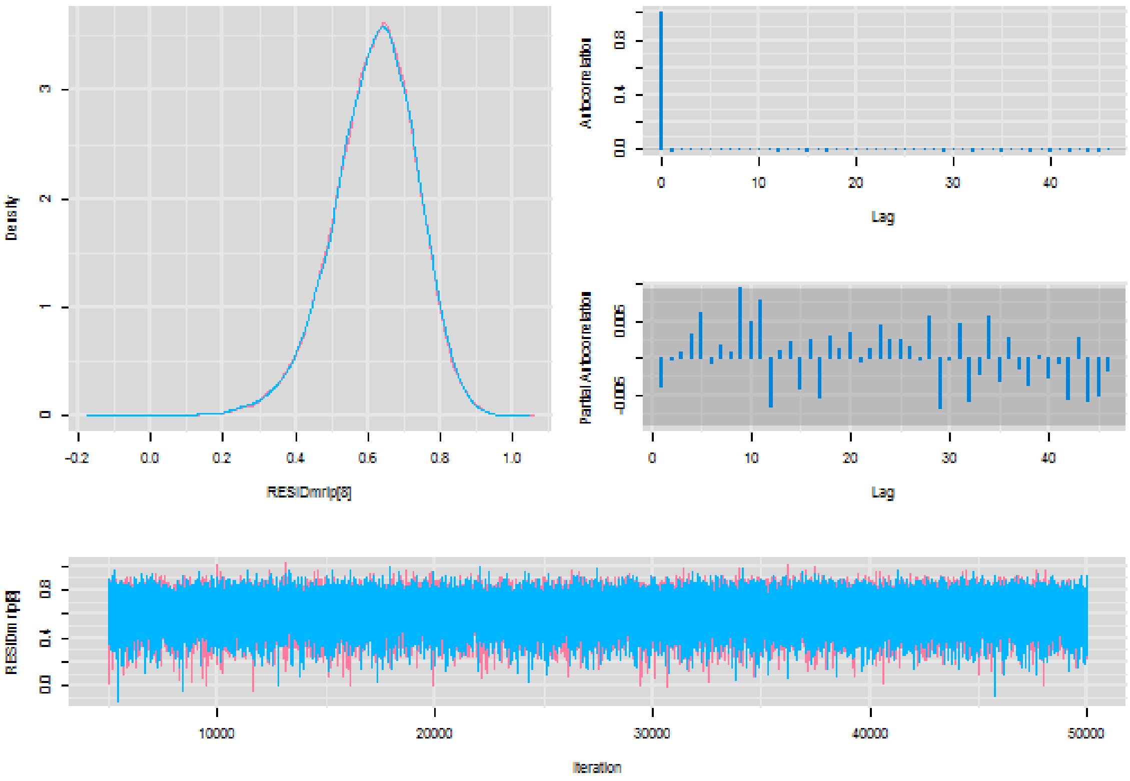
Diagnostics for RESIDmrip[6]



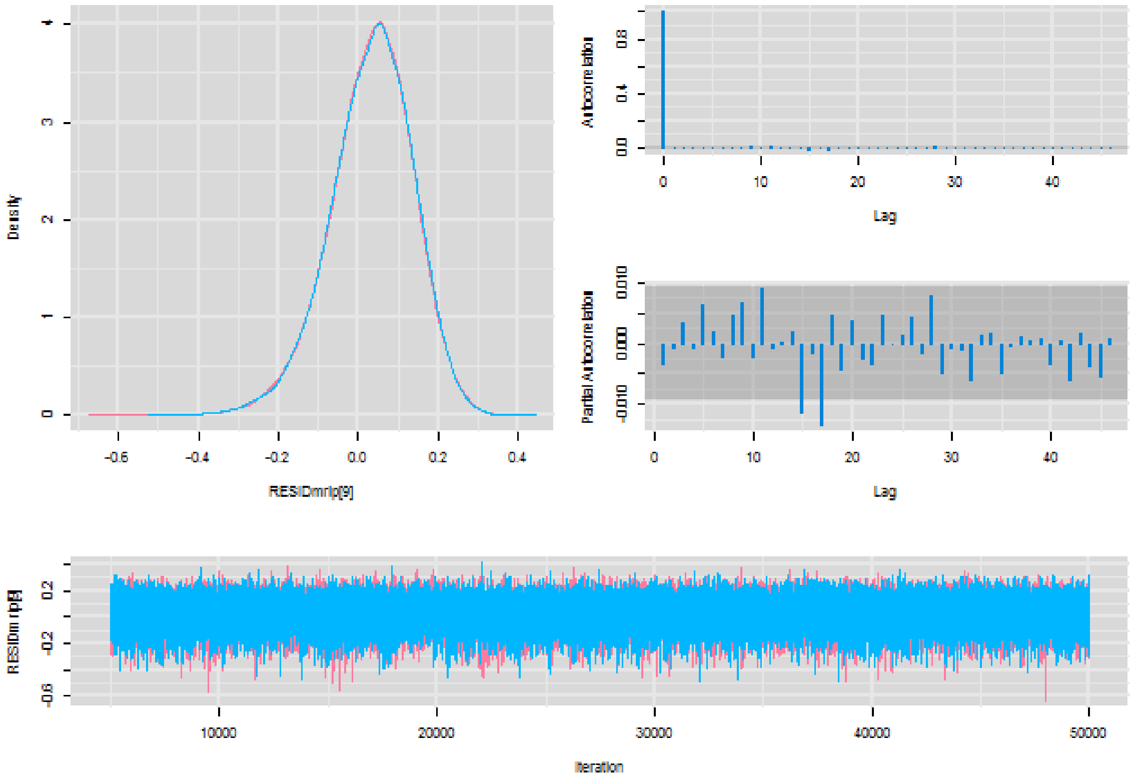
Diagnostics for RESIDmrip[7]



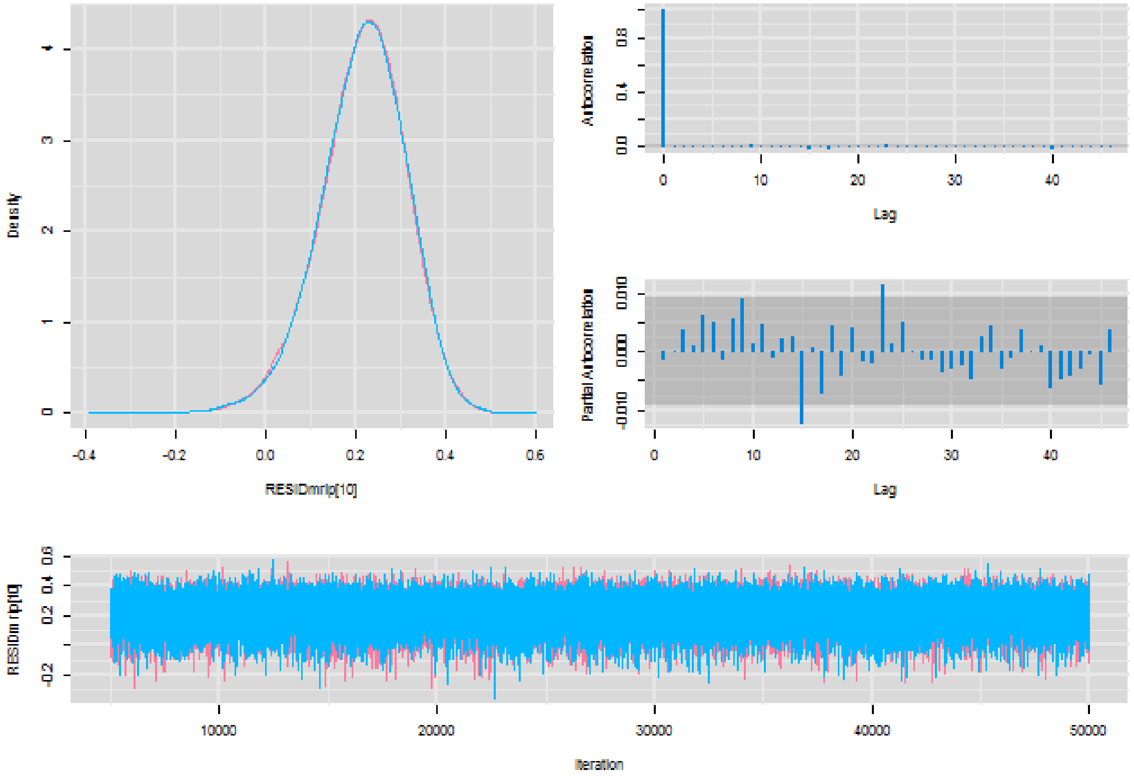
Diagnostics for RESIDmrip[8]



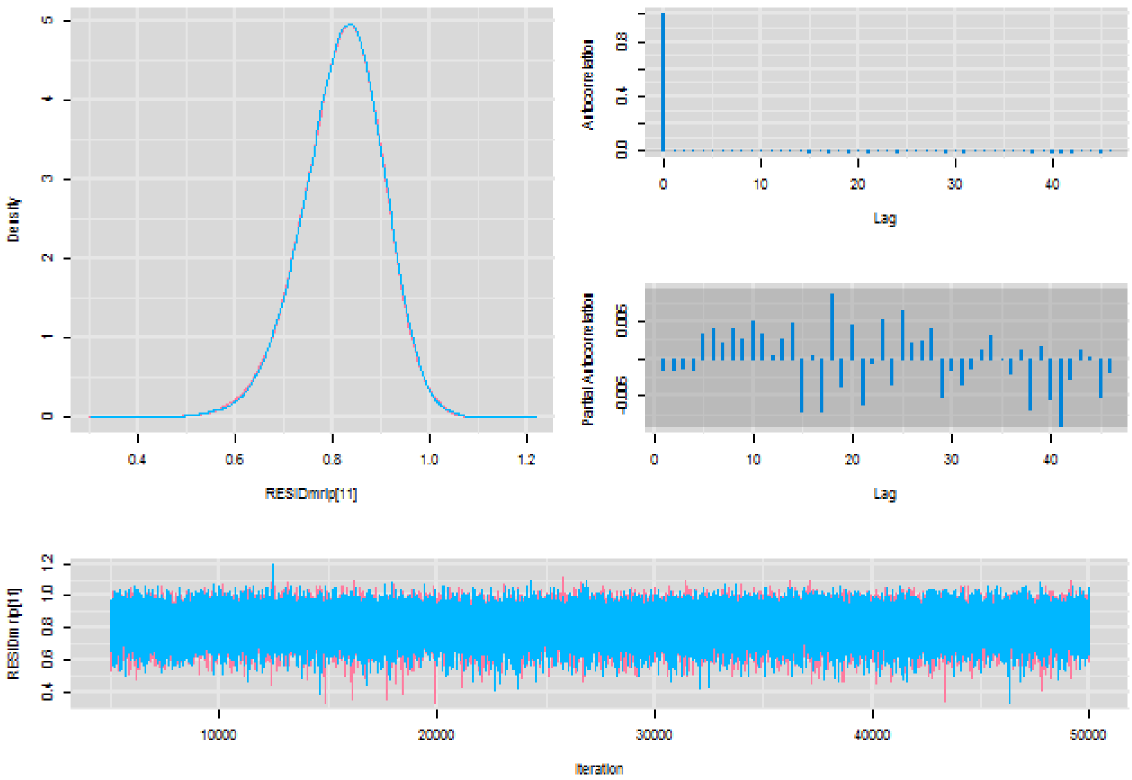
Diagnostics for RESIDmrip[9]



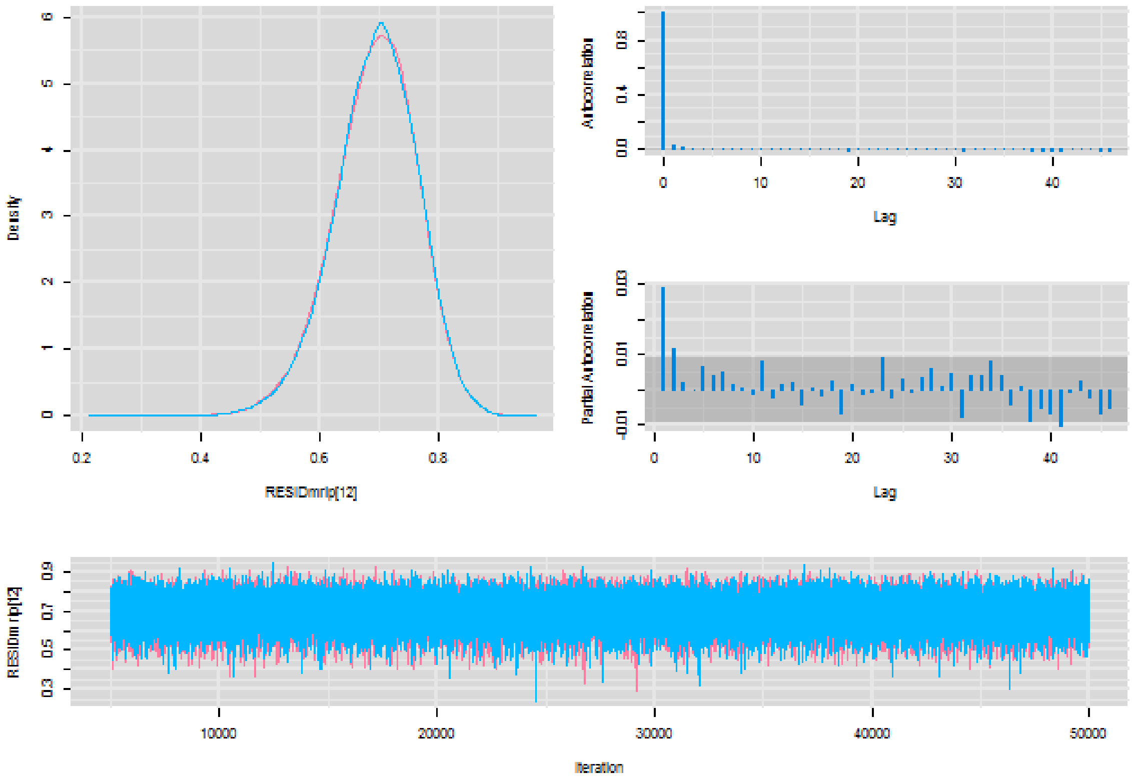
Diagnostics for RESIDmrip[10]



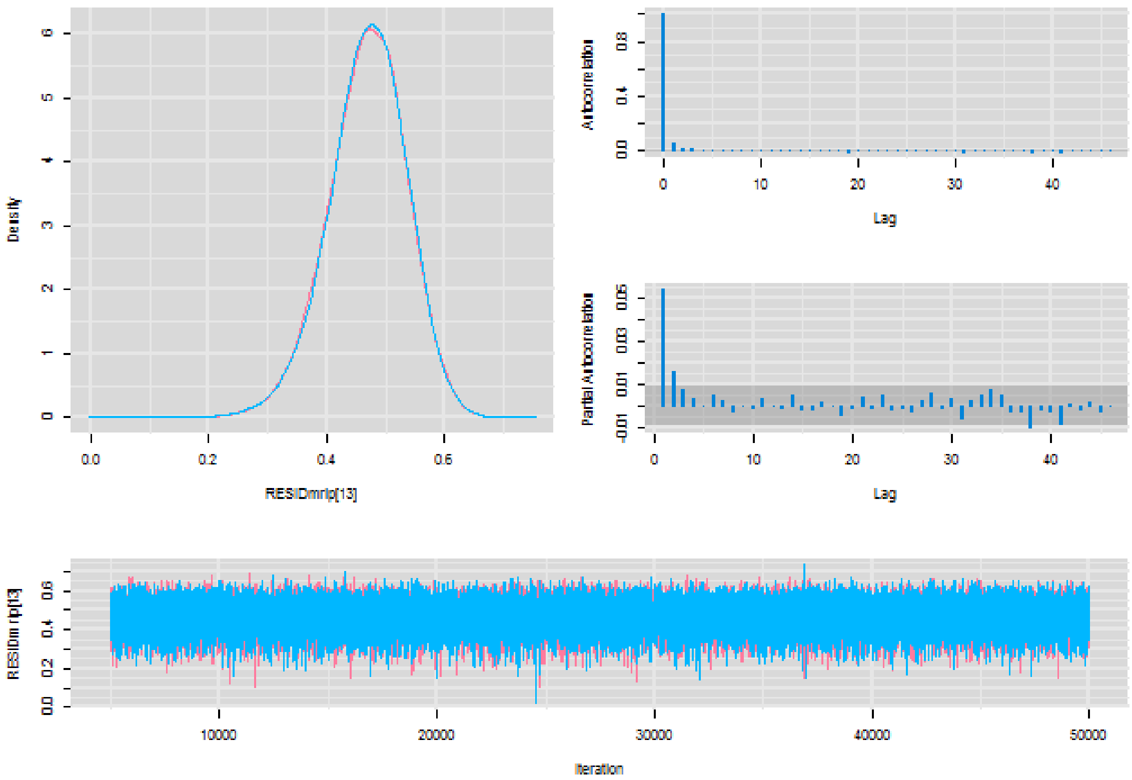
Diagnostics for RESIDmrip[11]



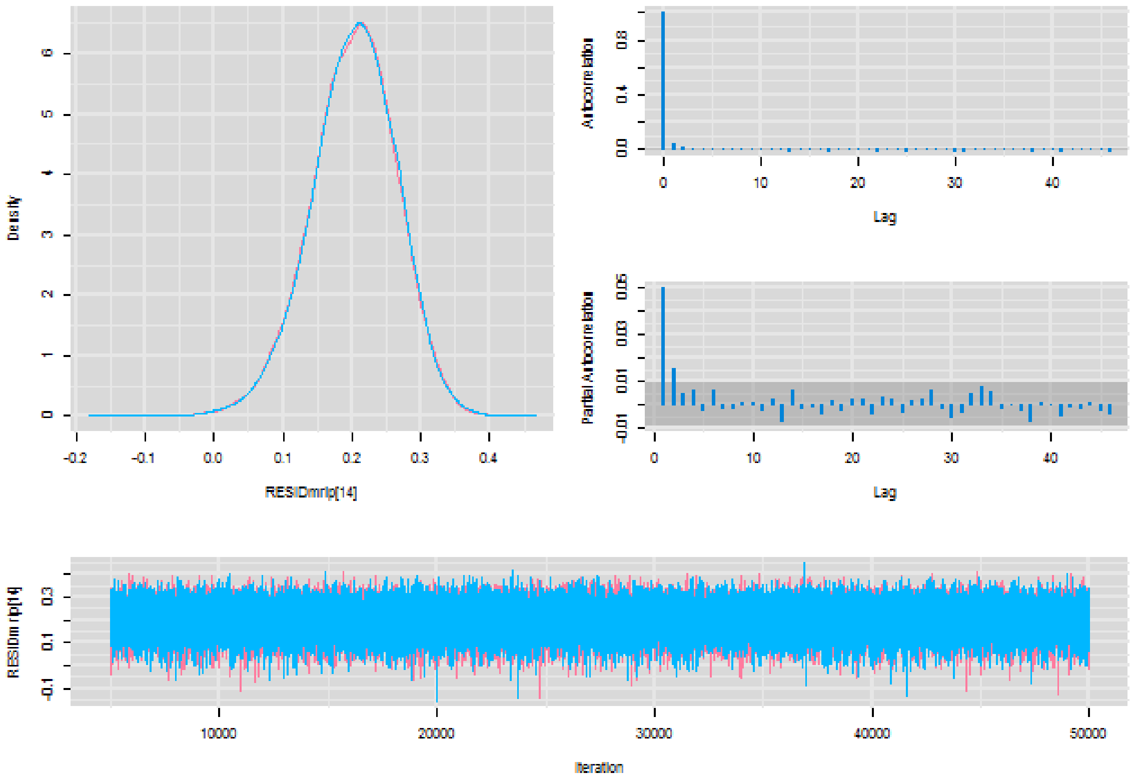
Diagnostics for RESIDmrip[12]



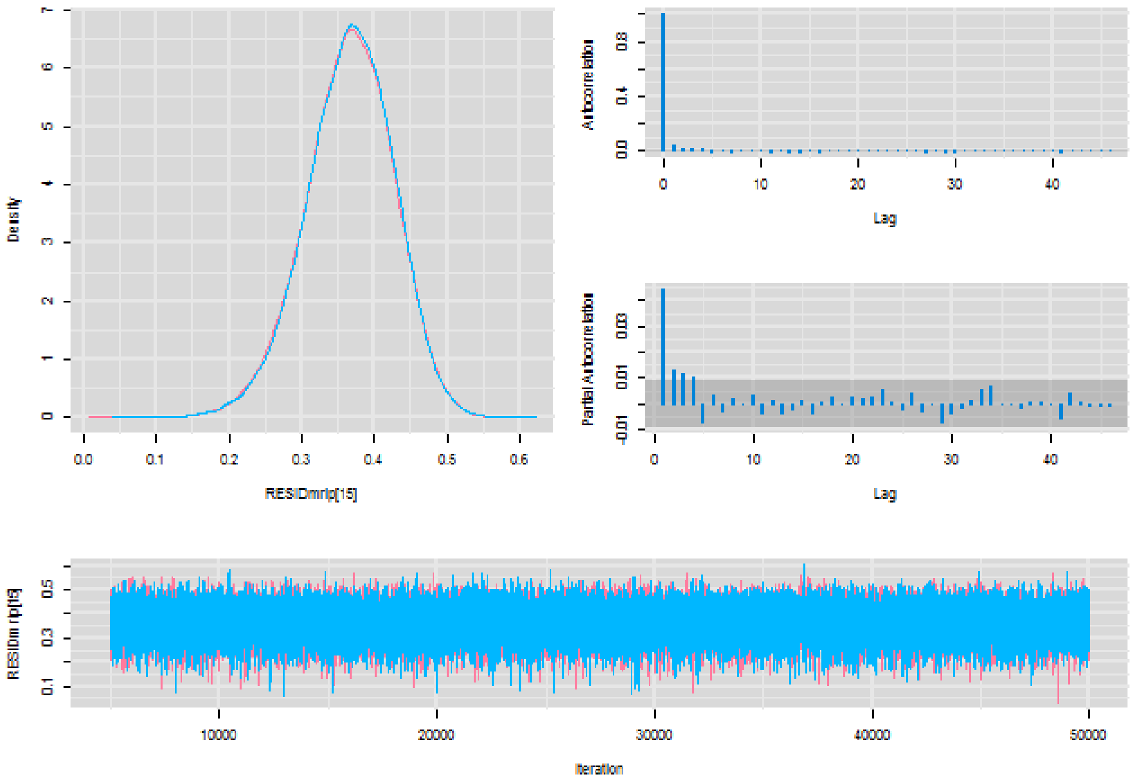
Diagnostics for RESIDmrip[13]



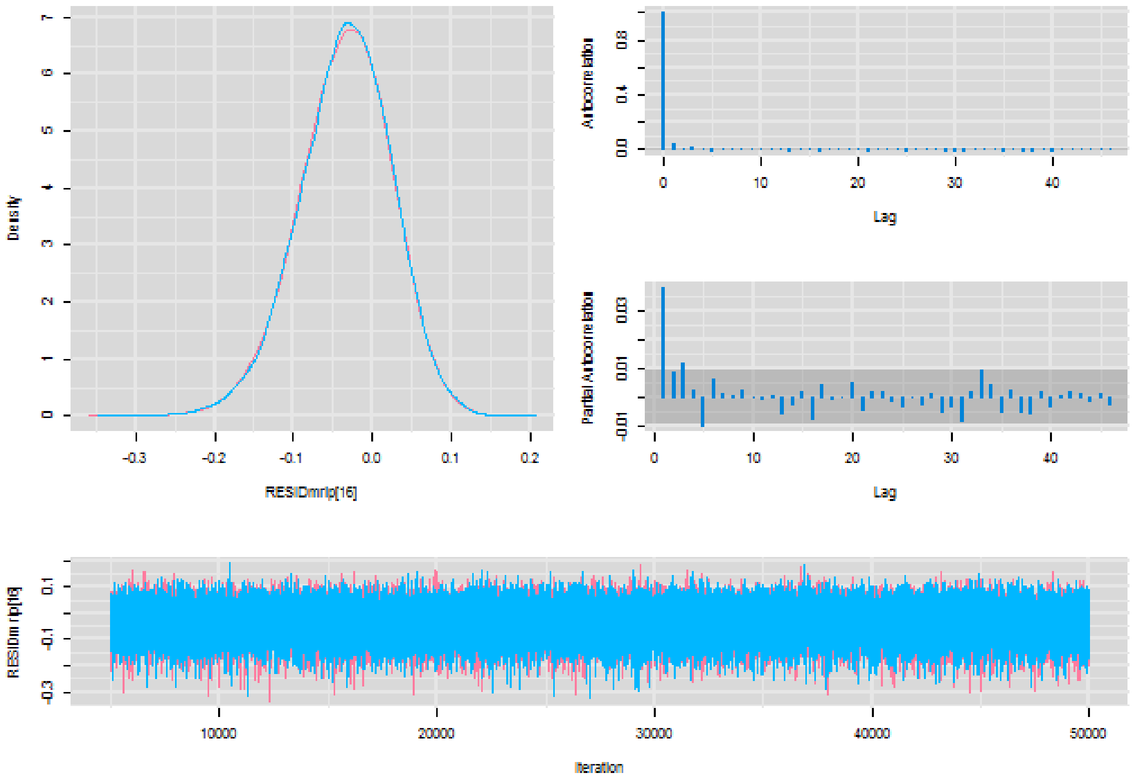
Diagnostics for RESIDmrip[14]



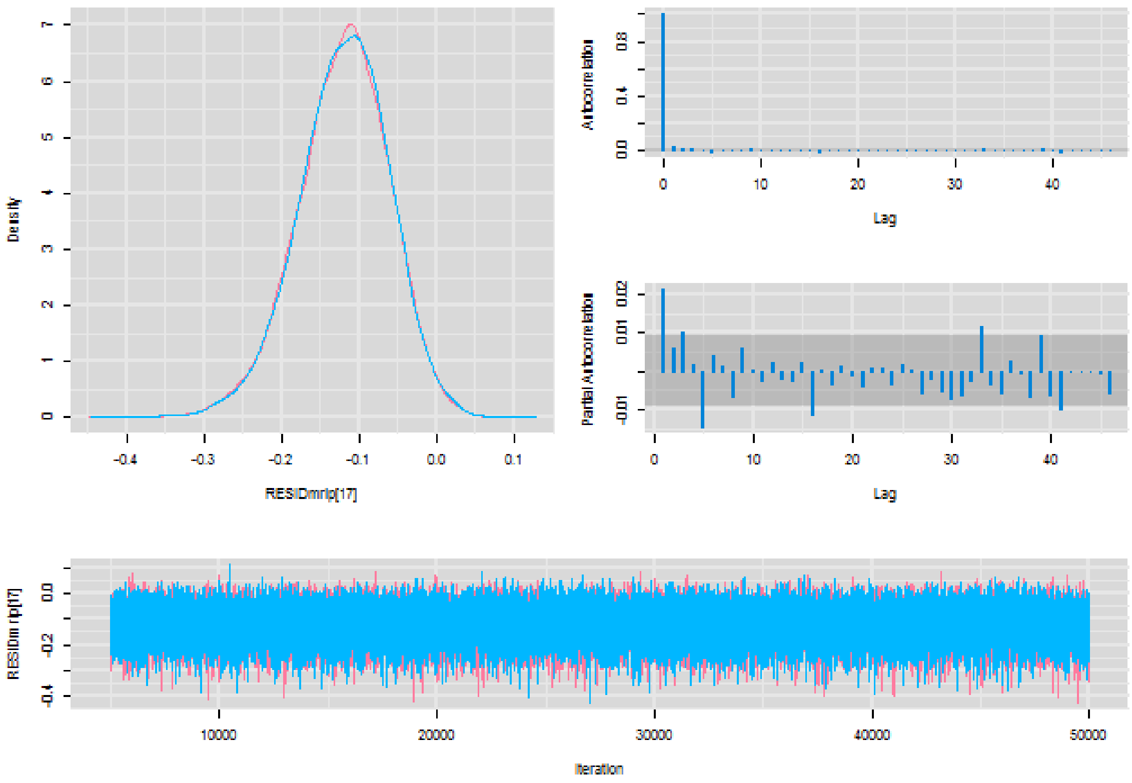
Diagnostics for RESIDmrip[15]



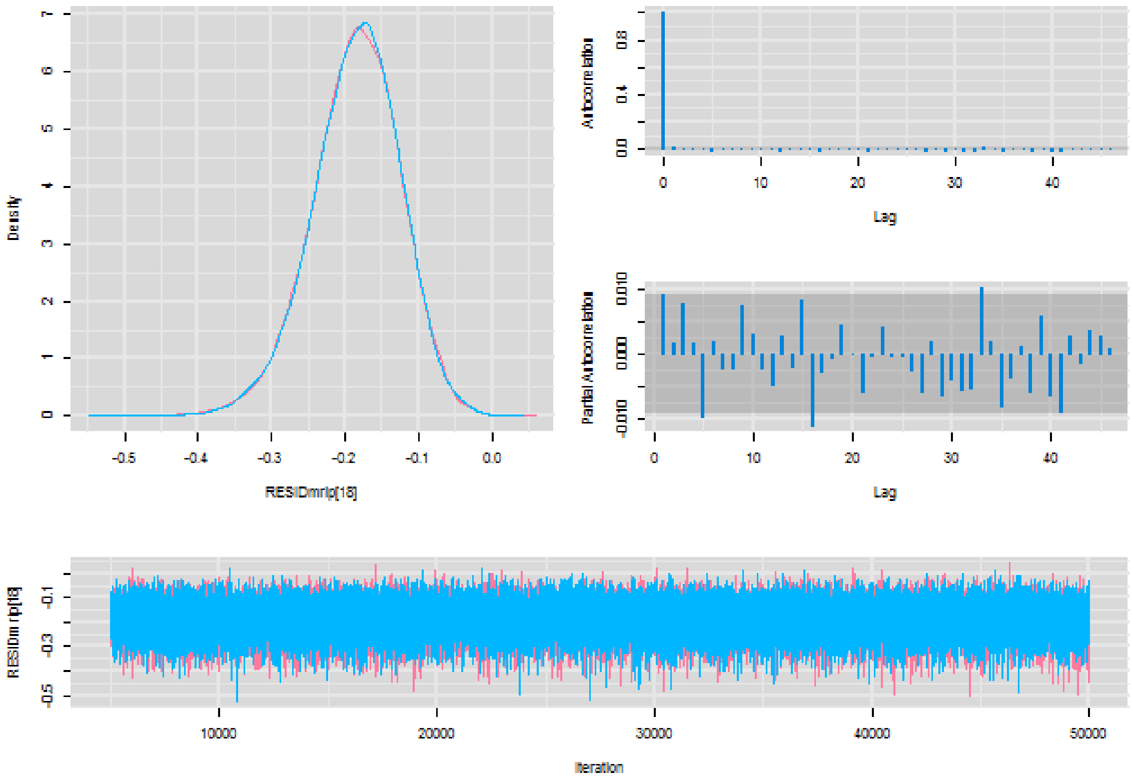
Diagnostics for RESIDmrip[16]



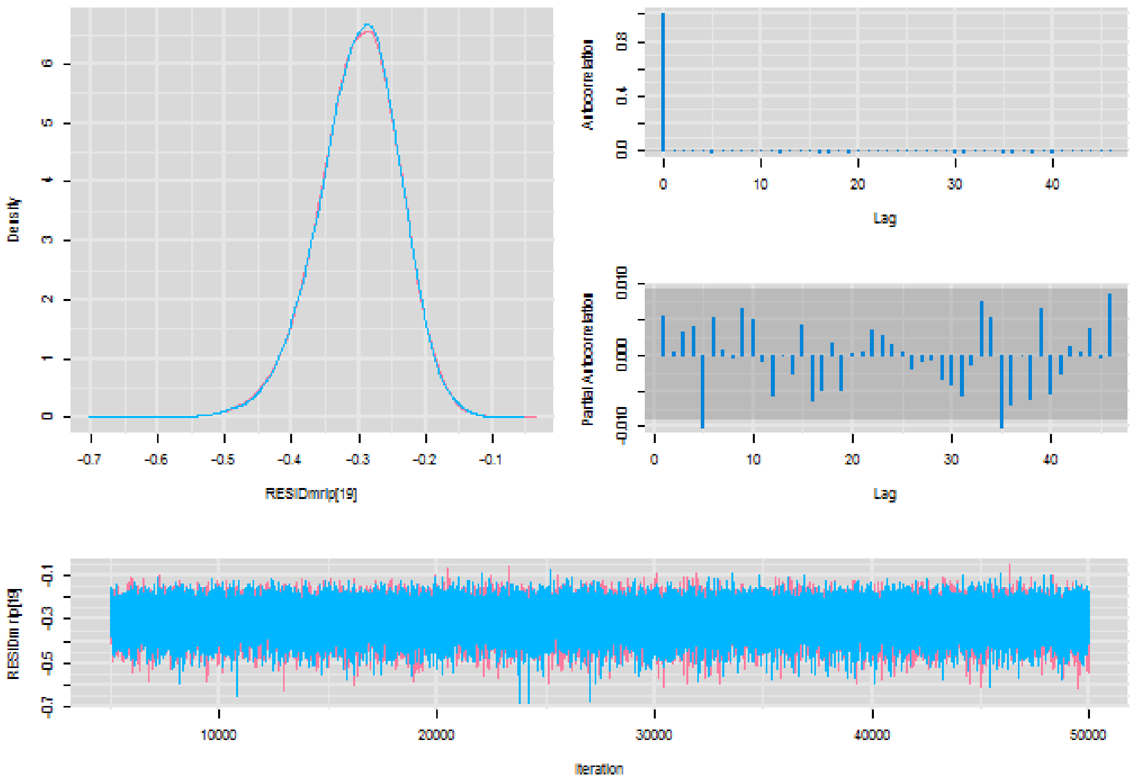
Diagnostics for RESIDmrip[17]



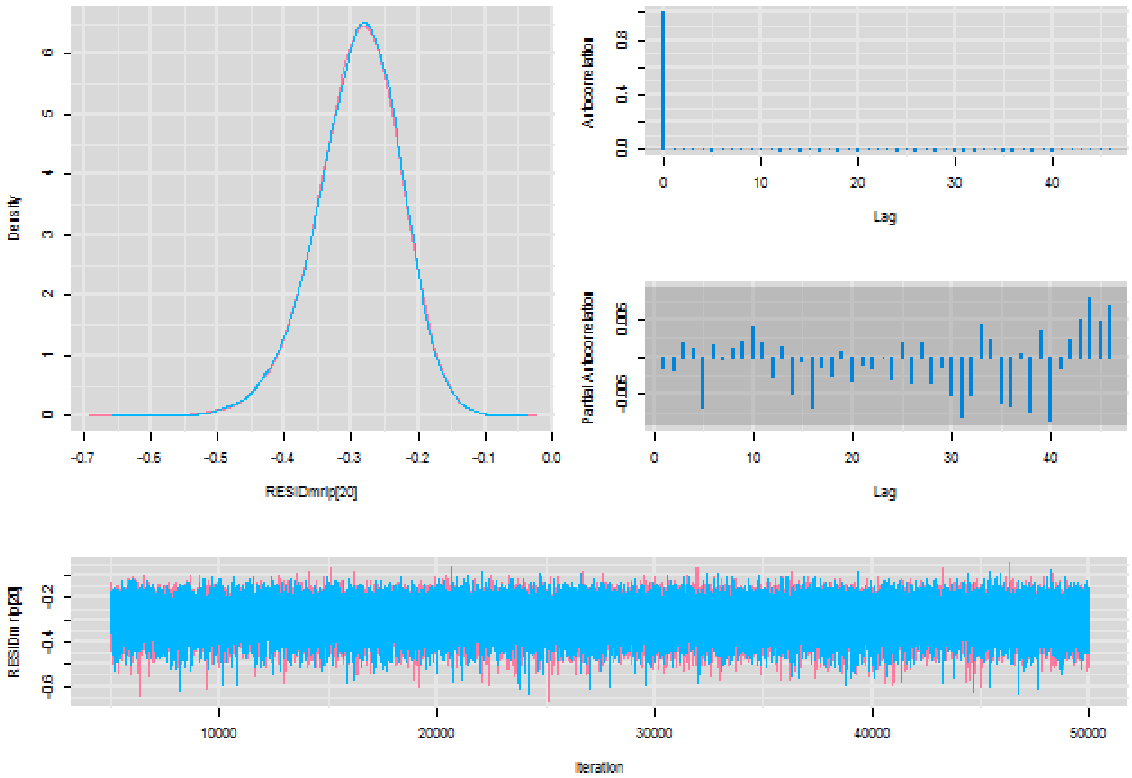
Diagnostics for RESIDmrip[18]



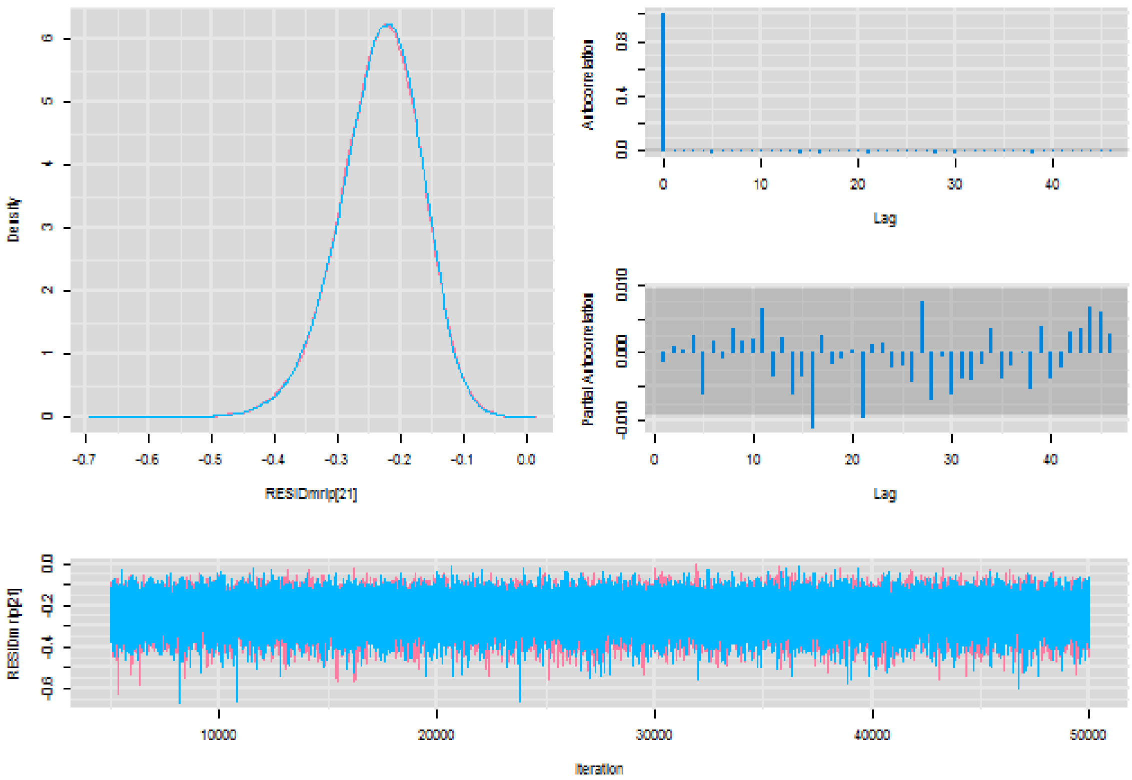
Diagnostics for RESIDmrip[19]



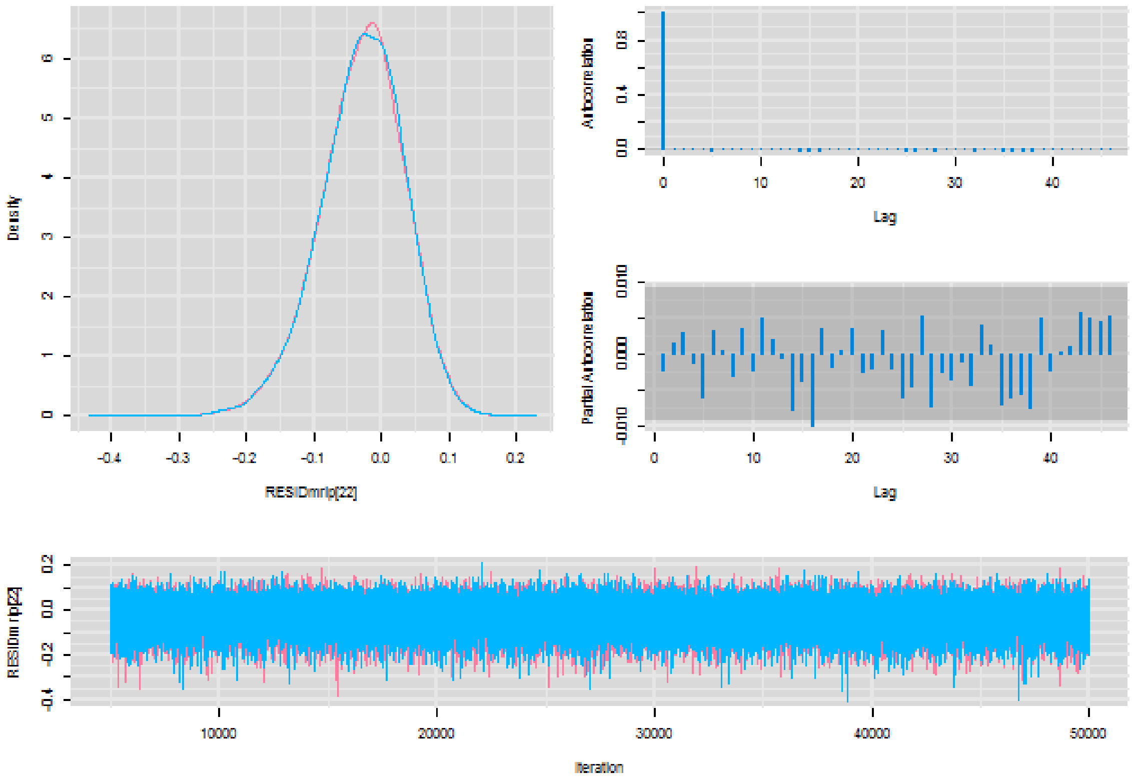
Diagnostics for RESIDmrip[20]



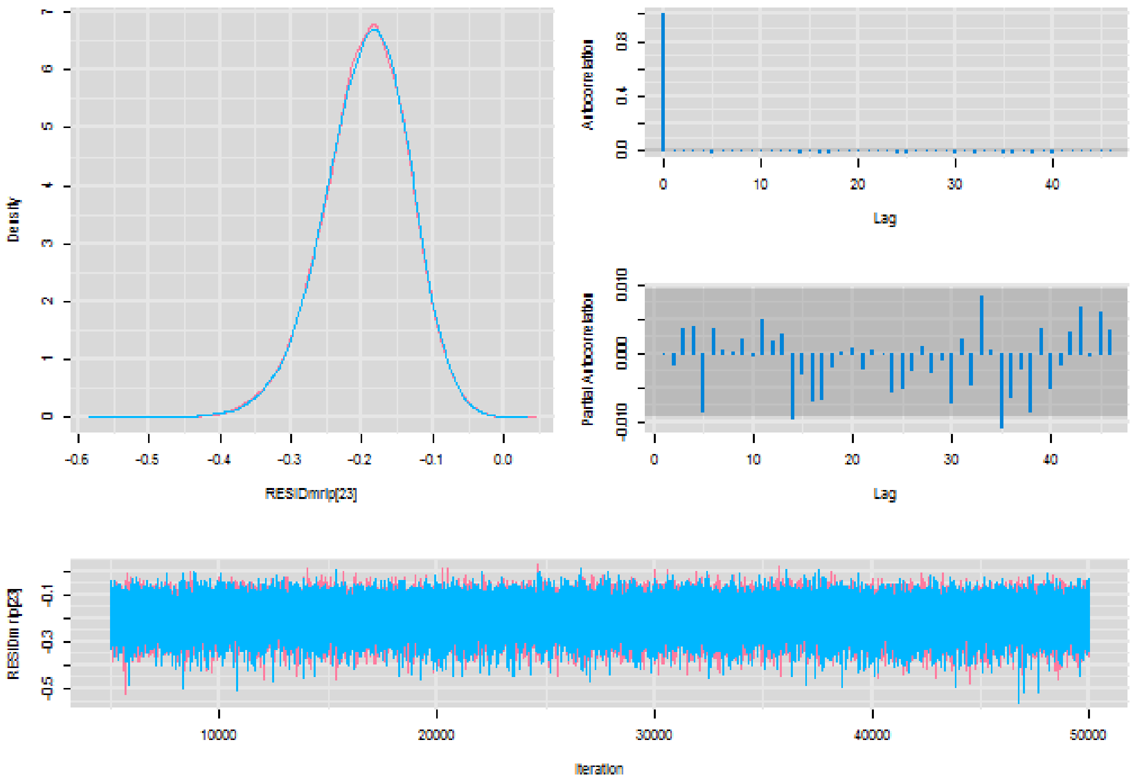
Diagnostics for RESIDmrip[21]



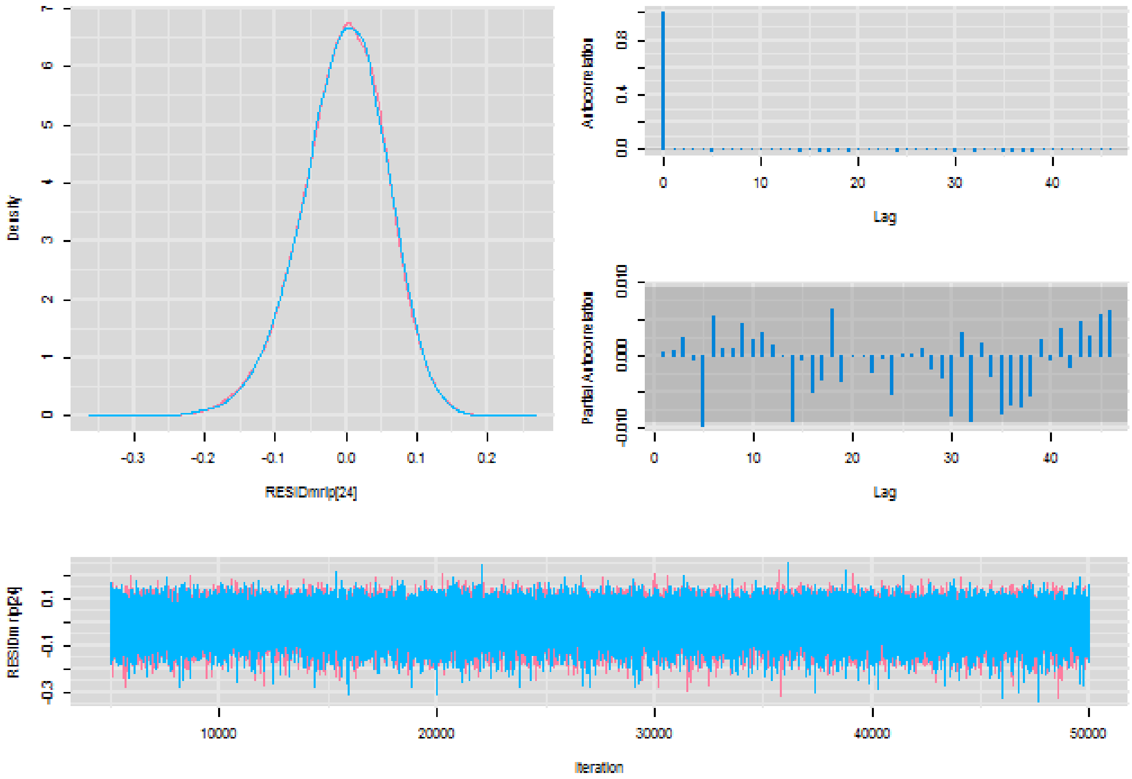
Diagnostics for RESIDmrip[22]



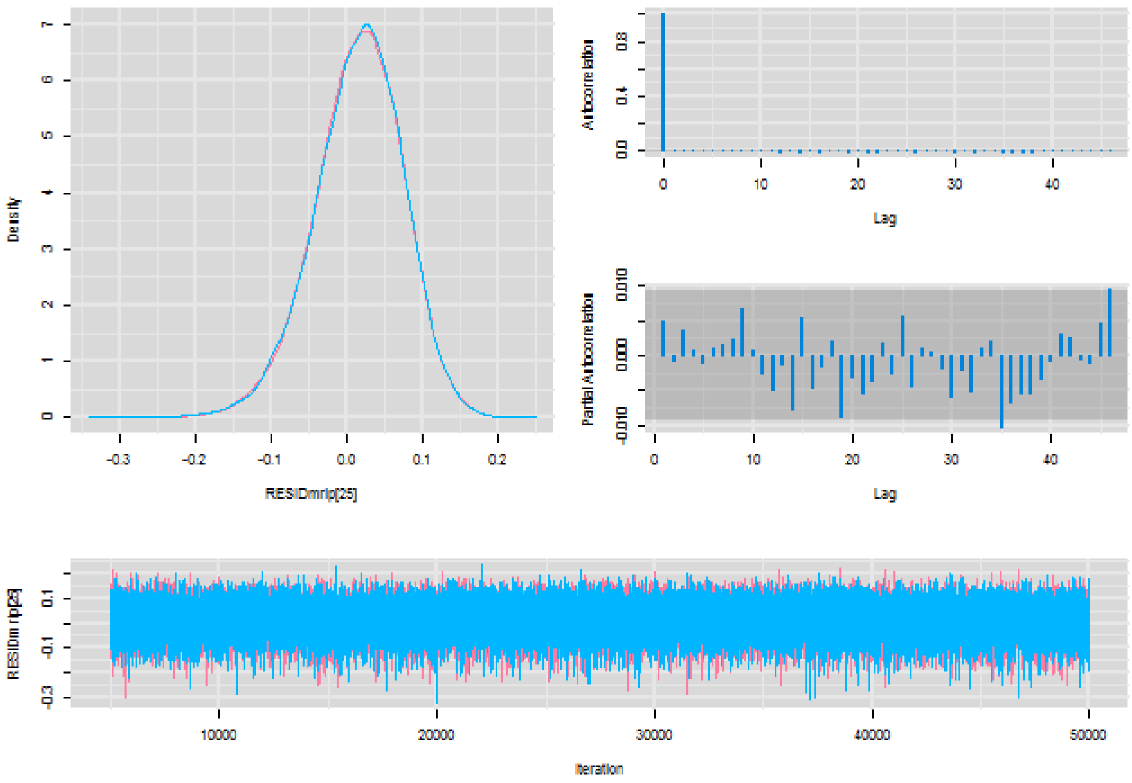
Diagnostics for RESIDmrip[23]



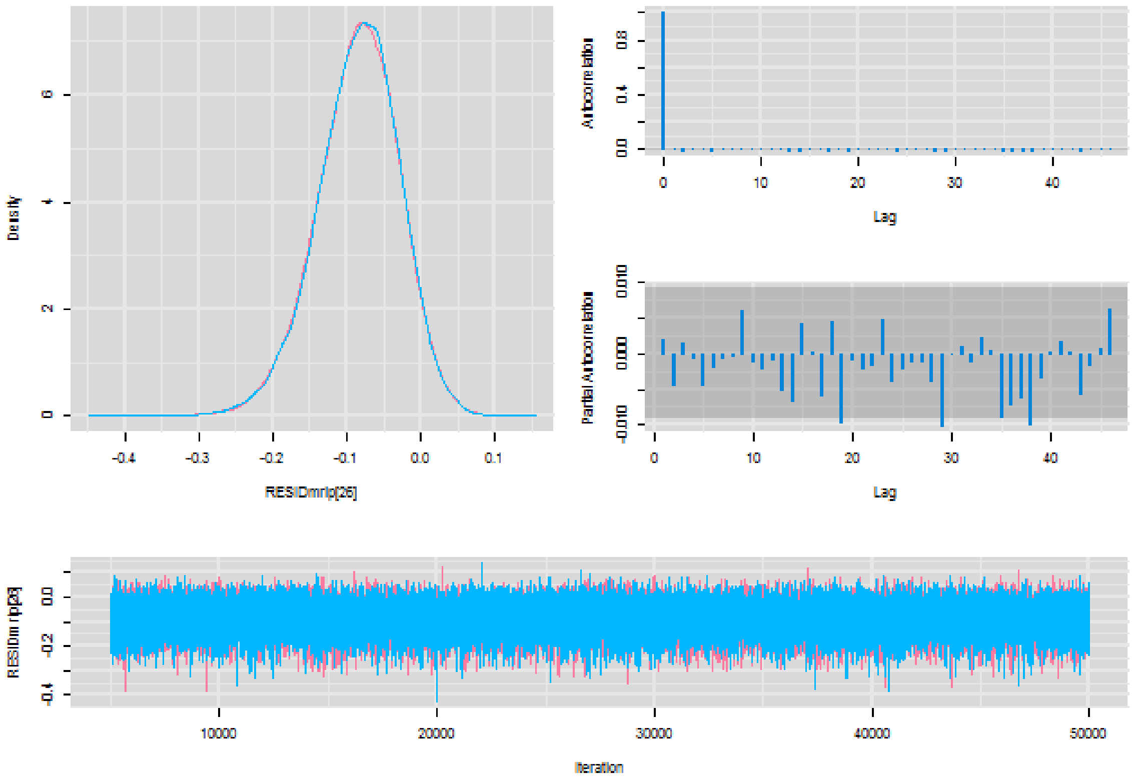
Diagnostics for RESIDmrip[24]



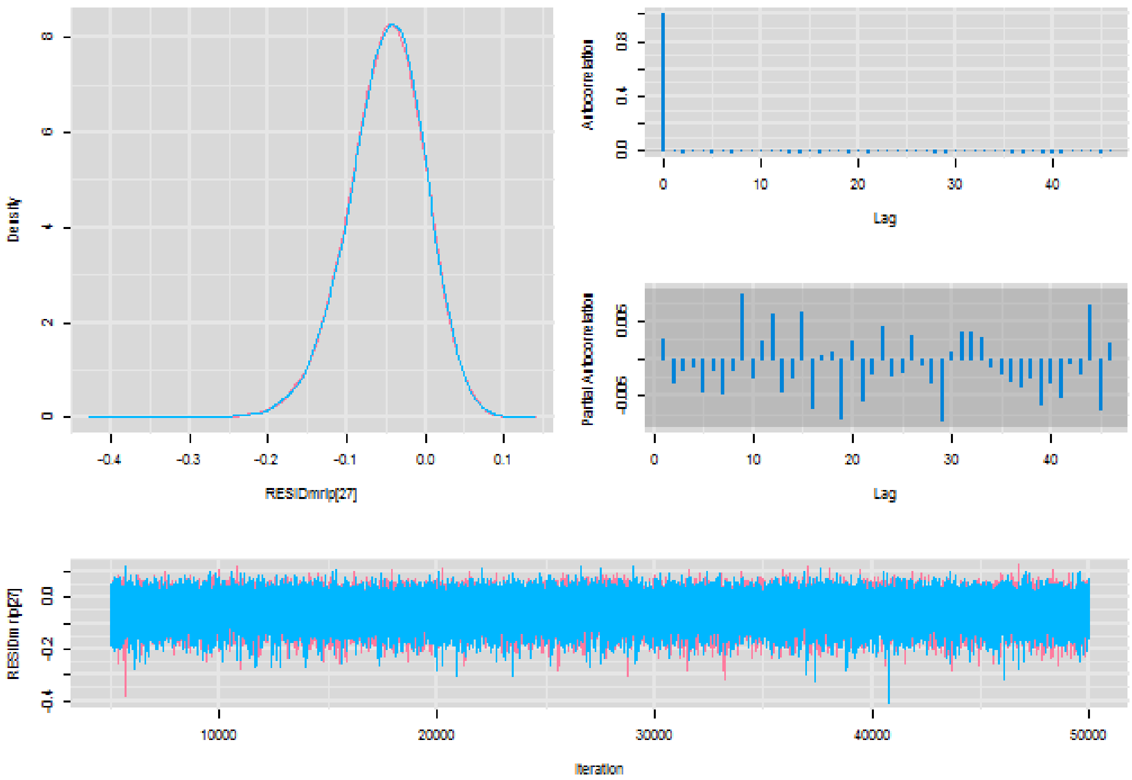
Diagnostics for RESIDmrip[25]



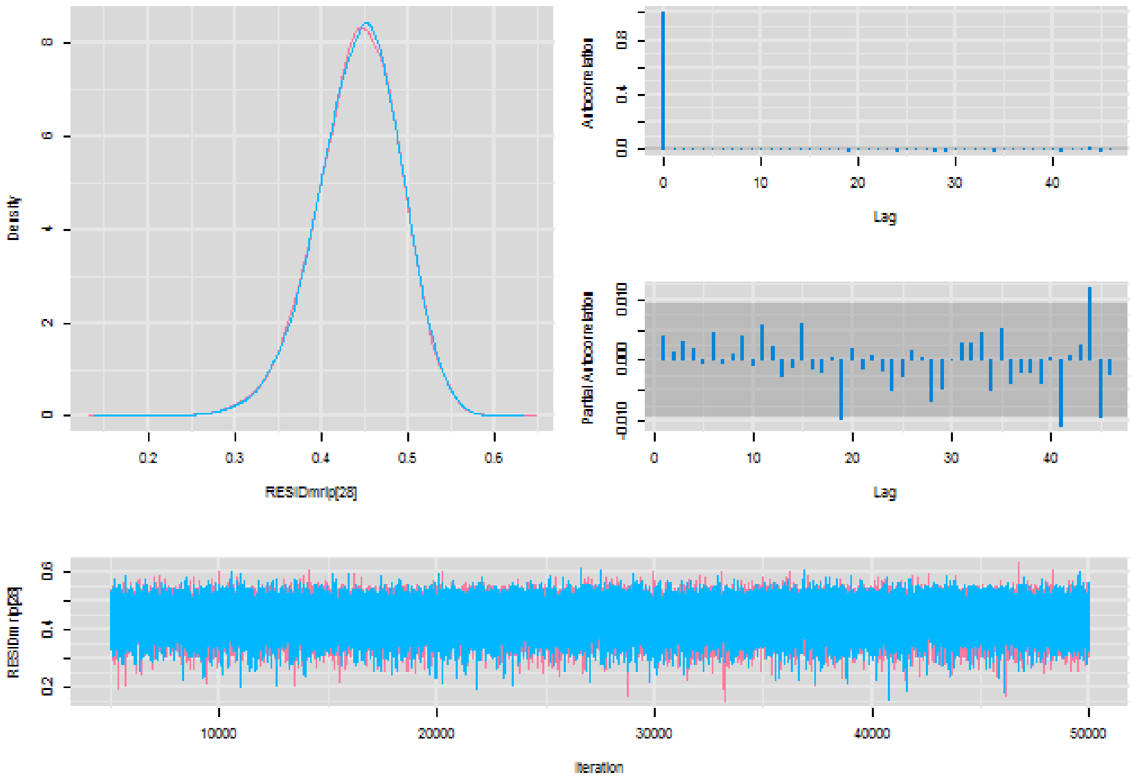
Diagnostics for RESIDmrip[26]



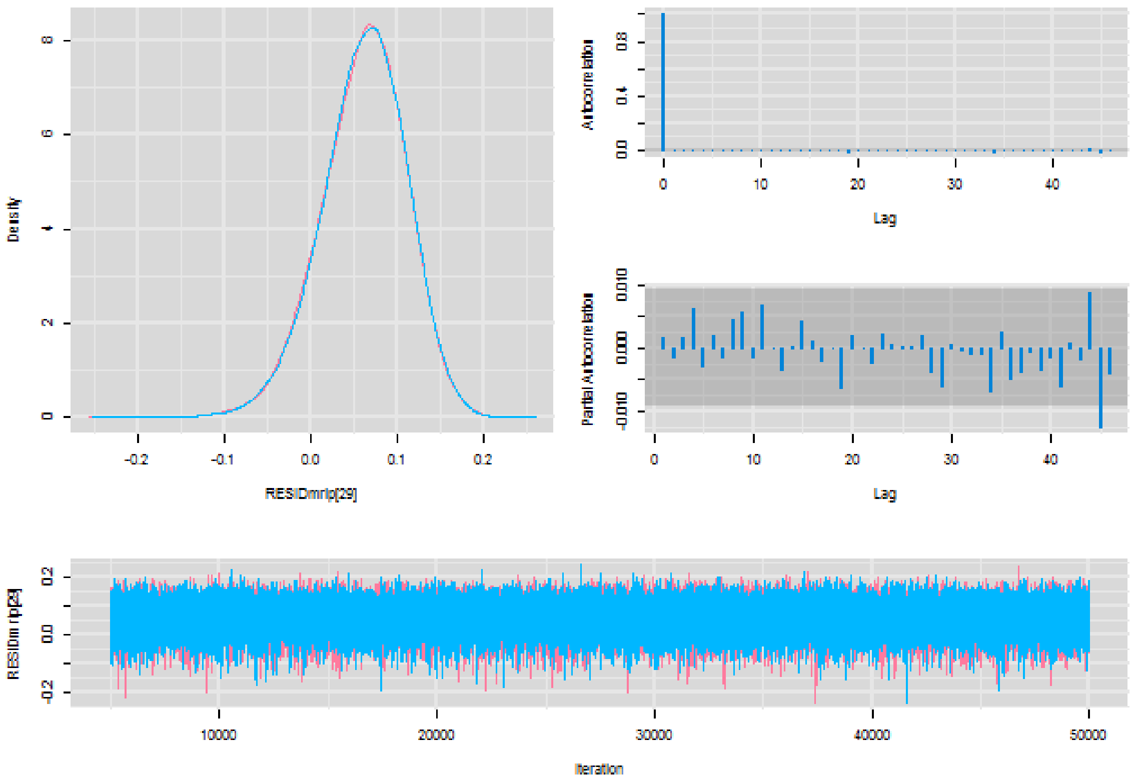
Diagnostics for RESIDmrip[27]



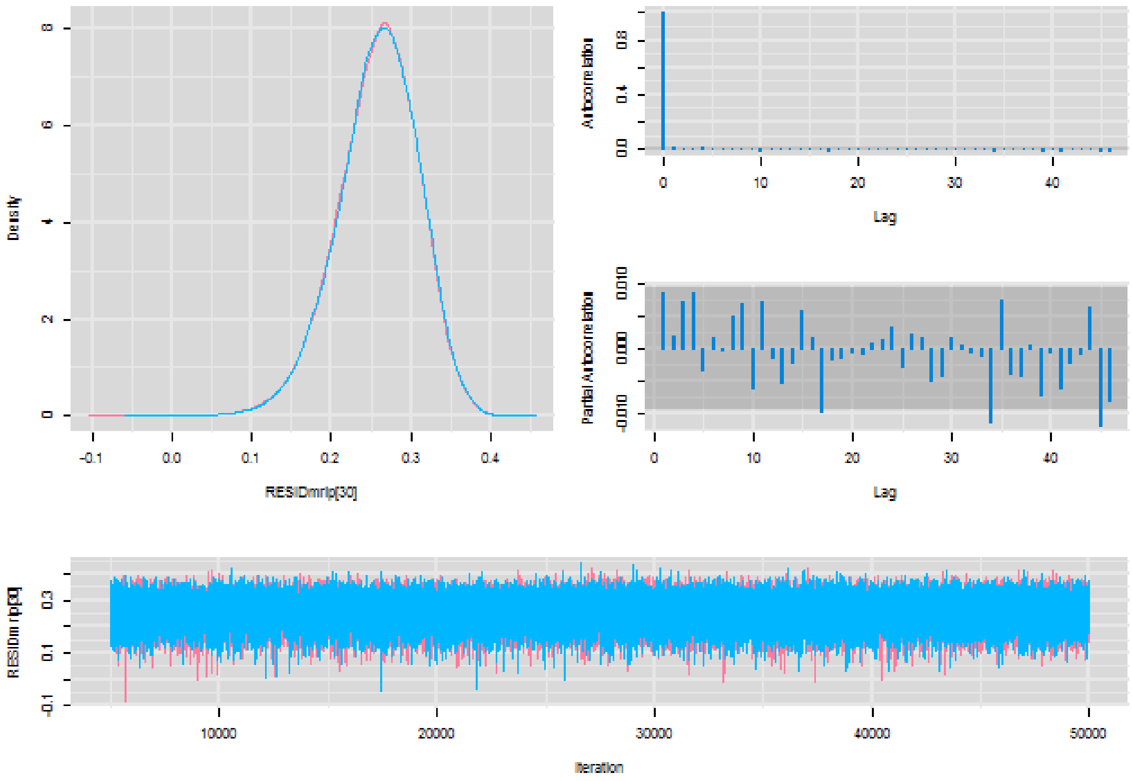
Diagnostics for RESIDmrip[28]



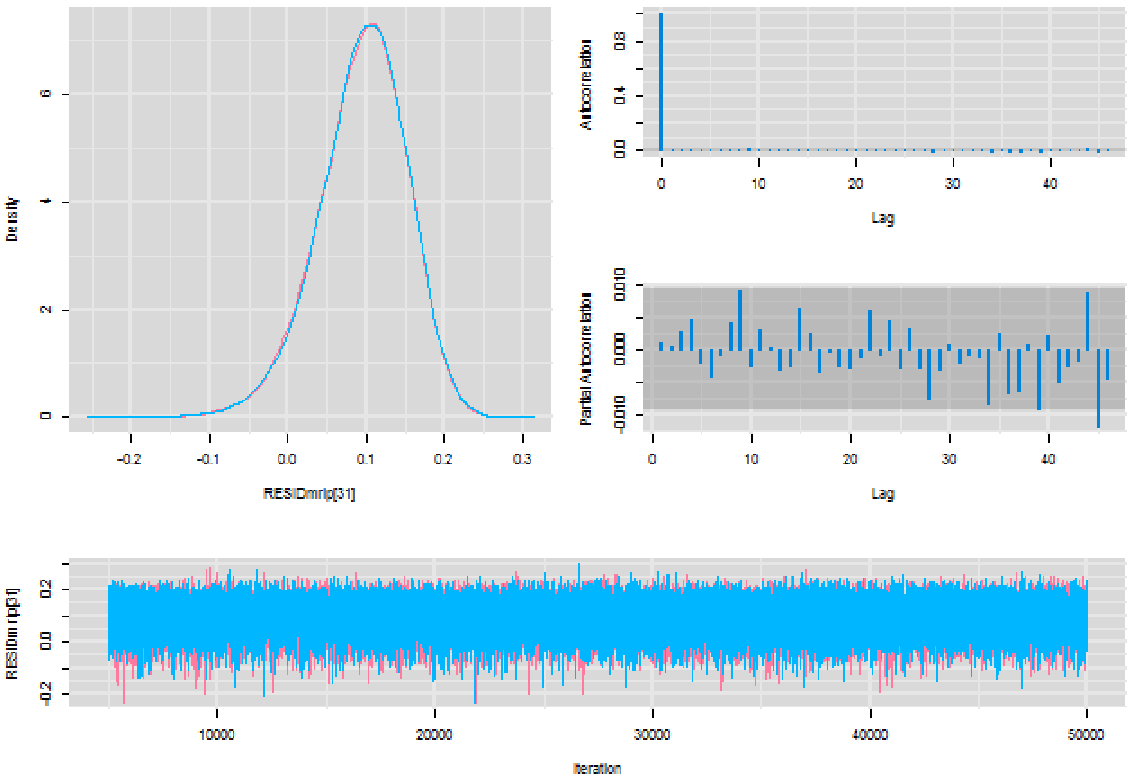
Diagnostics for RESIDmrip[29]



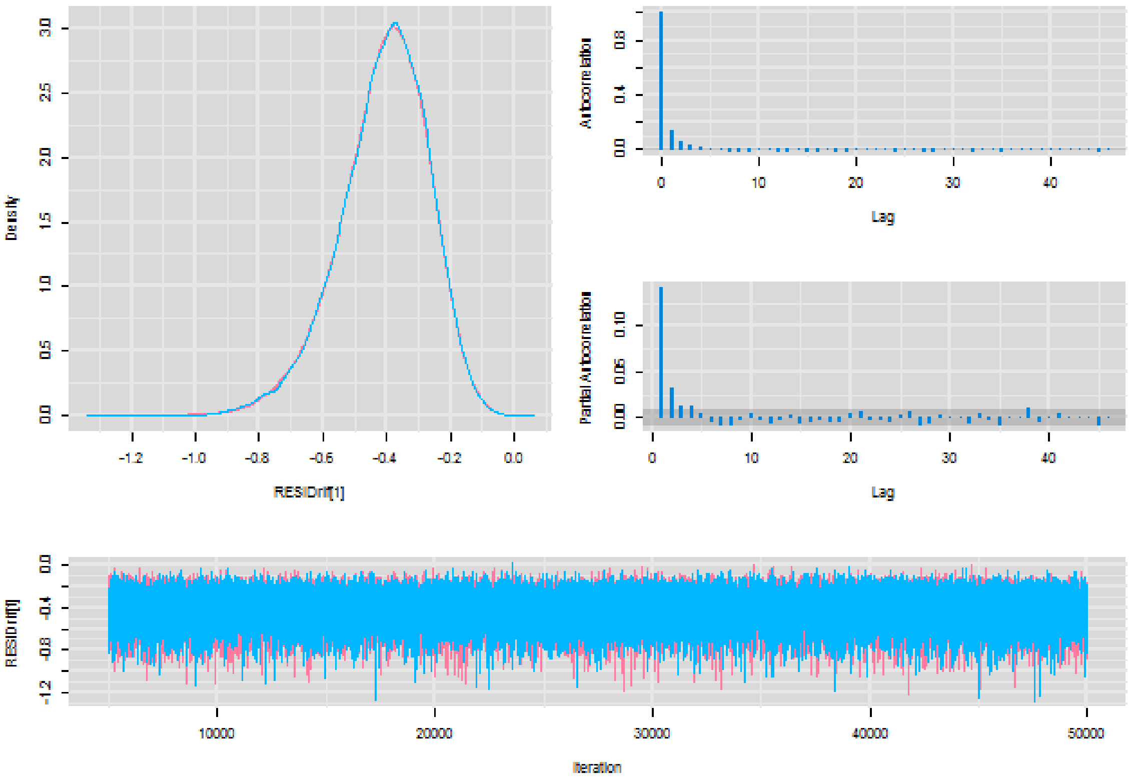
Diagnostics for RESIDmrip[30]



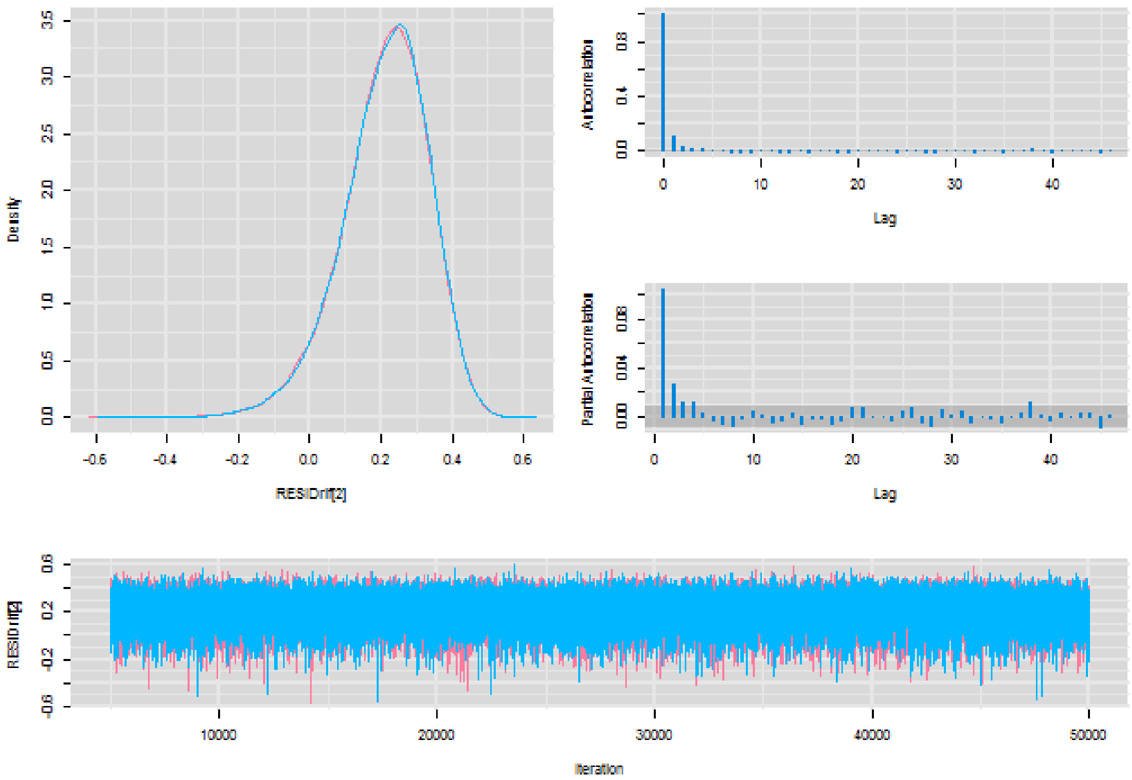
Diagnostics for RESIDmrip[31]



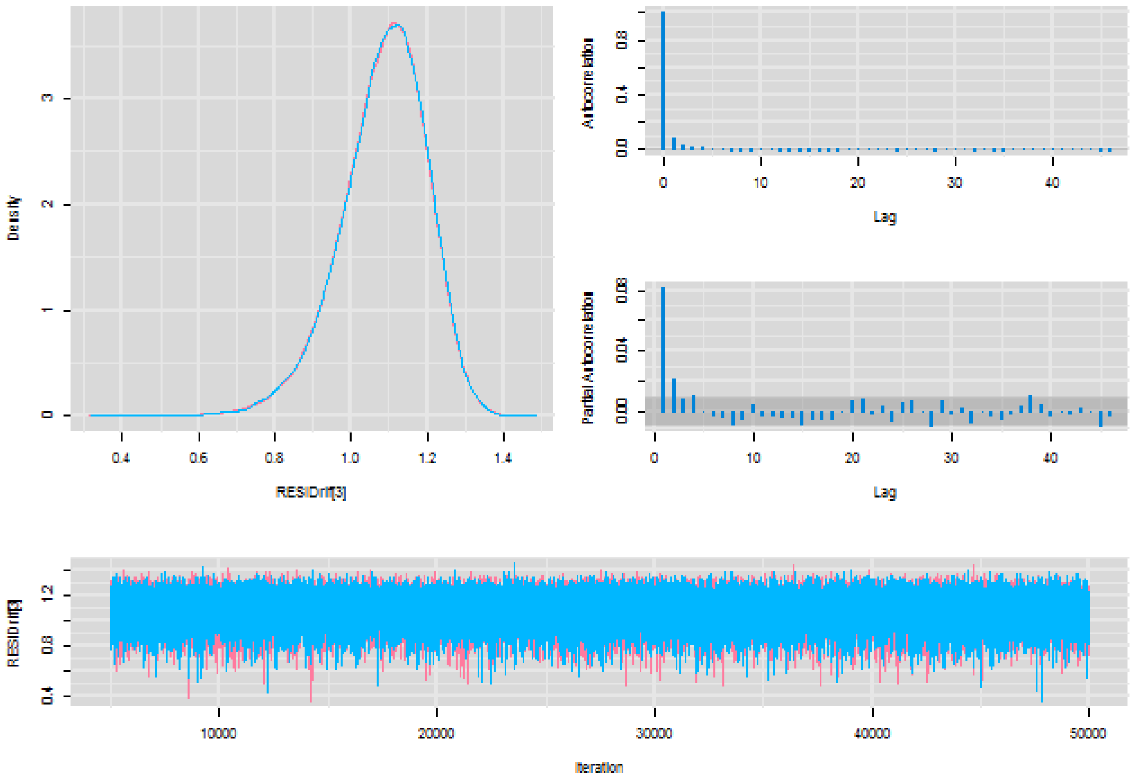
Diagnostics for RESIDrif[1]

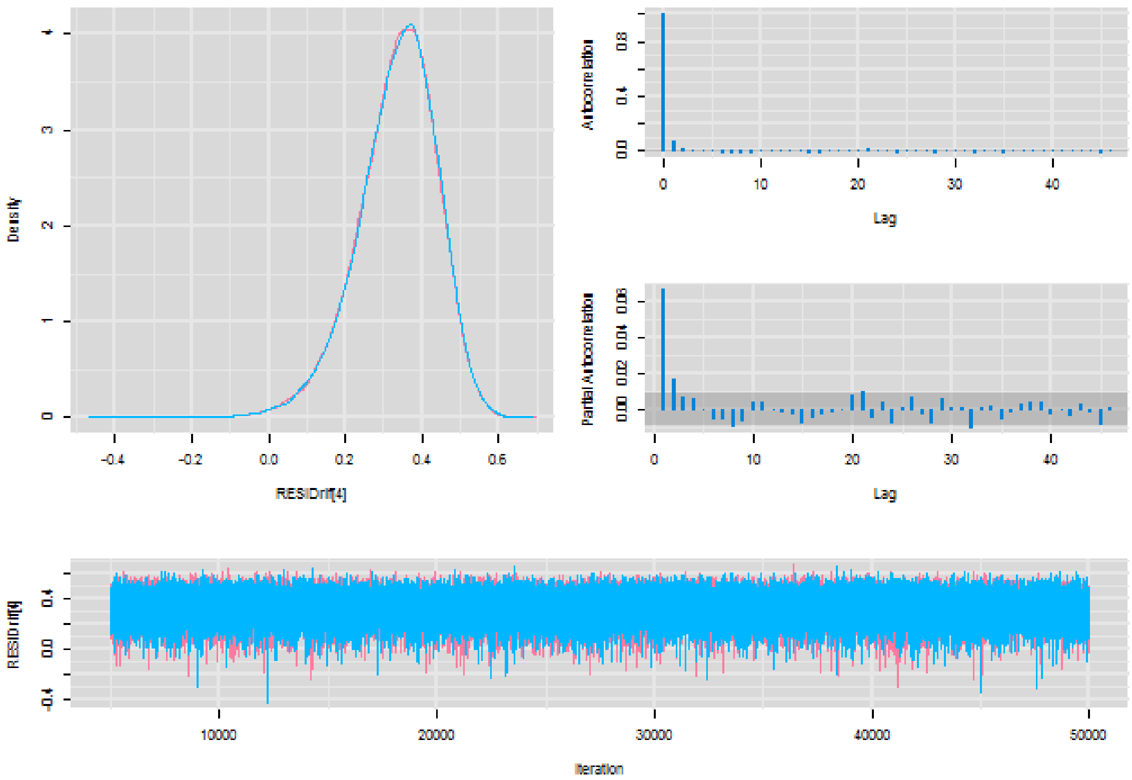


Diagnostics for RESIDrif[2]

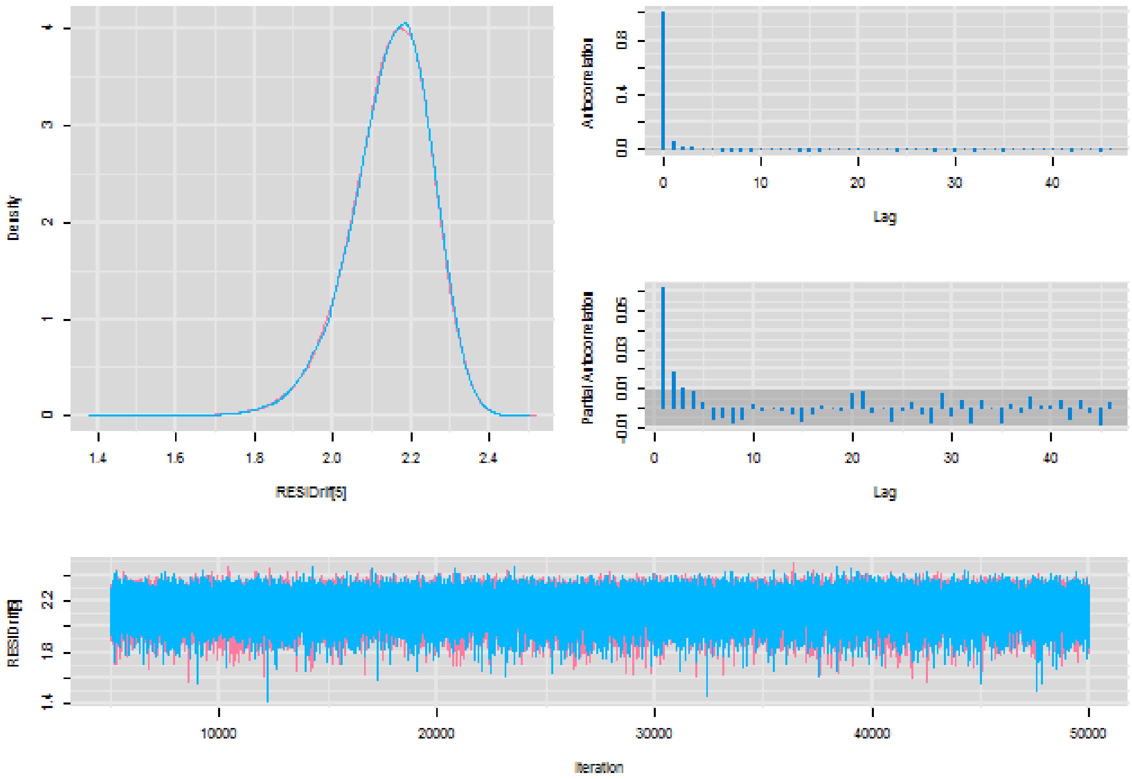


Diagnostics for RESIDrif[3]



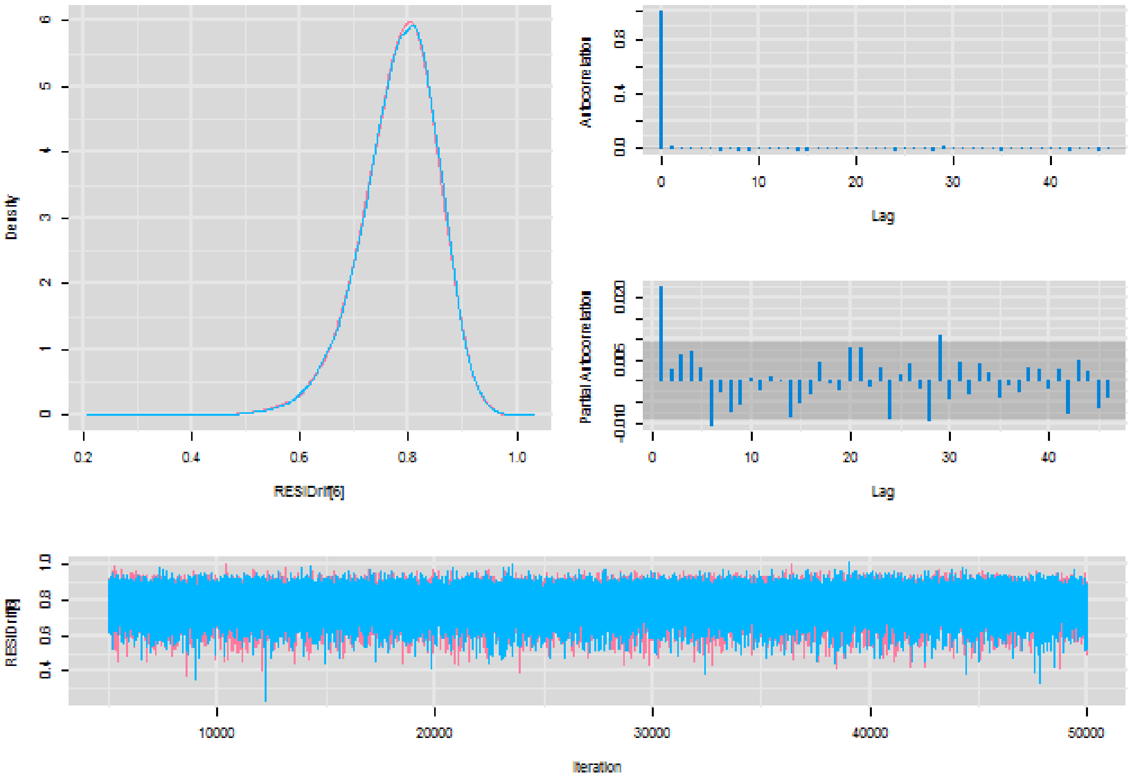


Diagnostics for RESIDrif[4]

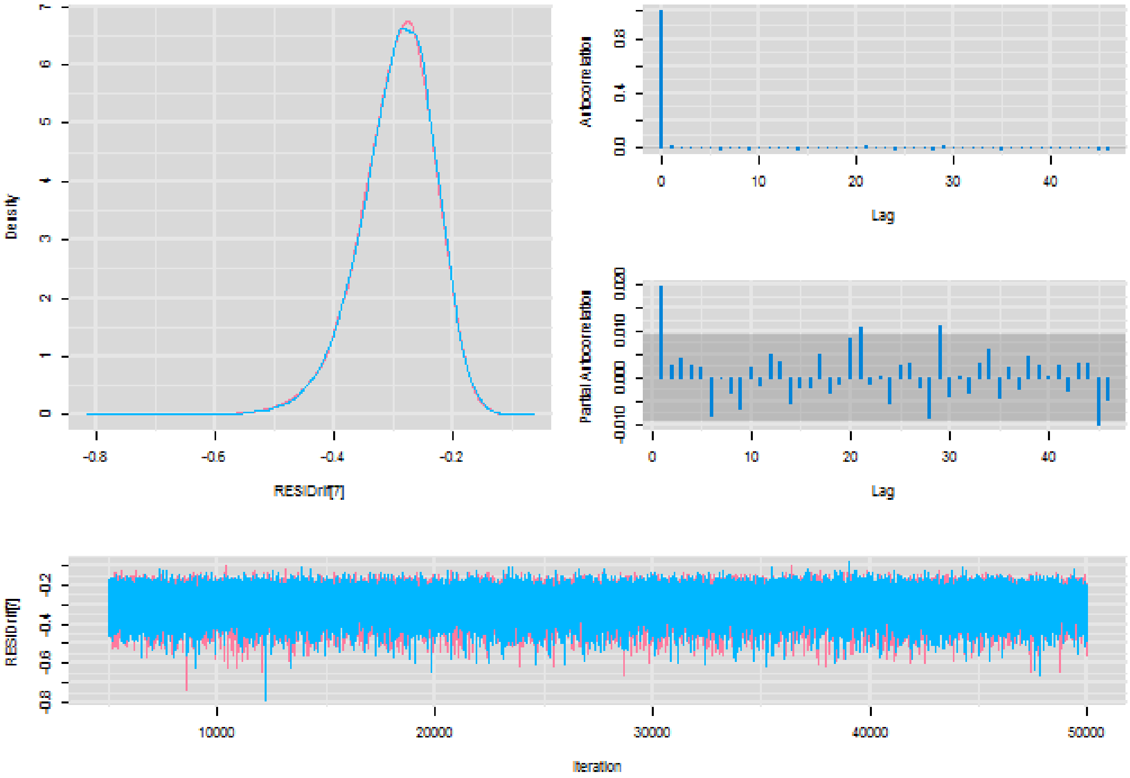


Diagnostics for RESIDrif[5]

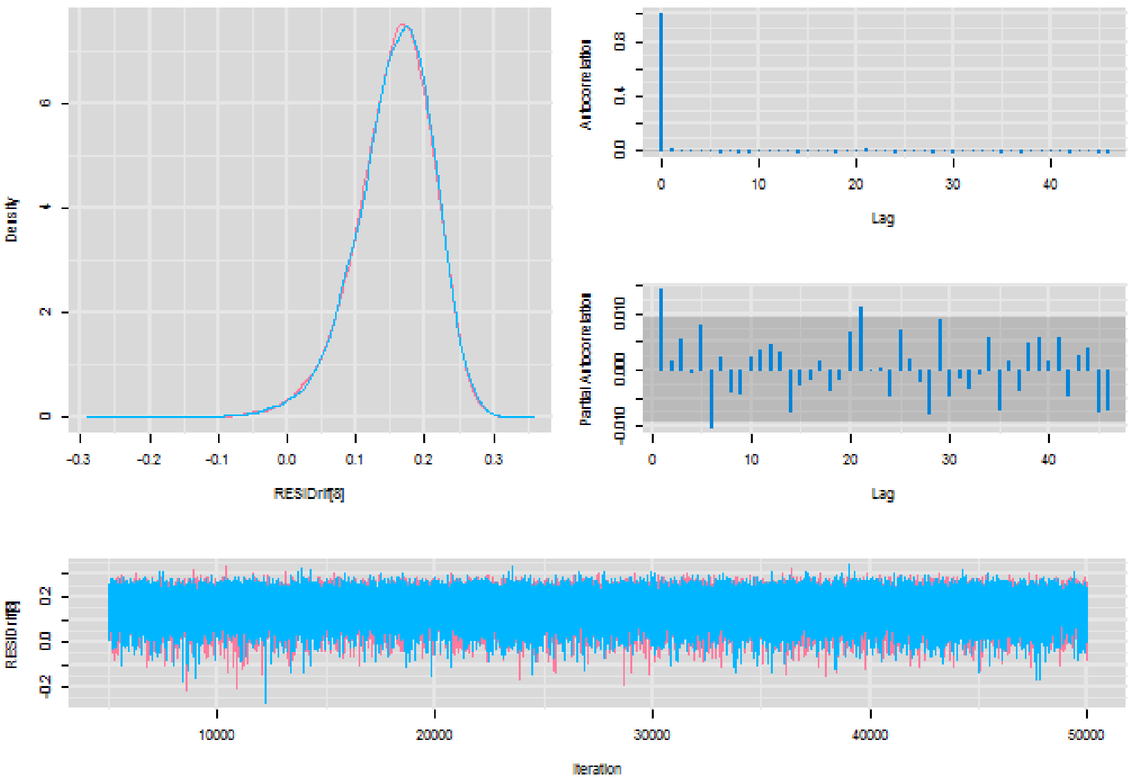
Diagnostics for RESIDrif[6]



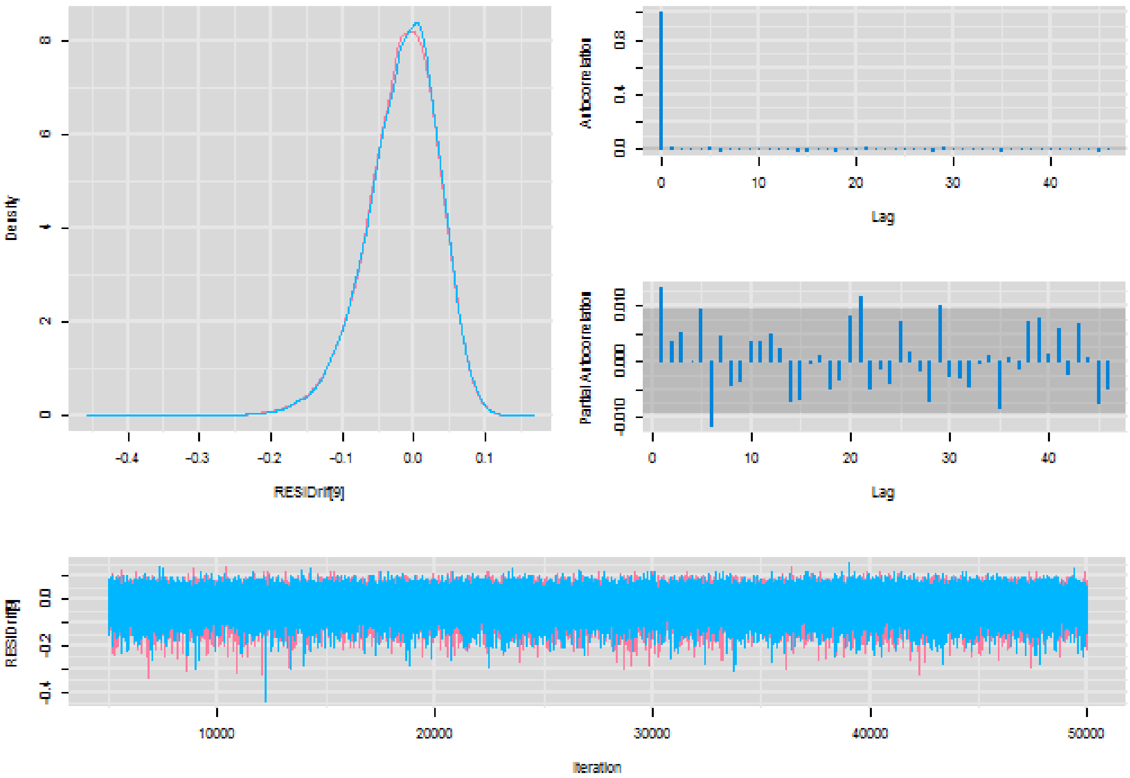
Diagnostics for RESIDrif[7]



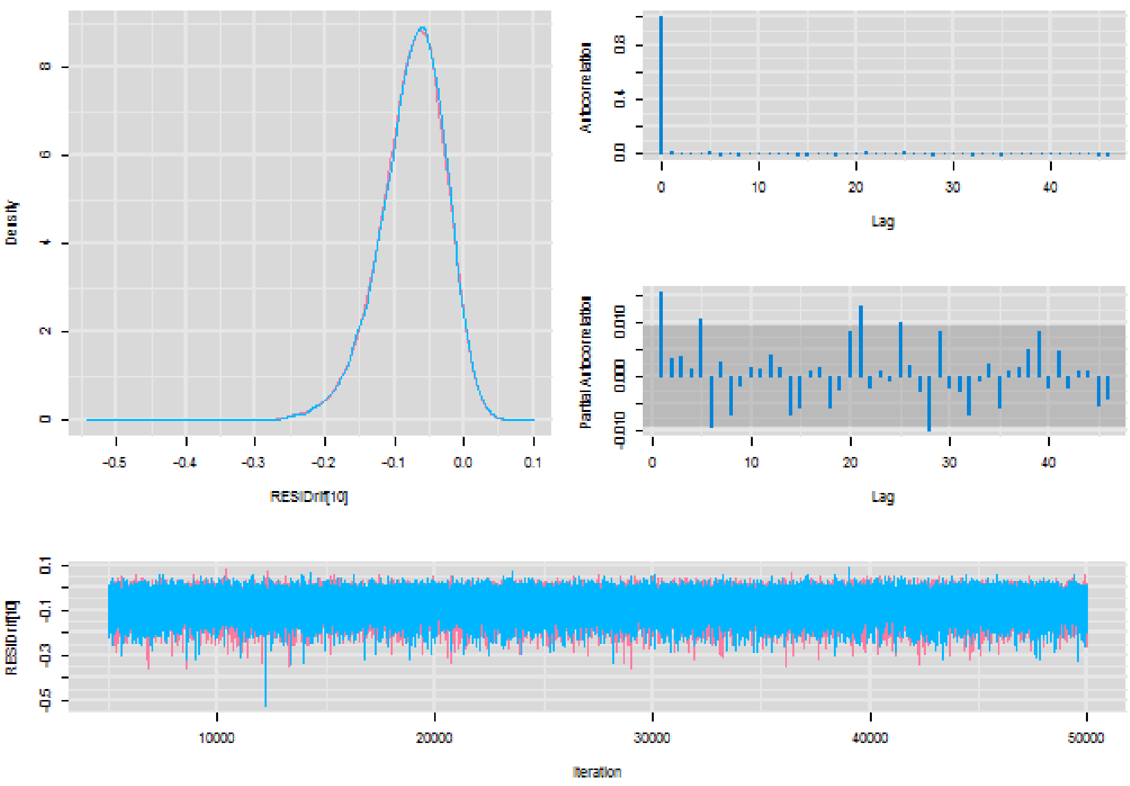
Diagnostics for RESIDrif[8]



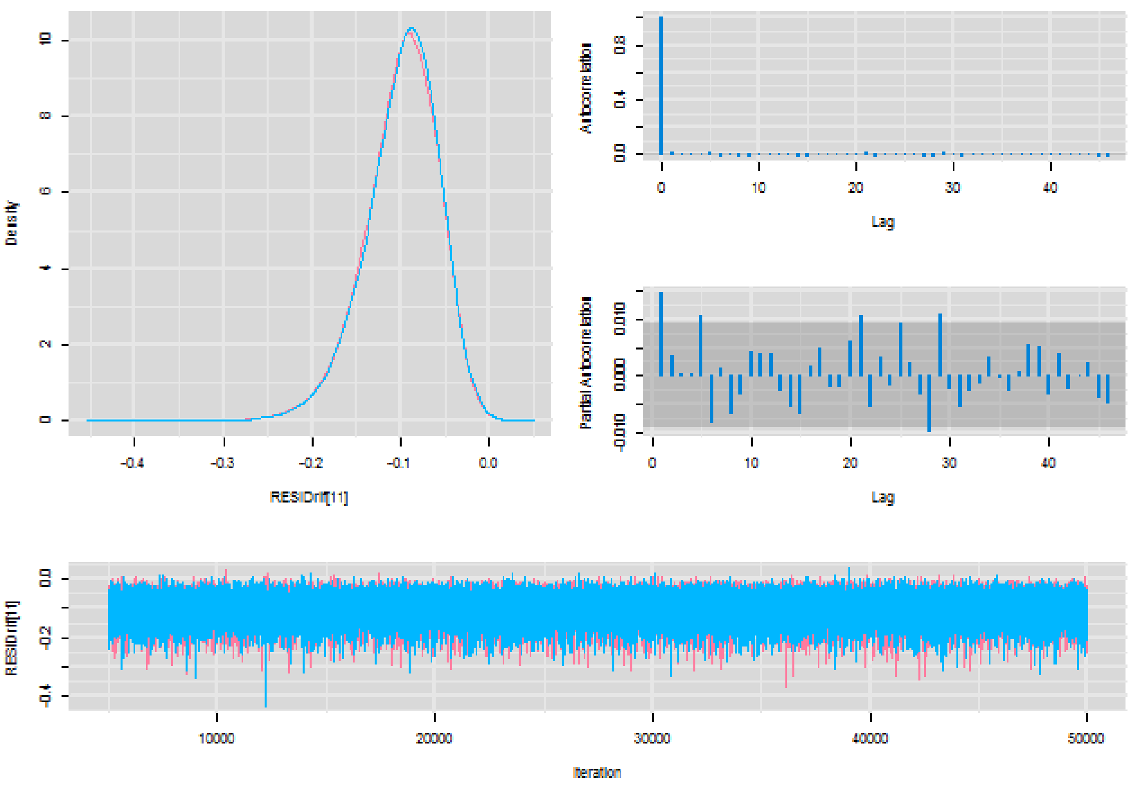
Diagnostics for RESIDrif[9]



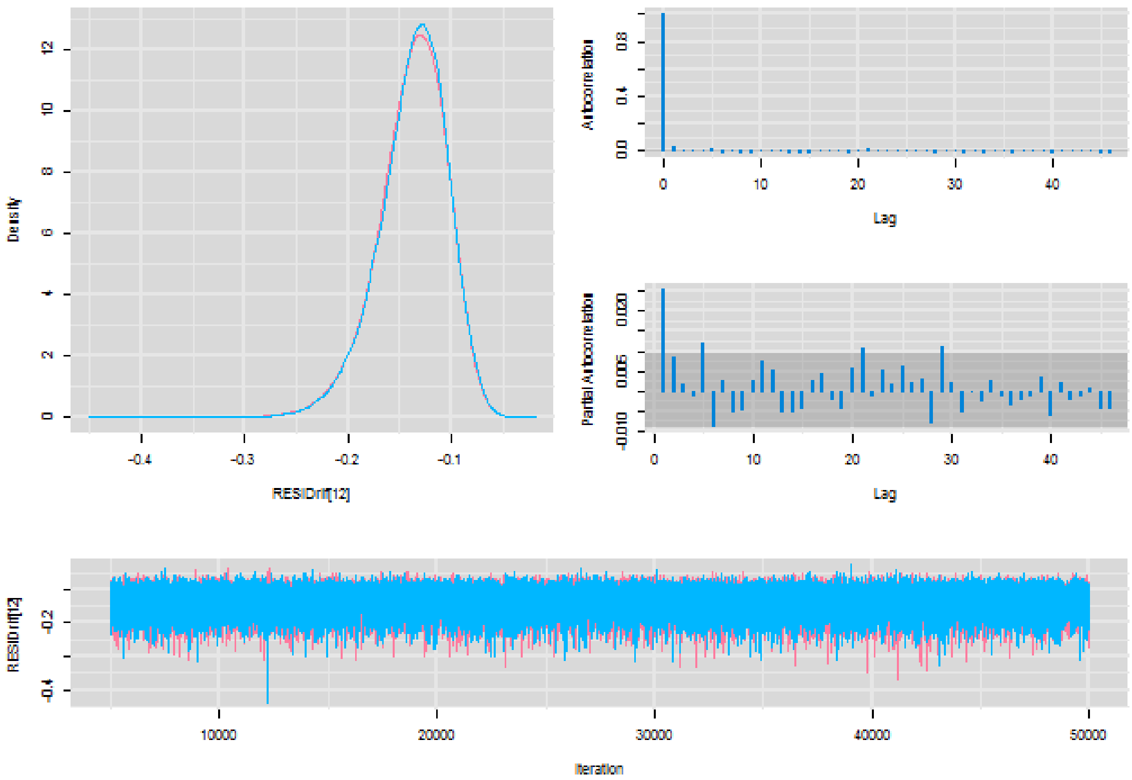
Diagnostics for RESIDrif[10]



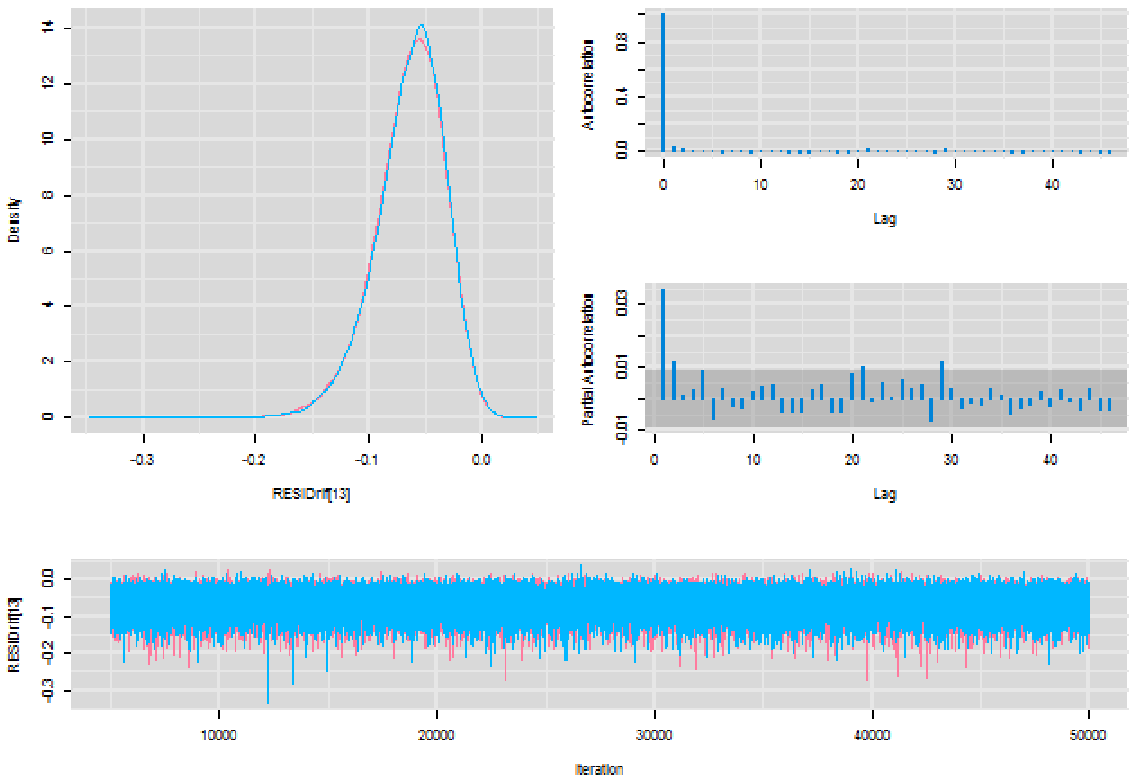
Diagnostics for RESIDrif[11]



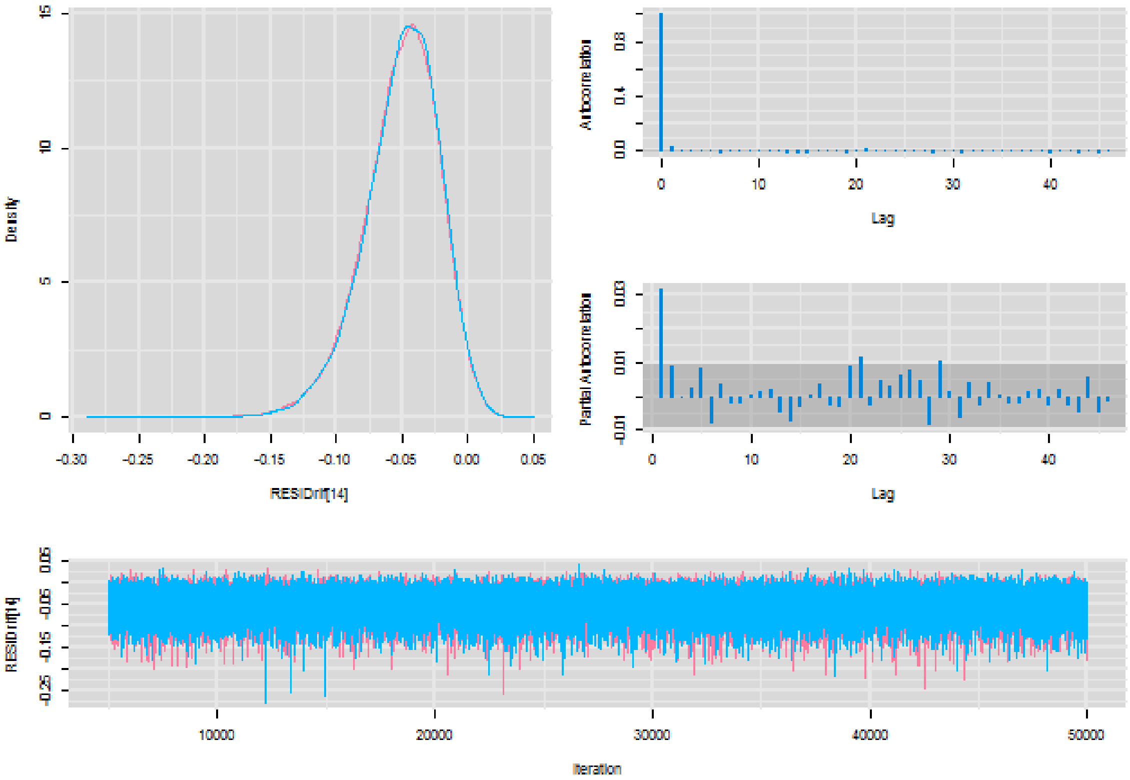
Diagnostics for RESIDrif[12]



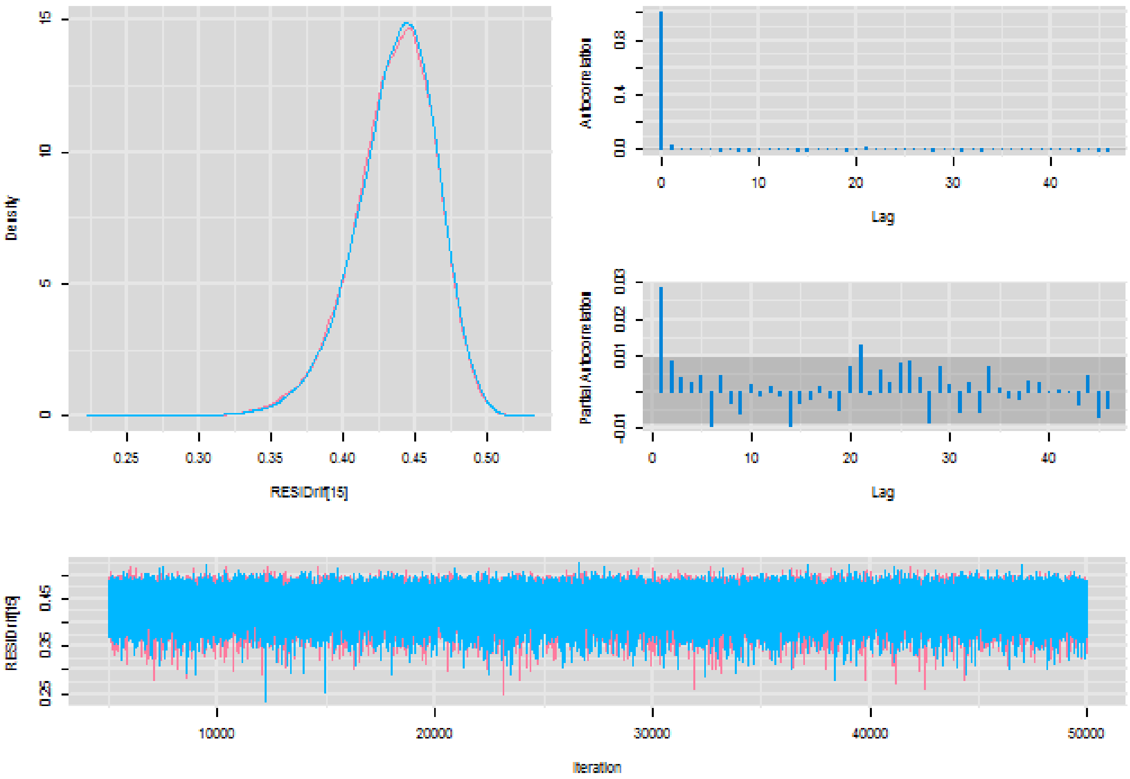
Diagnostics for RESIDrif[13]



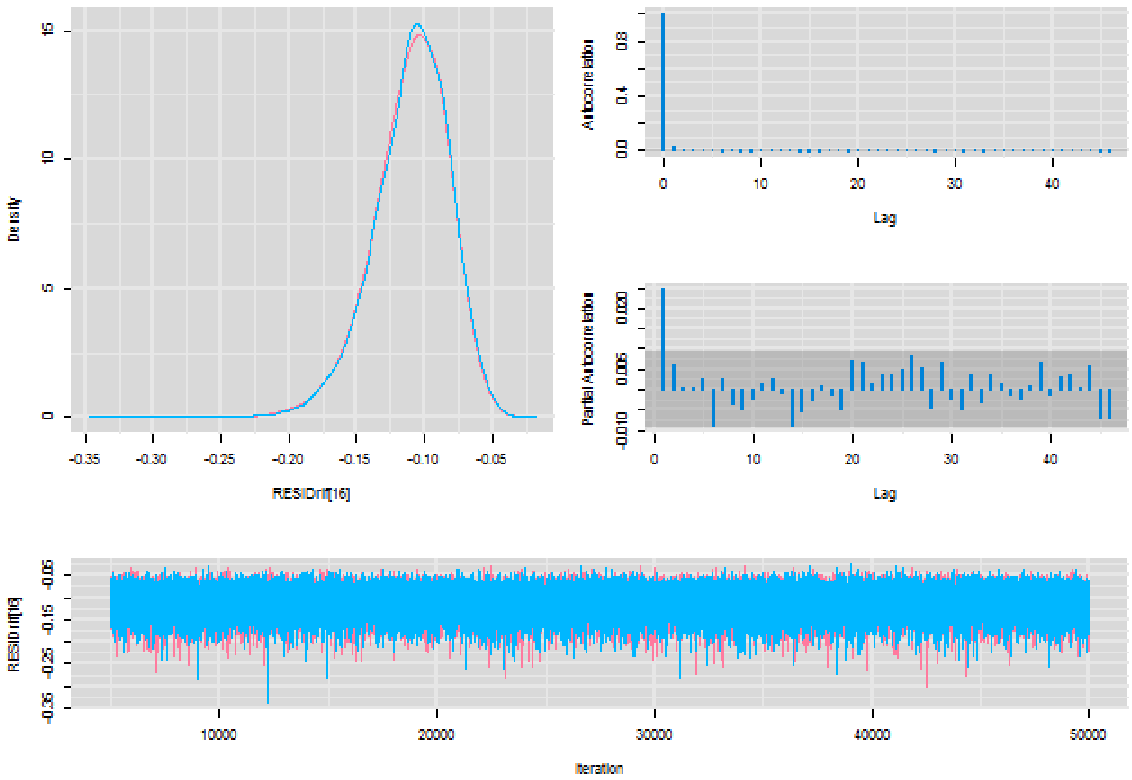
Diagnostics for RESIDrif[14]



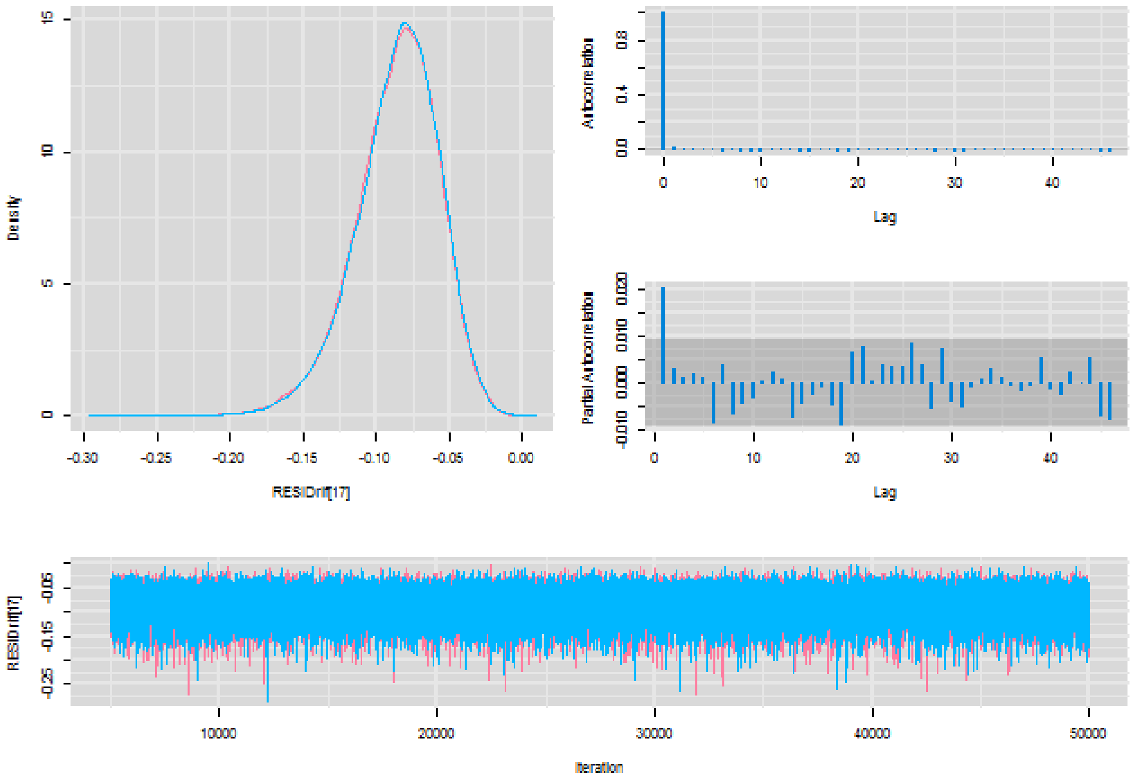
Diagnostics for RESIDrif[15]



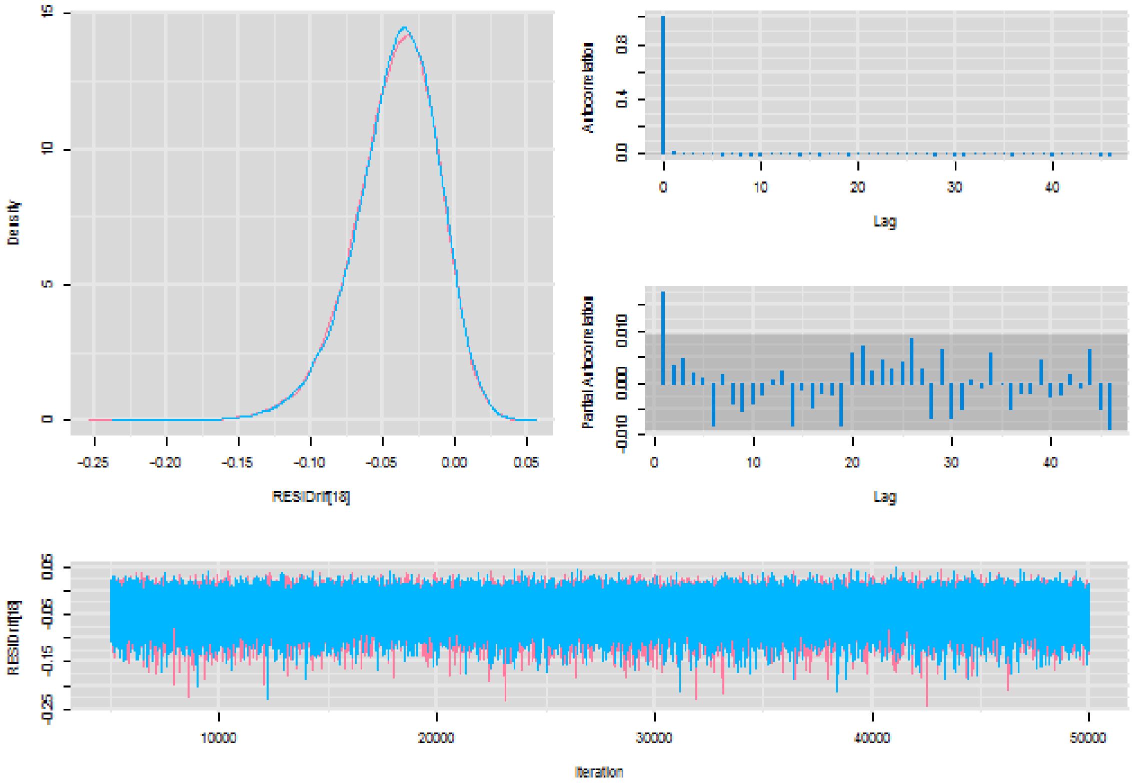
Diagnostics for RESIDrif[16]



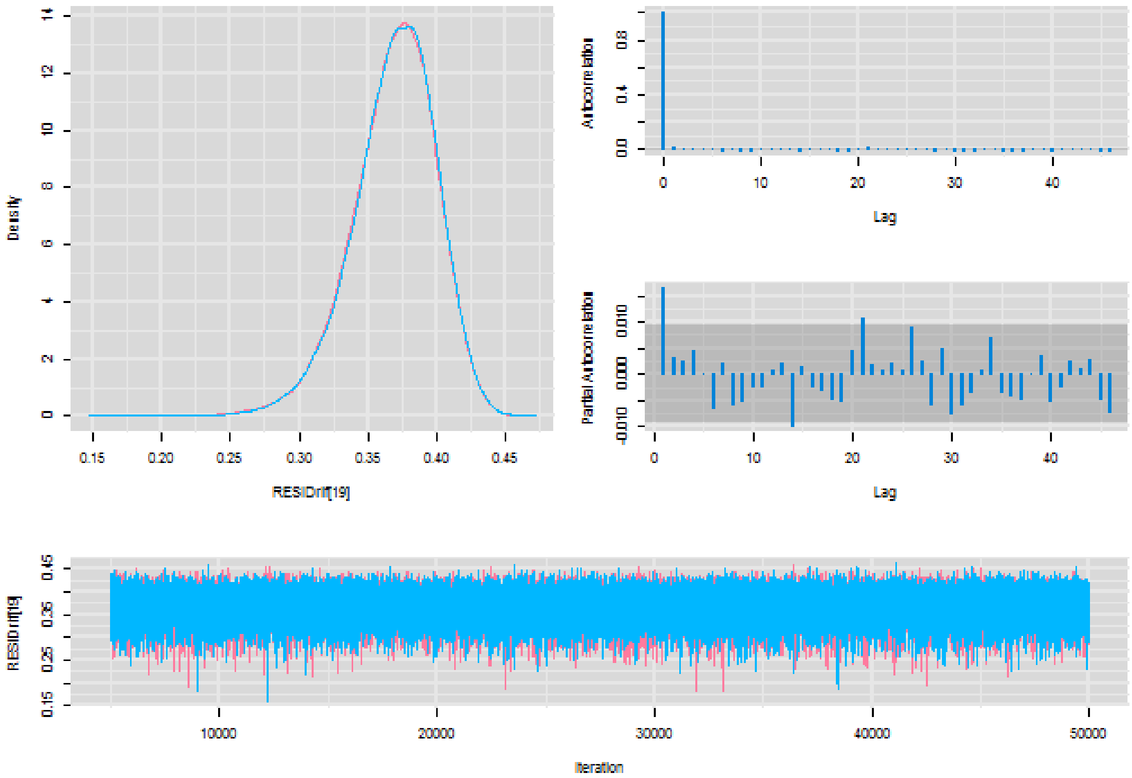
Diagnostics for RESIDrif[17]



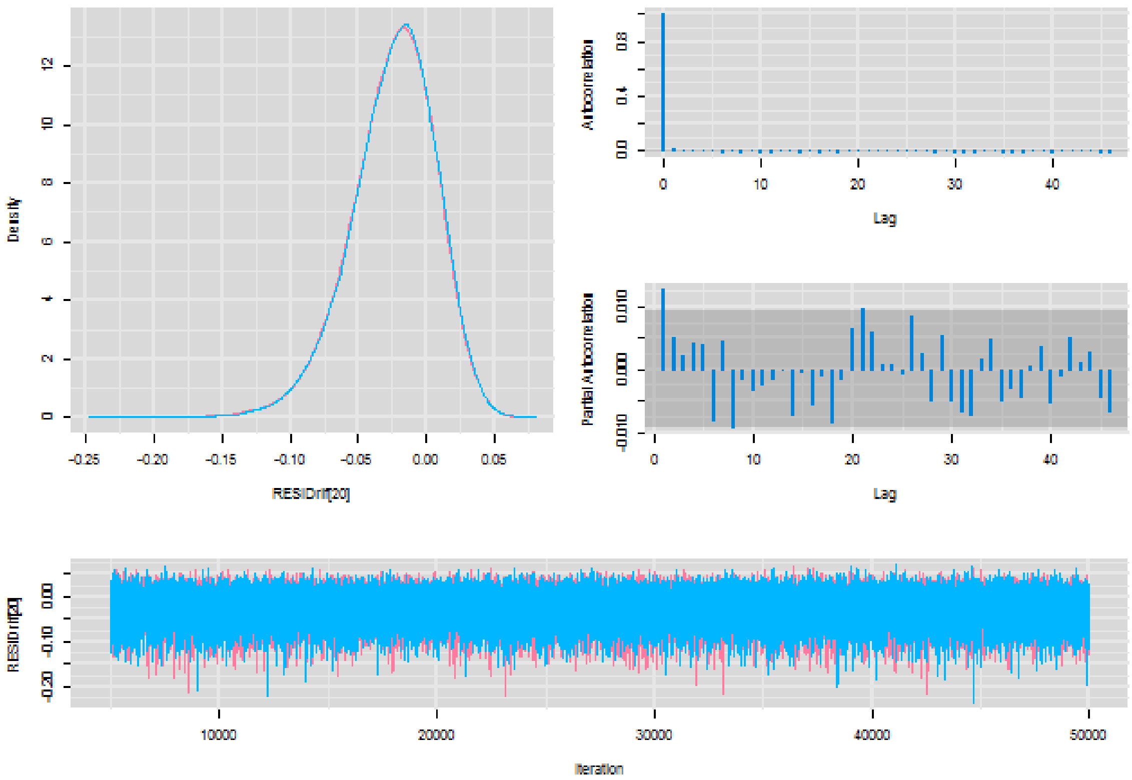
Diagnostics for RESIDrif[18]



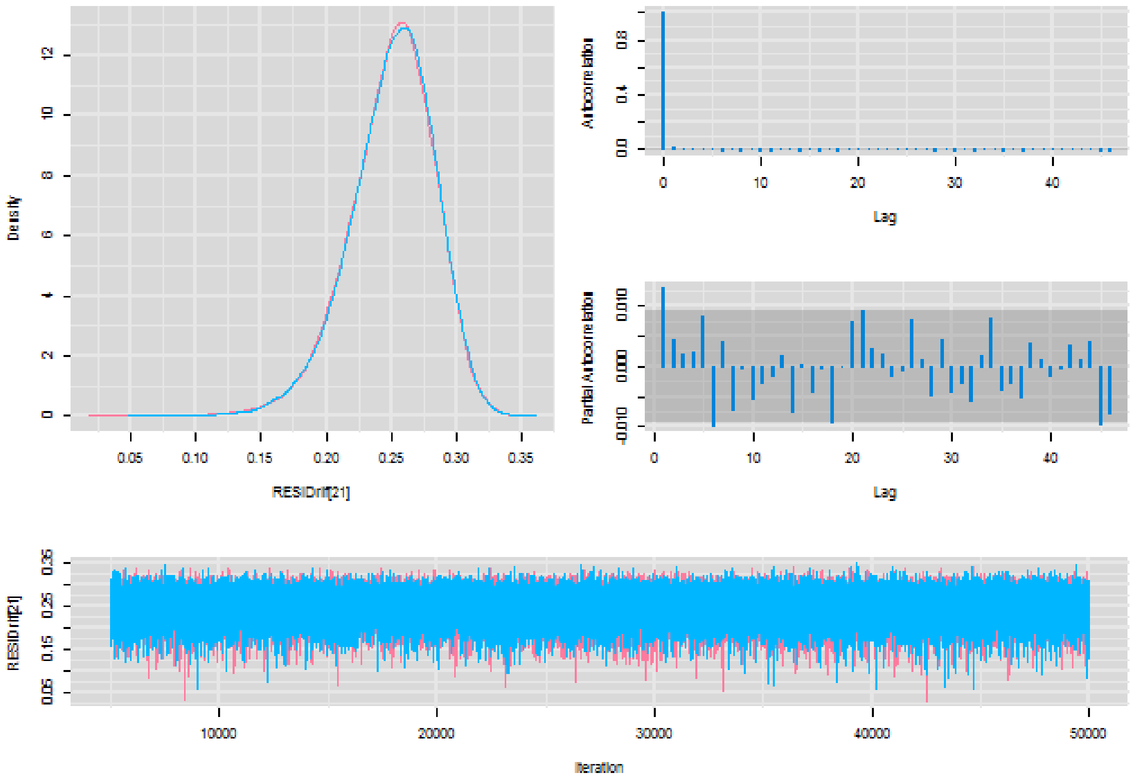
Diagnostics for RESIDrif[19]



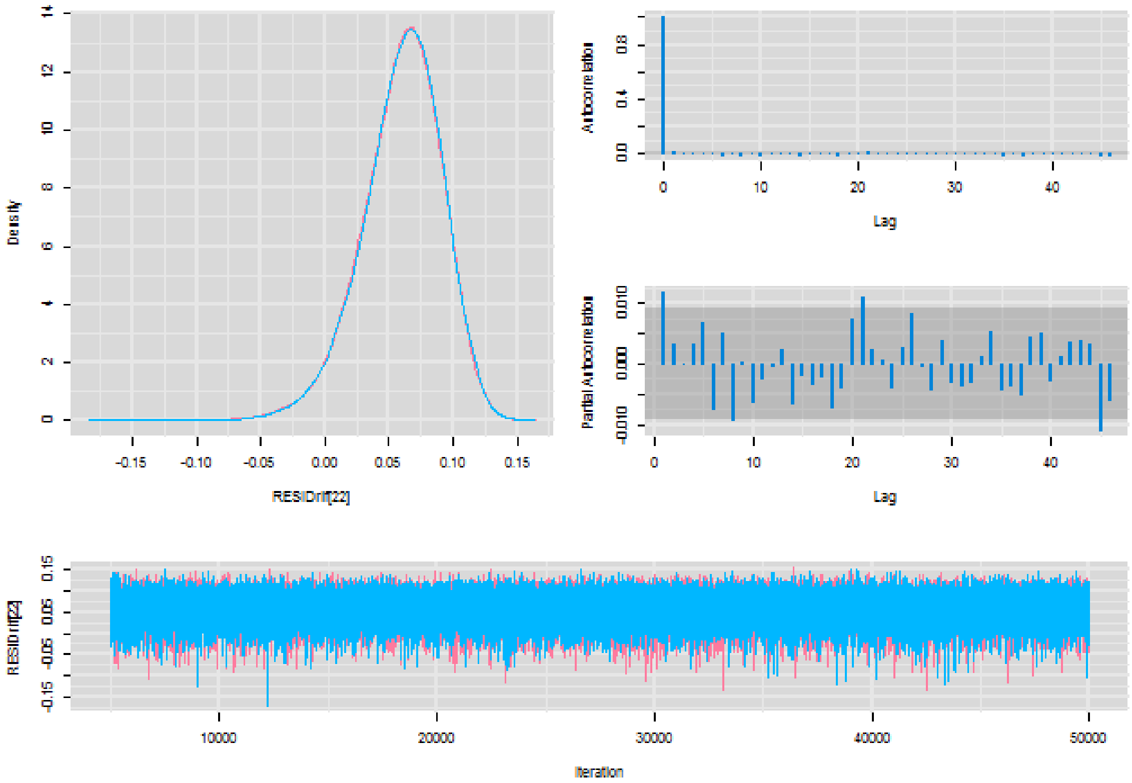
Diagnostics for RESIDrif[20]



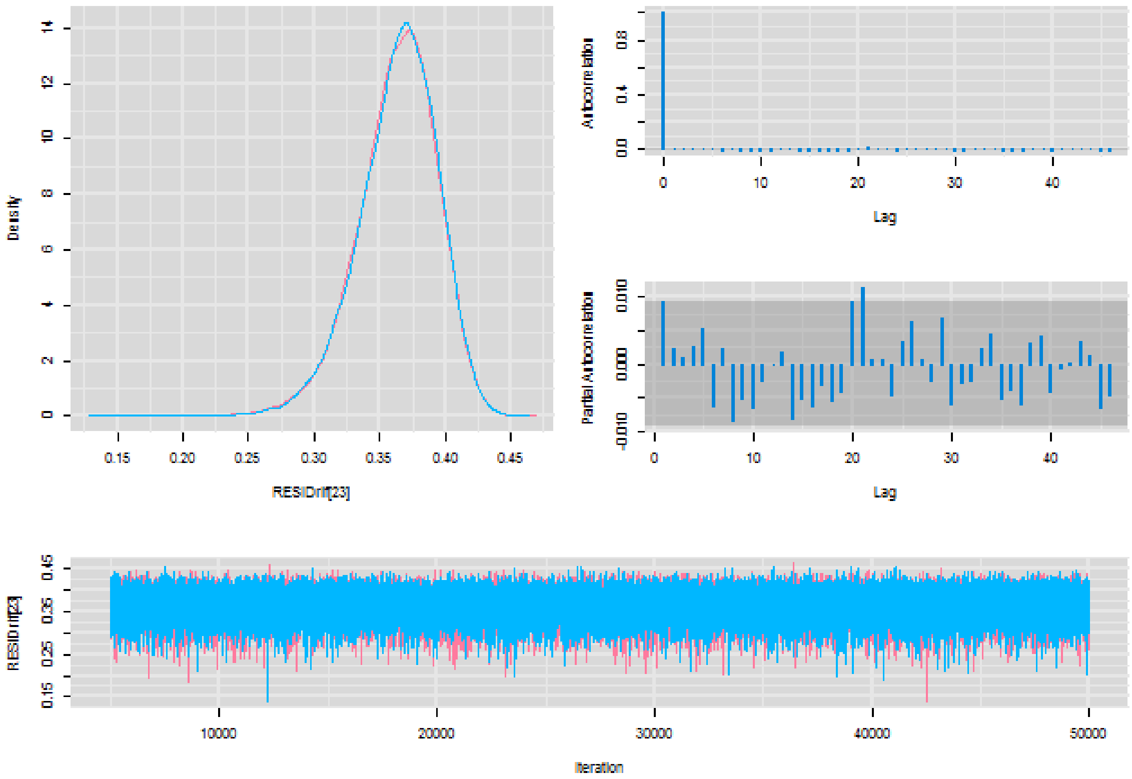
Diagnostics for RESIDrif[21]



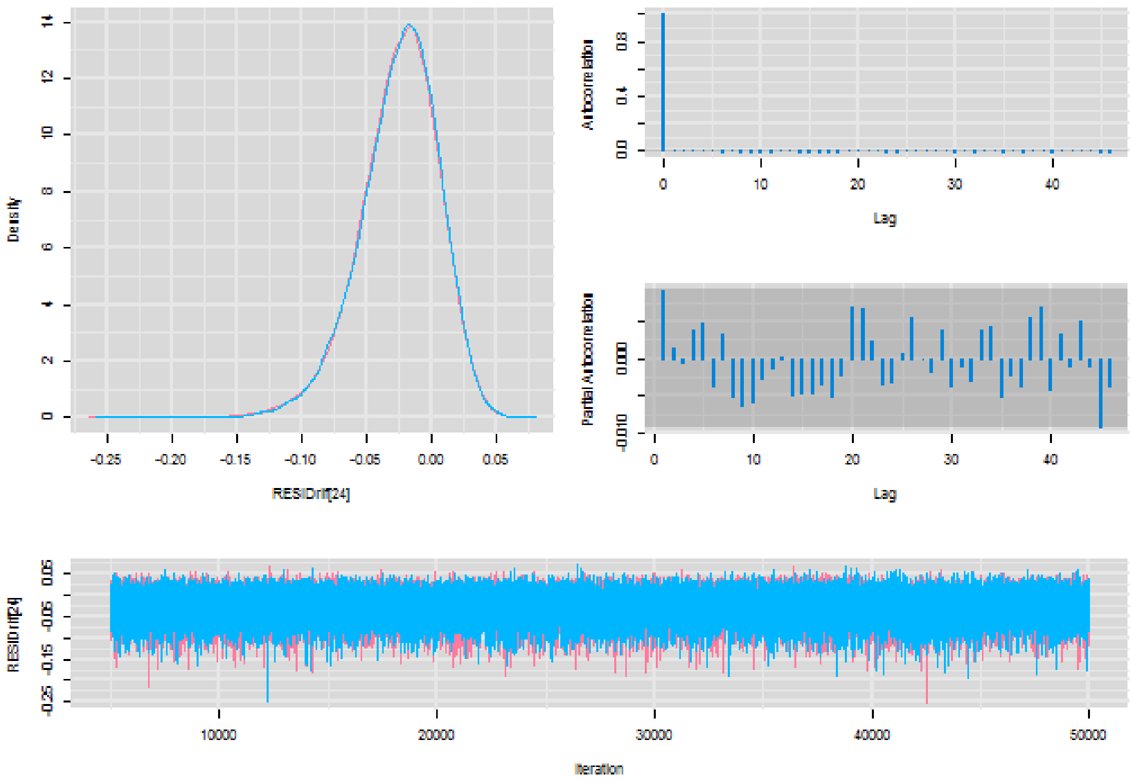
Diagnostics for RESIDrif[22]



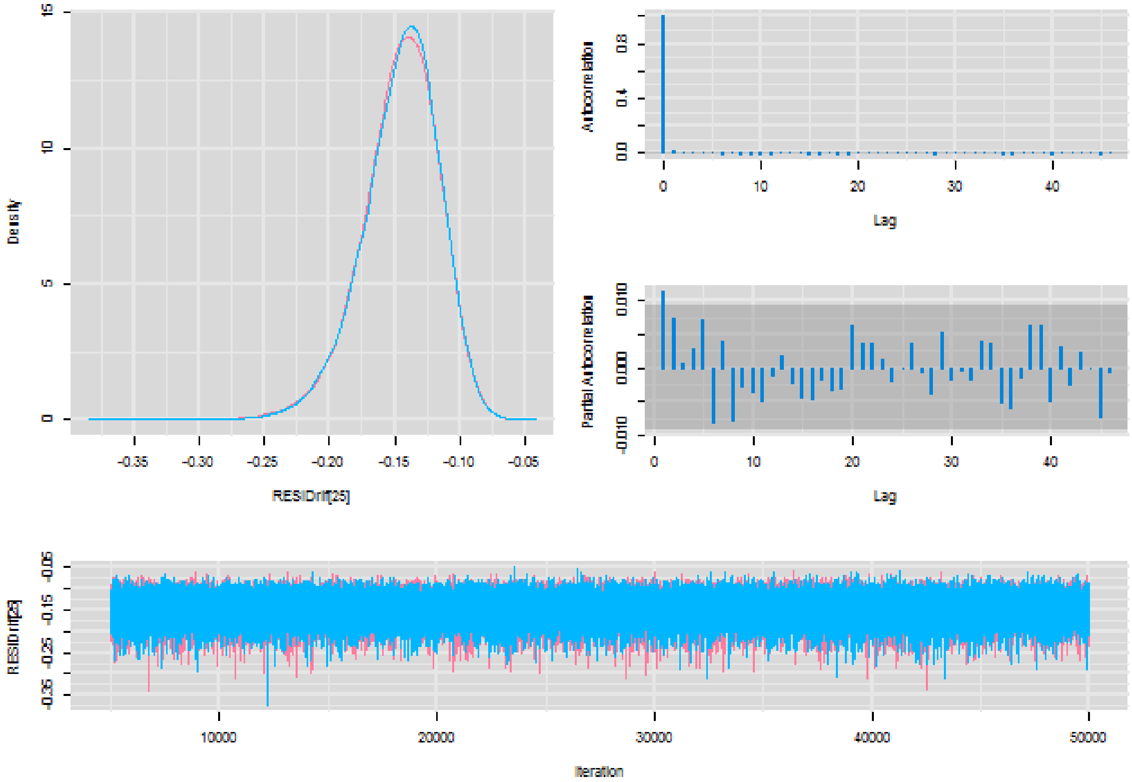
Diagnostics for RESIDrif[23]



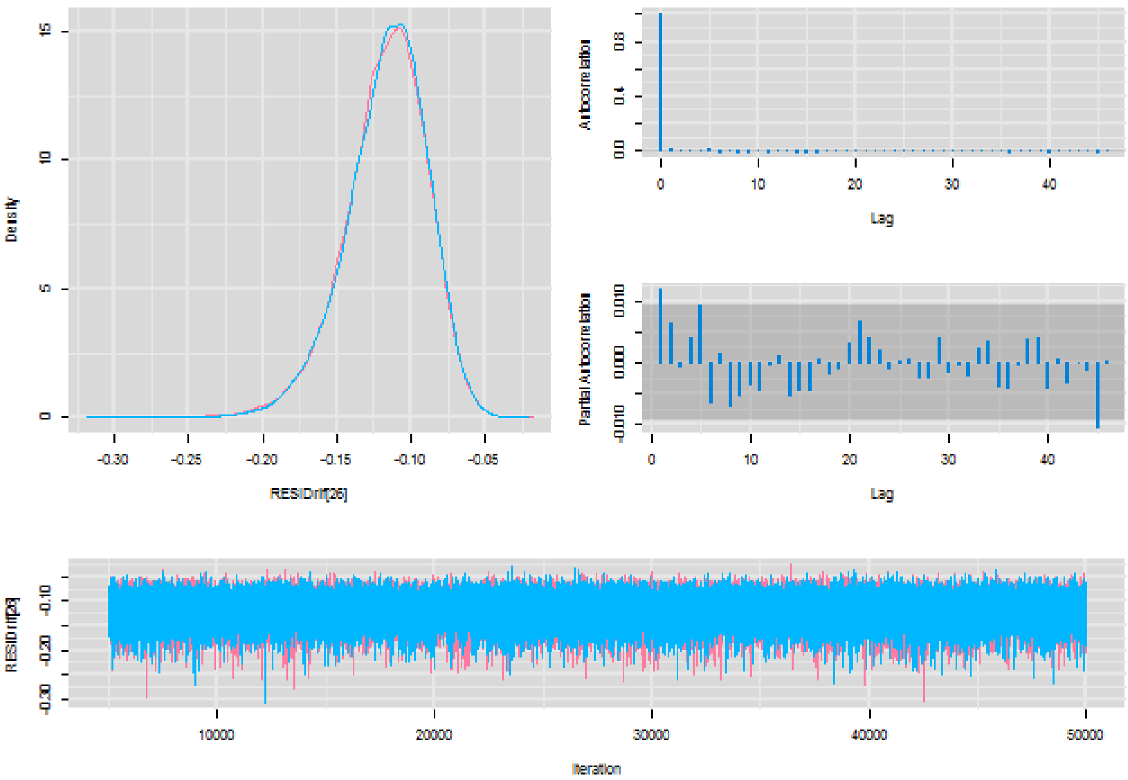
Diagnostics for RESIDrif[24]



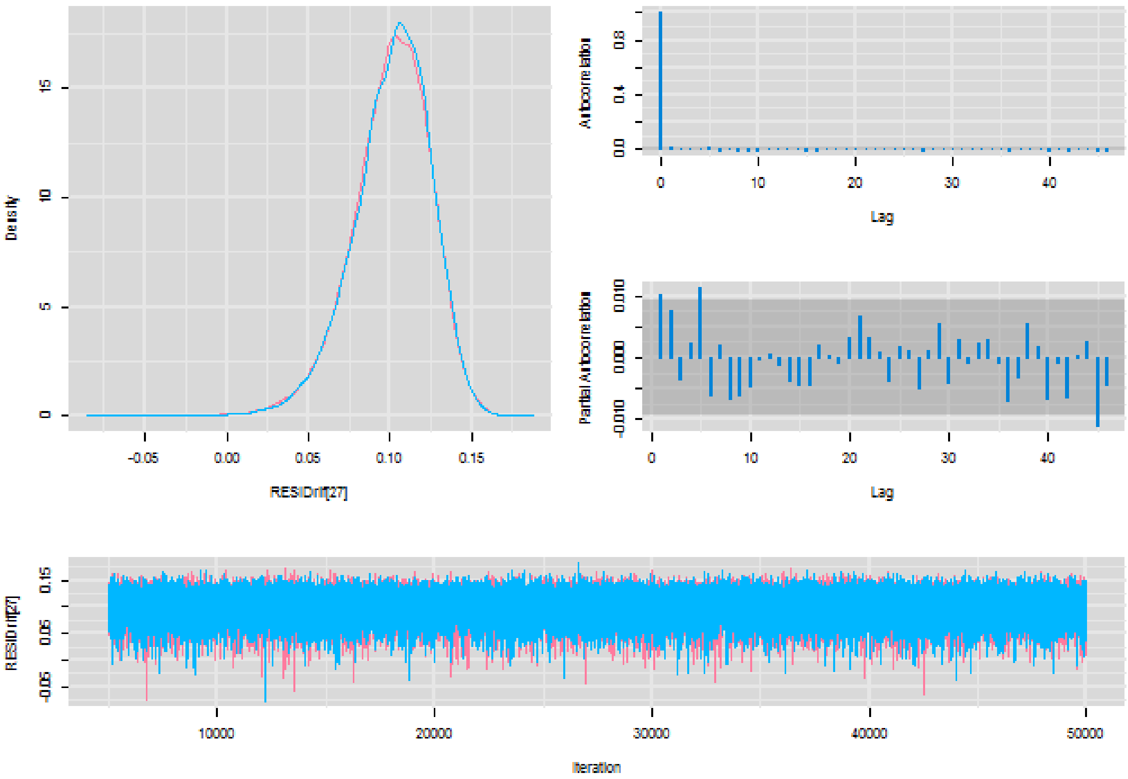
Diagnostics for RESIDrif[25]



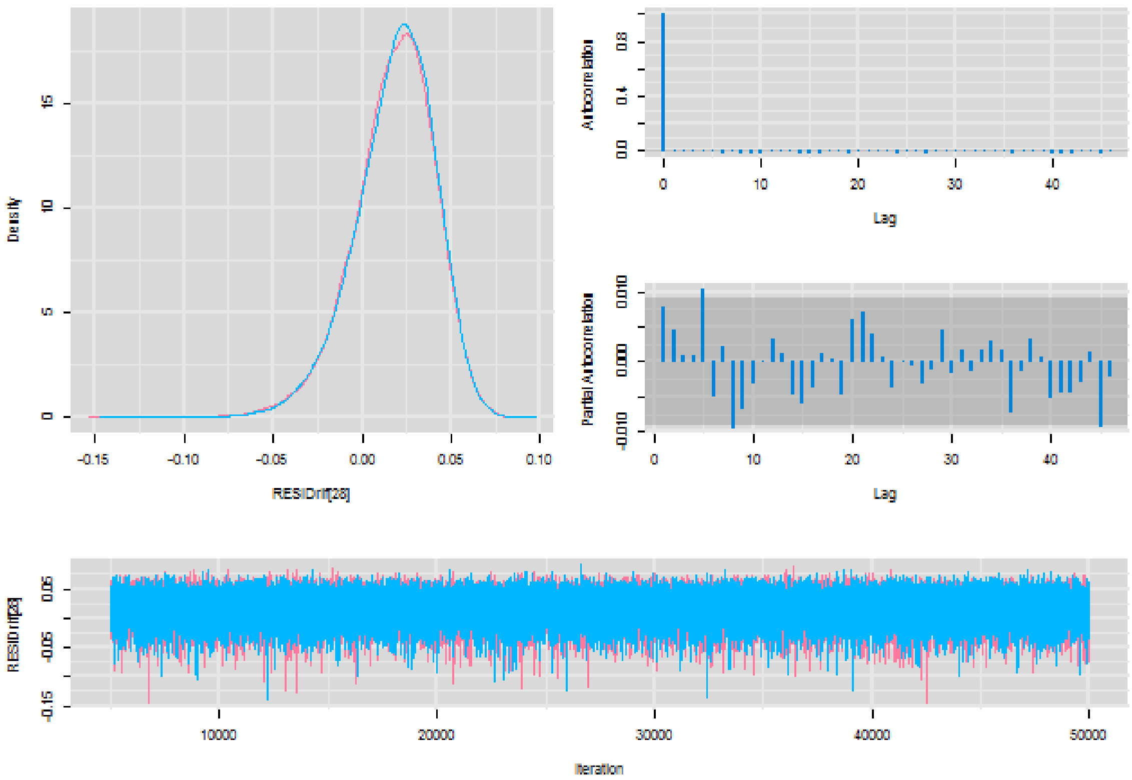
Diagnostics for RESIDrif[26]



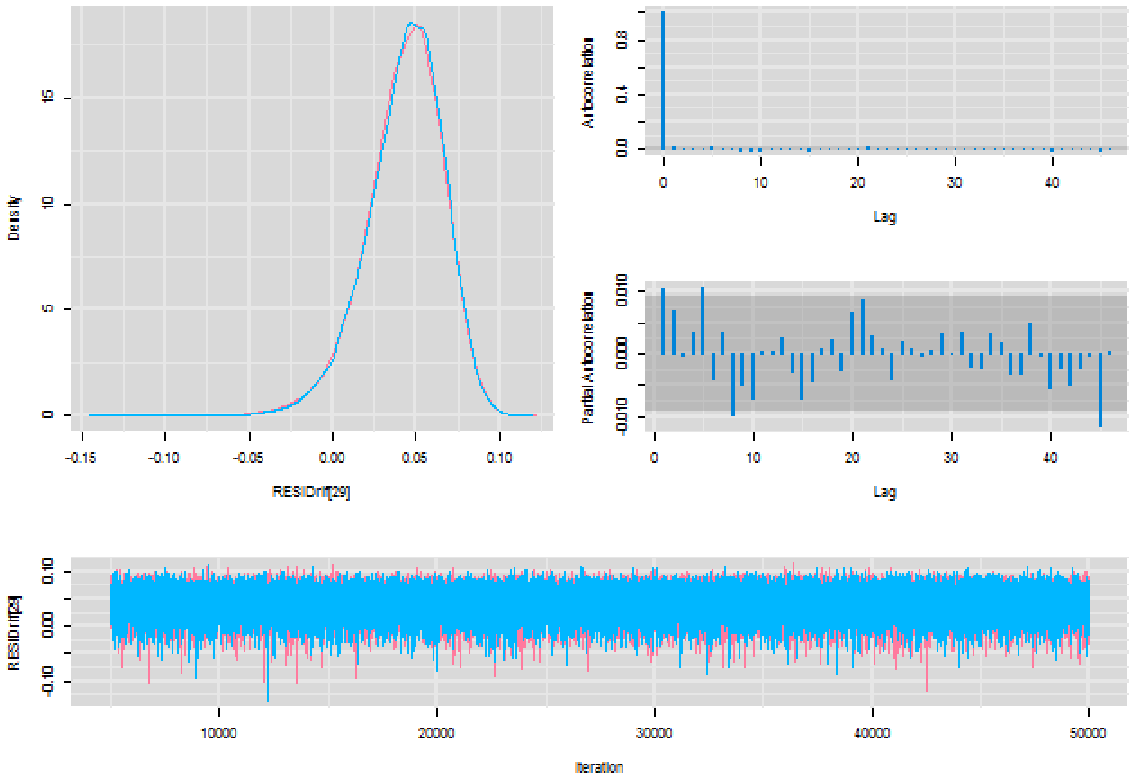
Diagnostics for RESIDrif[27]



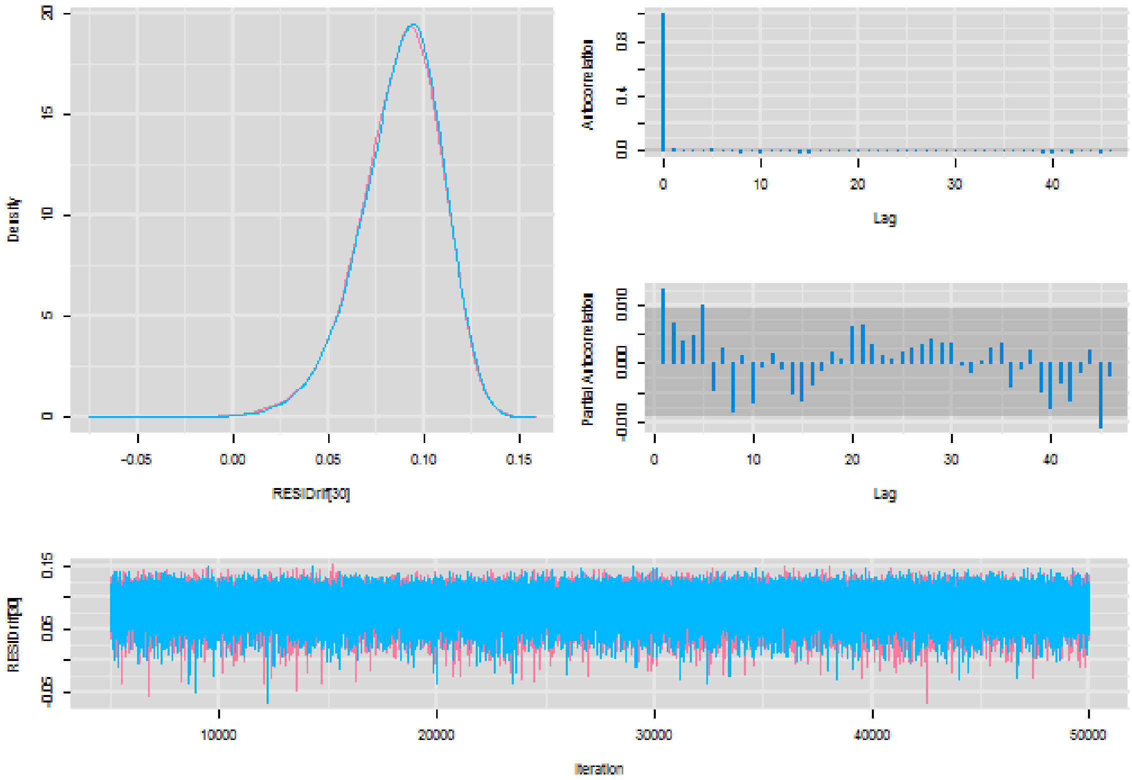
Diagnostics for RESIDrif[28]



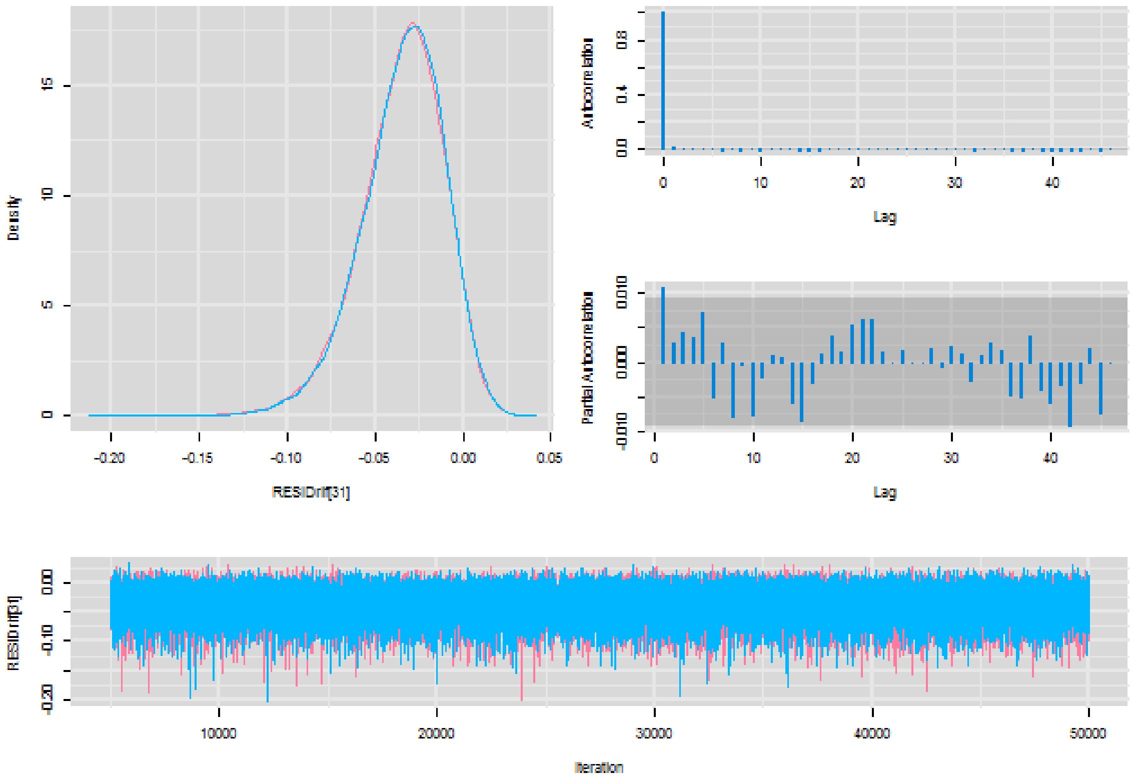
Diagnostics for RESIDrif[29]



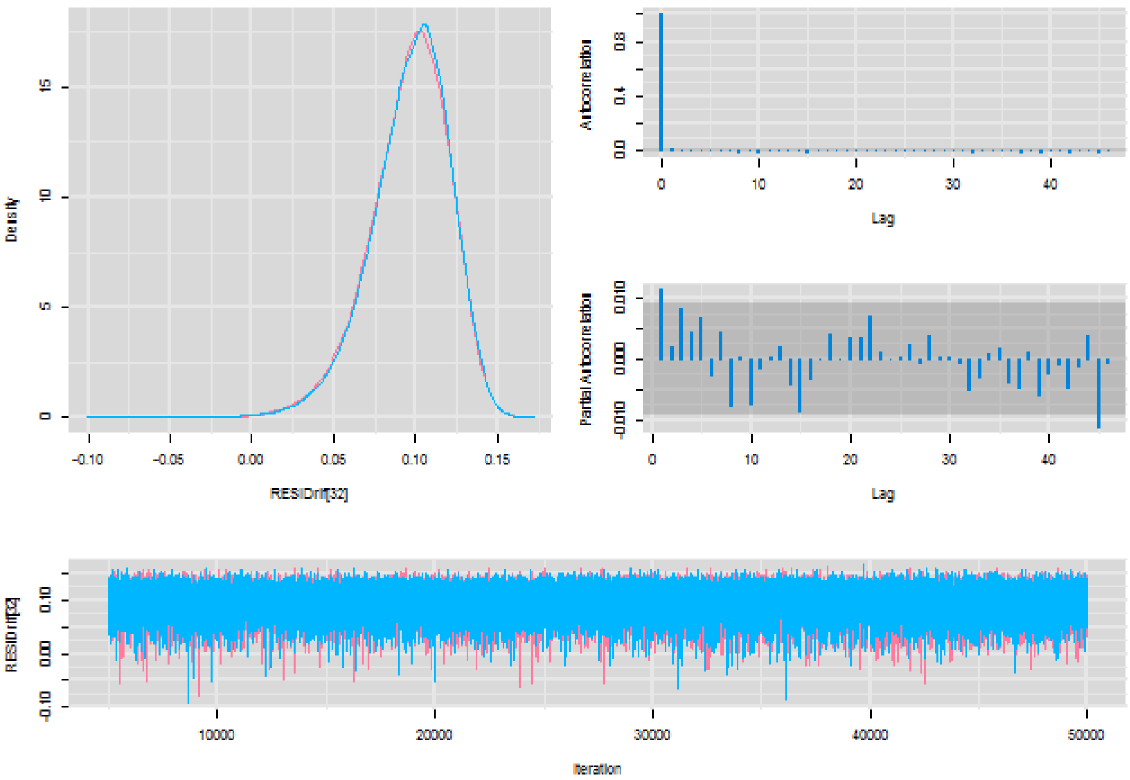
Diagnostics for RESIDrif[30]



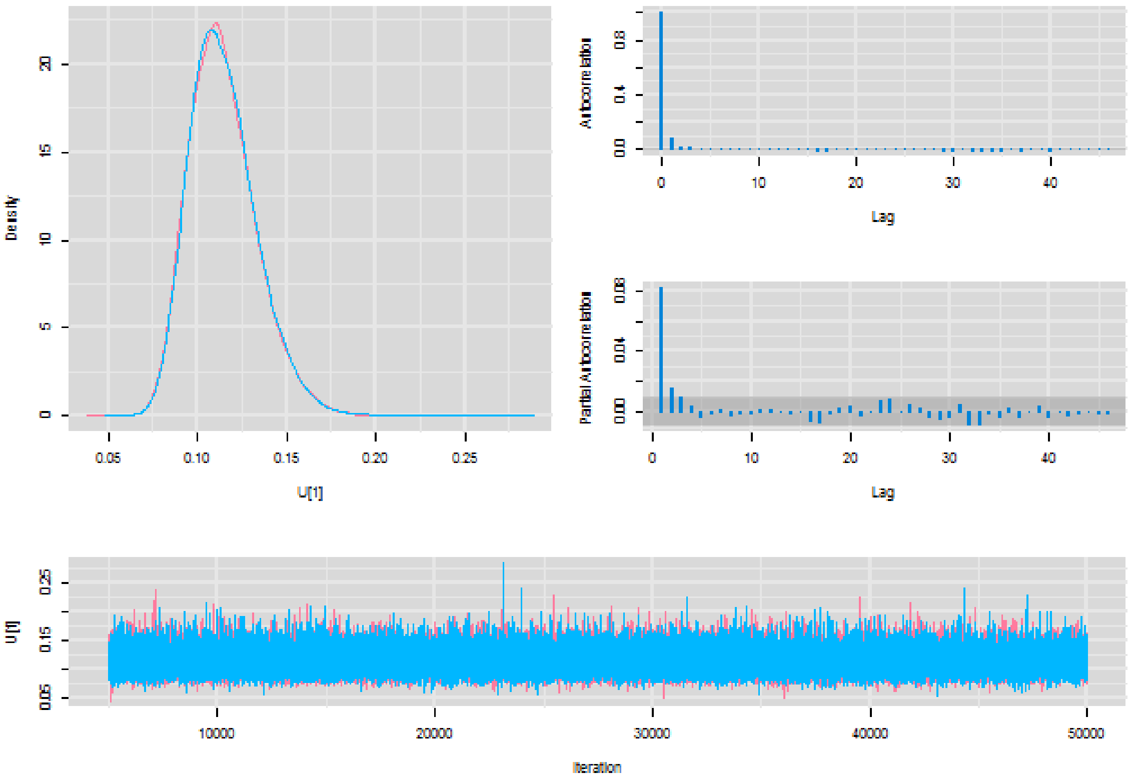
Diagnostics for RESIDrif[31]



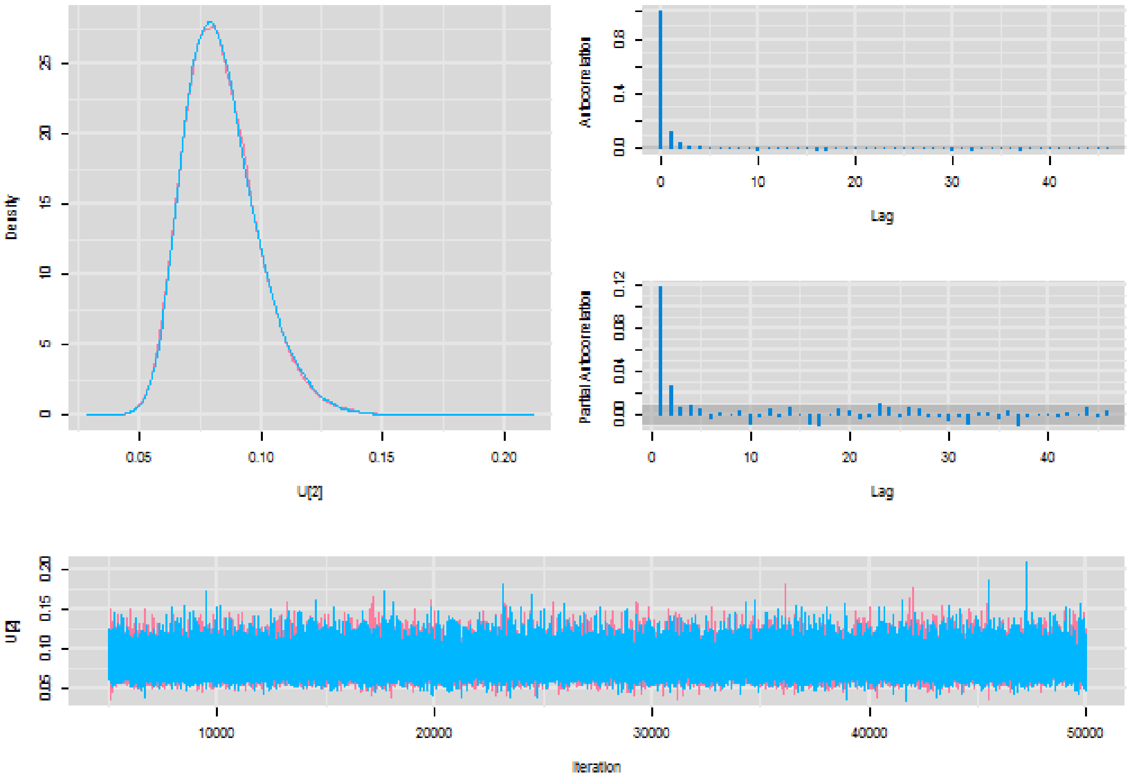
Diagnostics for RESIDrif[32]



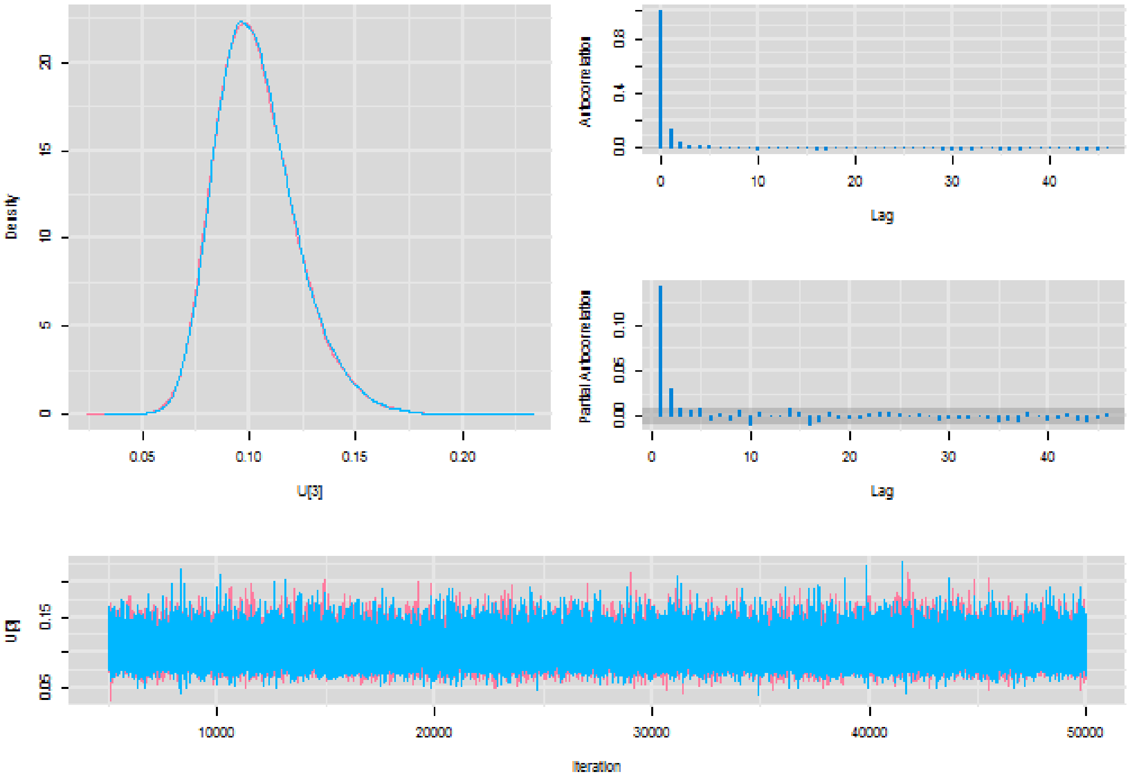
Diagnostics for U[1]



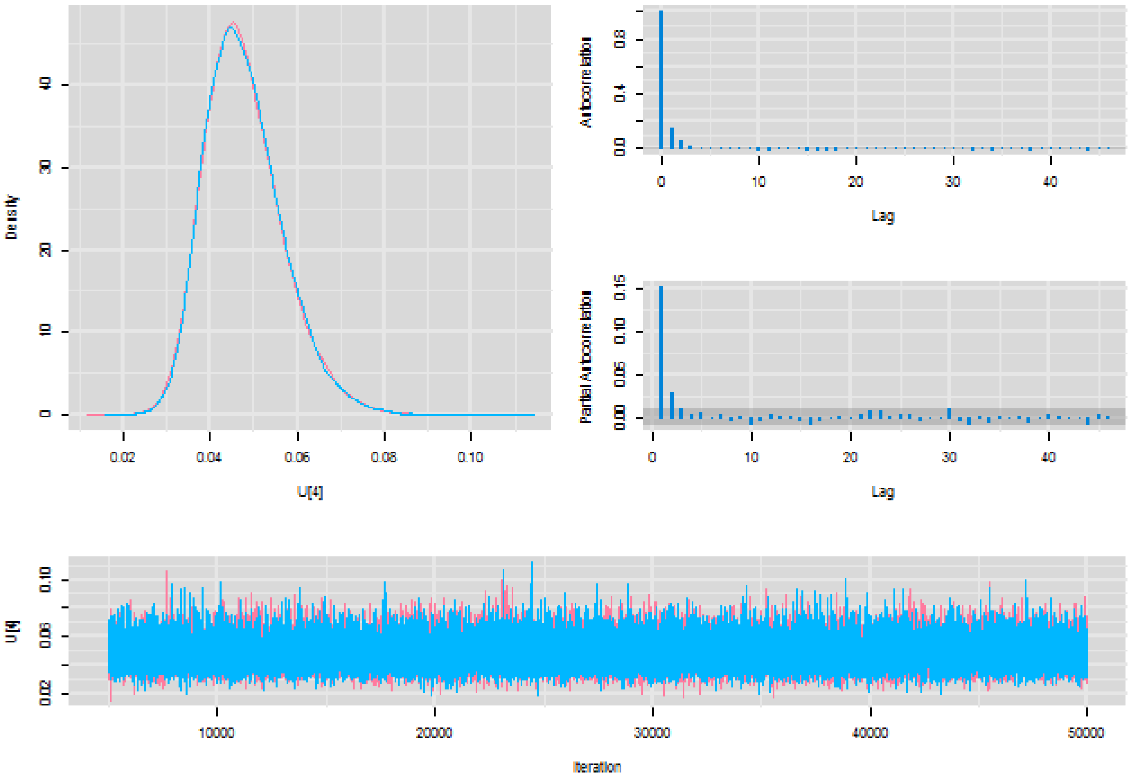
Diagnostics for U[2]



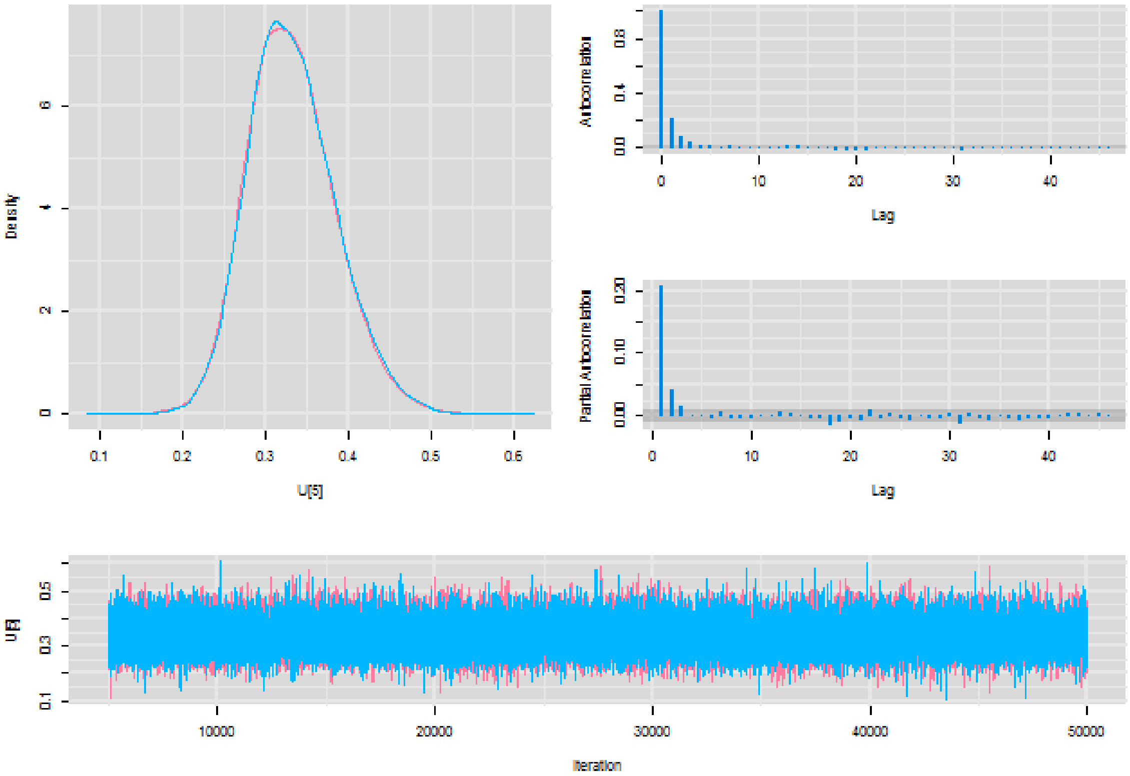
Diagnostics for U[3]



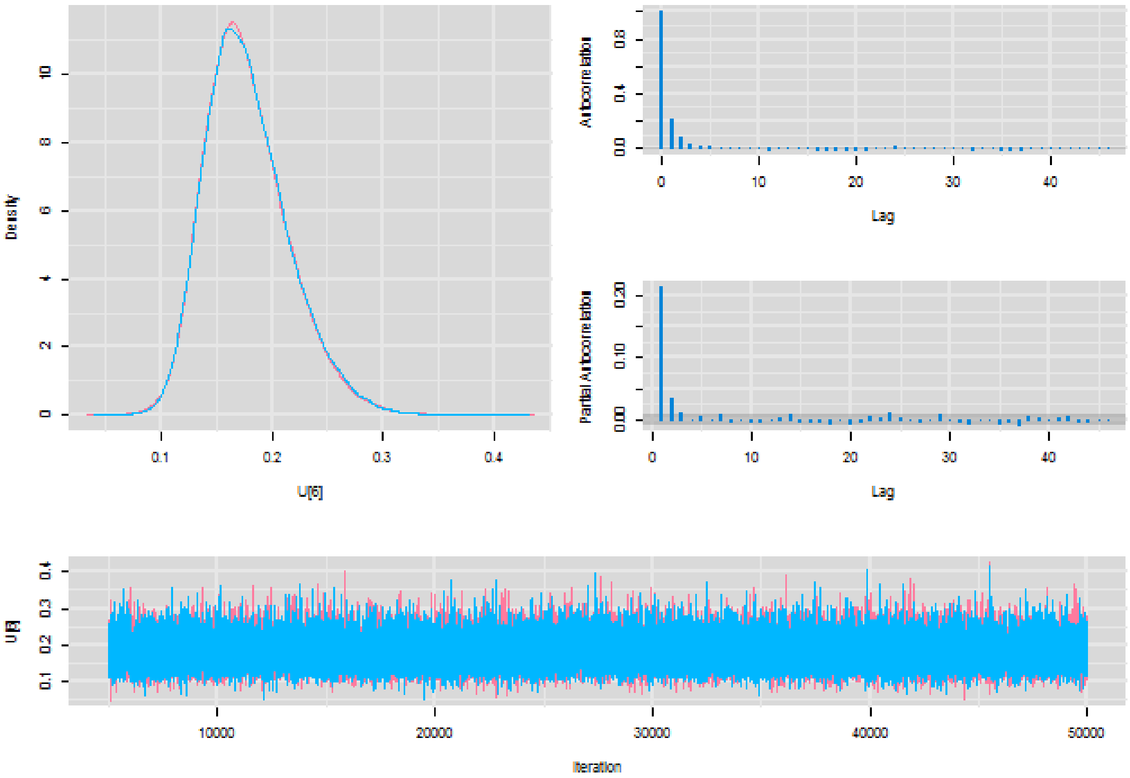
Diagnostics for U[4]



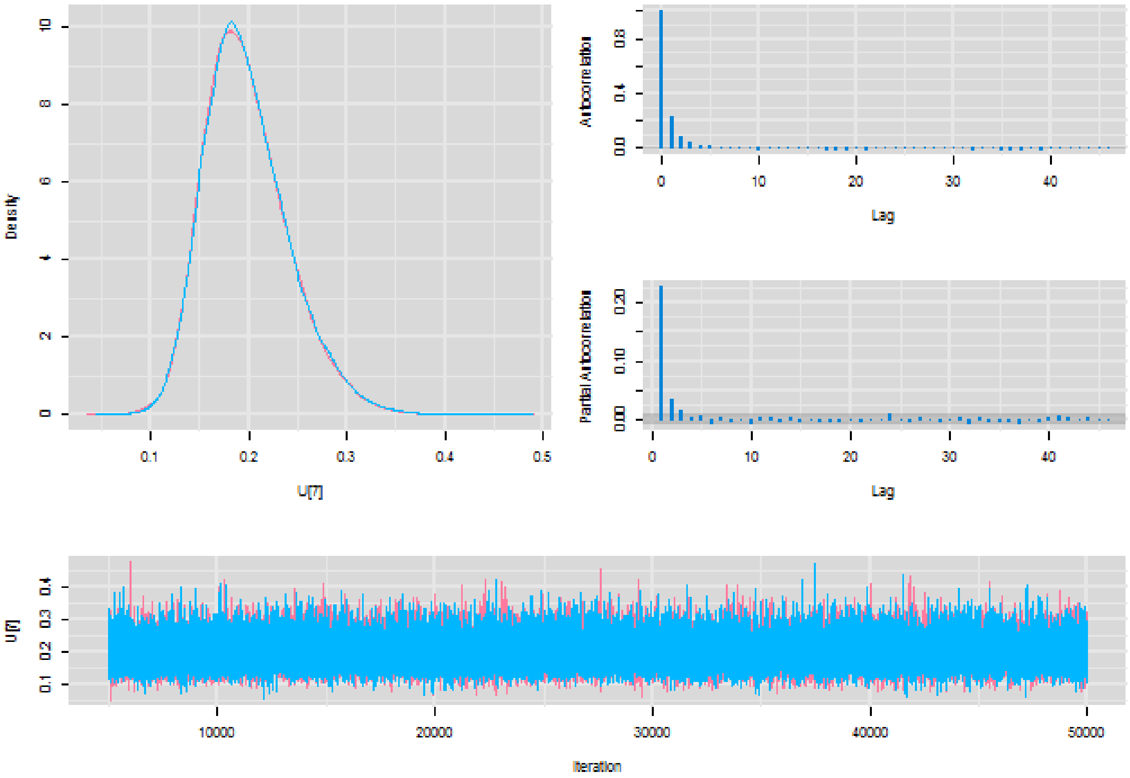
Diagnostics for U[5]



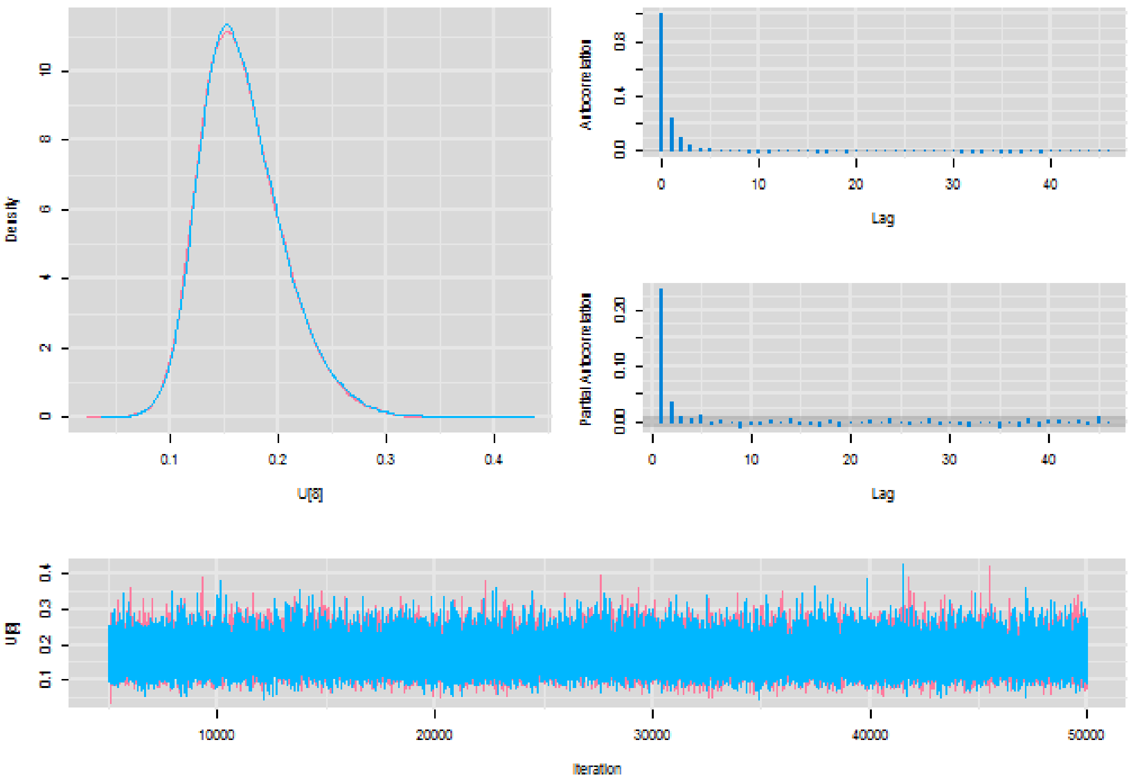
Diagnostics for U[6]



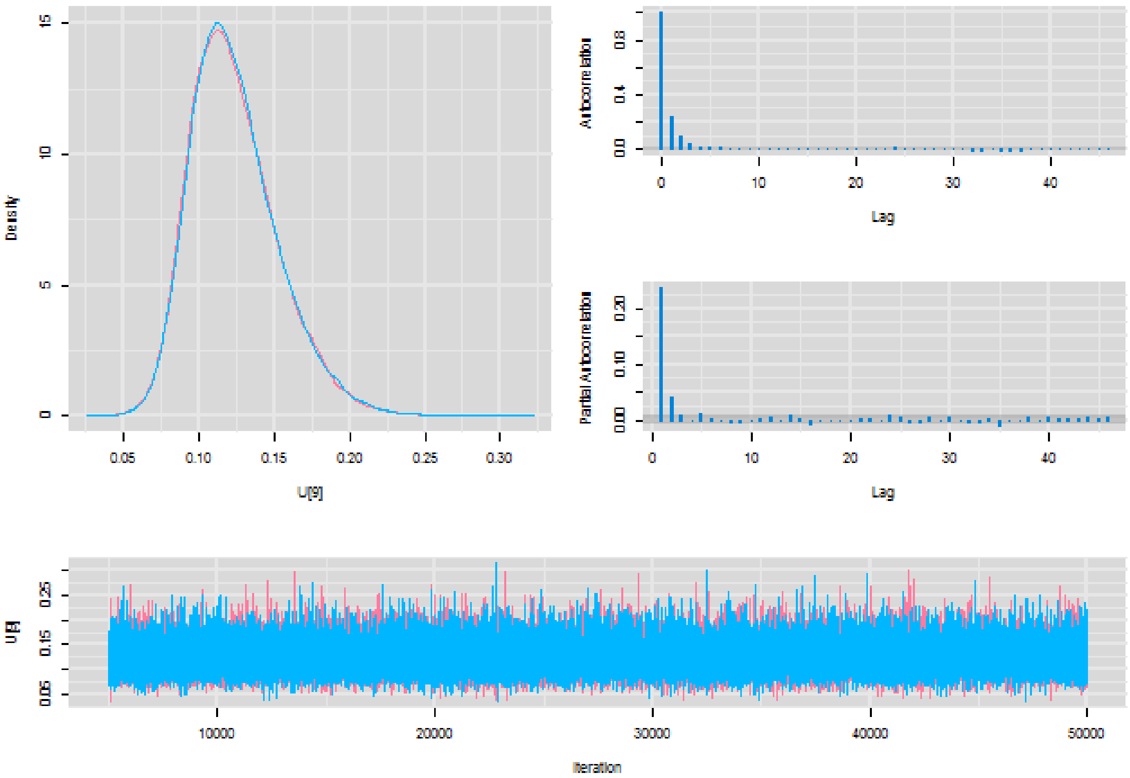
Diagnostics for U[7]



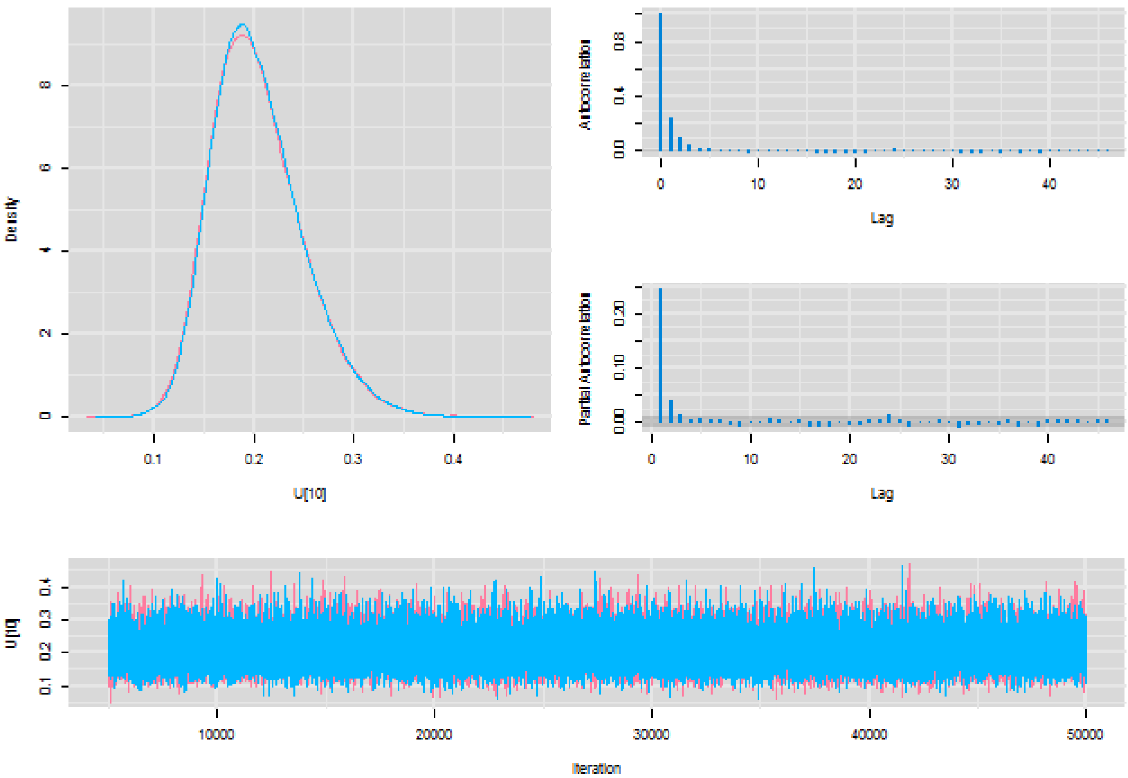
Diagnostics for U[8]



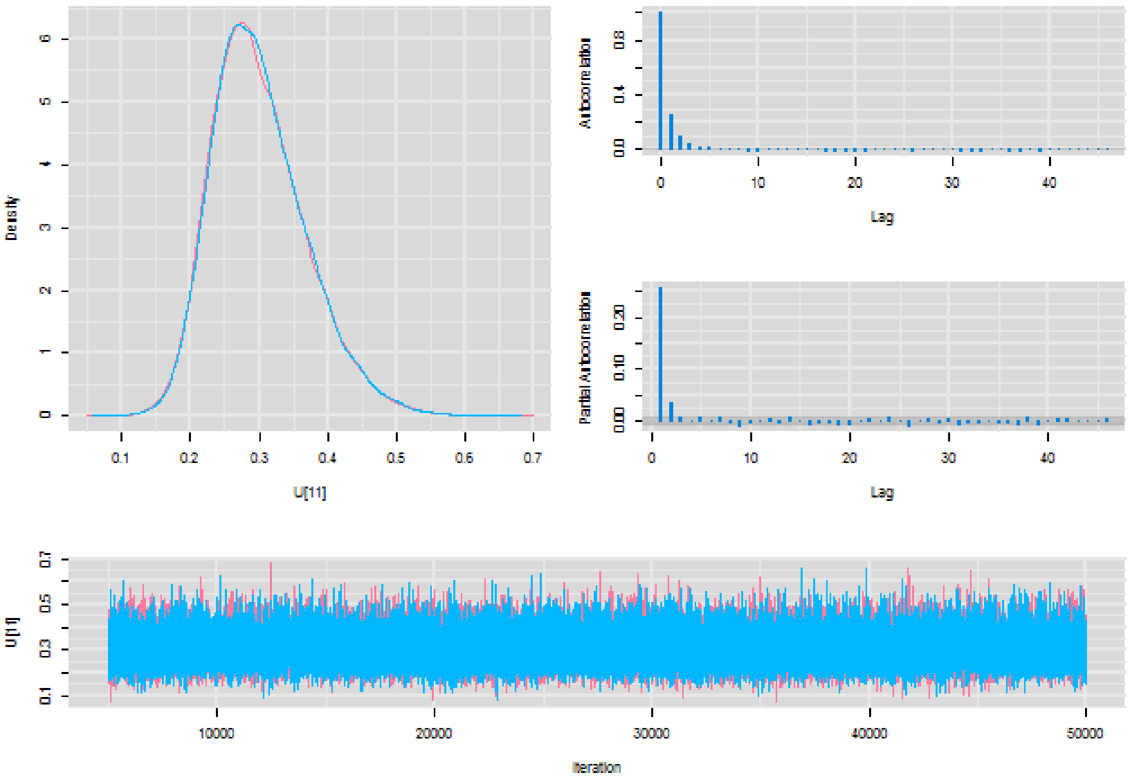
Diagnostics for U[9]



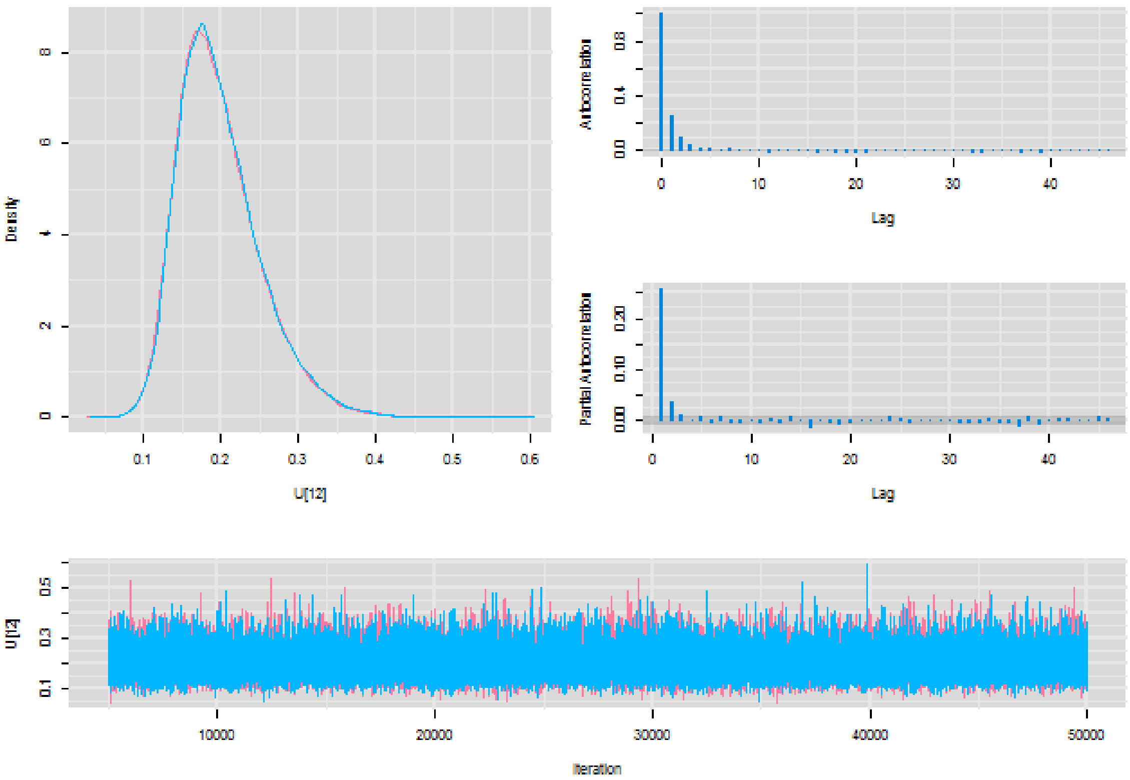
Diagnostics for U[10]



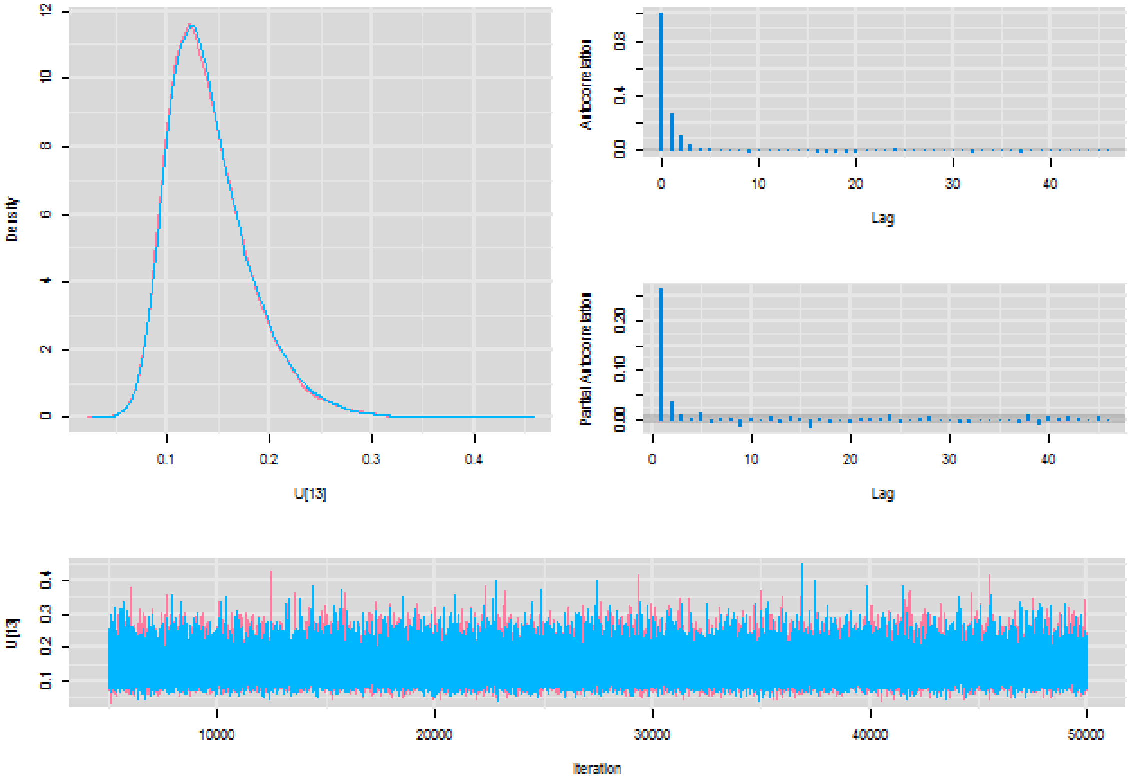
Diagnostics for U[11]



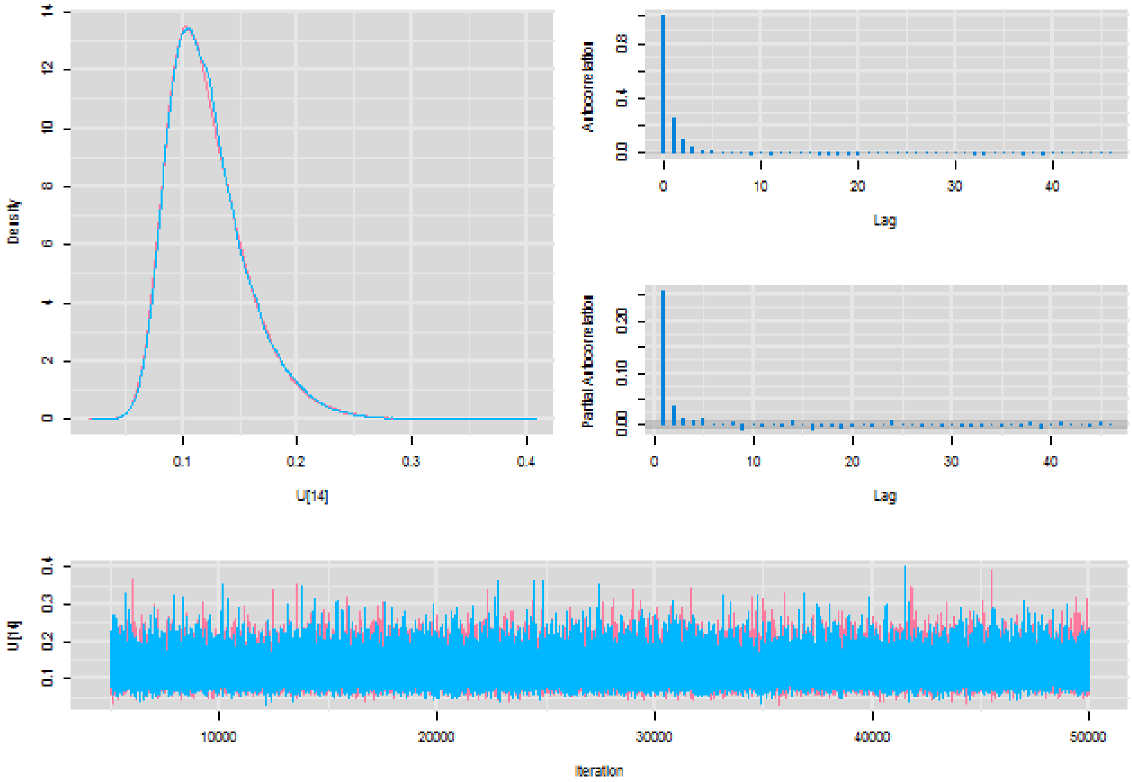
Diagnostics for U[12]



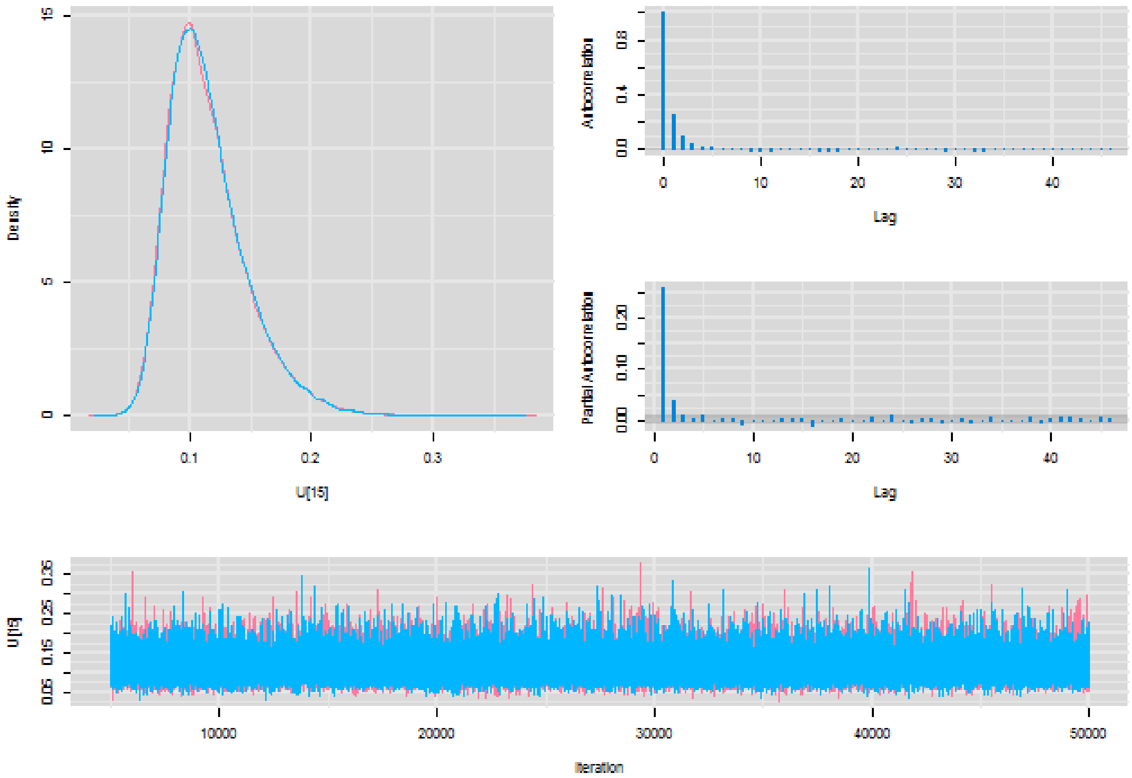
Diagnostics for U[13]



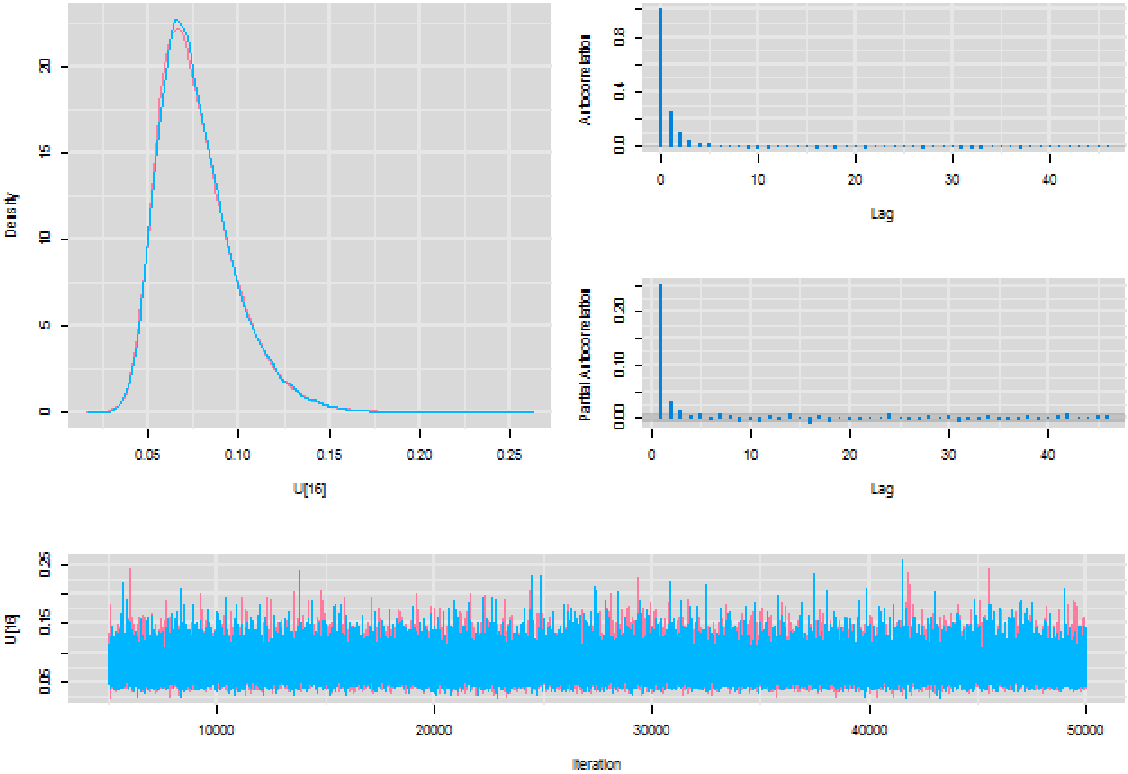
Diagnostics for U[14]



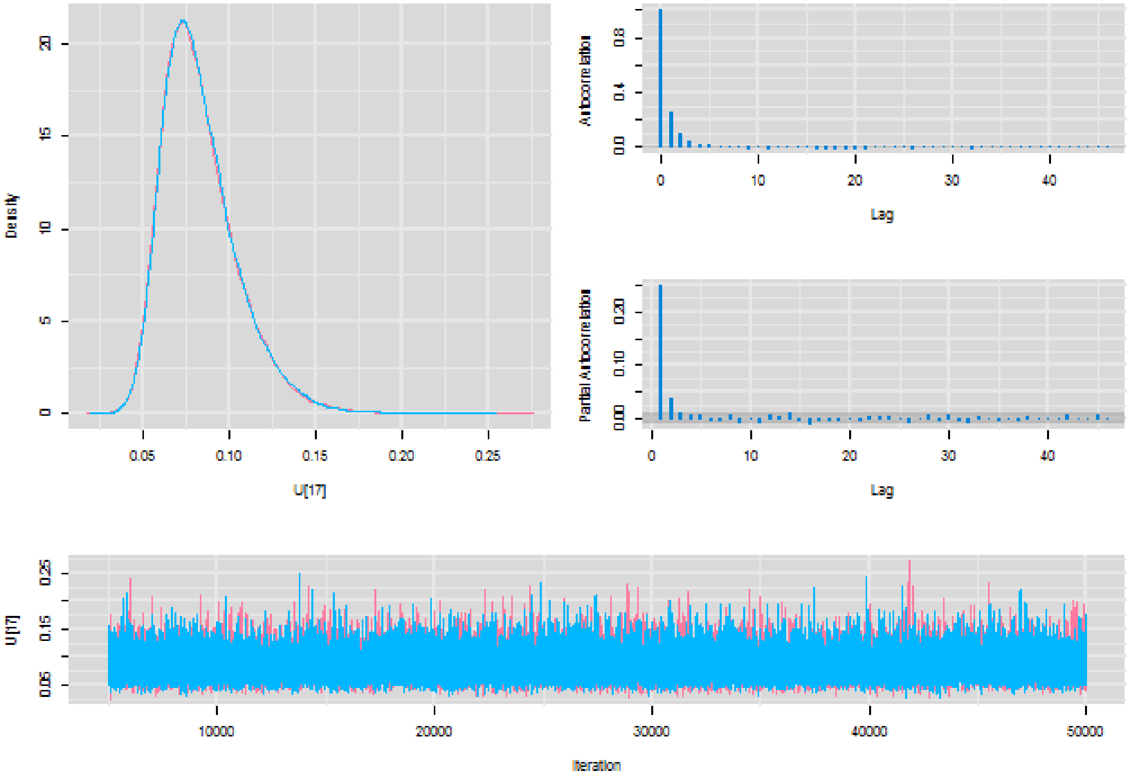
Diagnostics for U[15]



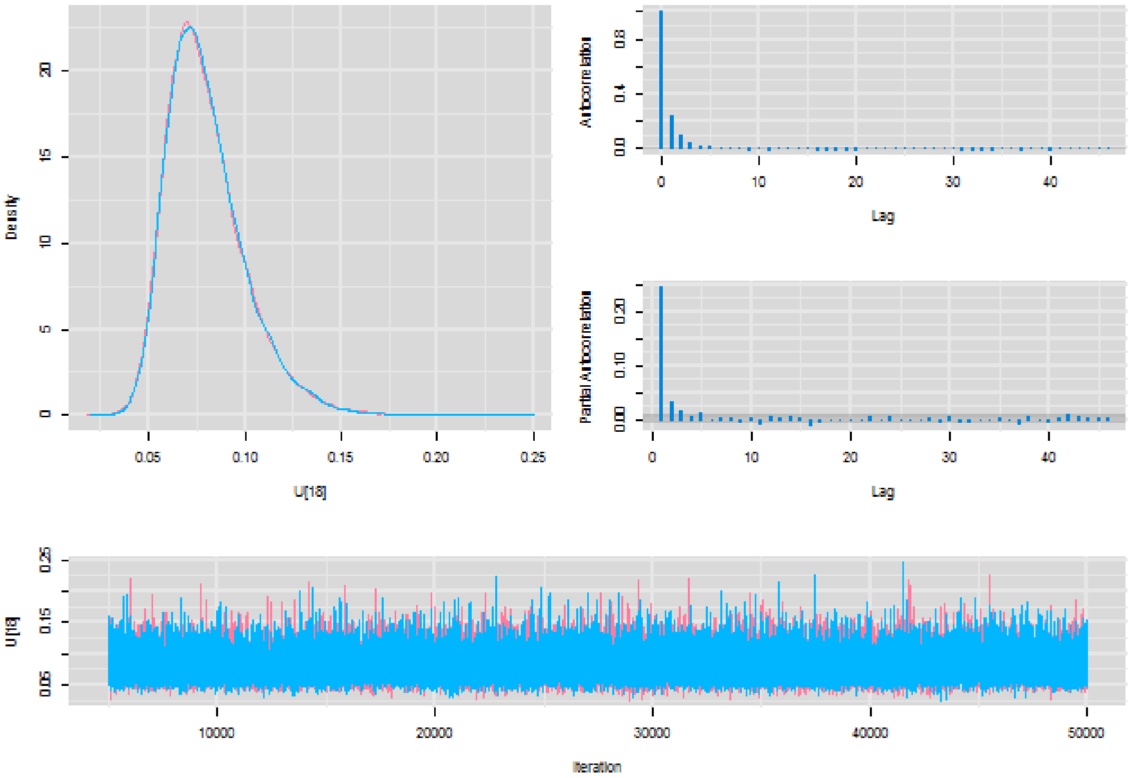
Diagnostics for U[16]



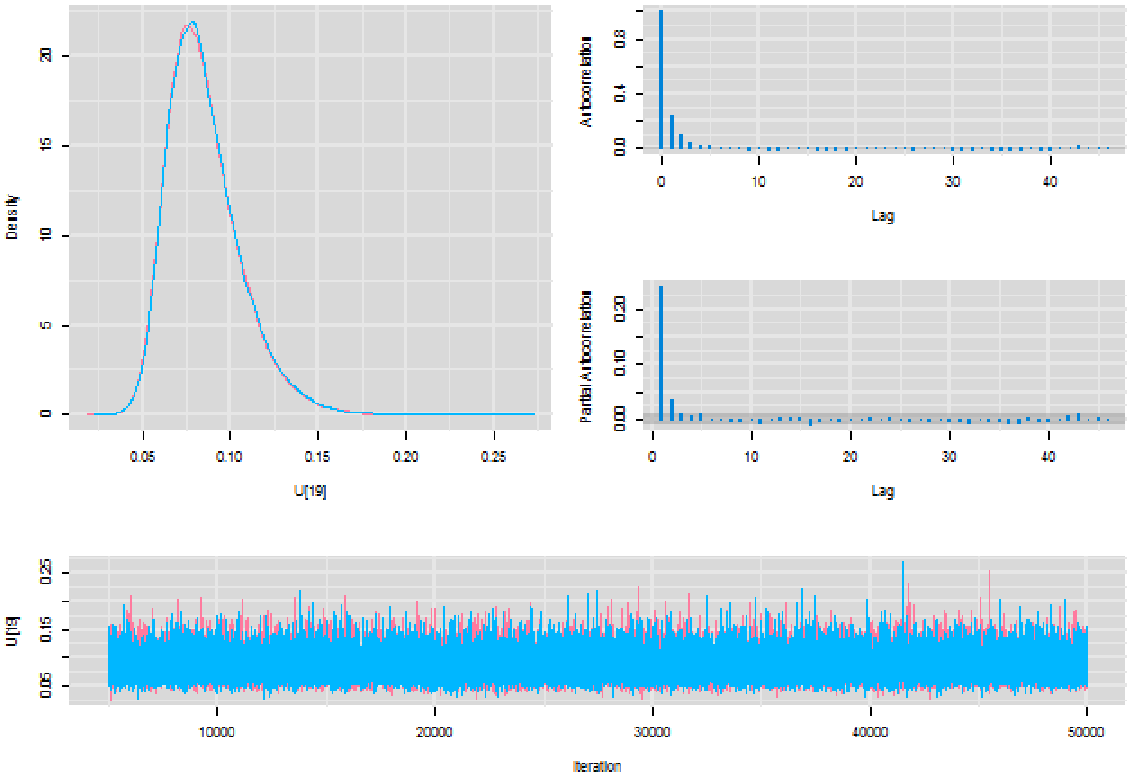
Diagnostics for U[17]



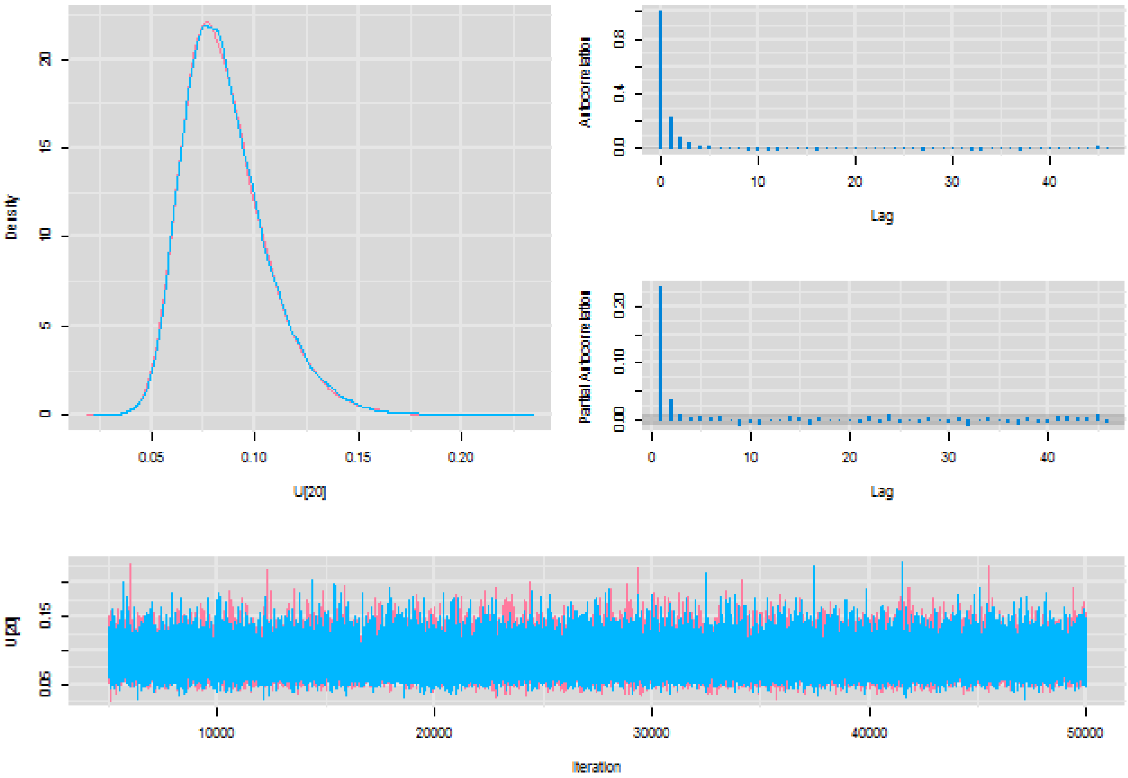
Diagnostics for U[18]



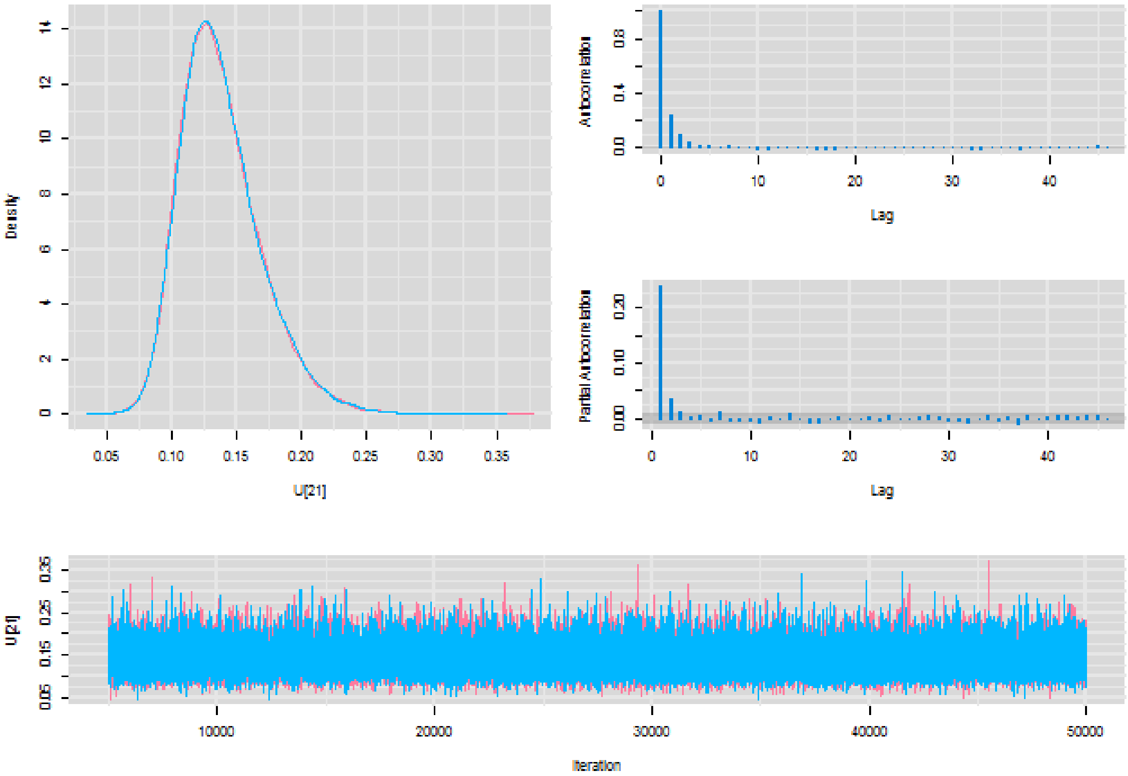
Diagnostics for U[19]



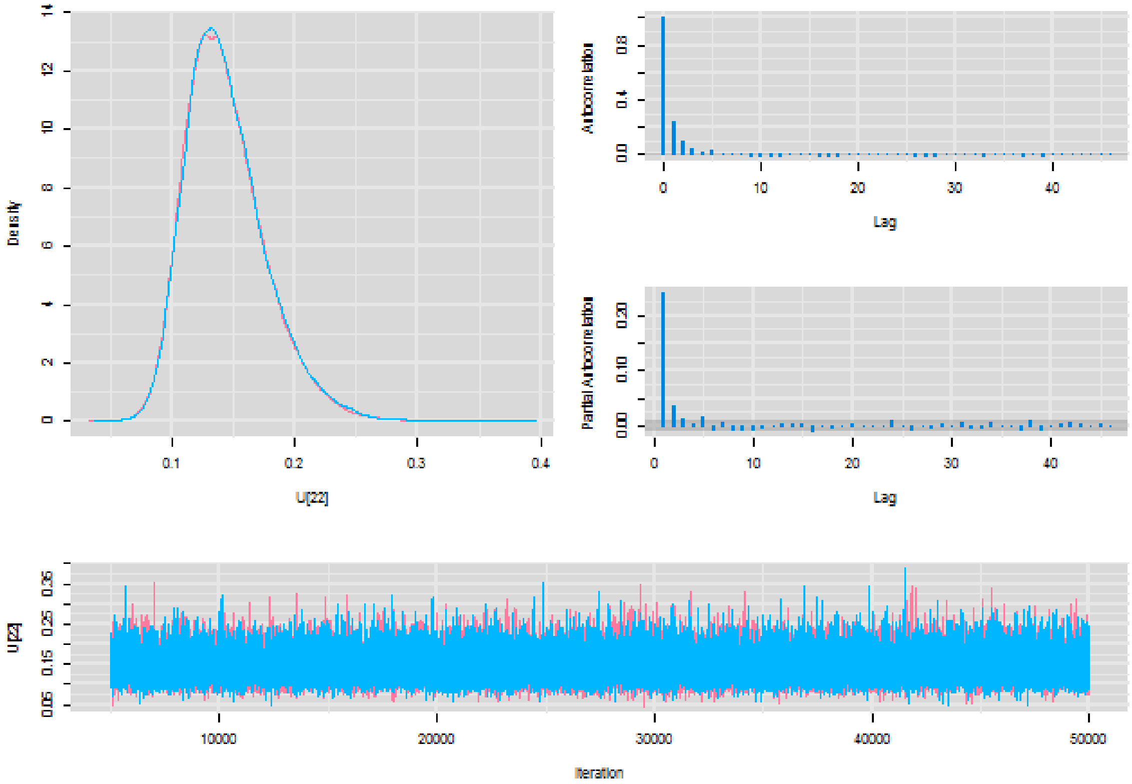
Diagnostics for U[20]



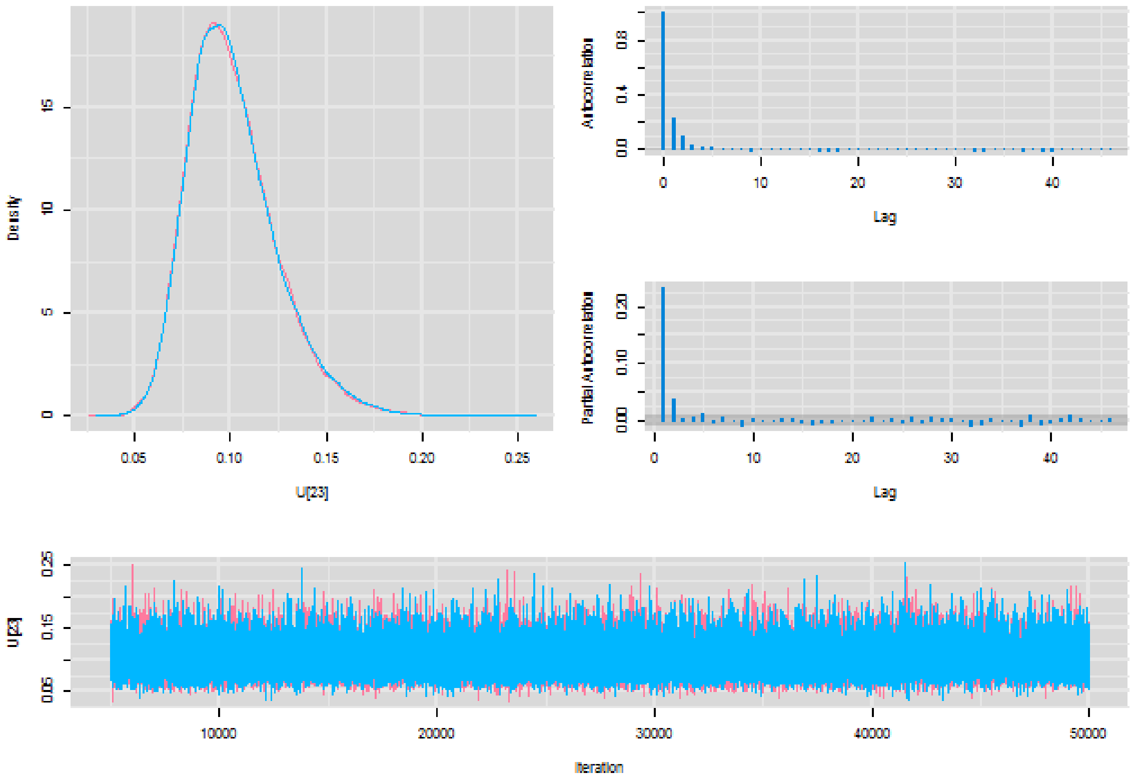
Diagnostics for U[21]



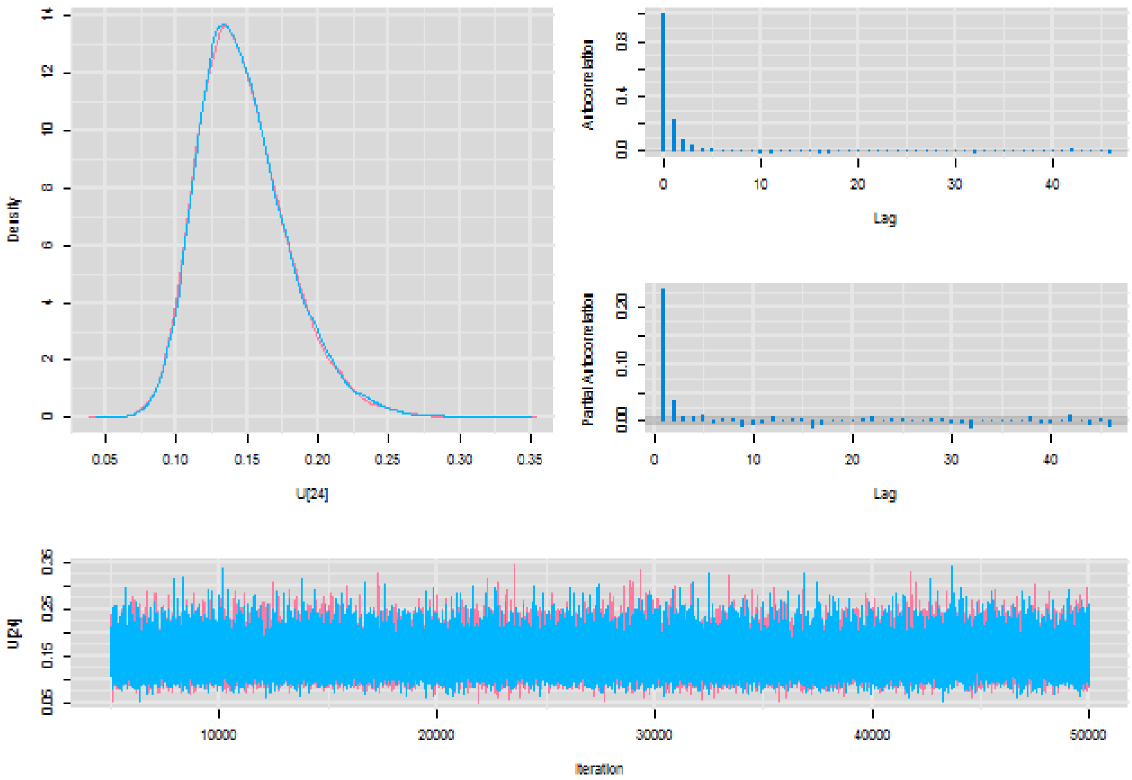
Diagnostics for U[22]



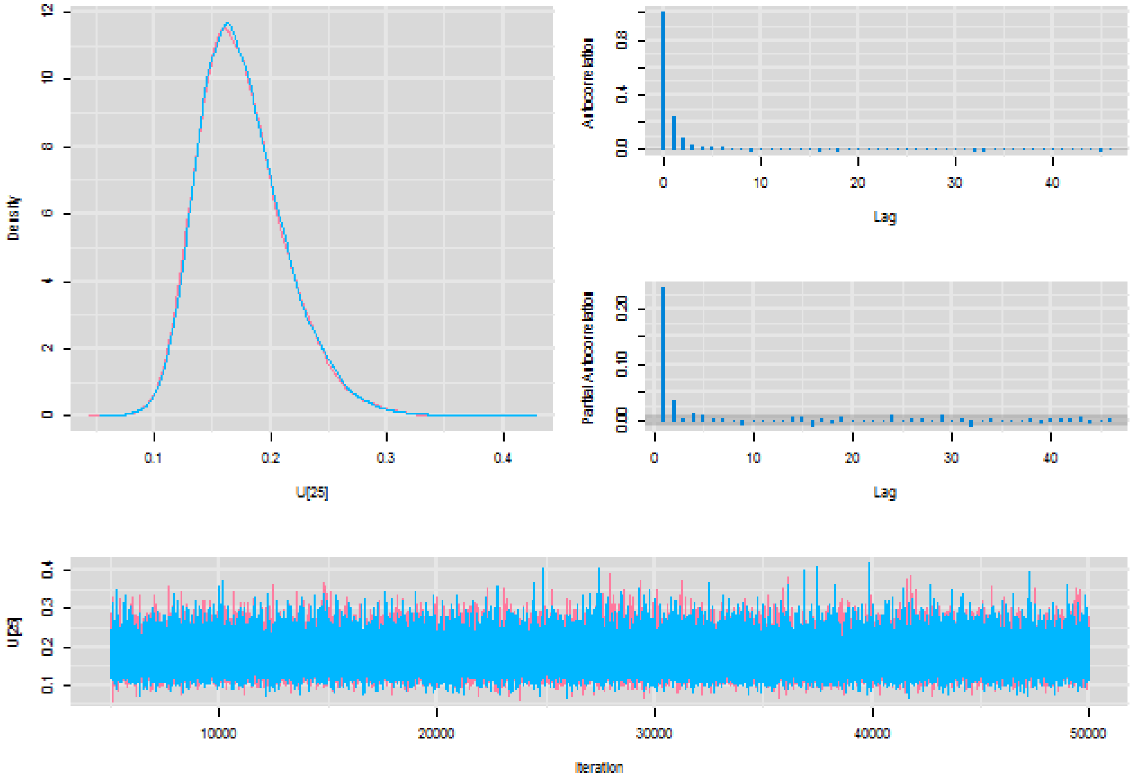
Diagnostics for U[23]



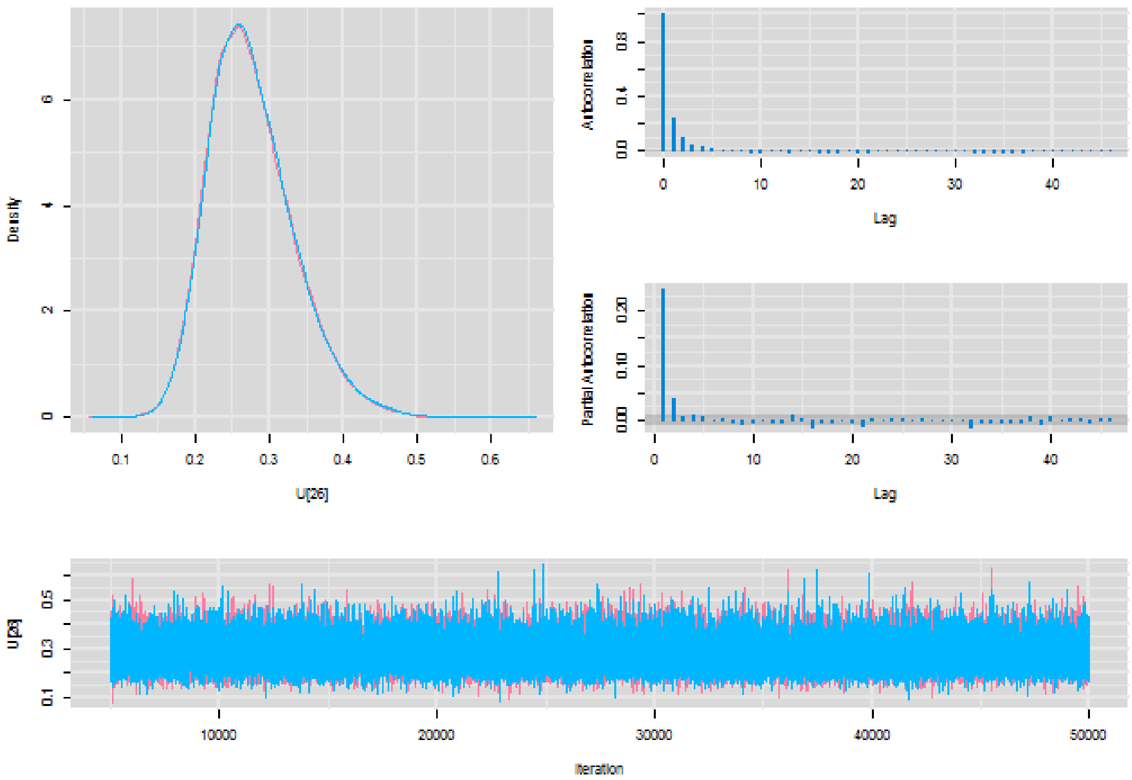
Diagnostics for U[24]



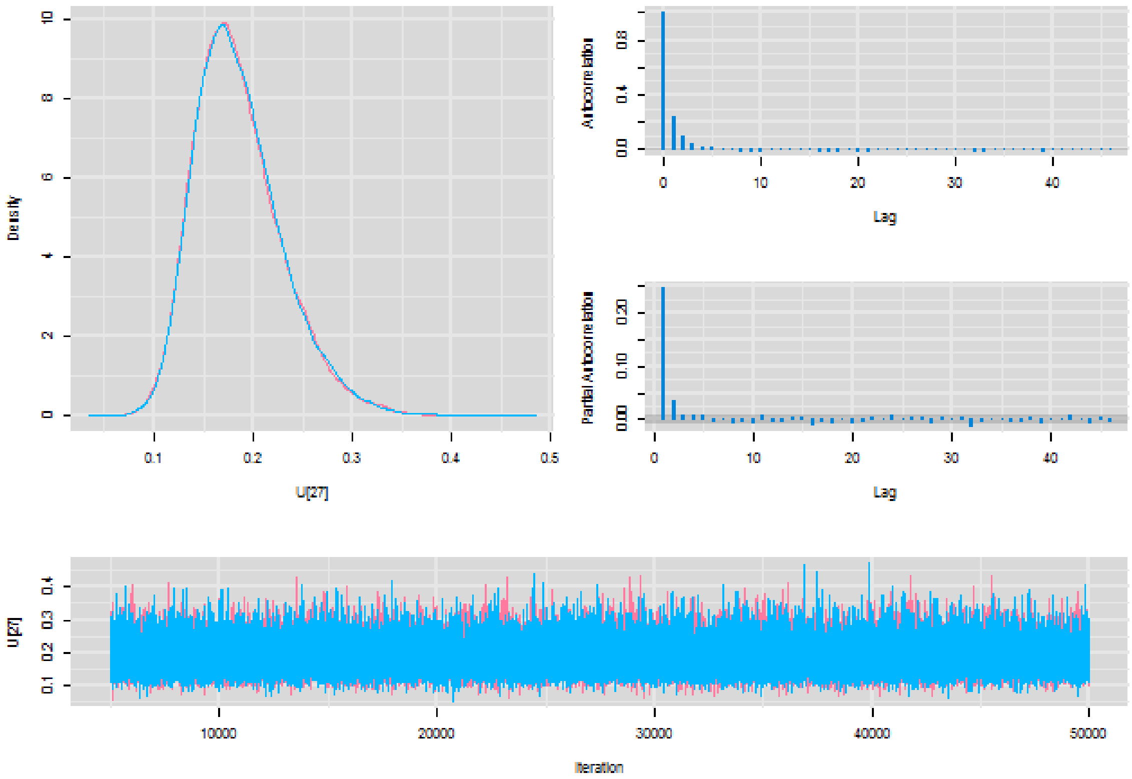
Diagnostics for U[25]



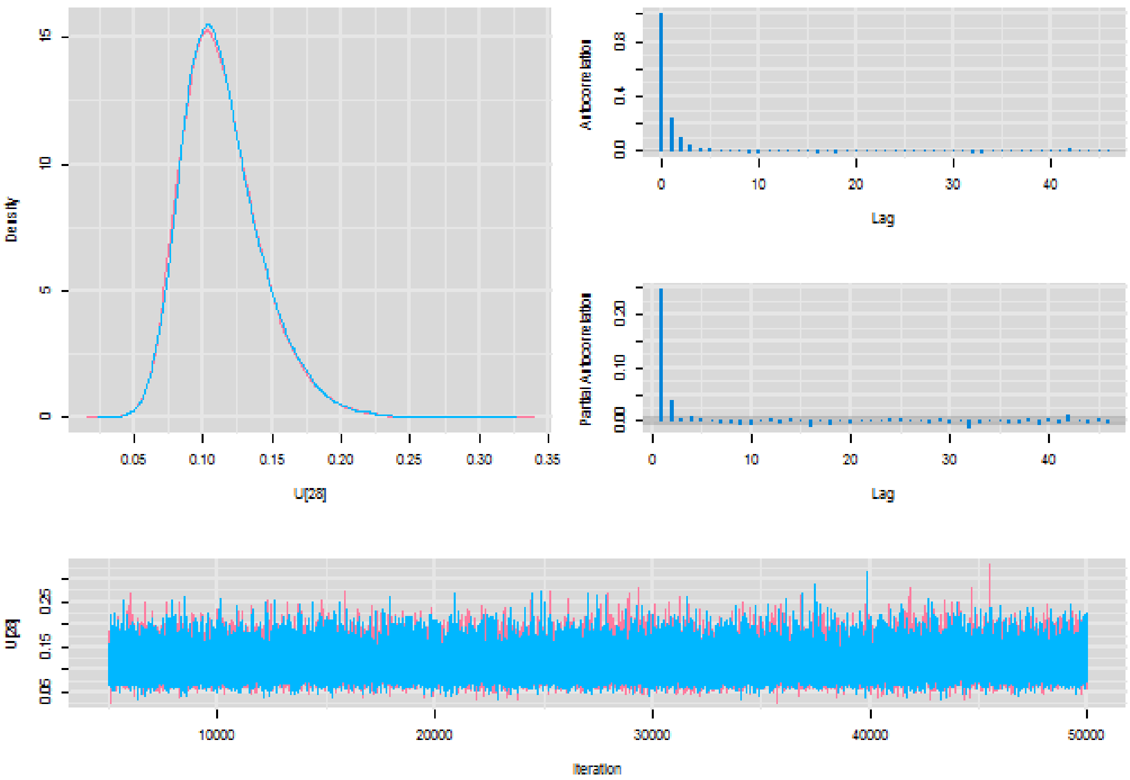
Diagnostics for U[26]



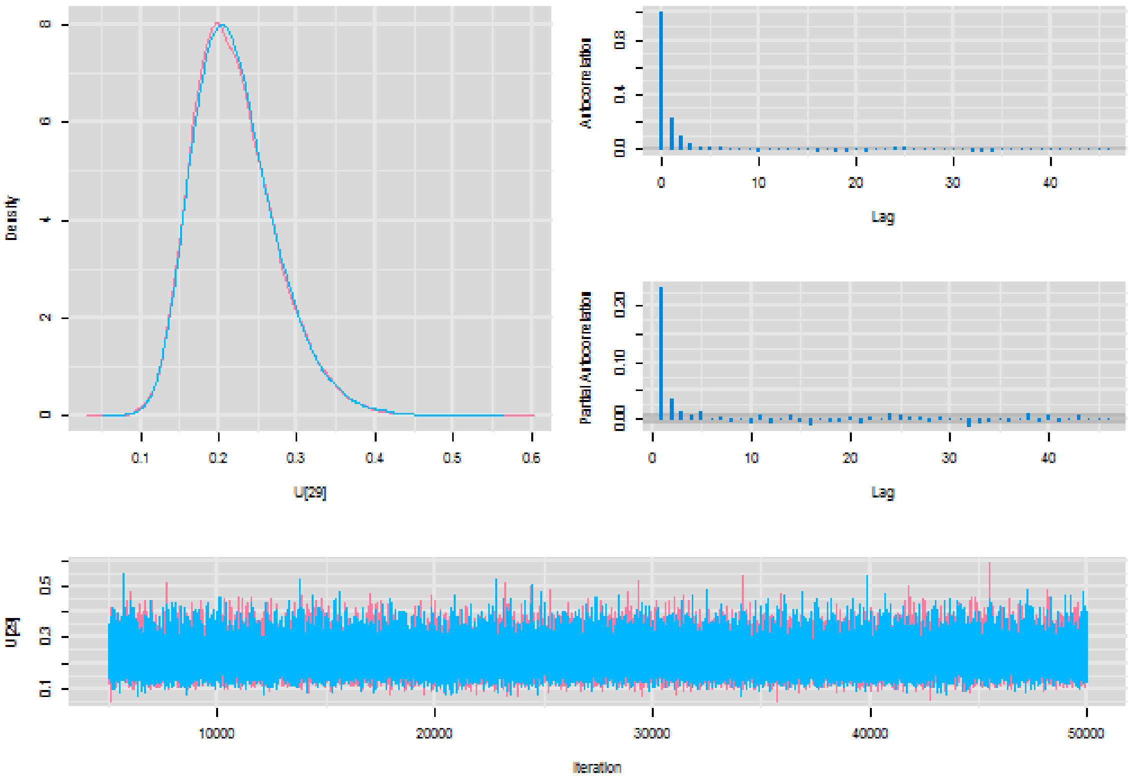
Diagnostics for U[27]



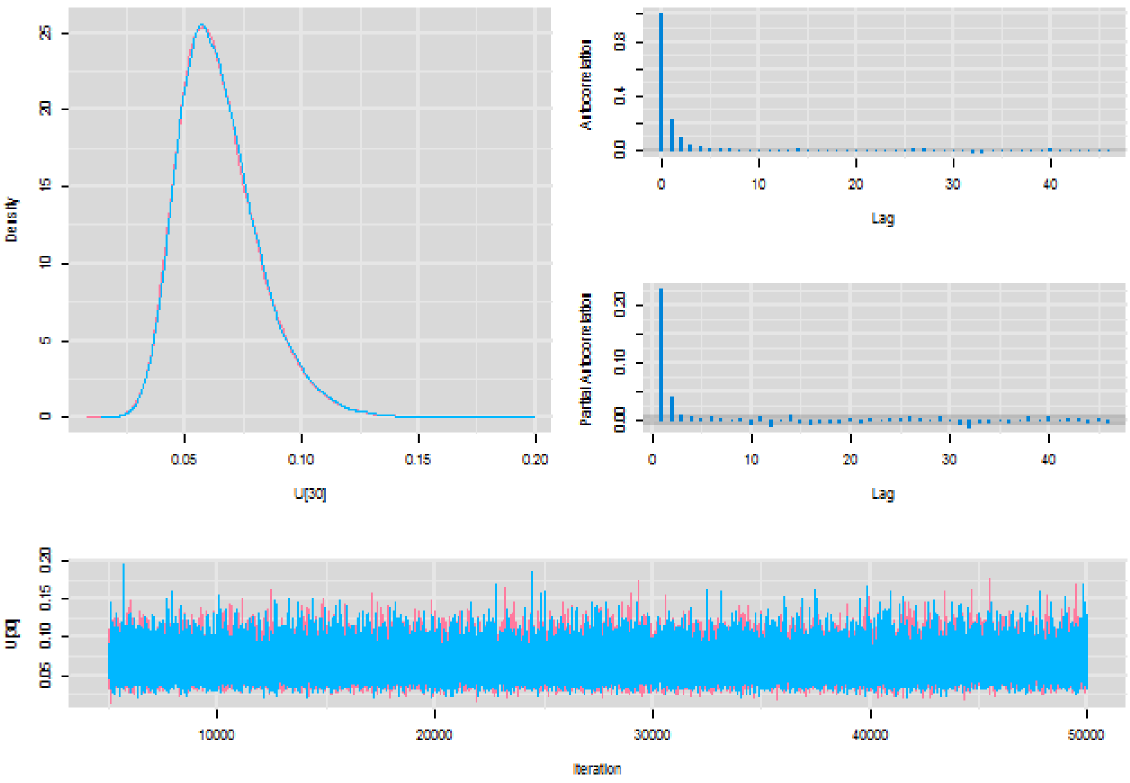
Diagnostics for U[28]



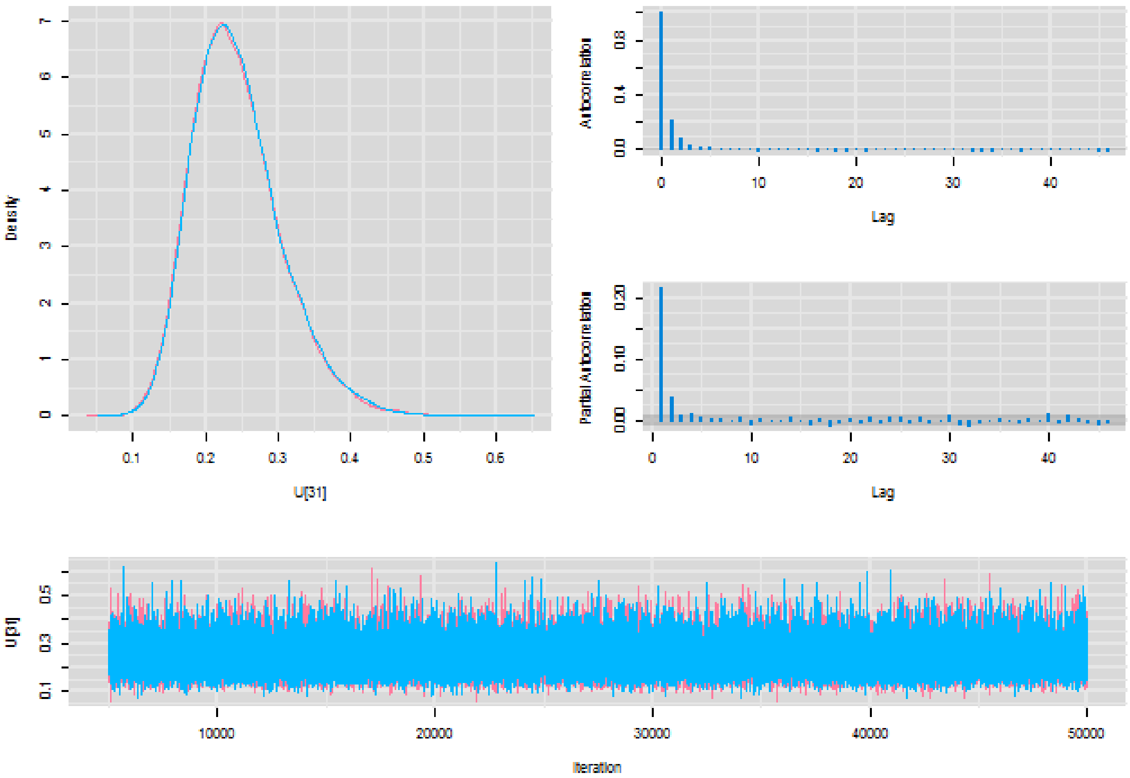
Diagnostics for U[29]



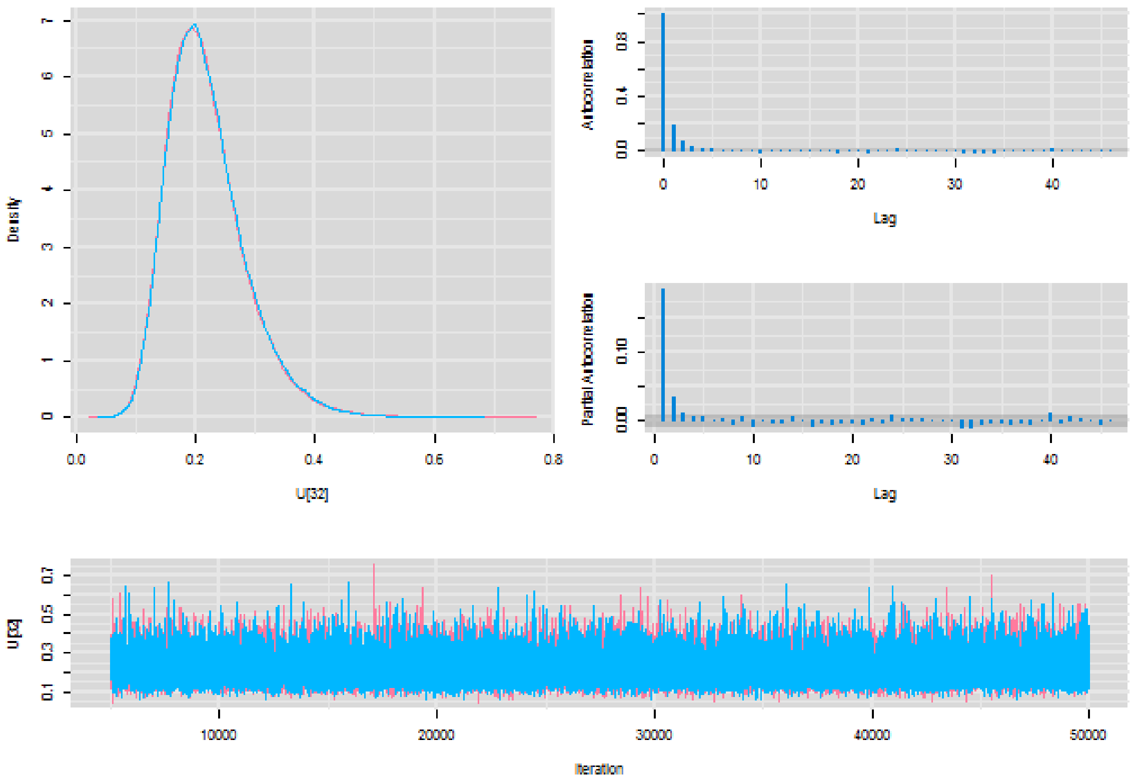
Diagnostics for U[30]



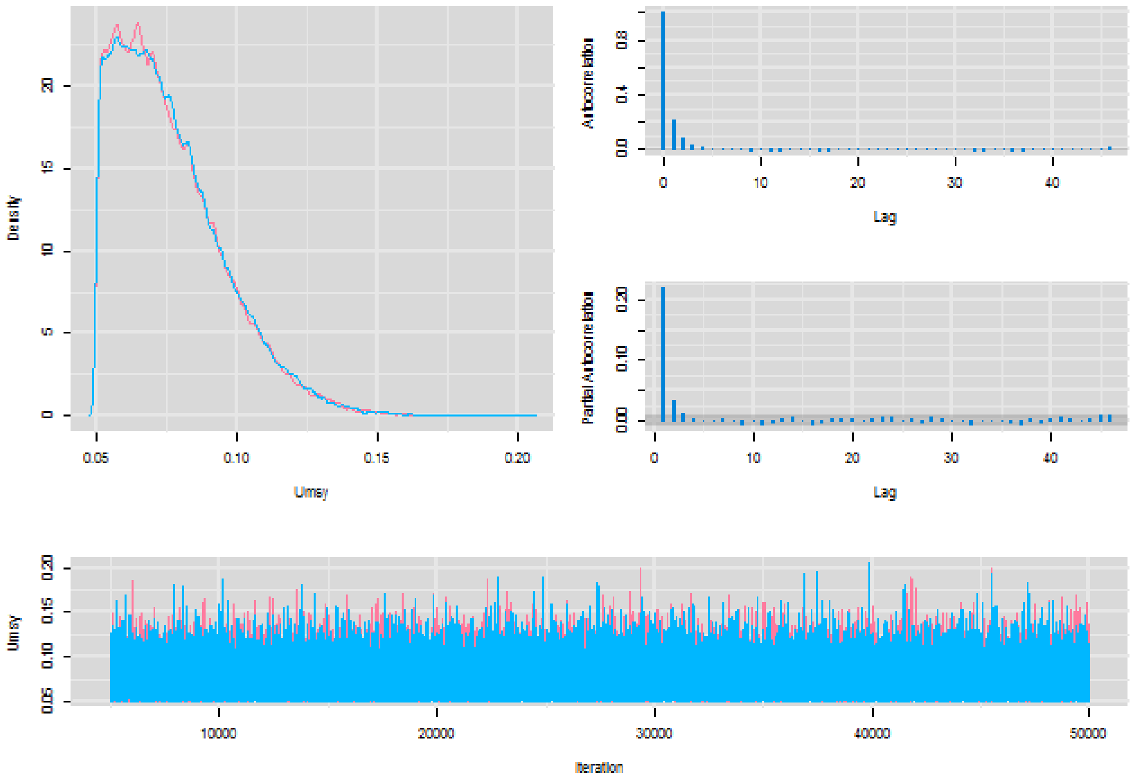
Diagnostics for U[31]



Diagnostics for U[32]

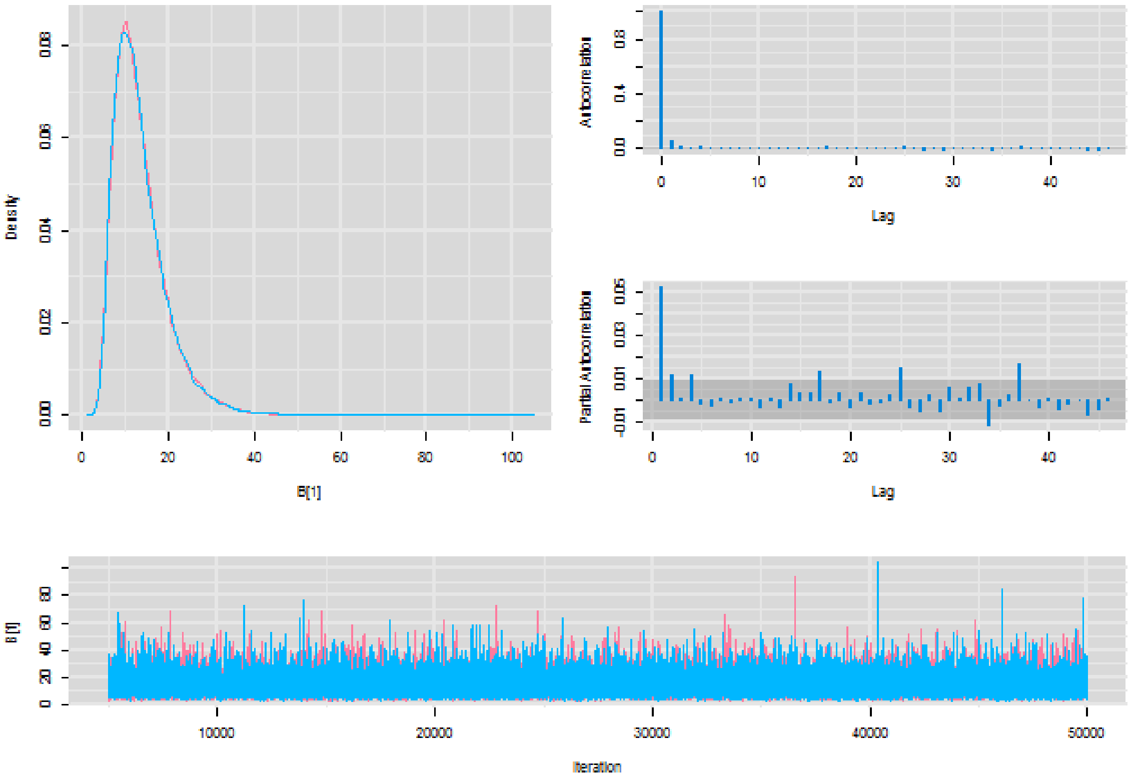


Diagnostics for Umsy

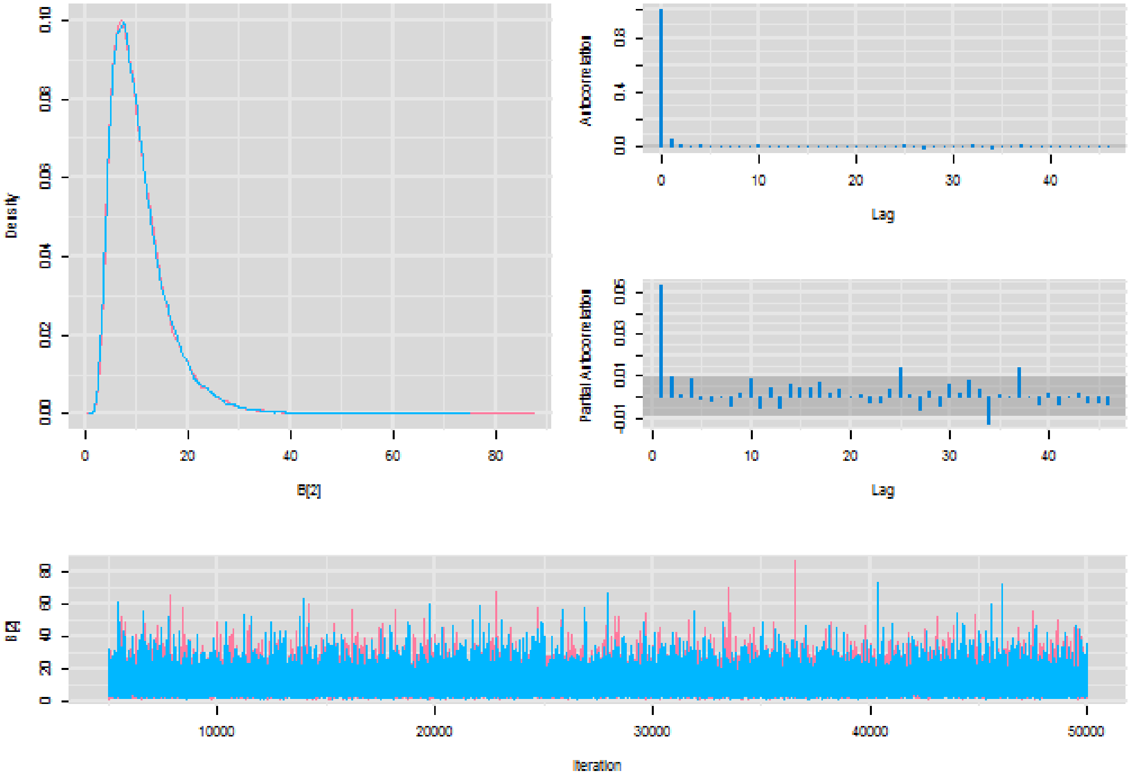


Appendix 1.2 – Diagnostic plots for the New York – New Jersey base run of the Bayesian State Space Surplus Production Model

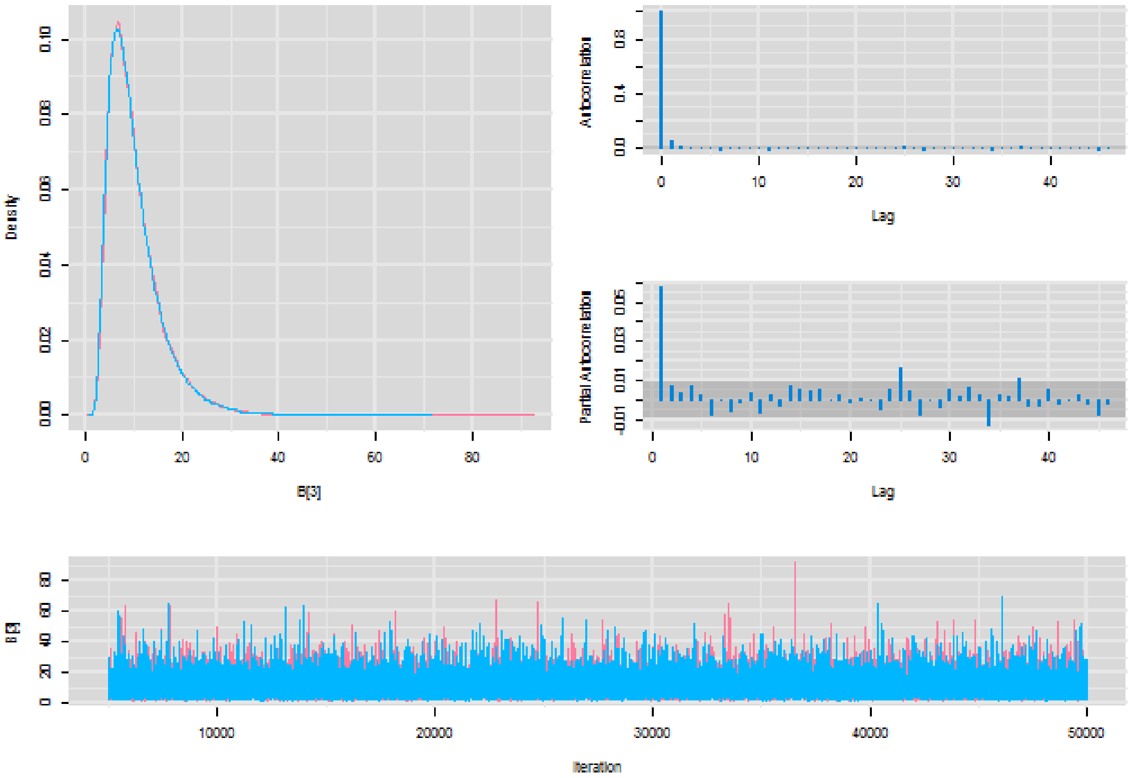
Diagnostics for B[1]



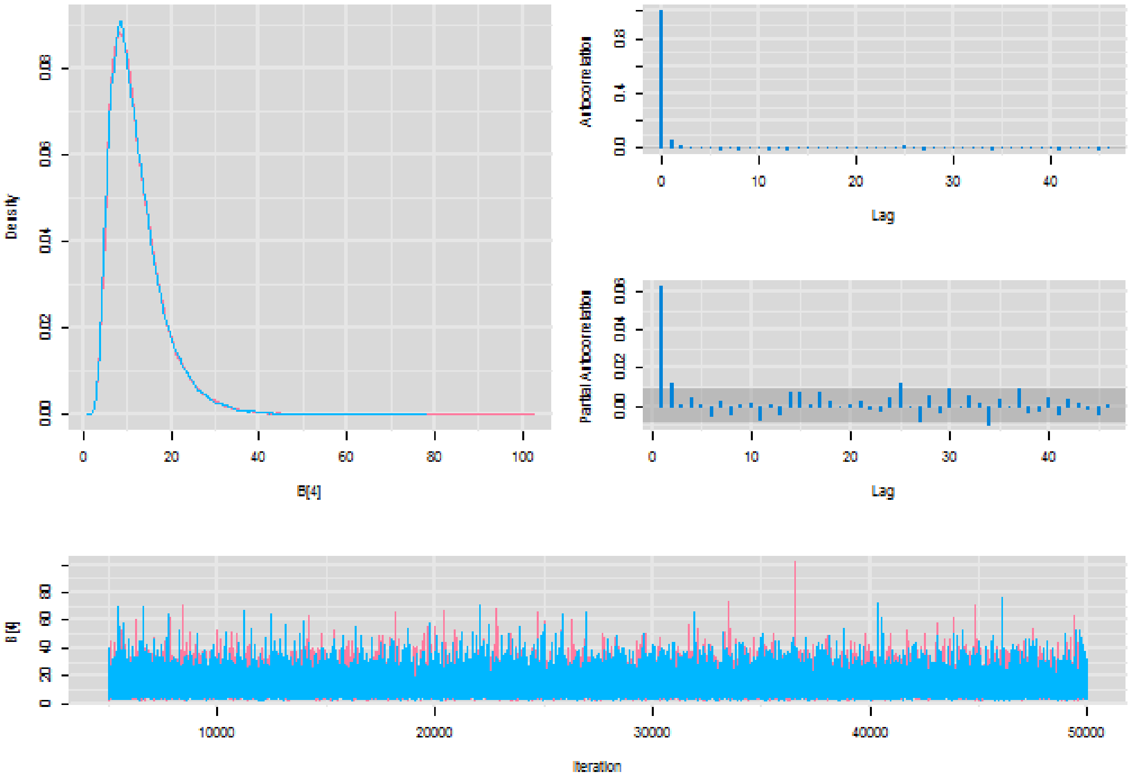
Diagnostics for B[2]



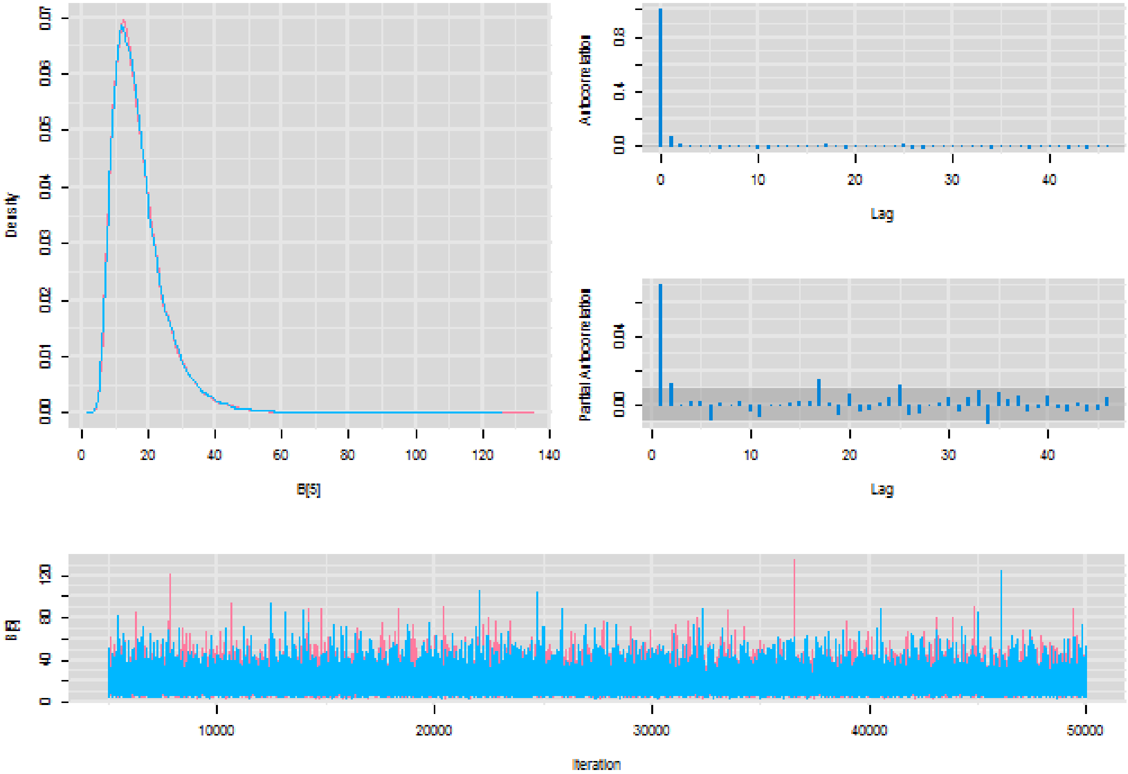
Diagnostics for B[3]



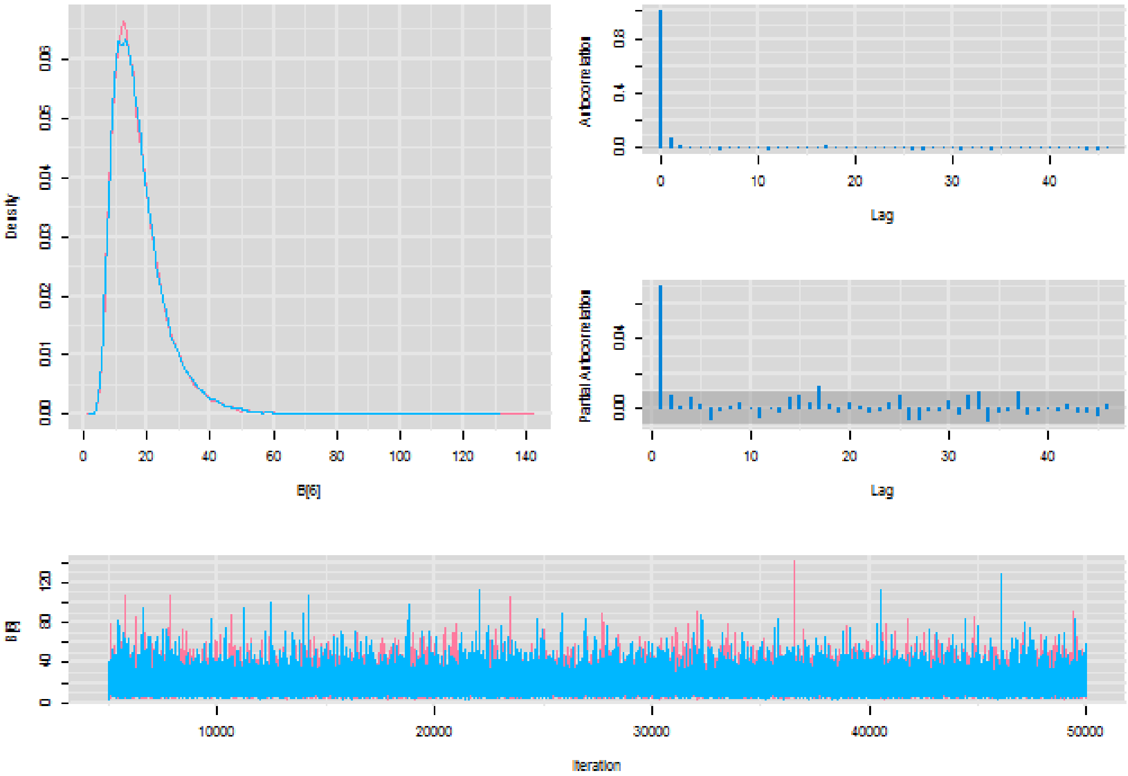
Diagnostics for B[4]



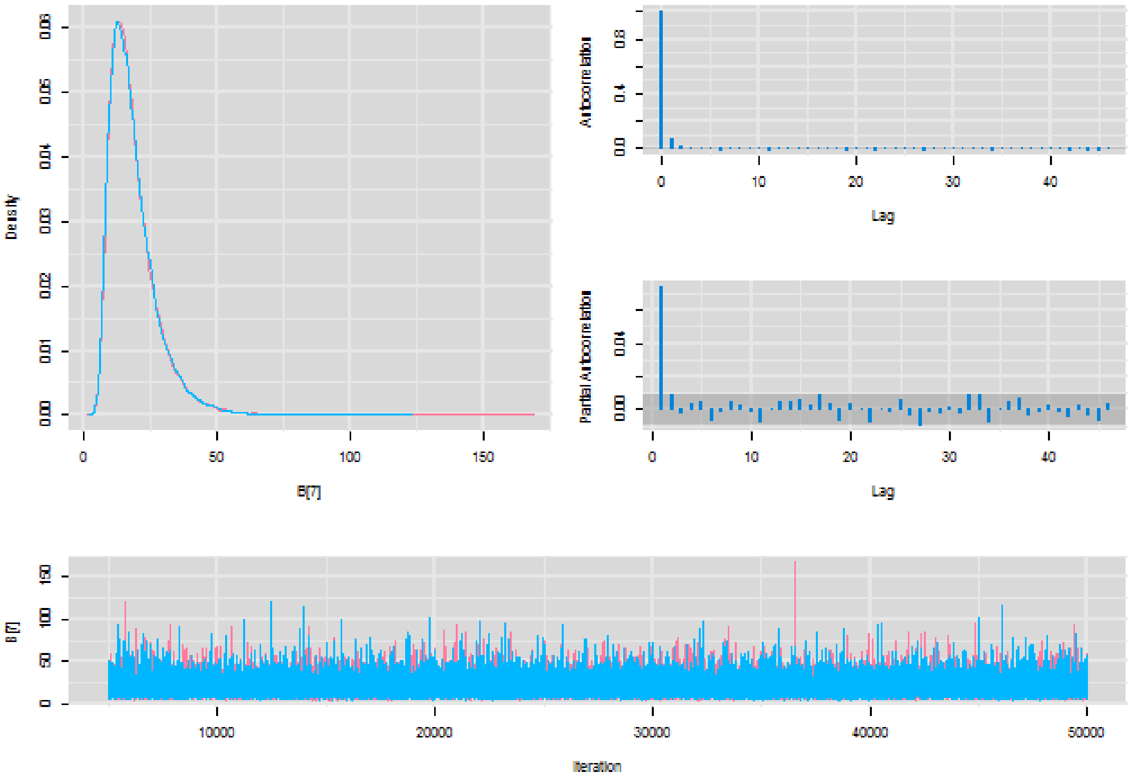
Diagnostics for B[5]



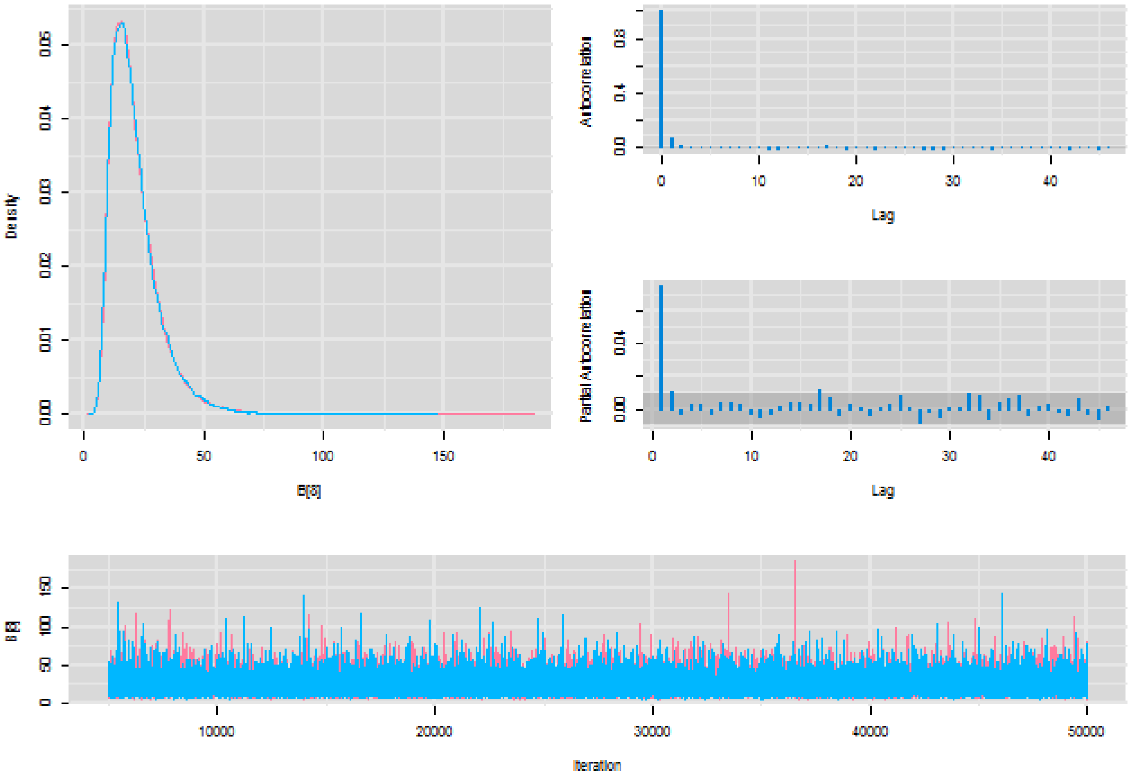
Diagnostics for B[6]



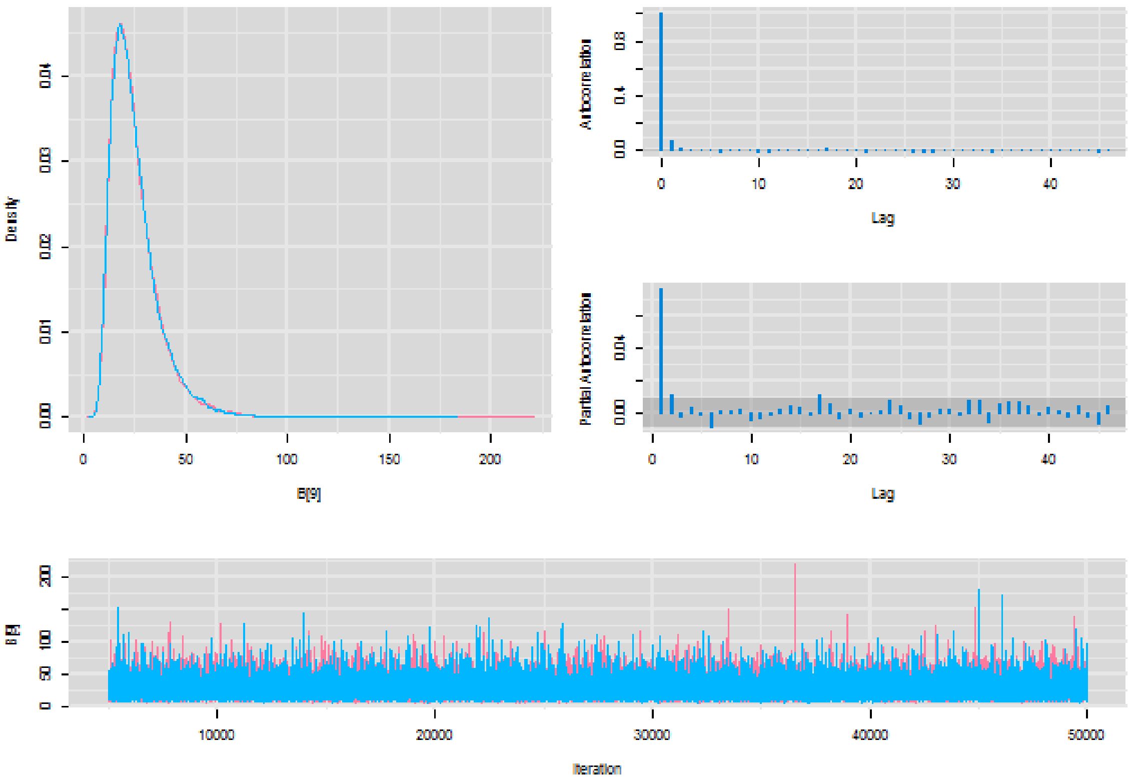
Diagnostics for B[7]



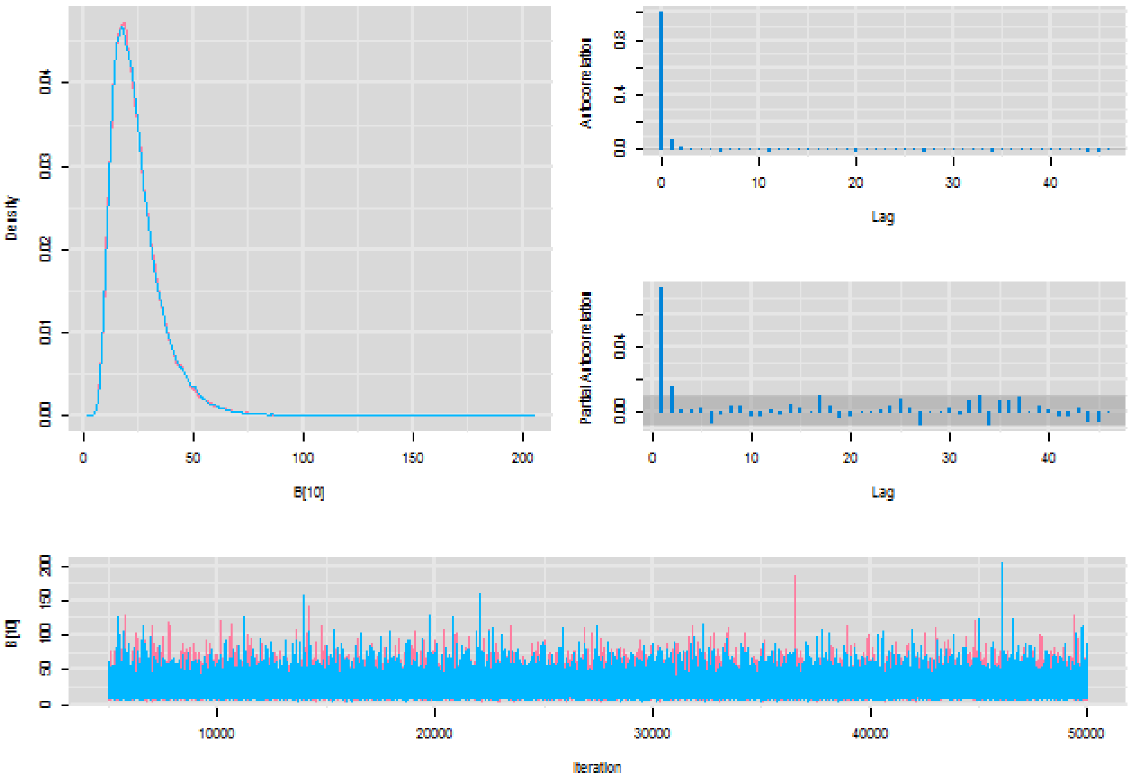
Diagnostics for B[8]



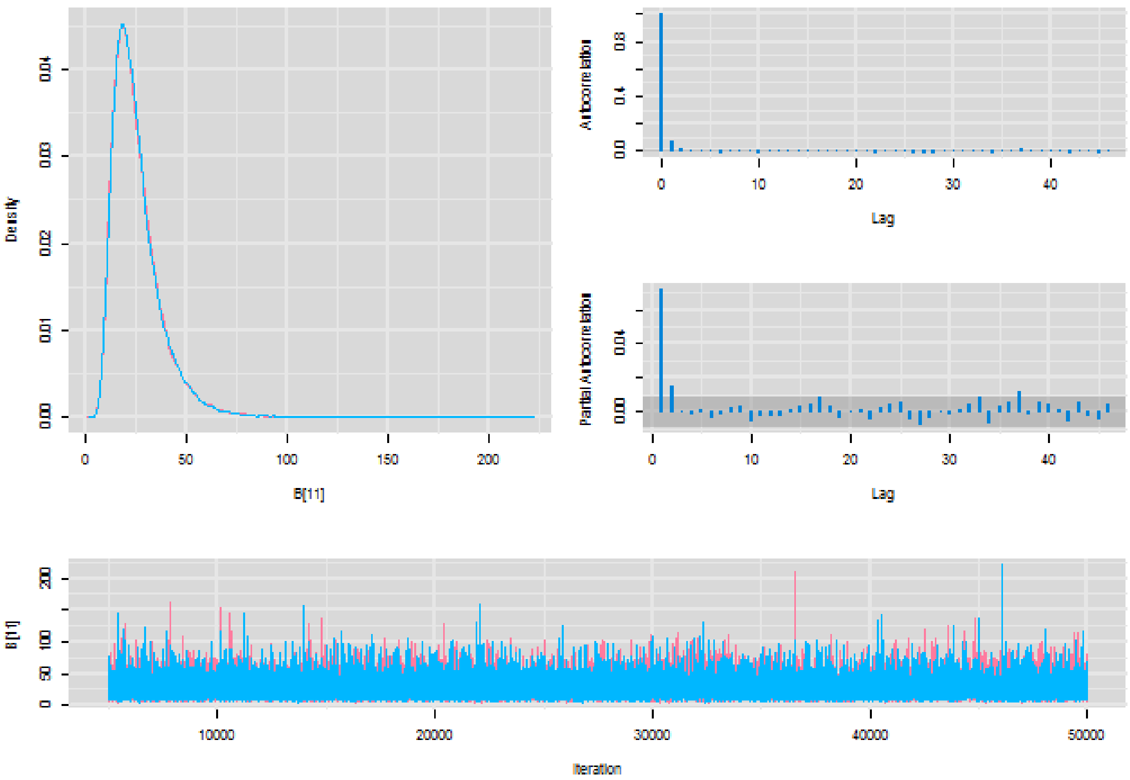
Diagnostics for B[9]



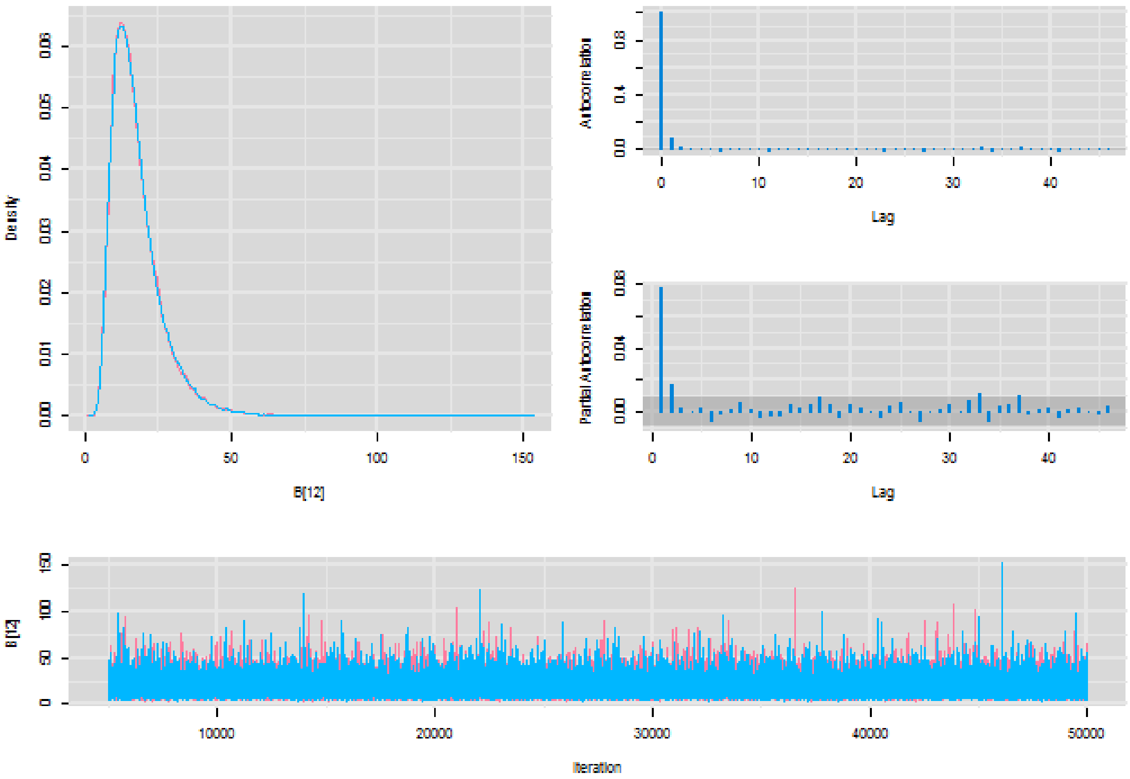
Diagnostics for B[10]



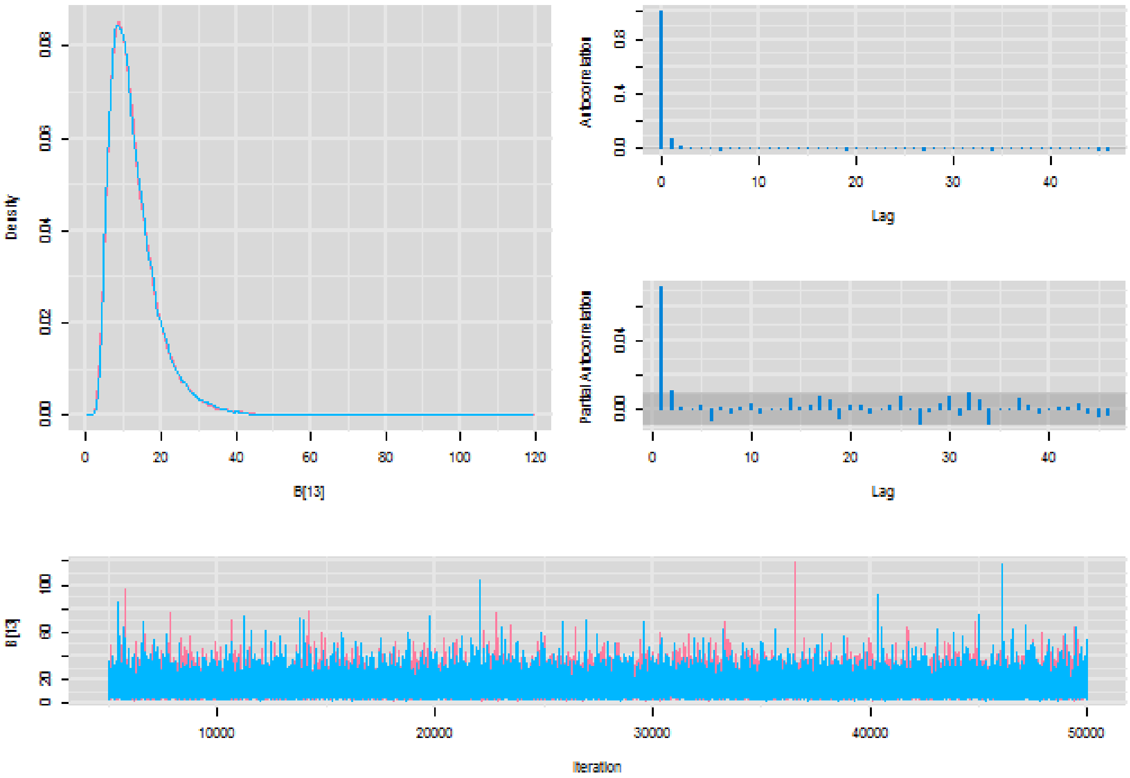
Diagnostics for B[11]



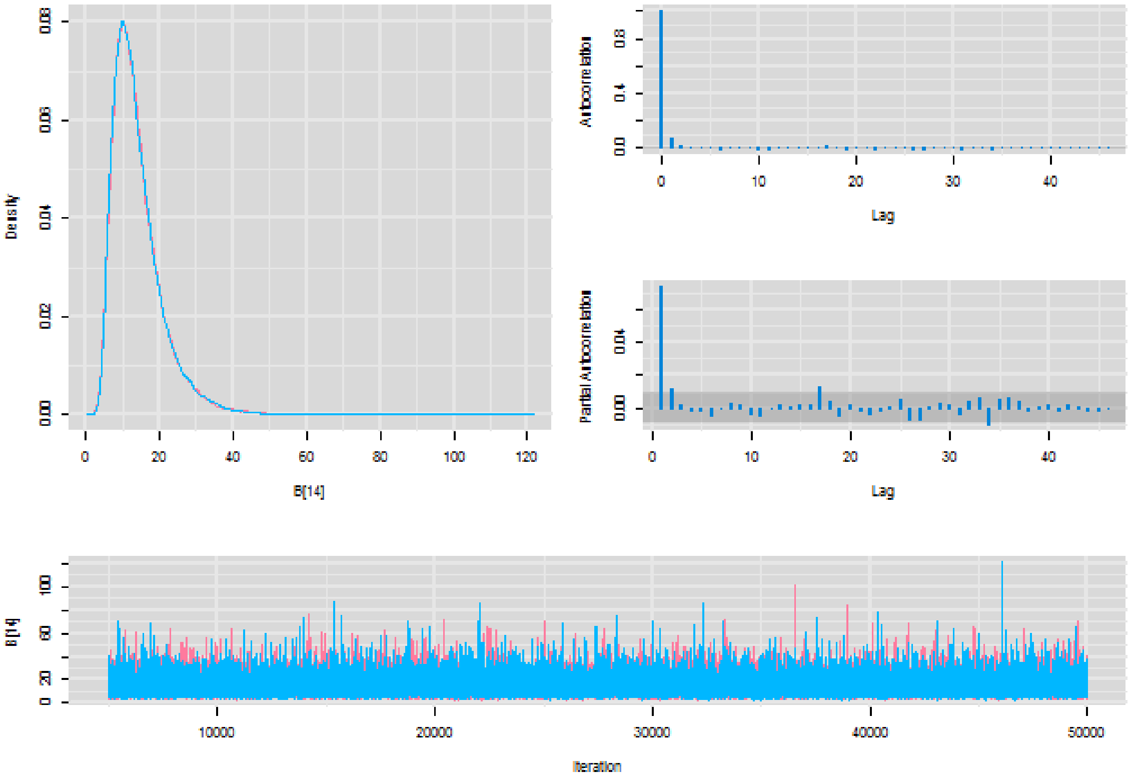
Diagnostics for B[12]



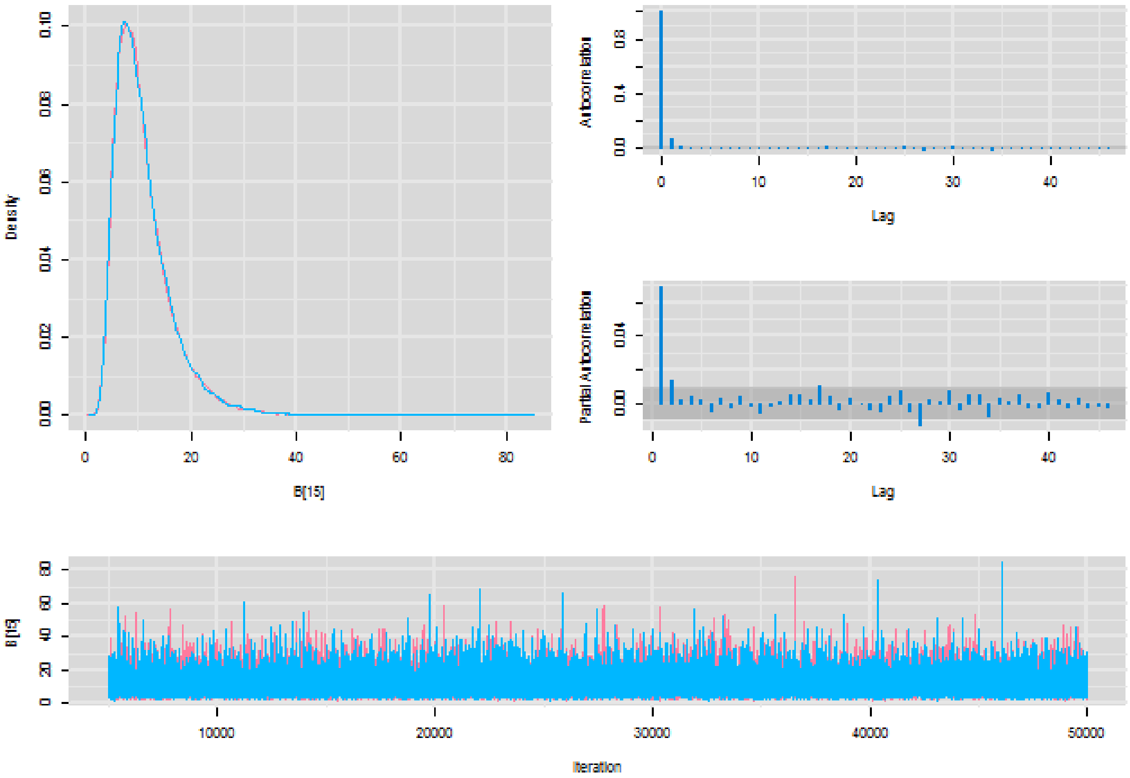
Diagnostics for B[13]



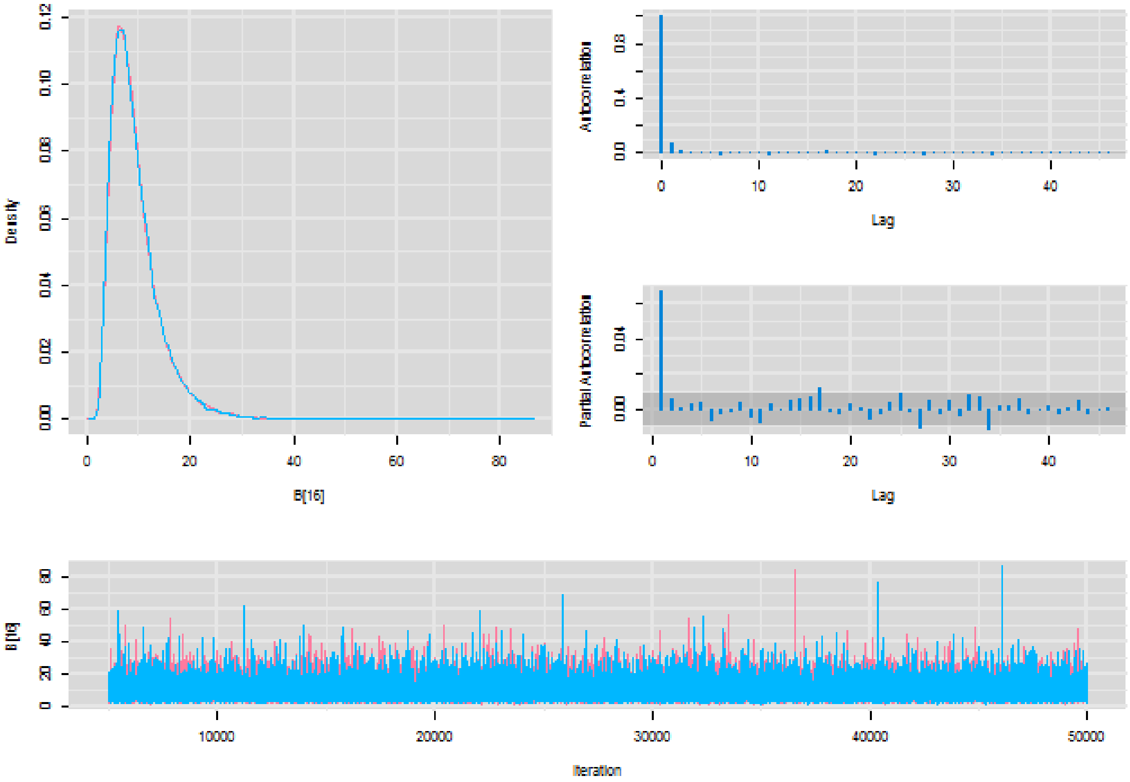
Diagnostics for B[14]



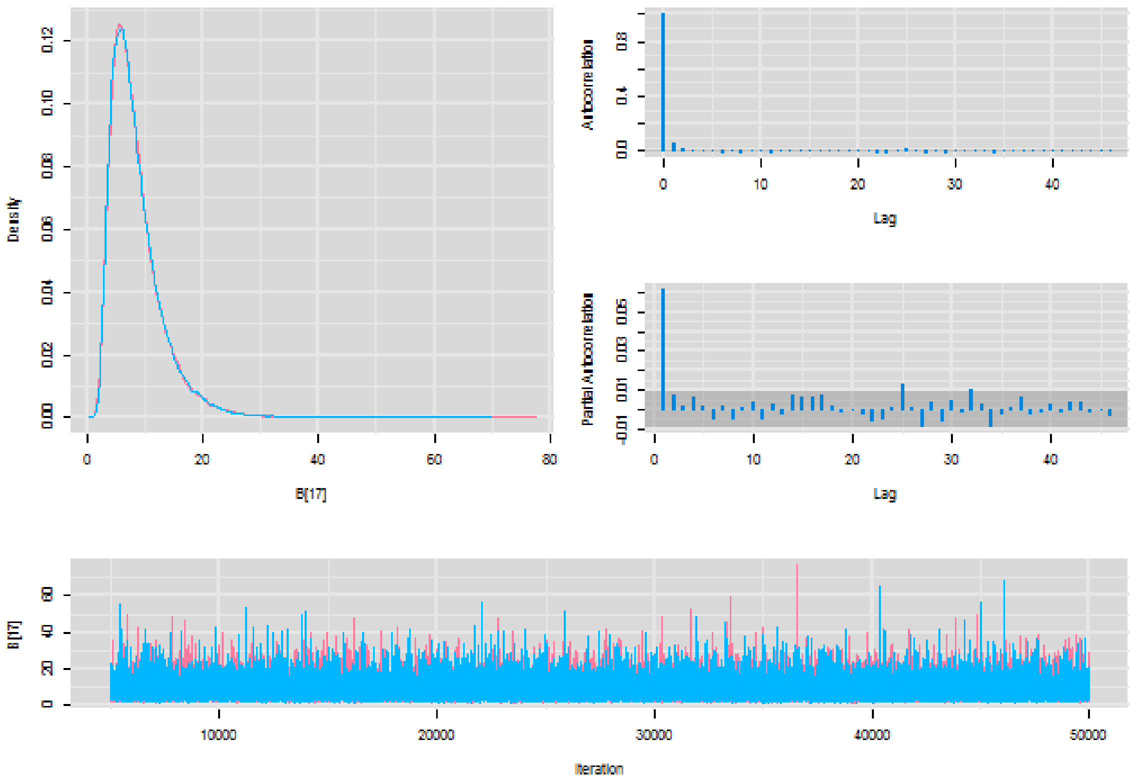
Diagnostics for B[15]



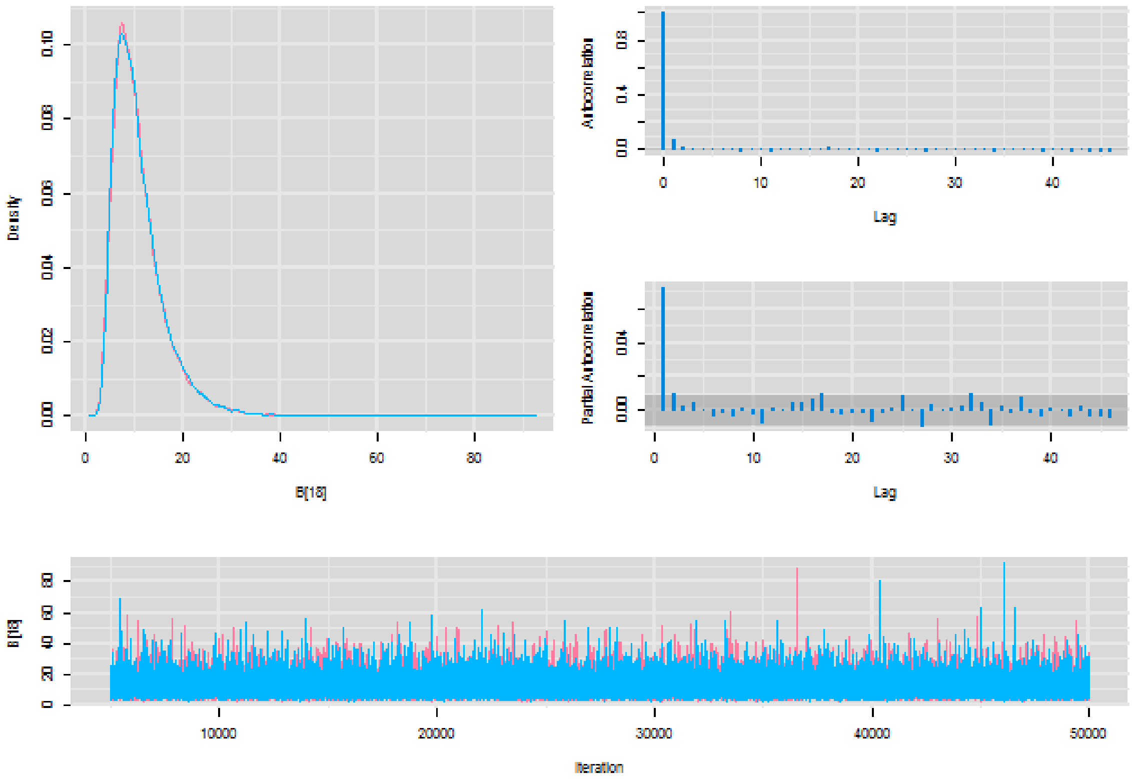
Diagnostics for B[16]



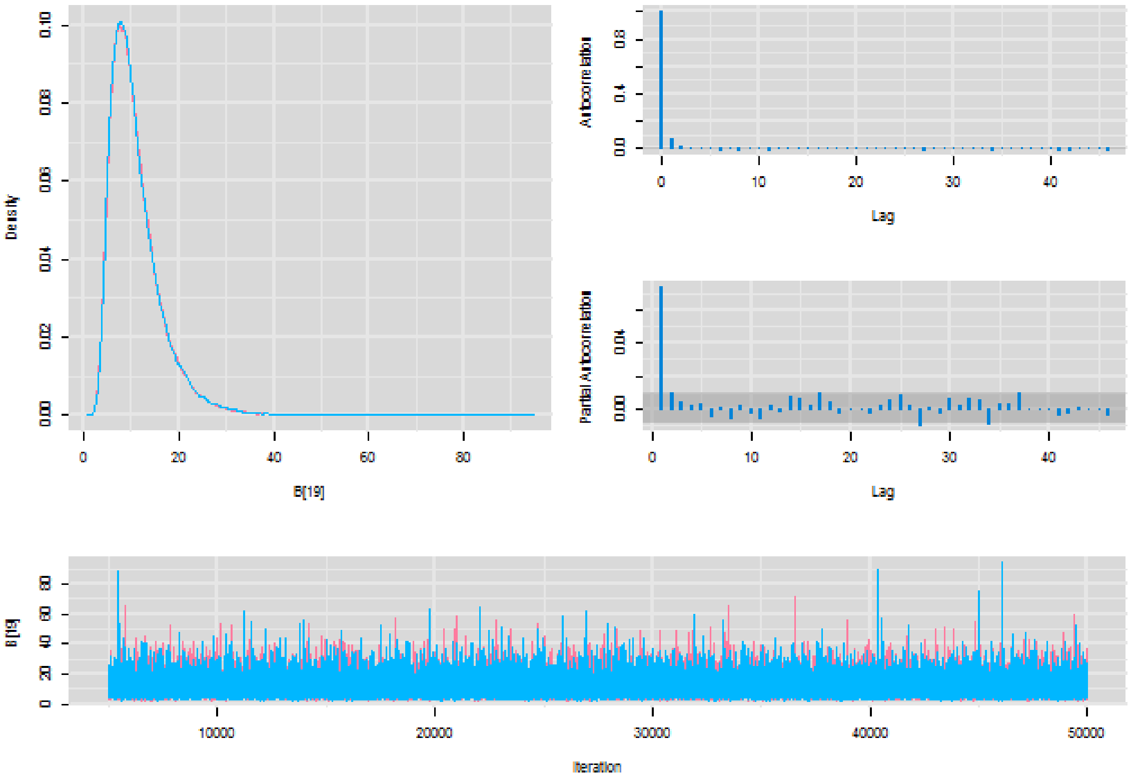
Diagnostics for B[17]



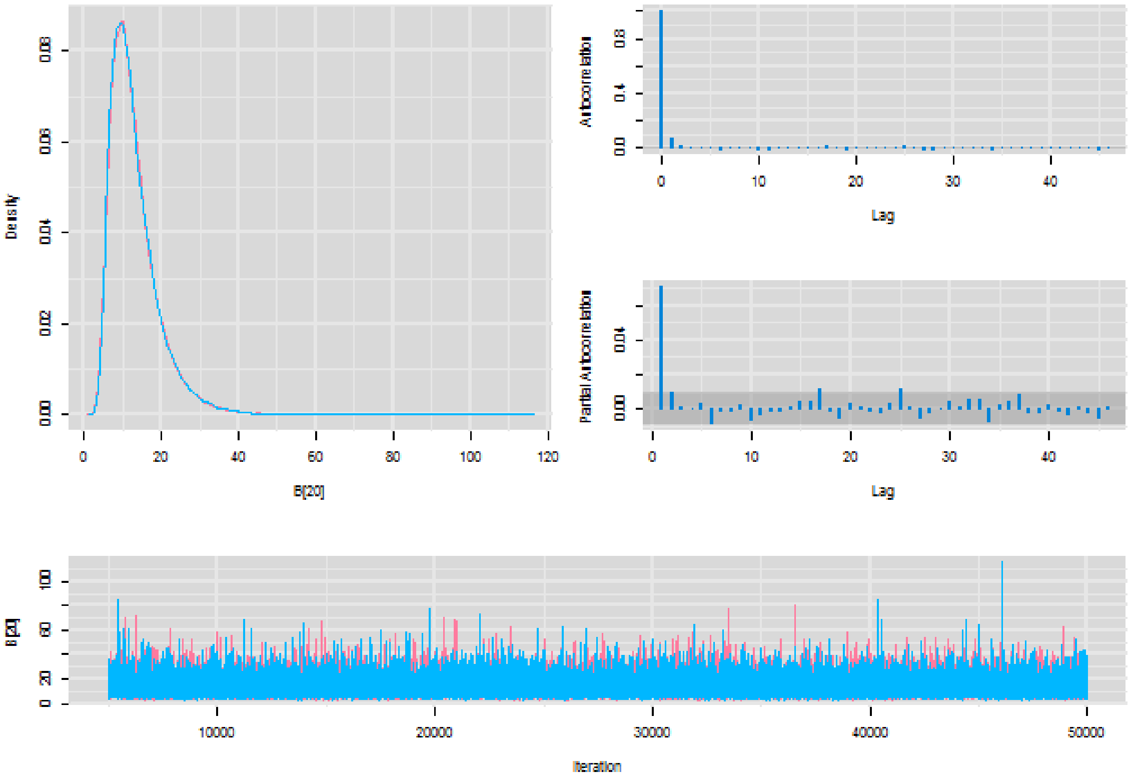
Diagnostics for B[18]



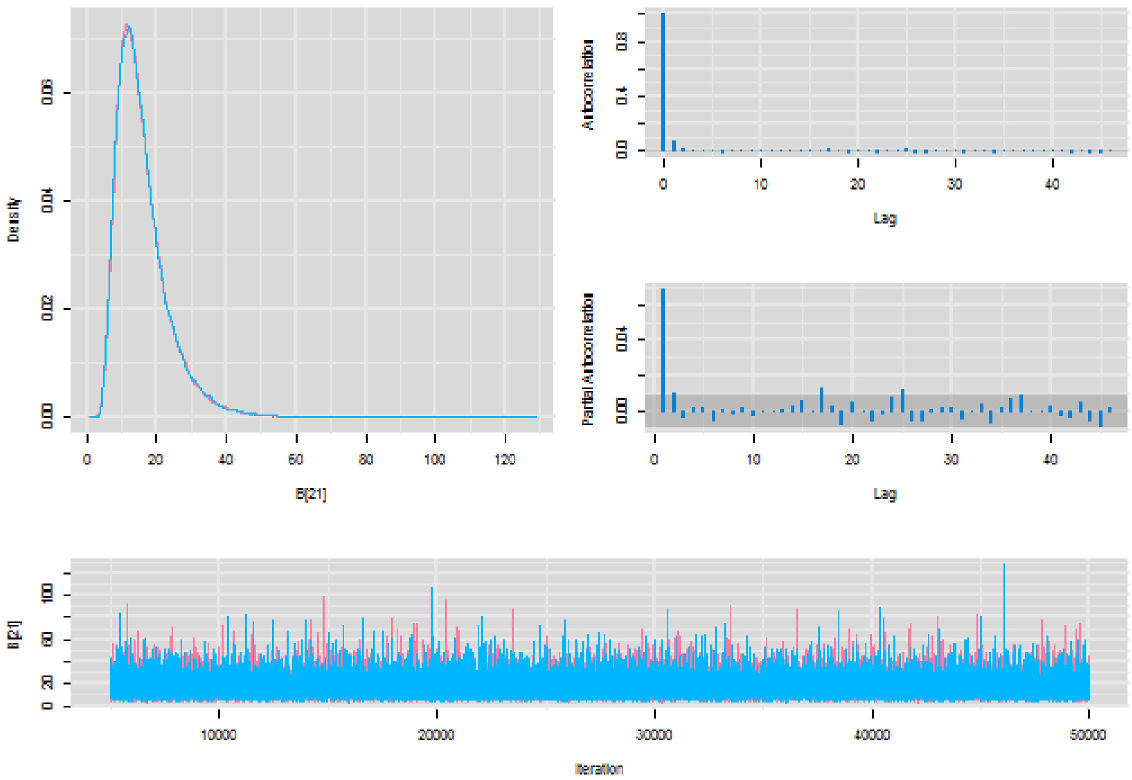
Diagnostics for B[19]



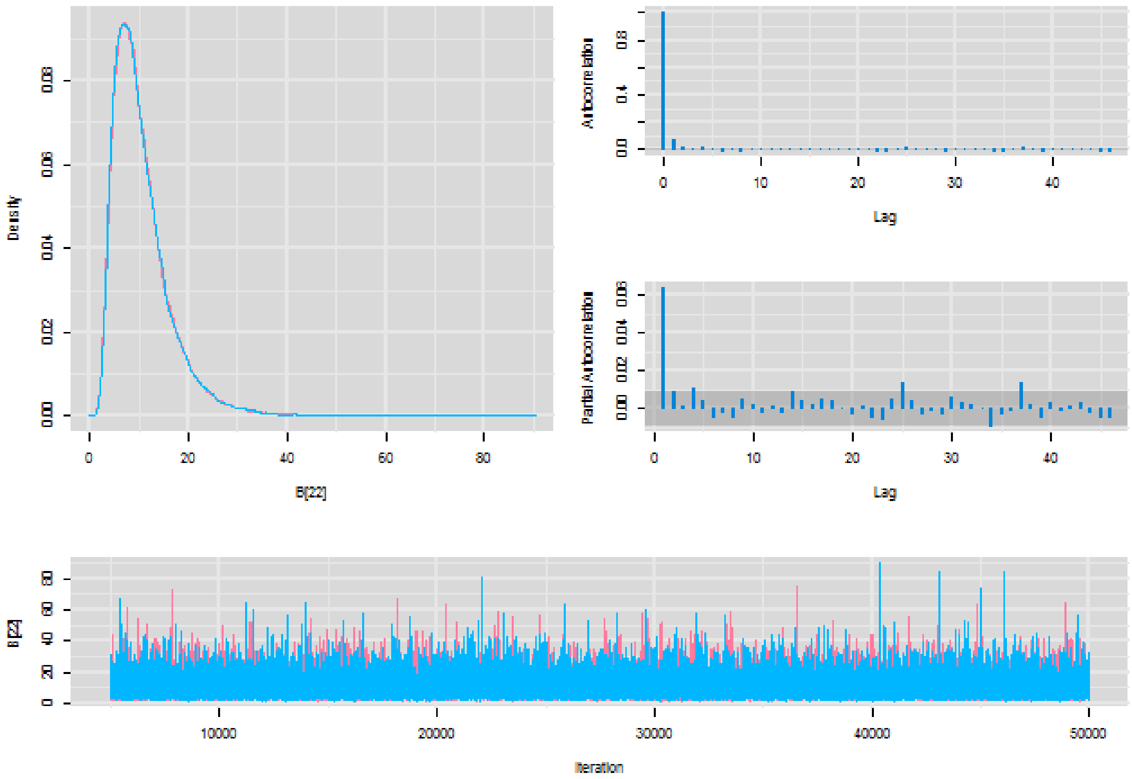
Diagnostics for B[20]



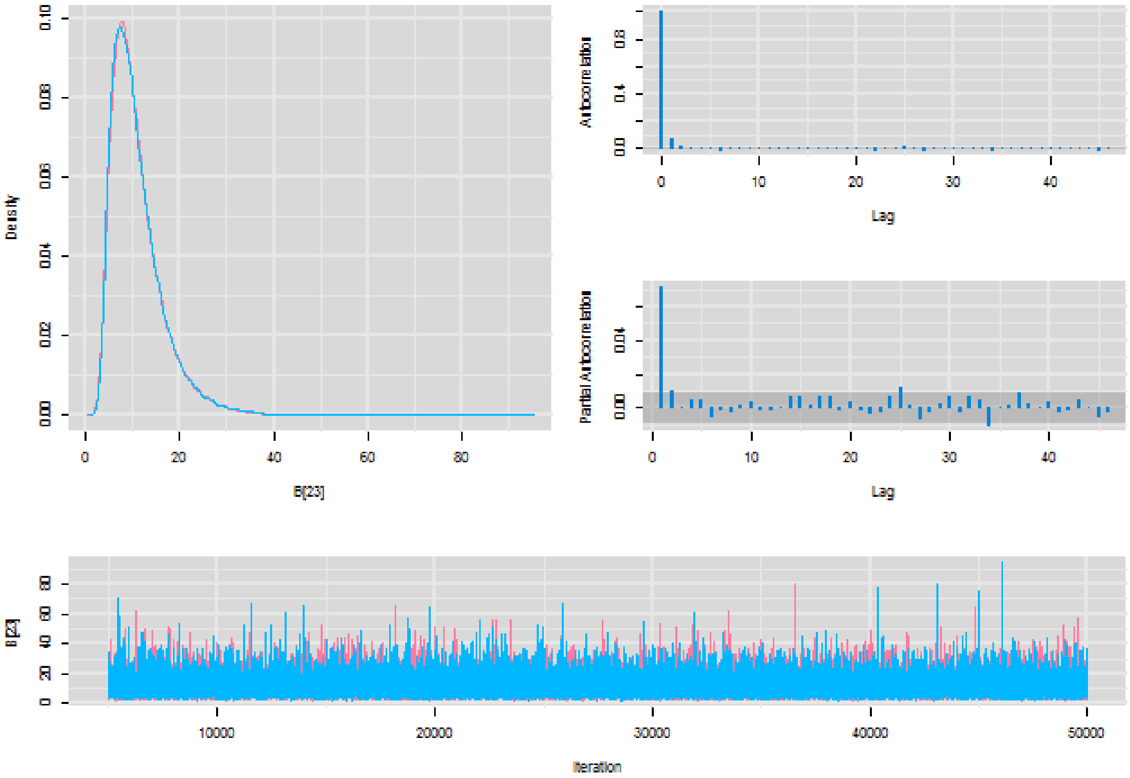
Diagnostics for B[21]



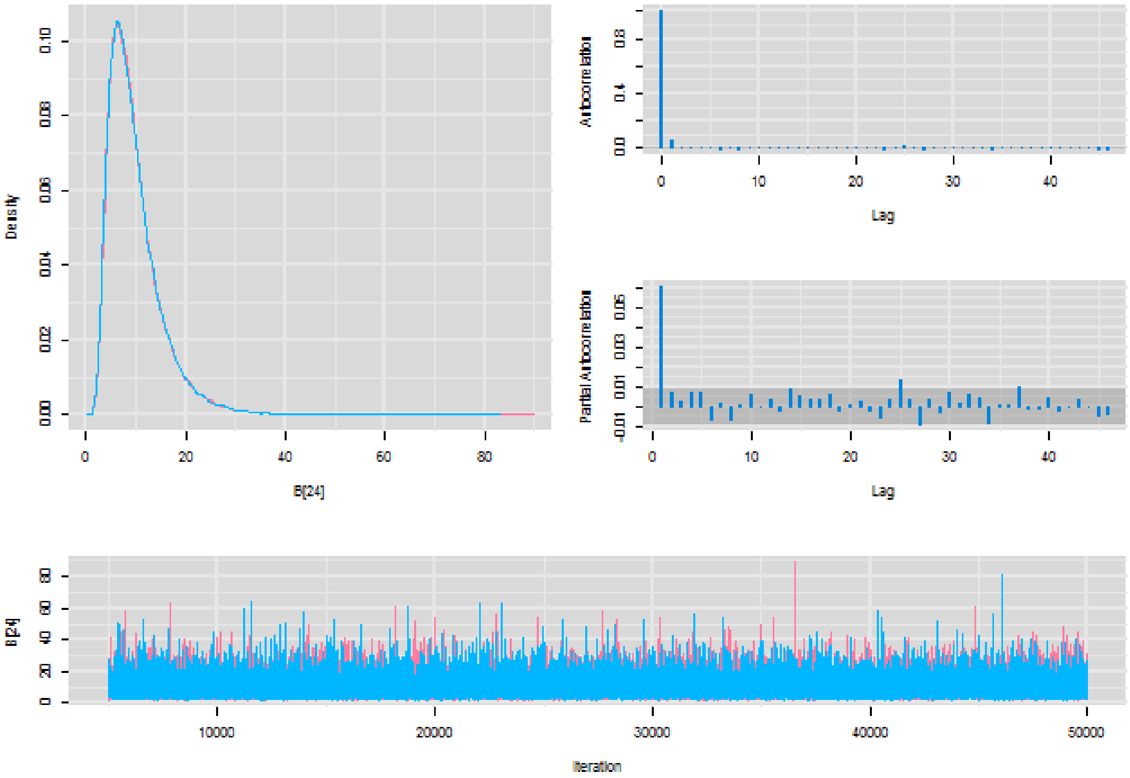
Diagnostics for B[22]



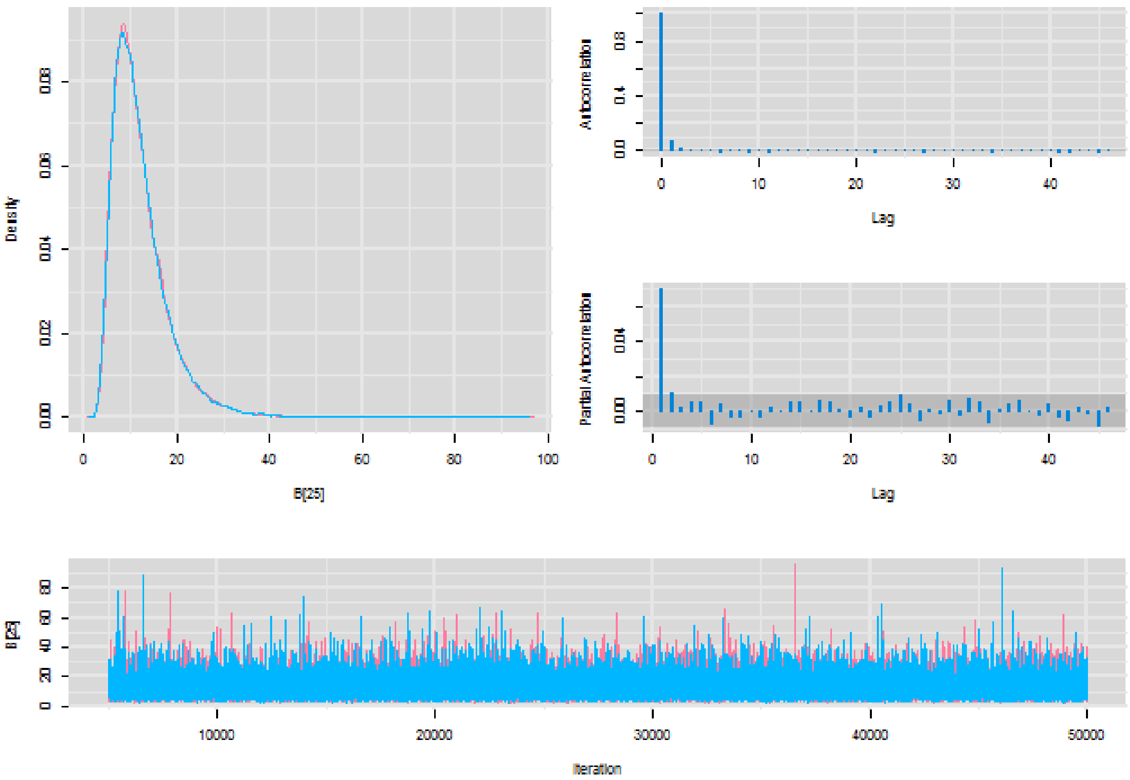
Diagnostics for B[23]



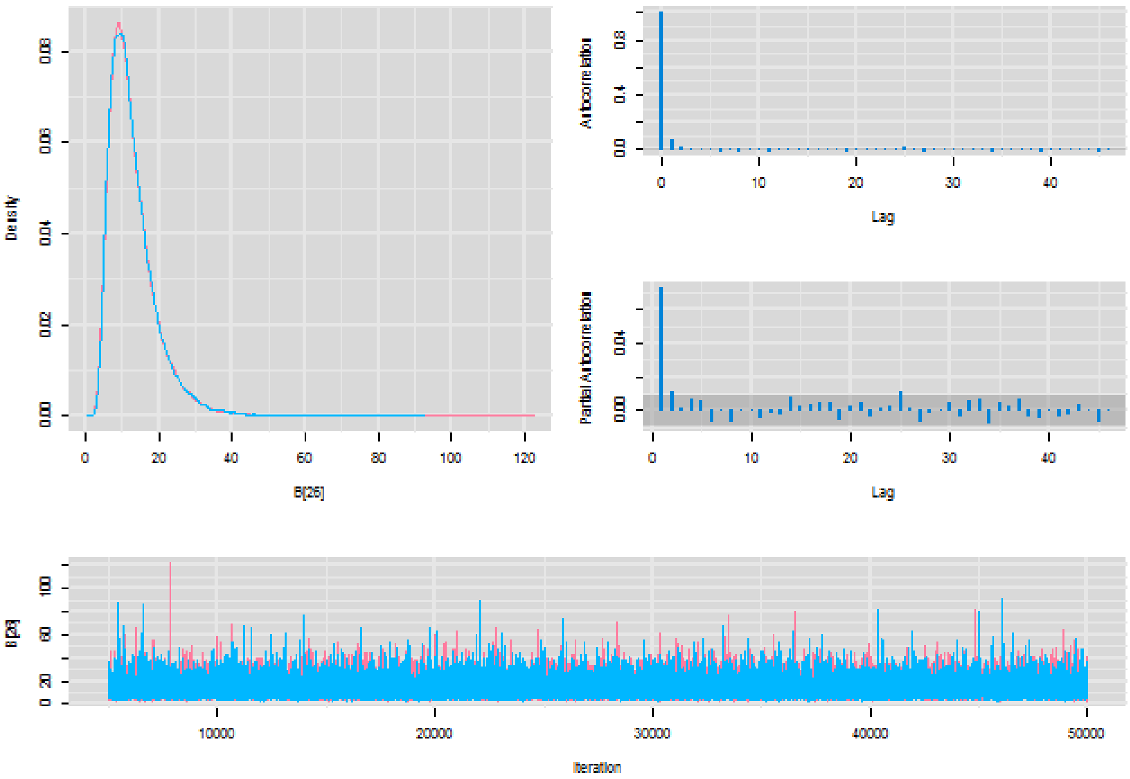
Diagnostics for B[24]



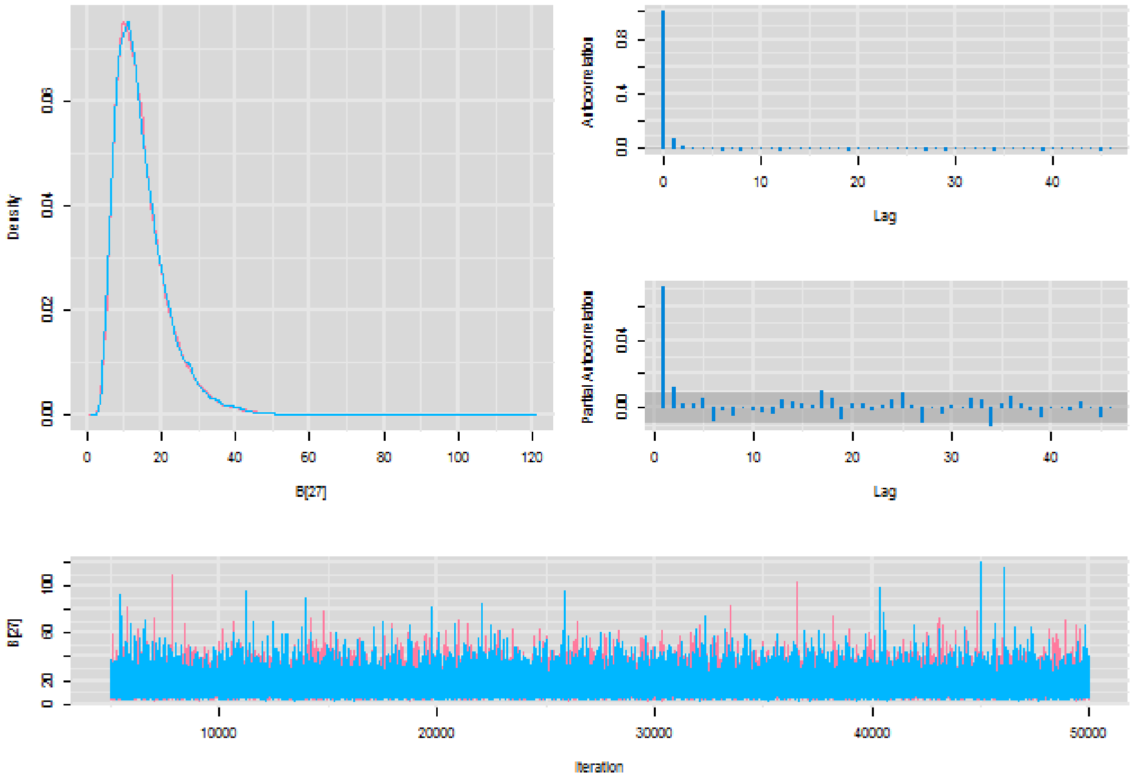
Diagnostics for B[25]



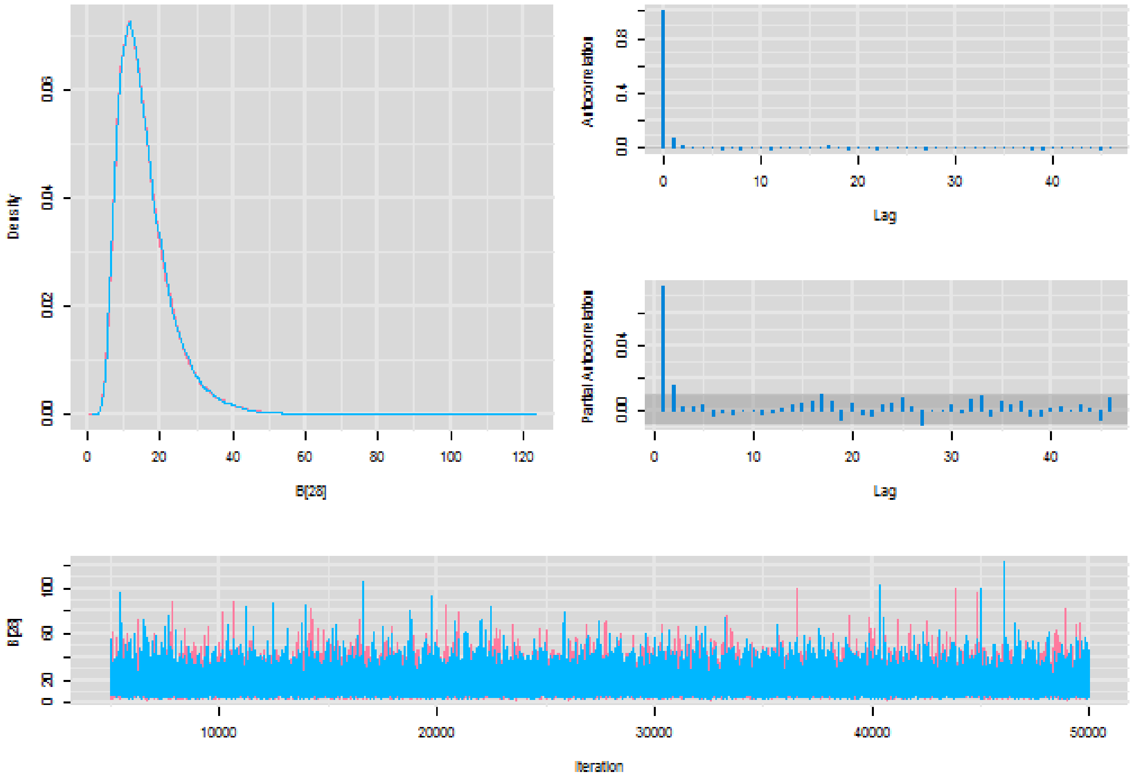
Diagnostics for B[26]



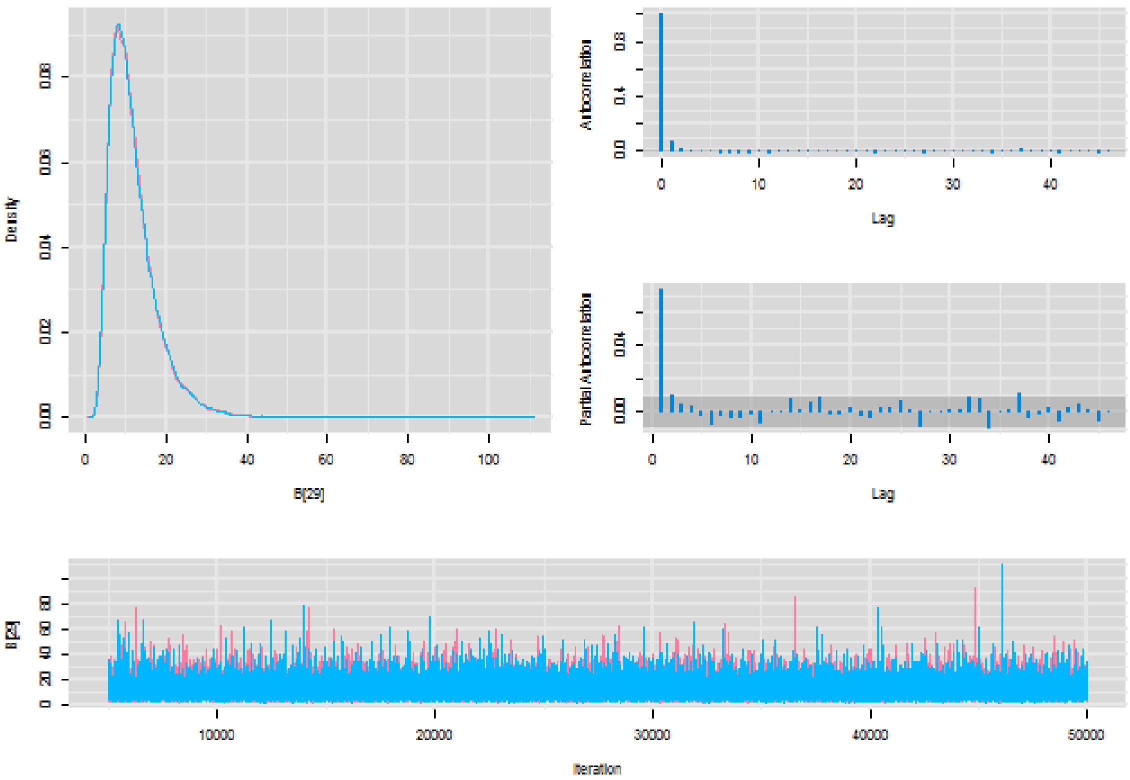
Diagnostics for B[27]



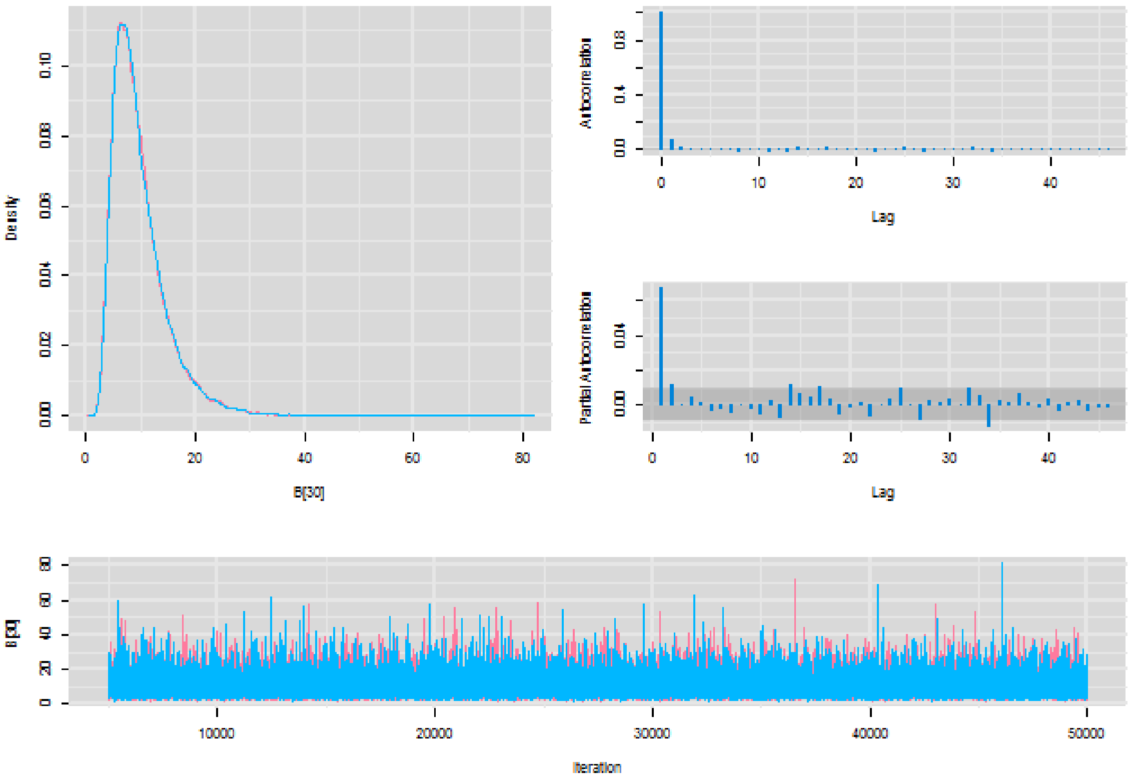
Diagnostics for B[28]



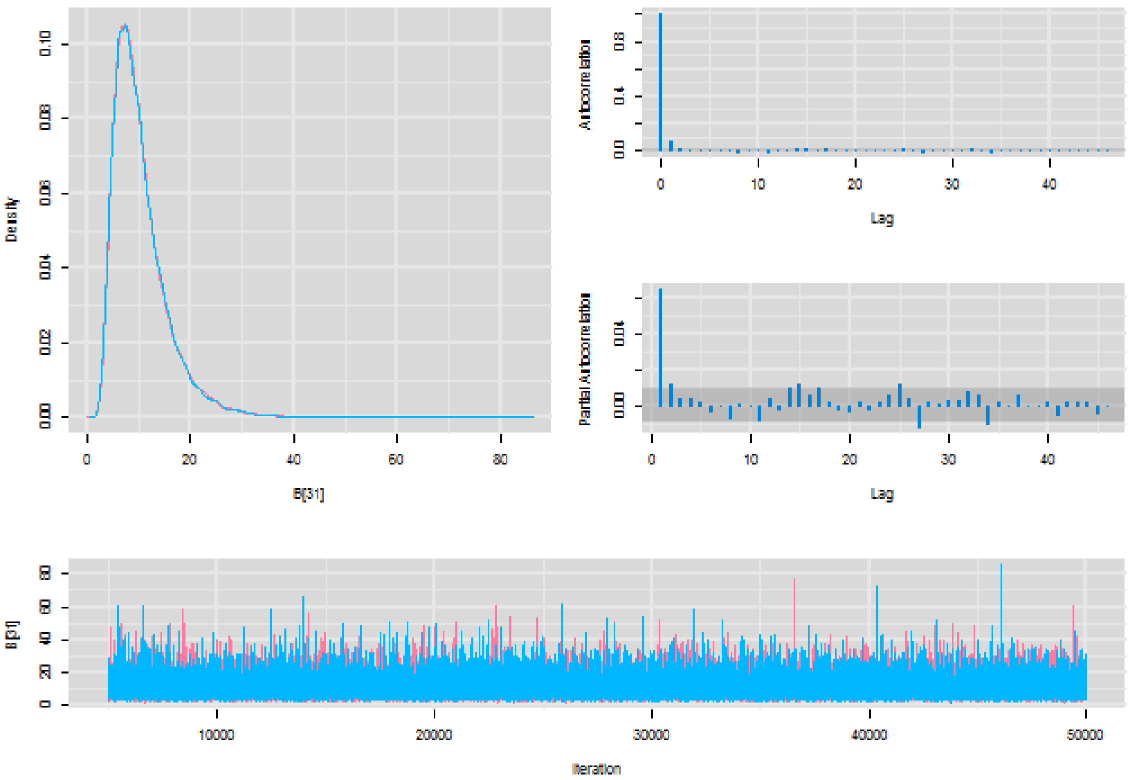
Diagnostics for B[29]



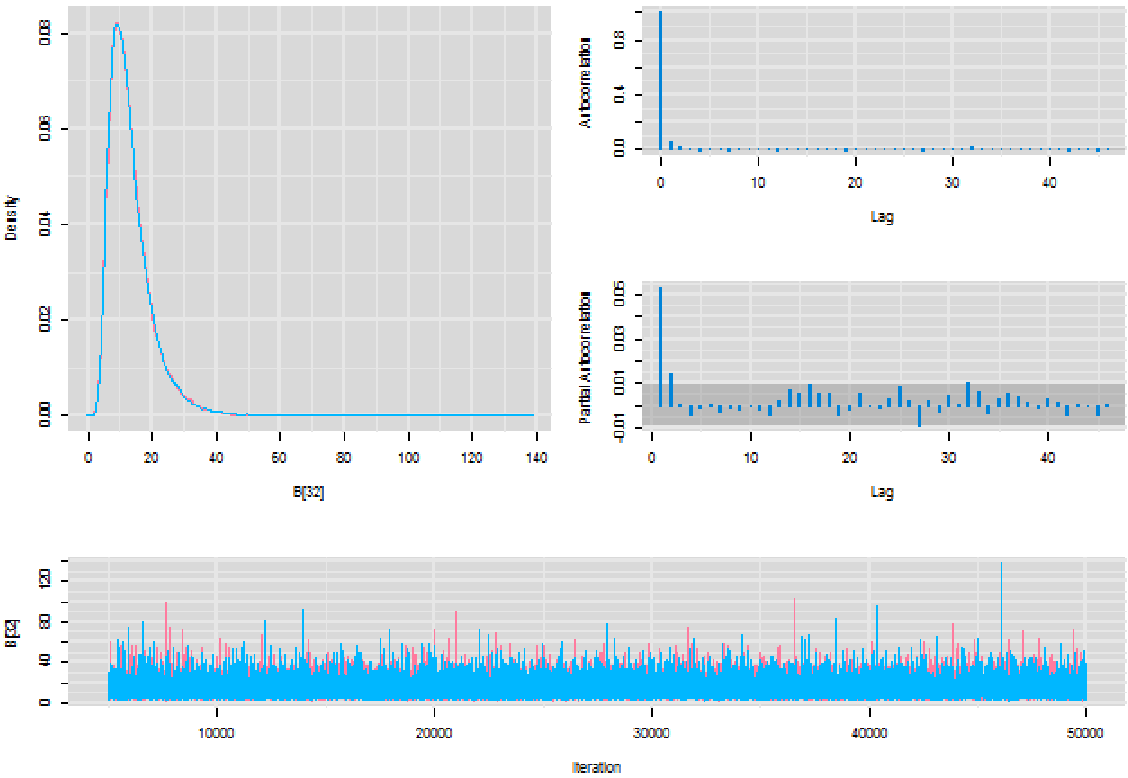
Diagnostics for B[30]



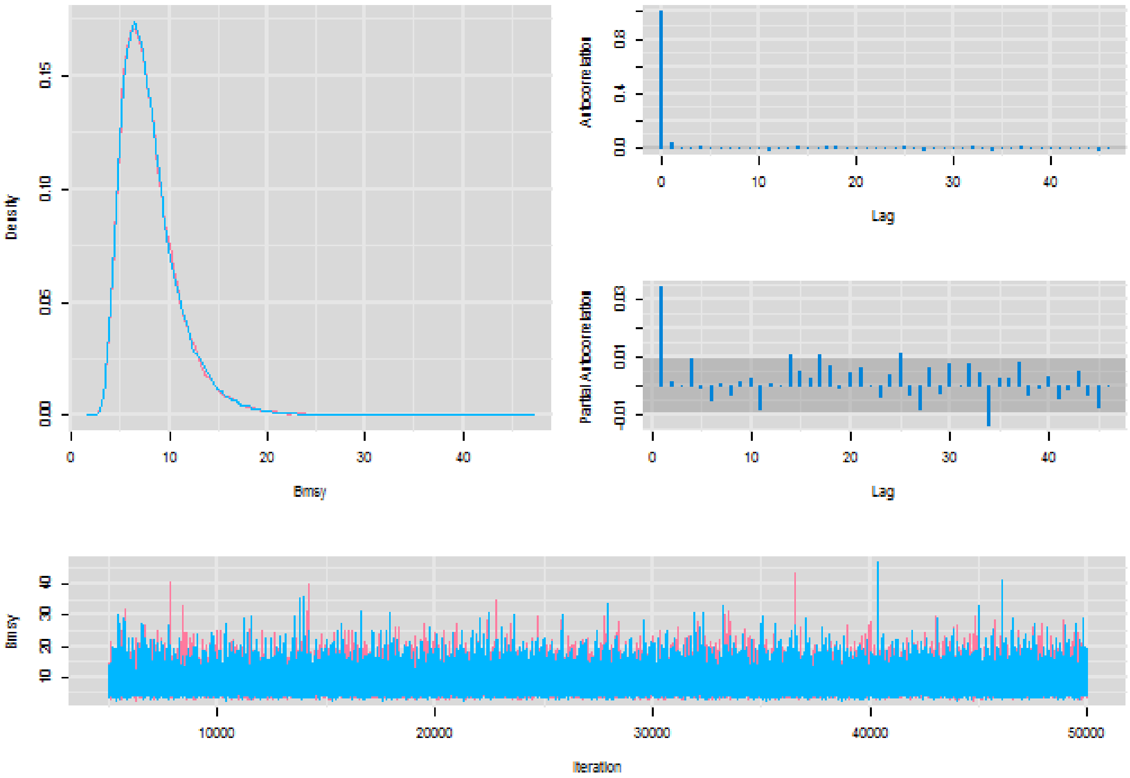
Diagnostics for B[31]



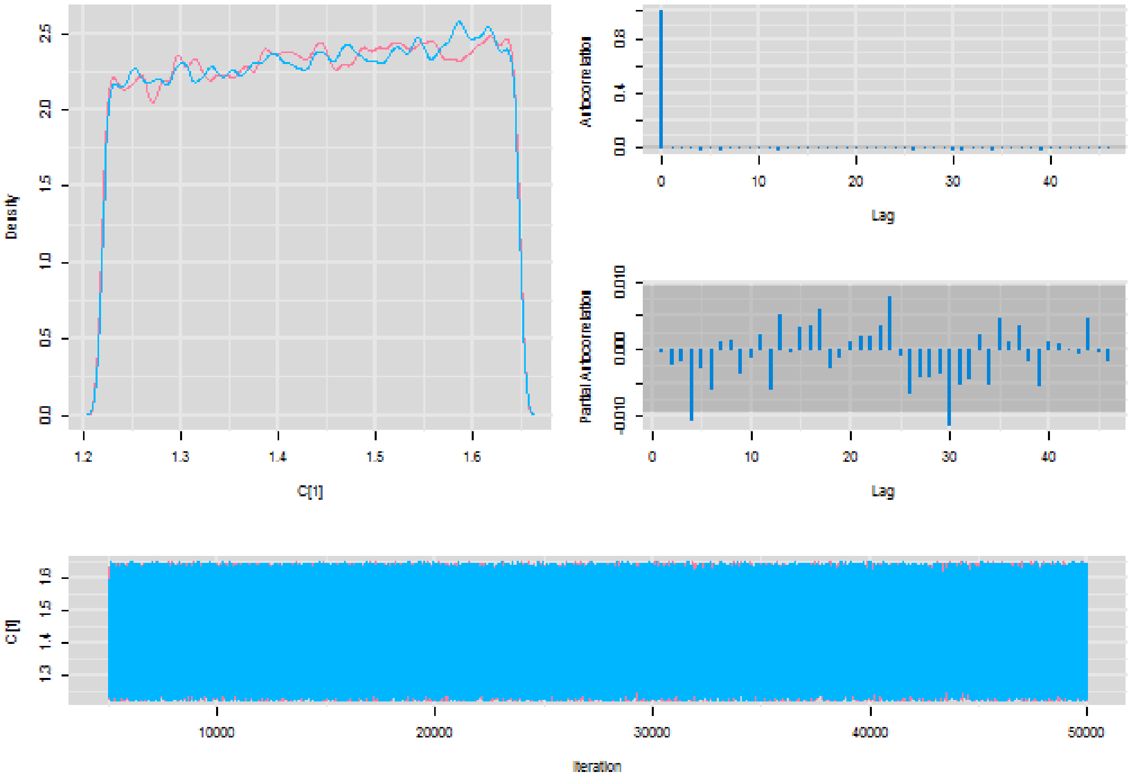
Diagnostics for B[32]



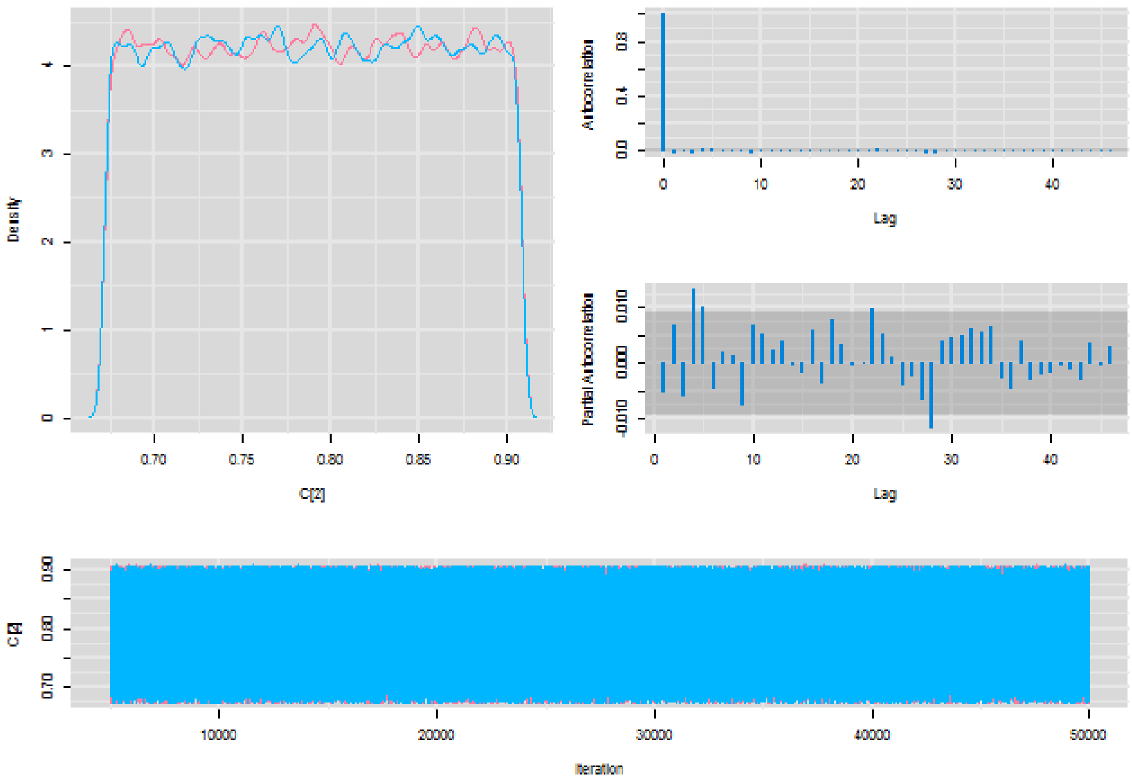
Diagnostics for Bmsy



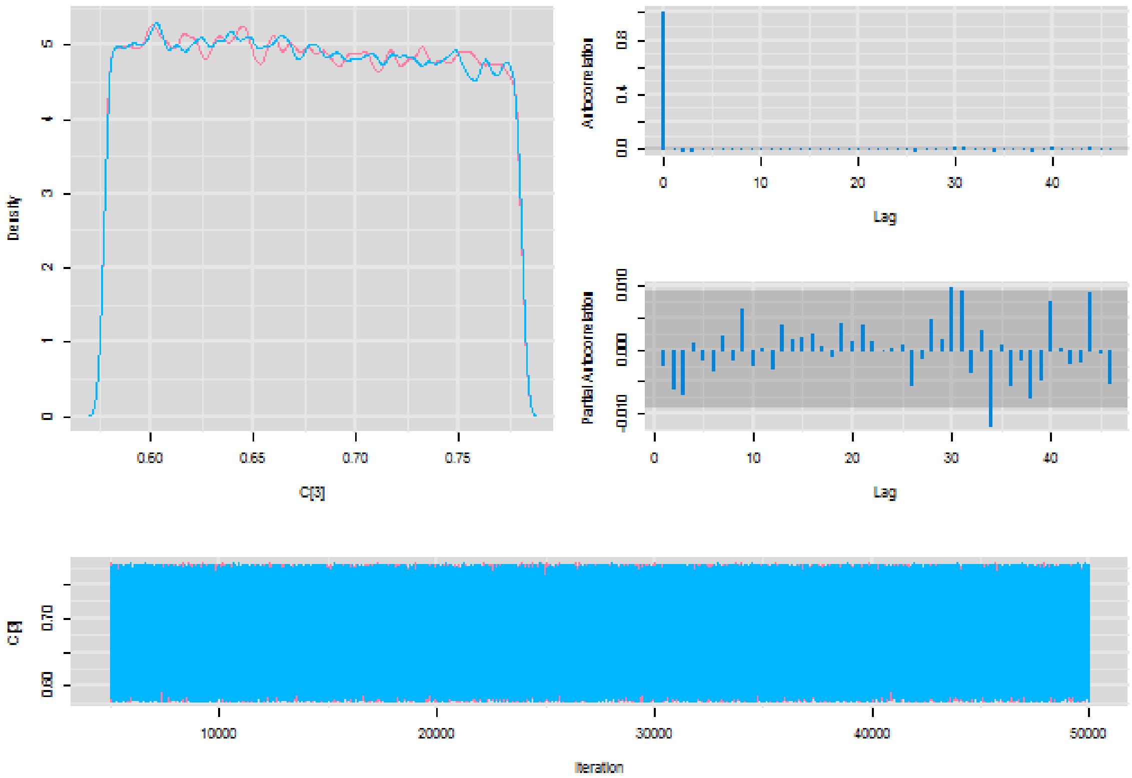
Diagnostics for C[1]



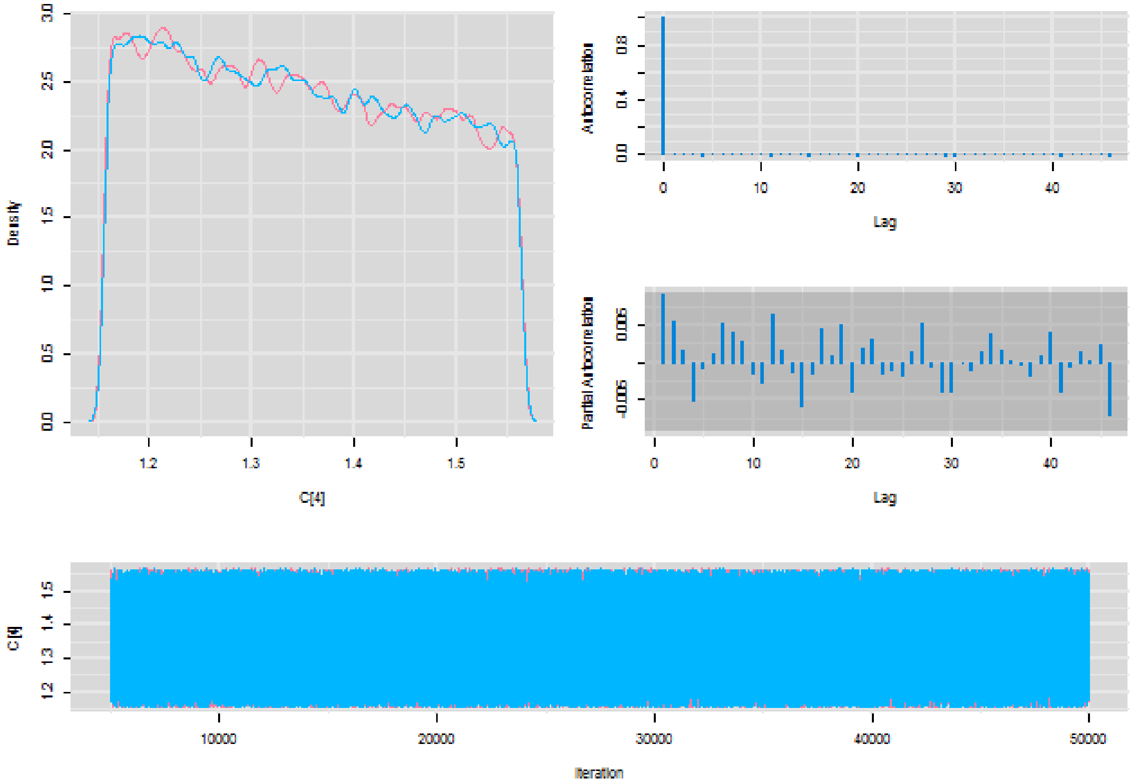
Diagnostics for C[2]



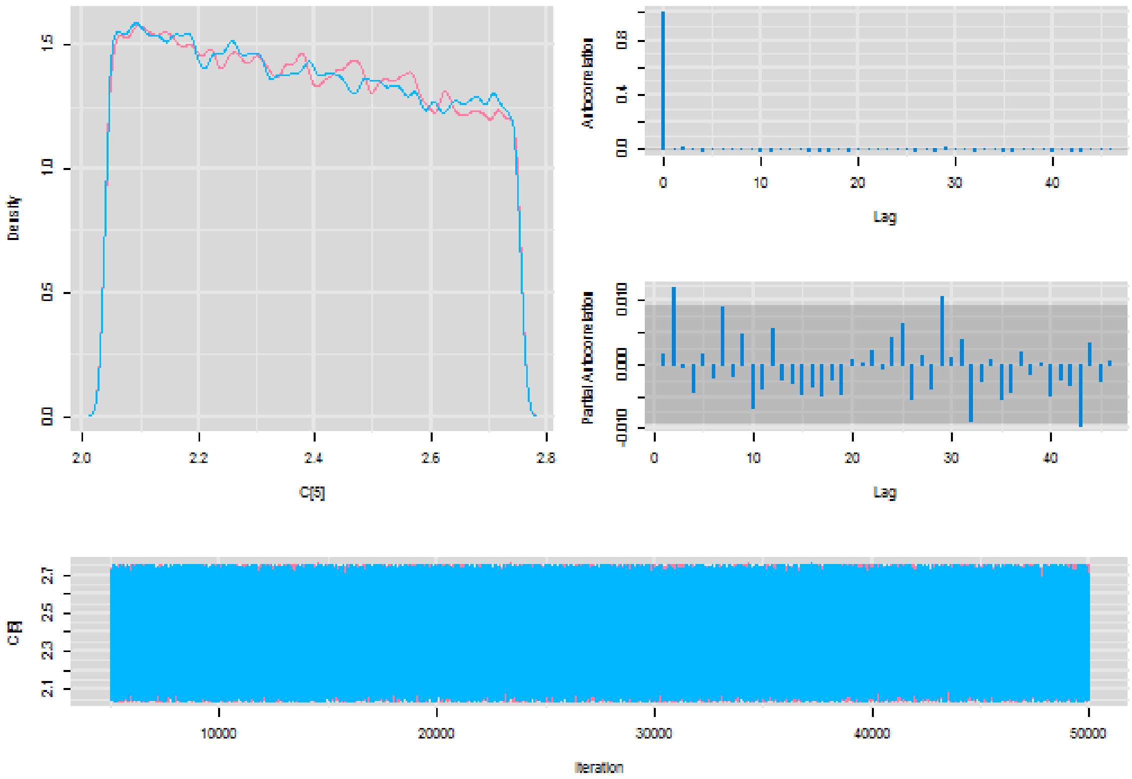
Diagnostics for C[3]



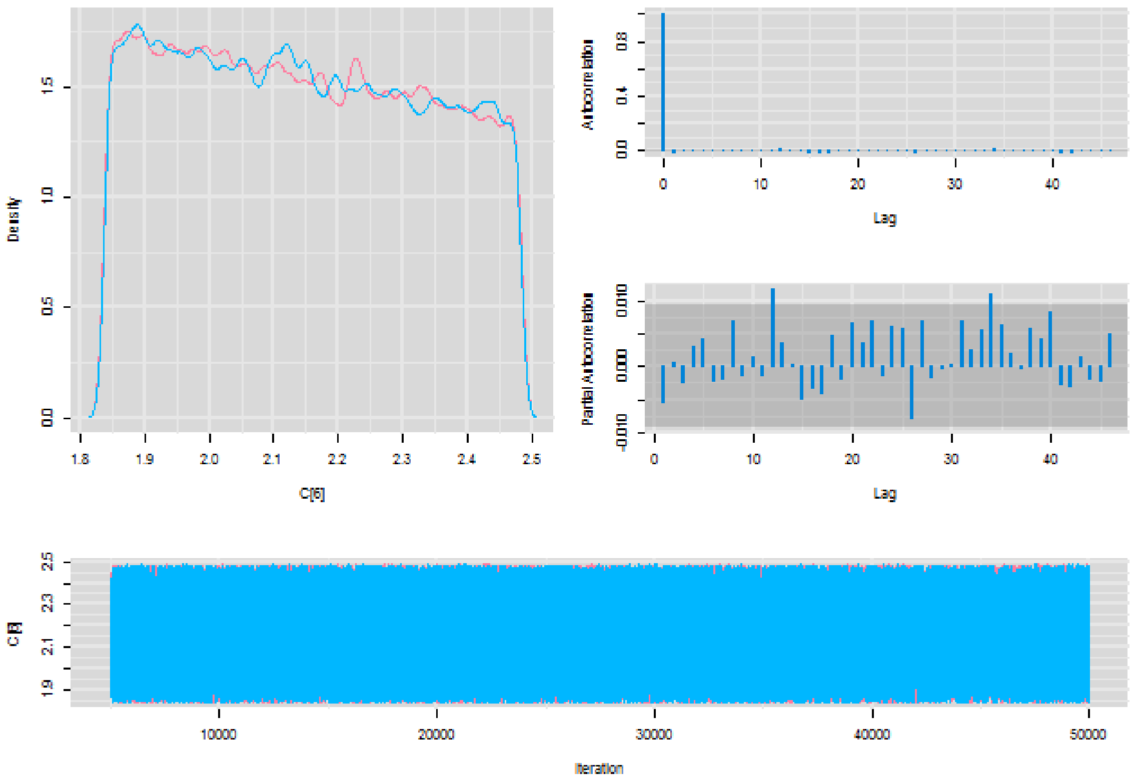
Diagnostics for C[4]



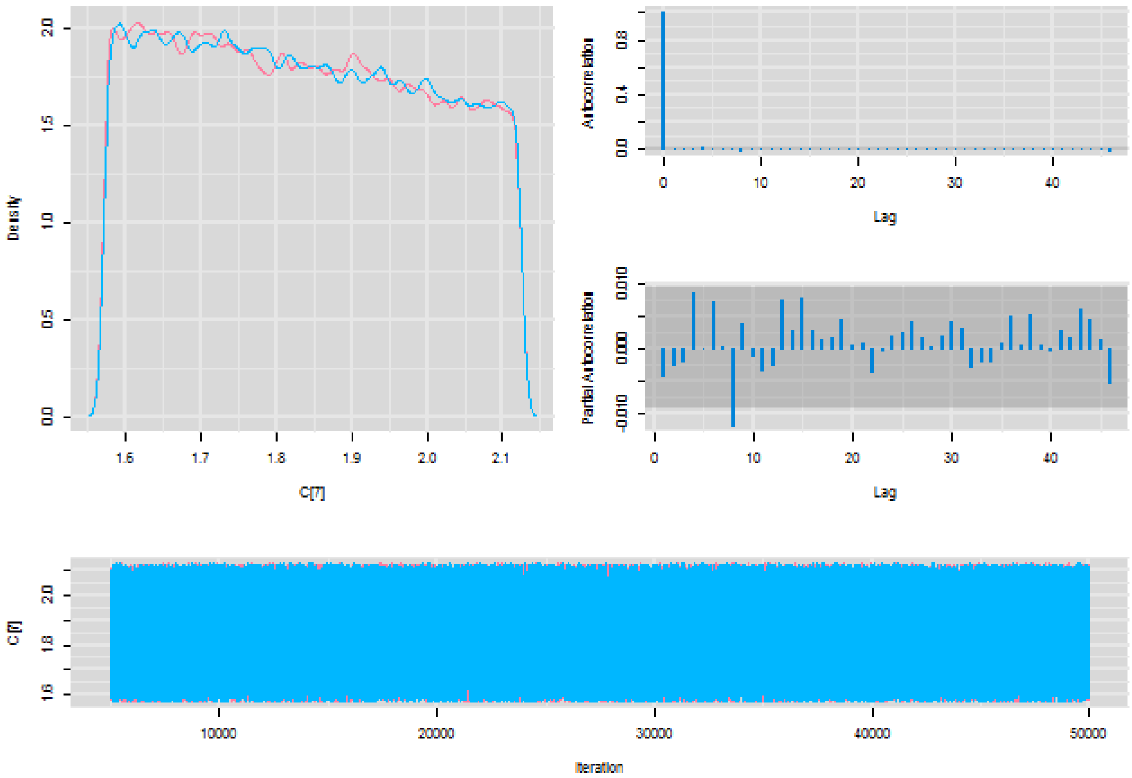
Diagnostics for C[5]



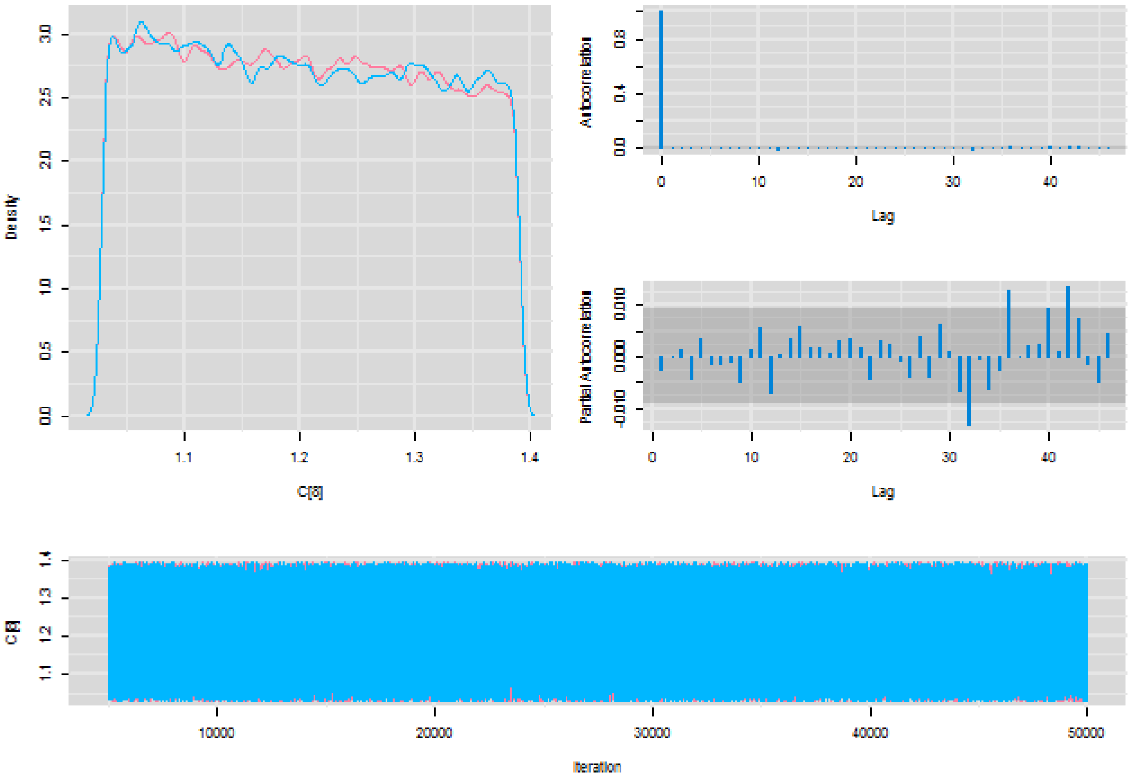
Diagnostics for C[6]



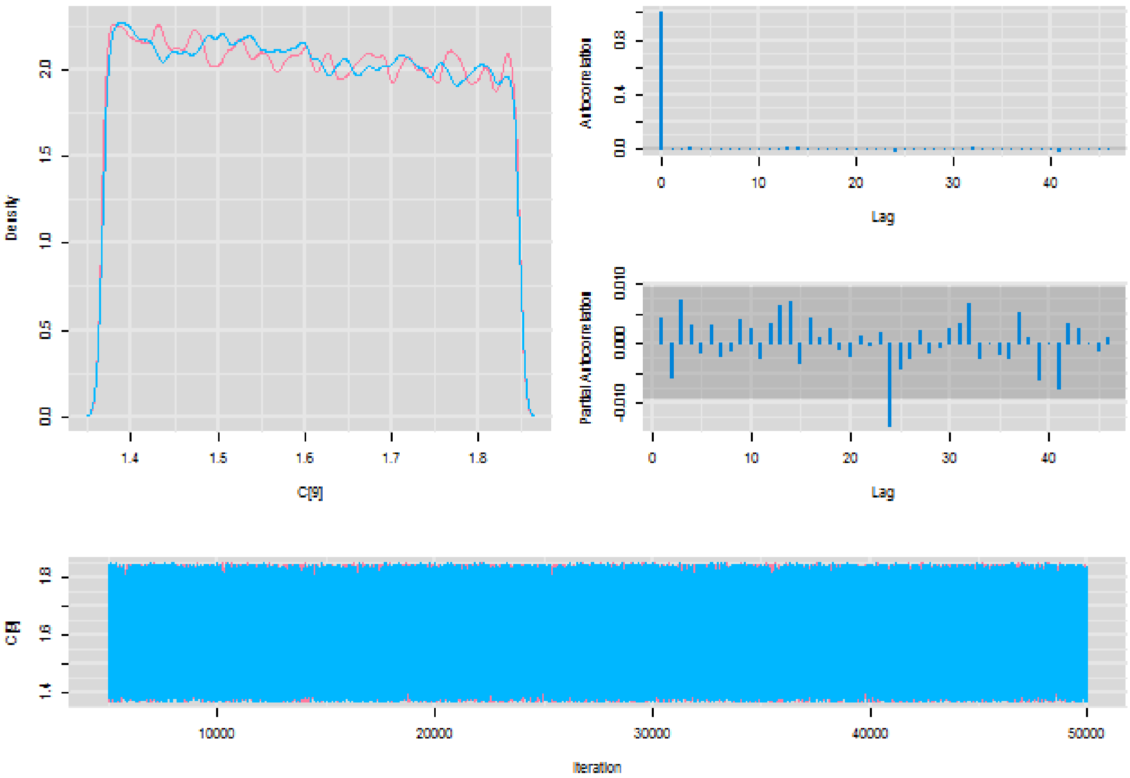
Diagnostics for C[7]



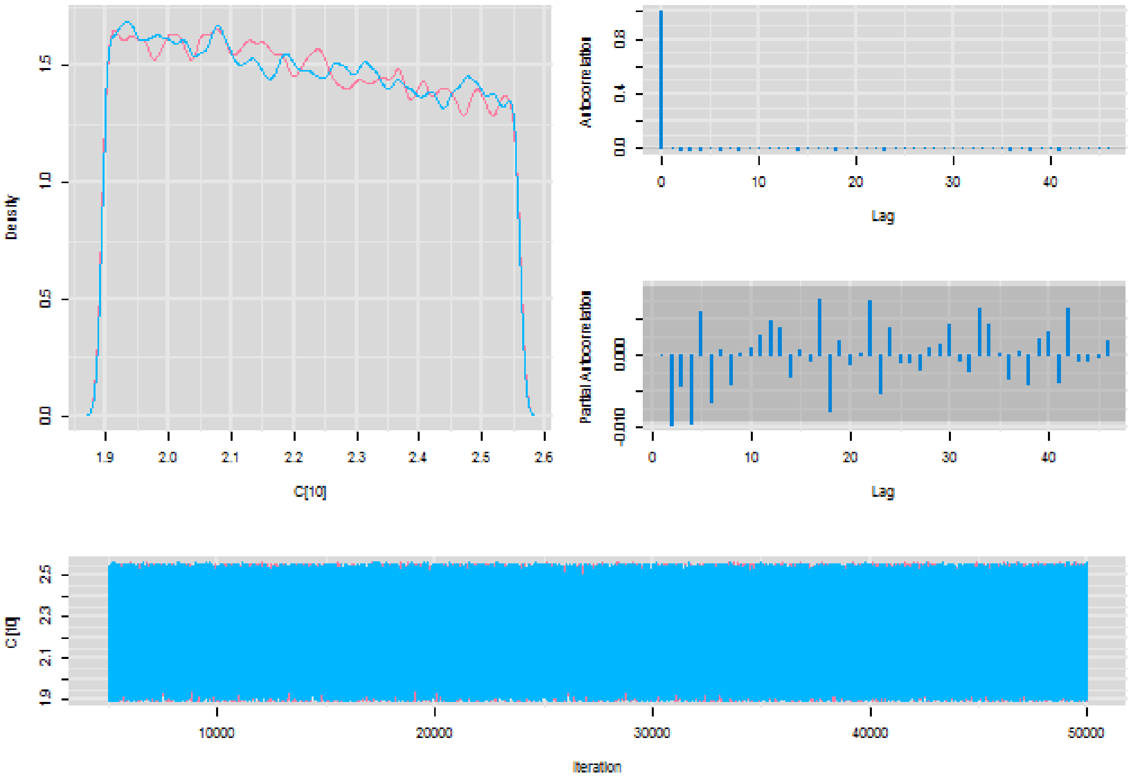
Diagnostics for C[8]



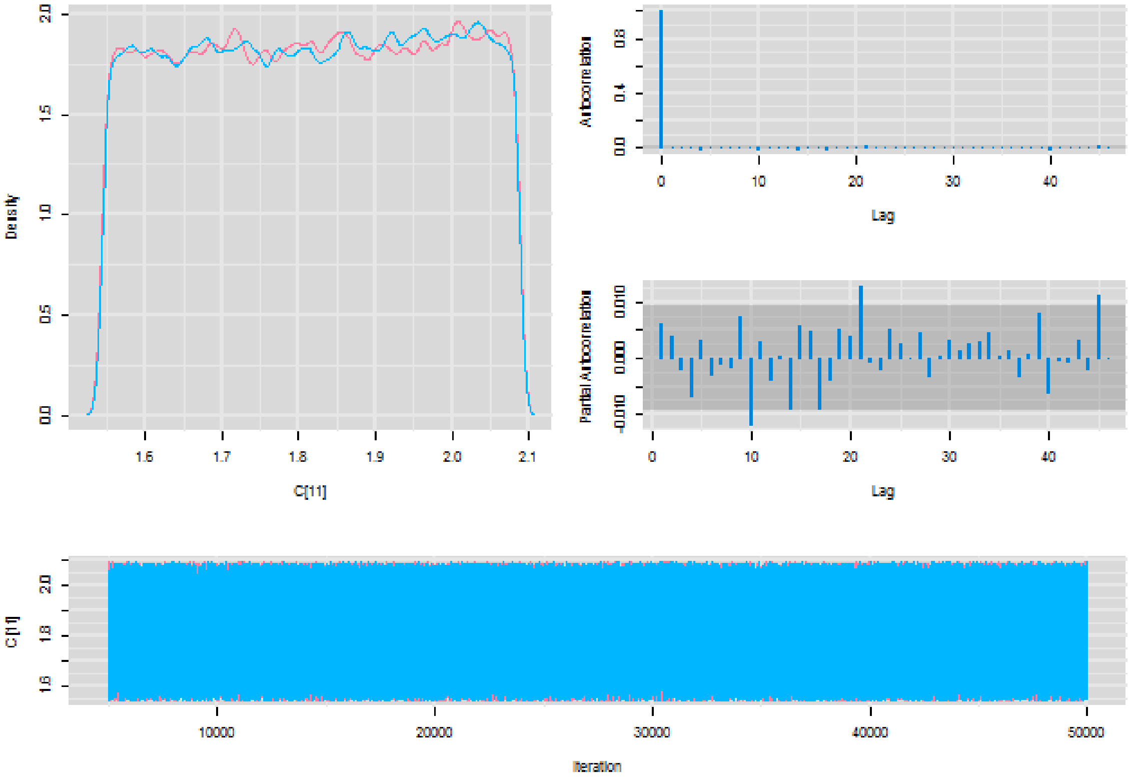
Diagnostics for C[9]



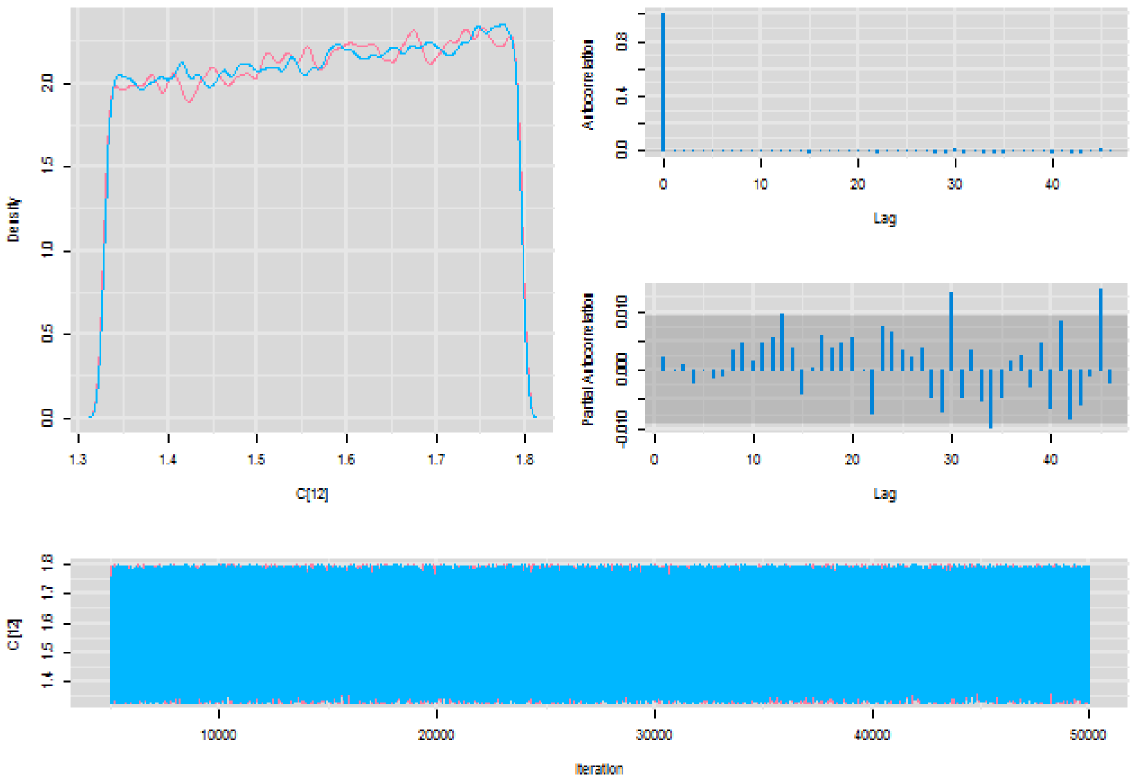
Diagnostics for C[10]



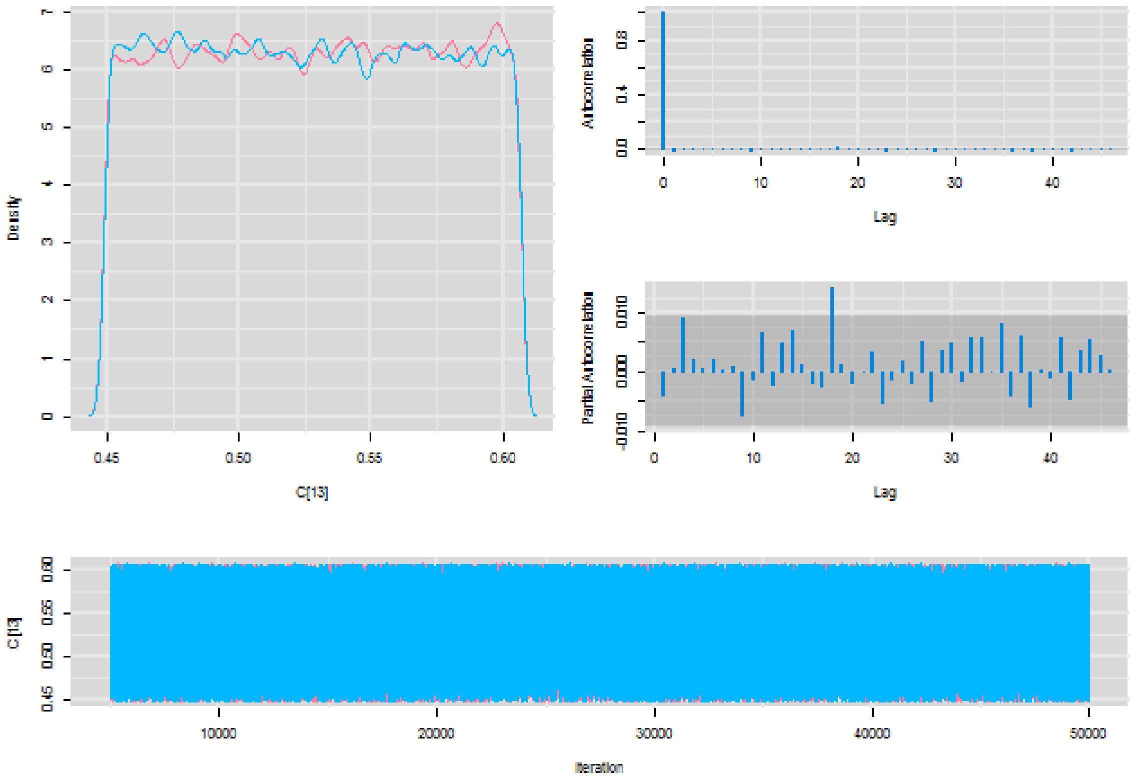
Diagnostics for C[11]



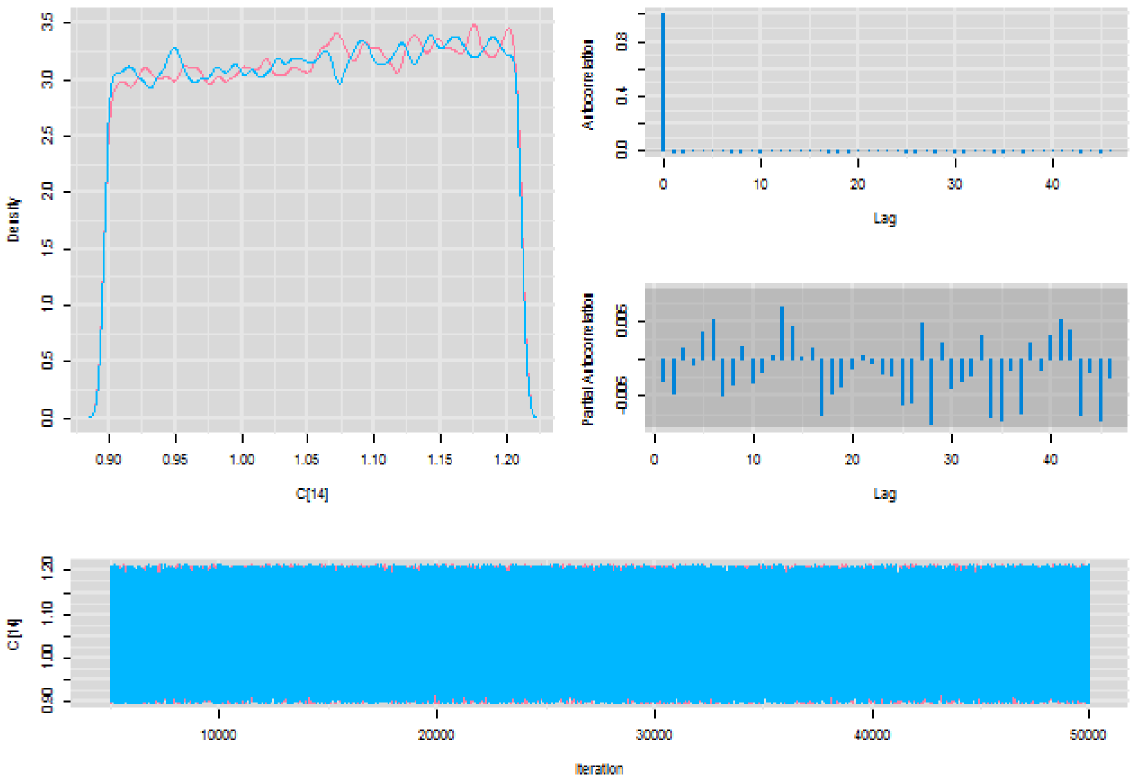
Diagnostics for C[12]



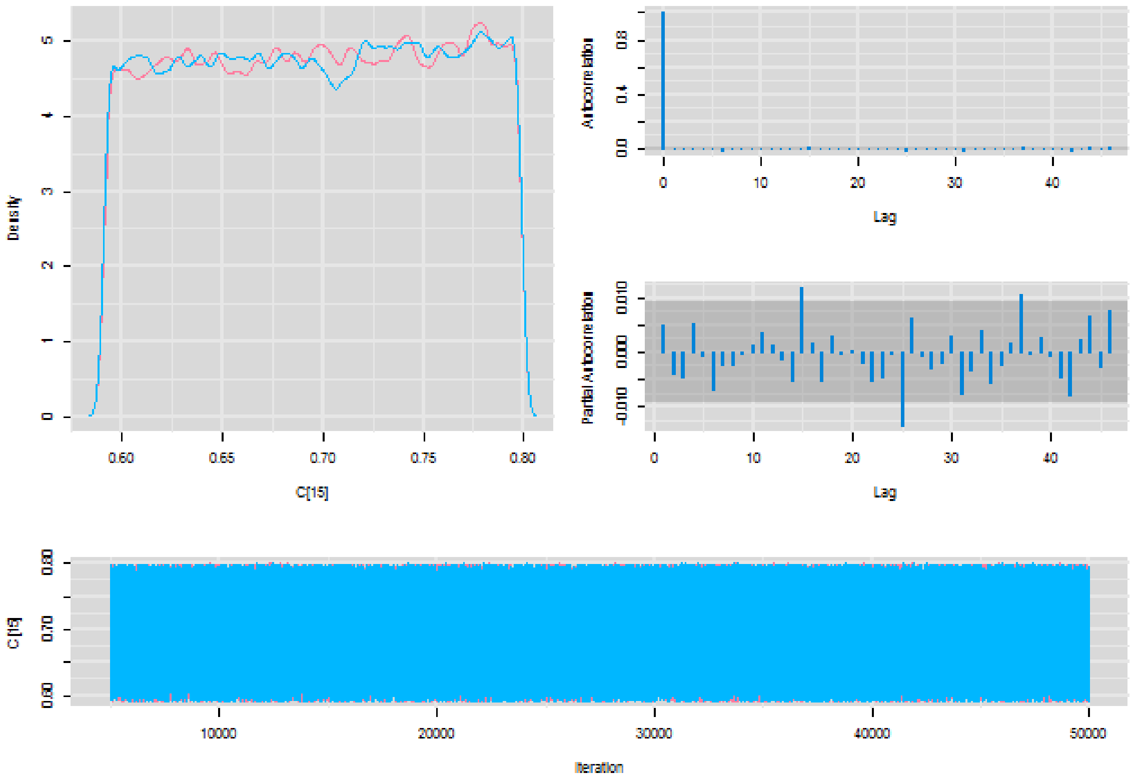
Diagnostics for C[13]



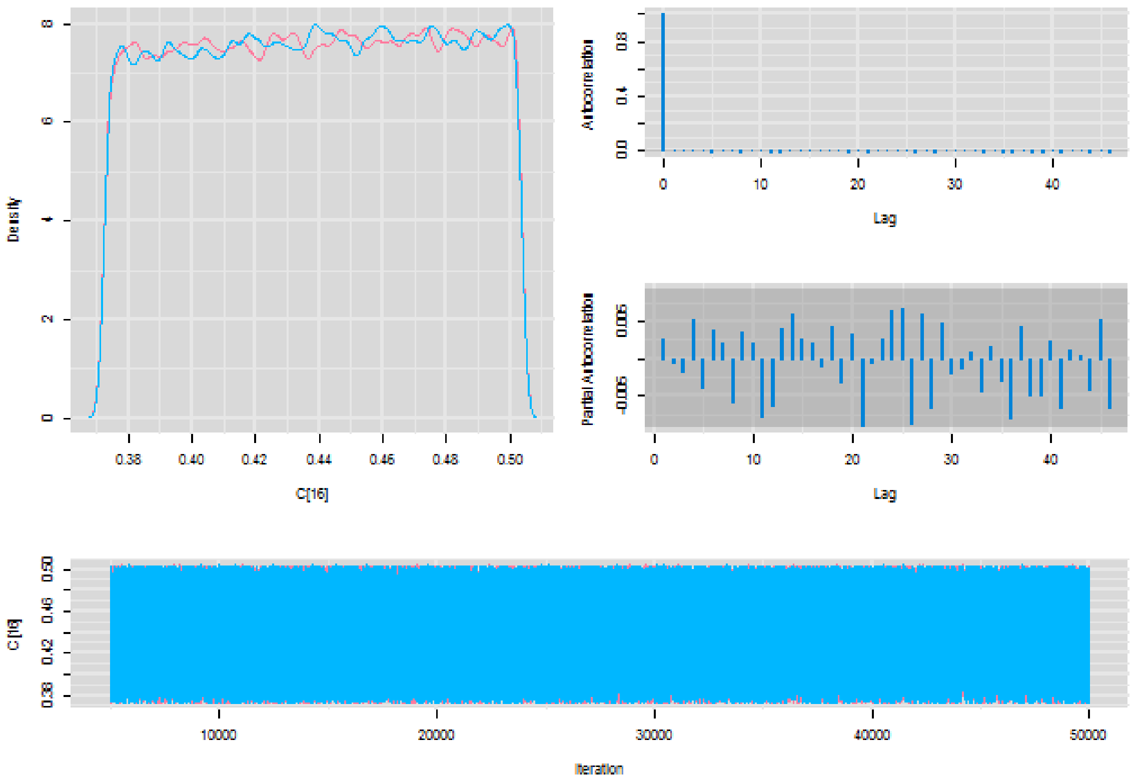
Diagnostics for C[14]



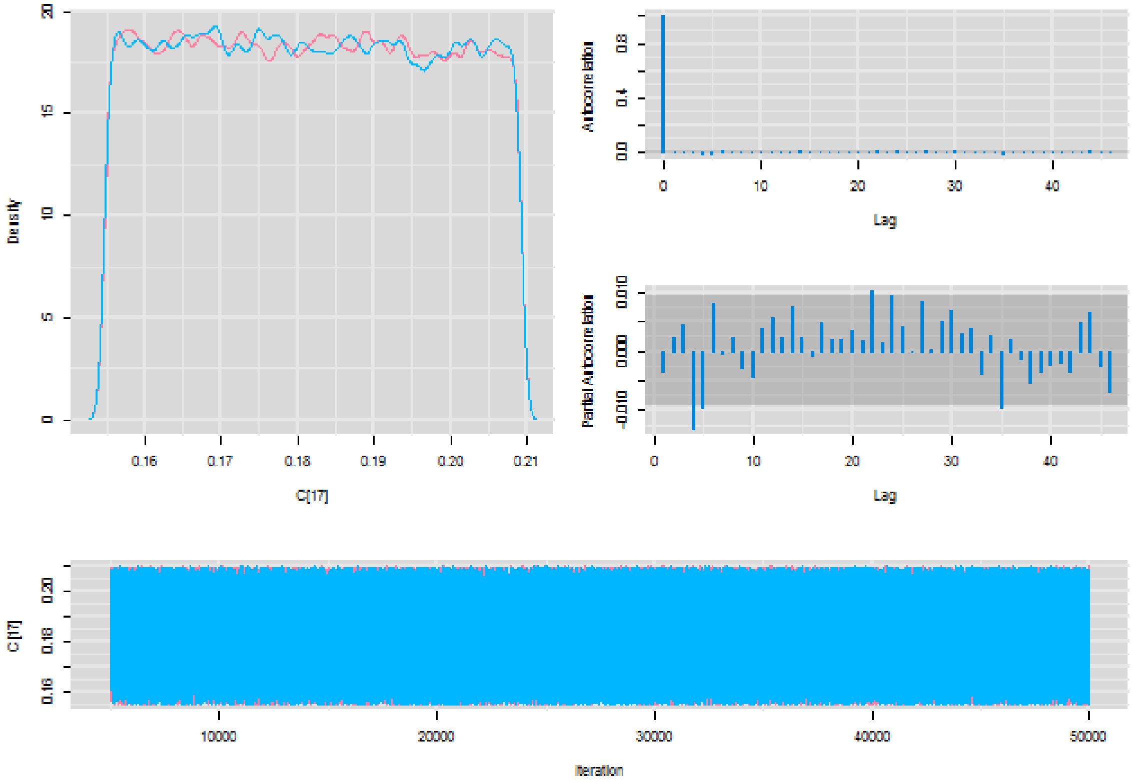
Diagnostics for C[15]



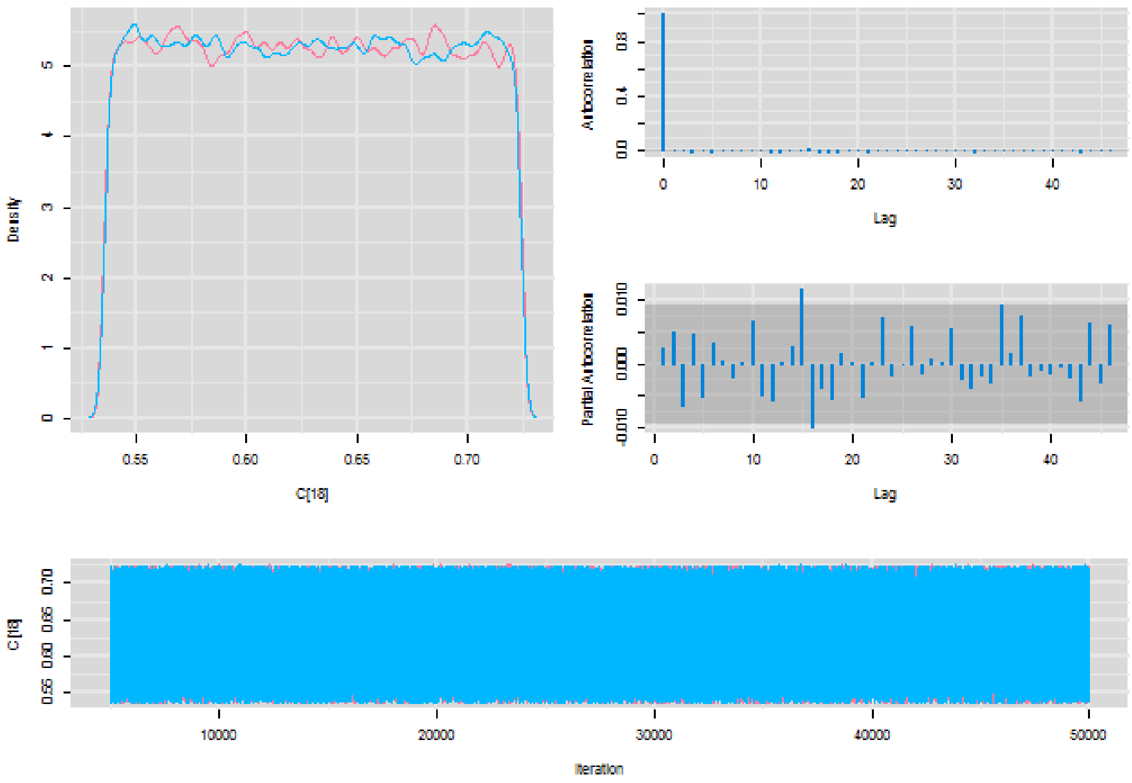
Diagnostics for C[16]



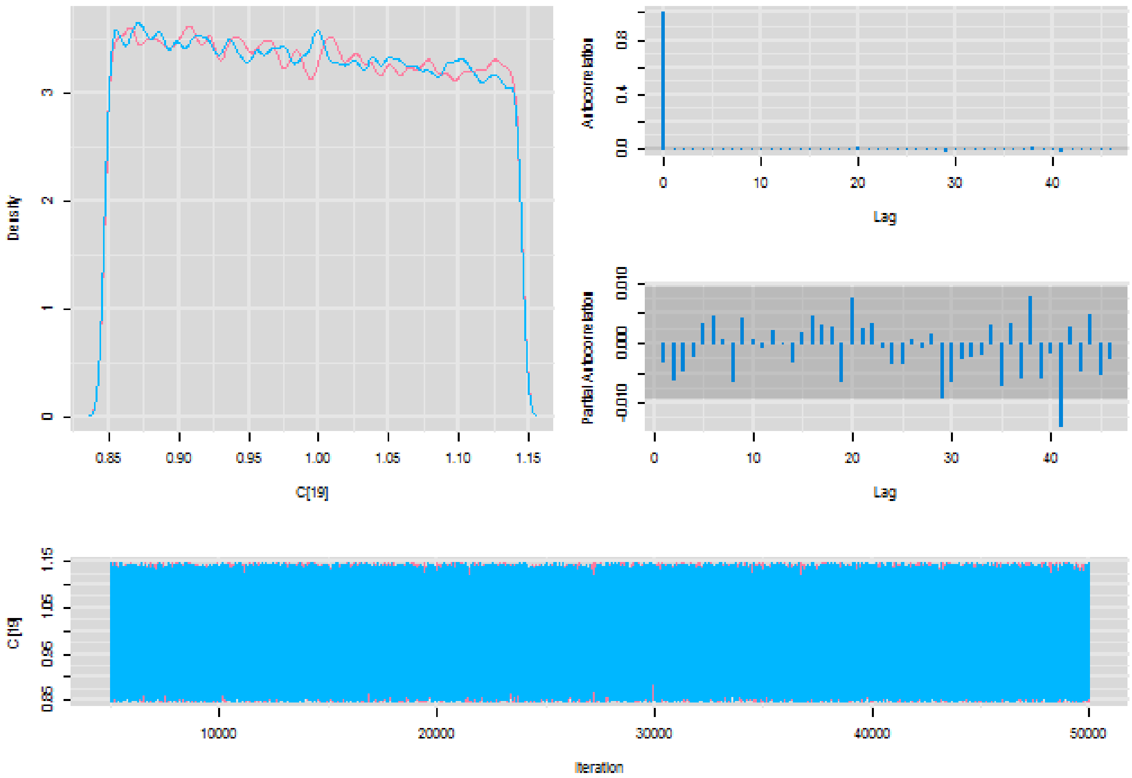
Diagnostics for C[17]



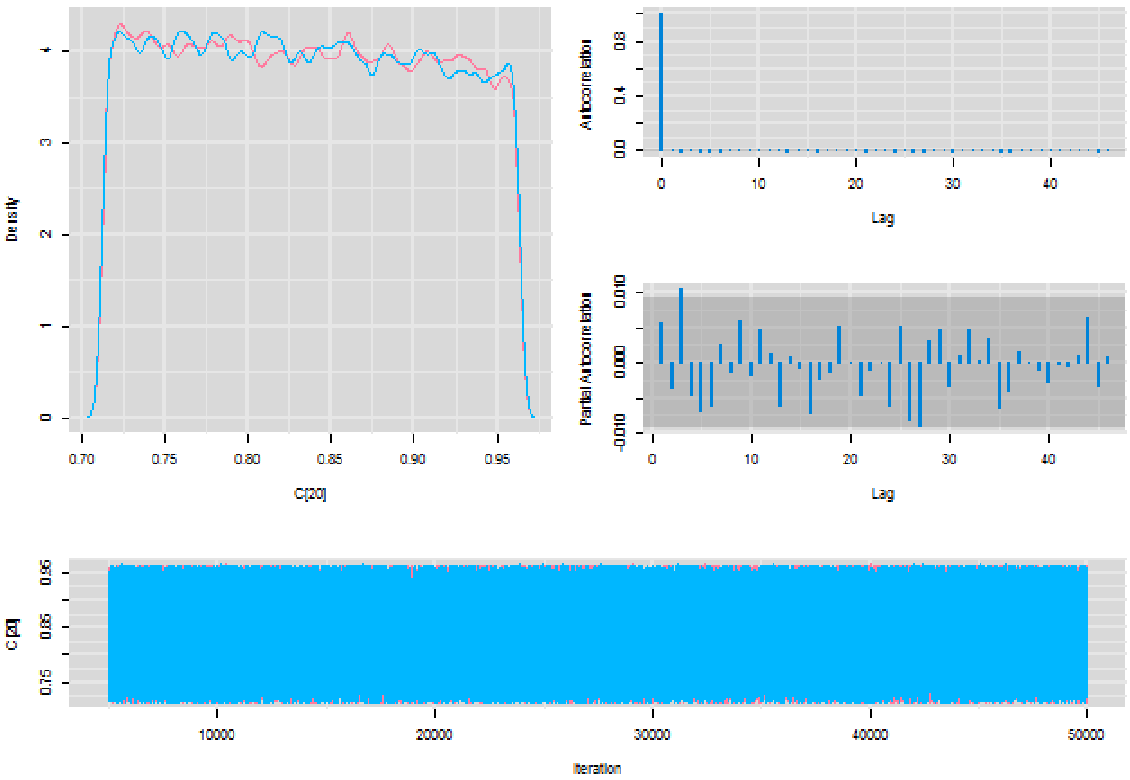
Diagnostics for C[18]



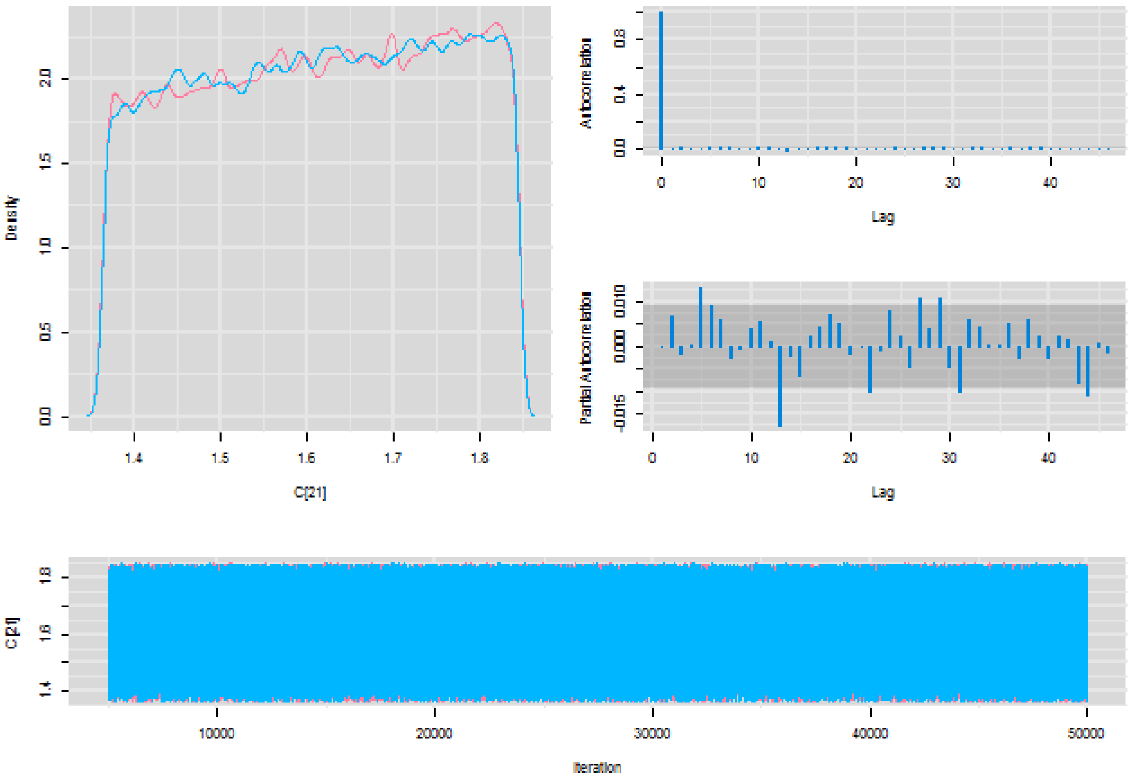
Diagnostics for C[19]



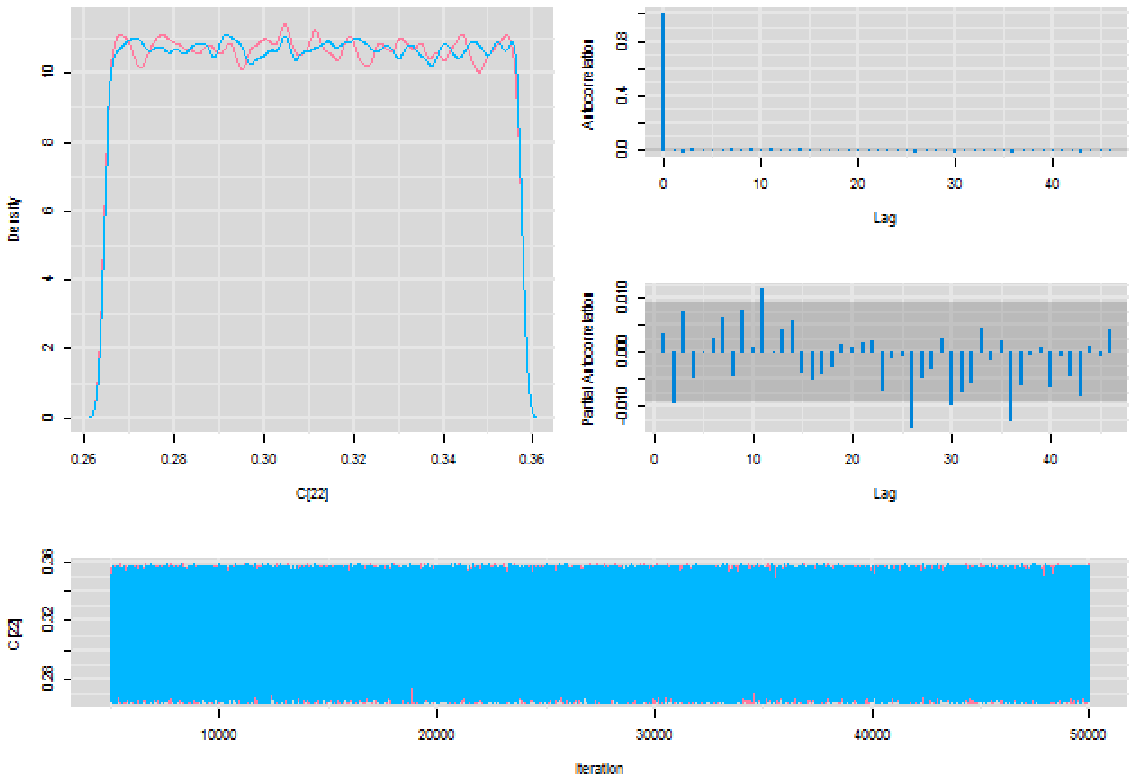
Diagnostics for C[20]



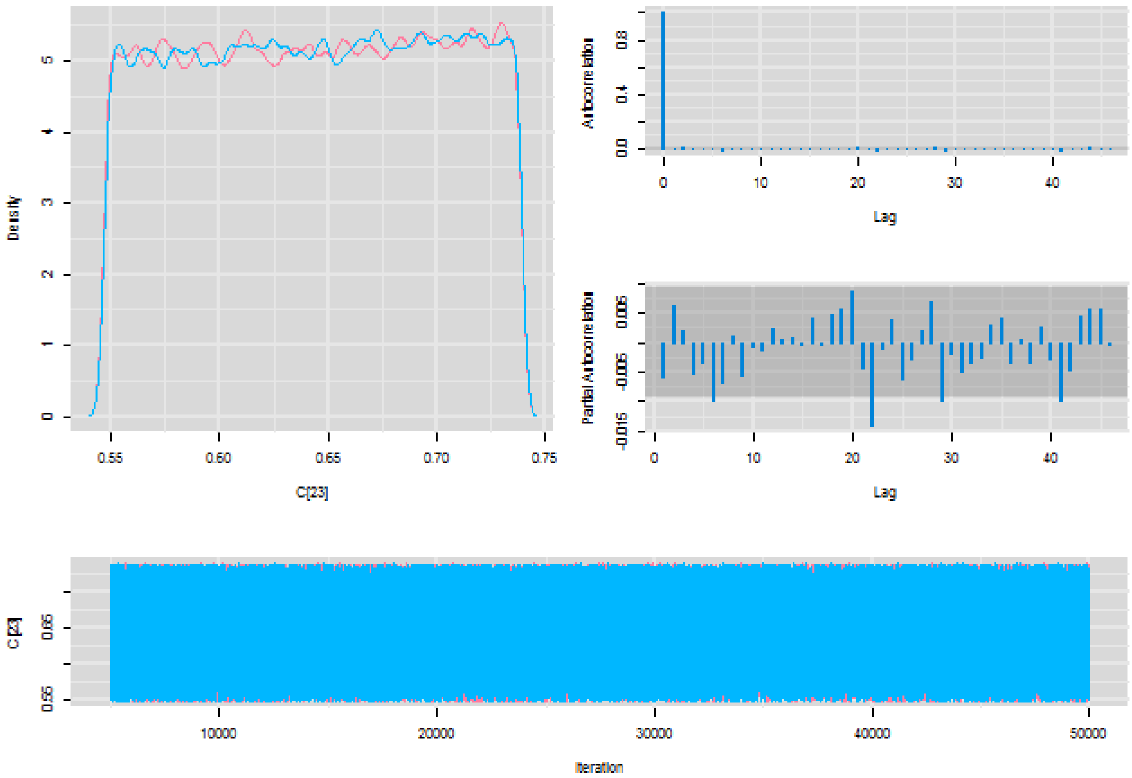
Diagnostics for C[21]



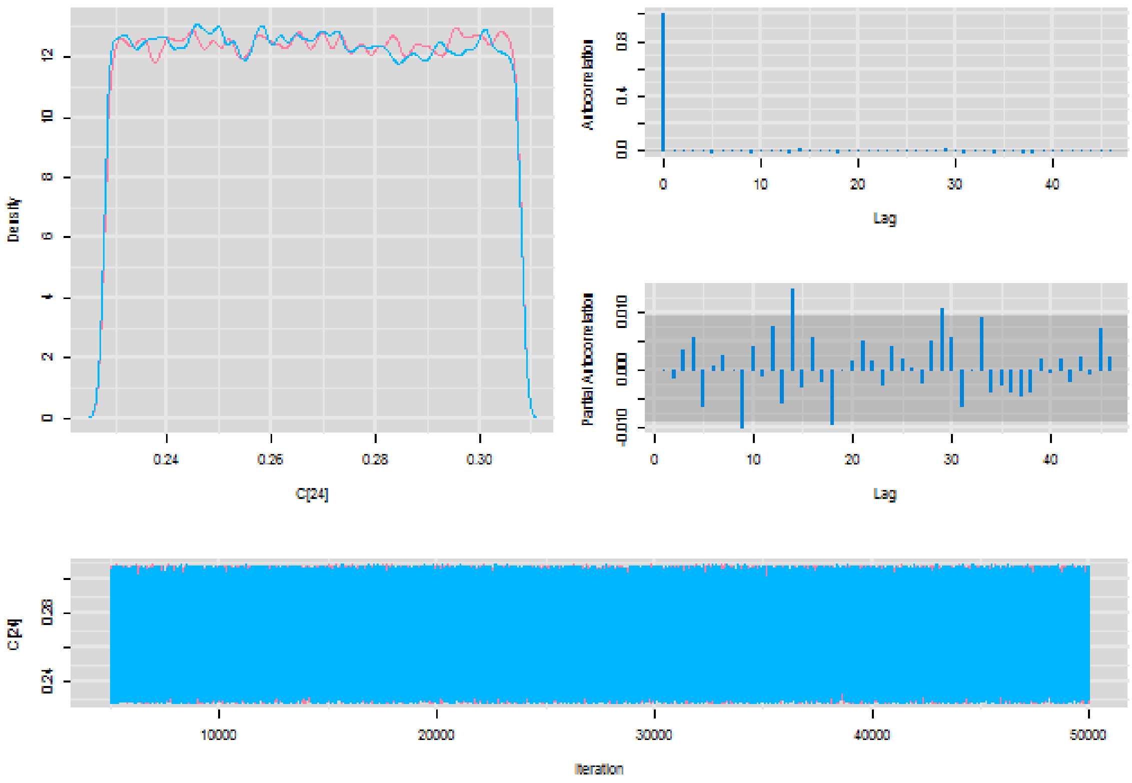
Diagnostics for C[22]



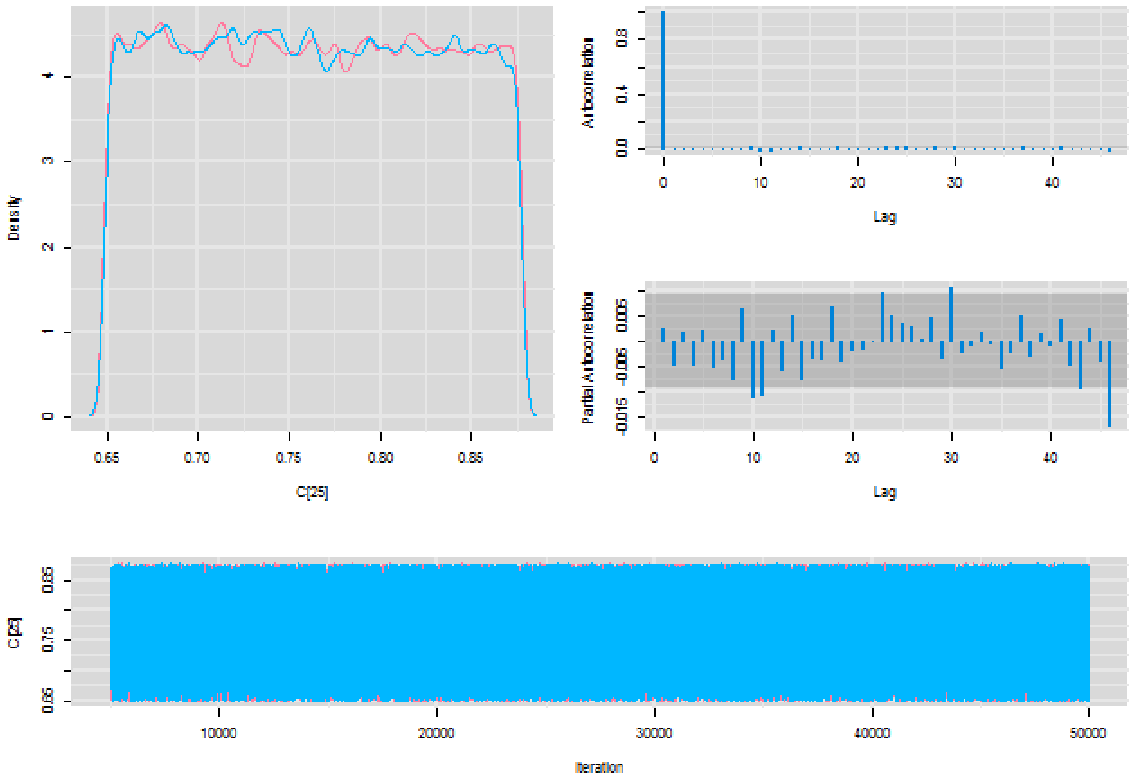
Diagnostics for C[23]



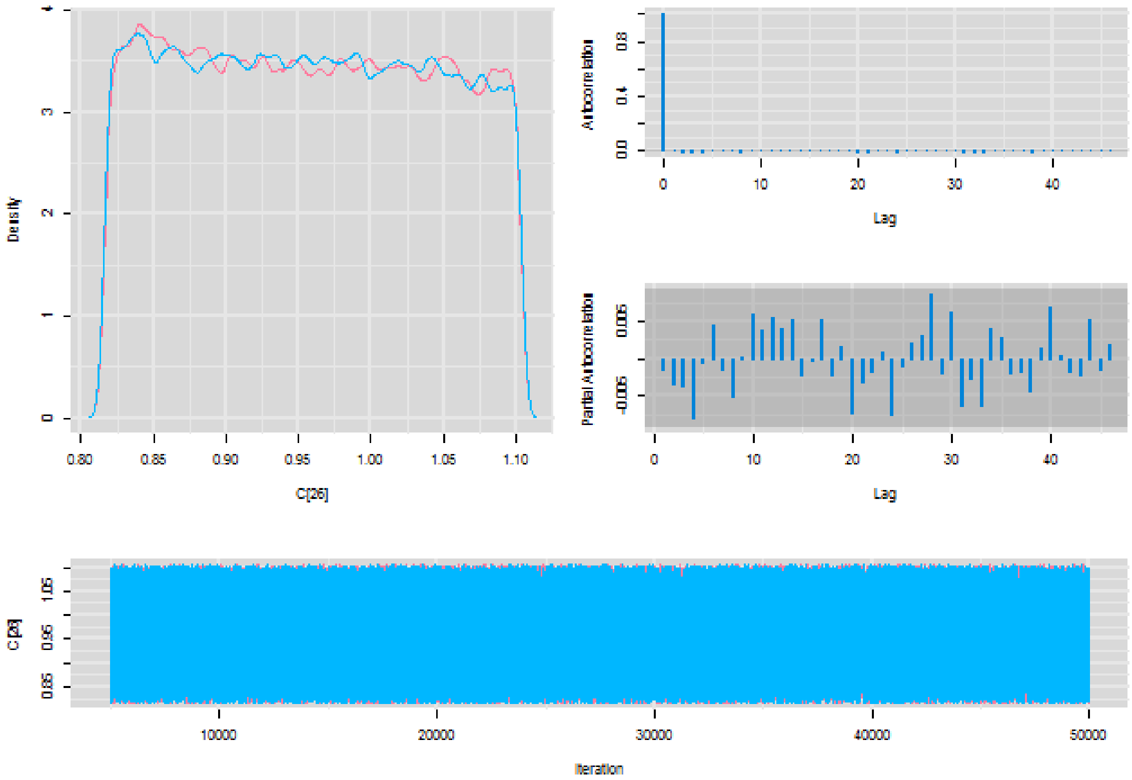
Diagnostics for C[24]



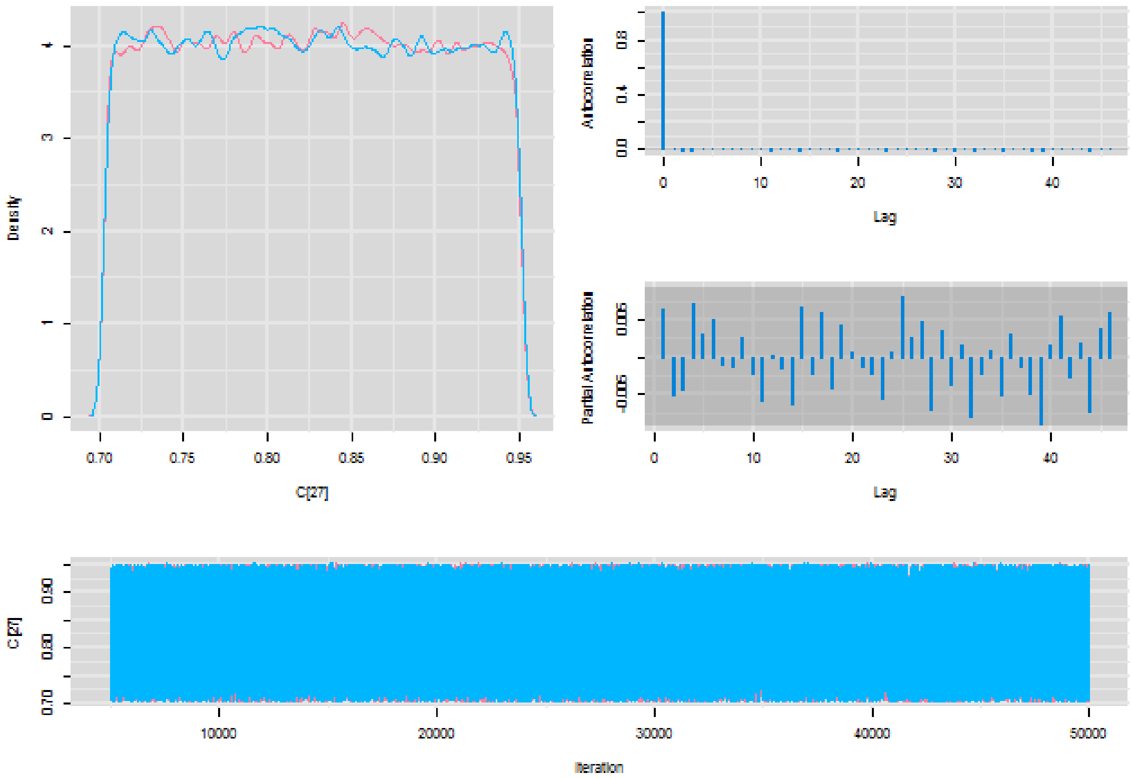
Diagnostics for C[25]



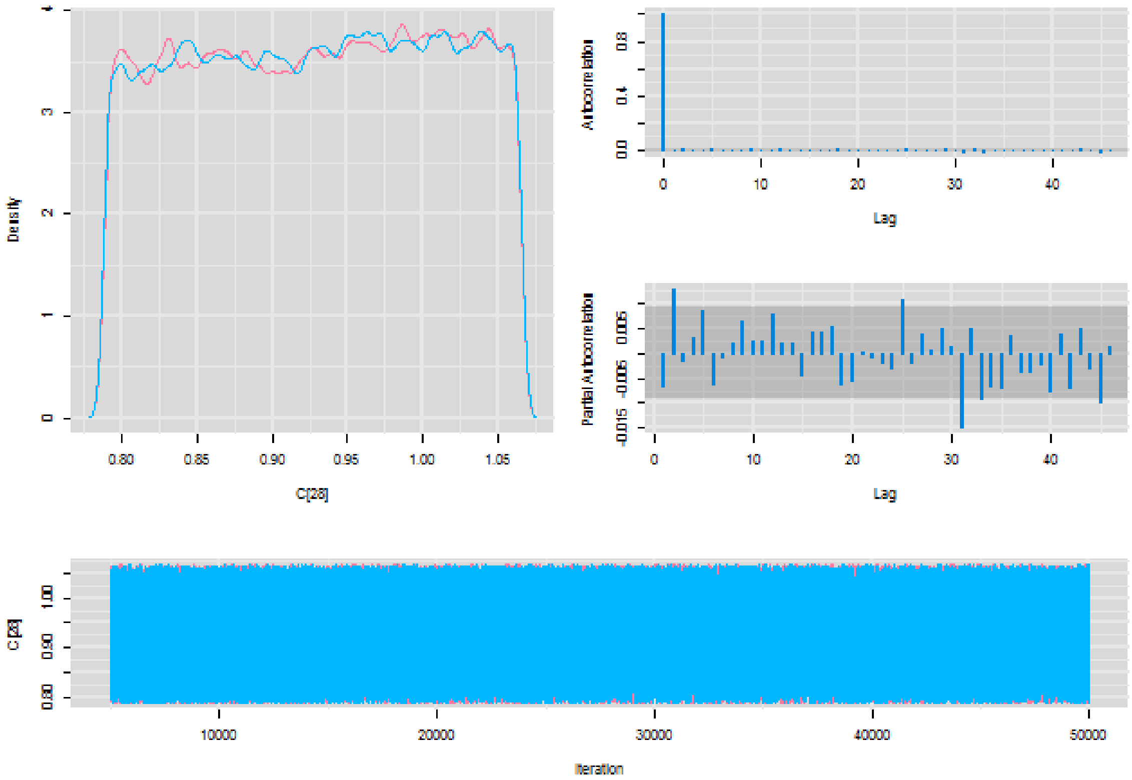
Diagnostics for C[26]



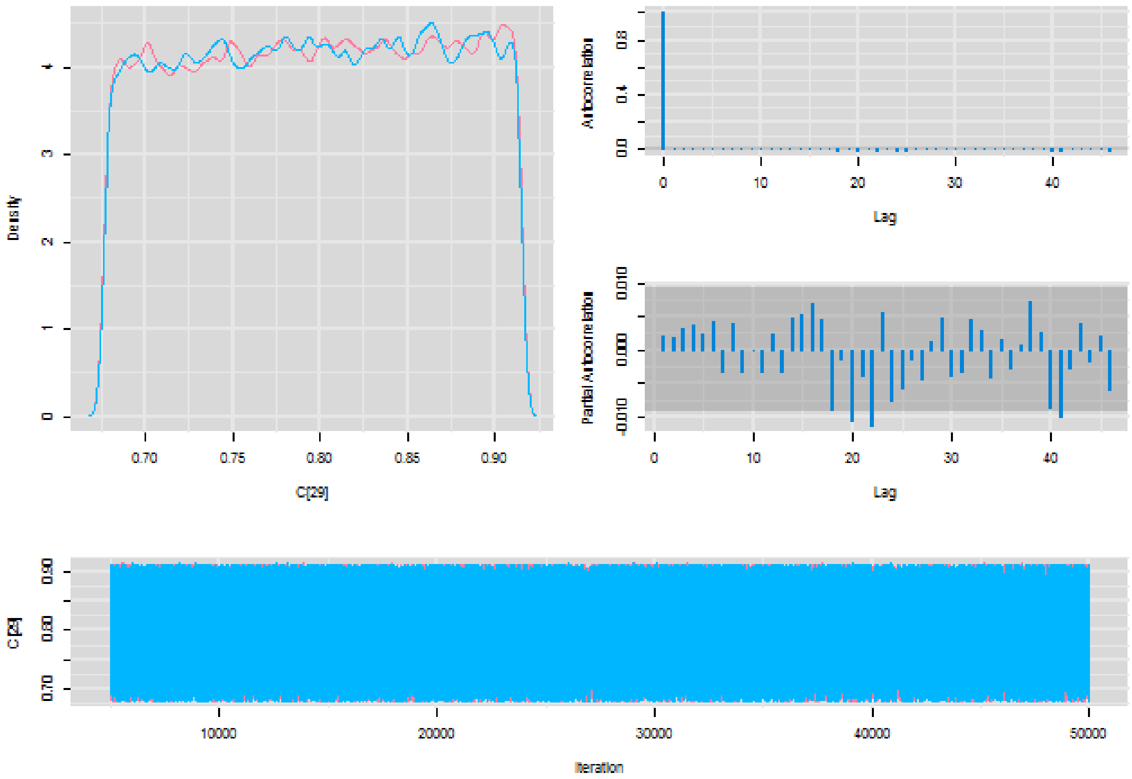
Diagnostics for C[27]



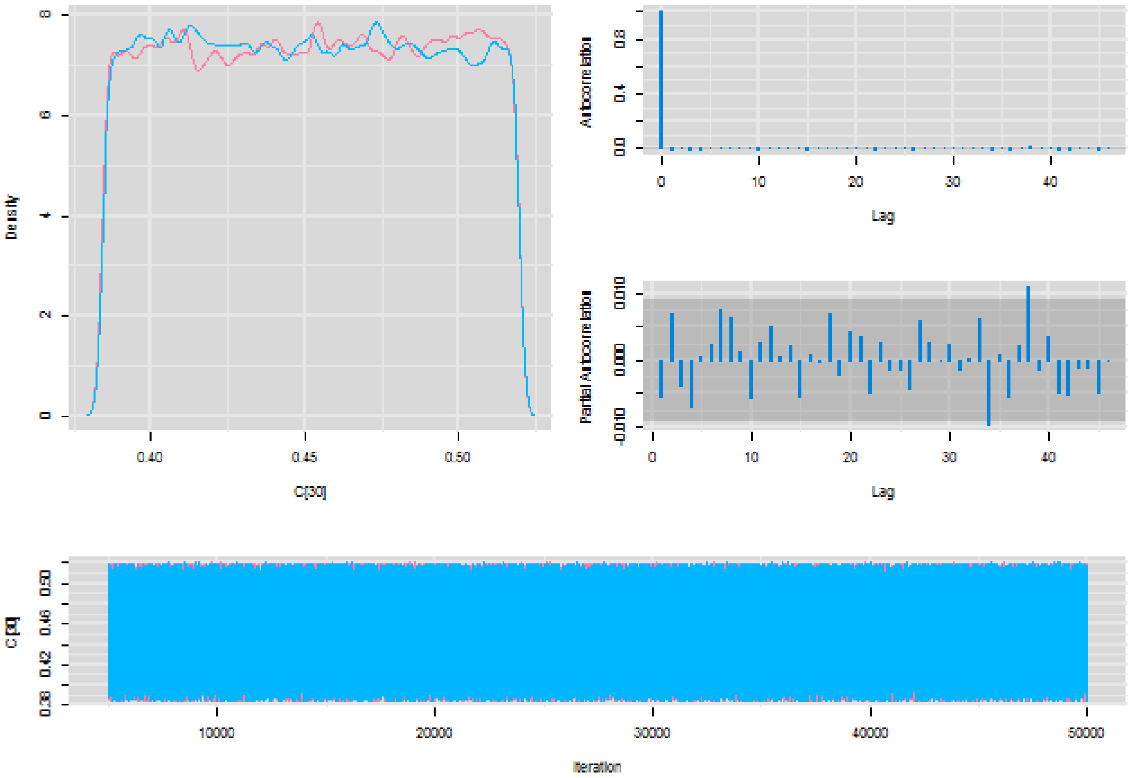
Diagnostics for C[28]



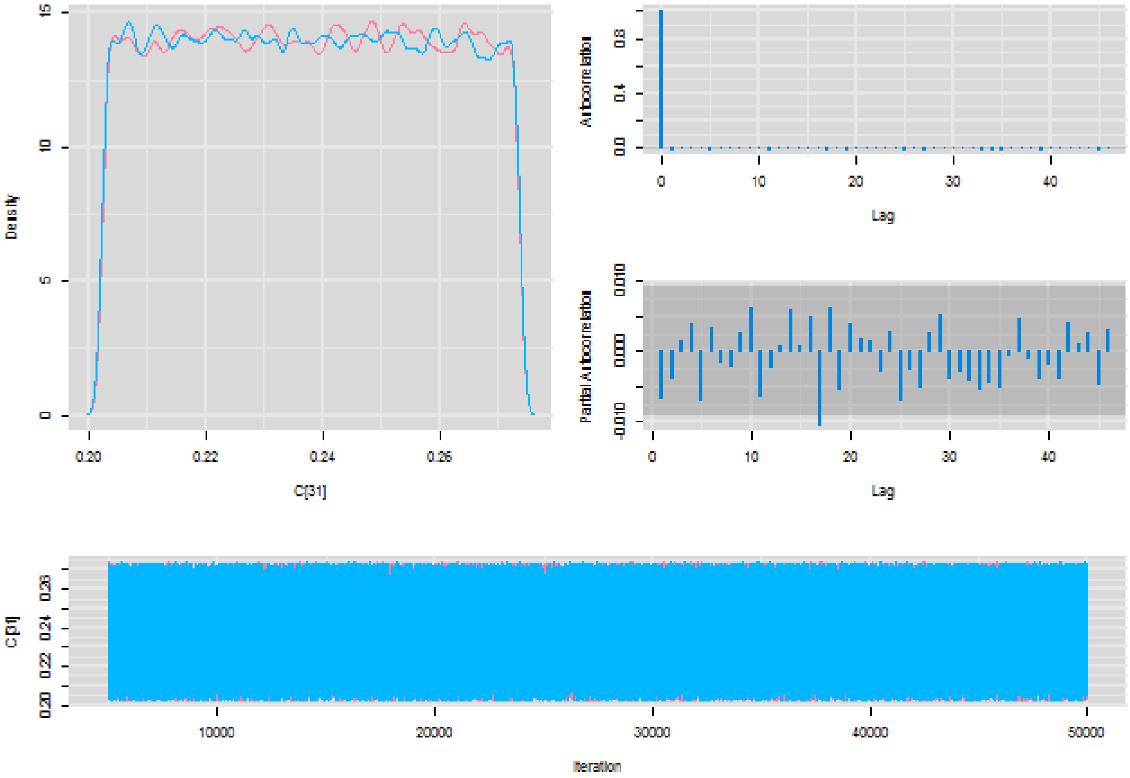
Diagnostics for C[29]



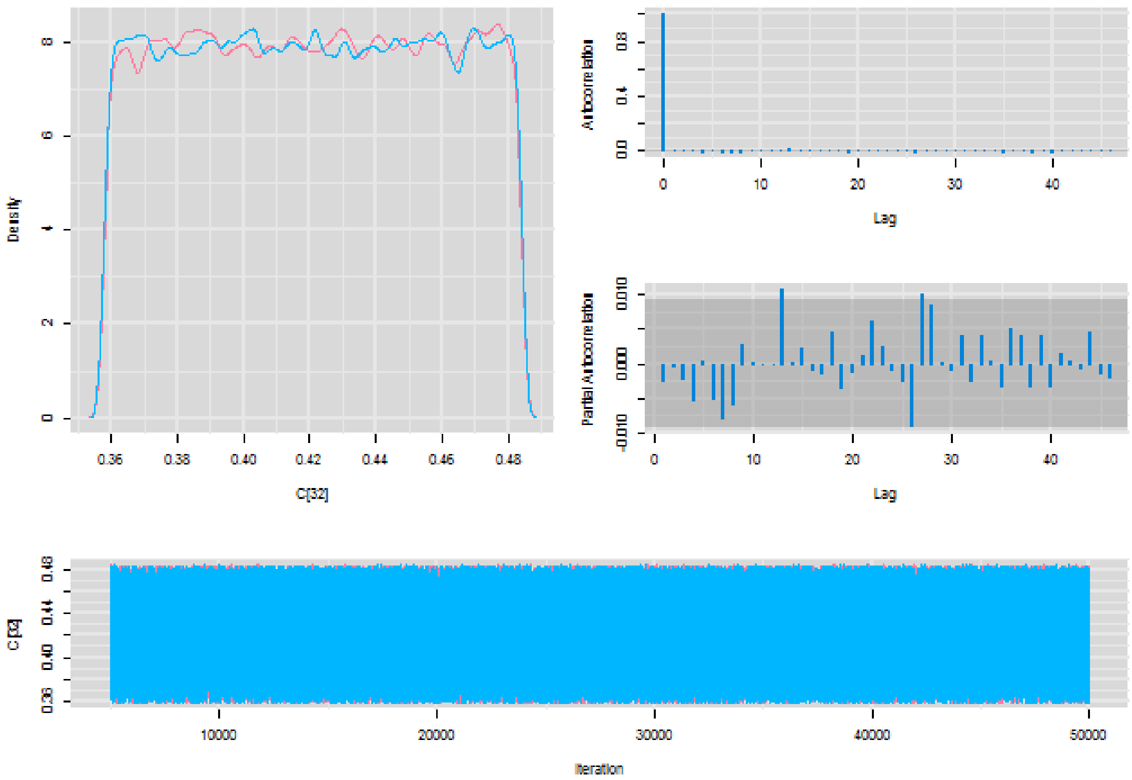
Diagnostics for C[30]



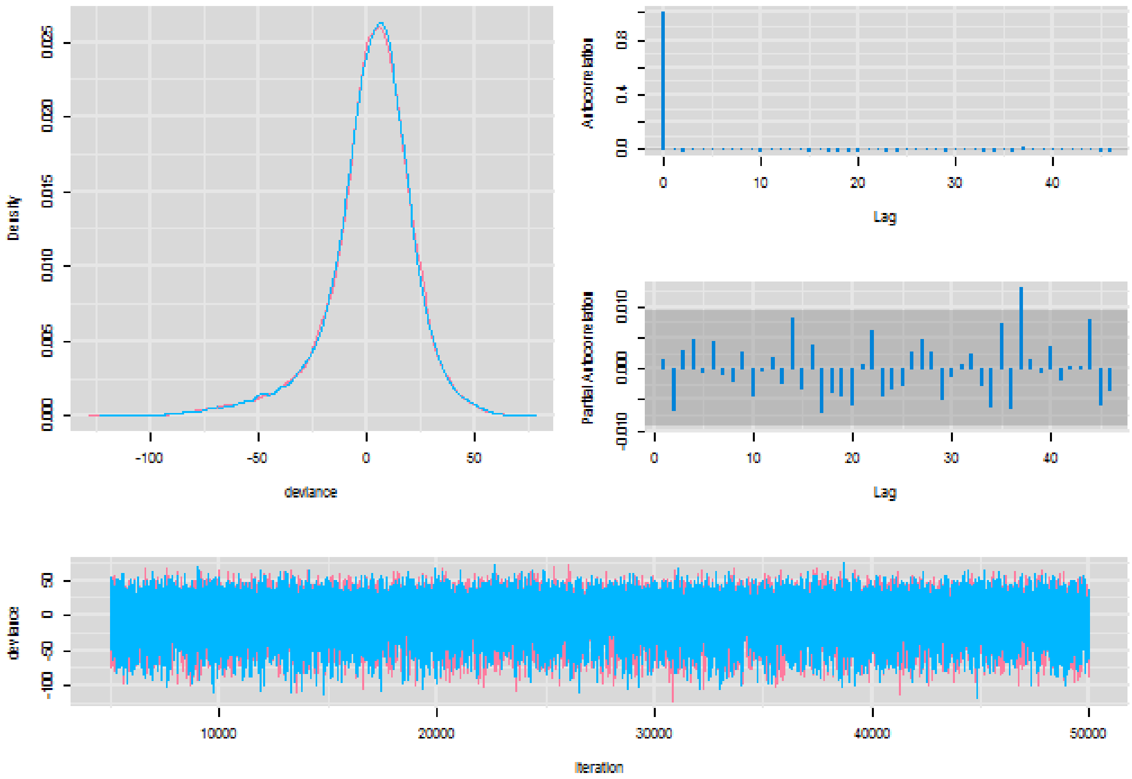
Diagnostics for C[31]



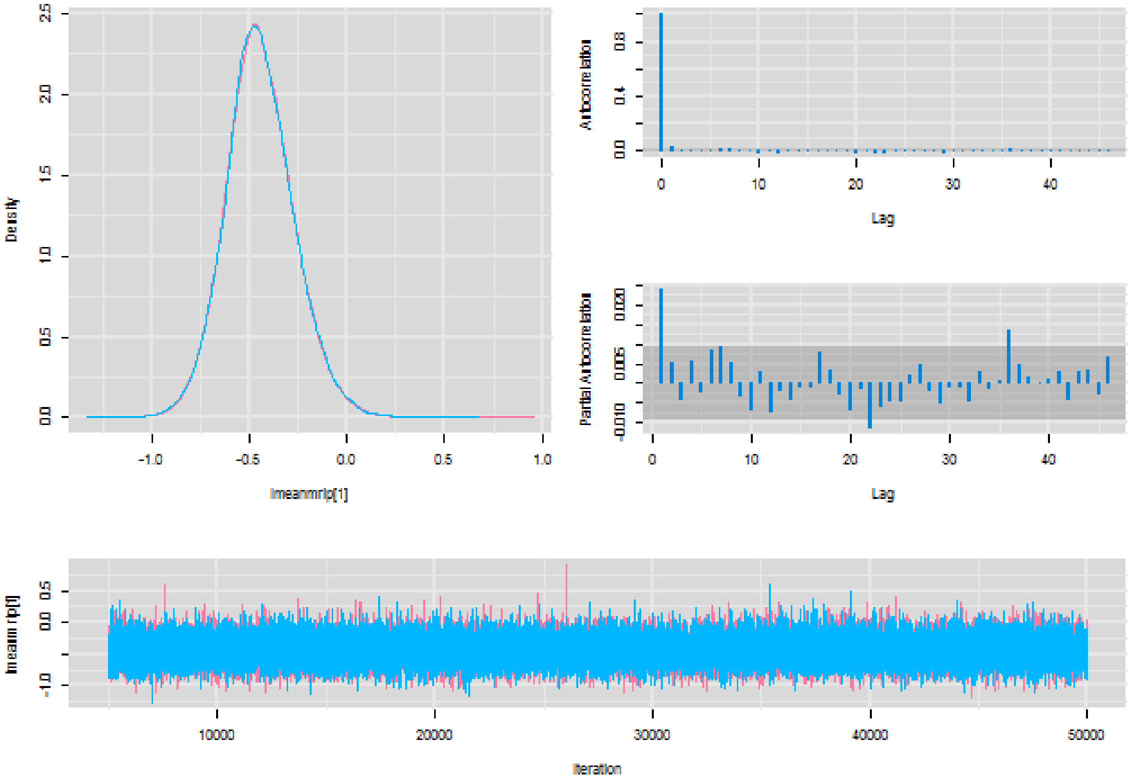
Diagnostics for C[32]



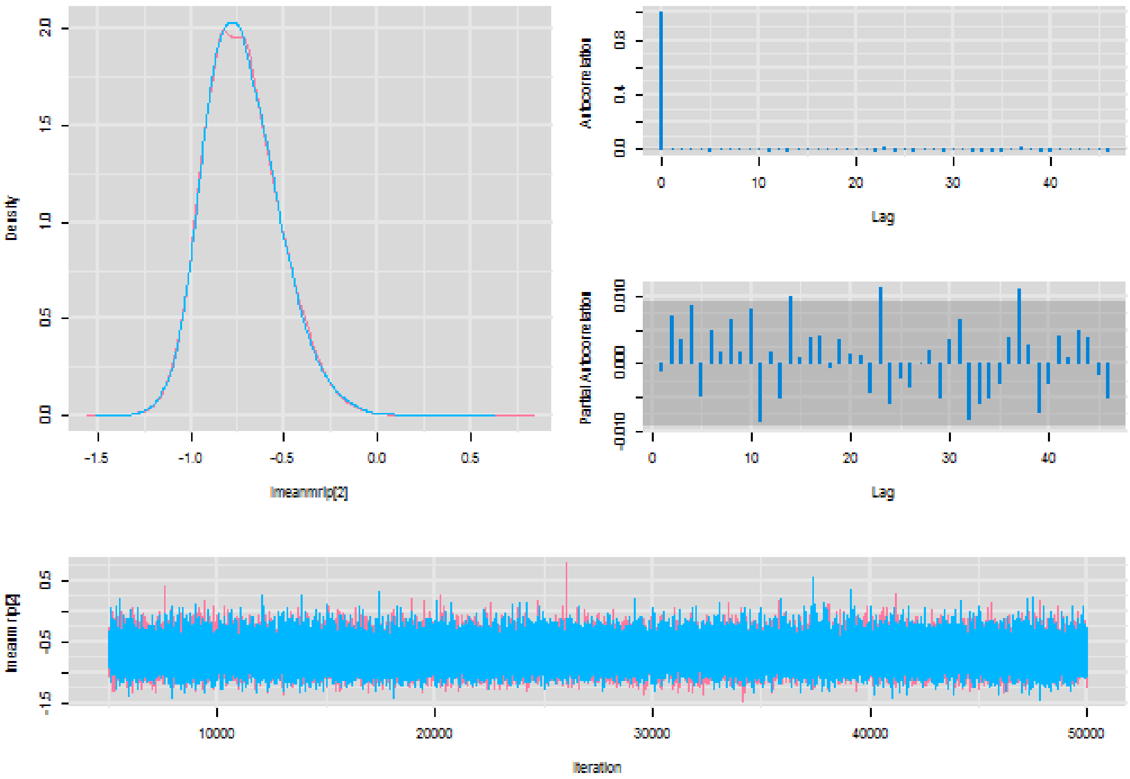
Diagnostics for deviance



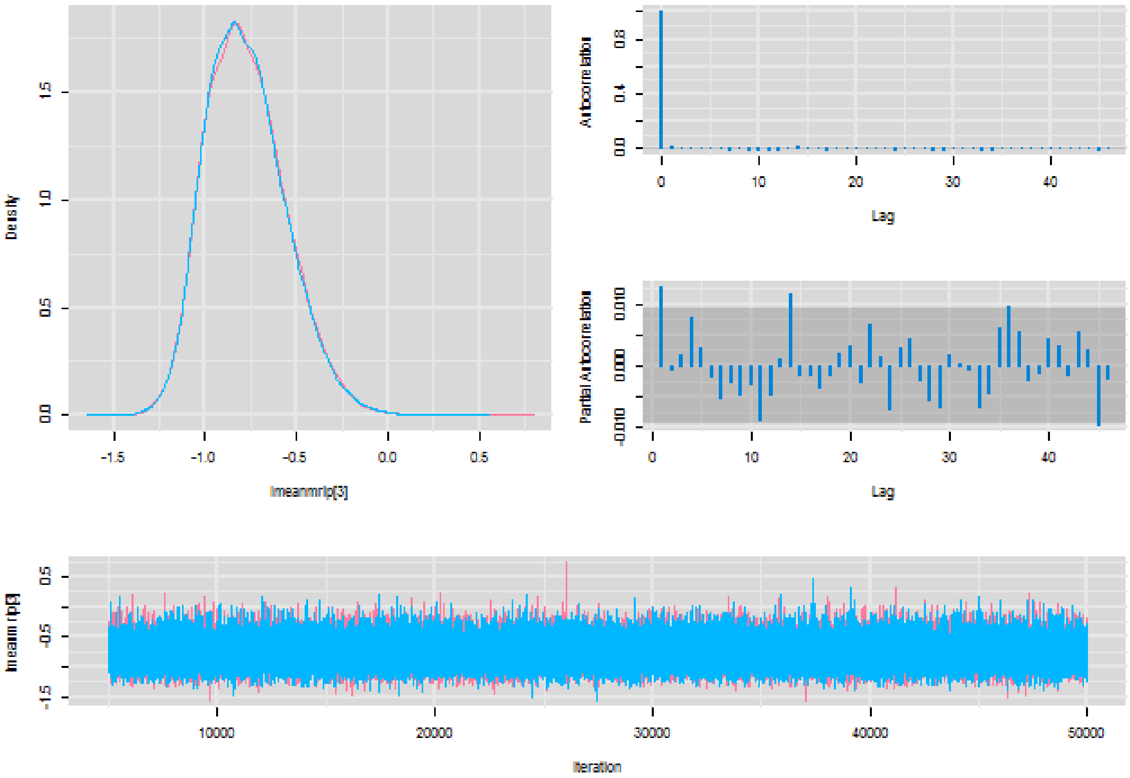
Diagnostics for lmeanmrip[1]



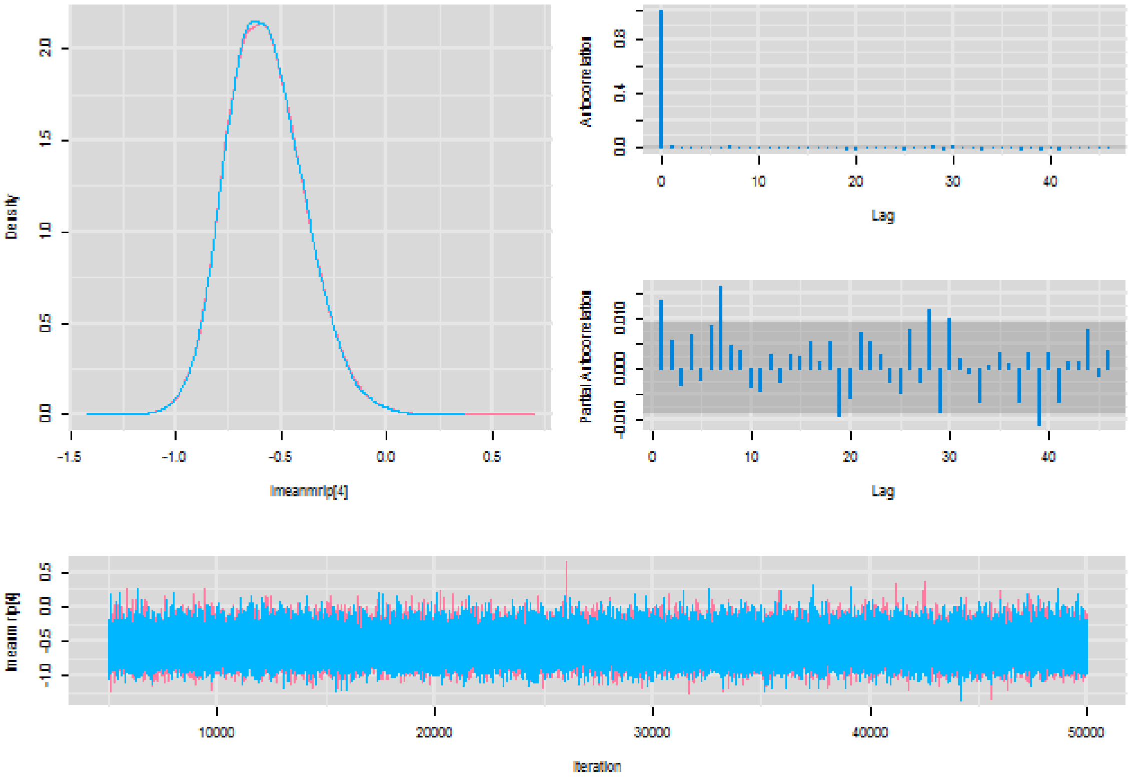
Diagnostics for lmeanmrip[2]



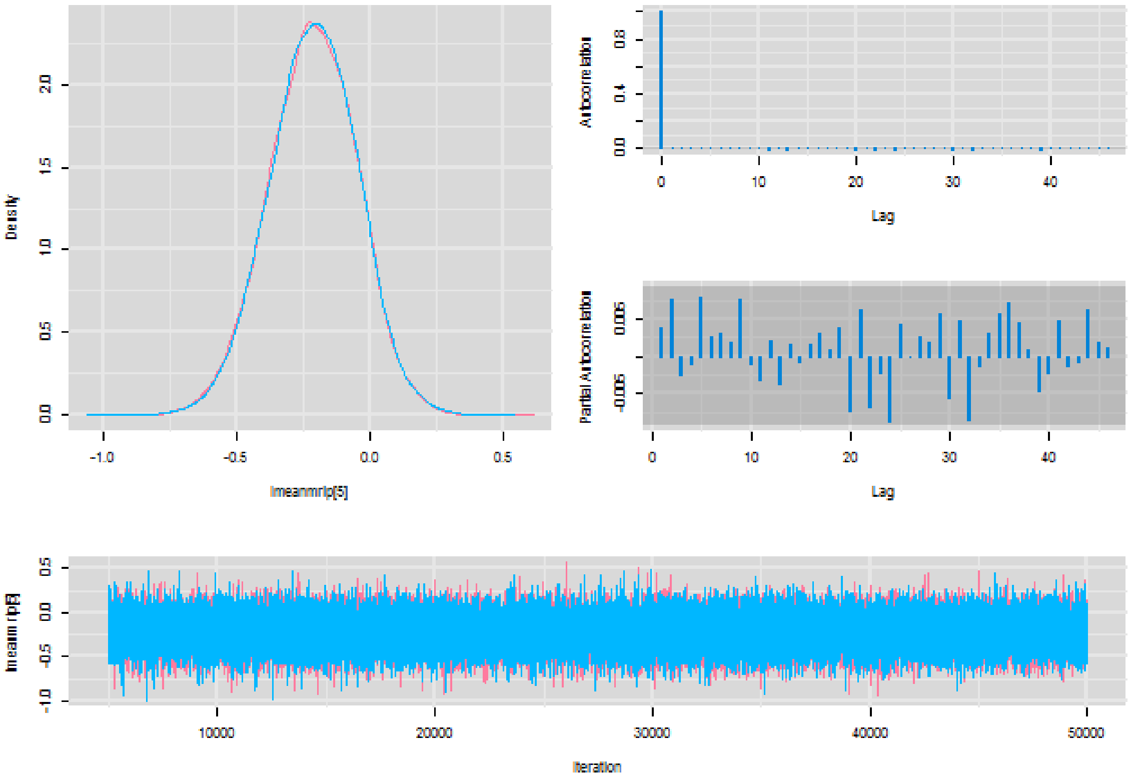
Diagnostics for lmeanmrip[3]



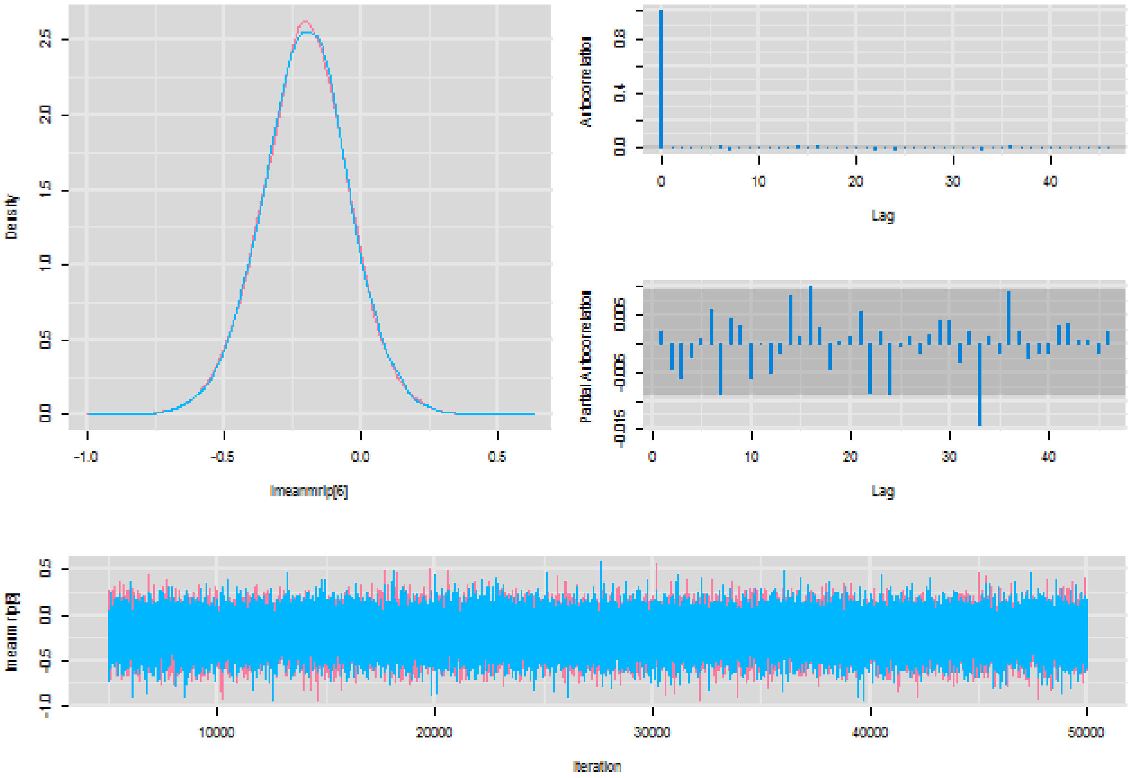
Diagnostics for lmeanmrip[4]



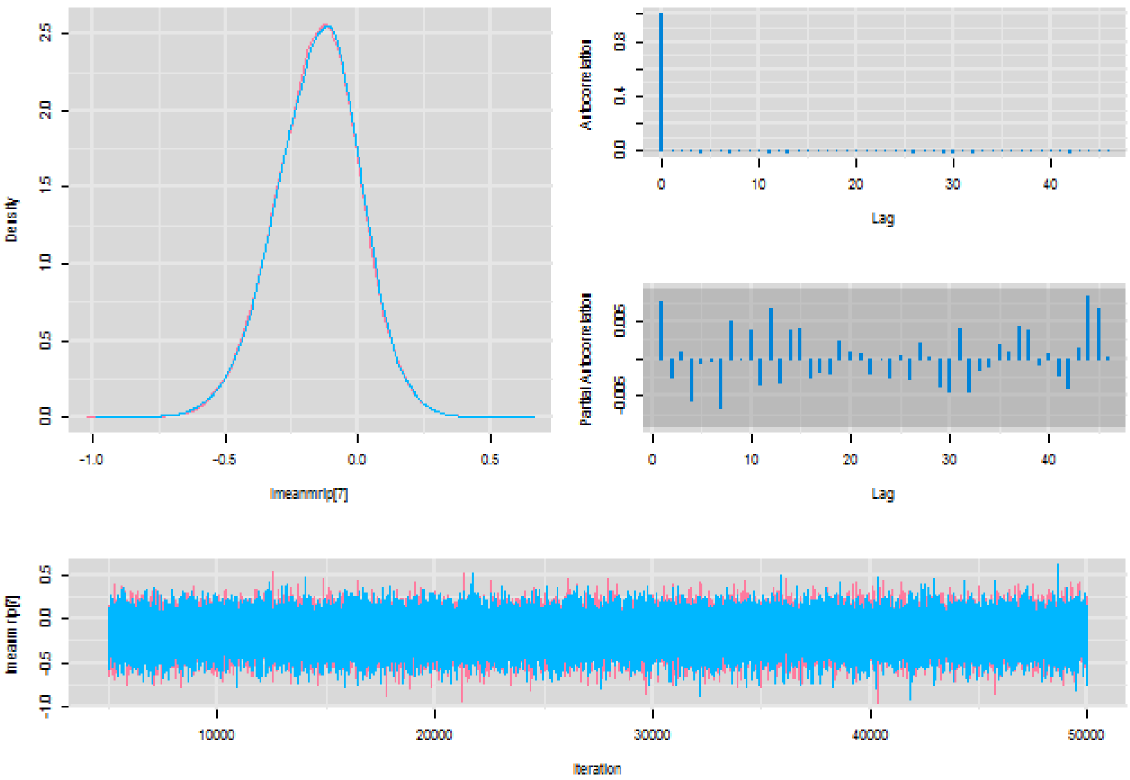
Diagnostics for lmeanmrip[5]



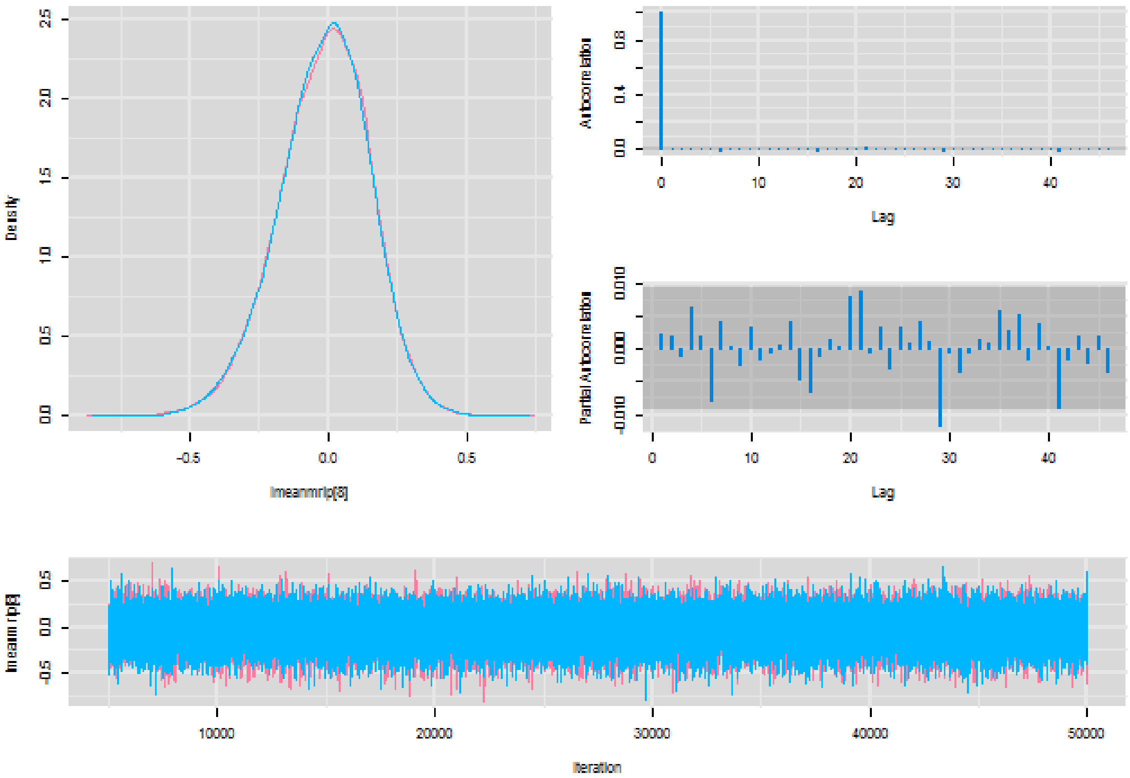
Diagnostics for lmeanmrip[6]



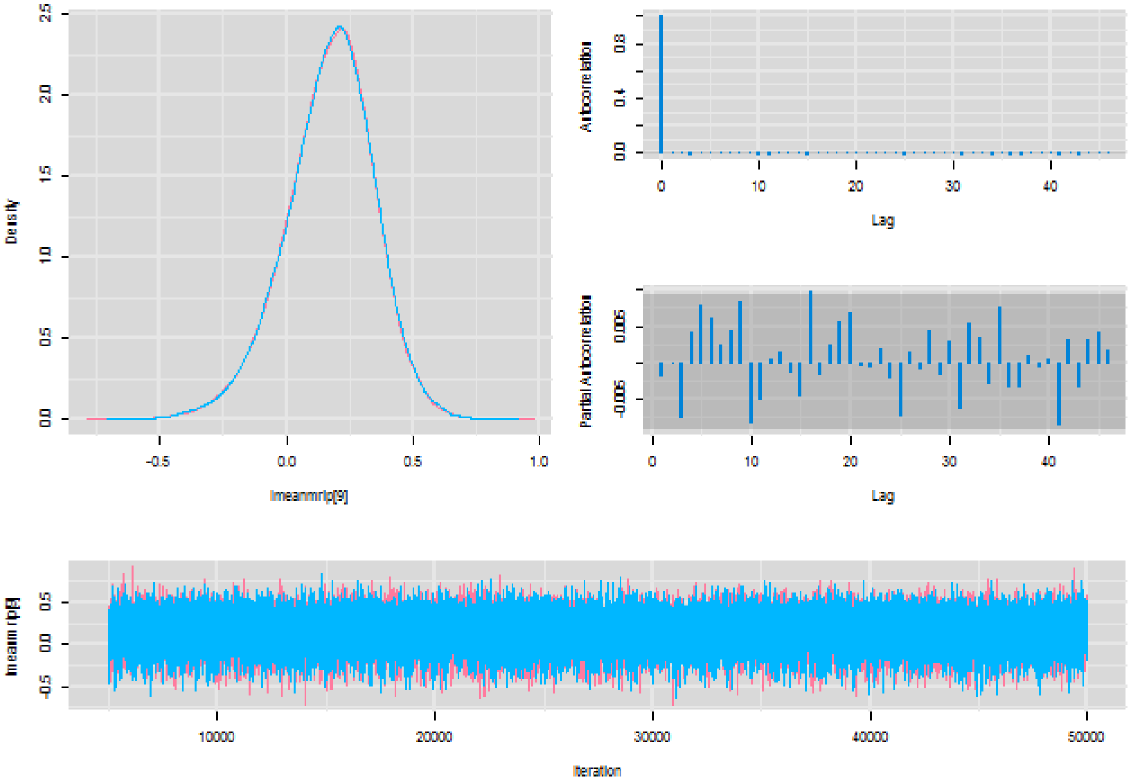
Diagnostics for lmeanmrip[7]



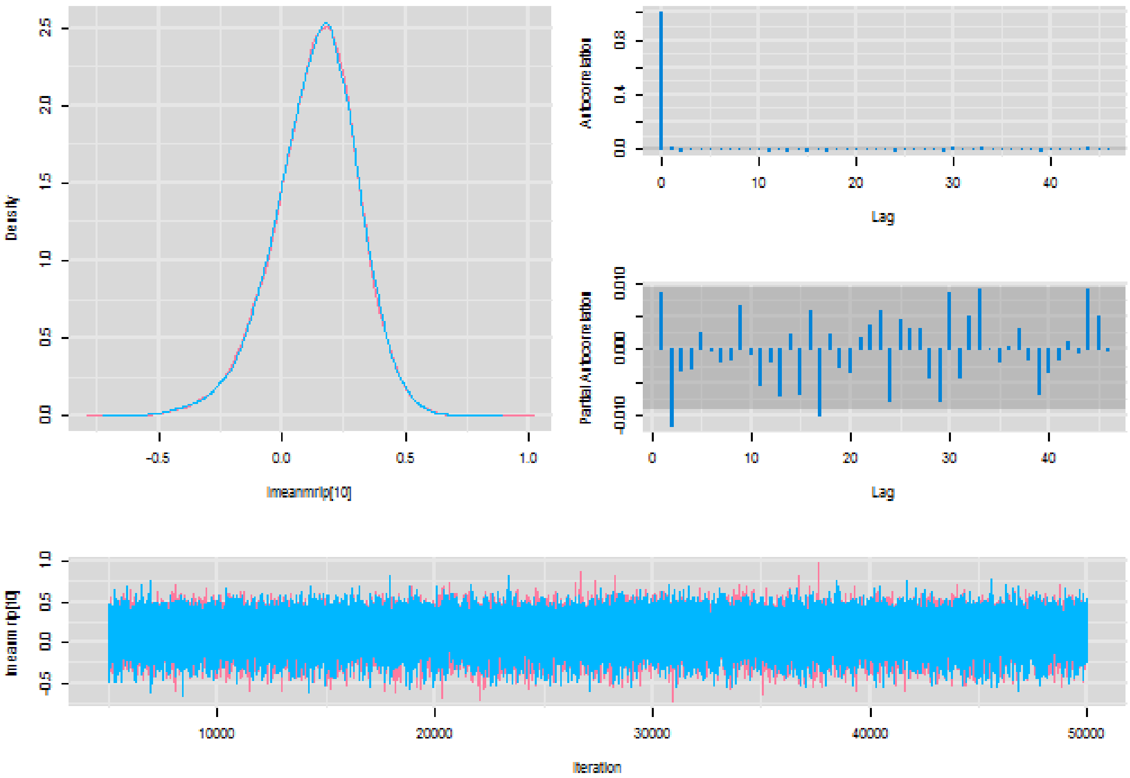
Diagnostics for lmeanmrip[8]



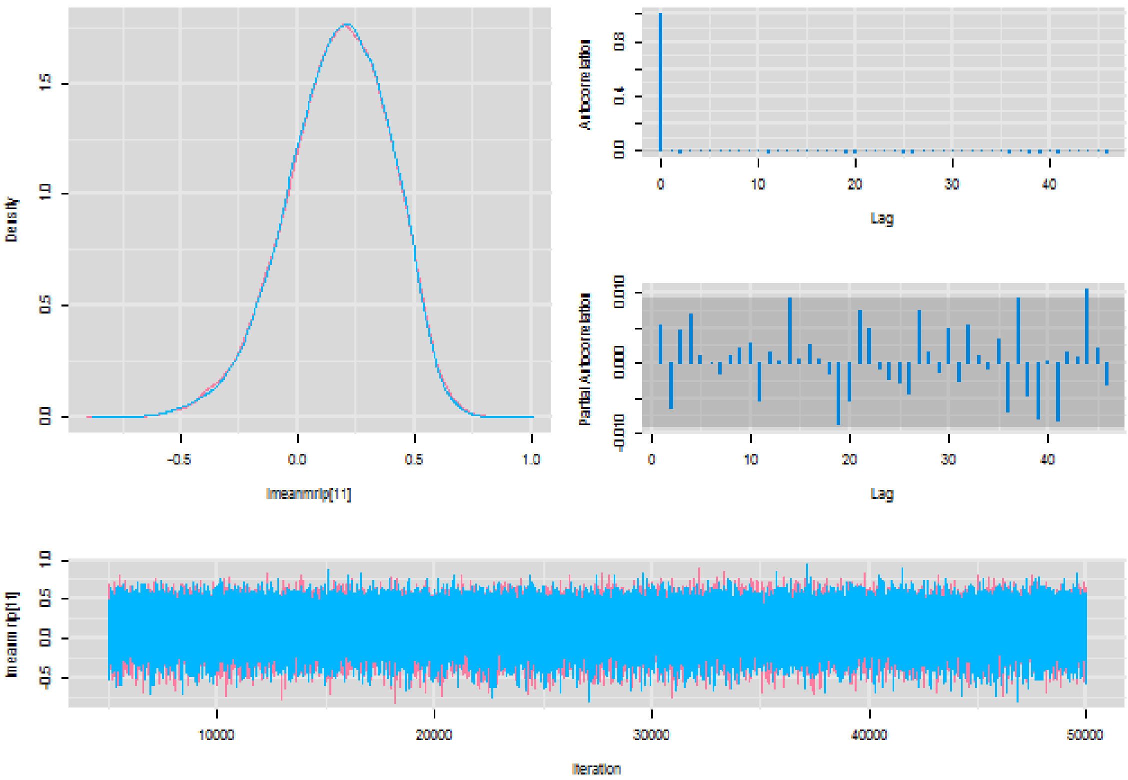
Diagnostics for lmeanmrip[9]



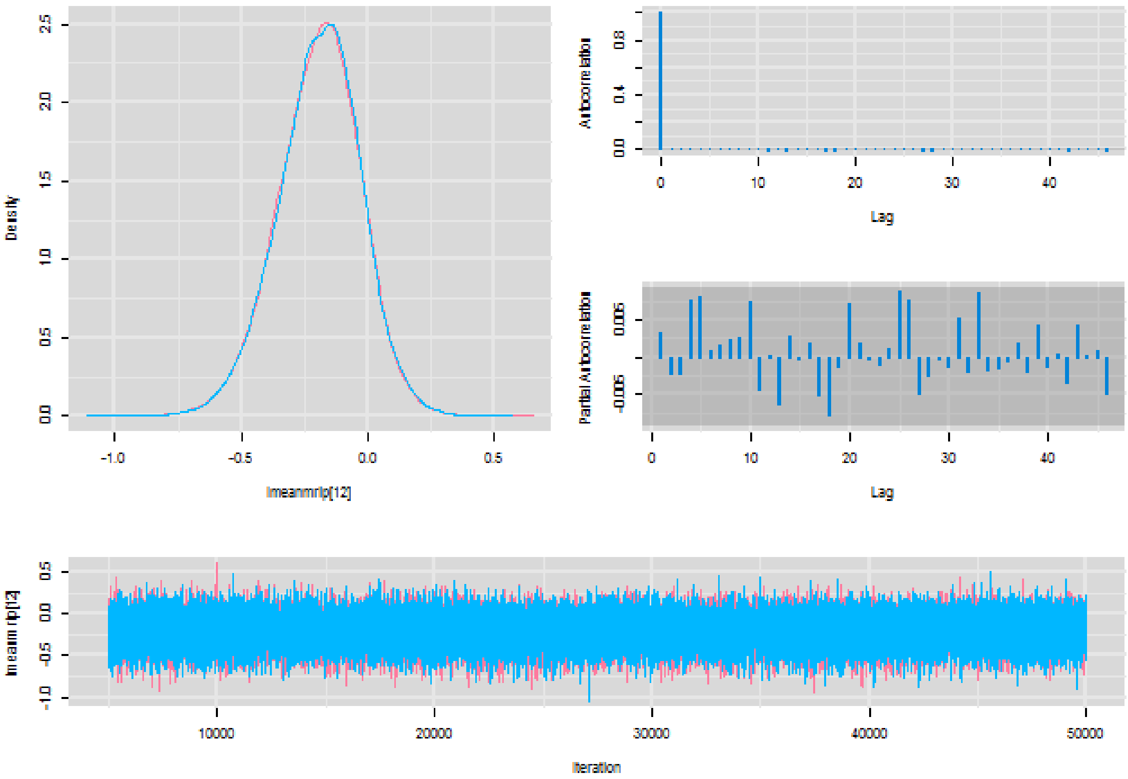
Diagnostics for lmeanmrip[10]



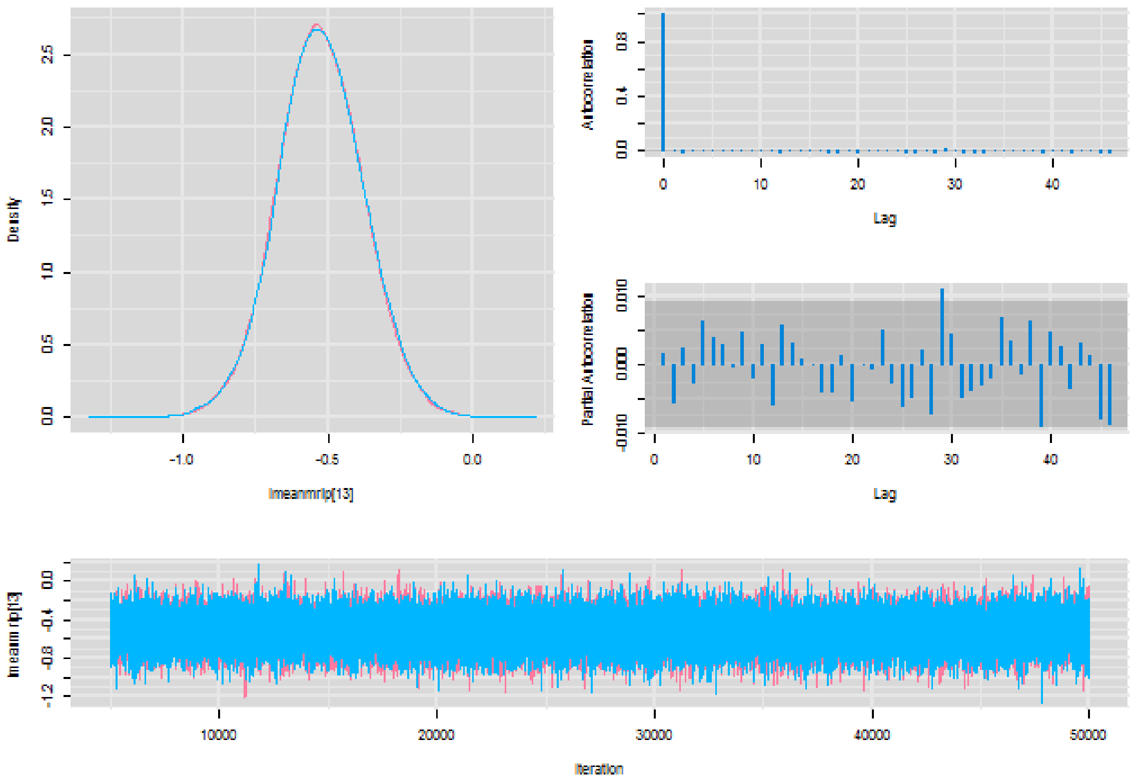
Diagnostics for lmeanmrip[11]



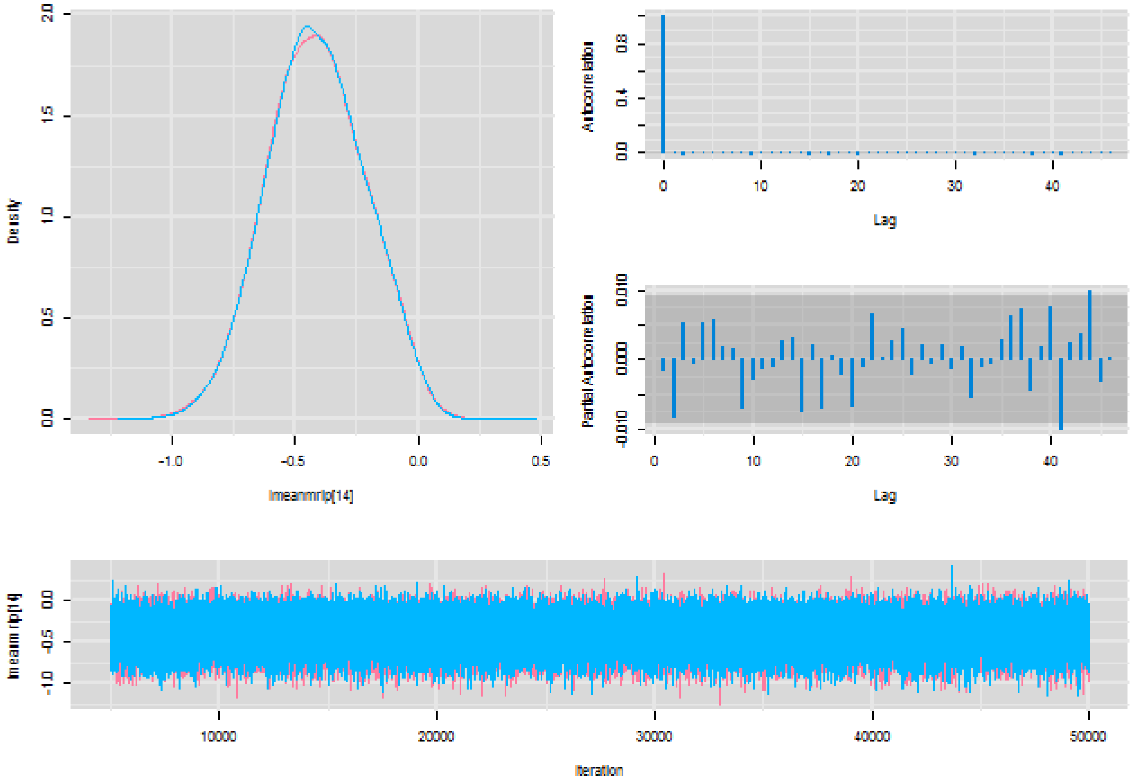
Diagnostics for lmeanmrip[12]



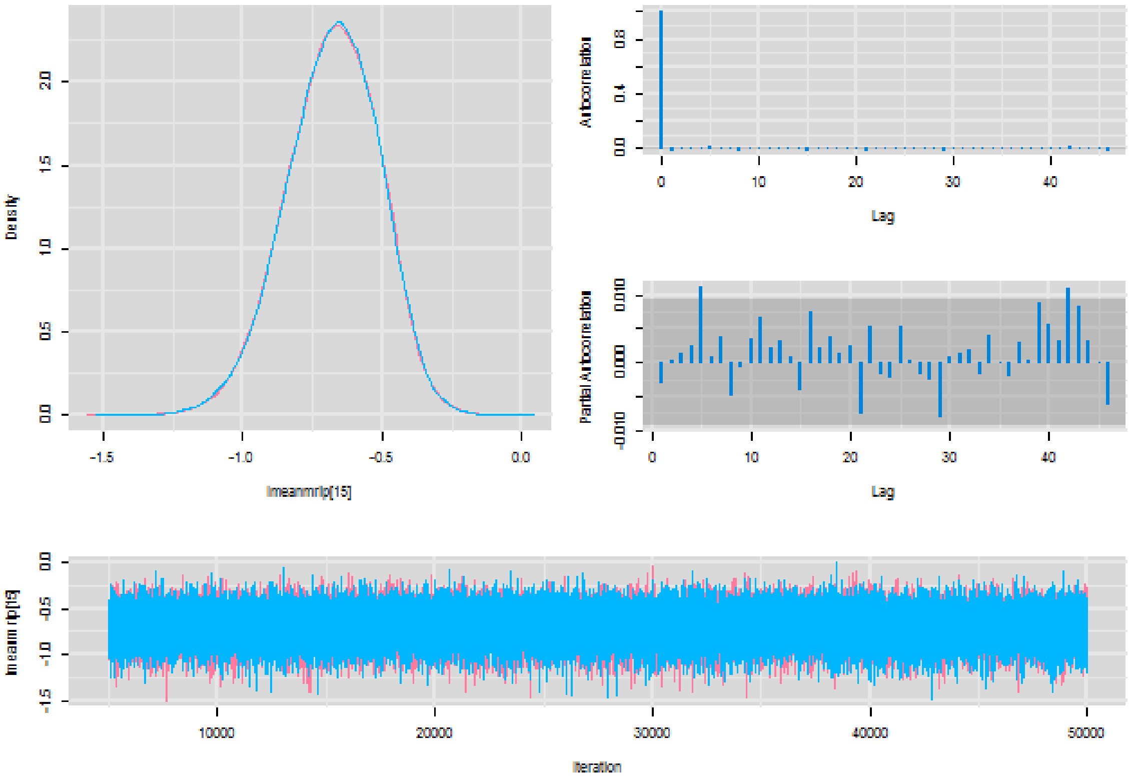
Diagnostics for lmeanmrip[13]



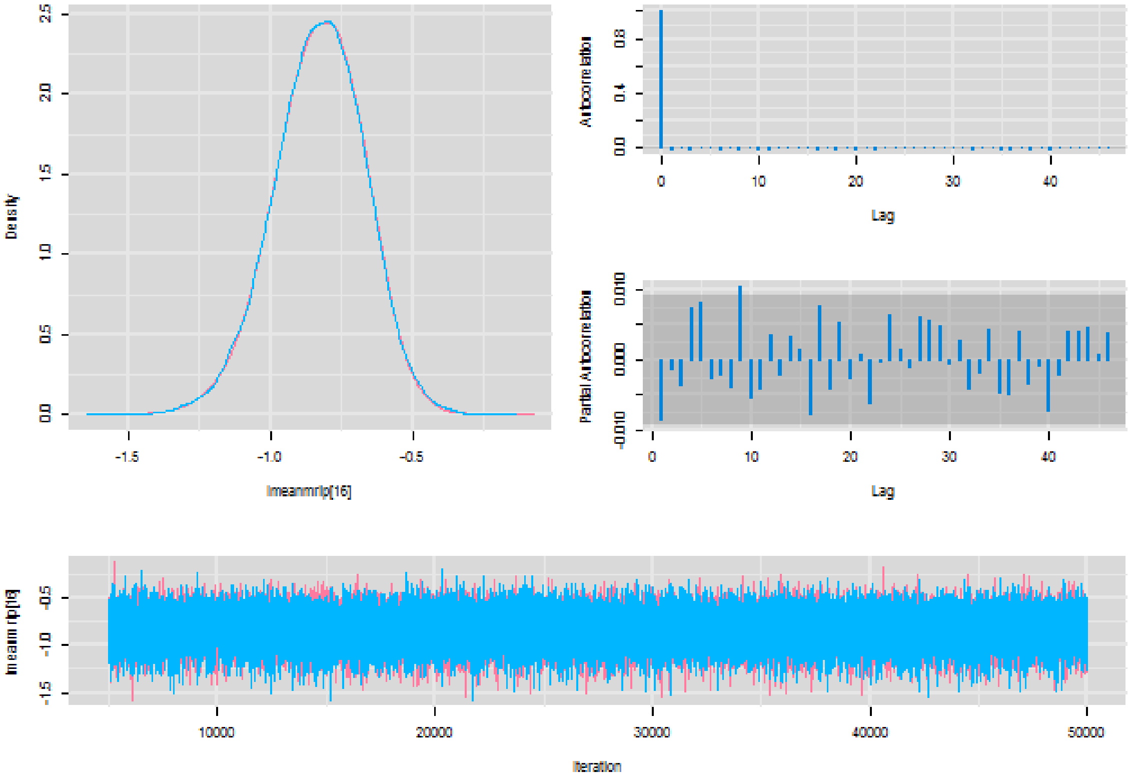
Diagnostics for lmeanmrip[14]



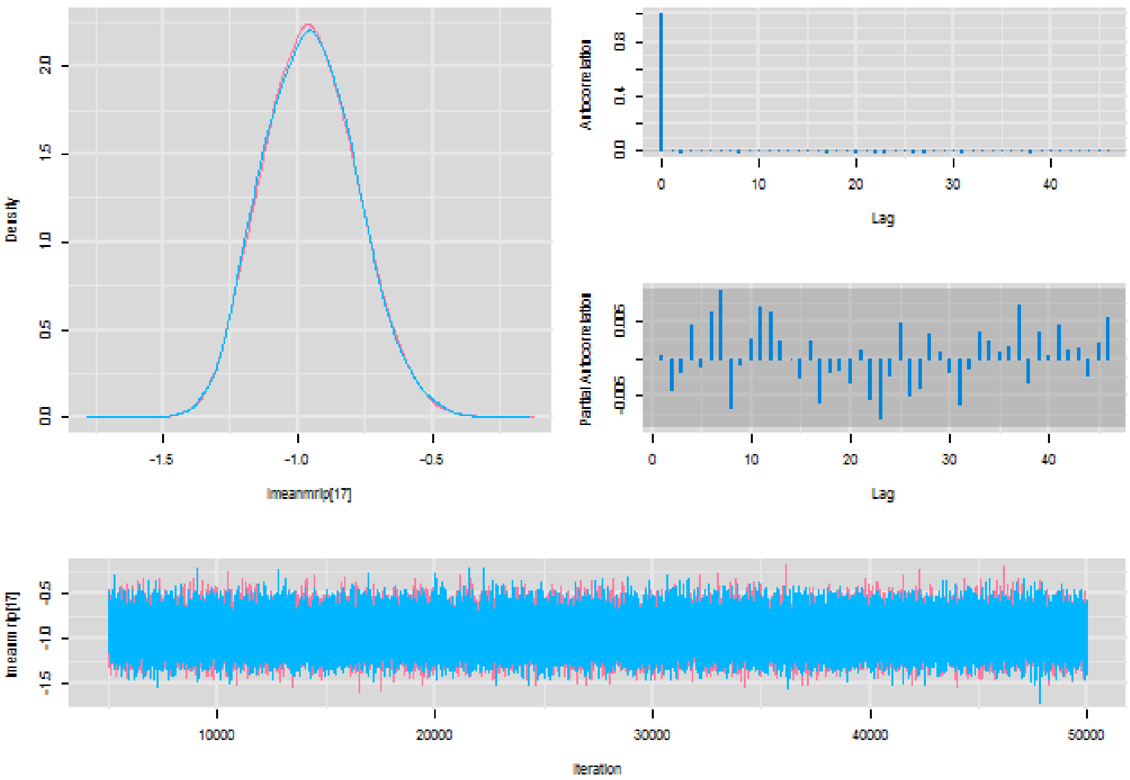
Diagnostics for lmeanmrip[15]



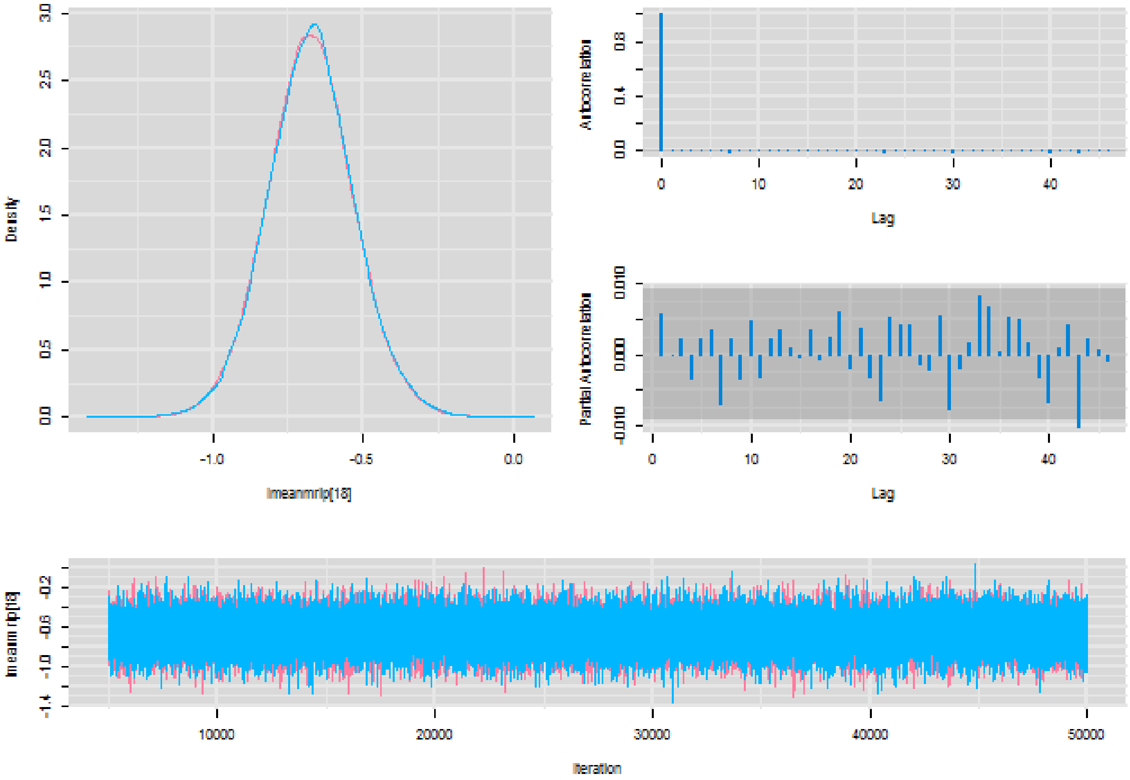
Diagnostics for lmeanmrip[16]



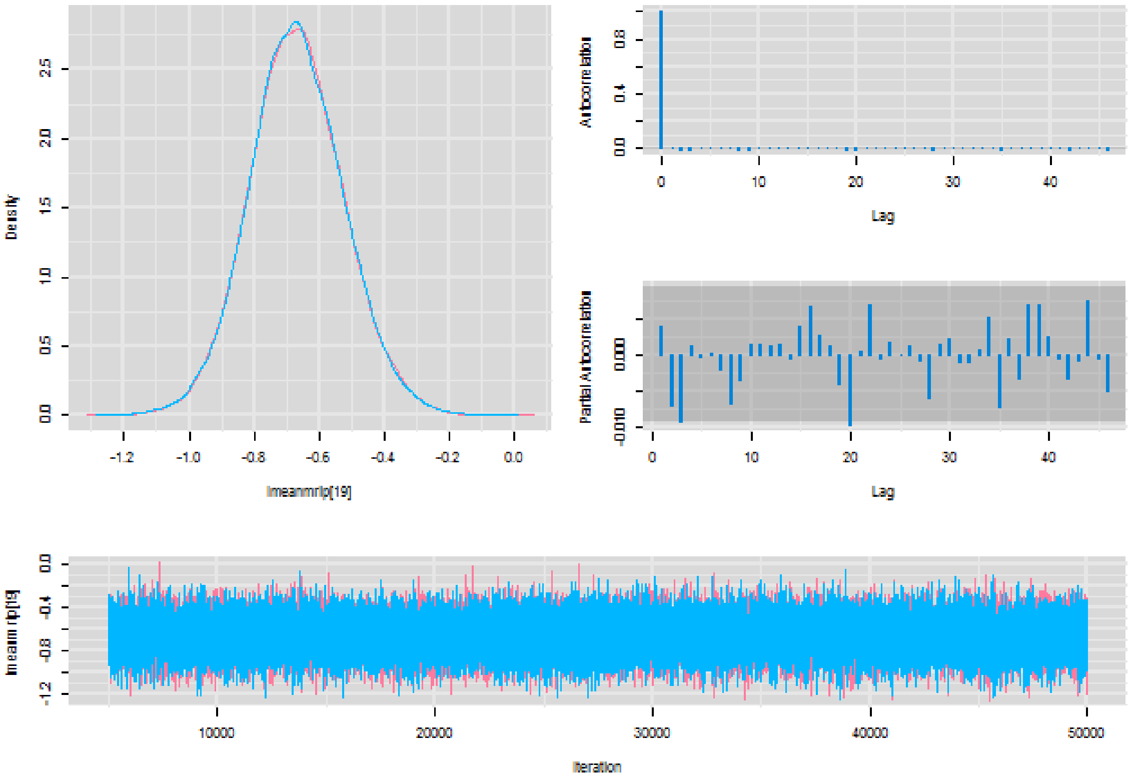
Diagnostics for lmeanmrip[17]



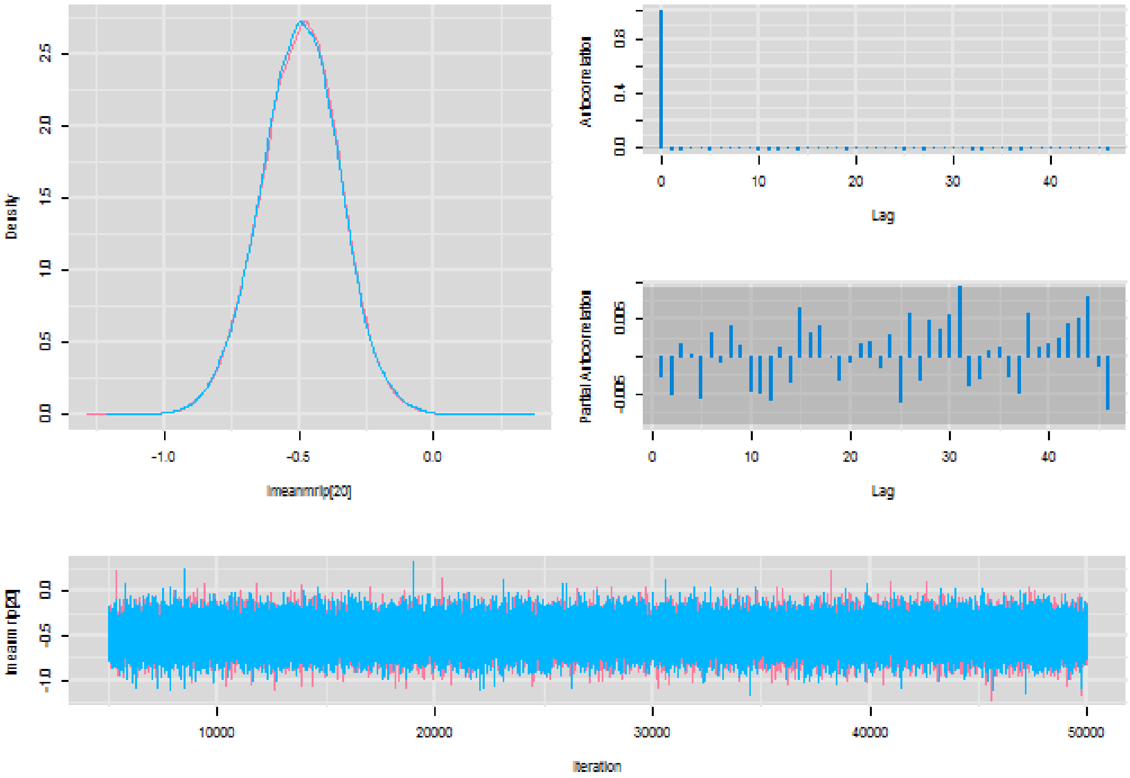
Diagnostics for lmeanmrip[18]



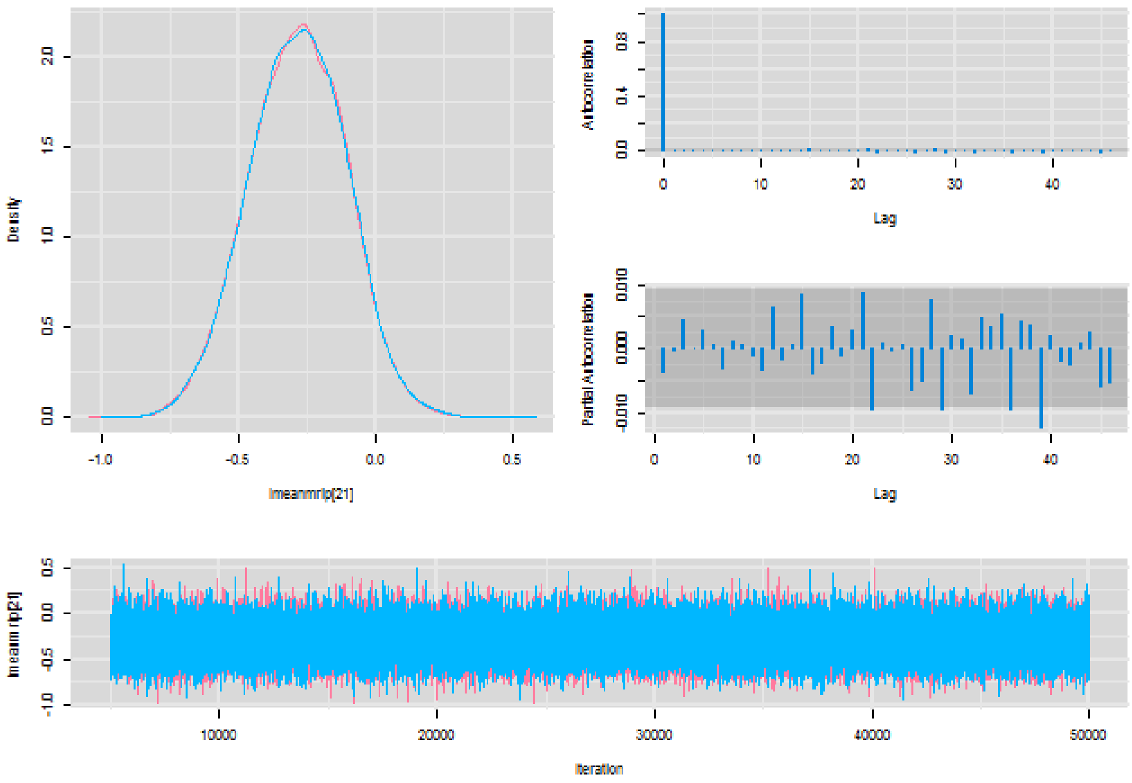
Diagnostics for lmeanmrip[19]



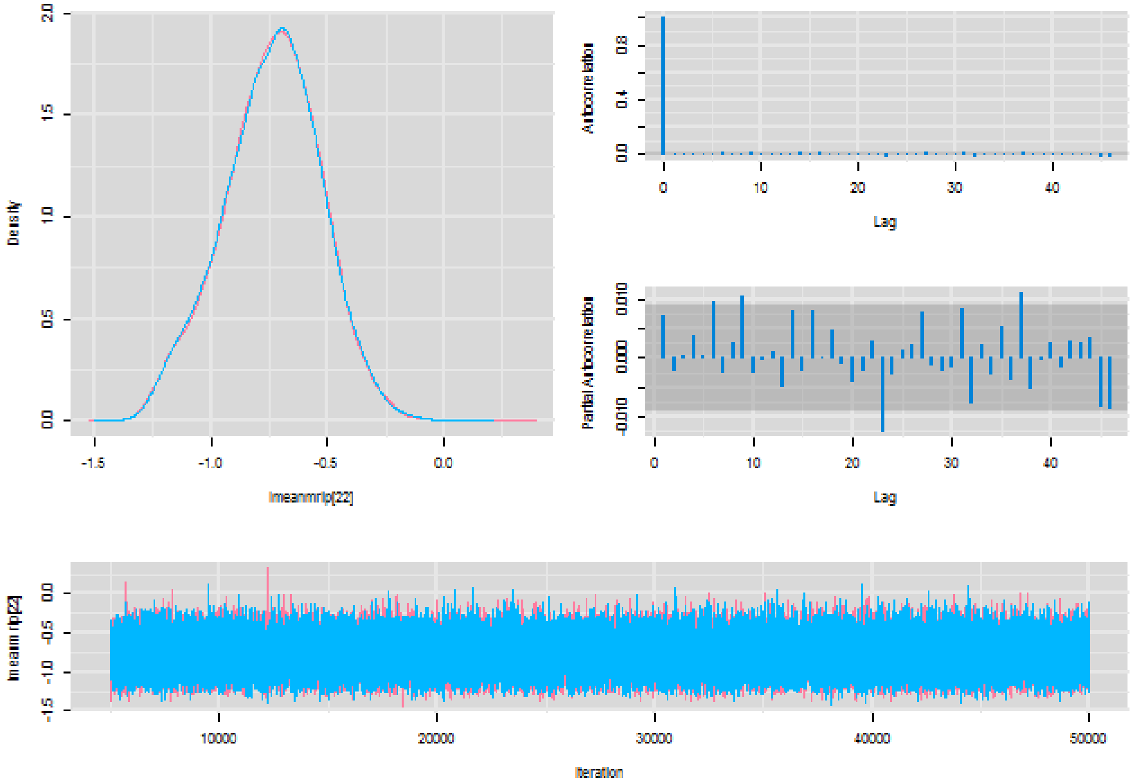
Diagnostics for lmeanmrip[20]



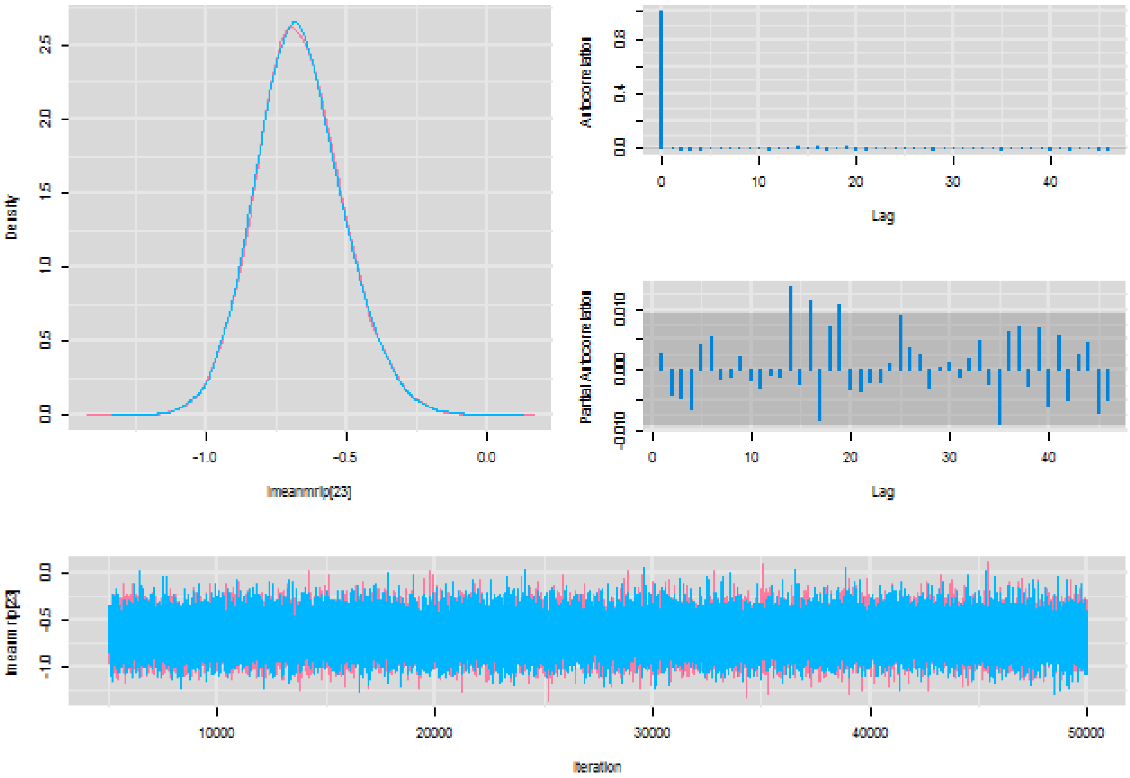
Diagnostics for lmeanmrip[21]



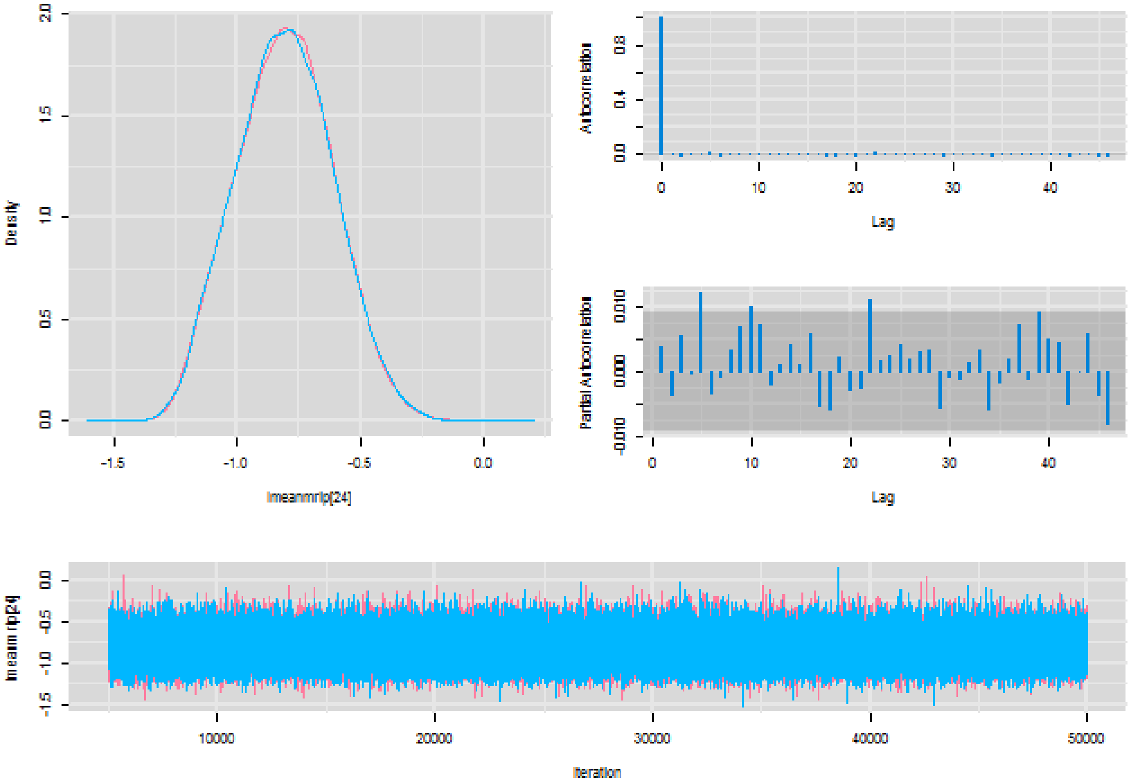
Diagnostics for lmeanmrip[22]



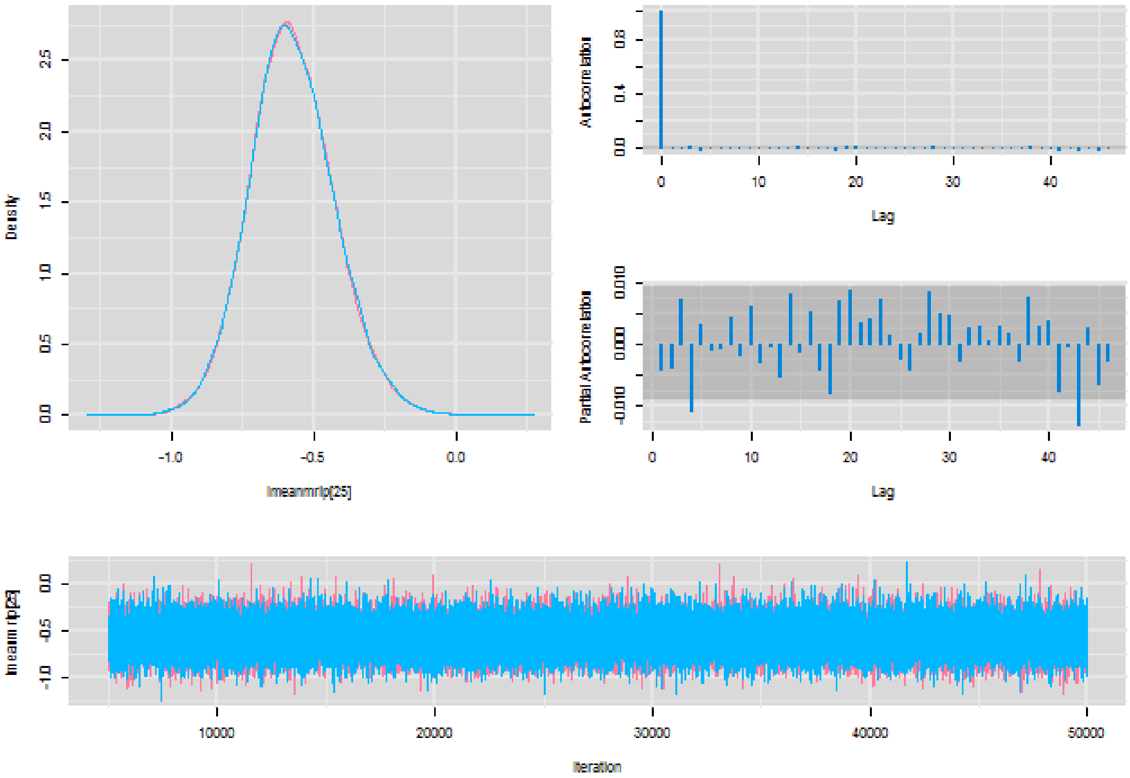
Diagnostics for lmeanmrip[23]



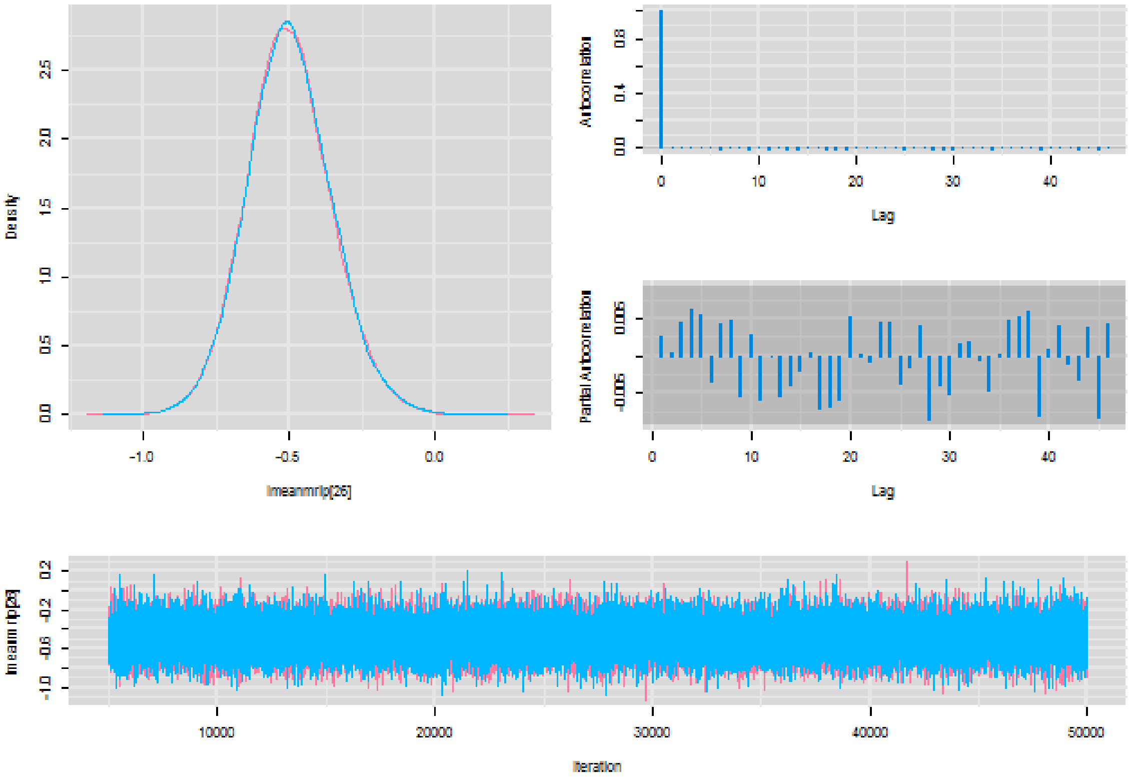
Diagnostics for lmeanmrip[24]



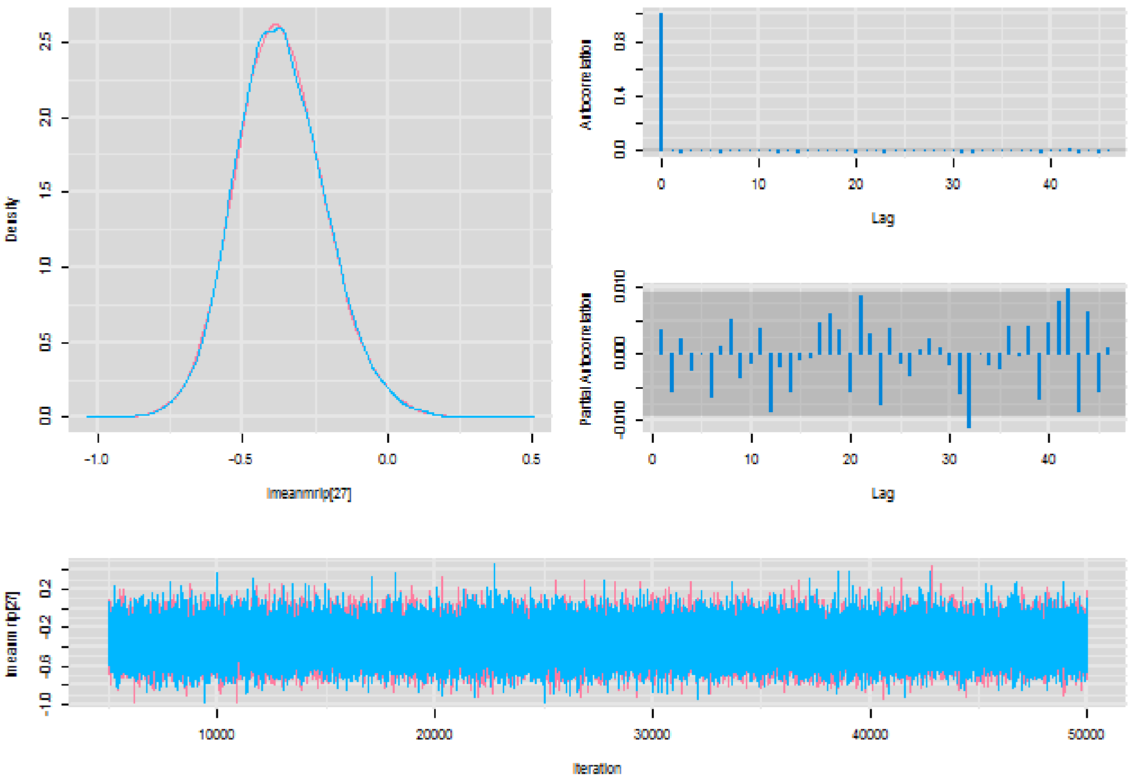
Diagnostics for lmeanmrip[25]



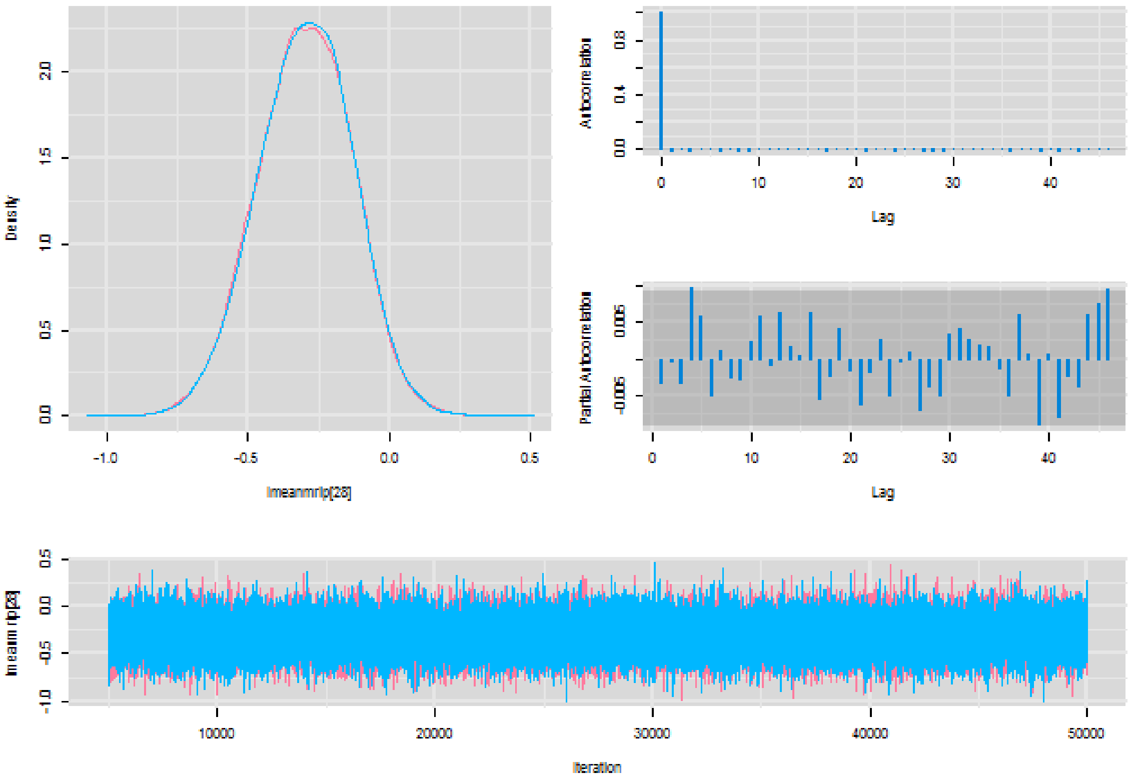
Diagnostics for lmeanmrip[26]



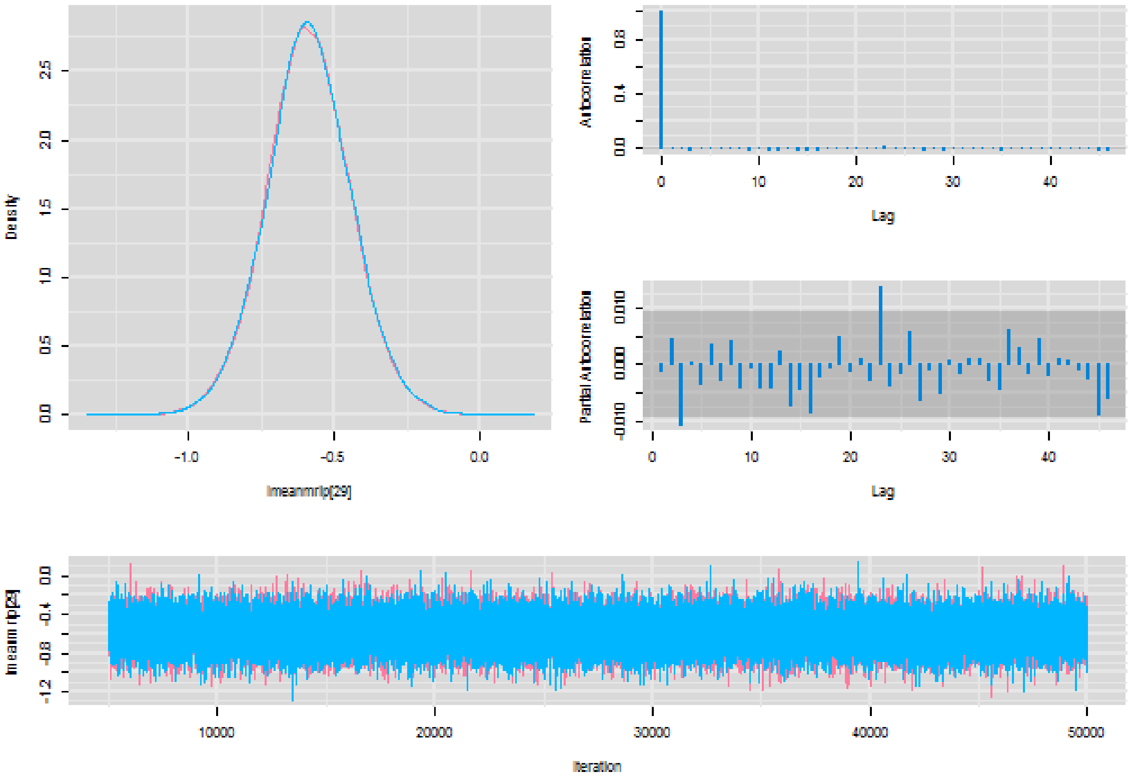
Diagnostics for lmeanmrip[27]



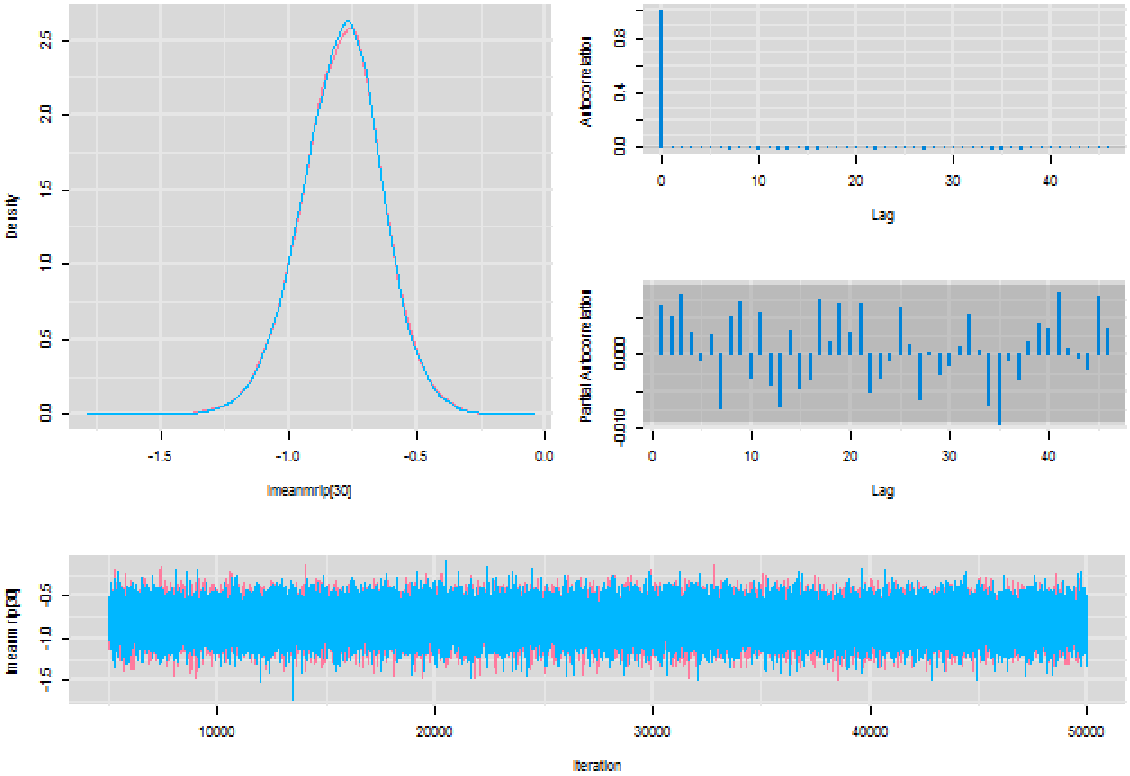
Diagnostics for lmeanmrip[28]



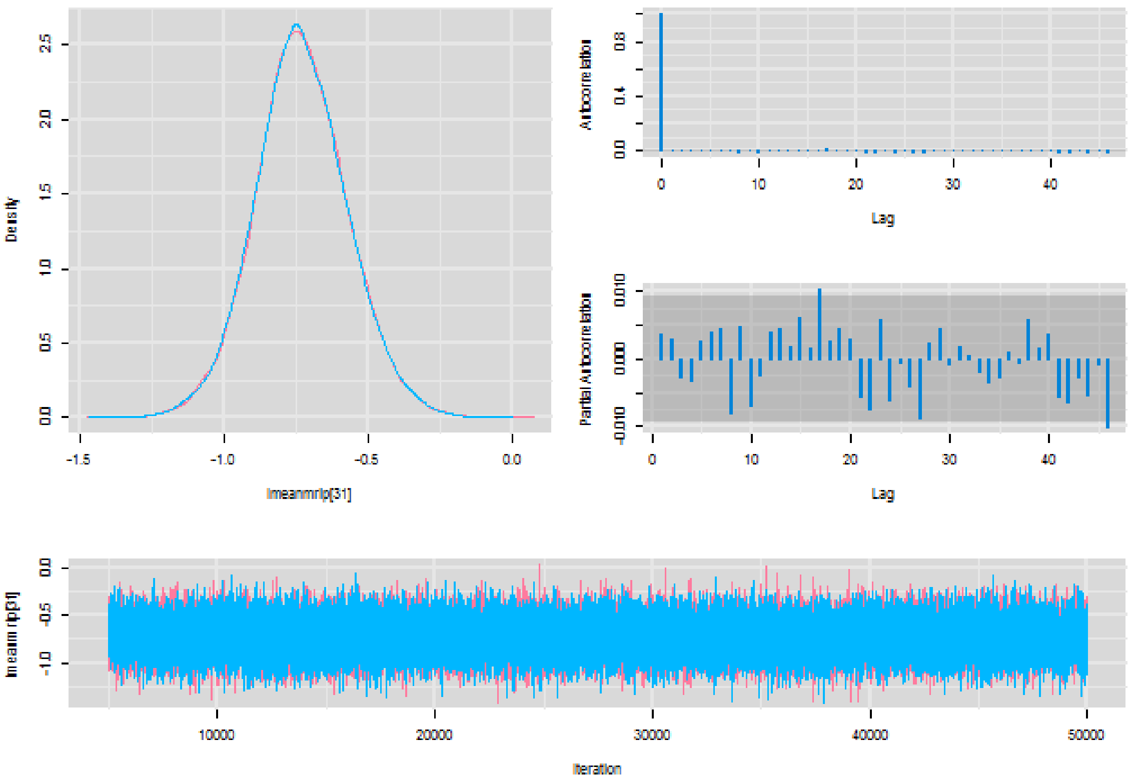
Diagnostics for lmeanmrip[29]



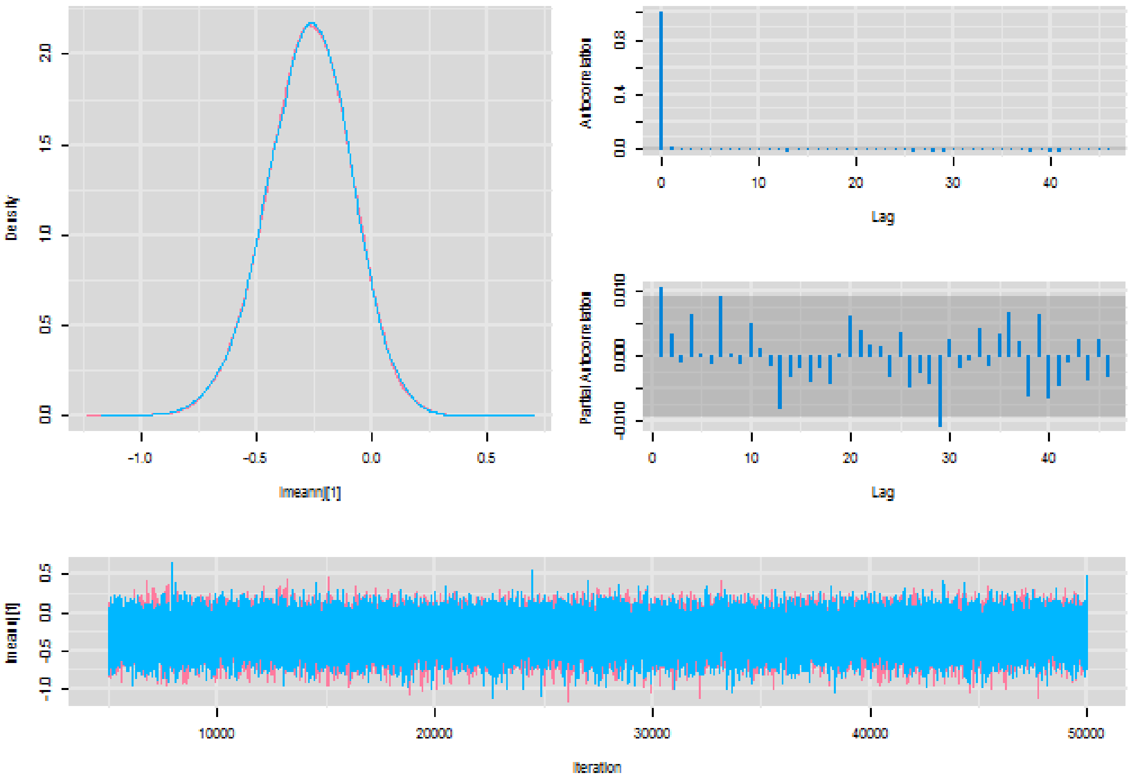
Diagnostics for lmeanmrip[30]



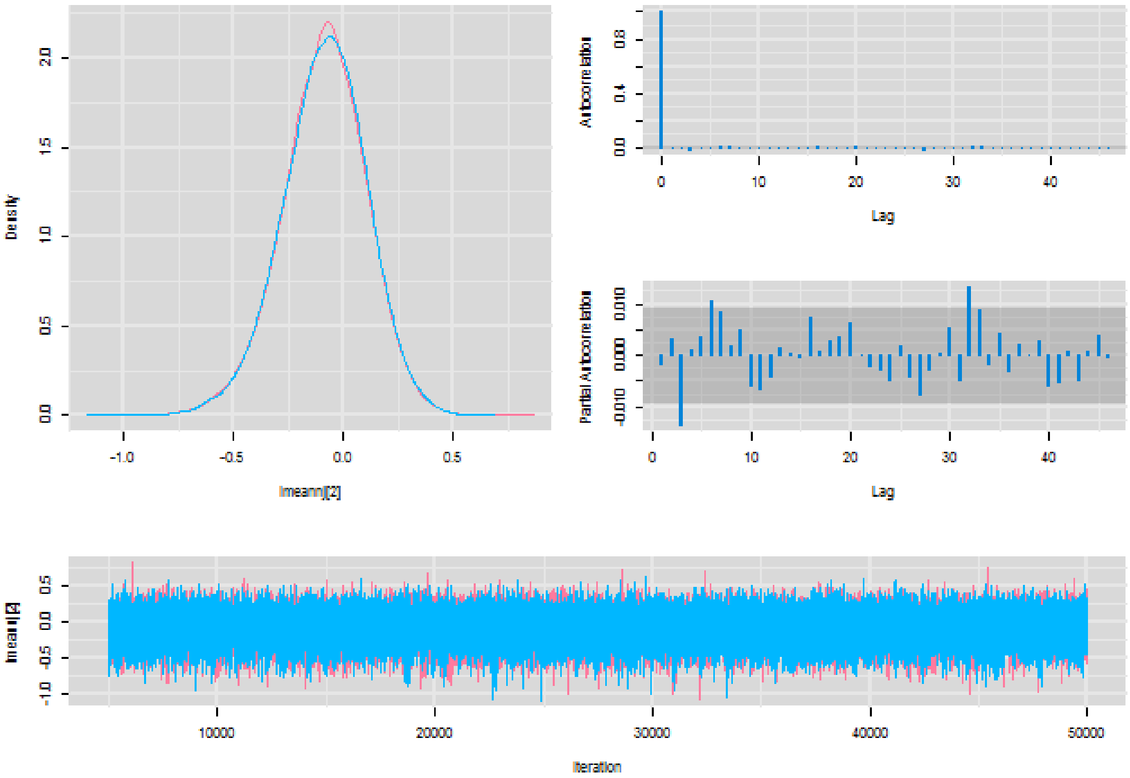
Diagnostics for lmeanmrip[31]



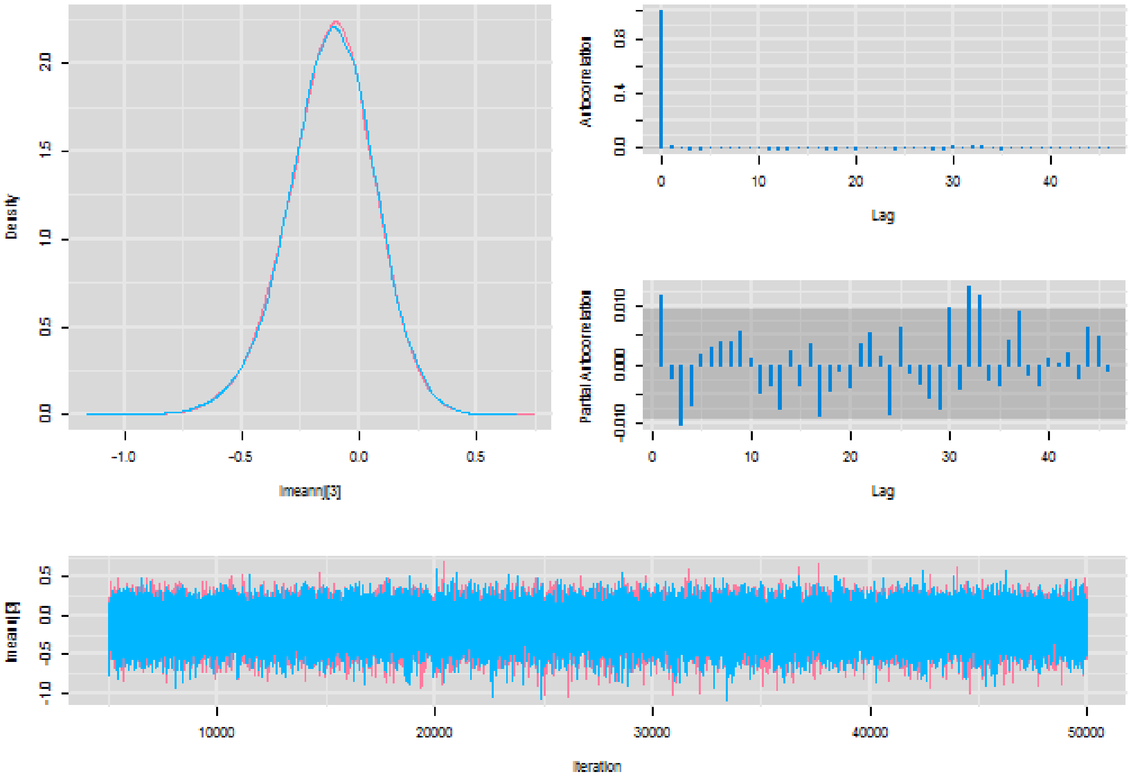
Diagnostics for lmeannj[1]



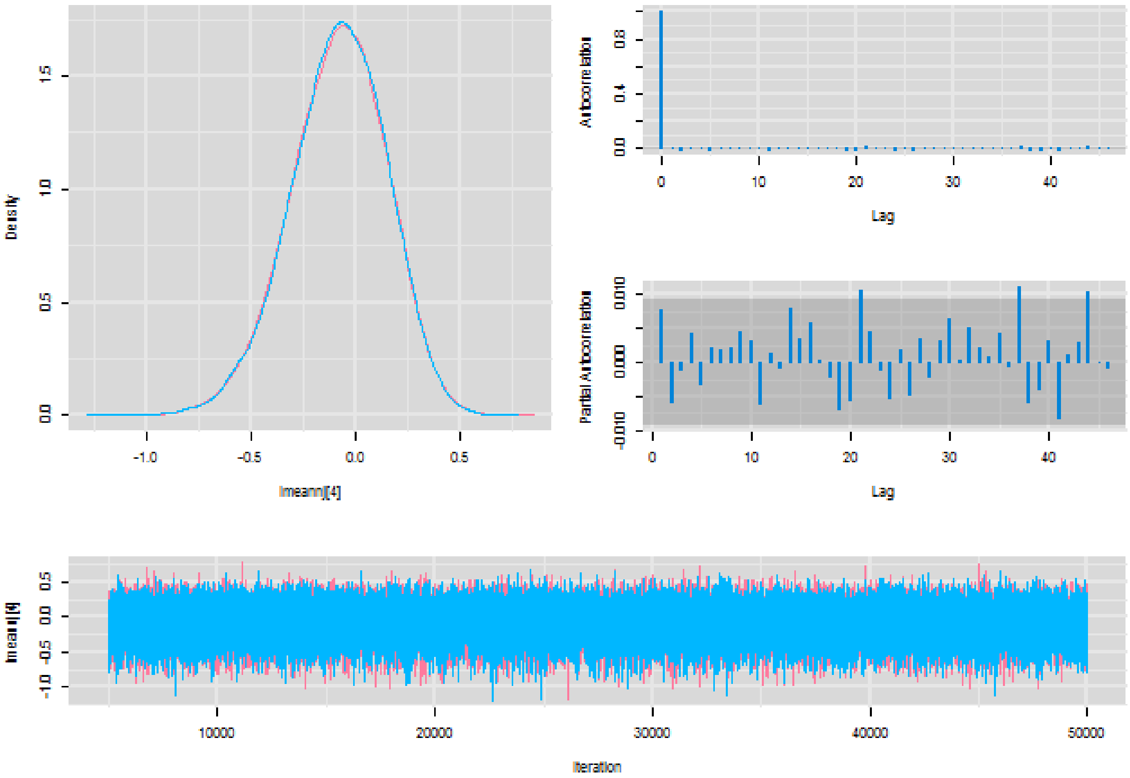
Diagnostics for lmeannj[2]



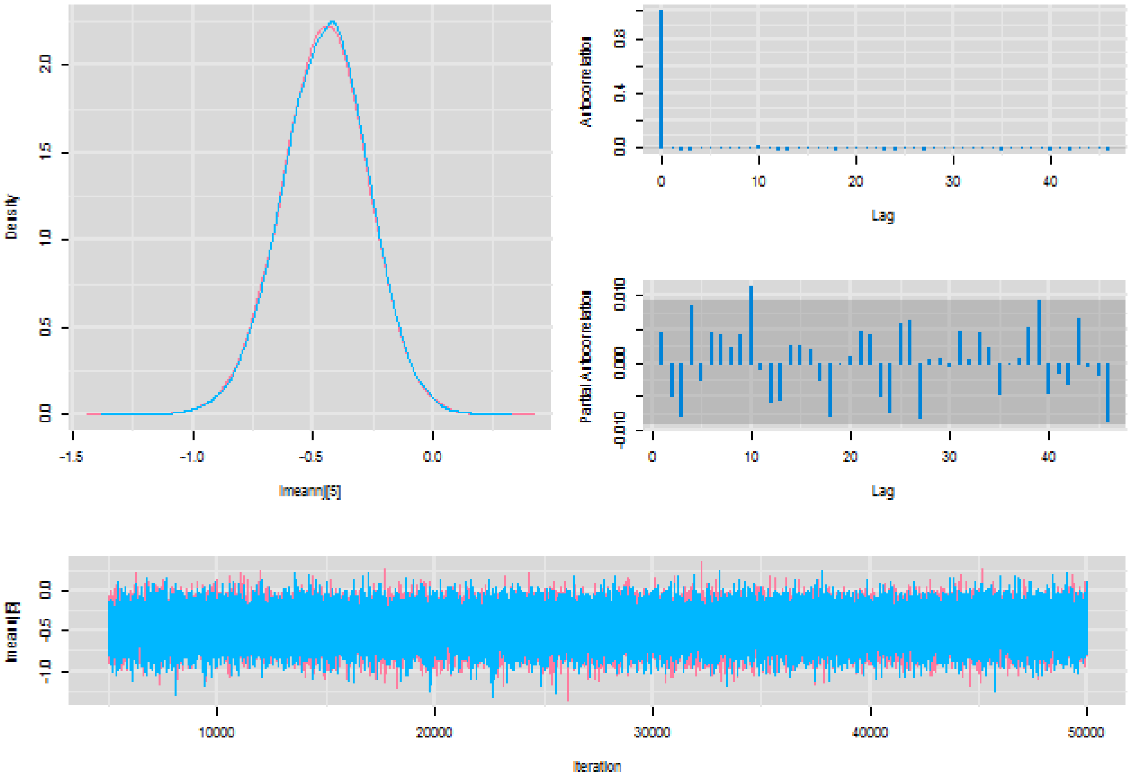
Diagnostics for lmeannj[3]



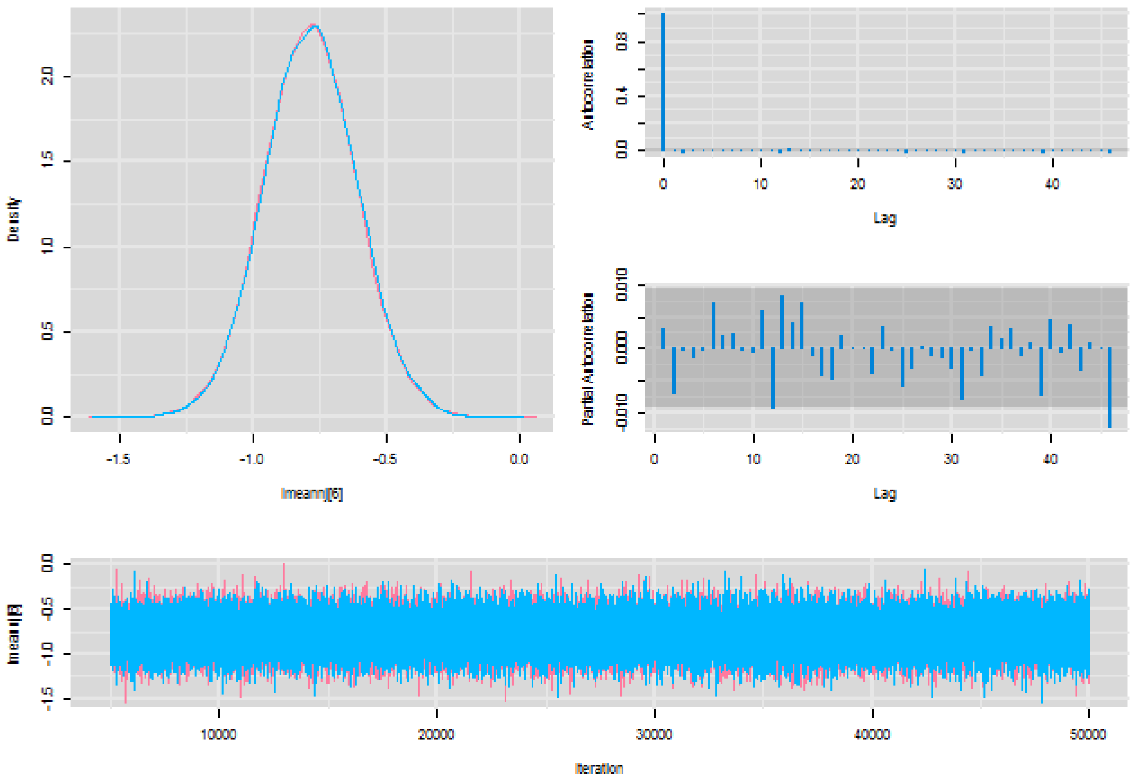
Diagnostics for lmeannj[4]



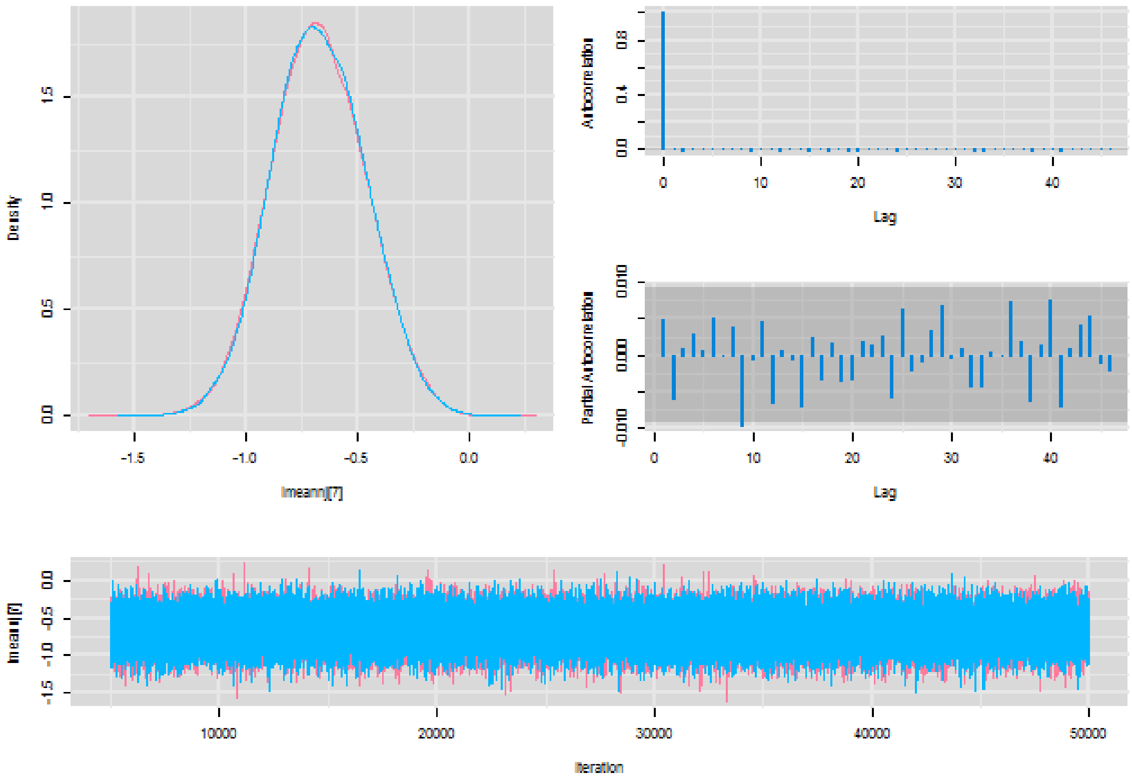
Diagnostics for lmeannj[5]



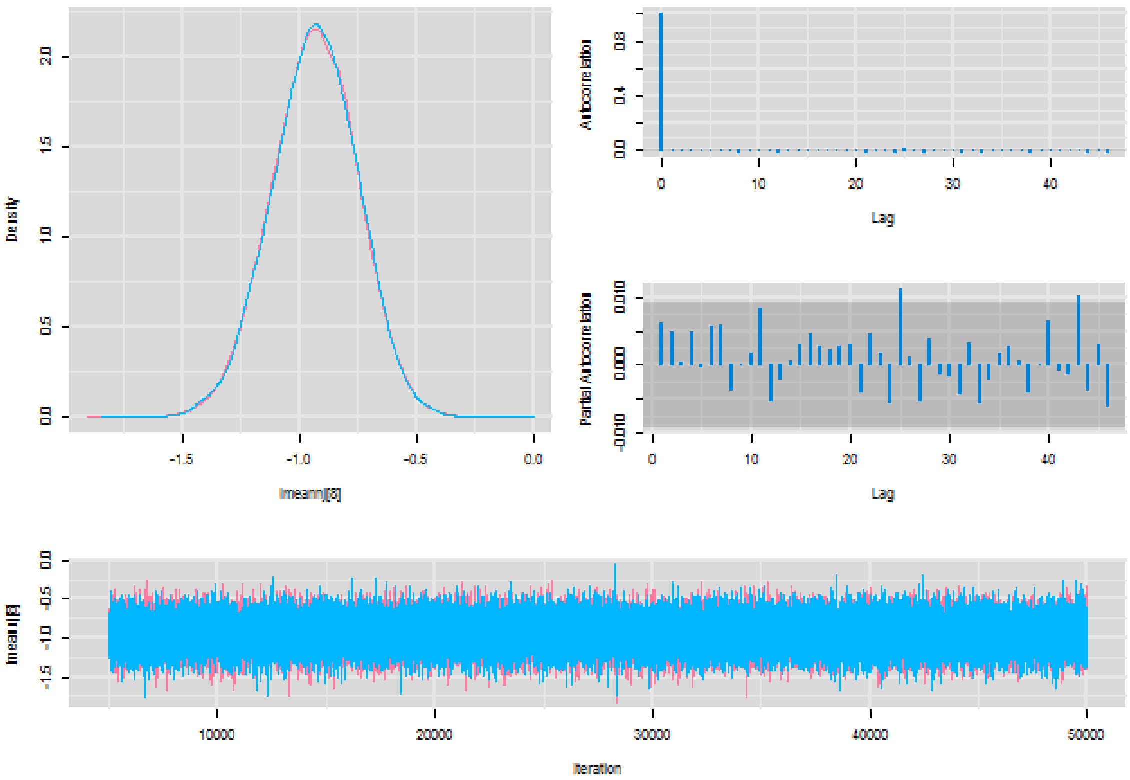
Diagnostics for lmeannj[6]



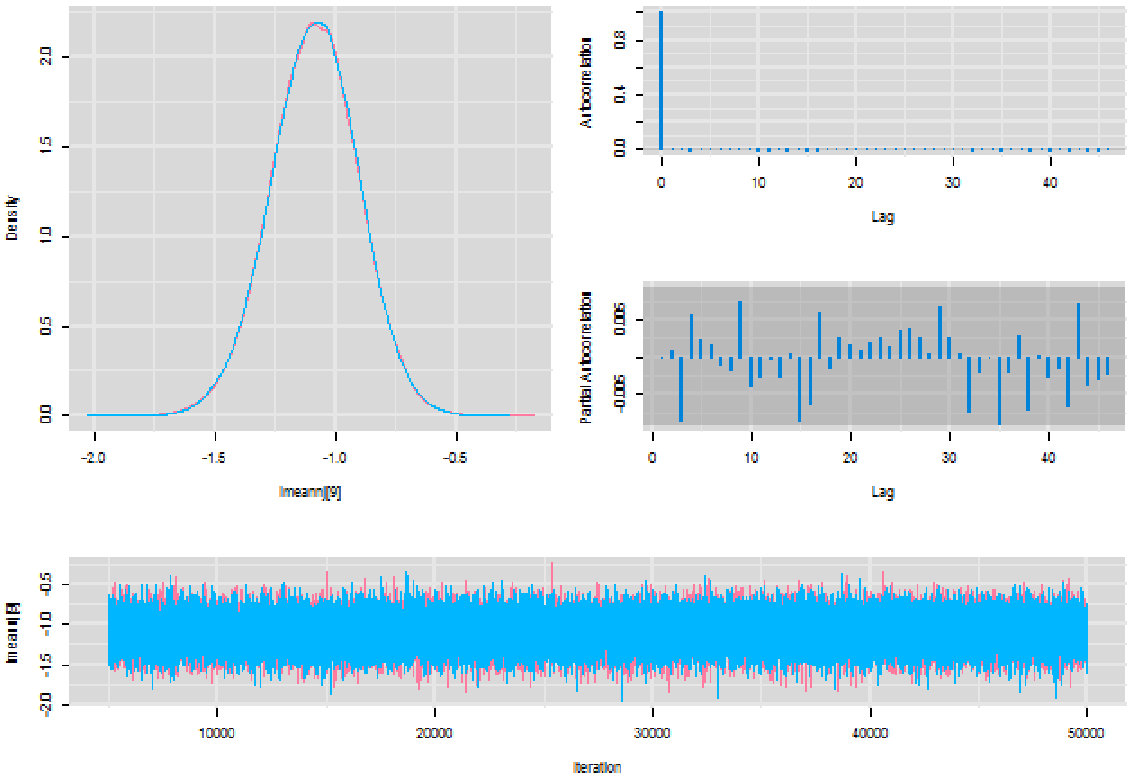
Diagnostics for lmeannj[7]



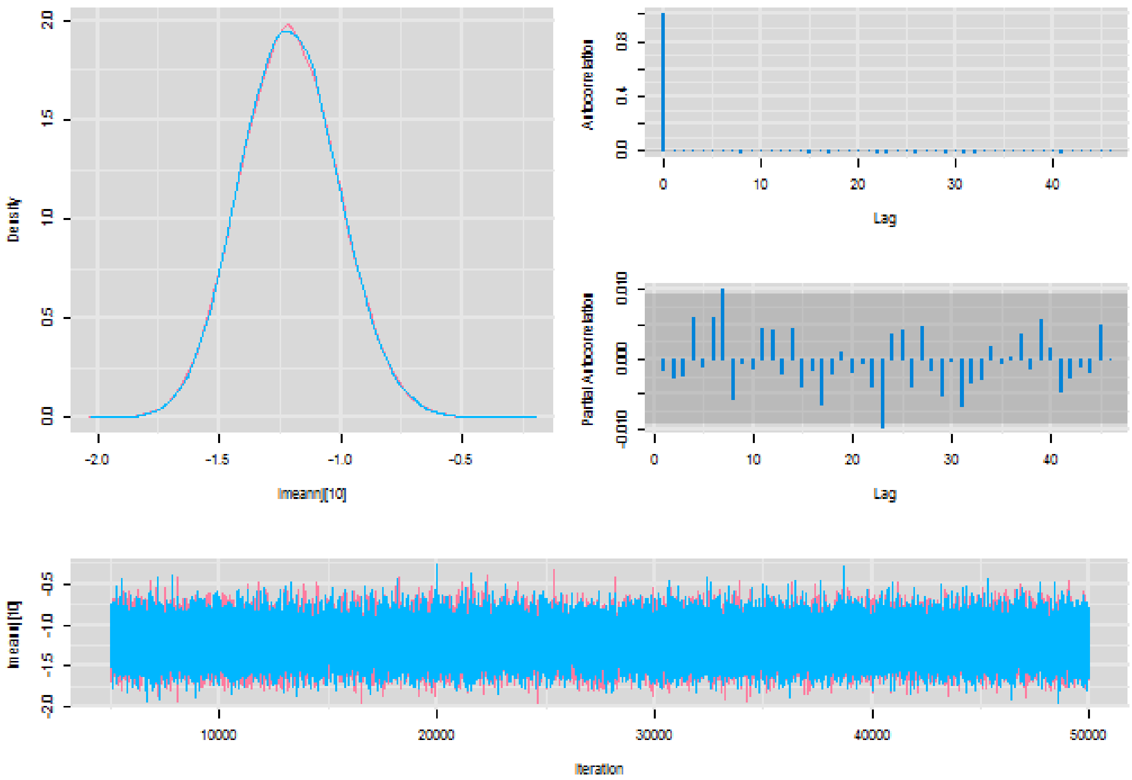
Diagnostics for lmeannj[8]



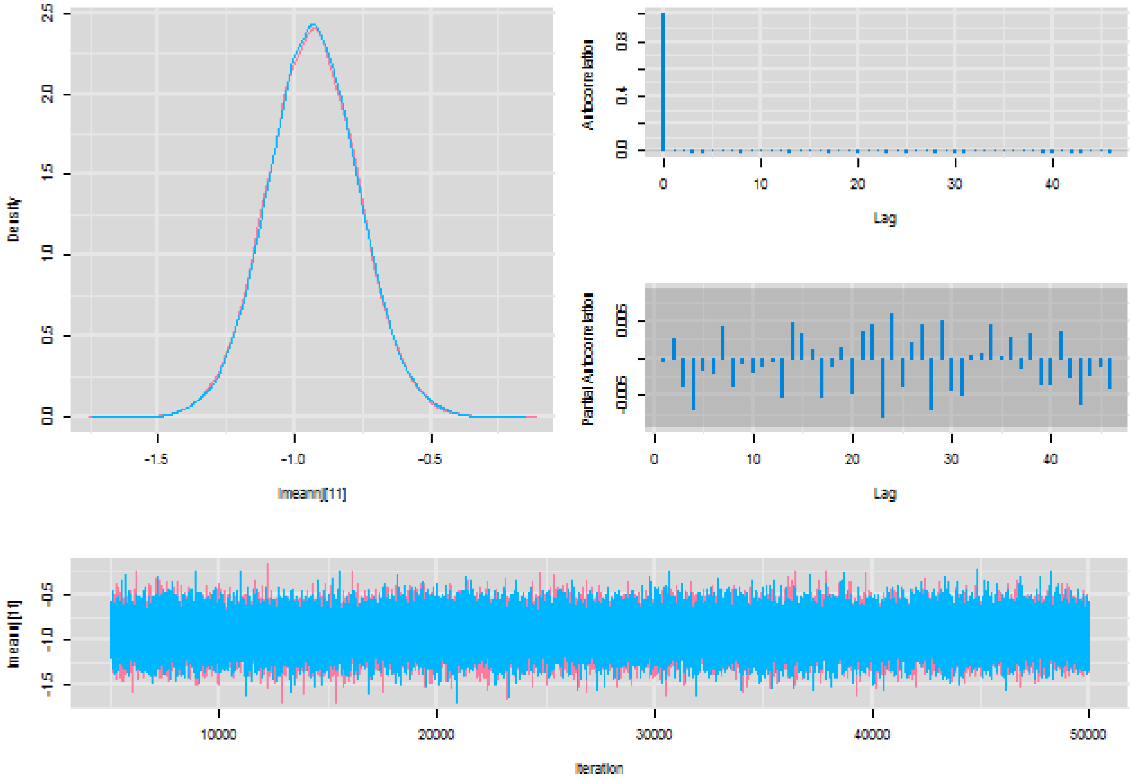
Diagnostics for lmeannj[9]



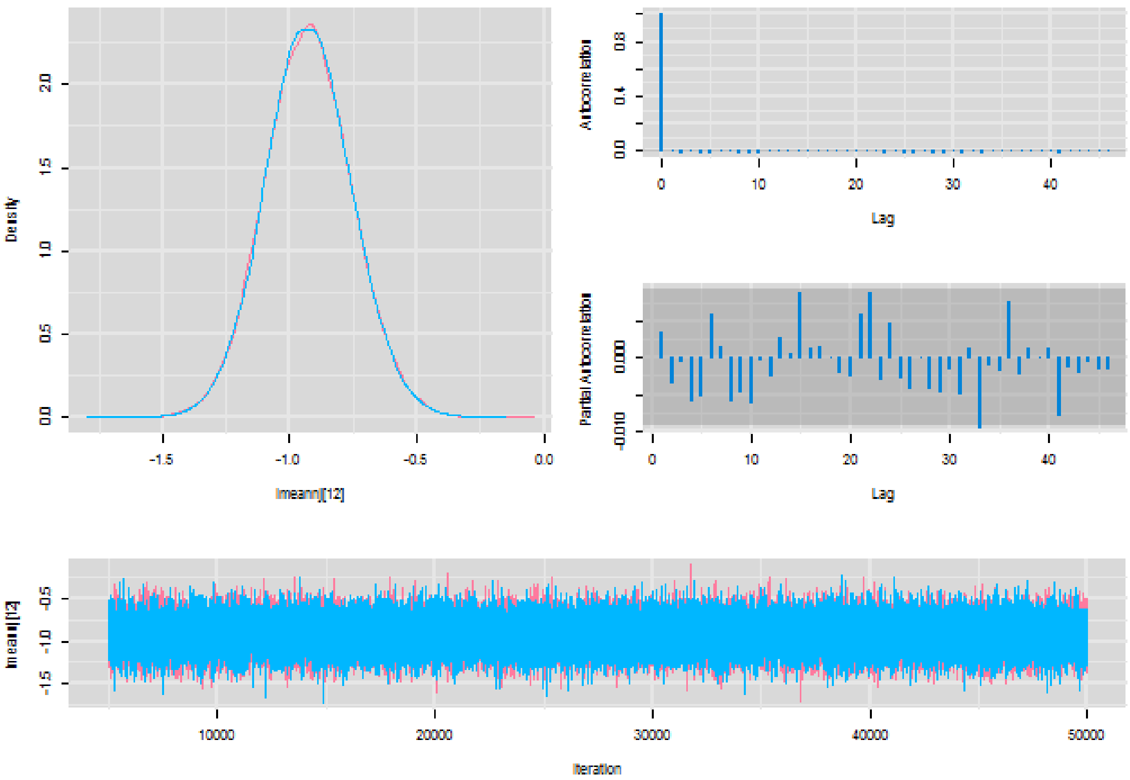
Diagnostics for lmeannj[10]



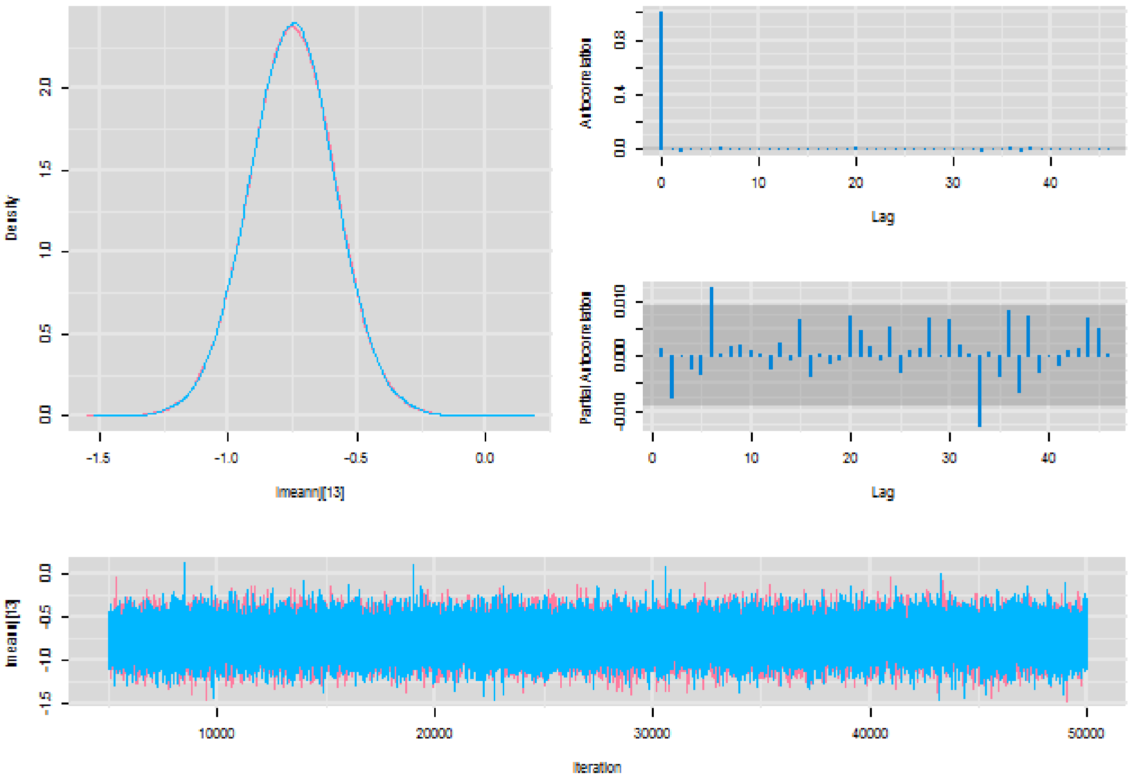
Diagnostics for lmeannj[11]



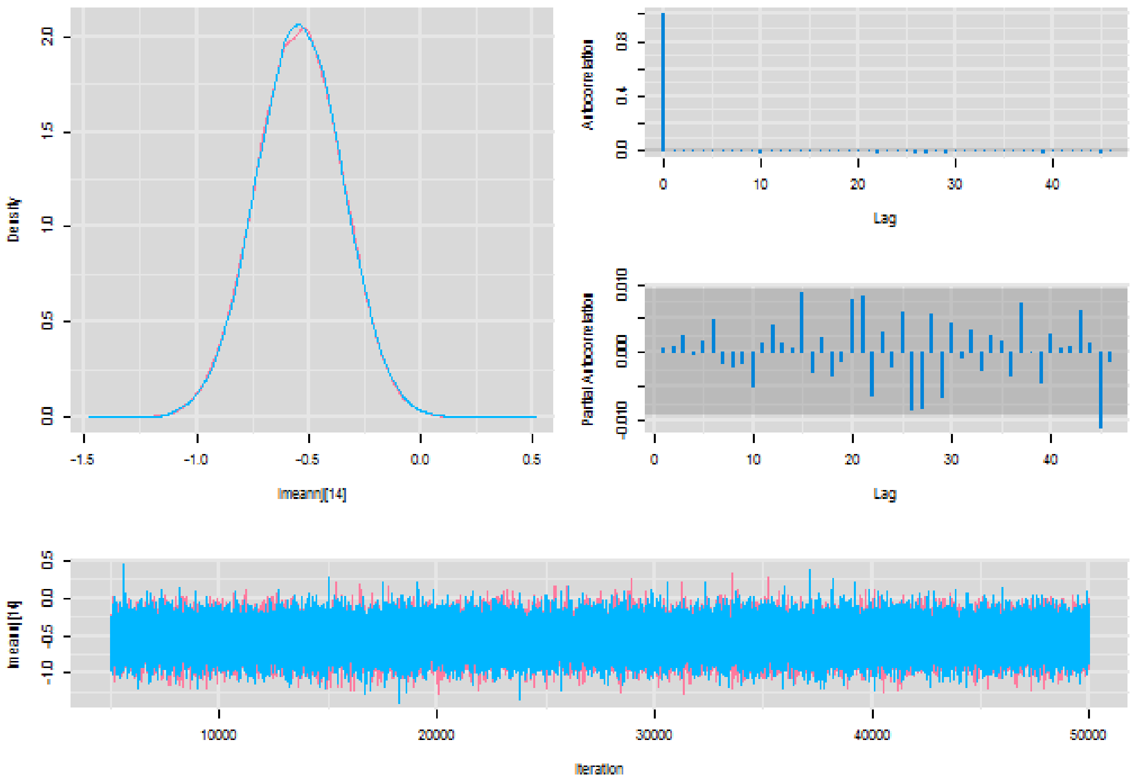
Diagnostics for lmeannj[12]



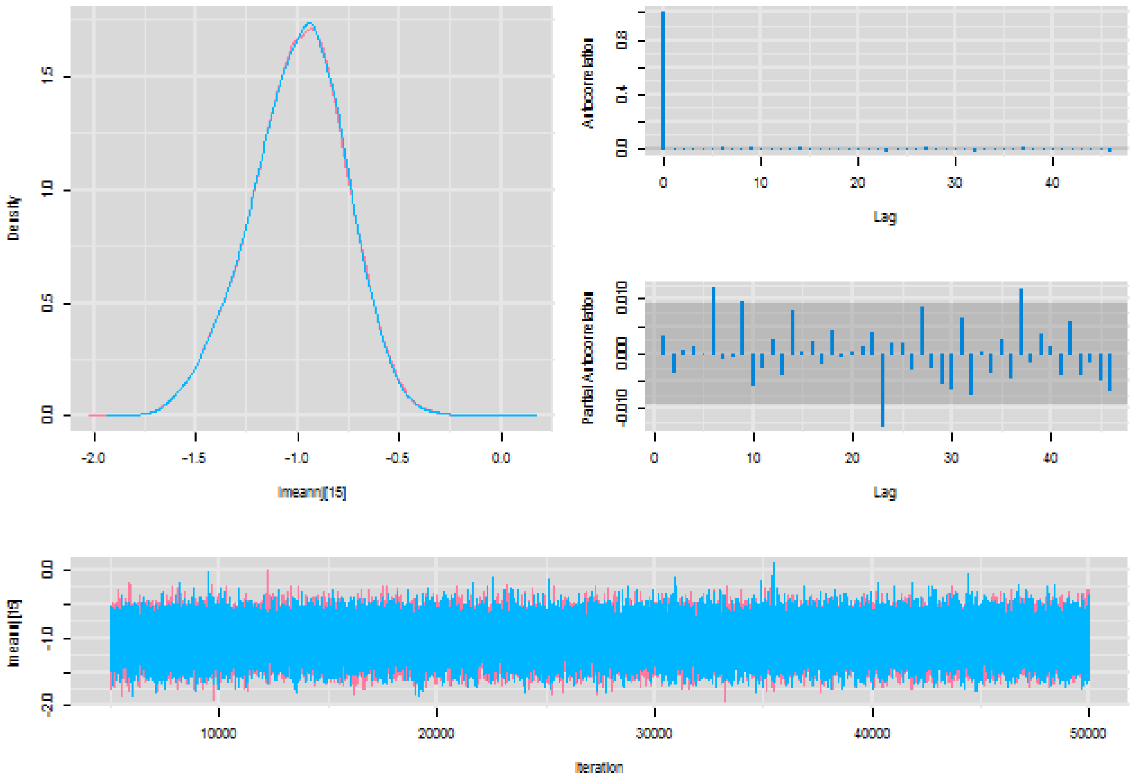
Diagnostics for lmeannj[13]



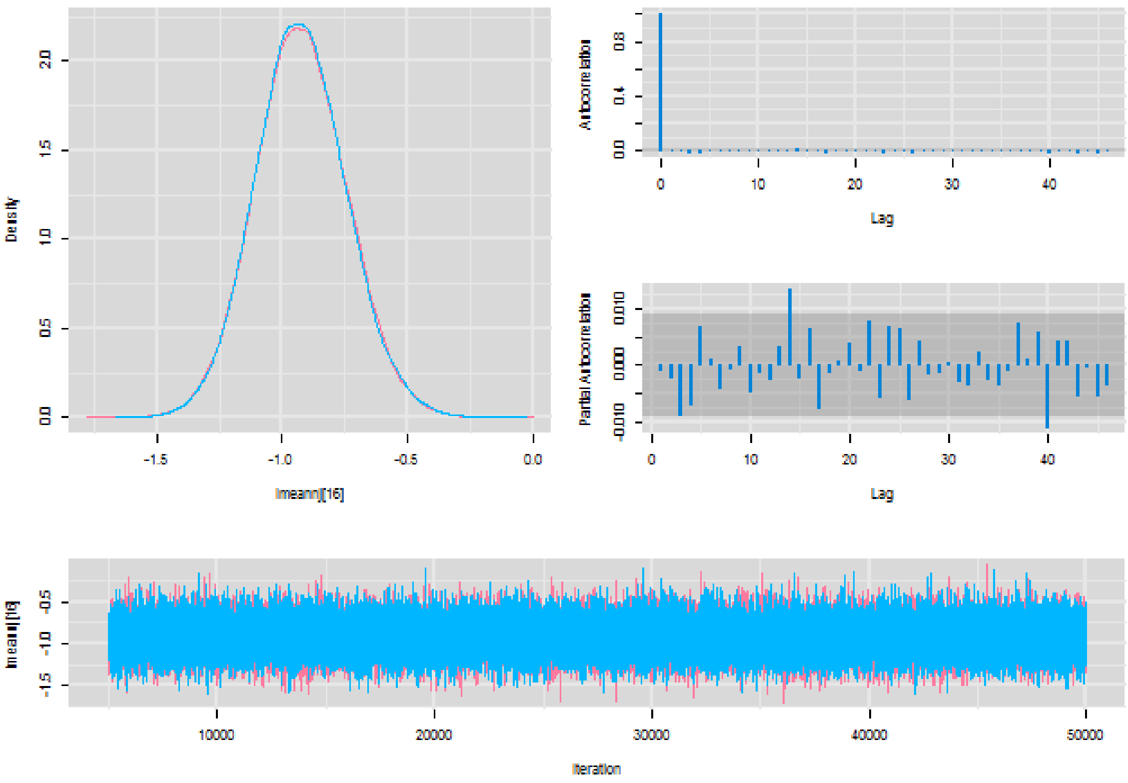
Diagnostics for lmeannj[14]



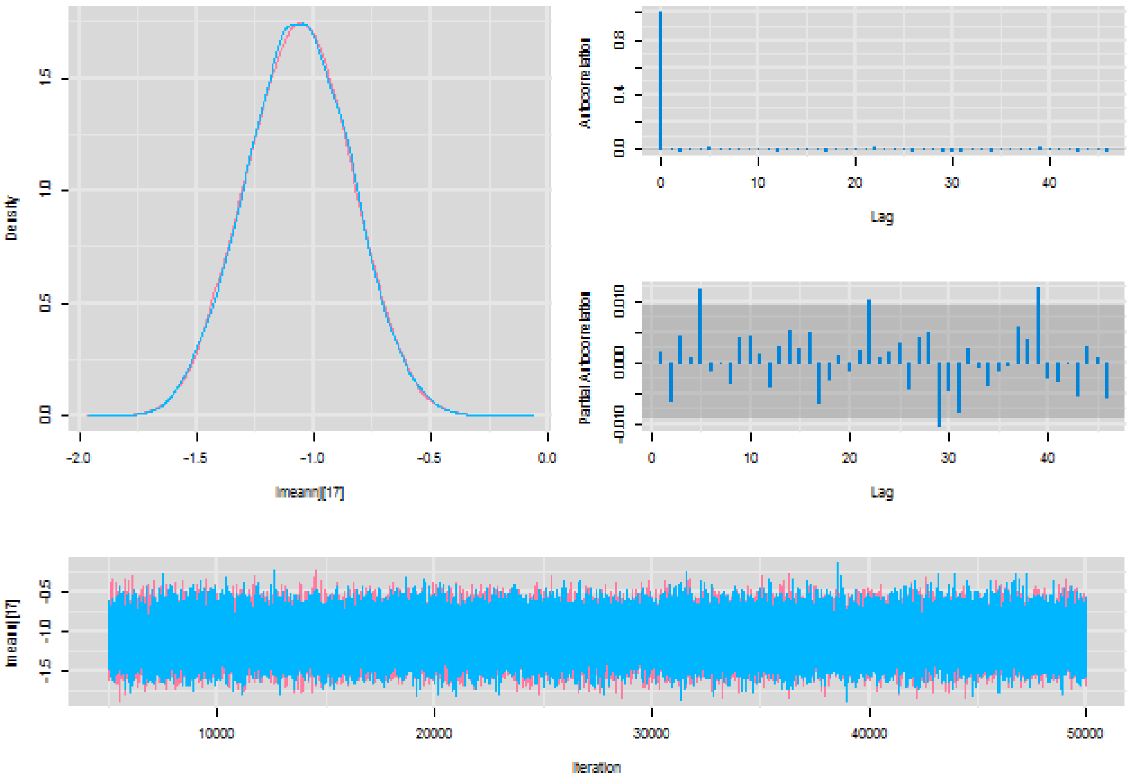
Diagnostics for lmeannj[15]



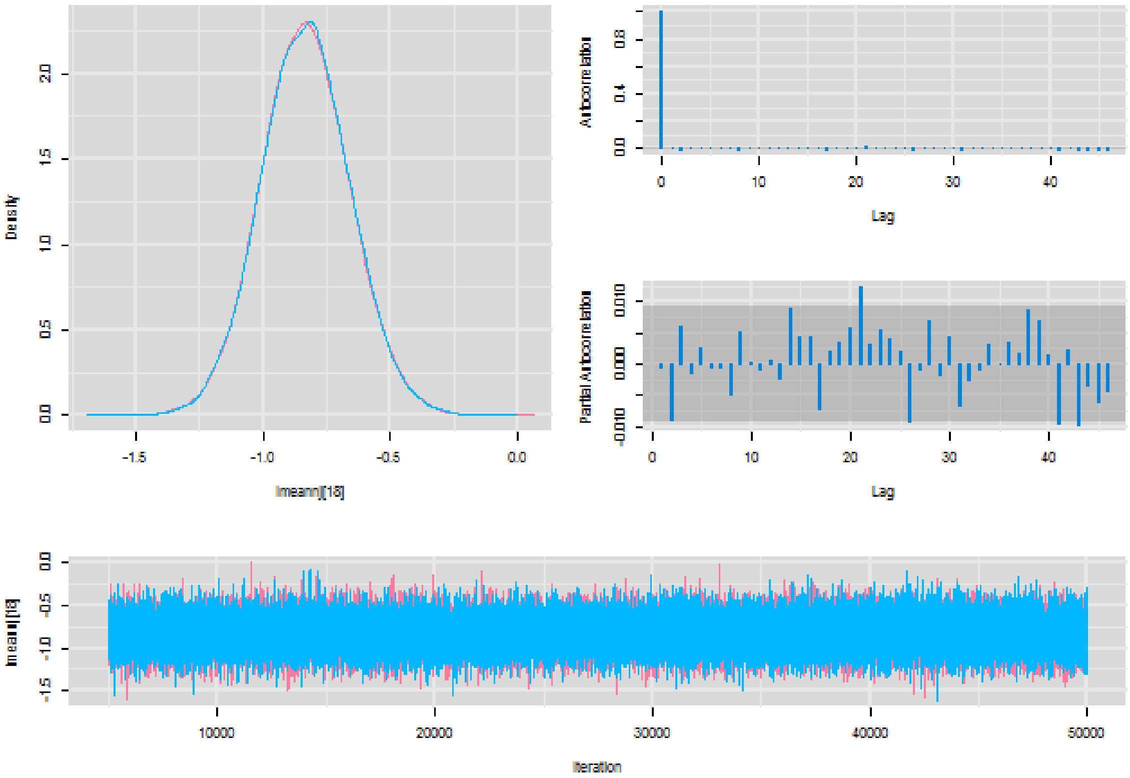
Diagnostics for lmeannj[16]



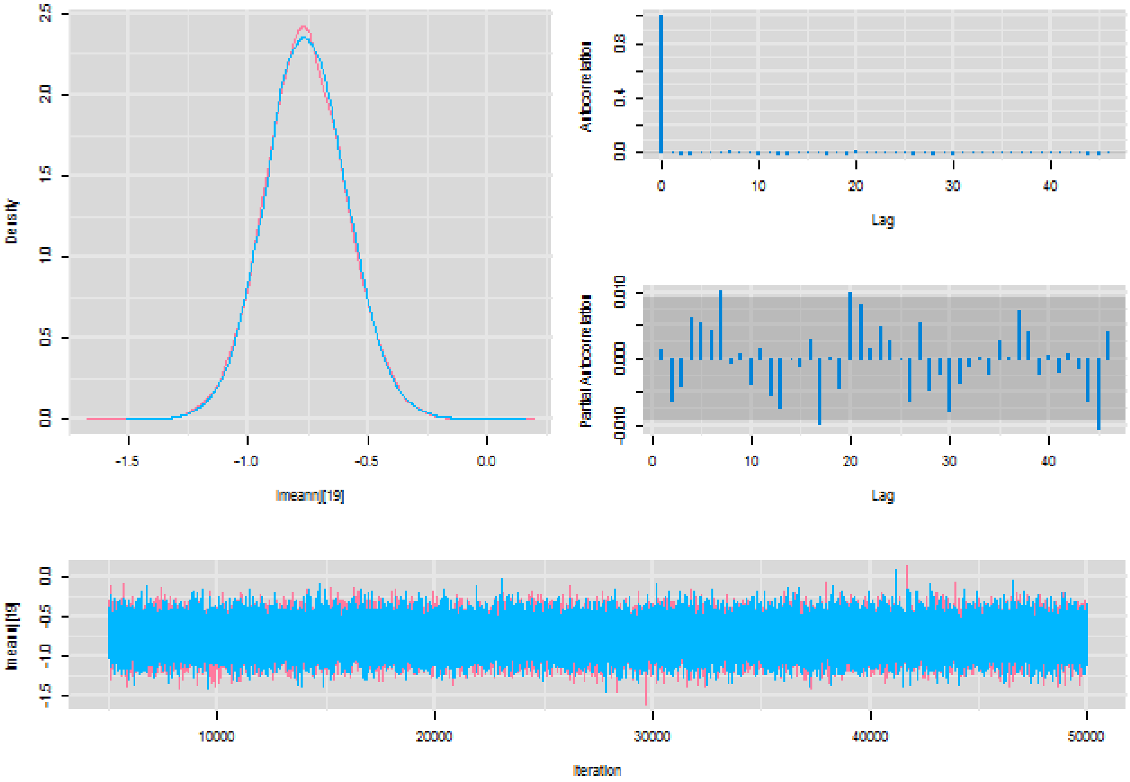
Diagnostics for lmeannj[17]



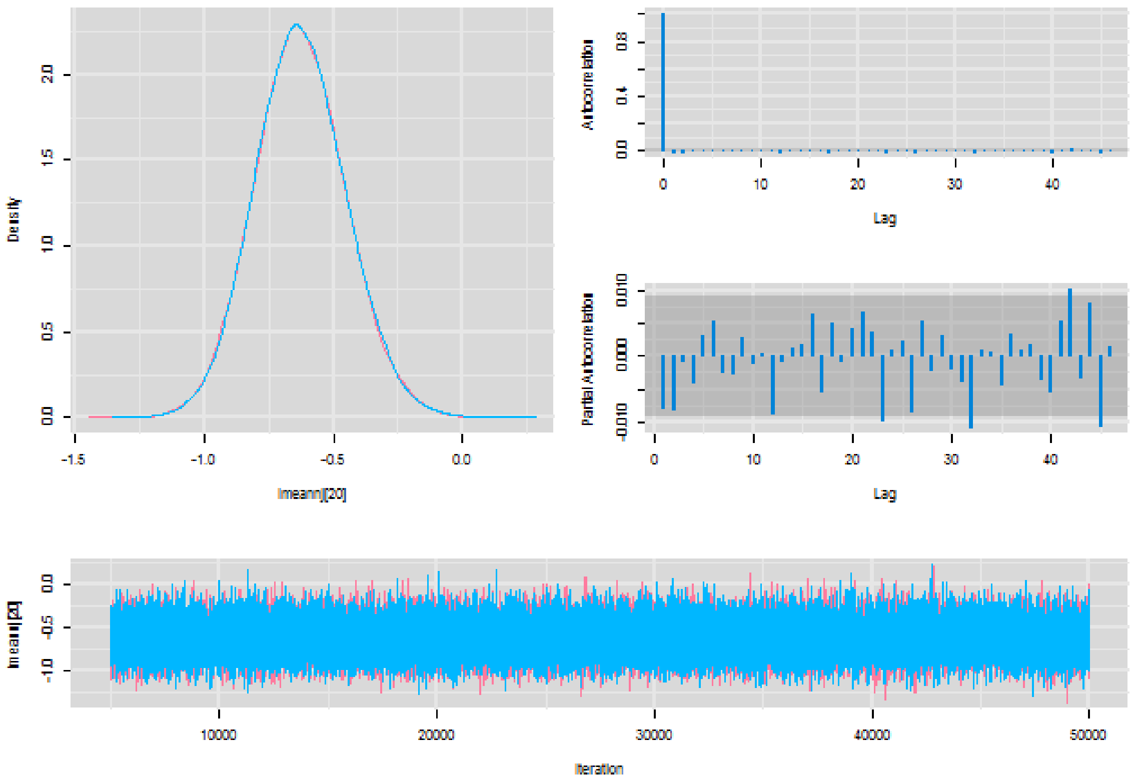
Diagnostics for lmeannj[18]



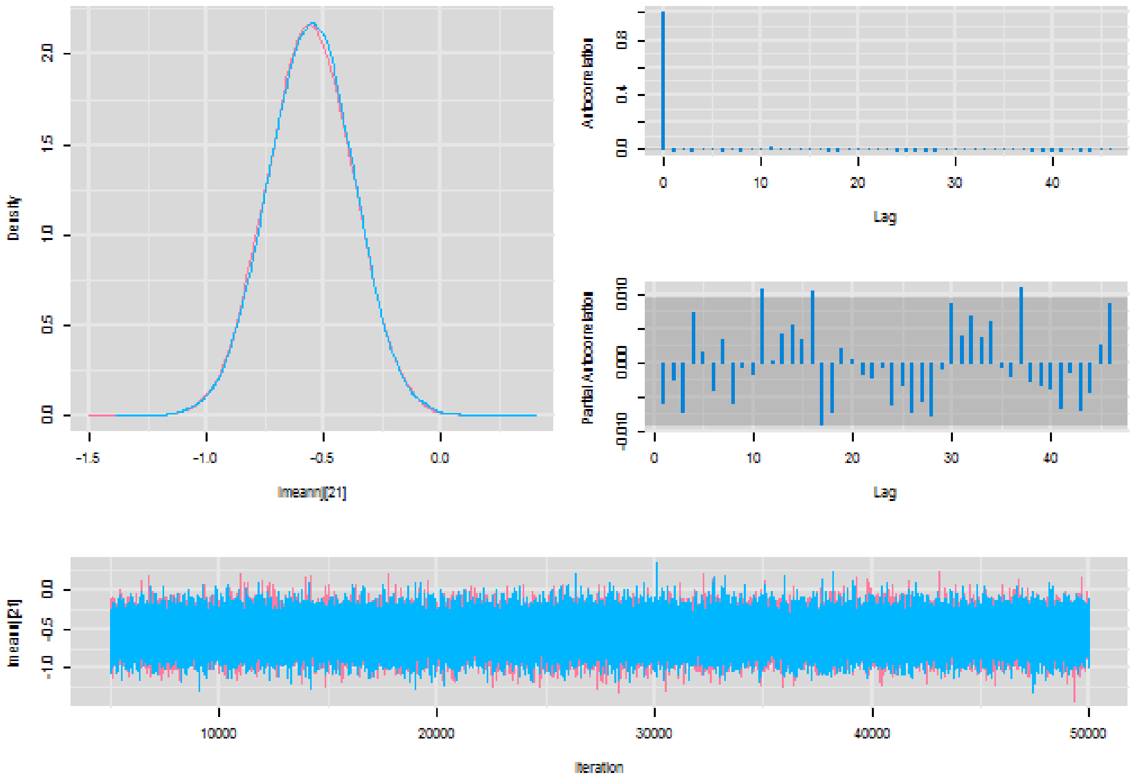
Diagnostics for lmeannj[19]



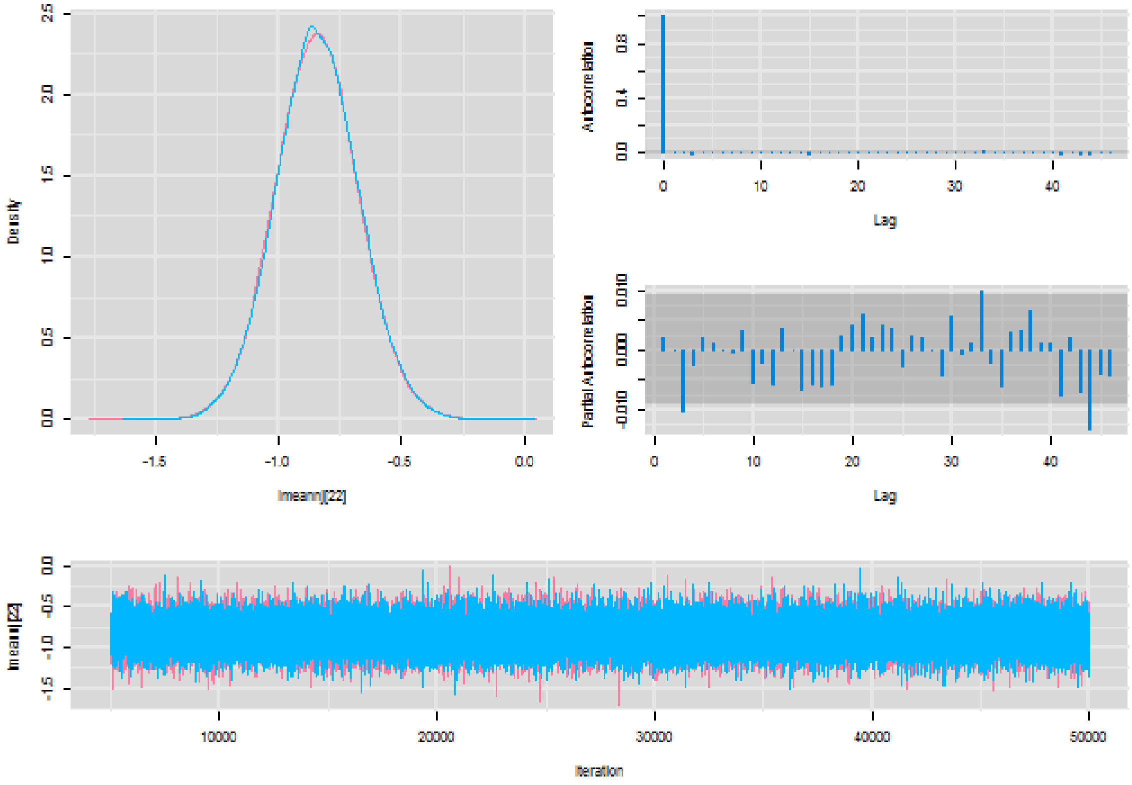
Diagnostics for lmeannj[20]



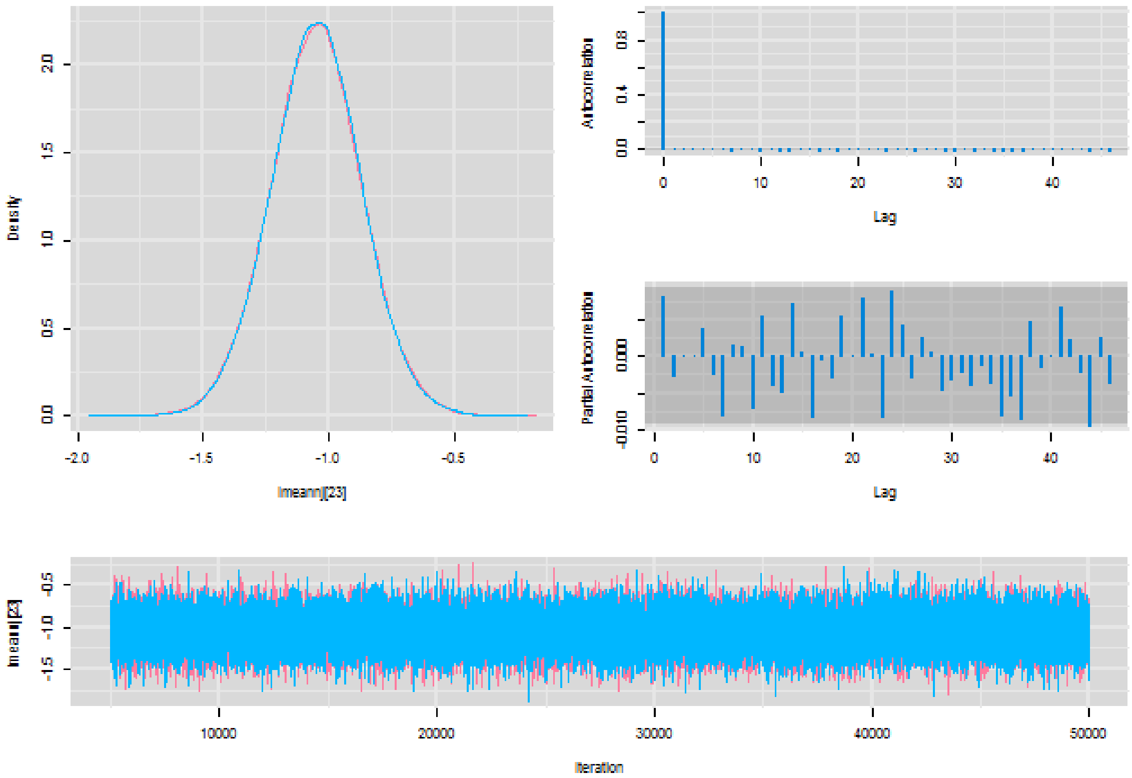
Diagnostics for lmeannj[21]



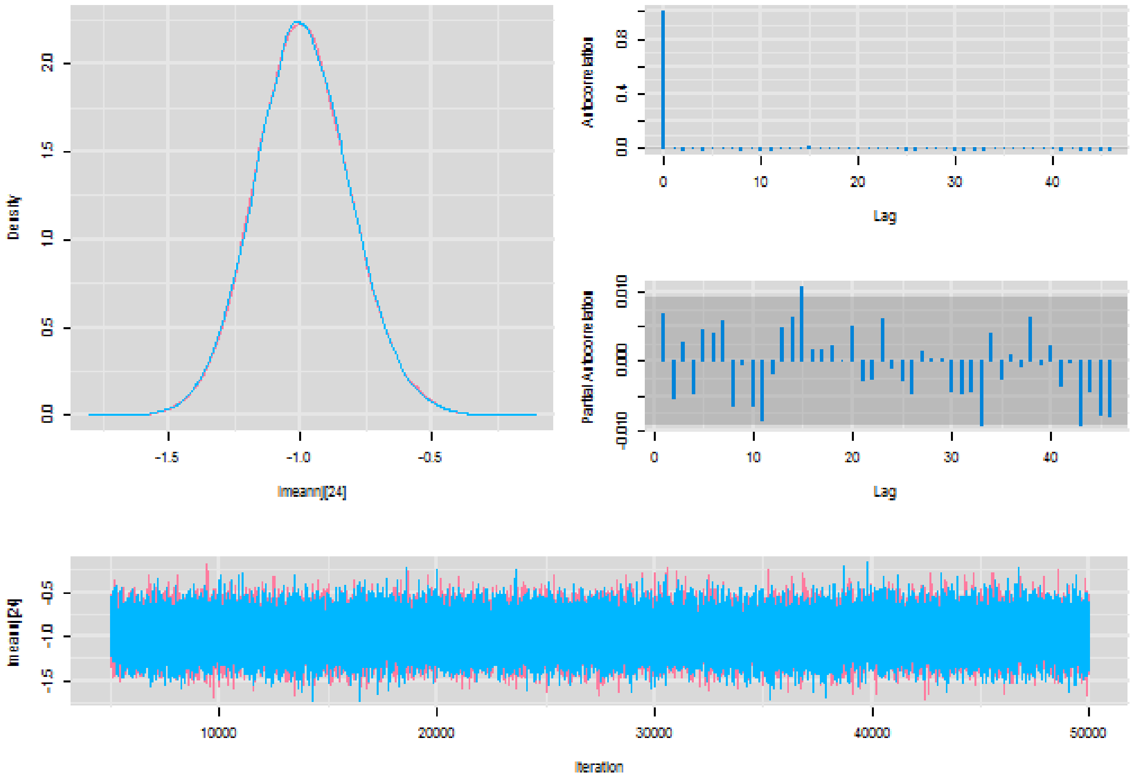
Diagnostics for lmeannj[22]



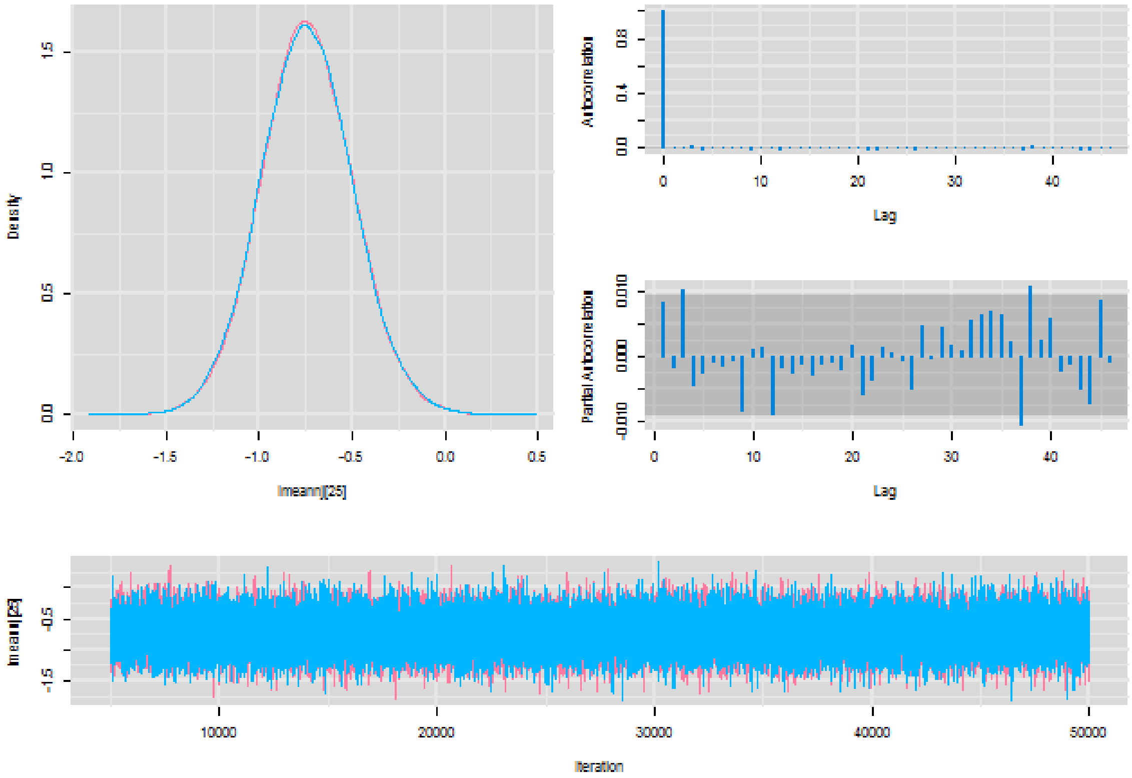
Diagnostics for lmeannj[23]



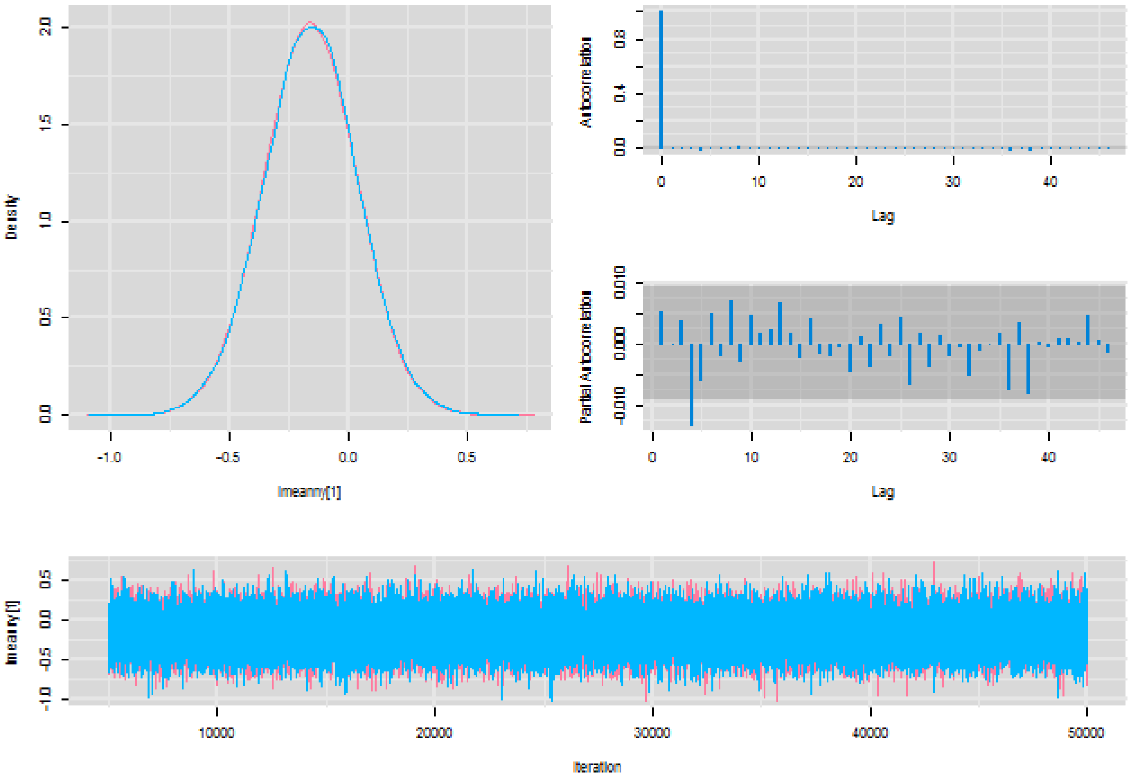
Diagnostics for lmeannj[24]



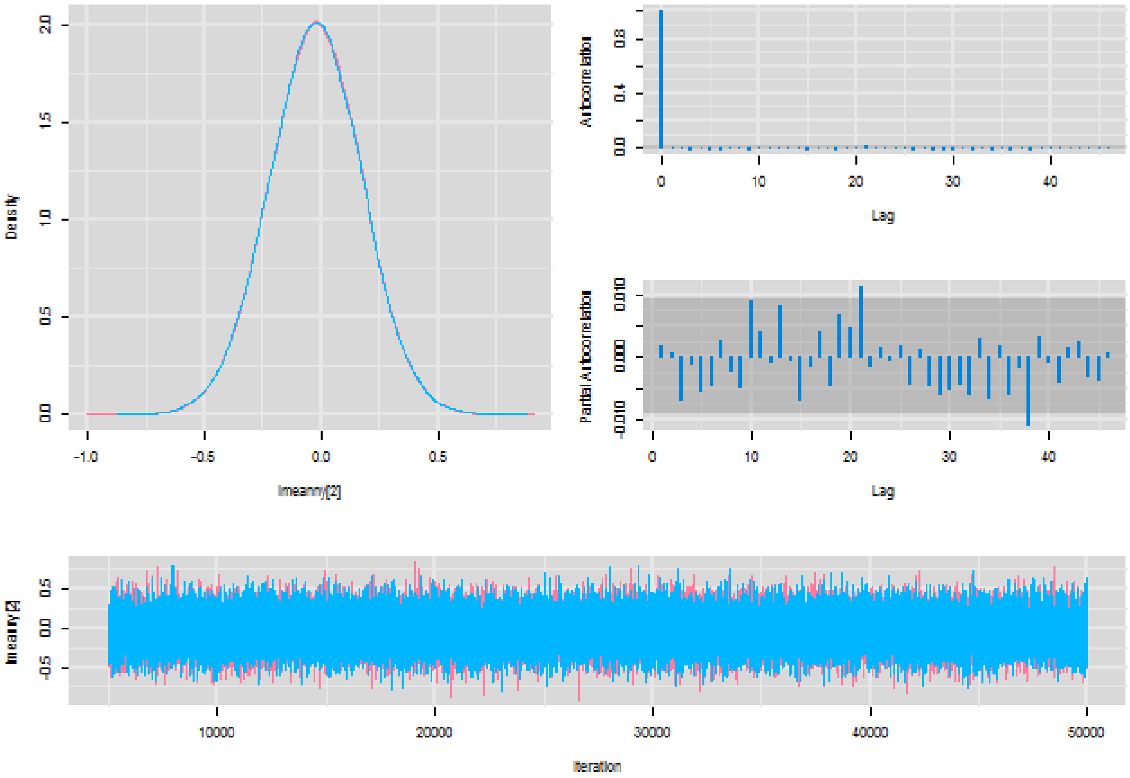
Diagnostics for lmeannj[25]



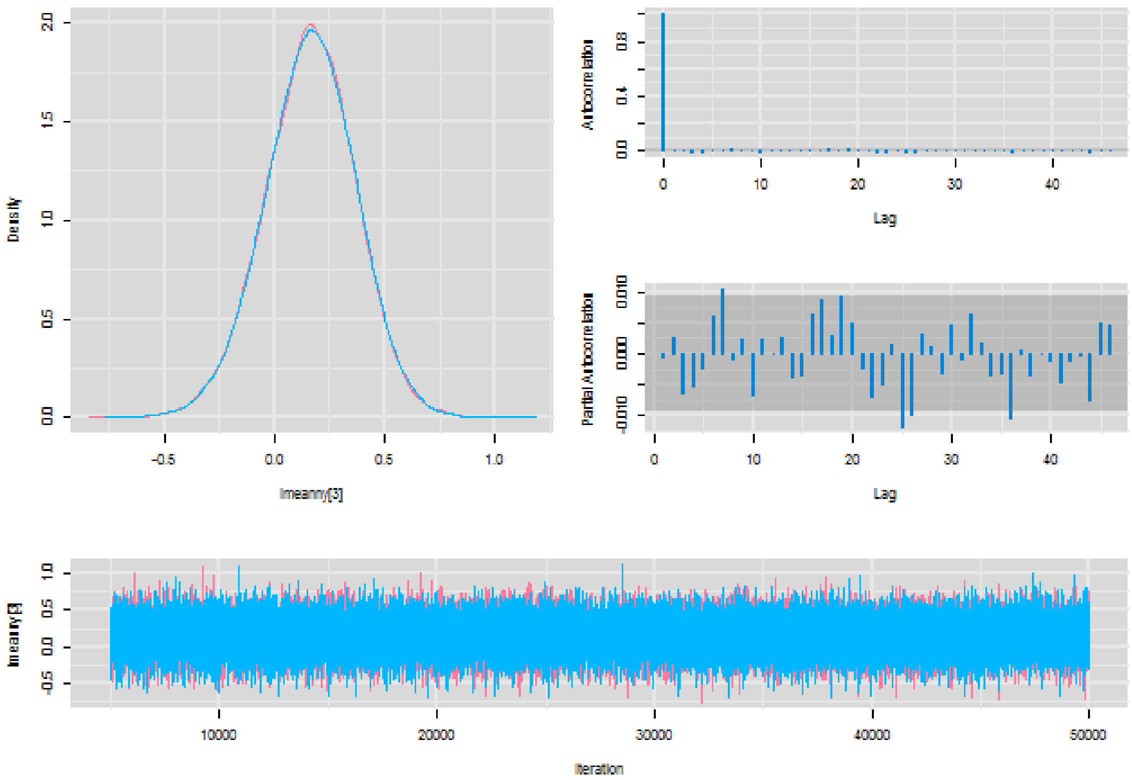
Diagnostics for lmeanny[1]



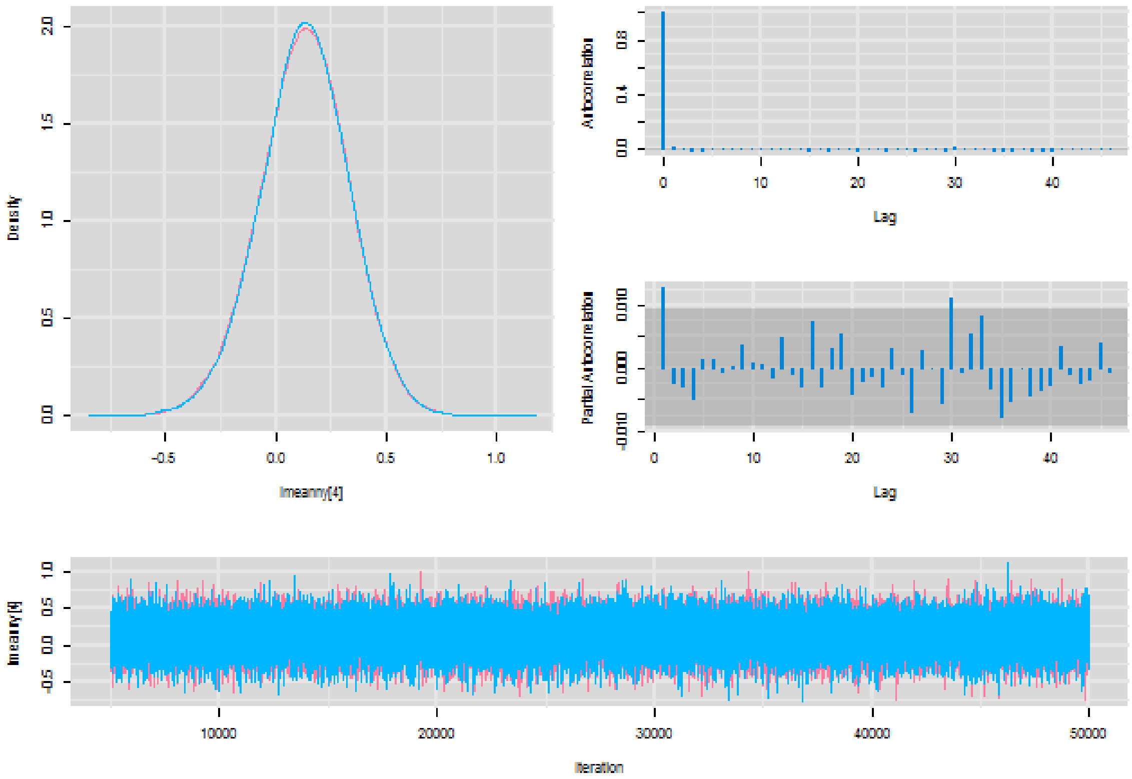
Diagnostics for lmeanny[2]



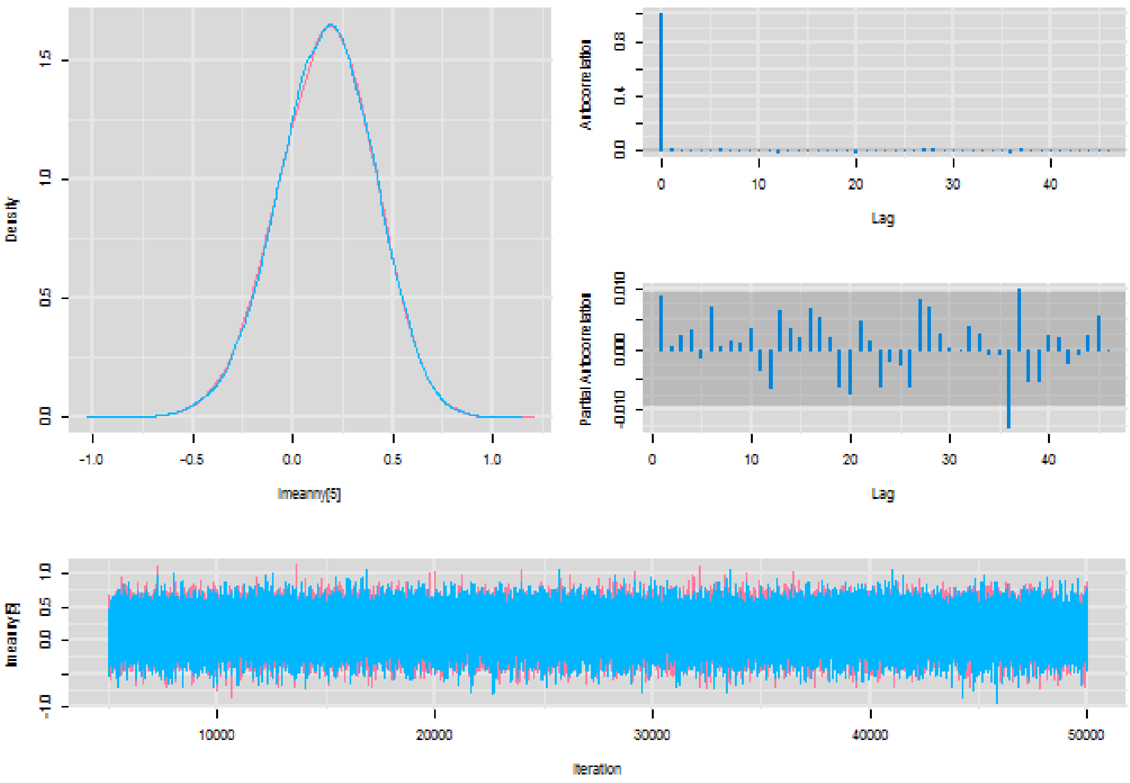
Diagnostics for lmeanny[3]



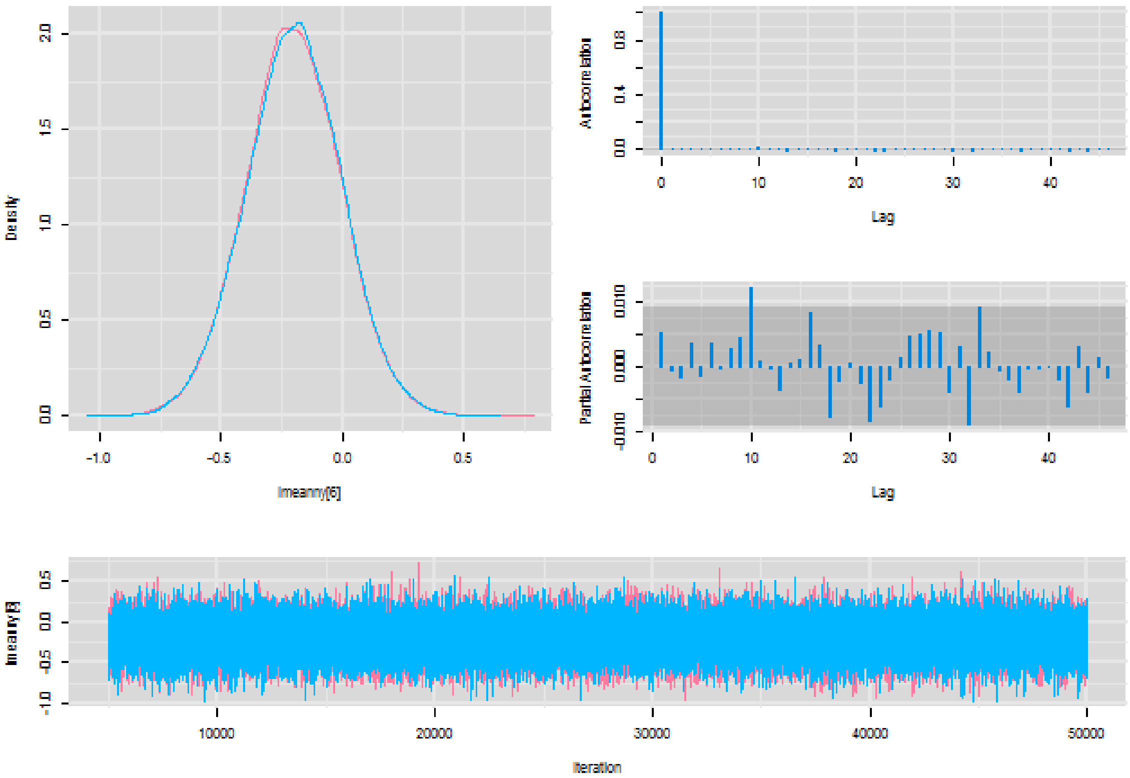
Diagnostics for lmeanny[4]



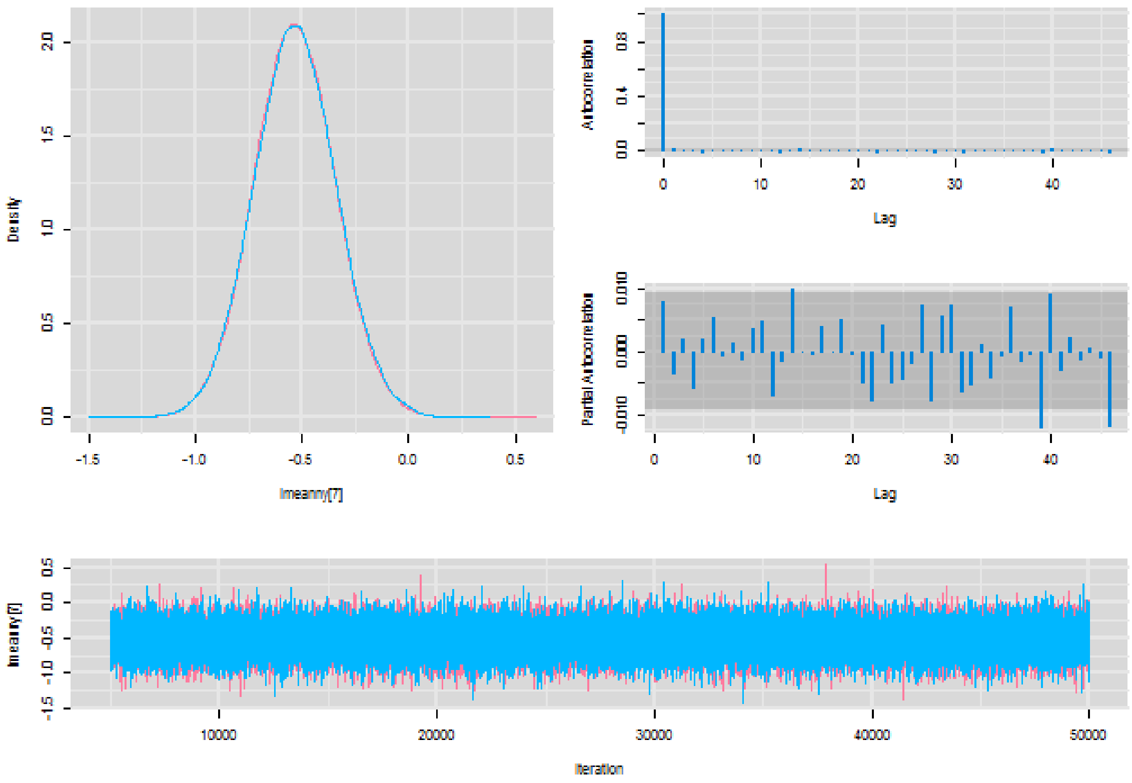
Diagnostics for lmeanny[5]



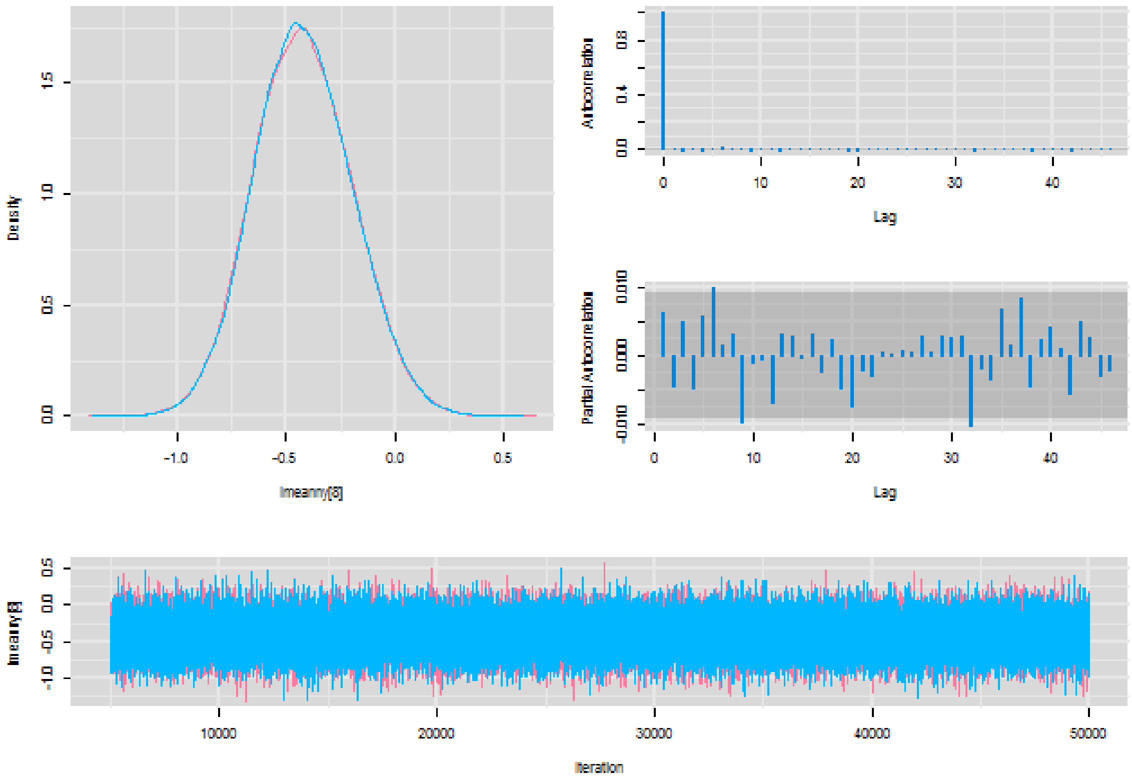
Diagnostics for lmeanny[6]



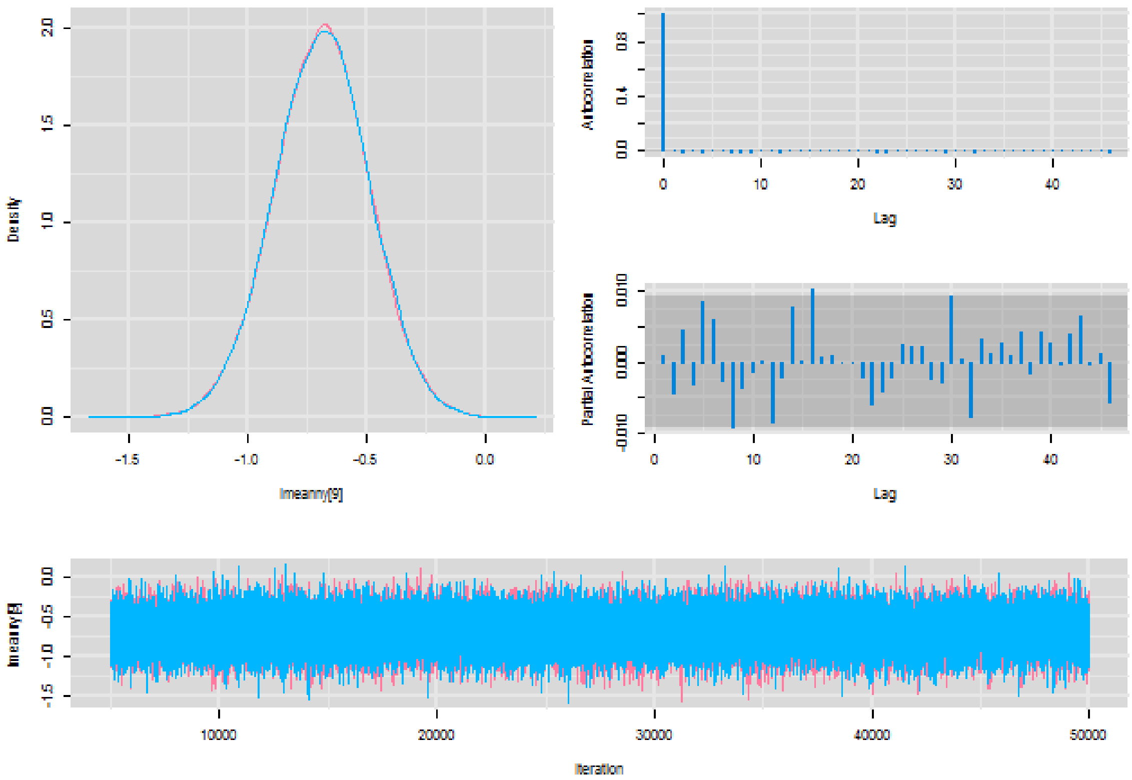
Diagnostics for lmeanny[7]



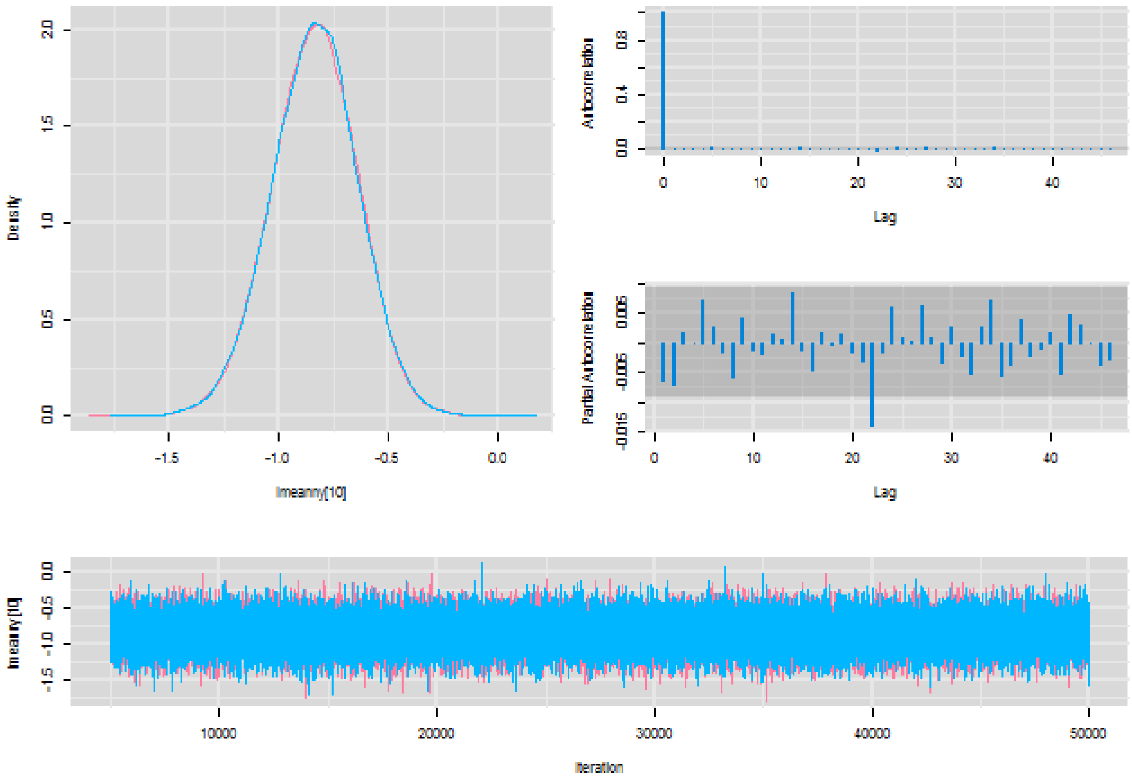
Diagnostics for lmeanny[8]



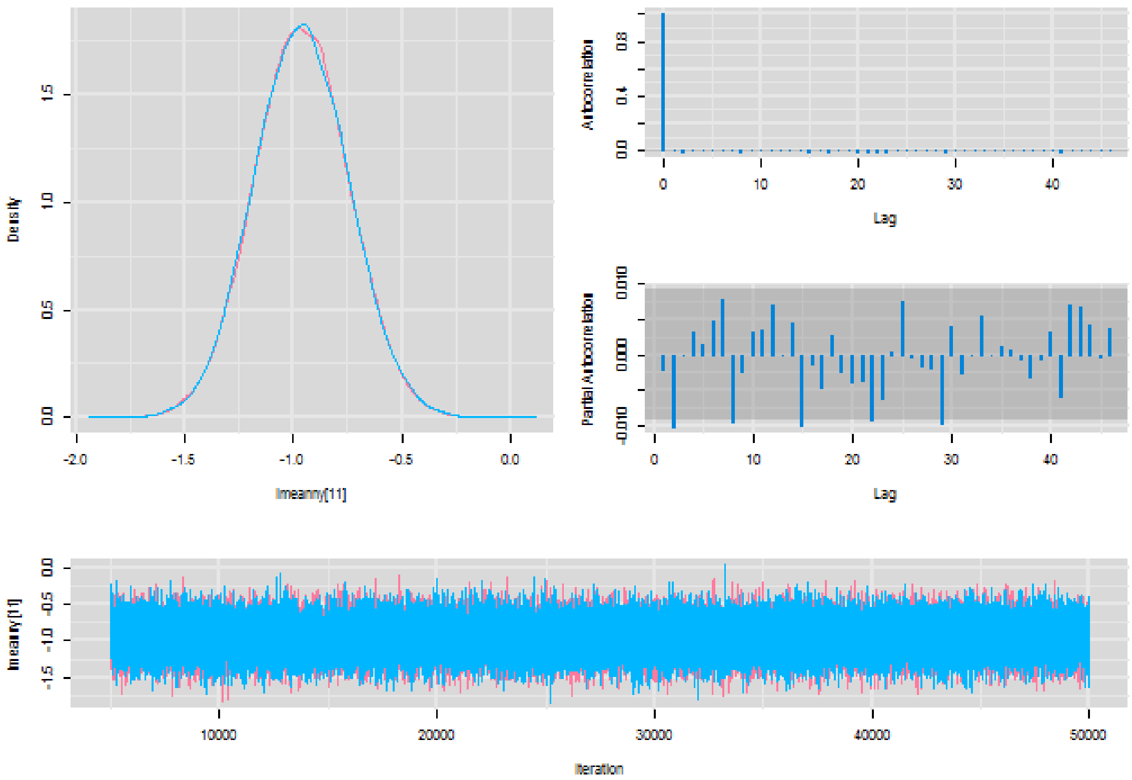
Diagnostics for lmeanny[9]



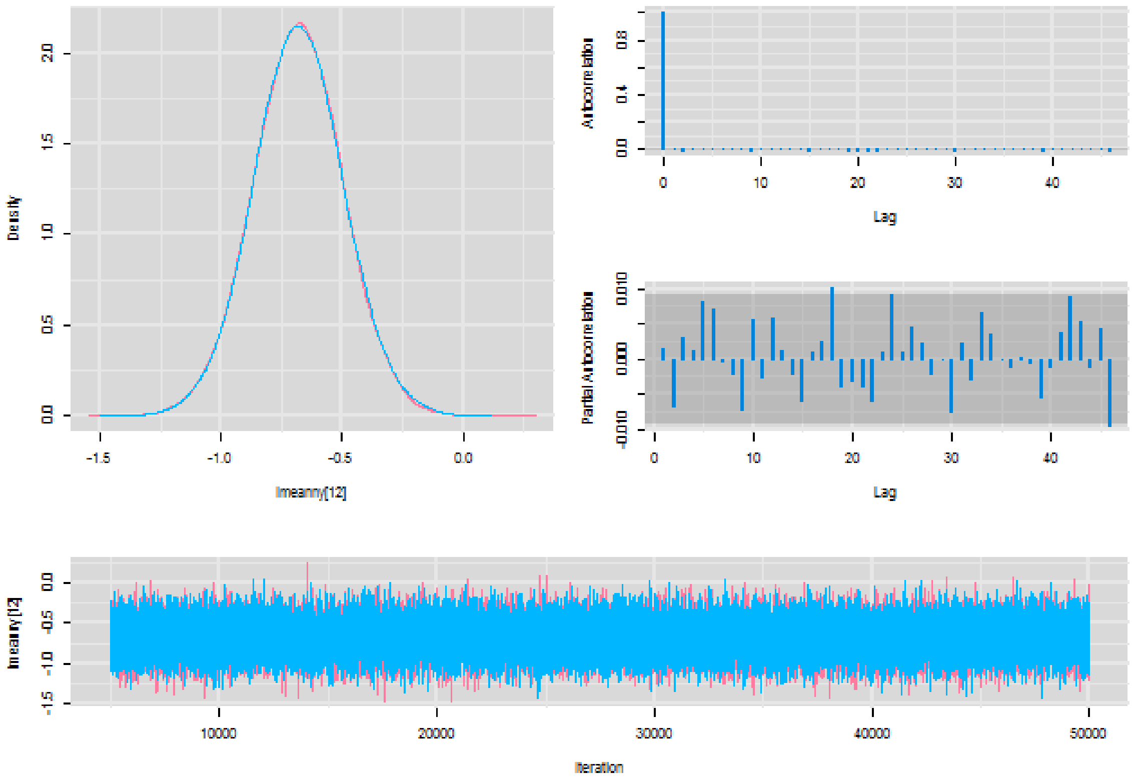
Diagnostics for lmeanny[10]



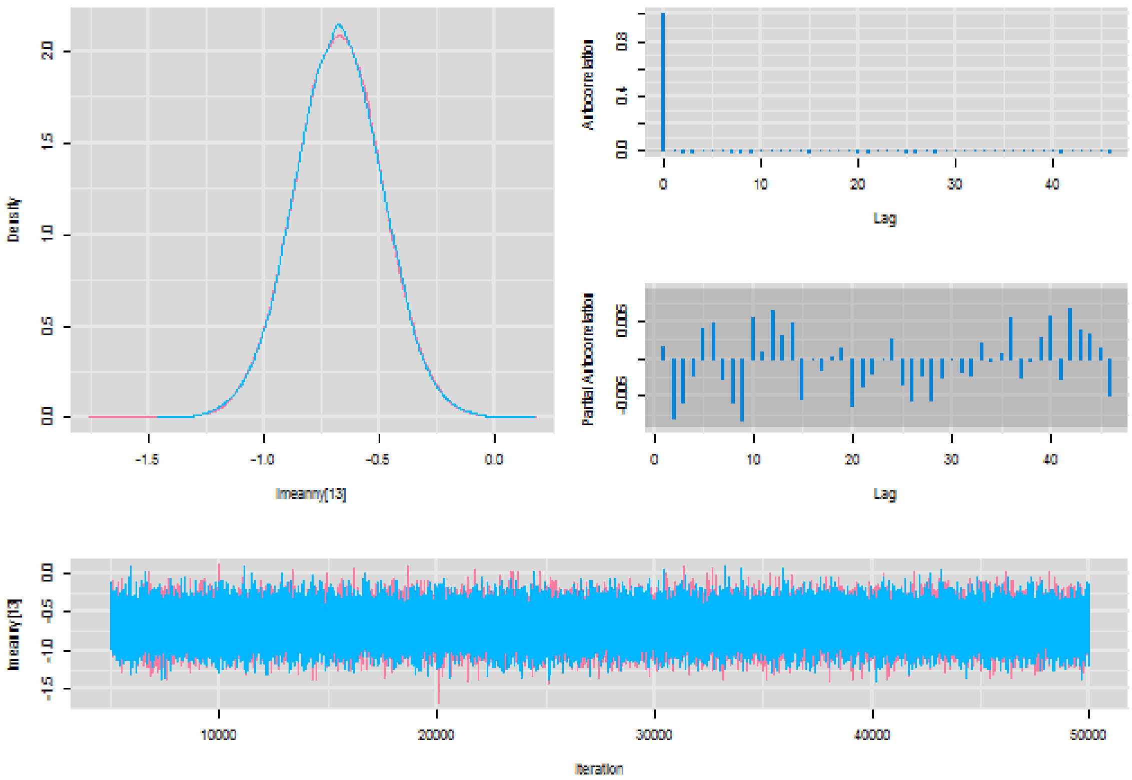
Diagnostics for lmeanny[11]



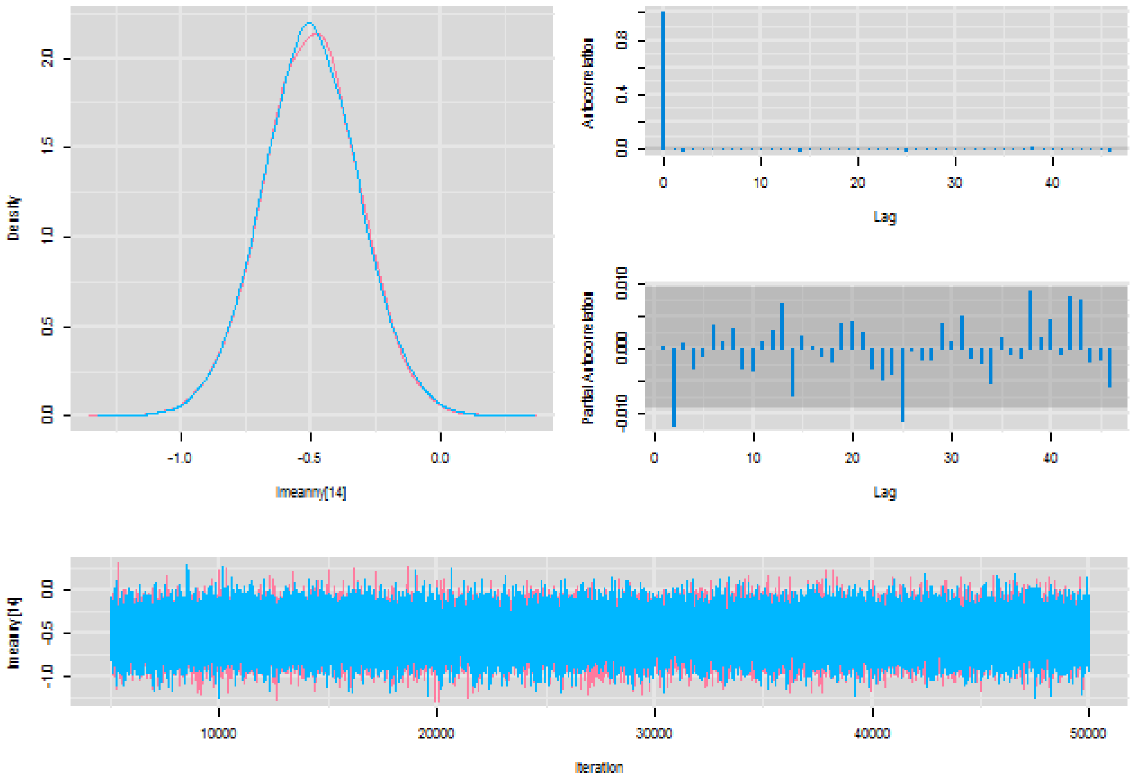
Diagnostics for lmeanny[12]



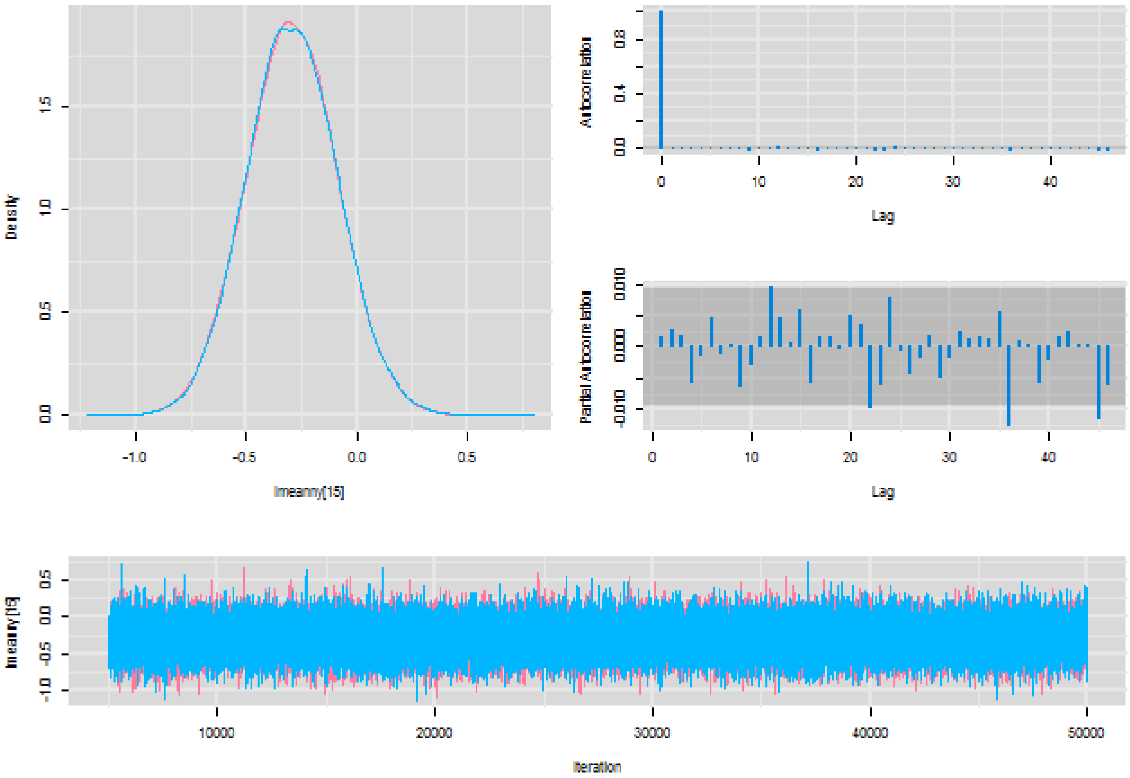
Diagnostics for lmeanny[13]



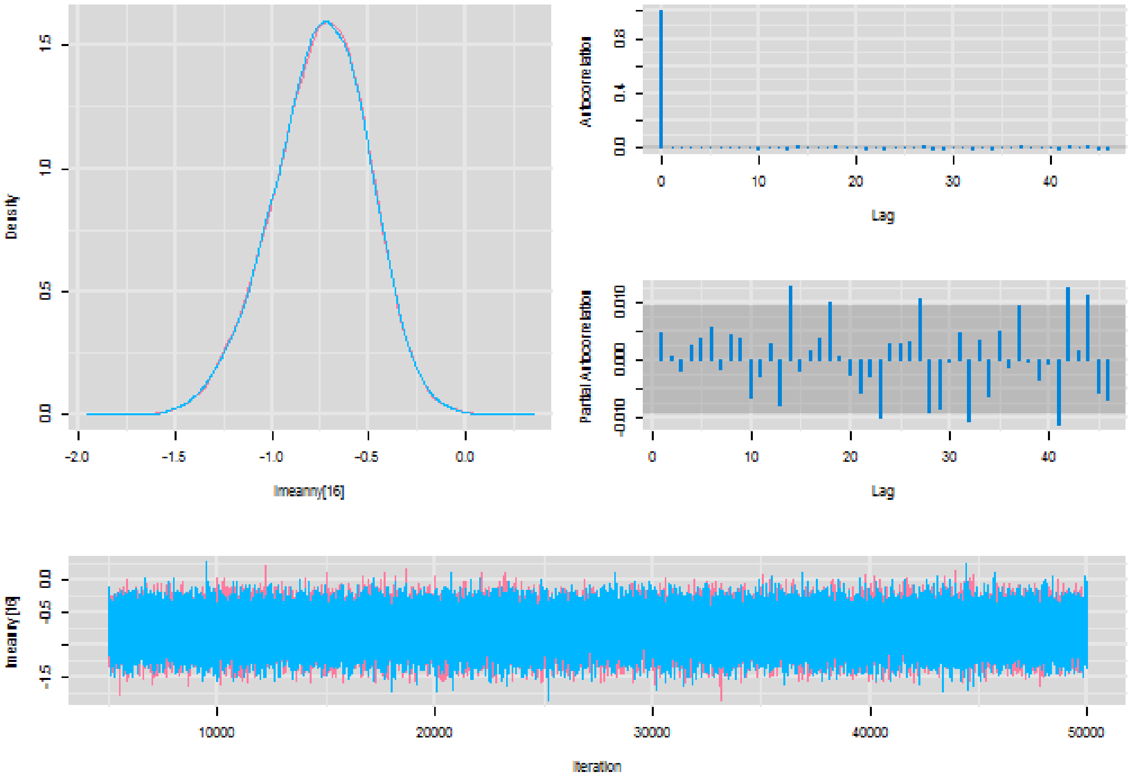
Diagnostics for lmeanny[14]



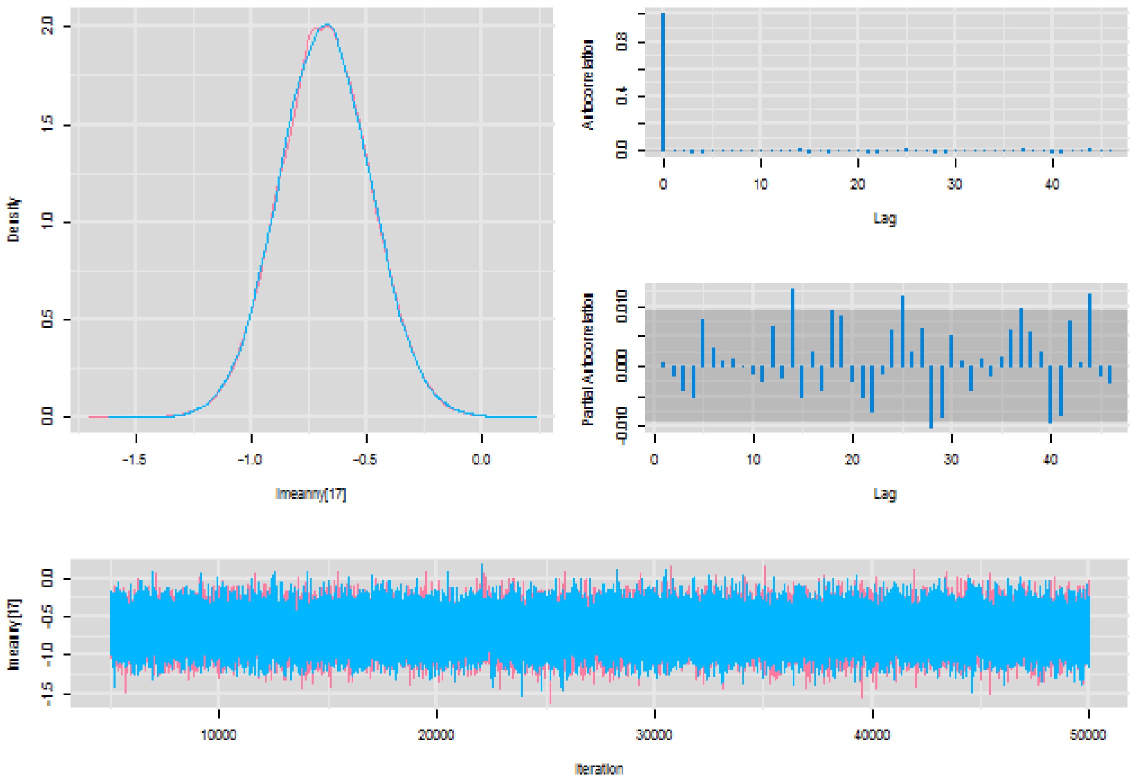
Diagnostics for lmeanny[15]



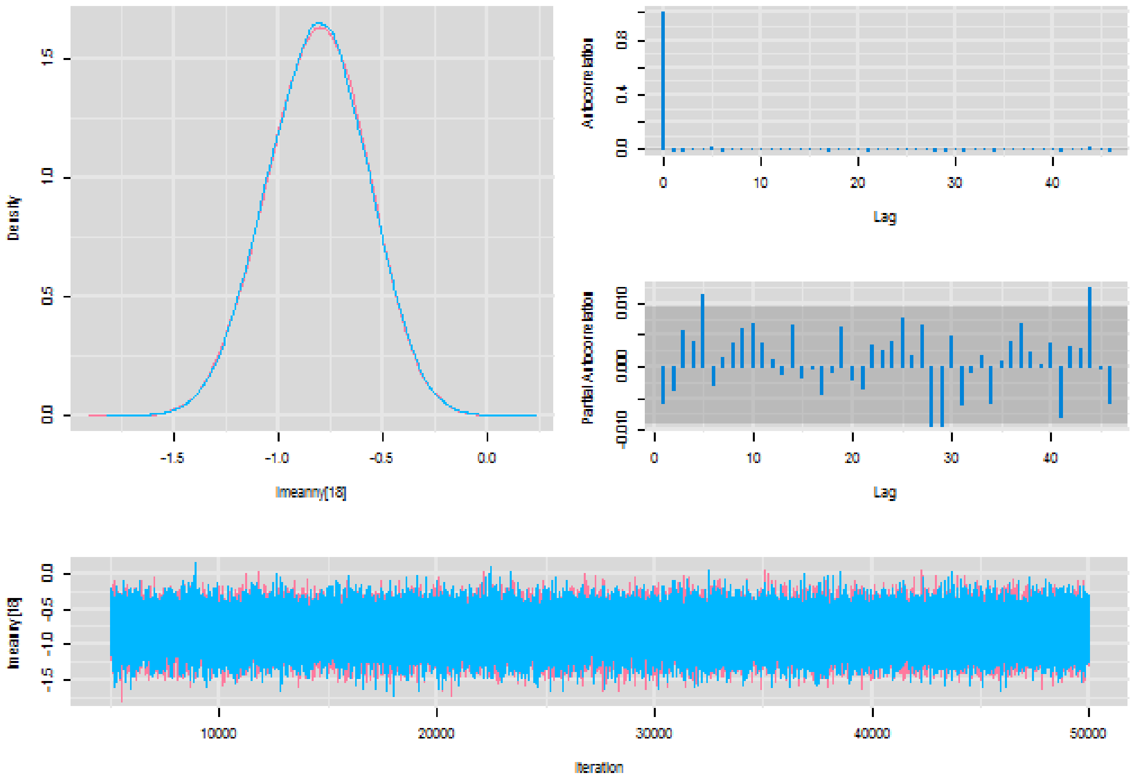
Diagnostics for lmeanny[16]



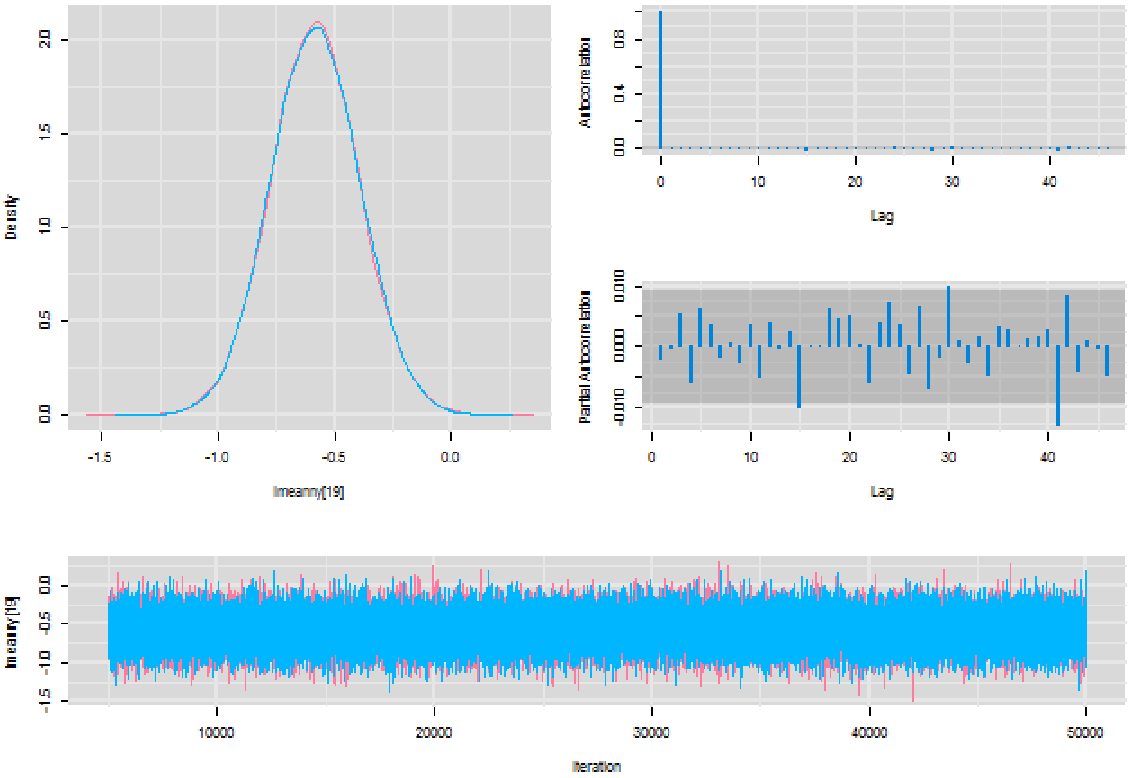
Diagnostics for lmeanny[17]



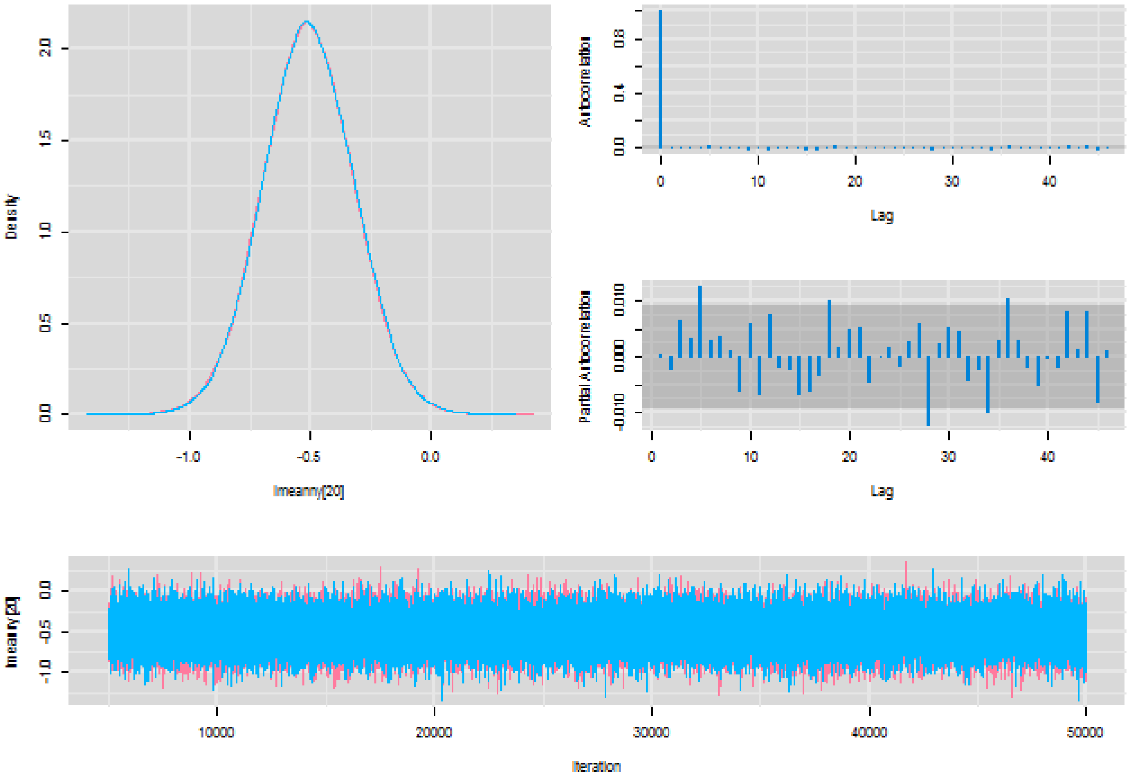
Diagnostics for lmeanny[18]



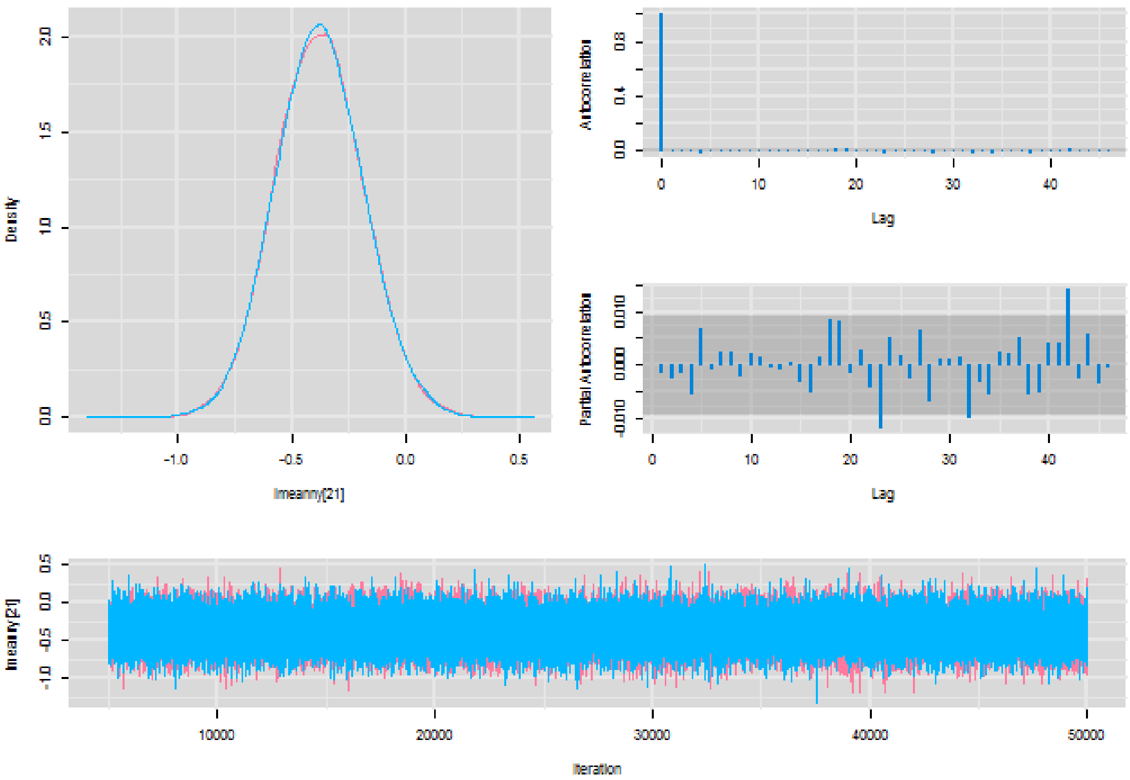
Diagnostics for lmeanny[19]



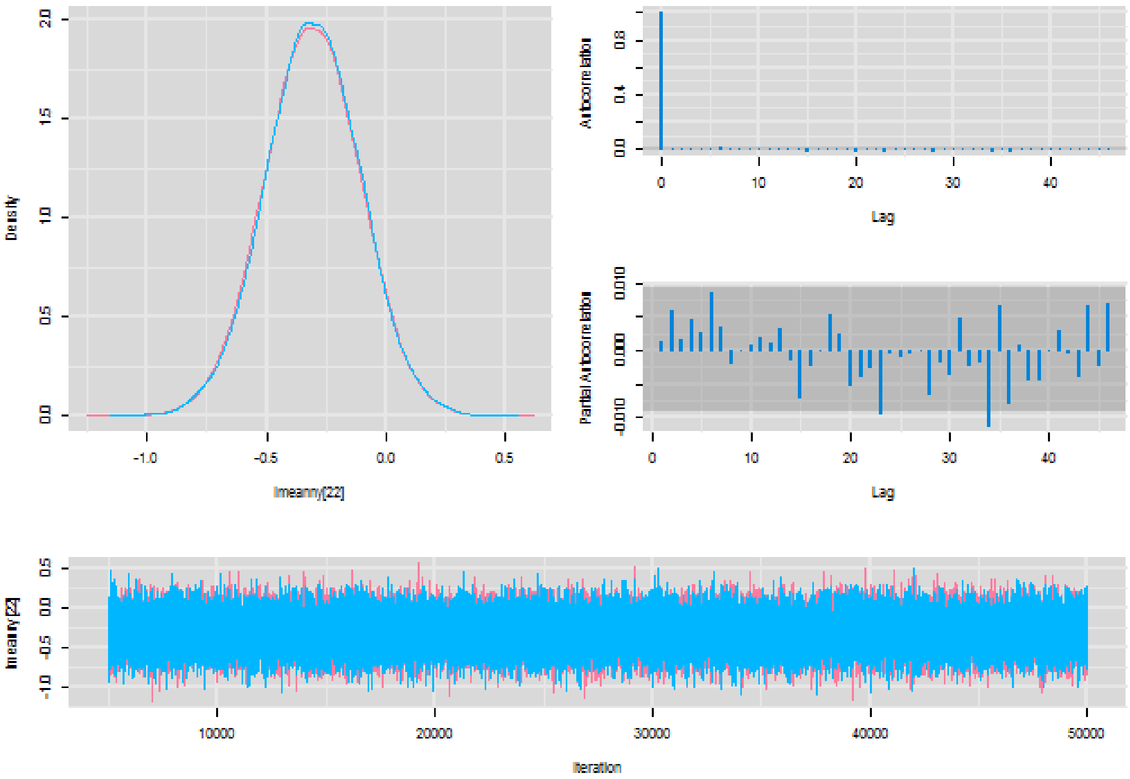
Diagnostics for lmeanny[20]



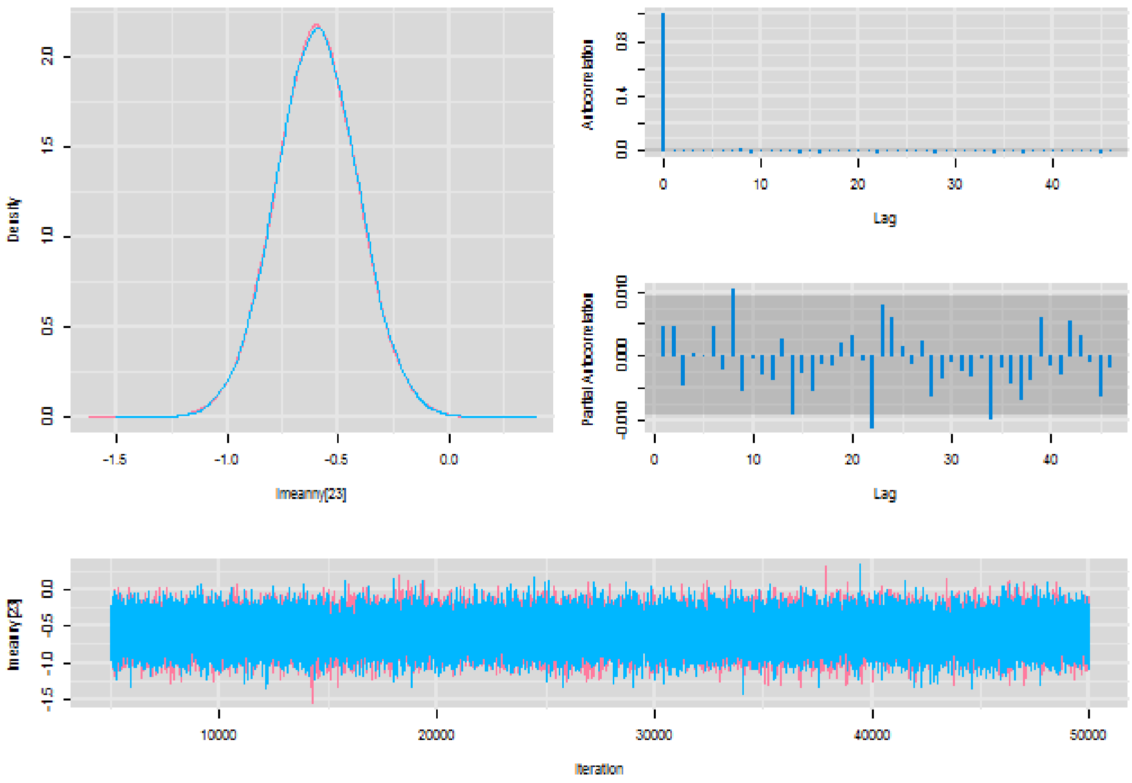
Diagnostics for lmeanny[21]



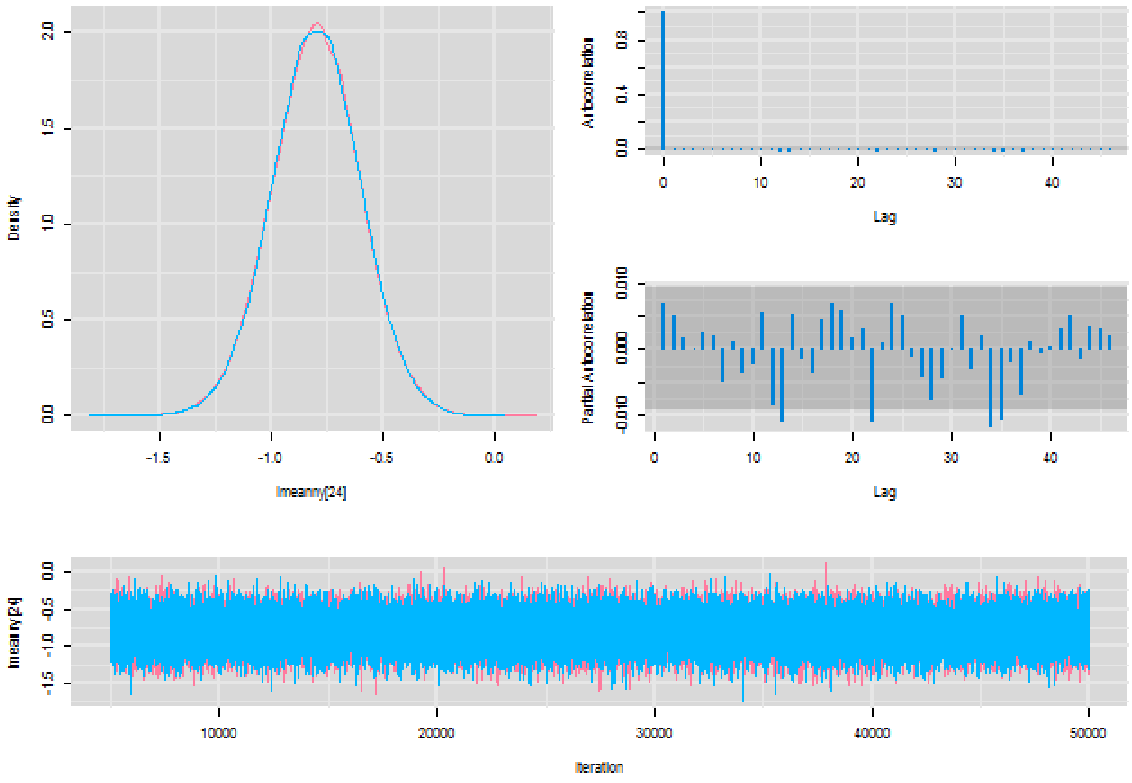
Diagnostics for lmeanny[22]



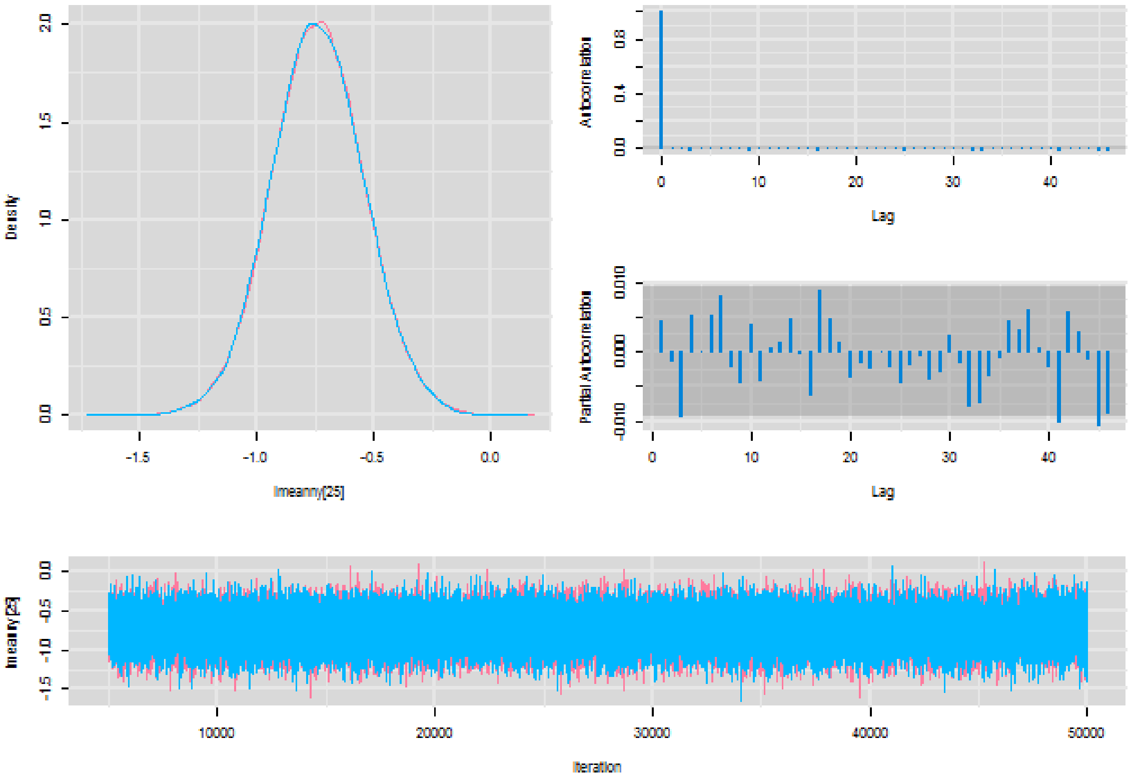
Diagnostics for lmeanny[23]



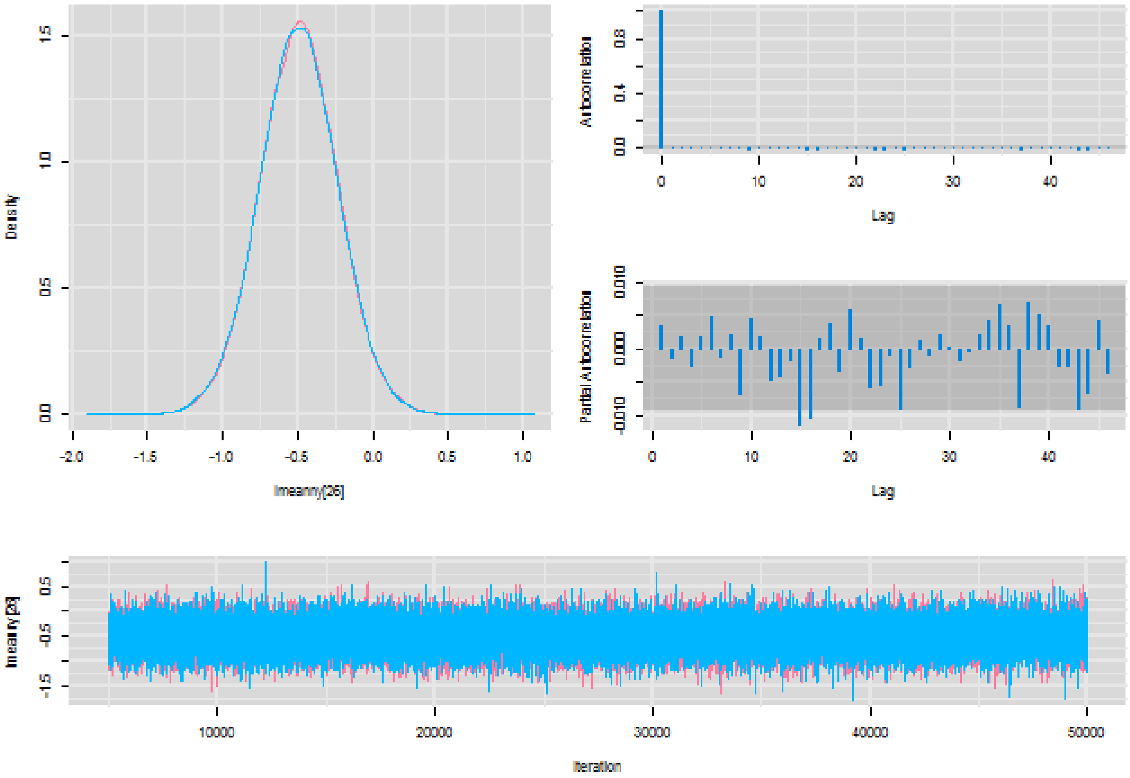
Diagnostics for lmeanny[24]



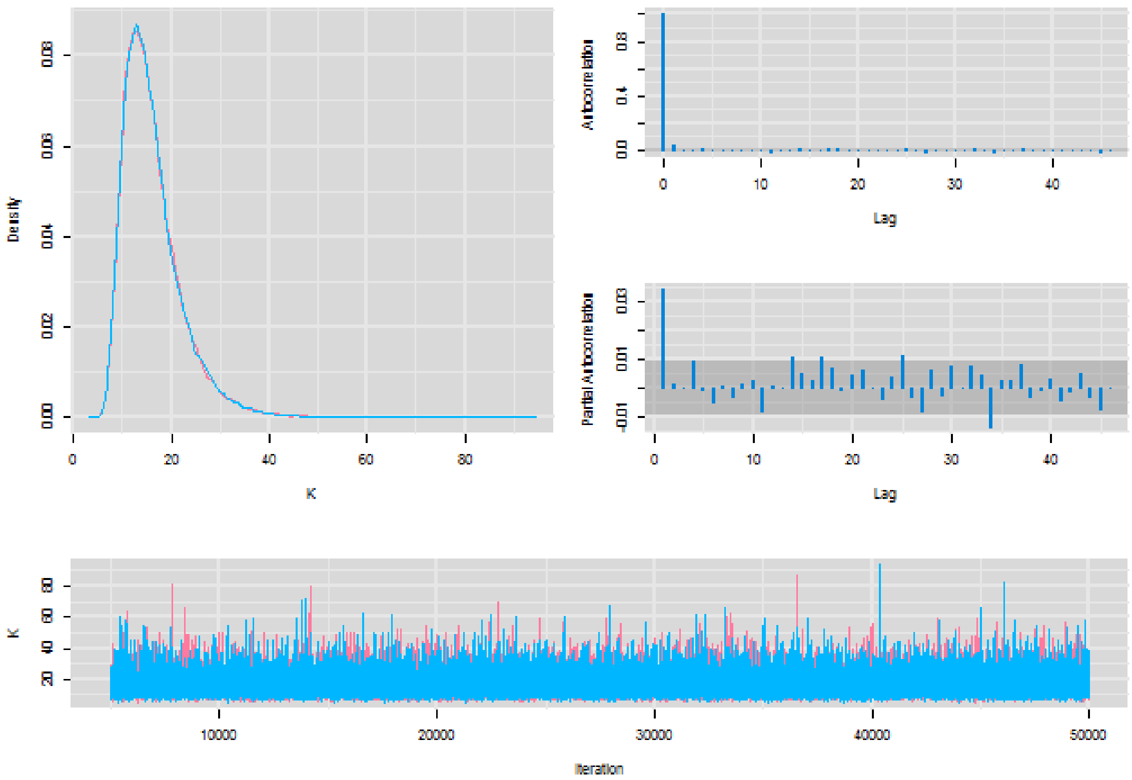
Diagnostics for lmeanny[25]



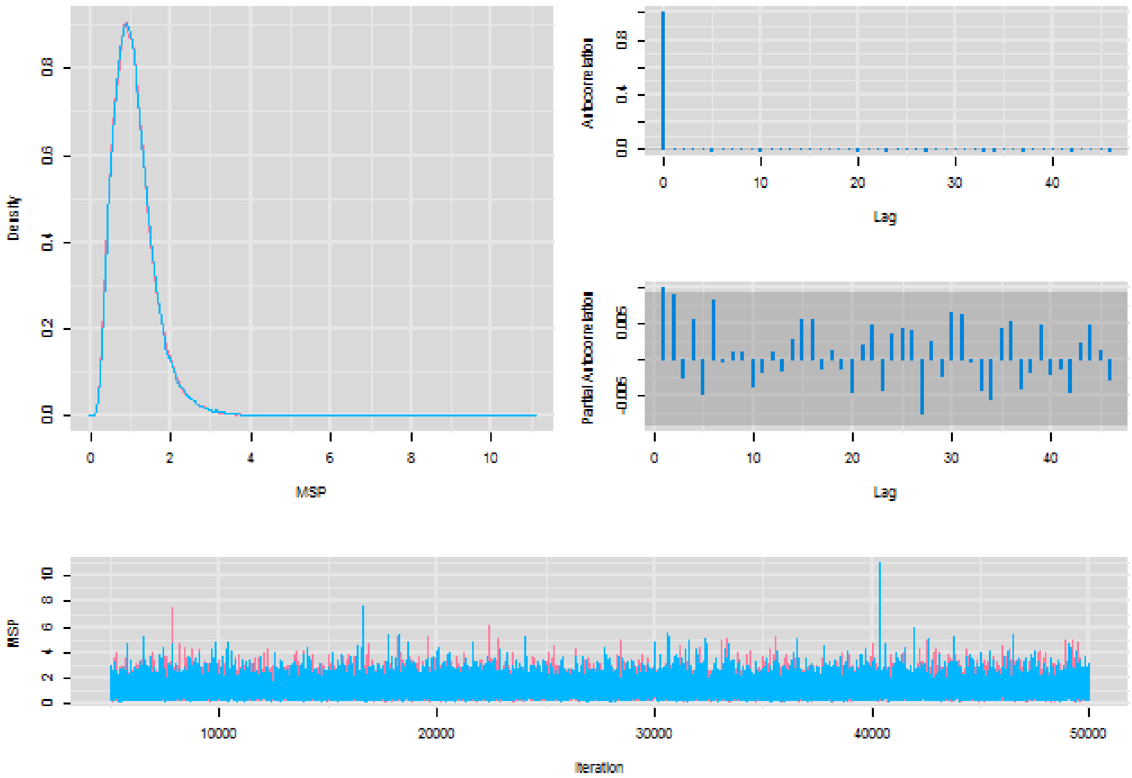
Diagnostics for lmeanny[26]



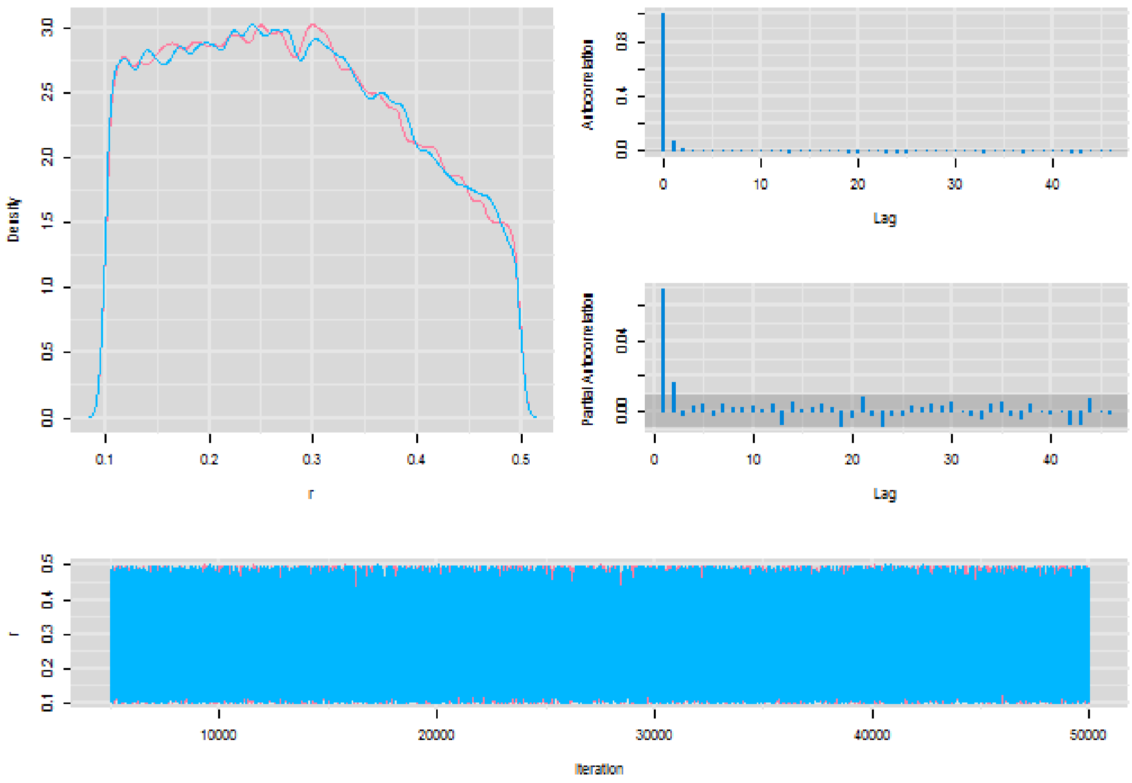
Diagnostics for K



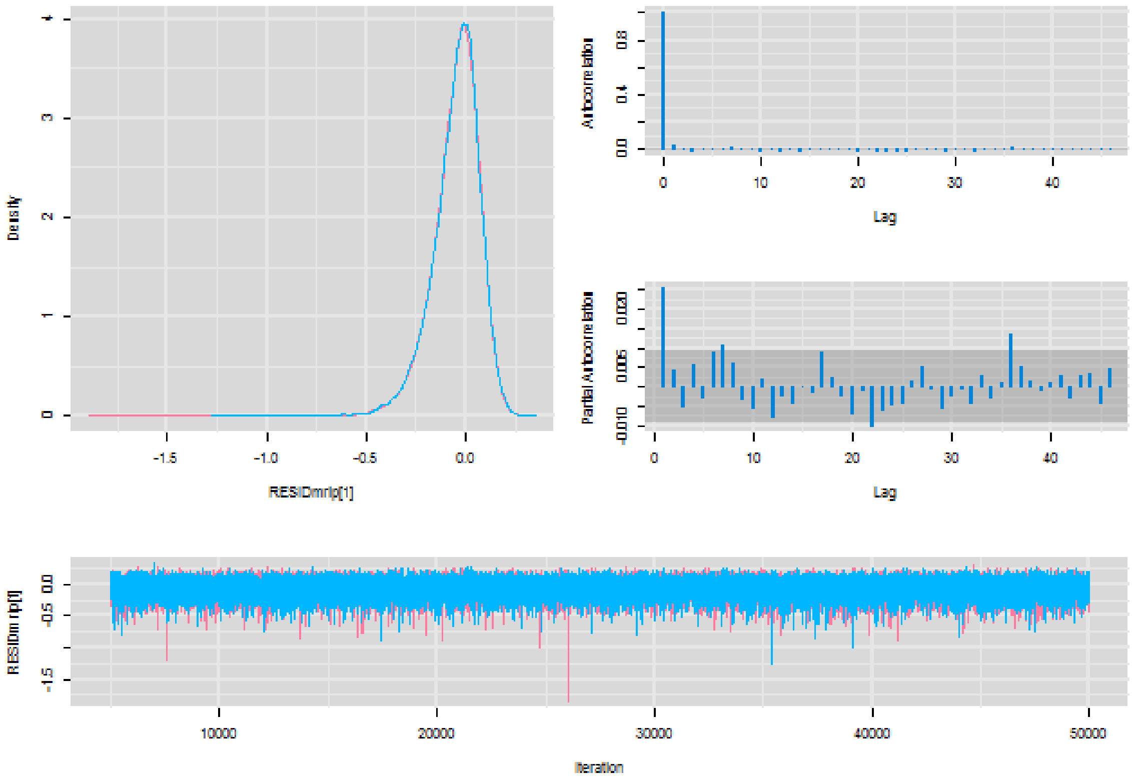
Diagnostics for MSP



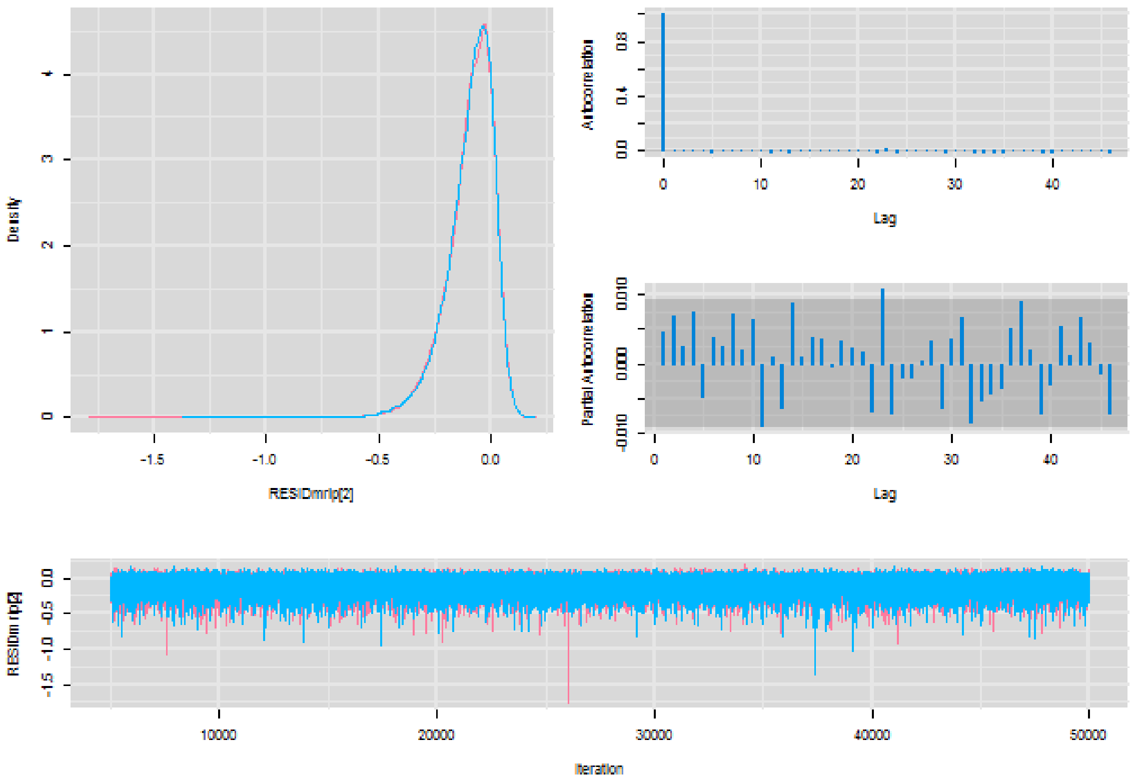
Diagnostics for r



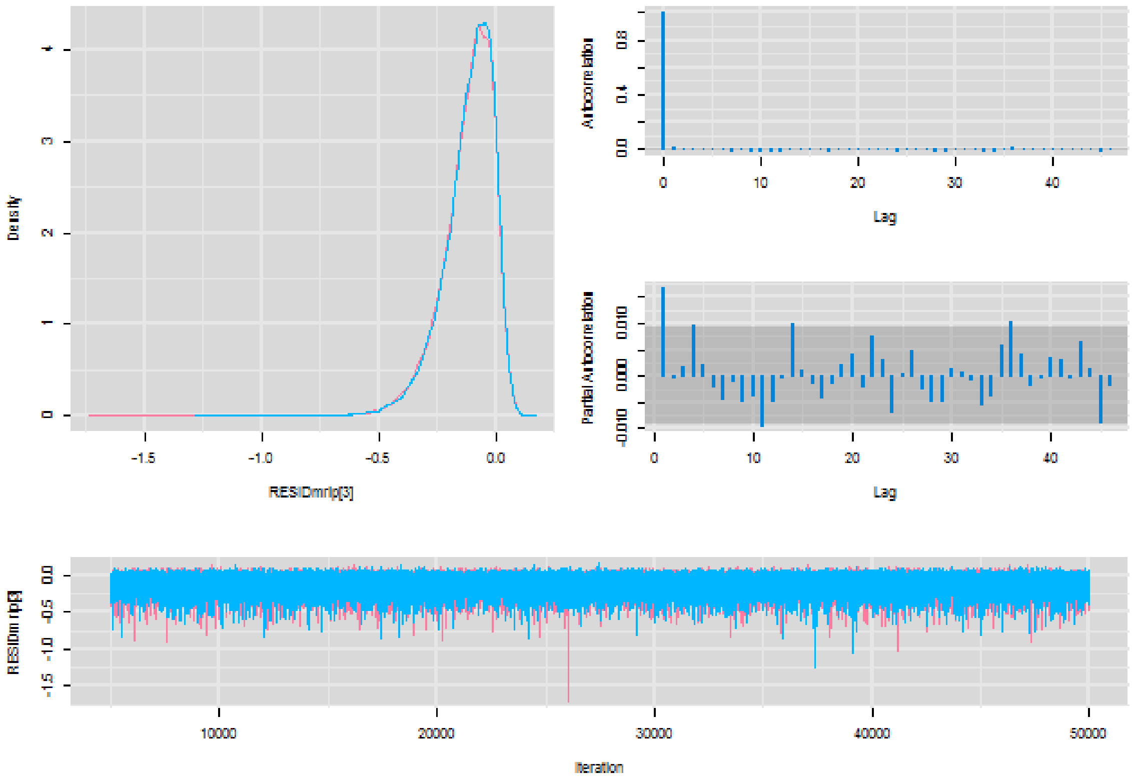
Diagnostics for RESIDmrip[1]



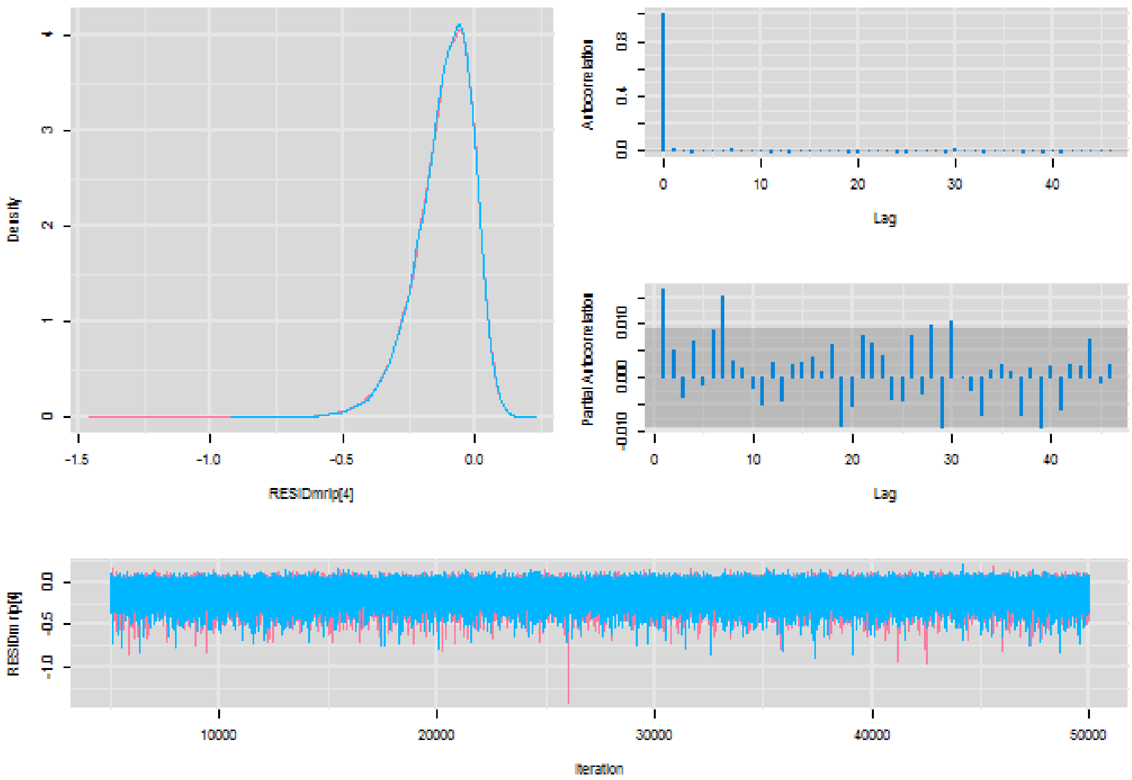
Diagnostics for RESIDmrip[2]



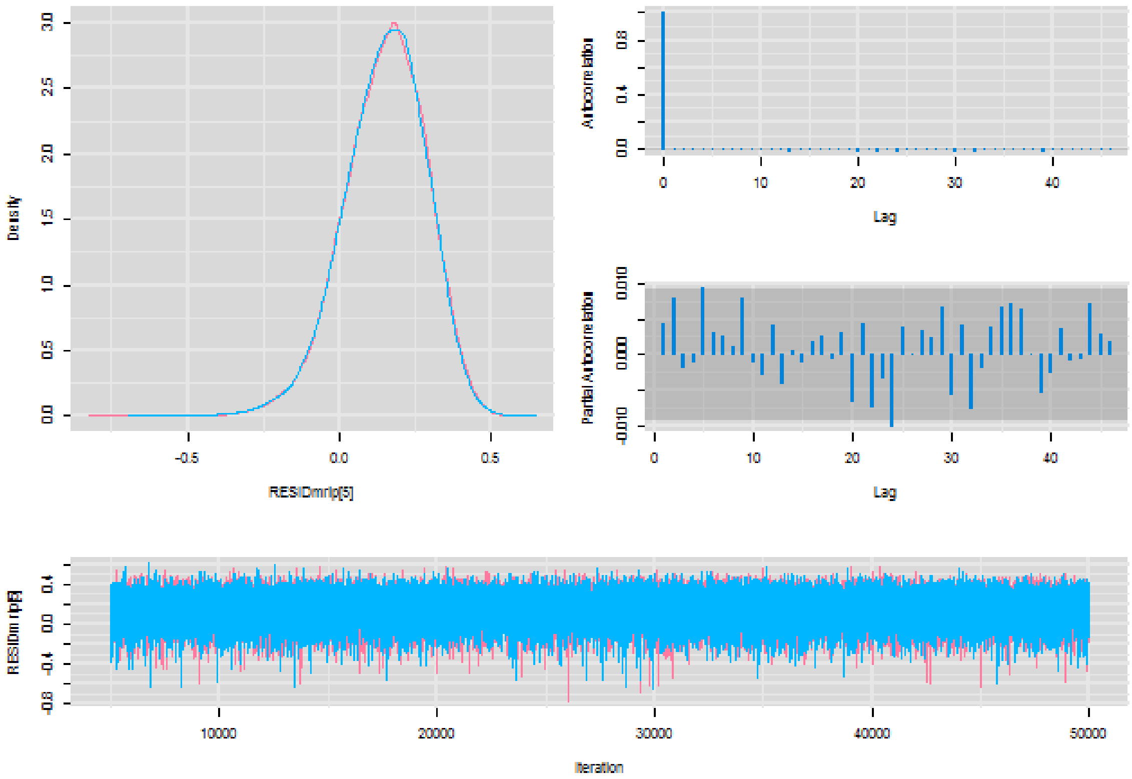
Diagnostics for RESIDmrip[3]



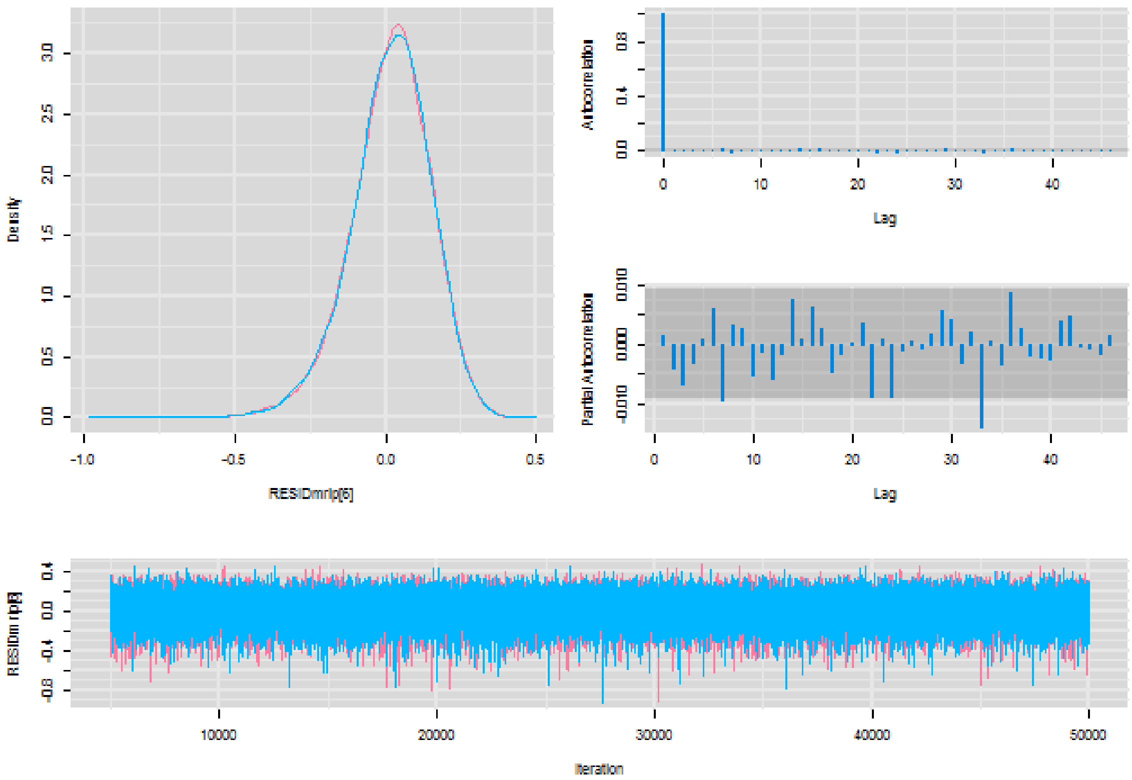
Diagnostics for RESIDmrip[4]



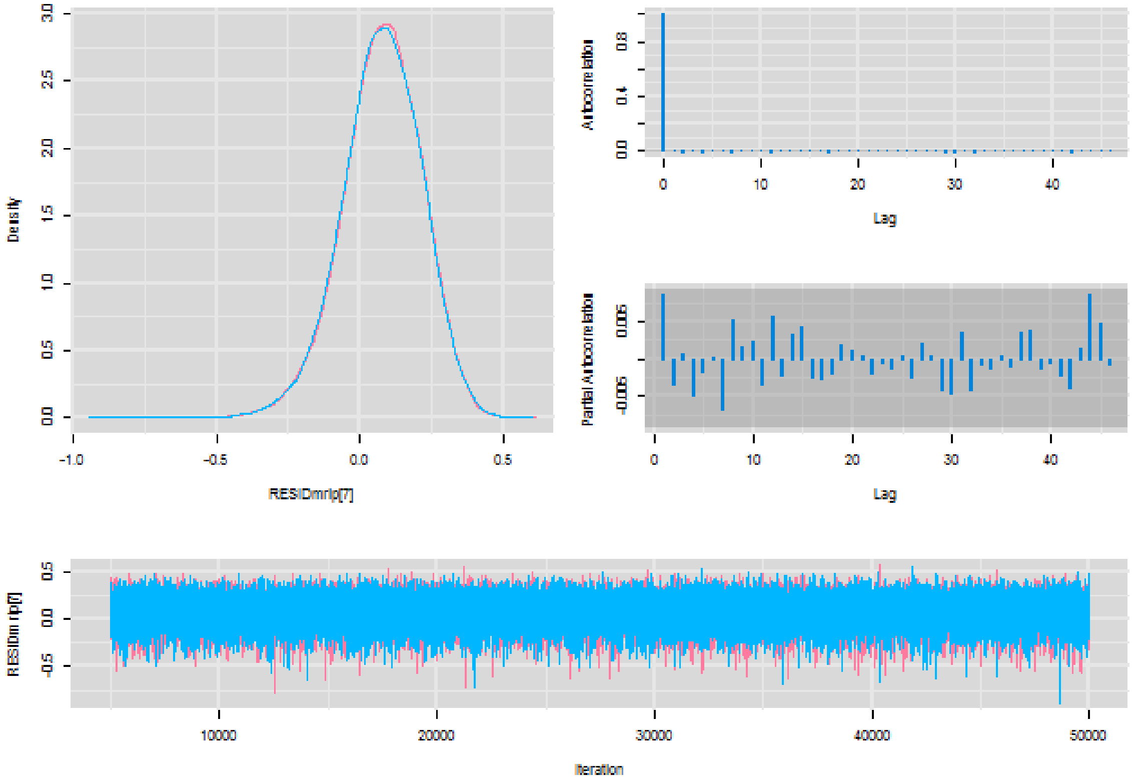
Diagnostics for RESIDmrip[5]



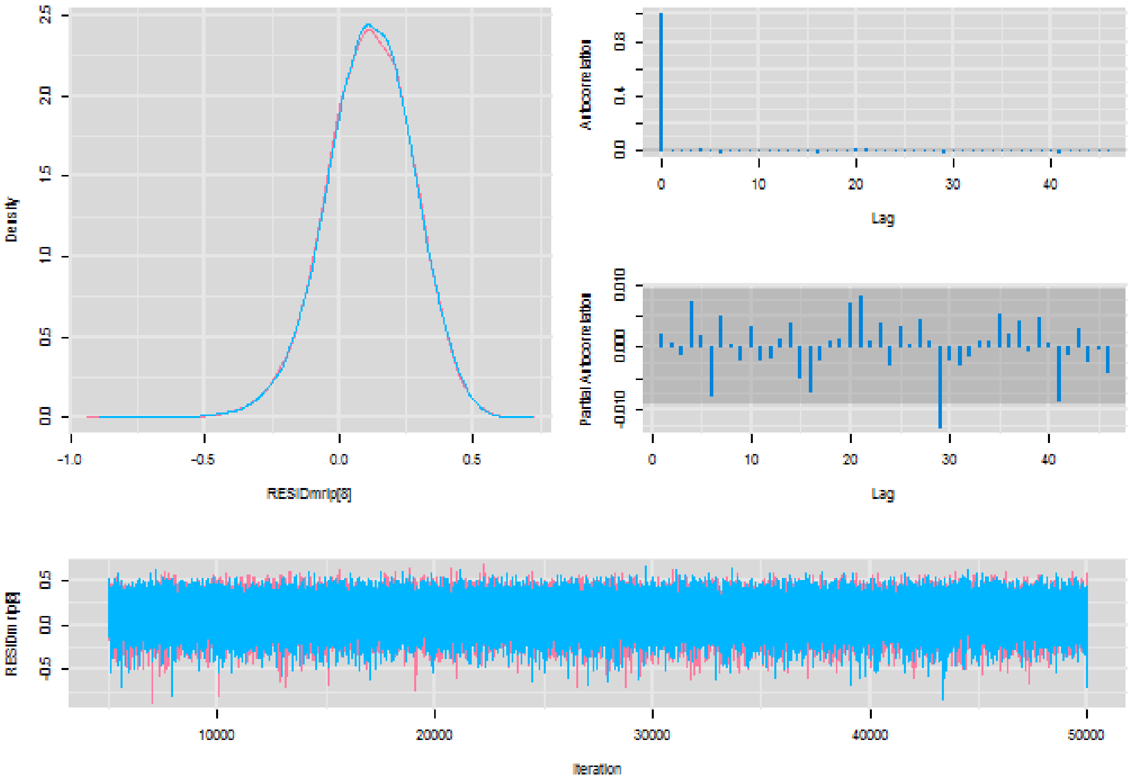
Diagnostics for RESIDmrip[6]



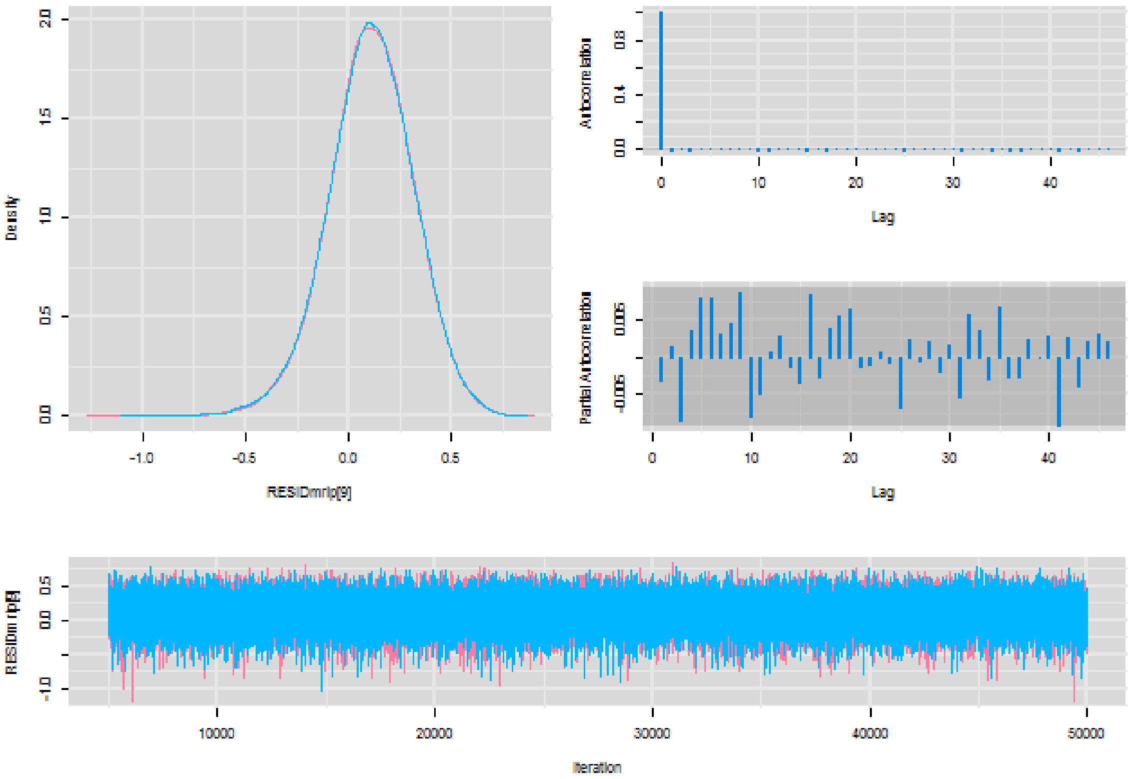
Diagnostics for RESIDmrip[7]



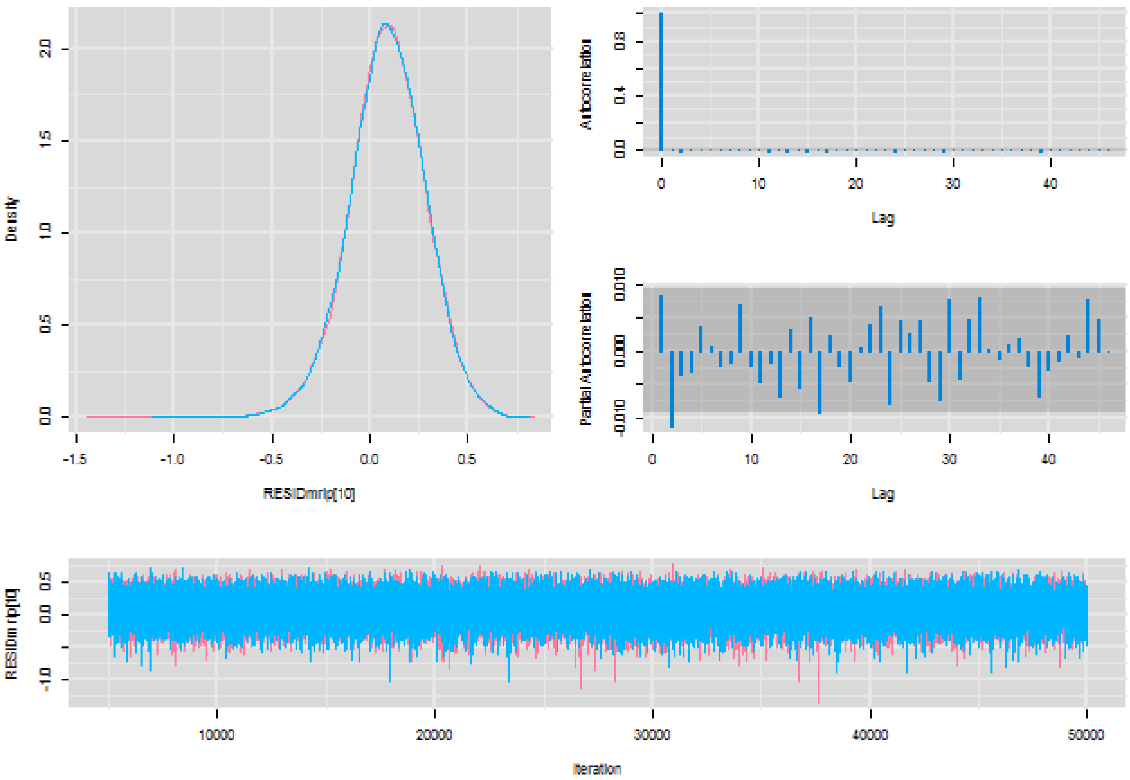
Diagnostics for RESIDmrip[8]



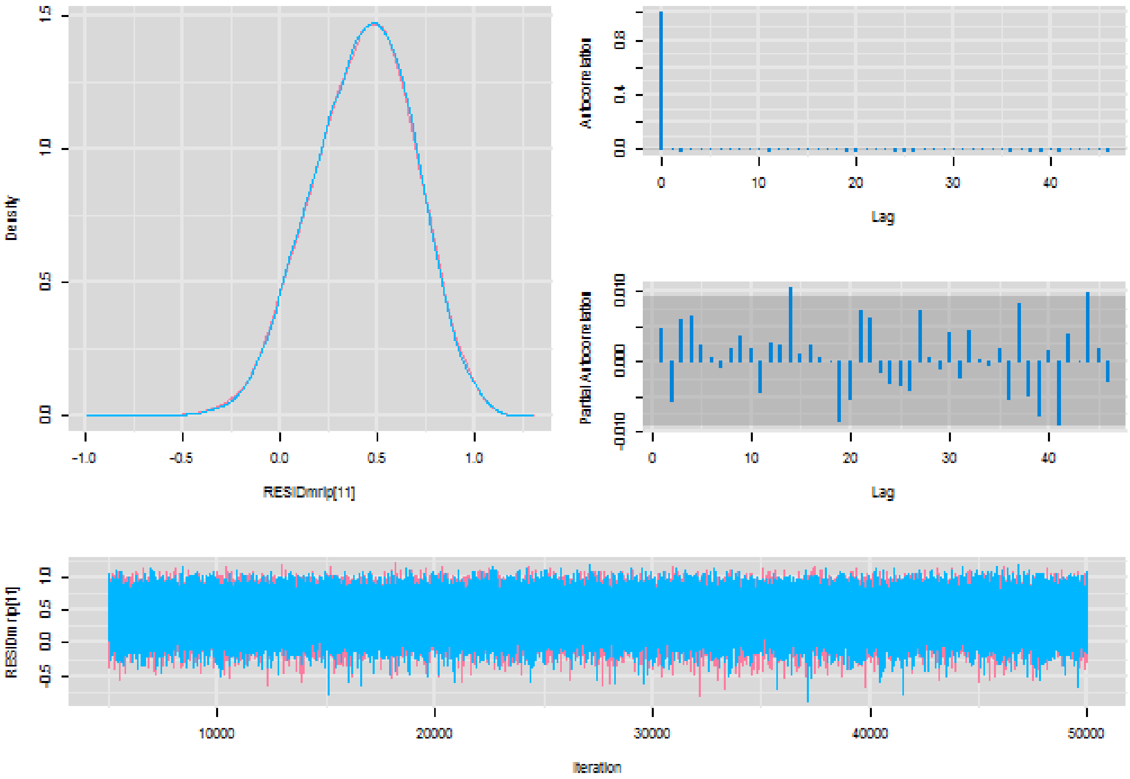
Diagnostics for RESIDmrip[9]



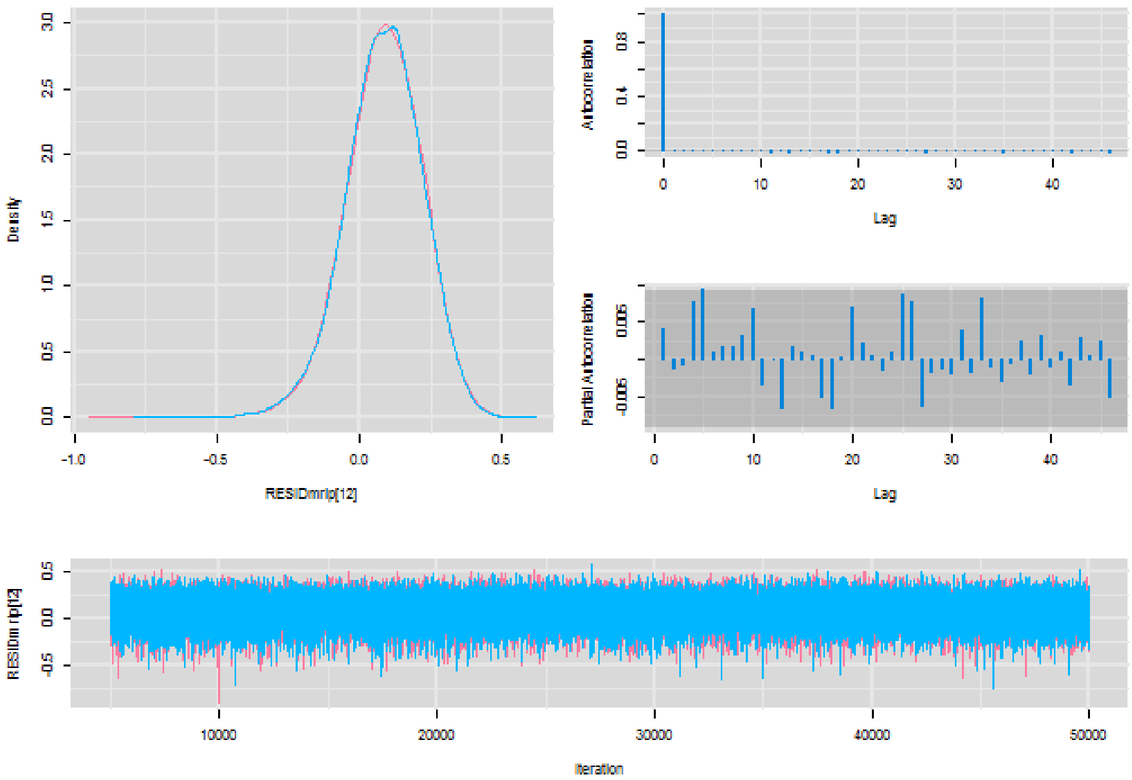
Diagnostics for RESIDmrip[10]



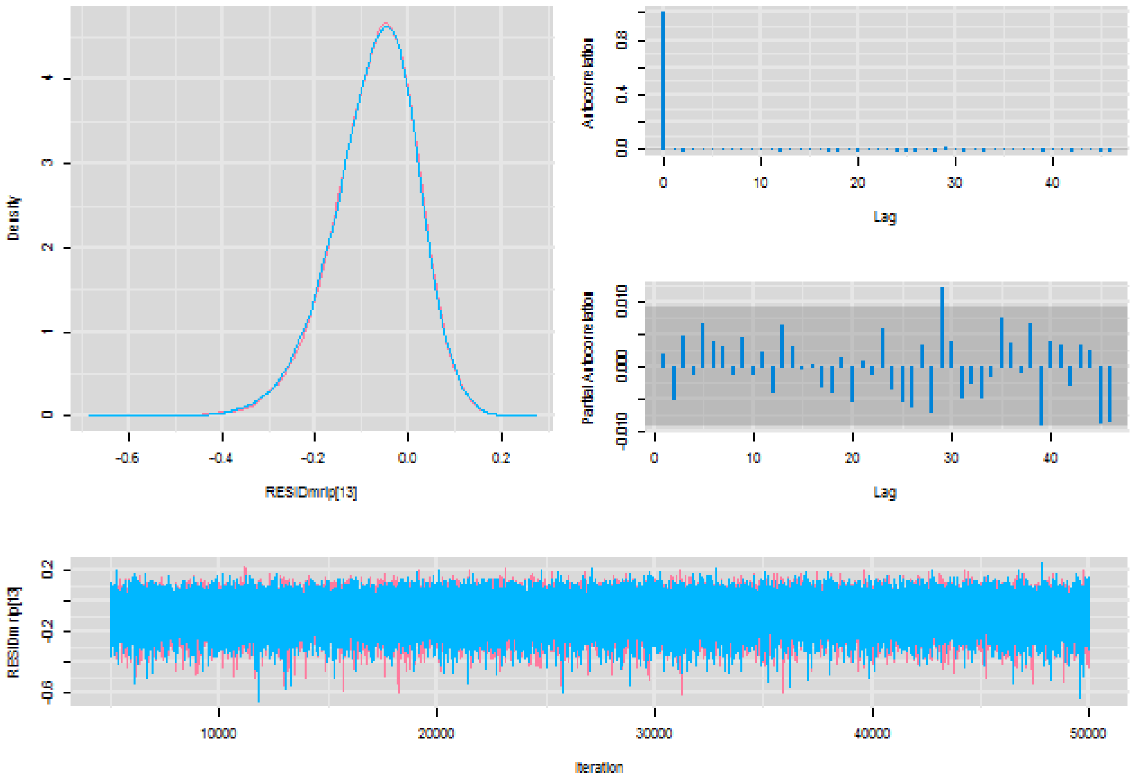
Diagnostics for RESIDmrip[11]



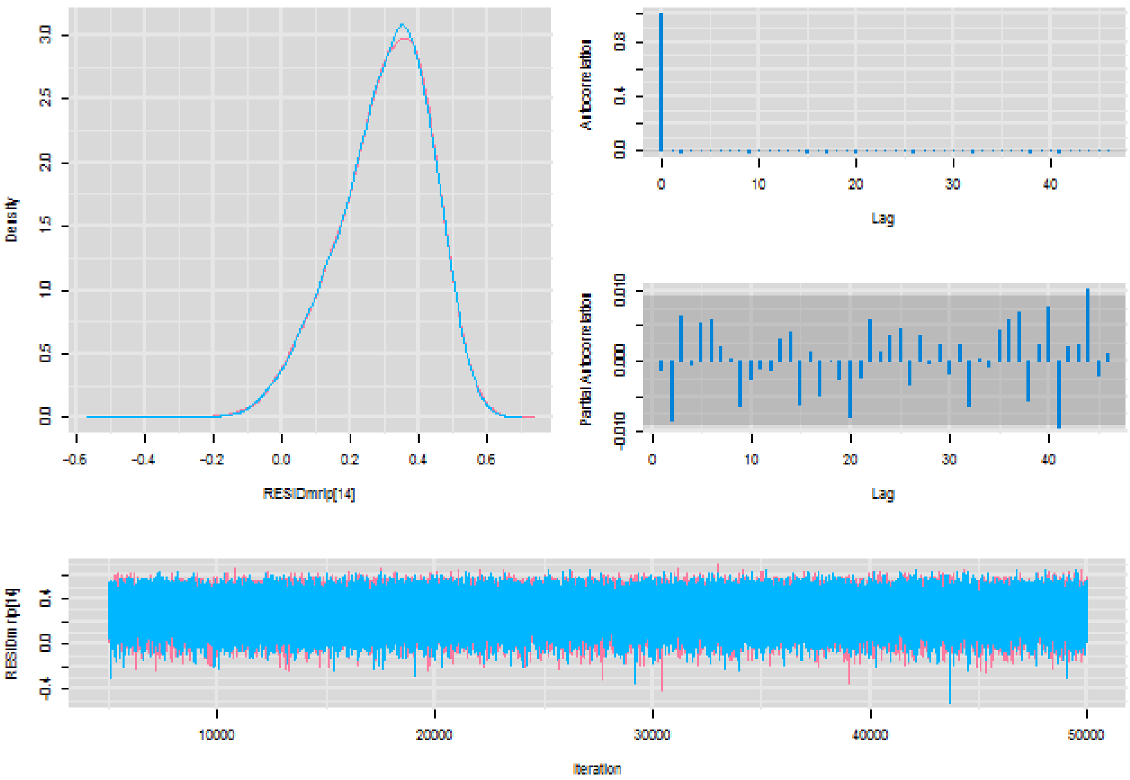
Diagnostics for RESIDmrip[12]



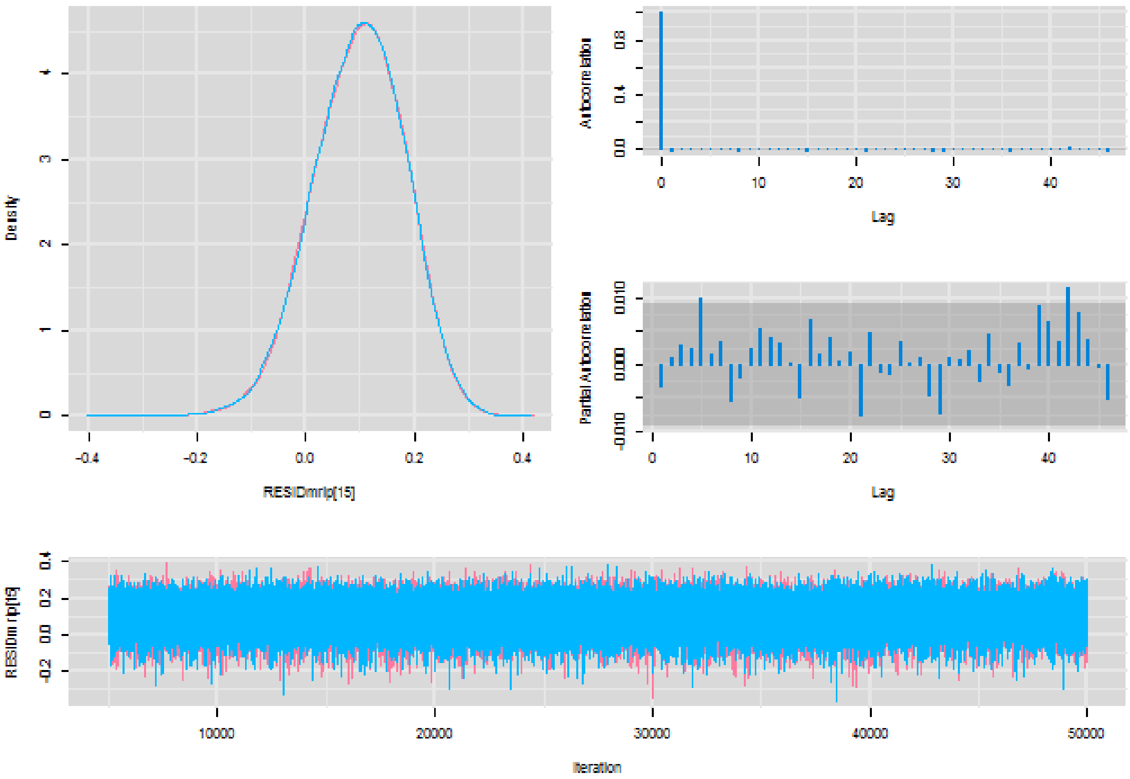
Diagnostics for RESIDmrip[13]



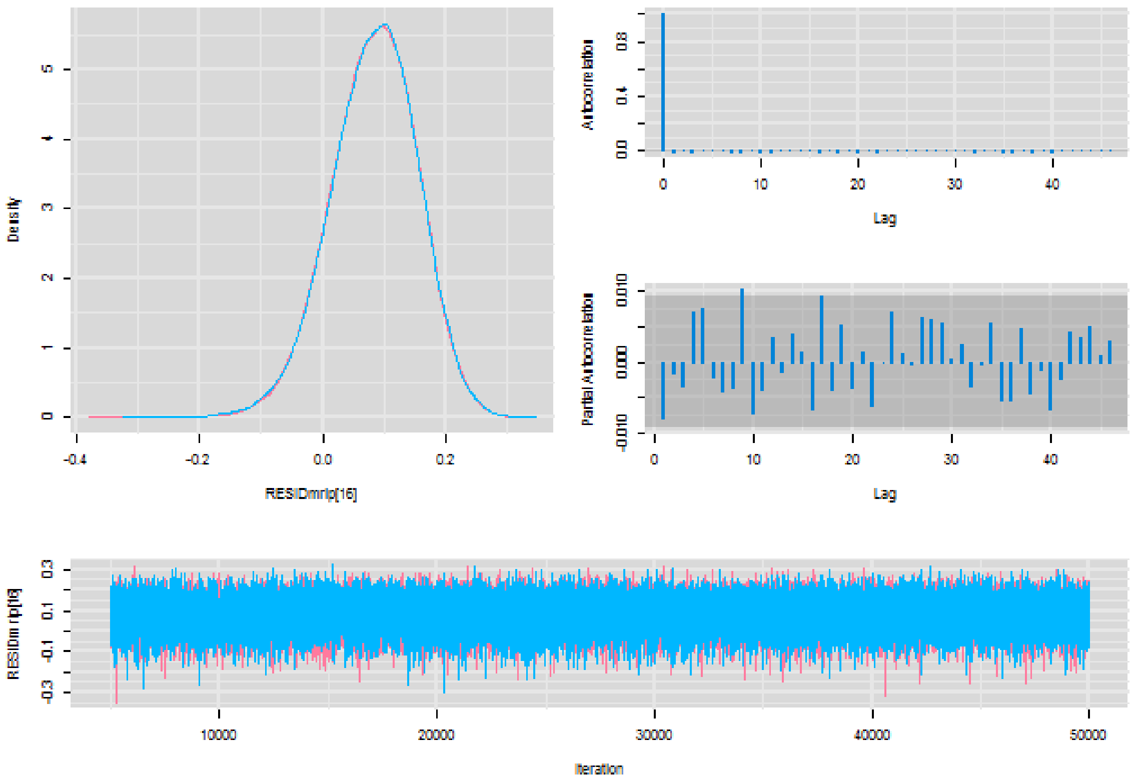
Diagnostics for RESIDmrip[14]



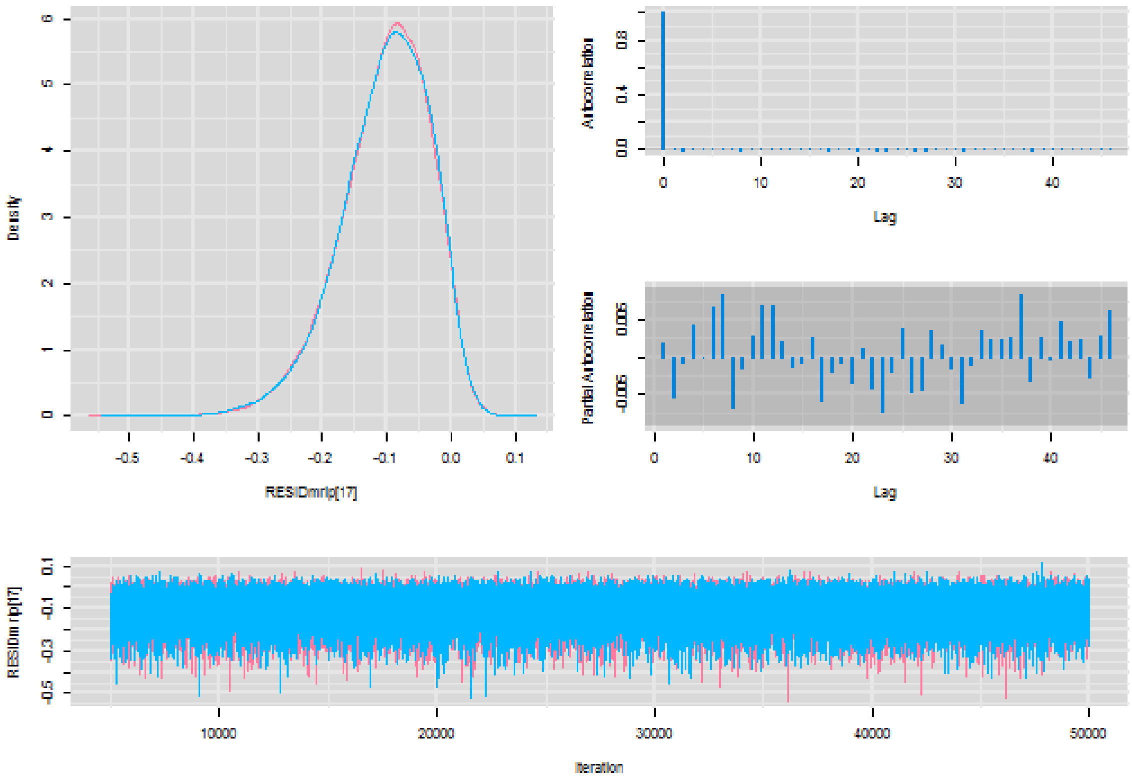
Diagnostics for RESIDmrip[15]



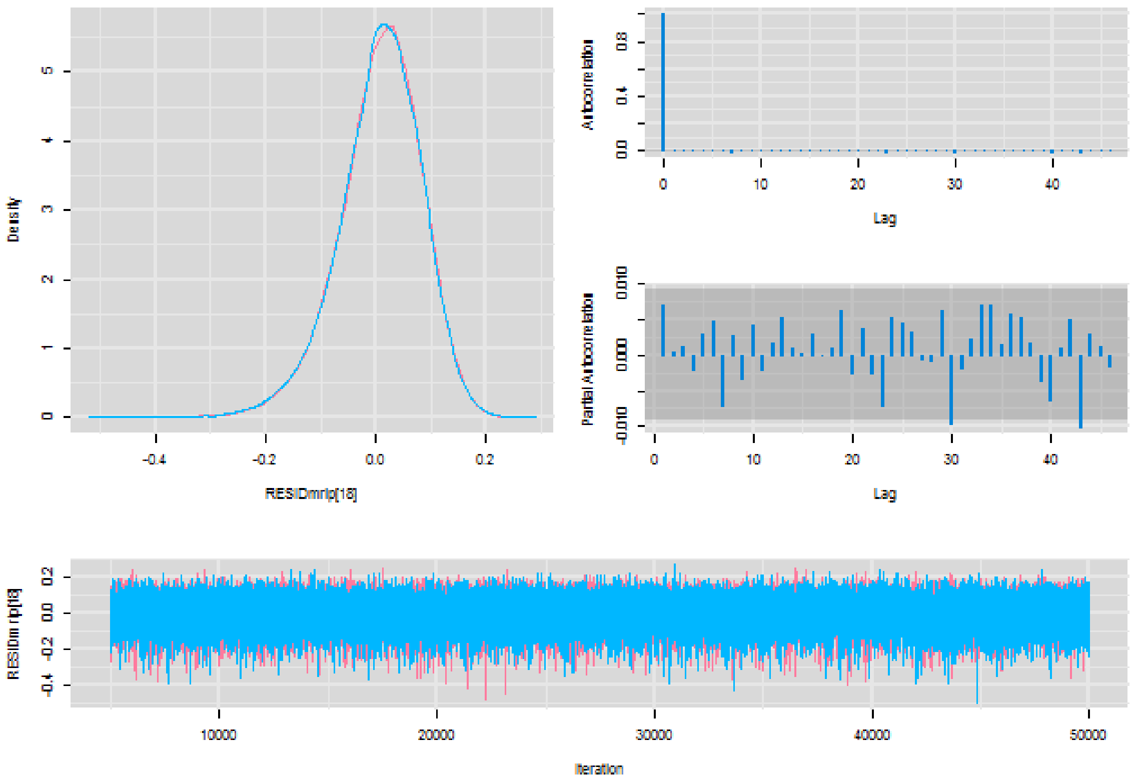
Diagnostics for RESIDmrip[16]



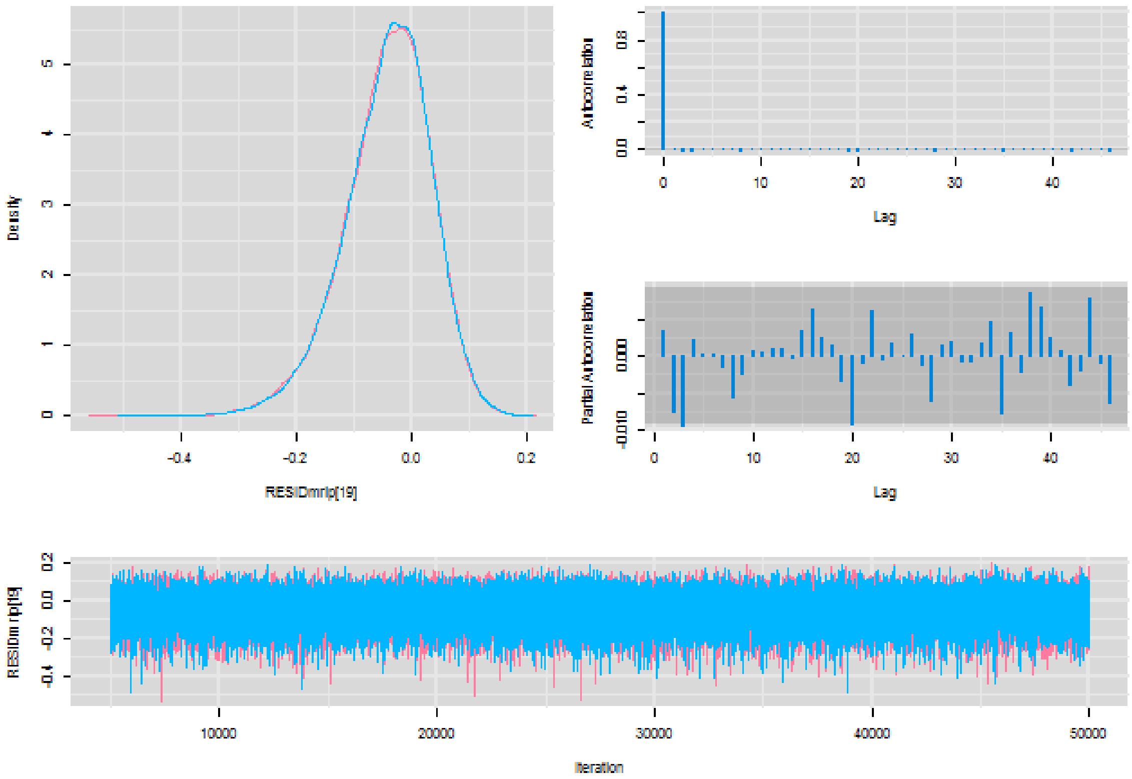
Diagnostics for RESIDmrip[17]



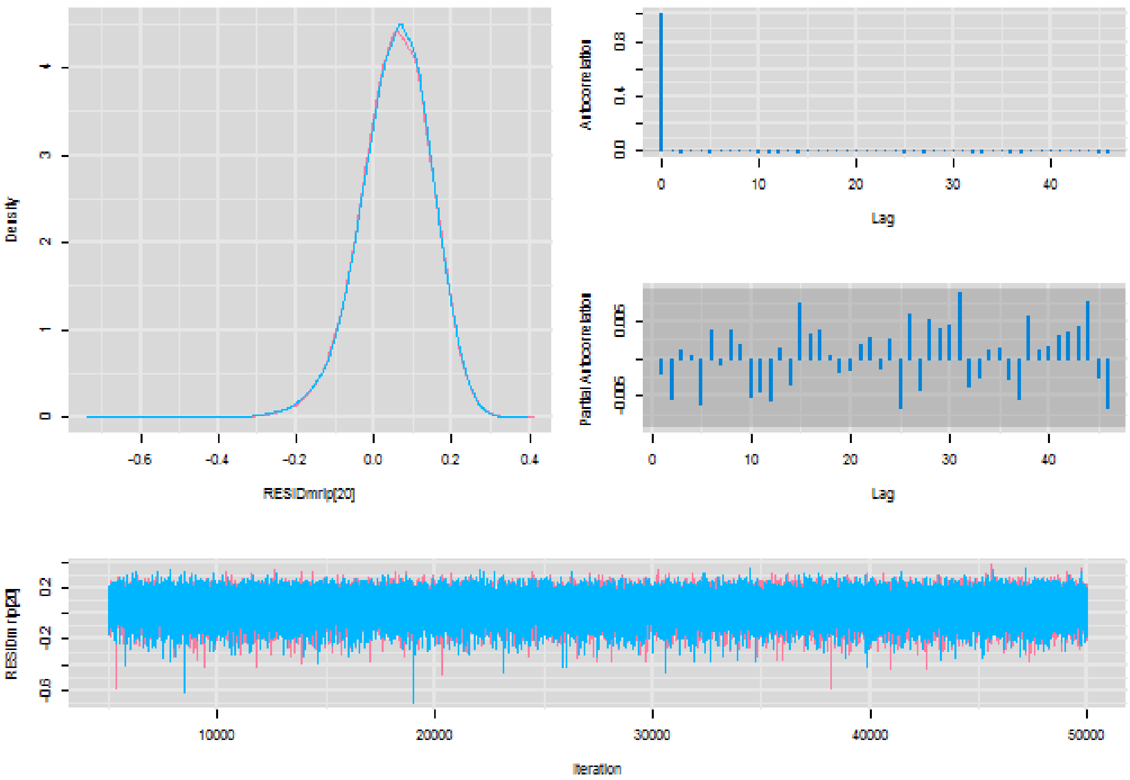
Diagnostics for RESIDmrip[18]



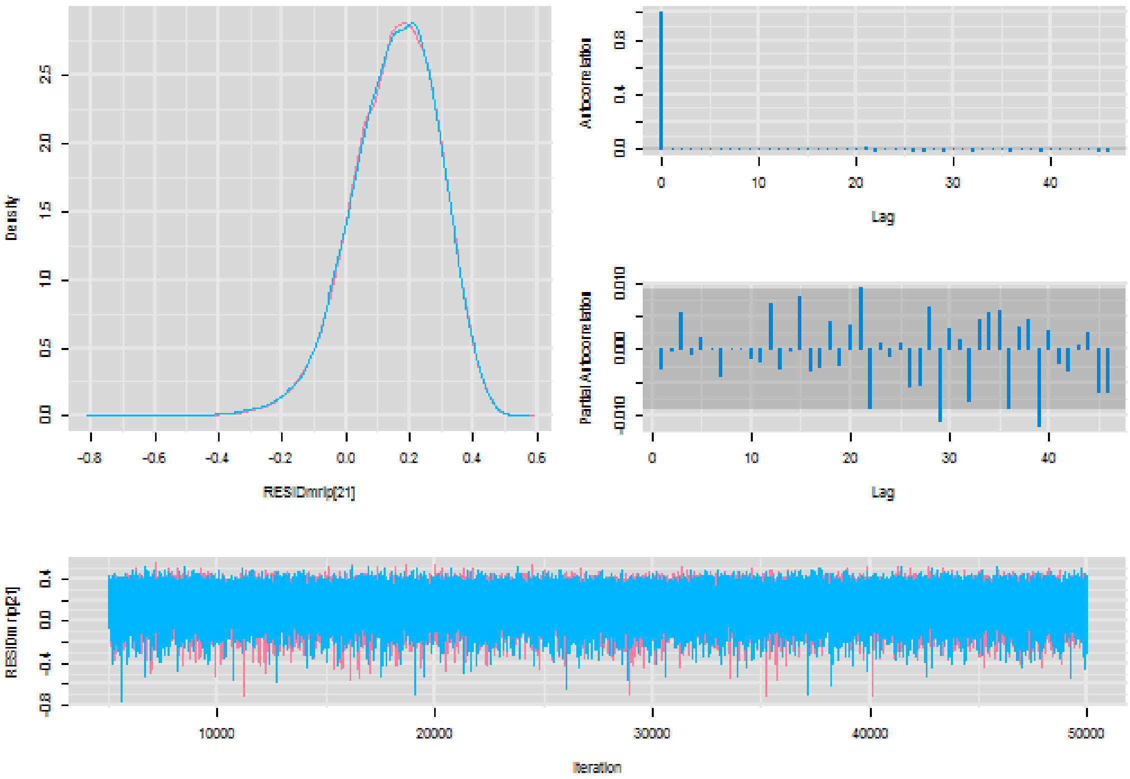
Diagnostics for RESIDmrip[19]



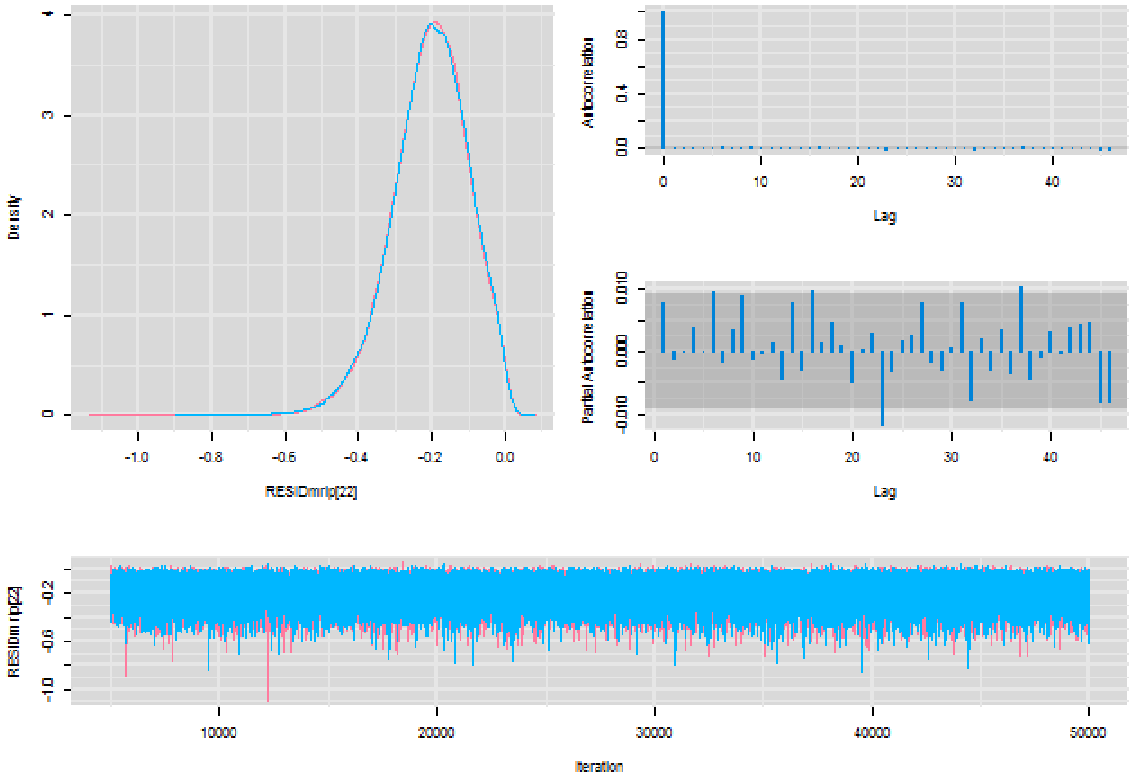
Diagnostics for RESIDmrip[20]



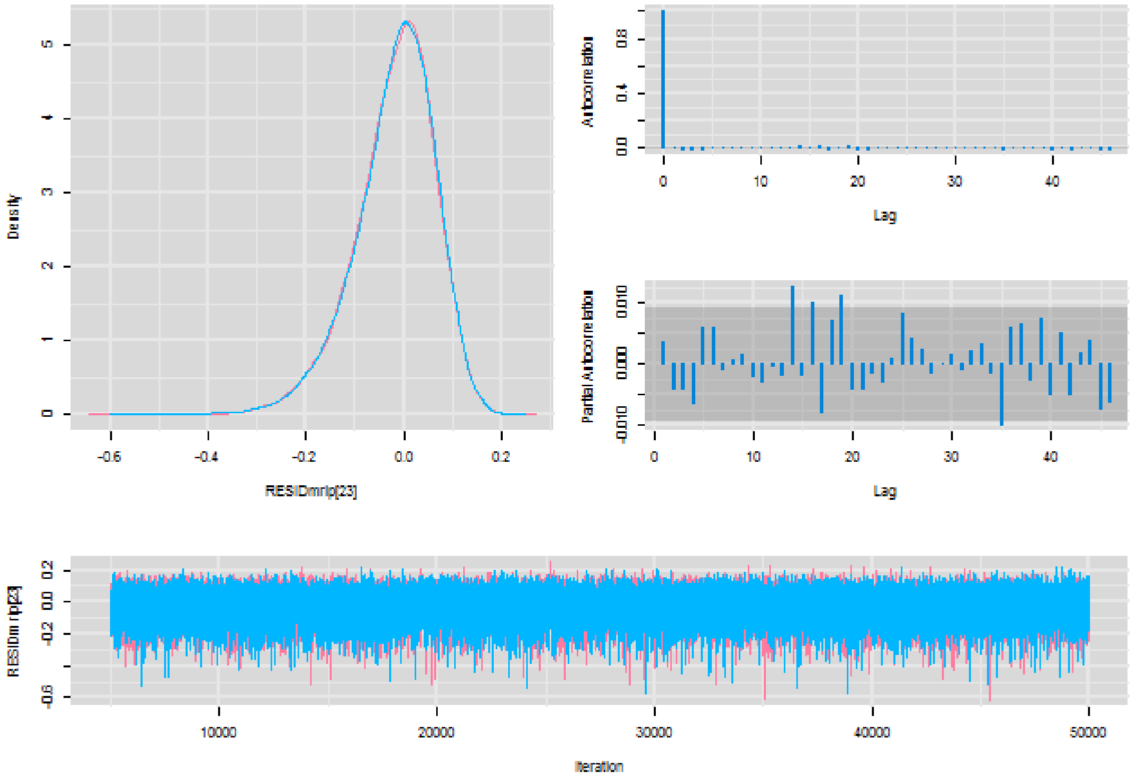
Diagnostics for RESIDmrip[21]



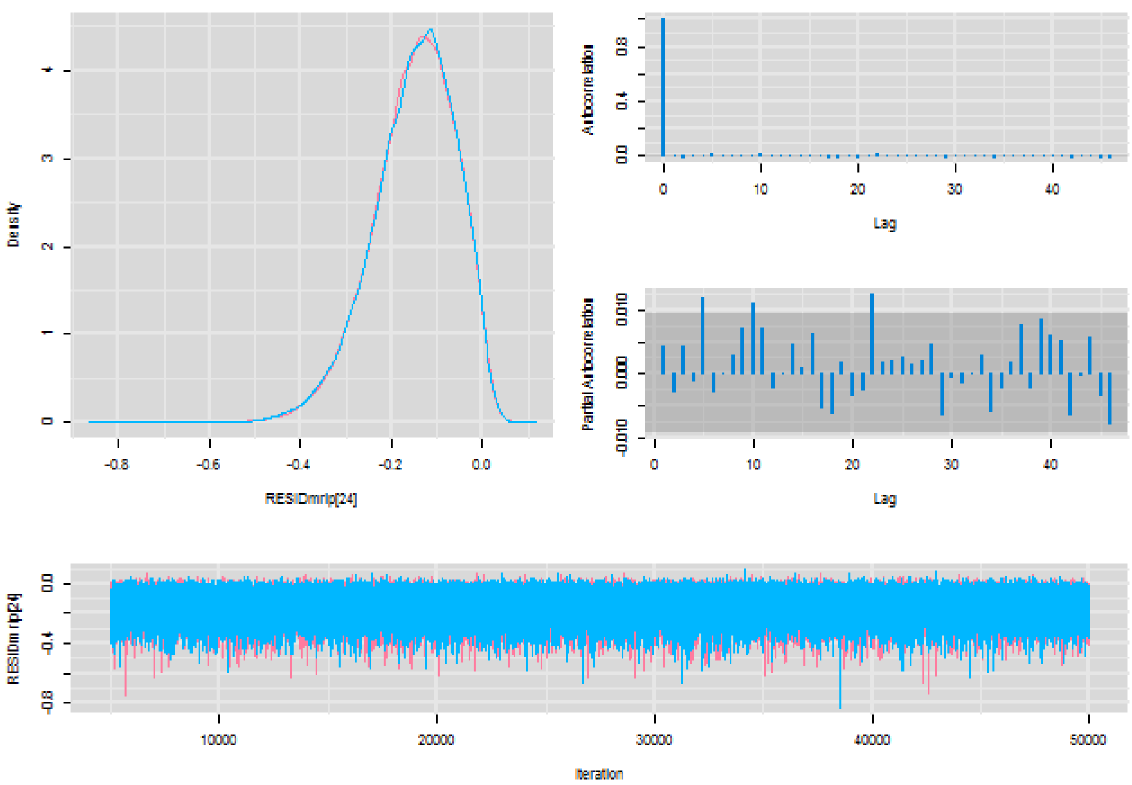
Diagnostics for RESIDmrip[22]



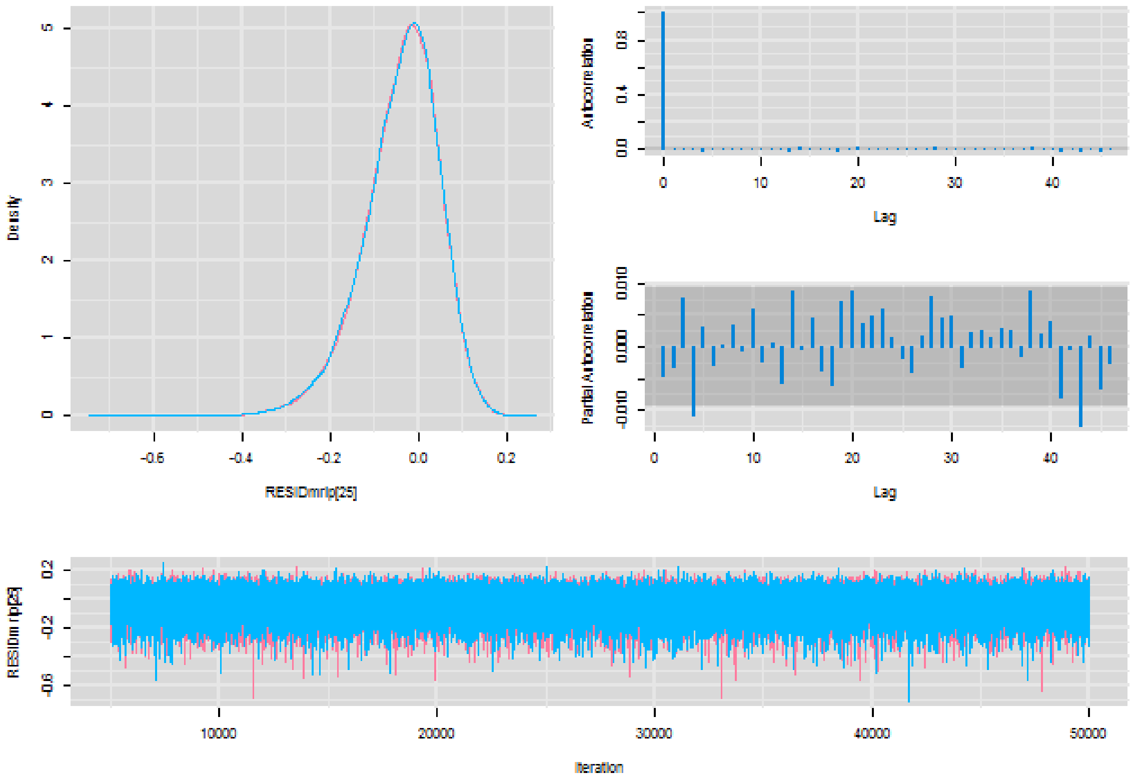
Diagnostics for RESIDmrip[23]



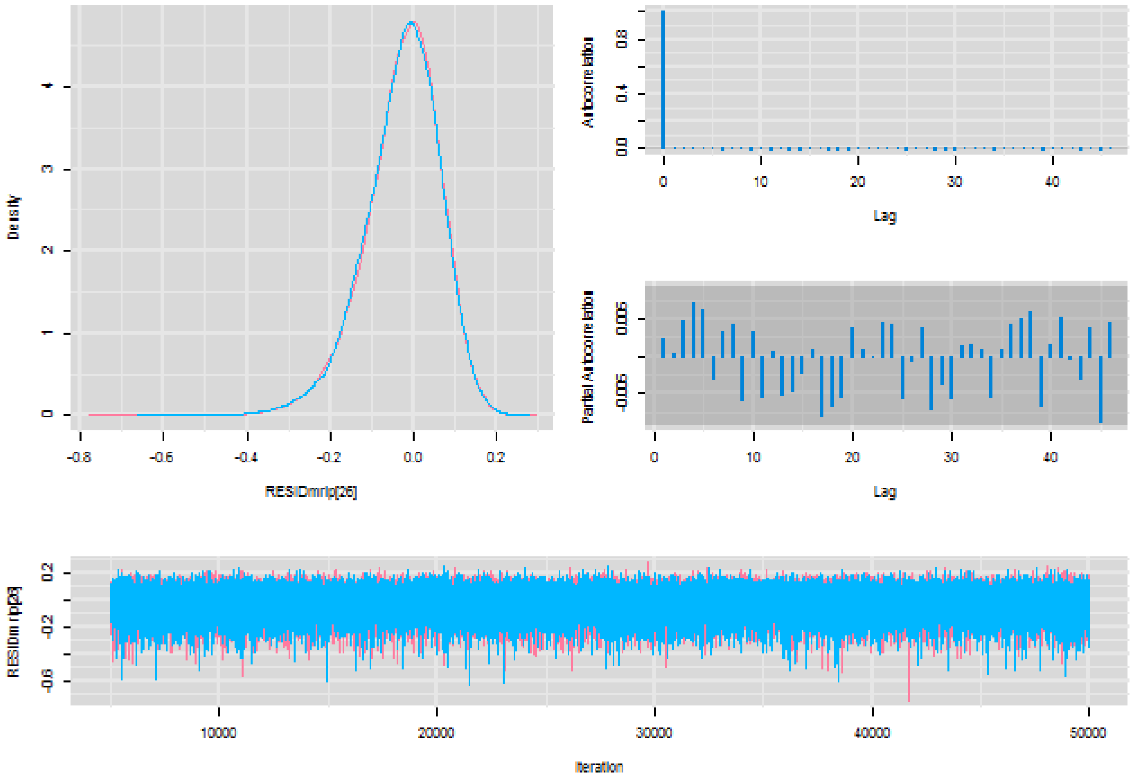
Diagnostics for RESIDmrip[24]



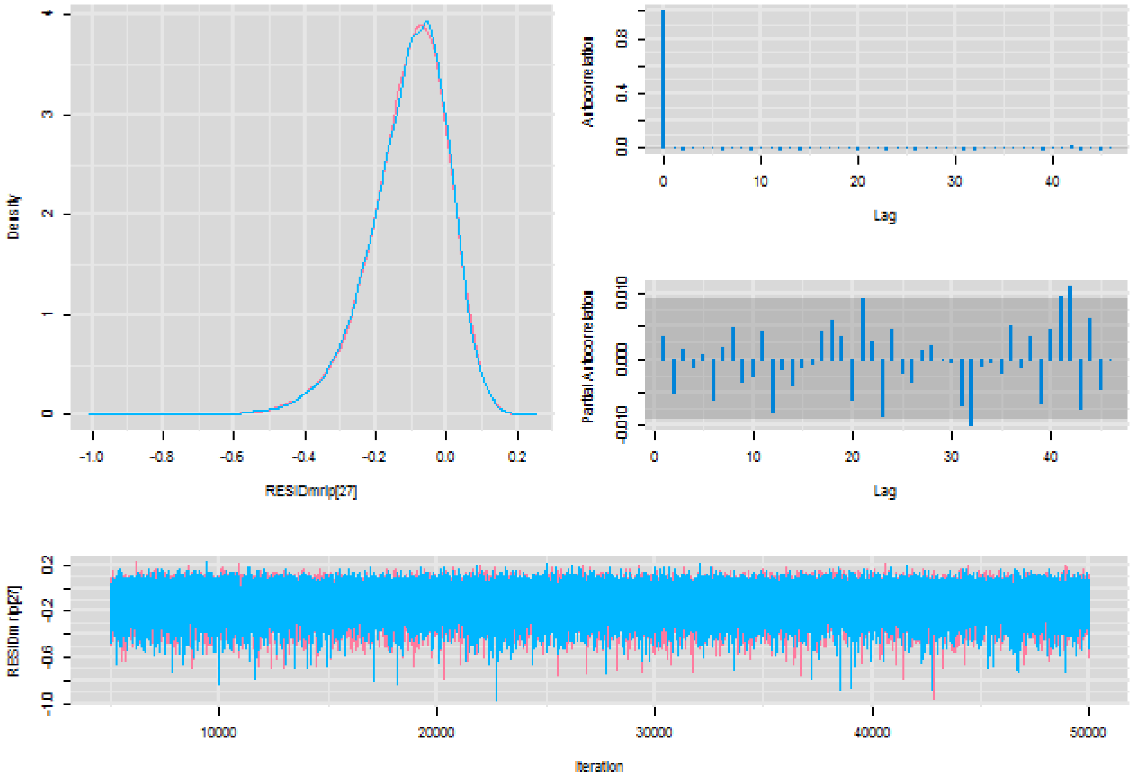
Diagnostics for RESIDmrip[25]



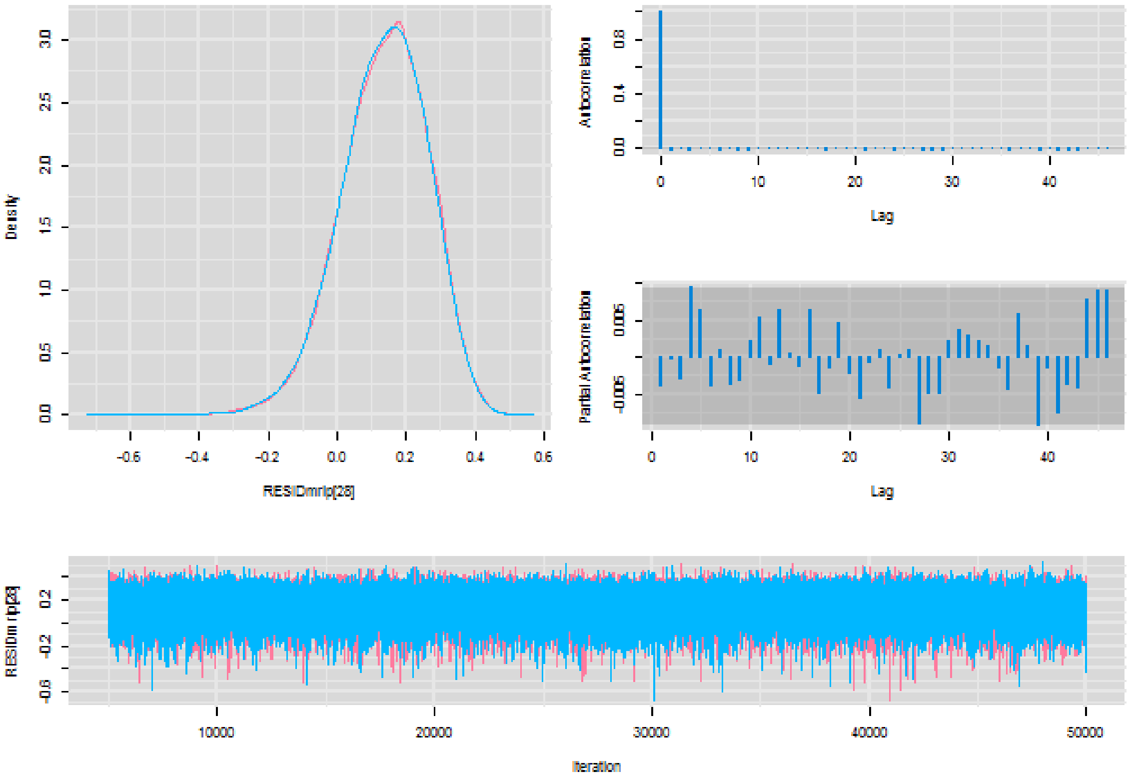
Diagnostics for RESIDmrip[26]



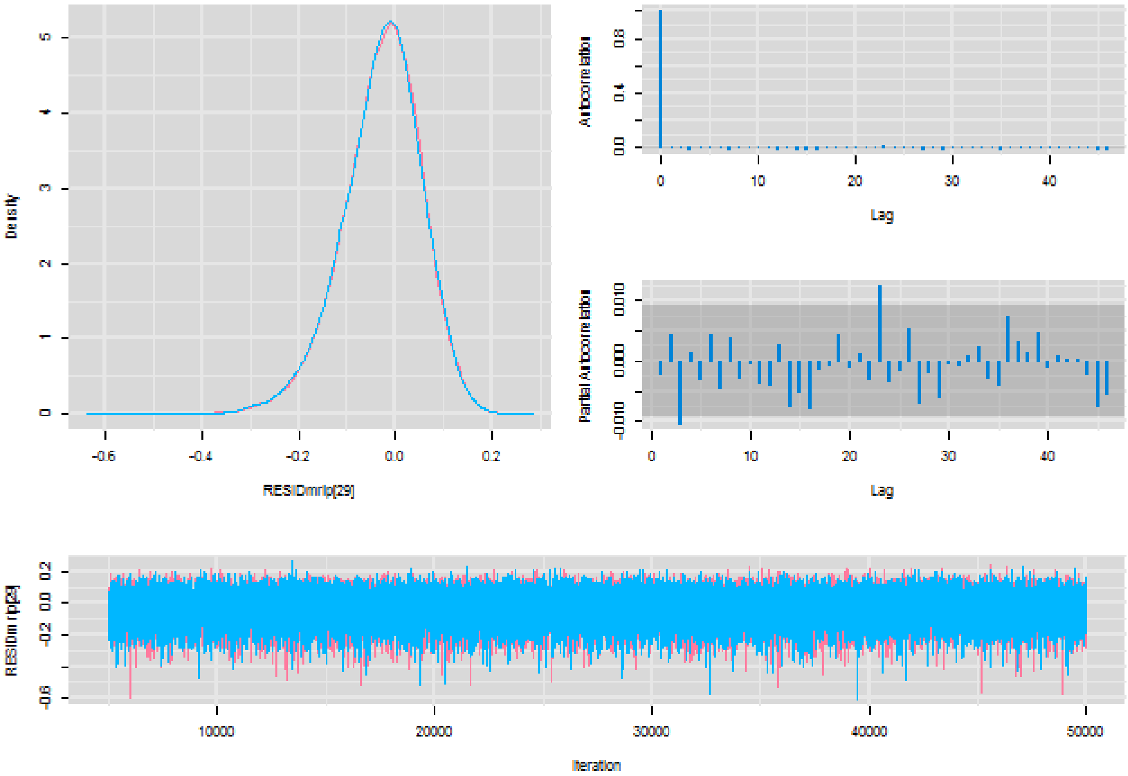
Diagnostics for RESIDmrip[27]



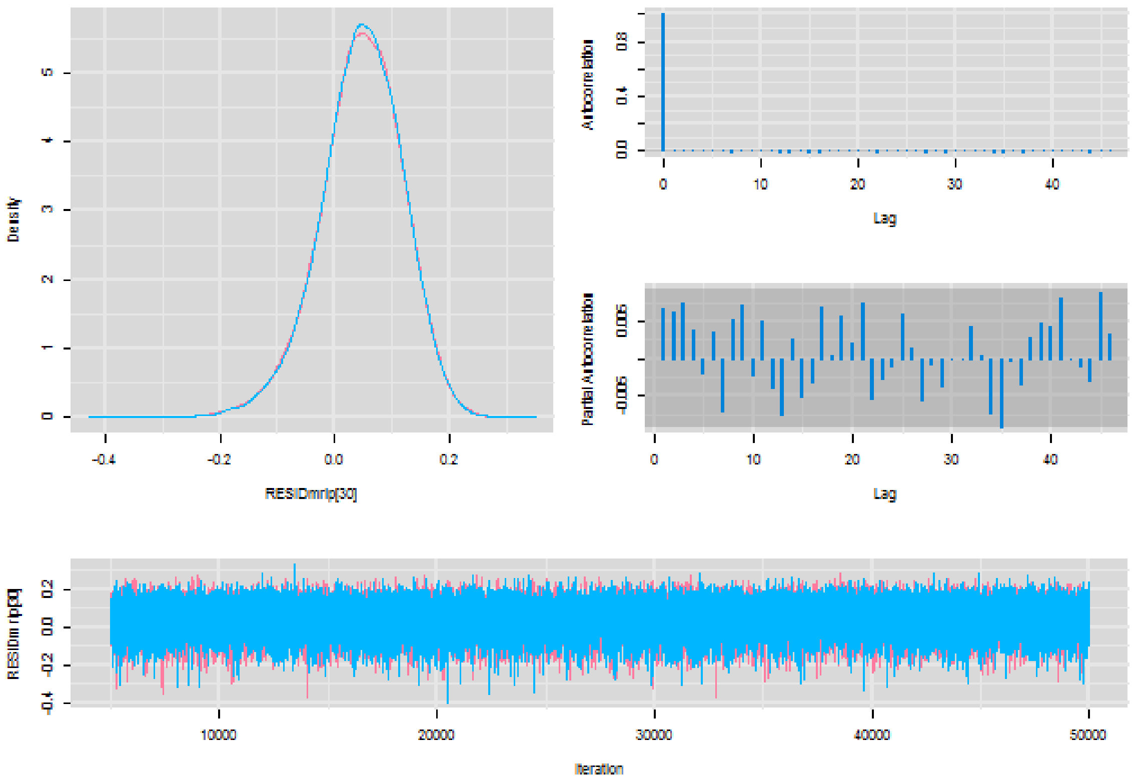
Diagnostics for RESIDmrip[28]



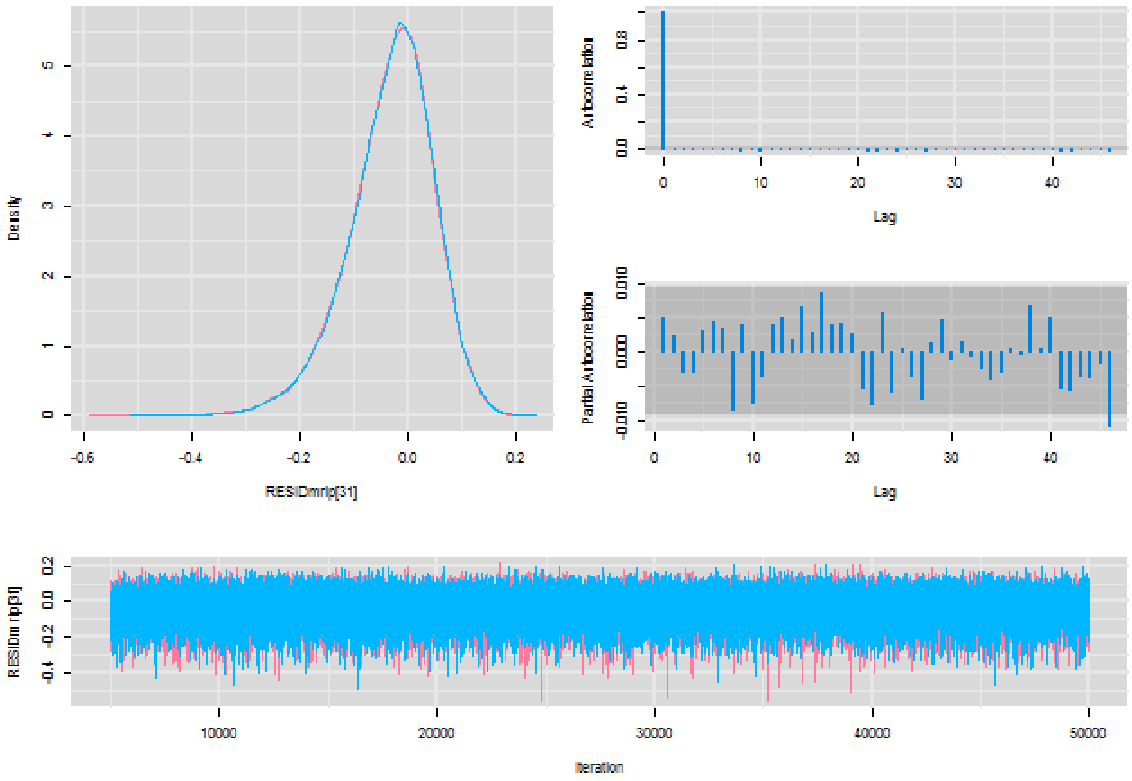
Diagnostics for RESIDmrip[29]



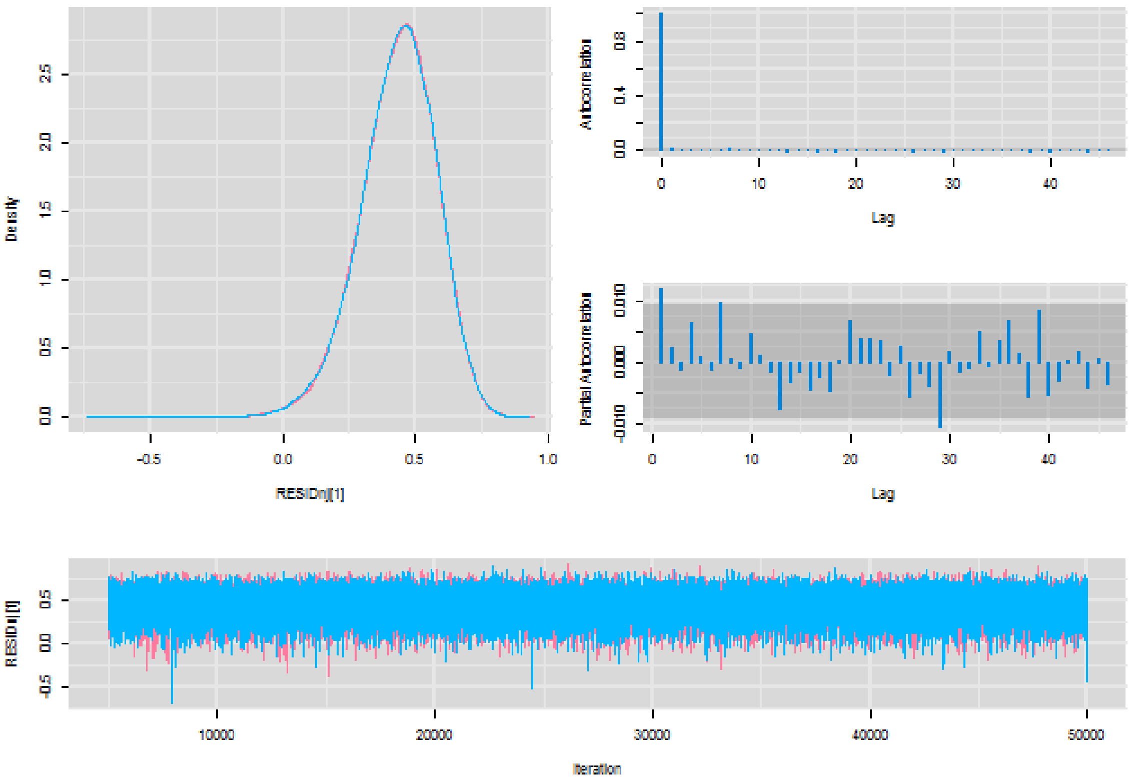
Diagnostics for RESIDmrip[30]



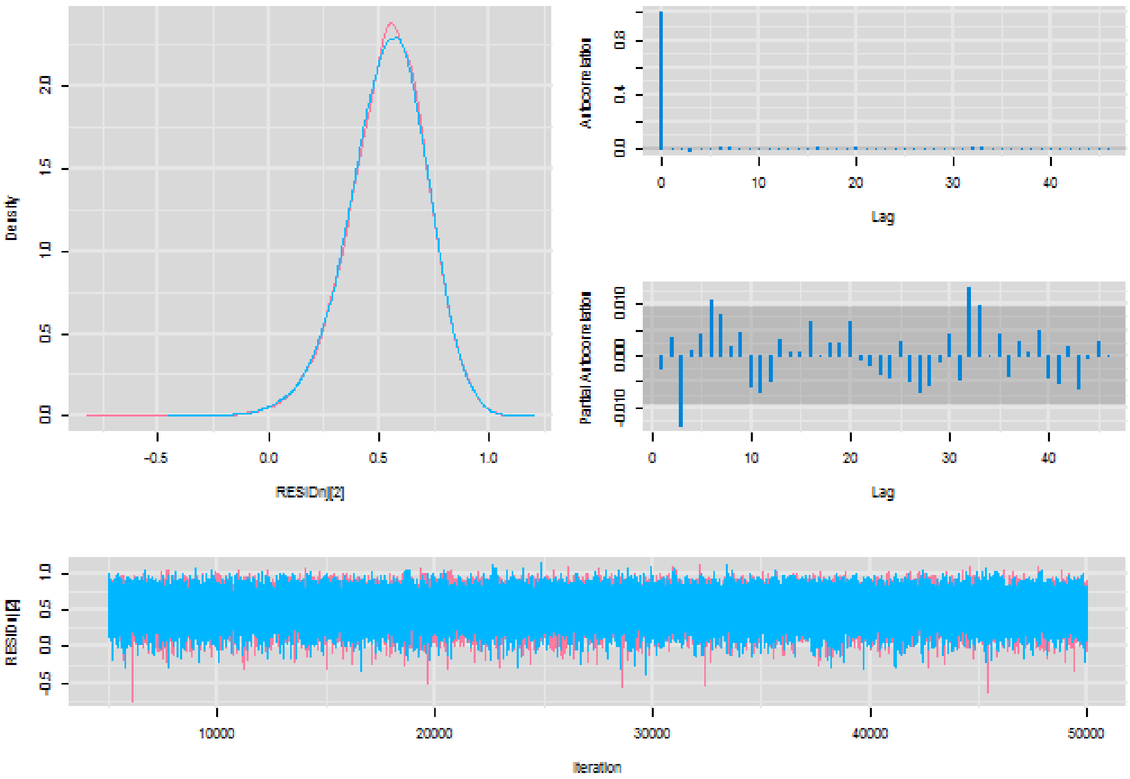
Diagnostics for RESIDmrip[31]



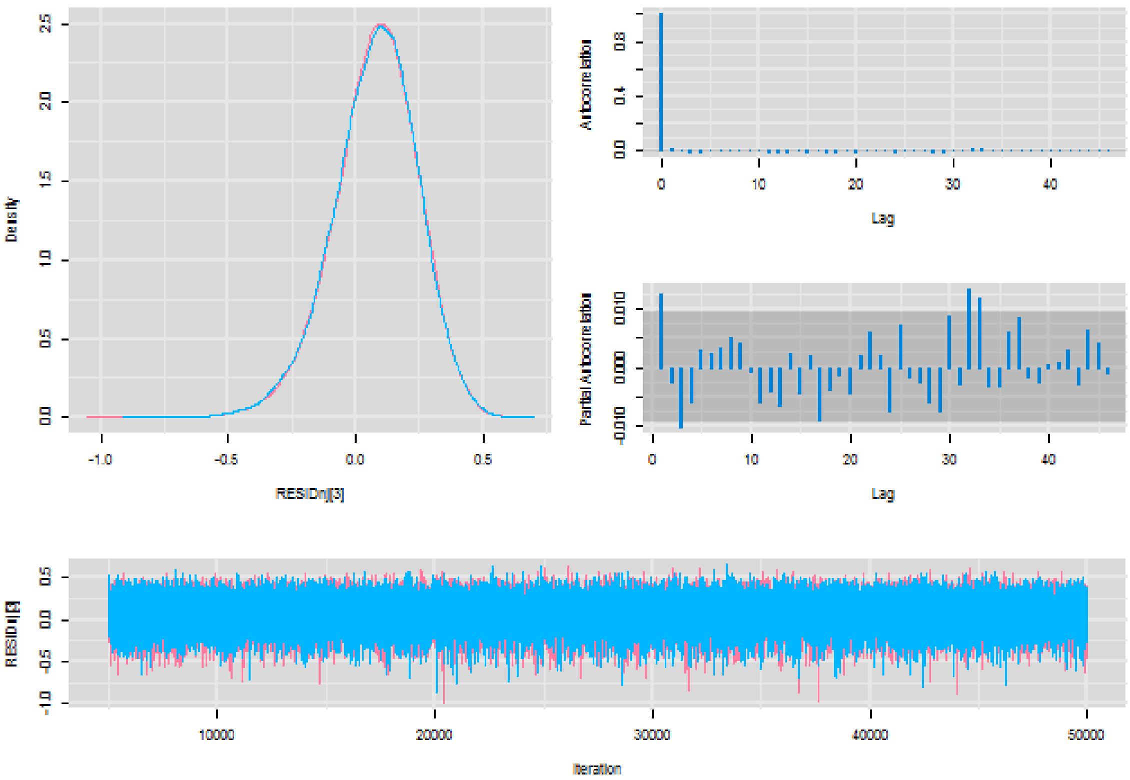
Diagnostics for RESIDnj[1]



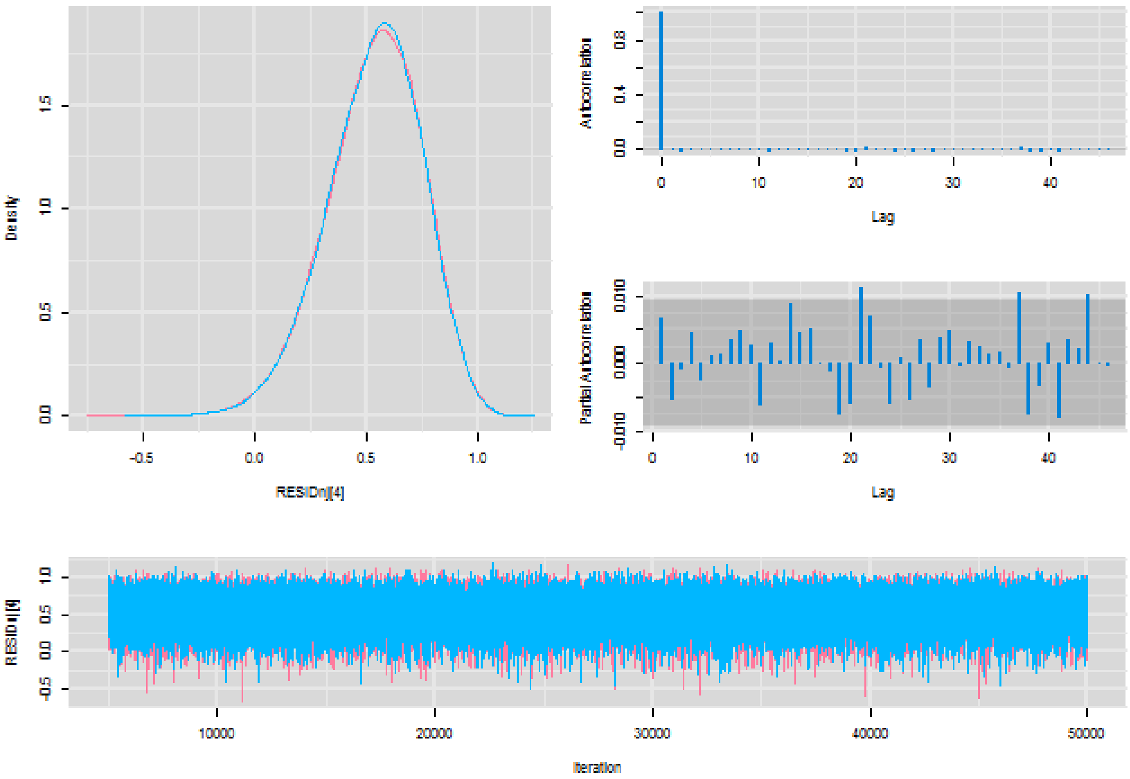
Diagnostics for RESIDnj[2]



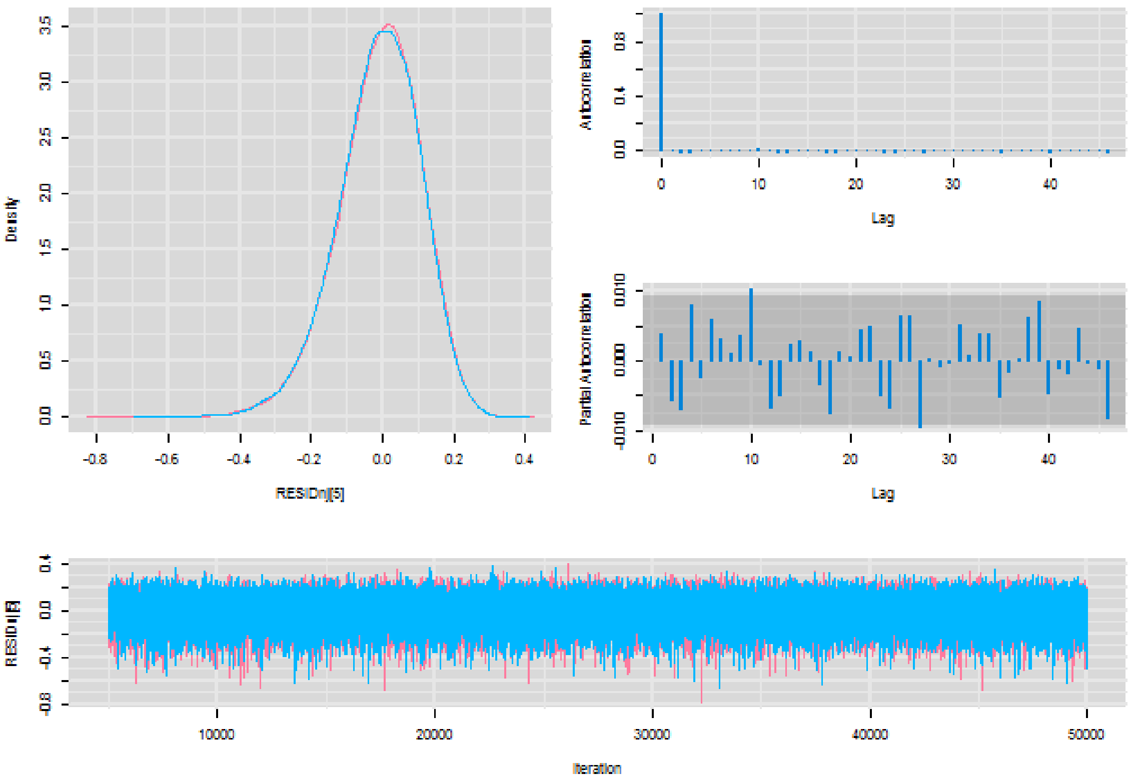
Diagnostics for RESIDnj[3]



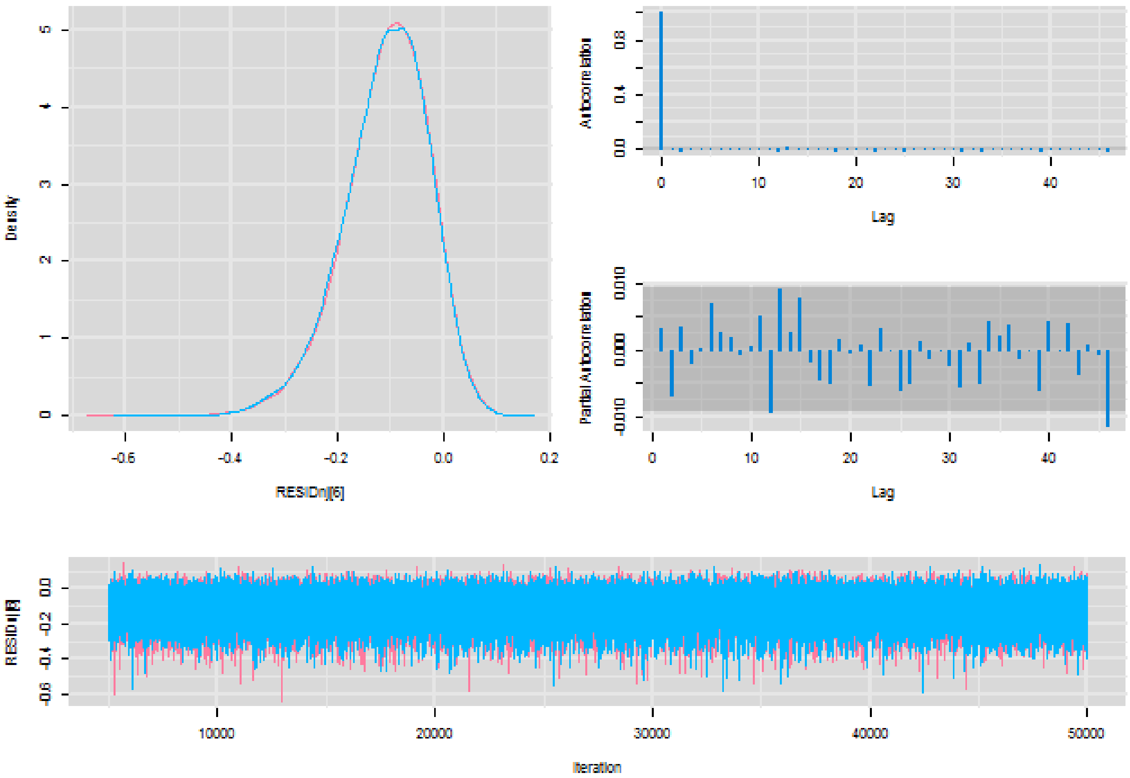
Diagnostics for RESIDnj[4]



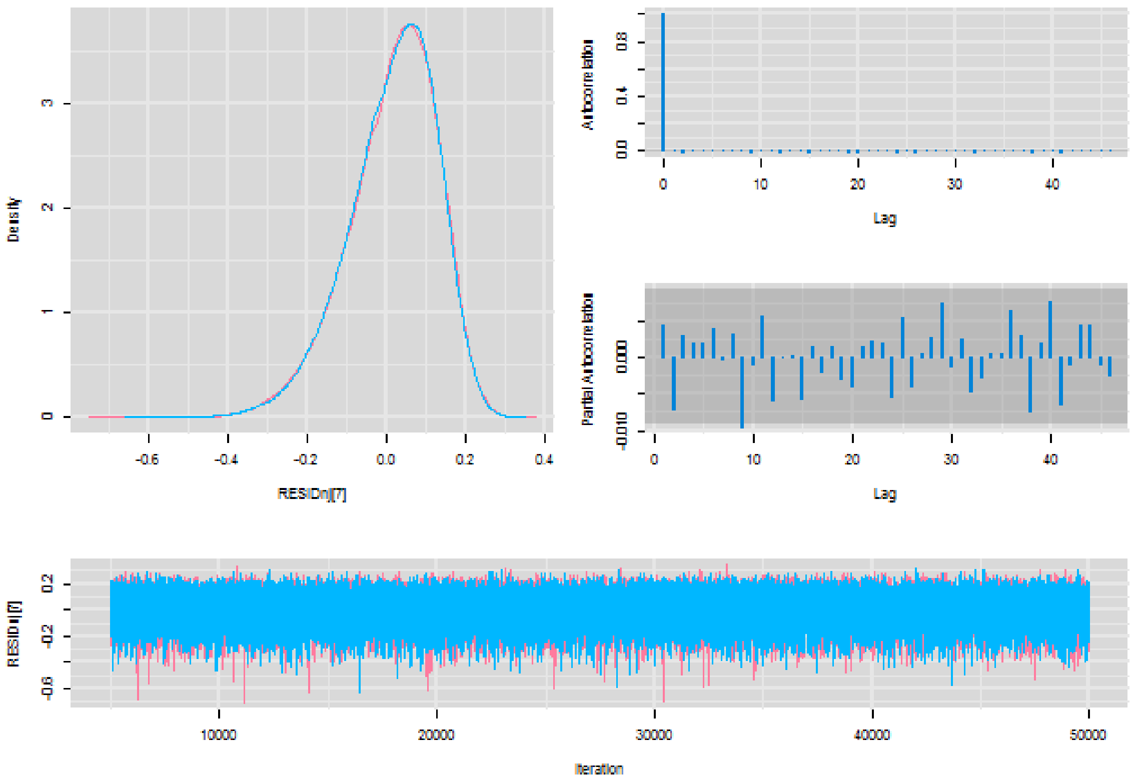
Diagnostics for RESIDnj[5]



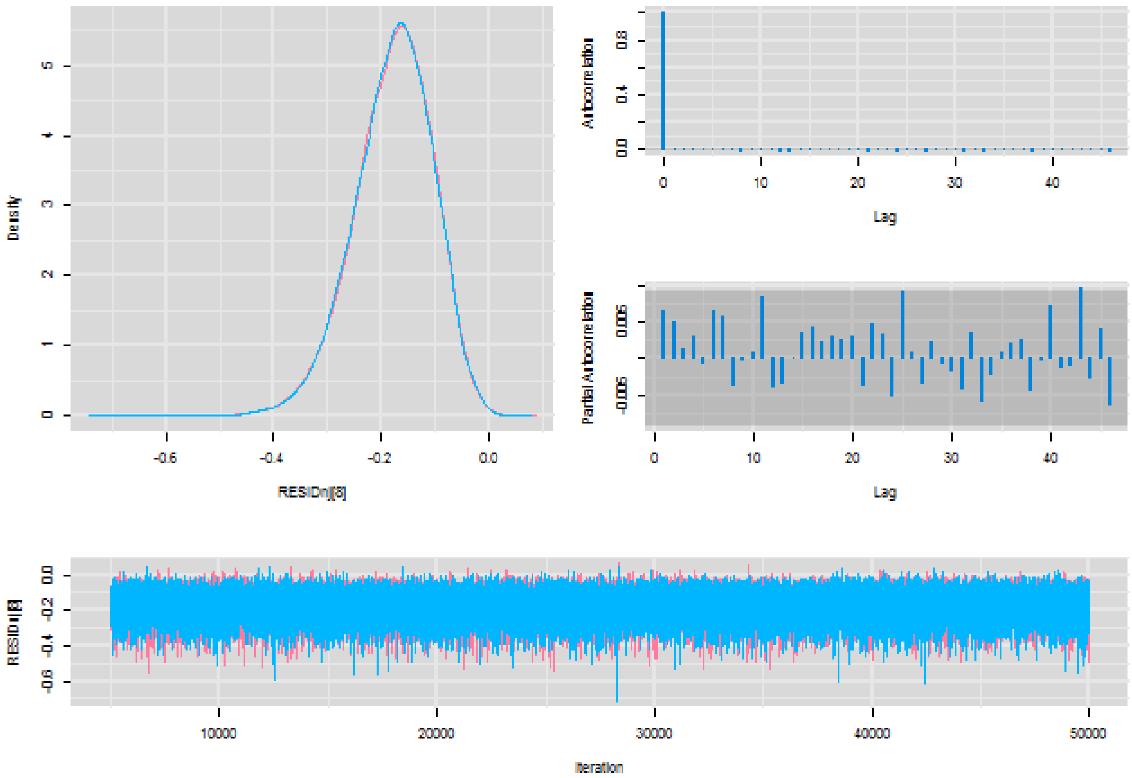
Diagnostics for RESIDnj[6]



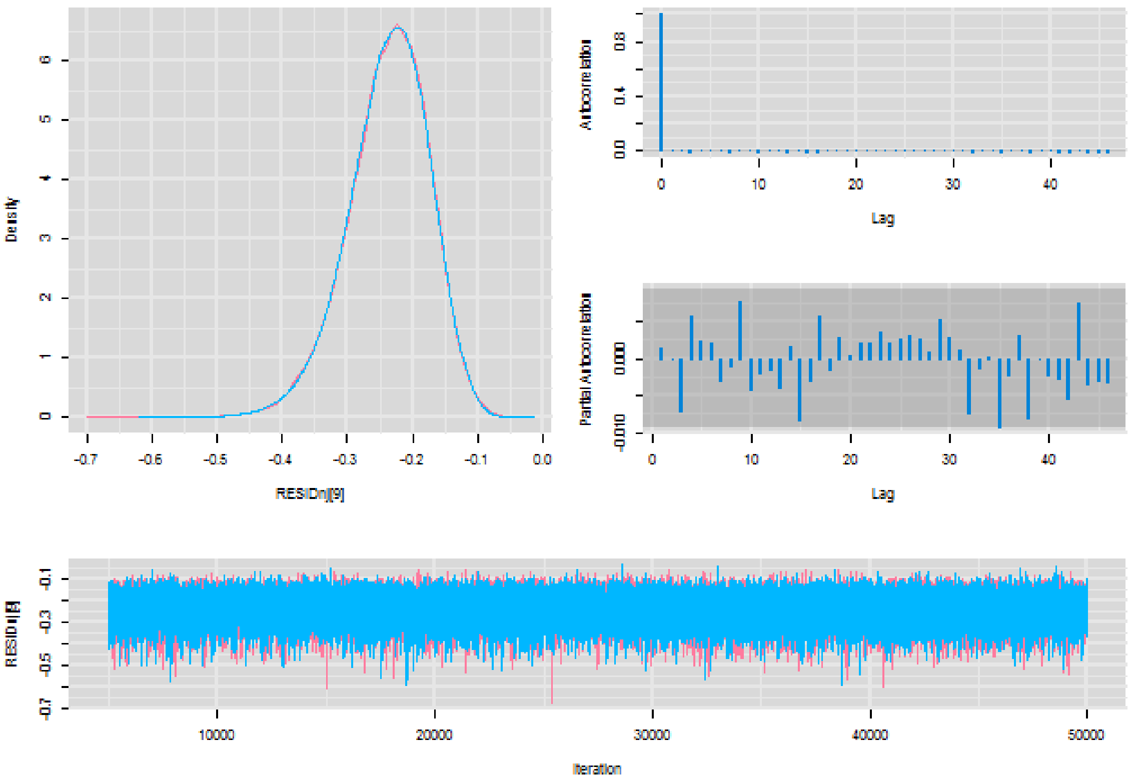
Diagnostics for RESIDnj[7]



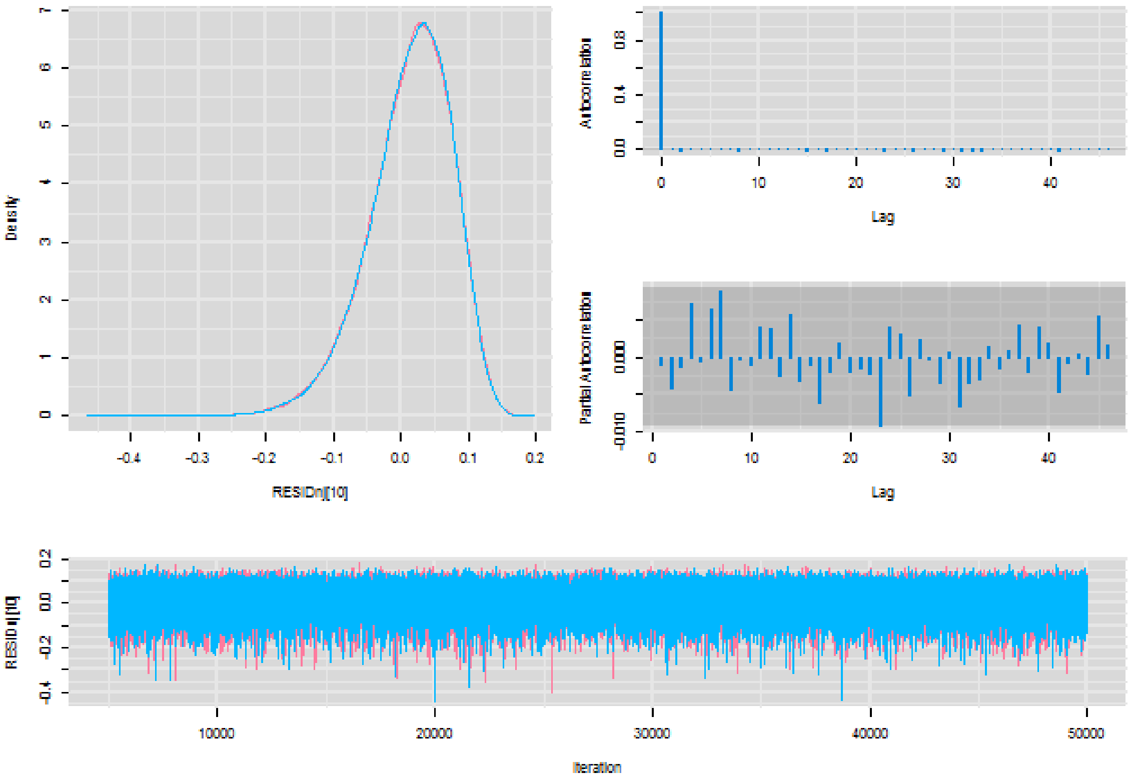
Diagnostics for RESIDnj[8]



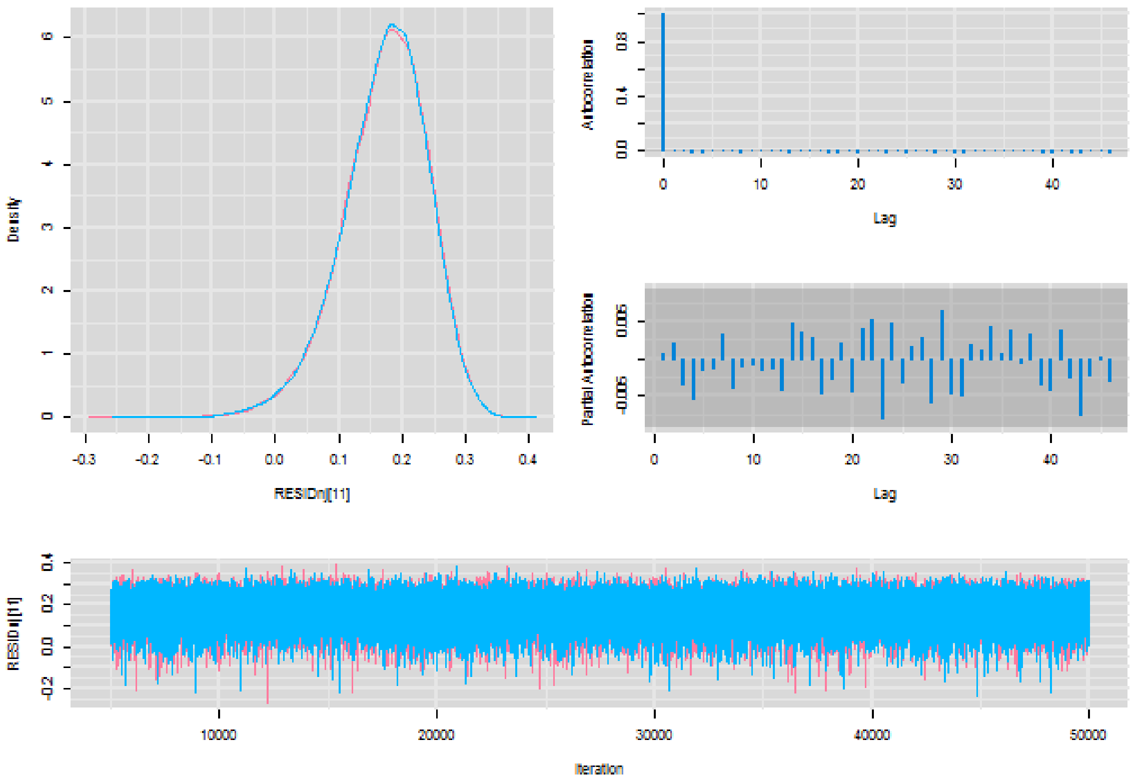
Diagnostics for RESIDnj[9]



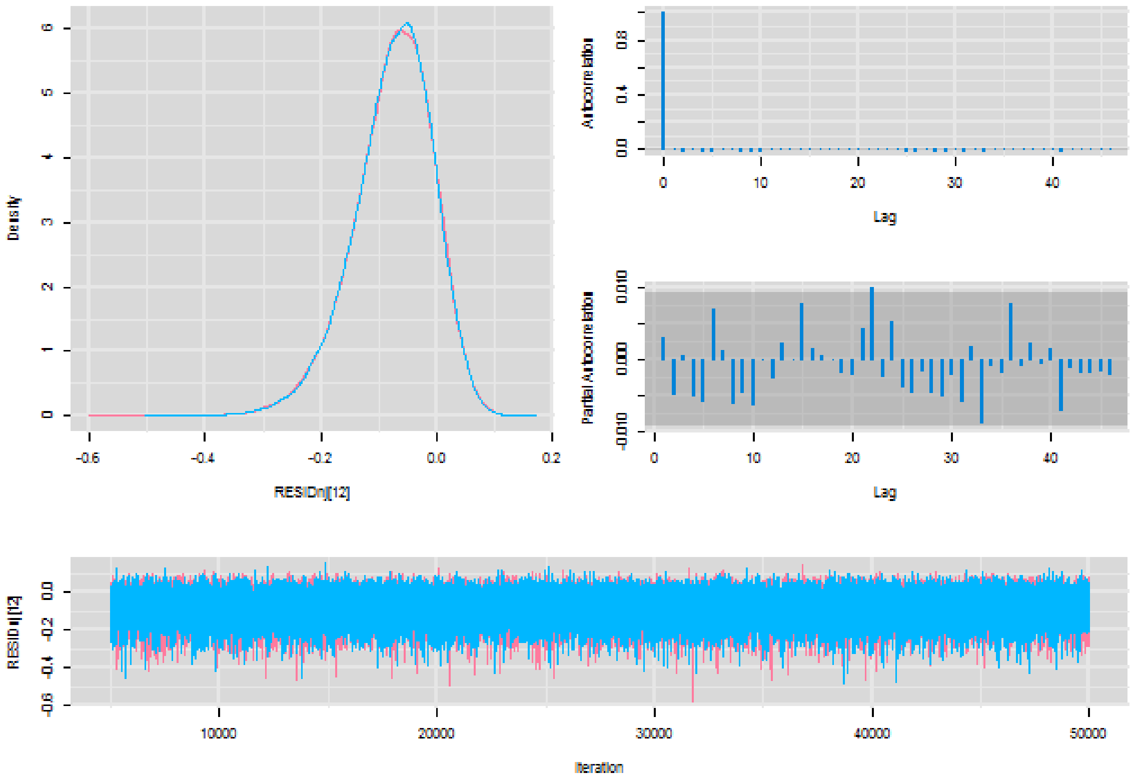
Diagnostics for RESIDnj[10]



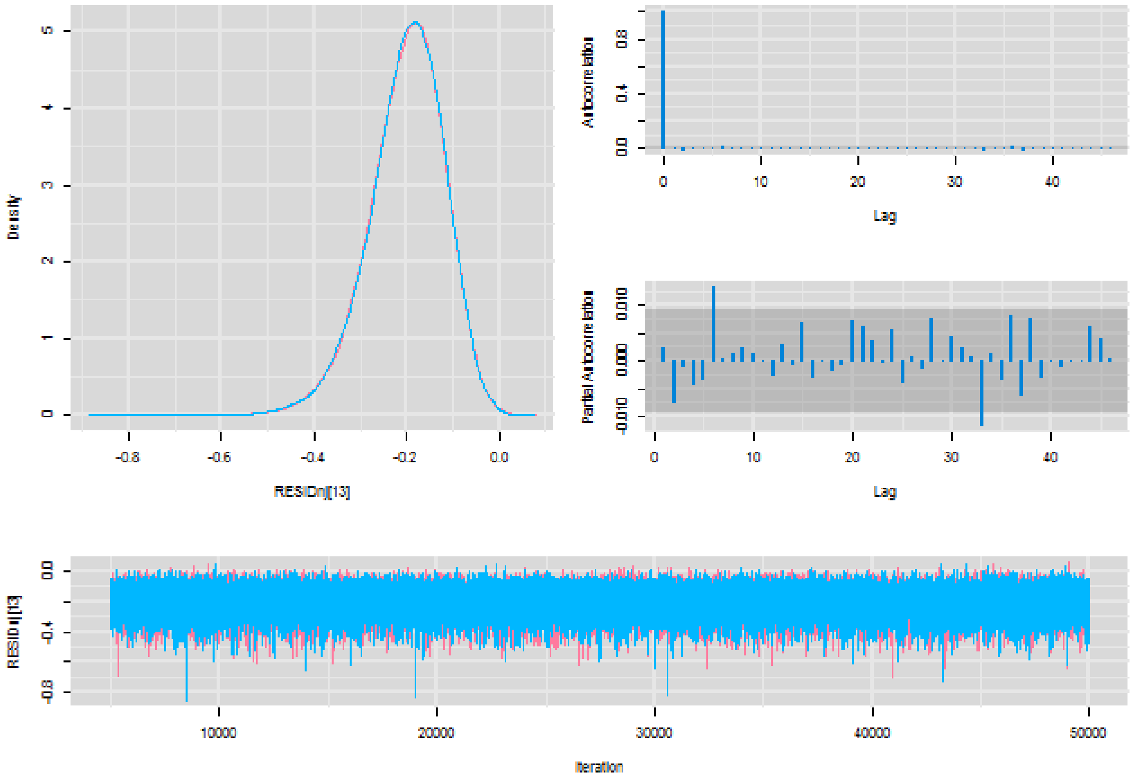
Diagnostics for RESIDnj[11]



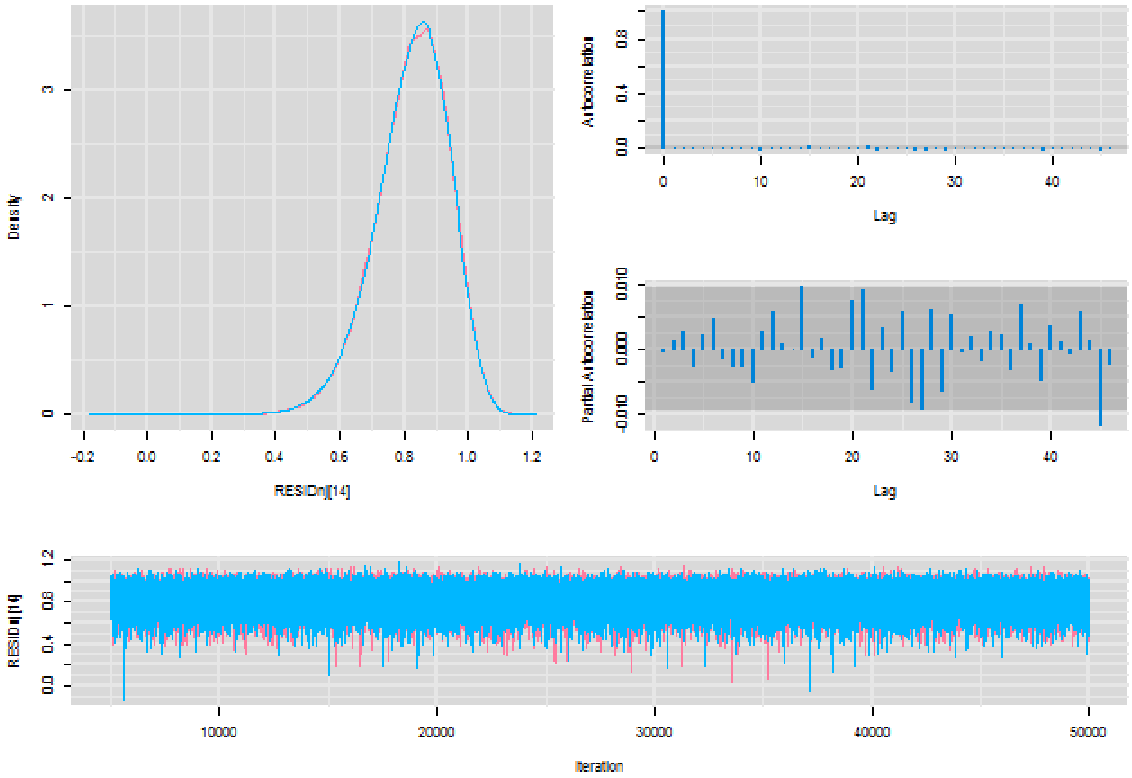
Diagnostics for RESIDnj[12]



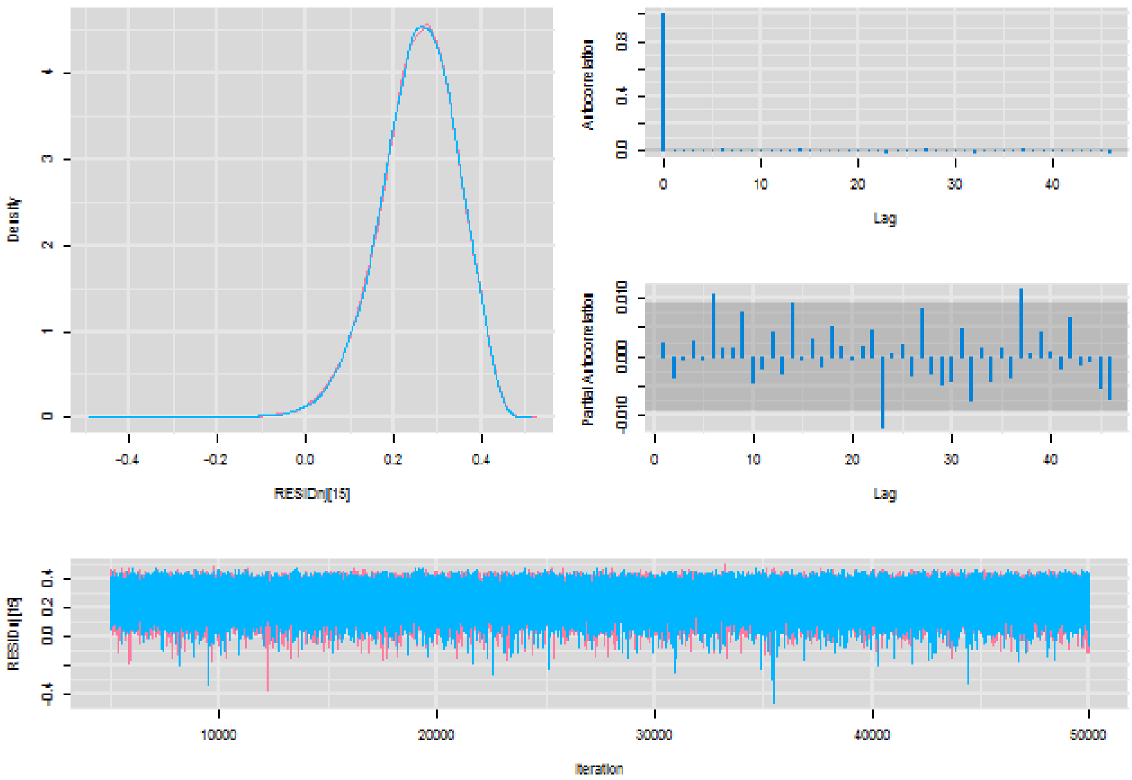
Diagnostics for RESIDnj[13]



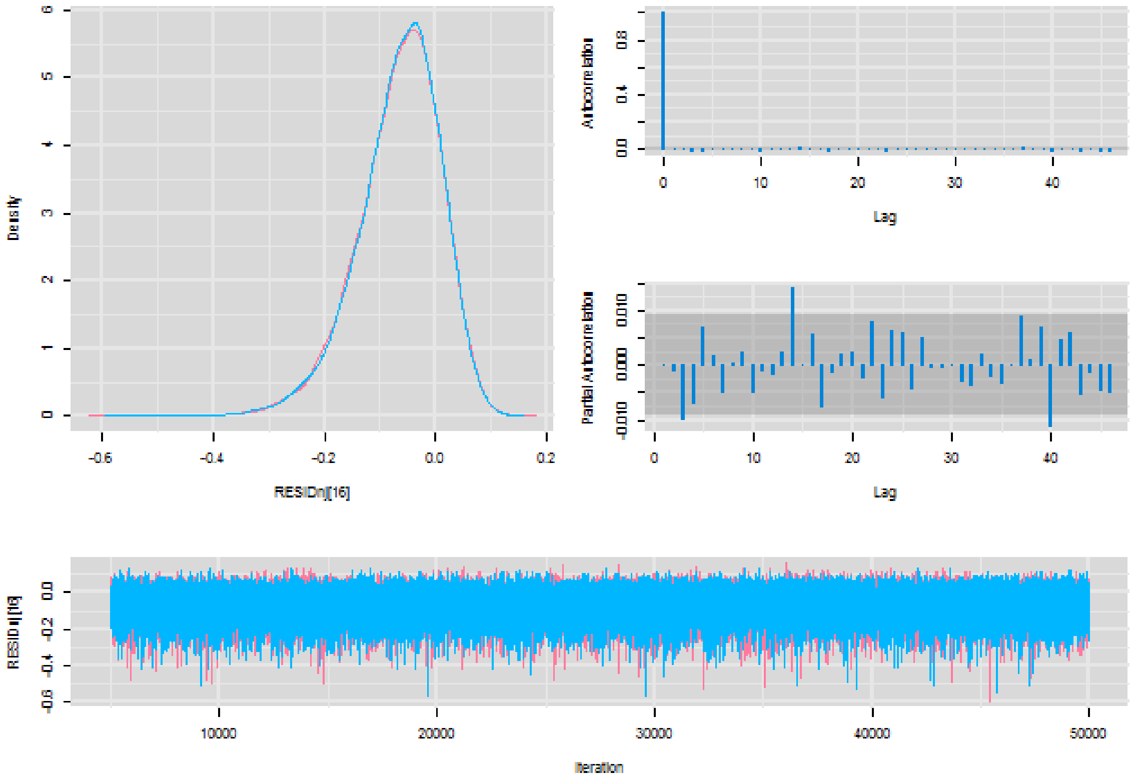
Diagnostics for RESIDnj[14]



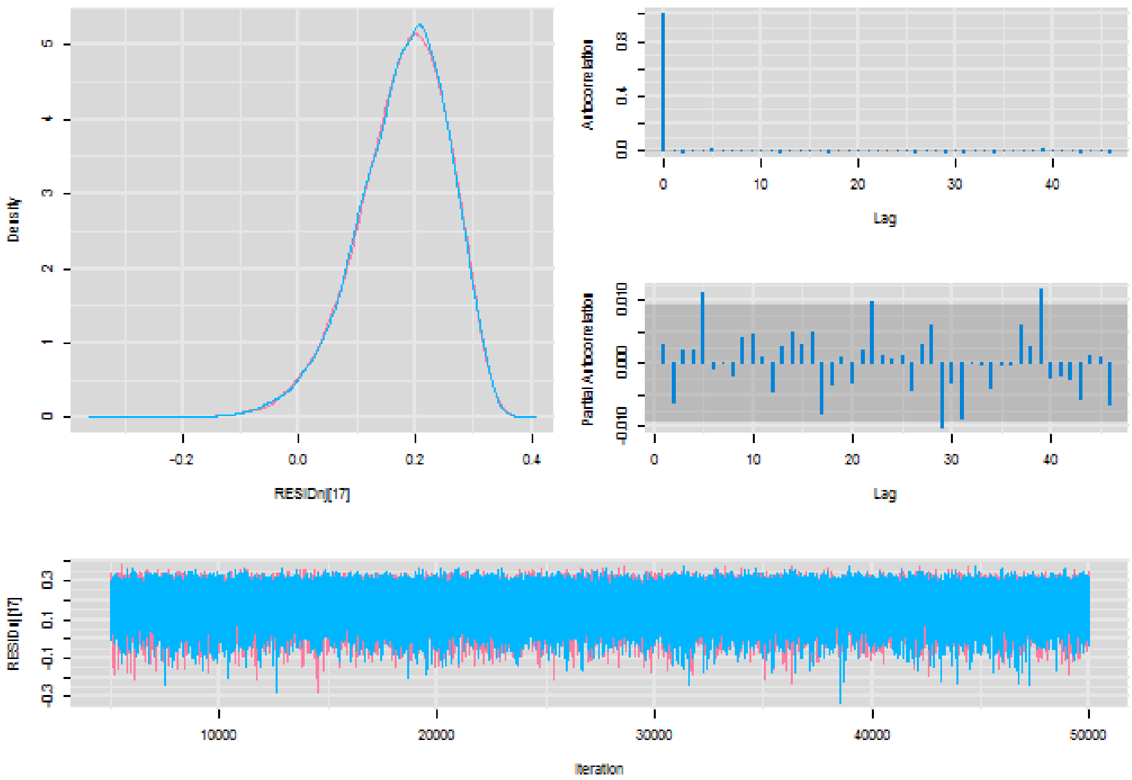
Diagnostics for RESIDnj[15]



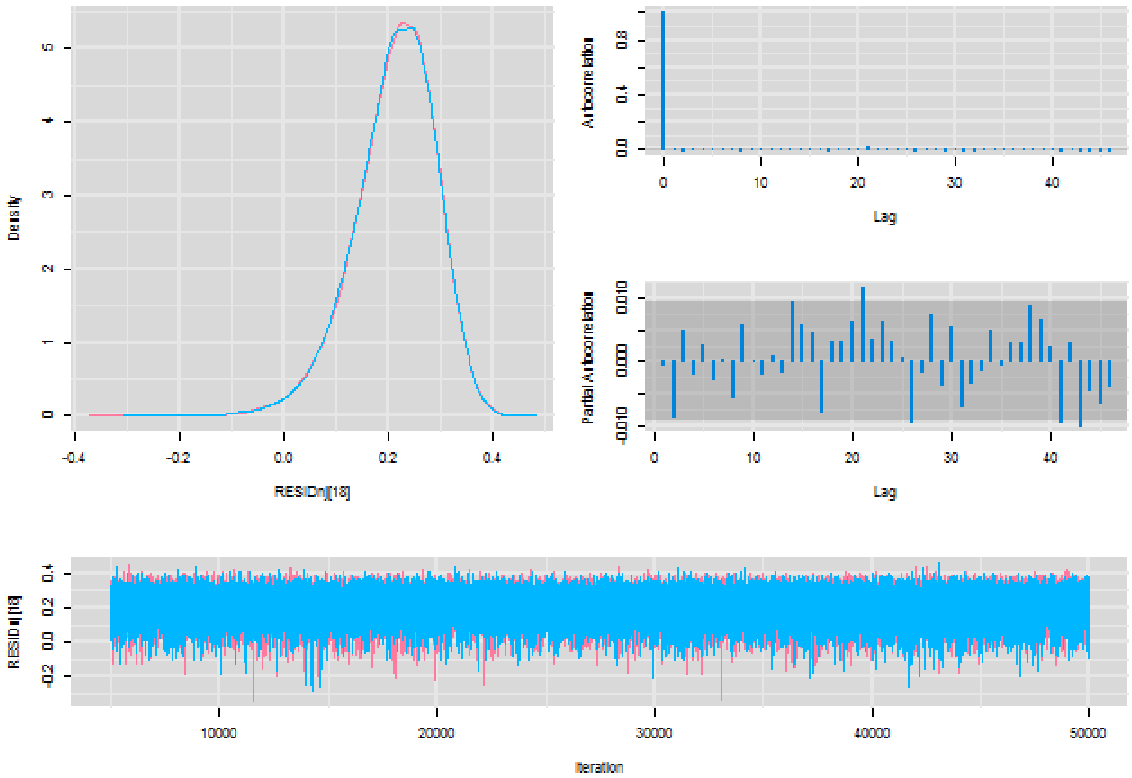
Diagnostics for RESIDnj[16]



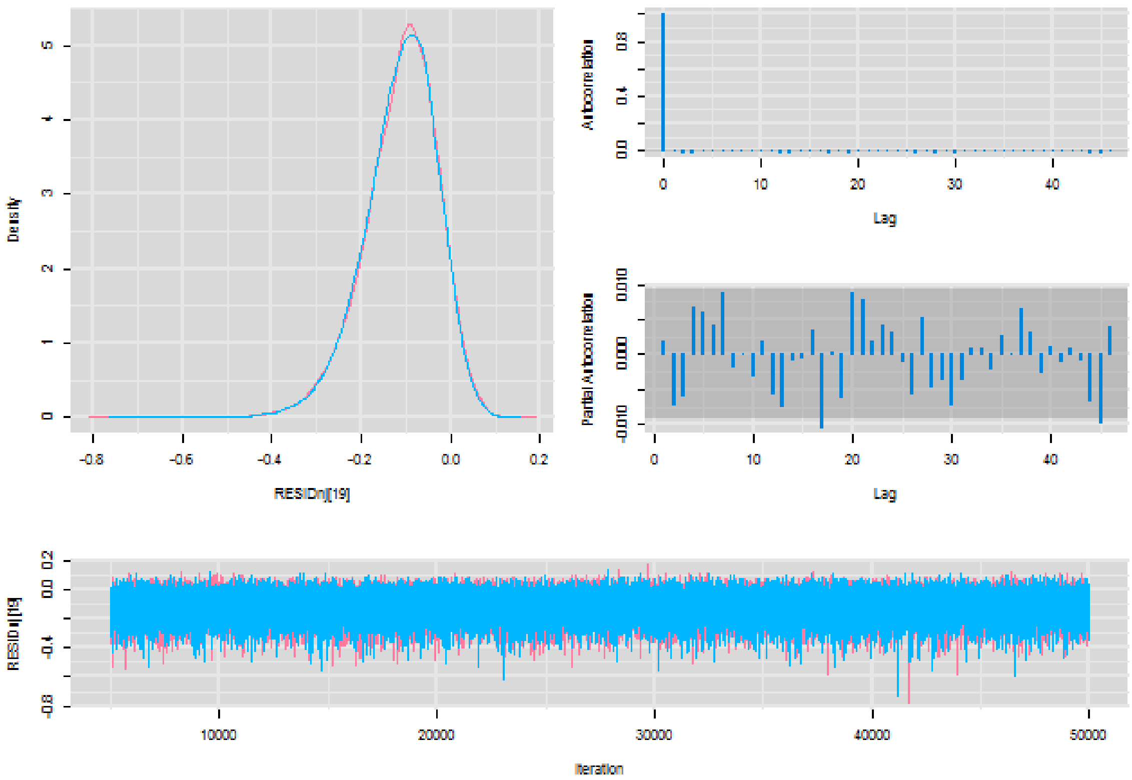
Diagnostics for RESIDnj[17]



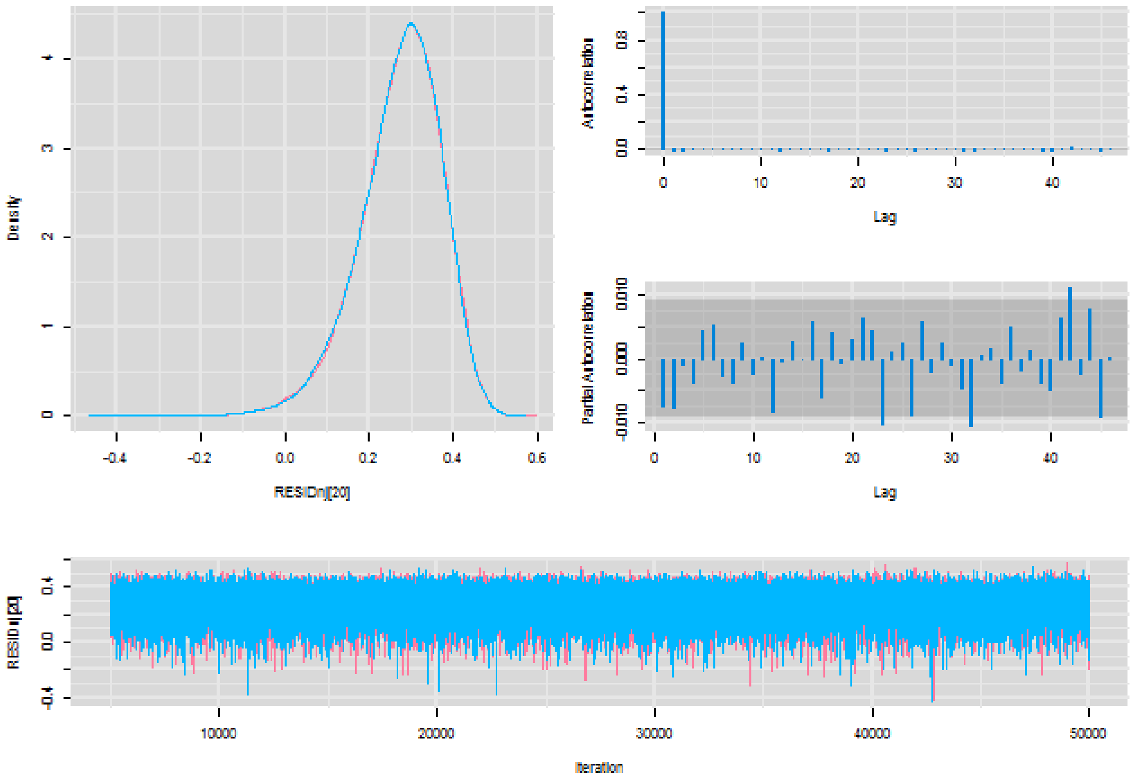
Diagnostics for RESIDnj[18]



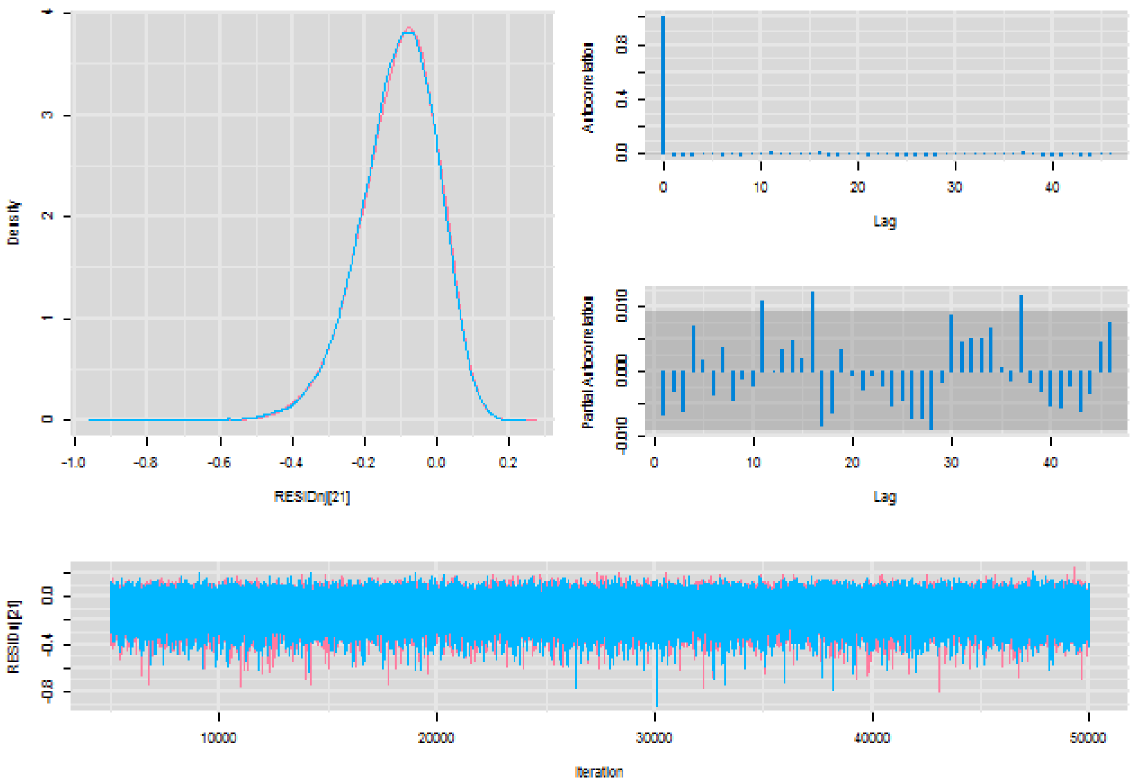
Diagnostics for RESIDnj[19]



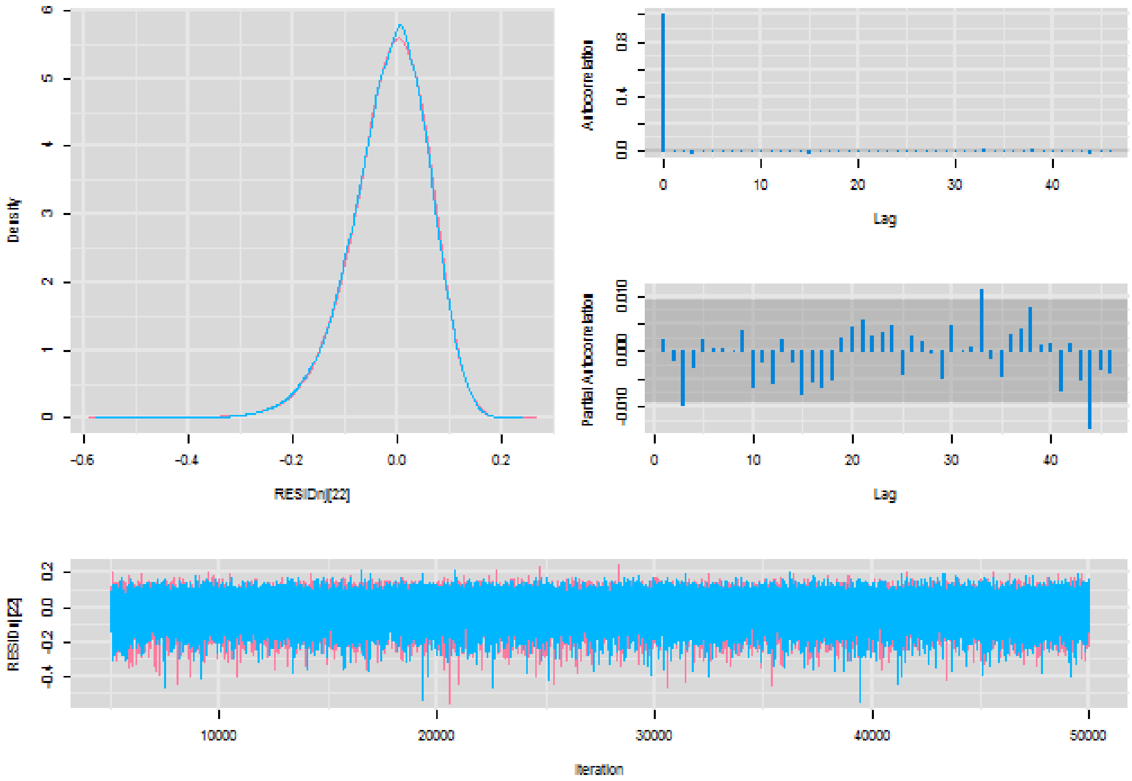
Diagnostics for RESIDnj[20]



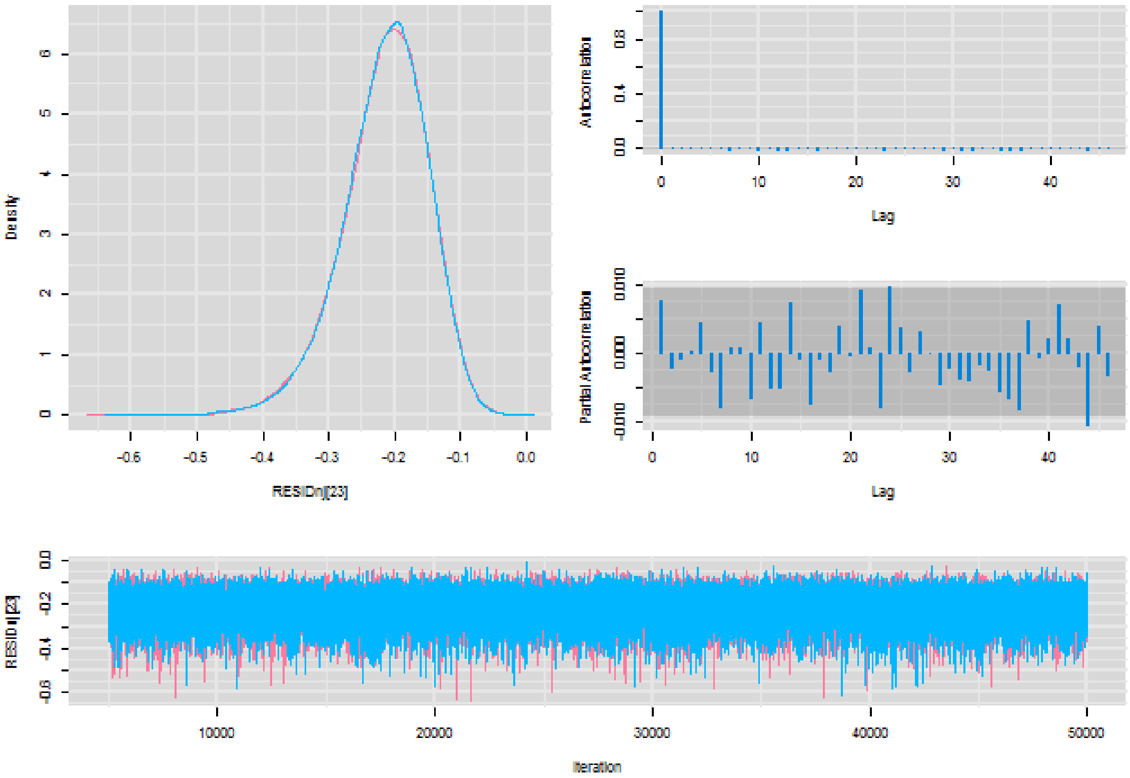
Diagnostics for RESIDnj[21]



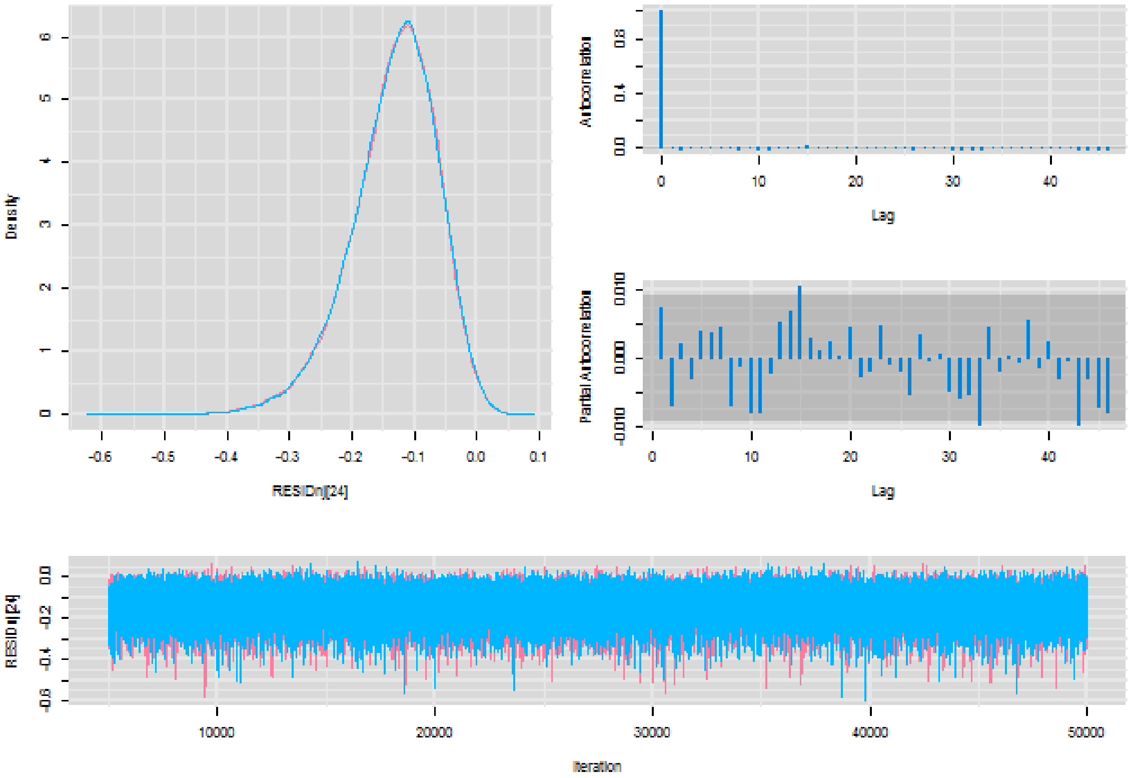
Diagnostics for RESIDnj[22]



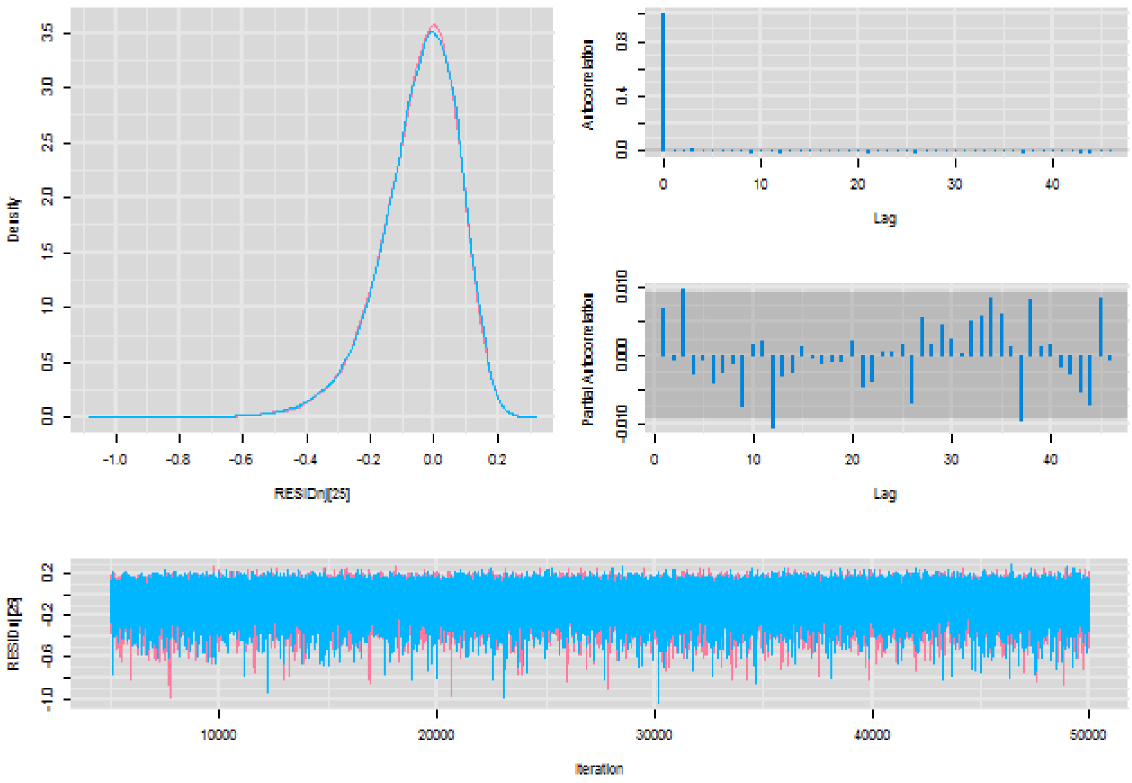
Diagnostics for RESIDnj[23]



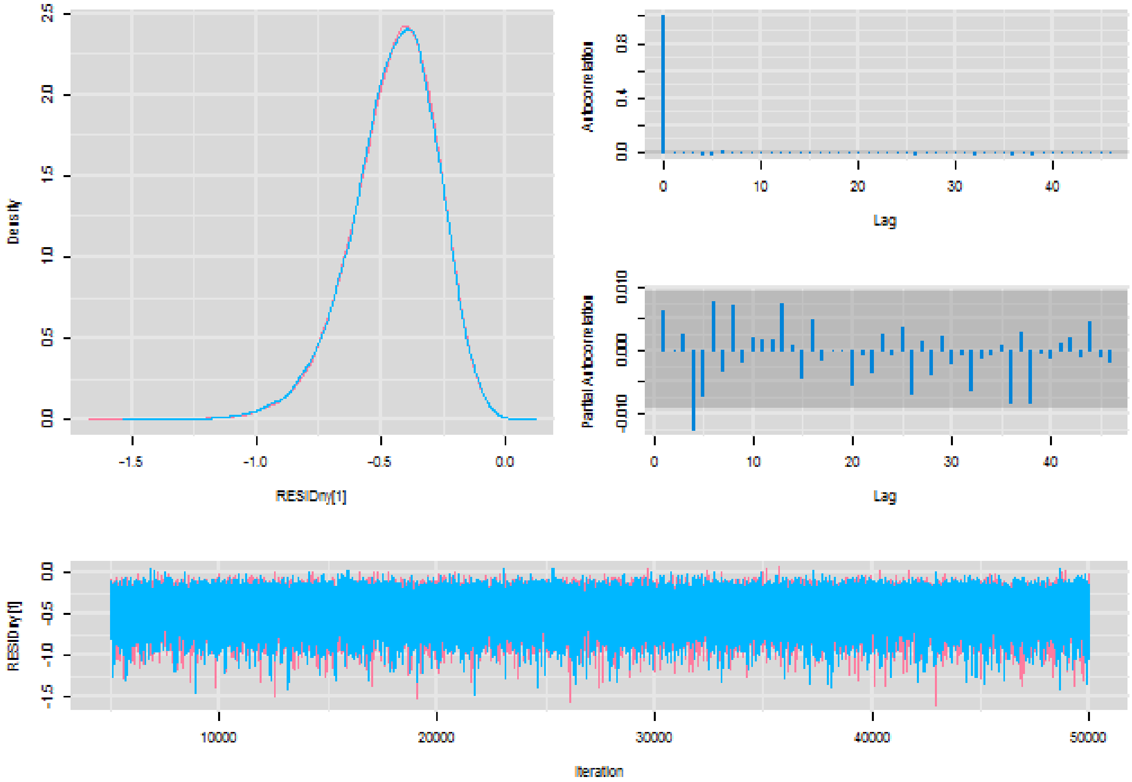
Diagnostics for RESIDnj[24]



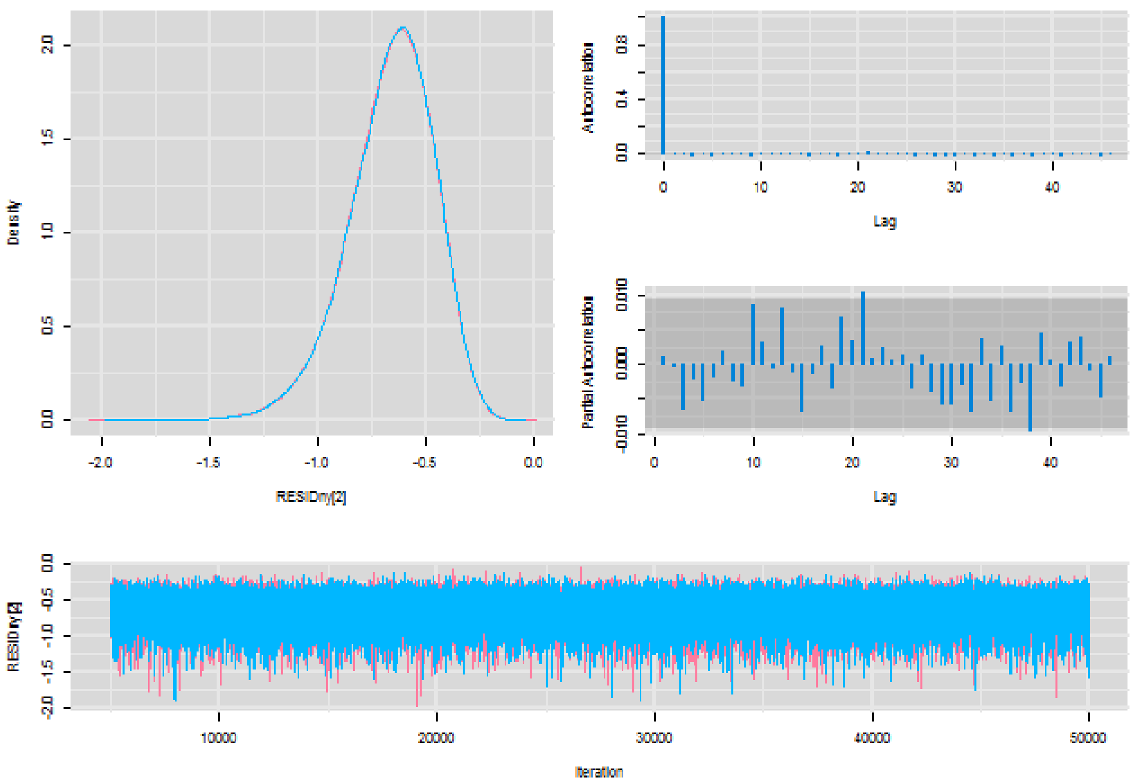
Diagnostics for RESIDnj[25]



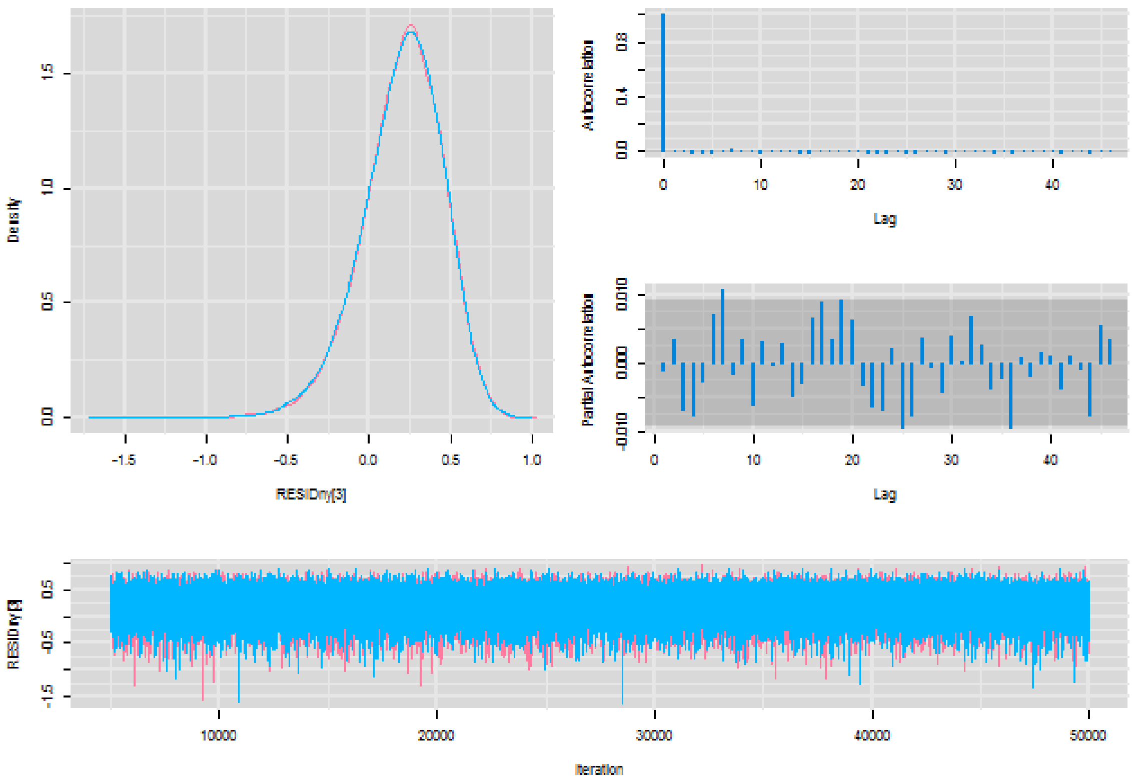
Diagnostics for RESIDny[1]



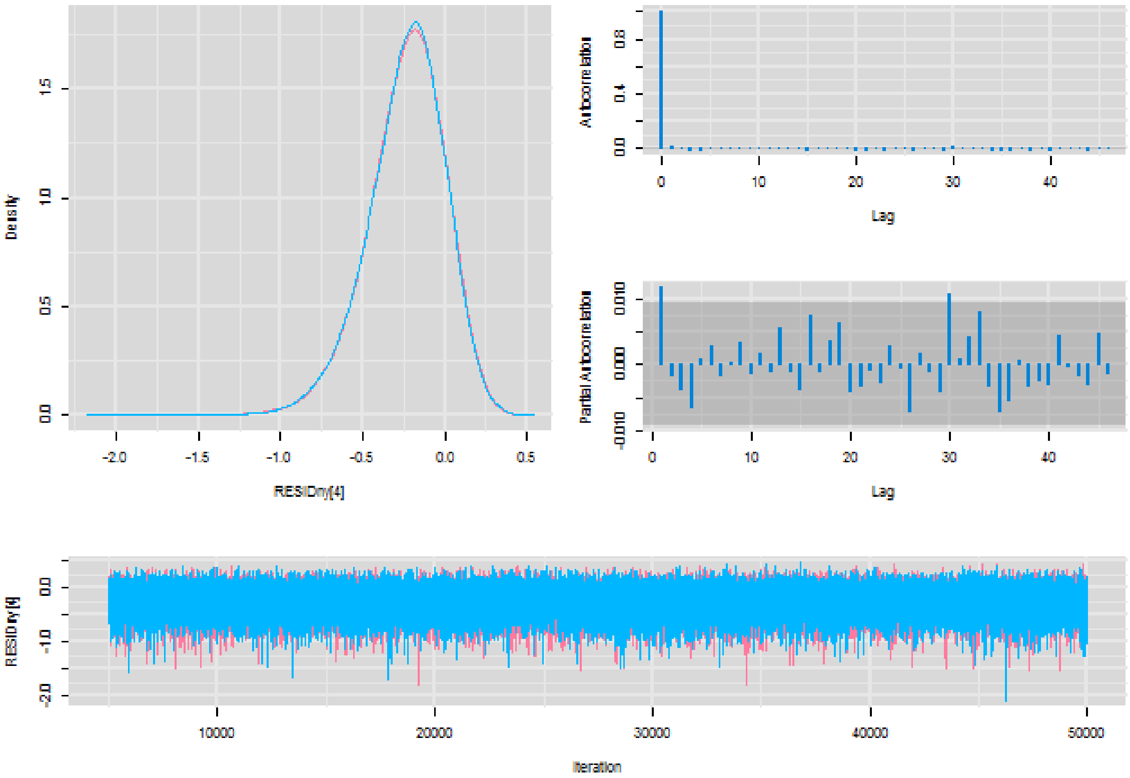
Diagnostics for RESIDny[2]



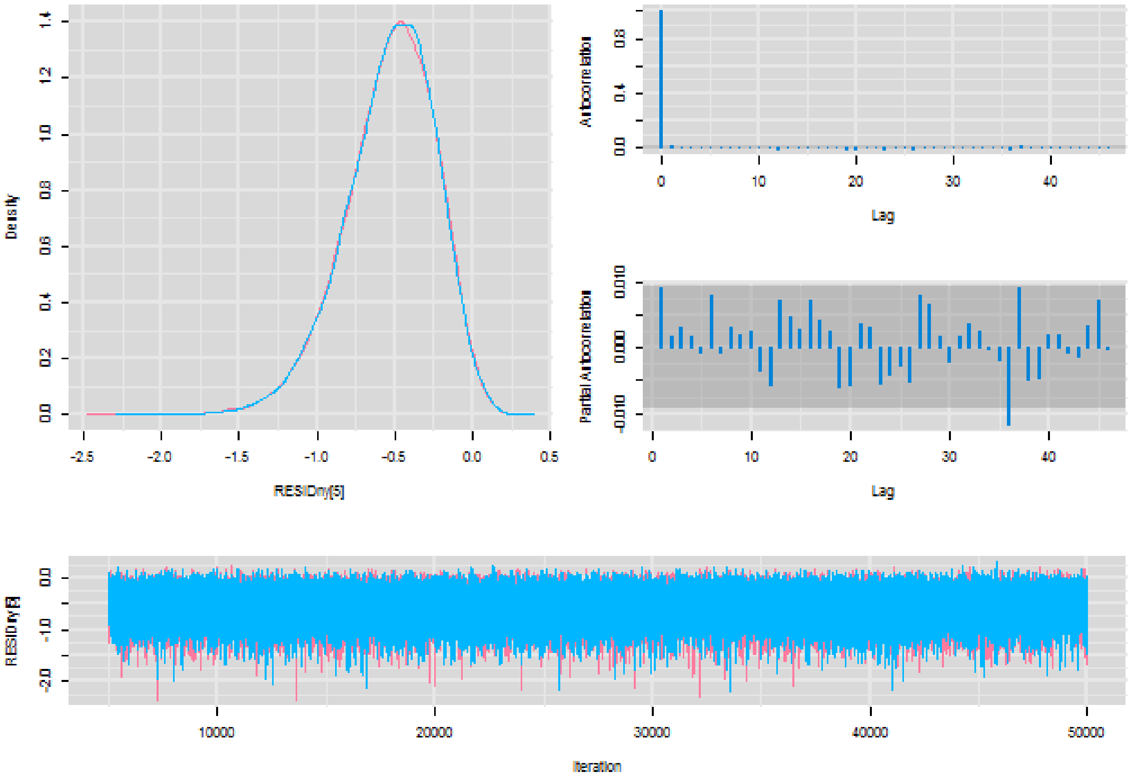
Diagnostics for RESIDny[3]



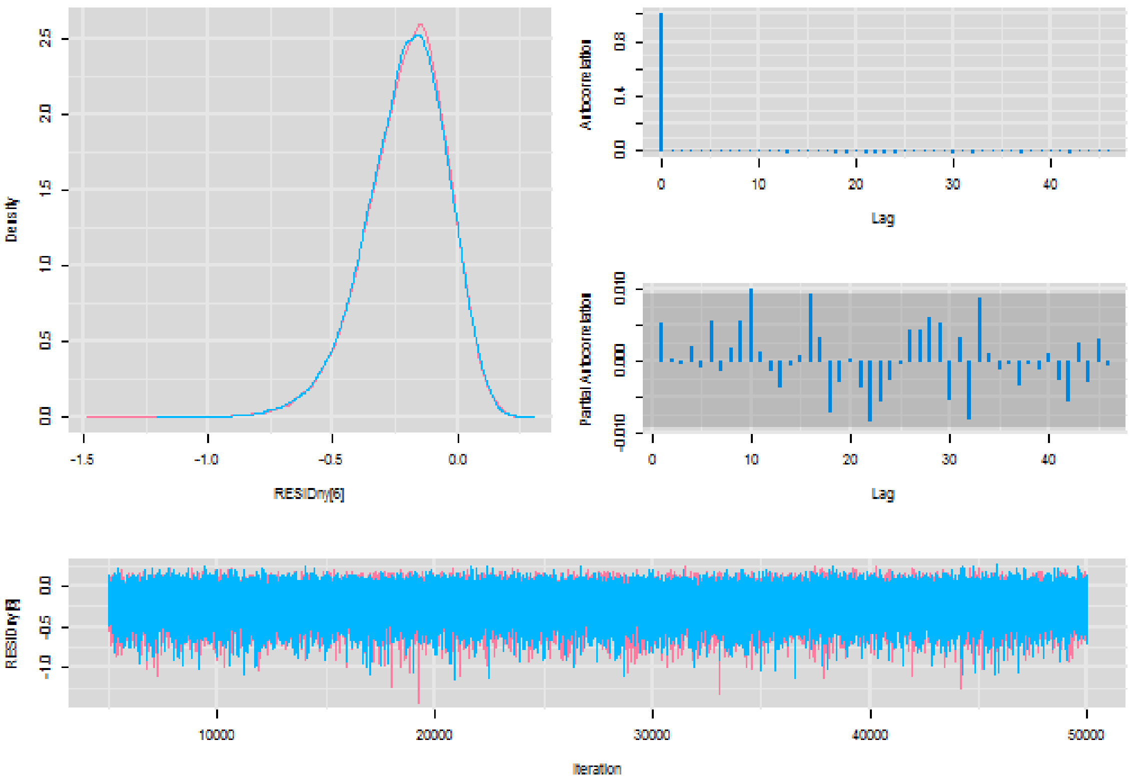
Diagnostics for RESIDny[4]



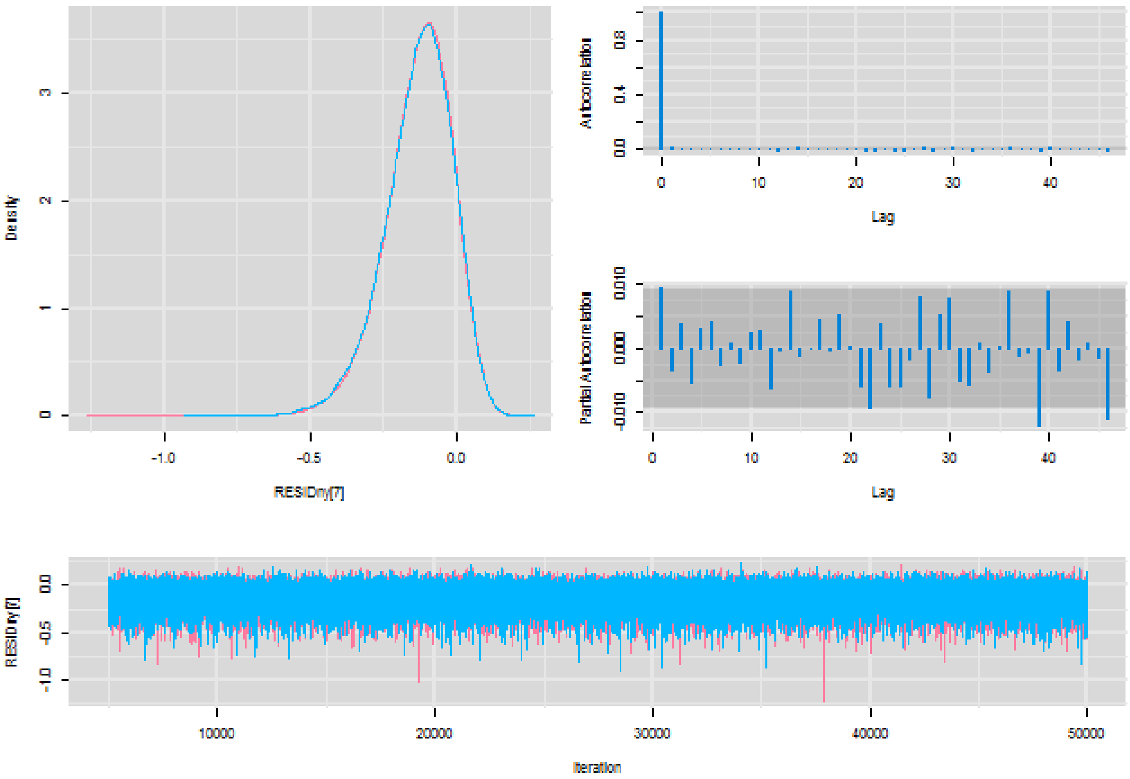
Diagnostics for RESIDny[5]



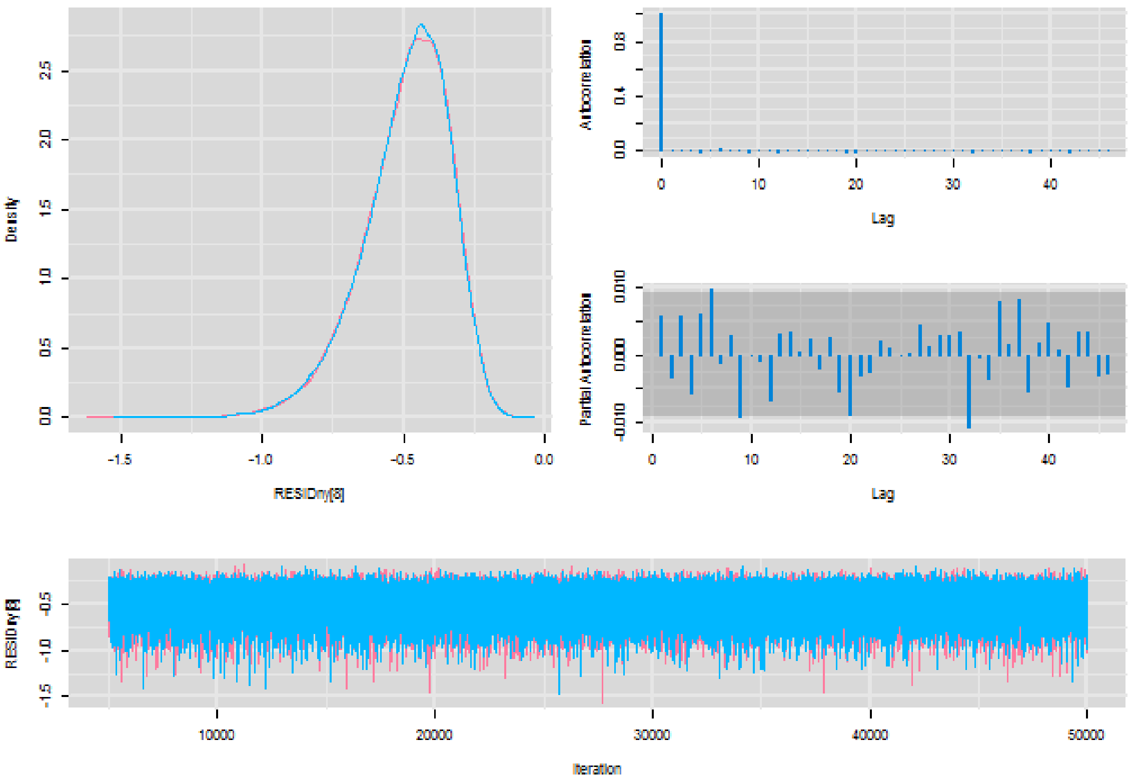
Diagnostics for RESIDny[6]



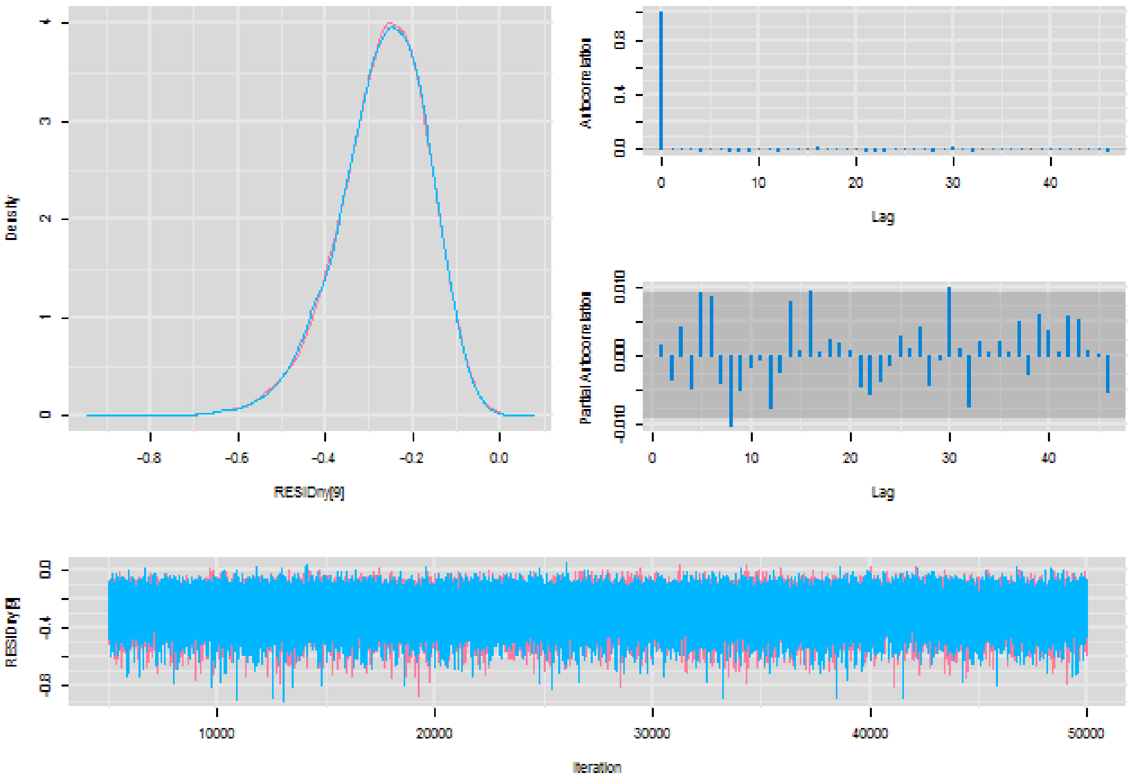
Diagnostics for RESIDny[7]



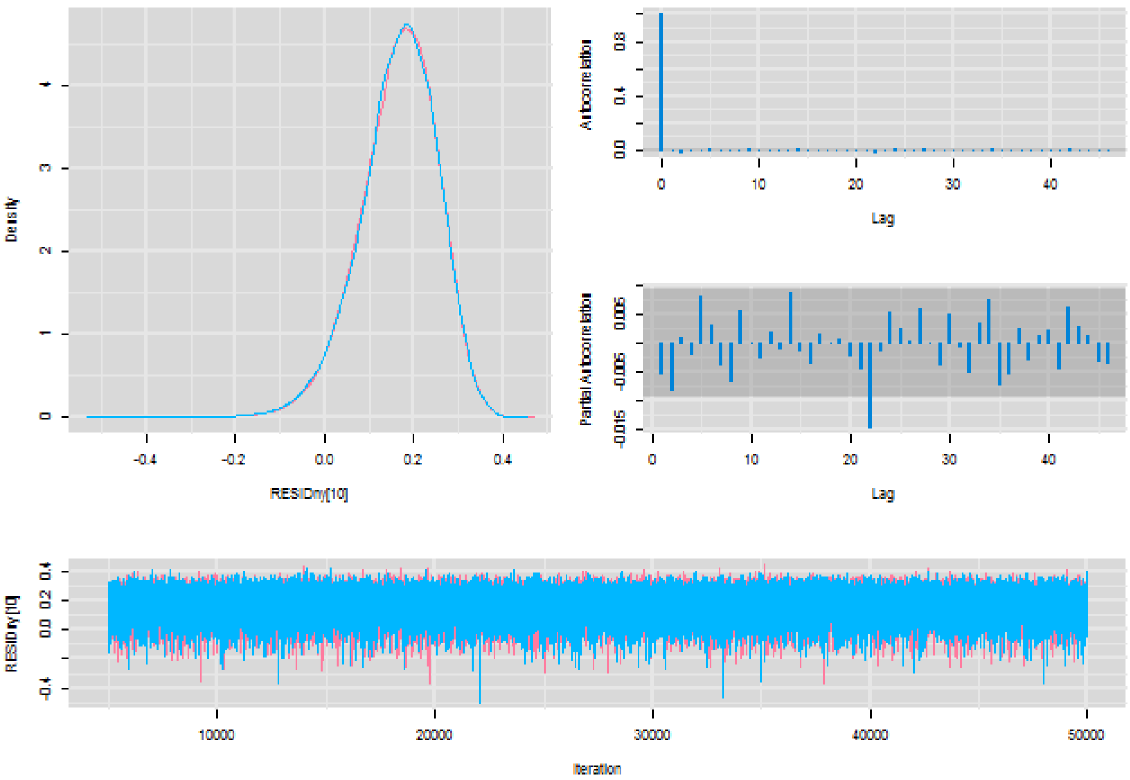
Diagnostics for RESIDny[8]



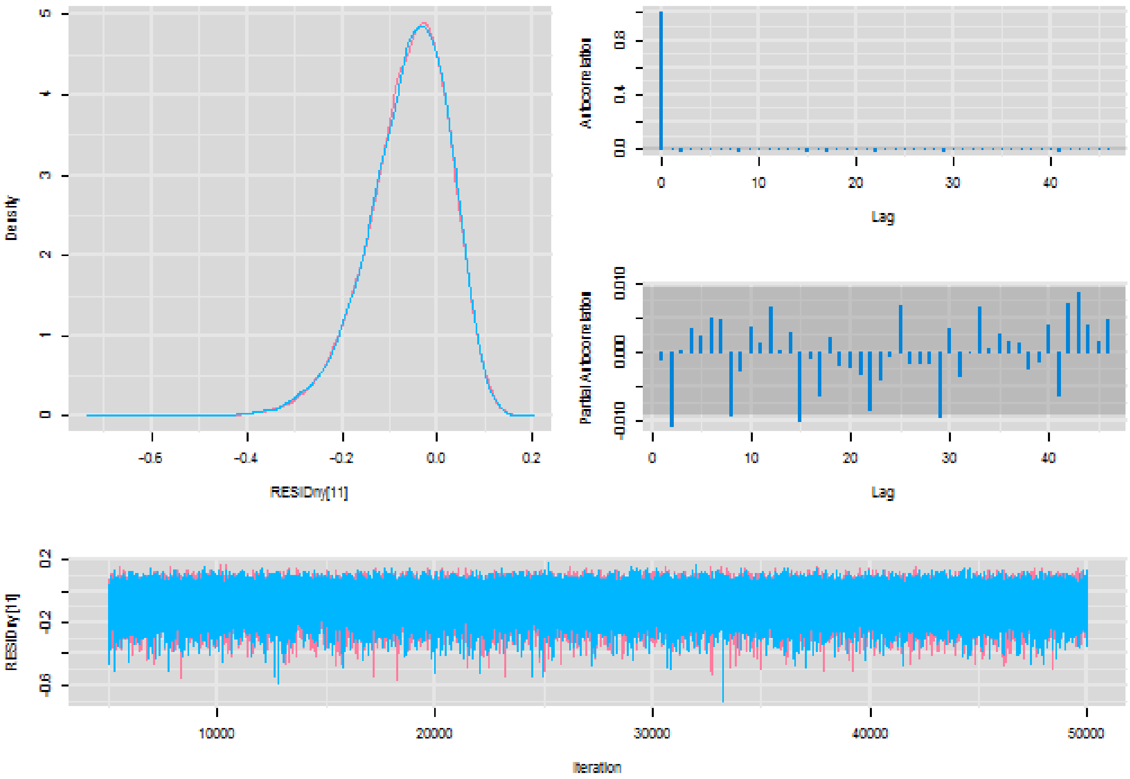
Diagnostics for RESIDny[9]



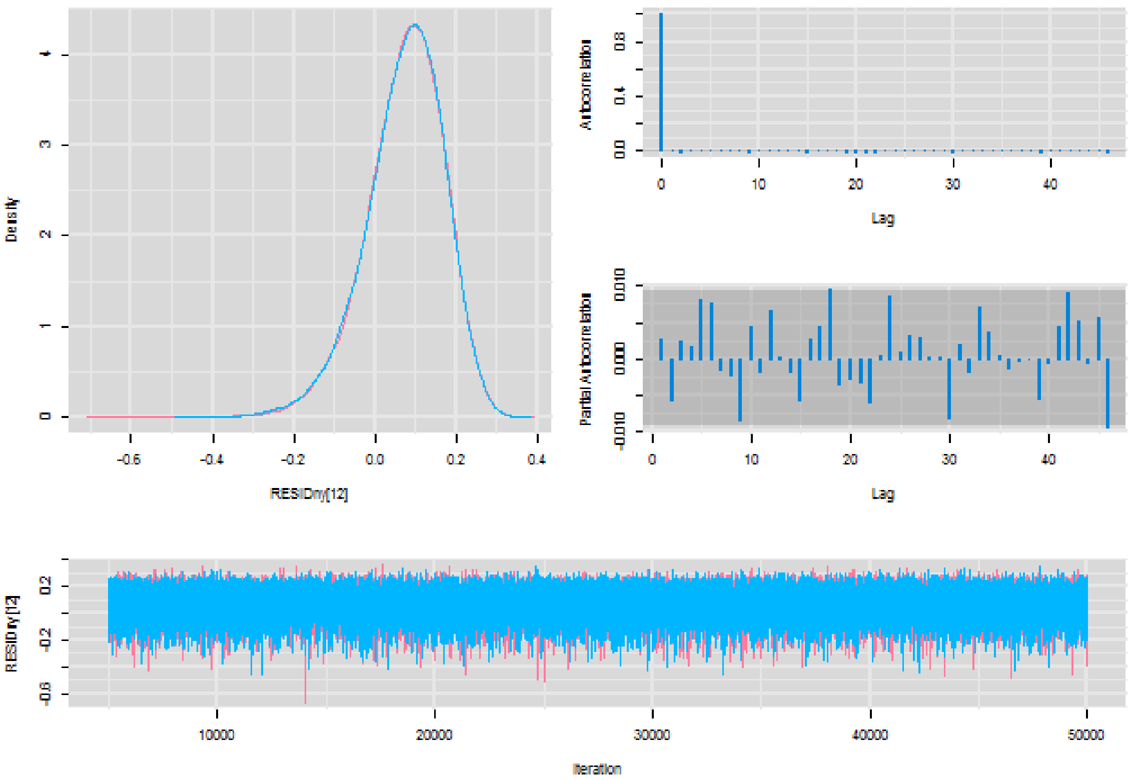
Diagnostics for RESIDny[10]



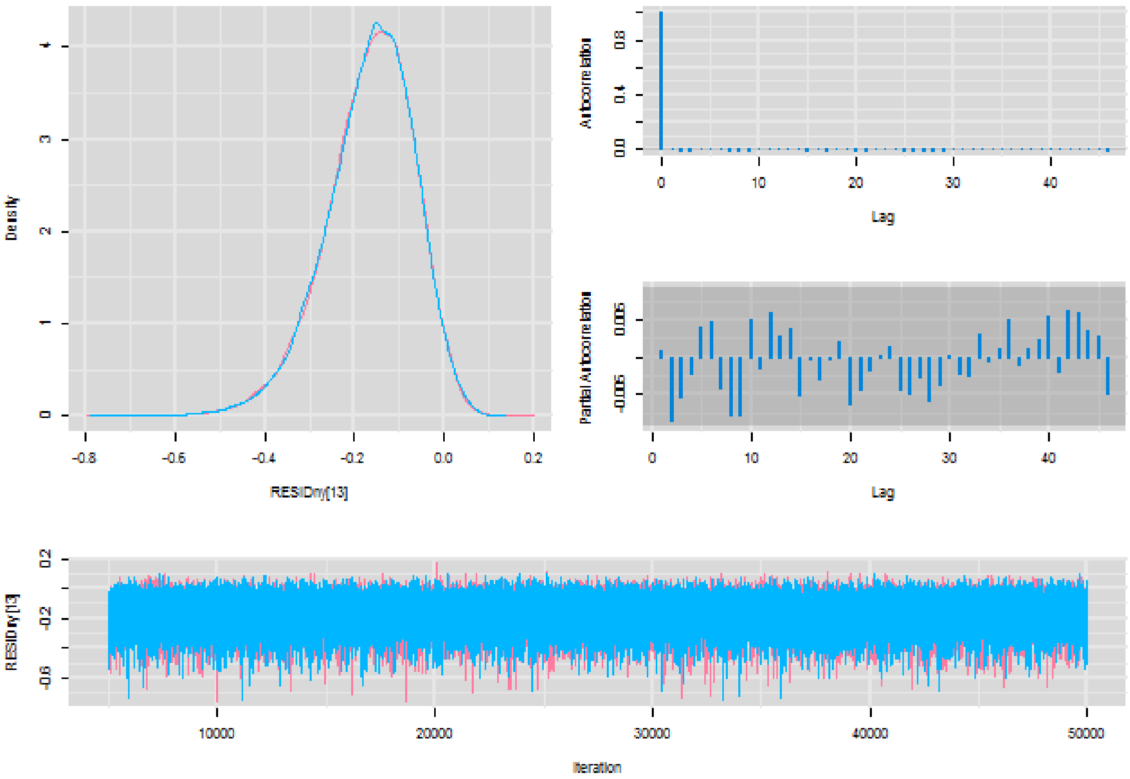
Diagnostics for RESIDny[11]



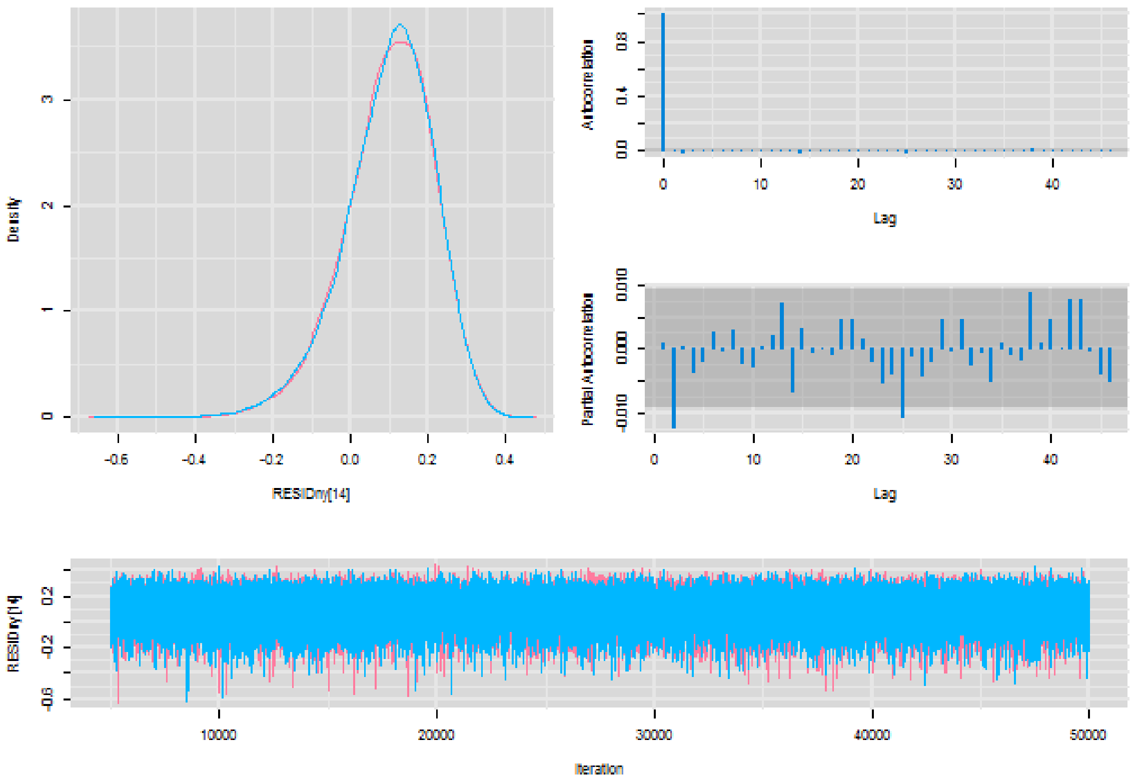
Diagnostics for RESIDny[12]



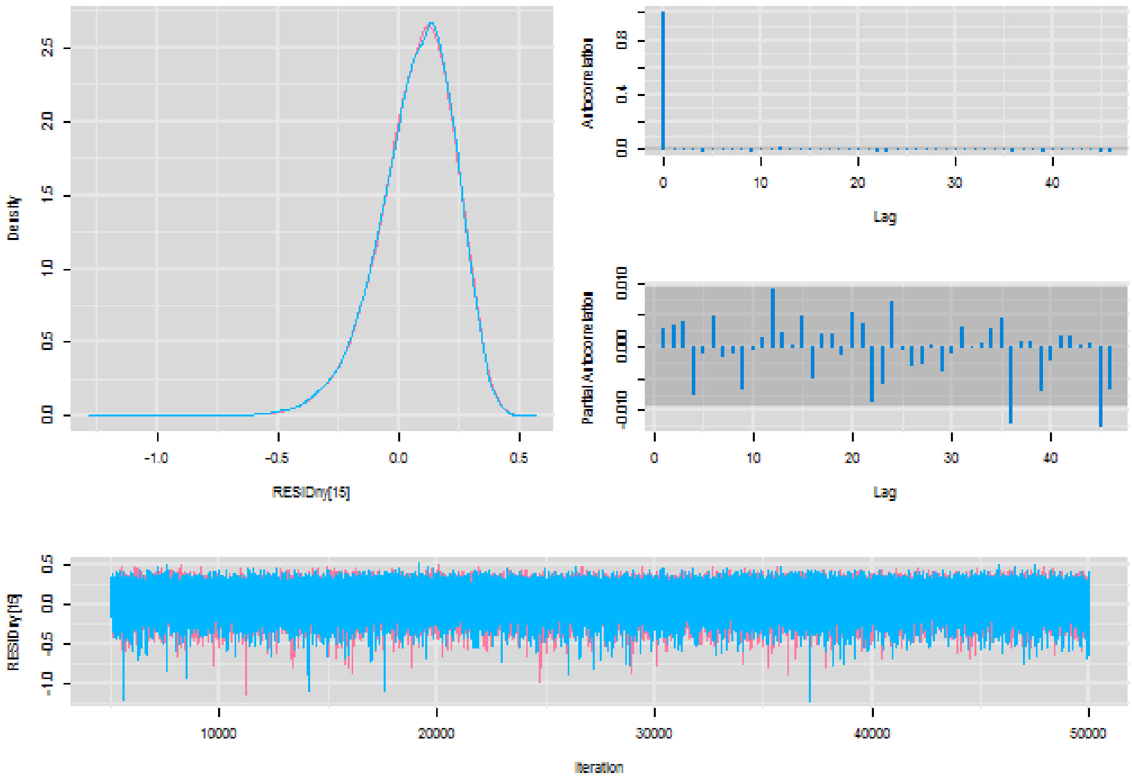
Diagnostics for RESIDny[13]



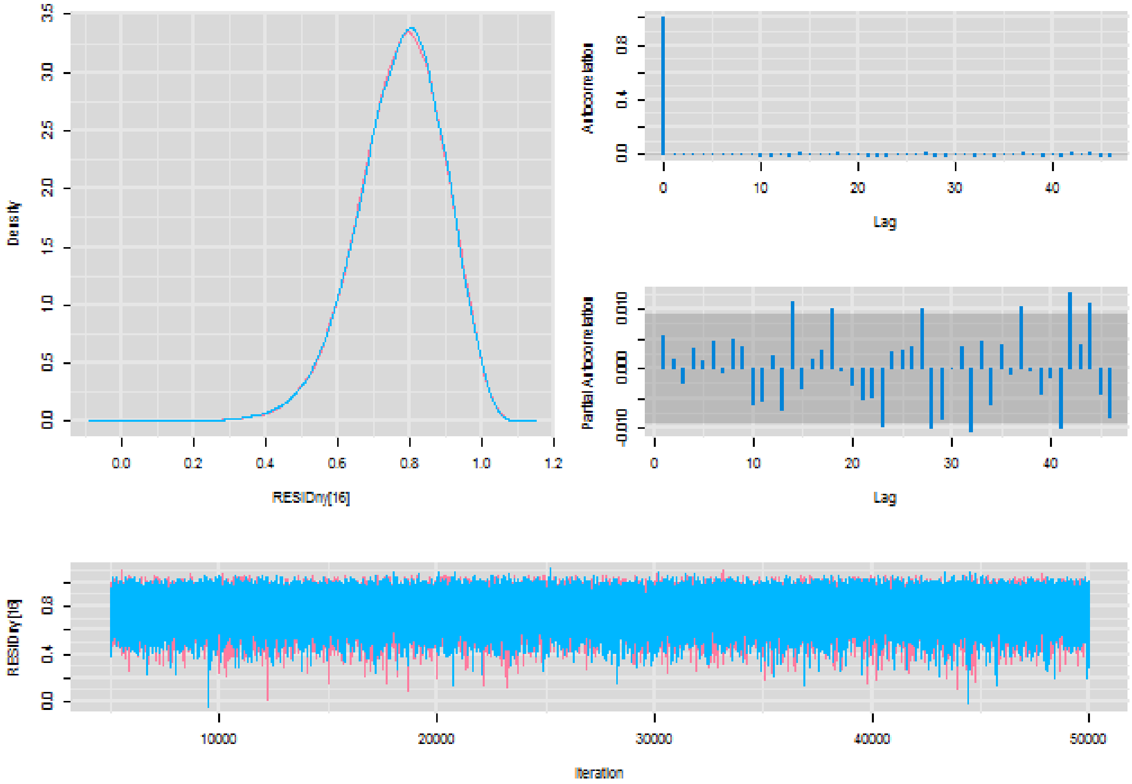
Diagnostics for RESIDny[14]



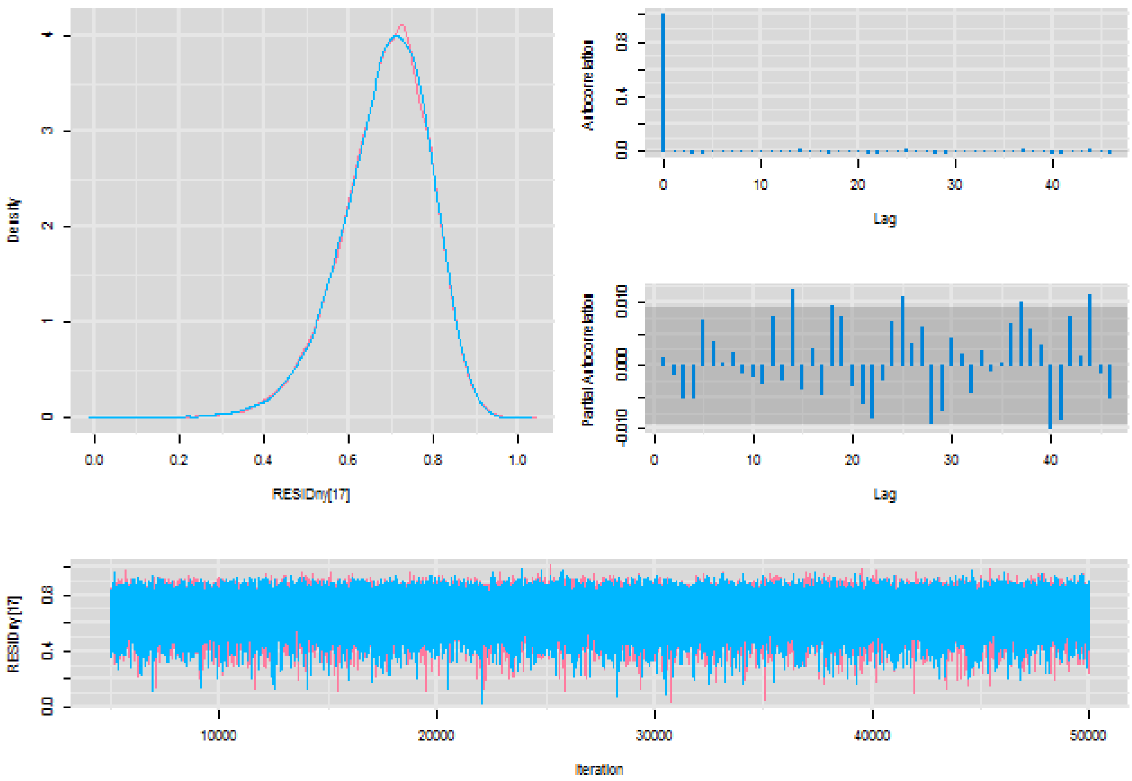
Diagnostics for RESIDny[15]



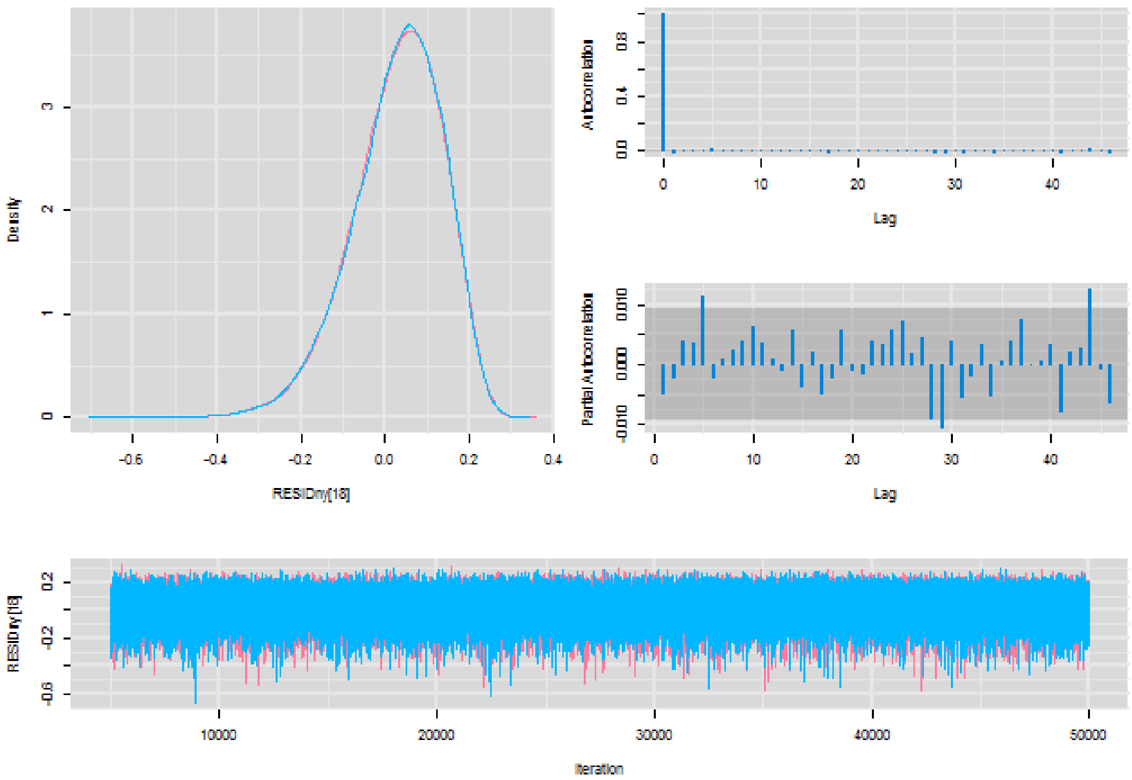
Diagnostics for RESIDny[16]



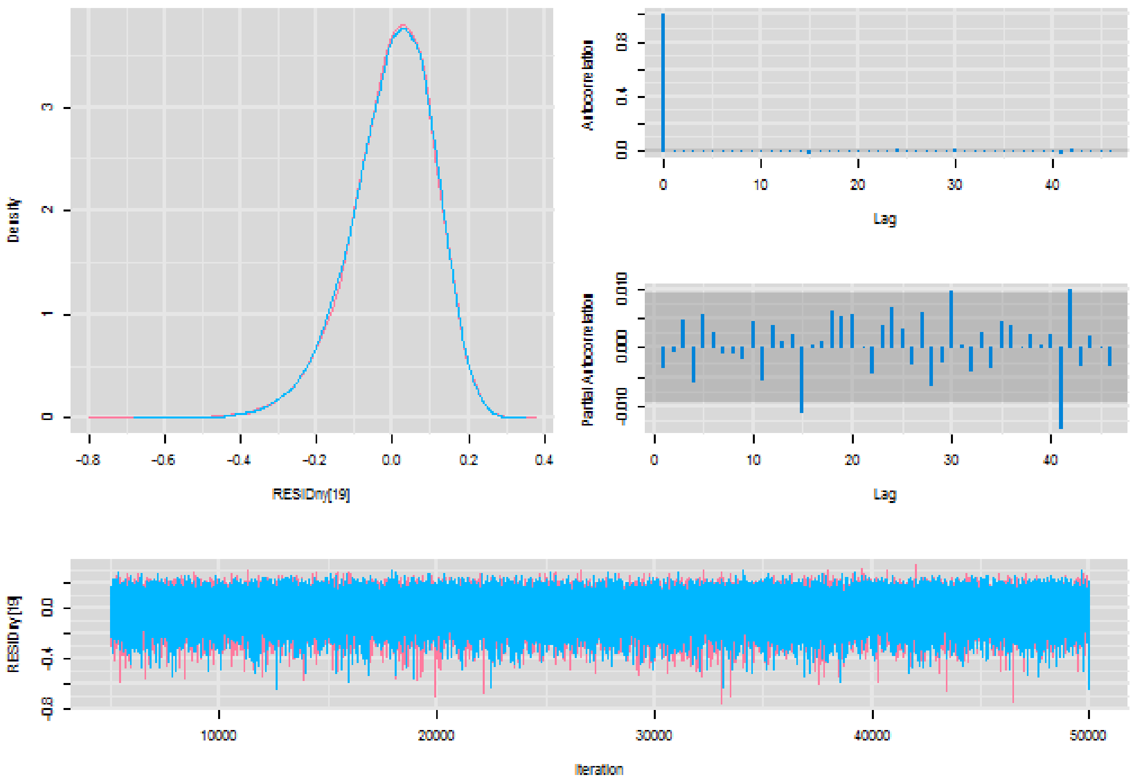
Diagnostics for RESIDny[17]



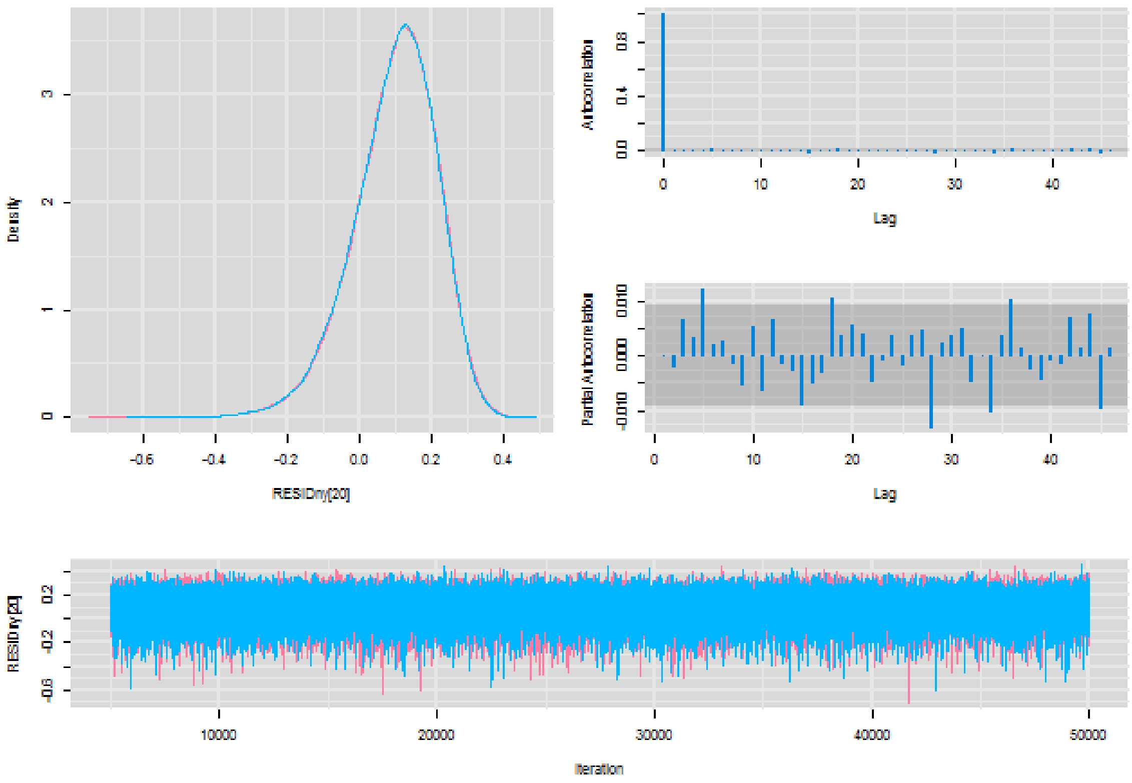
Diagnostics for RESIDny[18]



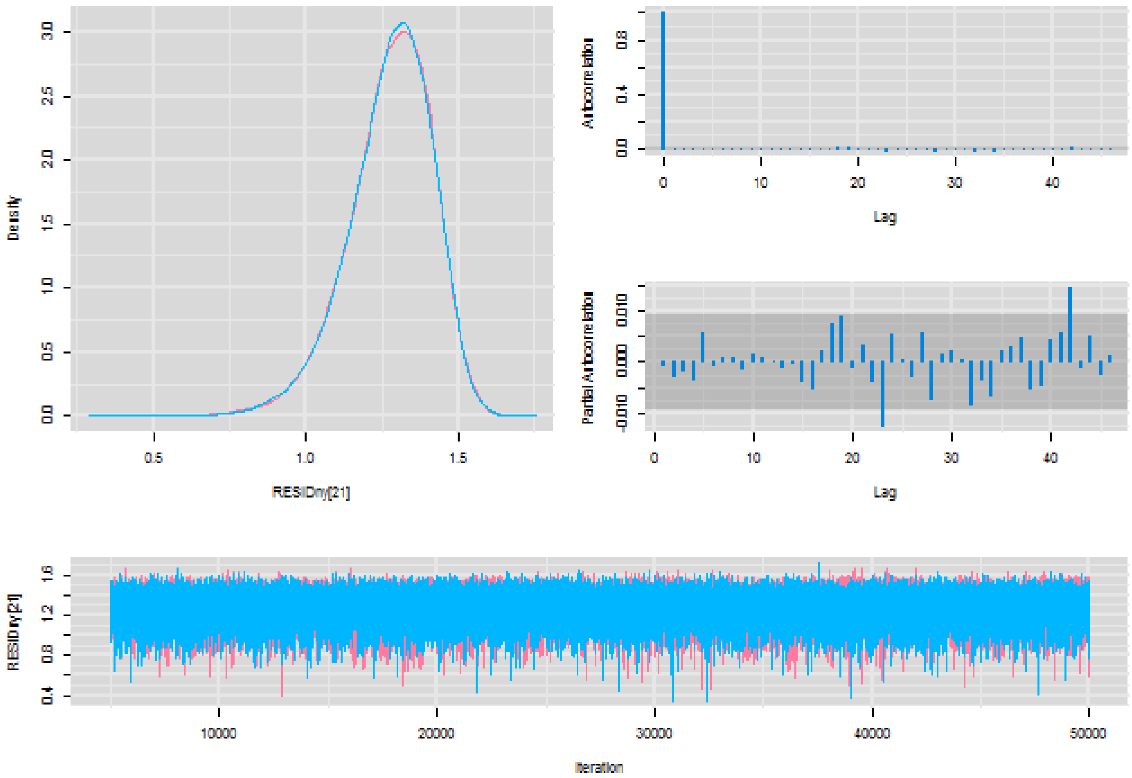
Diagnostics for RESIDny[19]



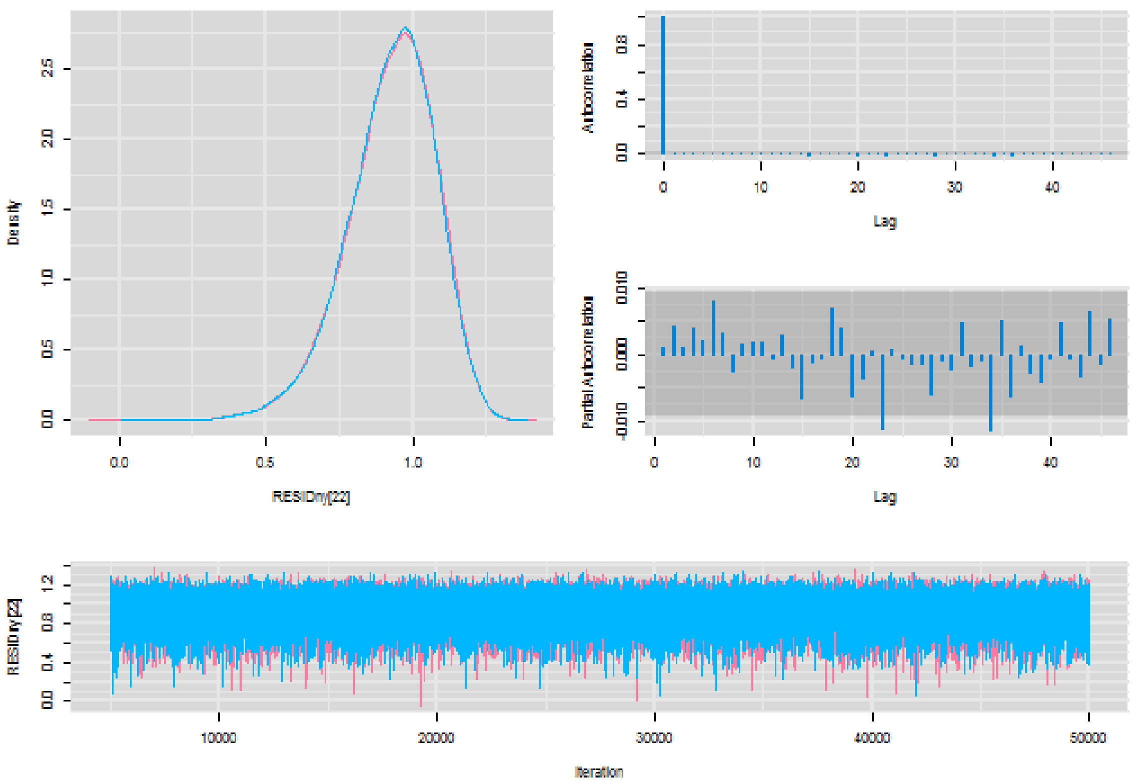
Diagnostics for RESIDny[20]



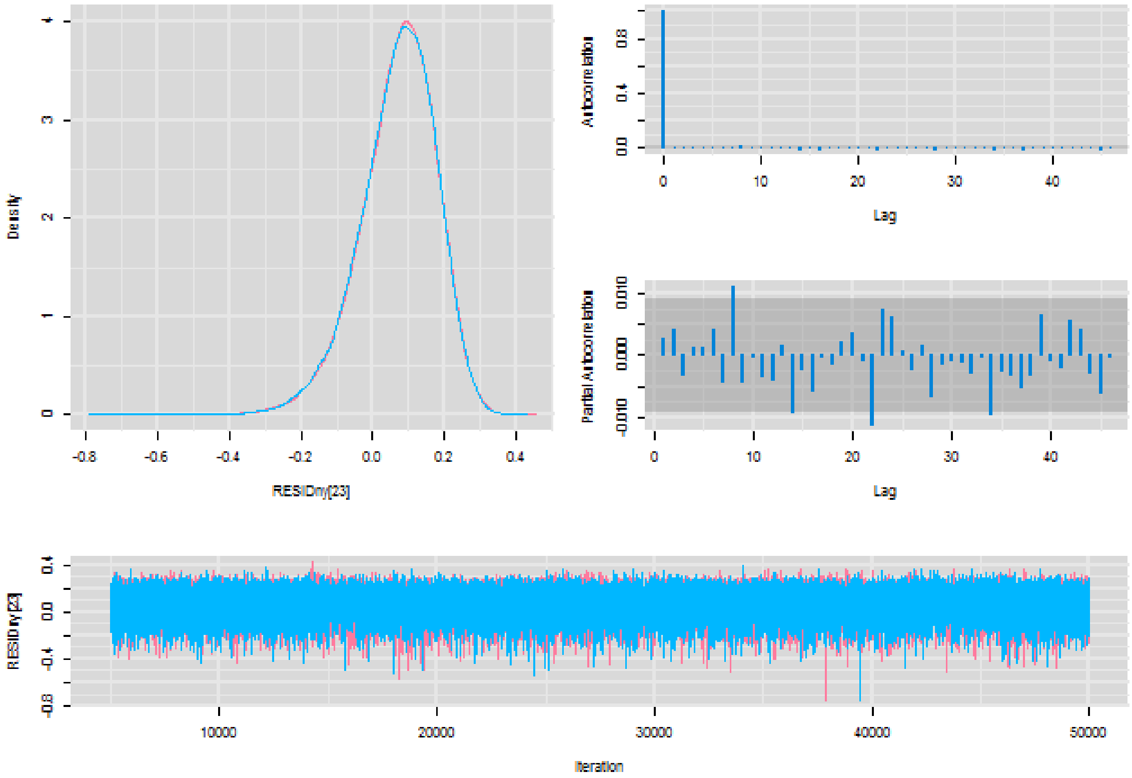
Diagnostics for RESIDny[21]



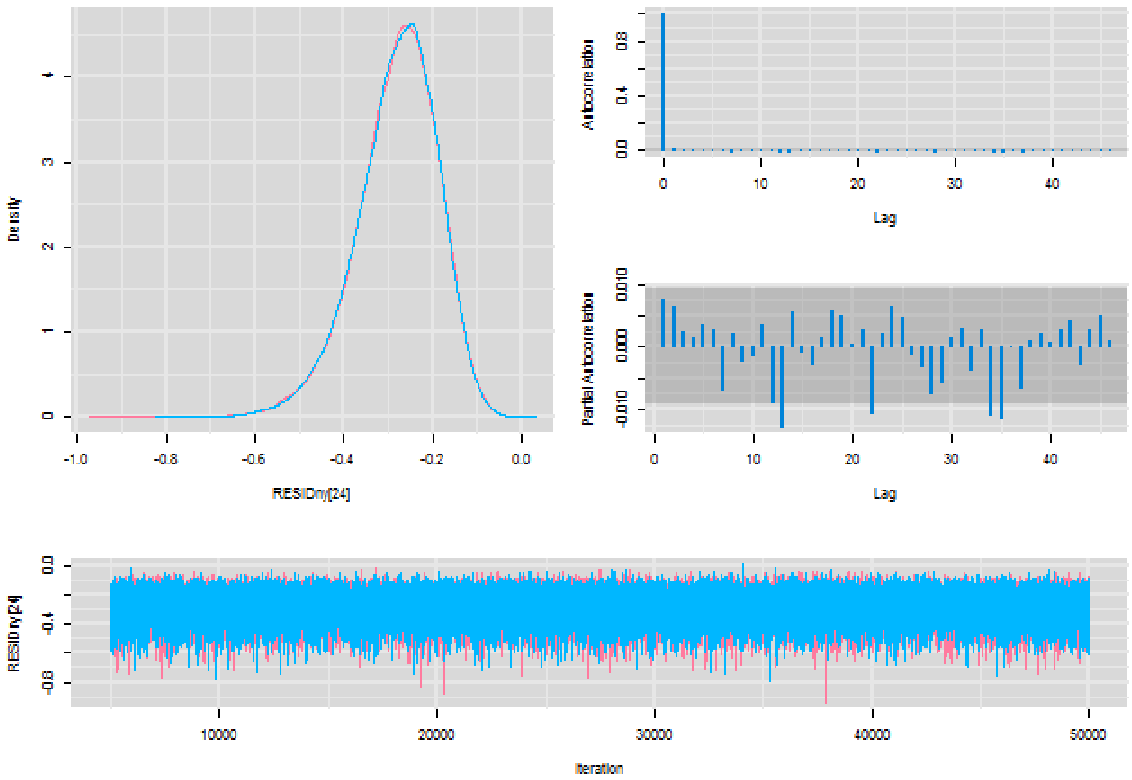
Diagnostics for RESIDny[22]



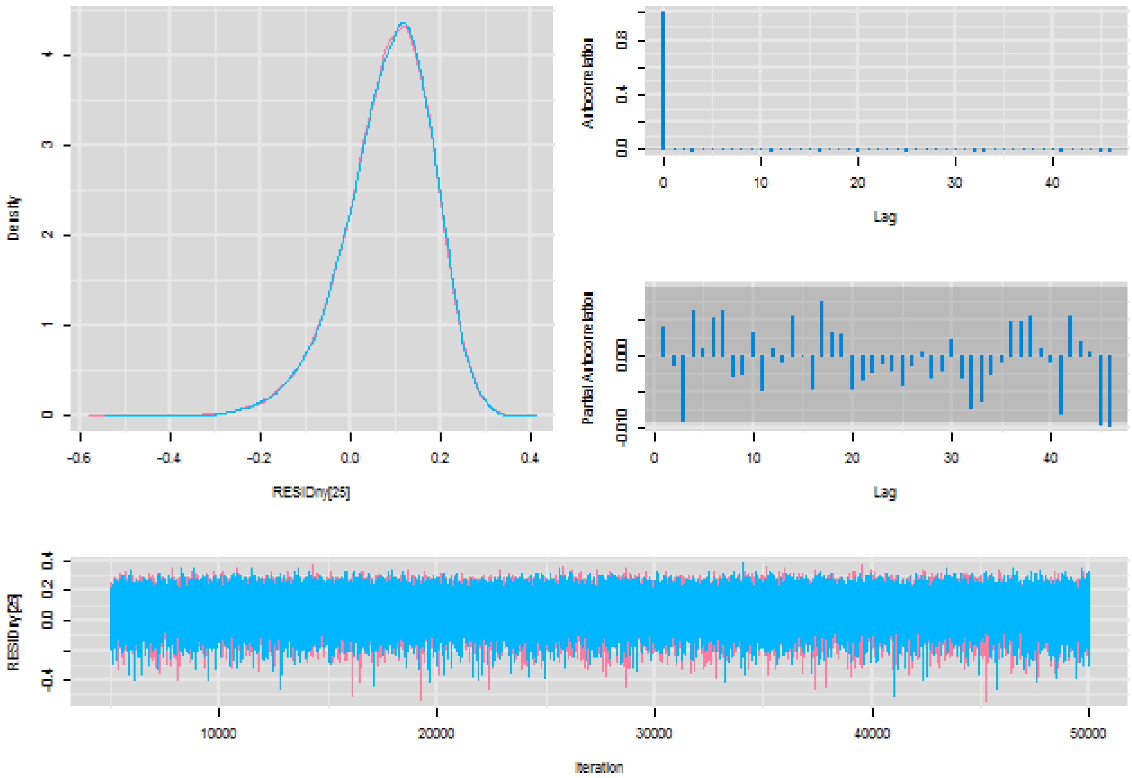
Diagnostics for RESIDny[23]



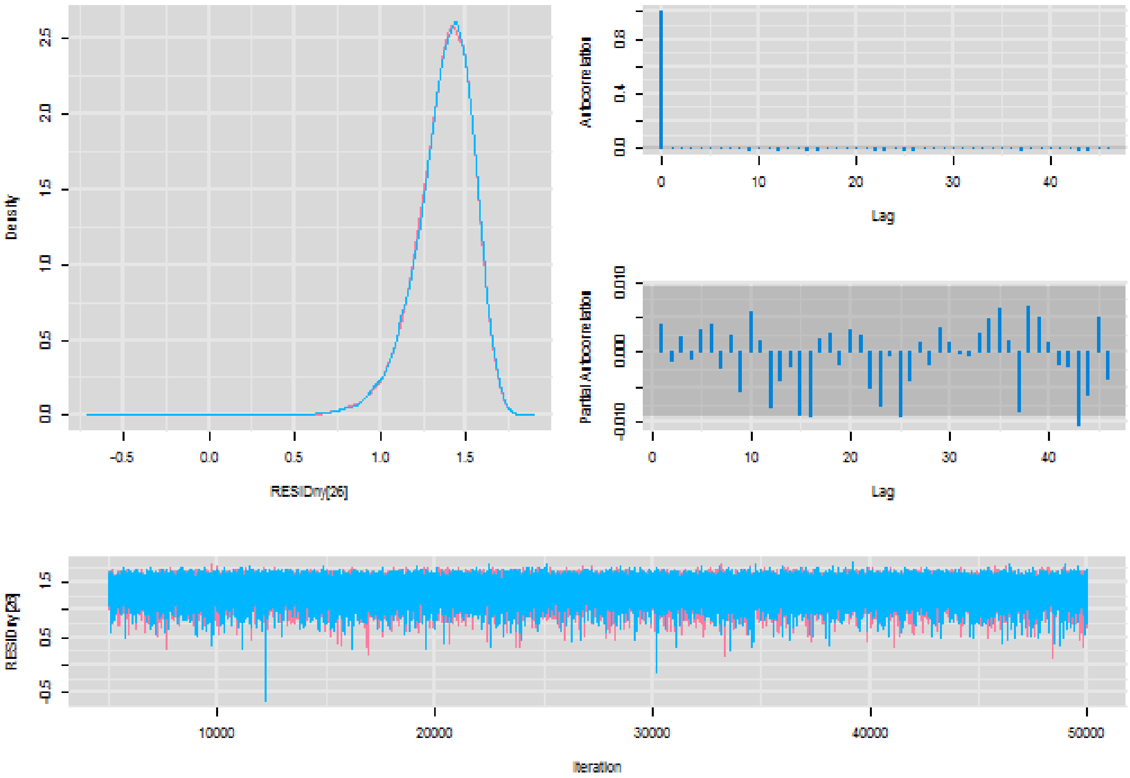
Diagnostics for RESIDny[24]



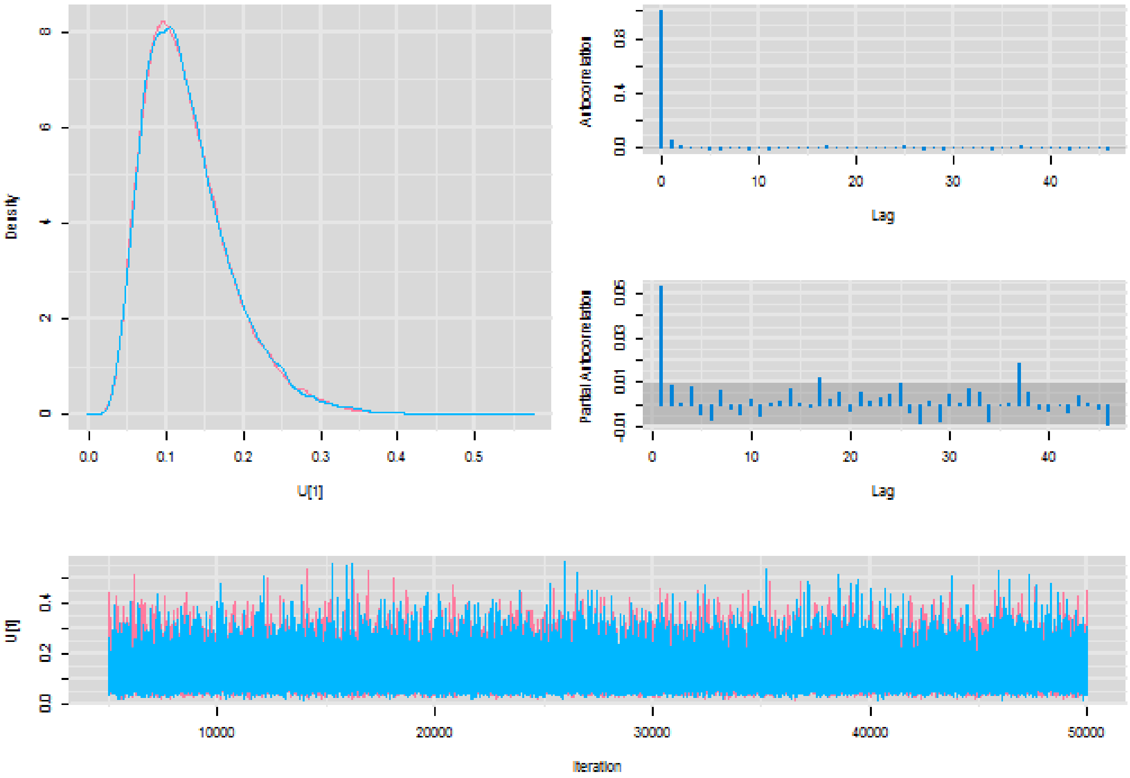
Diagnostics for RESIDny[25]



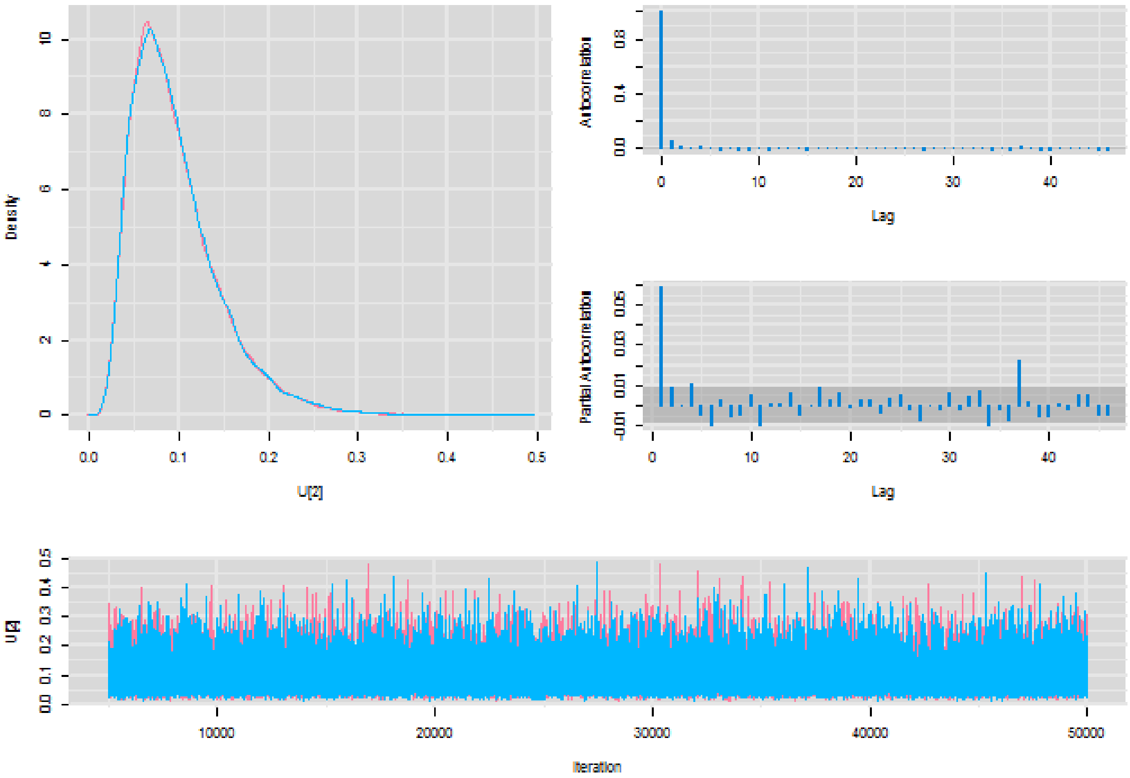
Diagnostics for RESIDny[26]



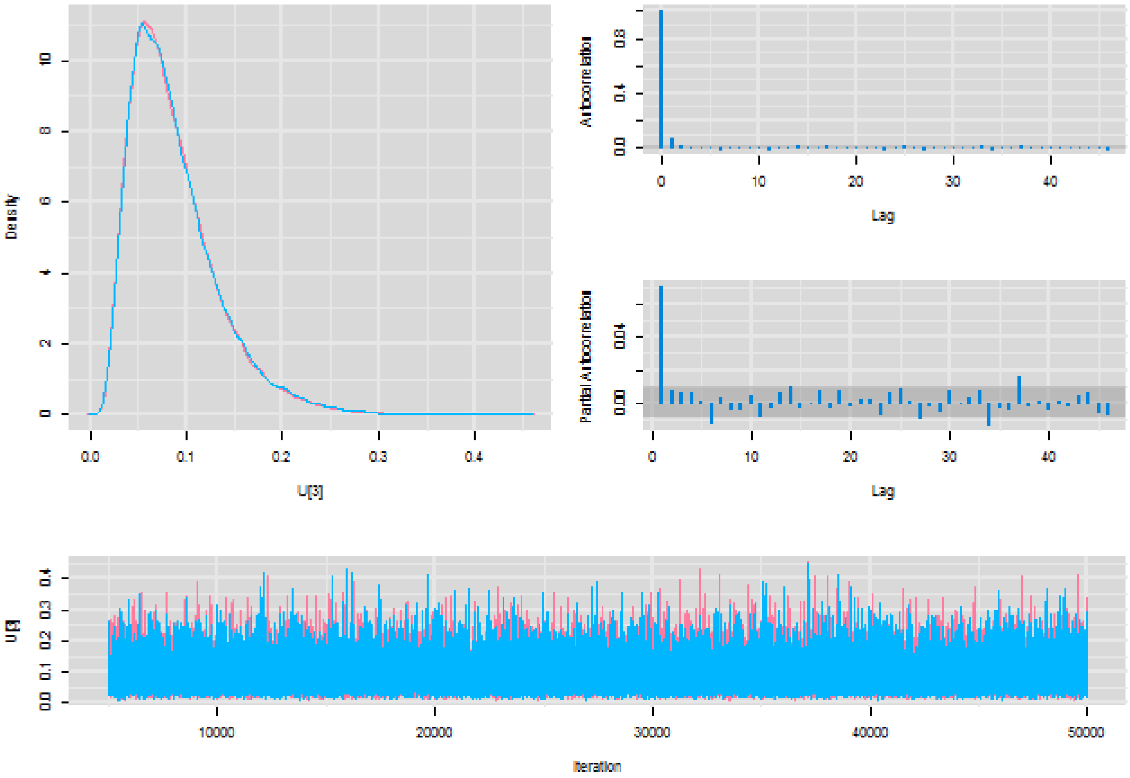
Diagnostics for U[1]



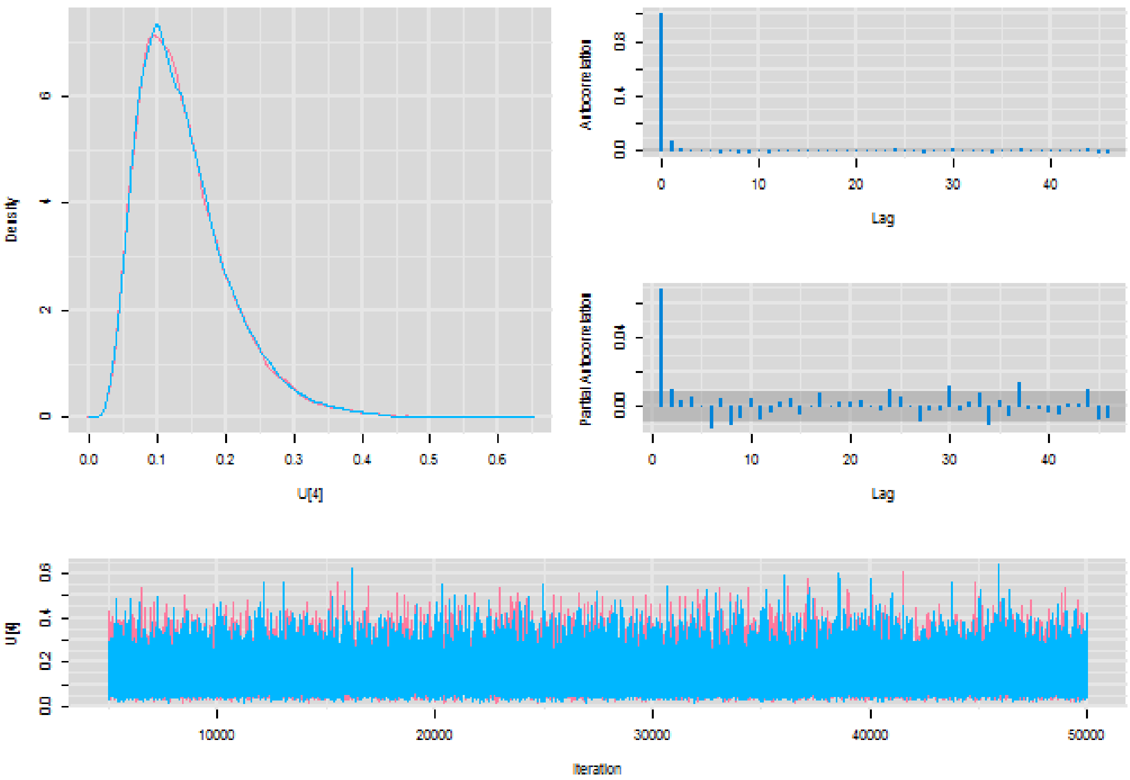
Diagnostics for U[2]



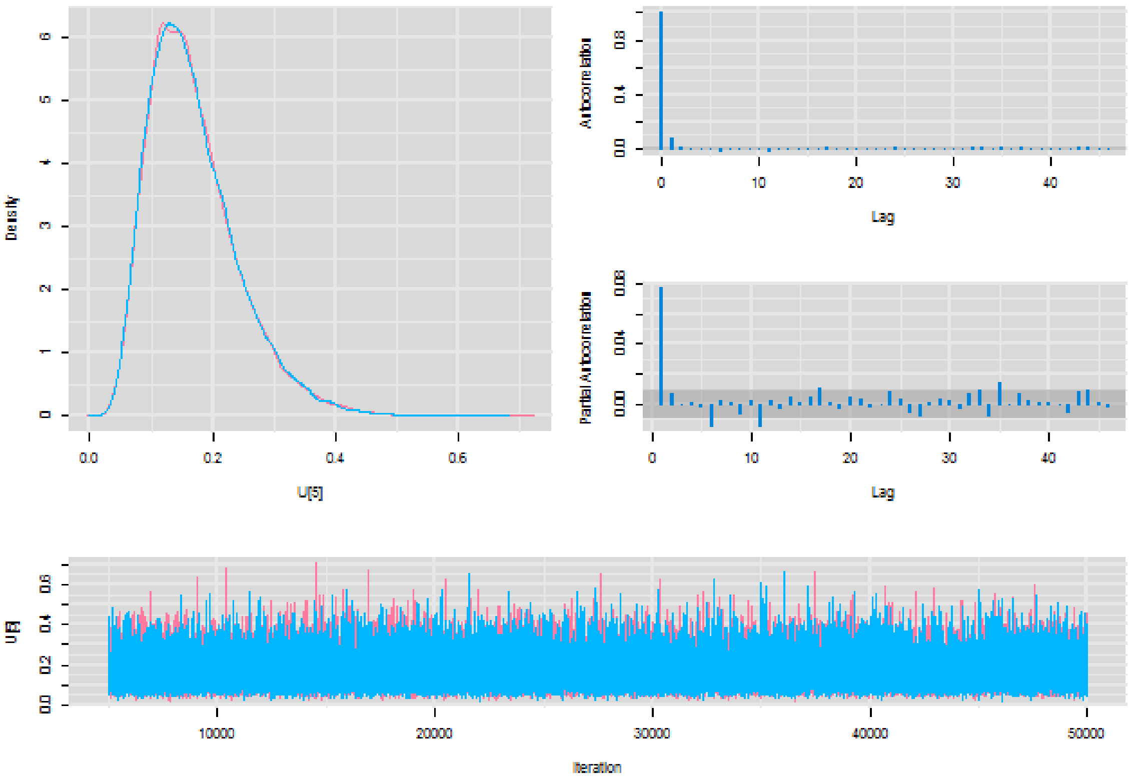
Diagnostics for U[3]



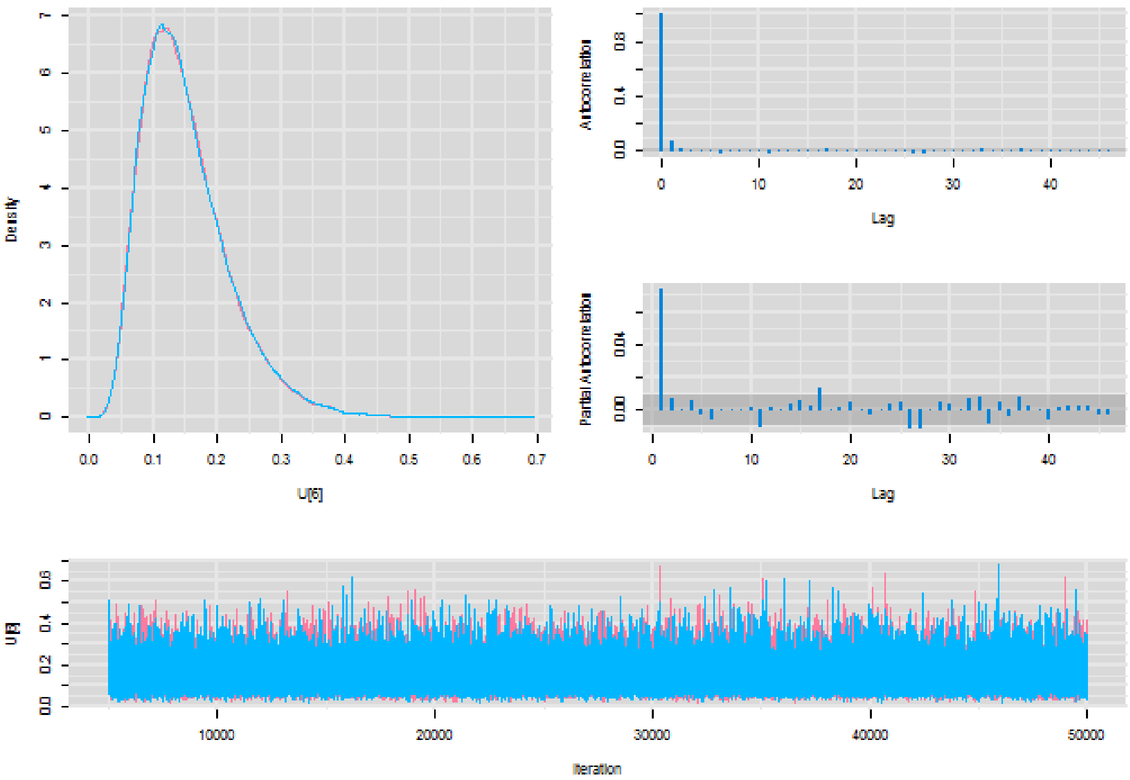
Diagnostics for U[4]



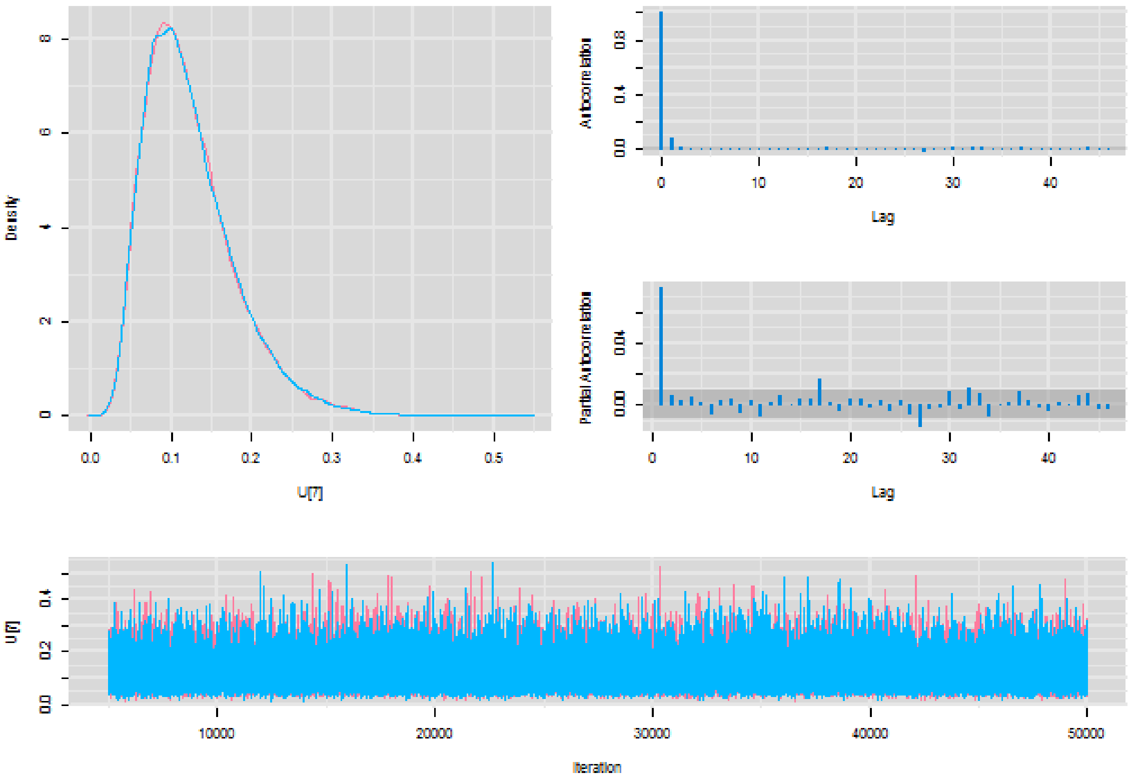
Diagnostics for U[5]



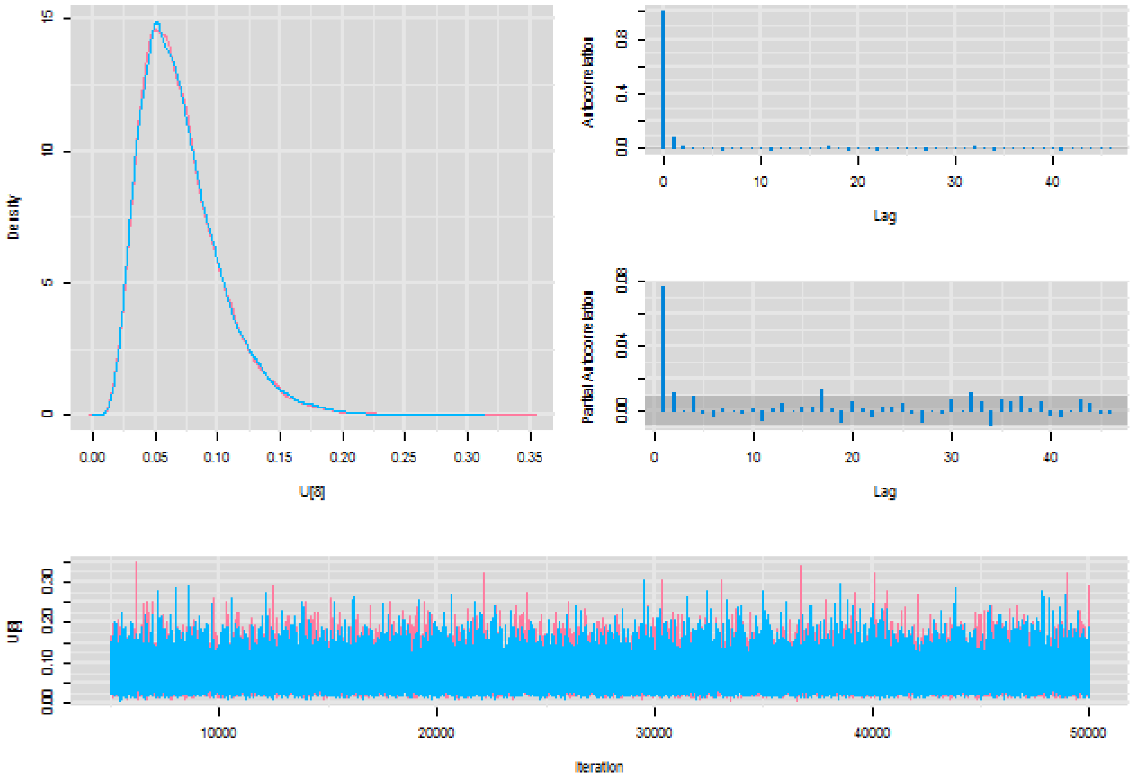
Diagnostics for U[6]



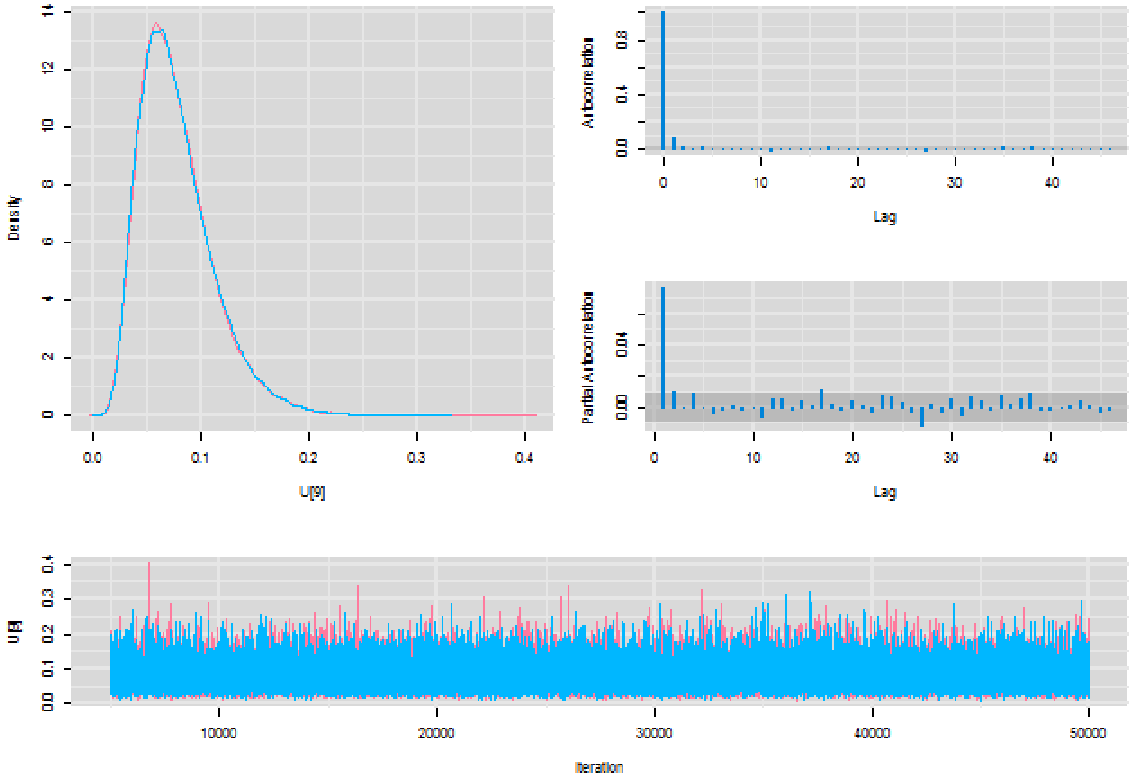
Diagnostics for U[7]



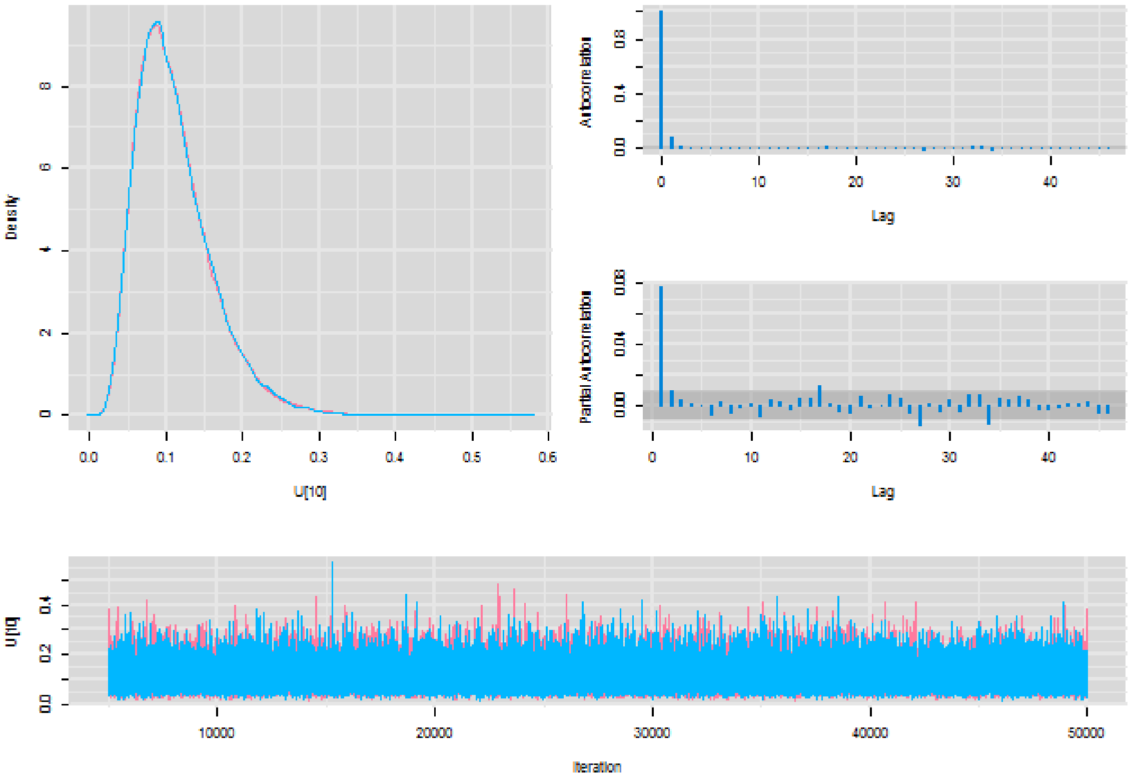
Diagnostics for U[8]



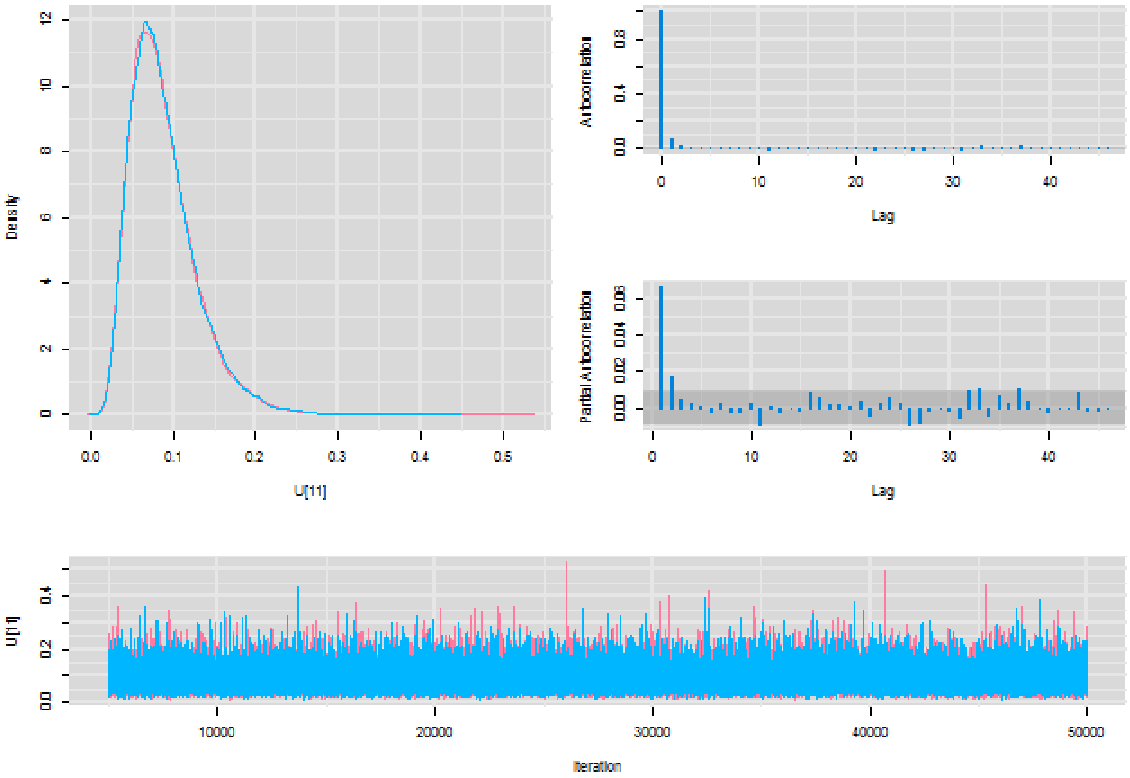
Diagnostics for U[9]



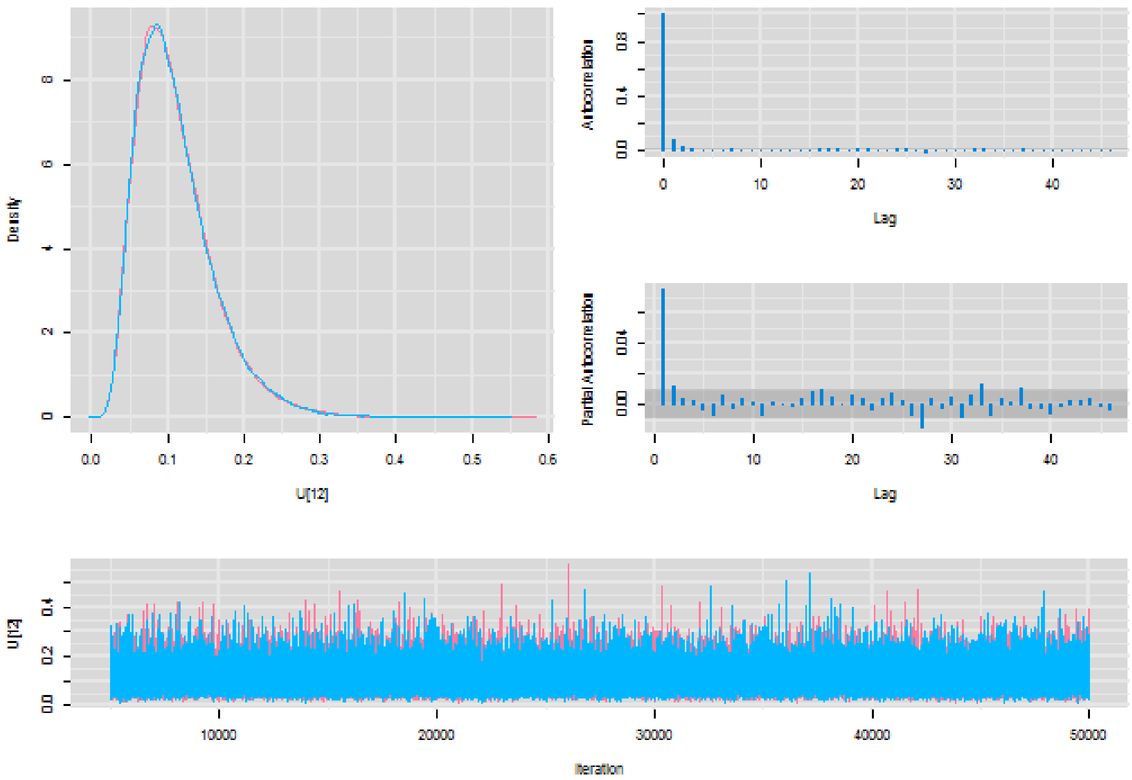
Diagnostics for U[10]



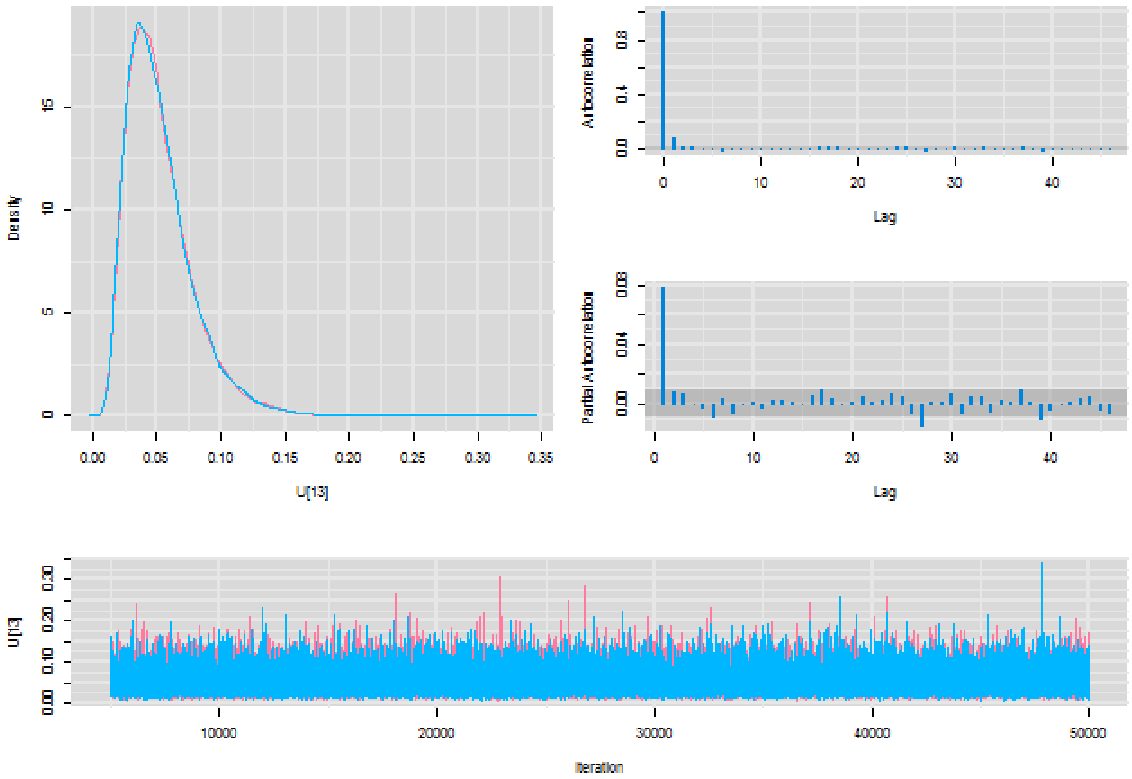
Diagnostics for U[11]



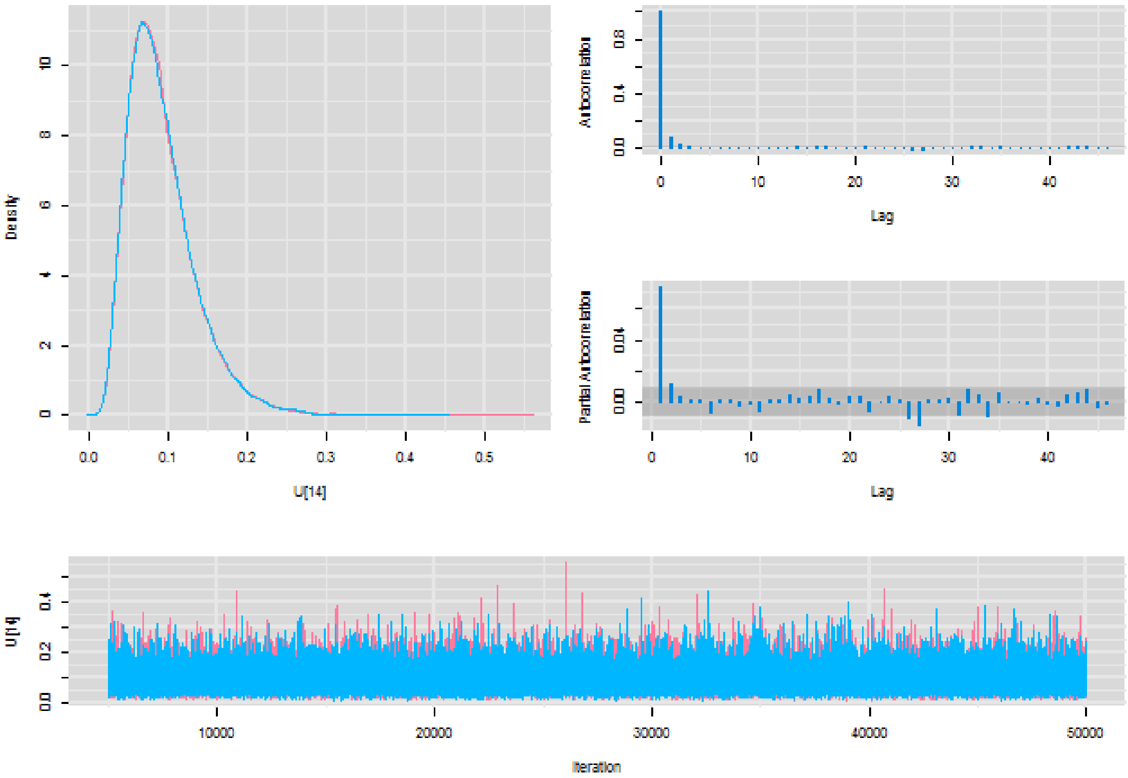
Diagnostics for U[12]



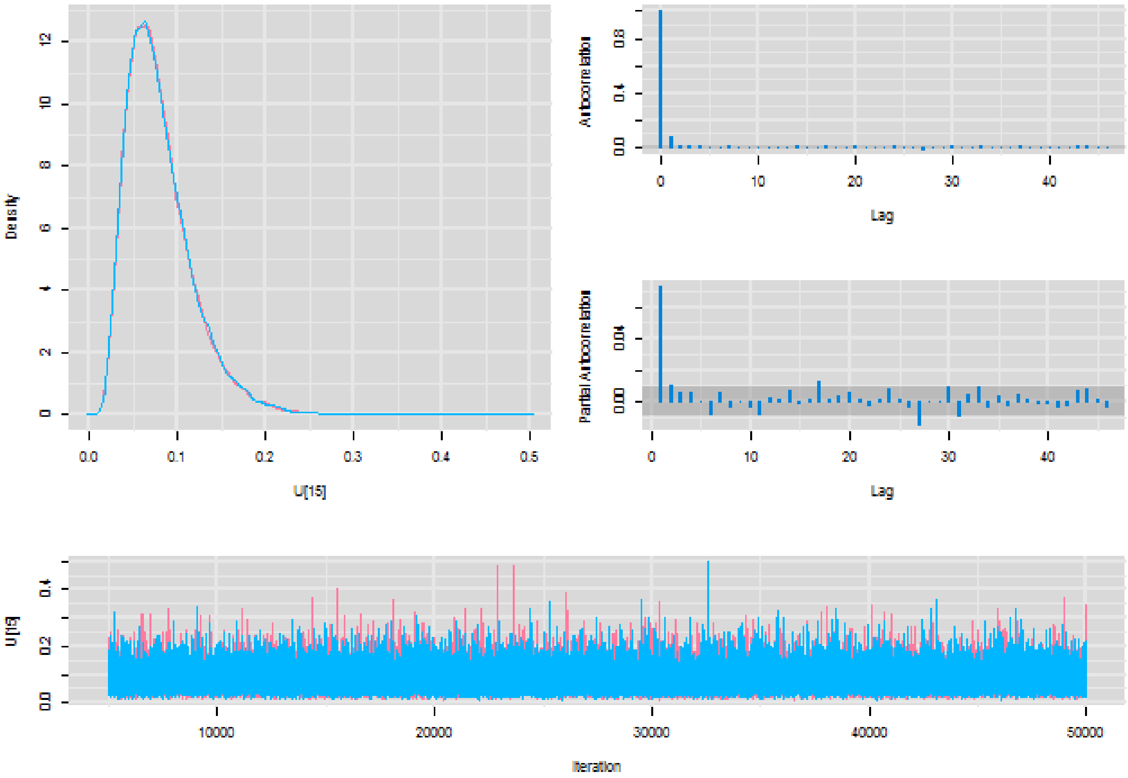
Diagnostics for U[13]



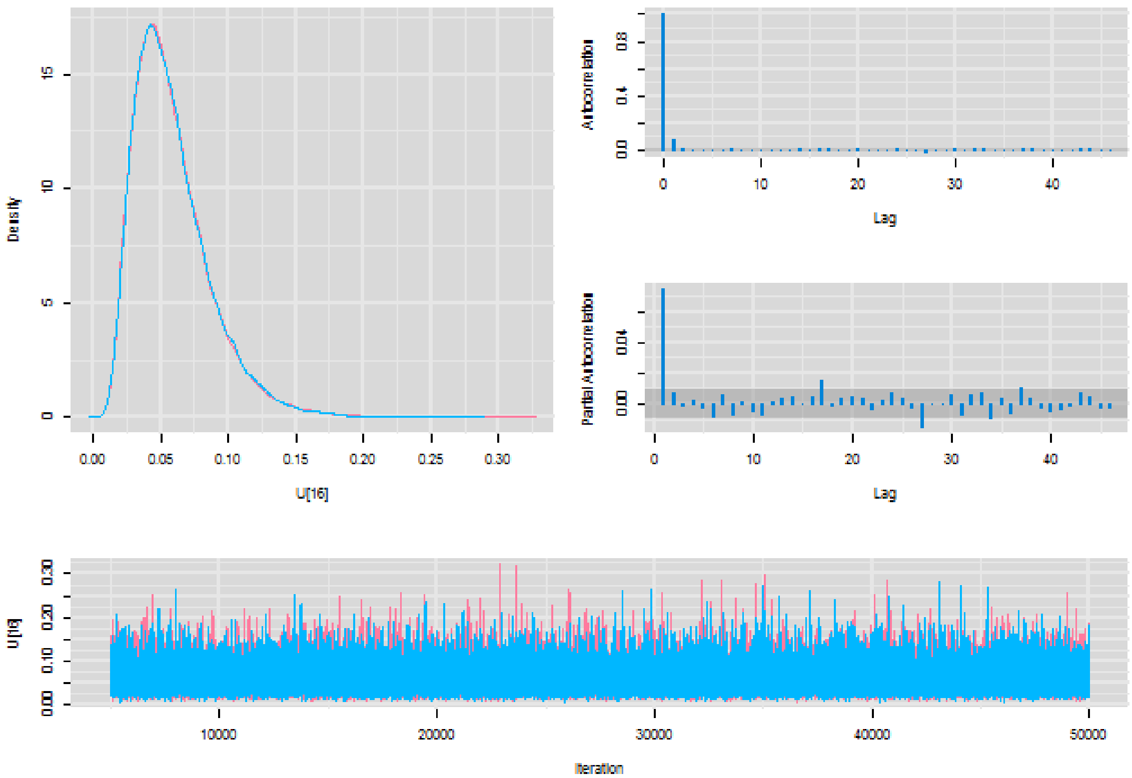
Diagnostics for U[14]



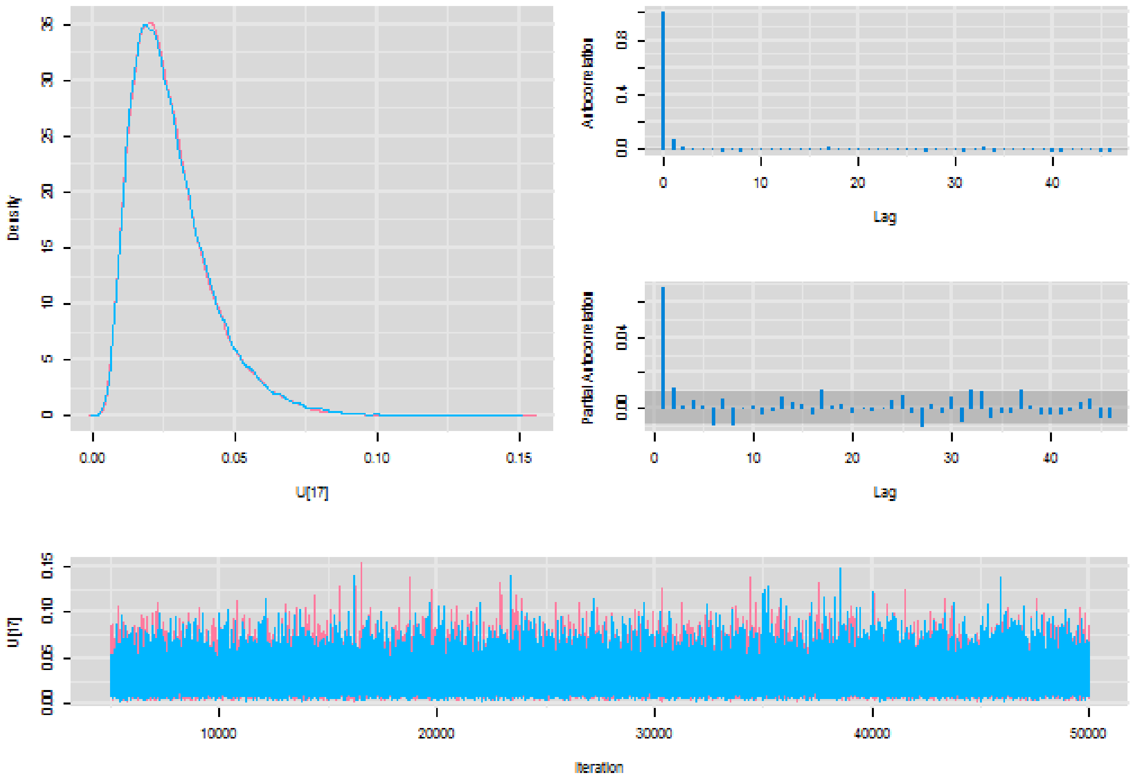
Diagnostics for U[15]



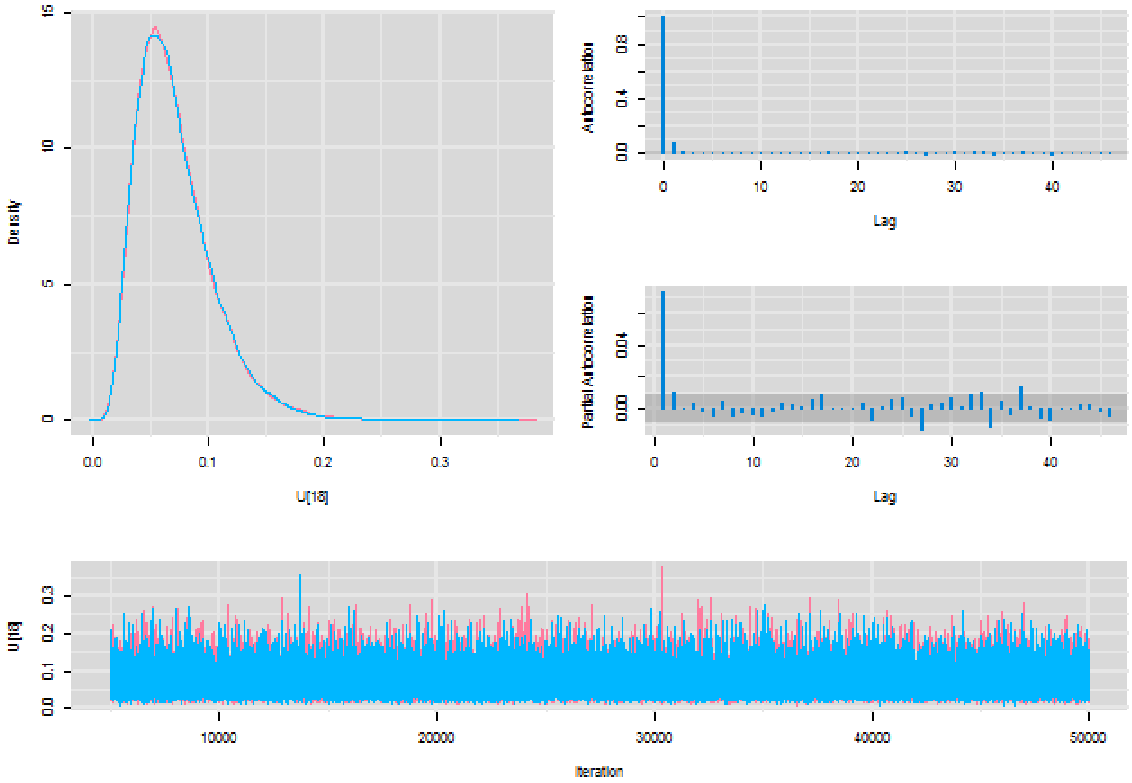
Diagnostics for U[16]



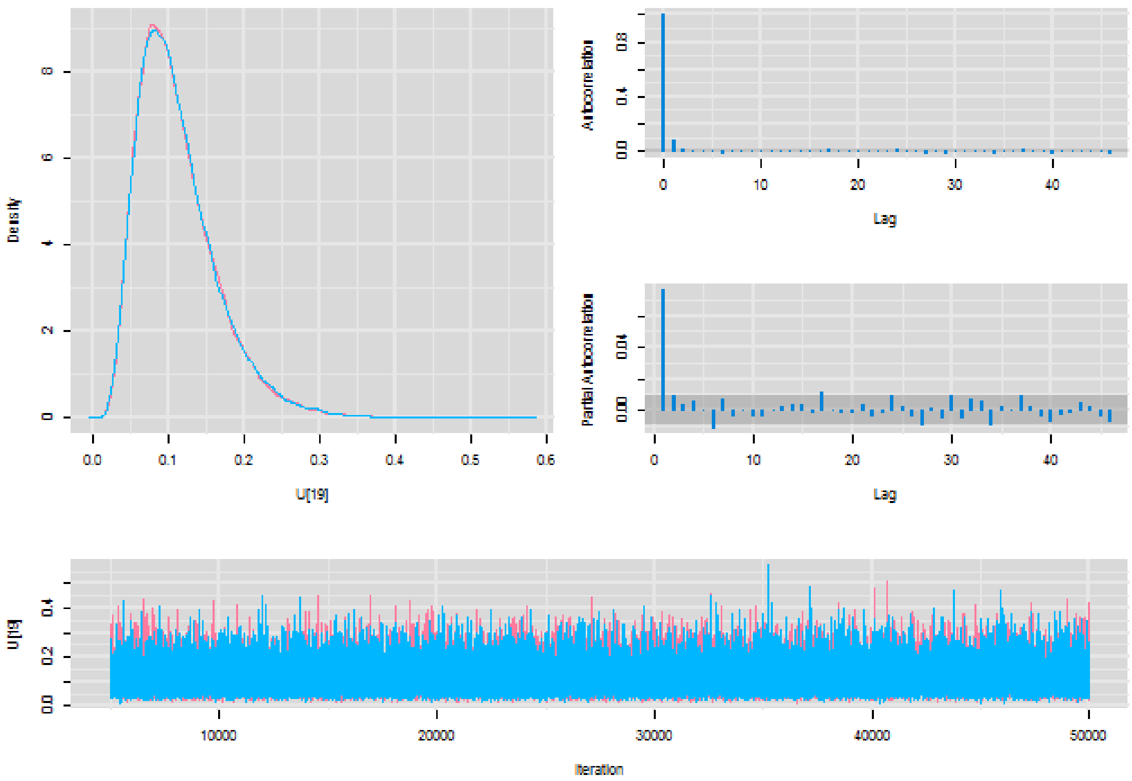
Diagnostics for U[17]



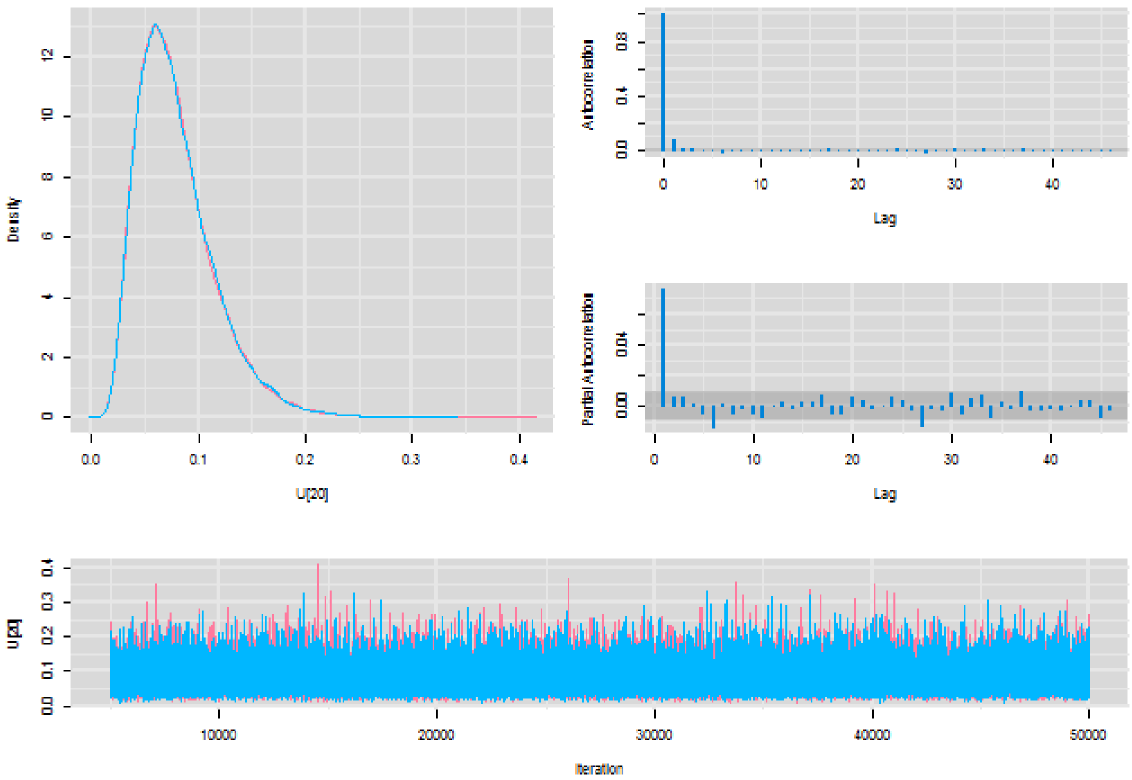
Diagnostics for U[18]



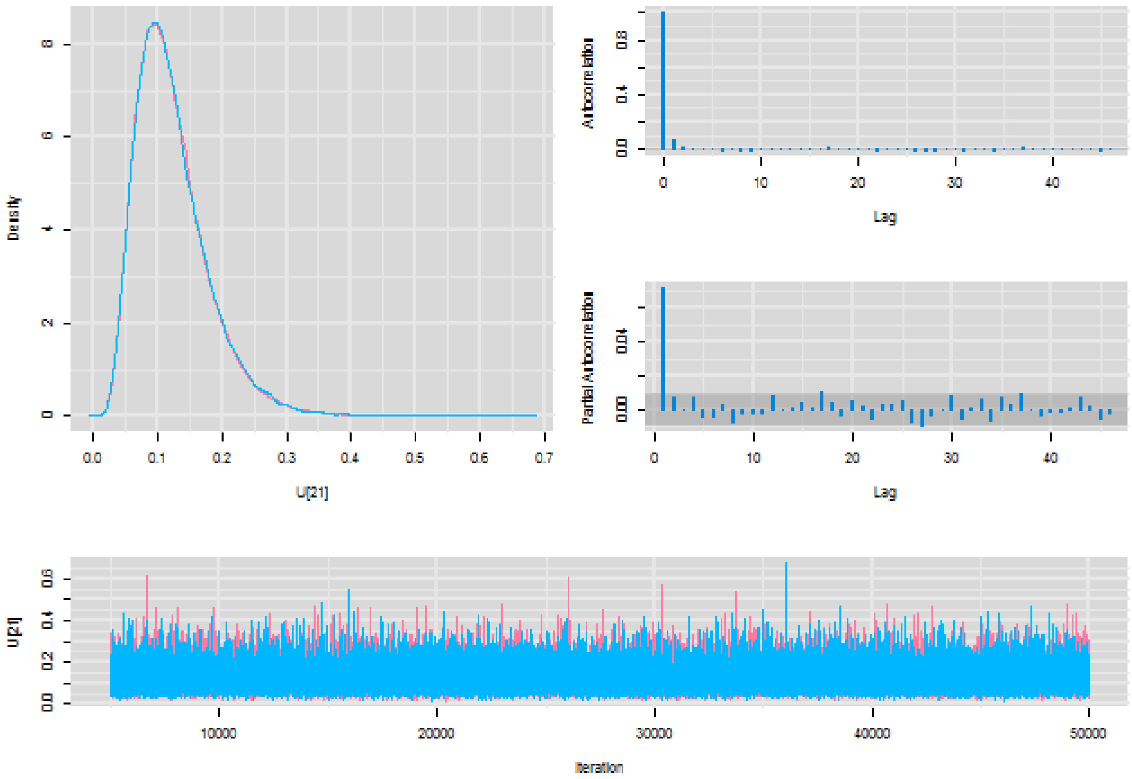
Diagnostics for U[19]



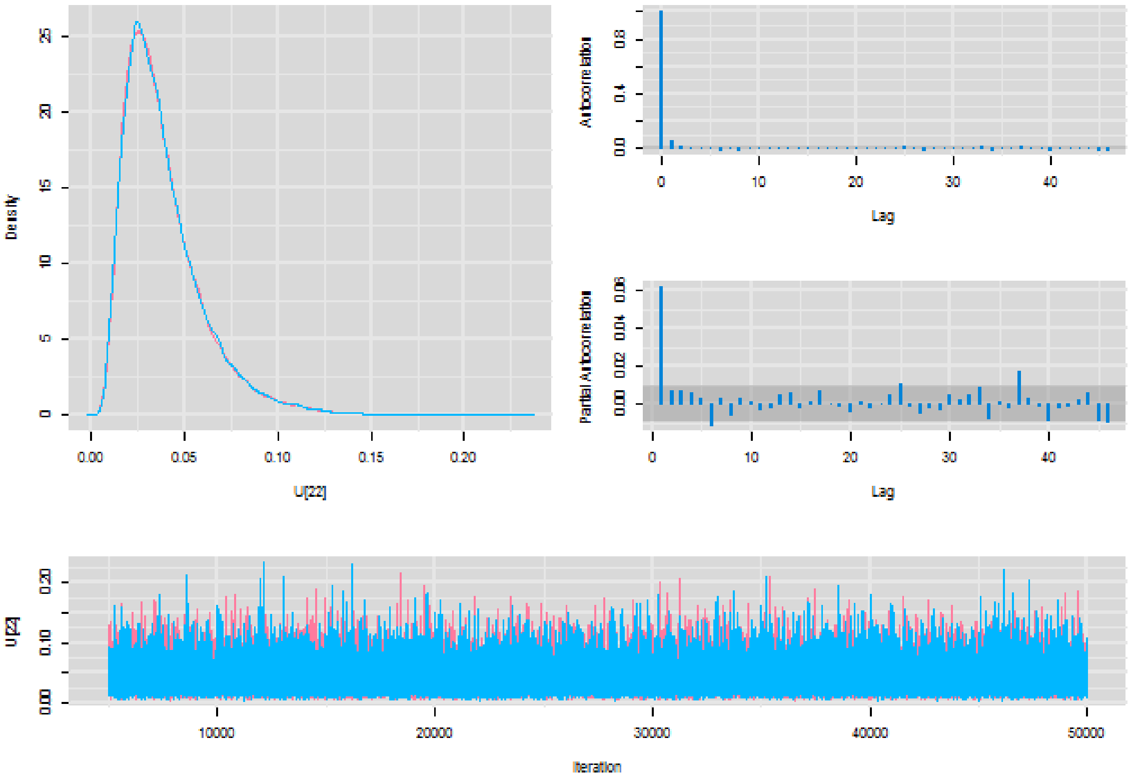
Diagnostics for U[20]



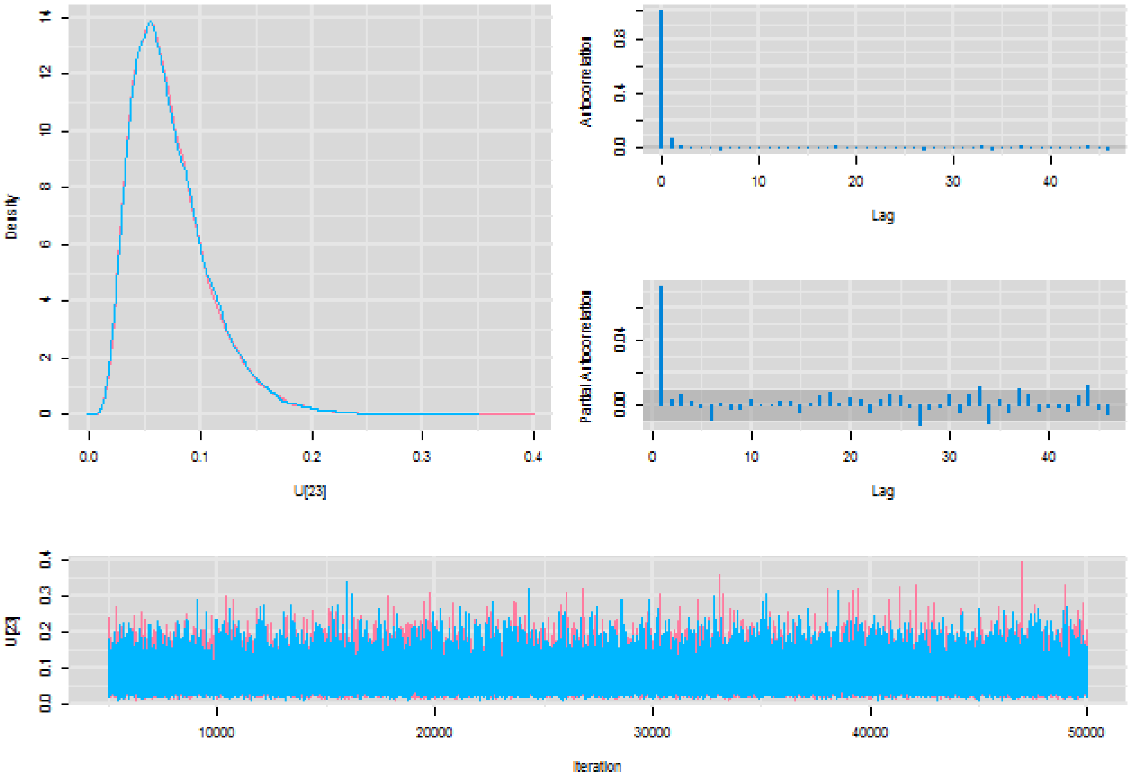
Diagnostics for U[21]



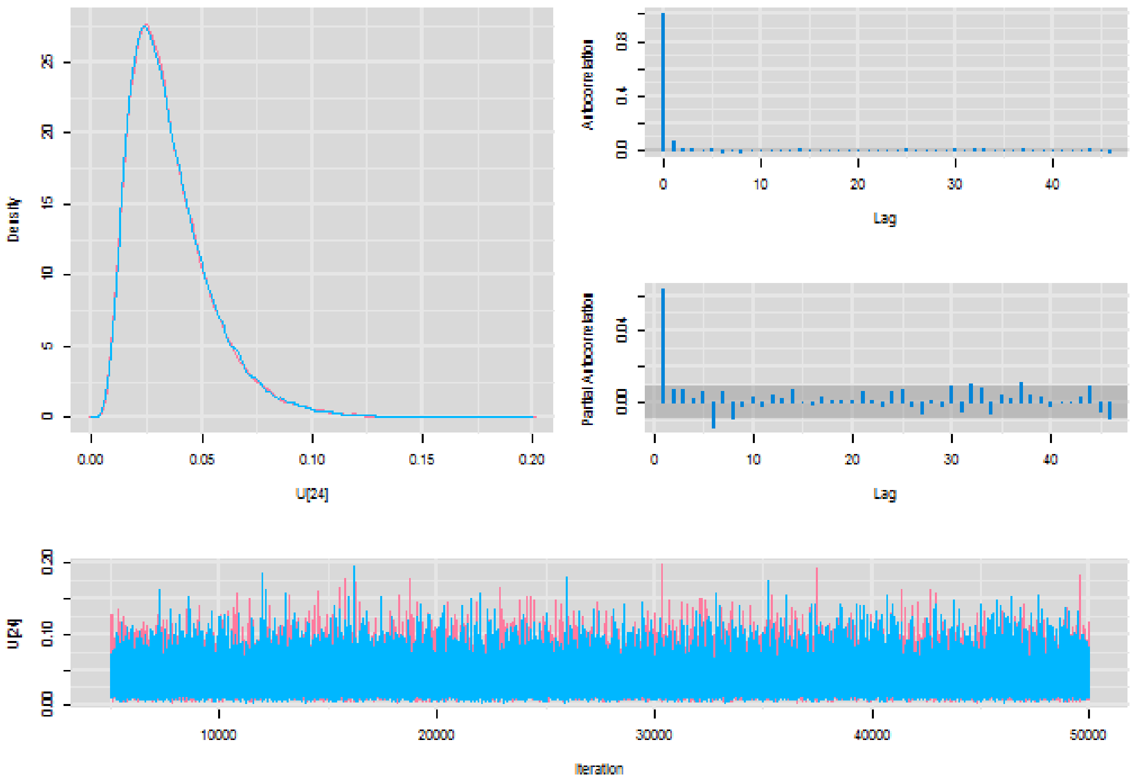
Diagnostics for U[22]



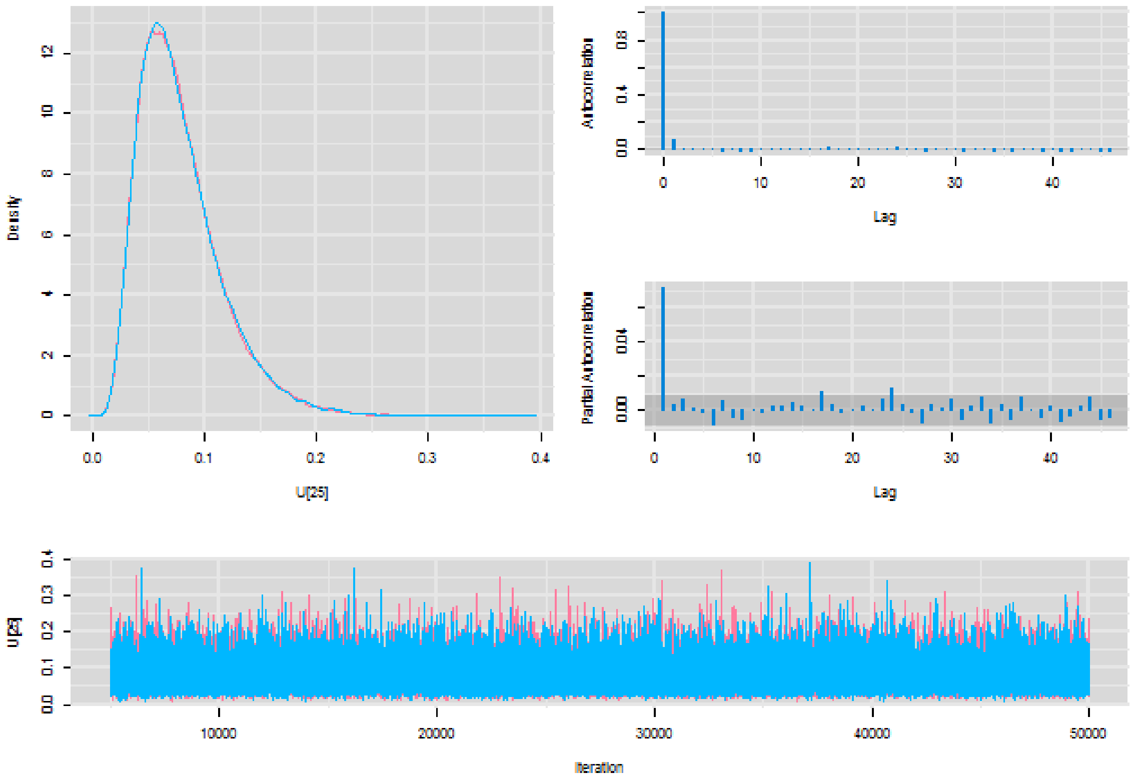
Diagnostics for U[23]



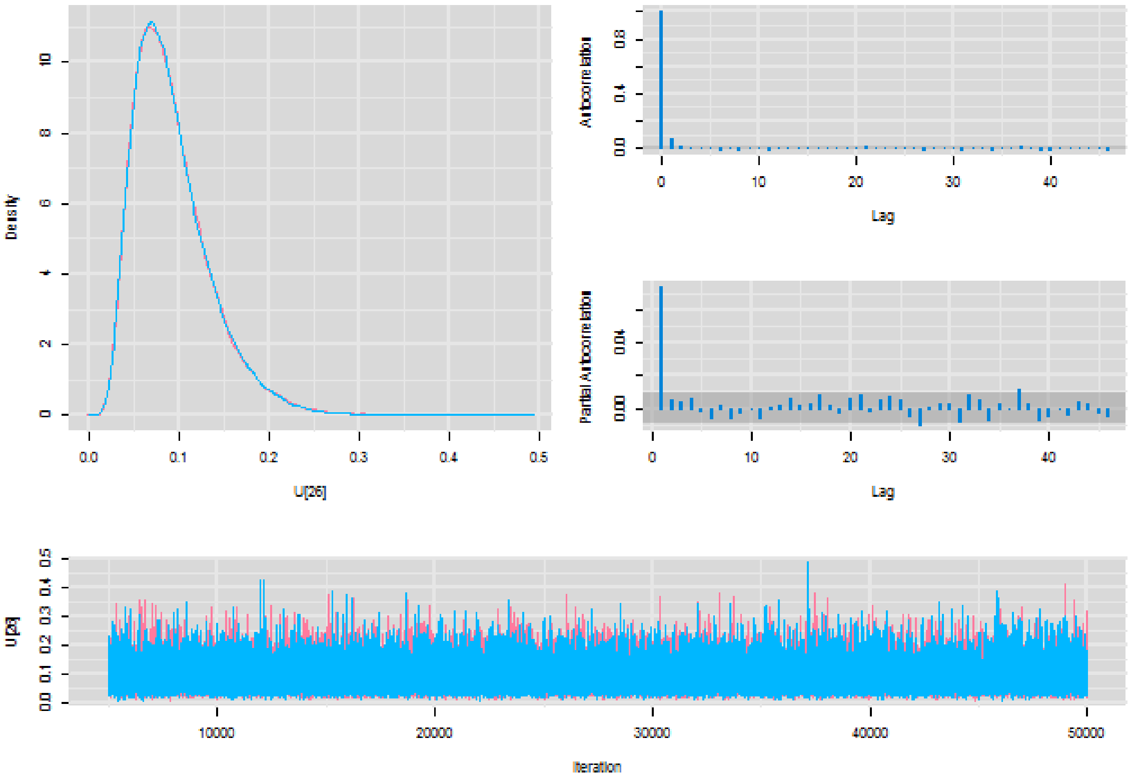
Diagnostics for U[24]



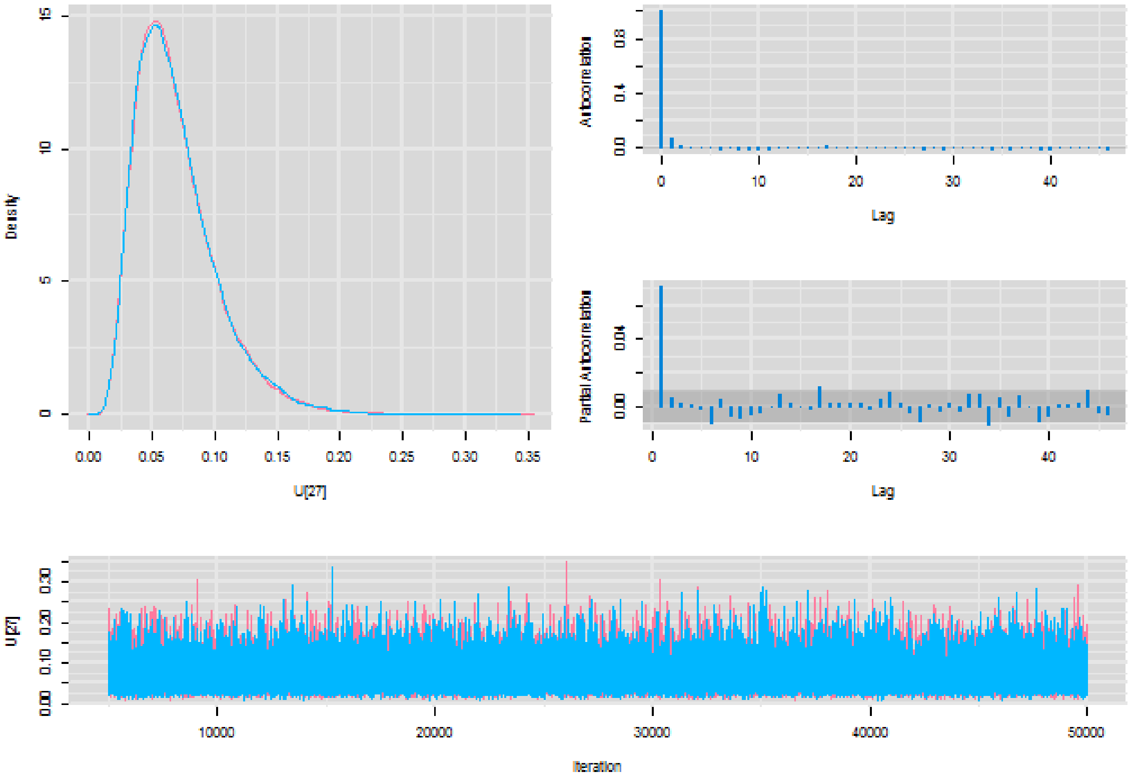
Diagnostics for U[25]



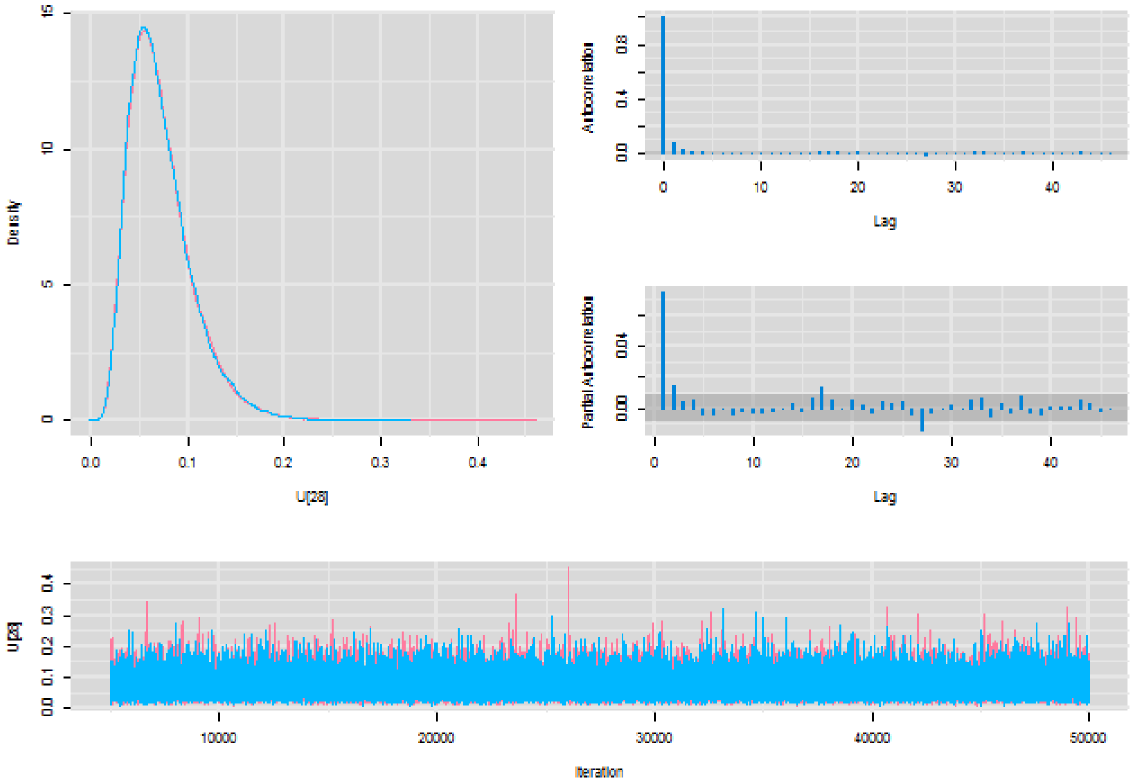
Diagnostics for U[26]



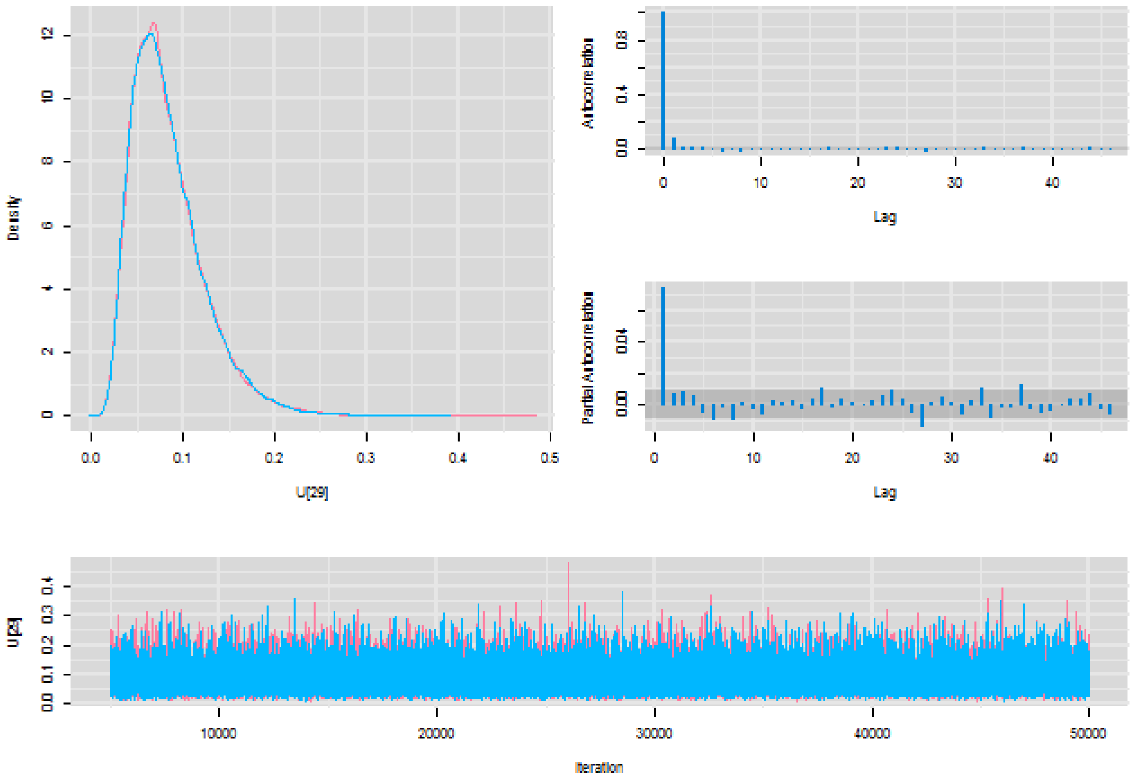
Diagnostics for U[27]



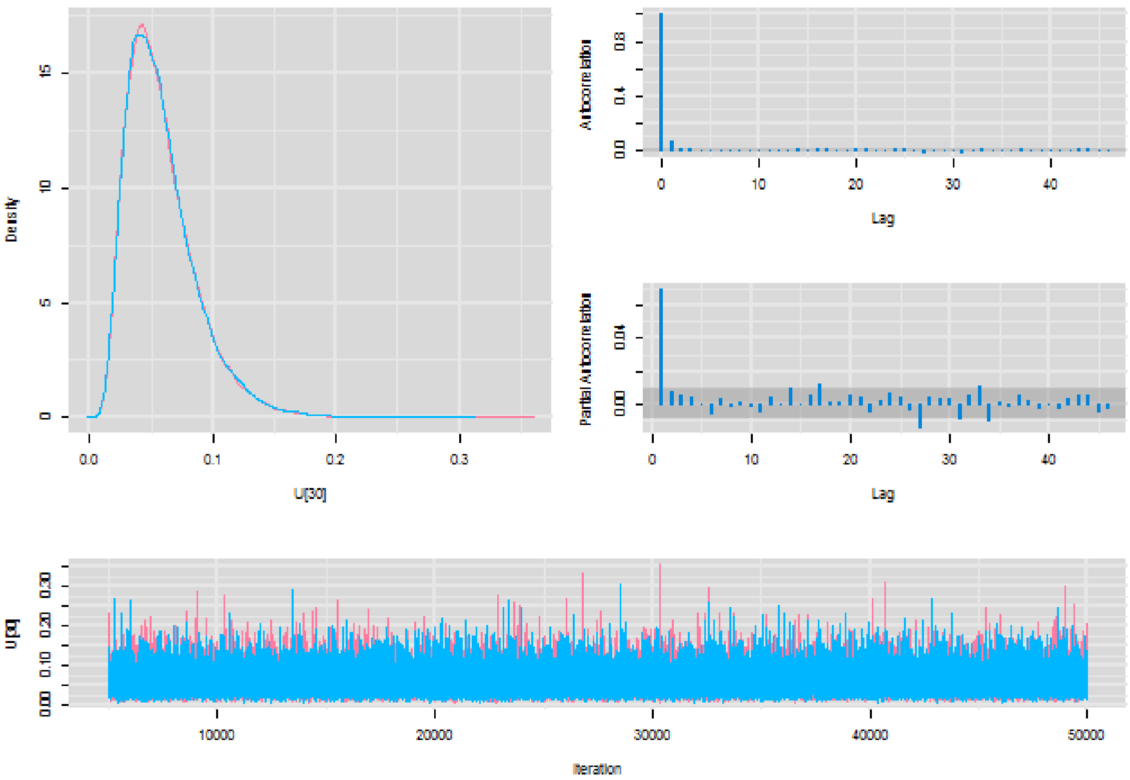
Diagnostics for U[28]



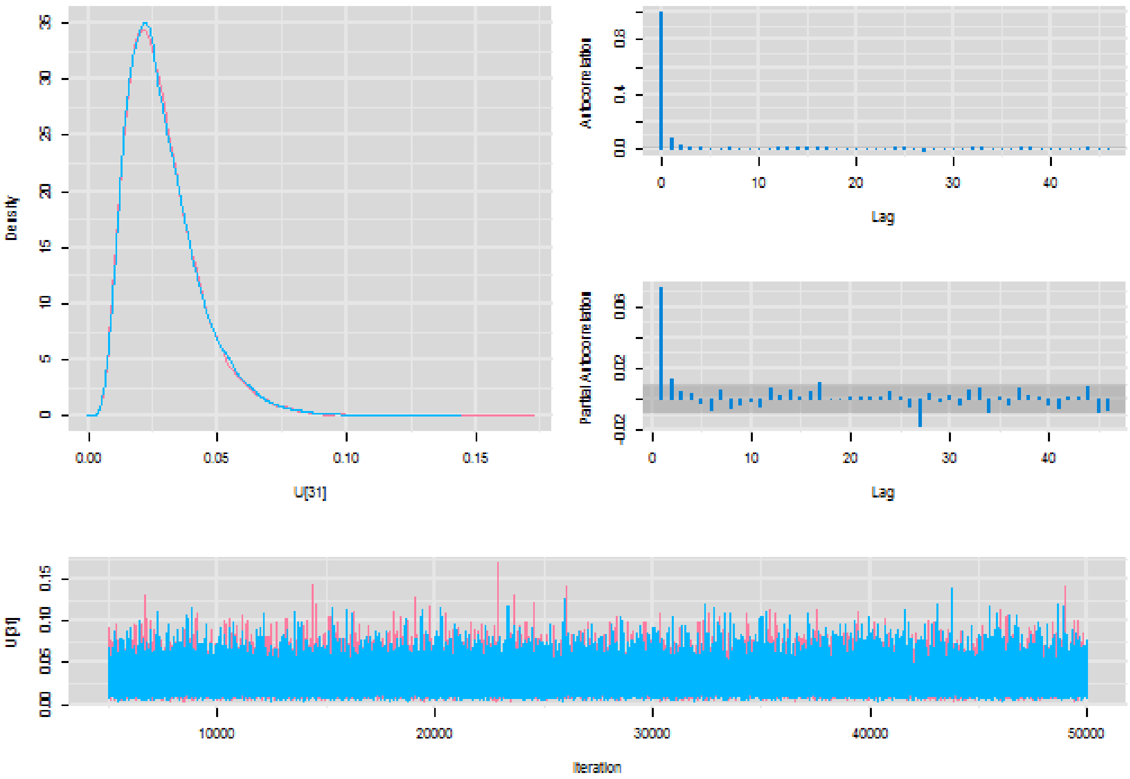
Diagnostics for U[29]



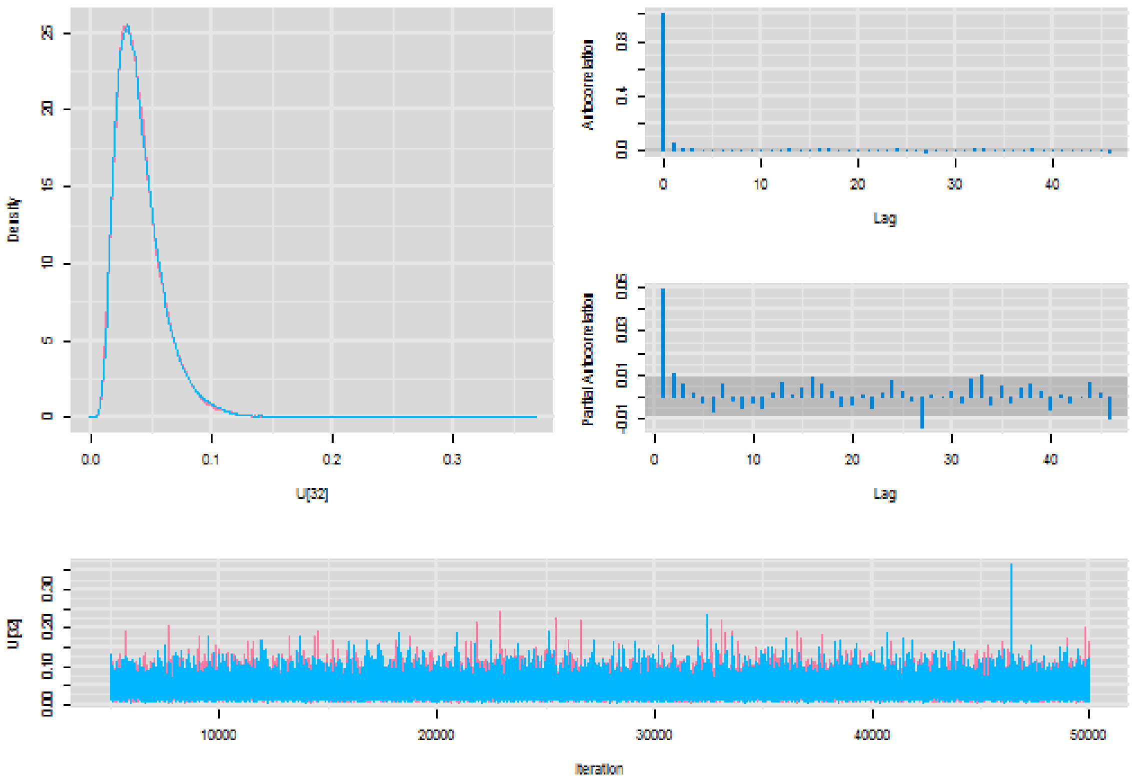
Diagnostics for U[30]



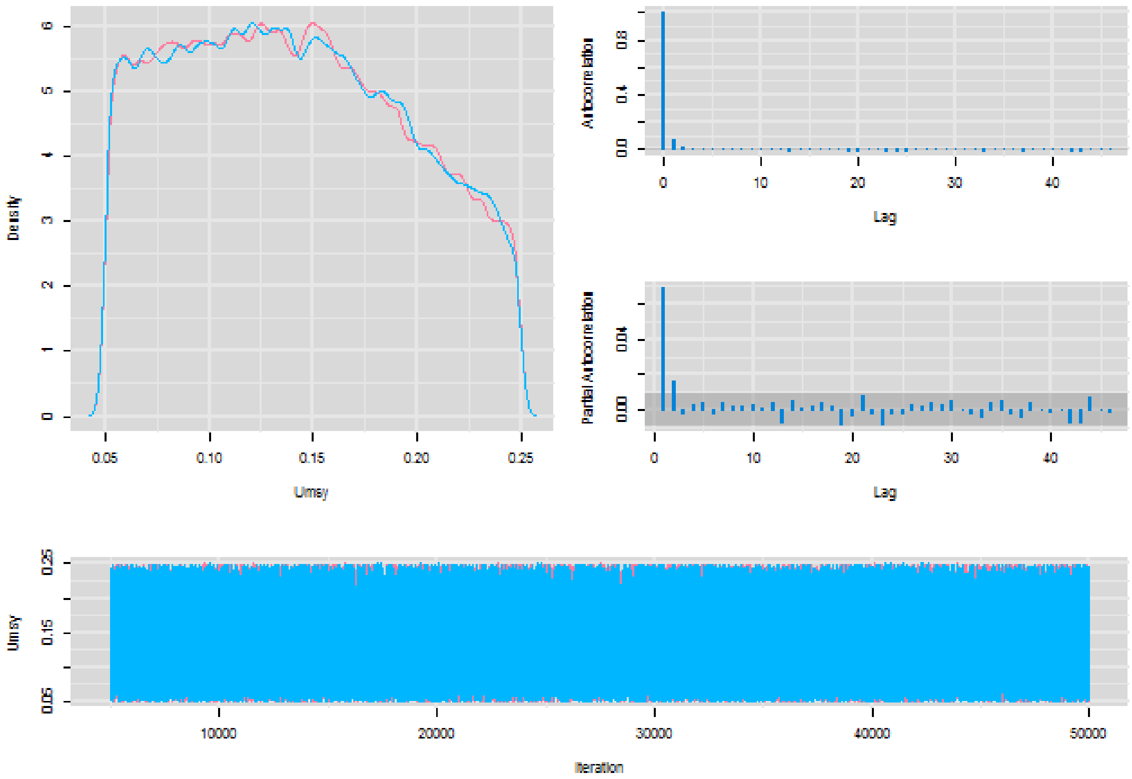
Diagnostics for U[31]



Diagnostics for U[32]

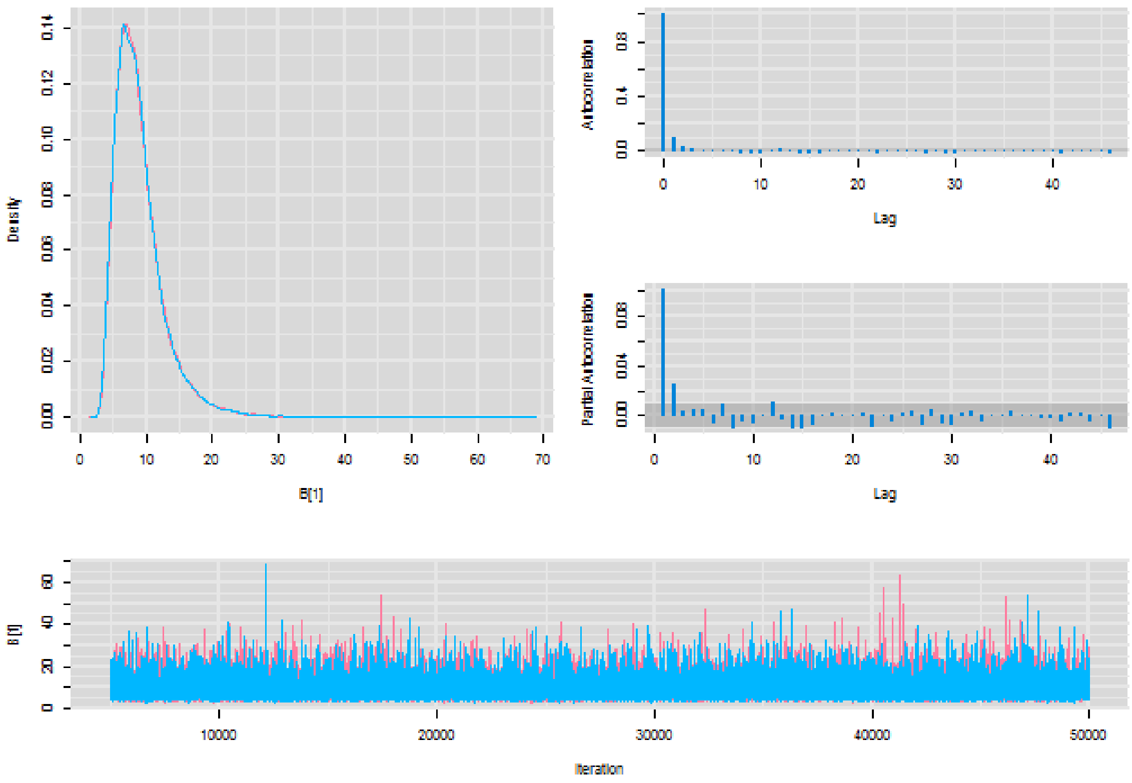


Diagnostics for Umsy

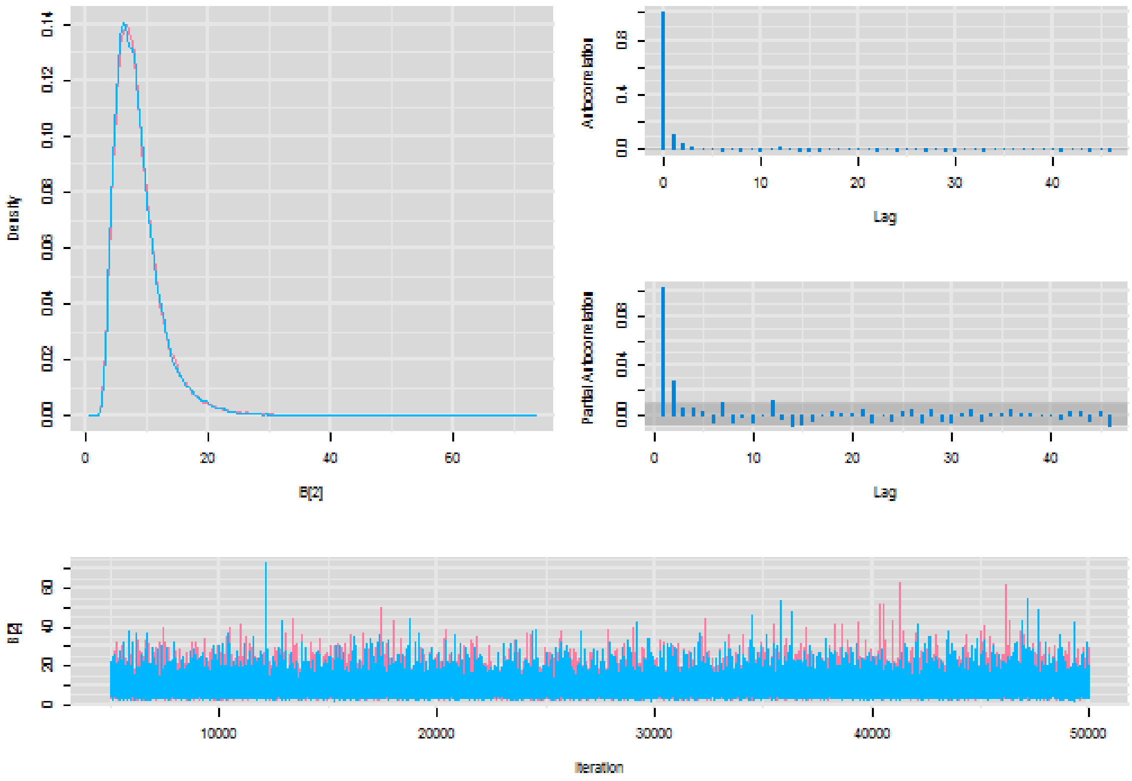


Appendix 1.3 – Diagnostic plots for the DelMarVa base run of the Bayesian State Space Surplus Production Model

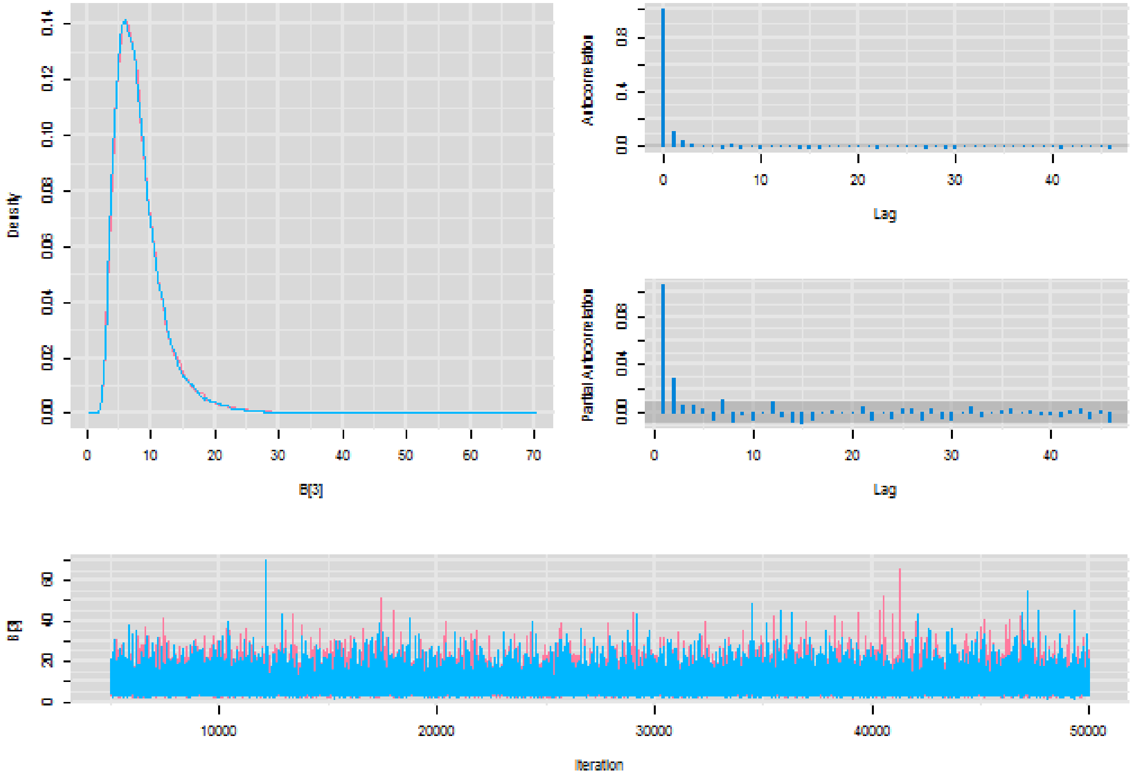
Diagnostics for B[1]



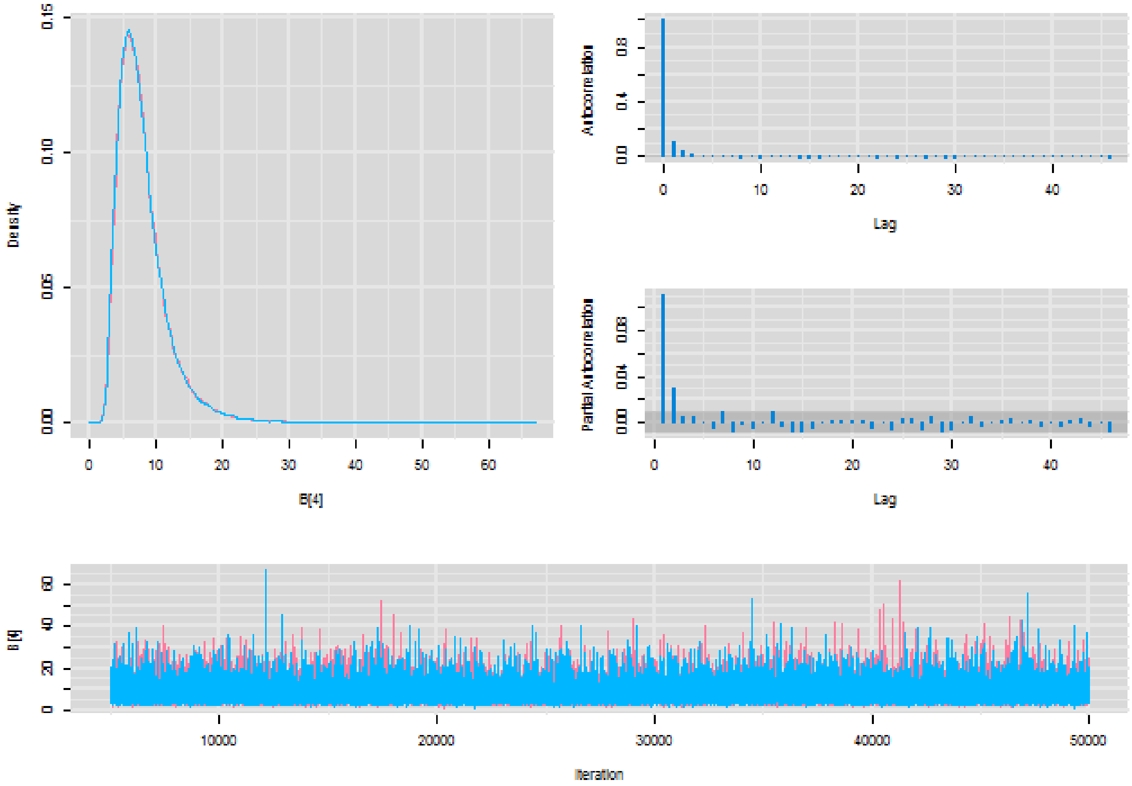
Diagnostics for B[2]



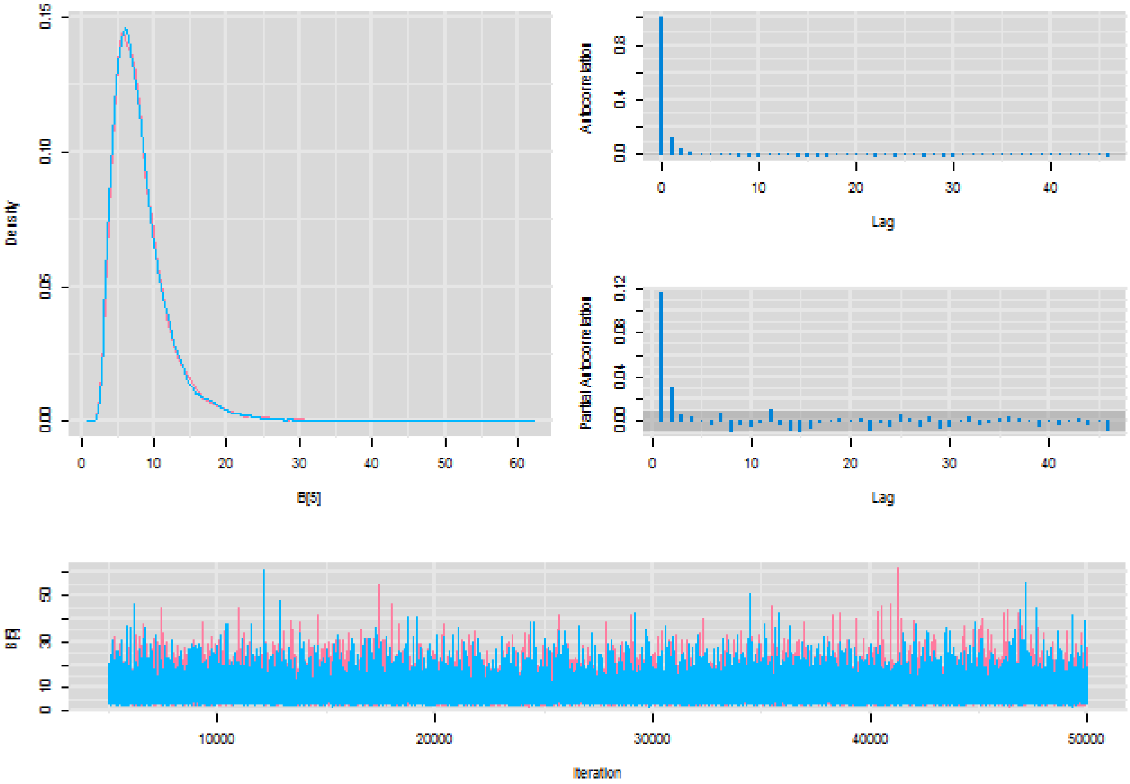
Diagnostics for B[3]



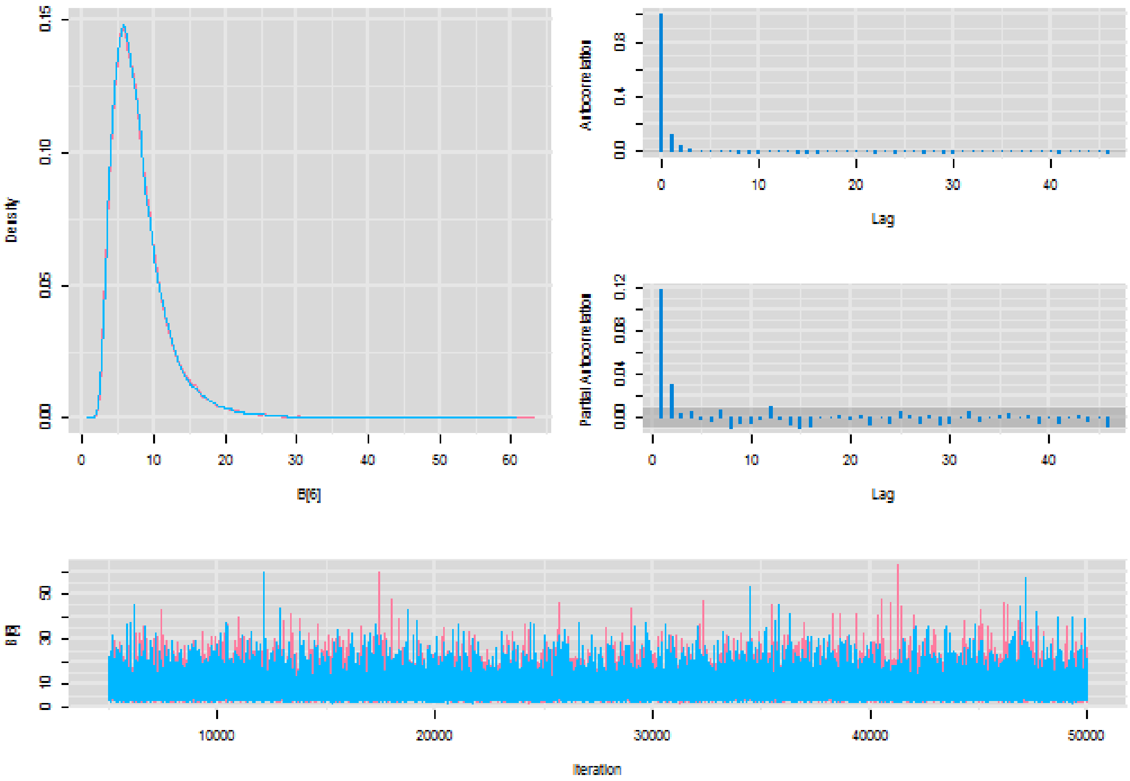
Diagnostics for B[4]



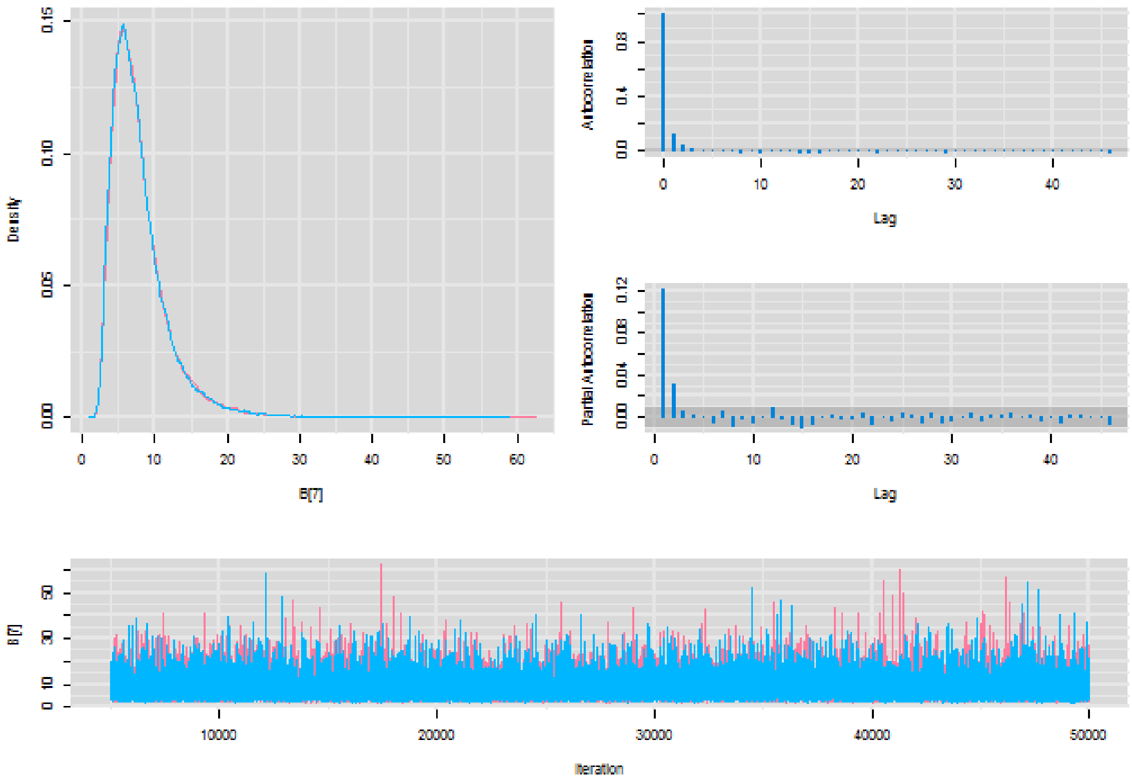
Diagnostics for B[5]



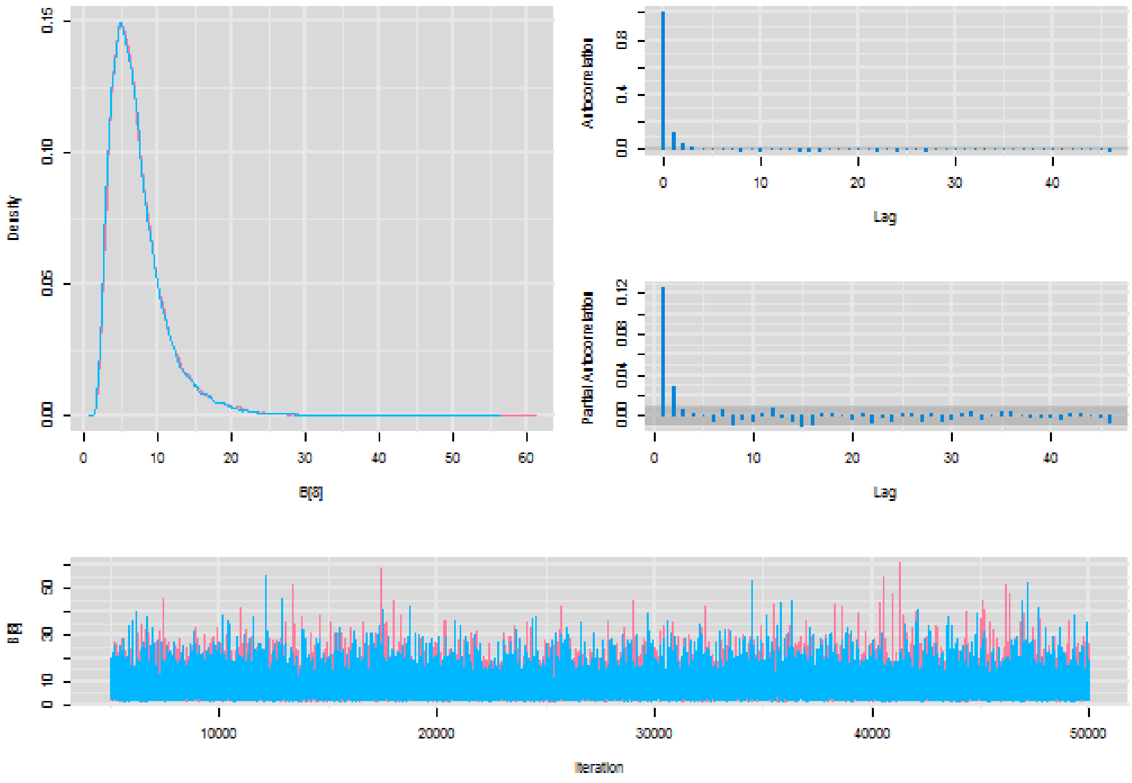
Diagnostics for B[6]



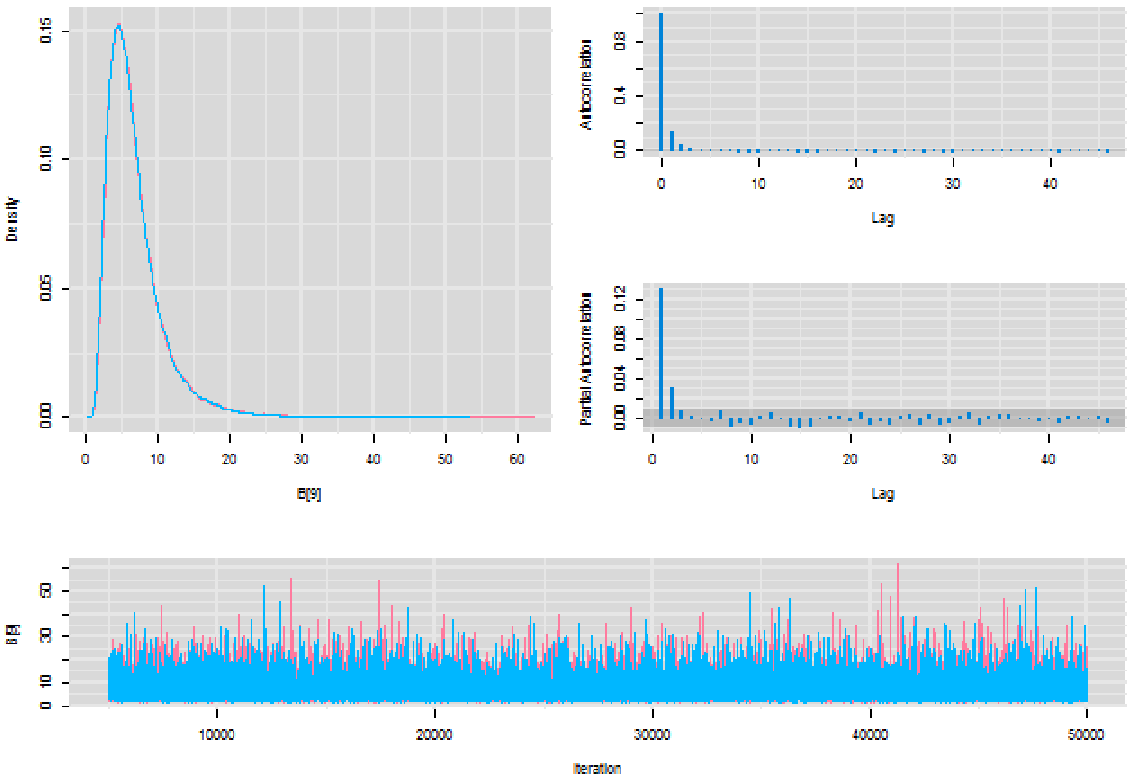
Diagnostics for B[7]



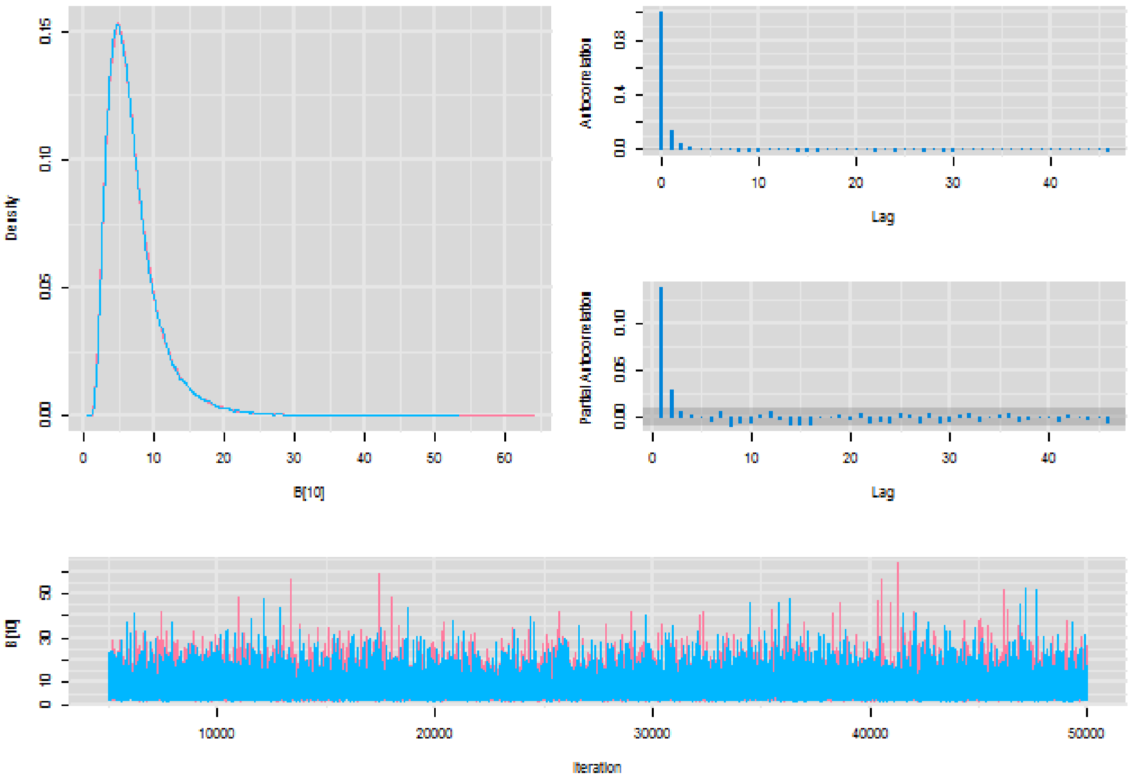
Diagnostics for B[8]



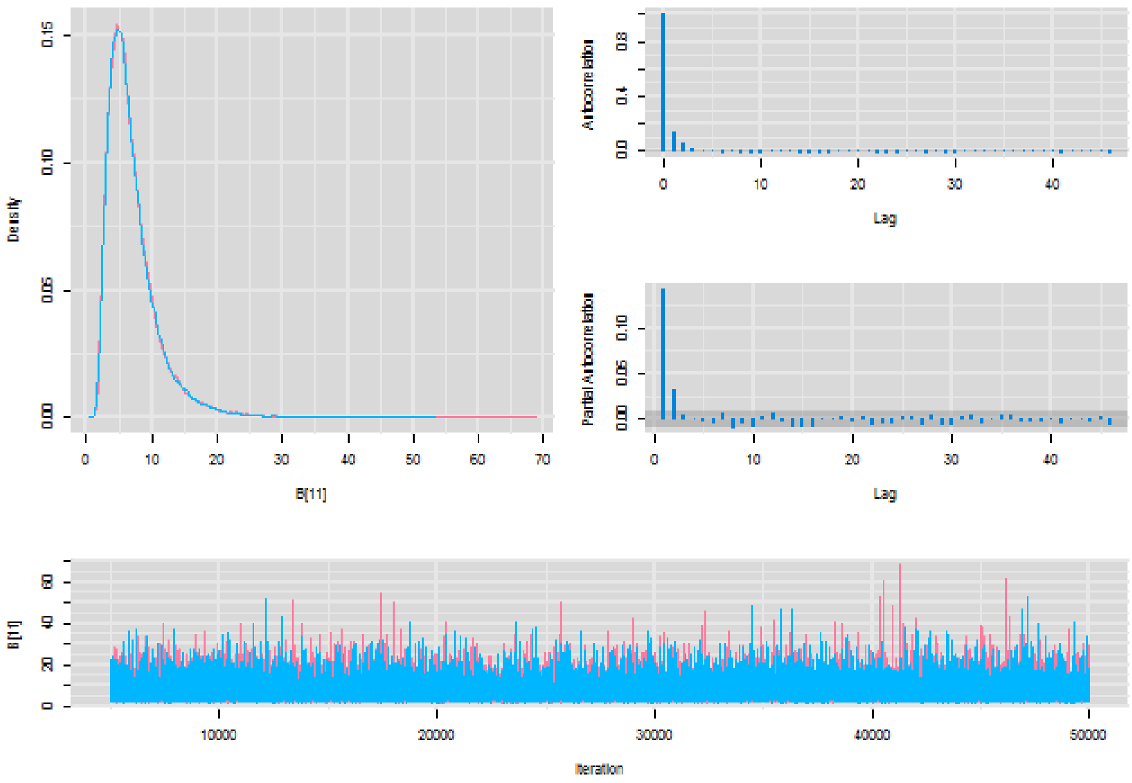
Diagnostics for B[9]



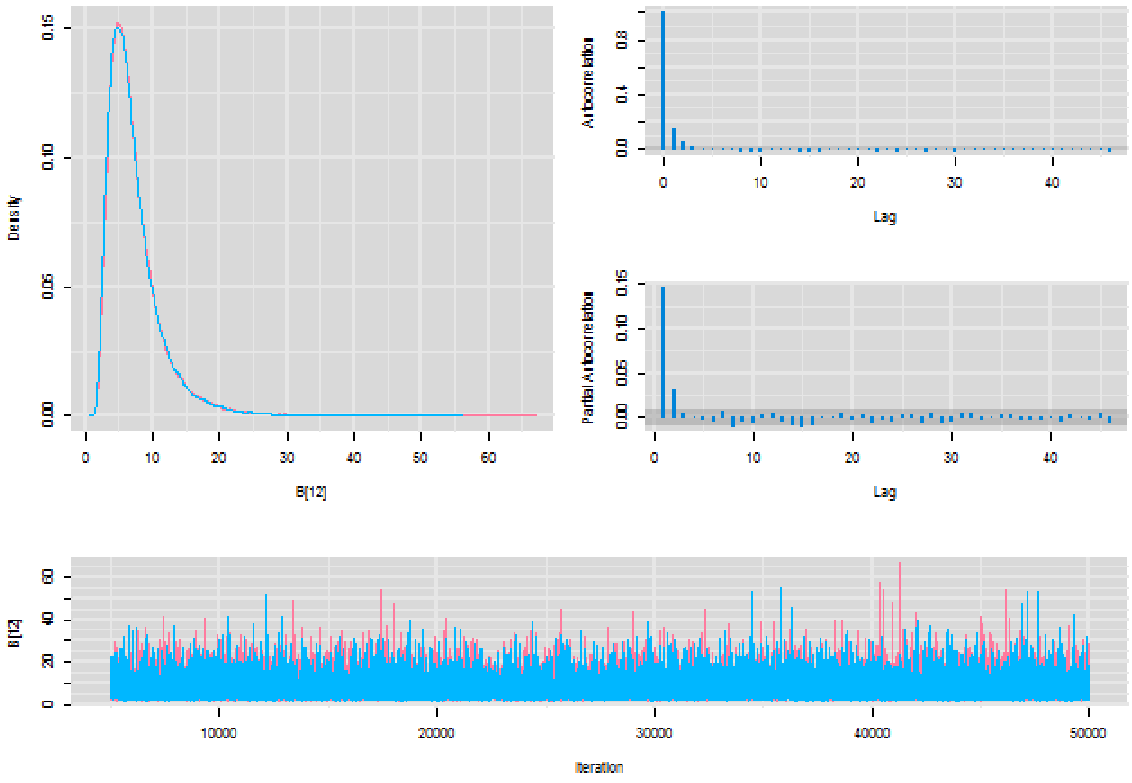
Diagnostics for B[10]



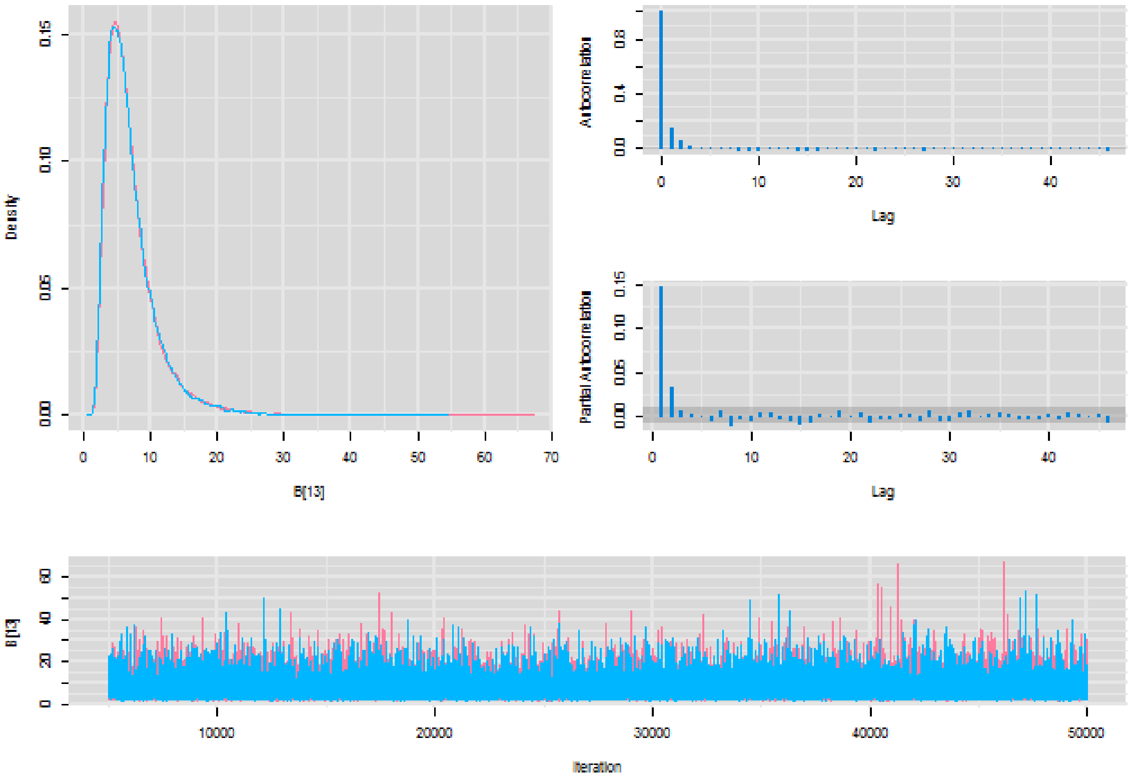
Diagnostics for B[11]



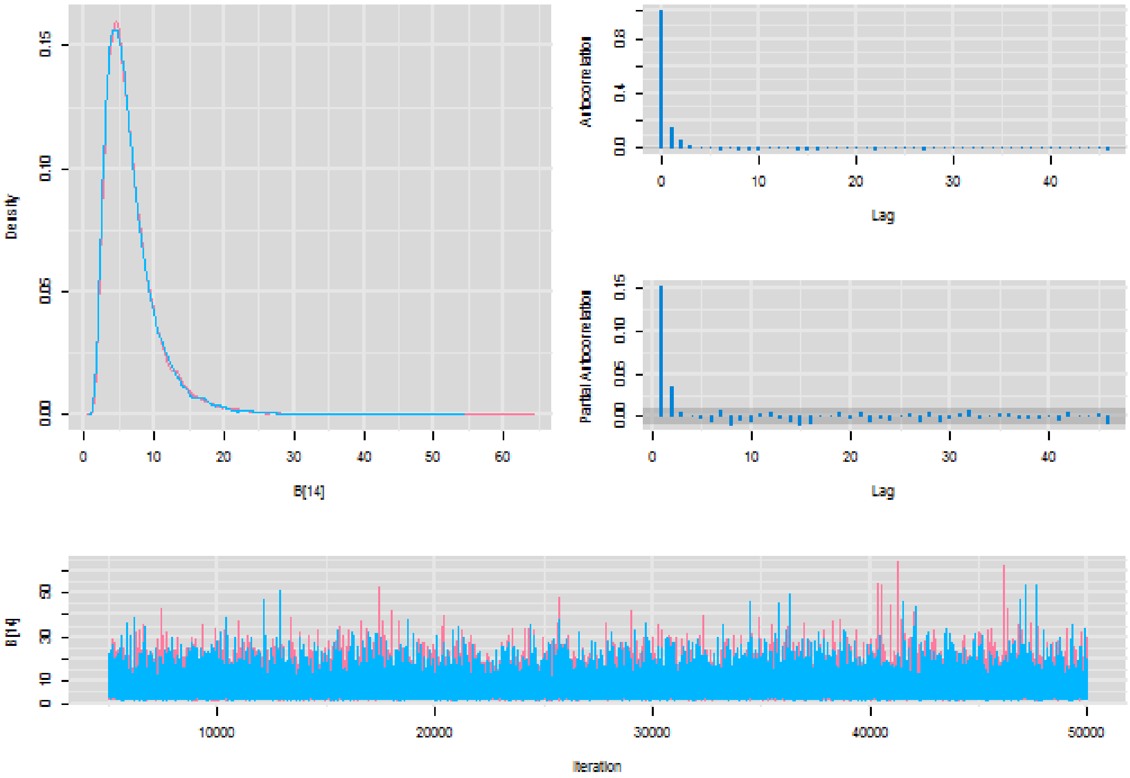
Diagnostics for B[12]



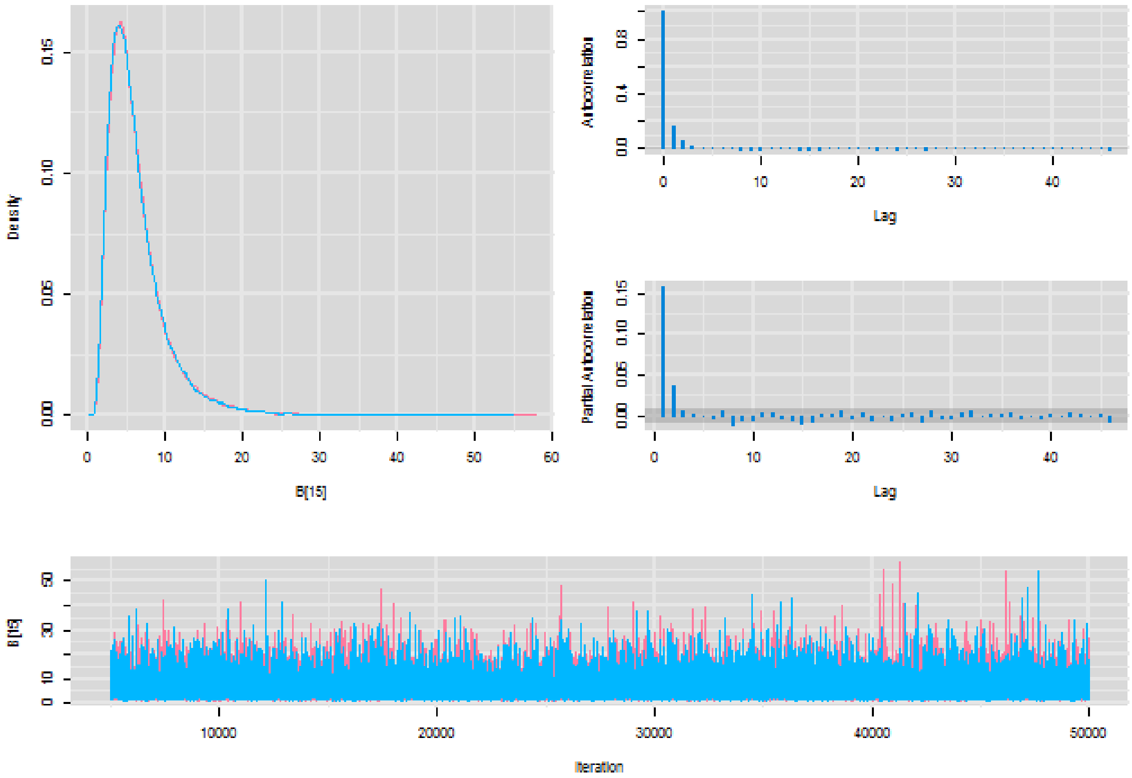
Diagnostics for B[13]



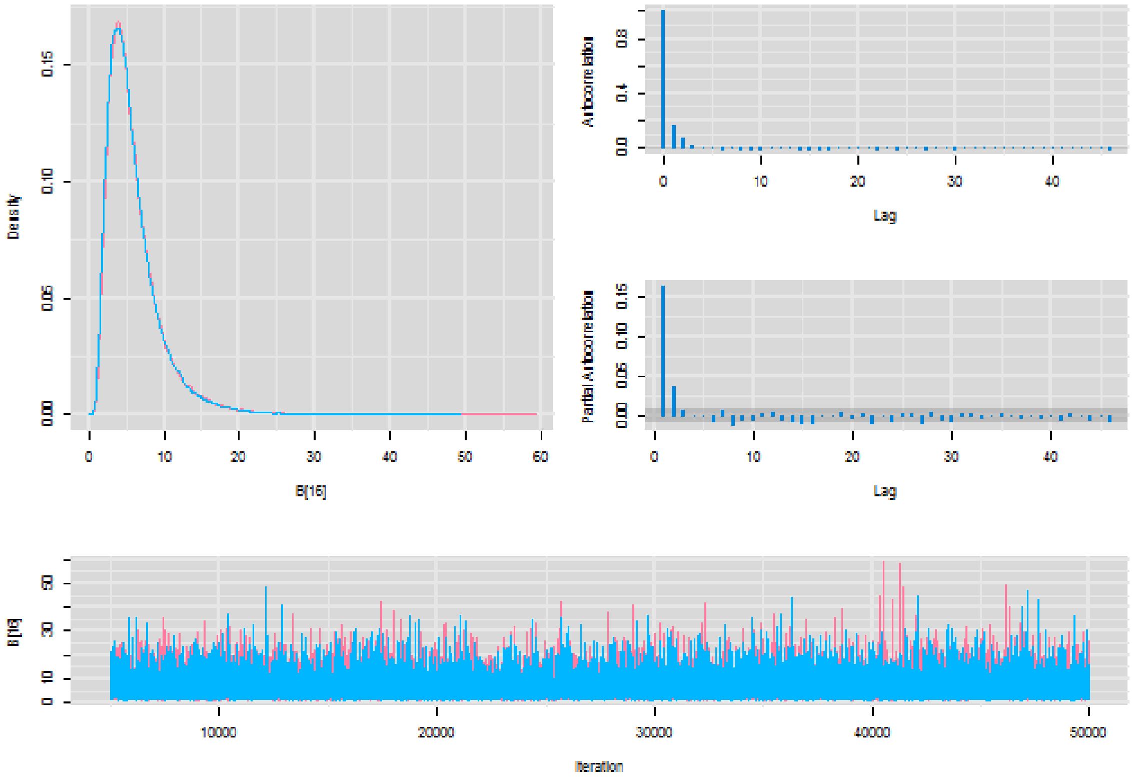
Diagnostics for B[14]



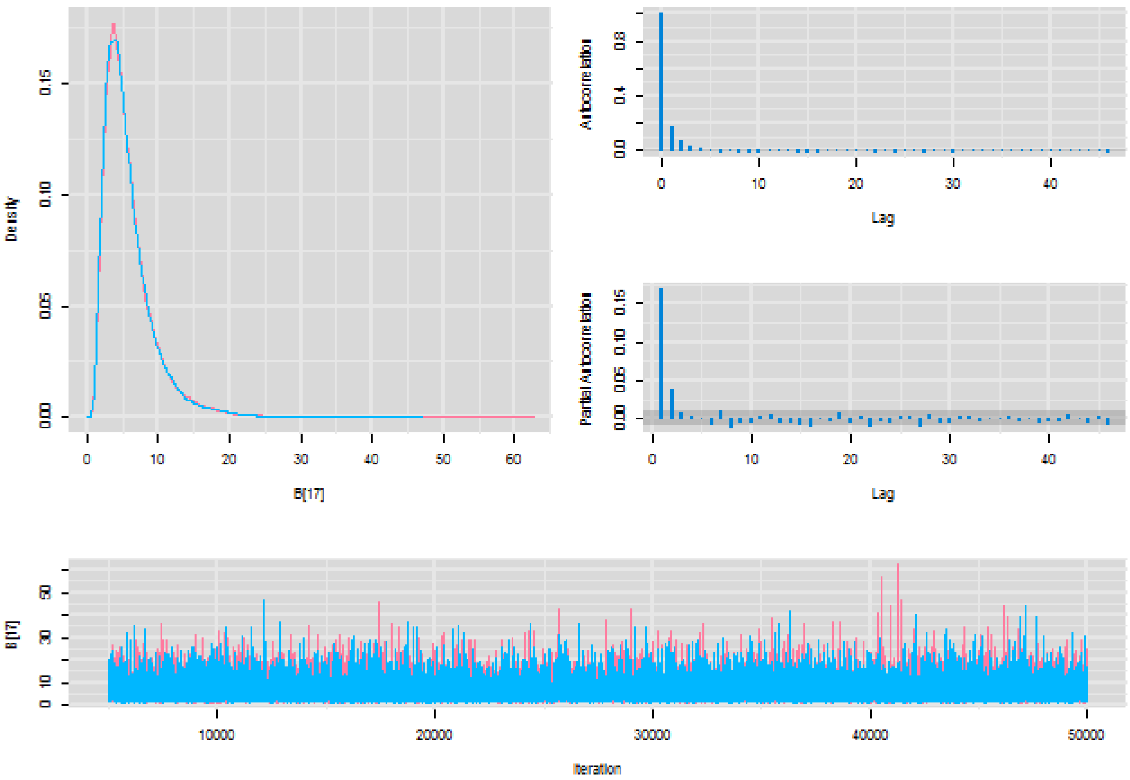
Diagnostics for B[15]



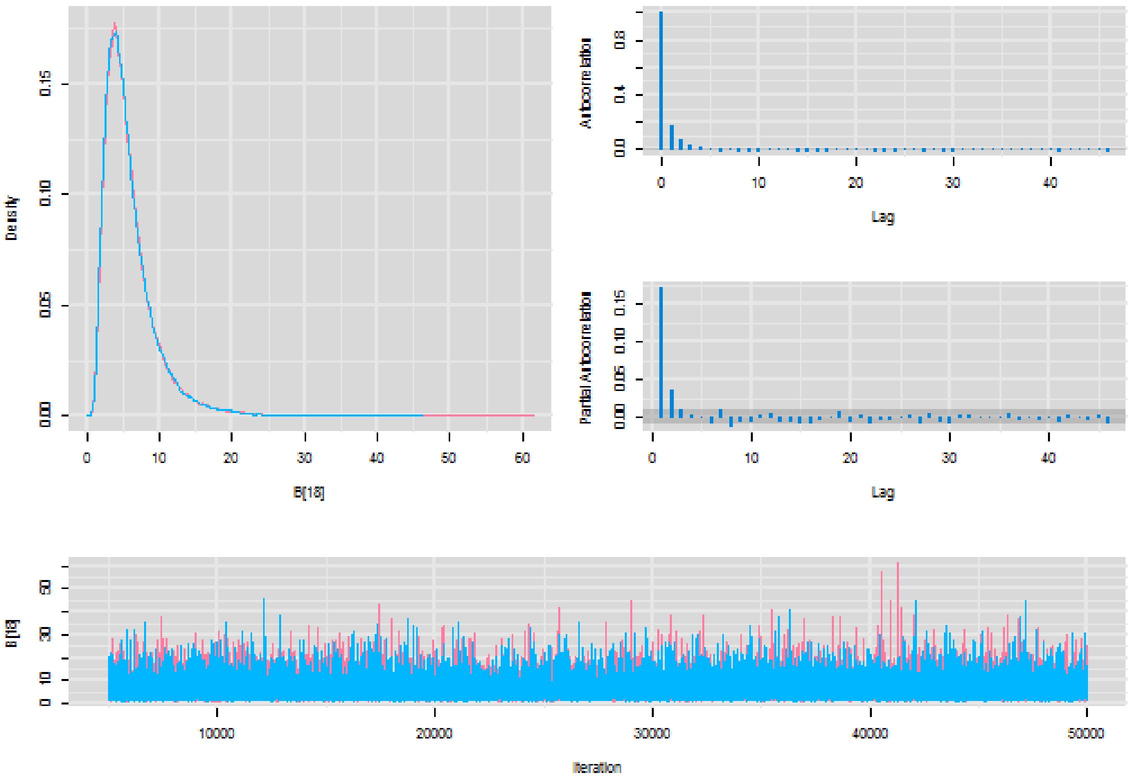
Diagnostics for B[16]



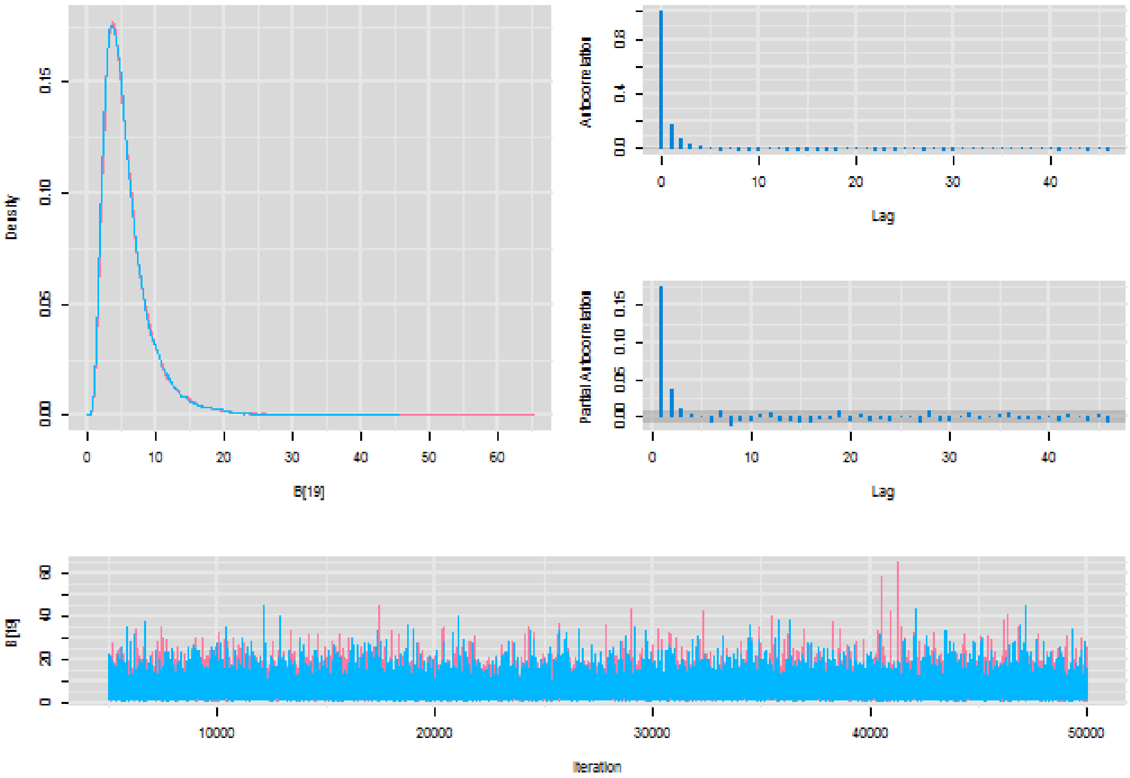
Diagnostics for B[17]



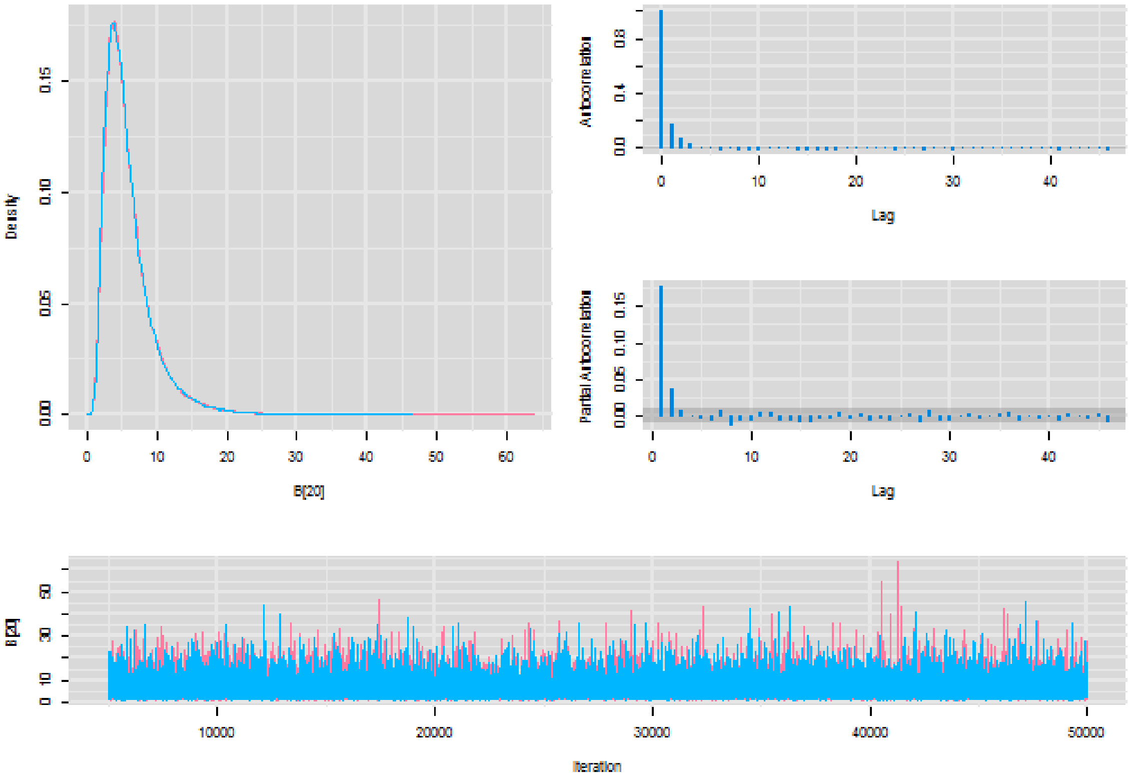
Diagnostics for B[18]



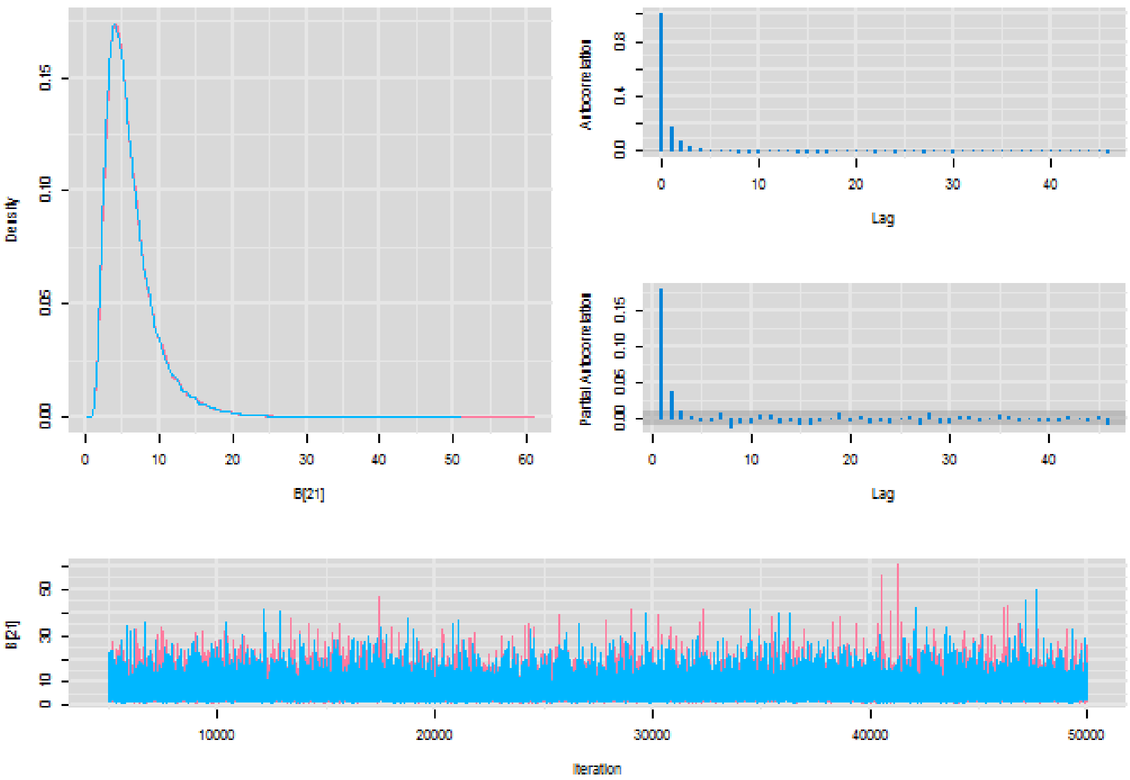
Diagnostics for B[19]



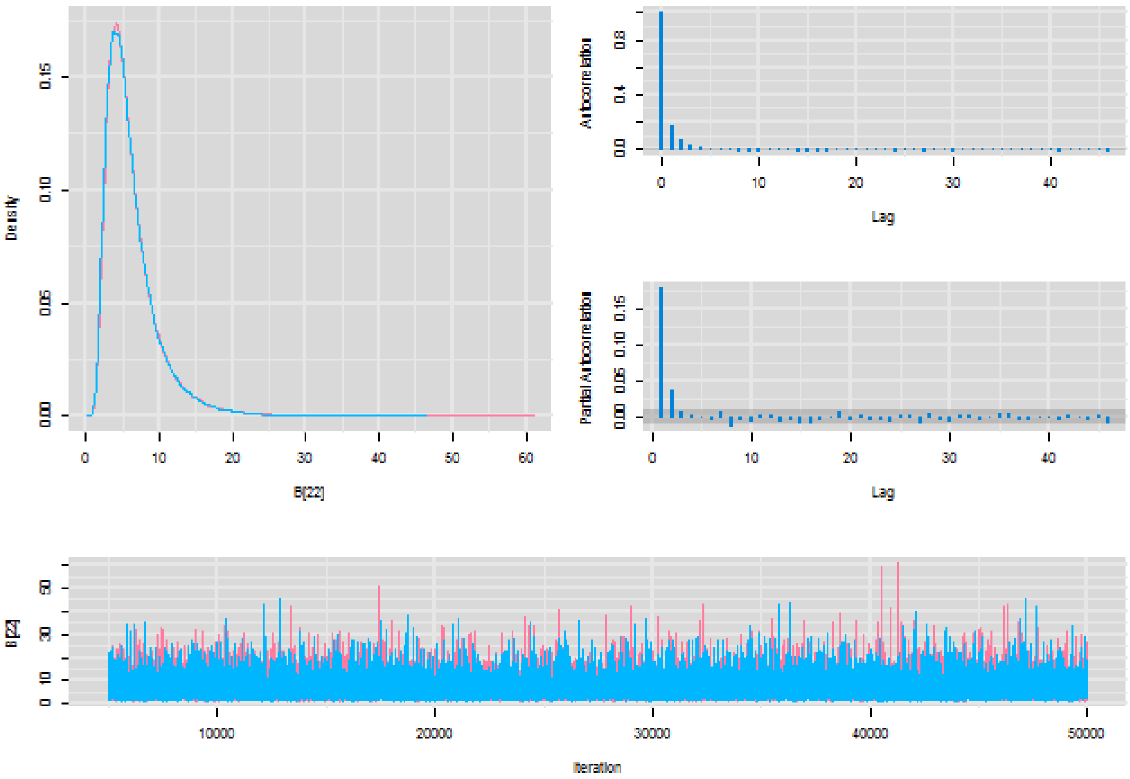
Diagnostics for B[20]



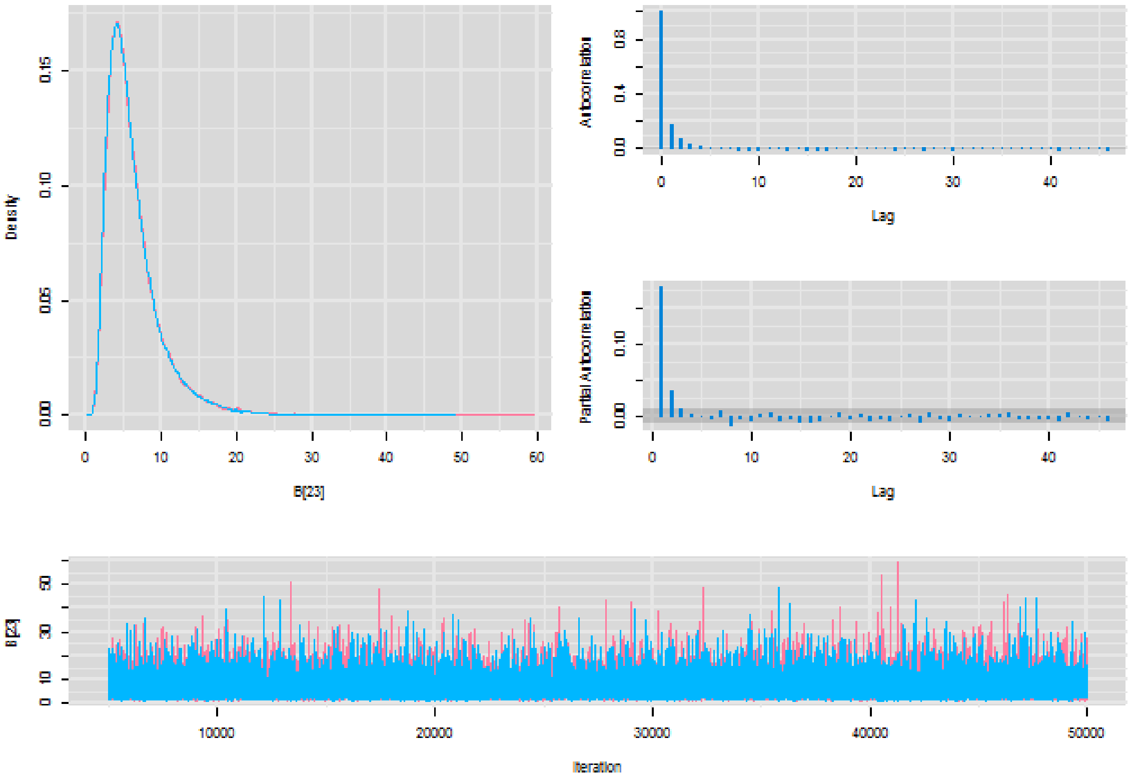
Diagnostics for B[21]



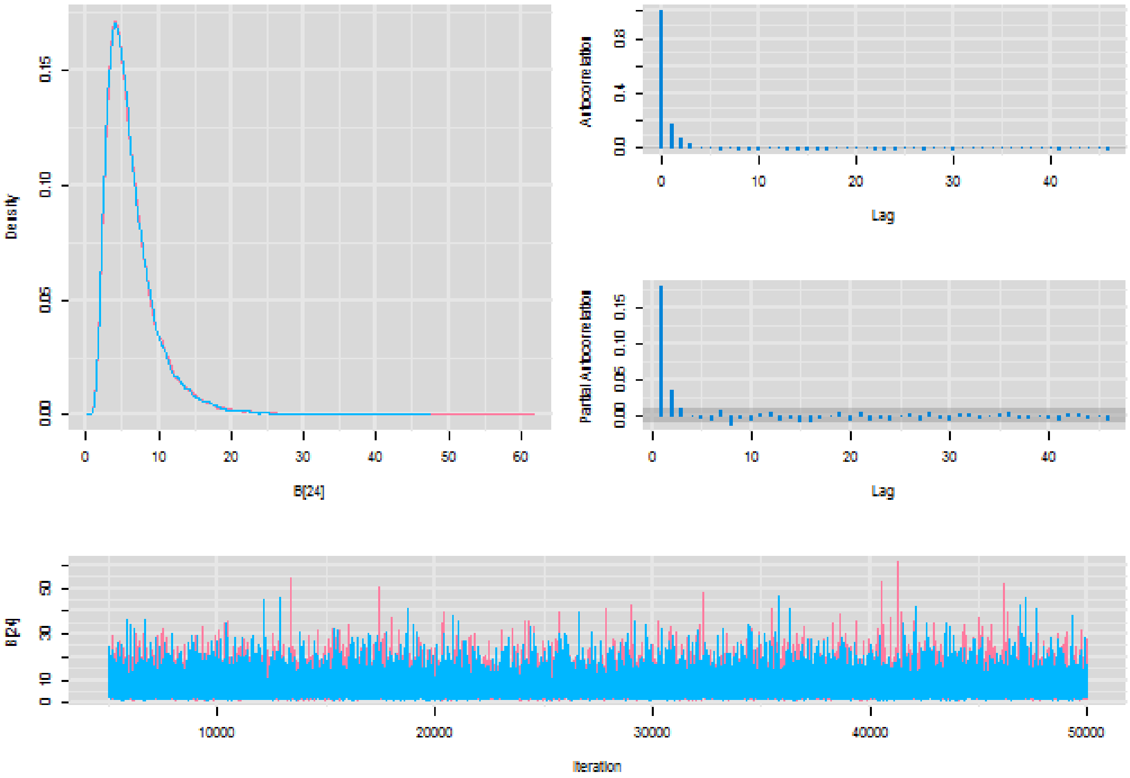
Diagnostics for B[22]



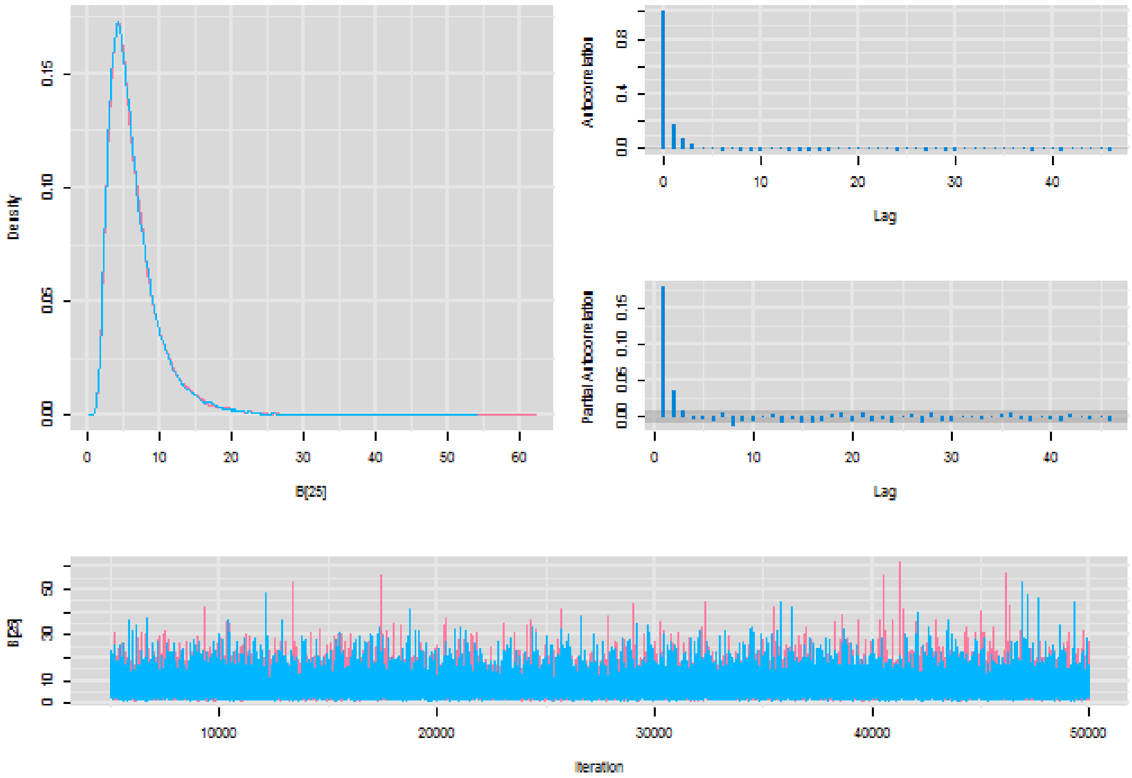
Diagnostics for B[23]



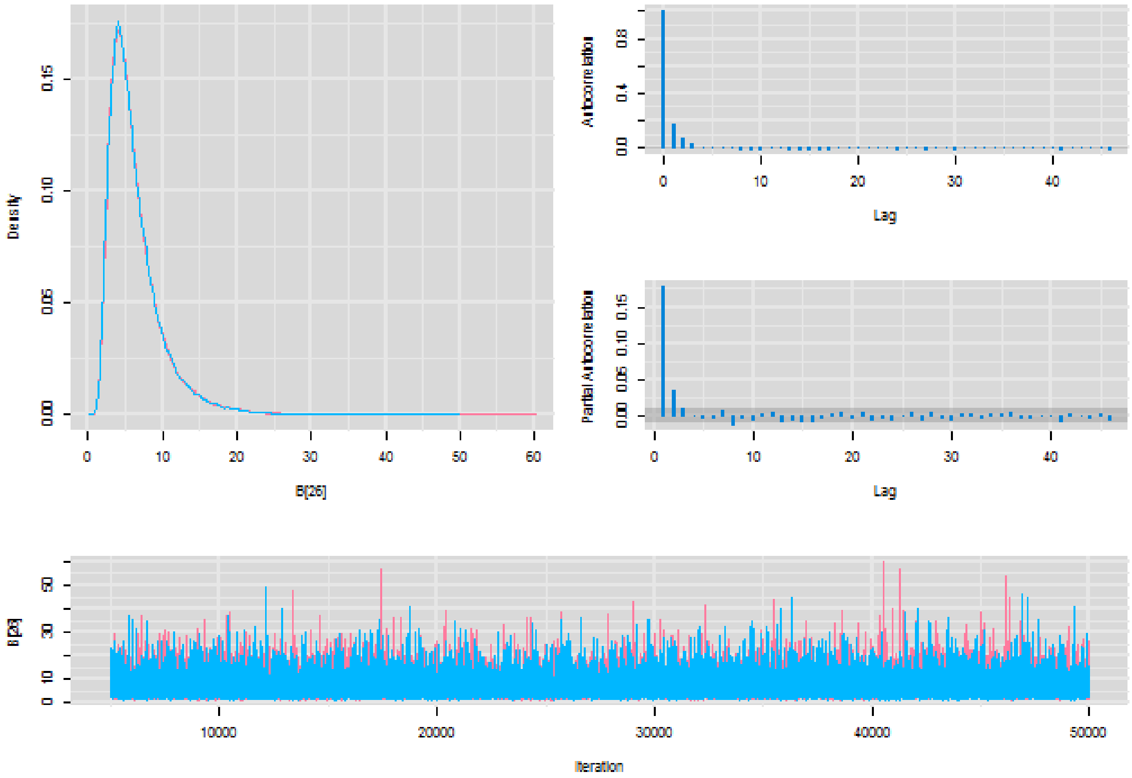
Diagnostics for B[24]



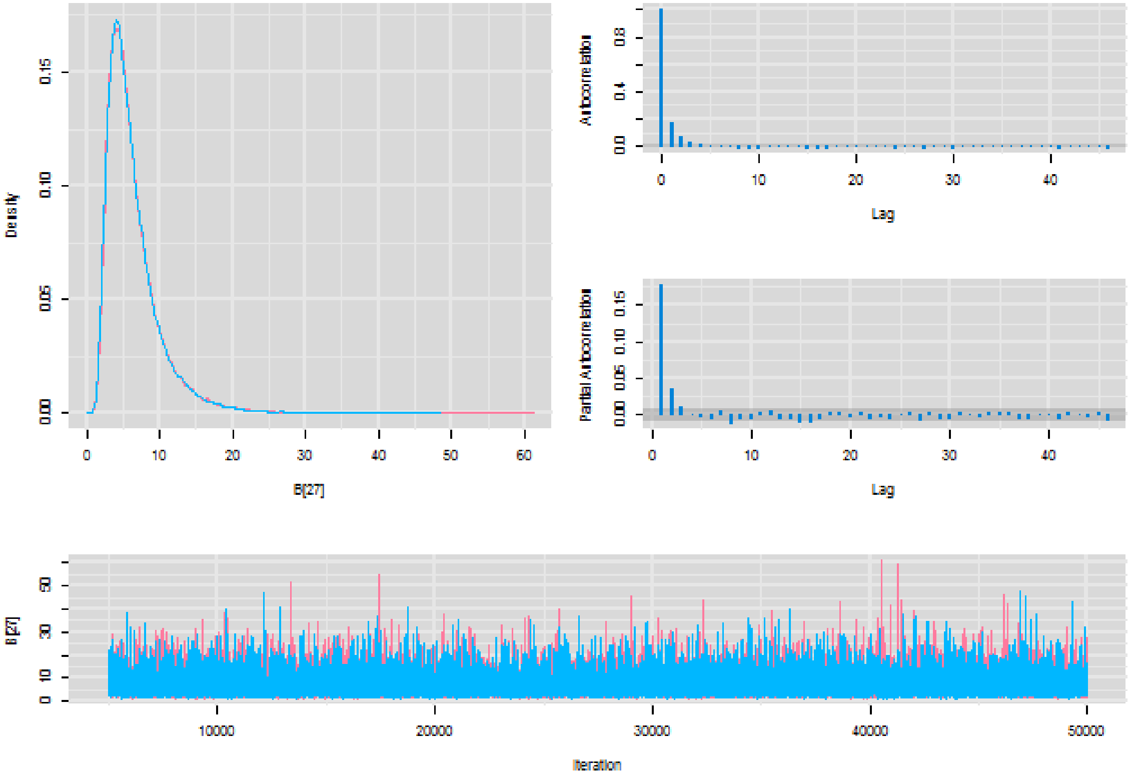
Diagnostics for B[25]



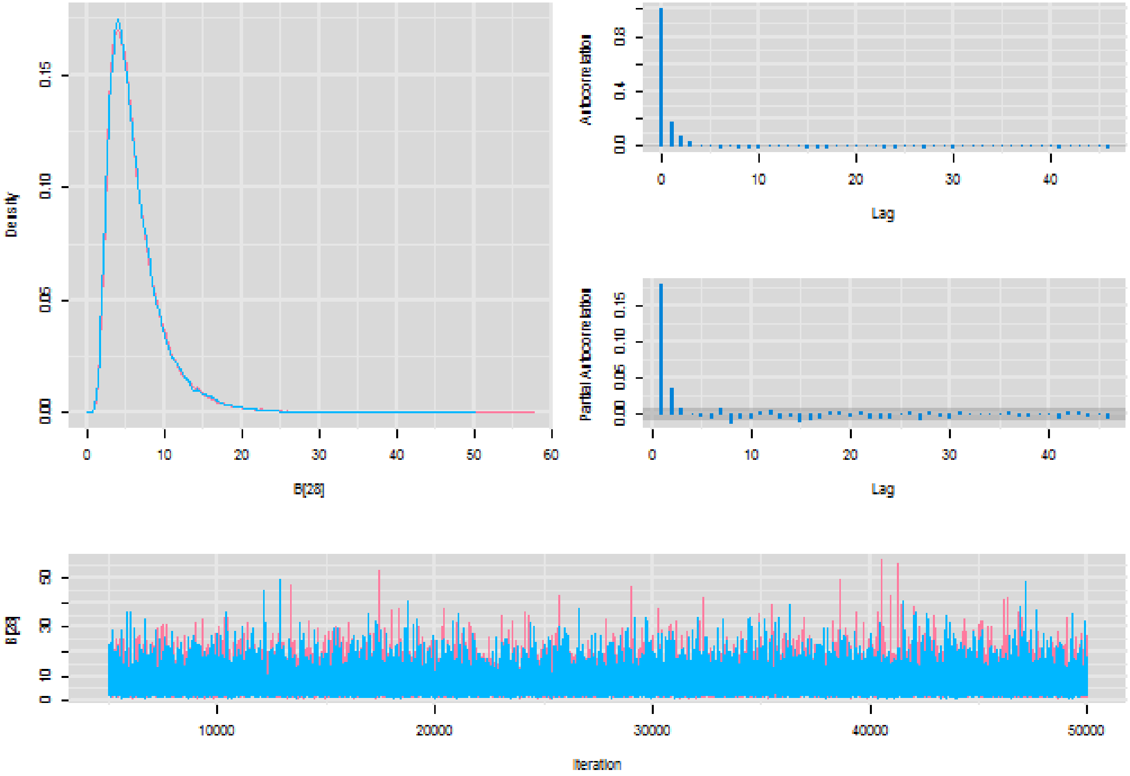
Diagnostics for B[26]



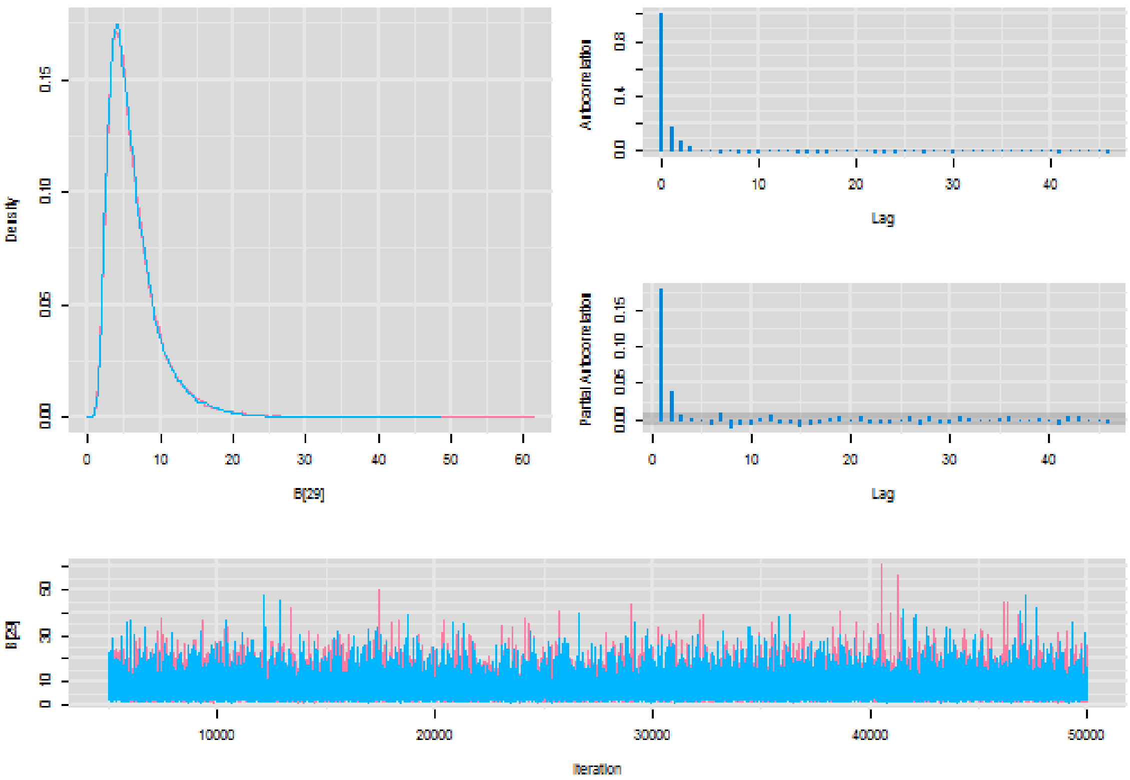
Diagnostics for B[27]



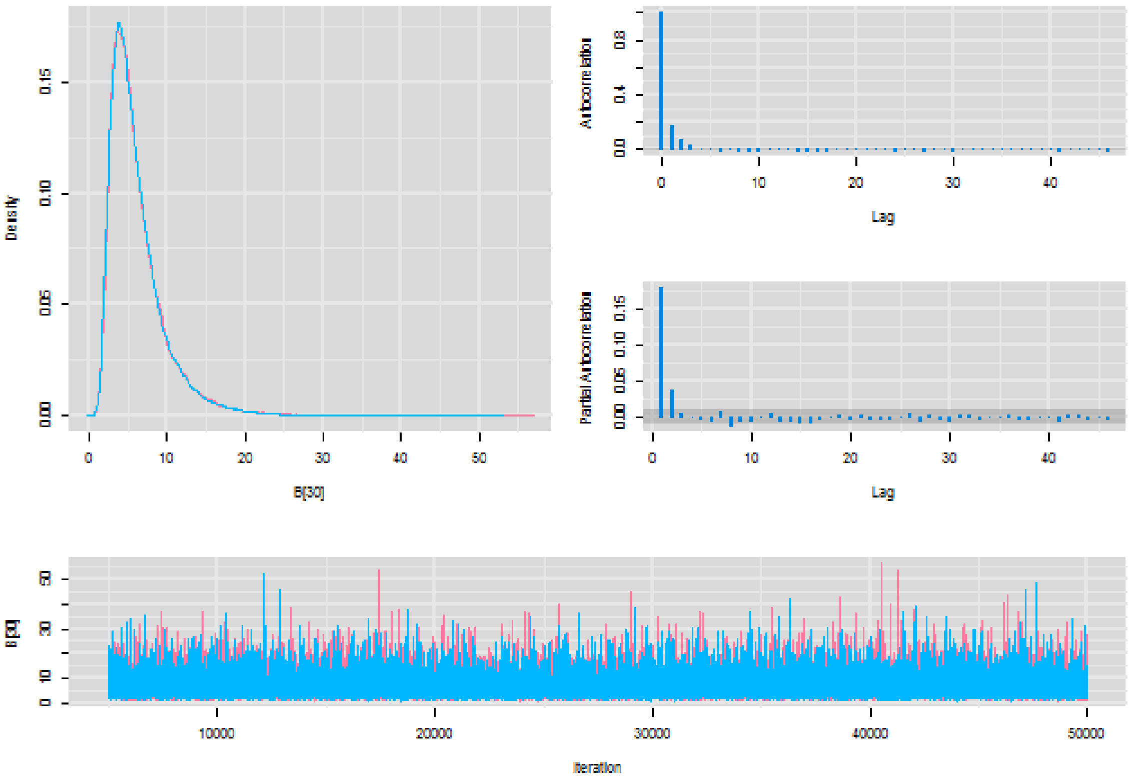
Diagnostics for B[28]



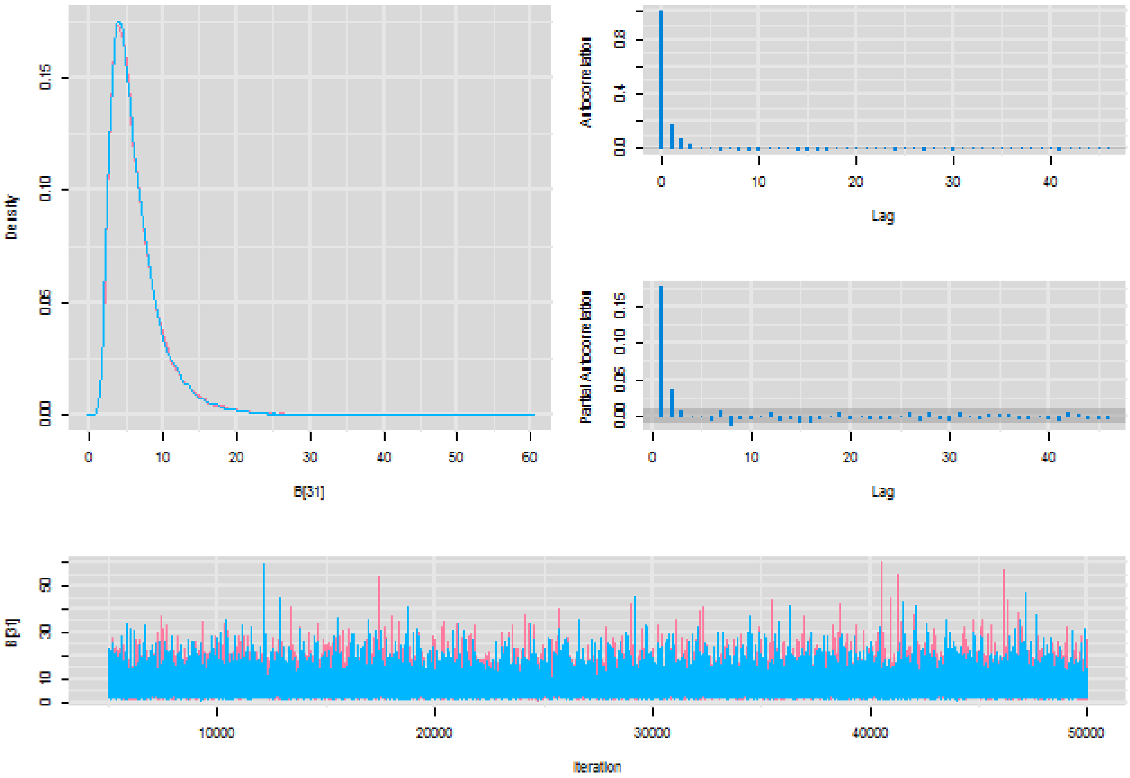
Diagnostics for B[29]



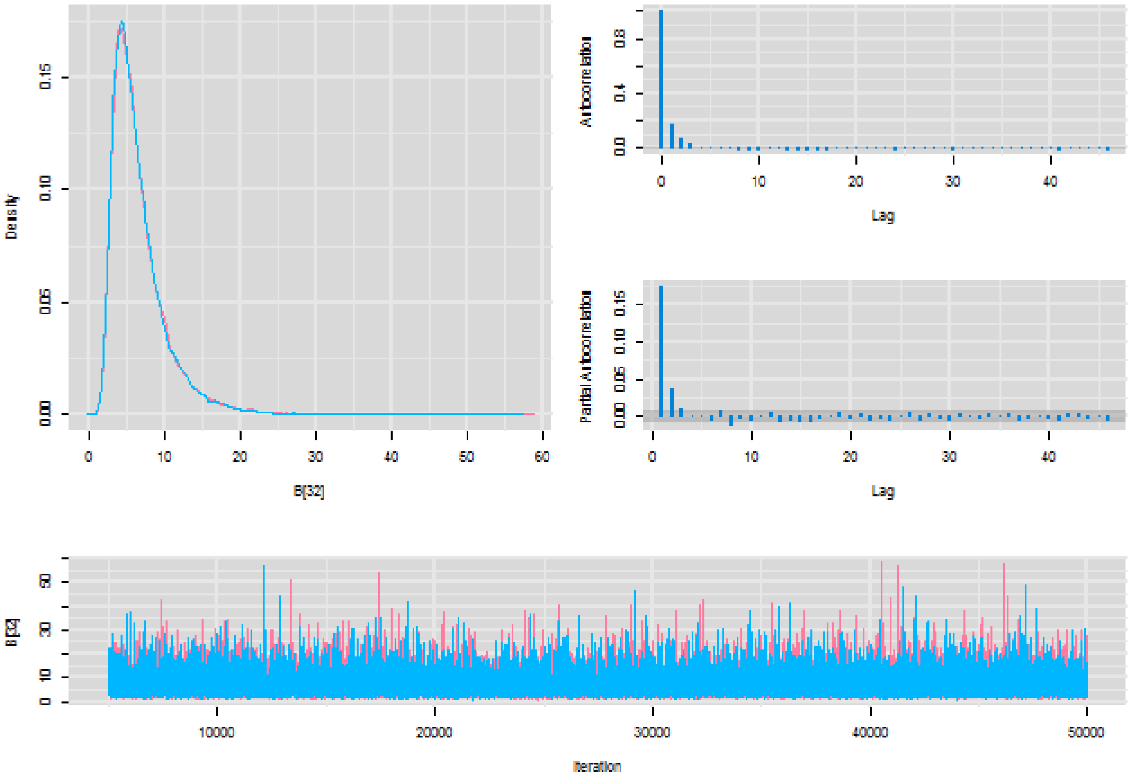
Diagnostics for B[30]



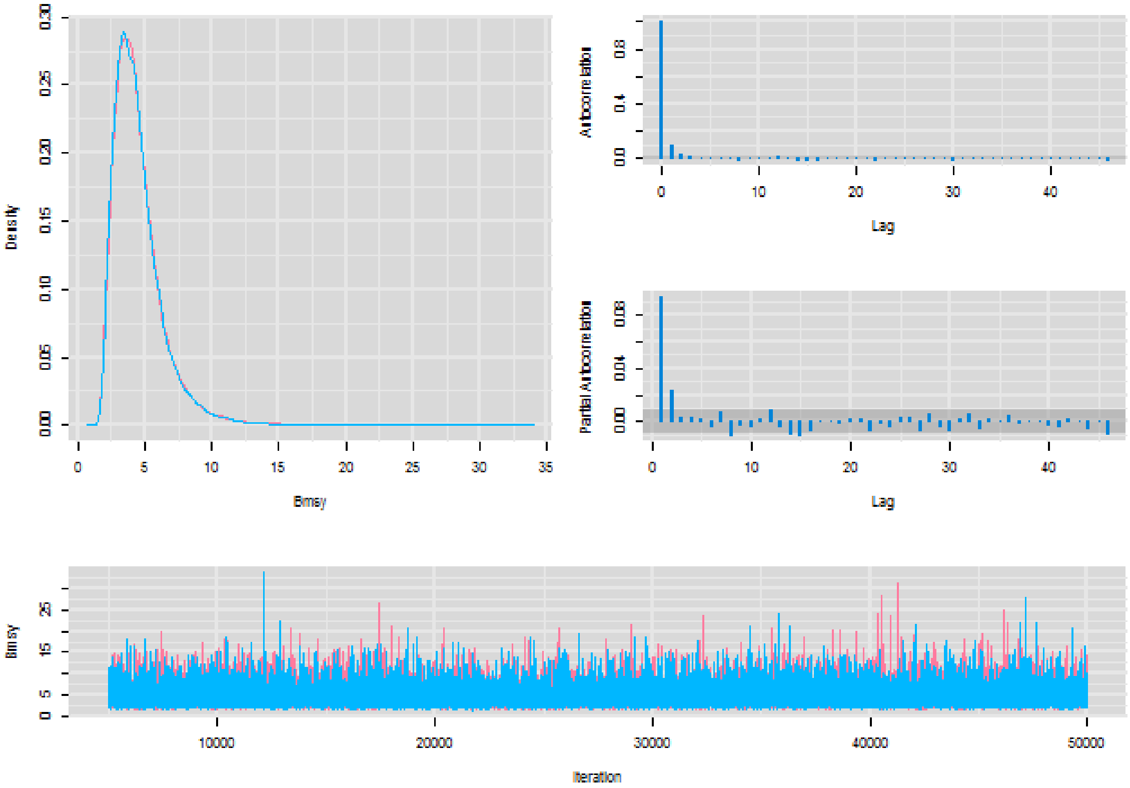
Diagnostics for B[31]



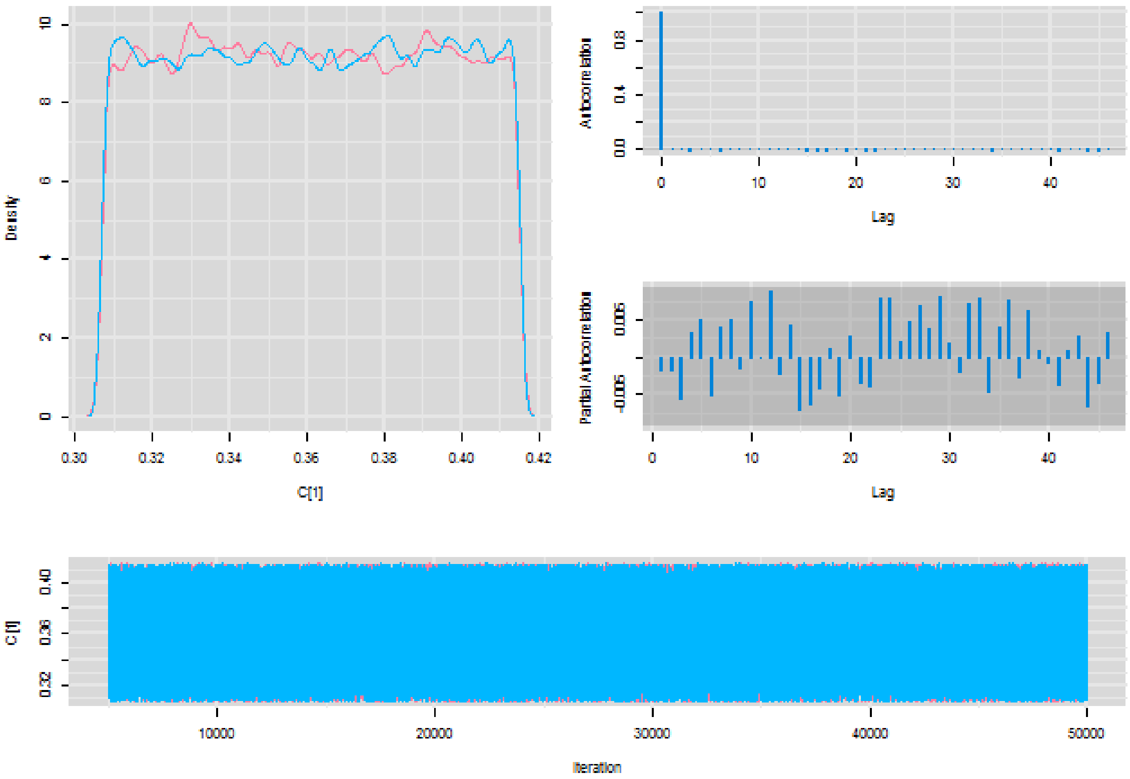
Diagnostics for B[32]



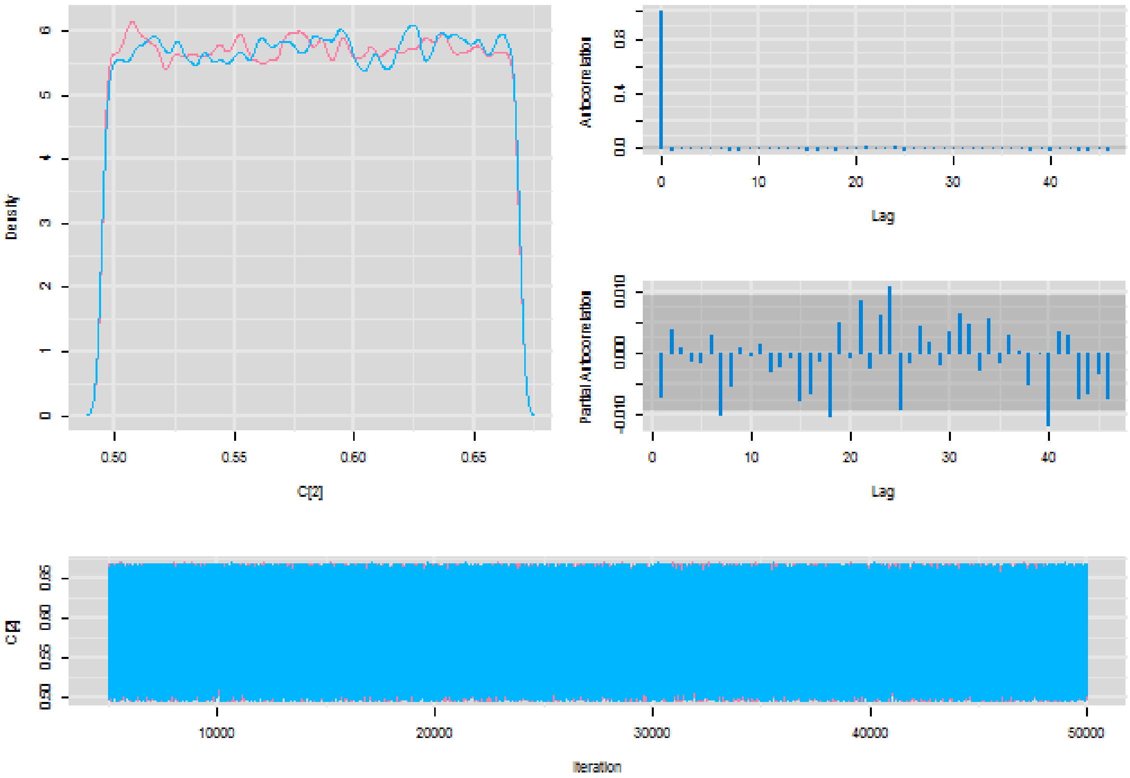
Diagnostics for Bmsy



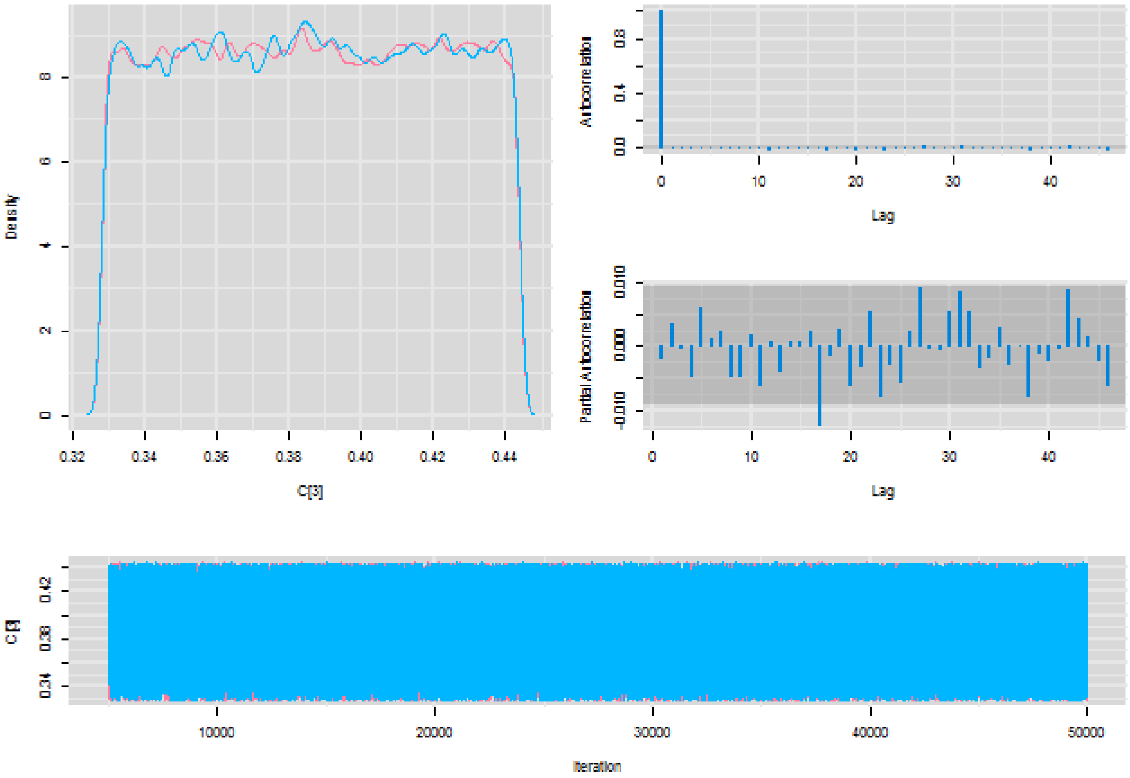
Diagnostics for C[1]



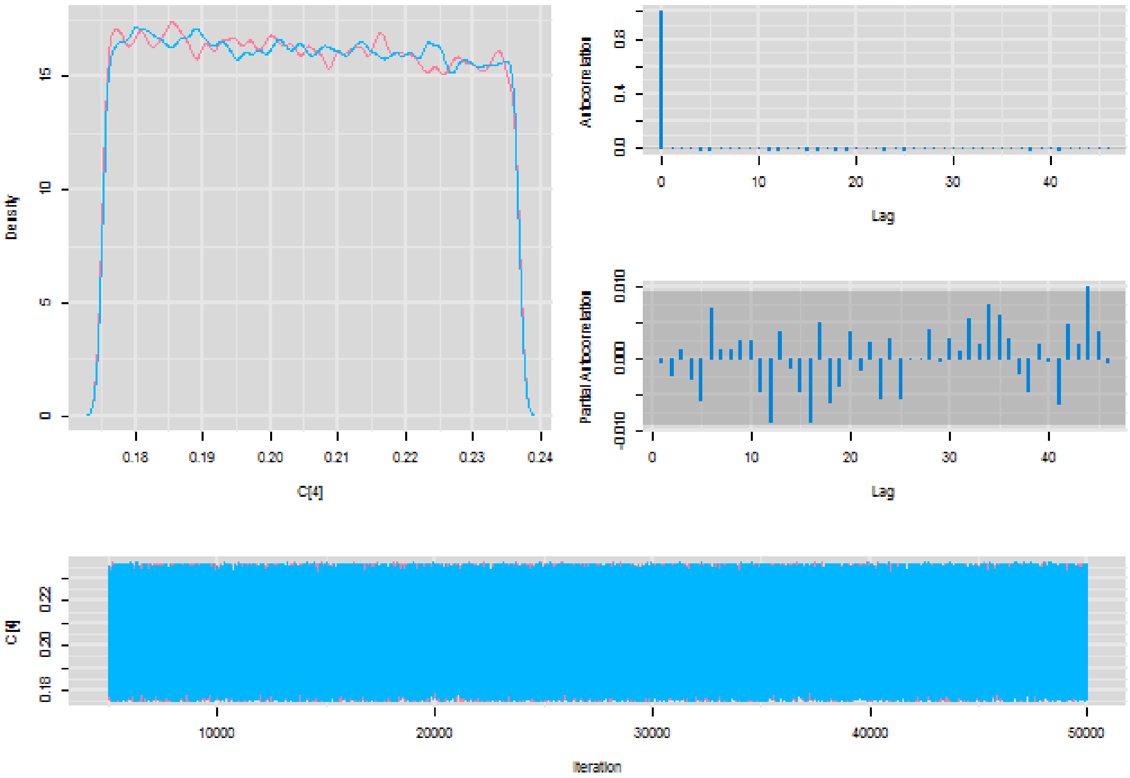
Diagnostics for C[2]



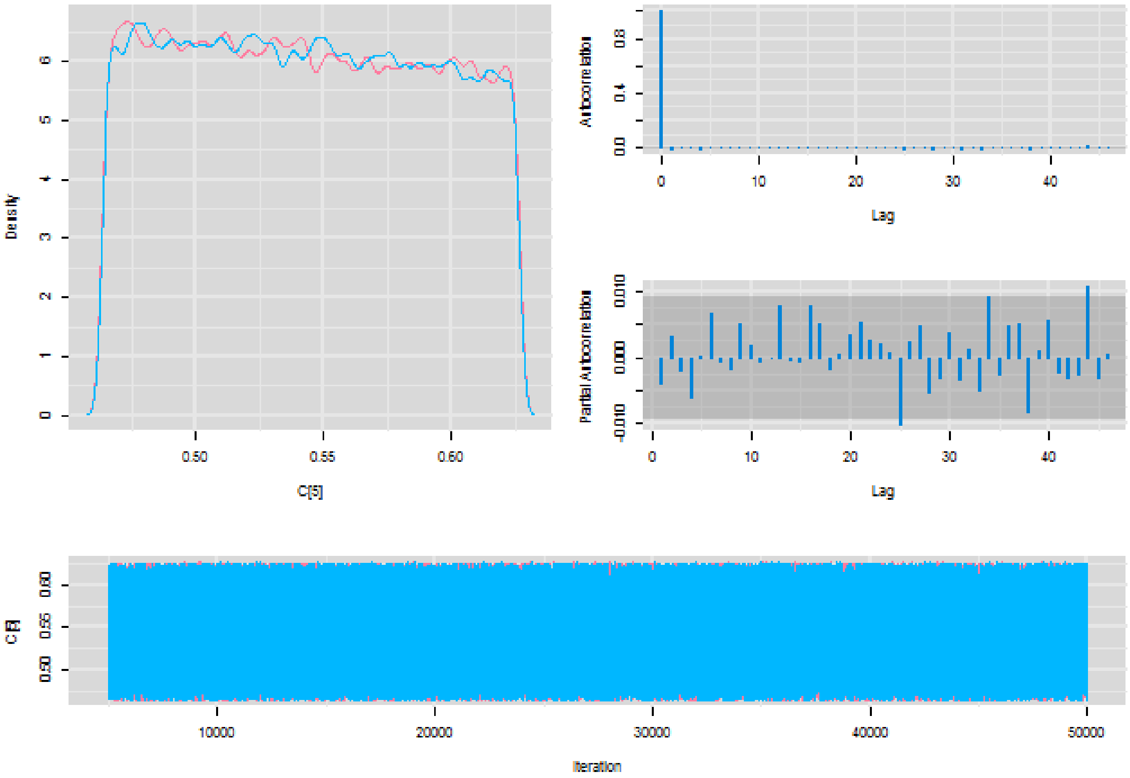
Diagnostics for C[3]



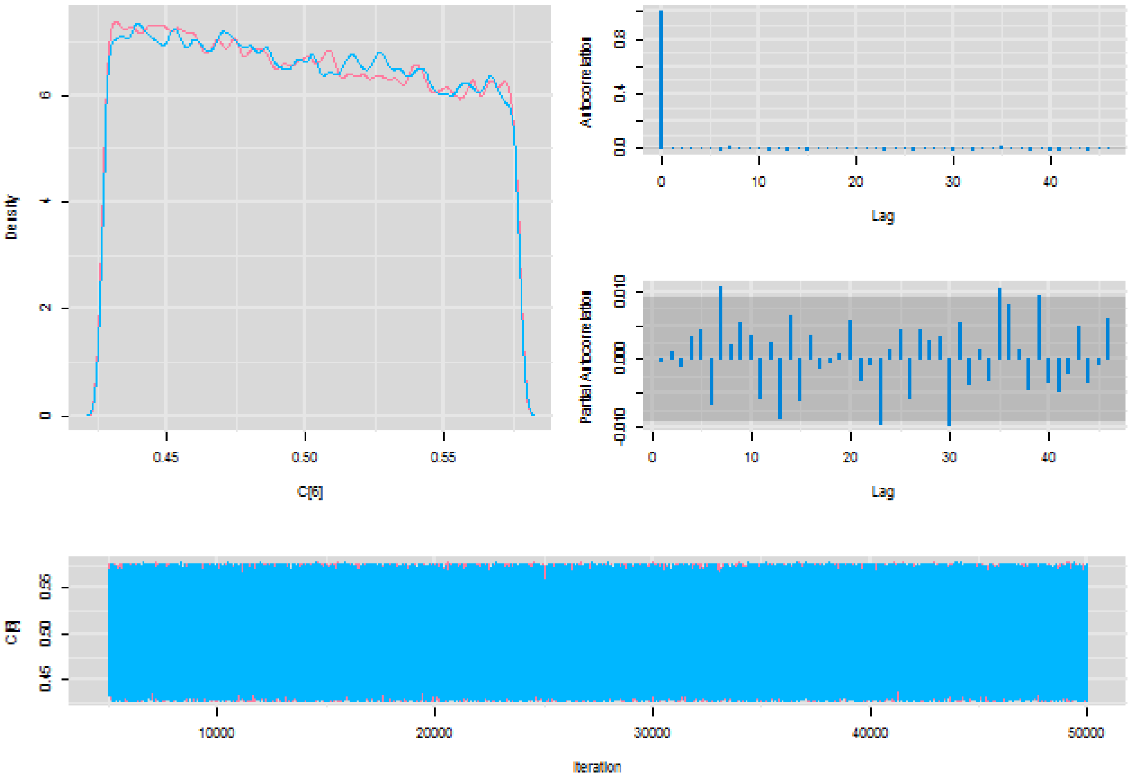
Diagnostics for C[4]



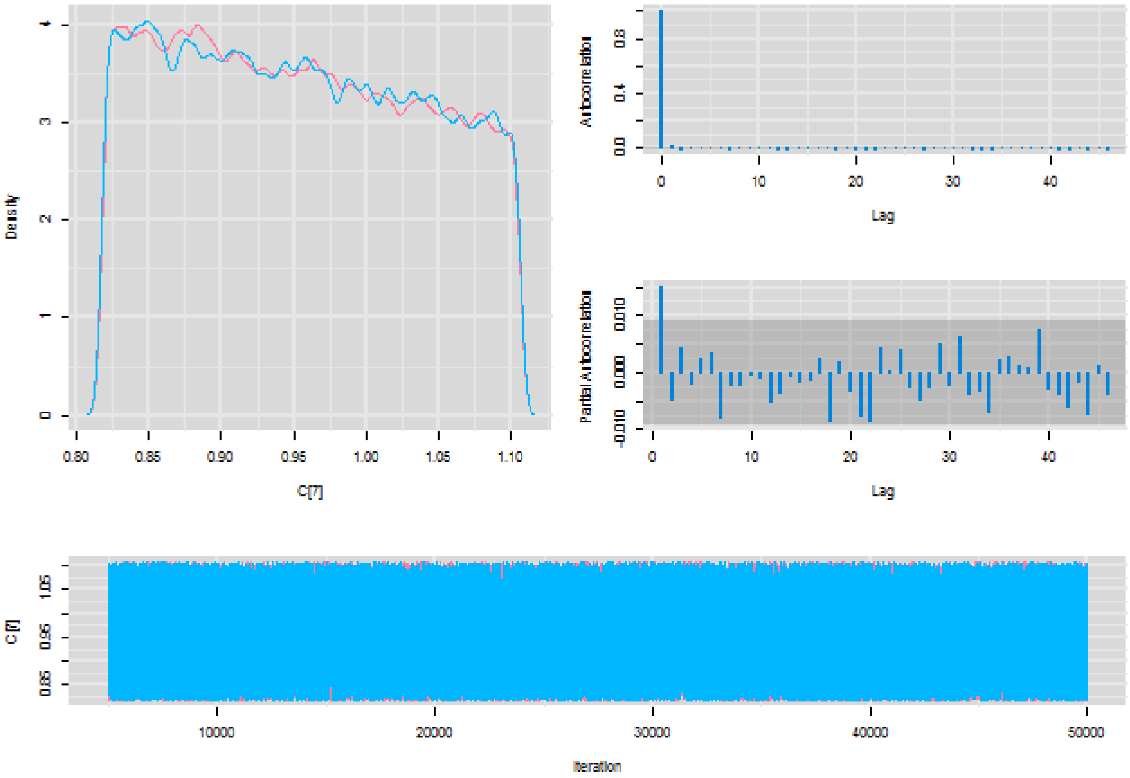
Diagnostics for C[5]



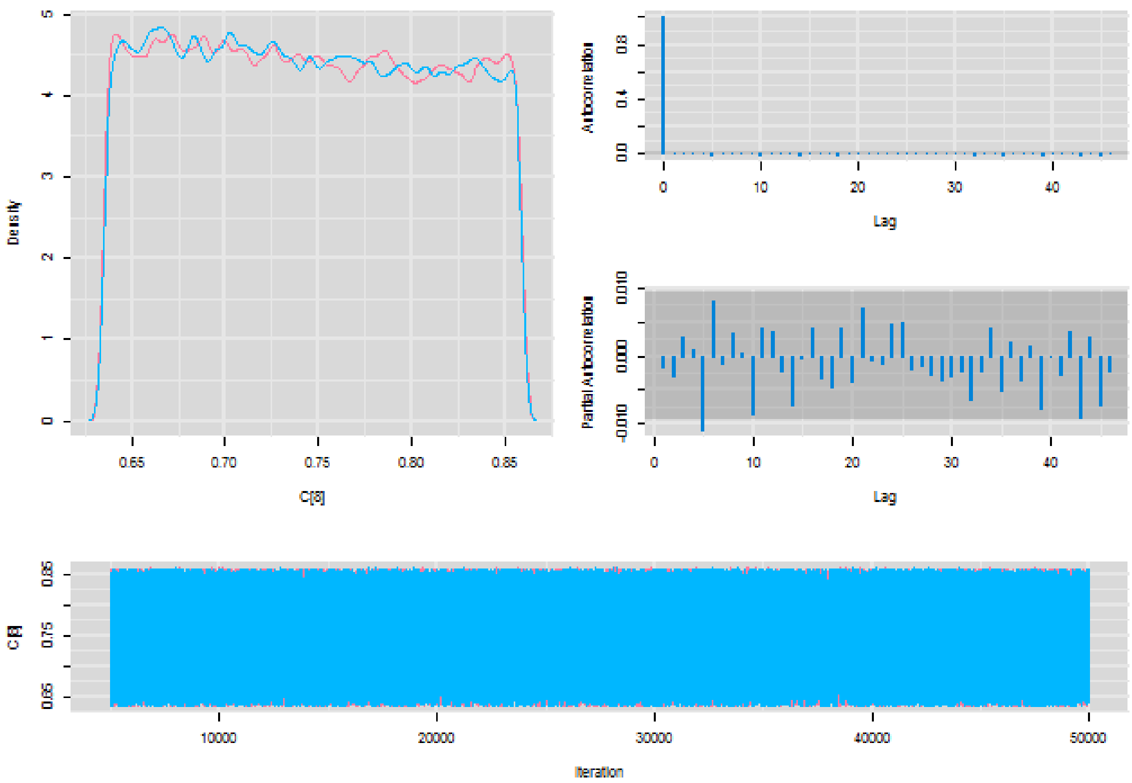
Diagnostics for C[6]



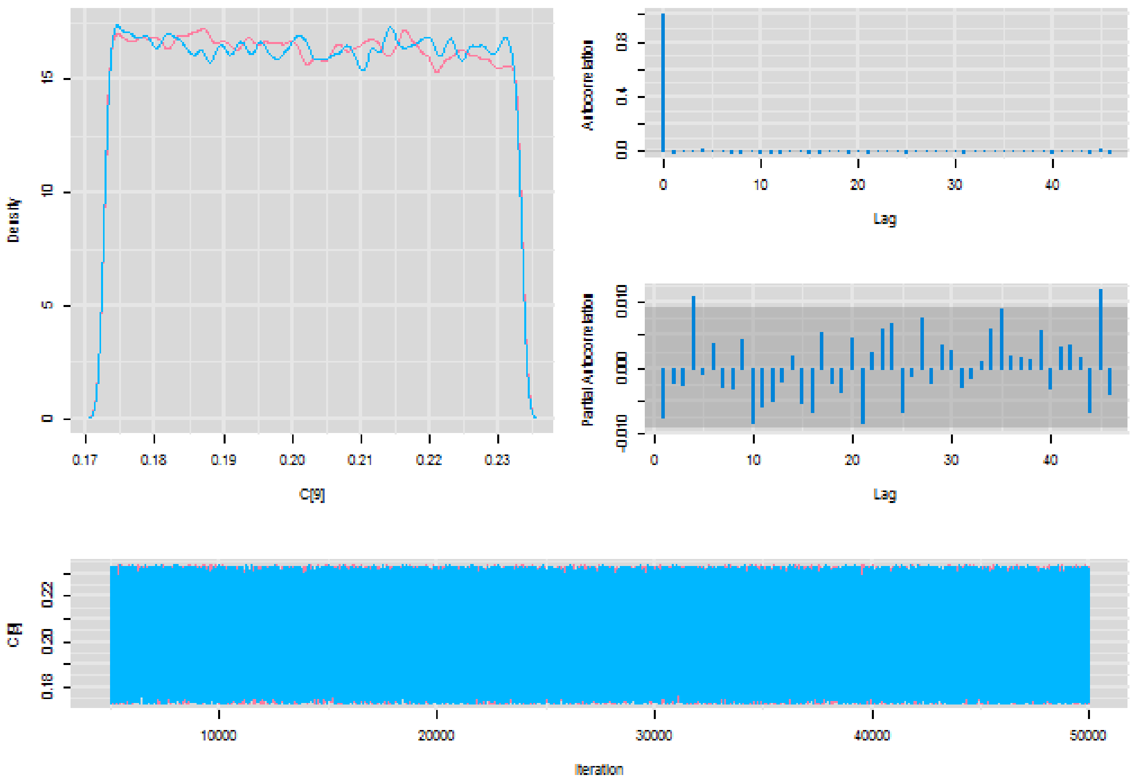
Diagnostics for C[7]



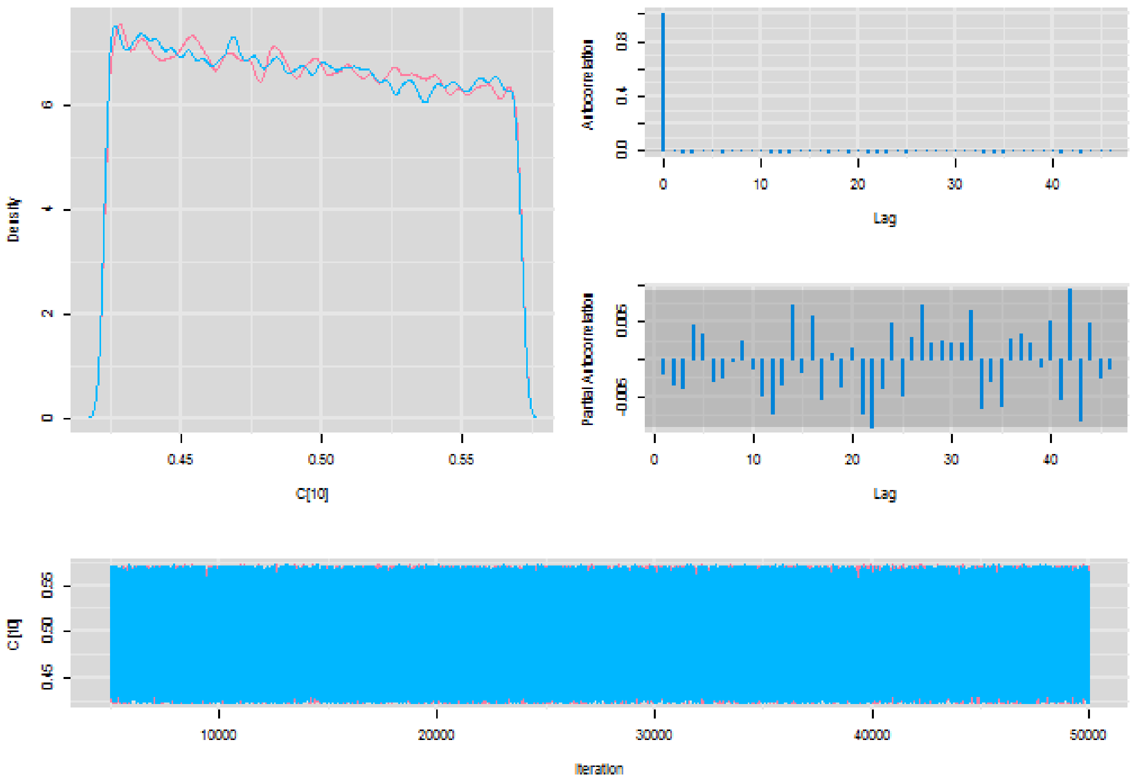
Diagnostics for C[8]



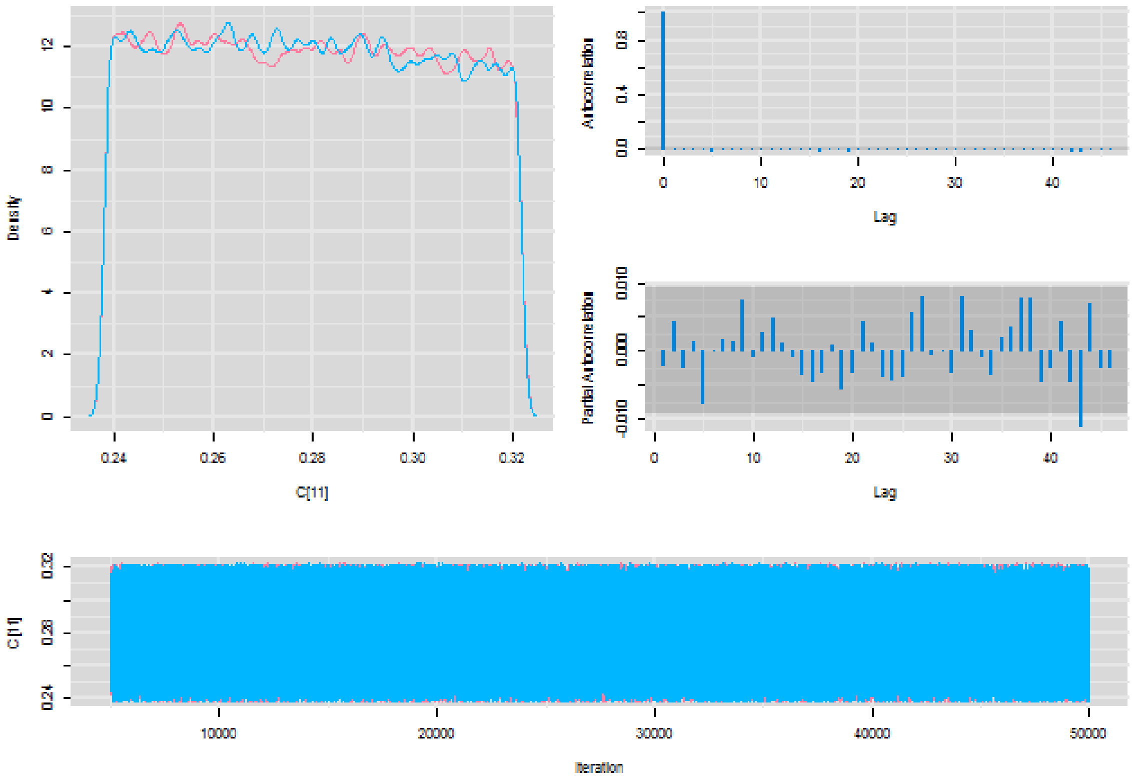
Diagnostics for C[9]



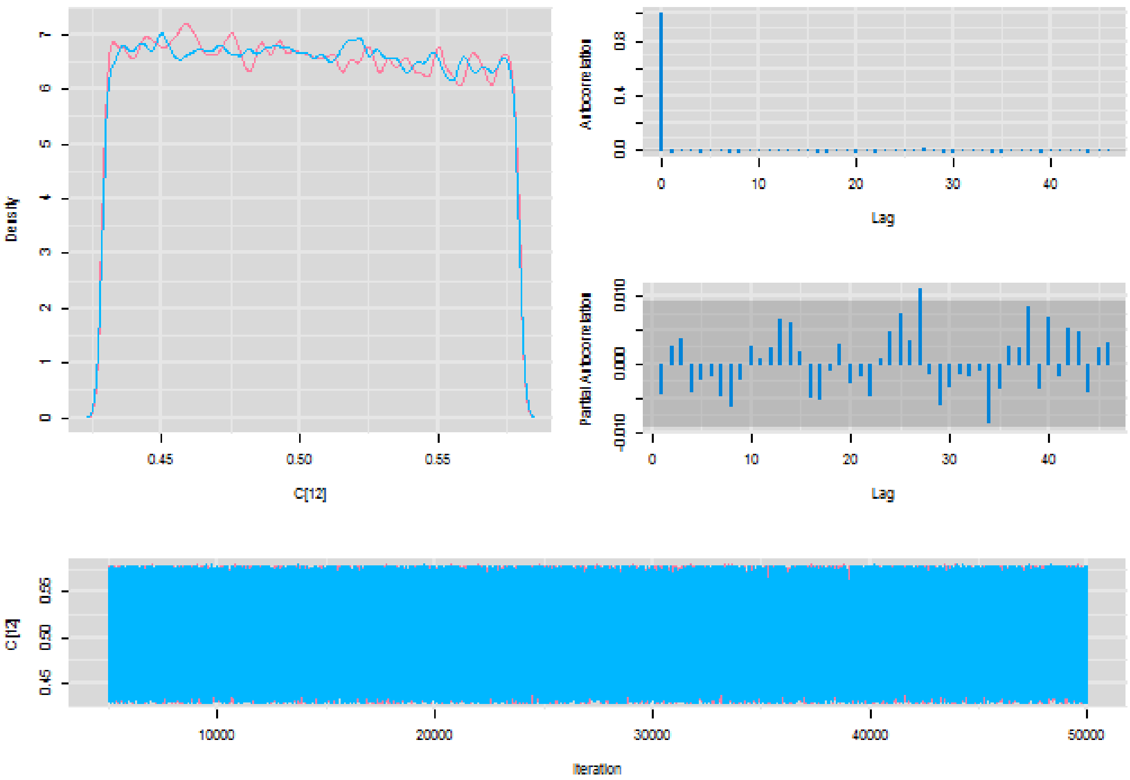
Diagnostics for C[10]



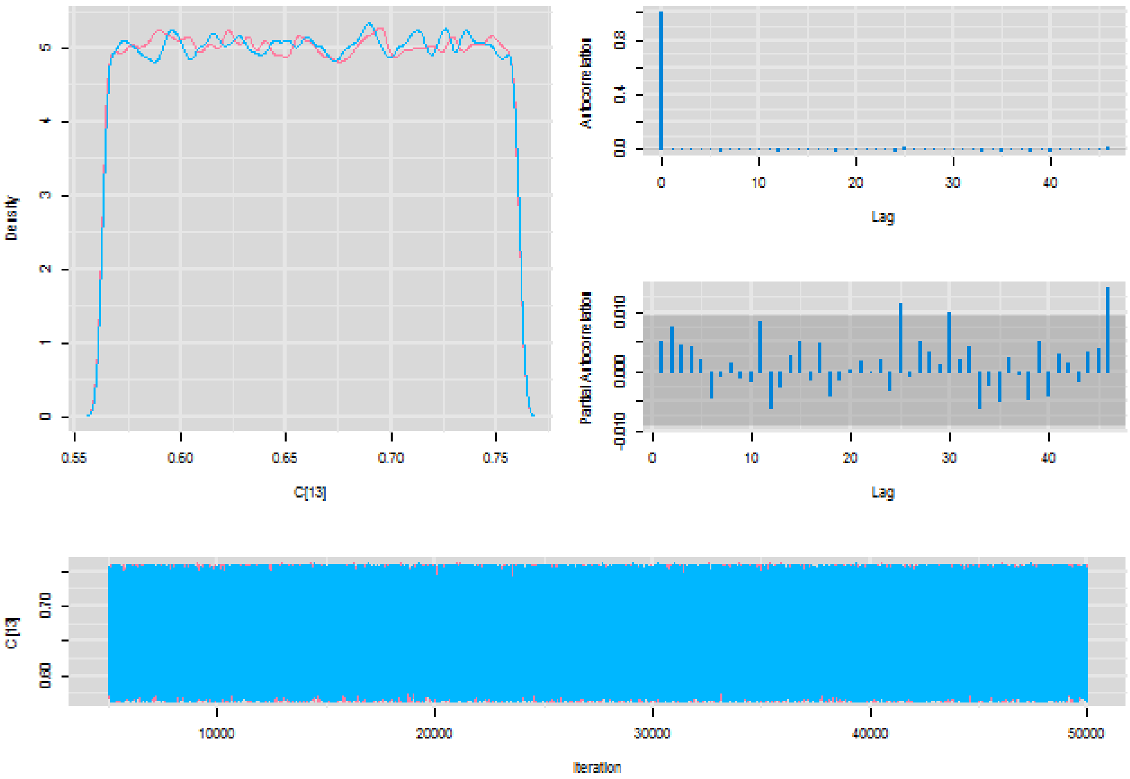
Diagnostics for C[11]



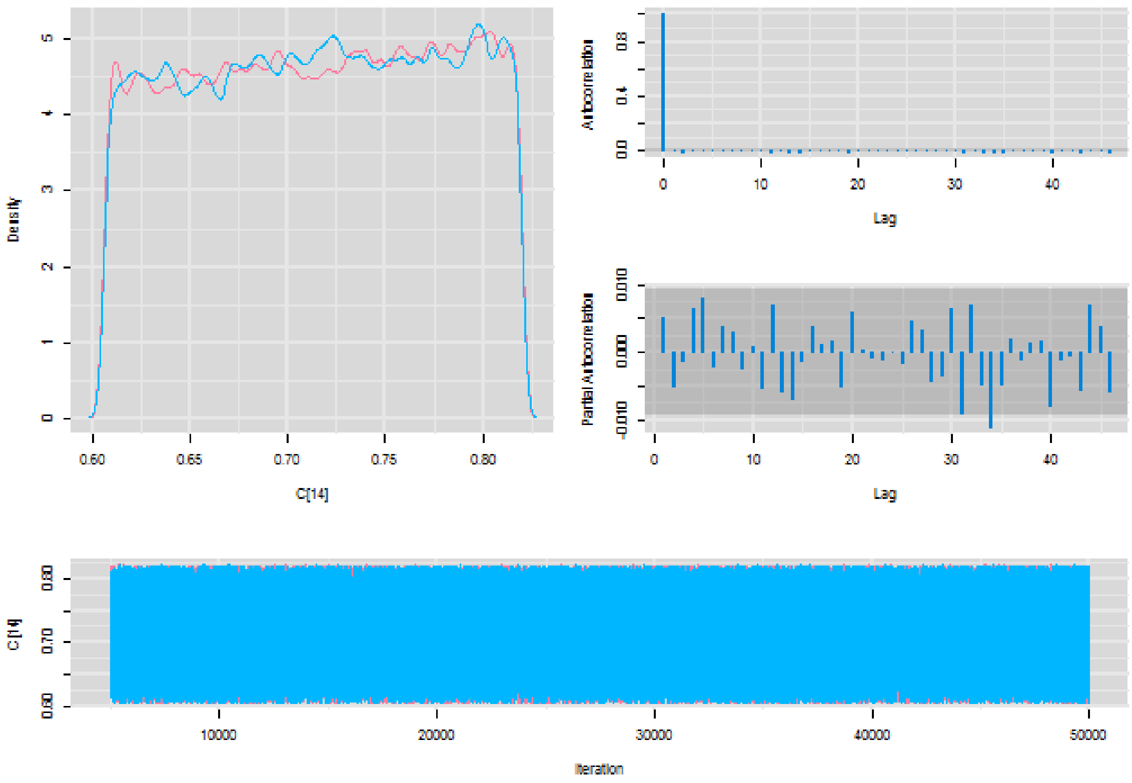
Diagnostics for C[12]



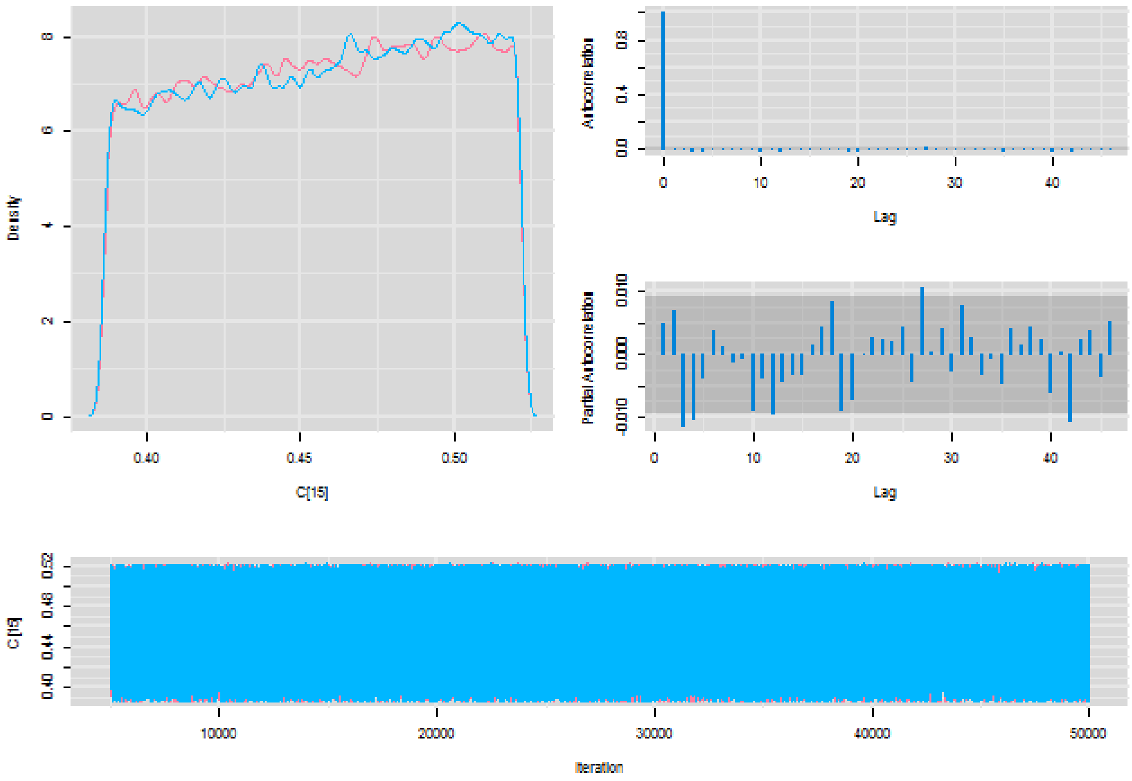
Diagnostics for C[13]



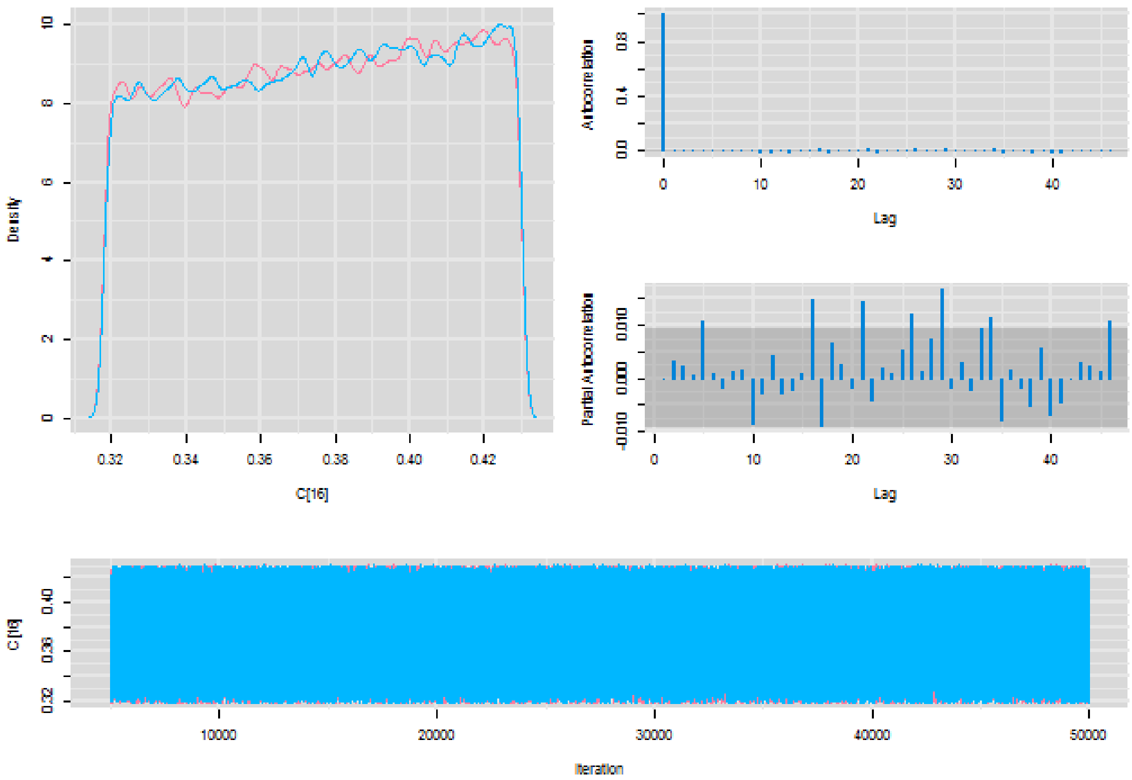
Diagnostics for C[14]



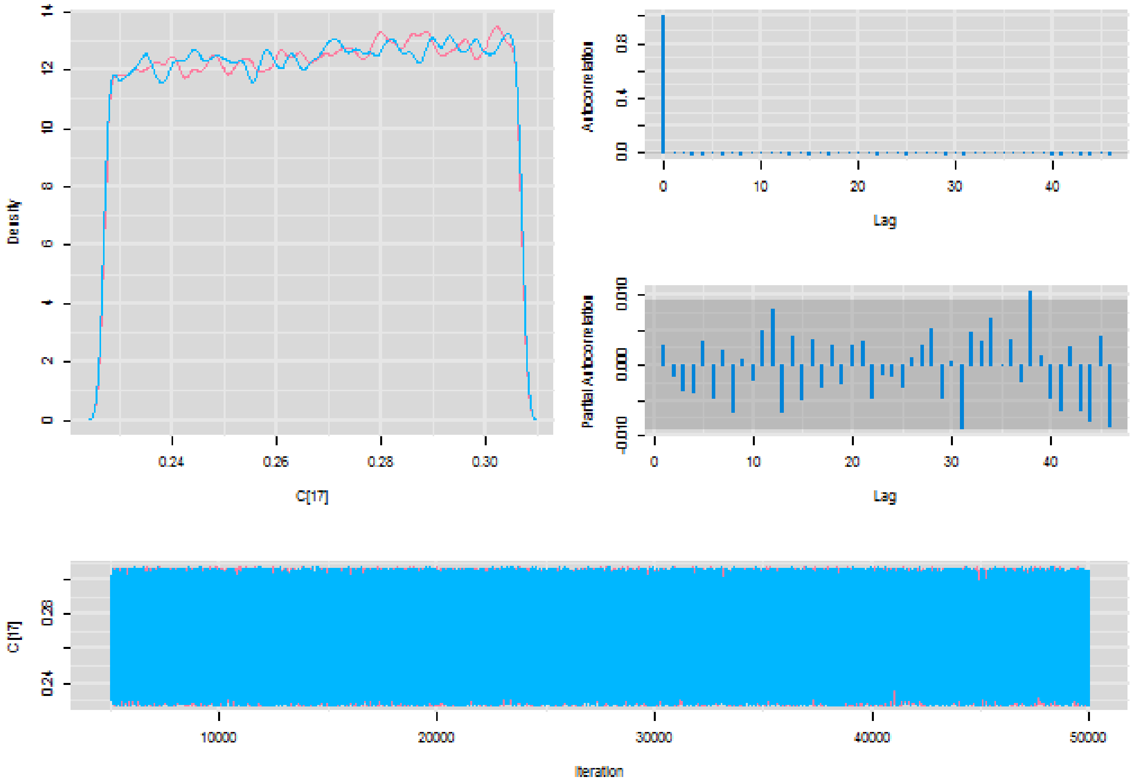
Diagnostics for C[15]



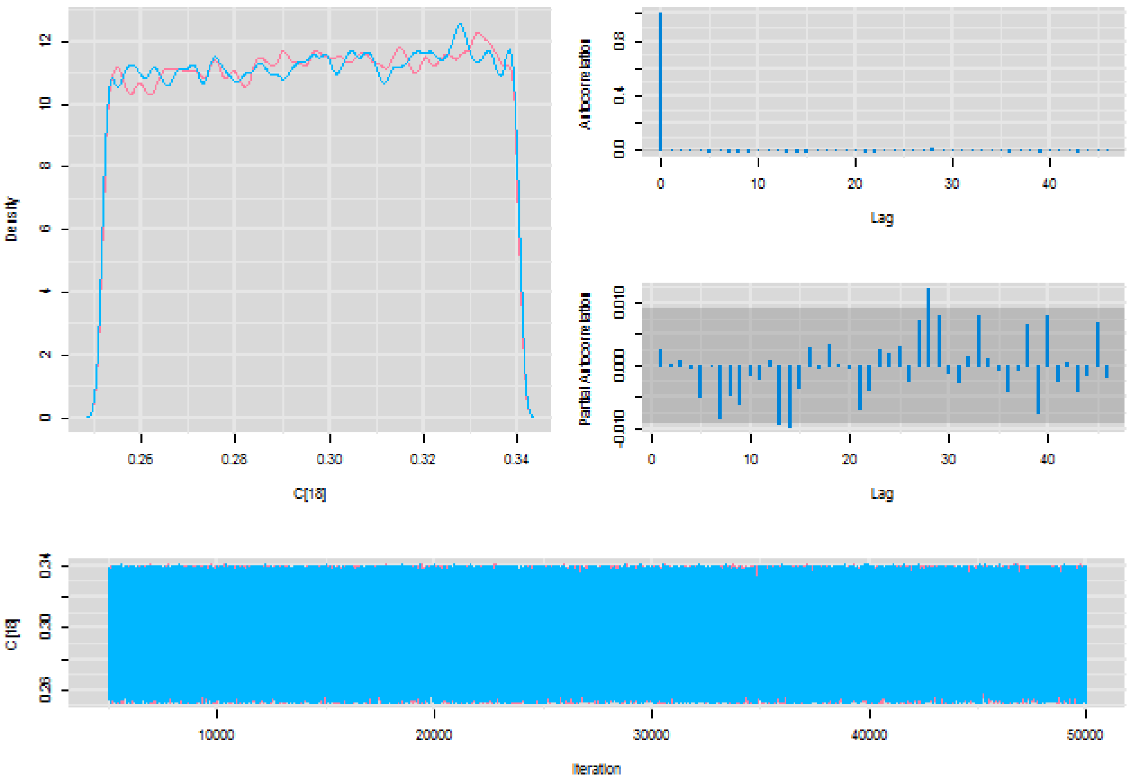
Diagnostics for C[16]



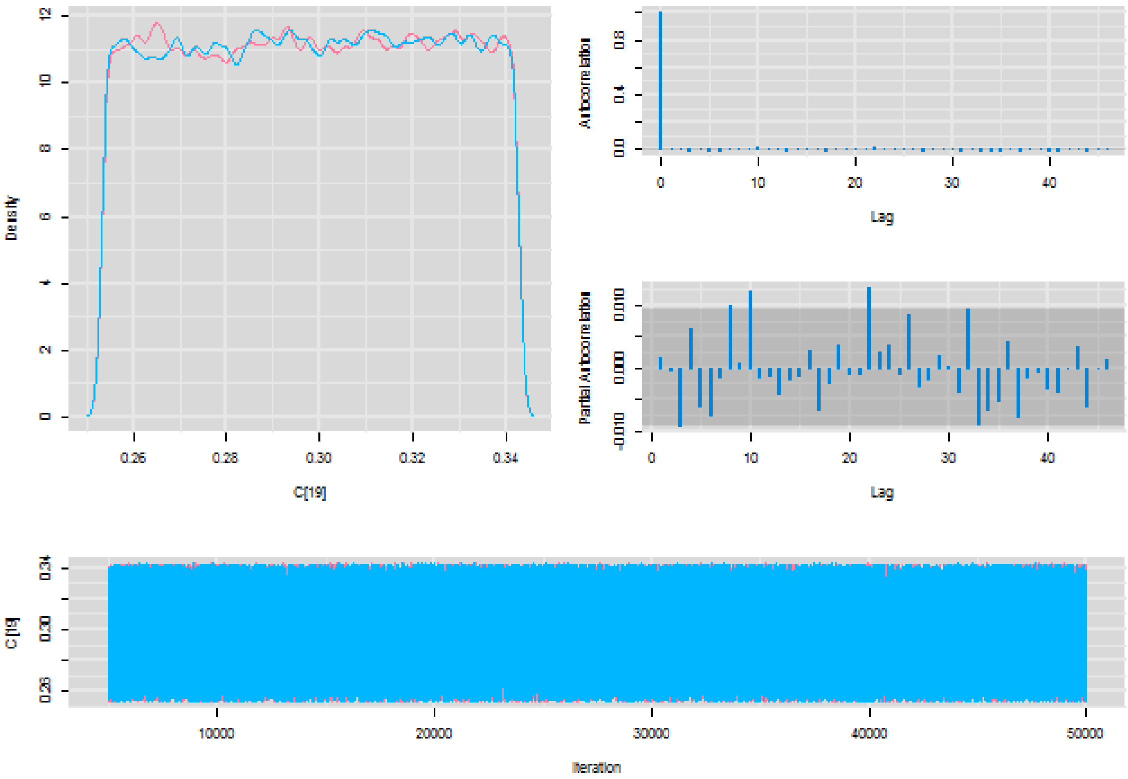
Diagnostics for C[17]



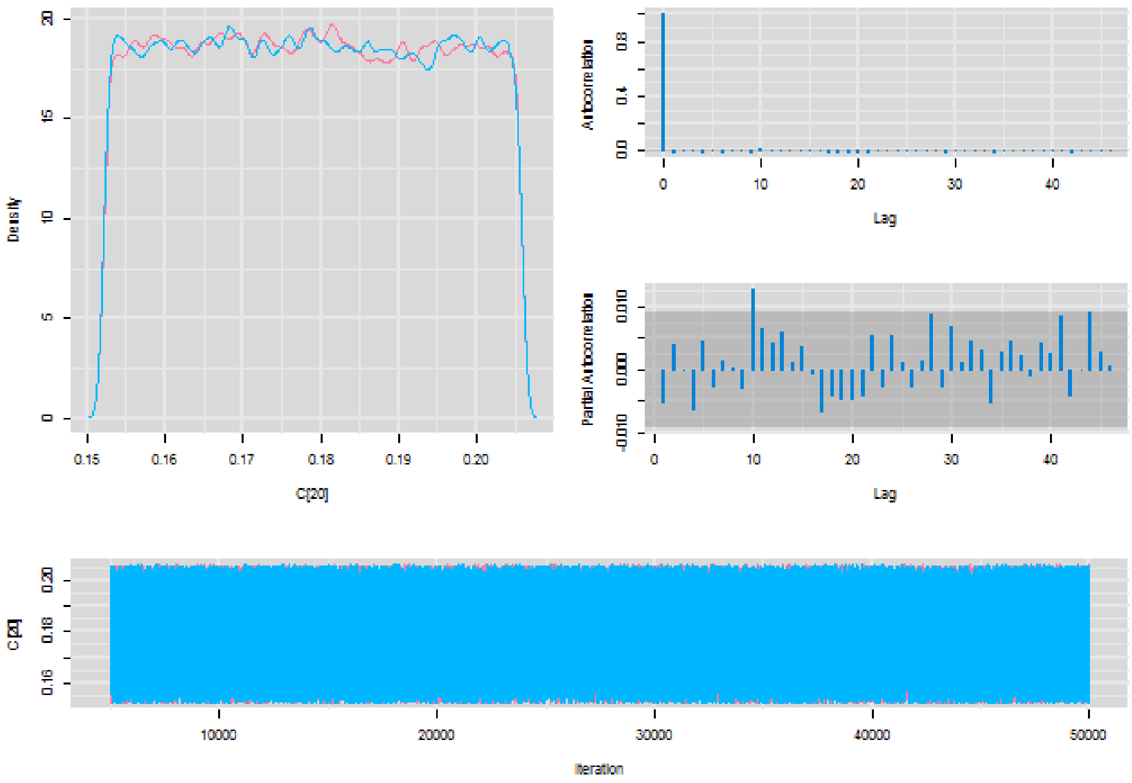
Diagnostics for C[18]



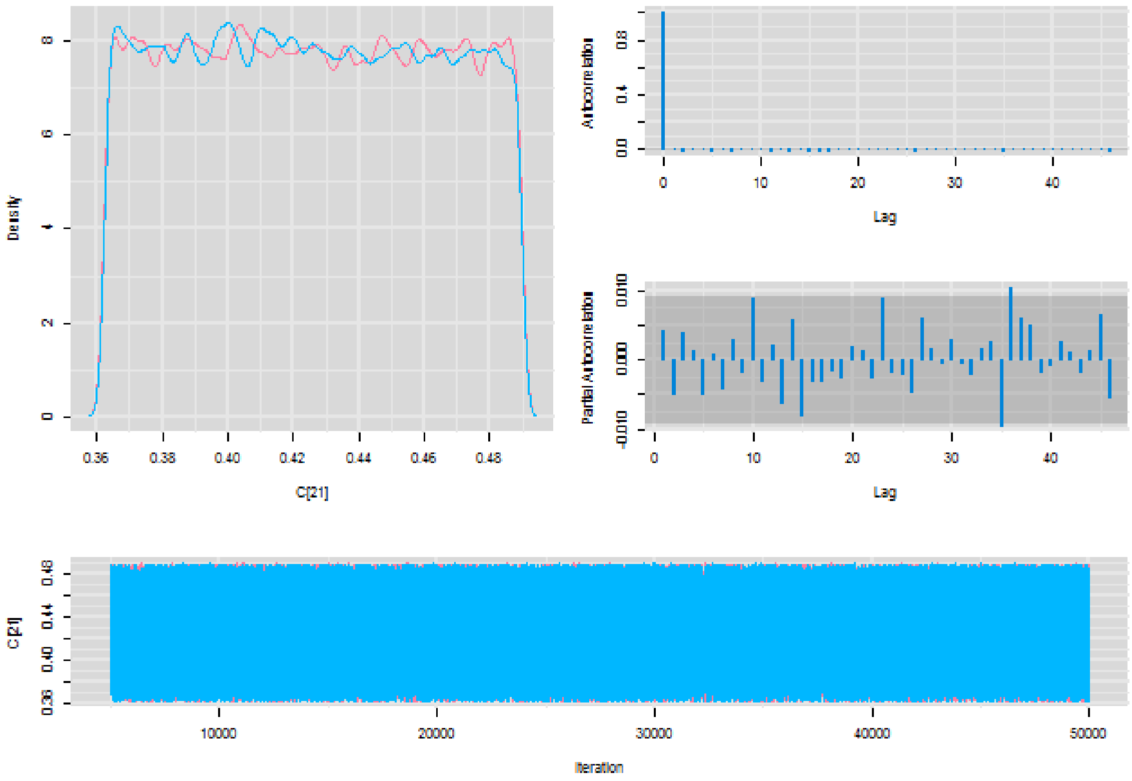
Diagnostics for C[19]



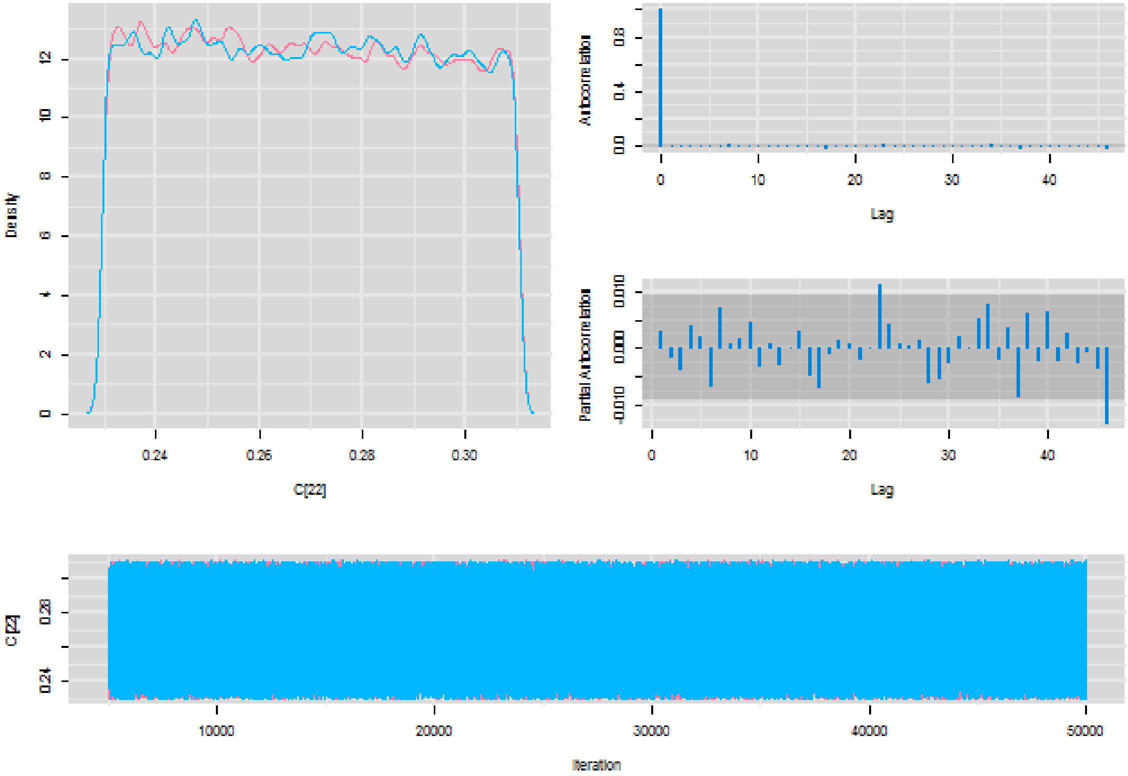
Diagnostics for C[20]



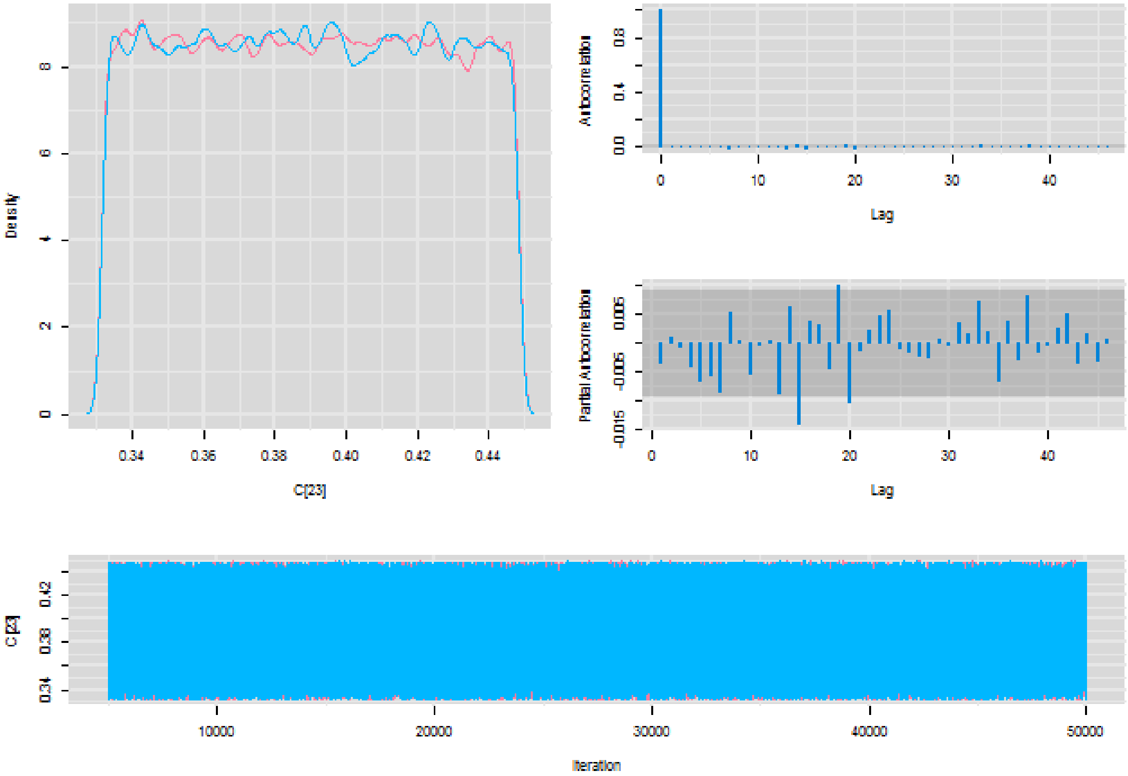
Diagnostics for C[21]



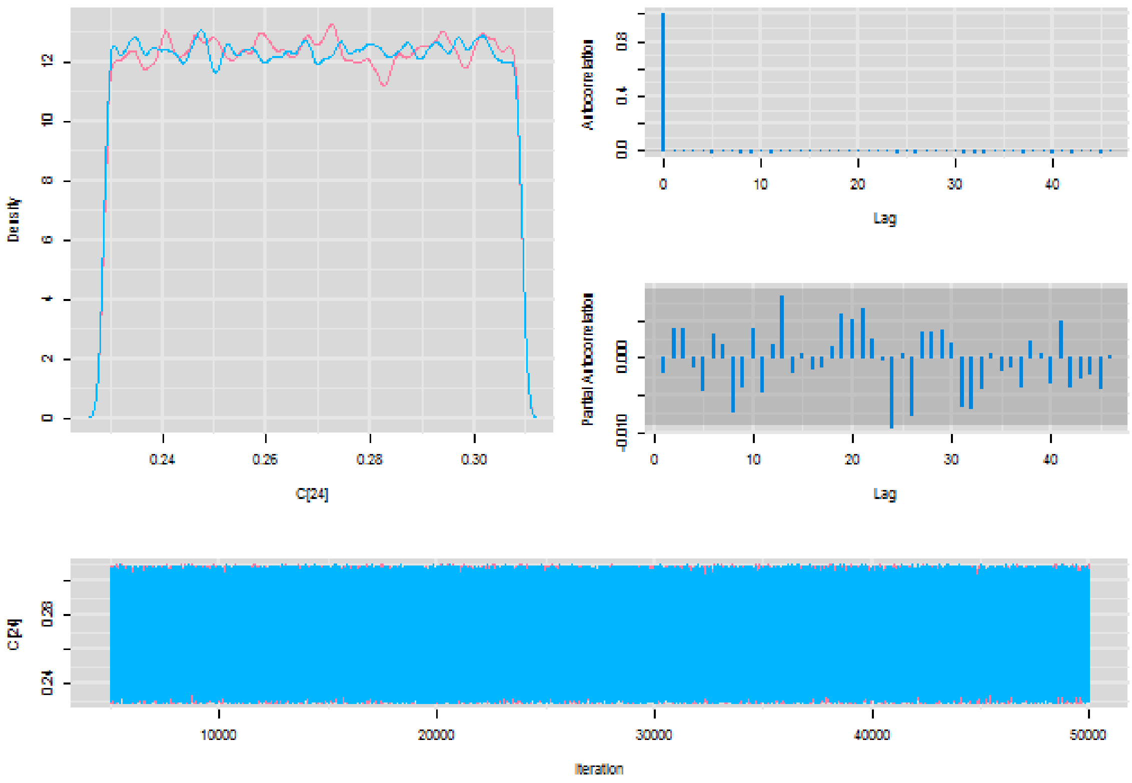
Diagnostics for C[22]



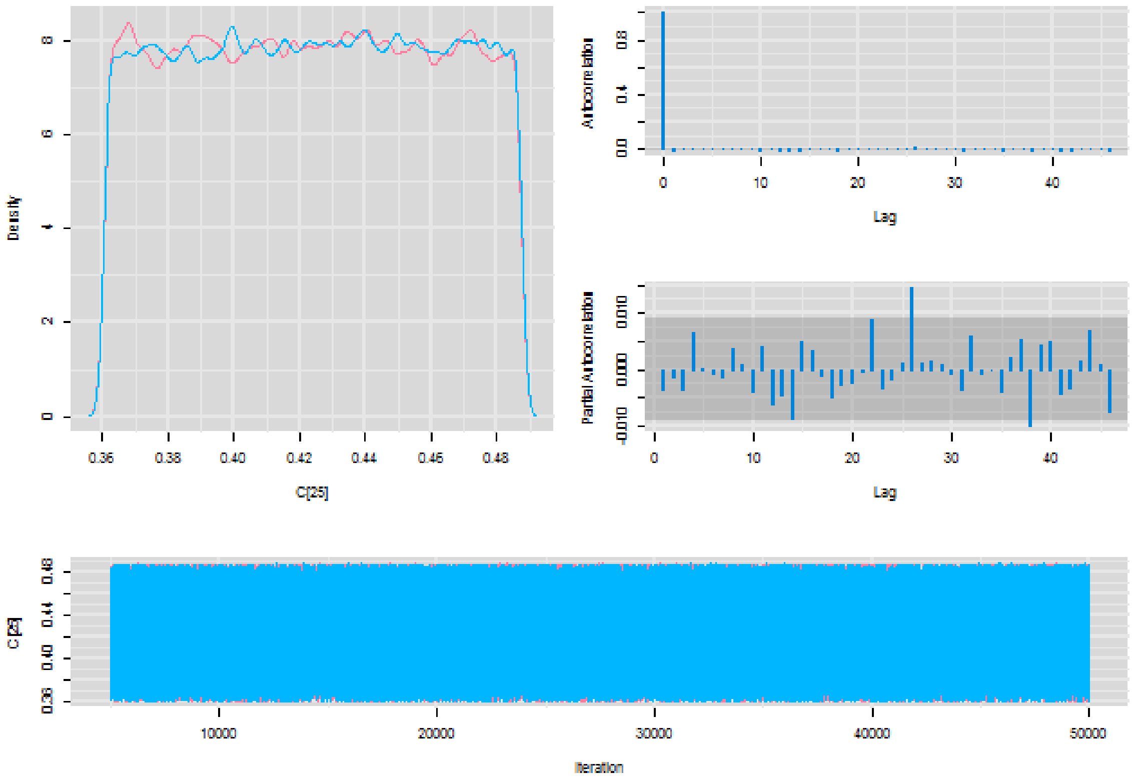
Diagnostics for C[23]



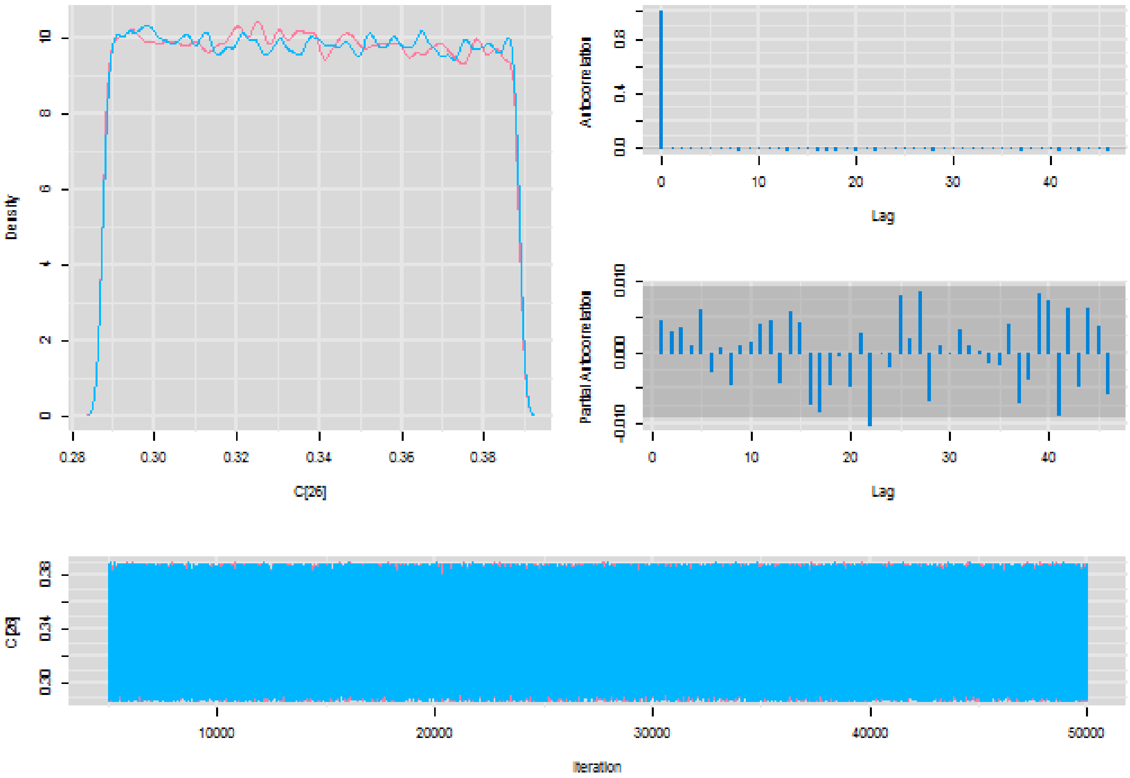
Diagnostics for C[24]



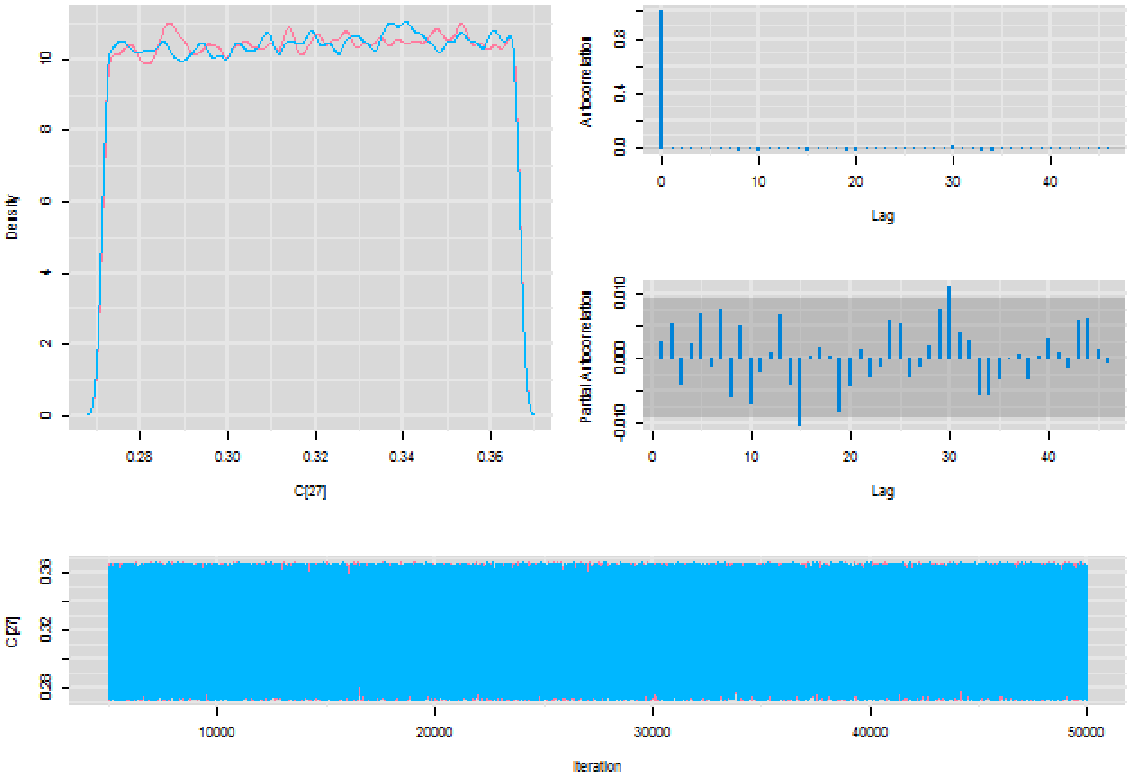
Diagnostics for C[25]



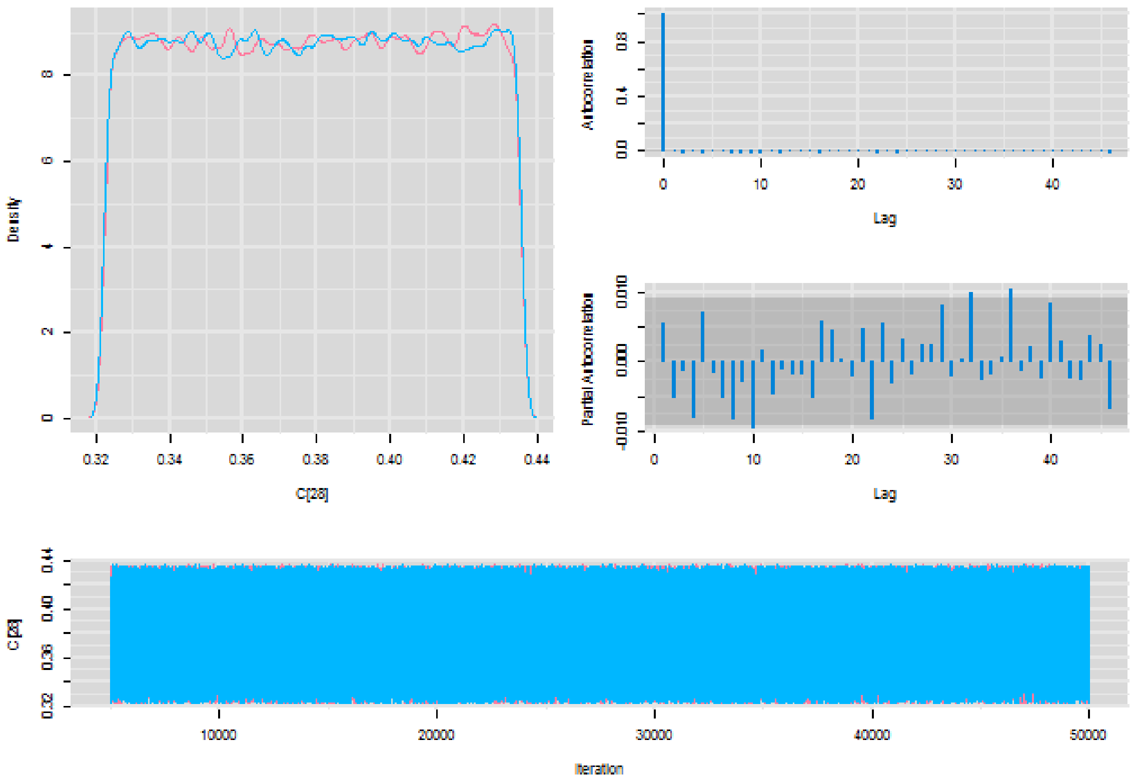
Diagnostics for C[26]



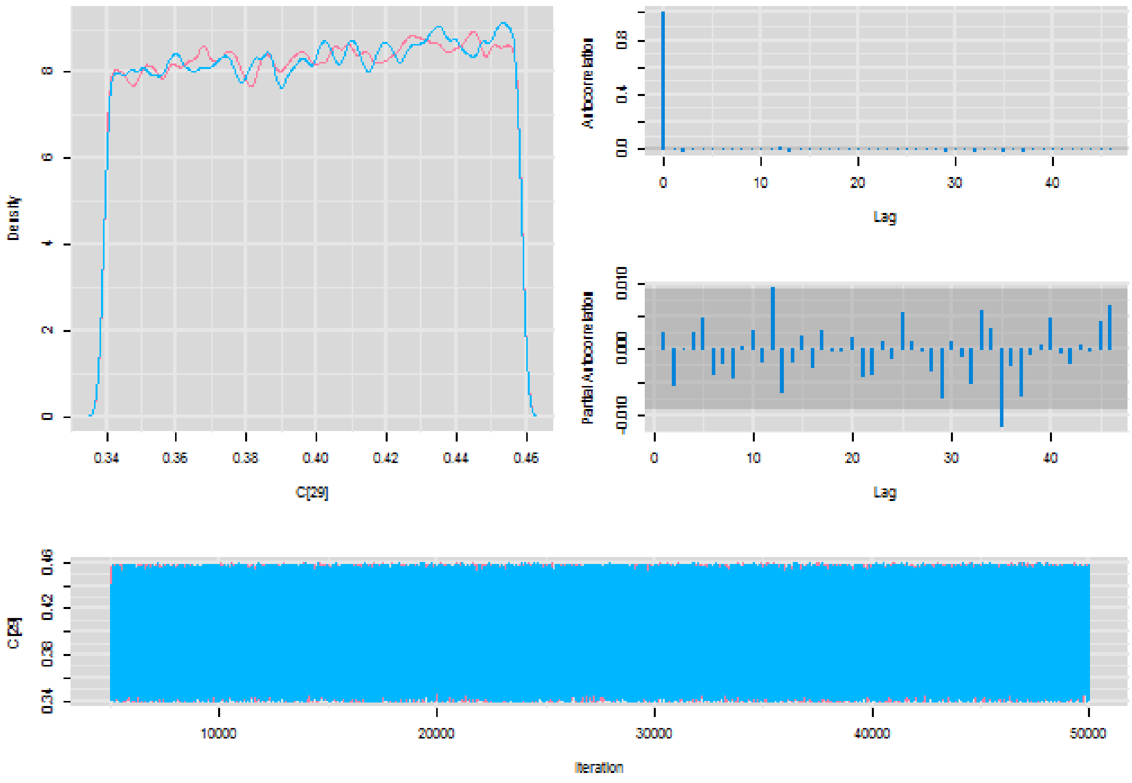
Diagnostics for C[27]



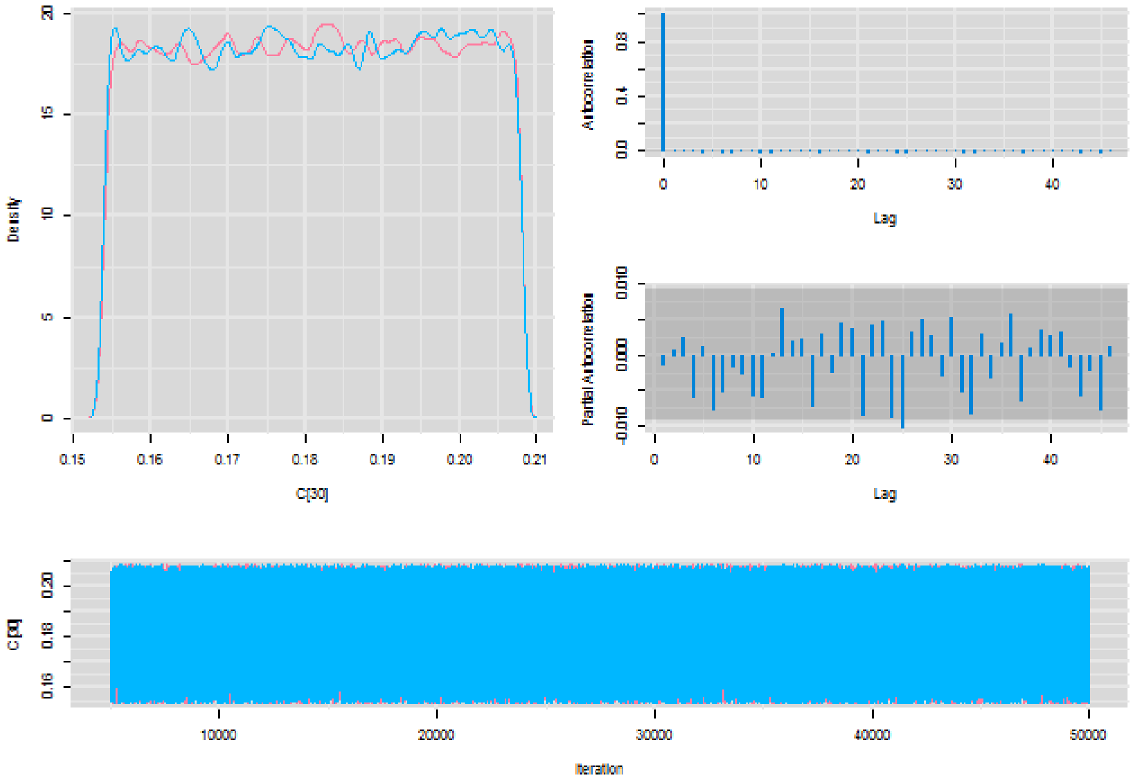
Diagnostics for C[28]



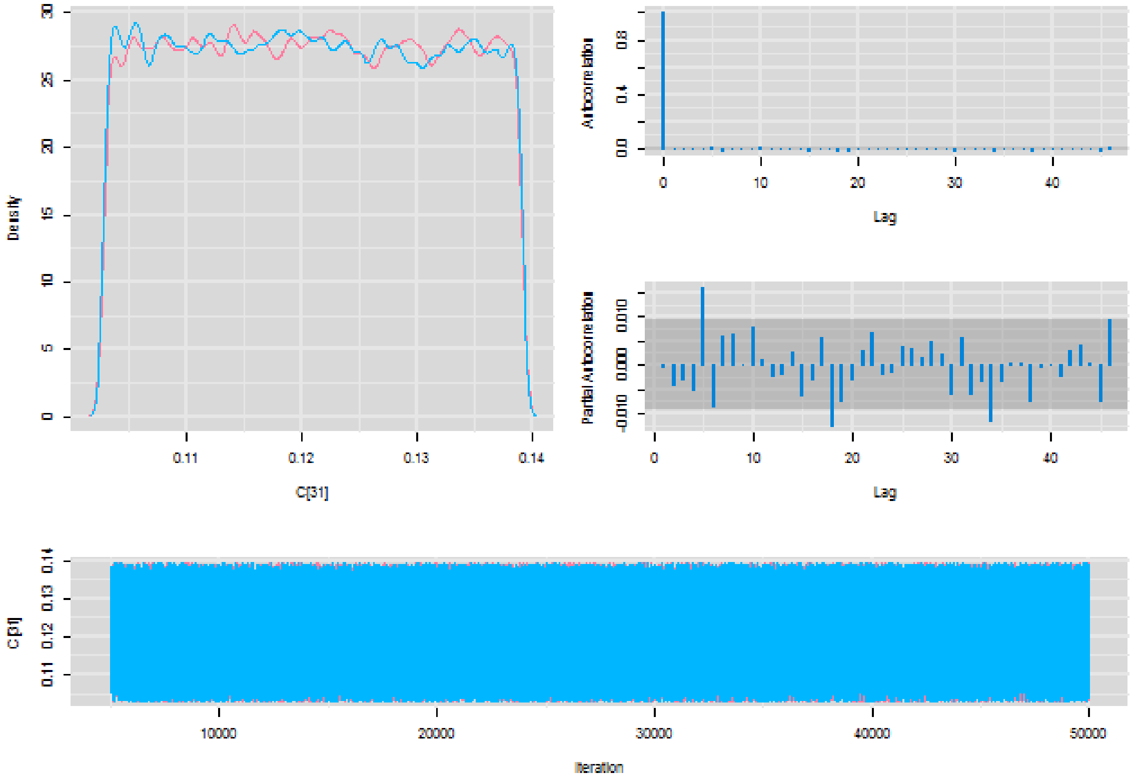
Diagnostics for C[29]



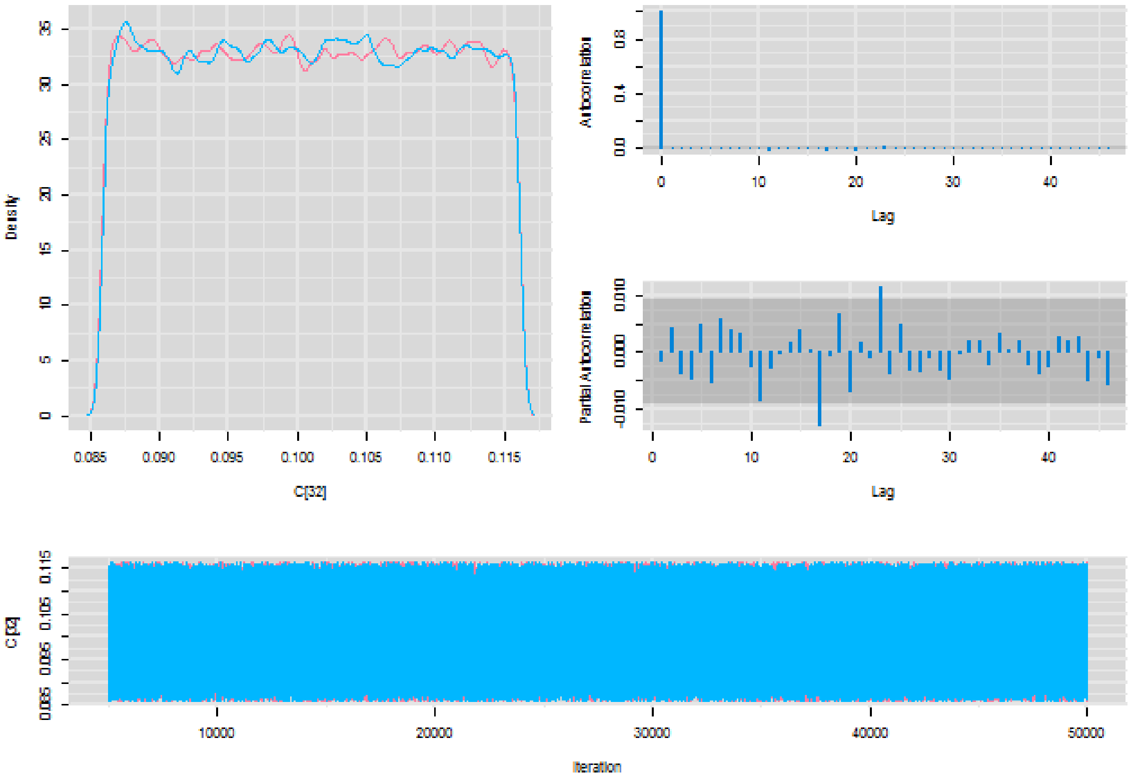
Diagnostics for C[30]



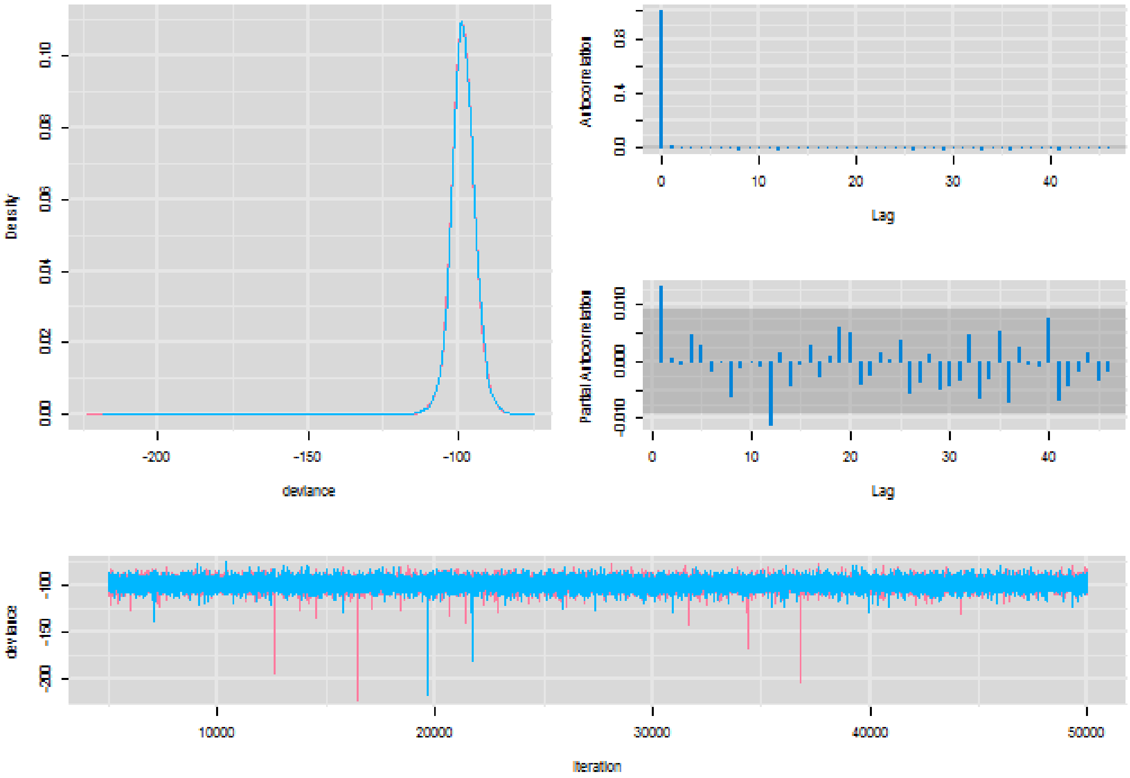
Diagnostics for C[31]



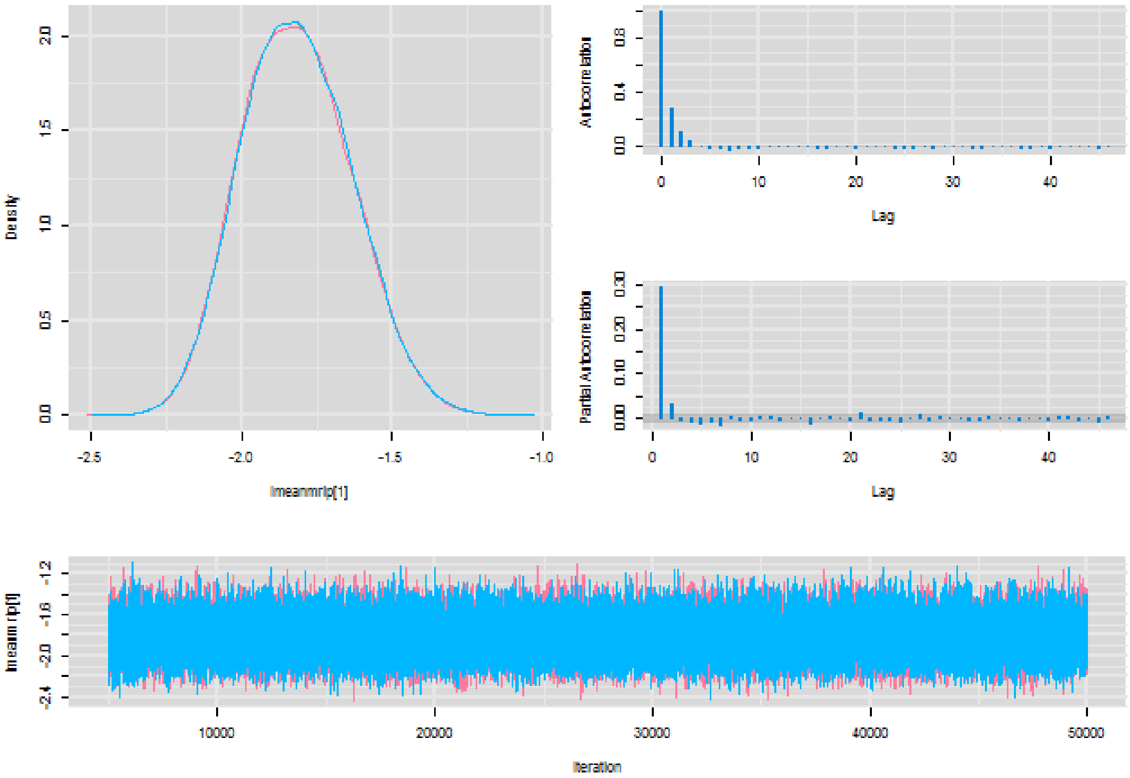
Diagnostics for C[32]



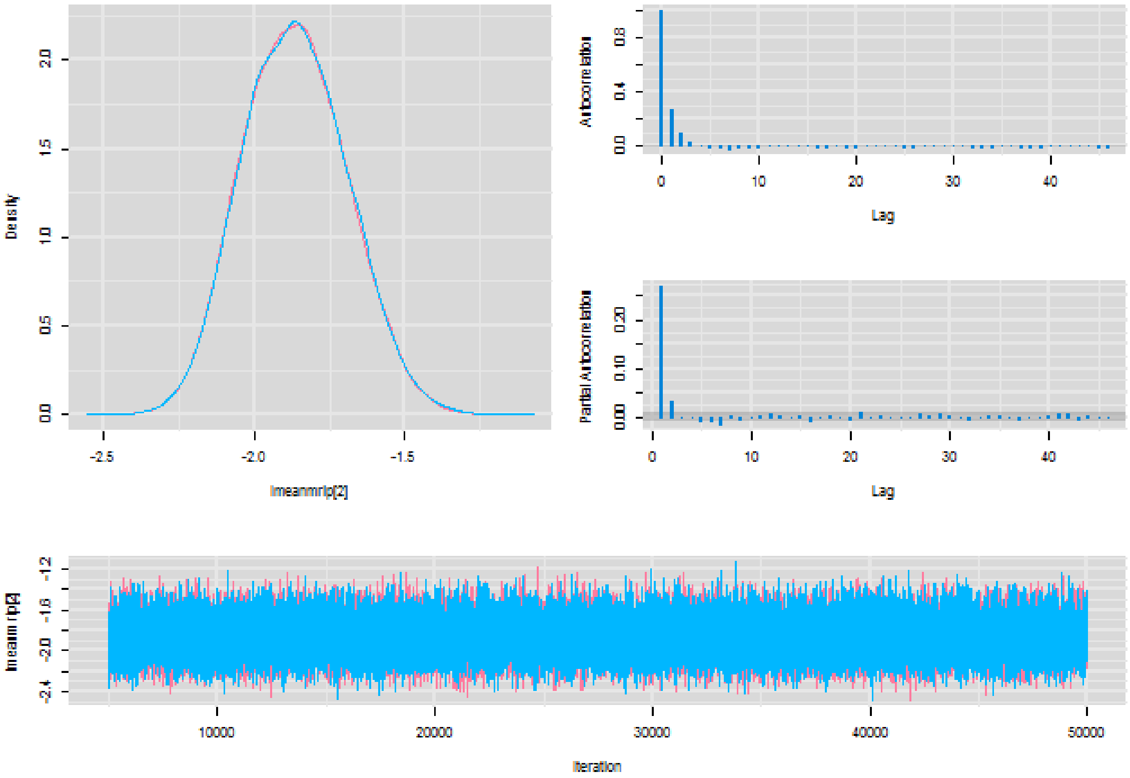
Diagnostics for deviance



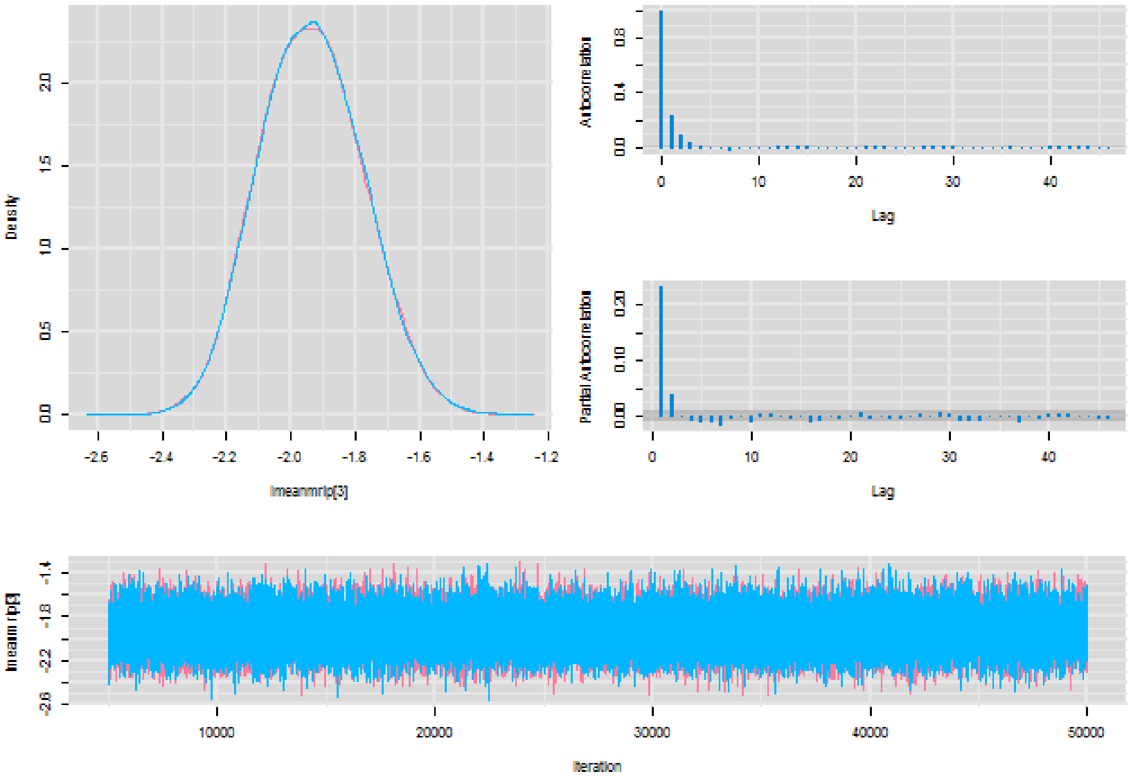
Diagnostics for lmeanmrip[1]



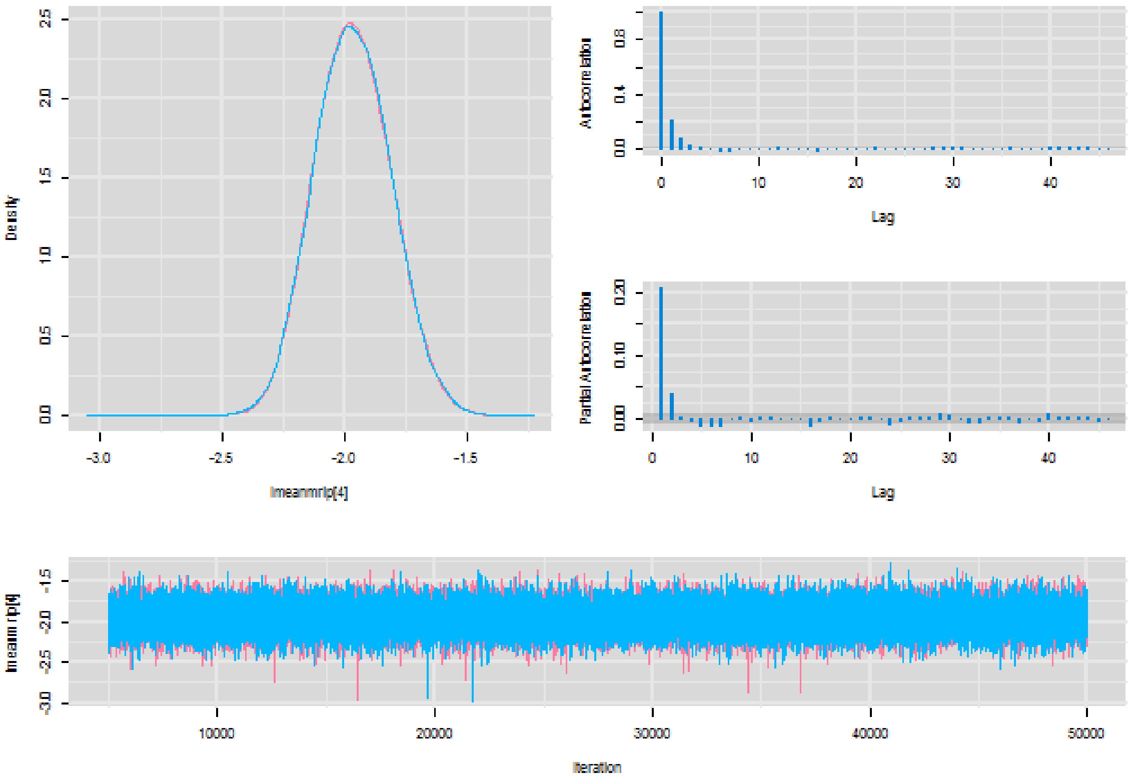
Diagnostics for lmeanmrip[2]



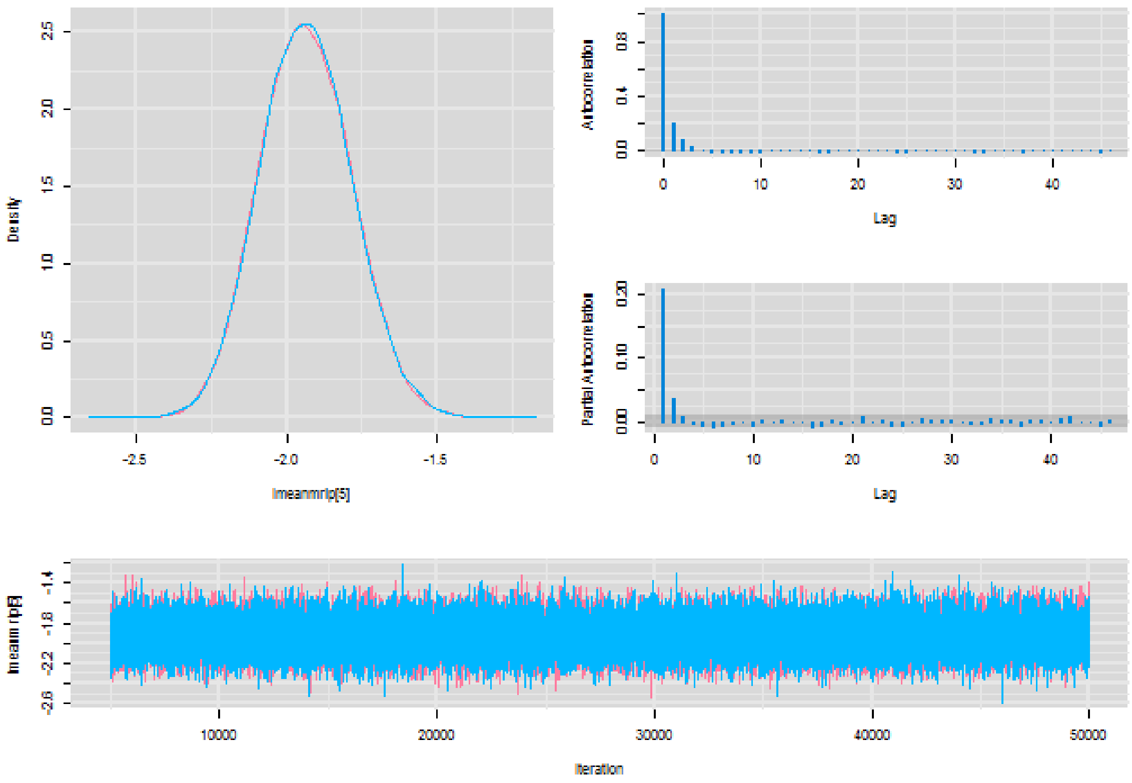
Diagnostics for lmeanmrip[3]



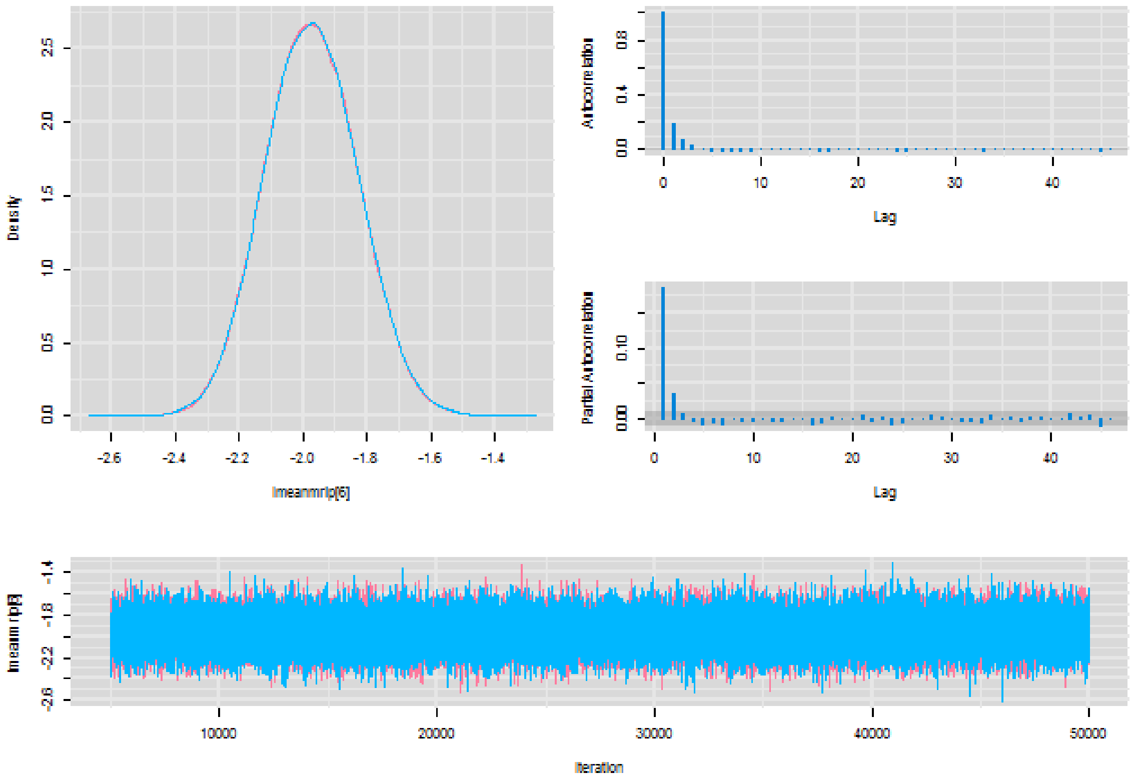
Diagnostics for lmeanmrip[4]



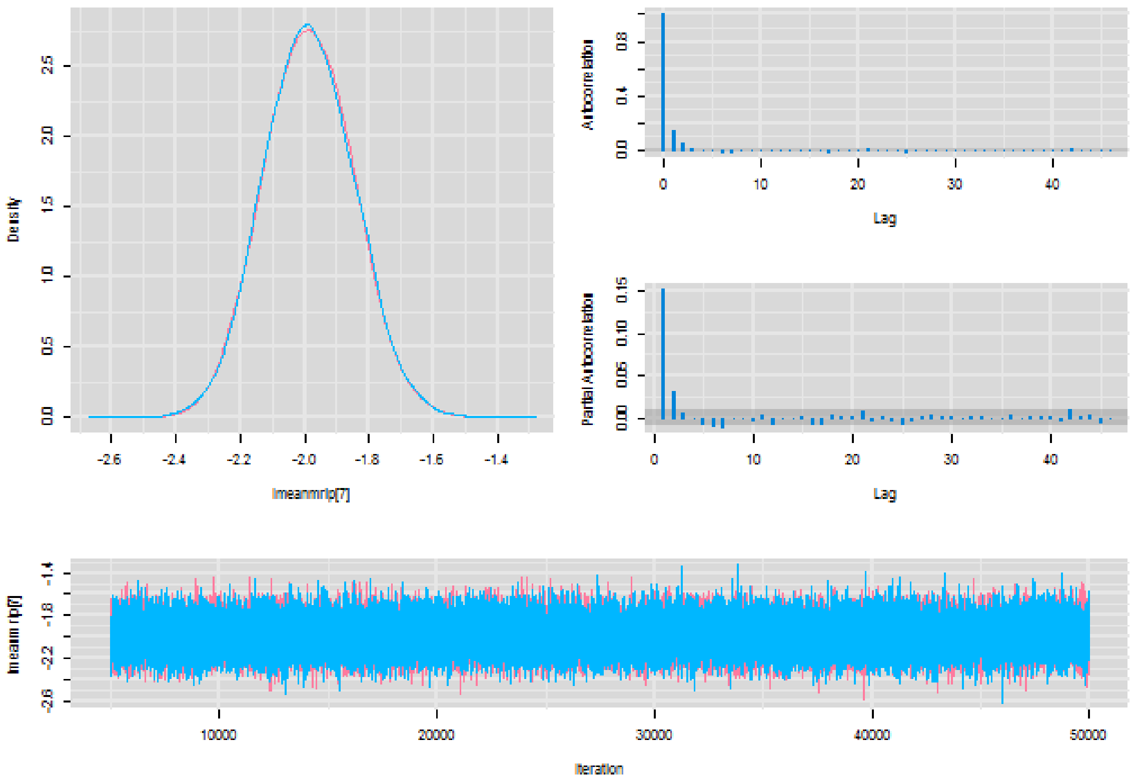
Diagnostics for lmeanmrip[5]



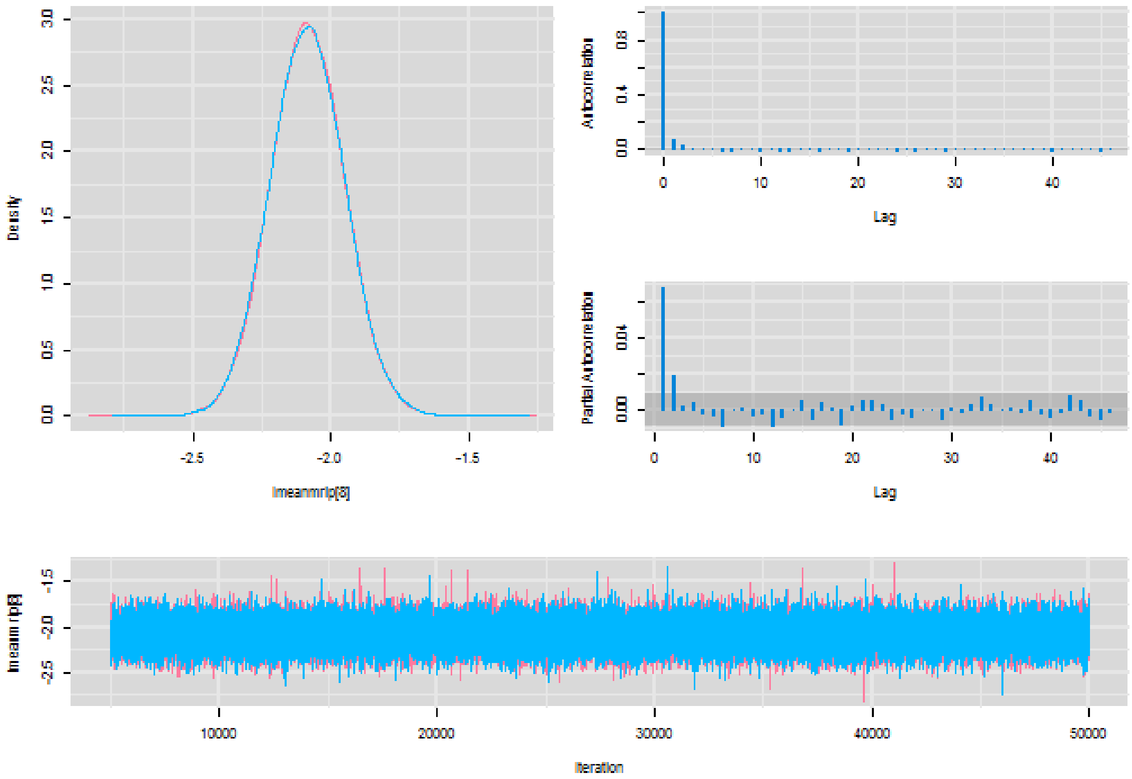
Diagnostics for lmeanmrip[6]



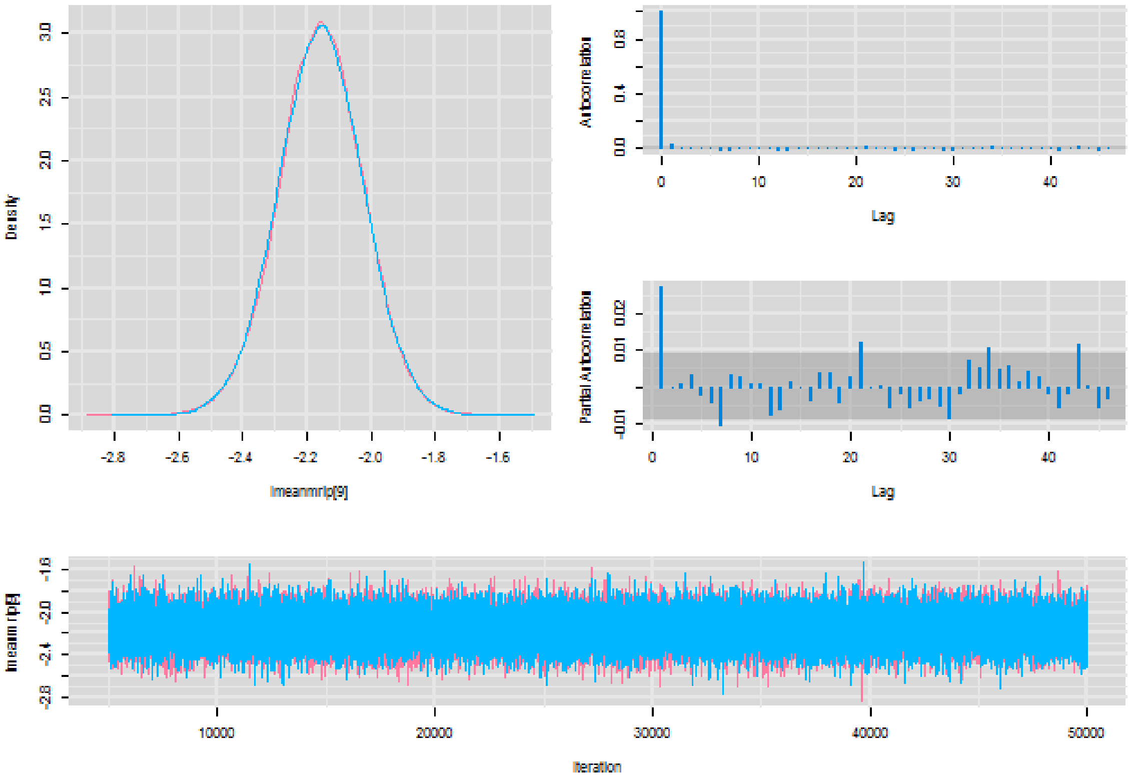
Diagnostics for lmeanmrip[7]



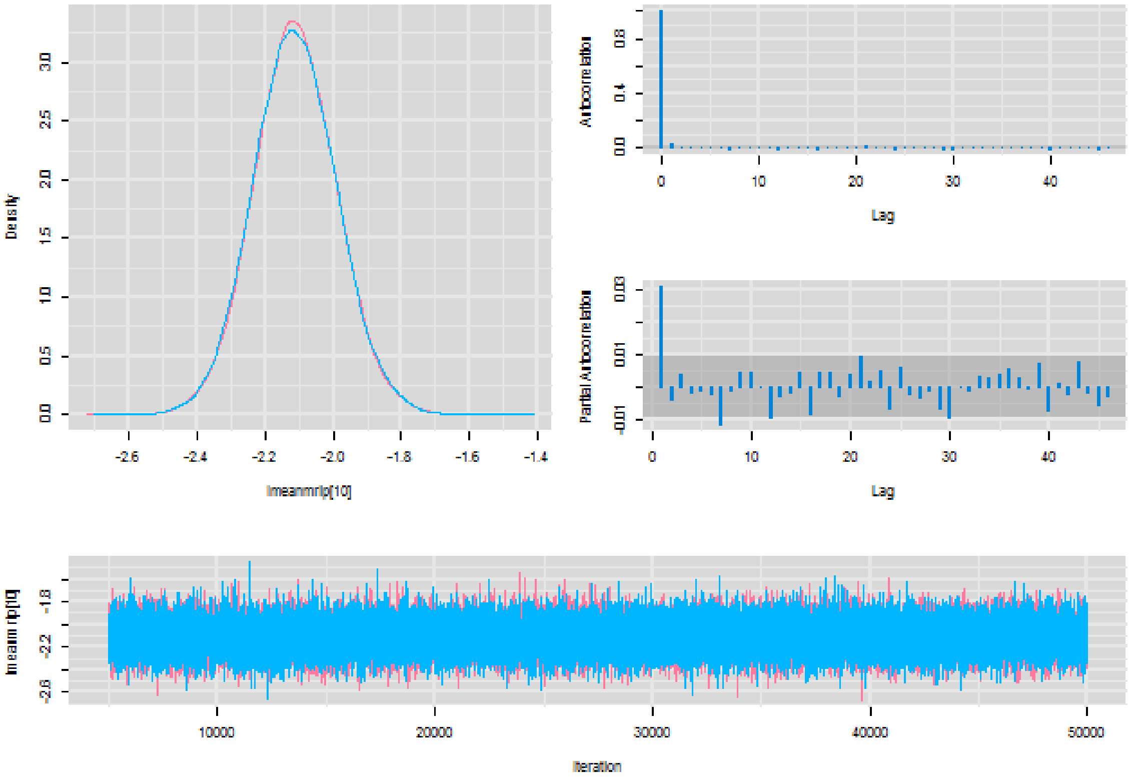
Diagnostics for lmeanmrip[8]



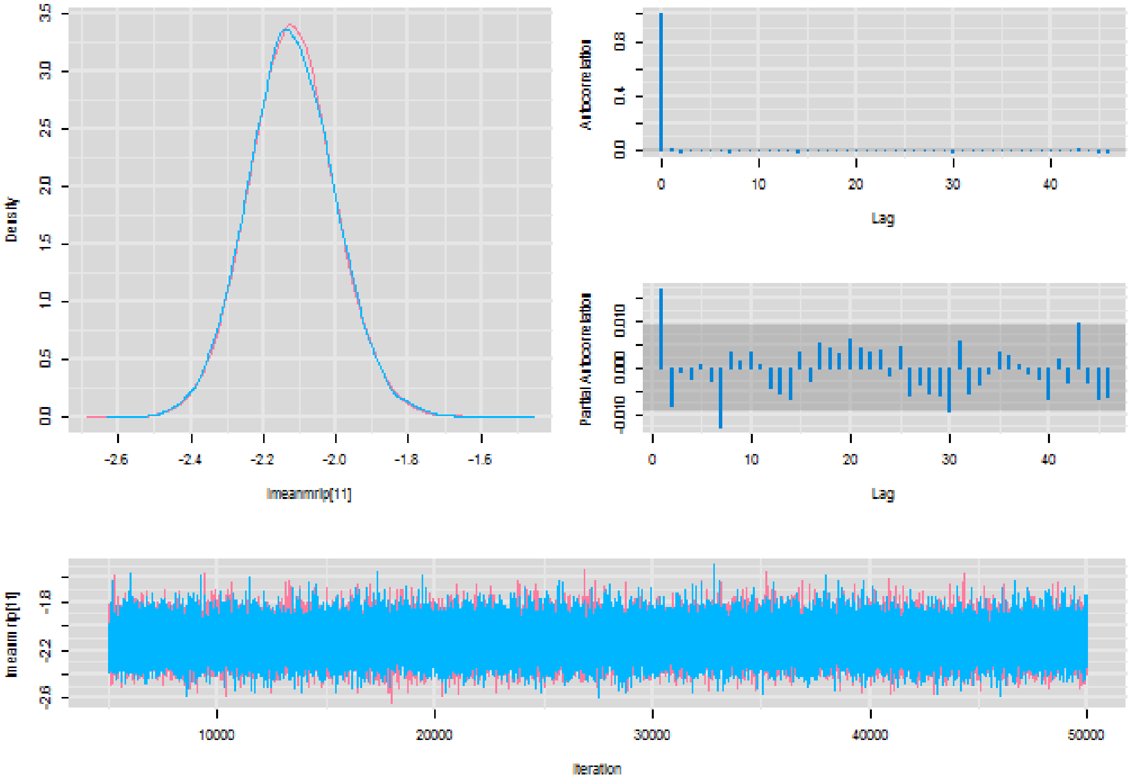
Diagnostics for lmeanmrip[9]



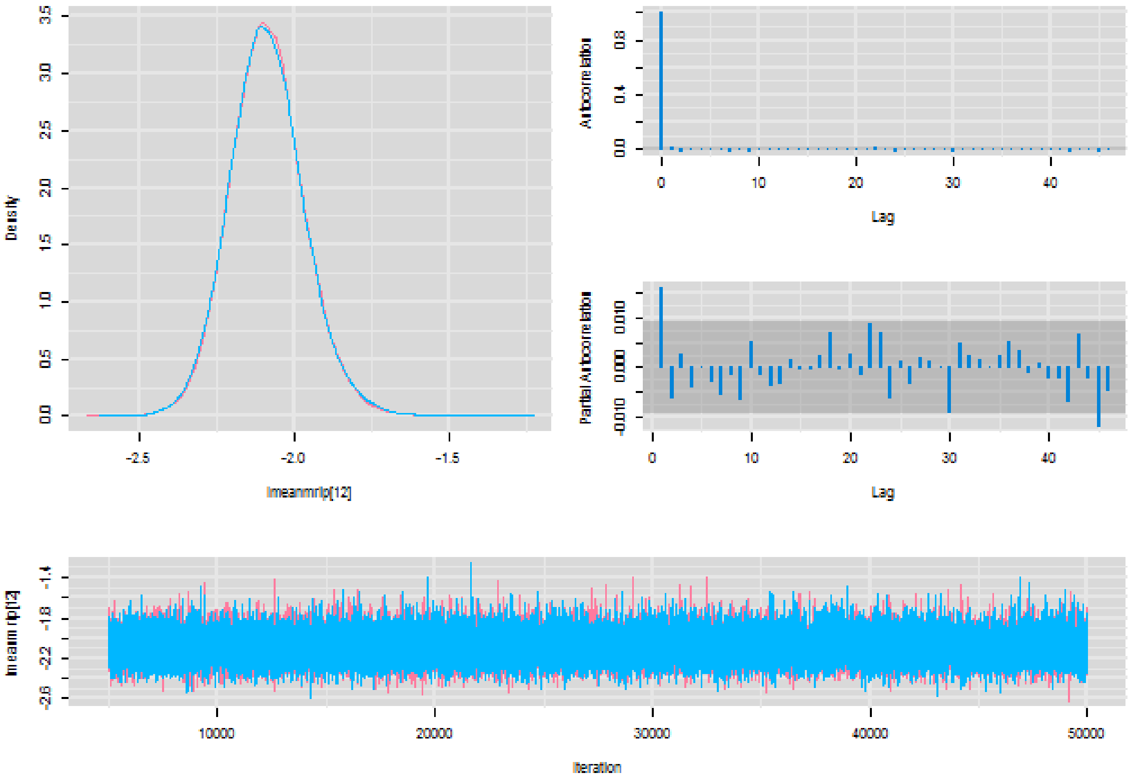
Diagnostics for lmeanmrip[10]



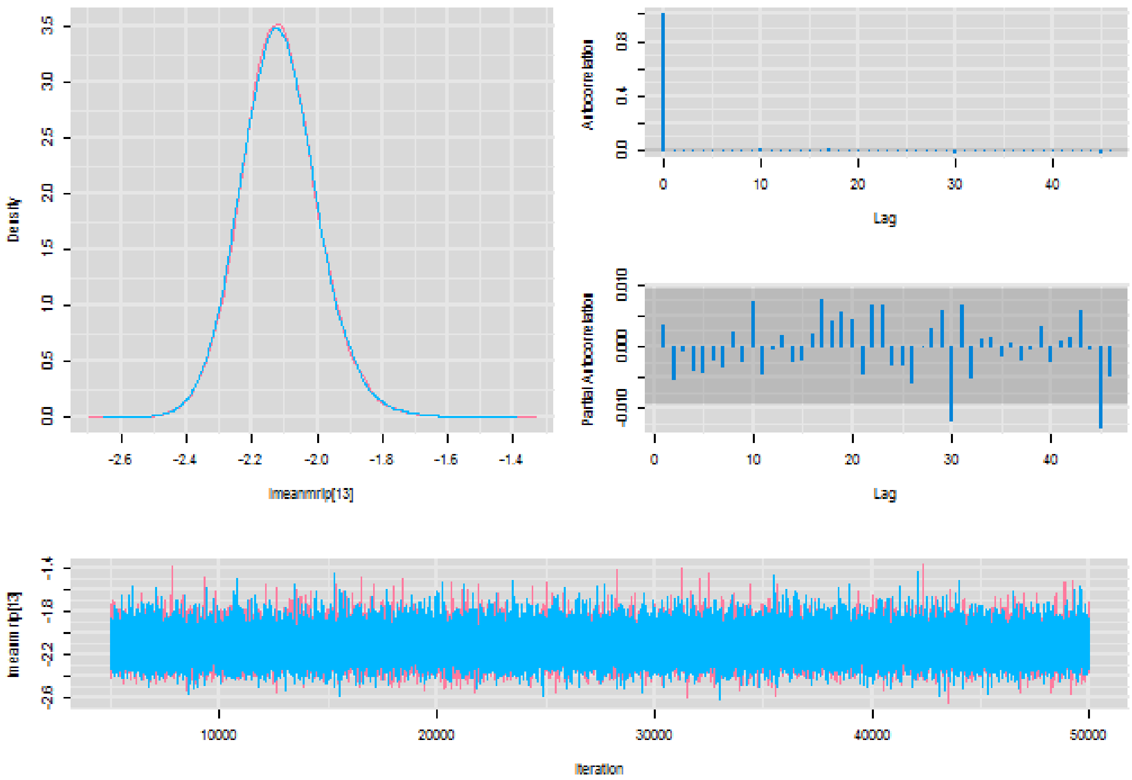
Diagnostics for lmeanmrip[11]



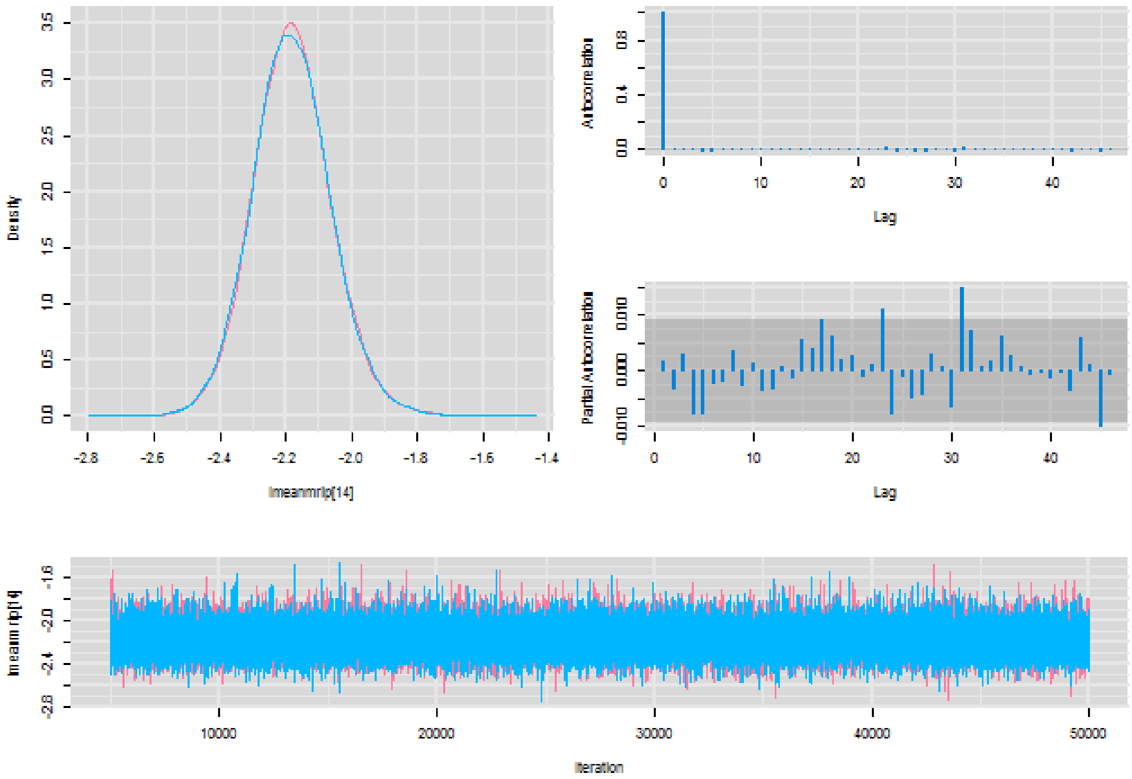
Diagnostics for lmeanmrip[12]



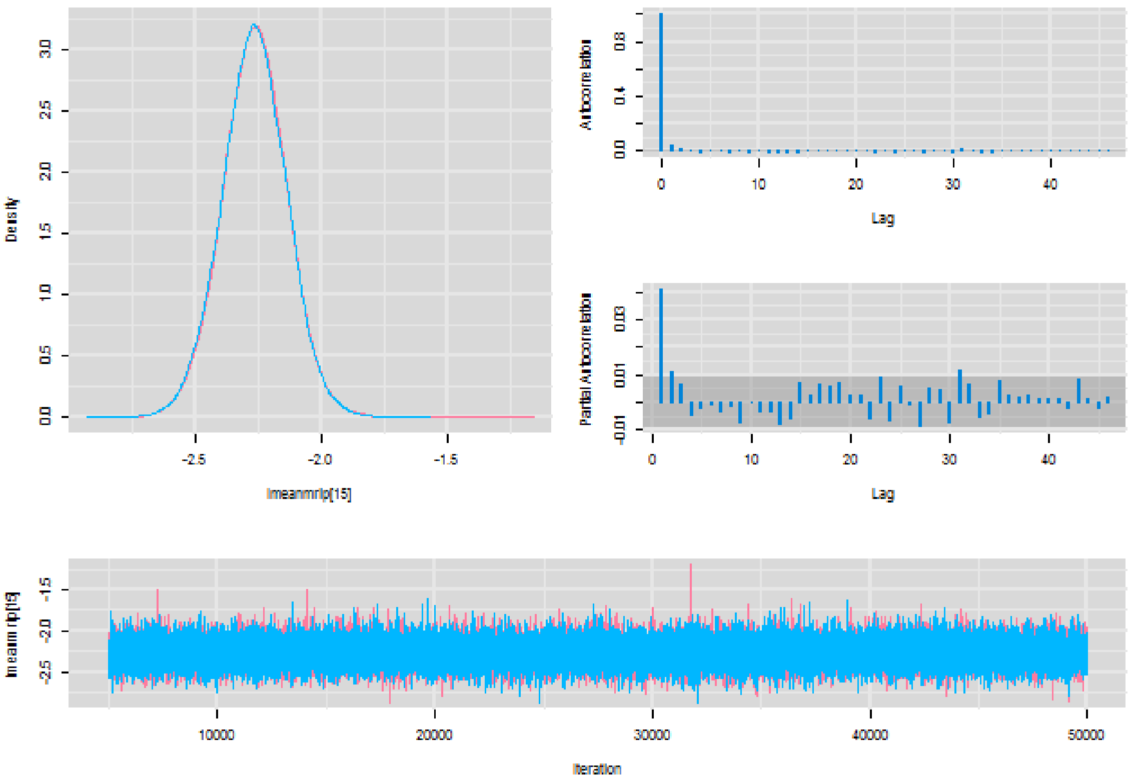
Diagnostics for lmeanmrip[13]



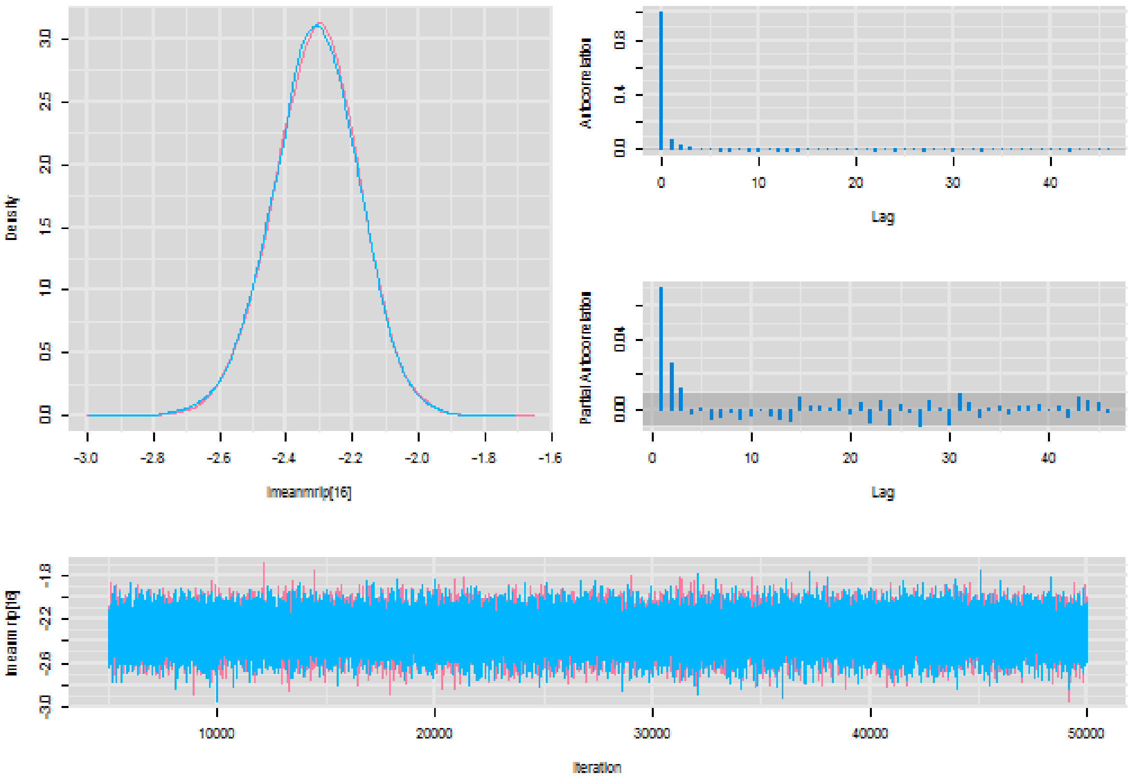
Diagnostics for lmeanmrip[14]



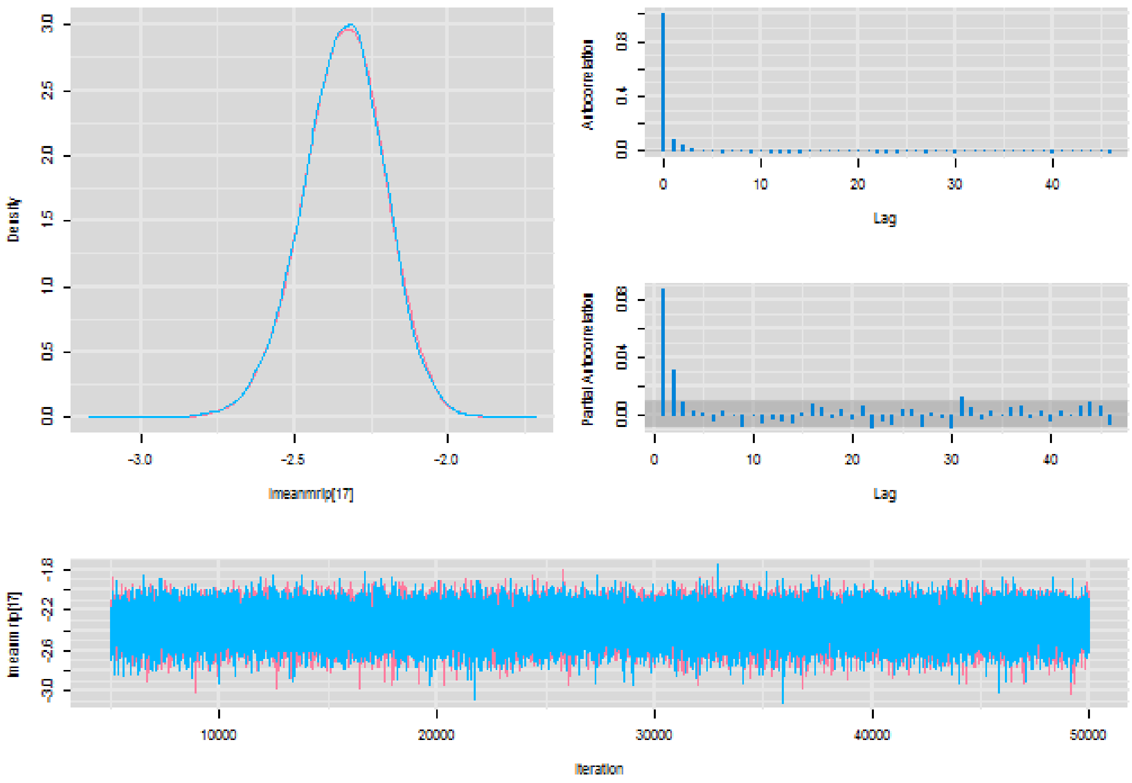
Diagnostics for lmeanmrip[15]



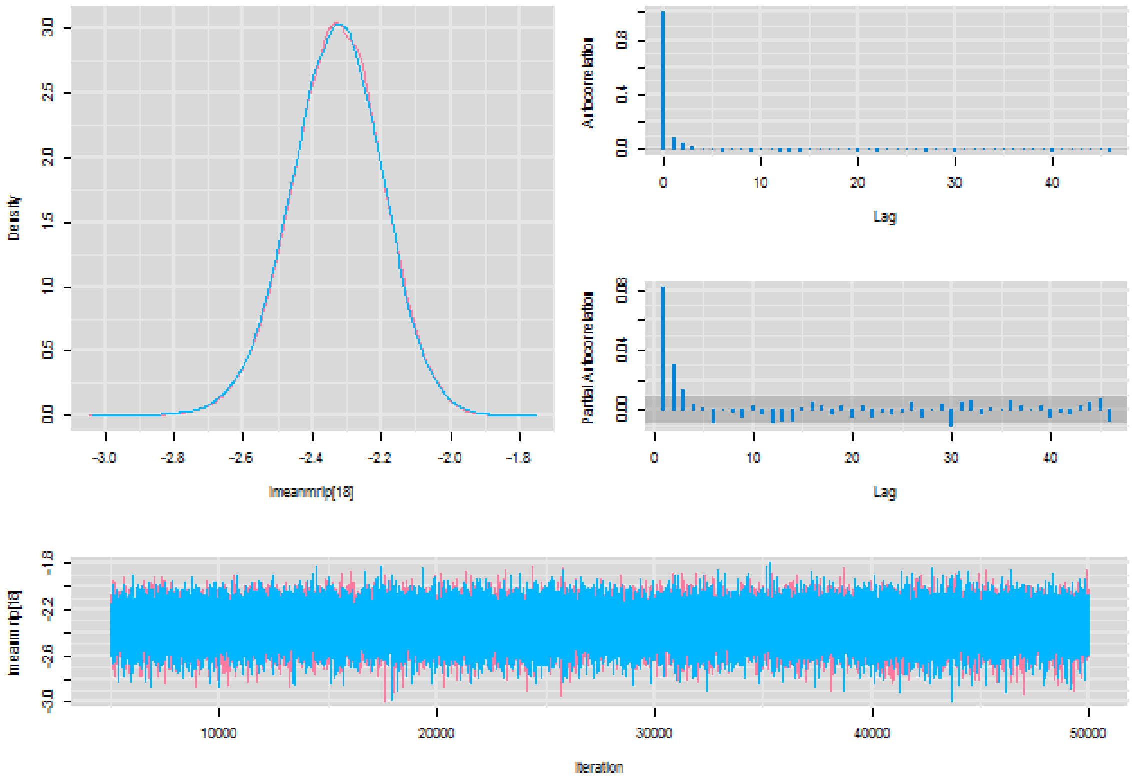
Diagnostics for lmeanmrip[16]



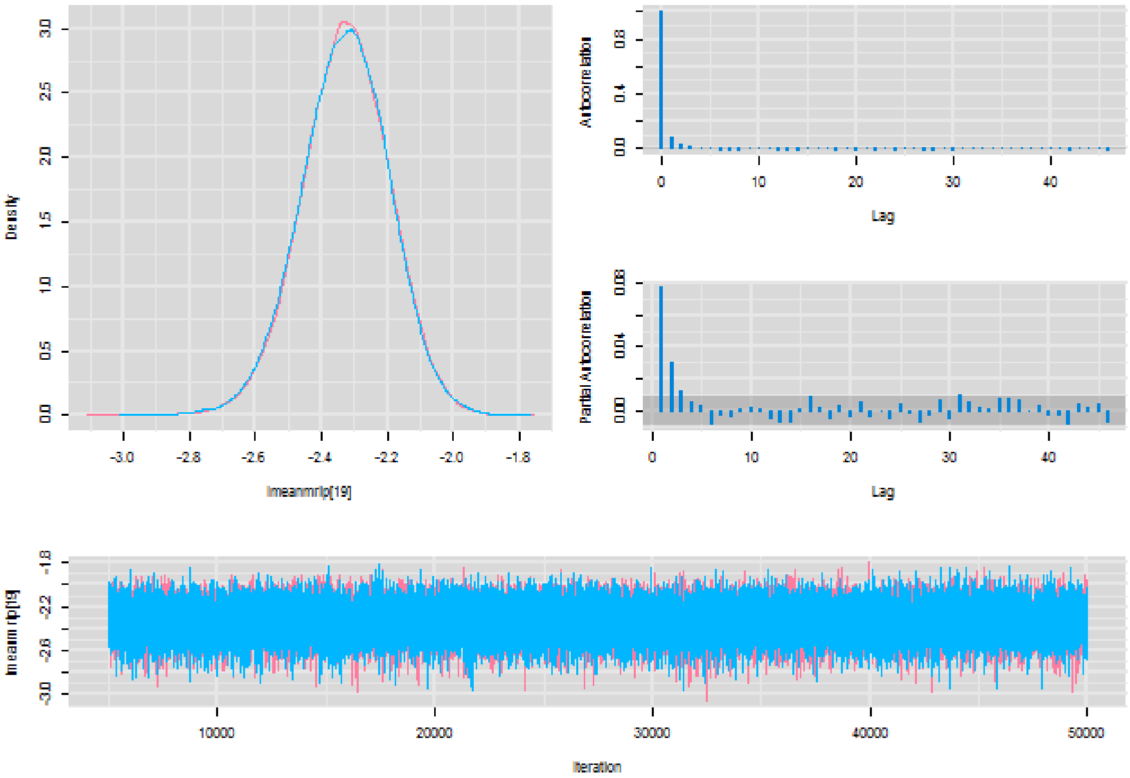
Diagnostics for lmeanmrip[17]



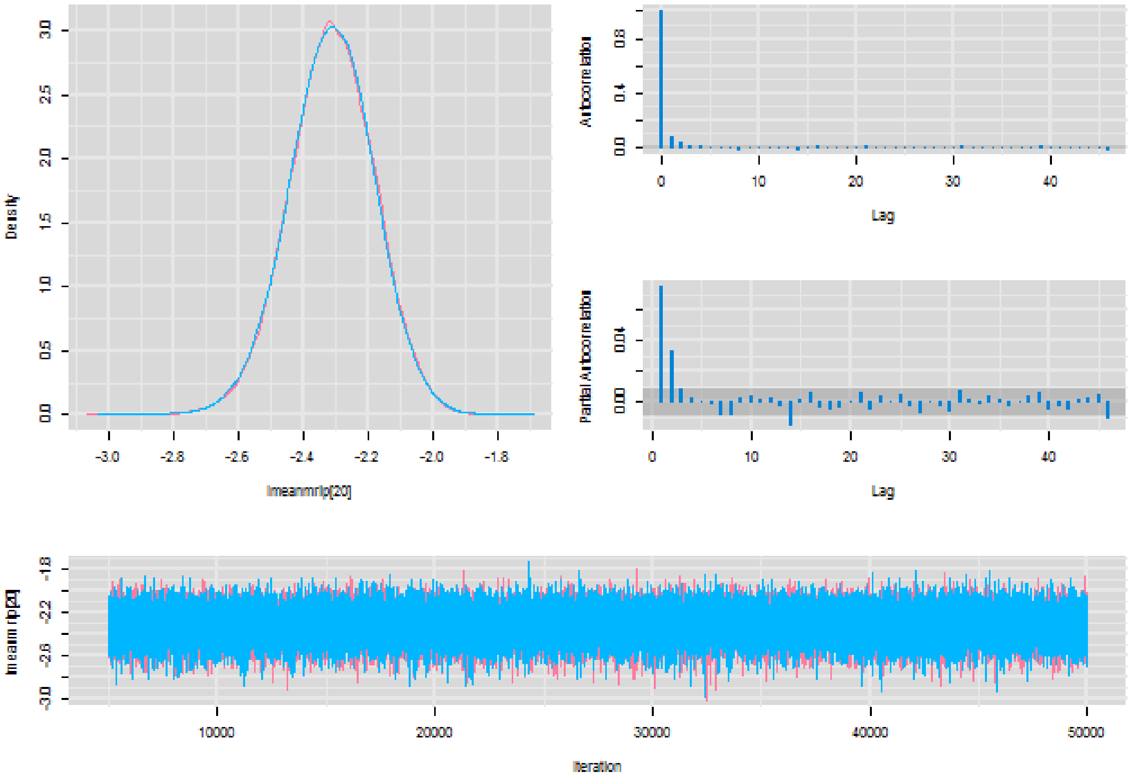
Diagnostics for lmeanmrip[18]



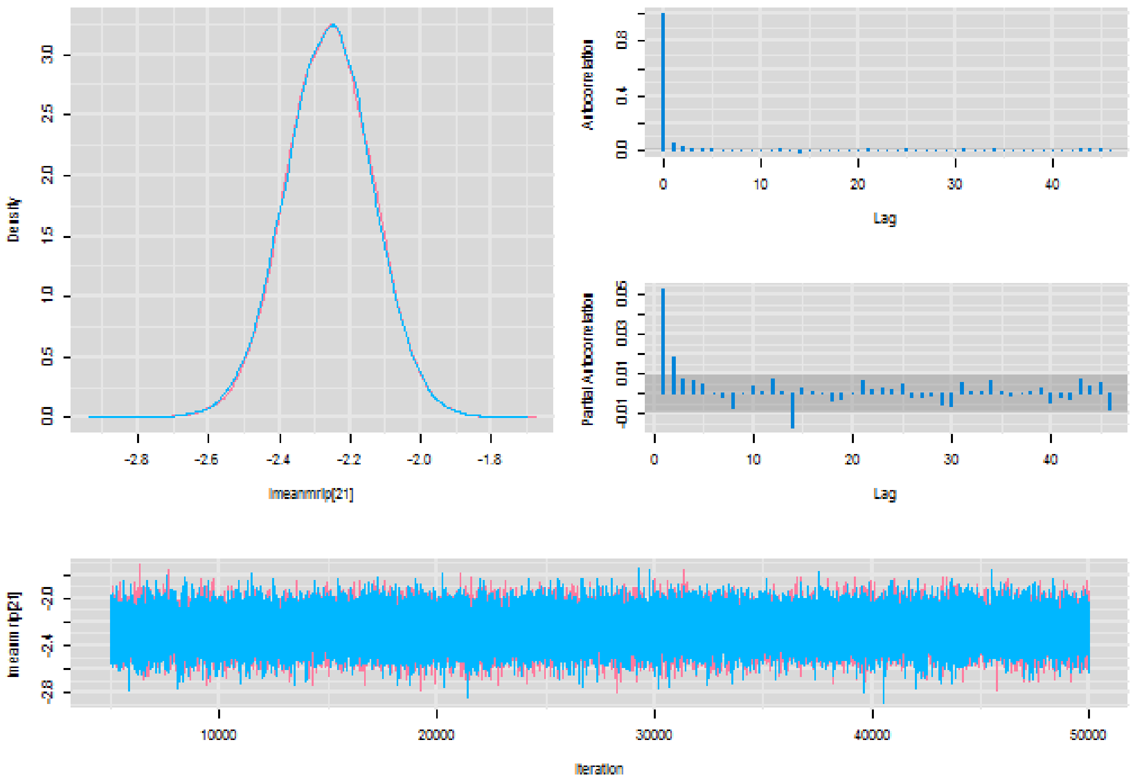
Diagnostics for lmeanmrip[19]



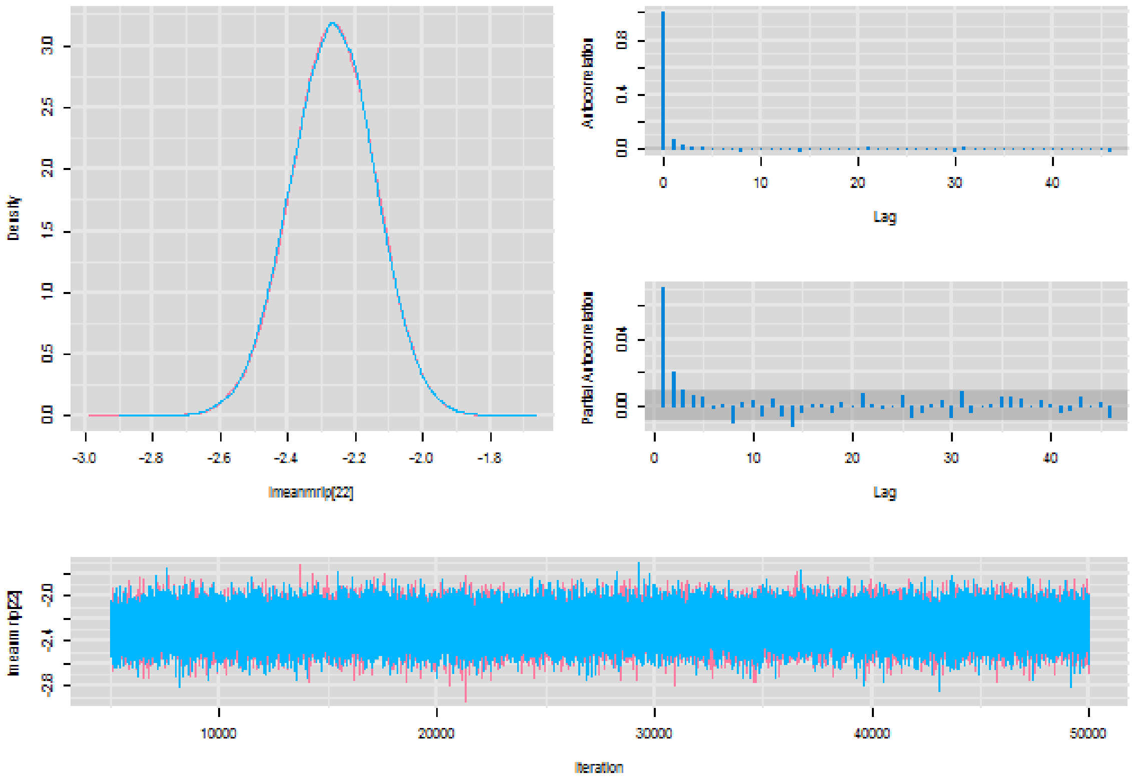
Diagnostics for lmeanmrip[20]



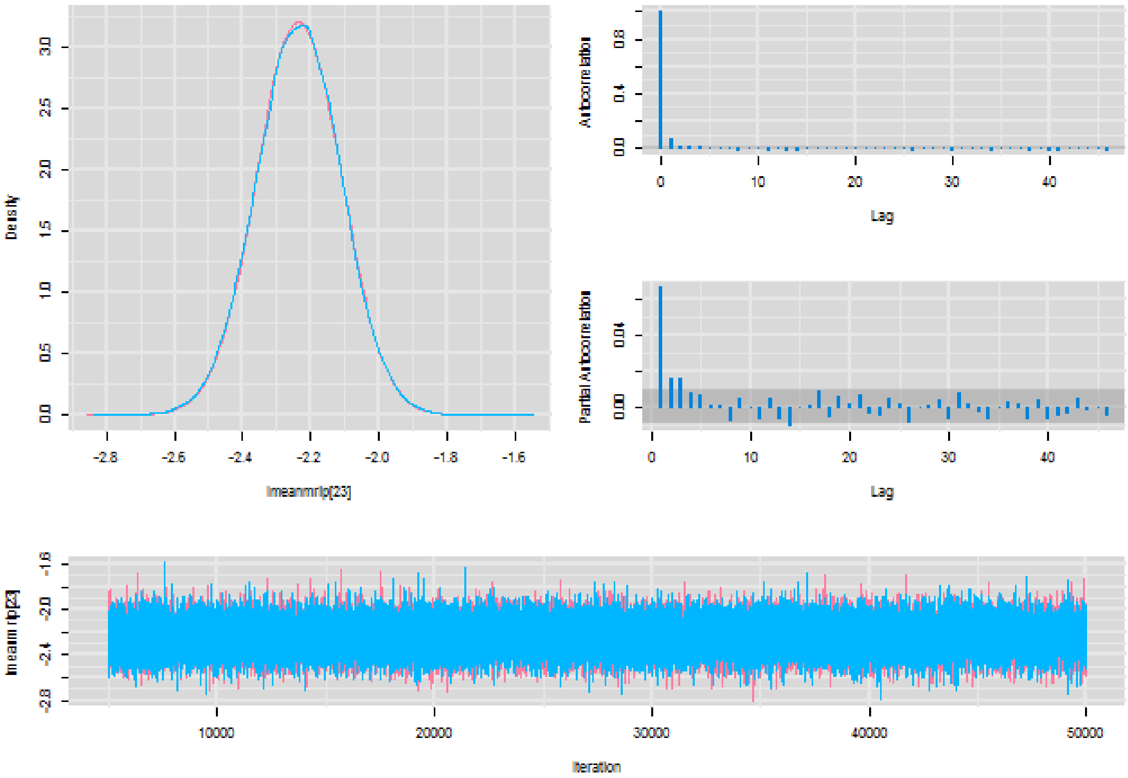
Diagnostics for lmeanmrip[21]



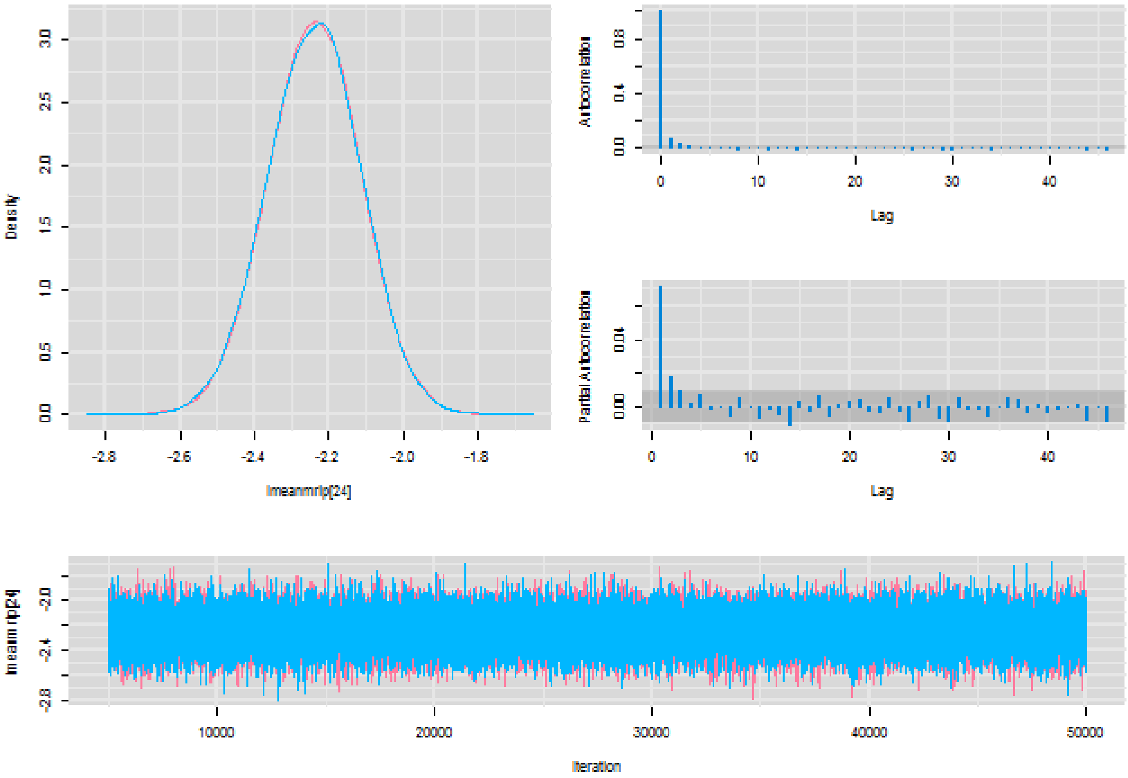
Diagnostics for lmeanmrip[22]



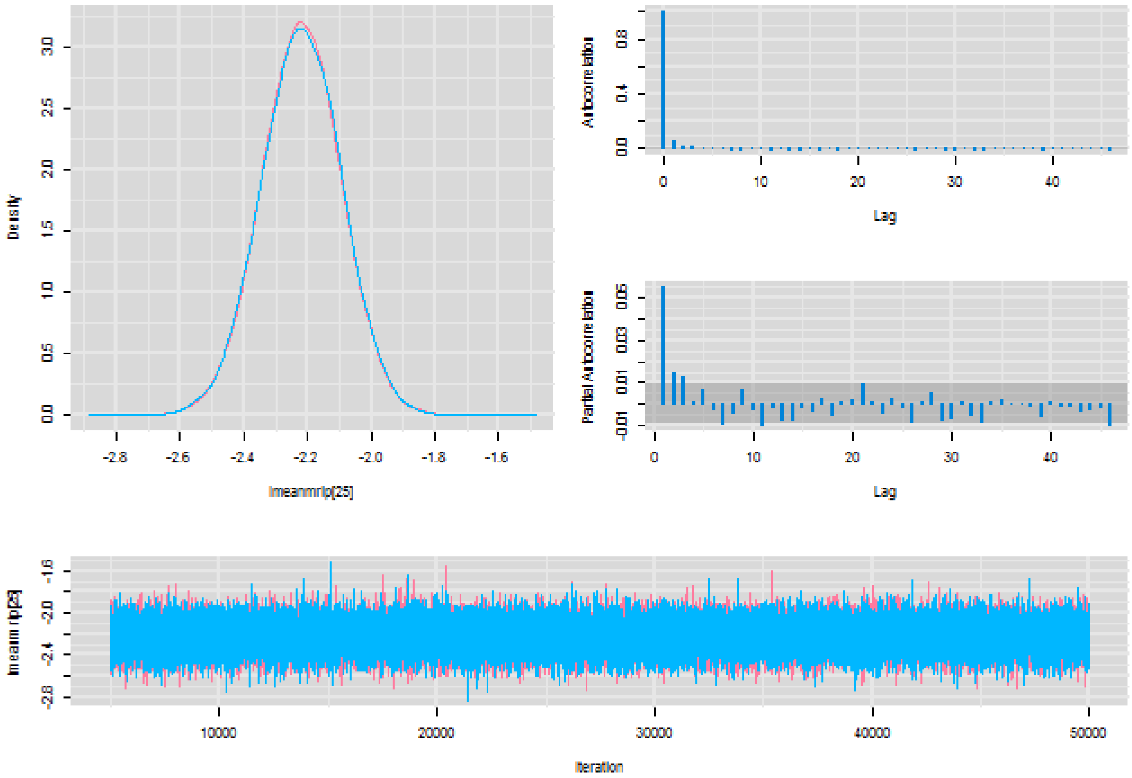
Diagnostics for lmeanmrip[23]



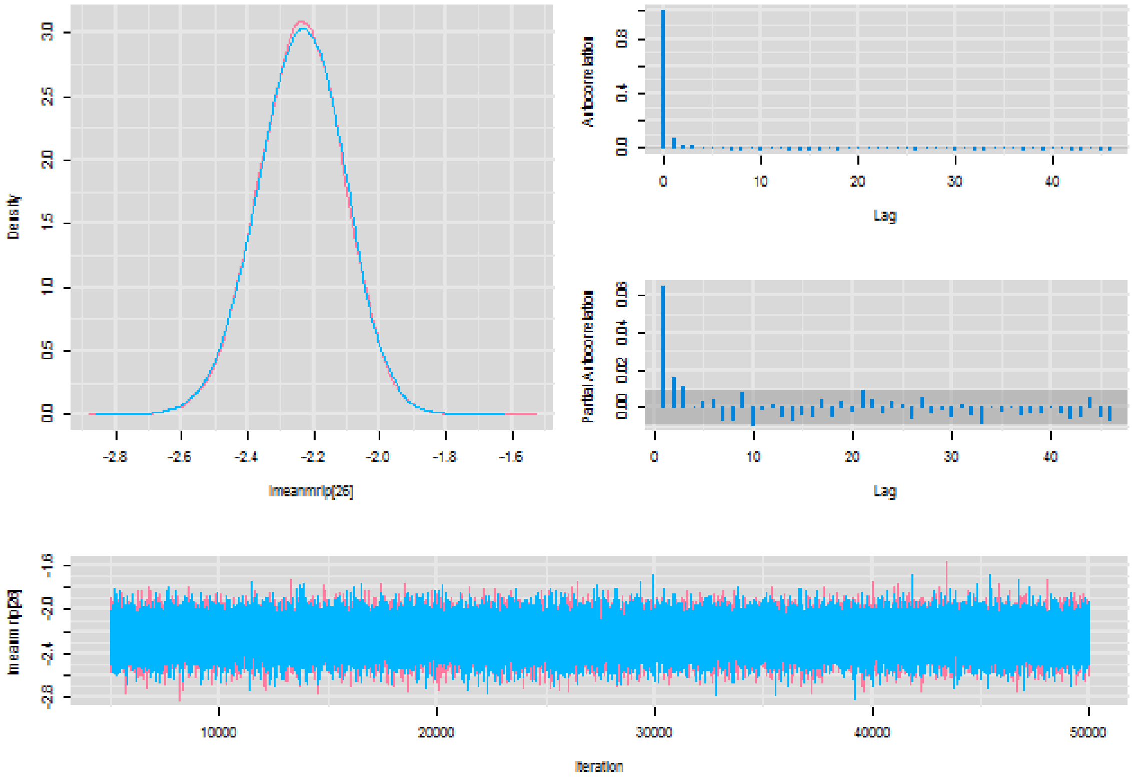
Diagnostics for lmeanmrip[24]



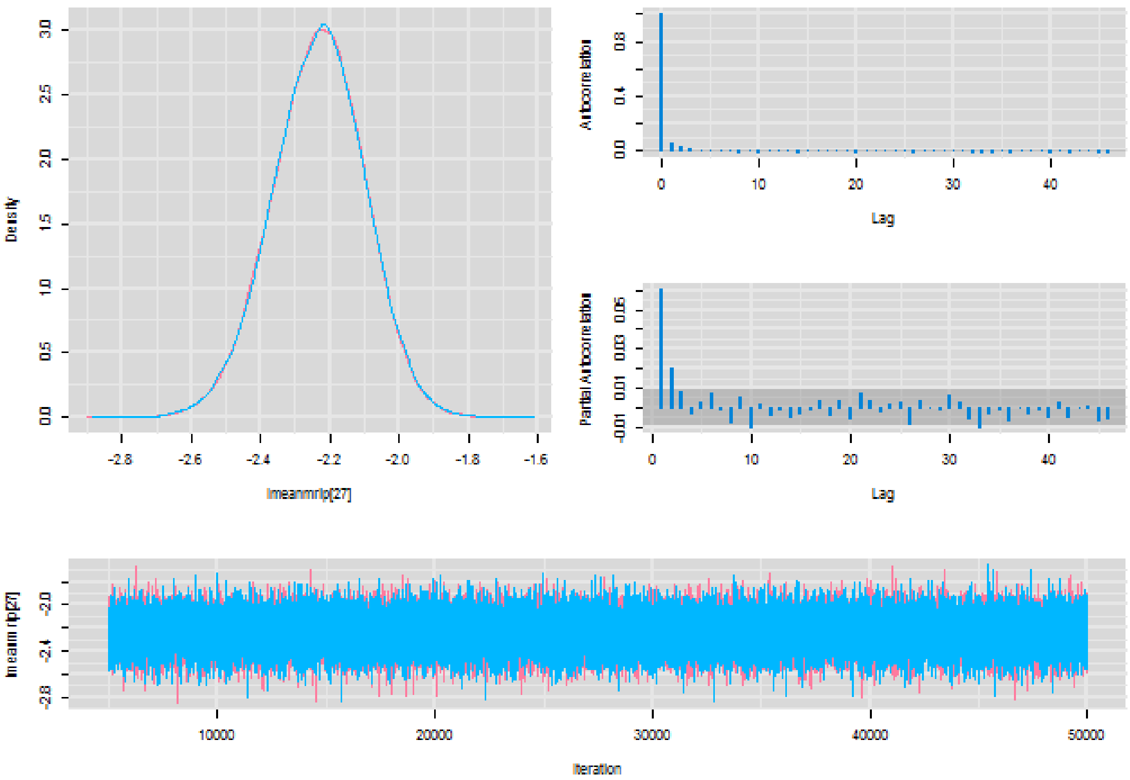
Diagnostics for lmeanmrip[25]



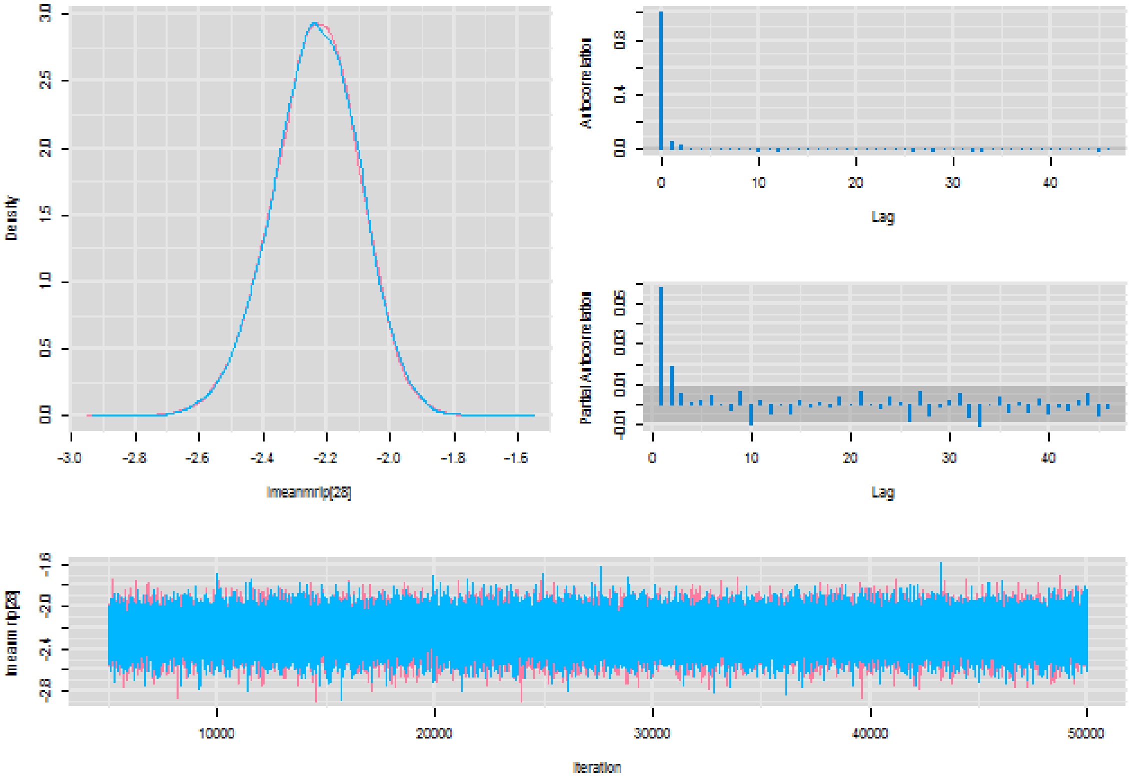
Diagnostics for lmeanmrip[26]



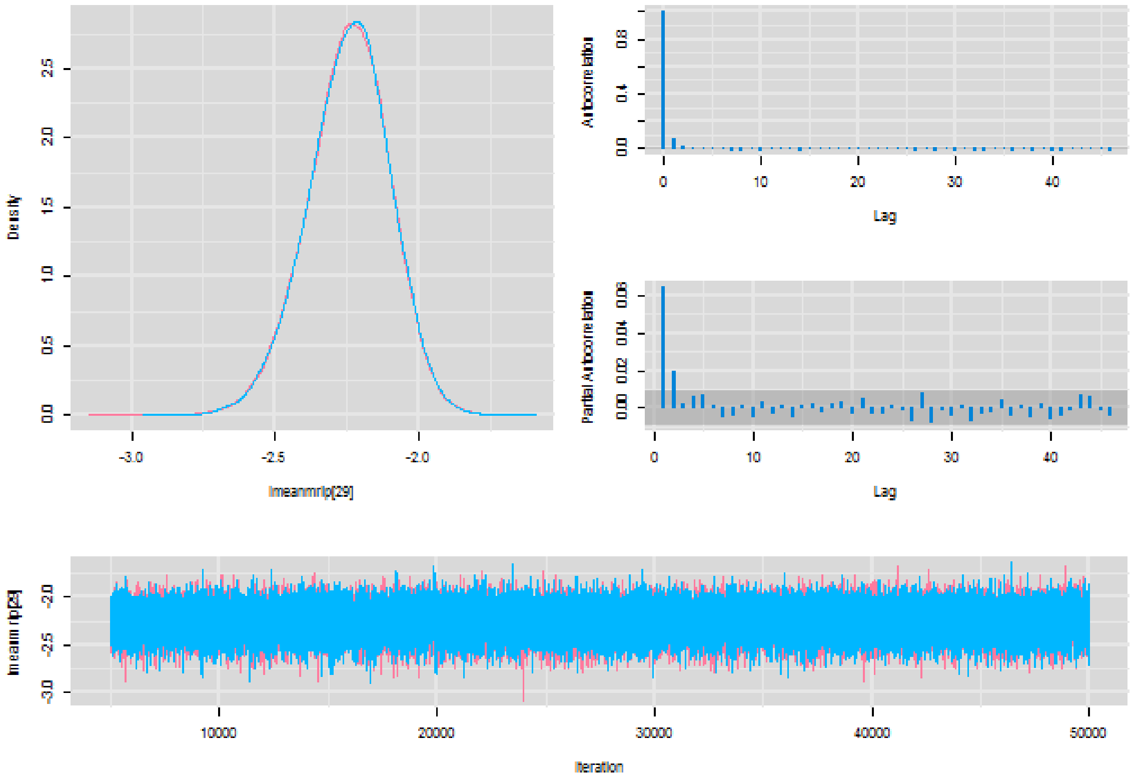
Diagnostics for lmeanmrip[27]



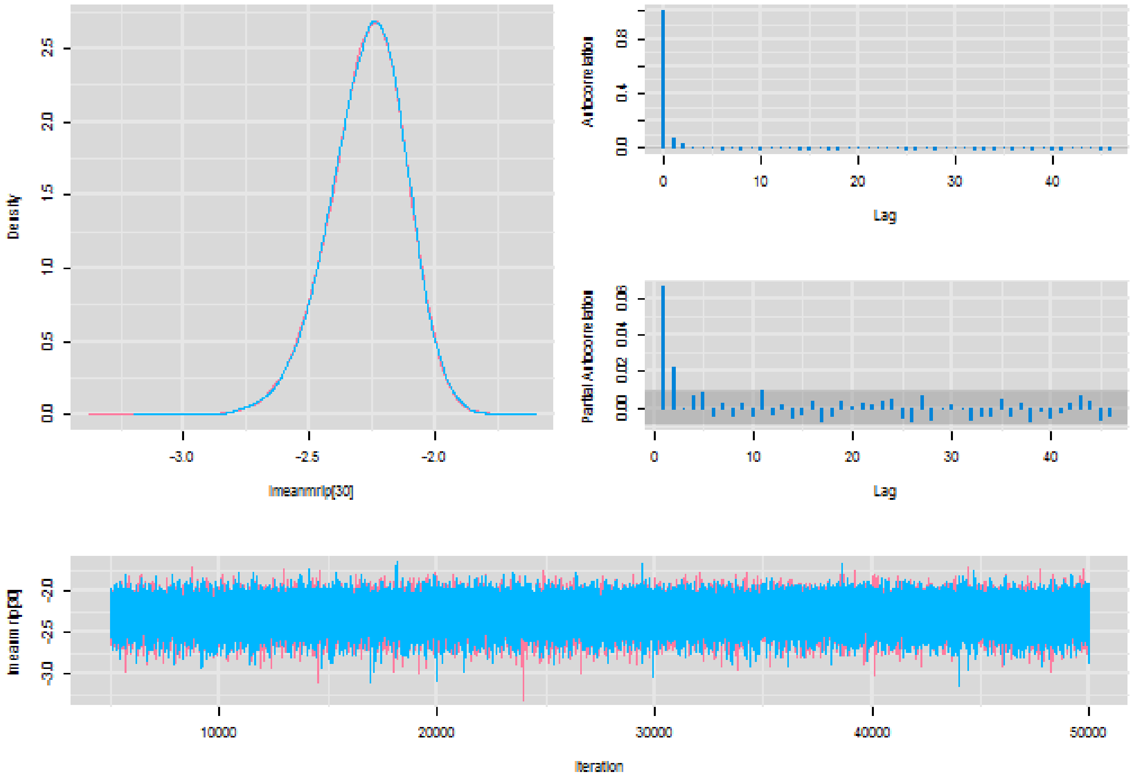
Diagnostics for lmeanmrip[28]



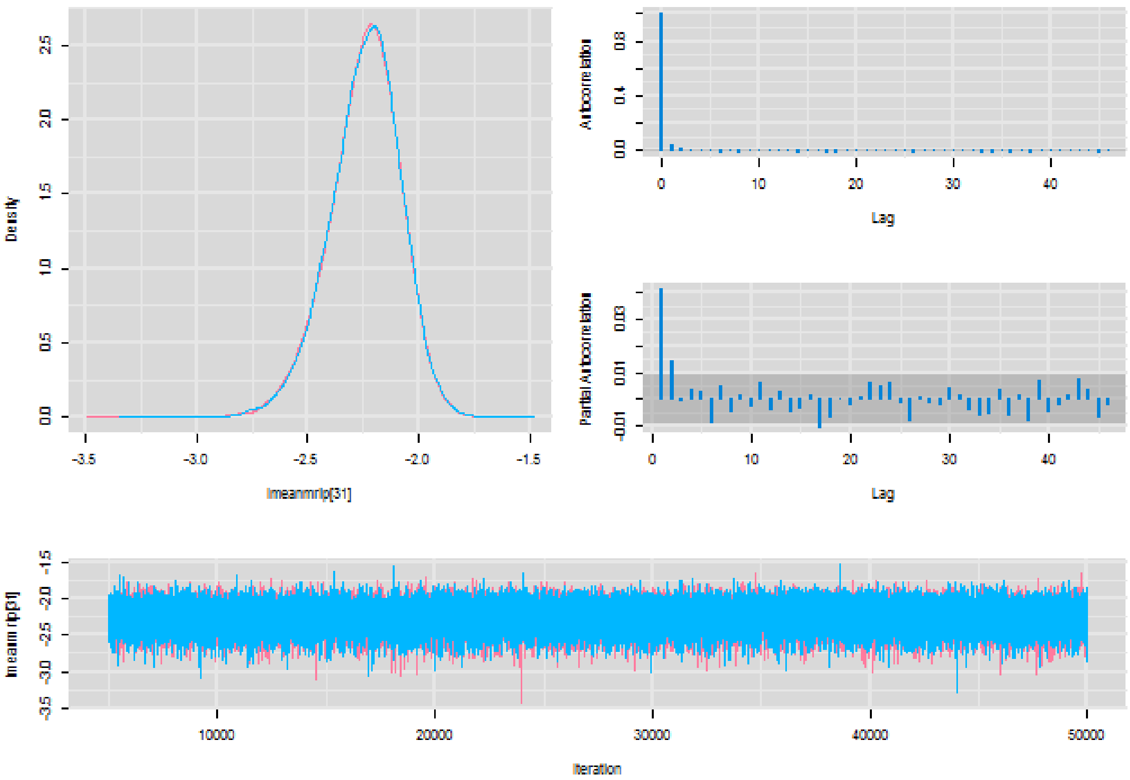
Diagnostics for lmeanmrip[29]



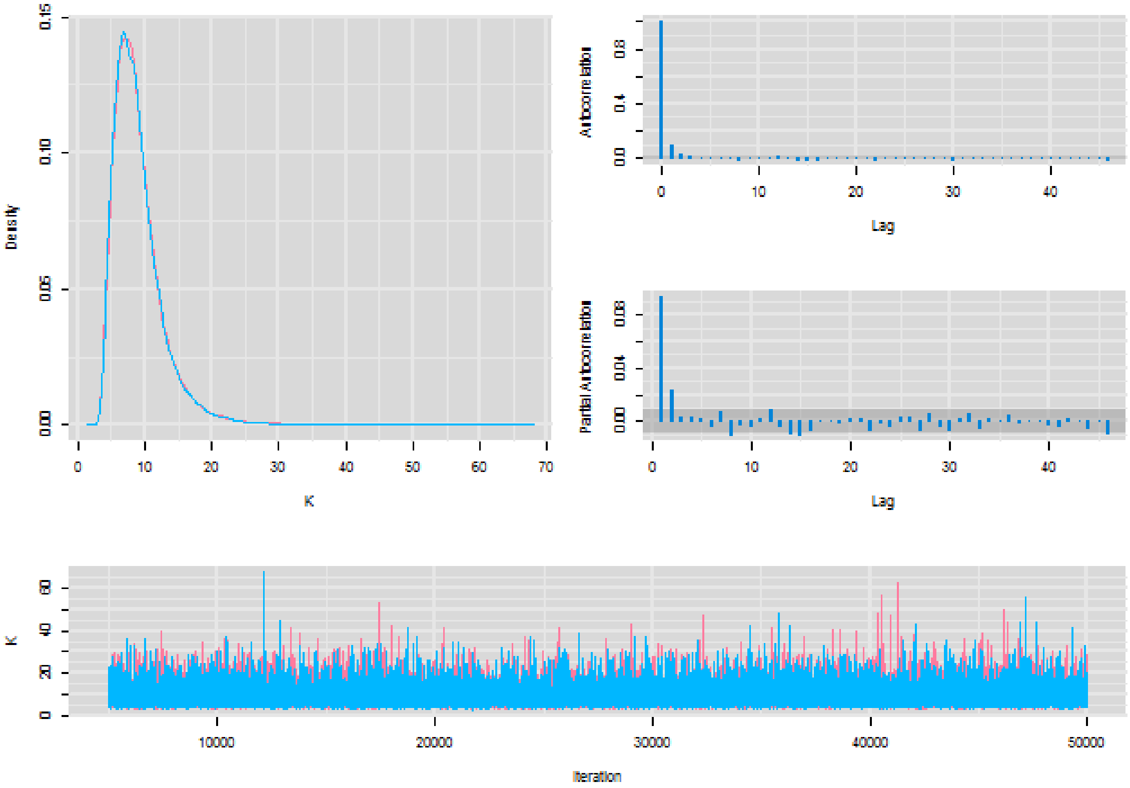
Diagnostics for lmeanmrip[30]



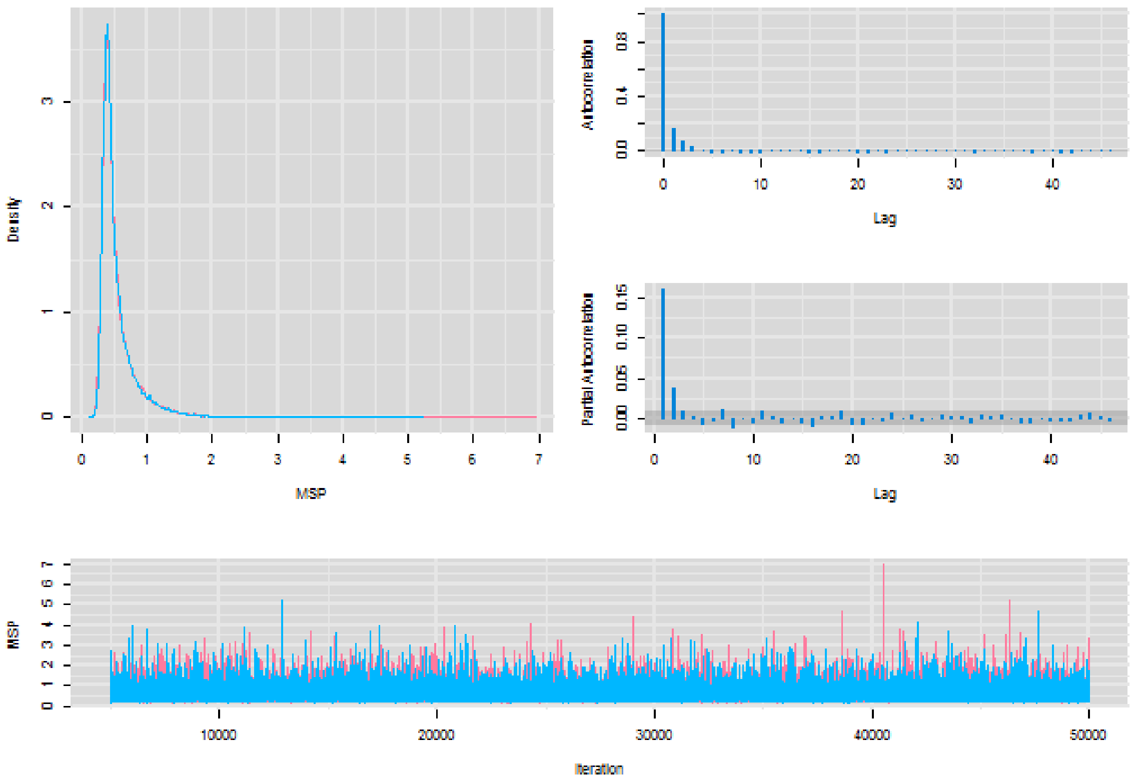
Diagnostics for lmeanmrip[31]



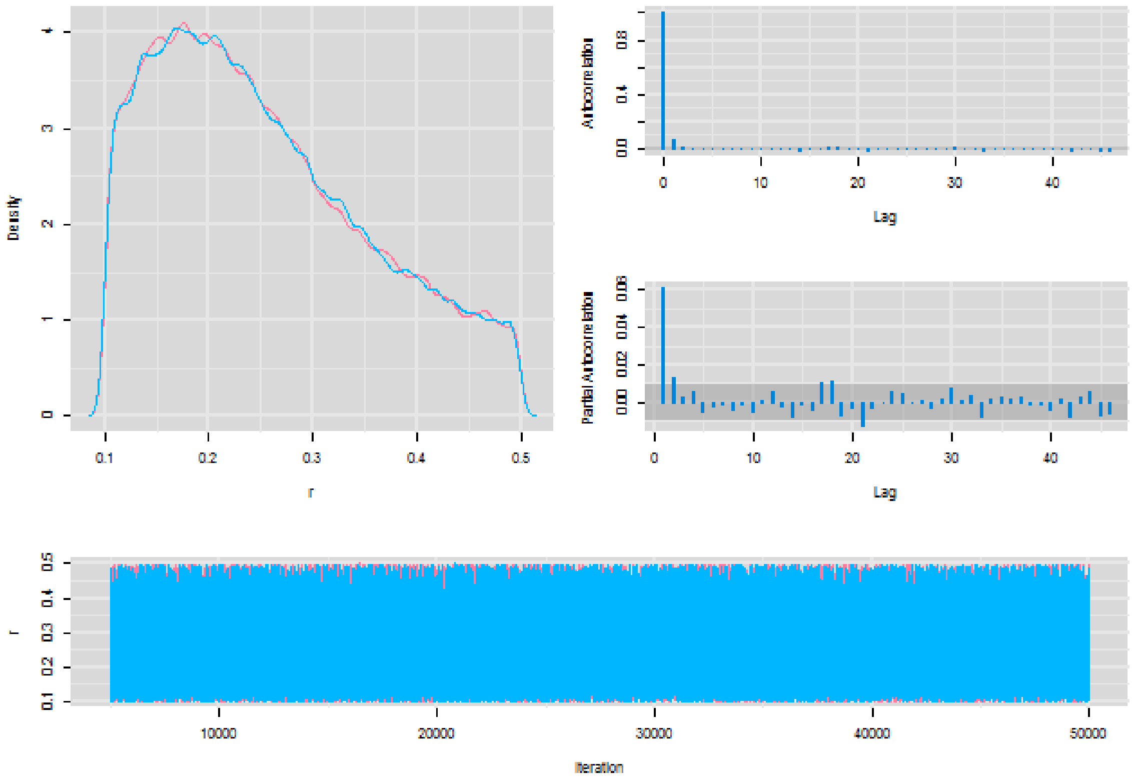
Diagnostics for K



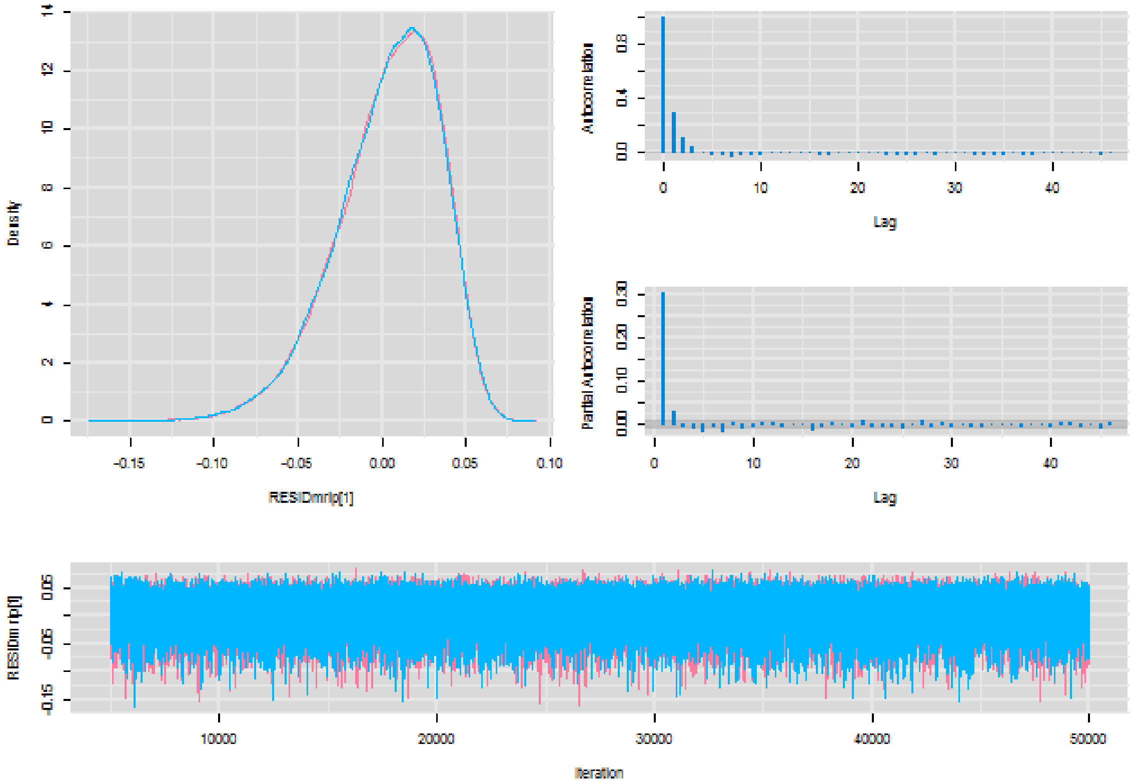
Diagnostics for MSP



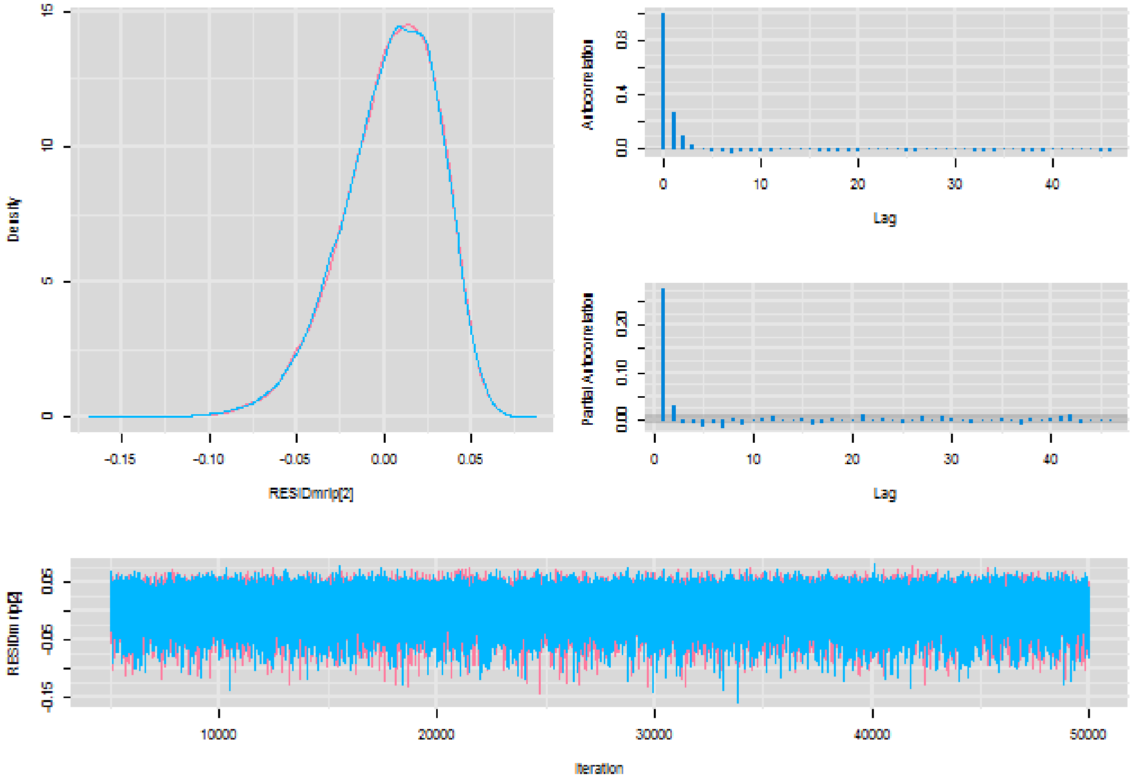
Diagnostics for r



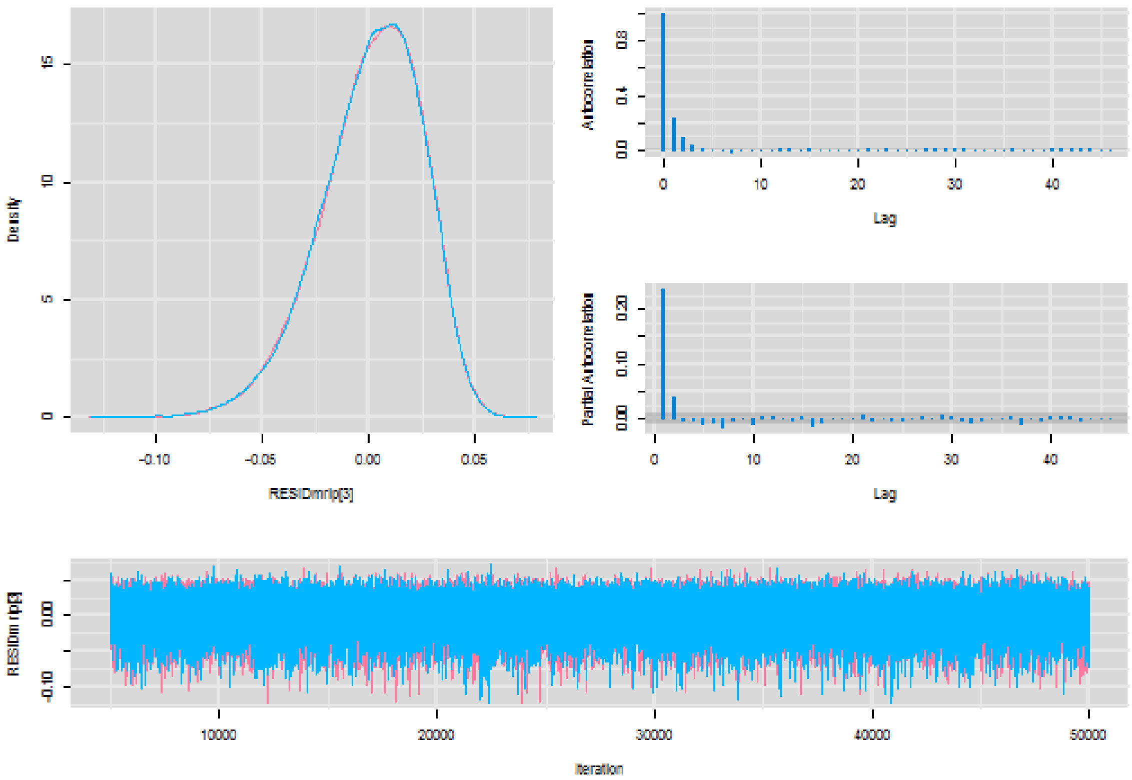
Diagnostics for RESIDmrip[1]



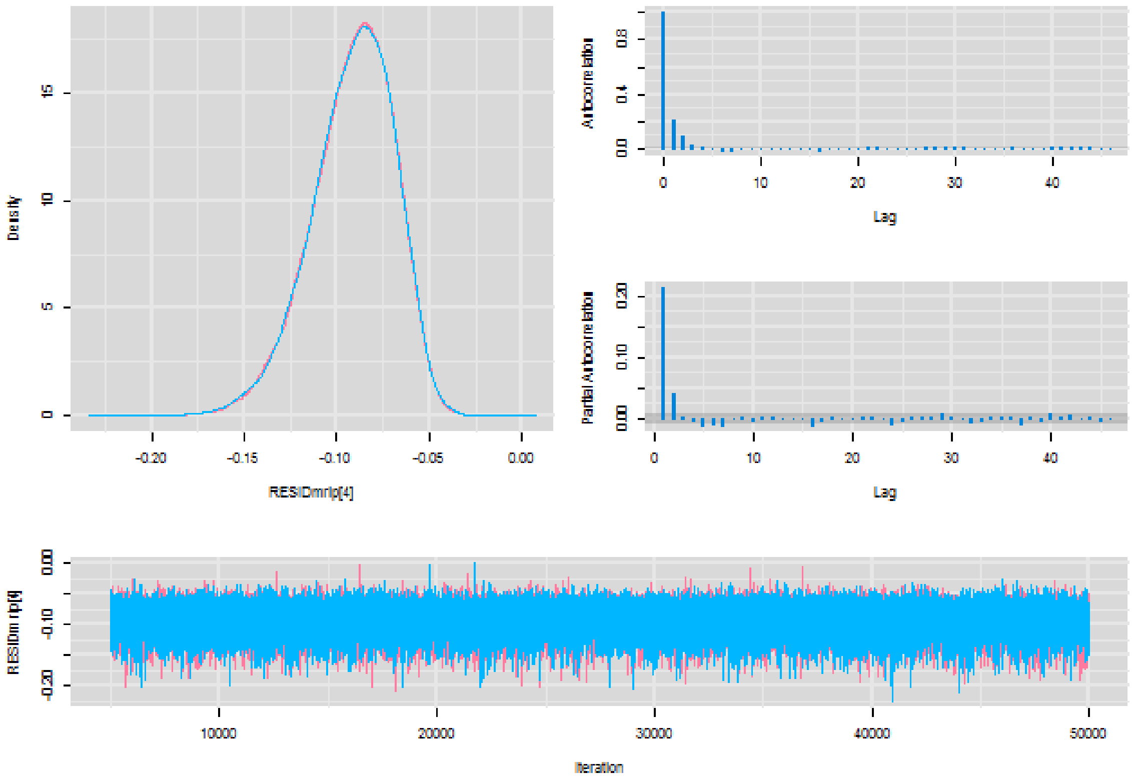
Diagnostics for RESIDmrip[2]



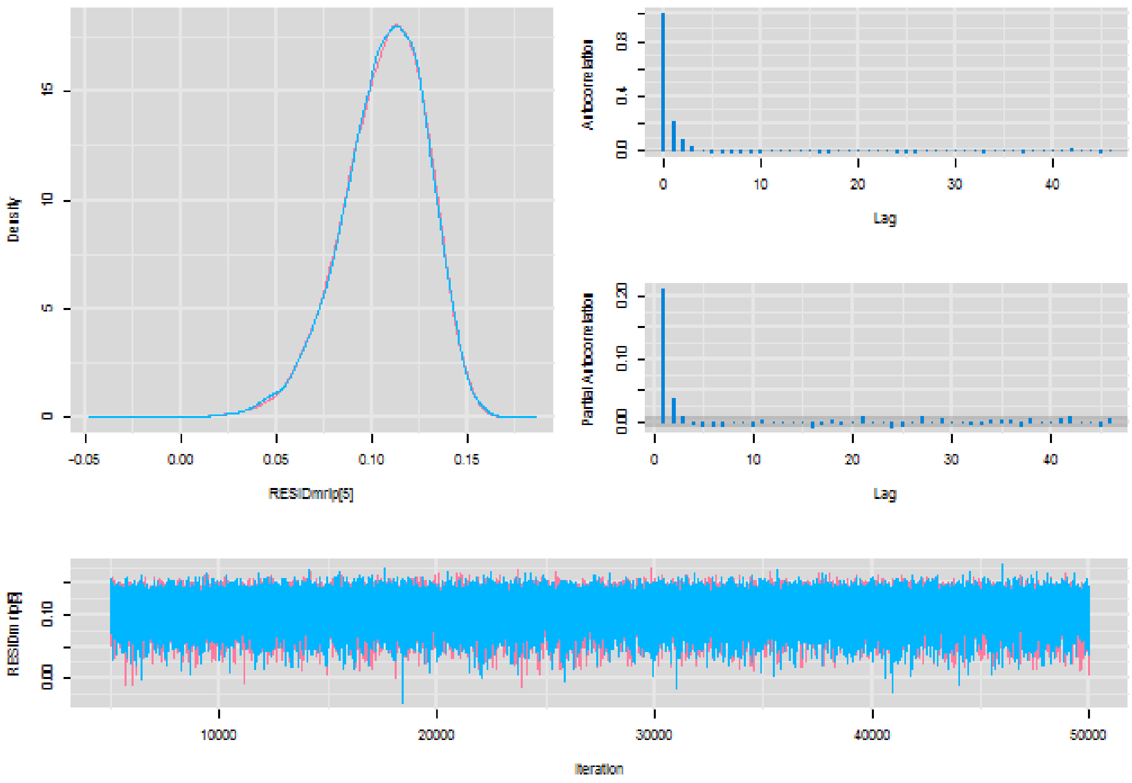
Diagnostics for RESIDmrip[3]



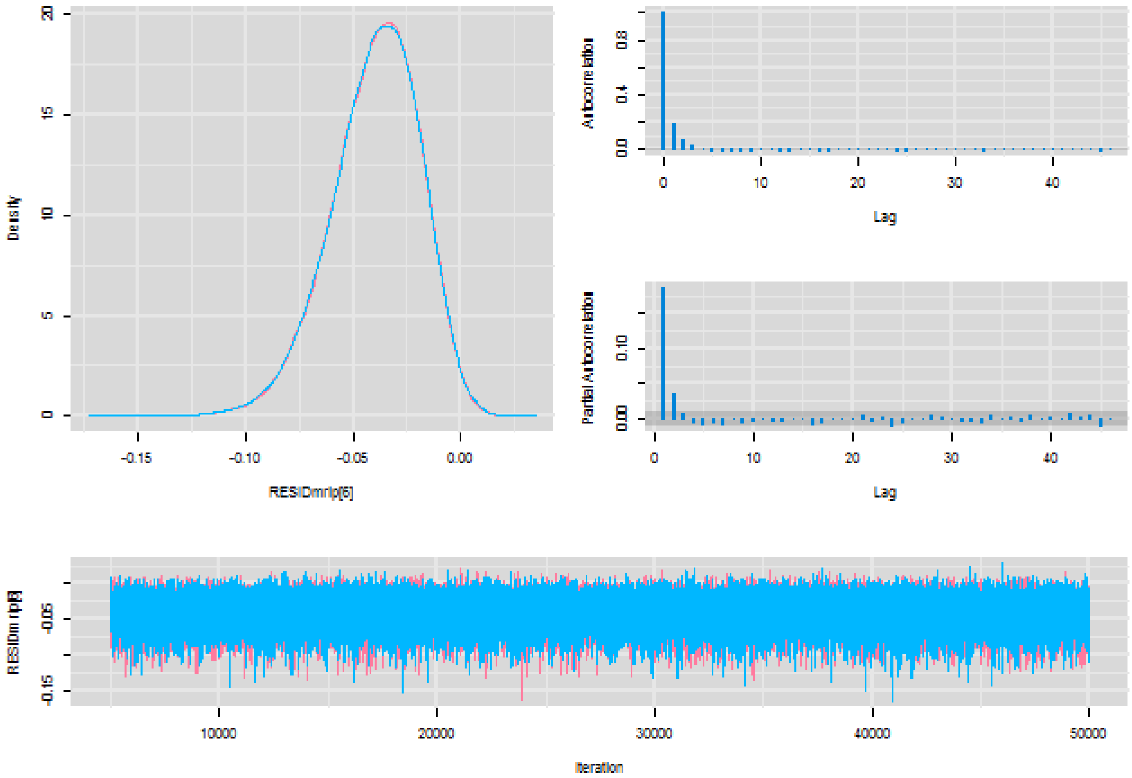
Diagnostics for RESIDmrip[4]



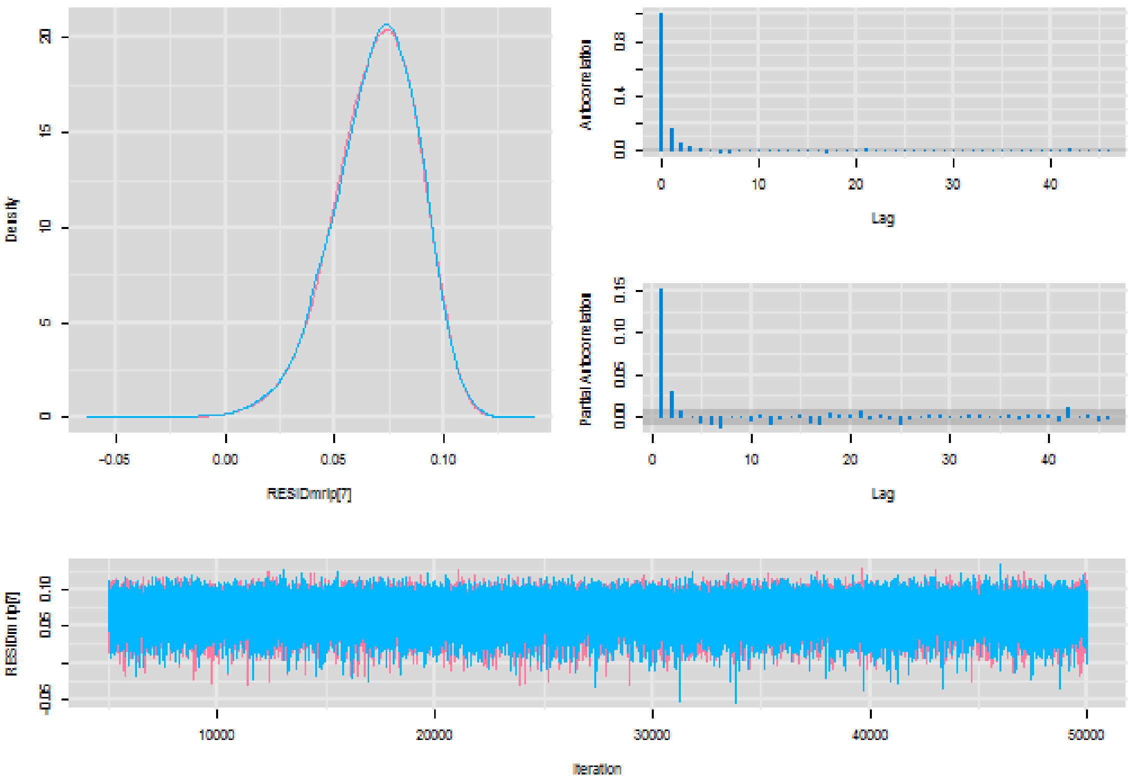
Diagnostics for RESIDmrip[5]



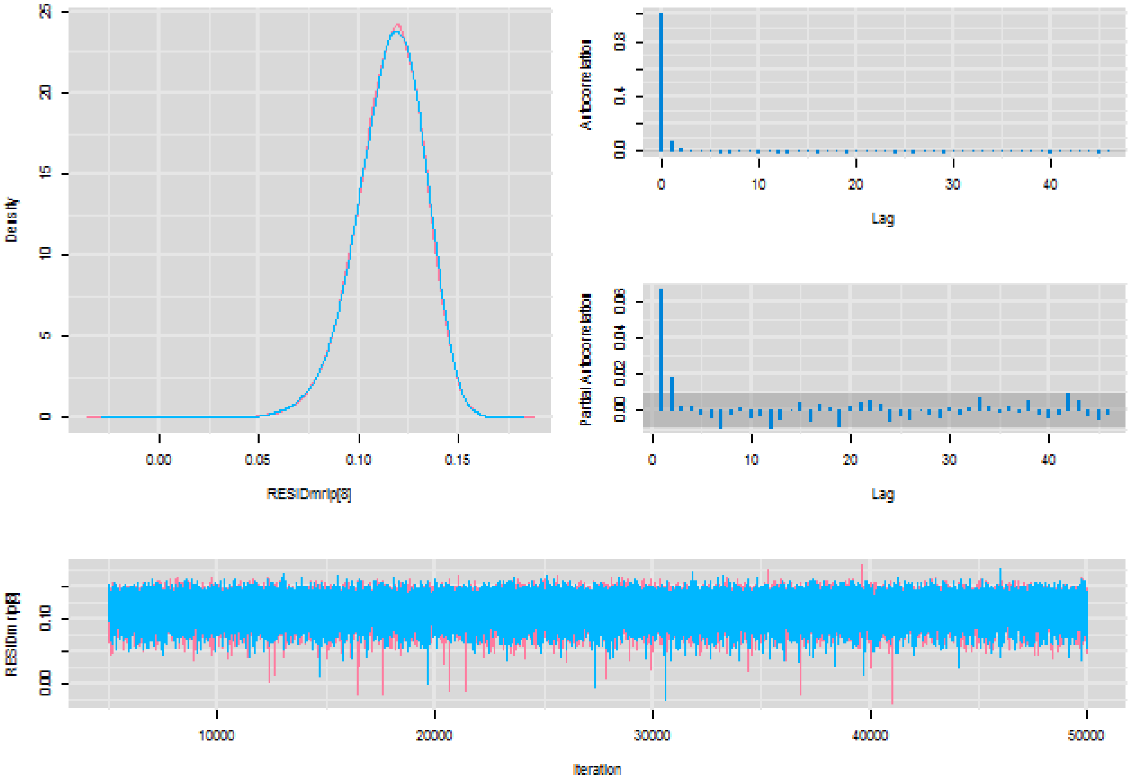
Diagnostics for RESIDmrip[6]



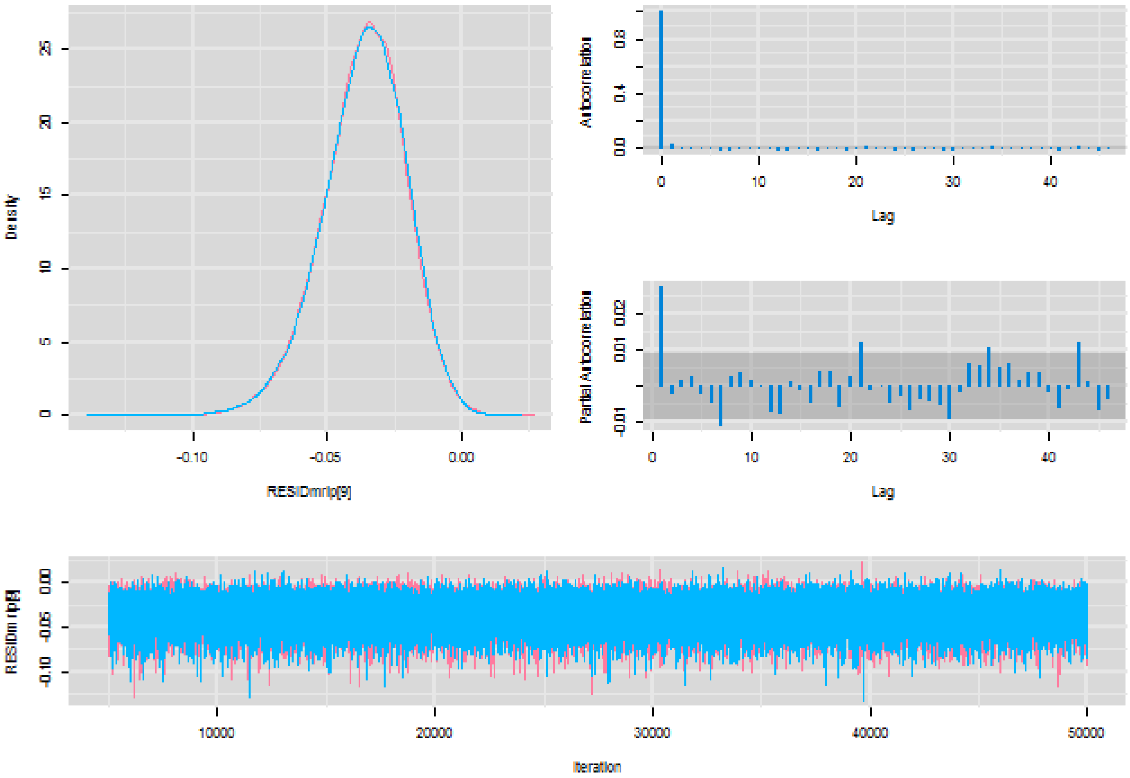
Diagnostics for RESIDmrip[7]



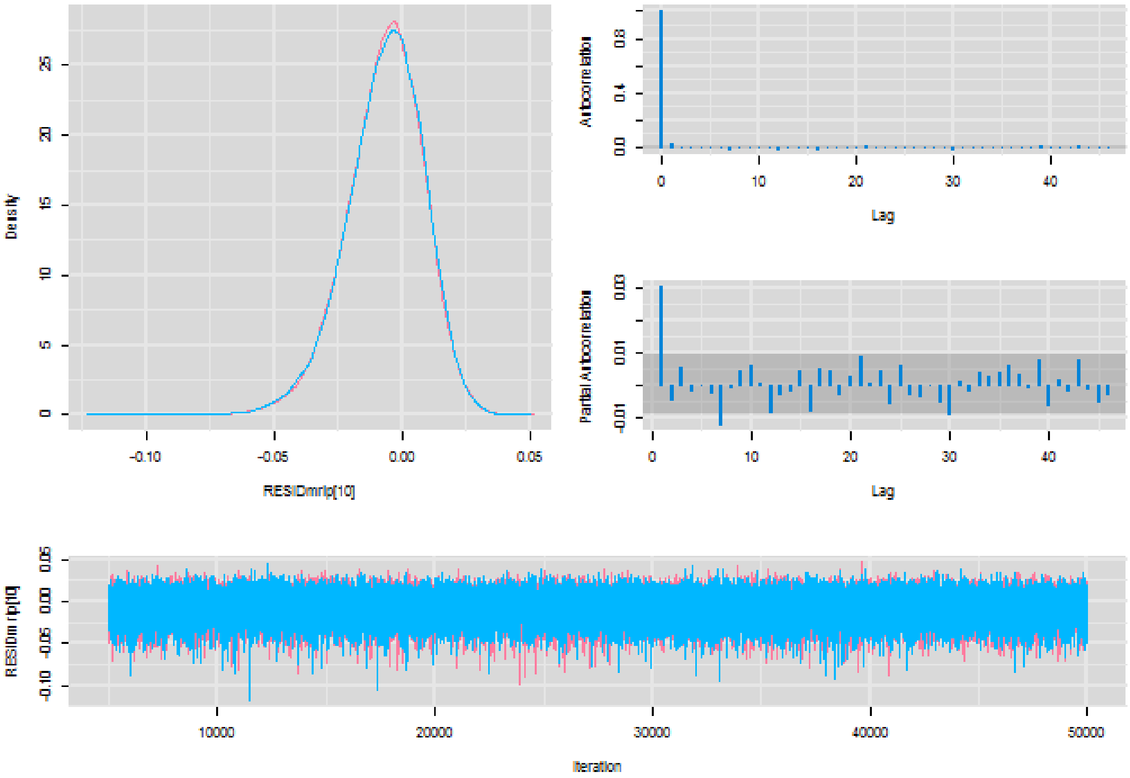
Diagnostics for RESIDmrip[8]



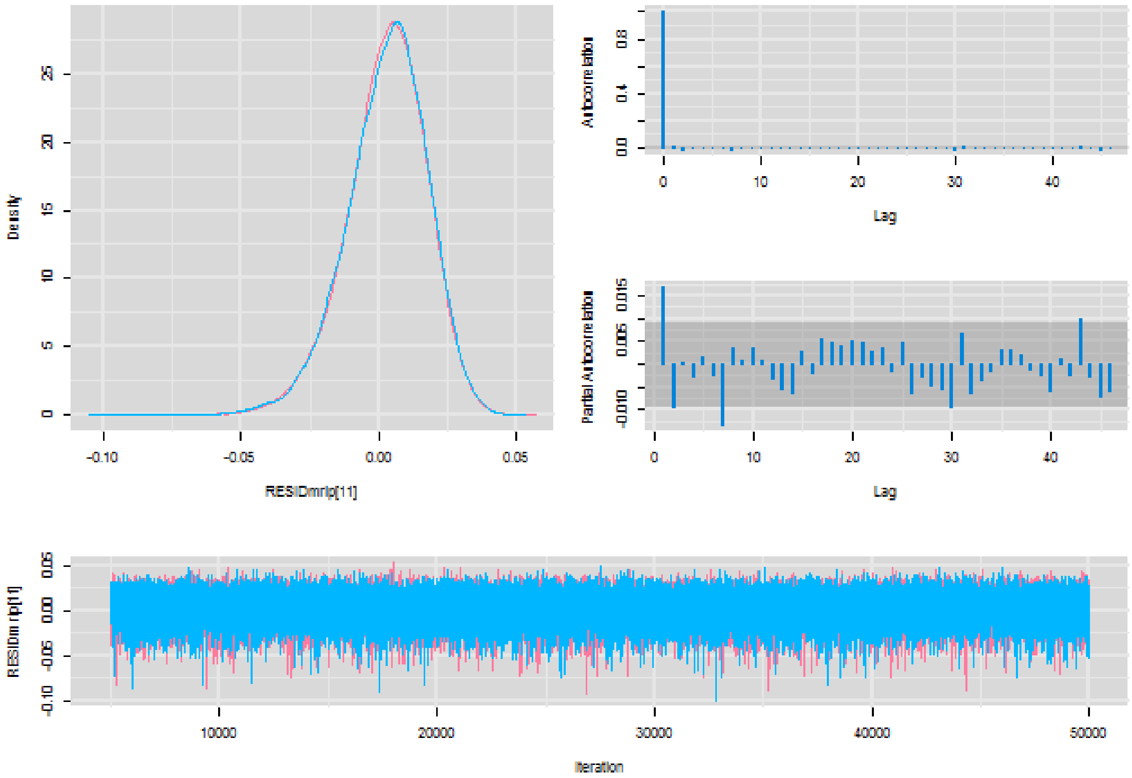
Diagnostics for RESIDmrip[9]



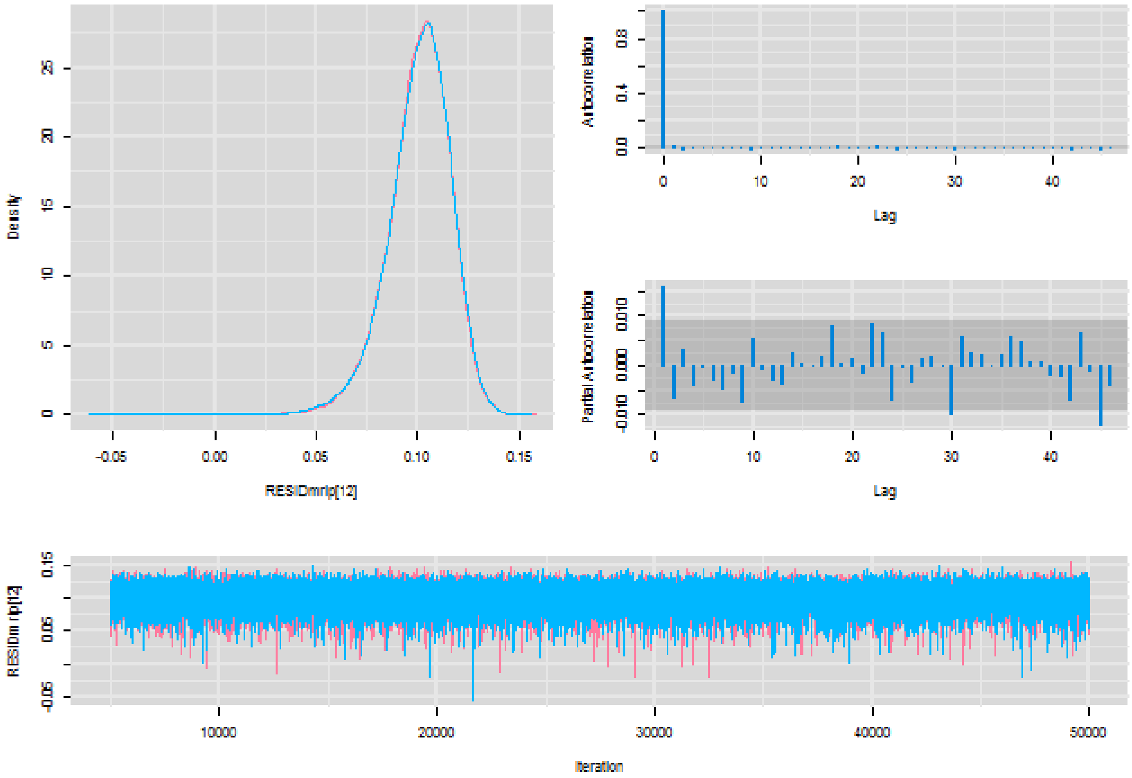
Diagnostics for RESIDmrip[10]



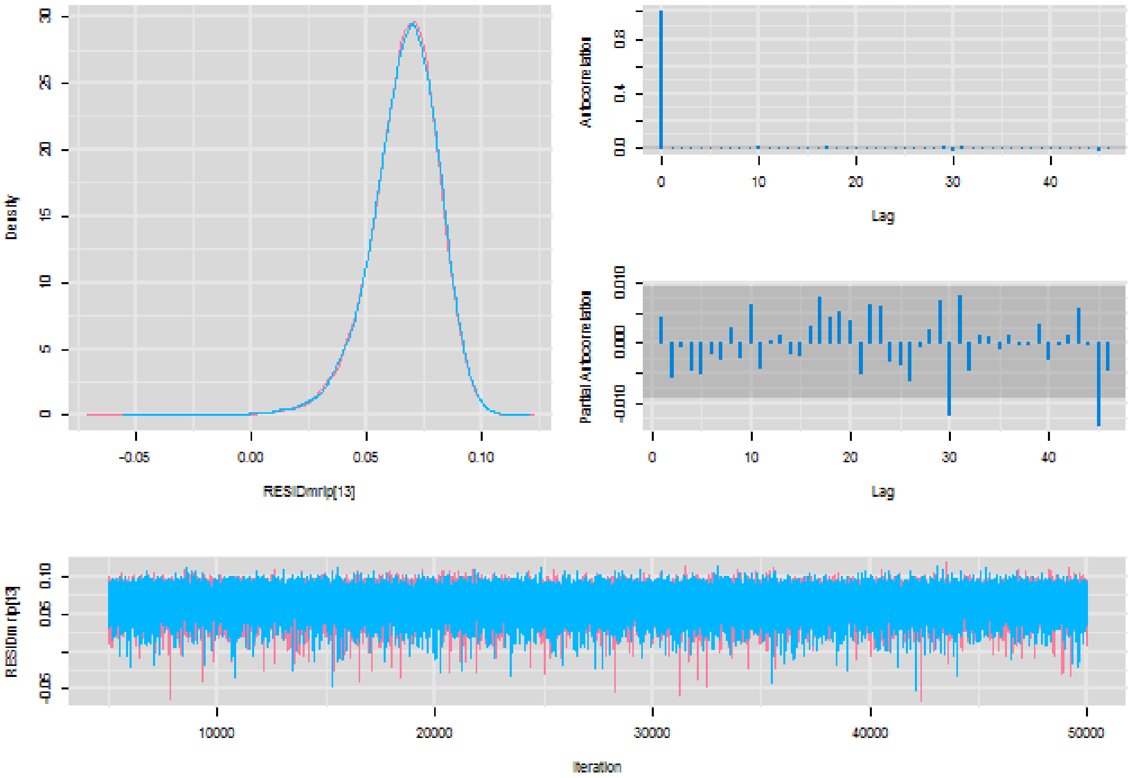
Diagnostics for RESIDmrip[11]



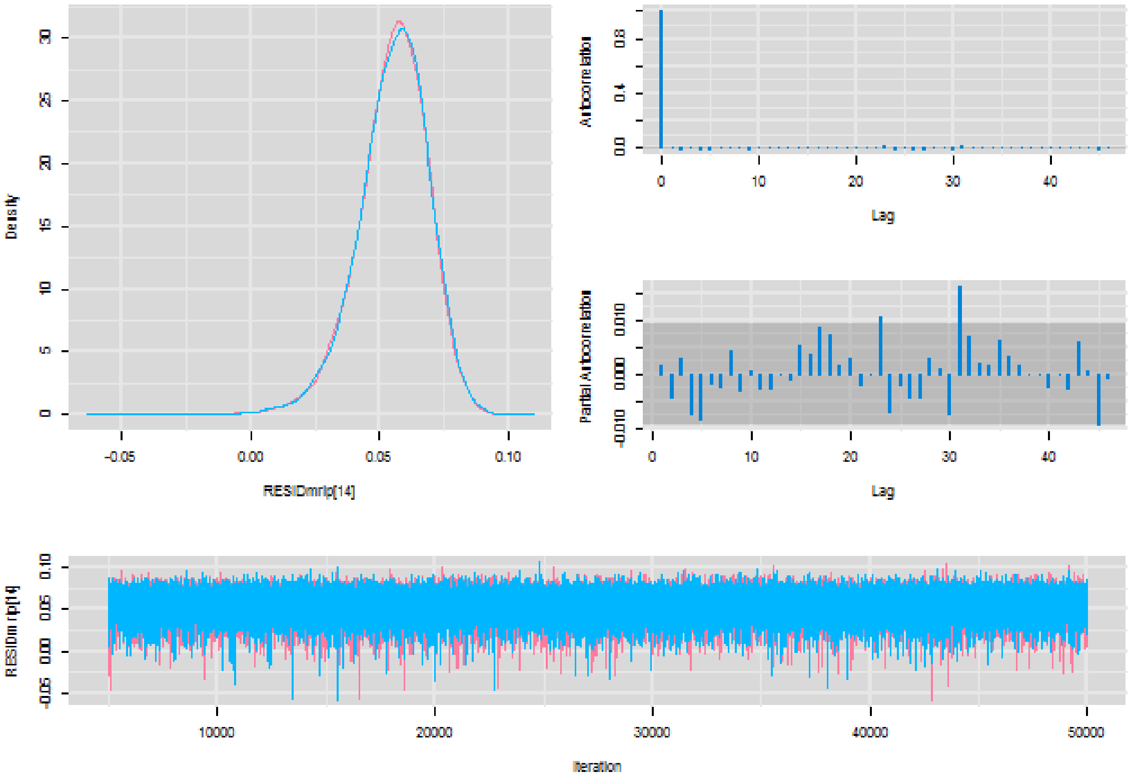
Diagnostics for RESIDmrip[12]



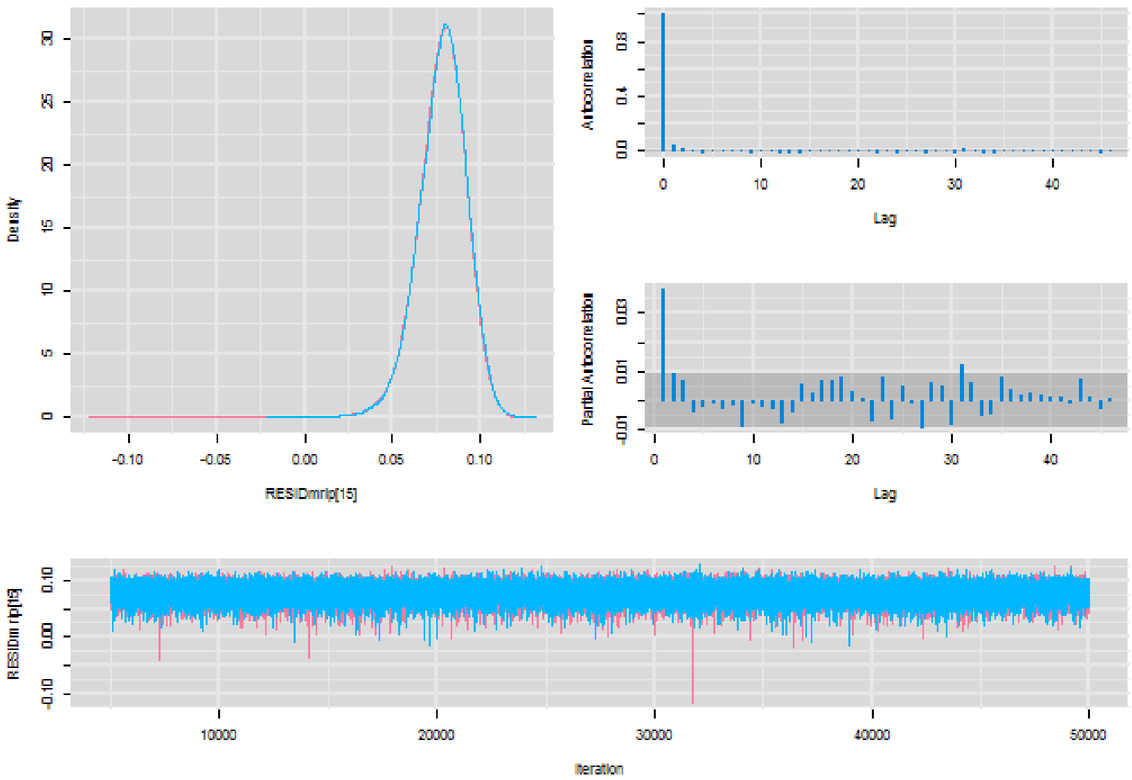
Diagnostics for RESIDmrip[13]



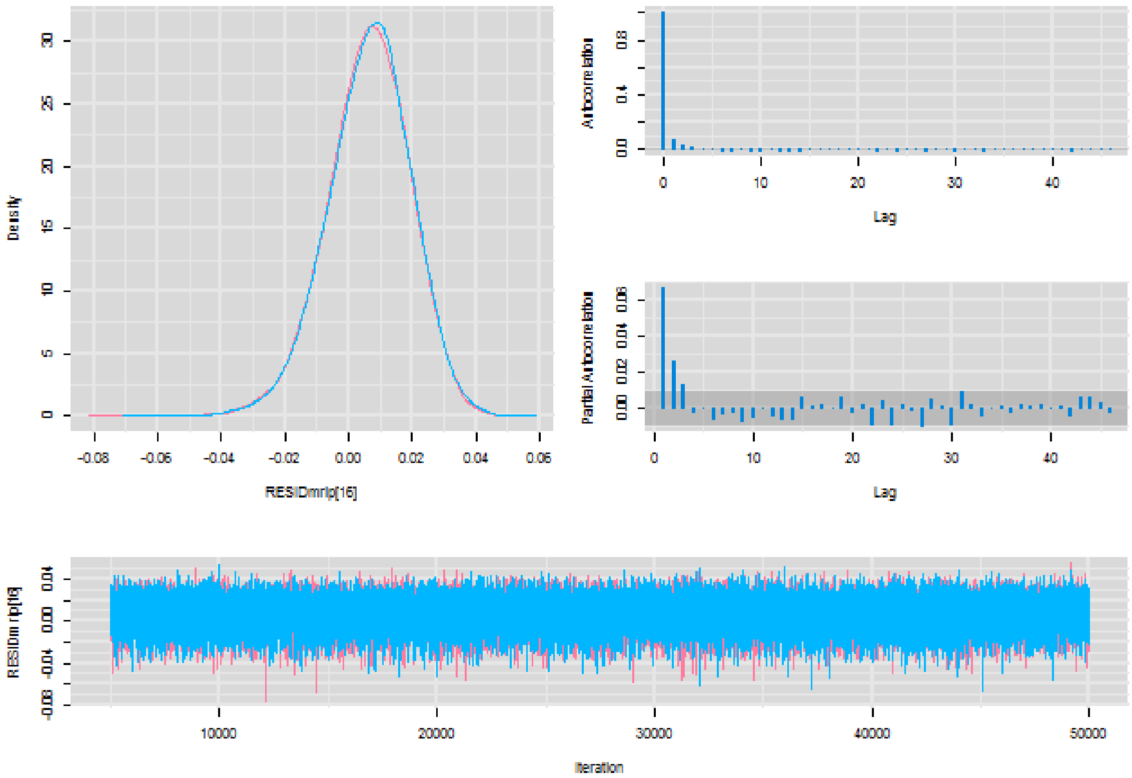
Diagnostics for RESIDmrip[14]



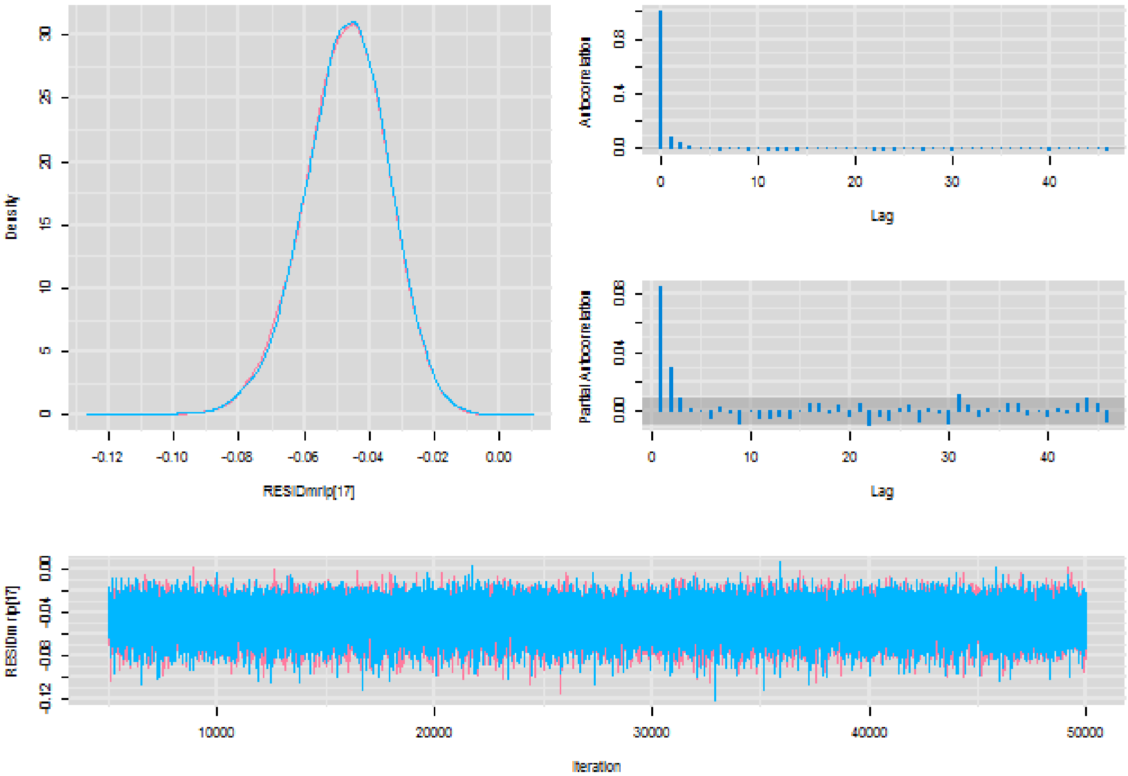
Diagnostics for RESIDmrip[15]



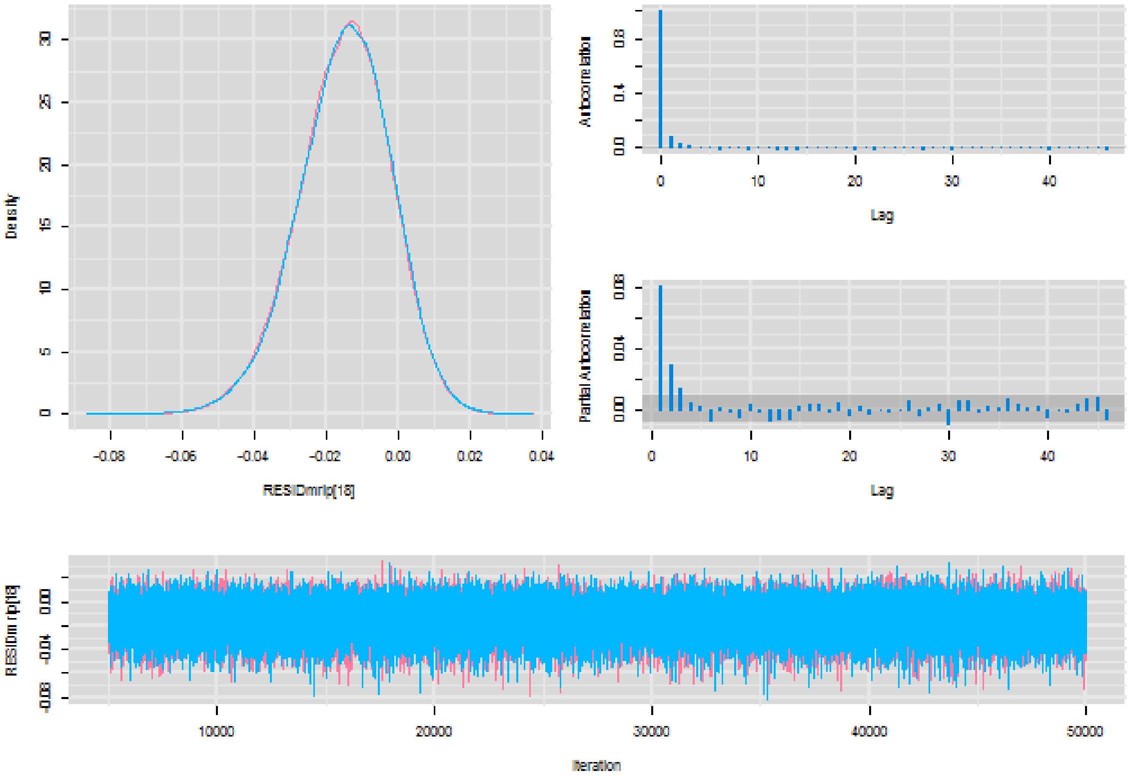
Diagnostics for RESIDmrip[16]



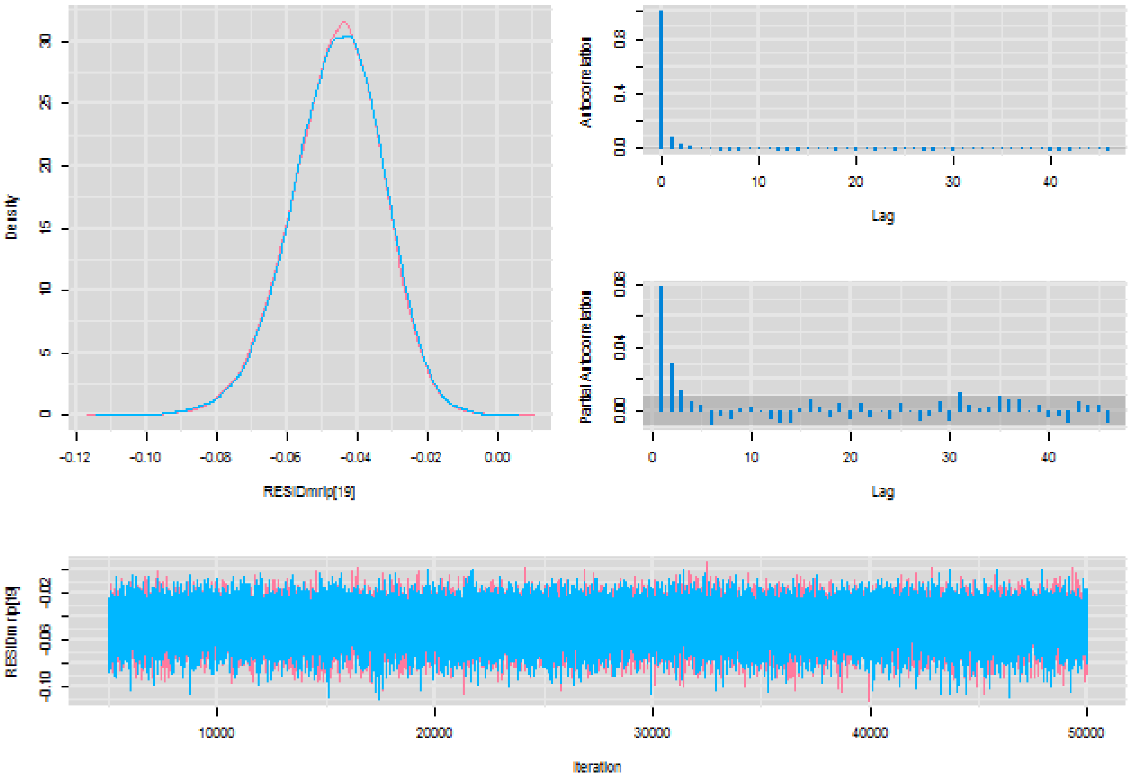
Diagnostics for RESIDmrip[17]



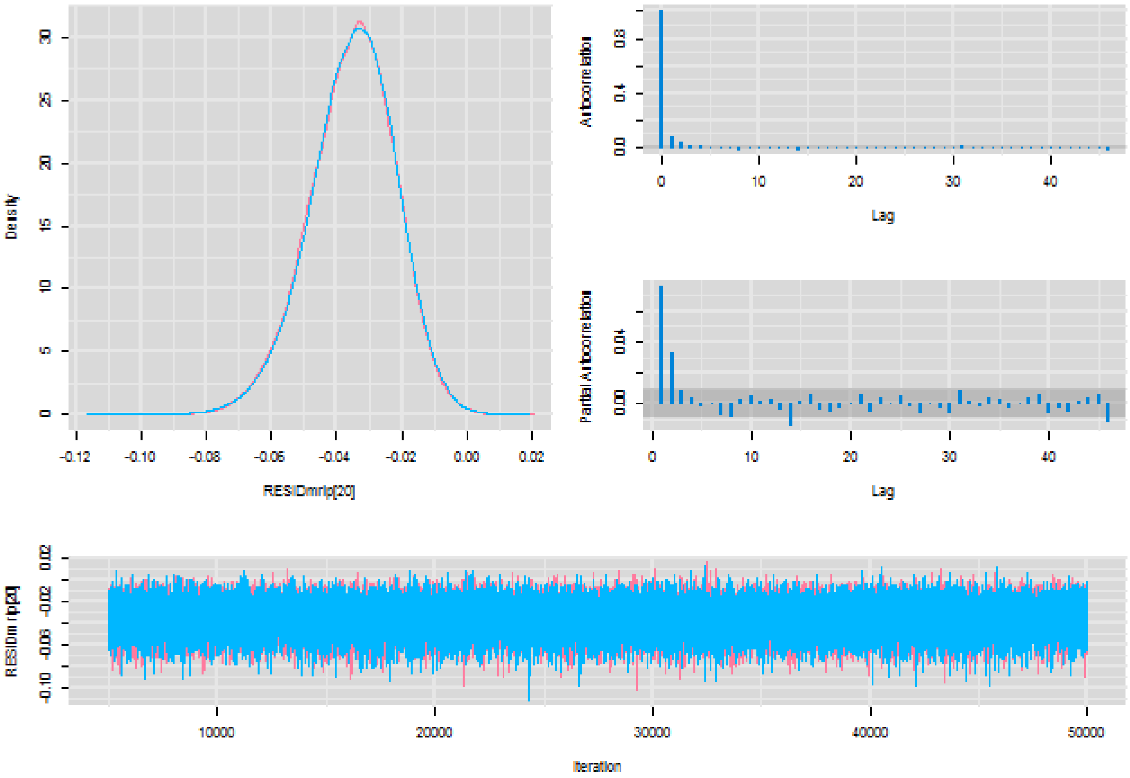
Diagnostics for RESIDmrip[18]



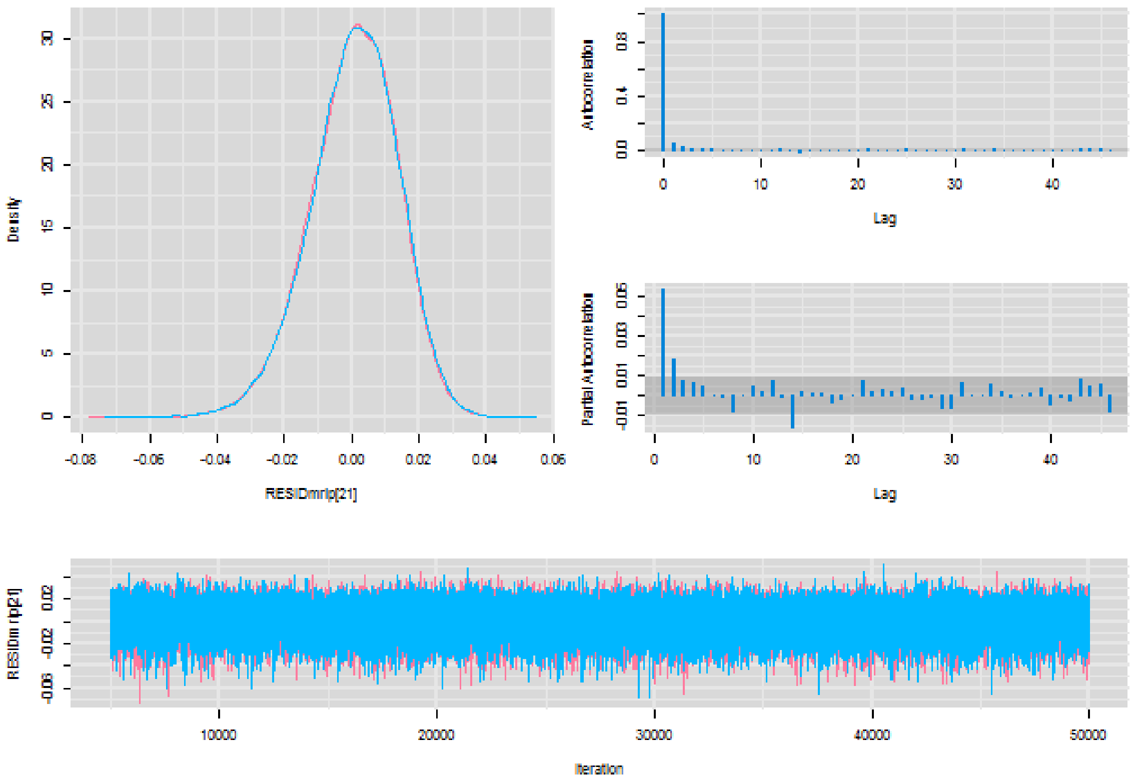
Diagnostics for RESIDmrip[19]



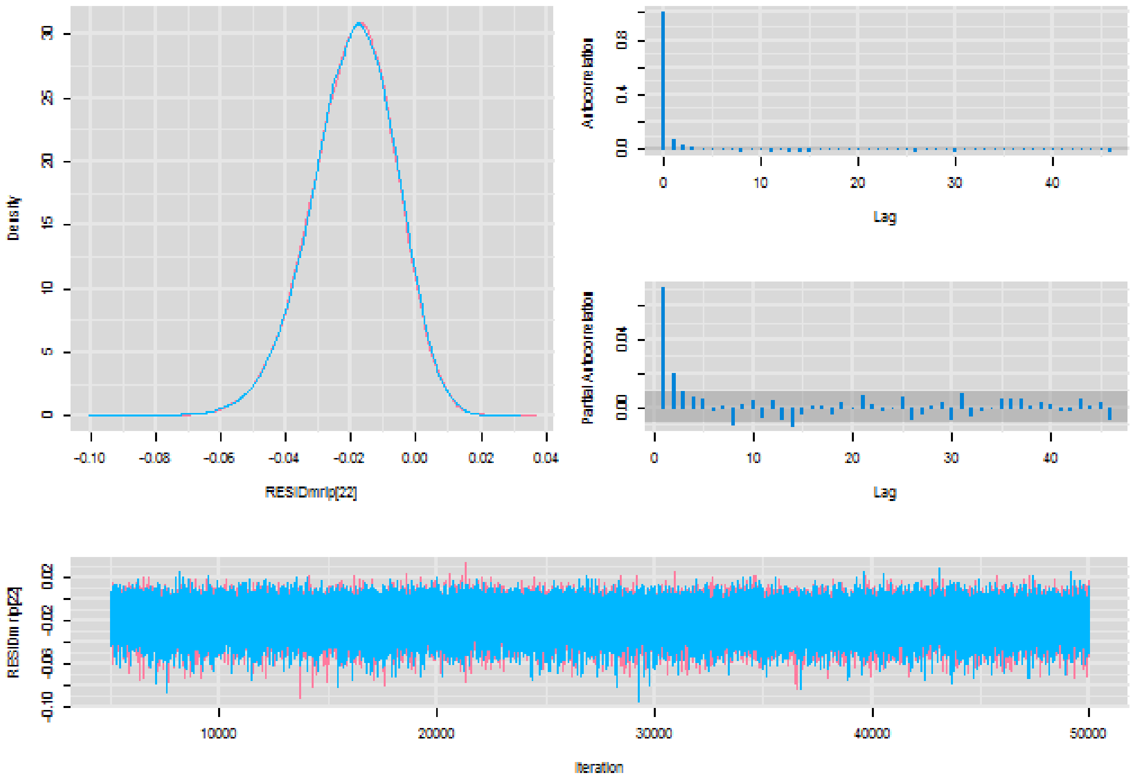
Diagnostics for RESIDmrip[20]



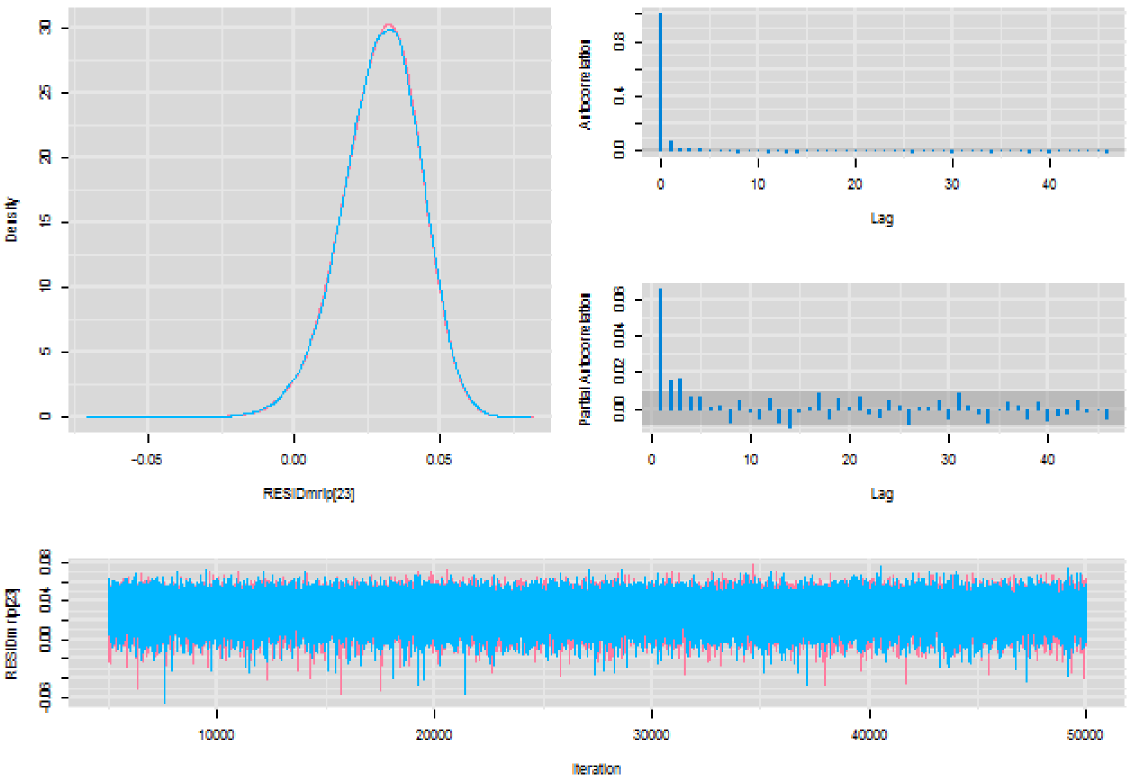
Diagnostics for RESIDmrip[21]



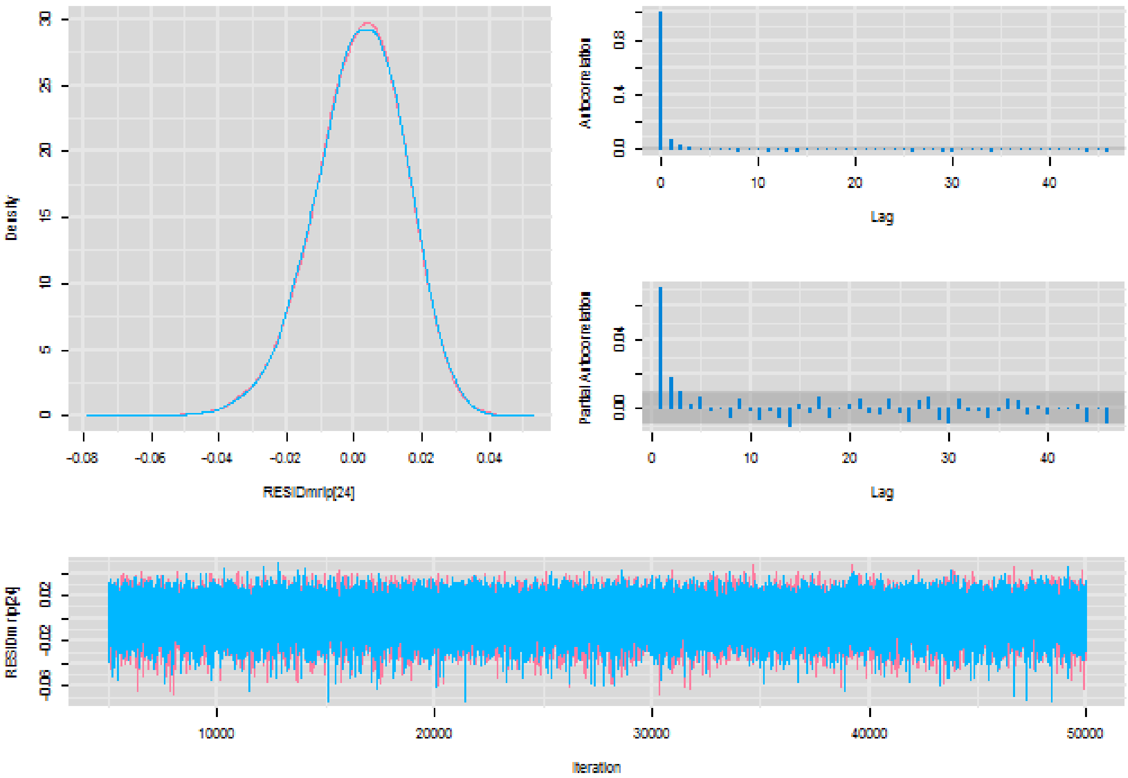
Diagnostics for RESIDmrip[22]



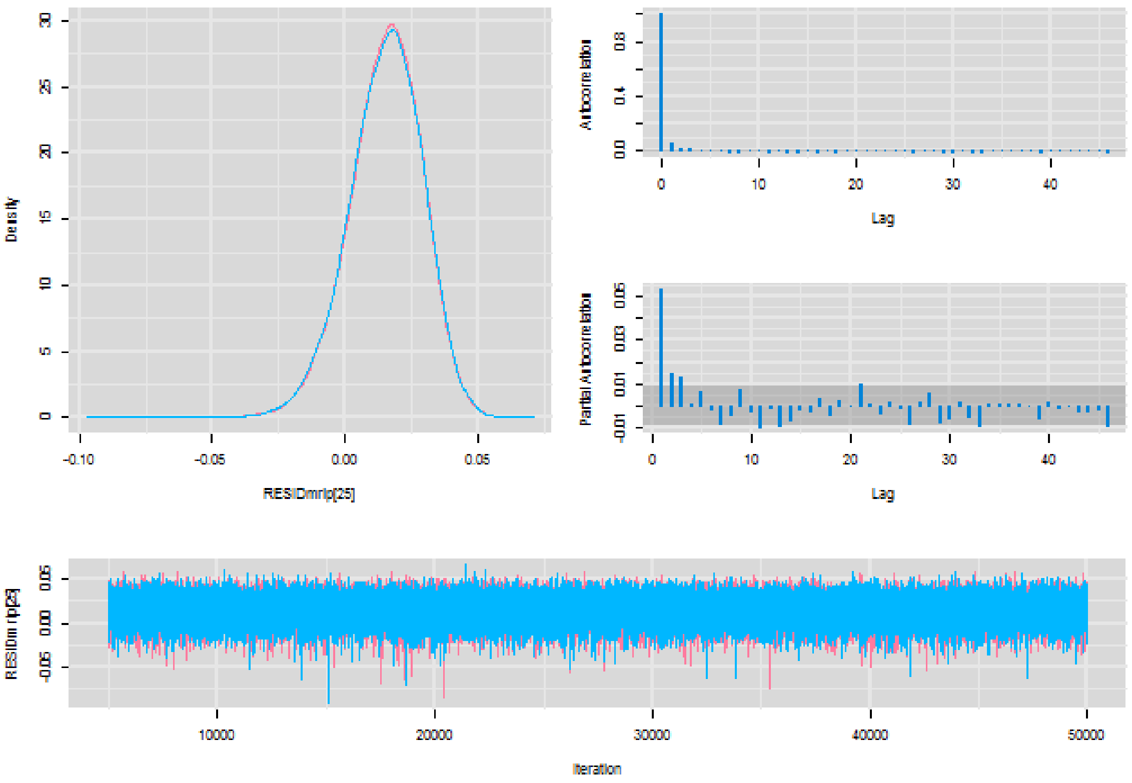
Diagnostics for RESIDmrip[23]



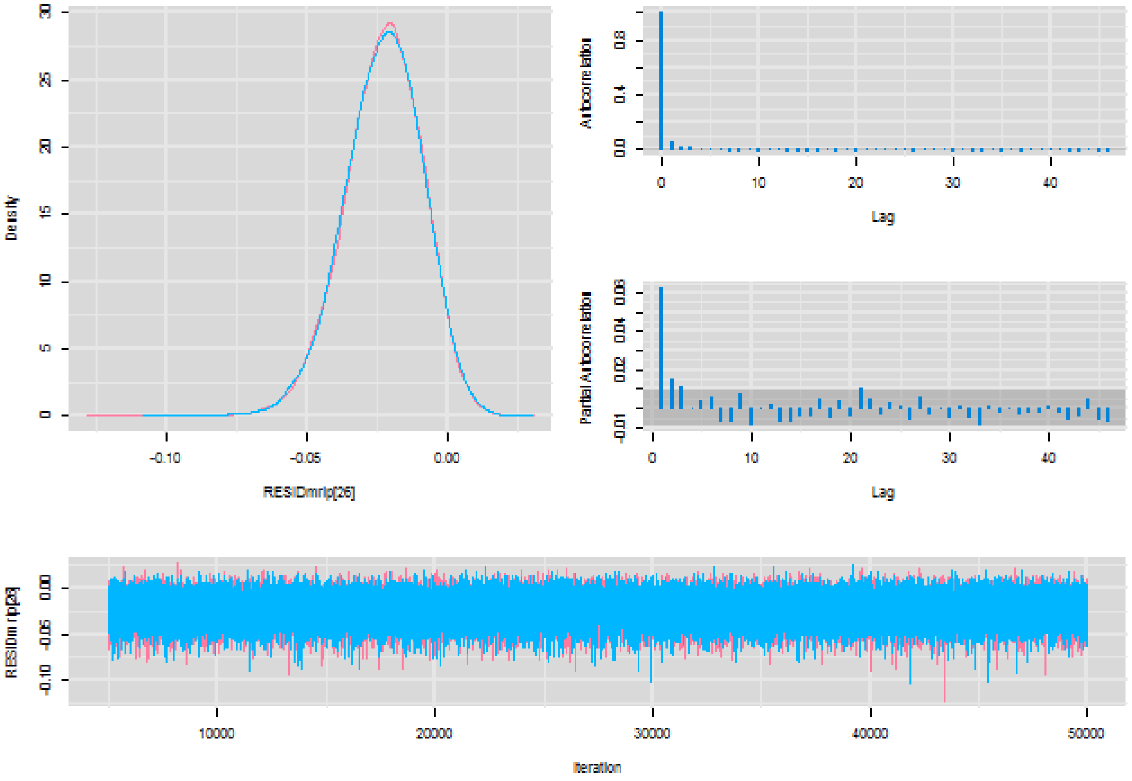
Diagnostics for RESIDmrip[24]



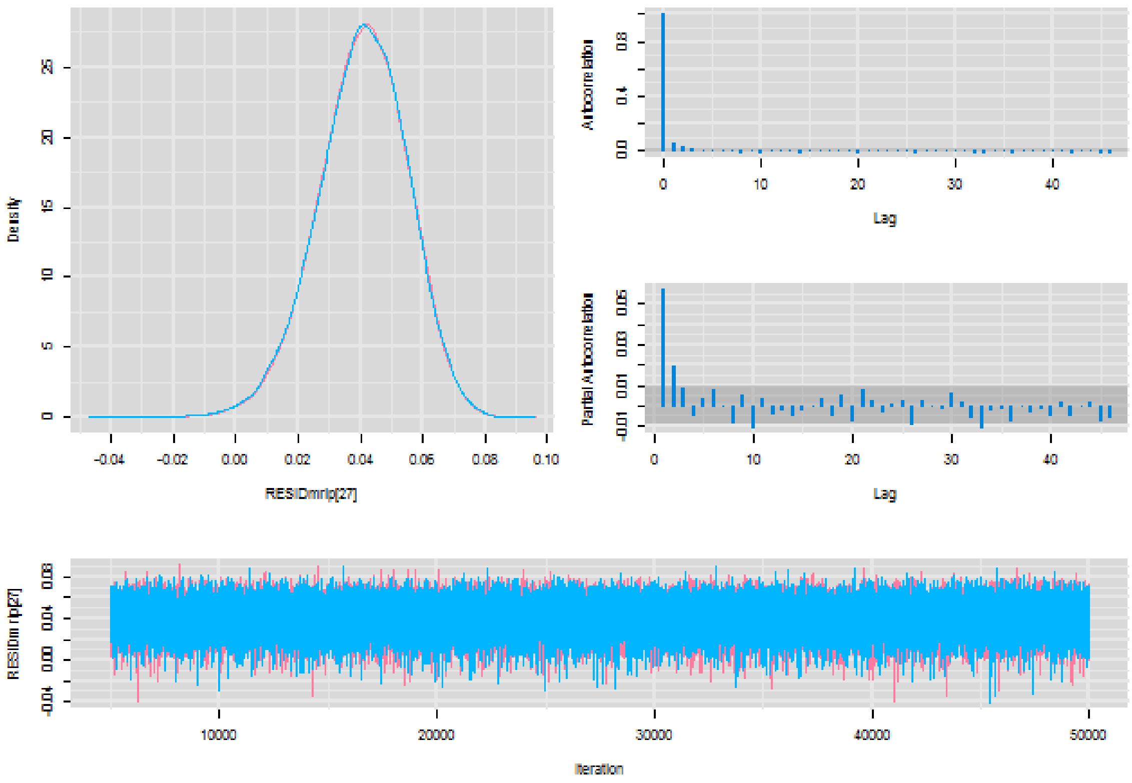
Diagnostics for RESIDmrip[25]



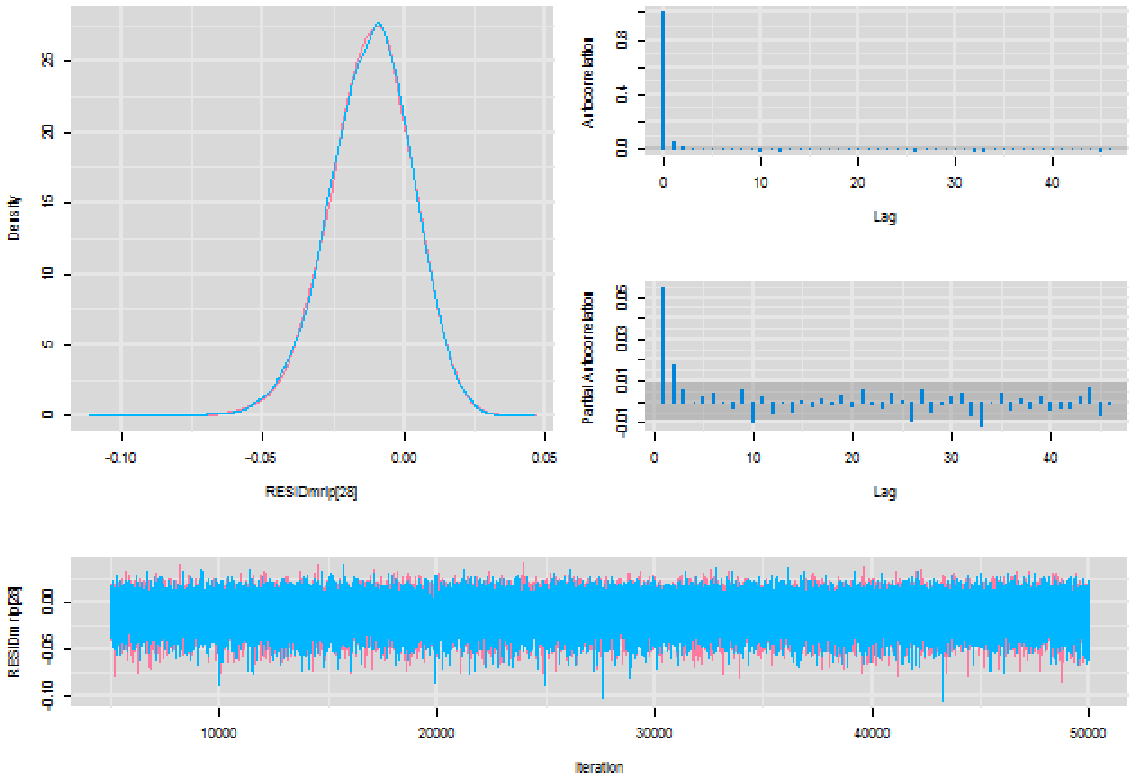
Diagnostics for RESIDmrip[26]



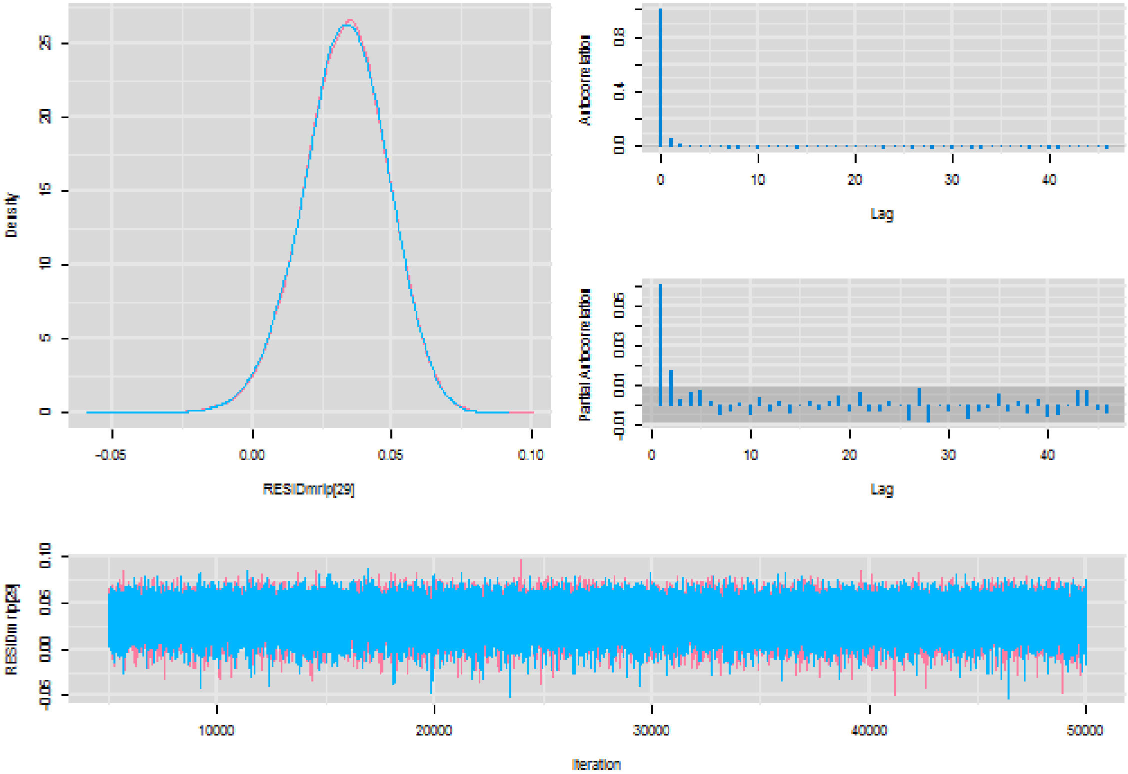
Diagnostics for RESIDmrip[27]



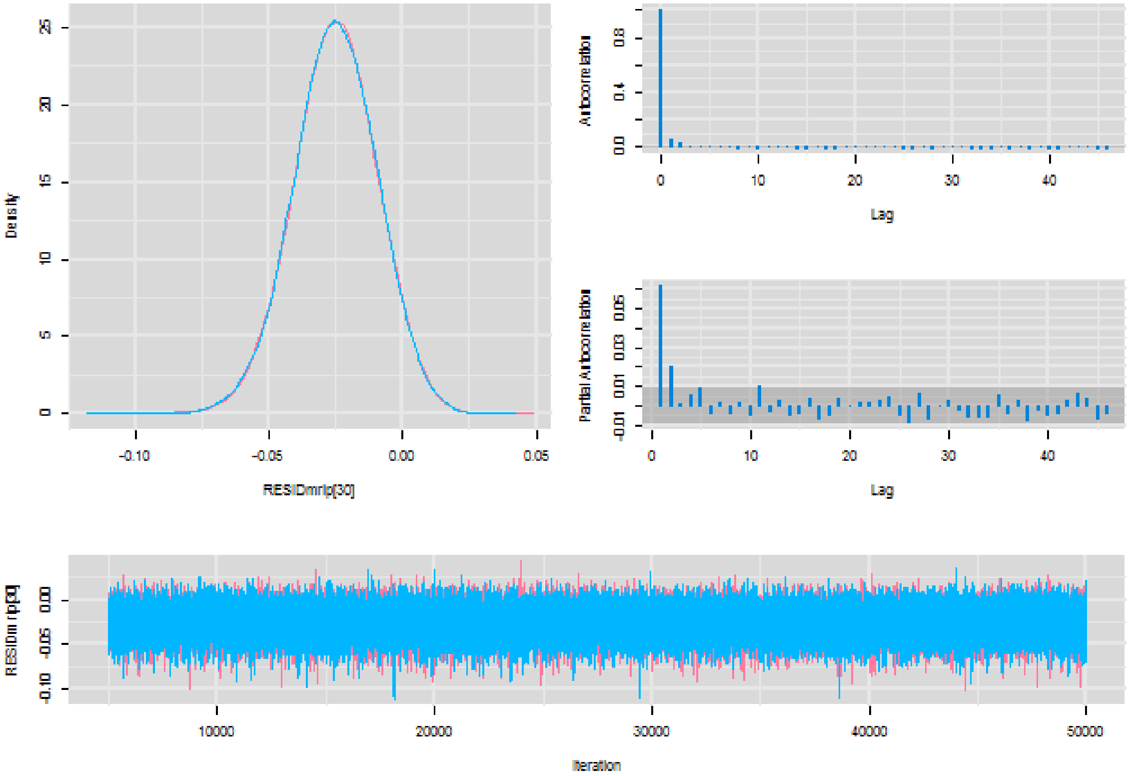
Diagnostics for RESIDmrip[28]



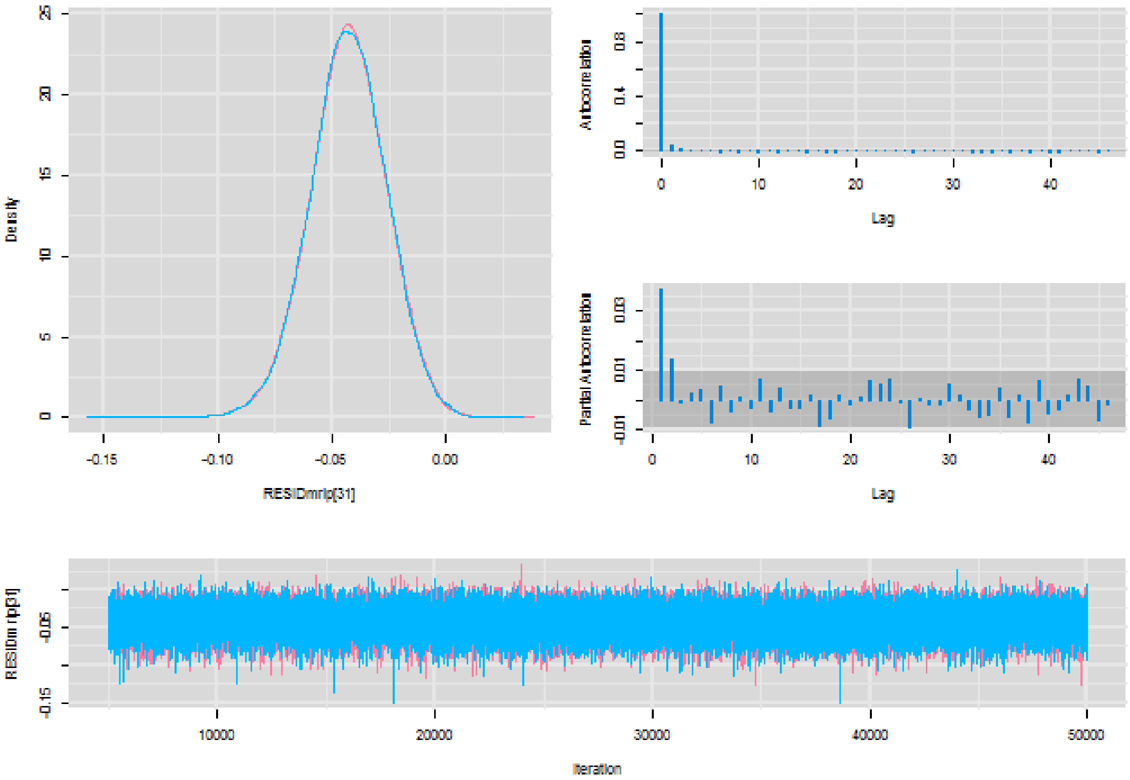
Diagnostics for RESIDmrip[29]



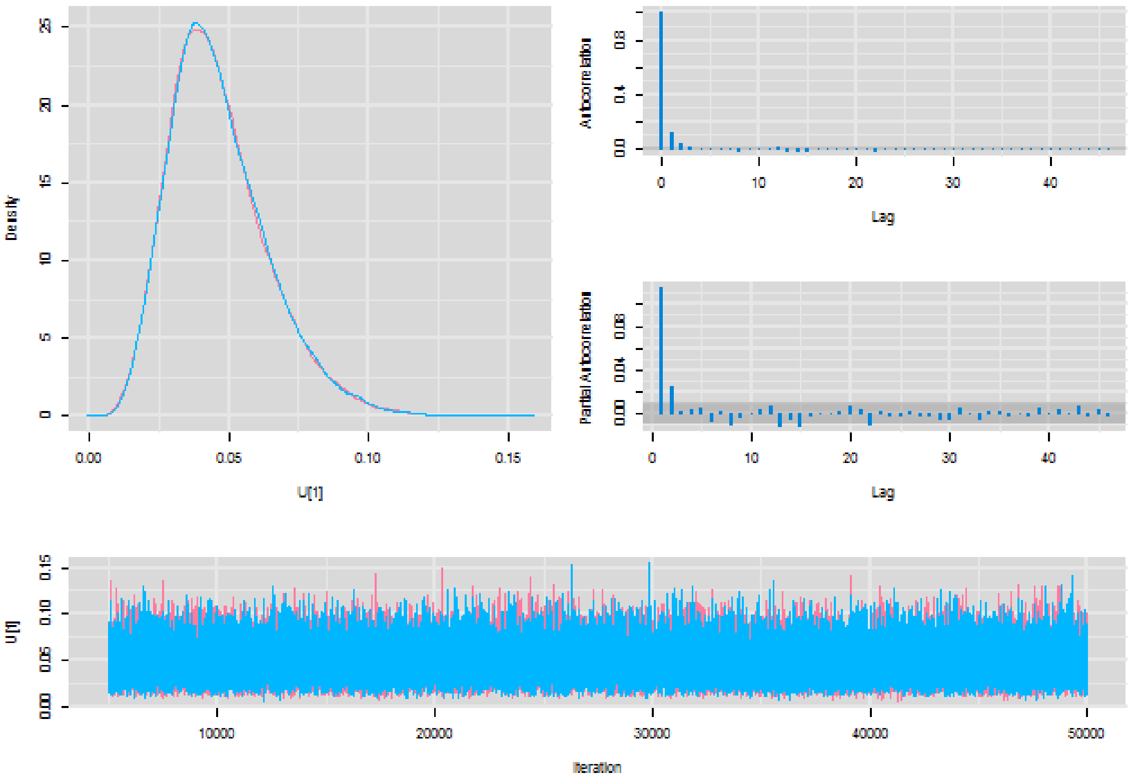
Diagnostics for RESIDmrip[30]



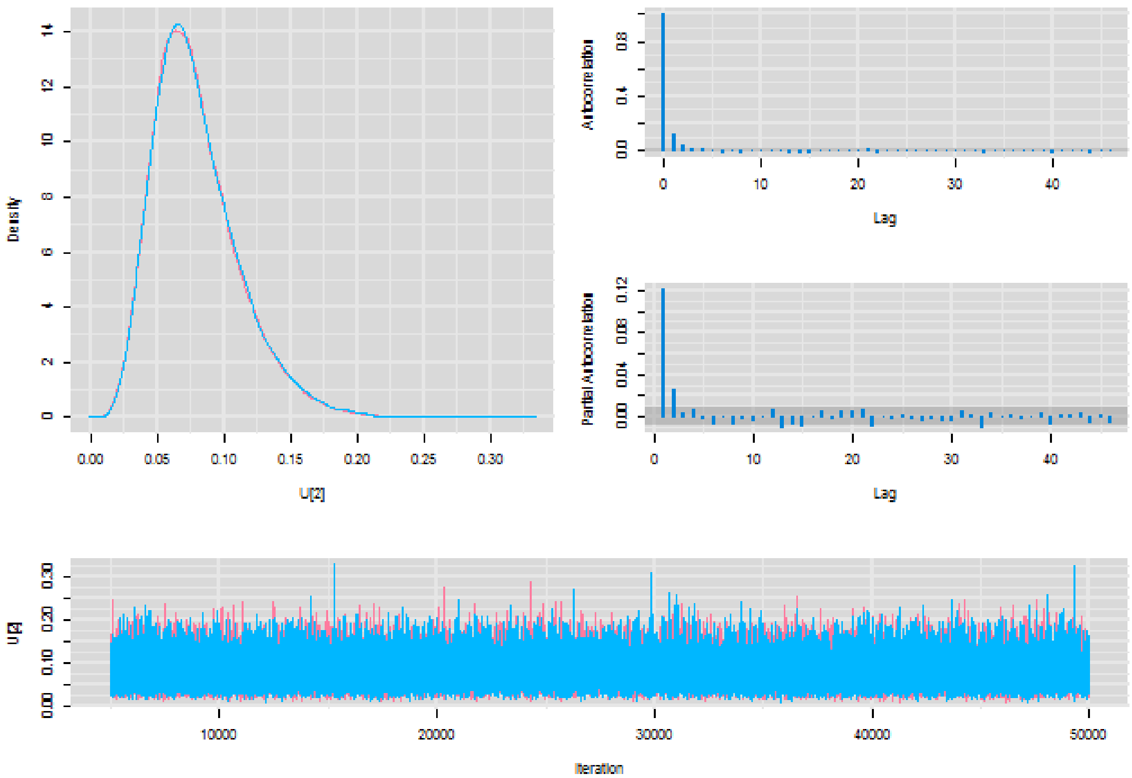
Diagnostics for RESIDmrip[31]



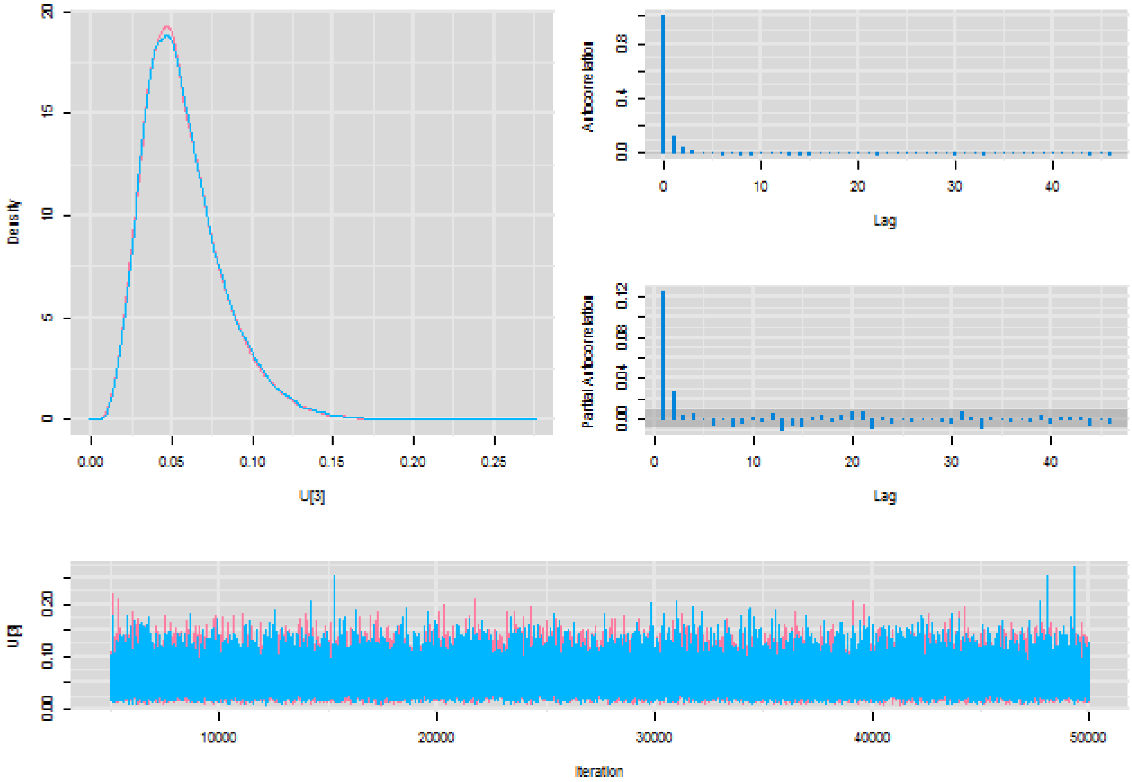
Diagnostics for U[1]



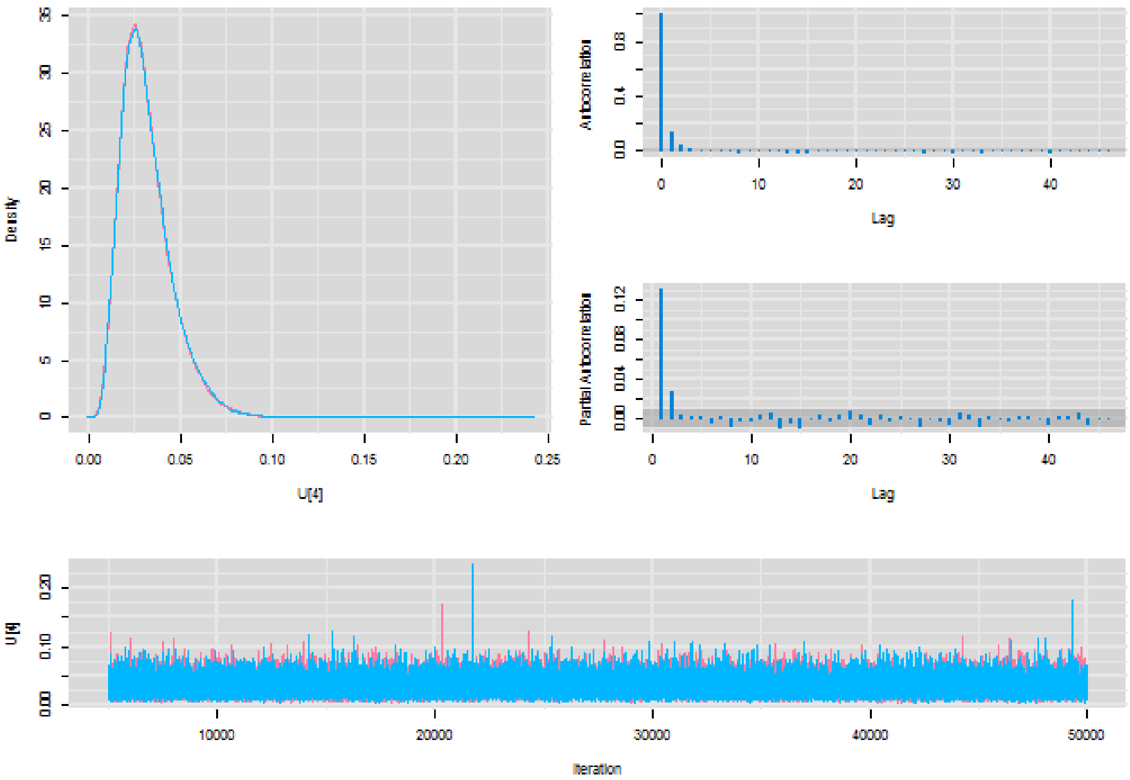
Diagnostics for U[2]



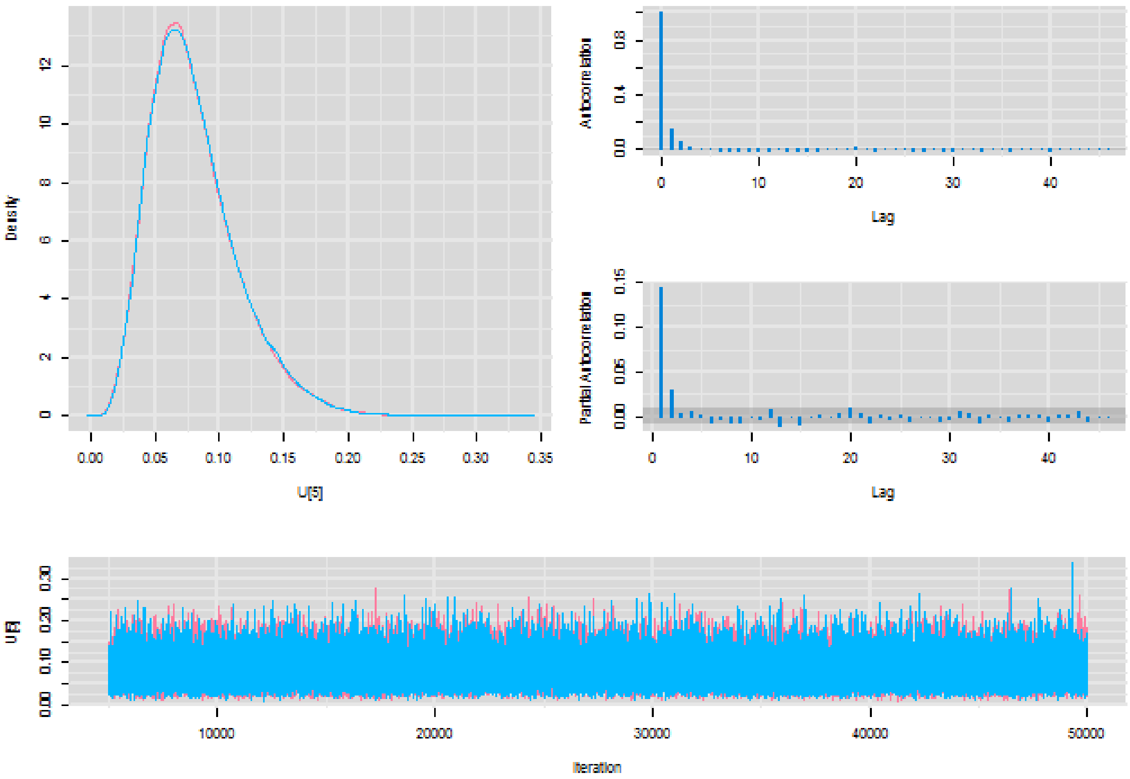
Diagnostics for U[3]



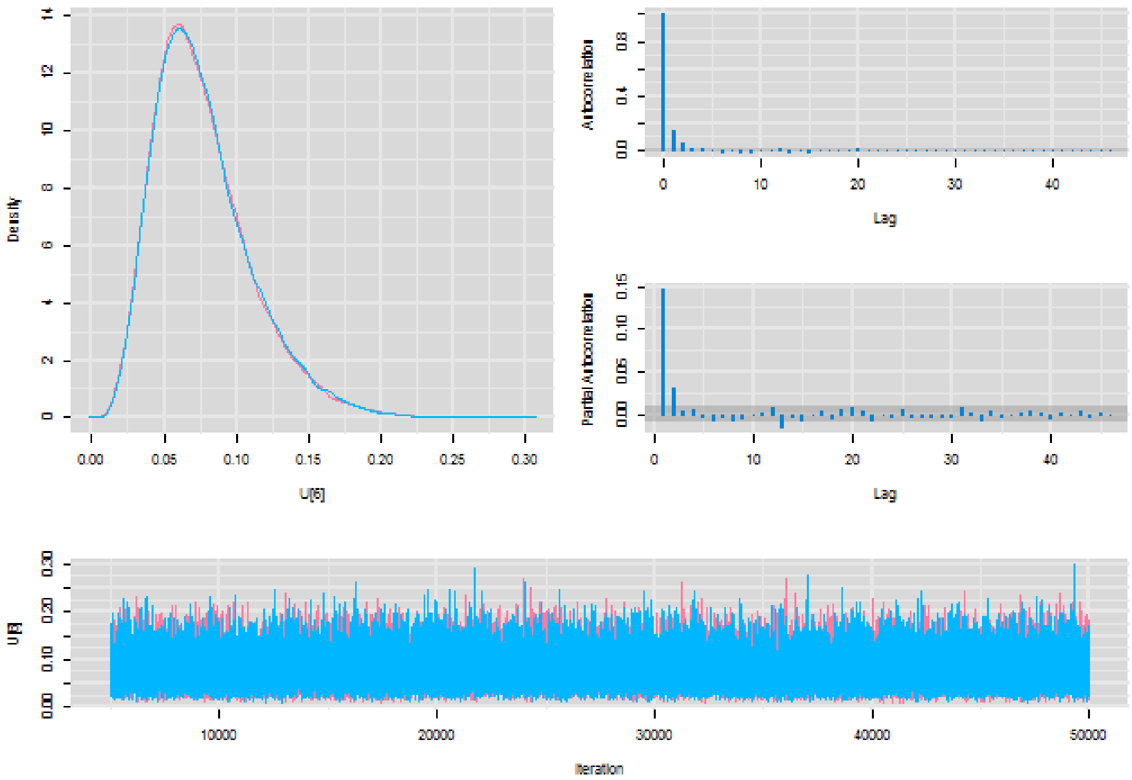
Diagnostics for U[4]



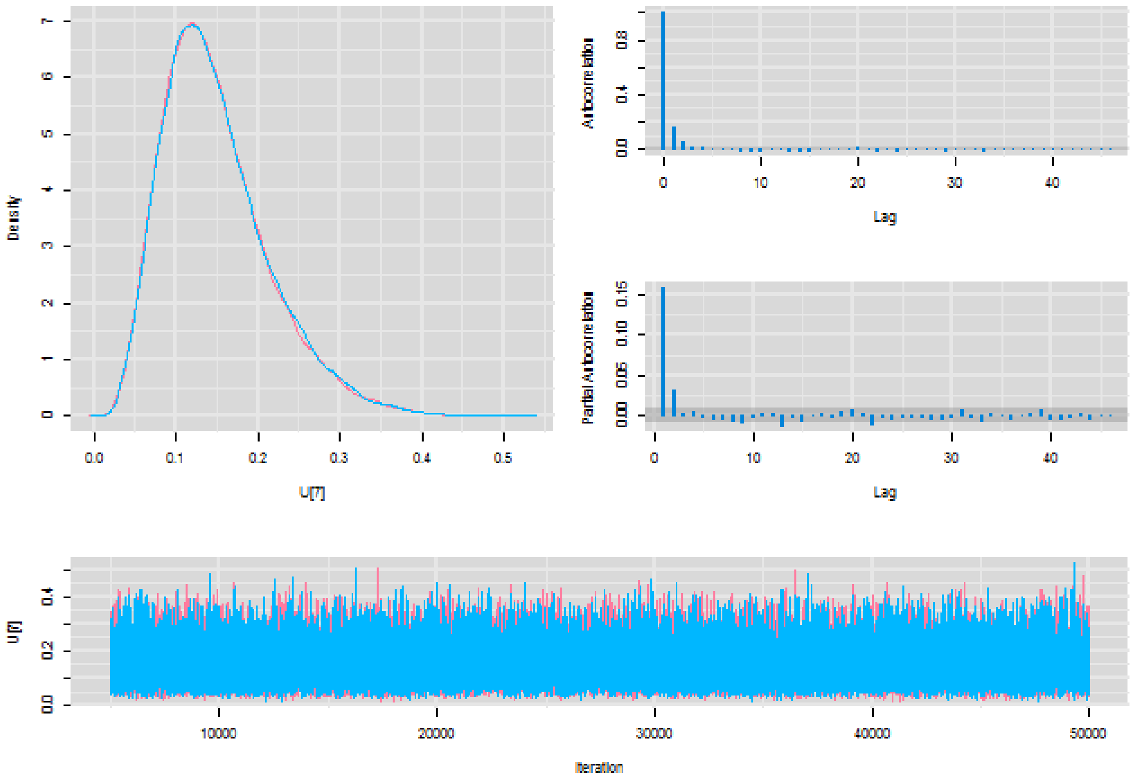
Diagnostics for U[5]



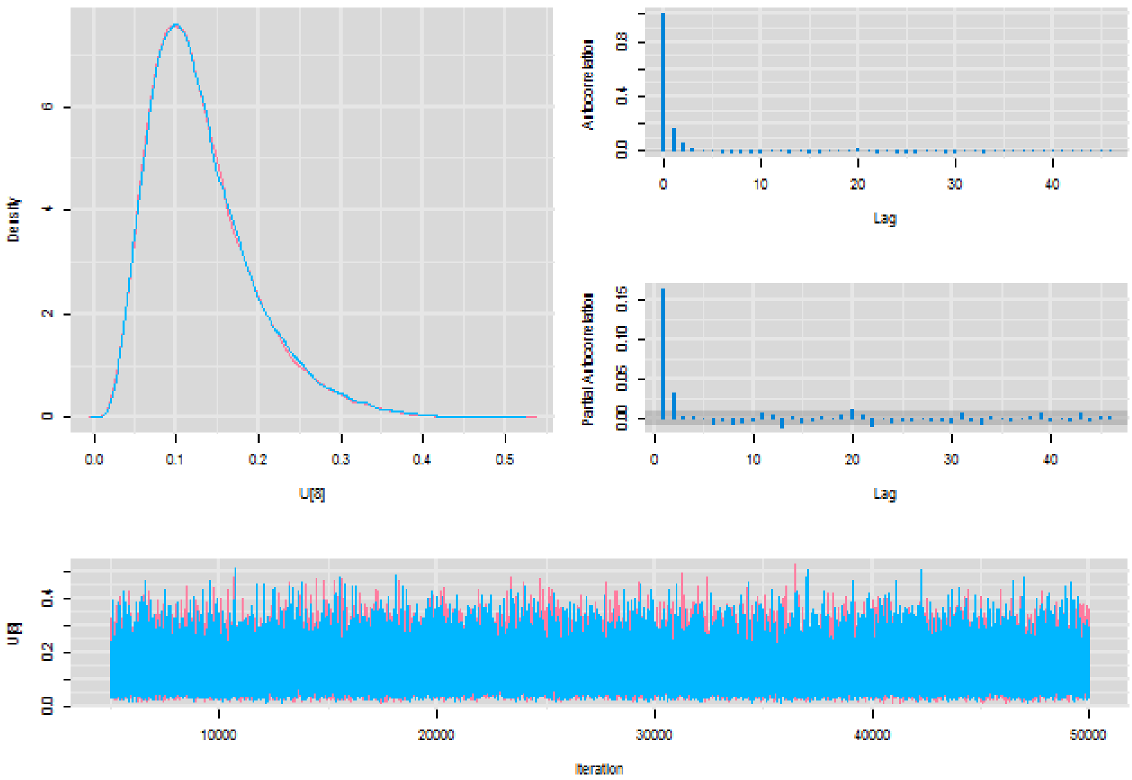
Diagnostics for U[6]



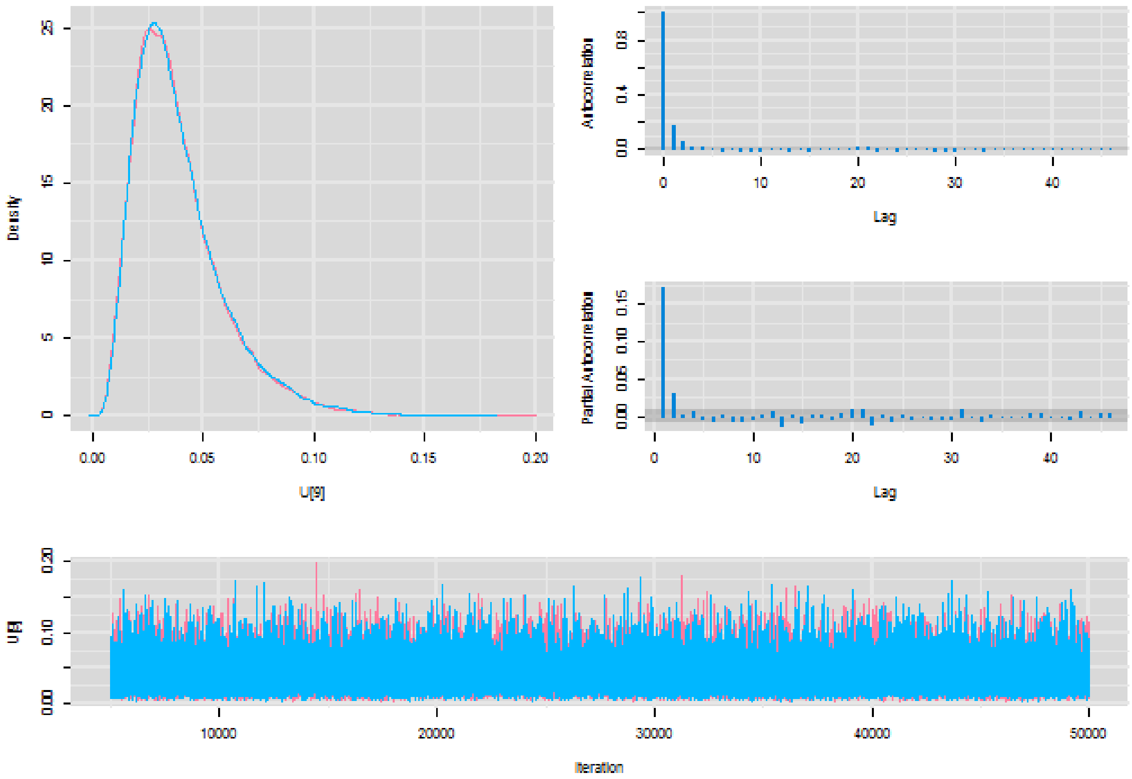
Diagnostics for U[7]



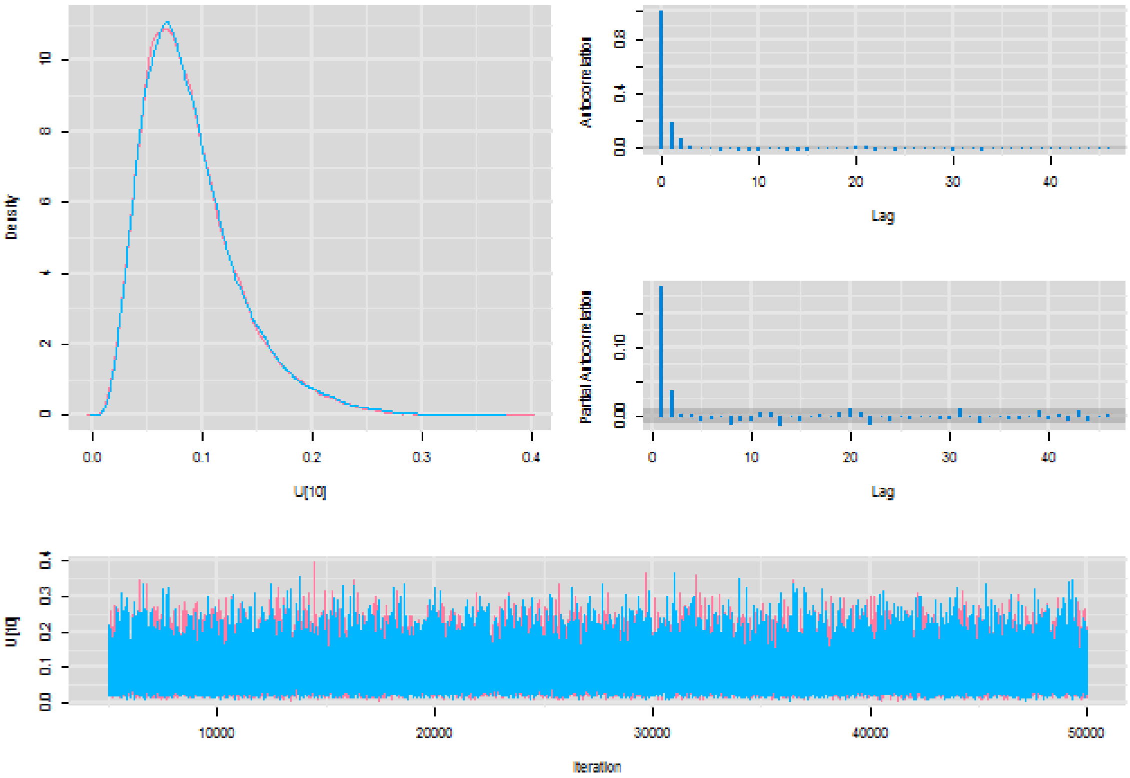
Diagnostics for U[8]



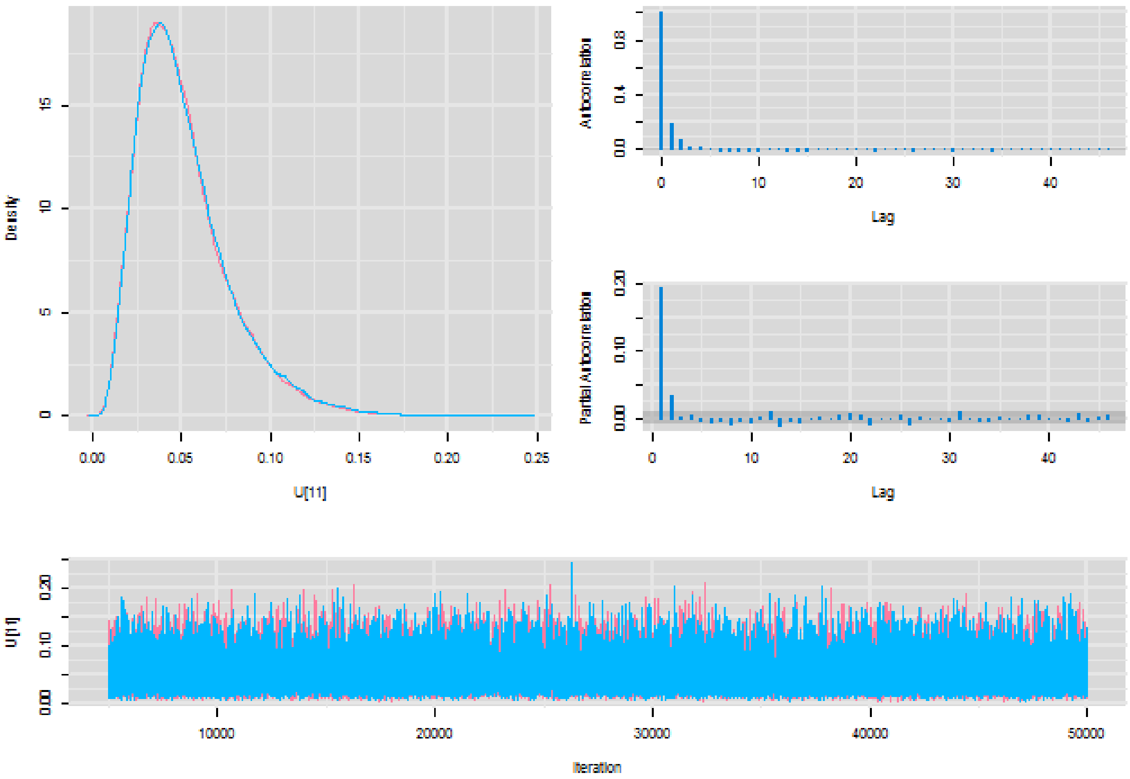
Diagnostics for U[9]



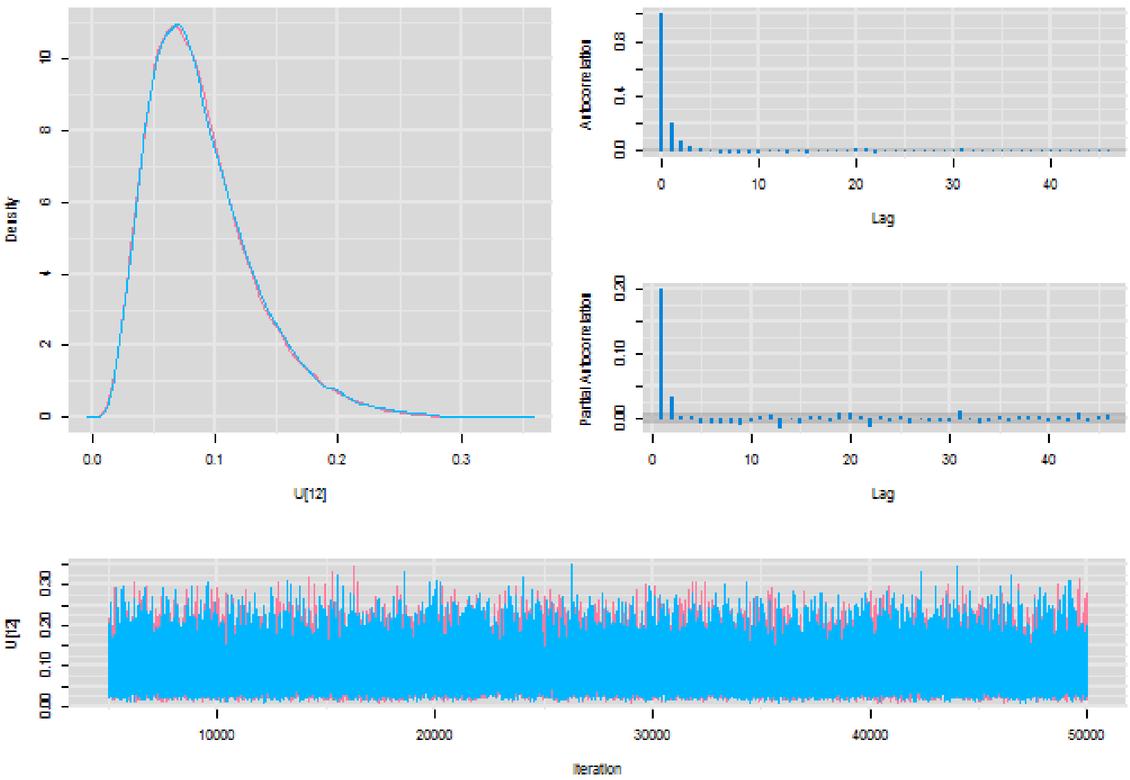
Diagnostics for U[10]



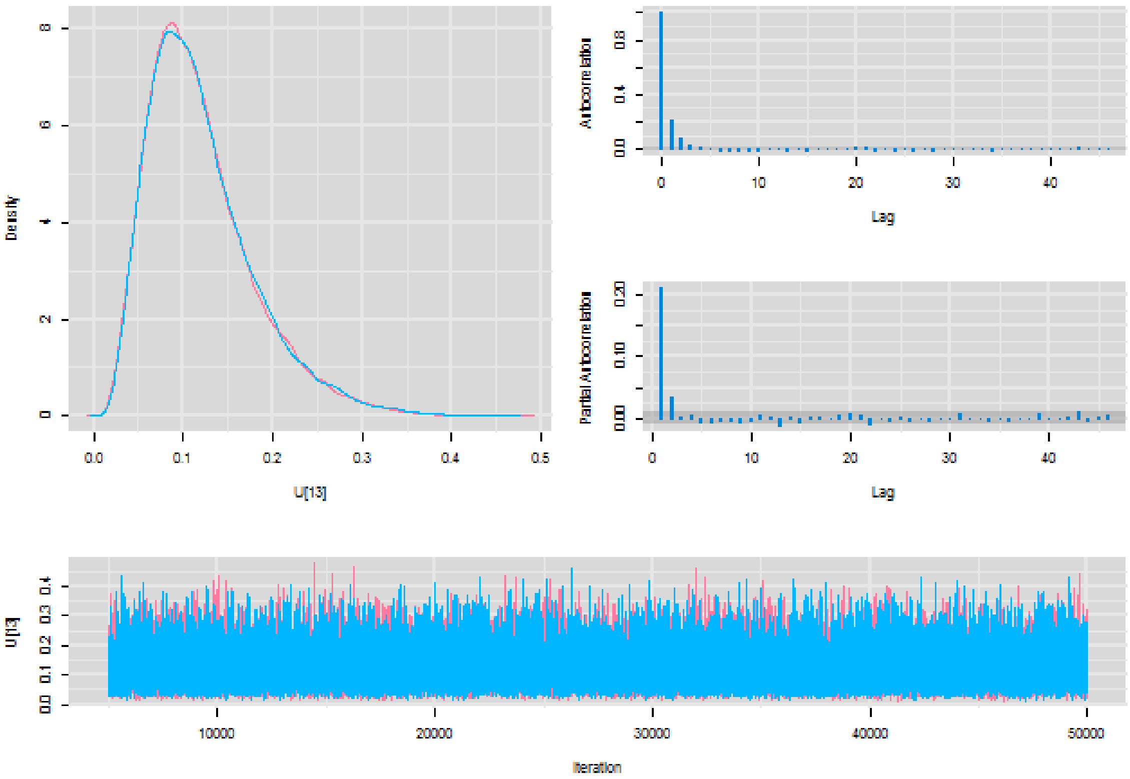
Diagnostics for U[11]



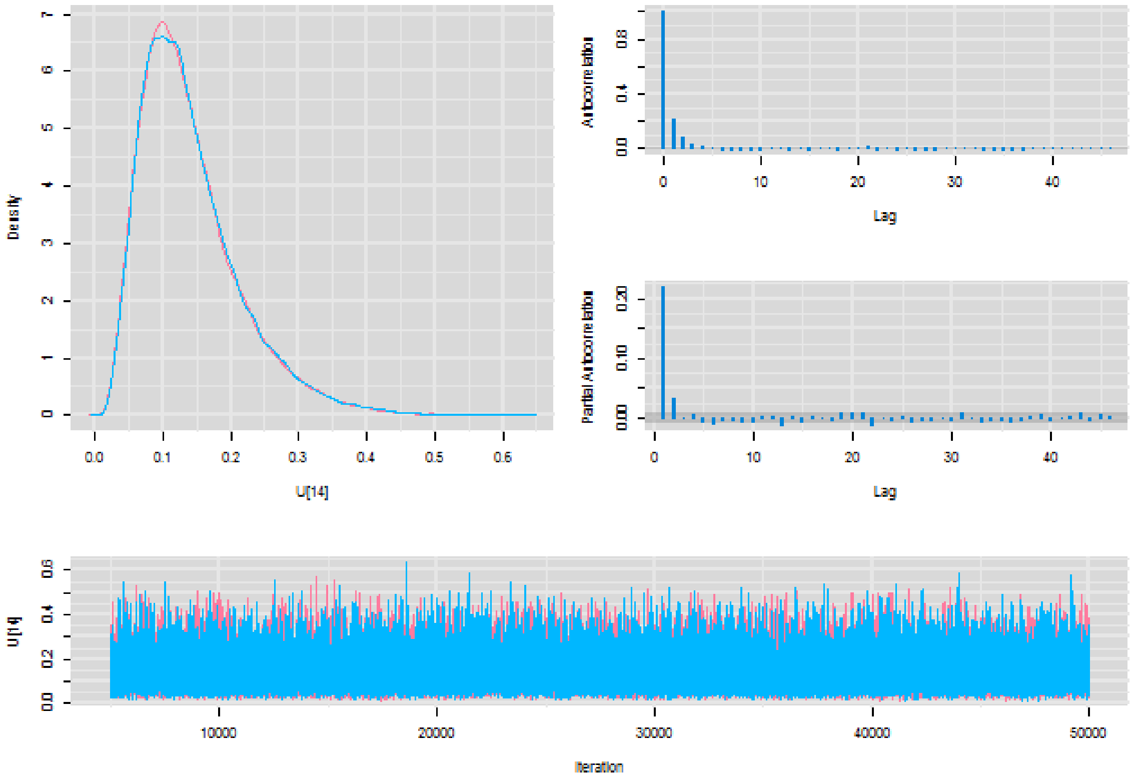
Diagnostics for U[12]



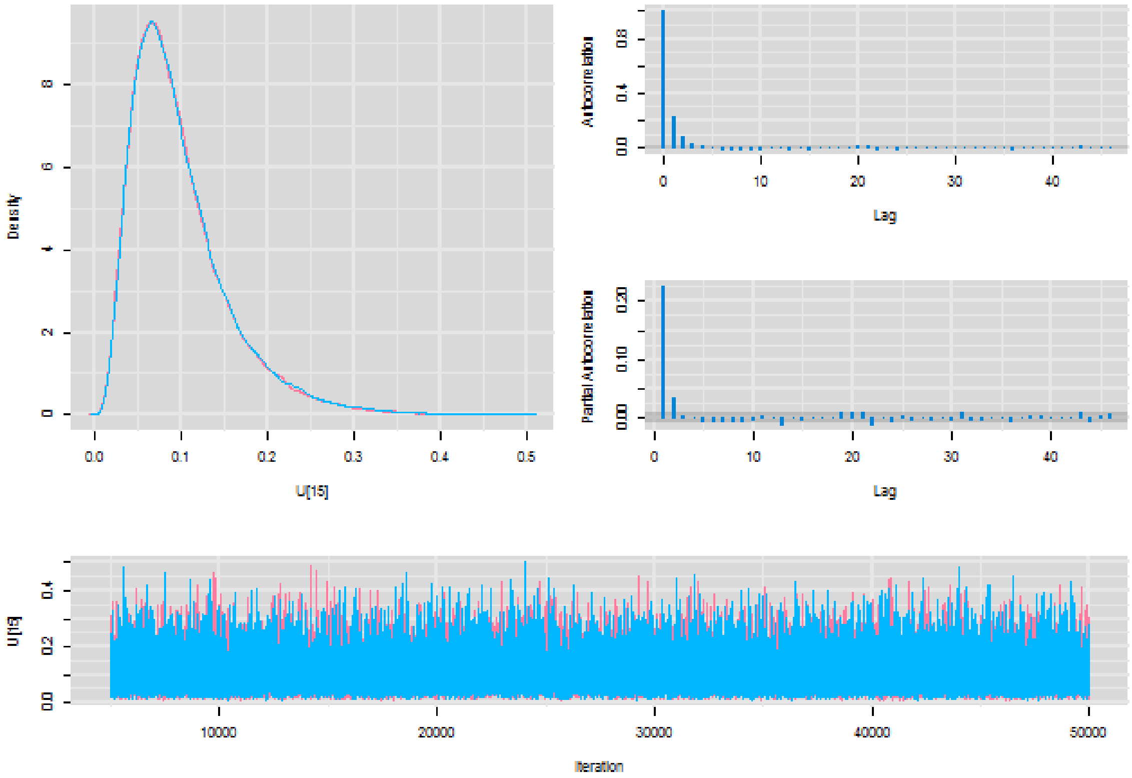
Diagnostics for U[13]



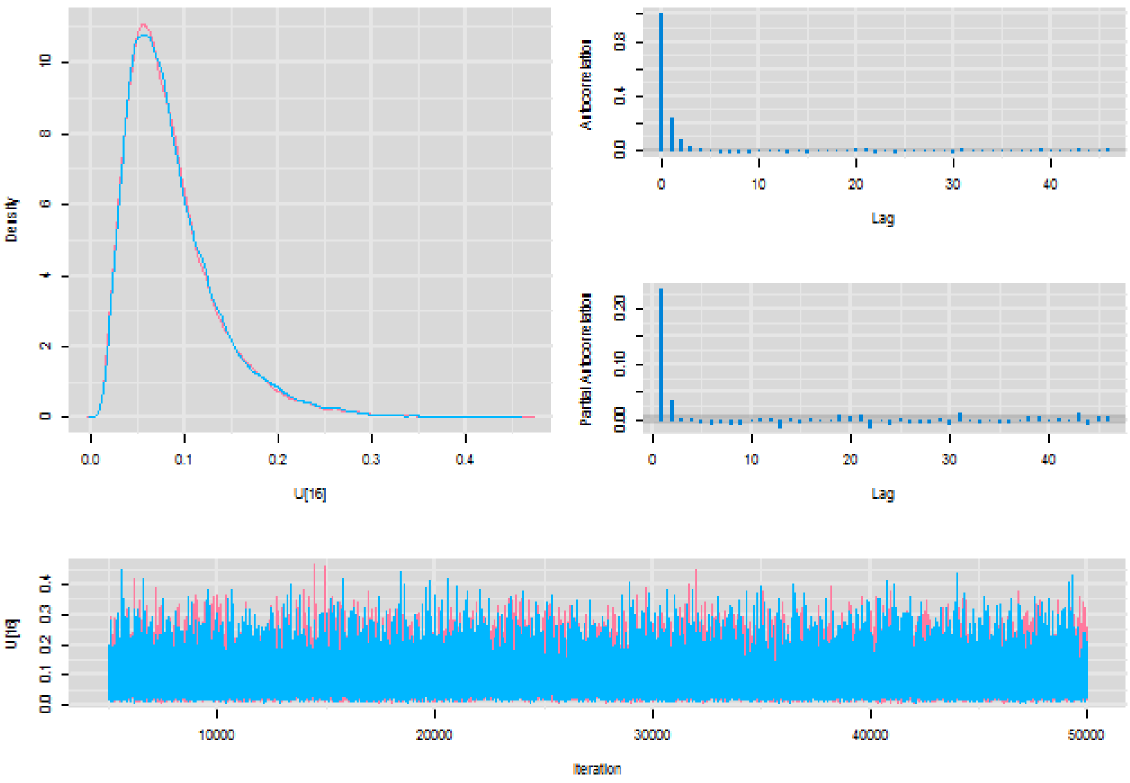
Diagnostics for U[14]



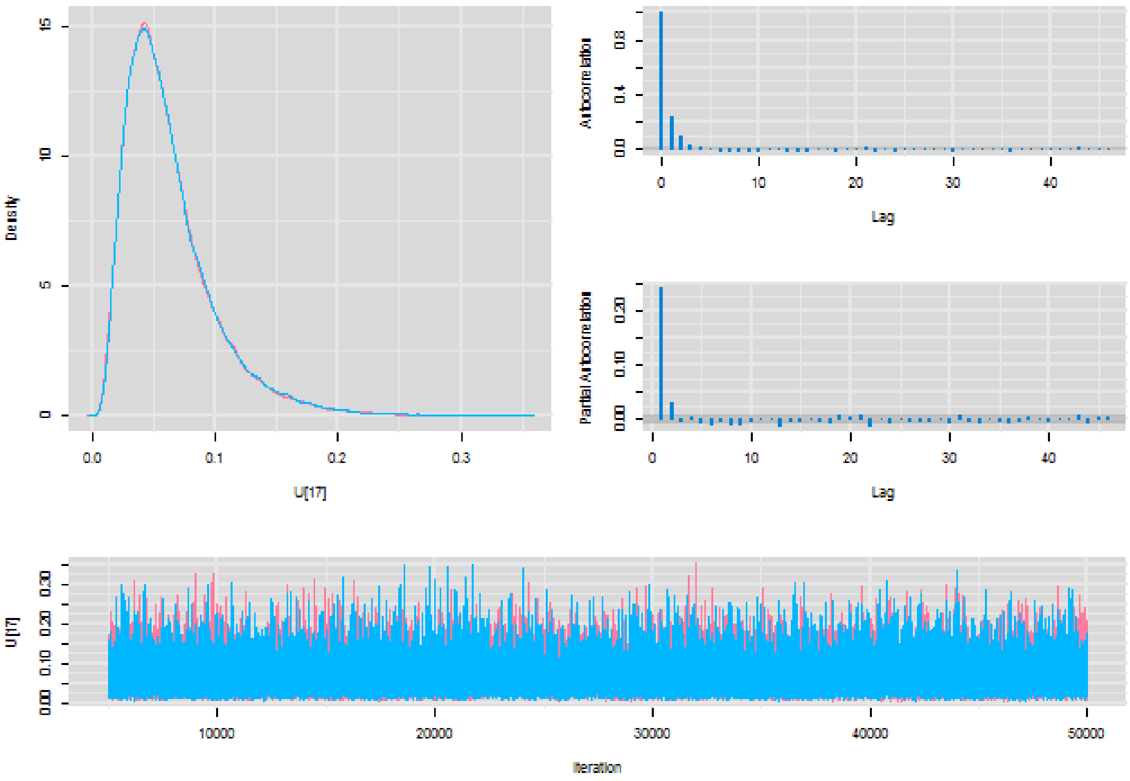
Diagnostics for U[15]



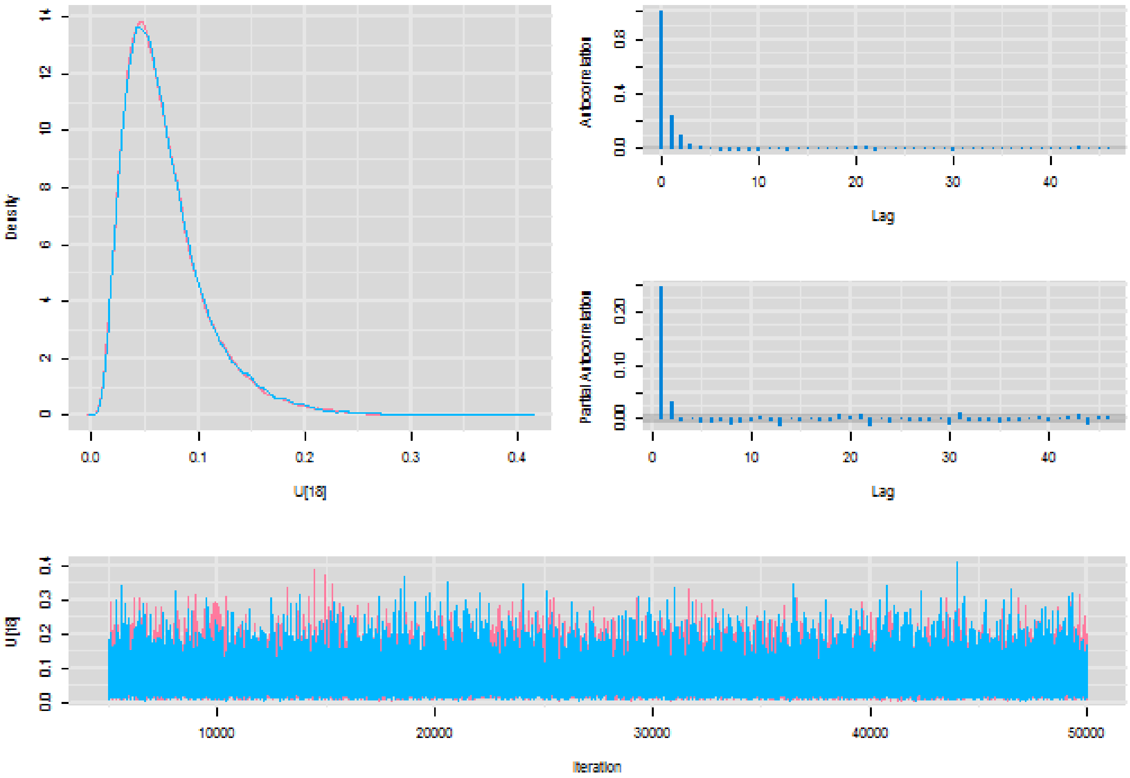
Diagnostics for U[16]



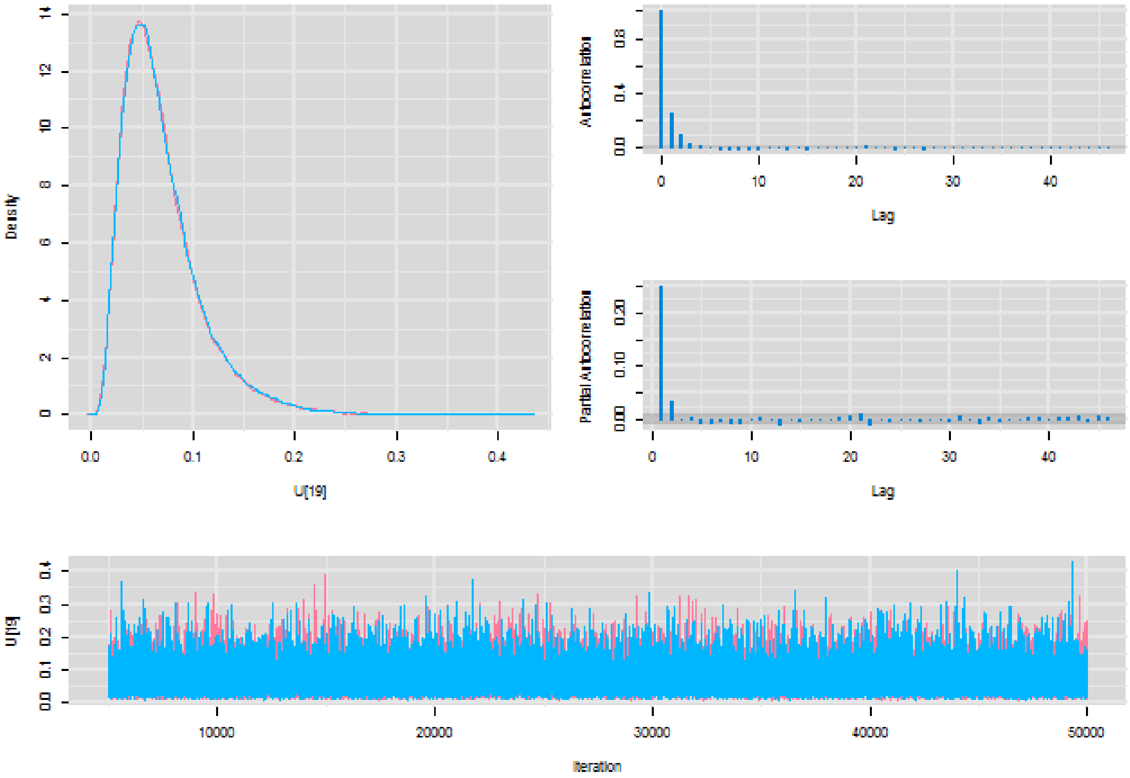
Diagnostics for U[17]



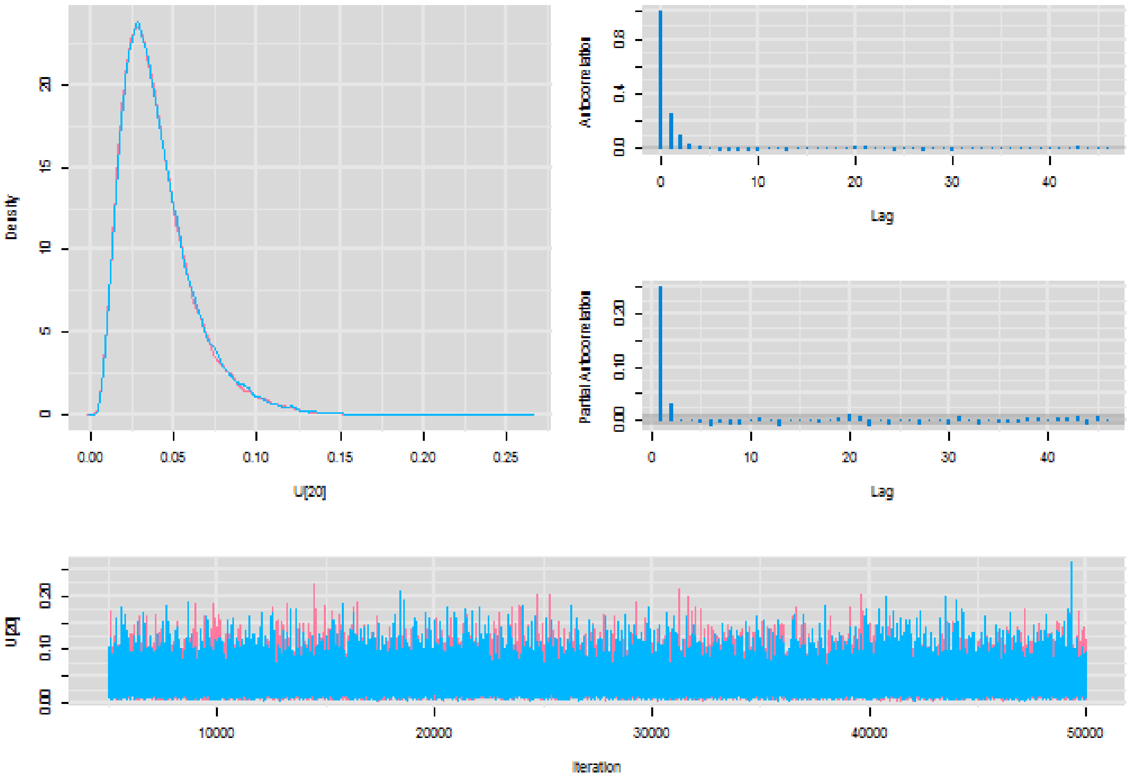
Diagnostics for U[18]



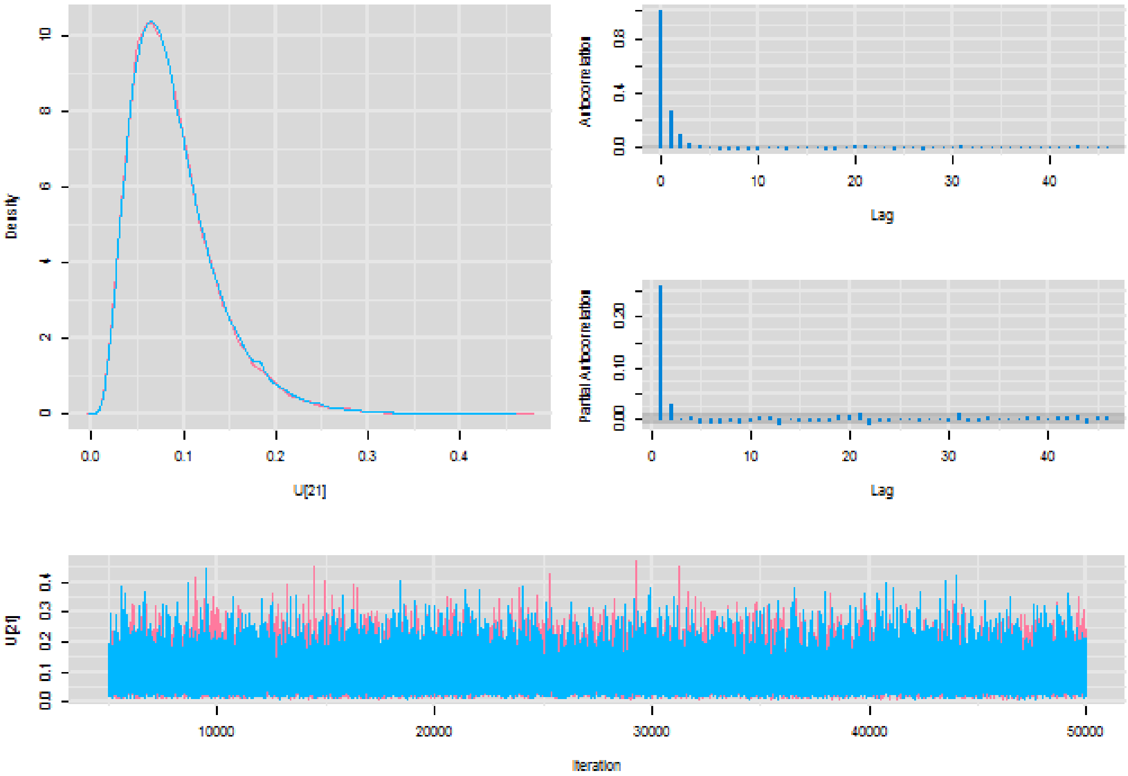
Diagnostics for U[19]



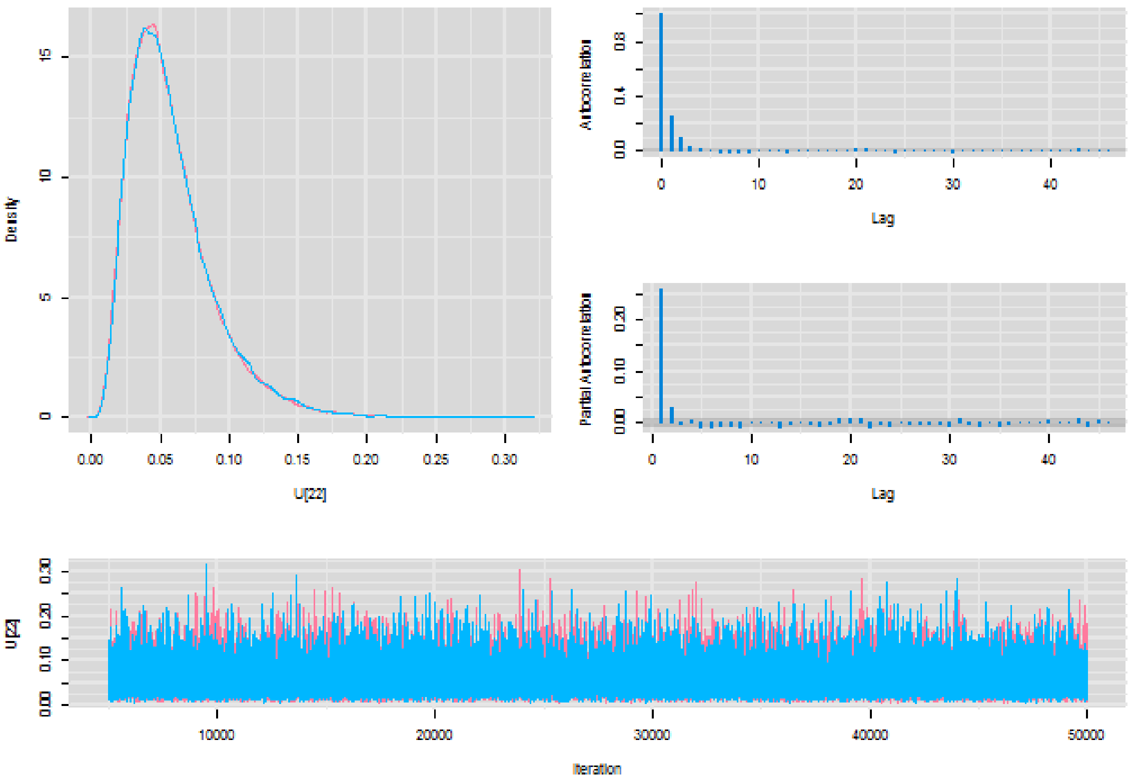
Diagnostics for U[20]



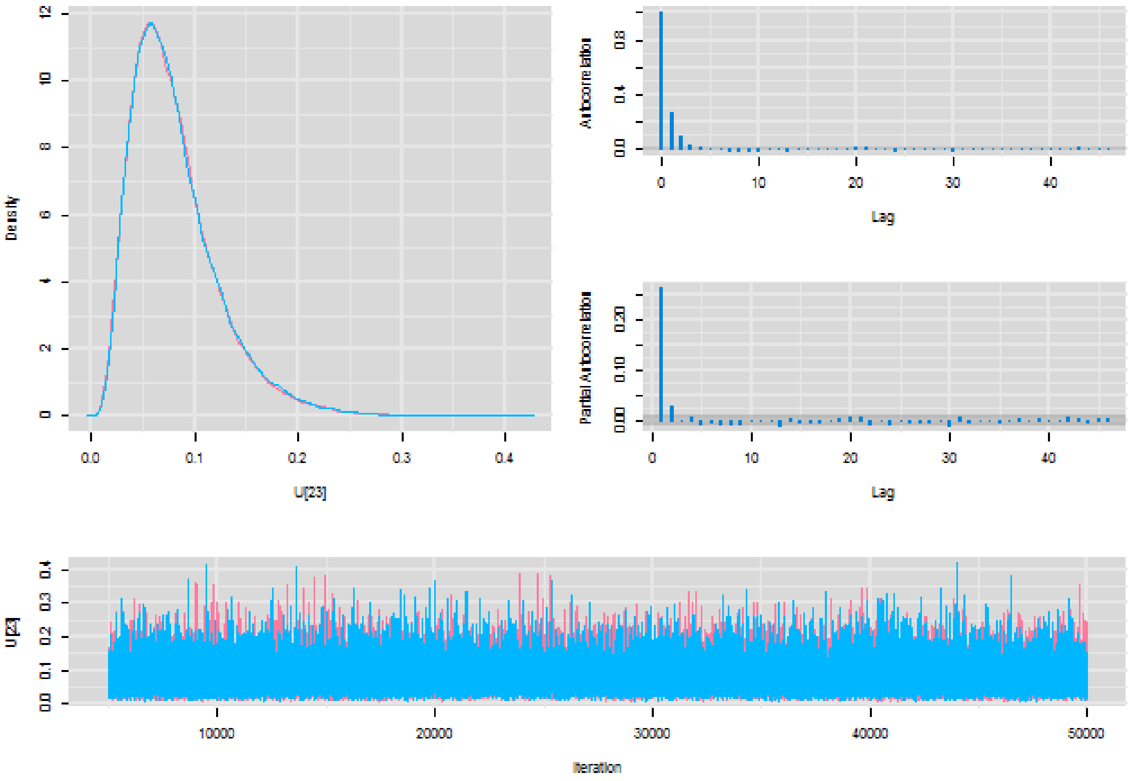
Diagnostics for U[21]



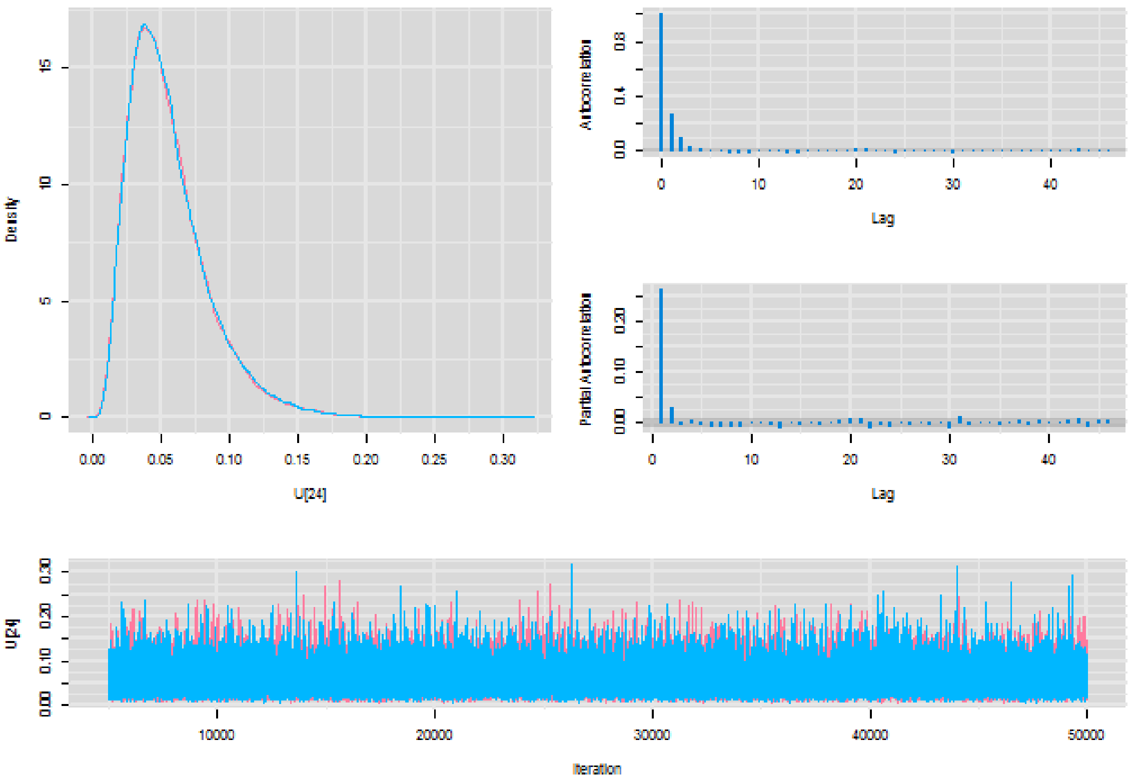
Diagnostics for U[22]



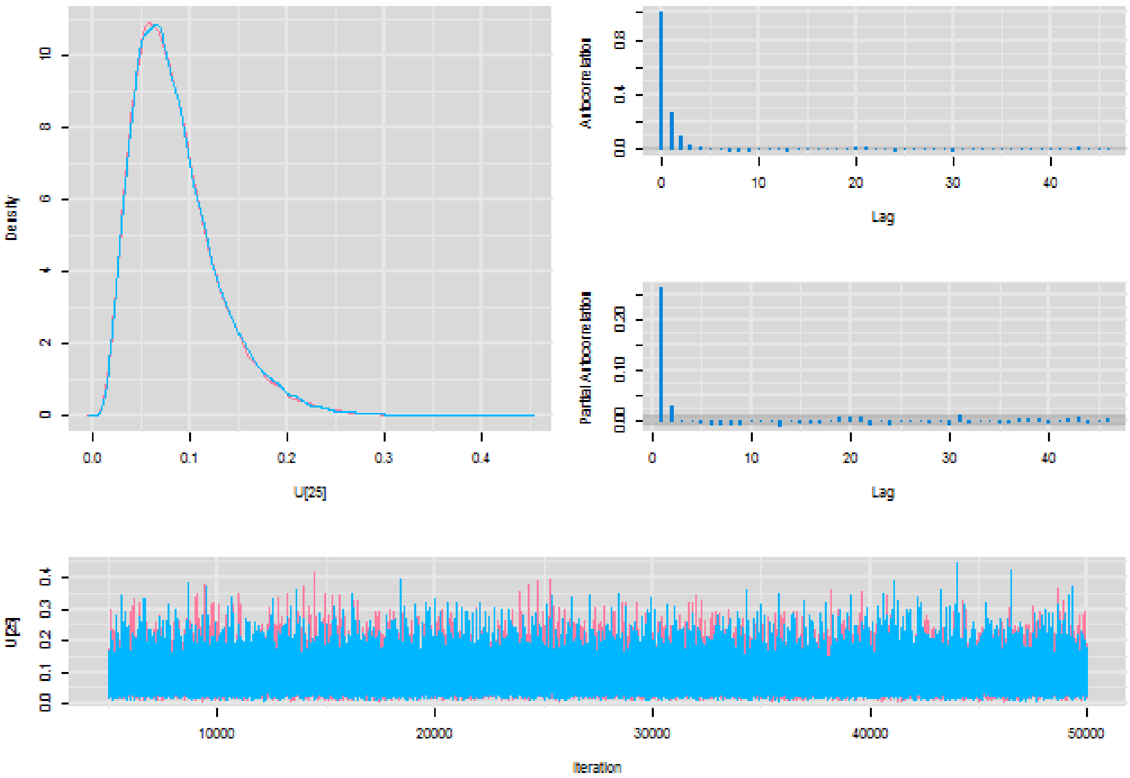
Diagnostics for U[23]



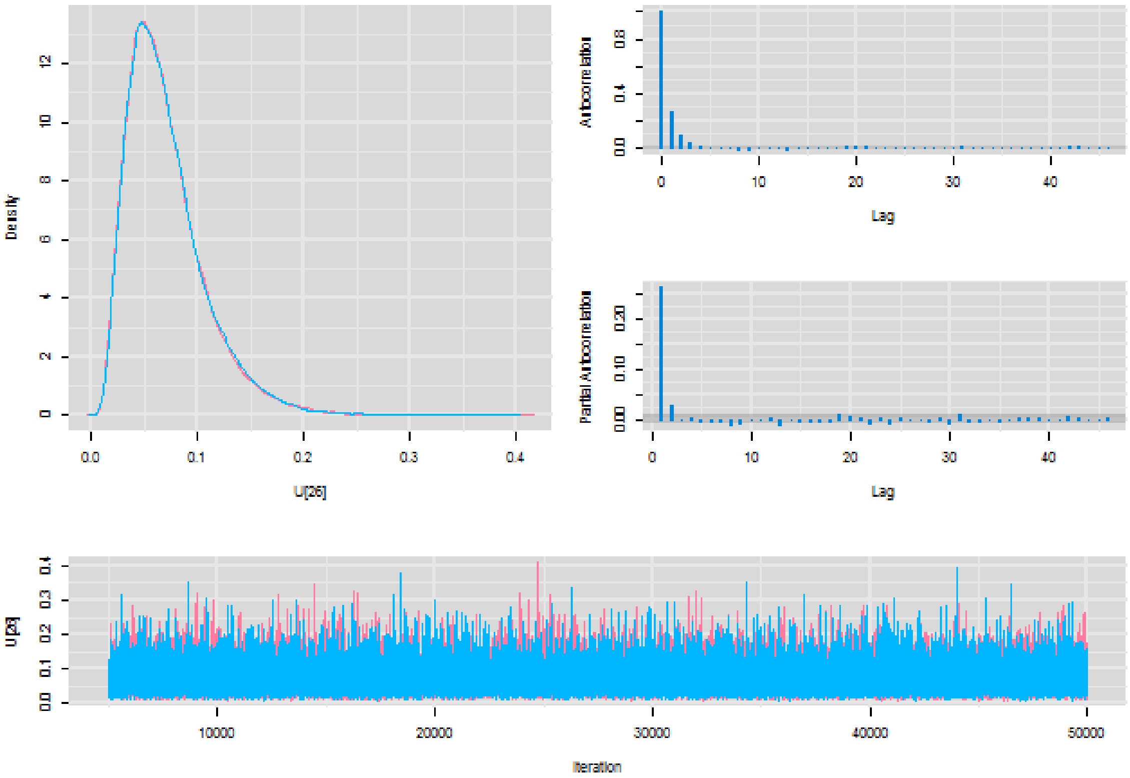
Diagnostics for U[24]



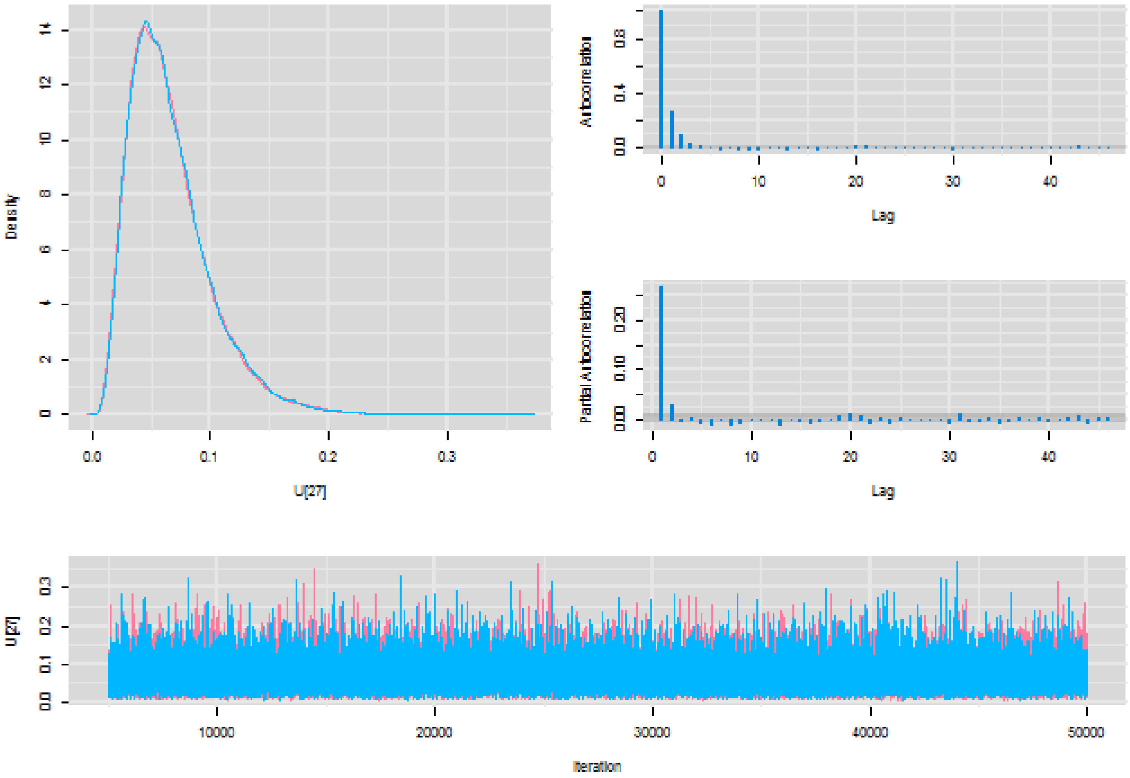
Diagnostics for U[25]



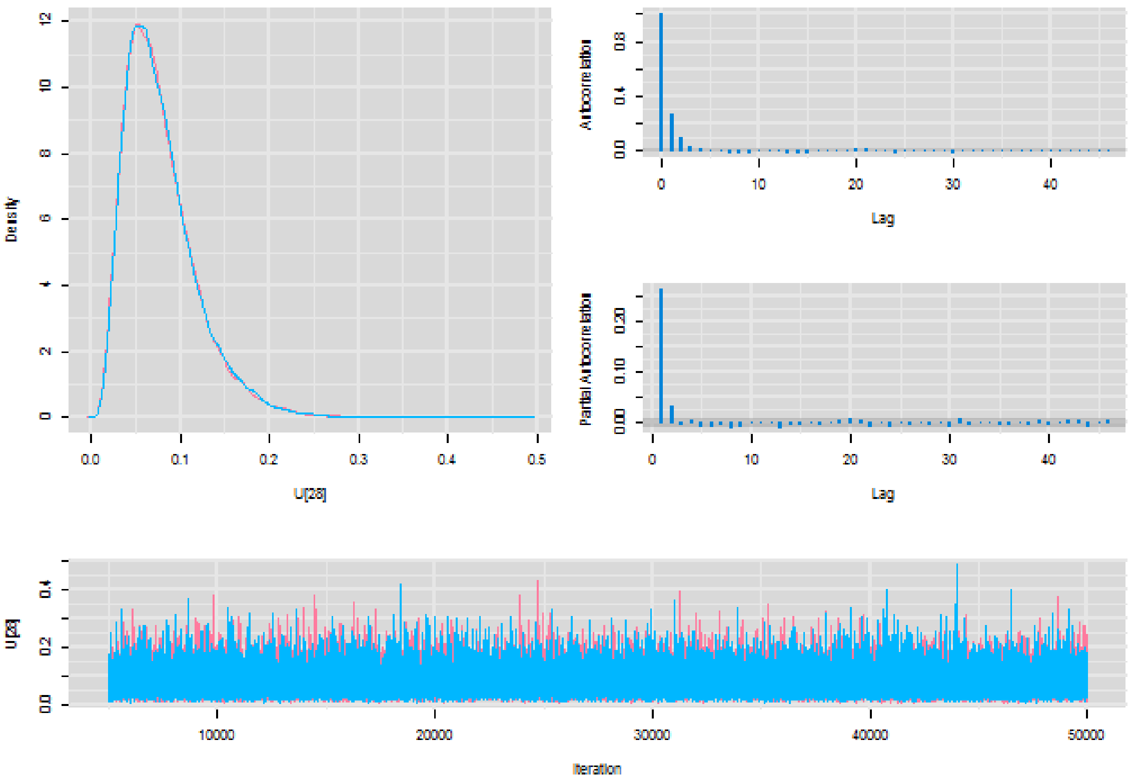
Diagnostics for U[26]



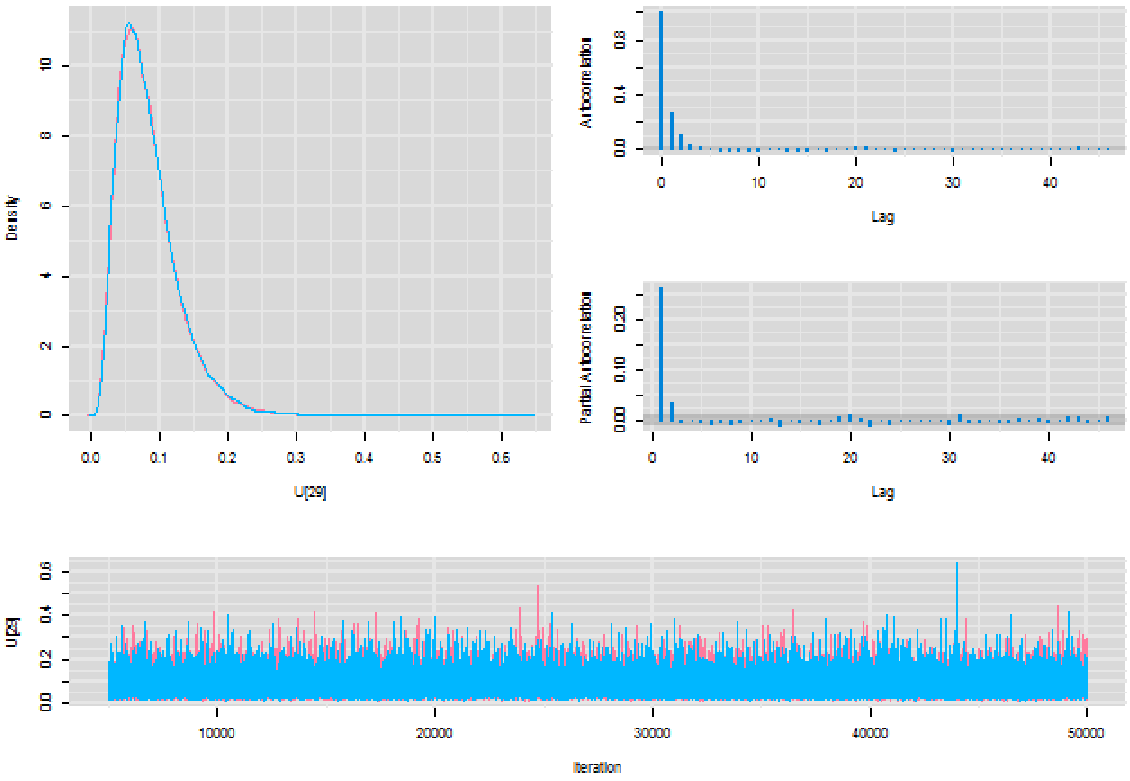
Diagnostics for U[27]



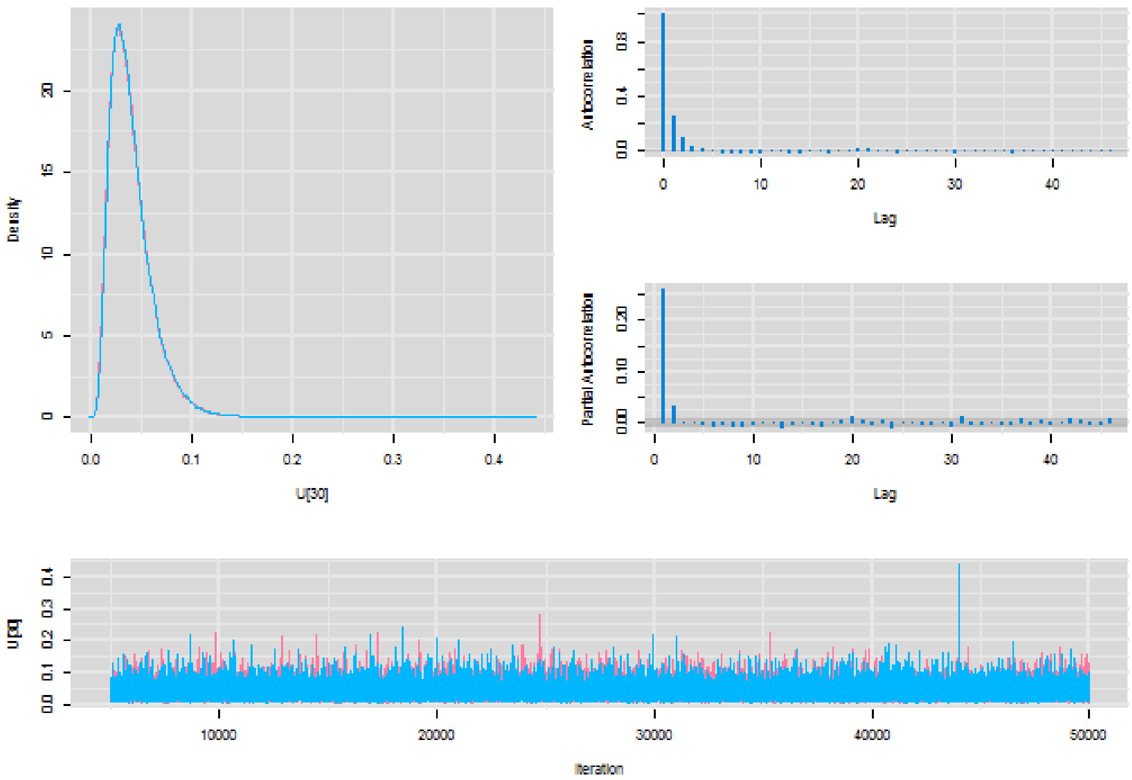
Diagnostics for U[28]



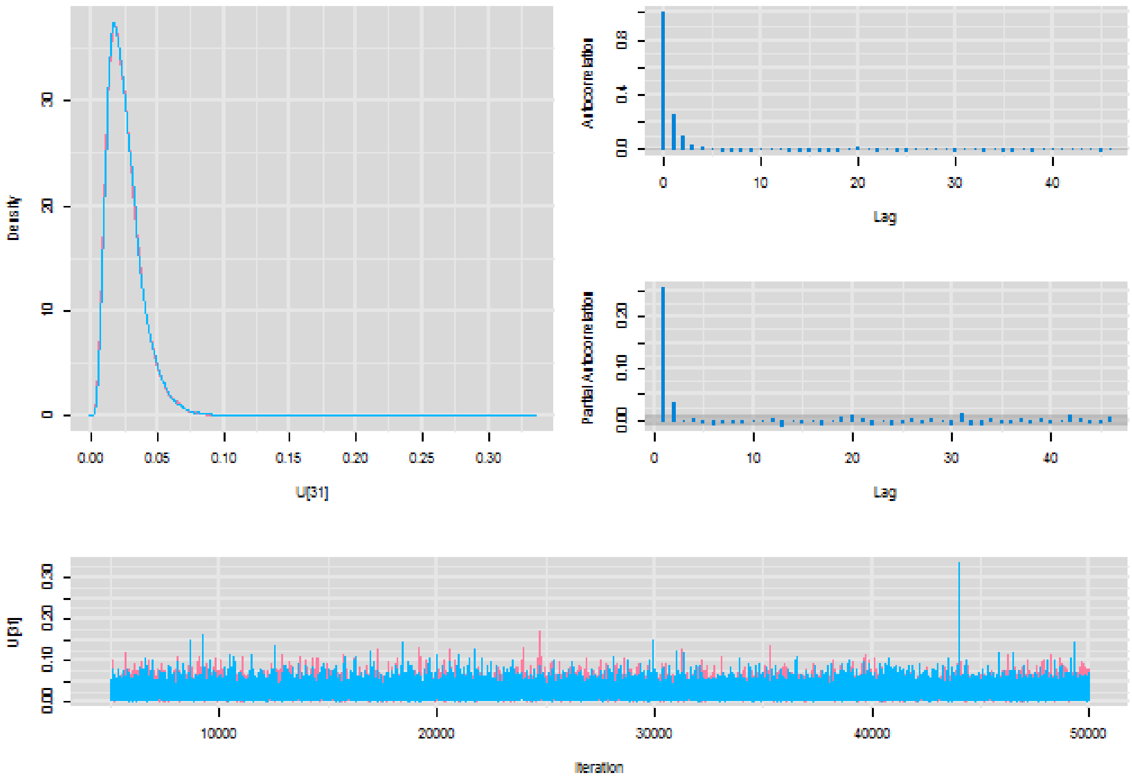
Diagnostics for U[29]



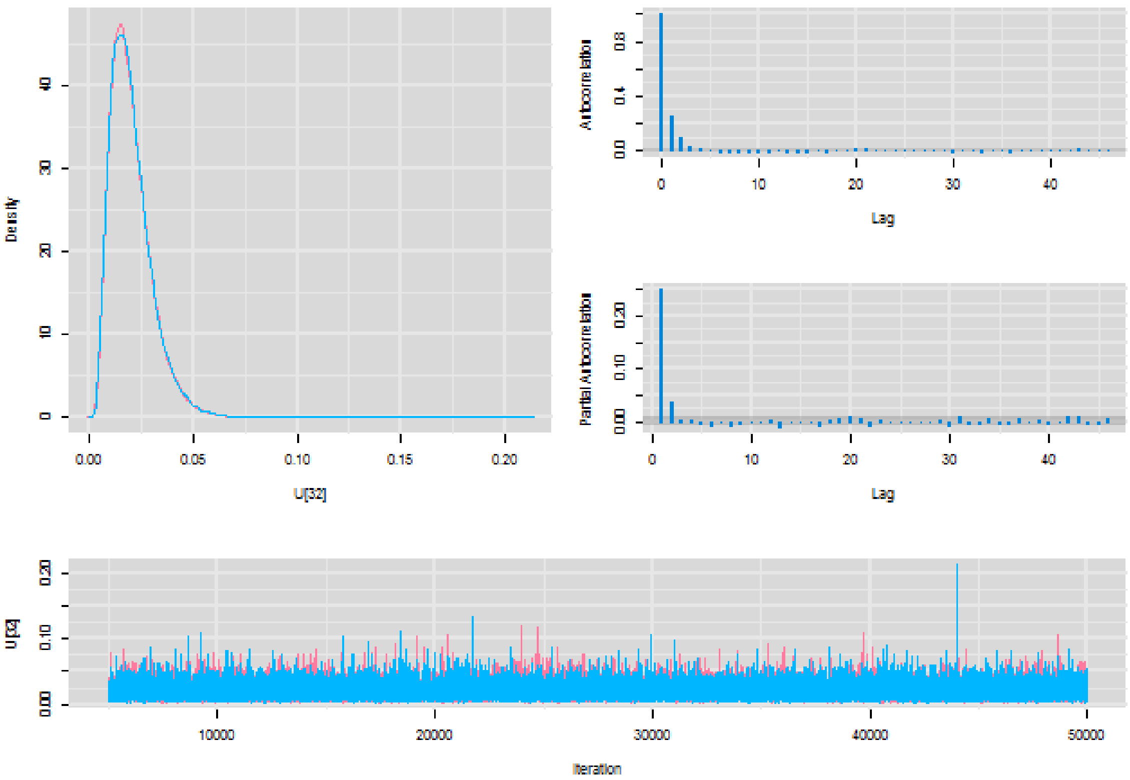
Diagnostics for U[30]



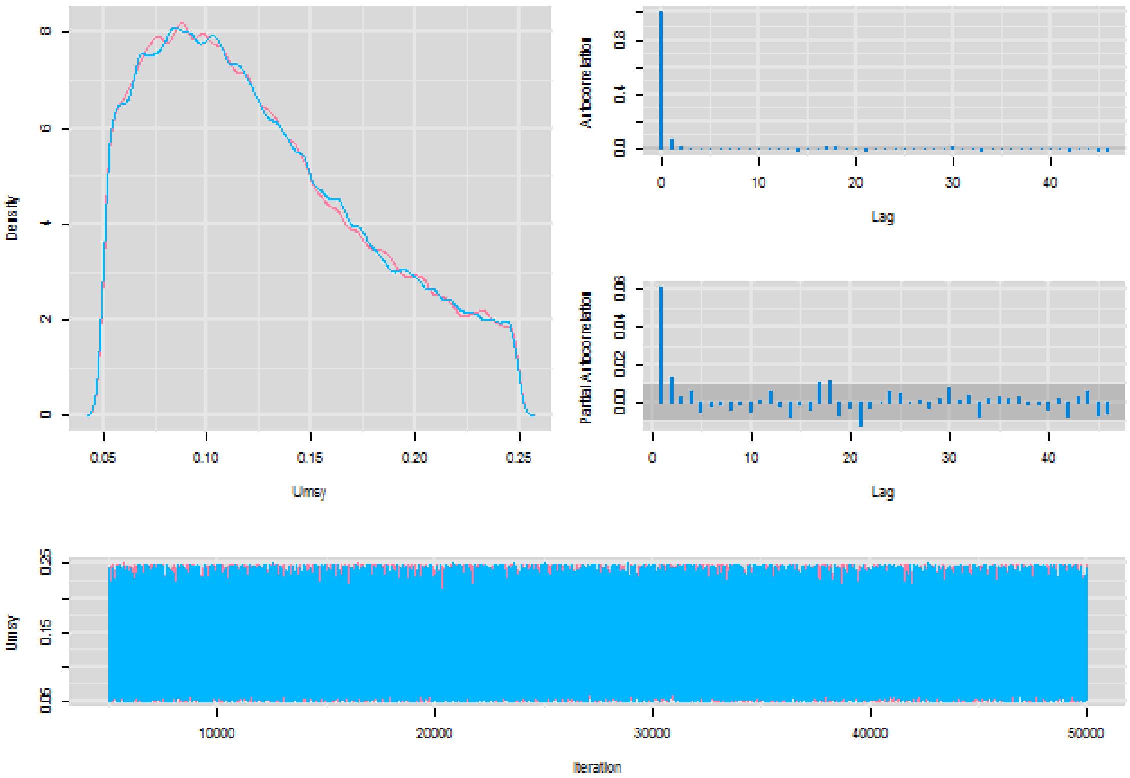
Diagnostics for U[31]



Diagnostics for U[32]



Diagnostics for Umsy



Appendix 5: ASAP Diagnostics of Alternative Regional Configuration Model Runs

The base model regions were southern New England (Massachusetts, Rhode Island, and Connecticut), New York-New Jersey, and DelMarva (Delaware, Maryland, and Virginia). The Tautog Technical Committee also examined a highly-regarded alternative Long Island Sound region created by moving Connecticut into the NY-NJ region, as well as the north-south split that has been used to develop the catch-at-age in older assessment models, which consisted of New York through Massachusetts in the north and New Jersey through Virginia in the south.

This appendix presents more detailed results of the three different regional configurations for comparison.

Table A5. 1. Estimates of F from northern region configurations.

	SNE		NY-NJ		MA-RI		CT-NY-NJ		North	
	Annual F	3-year Average	Annual F	3-year Average	Annual F	3-year Average	Annual F	3-year Average	Annual F	3-year Average
1982	0.17				0.20				0.17	
1983	0.13				0.14				0.12	
1984	0.13	0.14			0.13	0.16	0.11		0.12	0.14
1985	0.09	0.12			0.07	0.11	0.15		0.12	0.12
1986	0.34	0.18			0.45	0.22	0.25	0.17	0.37	0.20
1987	0.25	0.23			0.25	0.26	0.28	0.23	0.29	0.26
1988	0.25	0.28			0.30	0.33	0.23	0.26	0.31	0.32
1989	0.25	0.25	0.23		0.22	0.26	0.23	0.25	0.26	0.29
1990	0.18	0.23	0.28		0.22	0.25	0.23	0.23	0.24	0.27
1991	0.29	0.24	0.41	0.31	0.35	0.26	0.34	0.27	0.35	0.29
1992	0.46	0.31	0.43	0.37	0.54	0.37	0.39	0.32	0.45	0.35
1993	0.33	0.36	0.44	0.43	0.36	0.42	0.40	0.38	0.45	0.42
1994	0.27	0.36	0.19	0.35	0.25	0.39	0.20	0.33	0.28	0.39
1995	0.29	0.30	0.47	0.37	0.26	0.29	0.47	0.36	0.21	0.31
1996	0.29	0.29	0.35	0.34	0.28	0.26	0.36	0.35	0.15	0.21
1997	0.24	0.28	0.27	0.36	0.23	0.25	0.27	0.37	0.15	0.17
1998	0.22	0.25	0.12	0.25	0.19	0.23	0.15	0.26	0.15	0.15
1999	0.19	0.22	0.26	0.22	0.21	0.21	0.24	0.22	0.21	0.17
2000	0.19	0.20	0.32	0.24	0.23	0.21	0.27	0.22	0.17	0.17
2001	0.23	0.20	0.39	0.32	0.28	0.24	0.31	0.27	0.17	0.18
2002	0.32	0.24	0.54	0.42	0.32	0.28	0.45	0.34	0.32	0.22
2003	0.36	0.30	0.22	0.38	0.30	0.30	0.27	0.34	0.25	0.25
2004	0.22	0.30	0.29	0.35	0.22	0.28	0.27	0.33	0.24	0.27
2005	0.24	0.27	0.15	0.22	0.31	0.28	0.14	0.23	0.23	0.24
2006	0.31	0.26	0.32	0.25	0.32	0.28	0.33	0.25	0.30	0.26
2007	0.48	0.34	0.43	0.30	0.48	0.37	0.47	0.31	0.47	0.33
2008	0.47	0.42	0.49	0.41	0.41	0.40	0.48	0.43	0.46	0.41
2009	0.37	0.44	0.62	0.51	0.33	0.40	0.48	0.48	0.48	0.47
2010	0.50	0.44	0.63	0.58	0.54	0.43	0.60	0.52	0.48	0.47
2011	0.27	0.38	0.36	0.54	0.24	0.37	0.34	0.47	0.26	0.40
2012	0.54	0.44	0.17	0.39	0.39	0.39	0.37	0.44	0.42	0.39
2013	0.62	0.48	0.21	0.25	0.52	0.38	0.29	0.33	0.41	0.36

Table A5. 2. Estimates of F from southern region configurations.

	DelMarVa		South	
	Annual F	3-year Average	Annual F	3-year Average
1982			0.24	
1983			0.22	
1984			0.19	0.22
1985			0.16	0.19
1986			0.29	0.21
1987			0.32	0.26
1988			0.34	0.32
1989			0.35	0.34
1990	0.24		0.20	0.30
1991	0.29		0.33	0.29
1992	0.17	0.23	0.36	0.30
1993	0.27	0.24	0.32	0.34
1994	0.28	0.24	0.26	0.32
1995	0.43	0.32	0.37	0.32
1996	0.31	0.34	0.28	0.30
1997	0.34	0.36	0.21	0.29
1998	0.27	0.31	0.14	0.21
1999	0.29	0.30	0.25	0.20
2000	0.30	0.29	0.47	0.29
2001	0.21	0.27	0.43	0.38
2002	0.41	0.31	0.39	0.43
2003	0.28	0.30	0.27	0.36
2004	0.36	0.35	0.32	0.33
2005	0.29	0.31	0.23	0.27
2006	0.44	0.36	0.45	0.34
2007	0.35	0.36	0.55	0.41
2008	0.34	0.38	0.47	0.49
2009	0.45	0.38	0.51	0.51
2010	0.51	0.44	0.89	0.62
2011	0.26	0.41	0.51	0.64
2012	0.14	0.30	0.23	0.54
2013	0.10	0.17	0.25	0.33

Table A5. 3. Abundance and SSB estimates for SNE and NY-NJ regions.

	SNE			NY-NJ		
	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)
1982	14.20	11,377	2.34			
1983	13.01	11,376	1.66			
1984	11.82	11,447	1.29			
1985	10.62	11,367	1.10			
1986	10.04	10,242	1.38			
1987	8.55	8,369	1.30			
1988	7.67	7,180	1.20			
1989	6.84	6,289	0.98	8.58	5,504	1.49
1990	6.18	5,738	0.90	8.13	5,270	1.39
1991	5.81	5,210	0.92	7.83	4,705	1.60
1992	5.28	4,266	0.86	7.10	3,995	1.36
1993	4.52	3,485	0.74	6.39	3,525	1.15
1994	4.22	3,153	0.79	5.57	3,408	0.85
1995	4.12	2,924	0.84	5.33	3,220	0.88
1996	3.96	2,730	0.76	4.60	2,746	0.81
1997	3.91	2,680	0.82	4.39	2,565	0.97
1998	4.12	2,743	0.96	4.76	2,613	1.29
1999	4.50	2,847	1.15	4.95	2,716	1.00
2000	4.63	3,003	0.94	4.89	2,759	0.94
2001	4.58	3,191	0.78	4.74	2,665	0.91
2002	4.49	3,260	0.78	4.56	2,395	0.92
2003	4.43	3,174	0.86	4.39	2,271	1.04
2004	4.26	3,137	0.77	4.64	2,343	1.09
2005	4.16	3,189	0.71	4.78	2,479	1.11
2006	3.92	3,127	0.58	4.86	2,604	0.92
2007	3.58	2,821	0.50	4.63	2,469	0.84
2008	3.53	2,402	0.89	4.37	2,168	0.96
2009	3.33	2,128	0.66	4.06	1,816	0.87
2010	3.25	1,996	0.65	4.26	1,521	1.37
2011	3.42	1,961	0.94	4.14	1,436	1.02
2012	3.10	1,931	0.33	3.64	1,758	0.38
2013	2.91	1,839	0.55	4.05	2,079	1.08

Table A5. 4. Abundance and SSB estimates from MARI-LIS regional configuration.

	MA-RI			CT-NY-NJ		
	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)
1982	11.80	10,597	1.53			
1983	10.50	10,426	1.07			
1984	9.31	10,287	0.80	13.12	9,408	2.14
1985	8.21	10,091	0.69	12.71	9,483	1.98
1986	7.57	8,730	0.79	12.25	8,995	2.10
1987	5.97	6,808	0.74	11.54	7,963	2.22
1988	5.39	5,688	0.85	10.65	7,195	1.91
1989	4.80	4,823	0.74	10.22	6,818	1.93
1990	4.43	4,325	0.67	9.67	6,458	1.70
1991	4.19	3,799	0.70	9.37	5,912	1.83
1992	3.90	3,073	0.70	8.70	5,079	1.72
1993	3.47	2,575	0.61	7.84	4,400	1.43
1994	3.27	2,446	0.57	6.90	4,187	1.10
1995	3.16	2,408	0.55	6.67	3,867	1.21
1996	3.03	2,339	0.51	5.96	3,259	1.25
1997	2.98	2,283	0.59	5.78	3,083	1.33
1998	3.06	2,273	0.66	6.31	3,245	1.70
1999	3.20	2,281	0.71	6.76	3,464	1.54
2000	3.24	2,287	0.65	7.00	3,663	1.54
2001	3.15	2,282	0.53	6.96	3,770	1.35
2002	3.06	2,245	0.54	6.81	3,678	1.30
2003	2.97	2,189	0.54	6.60	3,573	1.43
2004	2.89	2,175	0.53	6.75	3,620	1.49
2005	2.86	2,142	0.53	6.84	3,816	1.48
2006	2.77	2,041	0.51	6.84	3,965	1.18
2007	2.62	1,889	0.44	6.31	3,629	0.99
2008	2.74	1,748	0.73	5.58	3,049	1.09
2009	2.71	1,687	0.55	5.08	2,549	1.10
2010	2.54	1,655	0.36	5.20	2,135	1.51
2011	2.47	1,674	0.52	5.19	1,972	1.43
2012	2.23	1,696	0.22	5.13	2,150	1.03
2013	2.15	1,612	0.40	5.54	2,359	1.56

Table A5. 5. Abundance and SSB estimates from North region.

	North		
	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)
1982	20.66	13,954	4.12
1983	19.63	17,027	3.25
1984	18.35	17,724	2.52
1985	16.81	17,328	2.03
1986	15.71	16,144	2.30
1987	13.50	12,426	2.50
1988	12.45	10,705	2.47
1989	11.01	8,895	1.75
1990	9.98	8,628	1.58
1991	9.21	8,144	1.58
1992	8.07	6,758	1.37
1993	6.96	5,348	1.29
1994	6.24	4,465	1.28
1995	6.18	4,688	1.41
1996	6.06	5,240	1.20
1997	6.32	5,923	1.45
1998	7.08	6,403	1.91
1999	7.89	4,009	2.07
2000	8.14	4,767	1.73
2001	8.20	4,595	1.53
2002	8.15	4,565	1.44
2003	8.03	4,815	1.63
2004	7.93	4,781	1.54
2005	7.65	4,757	1.34
2006	7.32	4,671	1.22
2007	6.82	4,306	1.12
2008	6.84	3,853	1.68
2009	6.78	3,458	1.53
2010	6.58	3,220	1.34
2011	6.63	3,339	1.53
2012	5.99	3,469	0.60
2013	6.14	3,447	1.50

Table A5. 6. Abundance and SSB estimates for DelMarVa and South regions.

	DMV			South		
	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)	Total Abundance (Millions)	SSB (MT)	Recruits (Millions)
1982				6.27	3,483	1.76
1983				6.70	3,929	1.83
1984				7.40	4,088	2.13
1985				7.77	4,352	1.87
1986				8.36	4,776	2.11
1987				8.52	4,576	2.14
1988				8.64	4,638	2.19
1989				8.30	4,294	1.80
1990	3.53	2,197	0.85	7.70	4,697	1.51
1991	3.75	2,285	0.96	7.72	5,114	1.67
1992	3.66	2,406	0.74	7.10	4,844	1.36
1993	3.45	2,581	0.51	6.10	4,421	0.93
1994	2.98	2,555	0.32	5.13	4,100	0.65
1995	2.53	2,268	0.29	4.47	4,080	0.63
1996	2.00	1,881	0.26	3.69	3,825	0.55
1997	1.88	1,592	0.43	3.50	3,586	0.79
1998	1.93	1,355	0.56	3.62	3,440	0.91
1999	1.97	1,270	0.49	3.71	2,072	0.81
2000	2.09	1,278	0.56	3.91	2,072	1.04
2001	2.27	1,330	0.64	4.03	1,553	1.19
2002	2.42	1,364	0.60	4.04	1,405	1.00
2003	2.29	1,395	0.47	3.91	1,588	0.83
2004	2.36	1,446	0.57	4.17	1,722	1.11
2005	2.41	1,418	0.62	4.37	1,785	1.16
2006	2.33	1,383	0.46	4.30	1,761	0.84
2007	2.25	1,347	0.53	4.08	1,605	0.94
2008	2.20	1,294	0.51	3.70	1,451	0.81
2009	2.16	1,217	0.51	3.46	1,325	0.77
2010	2.14	1,097	0.57	3.46	1,071	0.97
2011	2.09	1,085	0.54	3.19	898	0.89
2012	1.99	1,247	0.35	2.78	1,022	0.38
2013	2.01	1,459	0.40	2.72	1,254	0.52

Figure A5. 1. Predicted and observed catch (top) and standardized residuals for MARI ï LIS regions.

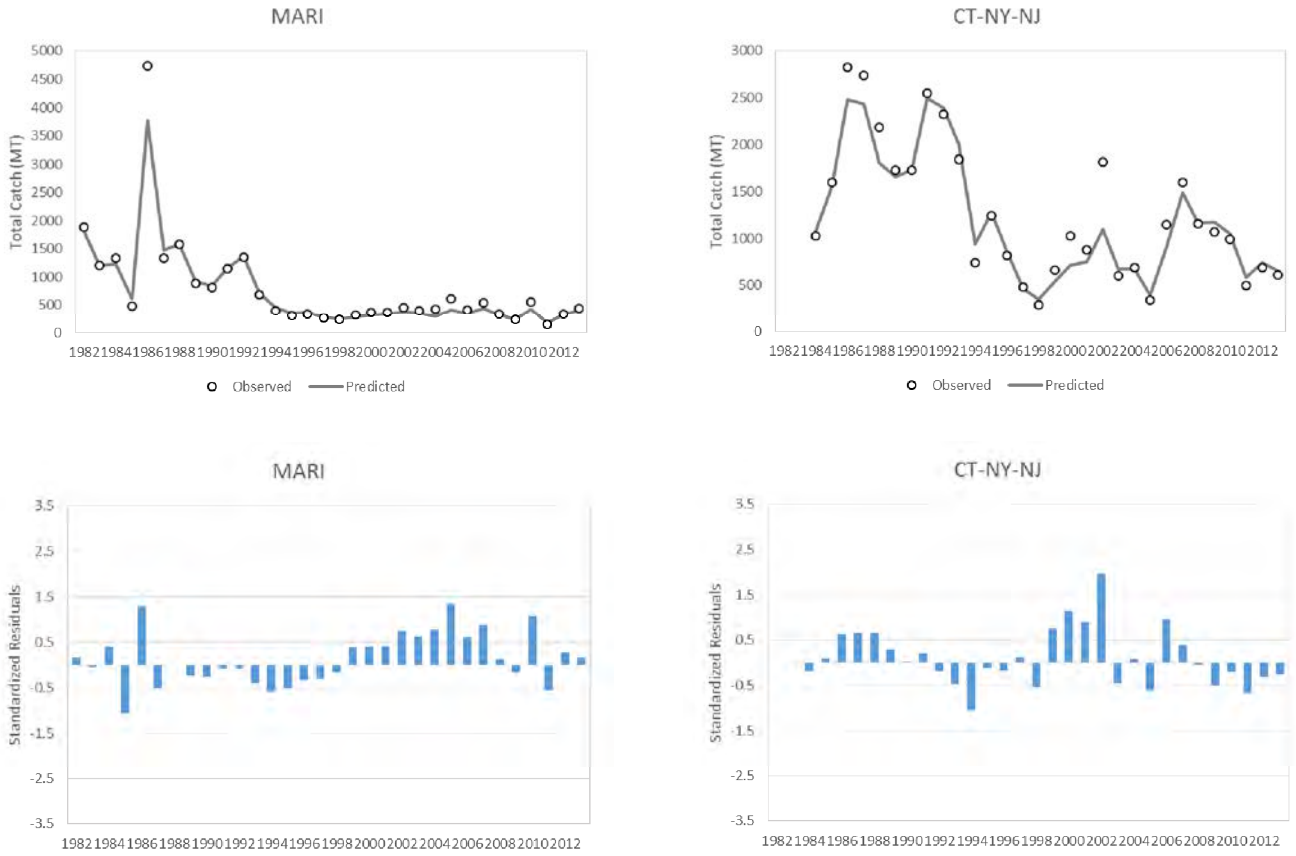


Figure A5. 2. Fishery independent index fit and residuals for LIS region (CT-NY-NJ)

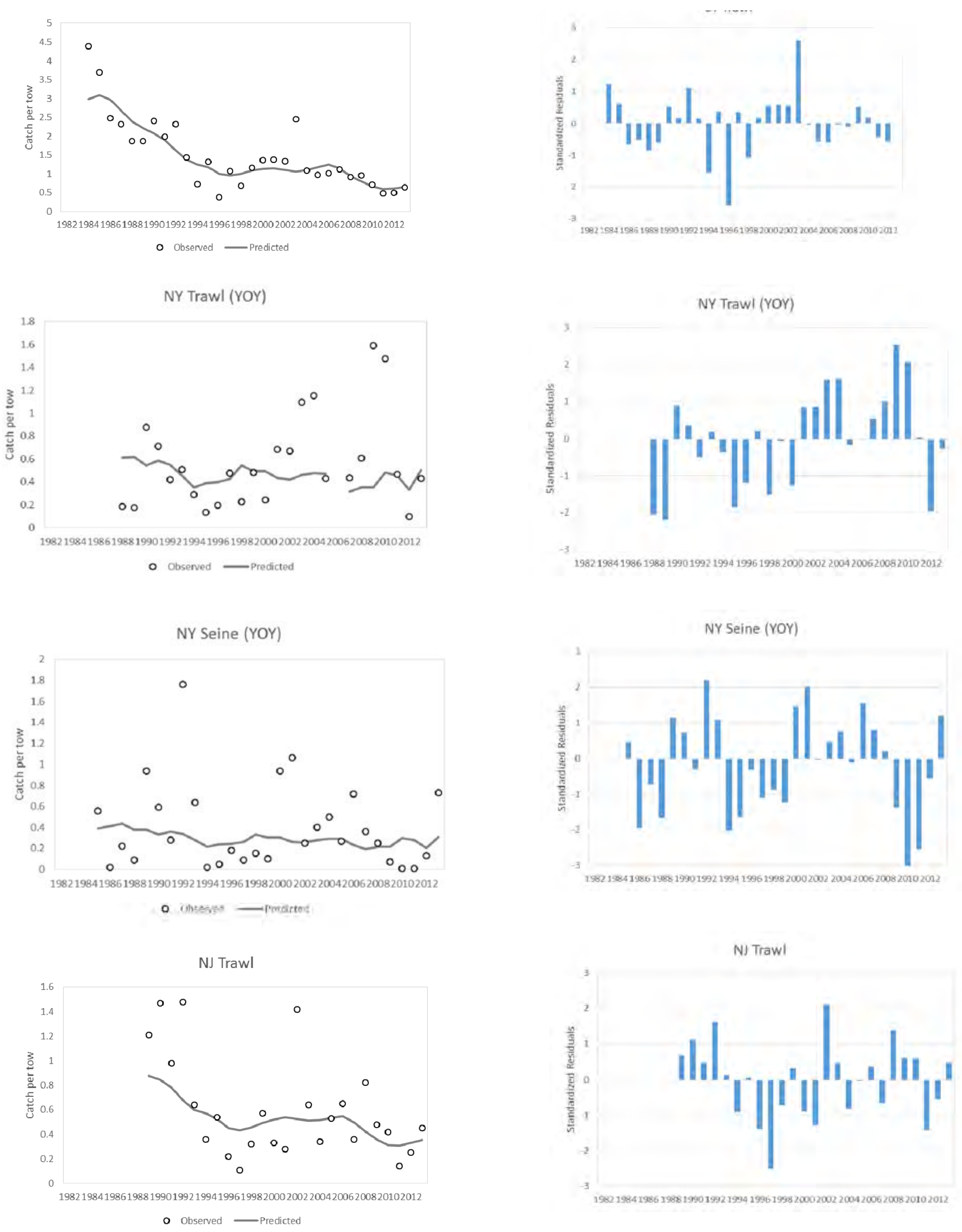


Figure A5. 3. Fishery independent index fit for MA-RI region.

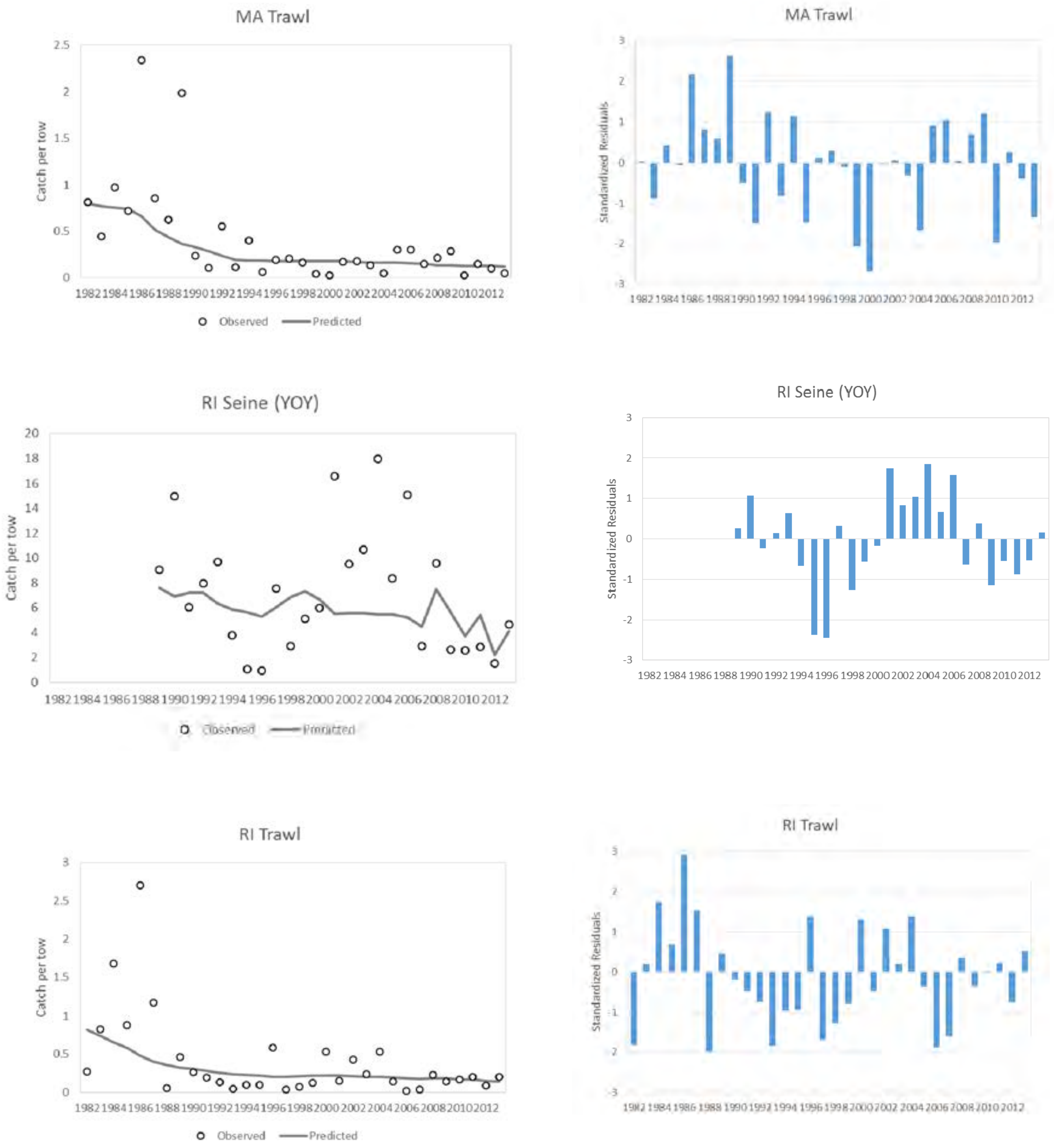


Figure A5. 4. Fishery dependent index fit for MARI-LIS regional split.

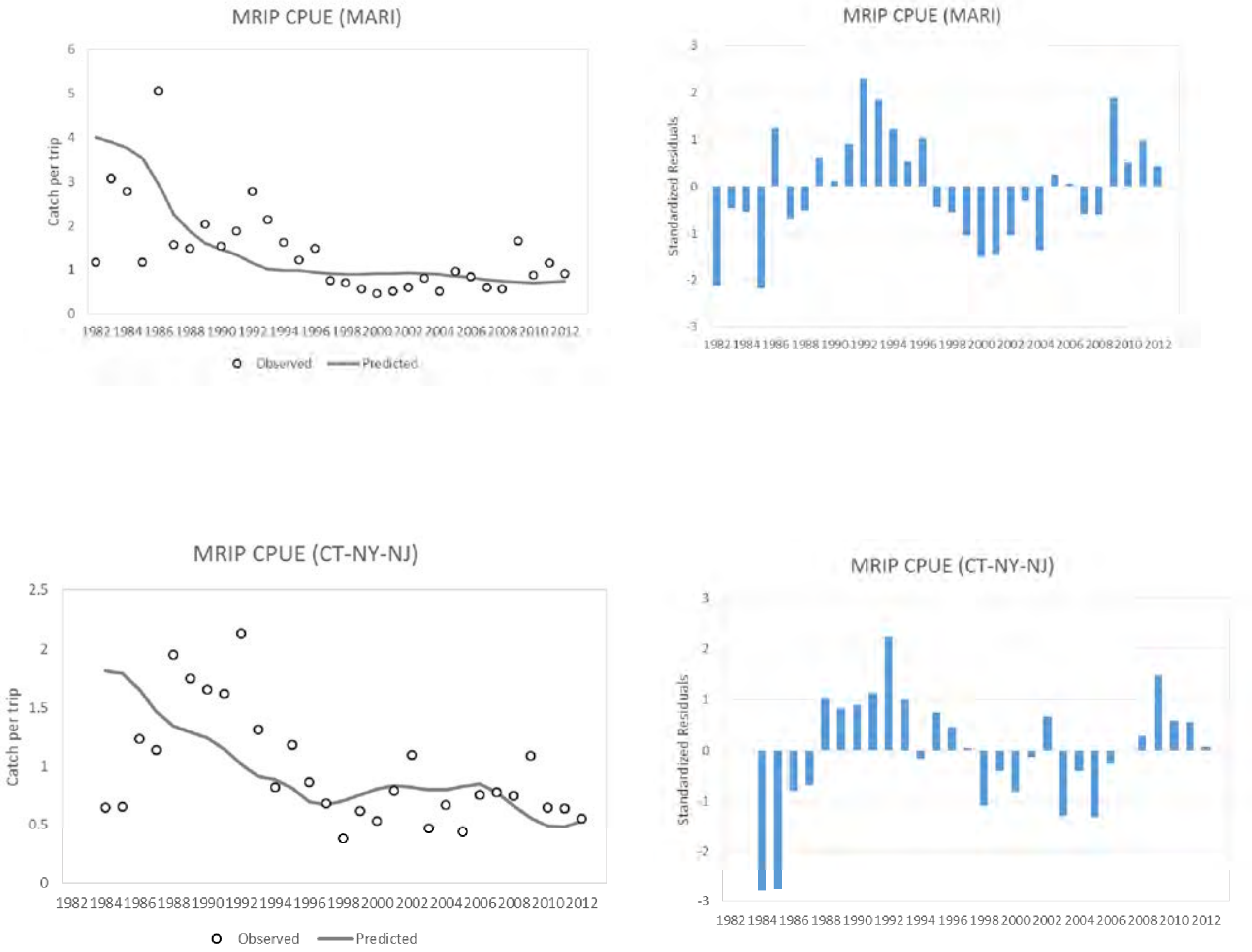


Figure A5. 5. Observed and predicted catch-at-age for MARI region.

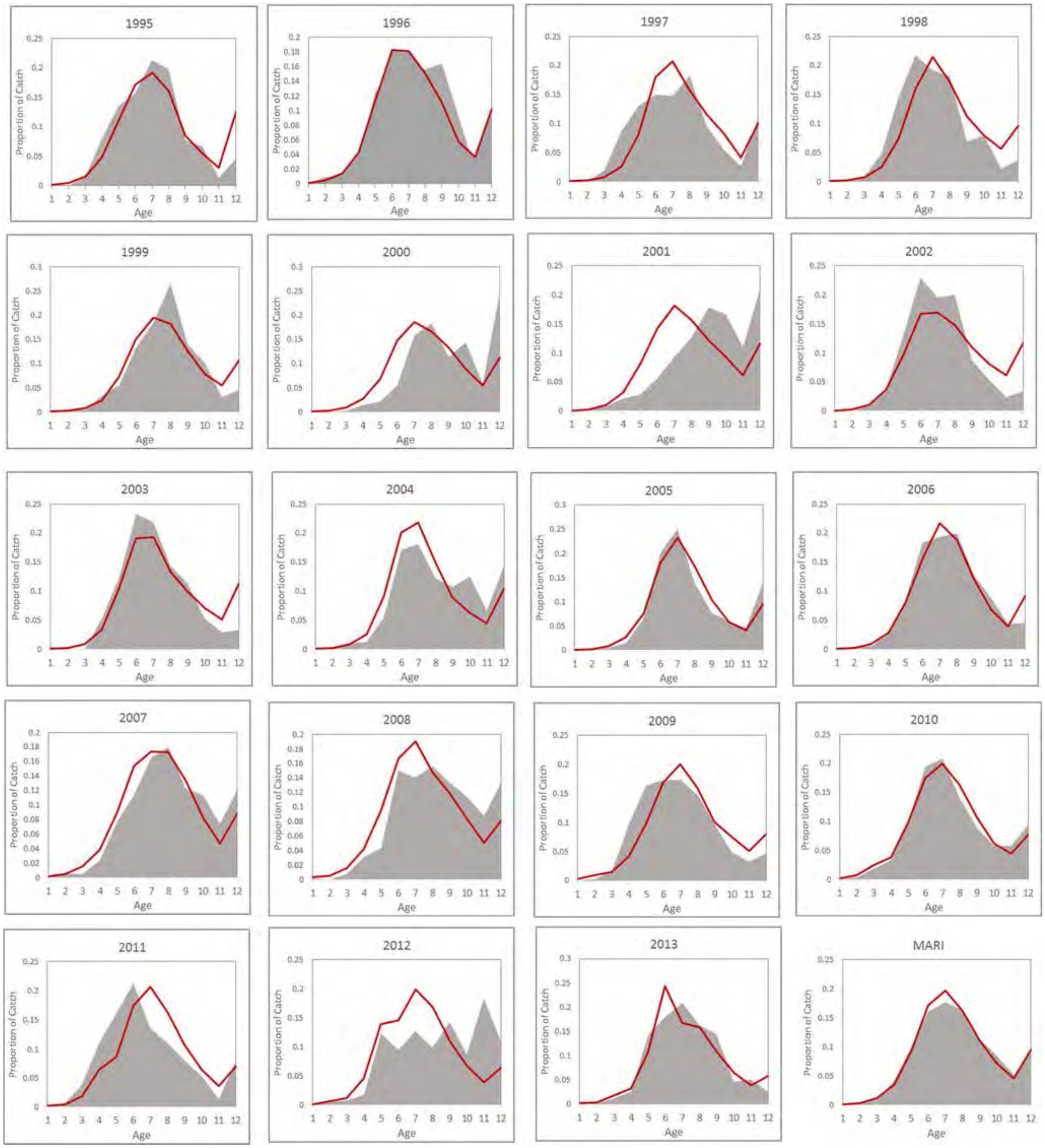


Figure A5. 6. Observed and predicted catch-at-age for LIS region (CT-NY-NJ)

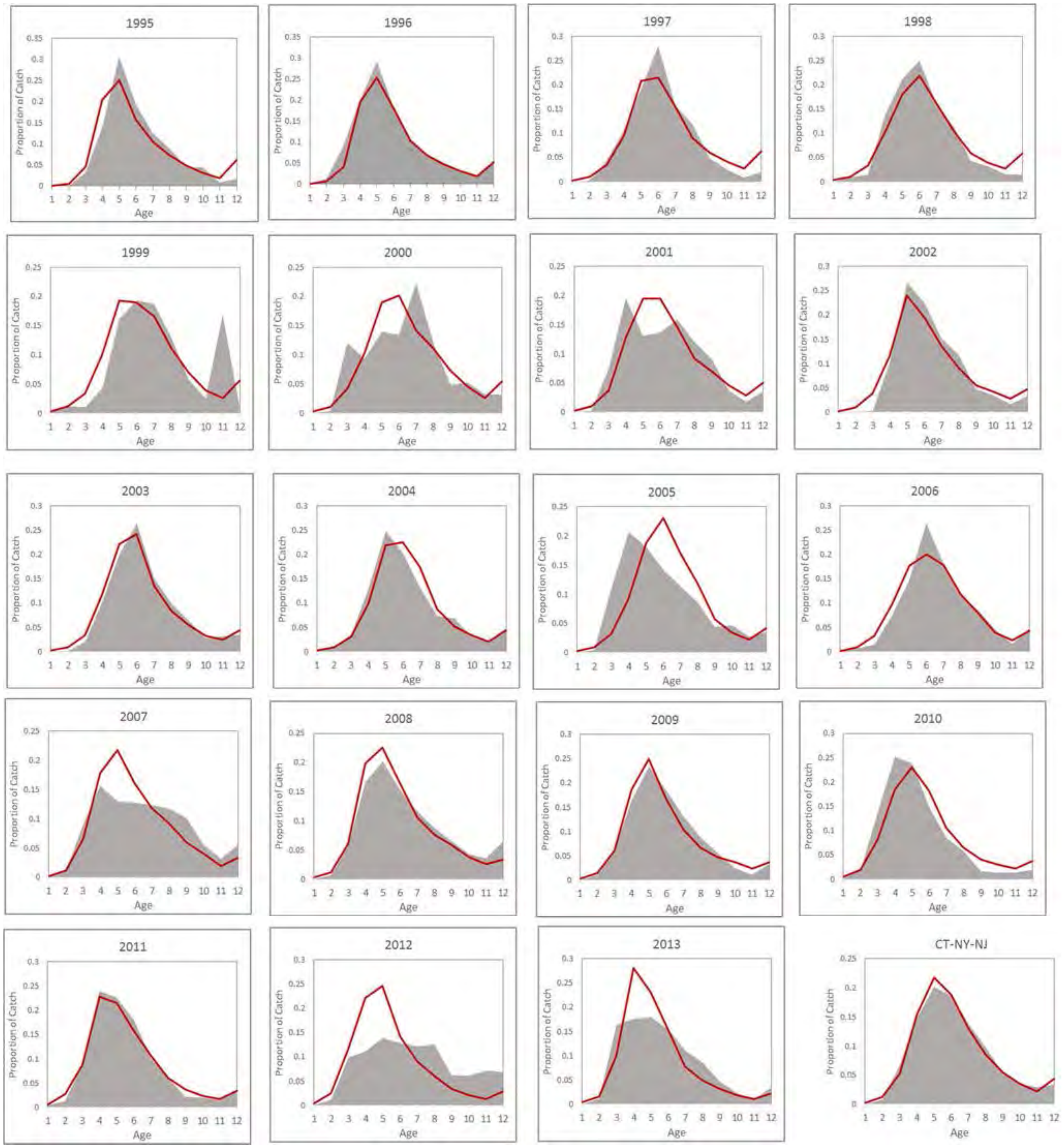


Figure A5. 7. Total observed and predicted index-at-age for MARI region.

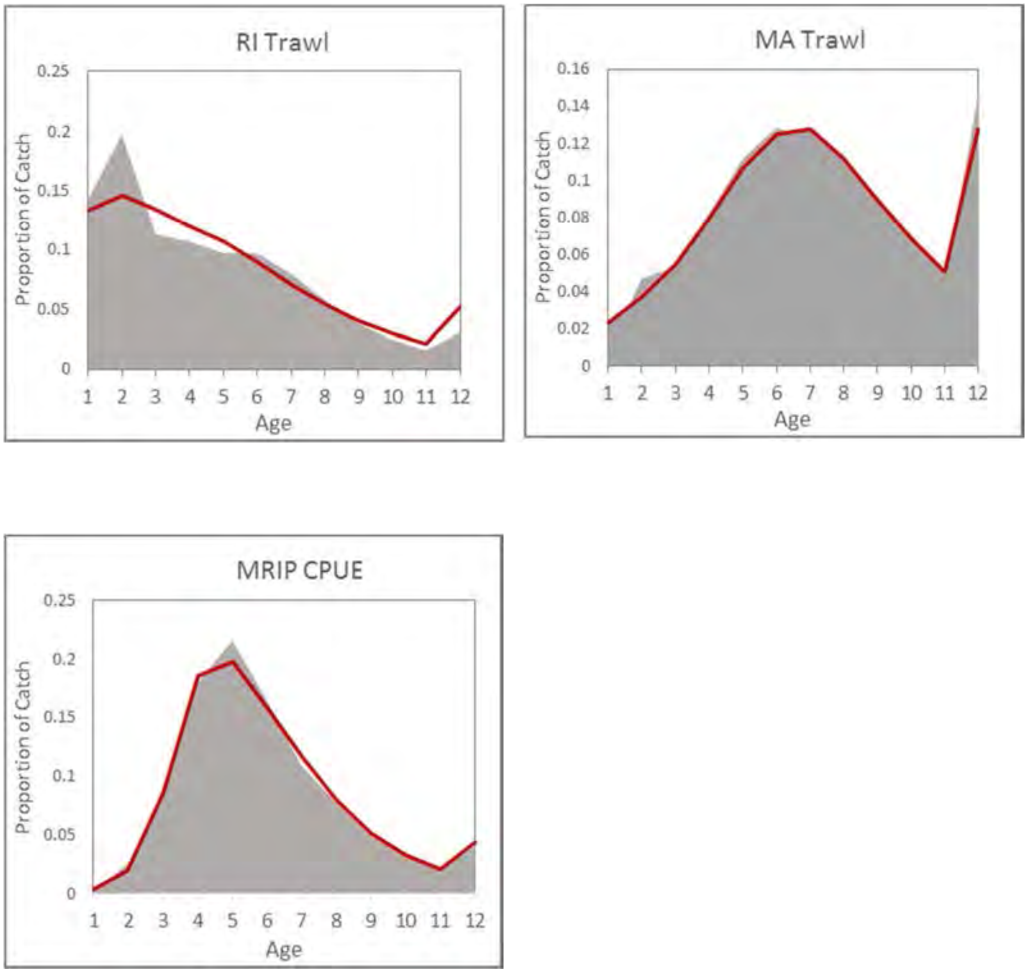


Figure A5. 8. Total observed and predicted index-at-age for LIS region (CT-NY-NJ).

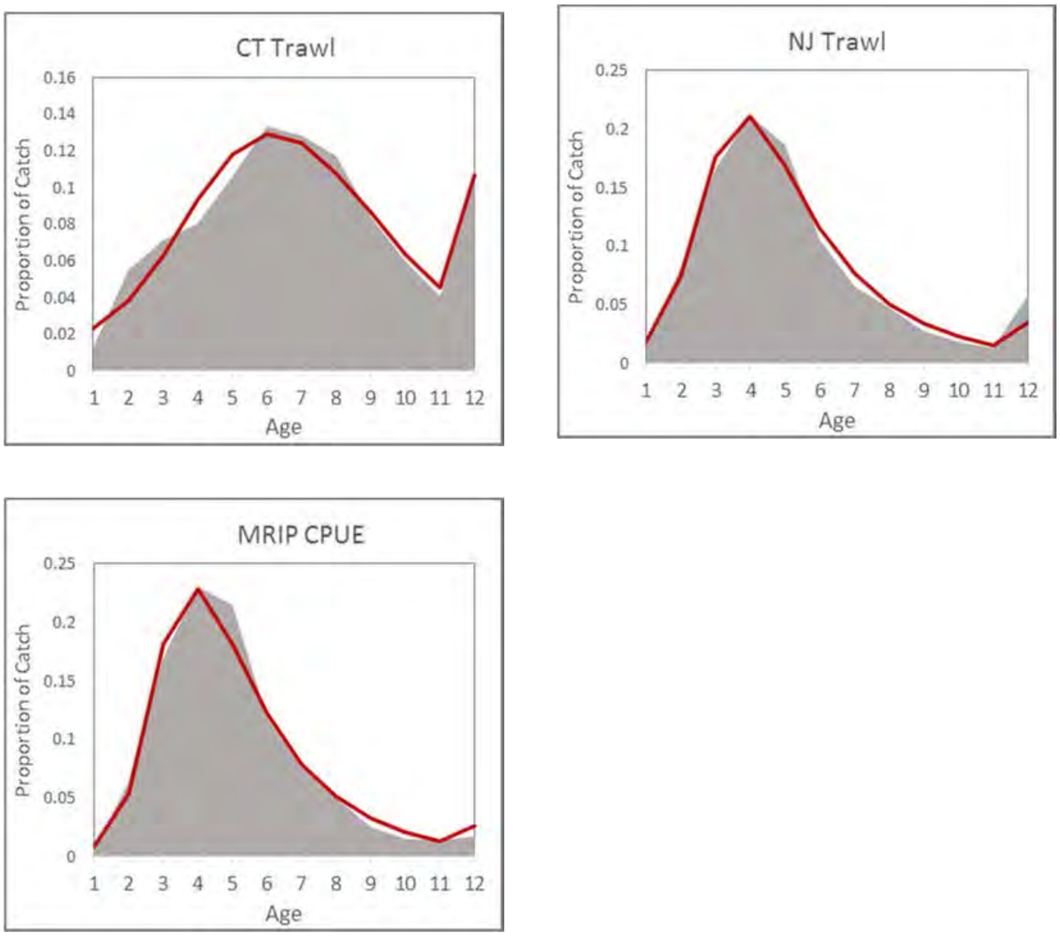
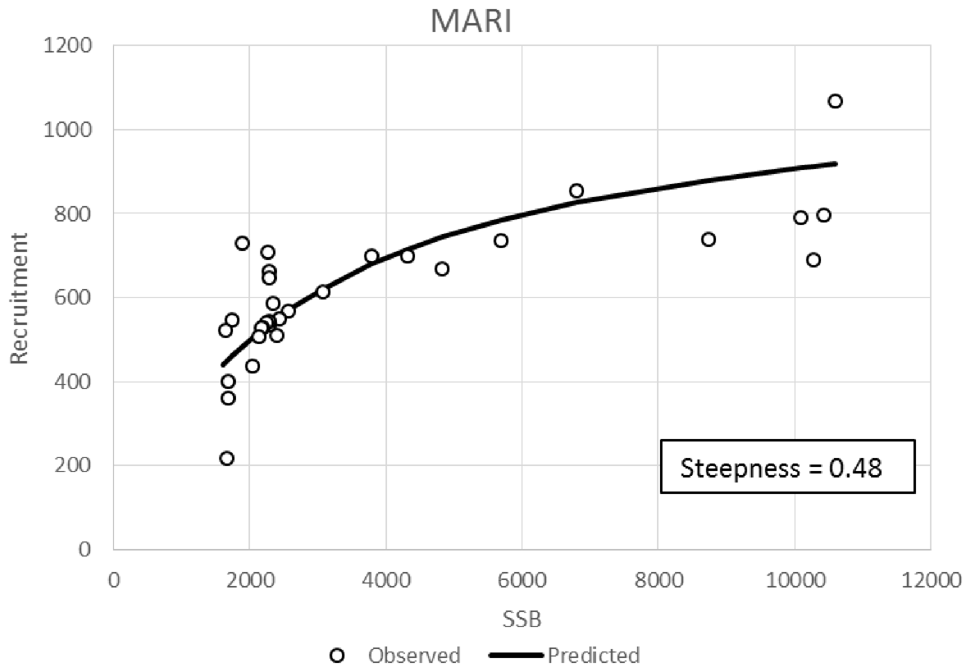


Figure A5. 9. Stock-recruitment curves for MARI (top) and LIS (bottom) regions.



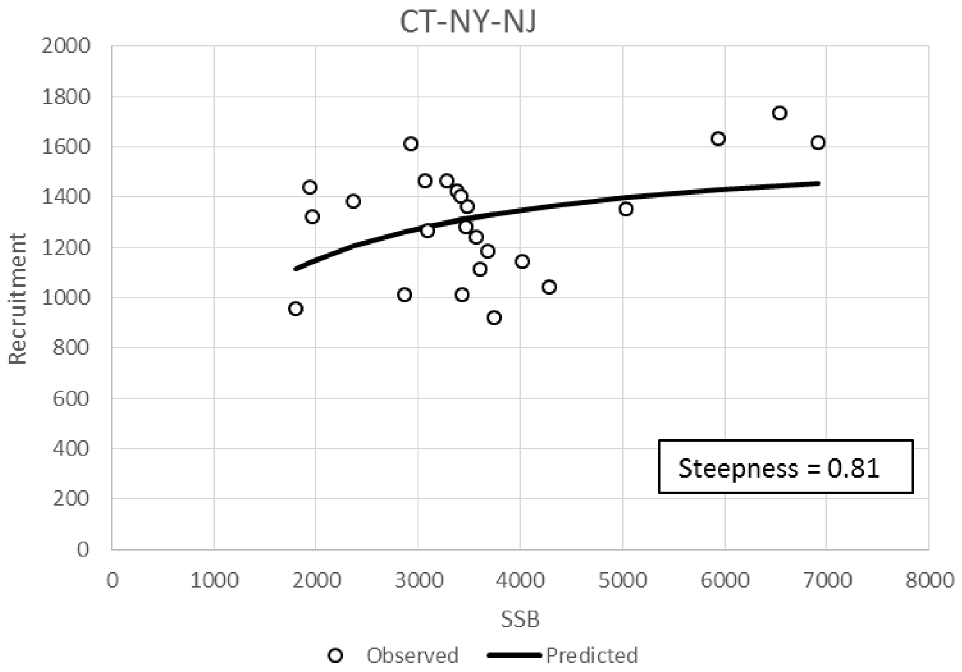
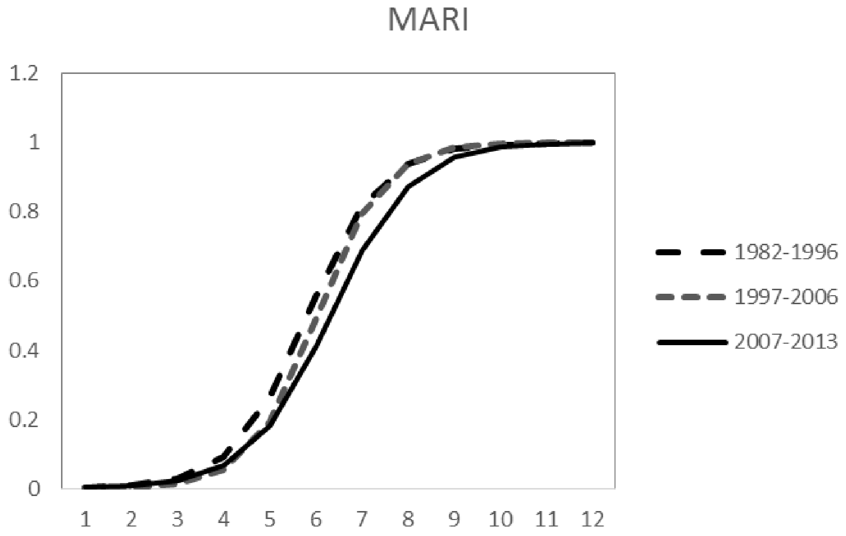


Figure A5. 10. Estimated selectivity curves for MARI (top) and LIS (bottom) regions.



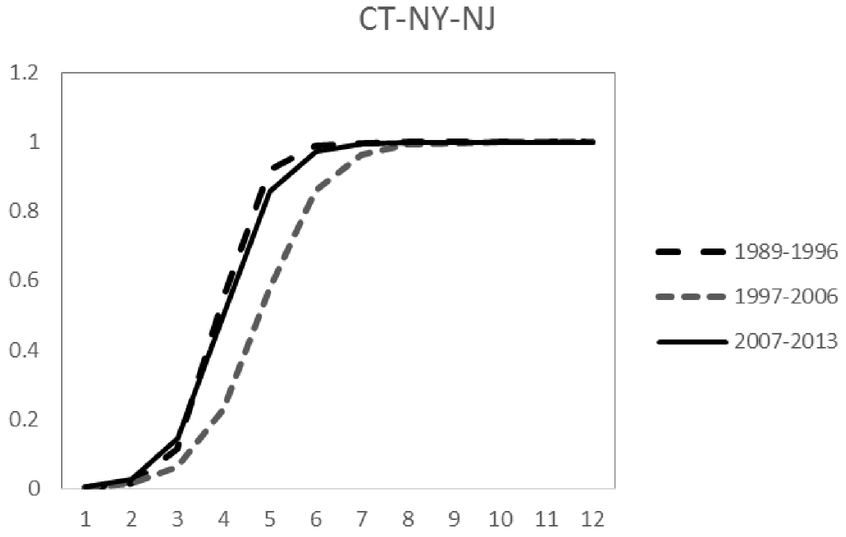
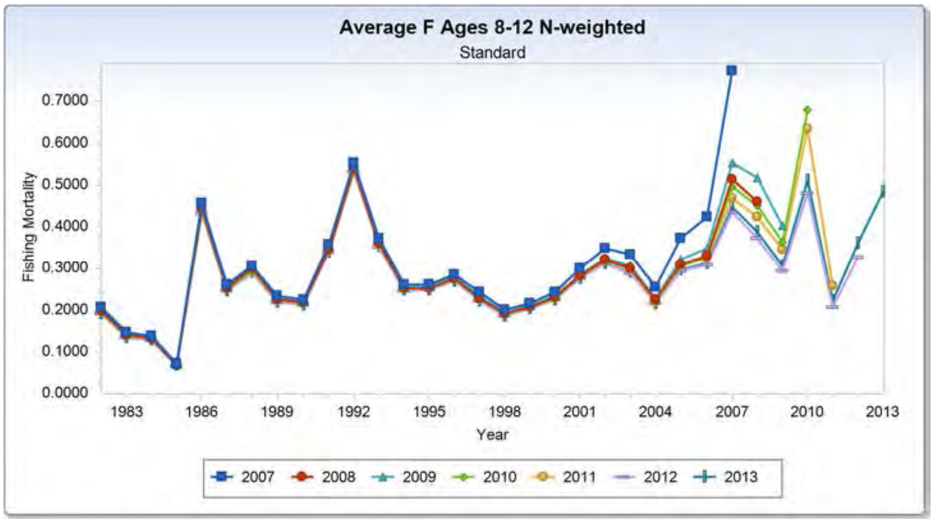
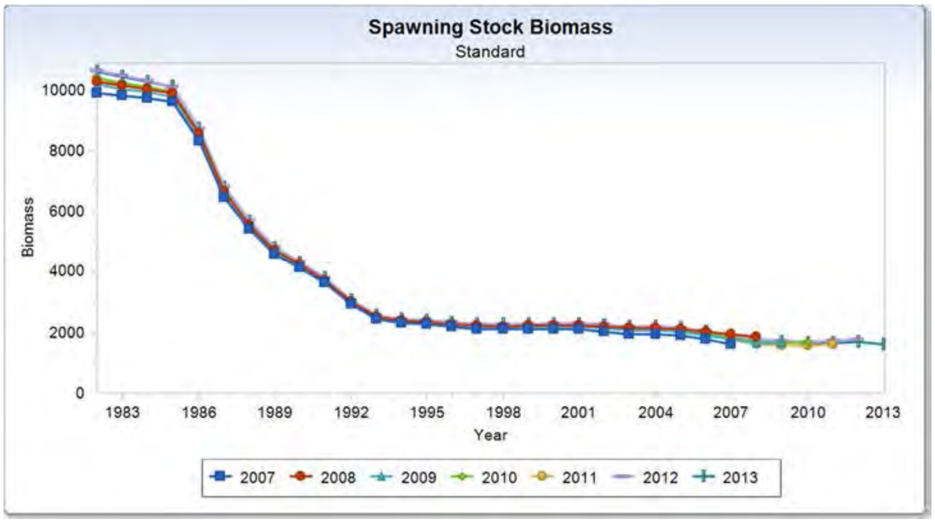


Figure A5. 11. Retrospective patterns for MARI region.





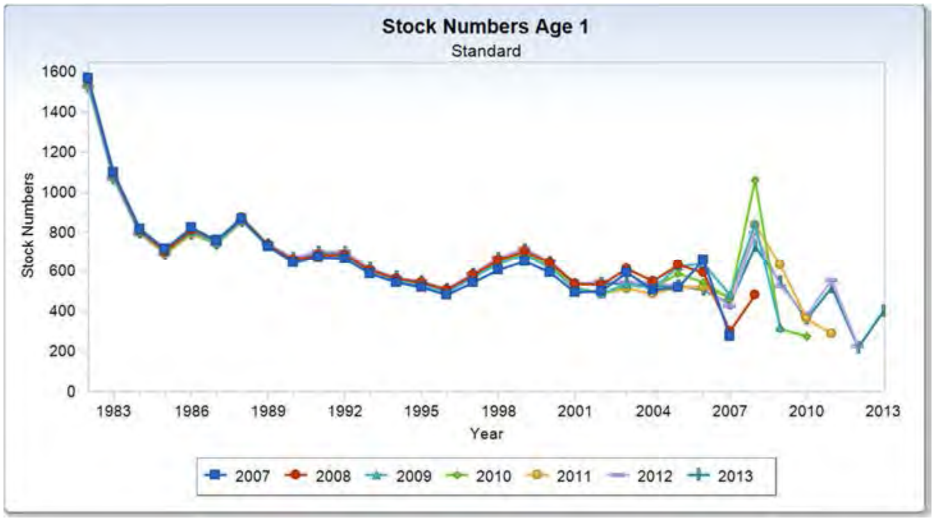


Figure A5. 12. Retrospective patterns for LIS (CT-NY-NJ) region.

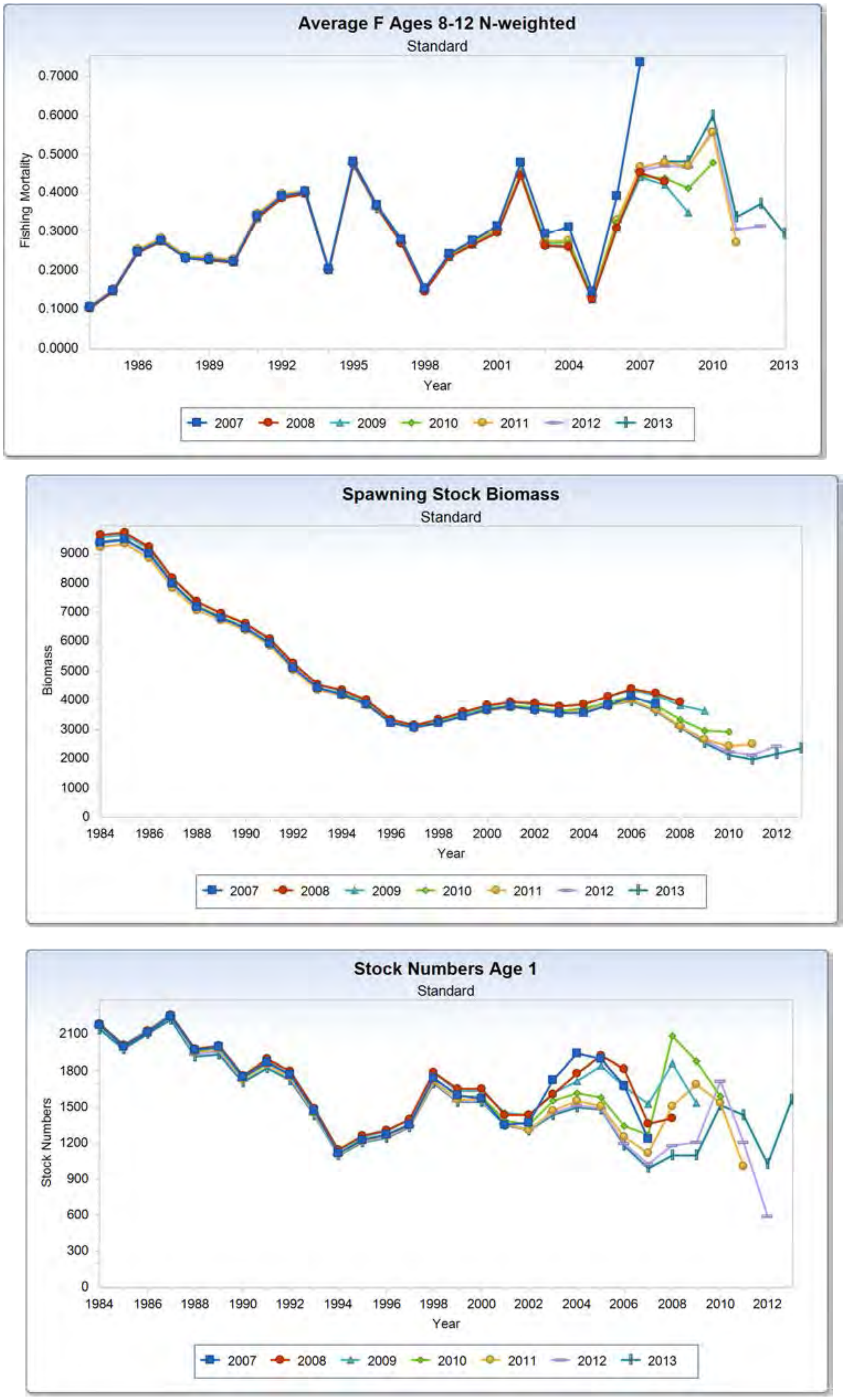


Figure A5. 13. Observed and predicted total catch and standardized residuals for North-South regional split.

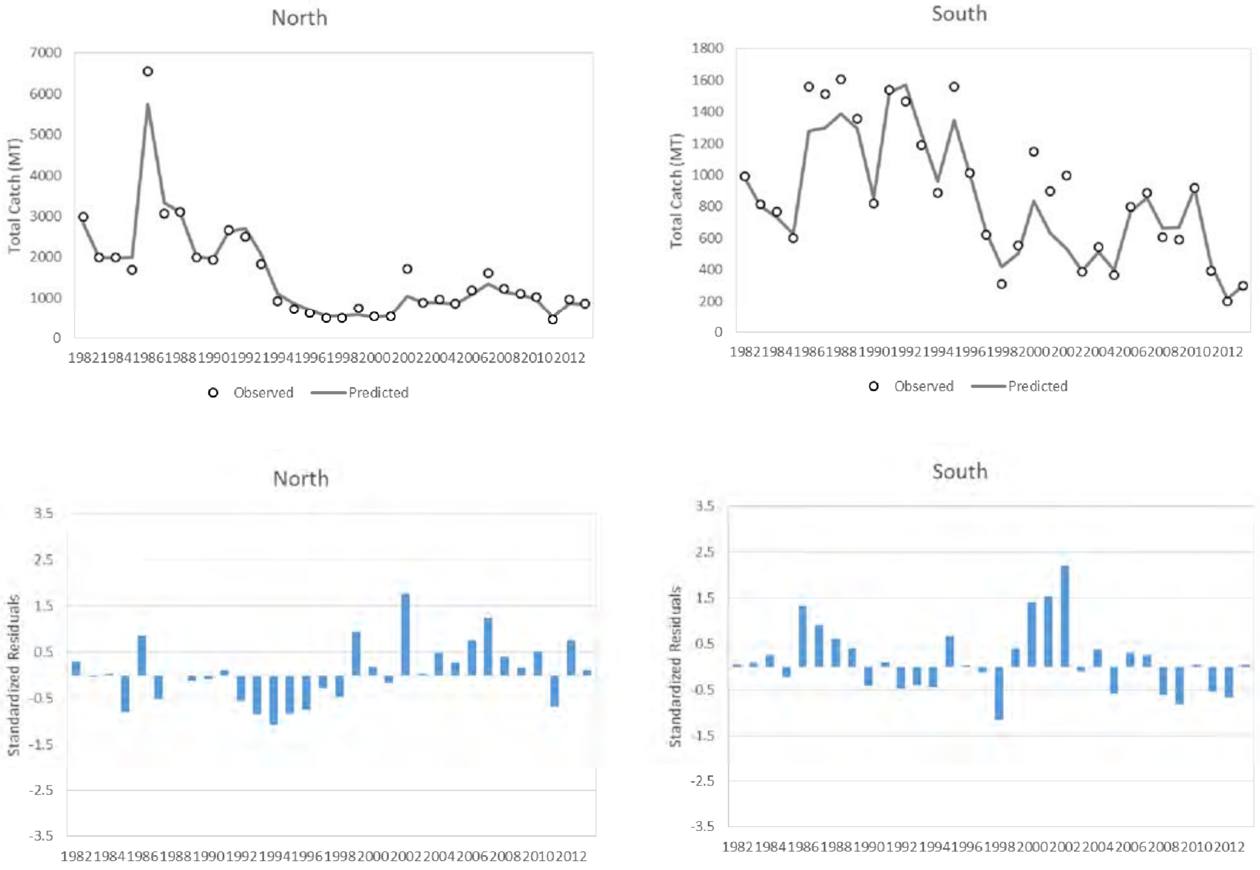


Figure A5. 14. Index fit for North region adult indices.

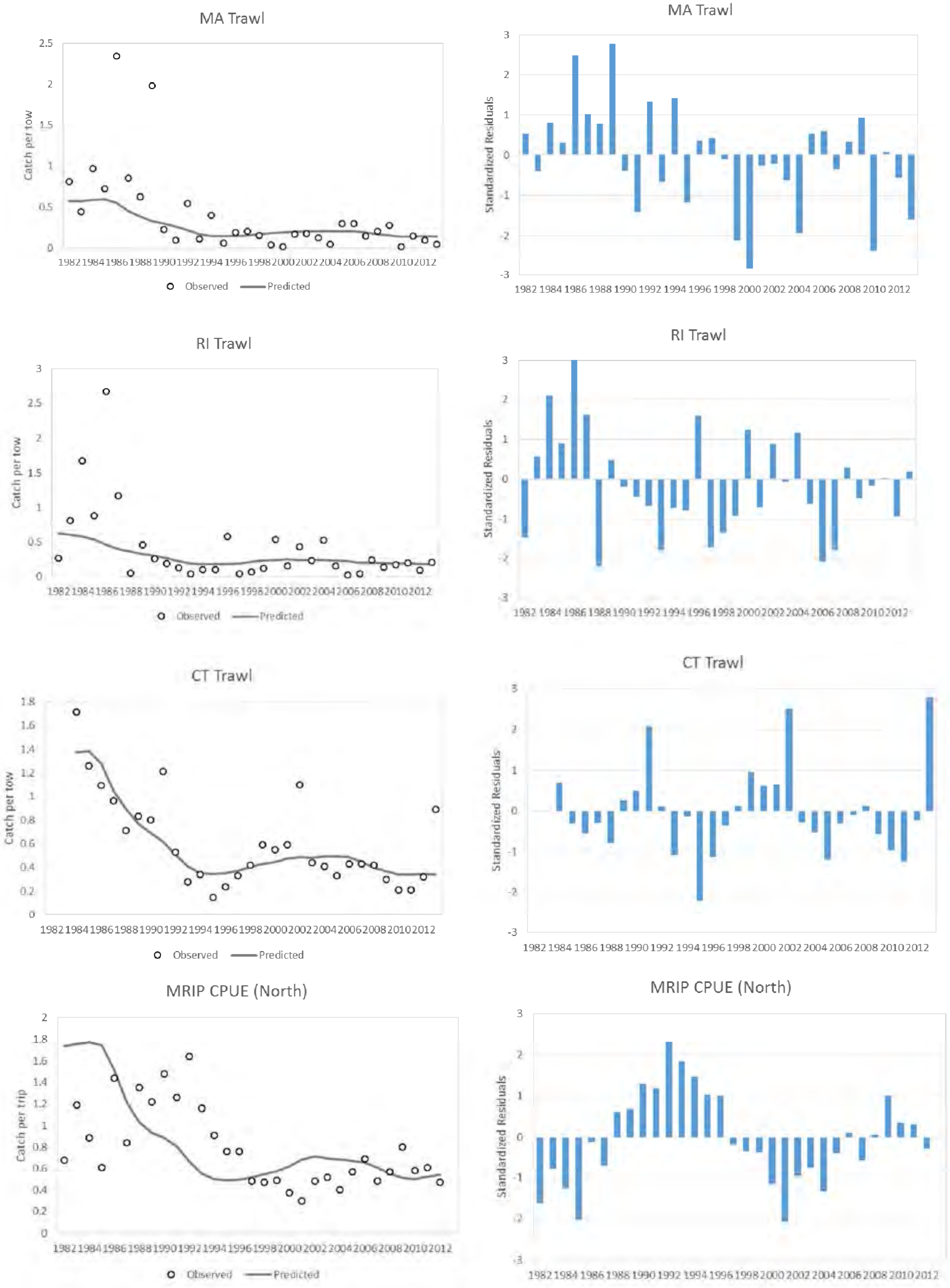


Figure A5. 15. Index fit for North region young-of-year indices.

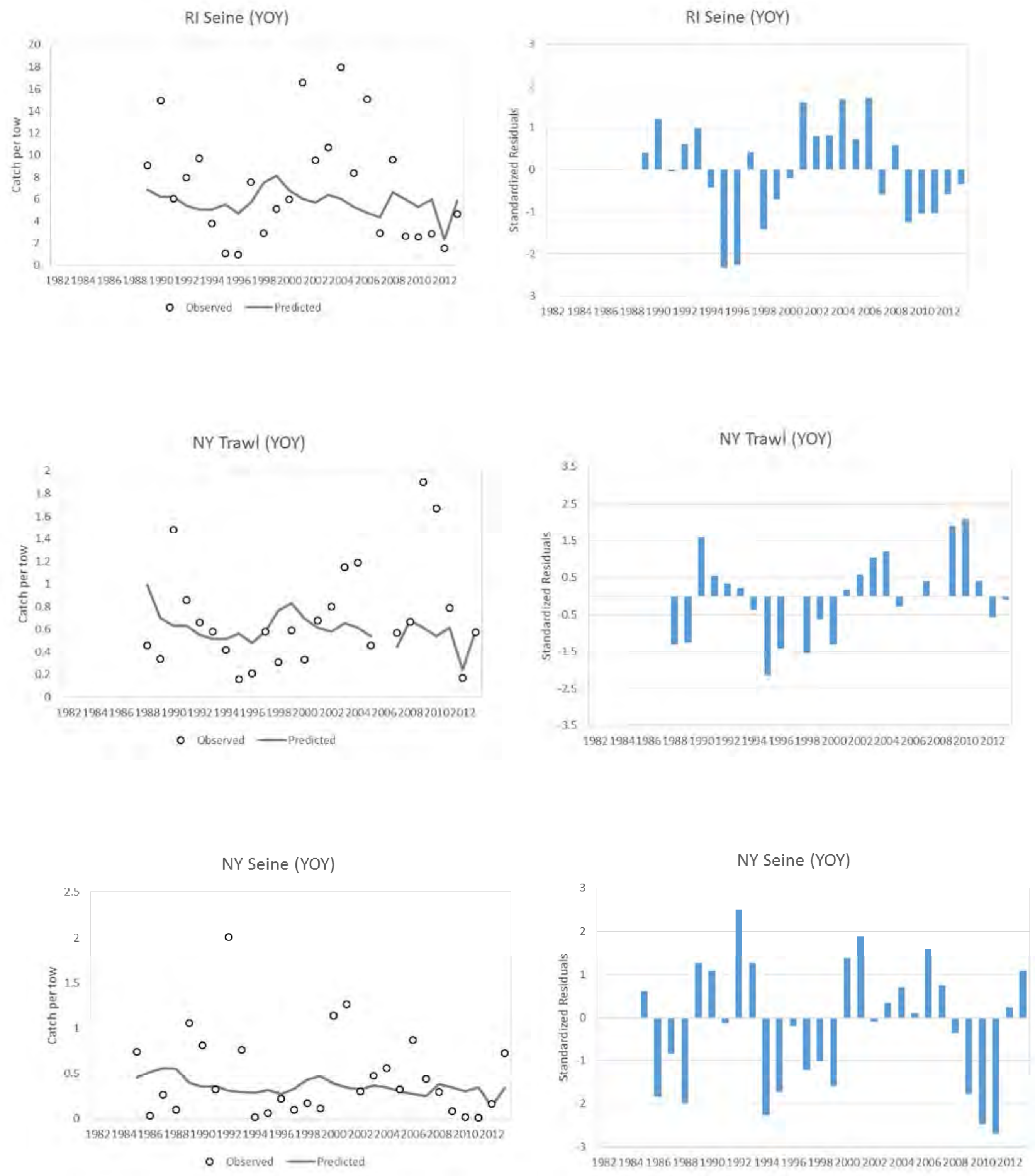


Figure A5. 16. Index fit for South region indices.

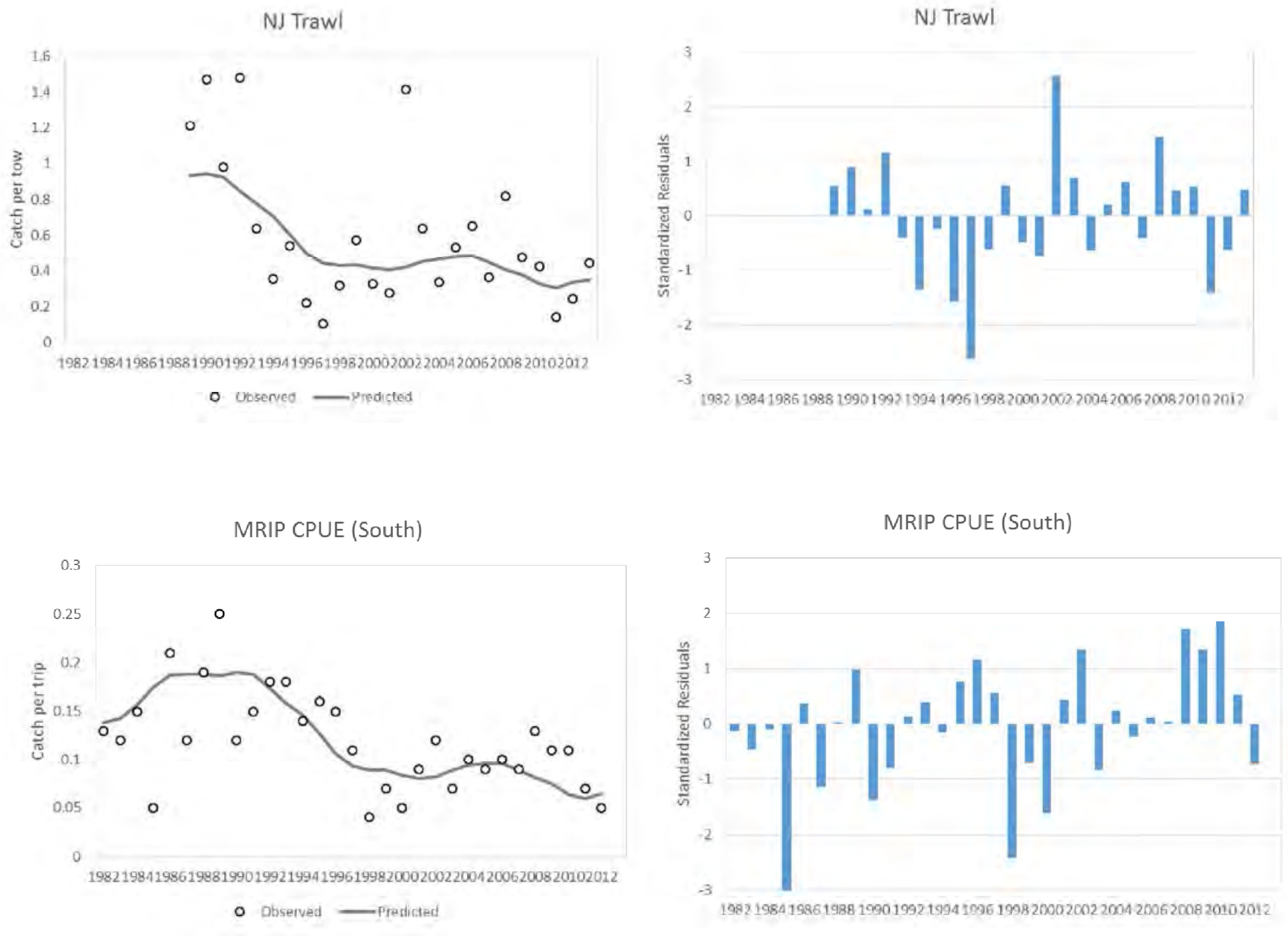
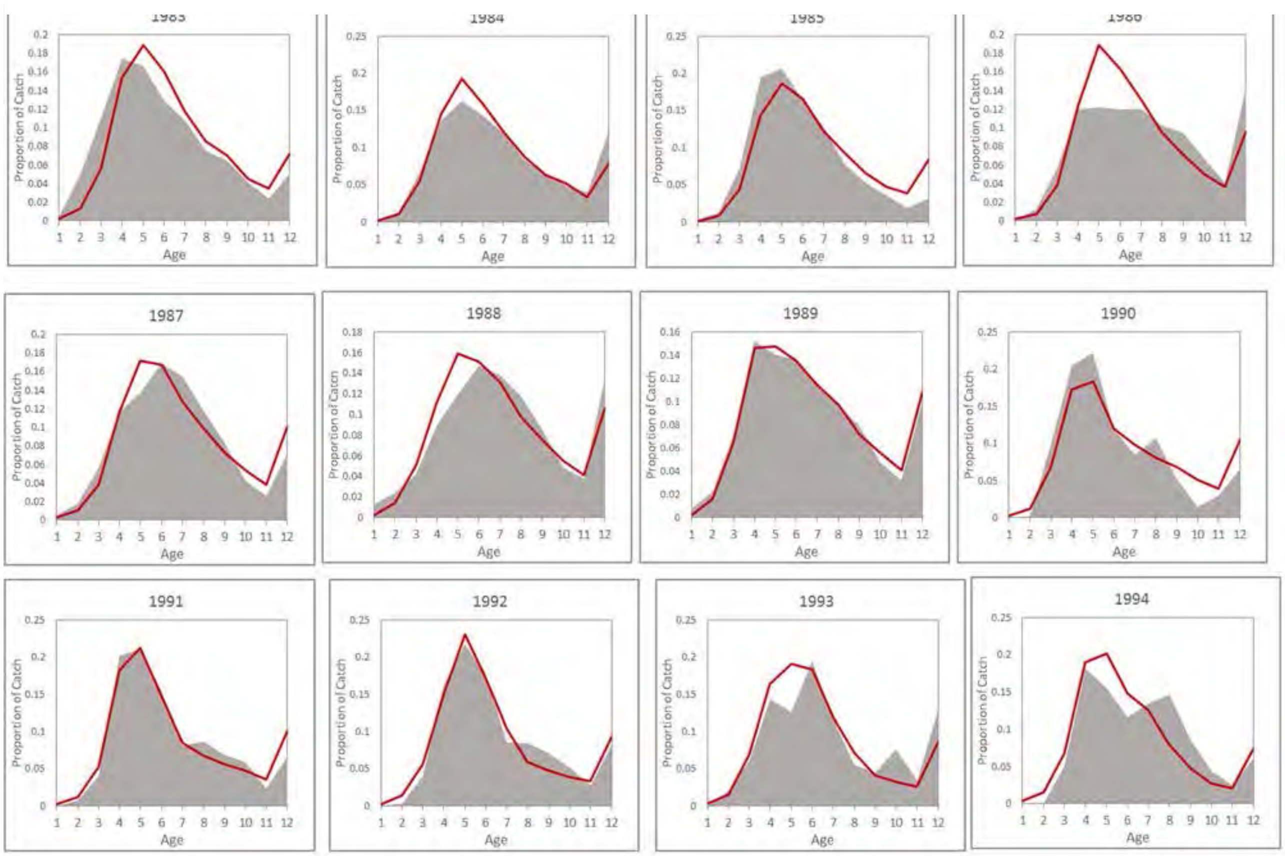


Figure A5. 17. Observed and predicted catch-at-age for the North region.



Observed and predicted catch-at-age for the North region (cont.).

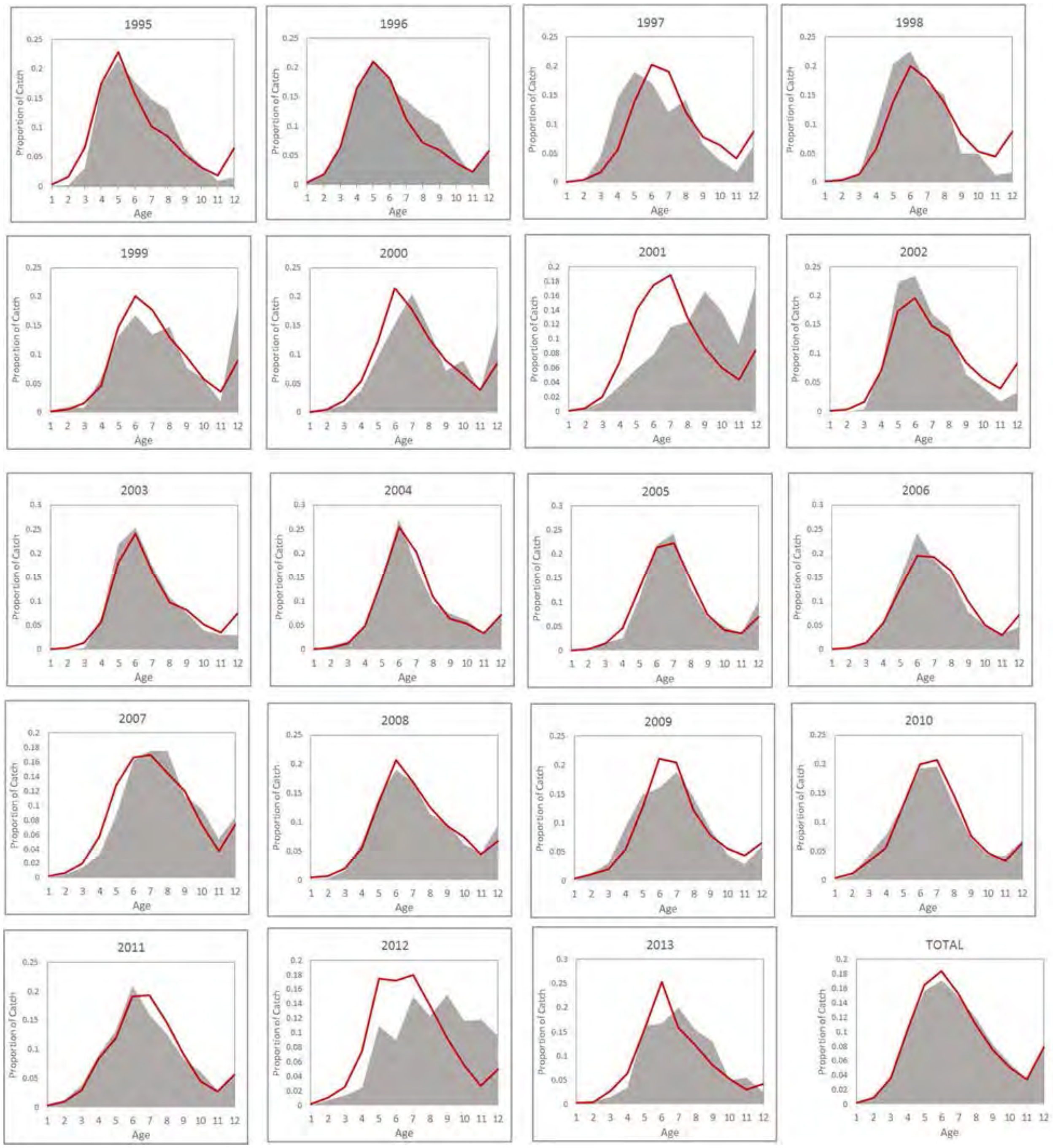
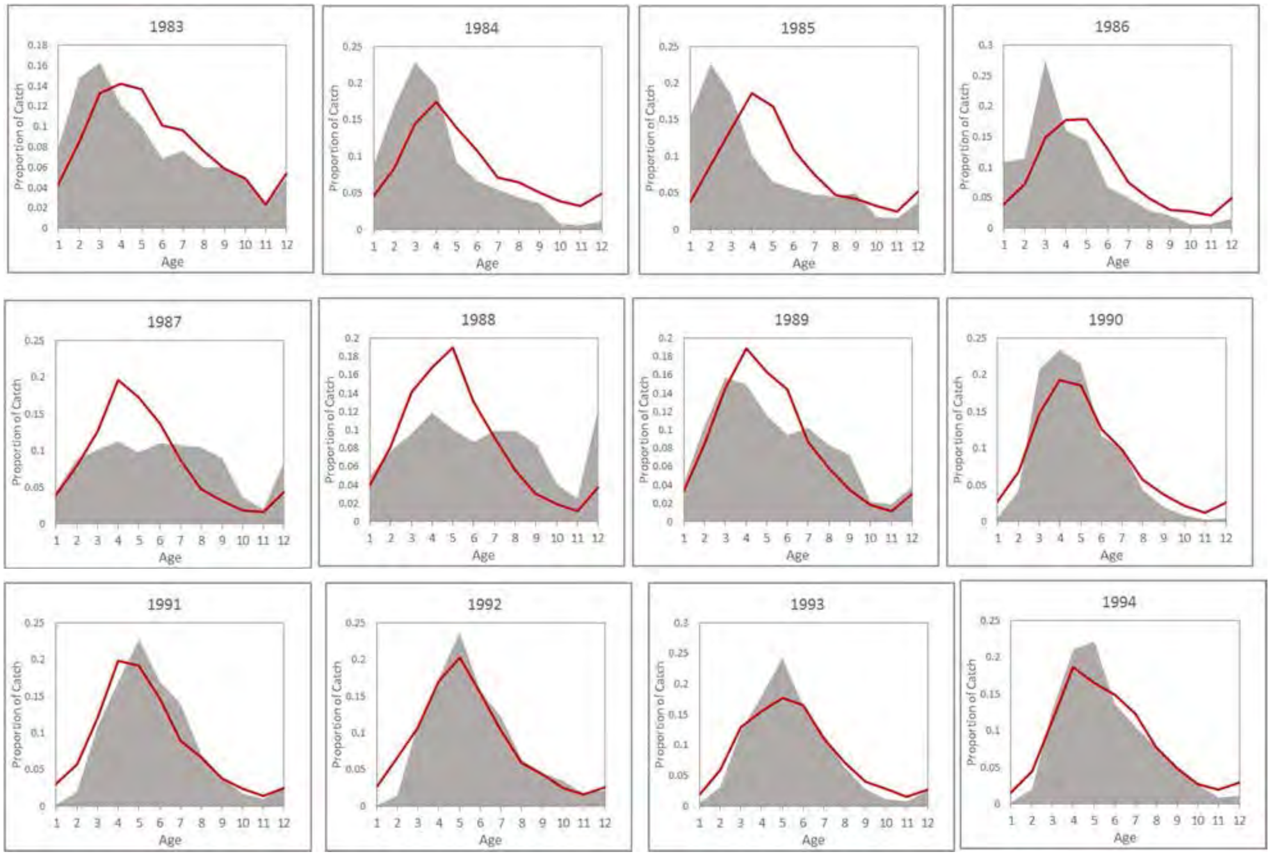


Figure A5. 18. Observed and predicted catch-at-age for the South region.



Observed and predicted catch-at-age for the South region (cont.)

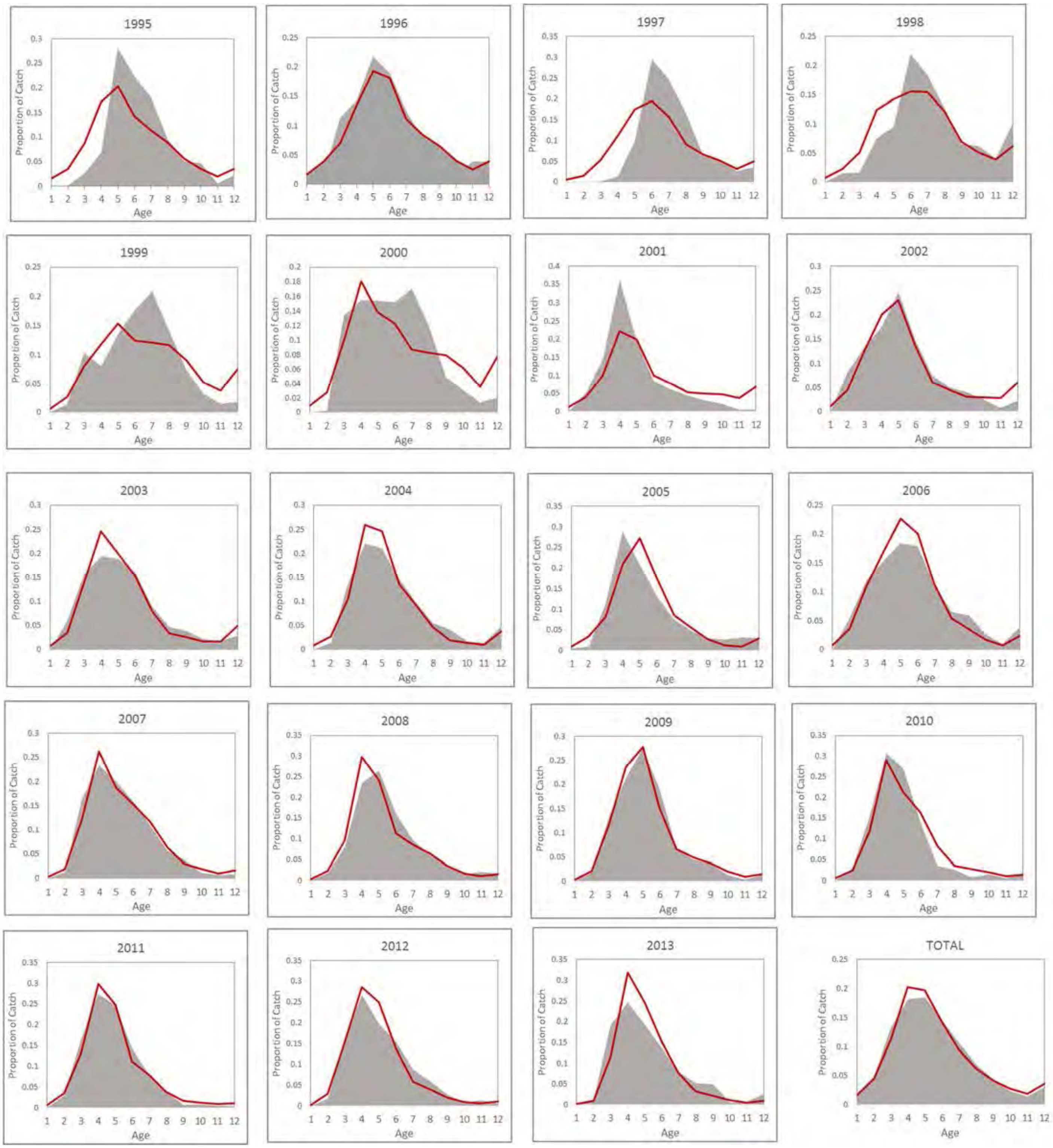


Figure A5. 19. Total observed and predicted index-at-age data for North region.

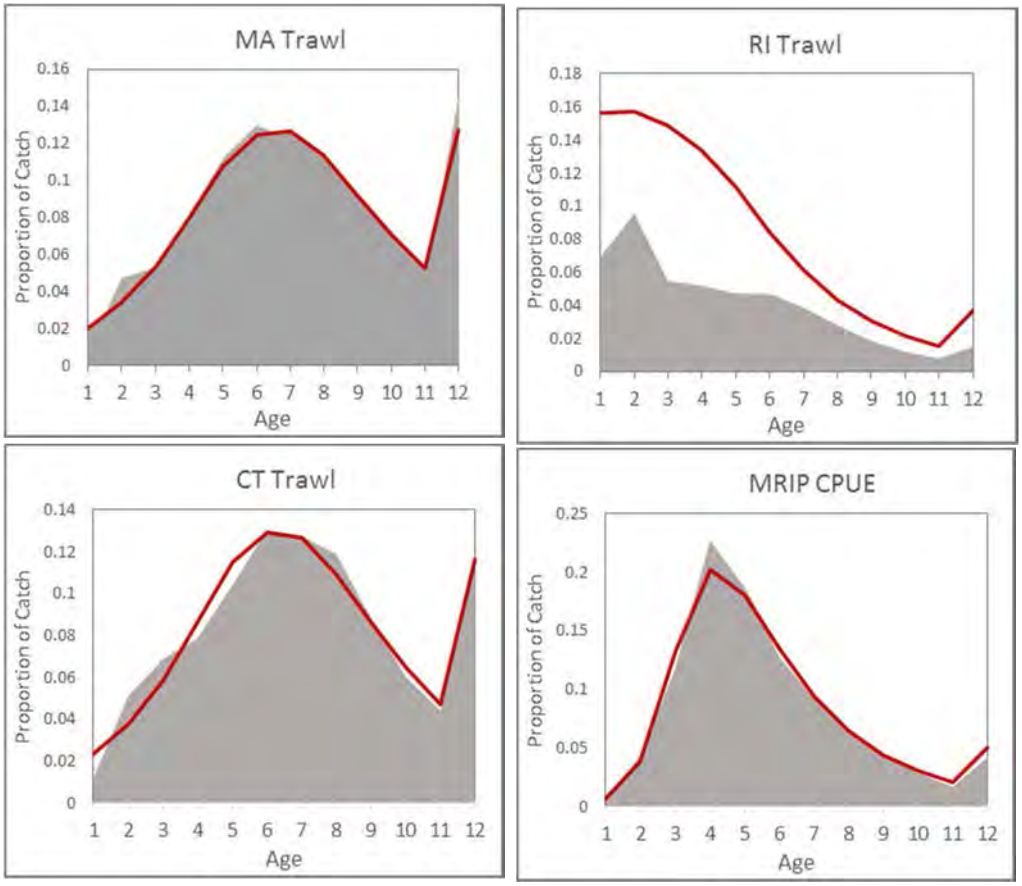


Figure A5. 20. Total observed and predicted index-at-age data for South region.

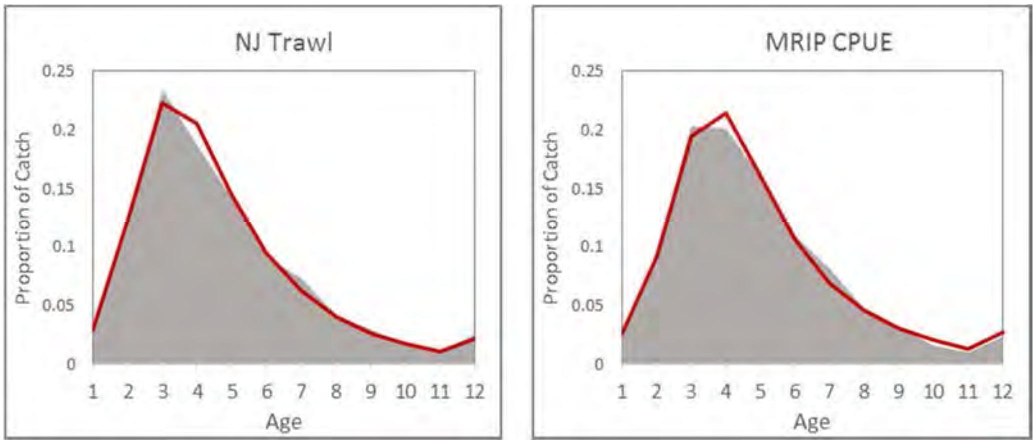
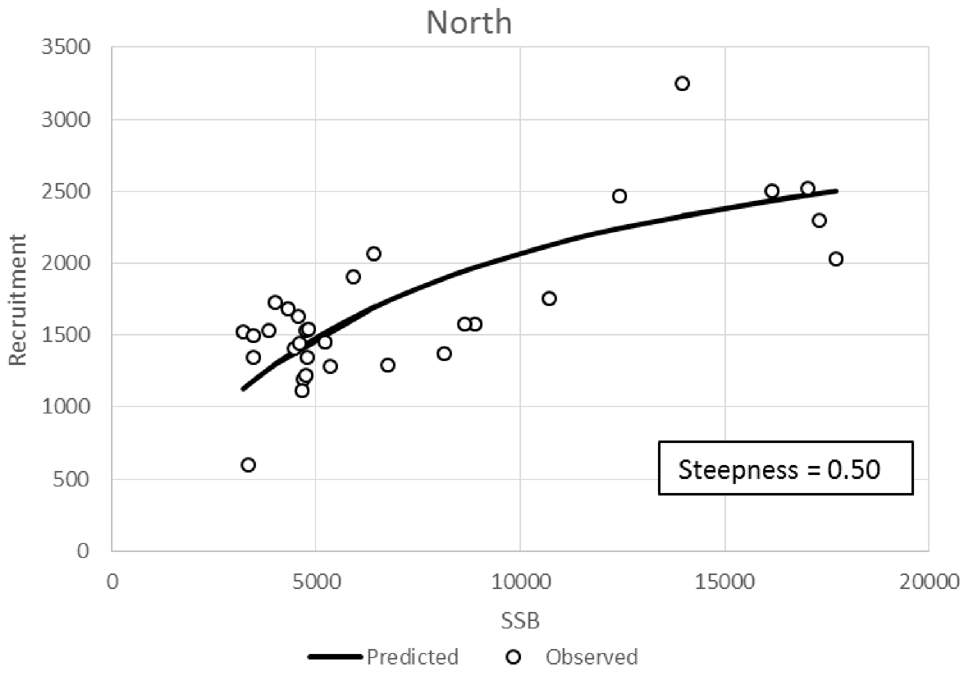


Figure A5. 21. Stock-recruitment curves for North and South regions.



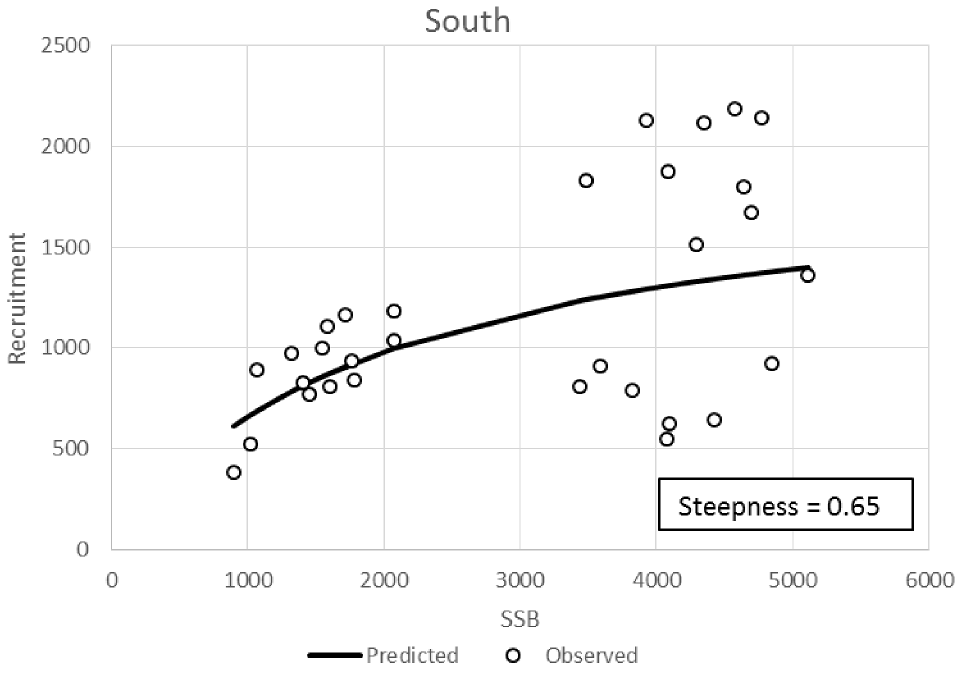


Figure A5. 22. Estimated selectivity curves for North and South regions.

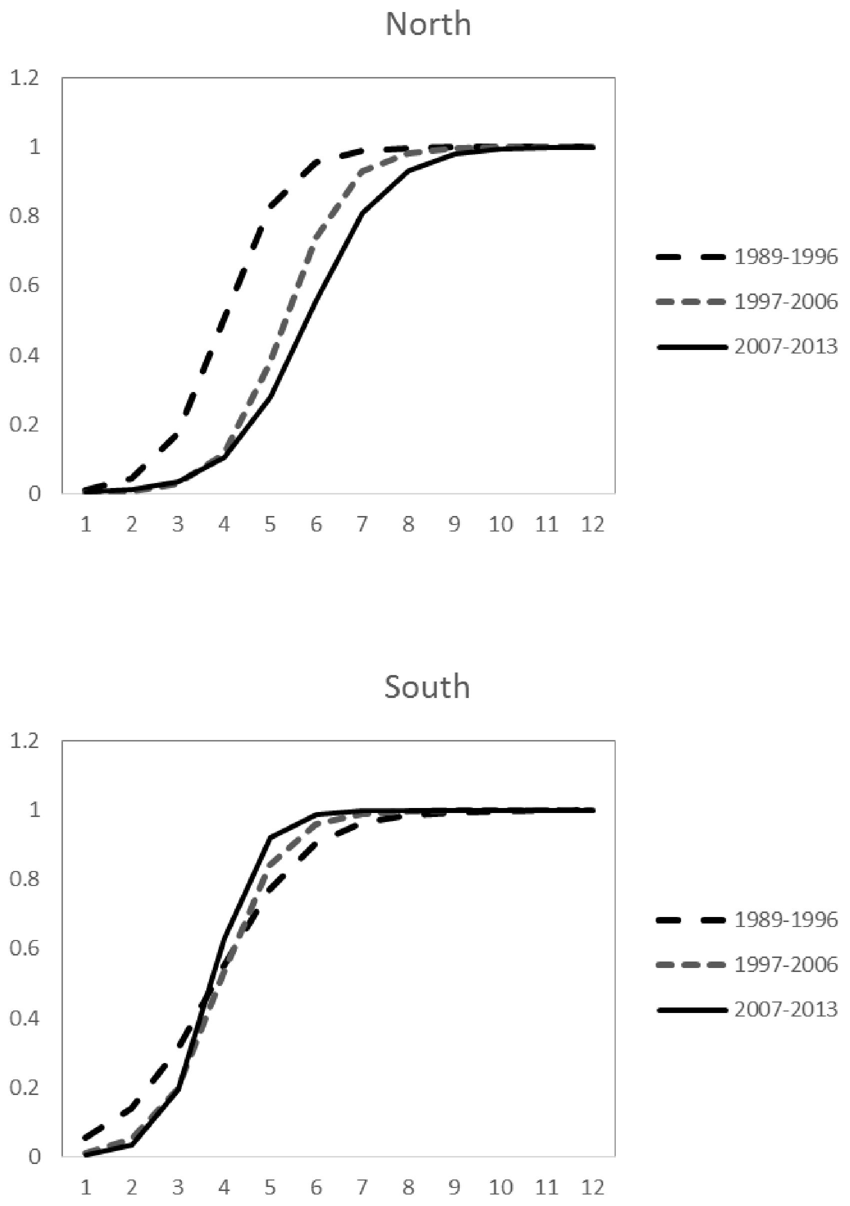


Figure A5. 23. Retrospective patterns for North region.

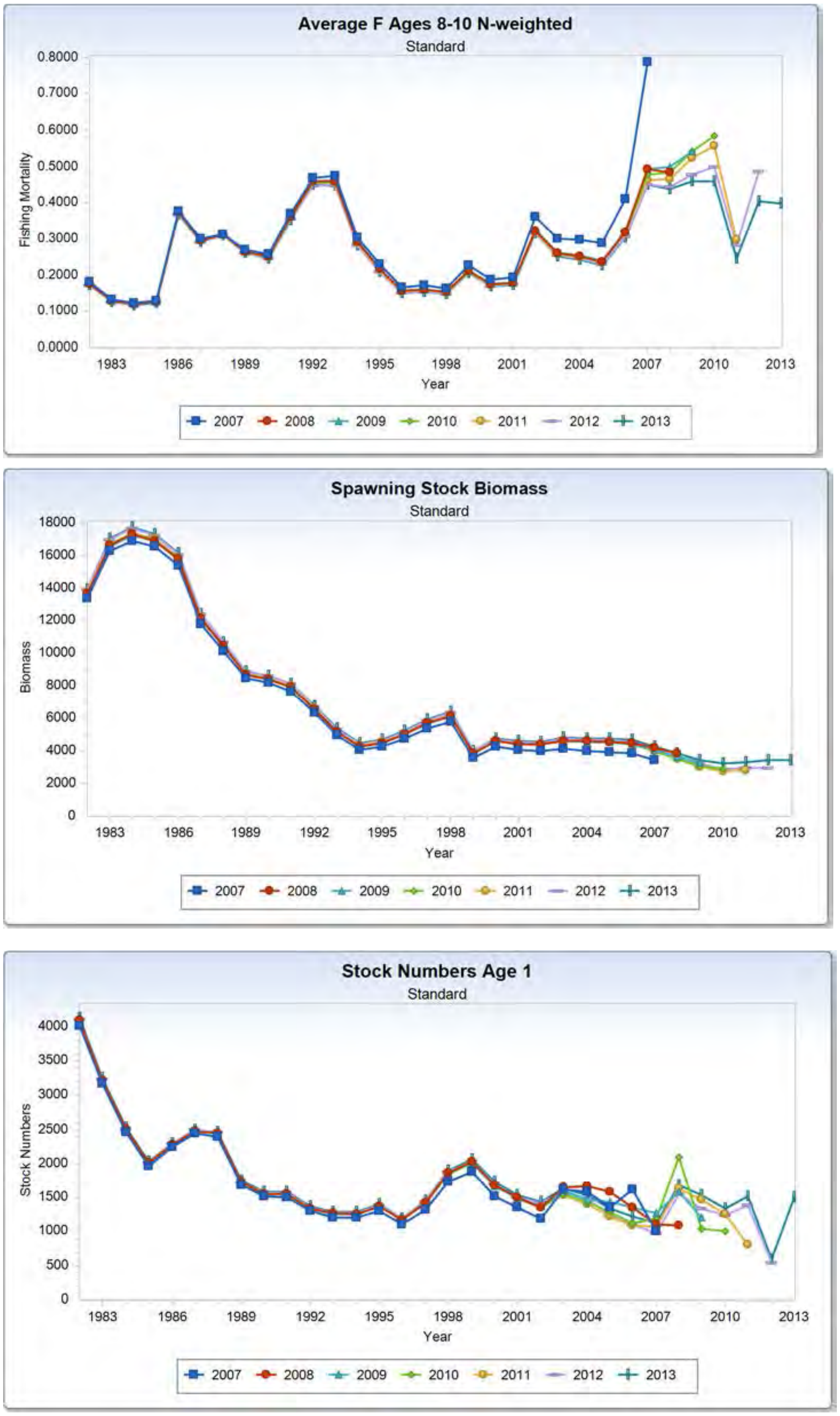
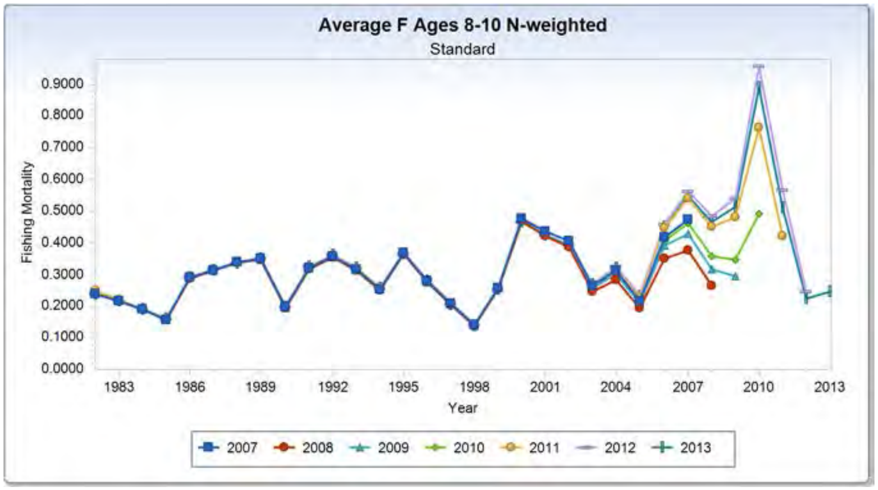
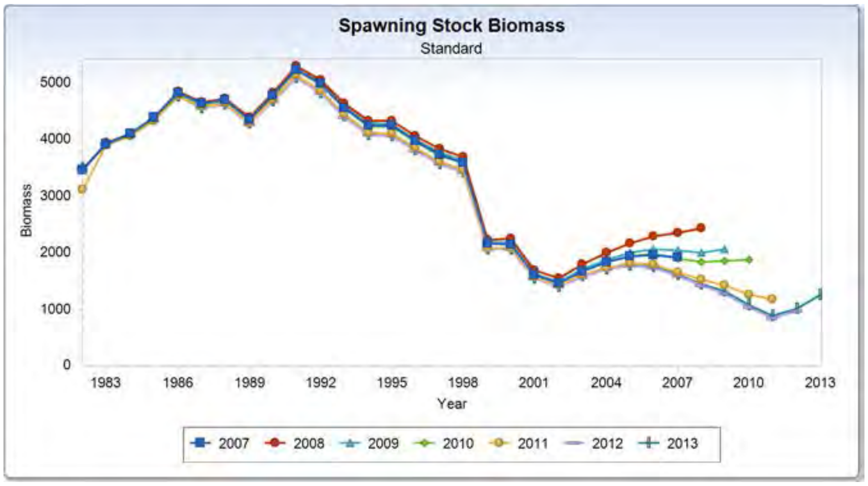
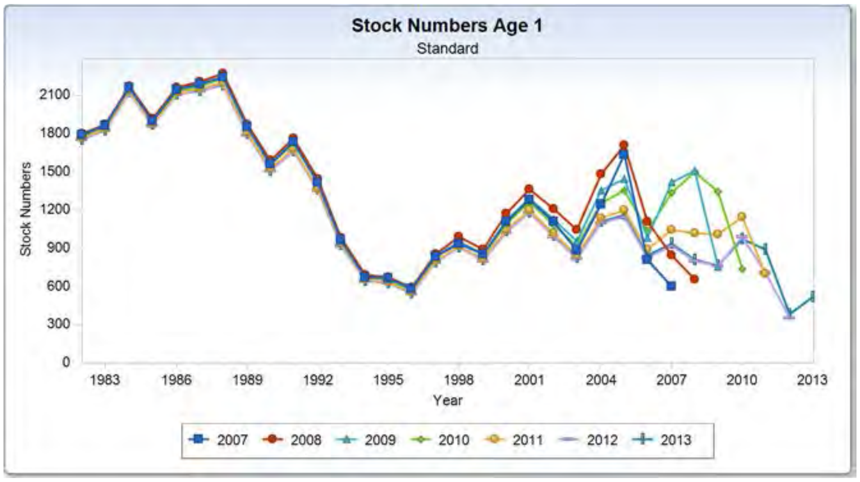


Figure A5. 24. Retrospective patterns for South region.







Appendix 6: Results of Additional Analyses Requested by the Review Panel

Figure 6.1. Estimated total biomass trends plus 95% confidence intervals for ASAP, XDBSRA, and BSSSPM models for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

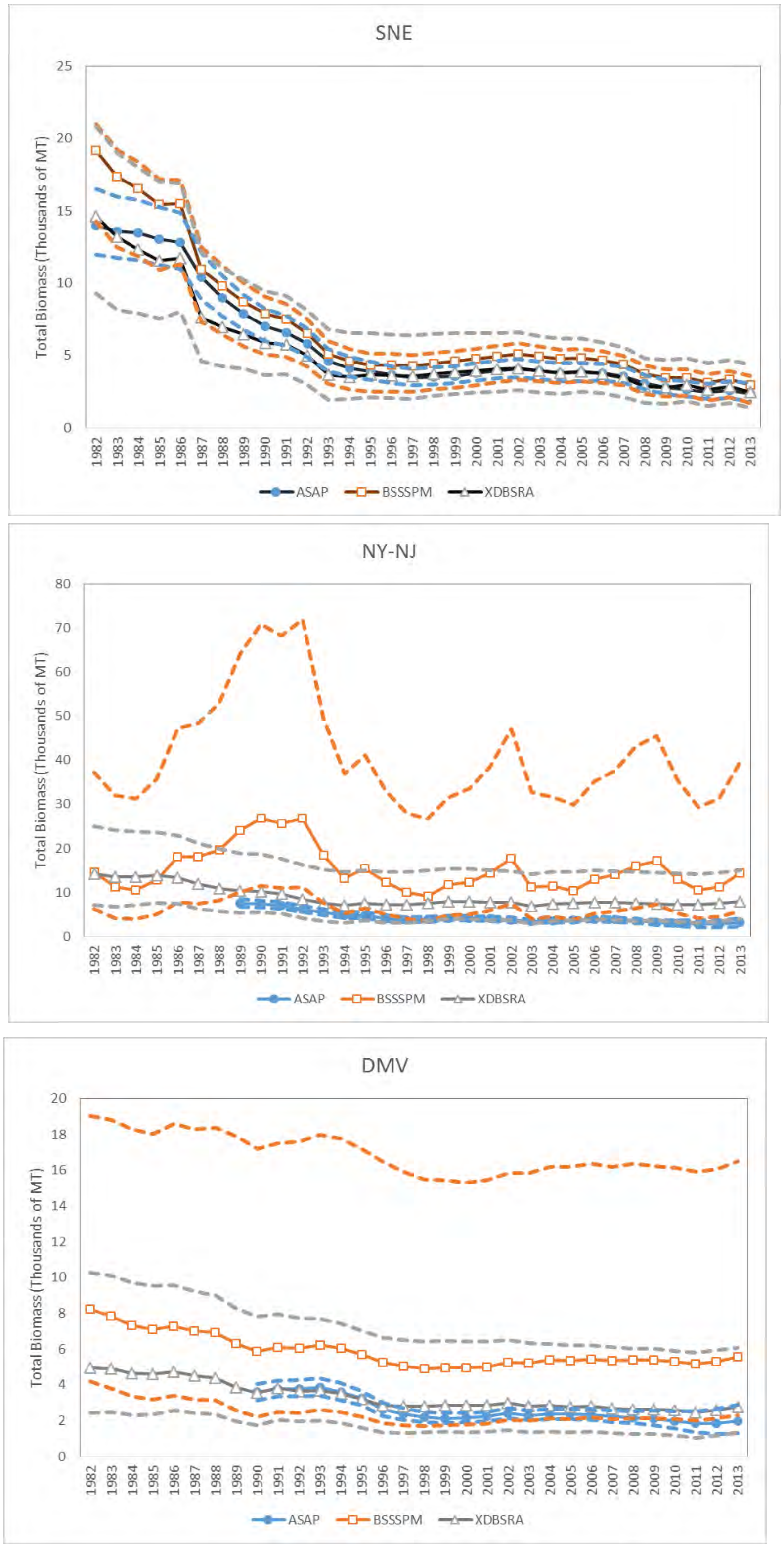


Figure 6.2. Estimated exploitation rates plus 95% confidence intervals for ASAP, XDBSRA, and BSSSPM models for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

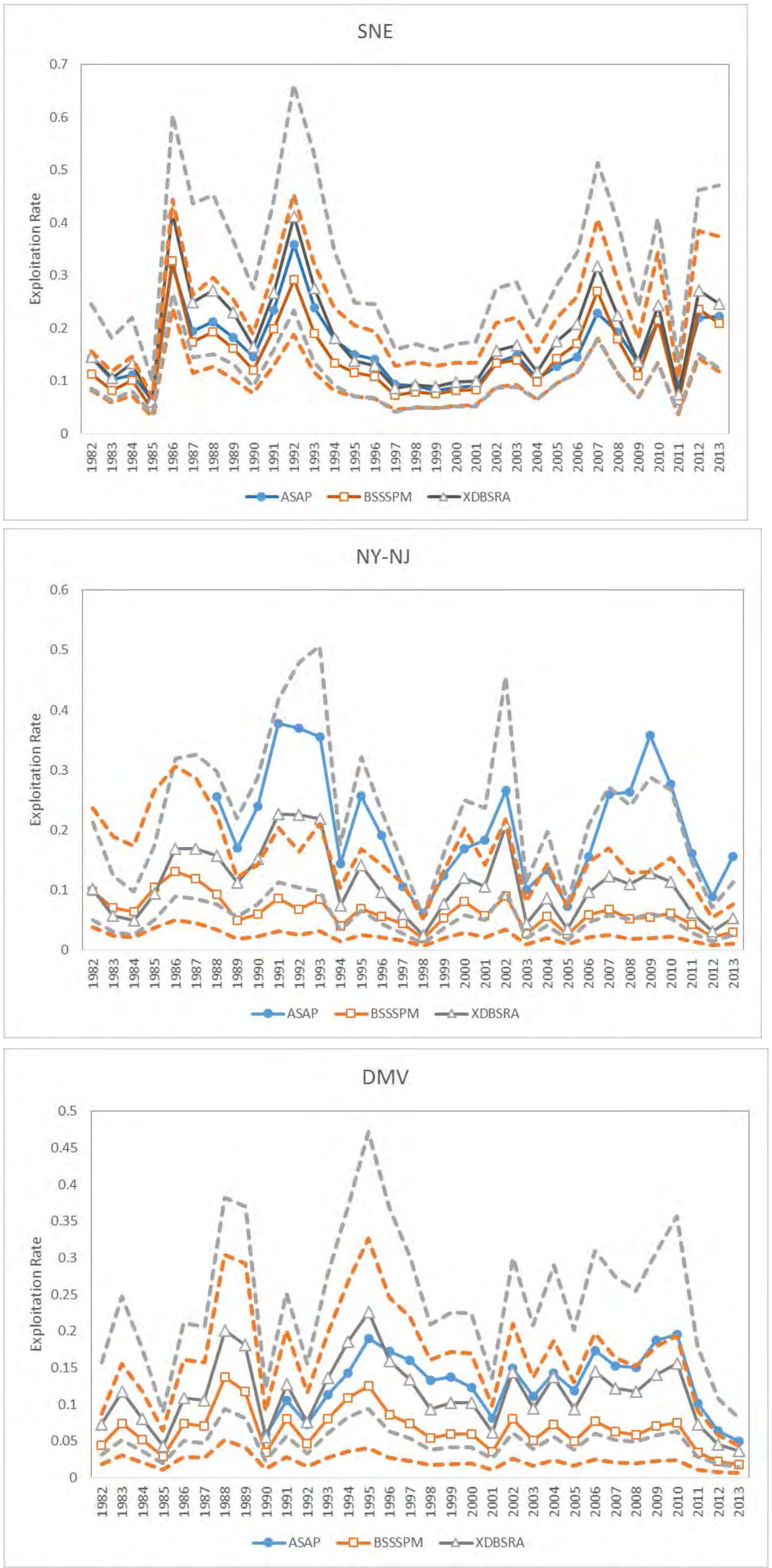


Figure 6.3a. Standardized indices (black line) for the SNE region plotted with ± 1 standard deviation calculated from the GLM standardized CVs (dotted line) and from the adjusted CVs (orange line). Adjusted CVs were used to bring the index RMSE of the ASAP model close to 1.

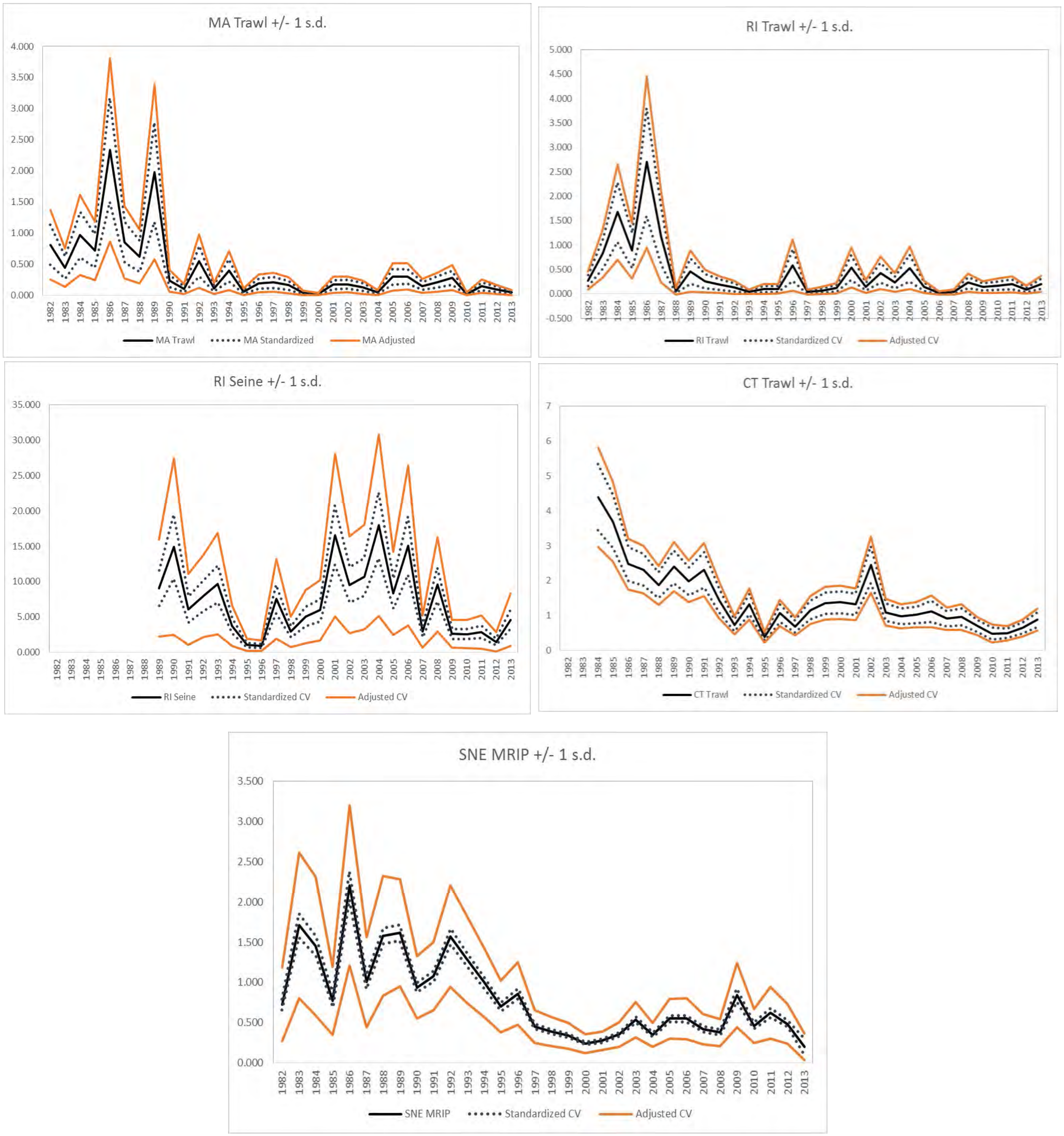


Figure 6.3b. Standardized indices (black line) for the NY-NJ region plotted with ± 1 standard deviation calculated from the GLM standardized CVs (dotted line) and from the adjusted CVs (orange line). Adjusted CVs were used to bring the index RMSE of the ASAP model close to 1.

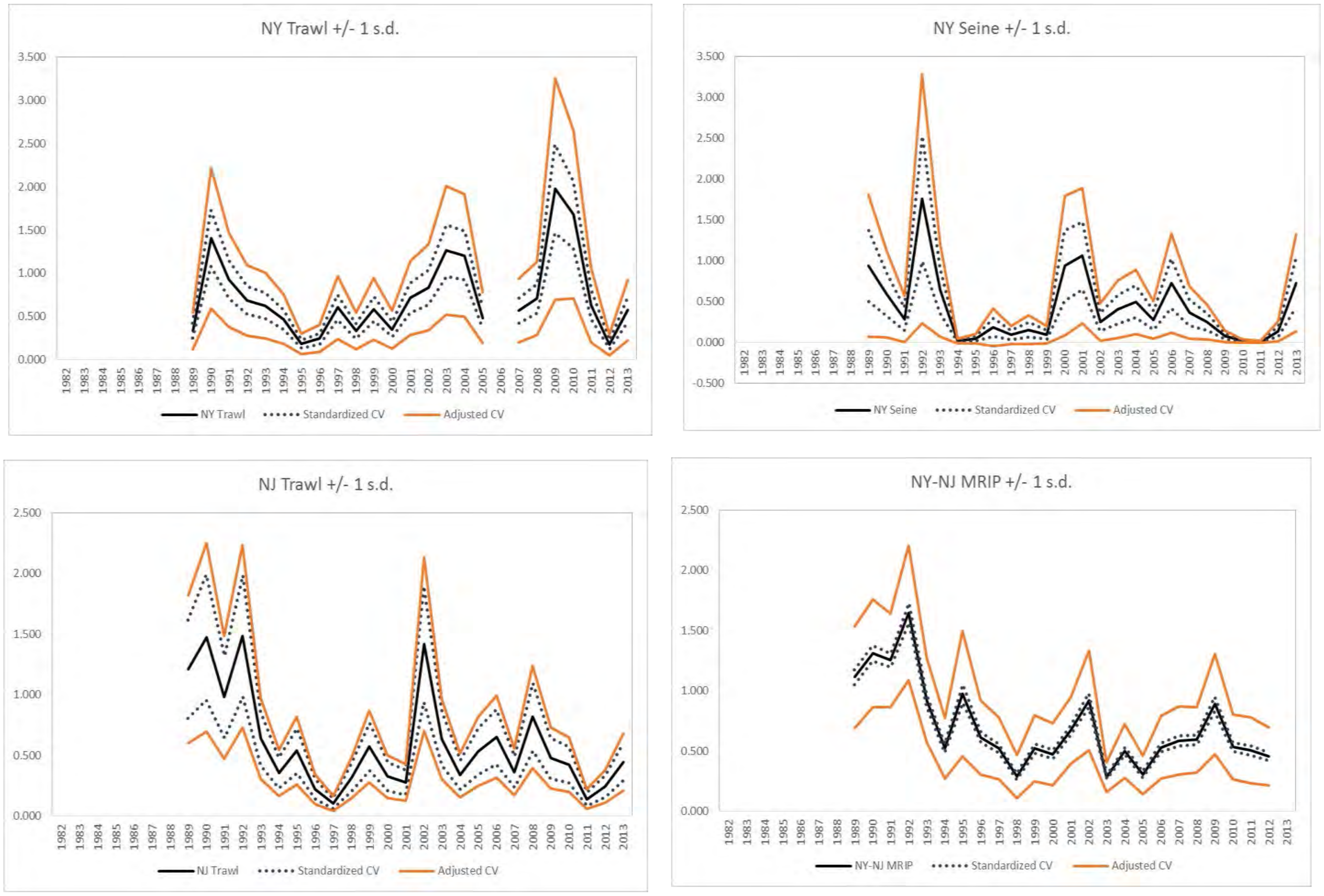


Figure 6.3c. Standardized index (black line) for the DelMarVa region plotted with ± 1 standard deviation calculated from the GLM standardized CVs (dotted line) and from the adjusted CVs (orange line). Adjusted CVs were used to bring the index RMSE of the ASAP model close to 1.

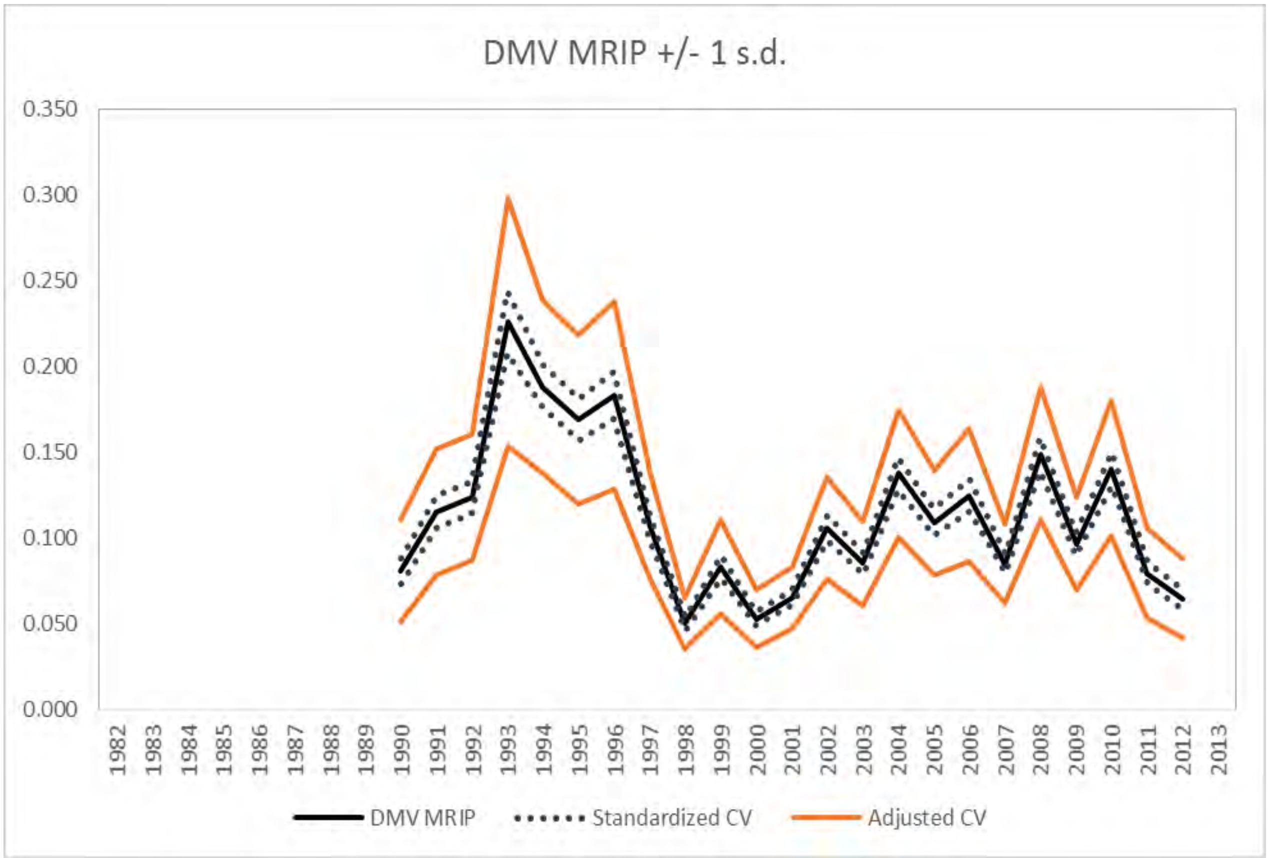


Figure 6.4. Histograms of randomly drawn catch estimates by year for resampled runs in the SNE region. Bars represent the frequency of draws for given catch values. The solid line describes a normal distribution of N(C_i, 0.2) where C_i is the observed catch for year *i*.

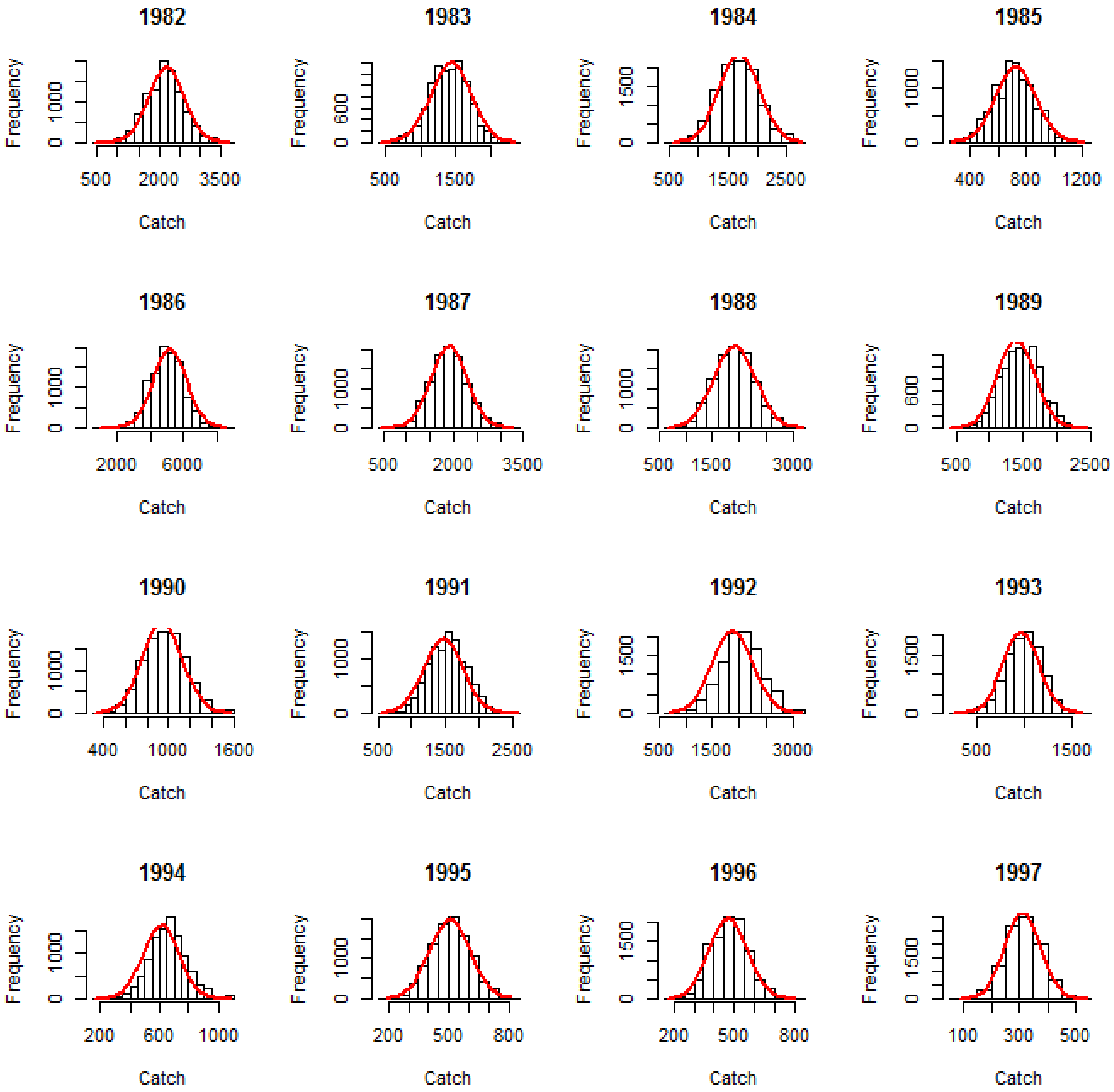


Figure 6.4 (cont.).

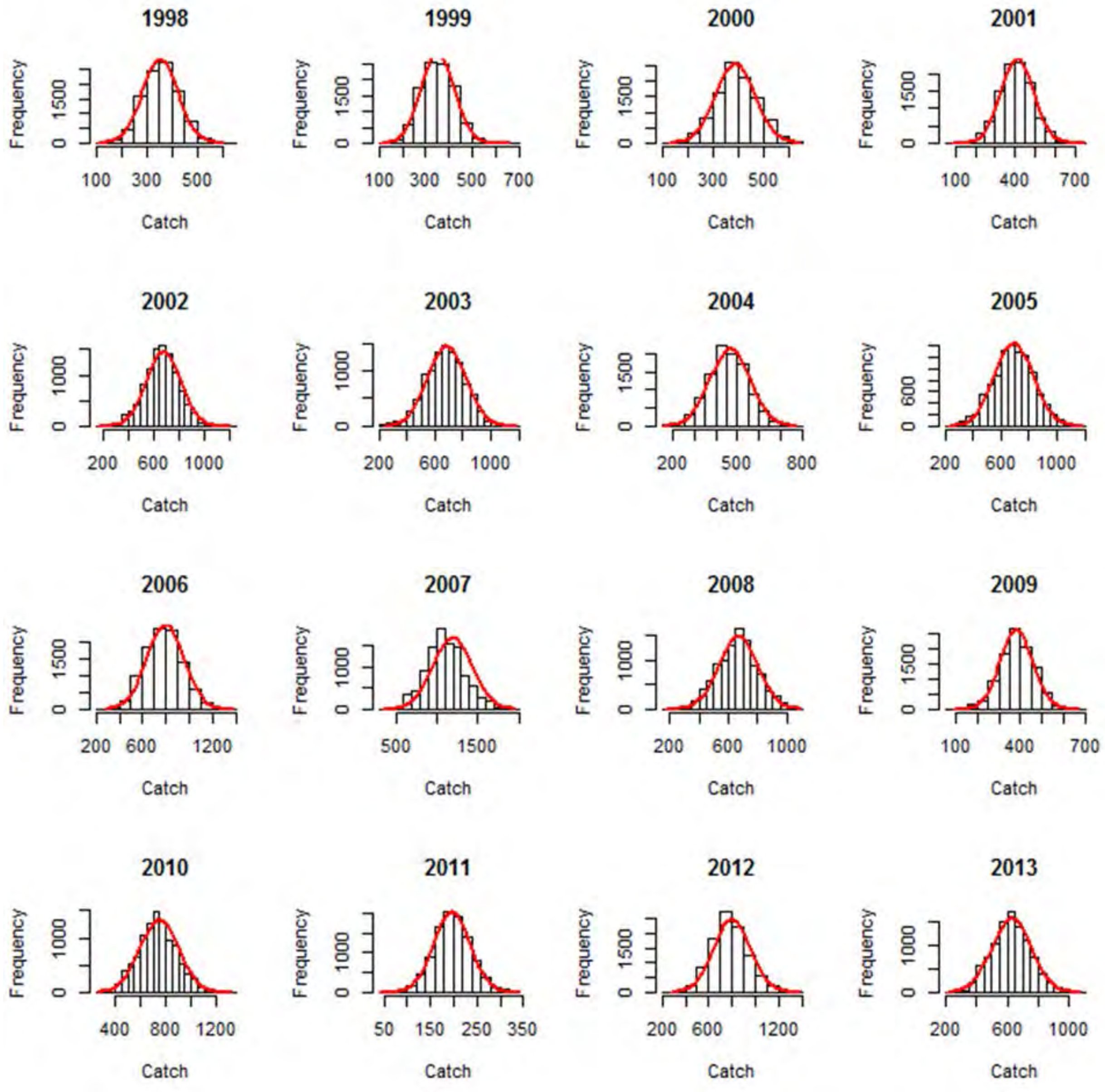


Figure 6.5. Histograms of randomly drawn catch estimates by year for resampled runs in the NY-NJ region. Bars represent the frequency of draws for given catch values. The solid line describes a normal distribution of N(C_i, 0.2) where C_i is the observed catch for year *i.*

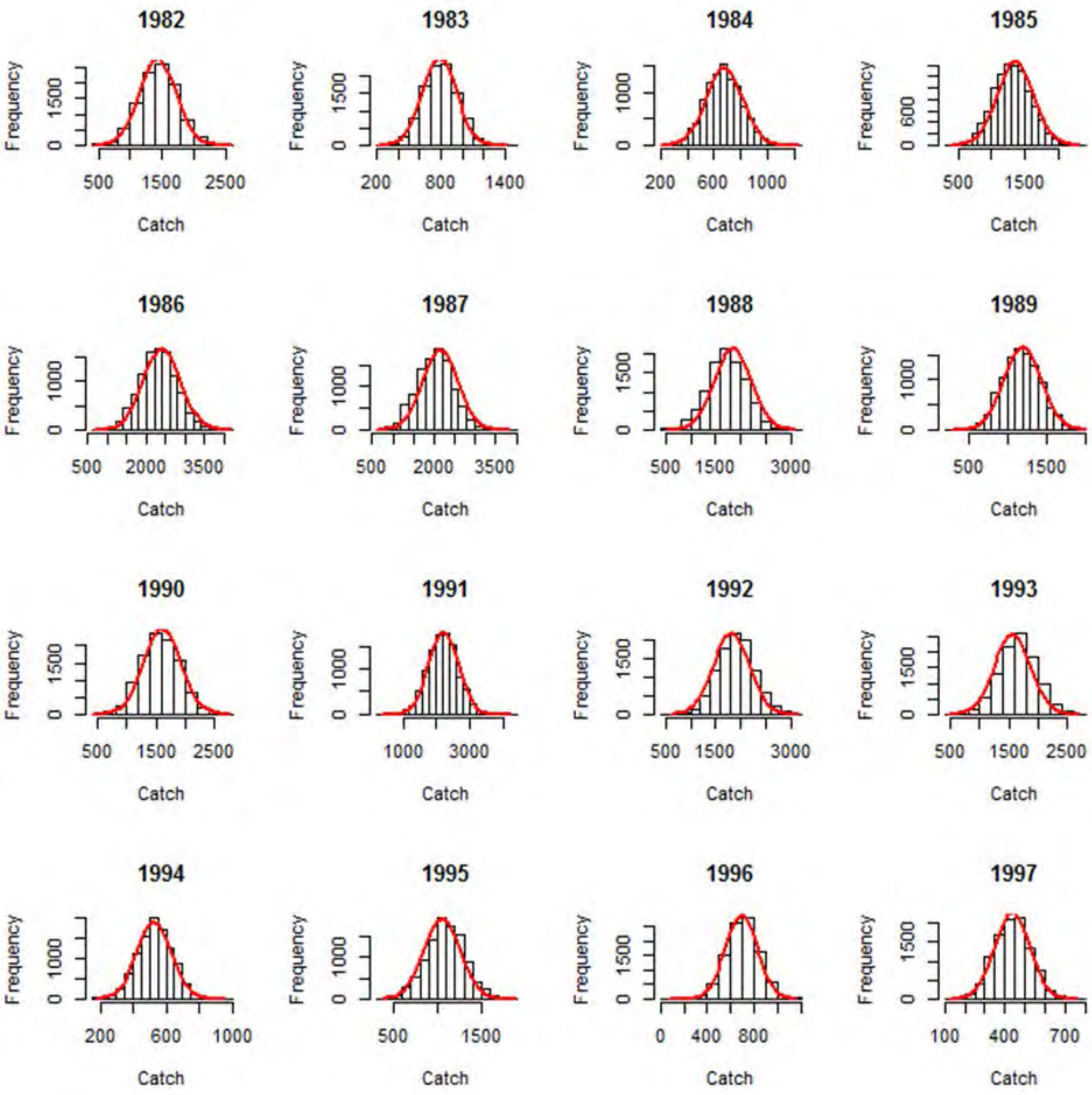


Figure 6.5 (cont.).

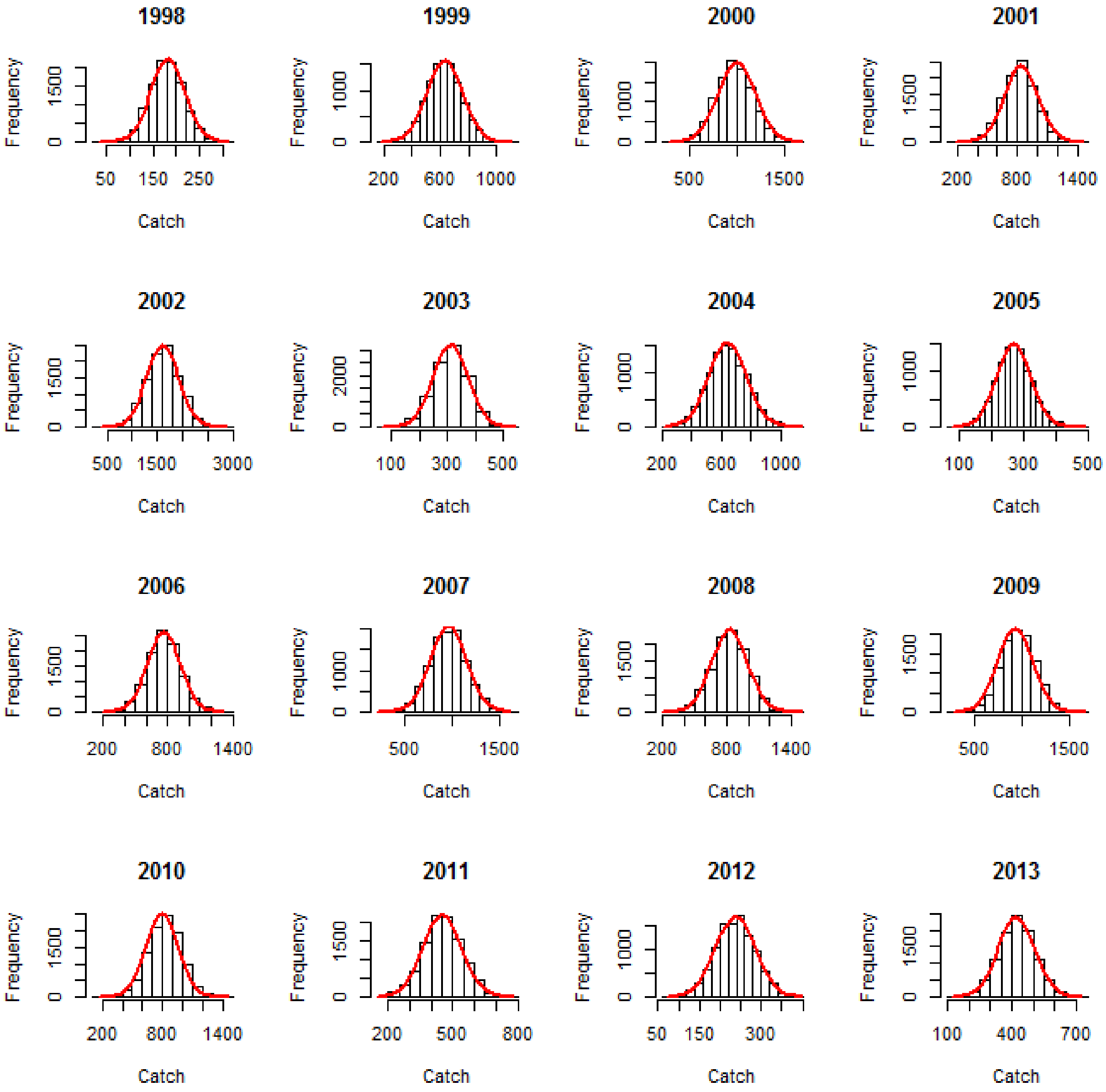


Figure 6.6. Histograms of randomly drawn catch estimates by year for resampled runs in the NYNJ region. Bars represent the frequency of draws for given catch values. The solid line describes a normal distribution of N(C_i, 0.2) where C_i is the observed catch for year *i*.

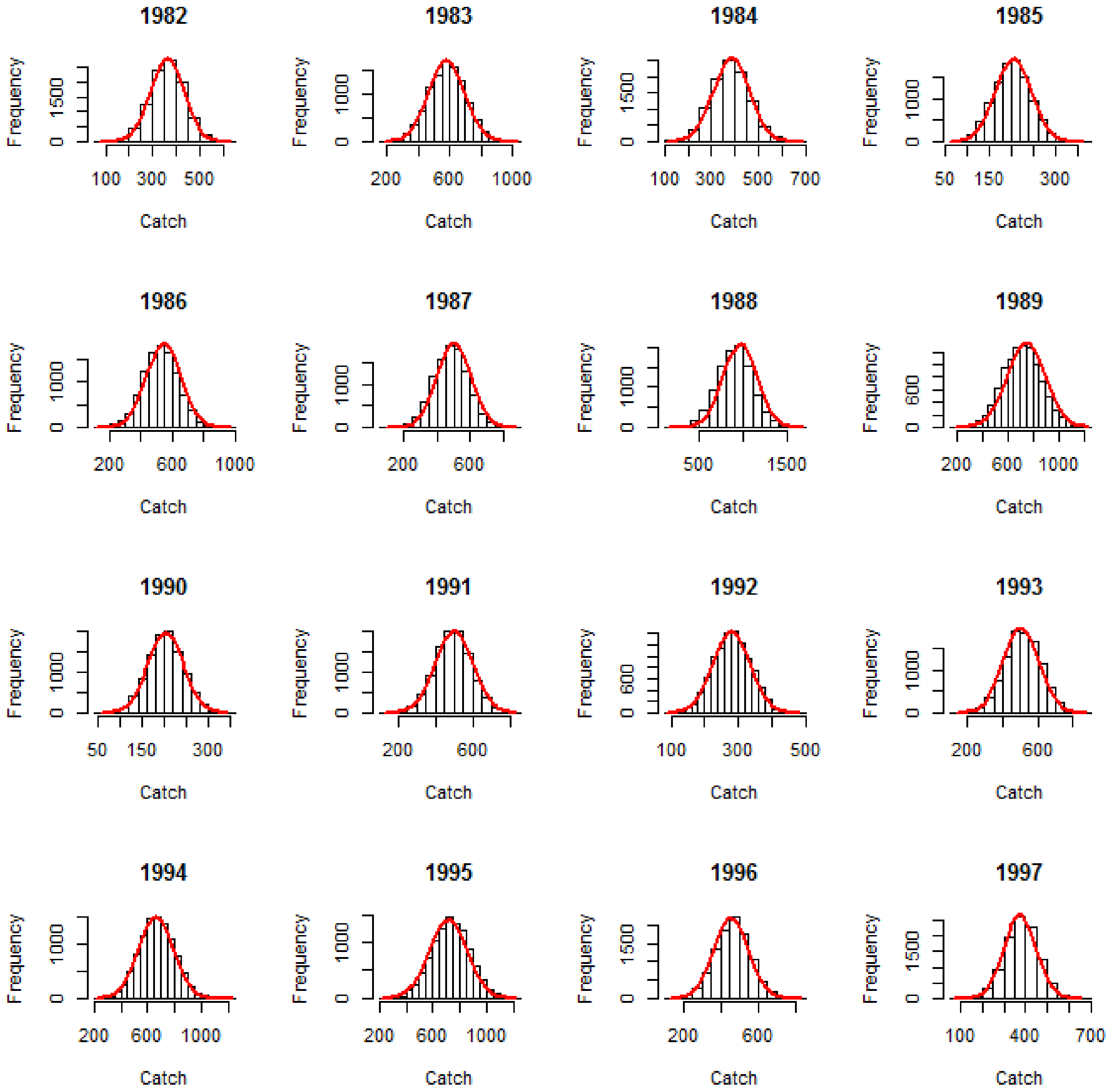
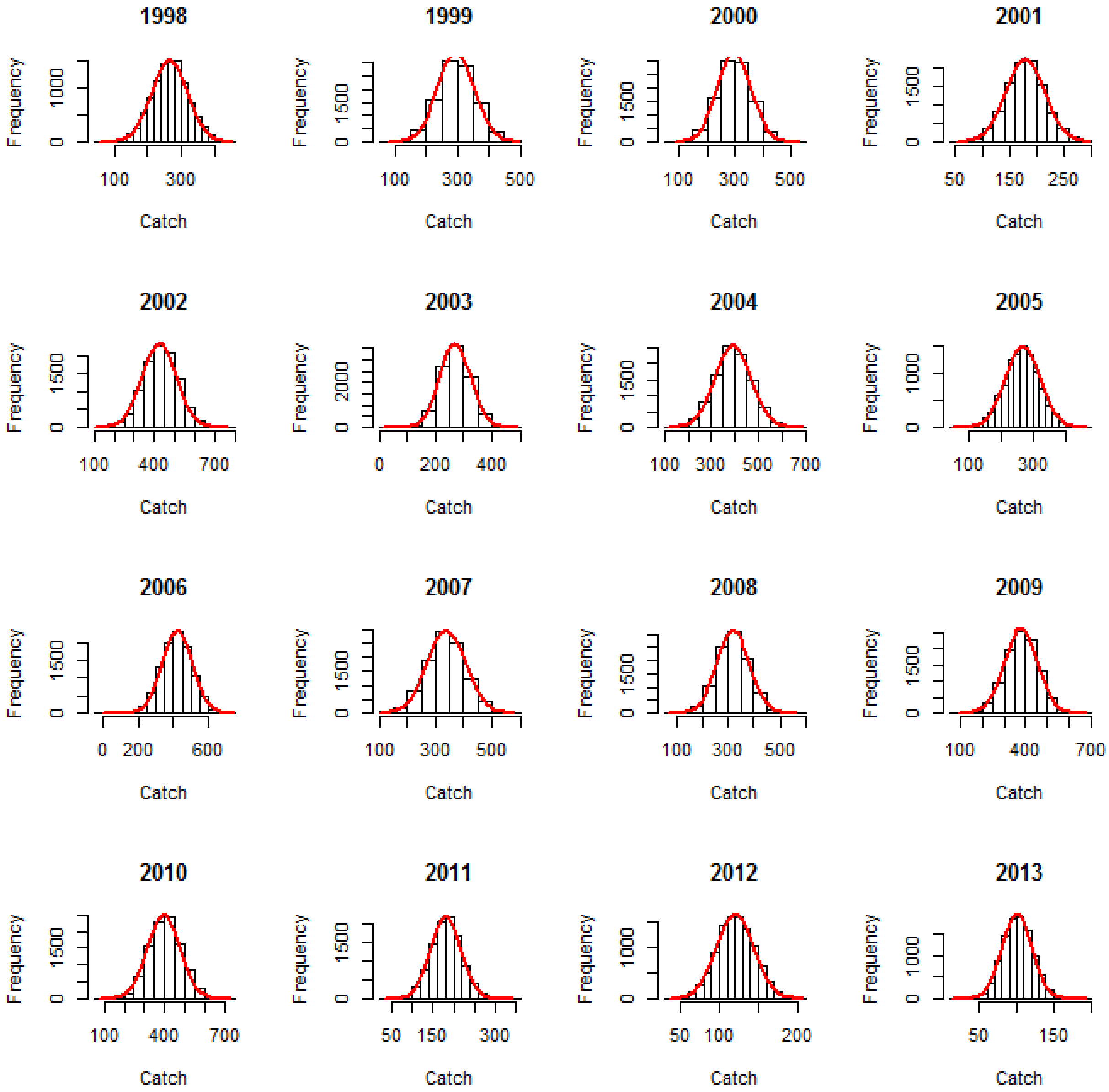
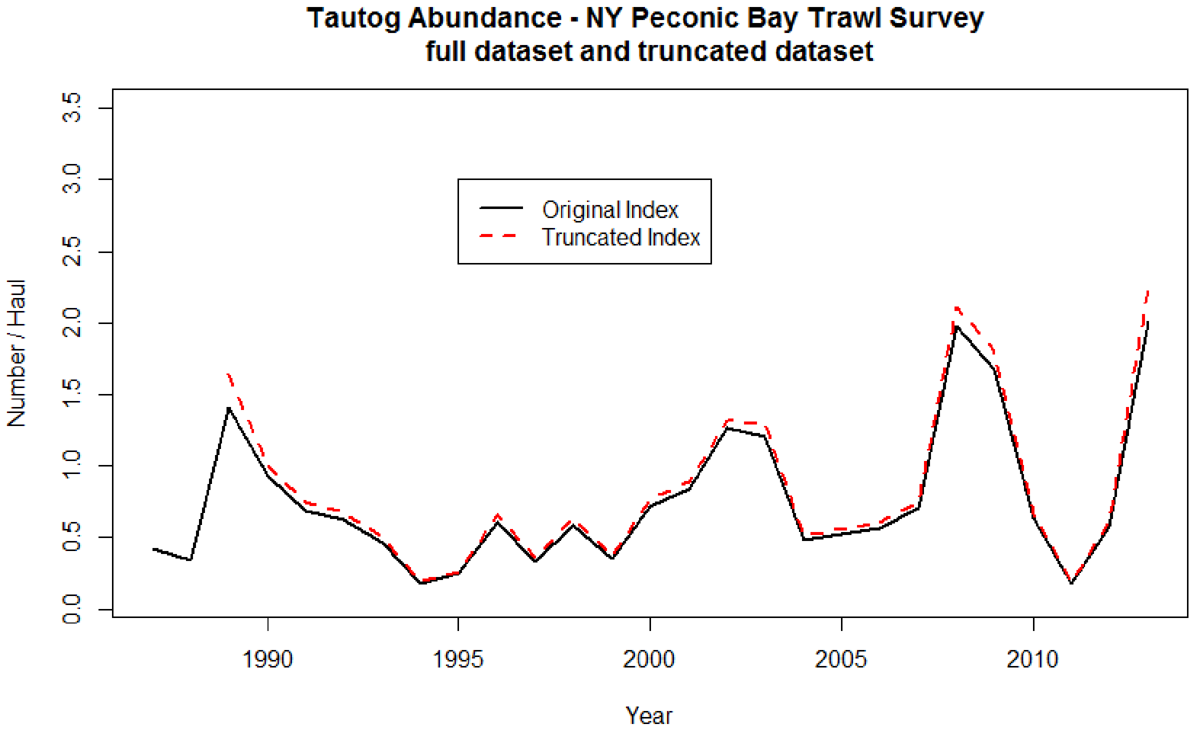


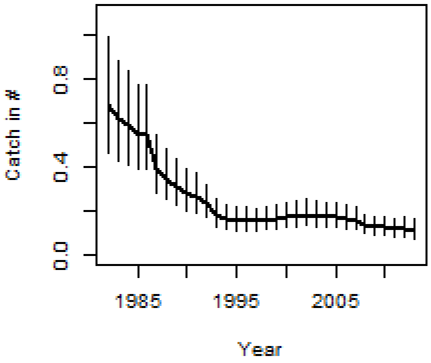
Figure 6.6 (cont.).

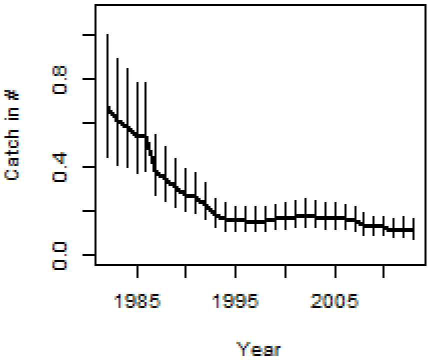


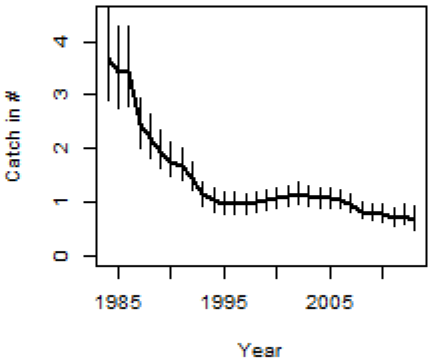
Review panel task: Diagnostic Fit Index: truncate NY Peconic Bay GLM to 1989.

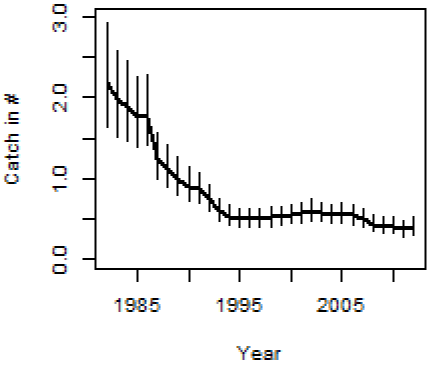


Review panel task: Sensitivity analysis: for index fit graphs, add residual fit bars if error bars are not possible. Error bars represent the 2.5 and 97.5 quantiles of the sample distribution.

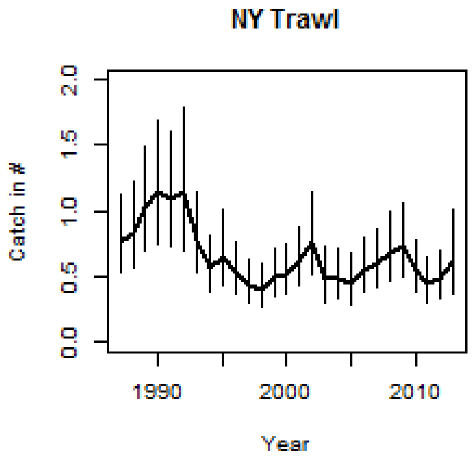

MA Spring Trawl

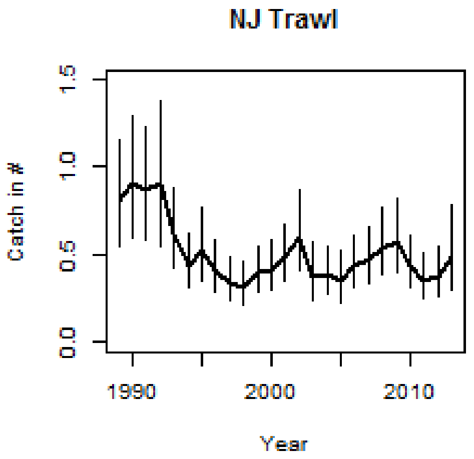

RI Fall Trawl

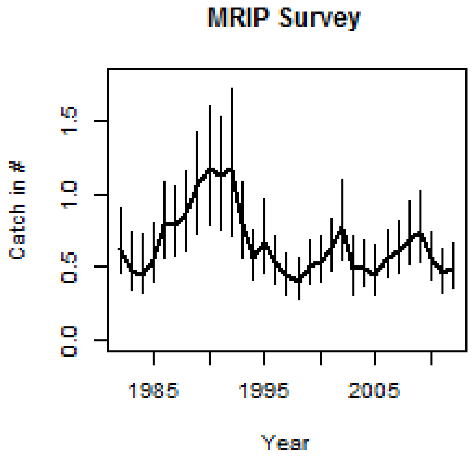

CT LIS Trawl


MRIP Survey

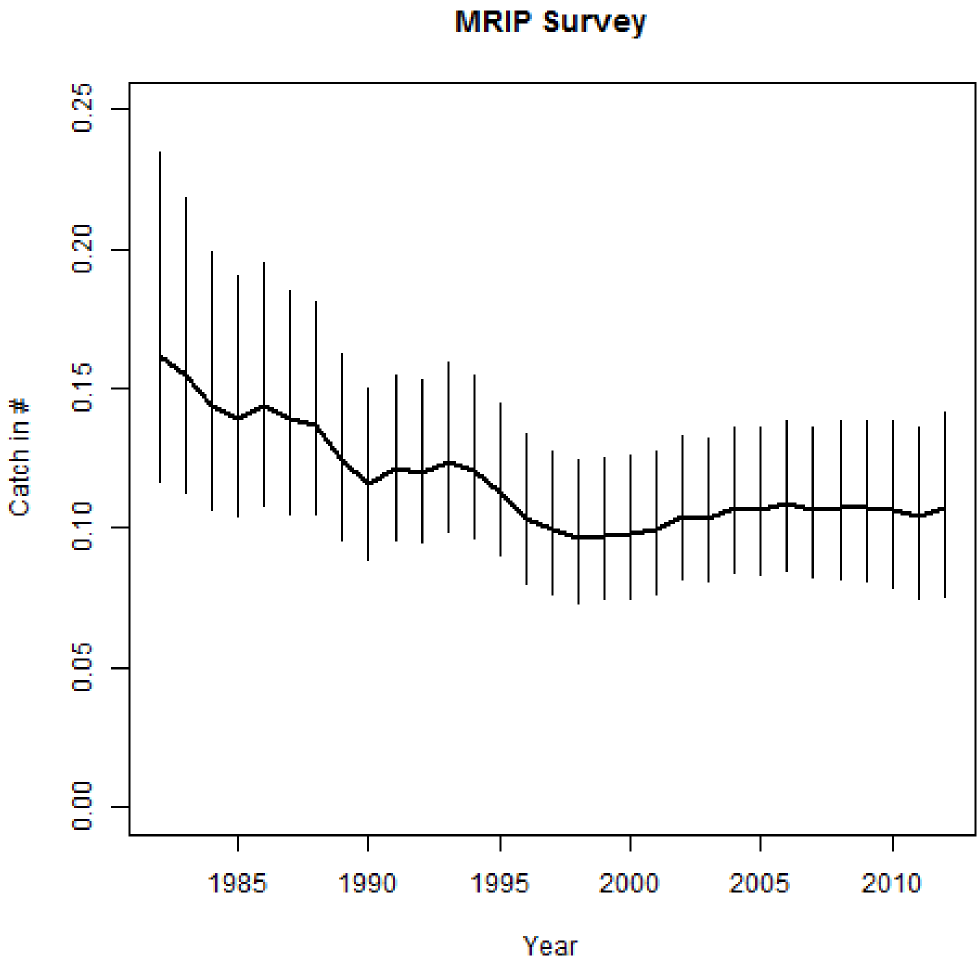
Review panel task: Sensitivity analysis: for index fit graphs, add residual fit bars if error bars are not possible. Error bars represent the 2.5 and 97.5 quantiles of the sample distribution.


NY Trawl

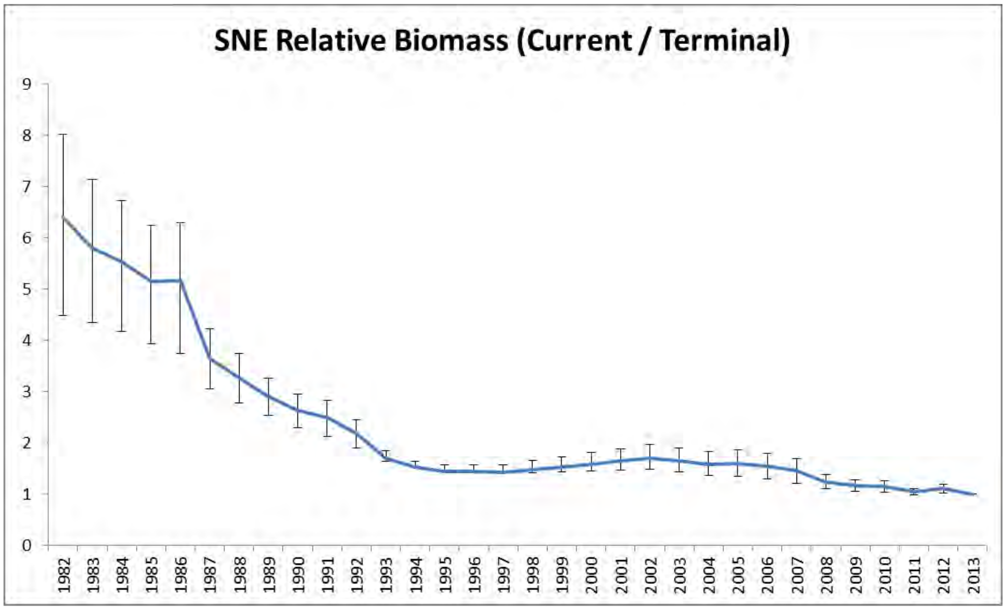

NJ Trawl

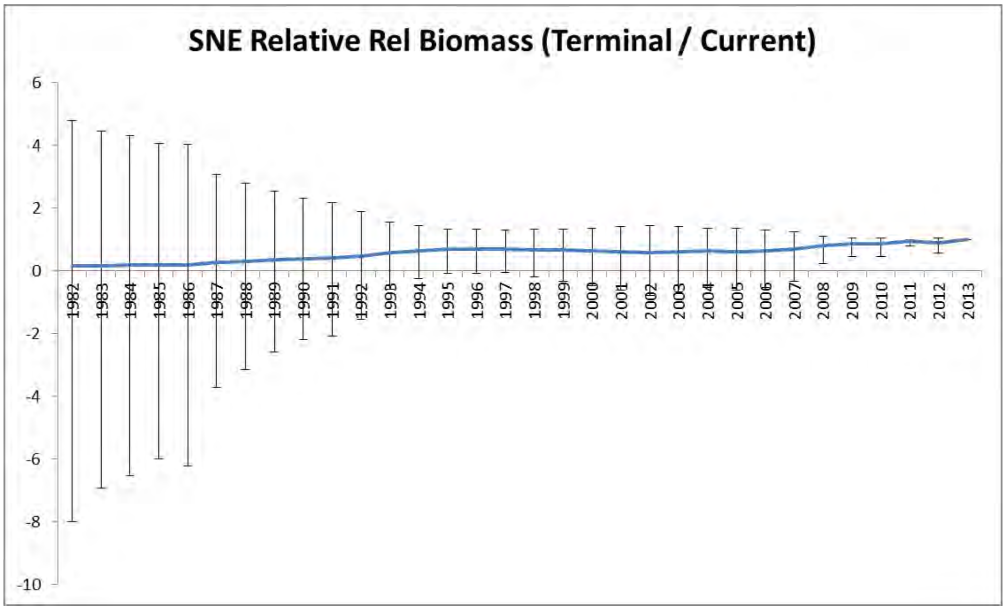

MRIP Survey

Review panel task: Sensitivity analysis: for index fit graphs, add residual fit bars if error bars are not possible. Error bars represent the 2.5 and 97.5 quantiles of the sample distribution

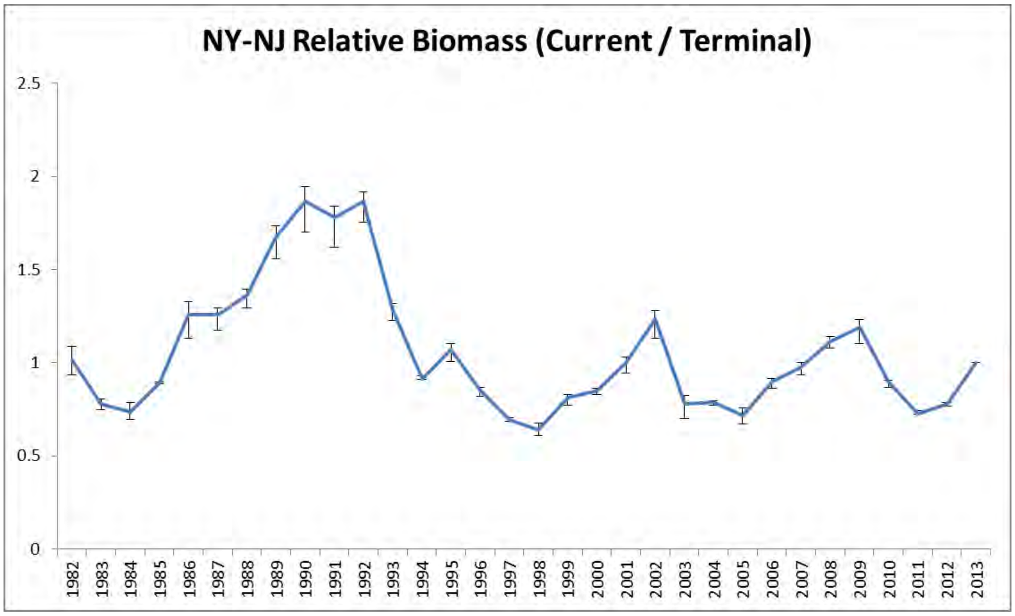


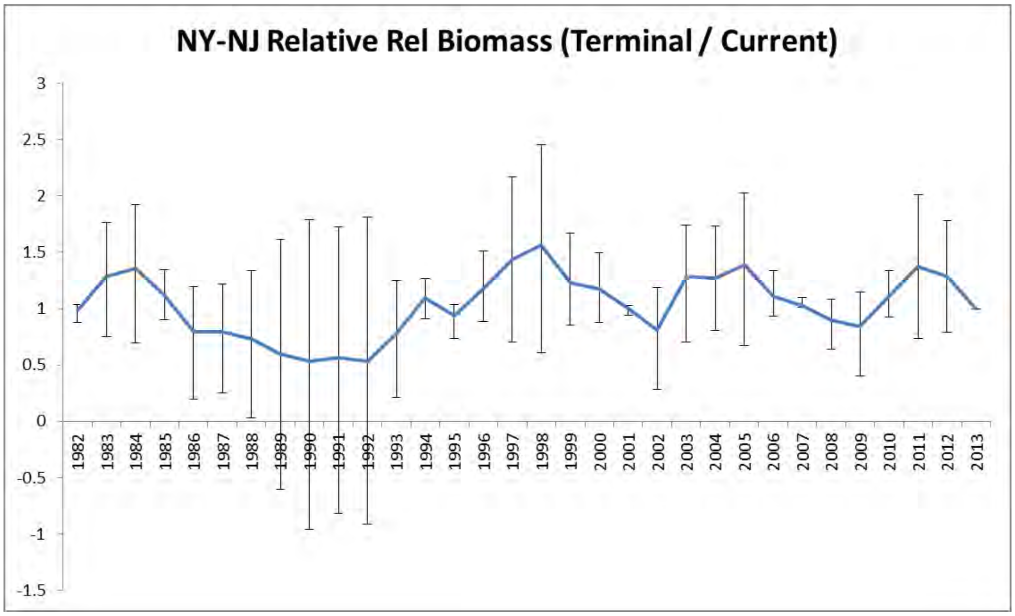
Review panel task: Sensitivity analysis: Relative biomass across the time series for scale.



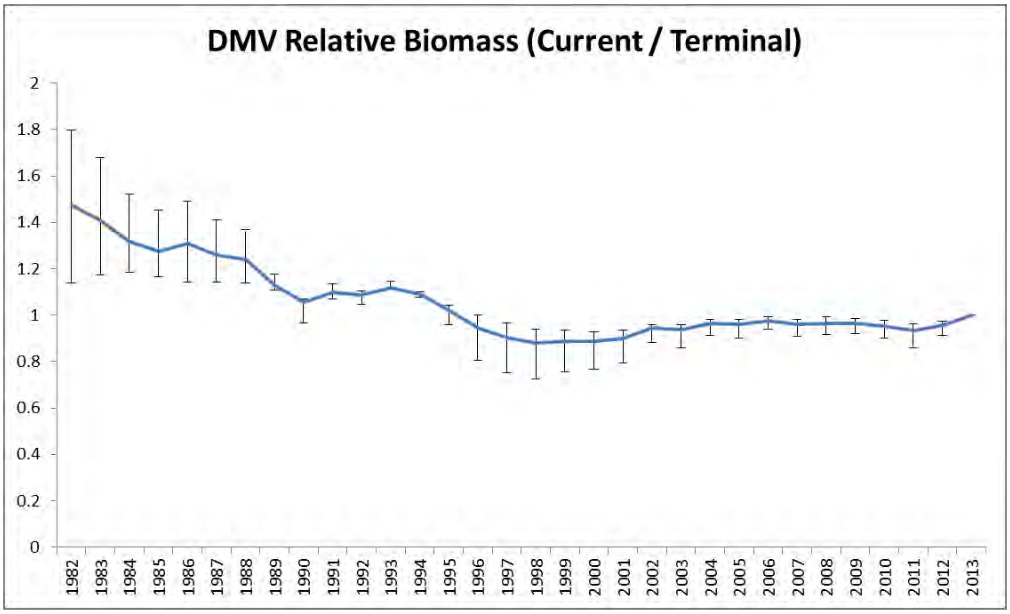


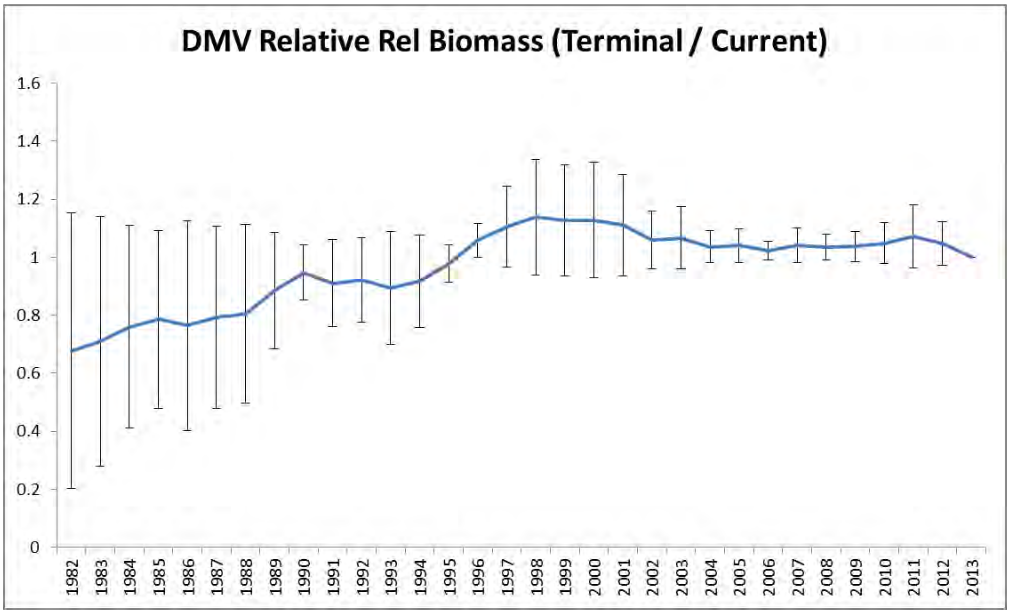
Review panel task: Sensitivity analysis: Relative biomass across the time series for scale .





Review panel task: Sensitivity analysis: Relative biomass across the time series for scale .





DRAFT FOR MANAGEMENT BOARD REVIEW

Atlantic States Marine Fisheries Commission

Tautog Stock Assessment Peer Review Report

January 2015

Vision: Sustainably Managing Atlantic Coastal Fisheries

DRAFT FOR MANAGEMENT BOARD REVIEW

Atlantic States Marine Fisheries Commission

Tautog Stock Assessment Peer Review Report

Conducted on
November 11-14, 2014
Virginia Beach, Virginia

Prepared by the
ASMFC Tautog Stock Assessment Review Panel

Dr. Cynthia Jones, Panel Chair, Old Dominion University
Dr. Gary Nelson, Massachusetts Division of Marine Fisheries
Dr. Yan Jiao, Virginia Polytechnic University
Dr. Jason Cope, NMFS Northwest Fisheries Science Center

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA10NMF4740016

Table of Contents

Preface

Summary of the ASMFC Stock Assessment Review Process

The Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2002 and 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal independent review; (2) maintain the quality of Commission stock assessments; (3) ensure the credibility of the scientific basis for management; and (4) provide the public with a clear understanding of fisheries stock assessments. The Commission stock assessment review process includes an evaluation of input data, model development, model assumptions, scientific advice, and a review of broad scientific issues, where appropriate.

The Commission's *Benchmark Stock Assessment Framework* outlines options for conducting an independent review of stock assessments. These options are:

1. The stock assessment review process conducted by the Atlantic States Marine Fisheries Commission.
2. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).
3. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes stock assessments for all Commission managed species based on species management board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In November 2014, the Commission convened a Stock Assessment Review Panel comprised of scientists with expertise in stock assessment methods, data poor modeling, recreational fisheries data and indices, and tautog life history and ecology. The review of the tautog stock assessment was conducted at the Sheraton Oceanfront Hotel in Virginia Beach from November 11-14, 2014. Prior to the Review Workshop meeting, the Commission provided the Review Panel members with copies of the 2014 Tautog Stock Assessment Report.

The review process consisted of presentations by topic – data inputs, life history analyses, model results, reference points, and stock status – of the completed 2014 stock assessment. Each presentation was followed by general questions from the Panel. The second day involved a closed-door meeting of the Review Panel during which the documents and presentations were discussed and a review report prepared. The report is structured to closely follow the terms of reference provided to the Panel.

Acknowledgements

The Review Panel thanks members of the Tautog Stock Assessment Subcommittee and Technical Committee, as well as staff of the Atlantic States Marine Fisheries Commission, particularly Patrick Campfield, for support during the review process.

Executive Summary

The review panel met in Virginia Beach, VA from November 11-14, 2014. Prior to the review workshop, panel members read the stock assessment report and other relevant documents provided by ASMFC and the tautog (Tautoga onitis) stock assessment subcommittee (SASC). During the workshop, the panel reviewed results of the age structured and data-poor models, and requested additional model explorations, including alternative sensitivity runs to determine the models' robustness to inputs and parameters.

The model the SASC recommended to use for management was the age structured model (ASAP). The ASAP model proved to be relatively robust to estimates of spawning stock biomass, abundance, recruitment, and fishing mortality. Moreover, the Review Panel agreed that the region-level ASAP stock assessment models provided the best available scientific foundation for management. The Review Panel and the SASC team realized that the use of the logistic curve may be causing the selectivity curve to switch to a higher selectivity after increasing the catch size limit in all three regions and may also explain why the catch-at-age data did not fit well in some years.

The ASAP regional model results indicated the population abundance/biomass in the Southern New England (MA-CT) and NY-NJ regions declined (rate: 2.9/14.2; 2078/5500) since the starting year of the model to the present with the most recent two-year biomass increasing slightly. The DMV (DE, MA, VA) region model results show declining abundance, although not as steep as the other two regions, which may be due to the large influence of the MRIP index as the only abundance index used to tune the DMV model. Fishing mortality estimates were also highly variable because of the high variance of recreational harvest statistics. The recent F estimates for the NY-NJ and DMV regions were lower (0.21 versus 0.25 of 3-year average; 0.1 versus 0.17 of 3-year average), than the F estimates from the SNE region (0.59 versus 0.50 of 3-year average).

The Review Panel noted that the F_{target} and $F_{threshold}$ reference points varied among the three regions because they were influenced by the selectivity patterns estimated from each of the regional ASAP models. Variation in growth and maturity among the three regions may also contribute to variations in reference point estimation.

The Review Panel also noted that, by using regional models, the recommended SSB reference point is much smaller than historically recommended SSB reference point. The differences between cumulative SSB reference points from the regional models and the SSB reference point from the coast-wide model changes the stock status to a degree and at the same time increases the risk of the population being overfished. Precaution is needed when using the regional SSB reference point.

The tautog stock status in each region is overfished. Through a series of data analyses and modeling, the SASC has documented the overfished status. The following Review Report evaluates the stock assessment findings, comments on strengths and weaknesses, and makes recommendations for future research priorities and assessments.

Terms of Reference for the Tautog Stock Assessment Review

1. Evaluate the thoroughness of data collection and the presentation and treatment of fishery-dependent and fishery-independent data in the assessment, including the following but not limited to:
    a. Presentation of data source variance (e.g., standard errors).
    b. Justification for inclusion or elimination of available data sources.
    c. Consideration of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, ageing accuracy, sample size).
    d. Calculation and/or standardization of abundance indices.

The 2014 benchmark stock assessment of tautog provides up-to-date information on the biology and life-history of the species, as well as regional stock assessment models that are based on regional biological data and fisheries behavioral patterns in each region.

The Tautog Stock Assessment Subcommittee (SASC) provided a thorough review of all data sources considered for the assessment and provided detailed information on data sets used in the stock assessment. The fishery-dependent and fishery-independent sources of data used primarily by the SASC were the NMFS and state records for commercial landings; Northeast Fisheries Observer Program for commercial discards; state biosampling of commercial and recreational fisheries; the MRFSS/MRIP program for recreational landings, discards, and length frequency; and fishery-independent surveys in the states of MA, RI, CT, NY, NJ, DE, MD, and VA for biological data (lengths, ages, weights) and measures of relative abundance.

The SASC developed four criteria to use to determine if datasets should be retained or excluded in the assessment. A dataset was rejected if it had less than 10 consecutive years of data, or sampling over the 10 years was intermittent; it contained a small number of samples; it covered a small geographic area not representative of the regional stock or coast-wide stock unit; or it employed inconsistent methodologies. However, rejected datasets were used occasionally in a qualitative manner to inform some decisions made by the SASC. The review panel considered the SASC criteria reasonable and agreed with how they were used to include or exclude datasets.

The SASC presented data based on three regions – Southern New England (MA-CT), NY-NJ, and DMV (DE, MA, VA) – developed for management purposes. Commercial landings in weight for each region from 1950 to 2013 were reviewed. These data were considered a census, thus no estimates of error were given. Commercial landings in the earlier years (1950s-1970s) were likely underestimated given that reporting was not required and tautog was considered a 'trash' fish during those years. A small live-fish market exists currently along the coast, but there may be under-reporting of the landings. Estimates of commercial discards were poor given the small sample sizes and were not included in the assessment. Since length data from the commercial fishery were unavailable, the use of recreational length data to apportion the commercial catch into age classes may have introduced bias into age compositions. Regardless, the Panel believed these data were adequate for use in the assessment since the commercial landings comprised only a small portion of total landings.

The recreational landings and discards estimates for 1982-2013 from the MRFSS/MRIP program were the primary data used to characterize the recreational fisheries for tautog. The SASC reviewed the magnitudes and trends of the MRFSS/MRIP estimates for the three proposed management regions. When disaggregated by state, PSEs for the MRFSS/MRIP estimates of harvest and releases were generally high (>0.30), indicative of the low number of intercepts obtained by survey interviewers. When aggregated to the proposed regions used in the assessment, PSEs were reasonable (many <0.20). A release mortality of 0.025 was applied to the releases to obtain estimates of dead discards.

Sample sizes of length data collected to characterize the recreational fishery harvest and releases varied over year and among regions. Prior to 1995, sample sizes were reasonable for the number of anglers intercepted by MRFSS/MRIP. However, sample sizes declined in the SNE and NY-NJ regions through 2001. Since then, sample sizes have risen in the NY-NJ and DMV regions, but remain low in SNE. Prior to 2005, limited sampling of released fish occurred and length data from a volunteer tagging program were used. These data may not be representative of the fish being released. Sampling of released fish has increased but sample sizes remain low in the SNE region. However, the Panel believes these data are sufficient for use in the stock assessment.

Opercular bones were used to age tautog. An exchange of structures among states confirmed that opercular bones were aged consistently by state biologists. Annual age-length keys (ALKs) used to apportion catch data into age-classes were not available on a regional basis prior to 1995. Use of pooled data may have biased the age composition if there are regional growth differences among the regions, as purported by the TC/SASC. After 1995, annual ALKs were developed for each region by combining state data. The Panel agreed that the sample sizes of length-age data appeared adequate for the development of annual ALKs.

A number of regional fishery-dependent (2) and fishery-independent (15) indices for use in the stock assessment were reviewed by the SASC. Based on the inclusion/exclusion criteria developed by the SASC, only indices from one fishery-dependent source (MRFSS/MRIP) and four fishery-independent surveys (MA trawl survey, two bottom trawl surveys in RI, and one trawl survey in NY) were used in the stock assessment. The SASC discussed the potential biases of each survey. Recreational CPUE indices were developed for each region from MRFSS/MRIP intercepts of tautog trips (based on logical species guilds) by using a generalized linear modeling approach (assuming a negative binomial error structure) and standardizing by year, state, wave, and mode. Fishery-independent surveys were also standardized for design and environmental variables. Diagnostic plots were reviewed for each index to ensure adequate model fit. Error bounds for all estimates were provided by the SASC. The Panel believed the standardizations were appropriate and the resulting estimates were reasonable. The Panel was concerned that only one index, the recreational CPUE, was available for the DMV.

Overall, the Panel considers that a credible analysis of the available data was undertaken by the SASC.

2. Evaluate the assumptions of stock structure and the geographical scale at which the population was assessed.

The SASC presentations and assessment documents provided details on tautog life history supported by the peer-reviewed literature. Tautog is a temperate labrid whose distribution ranges from Nova Scotia to South Carolina with greatest abundance from Cape Cod to Chesapeake Bay. Its habitat is nearshore environments with structure (e.g., rocky reefs). Although it has a seasonal pattern of movement inshore during spring and summer to more offshore during fall and winter, tagging studies have shown recapture within a few miles of release indicating a limited scope of intermixing with other areas. Nonetheless, genetic results do not distinguish separate stocks along its range. However, genetic results do not preclude local stock structure in a 'stepping stone' pattern where some localized adaptation is retained in subareas. Moreover, tautog do not follow a typical labrid reproductive strategy of hermaphrodism, but are gonochoristic and have some sexual dimorphism in coloring and manible structure. Tautog are indeterminate and prolific serial spawners with a protracted spawning season. Eggs and sperm are pelagic and together, this reproductive strategy would permit some mixing with nearby spawners.

In the initial stock assessment and thereafter, tautog have been managed as a unit stock throughout its range. Our current understanding of tautog life history suggests there may be cause to assess and manage using a more regional stock structure. Although not affirmed in genetic studies, the regional basis could be shown with natural tags such as otolith chemistry, as suggested by Dr. Tom Miller during his integrated review of the tautog assessment's development. As Dr. Miller wrote, "Ideally, the spatial structure of the population should be matched by the scale at which the assessment and management are conducted. However, there are numerous examples of successful management of mixed populations within single management units, as well as examples of successful management of arbitrarily divided populations into separate sub-units. Thus, the spatial scale of the population and that of the assessment and management need not match."

The Review Panel also ascertained that there was a paucity of data at a fine spatial scales to support fine-scale models, but recommends that collecting these data could improve model performance and support of such studies would be justified.

3. Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) at the coastwide and regional basis, including but not limited to:
    a. Evaluate the choice and justification of the preferred model(s). Was the most appropriate model (or model averaging approach) chosen given available data and life history of the species?
    b. If multiple models were considered, evaluate the analysts' explanation of any differences in results.
    c. Evaluate model parameterization and specification.

d. Evaluate the diagnostic analyses performed, including sensitivity analyses to determine model stability and potential consequences of major model assumptions.

Three main models that use relative abundance indices were presented by the SASC to describe both area-specific and coastwide tautog population dynamics: 1) the Age Structured Assessment Program (ASAP), 2) extended Depletion-Based Stock Reduction Analysis (xDB-SRA), and 3) Bayesian State Space Surplus Production Model (BSSSP). Each is discussed in turn with regard to its suitability given the data and life history of the species, the parameterization and model specification, and model performance, including sensitivities. Other models using catch only (DCAC and Catch-MSY) were also discussed, but not put forward from the stock assessment team as viable candidates.

Age Structured Assessment Program (ASAP)

The SASC put forward ASAP as the preferred model. This is an age-structured approach using indices of abundance and age compositions to estimate initial age structure, recruitment deviations, index and fishery selectivities, fishing mortality, survey catchability, and stock-recruitment parameters. The underlying catch data are extremely uncertain, but this trait is common to any model that would use a catch time series, thus not a challenge unique to ASAP models. The ASAP model was considered the fullest use of available data in each area, though it was hindered in some respects. ASAP was sometimes restricted, relative to the other models, in its initial year of model estimation. However, comparisons to other models showed this did not cause major deviations in results.

There are at least three major advantages of ASAP over the other two models: 1) more detail in the underlying dynamics (age-structured vs. lumped biomass), 2) indices could be used as numbers rather than biomass only (which required additional assumptions to expand the numbers to biomass) and 3) the estimation of selectivity, rather than assuming selectivity is equal to maturity. Selectivity estimates from ASAP demonstrated significant differences in the assumption that selectivity equals maturity (as used in the other models).

The general parameterization of ASAP shared likelihood components common to other age-structured models, though the need to have an estimate of initial time series age-structure proved a challenge, limiting the capacity of this model to reach back in time to provide initial condition estimates. Likelihood weighting was maintained at 1 for catch and index fits, but downweighted by half for the recruitment and fishing mortality penalty functions. Downweighting the recruitment penalty allowed the model to stray from strict Beverton-Holt recruitment estimates, an assumption the review panel supported. Common data tuning techniques were also applied to make model input consistent with data treatment within the data, including inflation of measurement error on the indices. Selectivities were estimated in three time blocks to address changes in management. Natural mortality was assumed to be constant across ages and through time.

Model fits were adequate, with one or two indices usually dominating the fits. There was an initial concern that index uncertainty may have been underestimated, but subsequent model runs with added variance explored this issue. The recreational-based indices tended to be the most informative, thus much of the model interpretation hinges on the trust in these indices. Fits to the catch-at-age data showed lack of fits in several instances, underscoring the informational weakness in low sample sizes and possible need for additional selectivity blocks. Stock productivity (i.e., steepness) was estimable in two of three areas. The DMV area showed no contrast in the stock-recruitment relationship, thus steepness was not estimable.

Several sensitivities were performed in ASAP across a variety of model specifications. These included removal of indices, the treatment of natural mortality, less selectivity blocks, assumed steepness, and recruitment penalty likelihood weighting. The results were fairly robust to all of these explorations for the SNE model, which was generally the most informed model. Removal of the CT trawl survey and mortality assumptions caused the greatest sensitivities. First year biomass was consistently the most sensitive portion of the biomass estimates. The NY-NJ model showed most sensitivity to the removal of the NJ trawl survey and extension of the model back in time. The DMV model was the least informed model, though it showed the least sensitivity.

Retrospective analyses back to the year 2007 were also examined. SNE showed the least biased patterns, with the two less informed regional models (NY-NJ, DMV) showing more retrospective behavior.

<u>Extended Depletion-Based Stock Reduction Analysis (xDB-SRA)</u>

The xDB-SRA model was offered as another candidate model that shares catch, index, and some life history data with ASAP. The SASC also did some very nice work to incorporate catch uncertainty into the xDB-SRA model, something not traditionally done, and are commended for the creative extension, especially given the poorly informed nature of the catch history and the sensitivity of this method to catch history. Differences from ASAP include: assuming maturity and selectivity are the same function; using a biomass index based on numbers and assumptions on weight; biomass that is not age-structured; productivity based on a more flexible function; and the influence of a prior on relative abundance.

Model diagnostics showed both good post-model, pre-data behavior as well as posterior estimation. The Panel suggested the SASC also include the posterior distributions for yearly catches given those are also randomly drawn inputs to the model. Posteriors on relative stock abundance were highly influenced by the information coming from the indices. Base model runs were very similar to the results found in ASAP, but with much greater uncertainty.

Sensitivities were more limited than those performed in ASAP, and consisted mostly of removing indices and assuming a different production model (Schaefer). There were substantial sensitivities to removal of indices, particularly the MRIP-based indices. No retrospective analyses were conducted.

Bayesian State Space Surplus Production Model (BSSSP)

The state-space model shares in its dynamics a lumped biomass approach rather than the age-structured approach, but it also introduces the capacity to include both process (e.g., biomass) and observation (e.g., index uncertainty) error, an extension not in the xDB-SRA approach. The BSSSP uses a re-parameterization Schaefer model expressed in relative biomass instead of absolute biomass, and thus draws different parameters (i.e, r and K) than in xDB-SRA. Prior distributions used in the model were developed for BSSSP and not used in the other models. It shares the same initial model year with xDB-SRA, which is earlier than the ASAP model. The same indices were used in this model as in the other models, though the BSSSP model also required biomass indices (not as numbers), thus suffering, as xDB-SRA does, from possible issues of expanding numbers to biomass.

Convergence diagnostics were extensive and showed good searching behavior. Model fits to indices were similar in each region to the other models. Despite similar fits, there were very large biomass discrepancies in the NY-NJ and DMV model compared to the other models.

Sensitivities conducted focused on the removal of indices of abundance and different regional configurations. Models demonstrated more sensitivity to removal of indices than the other models. No retrospective analyses were conducted.

The Panel agrees with the SASC that due to model sensitivity to indices and the large discrepancies from the other models (both in trend and absolute biomass), the BSSSP model is not preferred for any of the tautog regional assessments.

The Panel endorsed the SASC's selection of the ASAP model for use in the stock assessment. The Panel concluded that the SASC undertook an appropriate model selection process, adequately derived the range of input parameters and undertook innovative model adjustments to addresses issues specific to tautog.

4. Evaluate the methods used to characterize uncertainty in estimated parameters. Ensure that the implications of uncertainty in technical conclusions are clearly stated.

Uncertainty was generally characterized in two ways for each model: Uncertainty within the base model specification and sensitivities (discussed in the previous section) to demonstrate uncertainty to model specifications. For base model uncertainty, ASAP used the Markov Chain Monte Carlo (MCMC) algorithm found in the Auto-Differentiating Model Builder (ADMB) programming platform to numerically estimate posterior values for derived quantities. Sampling Importance Resampling (SIR) was used to do the same thing for xDB-SRA. The BSSSP model used Gibbs sampling found in the OpenBUGS program. All methods are appropriate for each respective model.

The overall uncertainty in xDB-SRA and BSSSP was large and expected, but ASAP demonstrated unexpectedly low uncertainty in all base models. Sensitivity analysis also showed relatively low deviations from the base case, thus model specification also had low uncertainty. The largest sources of uncertainty remain the quality of the recreational fishery catch history, the lack of catch information prior to the 1980s, and the low biological sampling effort of tautog.

5. Evaluate the best estimates of stock biomass, abundance, and exploitation from the assessment for use in management, if possible, or specify alternative methods/measures.

The 2014 benchmark stock assessment for tautog provided estimates of stock biomass, abundance, and fishing mortality rate at the level of three regions: SNE, NY-NJ, and DMV. A coast wide ASAP model was run but mainly functioned to bridge the changes from the ADAPT-VPA model, used in the 2005 benchmark stock assessment, to the ASAP age-structured model. Analyses conducted both at the regional level and the coast wide level were reviewed, with greater focus on the regional analyses.

The model that the SASC team recommends to use for management purposes is the ASAP age-structured model. After multiple alternative sensitivity runs of the ASAP model, including additional runs requested by the Panel, the resulting estimates of spawning stock biomass, abundance, recruitment, and fishing mortality are relatively robust. The Panel agreed that the region level ASAP stock assessment models provided the best available scientific foundation for management. The Panel and the SASC realized that the use of the logistic curve may be what caused the selectivity curve to switch to a higher selectivity after increasing catch size limit in all three regions. This may also explain why the model struggled to fit the catch-at-age data in some years. An alternative flexible selectivity curve could be developed and used in the stock assessment model given the tautog fisheries’ use of multiple gear types.

The ASAP regional model results indicated that the population abundance/biomass in the SNE and NY-NJ regions declined (rate: 2.9/14.2; 2078/5500) from the starting year of the model to the present with biomass increasing slightly in the two most recent years. The DMV region model results also show a declining trend but it is not as severe as the other regions. The SASC and Panel suggest this is because of the large influence of the MRIP index, the only abundance index used to tune the DMV region model. Fishing mortality estimates have been highly variable because of the highly varied recreational harvest statistics. The recent F estimates for the NY-NJ and DMV regions were lower (0.21 versus 0.25 of 3-year average; 0.1 versus 0.17 of 3-year average), than the F estimates from the SNE region (0.59 versus 0.50 of 3-year average).

The ASAP results are very similar to the results of the DB-SRA and the BSSSP models. There is also a comparison of a coast wide ASAP model run with the ADAPT-VPA model used in past assessments. *In summary, the Panel is very encouraged by the modeling efforts of the SASC and finds they are a significant advance since the previous assessment. The Panel endorses the use of estimates from the ASAP regional models.*

6. Evaluate the choice of biological or empirical reference points and the methods used to estimate them. Recommend stock status determination from the assessment, or, if appropriate, specify alternative methods/measures.

Coast wide F BRP

Reference Point	Target	Threshold
Addendum IV (F=M)	0.15	
ASAP (Add. IV SSB)	0.02	0.06
F_{MSY}	0.10	
F_{SPR}	0.20	0.30
SNE -- Add. IV	0.05	0.03
SNE new	0.15	0.20

Coast wide SSB BRP

Reference Point	Target	Threshold
Addendum IV	26,800	20,100
VPA updated	26,700	20,015
ASAP	21,610	16,204
SSB MSY	19,125	14,340
SSB SPR	9,500	7,110
SSB F_{MSY}	13,720	10,290
SNE -- Add. IV	8,859	6,645
SNE new	3,883	2,912
NY-NJ	3,570	2,640
DMV	2,090	1,580
TOTAL	**9,543**	**7,132**

The SASC recommended different models to develop BRPs because of the quality of the stock-recruitment relationships. The Panel found the results of the SNE region model to be reasonable. The F_{msy} (0.15) is recommended as F_{target} and SSM_{msy} (3,883MT) is recommended as SSB_{target}. 75%SSB_{msy} is recommended as the $SSB_{threshold}$ and the $F_{threshold}$ based on $SSB_{threshold}$ is 0.20.

The NY-NJ and DMV region models had shorter time series which is reflected in the poor stock-recruitment relationship. $F_{40\%}$ is recommended as the F_{target} and $F_{30\%}$ is recommended as the $F_{threshold}$. See above tables for values.

The Panel noted that the F target and threshold reference points were influenced by the selectivity pattern estimated from the ASAP models, which varied among the 3 regions.

Variation in growth and maturity among the three regions also contributed to variation in the reference point estimates.

The Panel also noted that by using region level models, the recommended SSB_{BRP} is much smaller than SSB_{BRP} recommended historically for management purposes. The differences between cumulative SSB_{BRP} from the regional models and the SSB_{BRP} from the coast wide model changed the stock status to a degree and at the same time increased the risk of the population being overfished. Precaution is needed when using the regional SSB_{BRP} in this case.

Nevertheless, the Panel believes that the new reference points developed by the SASC should be used and, based on the new values, agrees with the stock determinations of the SASC. The Southern New England stock is overfished and overfishing is occurring, the NY-NJ stock is overfished, but overfishing is not occurring, and the DelMarVa stock is overfished, but overfishing is not occurring.

7. Review the research, data collection, and assessment methodology recommendations provided by the TC and make any additional recommendations warranted. Clearly prioritize the activities needed to inform and maintain the current assessment, and provide recommendations to improve the reliability of future assessments.

The recommendations provided by the SASC were comprehensive and the Panel concludes they covered the primary areas needed to improve future assessments. The Review Panel has the following additional research and modeling recommendations:

a. Obtain biological metrics to match the spatial scale of the proposed models, to determine if there is biological justification for such models.
b. Develop an alternative flexible selectivity curve to use in the stock assessment model given the characteristics of multiple gear types in the tautog fisheries.
c. Collect otoliths in addition to opercula from individual fish; invest in otolith microchemical analyses and next-generation sequencing to resolve finer-scale spatial issues.
d. Consider using alternative catch-at-age modeling frameworks (e.g., Stock Synthesis) in order to overcome some constraints of the ASAP model in the NMFS Toolbox. Simpler methods, such as xDB-SRA, can also be performed in Stock Synthesis, providing a common modeling framework to develop and compare different models and their specifications.

8. Recommend timing of the next benchmark assessment and updates, if necessary, relative to the life history and current management of the species.

An assessment update is suggested in another year to check the change of the fishery and population status and the appropriateness of the recommended BRPs from the 3 region-scale models. The next benchmark assessment may be done in 3 years or depend on the results of the update using the current stock assessment models, and the timeframe for developing the models in a new modeling framework.