Atlantic States Marine Fisheries Commission

Weakfish Management Board

May 5, 2016
8:00 – 10:00 a.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 *(R. Allen)* 8:00 a.m.
2. Board Consent 8:00 a.m.
    - Approval of Agenda
    - Approval of Proceedings from November 2015
3. Public Comment 8:05 a.m.
4. 2016 Weakfish Benchmark Stock Assessment **Action** 8:15 a.m.
    - Presentation of Stock Assessment Report (*J. Brust)*
    - Presentation of Peer Review Panel Report *(P. Campfield)*
    - Consider Acceptance of Benchmark Stock Assessment and Peer Review Report for Management Use
5. Discuss Next Steps for Management of Weakfish (*R. Allen)* **Possible Action** 9:15 a.m.
6. Other Business/Adjourn 10:00 a.m.

The meeting will be held at the Westin Alexandria; 400 Courthouse Square; Alexandria, VA 22314; 703.253.8600

Vision: Sustainably Managing Atlantic Coastal Fisheries

MEETING OVERVIEW

Weakfish Management Board Meeting
Thursday, May 5, 2016
8:00 – 10:00 a.m.
Alexandria, Virginia

Chair: Russ Allen (NJ) Assumed Chairmanship: 2/14	Technical Committee Chair: Joe Cimino (VA)	Law Enforcement Committee Representative: Steve Anthony (NC)
Vice Chair: Rob O'Reilly (VA)	Advisory Panel Chair: Billy Farmer (NC)	Previous Board Meeting: November 3, 2015
Voting Members: MA, RI, CT, NY, NJ, DE, MD, PRFC, VA, NC, SC, GA, FL, NMFS, USFWS (15 votes)		

2. Board Consent

- Approval of Agenda
- Approval of Proceedings from November 2015

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 Board 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 Board Chair may allow limited opportunity for comment. The Board Chair has the discretion to limit the number of speakers and/or the length of each comment.

4. 2016 Stock Assessment (8:15 a.m. – 9:15 a.m.) Action
Background • The 2016 benchmark stock assessment was completed in March **(Briefing Materials)** • A peer review was held March 30-April 1 **(Briefing Materials)**
Presentations • Assessment overview by J. Brust, Chair • Peer review summary by P. Campfield
Board actions for consideration at this meeting • Accept the Stock Assessment Report and Peer Review Report for management use.

5. Discuss Next Steps for Management of Weakfish **(9:15 a.m. – 10:00 a.m.) Possible Action**
Background • After reviewing the assessment, the Board may consider a management response.
Presentations • Discussion facilitated by R. Allen, Chair
Board actions for consideration at this meeting • Initiate an addendum to address reference points and stock status.

6. Other Business/Adjourn

DRAFT PROCEEDINGS OF THE

ATLANTIC STATES MARINE FISHERIES COMMISSION

WEAKFISH MANAGEMENT BOARD

World Golf Village Renaissance
St. Augustine, Florida
November 3, 2015

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

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1. **Motion to approve agenda by Consent** (Page 1).

2. **Motion to approve proceedings of February, 2014 by Consent** (Page 1).

3. **Move to approve the 2015 FMP Review including the state compliance reports and *de minimis* status for Massachusetts, Georgia, Florida and Connecticut** (Page 2). Motion by Steve Heins; second by Tom Fote. Motion carried (Page 2).

4. **Motion to adjourn by Consent** (Page 2).

ATTENDANCE

Board Members

Nicola Meserve, MA, proxy for D. Pierce (AA)
Bill Adler, MA (GA)
Eric Reid, RI, proxy for Sen. Sosnowski (LA)
David Borden, RI (GA)
Dave Simpson, CT (AA)
Lance Stewart, CT (GA)
Steve Heins, NY, proxy for J. Gilmore (AA)
Emerson Hasbrouck, NY (GA)
Roy Miller, DE (GA)
John Clark, DE, proxy for D. Saveikis (AA)
Bill Goldsborough, MD (GA)
Lynn Fegley, MD, proxy for D. Blazer (AA)
Robert Boyles, SC (LA)
Sen. Ronnie Cromer, SC (LA)
Malcolm Rhodes, SC (GA)
Spud Woodward, GA (AA)
Pat Geer, GA, proxy for Rep. Burns (LA)
Nancy Addison, GA (GA)
Jim Estes, FL, proxy for J. McCawley (AA)
Martin Gary, PRFC

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

Ex-Officio Members

Staff

Bob Beal
Toni Kerns
Megan Ware
Katie Drew
Kirby Rootes-Murdy

Guests

Jason McNamee, RI DEM
Capt. Steve T. Anthony

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

The Weakfish Management Board of the Atlantic States Marine Fisheries Commission convened in the St. Augustine Ballroom of the World Golf Village Renaissance, St. Augustine, Florida, November 3, 2015, and was called to order at 11:55 o'clock a.m. by Chairman Russ Allen.

CALL TO ORDER

CHAIRMAN RUSS ALLEN: We're ready to get started here. If you don't take a seat you miss out. I would like to get the Weakfish Board started.

APPROVAL OF AGENDA
APPROVAL OF PROCEEDINGS

The first thing on the agenda is approval of the agenda and approval of proceedings from the February, 2014 meeting. Are there any changes to the agenda or objections to those proceedings? Seeing none; we'll consider those approved.

PUBLIC COMMENT

There is no one signed up for public comment, but if someone wants to do that at this time, we'll take them to the front for a couple of minutes. Seeing none; we will move on.

UPDATE ON THE 2016 BENCHMARK STOCK ASSESSMENT

The first real agenda item here is an update on the 2016 benchmark stock assessment, and I'll turn it over to Katie.

DR. KATIE DREW: Modeling is well underway and we are still on track to have it peer reviewed at the beginning of 2015, so you will be able to receive the completed assessment and the peer review reports at the May meeting. Yes, 2016.

FISHERY MANAGEMENT PLAN REVIEW

CHAIRMAN ALLEN: Thank you, Katie, any questions for Katie? Seeing none; we'll move on to the Fishery Management Plan Review with Megan.

MS. MEGAN WARE: I am going to go quickly through this, and if anyone has any questions at the end you can let me know. First, I'll start with the landings here. Obviously, landings are down. Commercial harvest is in green, recreational harvest is in red. Total coast wide landings in 2014 were about 273,000 pounds; which is a noticeable decrease from 2013 and 2012. They were both over 500,000 in those previous years.

If we go to the next slide, this graph shows recreational harvest in blue and recreational releases in red. Landings in 2014 were 77,000 pounds or 62,000 fish; and this is well below the five-year average. In terms of pounds, North Carolina had the largest portion of recreational harvest and the number of fish released was a little over 550,000. Addendum 1 to Amendment 4 requires the collection of otoliths and lengths to characterize catch, and this year shows what all the states were required to sample and the actual sampling that took place.

All of the states that are not de minimis met that requirement so that is great for 2014. The starred states are those de minimis states. We have management measures in Addendum 4 that replace those in Addendum 2; however, the Plan Review Team continues to evaluate the management triggers in Addendum 2 to provide perspective on the fishery. The first one is to reevaluate management measures if commercial landings exceed 80 percent of the mean commercial landings form 2000-2004, and it is about 3 million pounds. This trigger was obviously not met. The second is if a single state's landings exceed the five-year mean by more than 25 percent in a single year; and this did occur in Georgia and South Carolina, however this increase is really due to extremely low landings so this is not something that the PRT felt was a need for immediate action. It is just something to keep in mind.

Status of the stock, the 2009 stock assessment said the stock is depleted but overfishing is not occurring; and as Katie just mentioned, we're on schedule to have the next assessment approved in 2016. For status of management, we don't have any new addendums in place. We're currently in to Amendment 4, Addenda 1 through 4.

In terms of state compliance, all states are found to be in compliance for de minimis. The definition of de minimis is, for the last two years, the combined average commercial and recreational landings by weight constitute less than 1 percent of the coast wide commercial and recreational landings in the same two-year period.

We got requests from Florida, Georgia, Connecticut and Massachusetts; Florida, Georgia, and Massachusetts qualify, Connecticut was just above the 1 percent at 1.07 percent. That is something that the board can discuss. In terms of recommendations, the PRT recommends the board approve the 2015 Weakfish FMP Review, state compliance reports and de minimis status for Florida, Georgia, and Massachusetts. With that I will take any questions.

CHAIRMAN ALLEN: Any questions for Megan? Seeing none; I'll be looking for a motion.

MR. STEVE HEINS: **I move that we approve the 2015 FMP Review including the state compliance reports and de minimis status for Massachusetts, Georgia, Florida and Connecticut.**

CHAIRMAN ALLEN: Tom Fote with a second on that. Discussion by the board.

MS. NICOLA MESERVE: Just a question. If Connecticut were to be found not de minimis, the only change would be the biological monitoring requirements, right; which I believe last year were something like five otoliths and nine lengths.

MS. WARE: That is correct. De minimis states are not required to implement the biological sampling. If Connecticut did not get that status granted they would have to implement that. The number of otoliths and lengths sampled is based on catch, so I believe it is six otoliths for metric tons of commercial landings and three for combined.

CHAIRMAN ALLEN: Anyone else?

CAPTAIN ANTHONY: I just want to say I can appreciate how hard it is to dedicate the resources to collect biological samples from a species that is very hard to find.

CHAIRMAN ALLEN: Yes, I echo your sentiments there. **Seeing no further discussion, is there any objection to this motion? Seeing no objection; the motion passes unanimously**. That pretty much wraps up the board meeting unless someone has something else.

MR. TOM FOTE: I was just wondering, probably about five weeks ago fishing for bluefish along the beach, all of a sudden they came up spitting up heads and then tails and I realized that what I thought was rain fish in the Wash were schools and schools of bluefish coming in along the beach.

They were all about five or six inches long. There were these bluefish that we're eating - only about a pound and a half. I was wondering if anybody else has seen the same thing. Usually, we were having a problem, we saw only two inch ones, but at least now I'm seeing five and six inch ones. I was just wondering if anybody else has seen that along the coast.

ADJOURNMENT

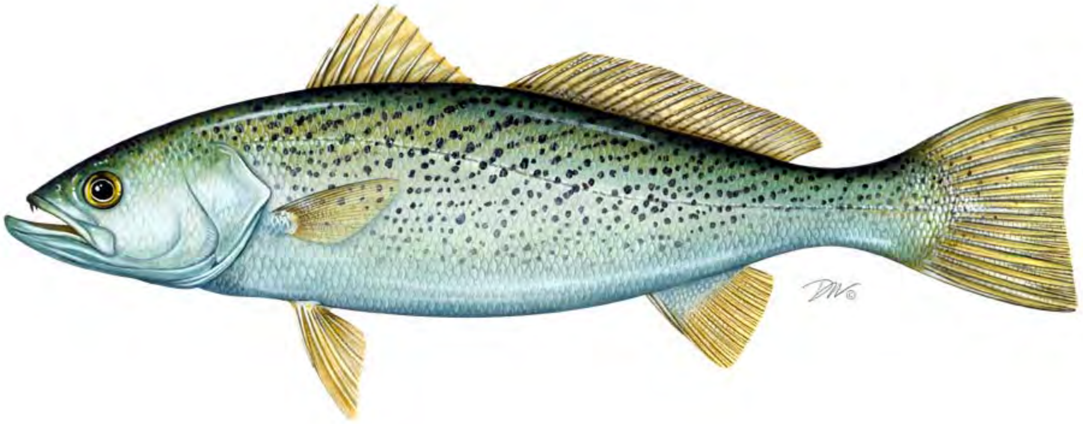
CHAIRMAN ALLEN: Nobody else? Is there anything else to come before the board? If you do see anything like that you can discuss that with Tom later. Seeing nothing else; I'll turn it over to Bob. I think we're done.

(Whereupon, the meeting was adjourned at 12:05 o'clock p.m., November 3, 2015.)

DRAFT FOR MANAGEMENT BOARD REVIEW

Atlantic States Marine Fisheries Commission

Terms of Reference & Advisory Report of the Weakfish Stock Assessment Peer Review



March 2016

Working towards healthy, self-sustaining populations for all Atlantic coast fish species
or successful restoration well in progress by the year 2015

Atlantic States Marine Fisheries Commission

Terms of Reference & Advisory Report of the Weakfish Stock Assessment Peer Review

Conducted on
March 30-April 1, 2016
Virginia Beach, Virginia

Prepared by the
ASMFC Weakfish Stock Assessment Review Panel

Dr. Patrick Sullivan, Panel Chair, Cornell University
Dr. Jeffrey Buckel, North Carolina State University
Dr. Jonathan Deroba, National Marine Fisheries Service, NEFSC

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA15NMF4740069

I. Introduction

The weakfish *Cynoscion regalis* is a member of the family Sciaenidae. Weakfish are found in estuarine and ocean waters of the U.S. Atlantic coast from Massachusetts Bay to Florida and are most abundant from North Carolina to New York. They mature at age 1 and spawn within estuaries during a protracted spawning period from late spring through summer. Young-of-the-year use estuarine habitats before joining the adult inshore-offshore and northern-southern migrations. During the last century, landings of weakfish have exhibited "boom and bust" cycles most likely as a result of large fluctuations in population size. The cause(s) of large variation in weakfish population sizes are unknown.

The Review Panel accepted the Bayesian statistical catch at age model with time varying natural mortality (*M*) and recommended its use for management. The model allows increases in total mortality (Z) to be accounted for by increases in *M*; currently, this is the most parsimonious explanation for increases in *Z*. *The 2014 estimate of weakfish Z (1.19) was above the target Z (0.93) but below the threshold Z (1.36); however, the annual estimates of Z from 2002-2013 were above the threshold.* The Review Panel agreed with the Technical Committee that *Z* be below the threshold for more than one year before management measures are taken.

The current estimates of spawning stock biomass (SSB) are low relative to SSB estimates in recent decades. The Review Panel recommends that the SSB reference point be used outside of the control rule (as biomass estimates are often unstable), to provide additional indication of when further precaution should be taken for stock management.

The following Review Report evaluates the data and approaches used to model the U.S. east coast weakfish stock; gives recommendations on how to interpret model output relative to benchmarks; and provides research recommendations for data collection and future model sensitivities and configurations.

II. Terms of Reference (addressed individually by number)

1. Evaluate the thoroughness of data collection and the presentation and treatment of fishery-dependent and fishery-independent data in the assessment.

Weakfish harvest and discard data were presented from four fishery sectors: commercial harvest, commercial discards, recreational harvest, and recreational discards. The data collection methods appear to be adequate and the methods were well documented by the Technical Committee. An additional source of removals identified during the review workshop was that due to scientific monitoring. With low population and catch, survey removals could prove to be a significant source of mortality. The panel recommends that removals of age-0 and age-1+ weakfish by scientific sampling be monitored for its potential effects on recruitment and mortality in the recruited stock.

As stated in the Technical Committee Report: "Harvest and discard estimates were stratified by region (north/south), year, and season (early/late). Commercial harvest was further stratified by state. Where available, stratum specific biological data (length data and length-weight equations) were used to convert harvest and discard weights to number of weakfish removals at size. Where stratum specific data were not available (some commercial harvest strata), samples were substituted from the next most representative stratum. Numbers at size were then converted to numbers at age using region/year/season specific age-length keys. Numbers at age were summed across strata within a year to develop annual estimates of total weakfish removals at age."

a. Presentation of data source variance (e.g., standard errors).

Several potential sources of bias that can result in uncertainty in annual removals at age estimates were identified by the Technical Committee and confirmed by the Review Panel. The following sources were not fully investigated during the assessment but should be evaluated in the future (see Research Recommendations):

- harvest/discard estimates as influenced by under/over reporting or inappropriate survey methods;
- sample sizes needed to sufficiently characterize length distributions;
- consistency in ageing techniques and the scale-otolith age conversion.

Additional sources of bias that were investigated during the assessment include:

- imputation of missing data using adjacent cells in the catch-at-size characterization and age-length keys;
- the use of statistical catch-at-age models, which can account for error in the catch matrix, which was found to be a significant improvement over previous assessments which assumed catch was known without error;

b. Justification for inclusion or elimination of available data sources.

The Technical Committee provided strong justification for inclusion or exclusion of fishery-independent and fishery-dependent indices. The Review Panel agreed with the choice of indices included in the preferred Bayesian model run and the ASAP model. However, the Panel noted concerns about the following indices:

- The utility of the MRFSS/MRIP statistics as a fishery-dependent index can be biased due to changes in catchability in the fishery. However, efforts continue to be made to identify any changes in the fishery and might influence catchability and it is recognized that the benefits of MRIP's long time series and broad geographic coverage outweighed existing concerns.
- Density-dependent processes may still be operating on age-0 fishes, as a consequence age-0 abundance is viewed to be a poor index of age-1 weakfish abundance. The Review Panel recommended a sensitivity run of the preferred Bayesian statistical catch-at-age model with and without using the age-0 indices of abundance to examine how this might influence demographic patterns in population estimates.

c. Consideration of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, aging accuracy, sample size).

These considerations are outlined in the comments made above.

d. Calculation and/or standardization of abundance indices.

A generalized linear model (GLM) was used to standardize data inputs for inclusion as abundance indices for the models. The standardization methods appear to be adequate and a detailed description of each index's standardization methods was included in the Technical Committee Report:

"The WTC evaluated 45 fishery independent surveys and one fishery dependent index against a set of criteria the WTC assembled to determine which surveys were might be representative of weakfish population trends. Criteria included survey length, geographic range, sampling methodology, and prevalence of weakfish in catches. Thirty-one data sources were considered not suitable for the assessment because they did not meet one or more of the criteria. The remaining indices were standardized using GLM incorporating appropriate environmental and methodological covariates. GLM are considered an improvement over previous methods (geometric mean), because GLM can account for species specific drivers that may not be captured by a generic statistical design. Many of the indices exhibited large interannual variation, and there was a general lack of coherence between the inshore and offshore surveys. Lack of coherence suggests the surveys may be capturing different components of the stock and/or there is spatial asynchrony in distribution which was tested for in one of the candidate models."

2. Evaluate evidence for constant or recent systematic changes in natural mortality, predator-prey dynamics, productivity, and/or discard mortality.

The Weakfish Technical Committee investigated time varying natural mortality using time varying changes in maximum age and the percentage of empty weakfish stomachs in NMFS NEFSC and NEAMAP trawl survey data. Results were inconclusive. The Review Panel agrees with the Technical Committee that using the maximum age approach to estimate natural mortality on a fished population is inappropriate.

Both an ASAP model and the preferred Bayesian statistical catch at age model provided better fit to the data when natural mortality was allowed to be time varying. Estimates indicated M increased during the 1990s to recent years where M ~1.0. For the Bayesian statistical catch-at-age model, there was a drop in the estimate of natural mortality in 2014 but this is likely a result of retrospective bias. The Review Panel suggests that factors influencing the estimability of a time varying M continue to be monitored. Time varying M is notoriously difficult to estimate, but the dramatic changes seen in weakfish biomass over the time series and the very low levels of harvest currently observed may allow estimation to be possible. Sensitivity of the estimates in time varying M to constraints imposed by priors in the Bayesian model should also be explored further.

The Technical Committee noted issues that resulted in some double counting of discards. This analysis resulted in a reduction in the magnitude of estimated discards relative to the previous assessment. Thus, there is less evidence for discard mortality causing the recent decreases in weakfish abundance.

Changes in productivity could result from changes in individual growth rate. The Technical Committee provided evidence for an initial increase followed by a decrease in size-at-age. It was not clear if this was due to a real change in weakfish growth rate or changes in geographic coverage of weakfish ageing samples. It is known that fish are smaller at age in the southern part of the range. (see Research Recommendations)

A correlative and/or mechanistic link between weakfish natural mortality and predictor variables would be useful for weakfish population projections. Correlations may exist between commercial landings and the Atlantic Multidecadal Oscilation (AMO) climate index, and between estimates of natural mortality from the Bayesian statistical catch at age model and the AMO index, but the Review Panel recommended against using the latter relationship for short term projections at this time. There have been cycles of weakfish abundance over time but the cause(s) of these cycles remain unknown.

As noted in the Technical Committee Report: "Time varying natural mortality rates based on changes in maximum age over time and diet studies were inconclusive due to the nature of the data. Commercial harvest (as proxy for weakfish abundance) still exhibits a strong negative relationship to sea surface temperature, as does recreational CPUE which is not affected by changes to regulations. A modified Catch Survey Analysis model indicated that M increased 3- to 4-fold during the late 1990s to early 2000s. Similarly, the Bayesian age structured model presented in this assessment estimates that M increased from less than 0.2 in the 1980s and early 1990s to M=0.95 by the late 2000s. Although not all of the methods investigated are appropriate for modeling time varying M, several of the methods investigated show similar patterns, lending credibility to the results. These methods all indicate an increase in natural mortality during the late 1990s and 2000s to values around M=1.0 in recent years."

3. Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, 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?

The Review Panel believes that the proposed Bayesian statistical catch at age model is appropriate and justified for use in making management decisions, with caveats to be considered:

Model selection was largely based on DIC, posterior p values, and a simulation/validation process, but DIC has not always performed well for selecting the true model using simulated datasets.

External evidence of temporal changes in *M* was inconclusive, and these parameters estimates may be aliased by other processes (e.g., time varying q). Spatial asynchrony in population density to account for inconsistent index trends could also likely alias other processes (e.g., time varying q). There is a tendency for models of this type to over fit the data through the inclusion of time-varying parameters. Some caution should be exercised in interpreting the results.

While examining for retrospective patterns from a model is useful, it should not be used in and of itself as a model selection criterion and care should be taken not to over-interpret such results. While the presence of a retrospective pattern is indicative of a structural misspecification in the assessment model, the absence of a retrospective pattern does not indicate the model is correct.

The use of average *M* for Biological Reference Points (BRPs) is based on historical performance and seems reasonable, but this approach will need to be updated later as *M* and productivity of the stock are likely to change in the future. The use of historical recruitment indices for creating projections should also be re-examined in the future as the productivity of the stock changes. The conclusions of the assessment in regards to stock status appear to be robust to model variants and the preferred model appeared to be reasonable and provided an improved fit to the data.

b. If multiple models were considered, evaluate the analysts' explanation of any differences in results.

Multiple models were explored in the assessment (relative F continuity, ADAPT VPA, ASAP, Bayesian SCA), but a single best model was chosen (Bayesian model M4). Multiple Bayesian models were examined (M1-M4, see Assessment Report pg. 68-71). Additionally, an ASAP and several continuity models were examined in order to relate current assessment methods to previous assessment methods.

Outputs from the four Bayesian models were presented for consideration. However, questions remained with regard to the level of uncertainty associated with each data source. Reporting on how the measurement and process variances changed among the various Bayesian model runs would have been informative. Some of this information was in appendices made available at the Review Workshop but a more systematic analysis of that information is warranted. For example, it would have been useful to evaluate if allowing for spatial asynchrony changes the measurement error variances for the indices or catch.

c. Evaluate model parameterization and specification (e.g., choice of CVs, effective sample sizes, likelihood weighting schemes, calculation/specification of M, stock-recruitment relationship, choice of time-varying parameters, plus group treatment).

In this section, only those parameters and specifications not already addressed above will be considered.

A stock-recruitment relationship was not estimated nor were reference points calculated from such an estimate. Stock-recruitment relationships for weakfish are likely to be complicated by time varying life history traits. The Review Panel recommends that if a stock-recruitment relationship is estimated it should not be estimated within the population model estimation framework as even low weighting given to that subcomponent of the estimation can influence the global assessment model results.

The ASAP runs were not iteratively reweighted. This can impact residual patterns and retrospective patterns. Carrying the fit to this step is important to ensure comparison of ‘best to best’ model runs. However, for the purposes of the current assessment, the ASAP runs were reasonable and were a useful addition to the overall assessment process.

Given questions about justification of plus-group minimum age, the Panel recommends in future assessments a sensitivity analysis be used to evaluate what affect the minimum age of the plus-group has on model results.

4. Evaluate the diagnostic analyses performed, including but not limited to:

a. Sensitivity analyses to determine model stability and potential consequences of major model assumptions

Sensitivity to a range of data inputs was well addressed and understood. Given the assessment model structure, outcomes were robust. While allowing for process errors in the Bayesian models allowed for improved fit to data (as would happen with any model where process errors are included), diagnostic issues (residual patterns, retrospective patterns) remained. The remaining diagnostic issues were not so severe as to invalidate the model results for management advice.

b. Retrospective analysis

Other than perhaps conducting a couple more peels, the retrospective analyses were adequately presented and interpreted. At this point, the remaining retrospective pattern is not cause for concern relative to management action. The Review Panel recommends in future assessments using more informative priors on non-essential components of the model to gain efficiency in conducting consecutive assessment runs while exploring retrospective patterns.

5. Evaluate the methods used to characterize uncertainty in estimated parameters. Ensure the implications of uncertainty in technical conclusions are clearly stated.

The Bayesian M4 age-structured assessment model, the preferred model for the stock assessment from both the Technical Committee and Review Panel perspectives, appropriately incorporates the uncertainty present at several levels through the use of Bayesian hierarchical modeling. The incorporated uncertainty includes much of the stochastic uncertainty in biological processes, as well as the observation uncertainty encountered through data collection and survey sampling. While no model can perfectly represent all uncertainty, the Bayesian framework is structured to allow the various known sources of uncertainty to be represented appropriately. The assessment team also explored other sources of uncertainty including the quality and appropriateness of the data collected, the sensitivity to certain key model assumptions such as constant or trending natural mortality (*M*) and the robustness of estimates to model structure. In particular, the assessment team explored several alternative assessment approaches and model formulations including continuity assessments using more traditional stock assessment methods such as ASAP and VPA, which proved useful for comparing the Bayesian model outputs to those obtained using earlier assessment methods.

The Markov Chain Monte Carlo algorithm used in the estimation of the Bayesian population modeling should facilitate probabilistic predictions including estimates of the probability of being above or below critical threshold levels for key model parameters such as fishing mortality, total mortality, and spawning stock biomass.

The Bayesian hierarchical model structure should also facilitate hypothesis testing of the likelihood that alternative environmental and anthropomorphic drivers influence stock condition as well as assist in determining appropriate sample sizes needed on data inputs to achieve efficient population estimates.

The use of the uniform distribution as an “uninformative” prior for many components of the Bayesian hierarchical model should be updated following Gelman’s (2006) recommendations. The uniform distribution can put too high a level of variation on the tails, may inadvertently and perhaps unknowingly result in some parameter estimates bumping up against the boundaries of the specified uniform and when the uniform is translated into the log form as was done for M and other model parameters, the transformed uniform distribution can become an informative prior on the log scale.

6. If a minority report has been filed, review minority opinion and any associated analyses. If possible, make recommendation on current or future use of alternative assessment approach presented in minority report.

No minority report was submitted.

7. Recommend best estimates of stock biomass, abundance, and exploitation from the assessment for use in management, if possible, or specify alternative estimation methods.

In the short term, over the next 5 years, the preferred Bayesian M4 age-structured assessment model and the associated spawning biomass per recruit (SPR) reference points under an assumed $M = 0.43$ should be considered to provide the best estimates for determining stock biomass, abundance, exploitation rates, and total mortality for use in management. (See Stock Assessment Report Section 3 for the specific estimates). In the future, however, if the weakfish stock begins to show signs of recovery, alternative yield-per-recruit, spawner-per-recruit, production modeling, and more general management strategy evaluation approaches should be used for determining updated exploitation rates as the capacity for stock growth will likely have changed due to changes in mortality and other drivers of production. The Bayesian M4 assessment model itself, however, should continue to be applicable as long as data inputs and incorporated biological processes are appropriately updated.

8. Evaluate the choice of reference points and the methods used to estimate them. Recommend stock status determination from the assessment, or, if appropriate, specify alternative methods/measures.

It is difficult, if not impossible, to determine a fixed set of reference points for any population that does not exhibit the potential for a stable equilibrium as is the case for weakfish where as yet unknown drivers of changes to natural mortality (*M*) and stock production appear to be quite variable. The Weakfish Technical Committee has proposed a set of total mortality reference points (*Z*) to establish a practical control rule that should be useful for management. Furthermore, a spawning stock biomass threshold was also provided to serve as an additional reference point. The Review Panel recommends that the SSB reference point be used outside of the control rule (as biomass estimates are often unstable), to provide additional indication of when further precaution should be taken for stock management. The yield-per-recruit SPR reference points derived from this assessment that assume an $M = 0.43$ should be updated when stock productivity appears to increase as this would indicate that changes in mortality and other drivers of stock production have altered and the current short-term estimates of the reference points should be updated.

9. 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.

In general, the Review Panel agrees with the research recommendations and priorities developed by the Weakfish Technical Committee (see Assessment Report, Section 10, pp. 80-82). The Panel provides the following suggested changes to existing research priorities, as well as a set of new research recommendations that are critical to advancing weakfish science, modeling, and future stock assessments.

Review Panel Modifications to Existing Research Priorities

Modeling / Quantitative Priorities
High

- Evaluate predation of weakfish, by an expanded suite of predators (e.g., marine mammals), including leveraging ongoing ASMFC work on multispecies models by including weakfish as both predator and prey.
- ~~Analyze the spawner-recruit relationship and examine the effects of the relationship between adult stock size and environmental factors on year class strength.~~
    REMOVE – there is no spawner-recruit relationship for weakfish

Life History, Biological, and Habitat Priorities
High

- Continue to monitor weakfish diets over a broad regional and spatial scale, with emphasis on new studies within estuaries.

Review Panel New Research Recommendations

Life History, Biological, and Habitat Priorities

- Estimate weakfish mortality through independent approaches (e.g. alternative models, tagging) to corroborate trends in mortality from the assessment model.
- Determine the impact of scientific monitoring surveys on juvenile weakfish mortality. Calculate the resulting impact on adult stock size.

Modeling / Quantitative Priorities

- Currently, spatial asynchrony in the Bayesian model includes a variance parameter for each age and year, but most of the variation seems to be among years. Evaluate whether annual variance is more parsimonious.
- Assessment model input weights-at-age are poorly estimated or at best variable. Conduct sensitivity analyses to evaluate how much of this is real and how it affects model performance.
- Age-length keys and catch data contain uncertainties, explore alternatives for dealing with uncertainties through length based or condition-based models, recognizing these come with new issues, like proper representation of growth.
- If understanding the dynamics of YOY indices continues to be important, explore inconsistencies with Age 1 results from the assessment model.
- Catch measurement errors appeared relatively small; explore whether other process or measurement error processes are perhaps overly constraining the fit; one method to evaluate is through simulation estimation.
- Transfer Bayesian model code to more broadly accessible platform. The method likely has broad applicability for other stocks in the region and beyond.
- Conduct a simulation-estimation analysis to explore the estimability of time trends in natural mortality. For example, it would be useful to simulate time series for the natural mortality parameter as increasing, remaining constant, and decreasing with time under population parameter conditions similar to those currently estimated for weakfish; explore and see if these trends can appropriately be estimated using the weakfish model that allows time varying M to be estimated; additionally, explore changes in other parameters that alias with mortality and that potentially could also change with time, including recruitment, catchability and selectivity, discard and discard mortality, survey removals, and emigration.
- Conduct simulations with the proposed Z based control rules, or thresholds/targets in a time varying environment to explore alternative management options. If the weakfish stock begins to show signs of recovery, alternative yield-per-recruit, spawner-per-recruit, production modeling, and more general management strategy evaluation approaches should be used for determining updated exploitation rates as the capacity for stock growth will likely have changed due to changes in mortality and other drivers of production.
- Conduct a meta-analysis of all factors likely to influence changes in natural mortality to see if the aggregate effect shows stronger statistical likelihood of occurrence than the significance shown by each individual driver effect on its own.

- Improve implementation of the process for organizing and collecting data from different agencies and sources to assure timely and high quality data input into the model.
- Look for consistency and similarity among GLM survey estimation methods and check for sensitivity to collinearity of different drivers with the YEAR effect.

10. Recommend timing of the next benchmark assessment and updates, if necessary, relative to the life history and current management of the species.

The Review Panel agrees with the Weakfish Technical Committee’s recommendations to conduct an assessment update in 2 years (2018) and a benchmark assessment in 5 years (2021).

Advisory Report

A. Status of Stocks

The Review Panel agreed with the Weakfish TC recommendations to implement new Z and SSB reference points, along with a two-stage control rule for evaluating weakfish stock status and management response.

The Review Panel agreed with the TC recommendations for an SSB threshold of $SSB_{30\%}$ = 6,880 MT that is equivalent to 30% of the projected SSB under average natural mortality (M=0.43) and no fishing. When SSB is below that threshold, the stock is considered depleted and management should act to minimize fishing pressure. (See Stock Assessment Report pg. iv for more details)

B. Stock Identification, Distribution, and Management Unit

The weakfish range extends along the Atlantic coast from southern Florida to Massachusetts, although strays are occasionally found in the eastern Gulf of Mexico and as far north as Nova Scotia, Canada. Primary abundance occurs between North Carolina and New York. The Review Panel agreed with the TC and the current ASMFC Weakfish FMP definition to continue managing Atlantic coast weakfish as a single unit stock throughout their coastal range. New tagging studies in North Carolina are underway and results should be considered in future assessments to re-evaluate weakfish

C. Data and Assessment

The biology, life history, and fishery characteristics of weakfish create a challenge for stock assessment. For example, their extensive inshore-offshore migrations are likely to create changes in the seasonal availability of weakfish to commercial and recreational fisheries, and the various surveys. Weakfish also seem to be experiencing temporal changes in productivity, with a likely explanation being natural mortality. Hybridization, climate change, and other possible factors that may vary spatially or temporally further compound these challenges. Traditional stock assessment techniques, such as VPA or statistical catch-at-age models, are likely incapable

of accounting for these complicating processes and so may be inadequate for the assessment of weakfish. Consequently, continued development of Bayesian techniques and models that generally allow for a range of process and measurement errors should be pursued.
The challenges that weakfish pose for stock assessment aside, some stock assessment issues are often created by data issues. Data issues are certainly problematic for weakfish, and these are highlighted in the Research Recommendations and review panels responses to the TORs. Resolving these data issues (e.g., weights at age, index standardization methods, age-length keys) should be taken just as seriously as the technical aspects of the stock assessment model.

D. Reference Points

Given the apparent time varying nature of weakfish productivity (e.g., natural mortality), traditional, equilibrium based reference points may not be useful for stock status or application to harvest control rules. In this assessment, a control rule based on total mortality was presented, as was a biomass threshold premised on some assumption about future natural mortality rates (i.e., time series average $M = 0.43$ was used for calculations). The suggested control rule and biomass threshold were developed with the intention of being robust to time varying productivity, but these suggestions should be simulation tested and will need to be revisited in upcoming weakfish assessment updates and benchmarks. Complications caused by time varying productivity are not unique to weakfish, but weakfish seems well suited to potentially pioneer explorations into the performance of various reference points and control rules in the presence of time varying processes. For example, do control rules premised on total mortality perform better than more traditional control rules premised on biomass levels? Such research would be of broad interest with regard to potential application to other stocks.

E. Other Comments

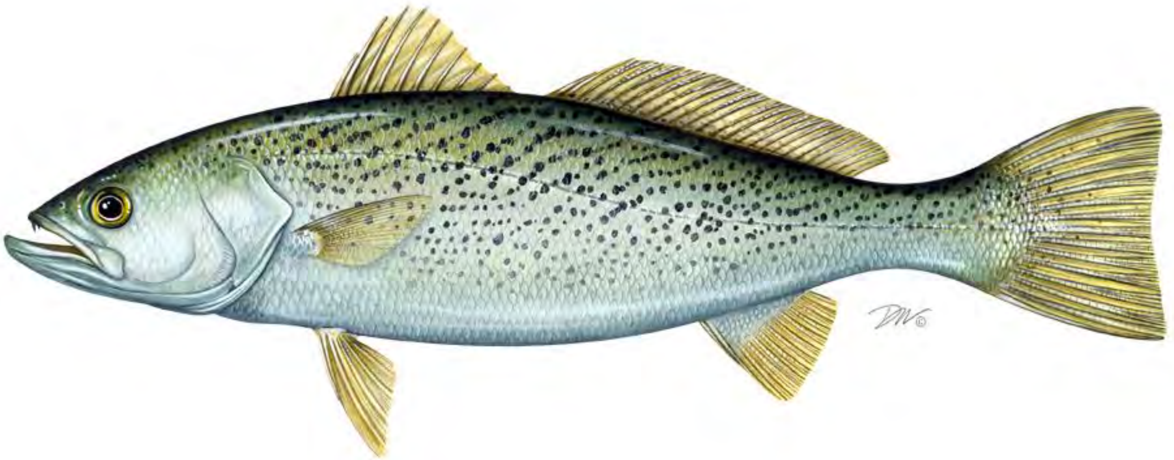
The Review Panel would like to recognize the tremendous work of the Weakfish Stock Assessment Subcommittee and support staff. In particular, the Review Panel appreciated the SASC's responsiveness and collegial approach. The assessment report was also generally well written and struck a reasonable balance between providing enough information for a thorough review without resulting in 'information overload'. Likewise, presentations were generally clear and prioritized topics appropriately, which resulted in an efficient and timely review workshop. These achievements should not be overlooked given the range of issues presented and discussed, from basic data inputs to a diversity of assessment models that included the rather complex preferred Bayesian model.

F. References

Gelman, A. 2006. Prior distributions for variance parameters in hierarchical models. Bayesian Analysis 1(3):515-533.

Atlantic States Marine Fisheries Commission

Weakfish Benchmark Stock Assessment



Draft for Peer Review

March 2016

Vision: Sustainably Managing Atlantic Coastal Fisheries

Atlantic States Marine Fisheries Commission

Weakfish Benchmark Stock Assessment

Prepared by the
ASMFC Weakfish Stock Assessment Sub-Committee

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EXECUTIVE SUMMARY

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

Weakfish fishery data were evaluated from four fishery sectors: commercial harvest, commercial discards, recreational harvest, and recreational discards. Commercial harvest data were obtained from state and federal harvest reporting systems. A new commercial discard estimation methodology was employed that resulted in lower discard estimates, but addressed the Weakfish Technical Committee's (WTC) concern of potential duplicate counting in previous methods. A 100% discard mortality rate was assumed. Recreational harvest and discards were obtained from the Marine Recreational Information Program (MRIP) conducted by the National Marine Fisheries Service. Harvest numbers and weight are directly available; discard numbers were estimated as the number of weakfish released alive times a discard mortality rate of 10% which is based on quantitative studies.

Harvest and discard estimates were stratified by region (north/south), year, and season (early/late). Commercial harvest was further stratified by state. Where available, stratum specific biological data (length data and length-weight equations) were used to convert harvest and discard weights to number of weakfish removals at size. Where stratum specific data were not available (some commercial harvest strata), samples were substituted from the next most representative stratum. Numbers at size were then converted to numbers at age using region/year/season specific age-length keys. Numbers at age were summed across strata within a year to develop annual estimates of total weakfish removals at age.

Several sources of potential bias were identified that may result in uncertainty in annual removals at age estimates. These include inaccurate harvest/discard estimates as a result of under/over reporting or inappropriate survey methods; insufficient sample size to characterize length distributions; substitution of data from alternate cells in the catch at size characterization and age-length keys; errors in aging techniques or the scale-otolith age conversion; and others. Several of these sources are generic and not specific to weakfish. Attempts have been made to quantify some of these error sources; however, the extent of uncertainty associated with each of these sources, and their cumulative effect, remains largely unknown. The use of statistical catch at age models, which can account for error in the catch matrix, is a significant improvement over previous assessments that assumed catch was known without error. Regardless, a persistent cumulative trend in either direction would result in inaccurate removals at age estimates and may influence assessment results.

The WTC evaluated 45 fishery independent surveys and one fishery dependent index against a set of criteria the WTC assembled to determine which surveys were might be representative of weakfish population trends. Criteria included survey length, geographic range, sampling methodology, and prevalence of weakfish in catches. Thirty-one data sources were considered not suitable for the assessment because they did not meet one or more of the criteria. The remaining indices were standardized using GLM incorporating appropriate environmental and methodological covariates. GLM are considered an improvement over previous methods (geometric mean), because GLM can account for species specific drivers that may not be captured by a generic statistical design. Many of the indices exhibited large interannual variation, and there was a general lack of coherence between the inshore and offshore surveys. Lack of coherence suggests the surveys may be capturing different components of the stock and/or there is spatial asynchrony in distribution which was tested for in one of the candidate models.

TOR 2: Review evidence for constant or recent systematic changes in natural mortality, predator-prey dynamics, productivity, and/or discard mortality.

The 2009 stock assessment presented results from several analyses that indicated weakfish natural mortality was not constant and had increased since the beginning of the time series. The peer review panel for that assessment concurred with this finding but noted that there was insufficient empirical evidence to attribute the increase in mortality to any specific driver (e.g. predation). For the current assessment, the WTC continued to investigate evidence of time varying natural mortality. Several of the previous analyses were updated, as well as new methods investigated.

Time varying natural mortality rates based on changes in maximum age over time and diet studies were inconclusive due to the nature of the data. Commercial harvest (as proxy for weakfish abundance) still exhibits a strong negative relationship to sea surface temperature, as does recreational CPUE which is not affected by changes to regulations. A modified Catch Survey Analysis model indicated that M increased 3- to 4-fold during the late 1990s to early 2000s. Similarly, the Bayesian age structured model presented in this assessment estimates that M increased from less than 0.2 in the 1980s and early 1990s to M=0.95 by the late 2000s. Although not all of the methods investigated are appropriate for modeling time varying M, several of the methods investigated show similar patterns, lending credibility to the results. These methods all indicate an increase in natural mortality during the late 1990s and 2000s to values around M=1.0 in recent years.

TOR 3: Develop models to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, and analyze model performance.

Several statistical catch-at-age models assess the population dynamics were constructed and compared. The 4 models focused on testing different hypotheses on natural mortality (constant or time-varying) and spatial asynchrony/synchrony reflected in the abundance indices. A Bayesian approach was used to estimate parameters, while performance of the models was compared by goodness-of-fit and the retrospective patterns of the models. As a complement to the Bayesian model, the SASC also explored the use of the NMFS Toolbox statistical catch-at-age model, ASAP, and a data poor model, X-DBSRA, and updated the models used in the last assessment (VPA, relative F) as a continuity run.

Biological reference points for total mortality were developed using a SPR-based approach with natural mortality set at the time-series average estimated by the Bayesian model. A SSB threshold was developed by projecting the population forward under average M and no fishing mortality. The SSB threshold was defined as 30% of that unfished SSB.

The Bayesian model with time-varying M and spatial heterogeneity performed the best. The model indicated natural mortality was low (averaging 0.15) from 1982-1995, then increased steadily in the late 1990s and early 2000s, stabilizing around 0.95 in 2007. M has declined slightly in the most recent two years, to 0.84 in 2014, but remains elevated.

Fishing mortality was high in the early part of the time-series, with total F averaging 1.99 from 1982-1993. Total F declined briefly after that, corresponding to the implementation of coastwide management measures including minimum size limits, but began increasing again in the late 1990s. Total F reached time-series highs from 2007-2010, averaging 2.27, before decreasing significantly in the most recent years, with total F in 2014 equal to 0.28. It should be noted that the selectivity patterns estimated by the Bayesian model indicate the age of full recruitment to the fishery is age 4 for the recreational fleet and age 5 for the commercial fleet, while the majority of the population is age 1-3. As a result, the N-weighted average F the population experiences is lower than the total full F estimated by the model and less than 1.0 in all years.

Spawning stock biomass was highest in the early part of the time-series, peaking at 23,149 MT in 1986 before declining into the early 1990s. The stock recovered somewhat in the mid to late 1990s, although not to the levels in the early part of the time-series, before declining steadily to a time-series low of 1,502 MT in 2010. SSB has increased slightly since then, reaching 2,711 MT in 2014, but remains low relative to the mid-1980s.

Total abundance showed a similar pattern, peaking in 1986 at 80.2 million fish, recovering in the mid to late 1990s, and then declining to a time-series low of 5.5 million fish in 2008. Total abundance has increased since then, reaching 19.4 million fish in 2014. Recruitment patterns mirror total abundance, declining steadily over time to a low of 3.8 million age-1 fish in 2008. Recruitment in 2014 was 15.2 million fish, slightly below the time-series average of 15.8 million fish.

The ASAP model produced similar results for both magnitude and trends in SSB, total abundance, and recruitment. The Bayesian model estimates of full F were higher at the beginning of the time-series and lower in more recent years, although estimates of Z were more similar. The ASAP model with its time-constant M estimated extremely high values of F from 2007-2009.

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

The Bayesian model estimates of F had an average CV of 0.22 for the commercial fleet and 0.28 for the recreational fleet. The Bayesian estimates of M had a CV of 0.18. Estimates of recruitment had an average CV of 0.11. There was more uncertainty around estimates in the most recent years. Sources of uncertainty in the data include lower sample size of biological samples from the catch in recent years and the issue of whether to use multinomial or traditional age-length keys to deal with those gaps, the conflicting trends in offshore and inshore indices, and the lack of fishery independent indices for age-1+ fish that cover the complete range of the time-series. In addition to the uncertainty from the data inputs, there was uncertainty from the model structure, with models that assumed time-varying M and spatial heterogeneity in the indices having differing trends from stationary models.

The uncertainty in the input data and the model results are propagated through the reference points, but there is the additional uncertainty of dealing with a non-equilibrium system and our inability to forecast changes in M and productivity in the future.

TOR 5: Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., F, SSB), reference points, and/or management measures.
All of the models considered exhibited some degree of retrospective bias, but models with time-varying M had the lowest levels. The retrospective pattern tended to underestimate F and M and overestimate abundance in the terminal year.

The stock shows some signs of recovery in the most recent years, with F and M starting to trend down and abundance and recruitment starting to trend up. However, managers should be cautious when interpreting these results as the retrospective pattern observed makes the perception of stock status more optimistic in the terminal year. An assessment update should be conducted in two years to verify that these trends are real and continuing.

TOR 6: Recommend stock status as related to reference points (if available).
As a result of this assessment, the Weakfish TC recommends new Z and SSB reference points, along with a two-stage control rule for evaluating weakfish stock status and management response.

The TC recommends an SSB threshold of $SSB_{30\%}$ = 6,880 MT that is equivalent to 30% of the projected SSB under average natural mortality (M=0.43) and no fishing. When SSB is below that threshold, the stock is considered depleted and management should act to minimize fishing pressure.

When SSB is above the SSB threshold, management should evaluate total mortality rates by comparing current Z relative to the Z target and threshold calculated based on average M, $Z_{SPR30\%}$ = 0.98 and $Z_{SPR20\%}$ = 1.36, respectively. If Z is above the $Z_{SPR20\%}$ threshold, then management should continue to minimize F. If Z is above the $Z_{SPR30\%}$ target but below $Z_{SPR20\%}$, then limited fishing pressure would be allowed. If Z is below $Z_{SPR30\%}$ target, then fishing will be managed with standard F reference points ($F_{SPR30\%}$ = 0.55 and $F_{SPR20\%}$ = 0.93 with M=0.43). Overfishing status will be determined relative to the F reference points when SSB is above the threshold and Z is below the threshold.

SSB in 2014 was 2,548 MT, below the SSB threshold, indicating the stock is depleted. SSB has been below the threshold for the last 13 years. Z in 2014 was 1.11, above the Z target, but below the Z threshold. Z was above the threshold from 2002-2013. The TC recommends that SSB be above the threshold and Z be below the threshold for more than one year before management changes are implemented.

	Threshold	Target	2014 Value
SSB	6,880 MT	n.a.	2,548 MT
Z	1.36	0.93	1.11
F	0.93	0.55	0.25

TOR 7: Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

The Weakfish TC identified a number of research recommendations to improve future stock assessments. The high priority topics included increased observer coverage to improve estimates of commercial discards, the development of improved predation and bioenergetic models for weakfish, development of stock-recruitment models that incorporate environmental covariates, a coastwide tagging program to identify migration patterns and potential substock dynamics, and continued investigation on the spatial and temporal extent of weakfish hybridization.

TOR 8: Recommend timing of next benchmark assessment and intermediate updates, if necessary relative to biology and current management of the species.

The Weakfish TC recommends that an assessment update be conducted in two years and a benchmark assessment conducted in five years.

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TERMS OF REFERENCE

For the Weakfish Benchmark Stock Assessment and Peer Review

Board Approved February 2015

Terms of Reference for Weakfish Stock Assessment

1. Characterize precision and accuracy of fishery-dependent and fishery-independent data used in the assessment, including the following 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 selectivities, aging accuracy, sample size) on model inputs and outputs.
    f. Review estimates and PSEs of MRIP recreational fishing estimates.

2. Review evidence for constant or recent systematic changes in natural mortality, predator-prey dynamics, productivity, and/or discard mortality.

3. Develop models to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, and analyze model performance.
    a. Describe model structure, assumptions and parameterization of both population and reference point models.
    b. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    c. Perform sensitivity analyses for starting parameter values, priors, calculation of M, etc., and conduct other model diagnostics as necessary.
    d. Clearly and thoroughly explain model strengths and limitations.
    e. Briefly describe history of model usage, its theory and framework, and document associated peer-reviewed literature. If using a new model, test using simulated data.
    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. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., F, SSB), reference points, and/or management measures.

6. 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 threshold?

7. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

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

Terms of Reference for Weakfish Peer 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, aging accuracy, sample size).
    d. Calculation and/or standardization of abundance indices.

2. Evaluate evidence for constant or recent systematic changes in natural mortality, predator-prey dynamics, productivity, and/or discard mortality.

3. Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, 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 (e.g., choice of CVs, effective sample sizes, likelihood weighting schemes, calculation/specification of M, stock-recruitment relationship, choice of time-varying parameters, plus group treatment).

4. Evaluate the diagnostic analyses performed, including but not limited to:
    a. Sensitivity analyses to determine model stability and potential consequences of major model assumptions.
    b. Retrospective analysis.

5. Evaluate the methods used to characterize uncertainty in estimated parameters. Ensure that the implications of uncertainty in technical conclusions are clearly stated.

6. If a minority report has been filed, review minority opinion and any associated analyses. If possible, make recommendation on current or future use of alternative assessment approach presented in minority report.

7. Recommend best estimates of stock biomass, abundance, and exploitation from the assessment for use in management, if possible, or specify alternative estimation methods.

8. Evaluate the choice of reference points and the methods used to estimate them. Recommend stock status determination from the assessment, or, if appropriate, specify alternative methods/measures.

9. 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.

10. Recommend timing of the next benchmark assessment and updates, if necessary, relative to the life history and current management of the species.

11. Prepare a peer review panel terms of reference and advisory report summarizing the panel's evaluation of the stock assessment and addressing each peer review term of reference. Develop a list of tasks to be completed following the workshop. Complete and submit the report within 4 weeks of workshop conclusion.

1.0 INTRODUCTION

1.1 Brief Overview and History of Fisheries

Weakfish (*Cynoscion regalis*, Bloch & Schneider, 1801) are an important sciaenid species of the Atlantic coast with its primary range from North Carolina through southern New England. Weakfish are subjected to estuarine and near-shore fisheries from a variety of gears as they move in and out of their estuarine spawning grounds. The largest landings, however, have historically occurred in North Carolina where the fishery has targeted overwintering aggregations off the Carolina coast.

The Atlantic States Marine Fisheries Commission (ASMFC) developed a Fishery Management Plan (FMP) in 1985, which was first amended in 1992, but these plans were not mandatory. In 1993, Delaware and New Jersey instituted management measures, but coastwide management measures were not implemented until 1995 when Amendment 2 to the Weakfish FMP was implemented under a mandatory basis governed by the Atlantic Coastal Cooperative Fisheries Management Act. Amendment 4 was passed in 2002 and made some relatively minor changes to regulations. Since 2002, four Addenda have been passed to respond to the 2006 and 2009 stock assessments which showed a severe decline in abundance and recruitment. Currently Addendum IV requires states to implement a one fish recreational creel limit, a 100 pound commercial trip limit, a 100 pound commercial bycatch limit, and 100 undersized fish per trip allowance for the finfish trawl fishery.

The first peer reviewed assessment for weakfish was completed in 1997. Subsequent assessments occurred in 1999, 2002, 2006 and 2009. While there were concerns over the stock structure, age composition data, and fishery discards in the 2006 assessment, the report was able to conclude that the weakfish stock was declining and total mortality was increasing. The 2009 stock assessment showed stocks were at an all-time low and fishery removals were unsustainable under existing stock conditions. Natural mortality rose substantially since 1995, with factors such as predation, competition, and changes in the environment having a stronger influence on recent weakfish stock dynamics than fishing mortality (Northeast Fisheries Science Center (NEFSC), 2009). Given current high natural mortality levels, stock projections from the 2009 Assessment indicated that the stock was unlikely to recover rapidly, even under a harvest moratorium. The stock assessment stated that, in order to rebuild the stock, total mortality would need to be reduced.

1.2 Management Unit Definition

Weakfish stocks on the U.S. Atlantic coast are managed through the ASMFC FMP for Weakfish (Mercer 1985). Under this FMP, weakfish are managed as a single unit stock throughout their coastal range. All states from Florida through Massachusetts have a declared interest in the species. Currently, Florida, Georgia, Connecticut and Massachusetts maintain *de minimis* status and are therefore exempt from certain regulatory and monitoring requirements.

1.3 Regulatory History

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

The first fishery management plan for weakfish was implemented by ASMFC in 1985 to address stock declines, bycatch concerns, the lack of sufficient data for management, and interstate user conflicts (Mercer 1985). The management measures under the FMP were voluntary, and no state implemented the full set of management provisions outlined in the FMP.

Amendment 1, adopted in 1991, established a target fishing mortality rate (*F*) of *F*20% = 0.34 (Seagraves 1991). This target was to be achieved by a 52% reduction in directed harvest over the course of four years, as well as a 50% reduction in bycatch mortality in the penaeid shrimp fisheries by 1994. Although adoption of turtle excluder devices (TEDs) in the shrimp fishery led to bycatch reductions, none of the states with directed fisheries adopted the full complement of regulations recommended in the amendment.

Continued concern regarding the status of the weakfish stock was a major impetus for the development and passage of the Atlantic Coastal Fisheries Cooperative Management Act (1993), which made compliance with ASMFC fishery management plans mandatory for member states. Following the Act's passage, ASMFC approved Amendment 2 to the Weakfish FMP for implementation in April 1995 (ASMFC 1994). The provisions of Amendment 2 were mandatory and included harvest control strategies such as a 12" (305 mm) total length (TL) minimum size, maintenance of existing minimum mesh sizes, and a 50% shrimp trawl bycatch reduction requirement by 1996. Fishing mortality would be reduced in a stepwise fashion, with a 25% reduction in weakfish fishing mortality in 1995 followed by a 25% reduction in exploitation in 1996.

Following implementation of Amendment 2, below average fishery catch rates and spawning stock biomass continued. In response, Amendment 3 was developed to reduce fishing mortality to F = 0.50 by the year 2000, restore an expanded age structure, and restore fish to their full geographical range (ASMFC 1996). Commercial fisheries were regulated by a combination of season and area closures, mesh regulations to minimize harvest of fish less than 12" TL, and stricter requirements for bycatch reduction devices (BRDs). The minimum recreational requirements were a 12" TL minimum size limit and a four fish possession limit. States were allowed to implement alternate size and bag limit regulations if they were conservationally equivalent to the minimum requirements. Bag limits were not required for minimum sizes of 16" TL or greater.

In 2000, a peer review of a stock assessment with data through 1998 indicated that weakfish biomass was high and fishing mortality rate was below the target of F = 0.50. Despite being ahead of schedule, it was recommended that low fishing mortality rates be continued to maintain an appropriate spawning biomass and promote expansion of stock size and age composition. Also as a result of the assessment, the Weakfish Technical Committee (WTC) recognized several inconsistencies between management practices and stock dynamics. These could only be addressed through the development of a new FMP amendment. In the meantime, however, Addendum I to Amendment 3 was passed to maintain existing regulations until approval of the new amendment.

Weakfish stocks on the U.S. Atlantic coast are currently managed under Amendment 4 to the FMP (ASMFC 2002). Reference points established in Amendment 3 were too high to ensure sufficient spawning stock biomass, and the reference period used to develop recreational management measures represented an overexploited stock (insufficient abundance of older, larger individuals). In response to these concerns, Amendment 4, implemented in July 2003, established new fishing mortality and spawning stock biomass reference points, and adjusted the reference period to a period of greater stock health (1981 to 1985). Amendment 4 established new reference points: a fishing mortality target of Ftarget = F30% = 0.31; a fishing mortality threshold of Fthreshold = F20% = 0.5; and a spawning stock biomass (SSB) threshold of SSBthreshold = SSB20% = 14,428 metric tons (31.8 million pounds). A fishing mortality rate greater than F = 0.5 constitutes overfishing, and the stock is considered overfished if SSB is less than 14,428 MT. If it is determined that the weakfish stock is overfished, Amendment 4 requires ASMFC to implement measures to rebuild the population within six years (1½ generations).

Several addenda were passed to improve management capabilities under Amendment 4. Addendum I was passed in December 2005 to modify biological sampling targets. Addendum III (May 2007) modified bycatch reduction requirements to maintain consistency with the South Atlantic Fishery Management Council. Of greater significance was passage of Addendum II in February 2007.

A stock assessment conducted in 2006 showed a significant turn of events from previous assessment results (see full discussion in Section 1.4, Assessment History). Model results indicated that weakfish stocks were at historic low levels, and that fishing mortality was a relatively minor component of total mortality. Projection analyses indicated that even with a full moratorium on harvest, stock rebuilding would occur slowly at best without a significant decrease in other sources of mortality. To minimize overall mortality without unduly penalizing fishermen, and to prevent expansion of the fishery in the event the stock begins to rebuild, Addendum II required that all states: 1) maintain current minimum sizes, 2) implement a recreational six fish bag limit (except South Carolina which was in the process of implementing a 10 fish limit), and 3) impose a 150 pound commercial bycatch trip limit (except *de minimis* states). Addendum II also established landings-based triggers to re-evaluate these criteria.

In August 2009, the Weakfish Management Board (Board) was provided with results of the 2009 peer-reviewed stock assessment (NEFSC 2009). The assessment indicated that weakfish abundance has declined markedly, total mortality is high, non-fishing (natural) mortality has recently increased, and the stock is currently in a depleted state. Consequently, the Board passed Addendum IV, which required states to implement a one fish recreational creel limit, a 100 pound commercial trip limit, a 100 pound commercial bycatch limit, and 100 undersized fish per trip allowance for the finfish trawl fishery. The addendum also removed the fishing mortality reference points and redefined spawning stock biomass reference points as being relative to an unfished stock. The SSB target and threshold were set at $SSB_{30\%}$ and $SSB_{20\%}$, respectively, such that the target represents a level of SSB that is 30% of an unfished stock.

In August 2010, the Board approved a conservation equivalency proposal from North Carolina to implement commercial regulations allowing 10 percent bycatch of weakfish up to 1000 lbs, in place of the 100 lb trip limit. Analysis of North Carolina commercial data for 2005-2008 indicated that the alternative regulations would result in an equivalent landings reduction as the 100 lb commercial trip limit. In November 2012, North Carolina removed the 10% bycatch provision and reinstated the 100 lb commercial trip limit as originally recommended in Addendum IV.

1.4 Assessment History

1.4.1 History of stock assessments

Early stock assessment analyses for weakfish were conducted using a variety of virtual population models, such as the Murphy Virtual Population Analysis (VPA; Vaughan et al 1991) and the statistical catch-at age (CAGEAN). The first peer reviewed assessment analyzed data through 1996 using Extended Survivor Analysis (XSA). The peer review was conducted in 1997 by the Stock Assessment Review Committee (SARC) at the 26th Northeast Regional Stock Assessment Workshop (SAW; NEFSC 1998). The SARC had concerns with the XSA model runs and requested updated runs as well as exploratory CAGEAN and Adaptive framework (ADAPT) VPA model runs. These were conducted during the stock assessment workshop (SAW), but there was insufficient time to fully review the results. As such, the SARC did not endorse the point estimates of *F* and SSB. Regardless, all models used indicated that SSB was increasing rapidly and fishing mortality rates were decreasing rapidly. Spawning stock biomass had increased an average of 22.5% per year since 1991, while *F* had decreased an average of 21.4% per year since 1990 (NEFSC 1998). The SARC concluded that continuation of low fishing mortality rates and good recruitment would allow for age expansion to a point comparable to that observed in the early 1980s.

The subsequent assessment, which included data through 1998, was peer reviewed at the 30th SAW/SARC in 1999 (NEFSC 2000). The stock was assessed using the ADAPT VPA as recommended by the 26th SARC. Ages in recent years were taken from otoliths, which required a conversion of scale-based ages from earlier years to otolith-based ages. The approved VPA run included only indices from the core abundance area (New York to North Carolina). The model indicated that fishing mortality rates had declined to 0.21 in 1998, well below both $F_{MAX} = 0.27$ and $F_{MSY} = 0.6$. In addition, SSB had increased to about 39,000 MT, approximately 55% of an unfished stock. The SARC did observe a noticeable retrospective pattern, which overestimated stock size and underestimated fishing mortality in the last few years. Regardless, the SARC concluded that results of the ADAPT VPA could be used to calculate biological reference points, and that figures illustrating the expanded size and age composition of weakfish would be useful for developing management advice.

A stock assessment update was conducted in 2002 (with data through 2000) using the SARC approved methodology (ADAPT VPA with tuning indices from the core area; Kahn 2002). The assessment showed that estimates of fishing mortality decreased further to F = 0.12, while SSB increased to over 50,000 MT. Although this assessment was not peer reviewed, the WTC expressed concern about a strong retrospective pattern that resulted in high levels of uncertainty. The WTC recognized poor biological sampling of commercial catches, commercial discards, and recreational discards as likely sources for much of this error, especially when coupled with the assumption of error-free catch at age estimates used by ADAPT VPA. Estimates of *F* and SSB were "corrected" by multiplying each parameter by the average amount each parameter changed in recent years with the addition of more data. Even so, the corrected estimate of F = 0.23 was substantially below $F_{Target} = 0.31$, and corrected SSB = 35,000 MT was more than double $SSB_{Threshold} = 14,428$ MT.

In 2003, the Weakfish Stock Assessment Subcommittee (WSASC) began preparation for a 2004 peer review through the 40th SAW. Model results using the SARC approved methodology still exhibited a strong retrospective pattern, and results from both ADAPT VPA and biomass dynamic models indicated the stock was at very high levels (carrying capacity in the case of the biomass dynamic model; see Uphoff 2005) with very low fishing mortality. The WTC was concerned that these results were not consistent with low catch rates and diminishing size structure being observed by commercial and recreational fishermen targeting weakfish.

For these reasons, the WSASC deemed the ADAPT VPA methodology as insufficient to characterize the weakfish resource and proceeded to investigate alternative assessment methods. Although the revised weakfish assessment was incomplete at the time of the 40th SAW, the SARC agreed to review the work and provide guidance on issues that were impeding the progress of the assessment (such as the inconsistency between survey indices and fishery-dependent indices of abundance and catch at age).

The stock assessment was completed in February 2006 and submitted to ASMFC for evaluation through the ASMFC External Peer Review process. The Peer Review Panel consisted of four fisheries biologists with expertise in population dynamics and stock assessment methods. The Panel did not endorse the statements regarding weakfish stock status and identified several issues that required additional work or attention by the WTC before the report would be suitable for management purposes (ASMFC 2006). In particular, the Panel had concerns regarding stock structure, age composition data, and fishery discards.

The Weakfish Management Board directed the WTC to address the issues identified by the Peer Review Panel. Specifically, the Board tasked the WTC to further investigate stock structure and discards; determine agreements and disagreements among the assessment report, the peer review panel report, and the 40th SARC report; and provide an account of the implementation of recommendations from the 40th SARC.

In August 2006, the WTC provided a response to these tasks (ASMFC 2006). Based on these responses, the WTC’s analyses, and significant evidence, the Board accepted the following five points for management use:

1. The stock is declining;
2. Total mortality is increasing;
3. There is little evidence of overfishing occurring;
4. Something other than fishing mortality is causing the stock decline, and;
5. There is a strong chance that regulating the fishery will not, in itself, reverse the stock decline.

The most recent stock assessment, with data through 2007, underwent an external peer review through the NEFSC SAW/SARC process in June 2009. Given the evidence indicating an increase in natural mortality rate in recent decades, the panel supported the WTCs determination that the ADAPT VPA was not appropriate for management use. Two alternate biomass dynamic models were presented that incorporated time varying natural mortality as functions of predation and competition, but the panel was reluctant to endorse these models without sufficient empirical data to support the predation/competition linkages. The accepted model was a rescaled relative F model based on a composite index of abundance and rescaled using a range of years from the converged portion of the VPA. Numbers based fishing mortality (age 1+) exceeded 0.5 during most of the 1980s and increased during the late 1980s to a peak in 1990. F declined quickly after that, dropping below 0.2 by 1994, where it has remained for most of the remainder of the time series. January 1 stock biomass (age 1+) declined steadily during the 1980s, from nearly 30,000 MT in 1982 to less than 4,000 MT by 1990. The early 1990s was a period of rebuilding, with the stock reaching a relative peak of 15,000 MT by

1996. From 1996 to 2008, the stock has declined steadily, reaching an all-time low of 1,300 MT in 2008. The stock was determined to be depleted, with the primary cause being attributed to the increased natural mortality rate. Juvenile abundance surveys indicated that young of the year weakfish continued to be present in numbers similar to previous years, suggesting that recruitment had not been severely limited despite the low stock size.

1.4.2 Historical retrospective patterns

A historical retrospective pattern analysis was conducted for both fishing mortality and spawning stock biomass. Comparisons were made between the 1998, 2002, 2006, and 2009 stock assessment final runs as well as the continuity run from 2006 assessment. A summary of the run specifics is shown in Table 1.4.1.

Patterns in SSB are relatively similar among the runs during the 1980s, although the scale is approximately doubled for the 1998 run compared to the 2002 and both 2006 runs (Figure 1.4.1). All models indicate a substantial increase in stock biomass beginning around 1990. This increasing trend persists through the terminal year in the 1998 final, 2002 final, and 2006 continuity runs, with terminal year biomass substantially higher than biomass in the first year of the assessment (by a factor of more than 7x in the case of the 2006 continuity run). In contrast, the 2006 final and 2009 runs indicate a decline in biomass beginning around 1998.

The differences in the SSB patterns are considered to be due to the influence of the tuning indices used, particularly the NEFSC trawl survey. Although several of the indices indicated an increase in abundance during the early 1990s, most of them exhibited a decrease in abundance by the late 1990s. The most prominent exception was the NEFSC index which indicated a highly variable but generally increasing trend through the end of the survey time series in 2008. An in-depth evaluation of the different trawl surveys determined that the NEFSC trawl survey was of limited value for tracking weakfish abundance (Uphoff 2009). In addition, the increasing abundance pattern exhibited by this survey was in direct contrast to decreasing commercial and recreational catch rates and shrinking age structure. Removing the NEFSC trawl survey from the suite of tuning indices produced a biomass trend that was more consistent with available anecdotal and empirical data.

Fishing mortality patterns during the 1980s show wide variability in both pattern and scale (Figure 1.4.1). The 1998 model increases from around 1.0 to over 2.5; the 2002 and both 2006 runs decrease from around 2.0 to 1.0; and the 2009 run is mostly stable around 0.5 but increases to nearly 1.0 by the end of the decade. Despite these differences in the early portion of the assessment time series, all model runs indicate a steep decline in fishing mortality during the early 1990s, from over 1.0 to less than 0.5. Most models remain at low levels of fishing mortality through their terminal year, but the 2006 final run indicates a steep increase in F during the late 1990s, peaking at nearly 1.7 in 2001.

Relatively stable harvest levels through the early 1990s during a period of stock rebuilding produced the decrease in fishing mortality rates indicated by all the models. Implementation of mandatory management measures in the mid-1990s reduced harvest further. Low catches coupled with increasing abundance during rebuilding drove fishing mortality even lower. The 1998, 2002, and 2006 continuity runs all assume abundance continues to increase through the terminal year, which keeps F at low levels. The 2009 run shows declining abundance through the terminal year so rescaled relative F estimates remain low as a result of decreased harvest alone. The pattern of increasing F observed in the 2006 final run is attributed to the ADAPT model assuming constant M and therefore attributing stock declines to fishing mortality.

For both SSB and F, there is uncertainty in stock and fishery dynamics during the 1980s, but consistency among the models increases in the early to mid-1990s when management began to take effect. Discrepancies between model output Z (increasing biomass) and anecdotal and empirical data (decreasing catches, shrinking age structure, large retrospective patterns) by the early 2000s led the WTC to evaluate the data sources and modeling framework. Had management continued under the ADAPT framework with the full suite of fishery independence indices, estimates of F would likely be on a similar scale (very low), but biomass estimates would likely be much higher which could influence managers to increase fishing pressure on what we currently believe to be a severely depleted stock. Alternatively, using the full suite of fishery dependent and independent surveys would indicate fishing mortality is driving stock dynamics, possibly resulting in even stricter regulations (*i.e.* moratorium).

2.0 LIFE HISTORY

Weakfish are estuarine dependent members of the drum family (Sciaenidae). Found from Massachusetts to Florida, weakfish are most common in the Mid-Atlantic region from North Carolina to New York (Wilk 1979). Common migration patterns for weakfish include spring spawning movement into estuaries and bays and reverse movements out of the estuaries in the fall either offshore and/or to more southern regions to overwinter (Bigelow and Schroeder 1953, Wilk 1979). Smaller fish tend to have longer residence times in the estuaries than larger weakfish, and egress from the estuary is likely triggered by decreasing water temperatures in the fall (Manderson et al. 2014, Turnure et al. 2015). While the majority of fish follow this pattern, there have been recent reports of YOY weakfish remaining in the Delaware Bay estuary through the winter, something not previously thought to happen north of Pamlico Sound, NC (Weinstein et al. 2009). The spawning season is protracted and begins in the spring, taking place in coastal estuaries and bays. Weakfish, like other sciaenids grow quickly and mature very early (by age 1). The maximum recorded age using otoliths is seventeen years (See Section 2.3 Age and Growth).

2.1 Stock Definitions

The weakfish range extends along the Atlantic coast from southern Florida to Massachusetts, although strays are occasionally found in the eastern Gulf of Mexico and as far north as Nova Scotia, Canada. Primary abundance occurs between North Carolina and New York. Within their range there is evidence of multiple stocks. Munyandorero (2006; see ASMFC 2006) provides a concise but thorough overview of available information on weakfish stock structure. The following is an excerpt.

> Investigations of weakfish population structure along the US Atlantic coast have been undertaken through tagging, meristic, morphological, life history, genetic and otolith chemistry. The conclusions reached are conflicting. While Crawford et al. (1988), Graves et al. (1992) and Cordes and Graves (2003) did not detect genetic differentiation within the weakfish population, Chapman et al. (unpublished report) found that weakfish are made up of a series of overlapping stocks, without complete panmixia. Non-genetic studies found evidence of existence of multiple weakfish sub-populations (e.g., Nesbit 1954; Shepherd & Grimes 1983, 1984; Scoles 1990) or important spatial structure of the weakfish population (Thorrold et al. 1998, 2001). Mark-recapture, meristic, morphological and life-history studies (e.g., review by Crawford et al. 1988) indicated that weakfish could be partitioned into sub-stocks…

Crawford et al. (1988) recommended that weakfish be managed as separate northern and southern stocks, while Graves et al. (1992) recommended management of a single unit stock. The WTC reviewed the available information and reached the following conclusions.

- Evidence of stock structure exists
- Data is inadequate to define stock structure, and there is enough potential mixing that pinpointing the location of a north/south split is not possible at this time
- If a north to mid-Atlantic subpopulation is in serious decline, this does not warrant a north- south split based on conservation concerns (ASMFC 2006, Part C).

Based on those recommendations, the ASMFC Weakfish FMP continues to manage Atlantic coast weakfish as a single unit stock throughout their coastal range.

2.2 Migration

Like many other North Atlantic species, weakfish exhibit a north-inshore/south-offshore migration pattern, although in the southern part of their range they are considered resident. Shepherd and Grimes (1983) observed that migrations occur in conjunction with movements of the 16-24^o C isotherms. Warming of coastal waters during springtime triggers a northward and inshore migration of adults from their wintering grounds in the Mid-Atlantic. The spring migration brings fish to nearshore coastal waters, coastal bays, and estuaries where spawning occurs.

2.3 Age and Growth

Weakfish growth is rapid during the first year, and age-1 fish typically cover a wide range of sizes, a result of the protracted spawning season. After age-1, length becomes much less reliable as a predictor of age due to an increasing overlap in lengths occurring over several age groups. Lowerre-Barbierri et al. (1995) found length at age to be similar between sexes, with females attaining slightly greater length at age than males. Pooled across sexes, they reported observed TLs for weakfish collected in the spring (1989-1992) from Chesapeake Bay to be 176, 311,412, 510, 558, and 631 mm for ages 1-6, respectively. Growth was described using the Von Bertalanffy growth model ($r^2 = 0.98$; $L\infty=919$; $K=0.19$; $t_0=-0.13$) (Lowerre-Barbierri et al 1995). The $L\infty$ reported for other regions were similar: 893 mm TL for Delaware Bay (Villoso 1990) and 917 mm FL for North Carolina (Hawkins 1988) with the exception of Shepherd and Grimes (1983) which reported lower $L\infty$ estimates for Chesapeake Bay (686 mm TL) and North Carolina (400 mm TL).

The historical maximum age recorded using otoliths is 17 years for a fish collected from Delaware Bay in 1985. The maximum age (t_{max}) used in previous assessments considers t_{max} to be 12 years (Kahn 2002). The world record weight for hook-and-line was captured on May 6, 2008 off of New York (8.67 kg). Weakfish have undergone large fluctuations in landings since the late 1800s, and there are reports from New England in the 1700s of decadal-scale abrupt shifts in abundance (Cushing 1982; Collette and Klein-MacPhee 2002). Similar to landings, historic changes in the maximum size and age have been reported with weakfish typically obtaining their maximum size and age during periods of higher landings (Lowerre-Barbieri et al. 1995). More recent growth rates have slowed to the point that mean lengths at age of adults are several centimeters shorter than they were in the early 1990s (Lowerre-Barbieri et al. 1995, Kahn 2002). Weakfish weight at age dropped by nearly half for 3-5 year-old weakfish between 1991 and 1996 (Table 2.3.1).

For the current assessment, state and regional differences in growth of known age fish were examined to identify potential regional differences in growth rates. Eleven states datasets or surveys were used to estimate growth including NEAMAP, Connecticut, Rhode Island, New York, New Jersey, Delaware, Maryland, Virginia, ChesMMAP, North Carolina and SEAMAP (NC to GA). Upon initial investigation, more than 65,000 individual data points with age at length were present, with the data set extending as far back as 1982 in some states (North Carolina). However, the time series for most states or larger surveys began somewhere from the mid 1990's (e.g. 1996 for Delaware) to the early 2000's (e.g. 2002 ChesMMAP), and extended through 2013. Age as a fraction of the year based on collection date was added to the nominal age in an effort to treat age as a continuous (or near continuous) variable to correct for sample timing issues across states/regions. Length of fish ranged from 19.9 to 915.8 mm FL with ages ranging from 0.0 to 15.4 years. If fork length (FL) was not available, total length in mm (TL) was converted to FL mm using:

$$FL = (TL + 5.8106) / 1.0437 \text{ (ASMFC 2006)}$$

Data were first analyzed by state or survey, year and season in an attempt to identify seasonal differences in growth rates in individual states or surveys using the 'Growth' function in the 'Fishmethods' package (Nelson 2014) of the R Statistical Software. Estimated growth parameters and fit curves of fork length-at-age using nonlinear least-squares were conducted using the von Bertalanffy Growth Model (VBGM). In many cases, the VBGM failed to converge on a solution for an individual season, as the sample sizes were reasonably low in individual seasons and most of the samples were collected in a single season. Also, the VBGM had problems fitting models to data that were skewed toward very small or very large lengths-at-age, which was present in most data sets, particularly in the last 10 years. Since the number of total models fit to the available data was so low in the seasonal analyses, growth by state or survey and year was examined using the VBGM pooling seasonal data. A small number of models successfully converged on a solution similar to the results of the seasonal analyses. Even in years where a model did successfully converge on a solution, the model fit was close to linear, e.g. Delaware 2006 (Figure 2.3.1). Based on those findings, linear models were used to determine if FL varied as a function of age differently by state for individuals < = 400 mm FL. The total number of models that converged improved using a linear model; however, the analysis generalized across years for a state and failed to provide any clear results regarding geographic differentiation (Figure 2.3.2).

Finally, regional surveys were broken down and added to state specific data, to examine the linear relationship between FL and age of individuals < = 400 mm FL in shared years between states. Unfortunately, no discernible difference in growth rate was detected using this method as well. It was not possible with the available data to discern spatial or temporal patterns in size at age. Low sample sizes, particularly at very small and very large sizes, made fitting models to the data highly uncertain. Specific biological sampling criteria were established under Addendum I in 2005 (ASMFC 2005), but low harvest and overall abundance have kept sample sizes low. In addition, it appears that samples may be affected by gear selectivity which would also bias the growth results (Binion et al. 2009; Gwinn et al. 2010). Based on these results, growth for this assessment was modeled as a single growth function for the whole stock.

2.4 Reproduction

Weakfish spawn in the nearshore and estuarine areas of the coast. In North Carolina, the spawning season occurs from March to September and peaks from April to June (Merriner 1976). Spawning in the northern range occurs later and is less protracted. In Chesapeake Bay, spawning has been documented to occur from May to August (Lowerre-Barbieri et al. 1996). From Delaware Bay to New York, spawning occurs from May to mid-July (Shepherd and Grimes 1984). Thorrold et al. (2001) showed evidence of natal homing for spawning weakfish, in an analysis of otolith chemistry for five estuaries (coastal Georgia, Pamlico Sound, Chesapeake Bay, Delaware Bay and Peconic Bay).

Early to mature, weakfish spawn multiple times in a season and have indeterminate fecundity (Lowerre-Barbieri et al. 1996). Reproductive work in Chesapeake Bay during 1991 and 1992 found that 90% of age-1 weakfish were mature. Batch fecundity ranged from 75,289 to 517,845 eggs/female and significantly increased with both total length and somatic weight (Lowerre-Barbieri et al. 1996). During 1999 and 2000, a study conducted in Delaware and Chesapeake Bays noted no increase in the size at maturity (168 mm) from that previously estimated despite a marked increase in the overall population size (Nye et al. 2008). Similarly, most (97%) age-1 fish were mature. Both studies indicated that spawning frequency and batch fecundity vary by year and that these two variables act jointly to determine total egg production (Nye et al. 2008). Nye et al. (2008) also noted that despite maturing early, age-1 weakfish spawned less frequently, arrived later to the estuary, and had lower batch fecundity than did older fish, likely resulting in an overly optimistic assumption about the contribution of age-1 fish to the overall reproductive success of the stock. This is currently amplified by the fact that larger, older fish comprise a small proportion of the overall population.

2.5 Natural Mortality

The 2006 stock assessment for weakfish assumed a coastwide constant natural mortality rate of M = 0.25 upon the recommendation of the 26th SARC. This estimate was derived using the rule-of-thumb approach in which $M = 3/t_{max}$, with the value for t_{max} set at 12. There was evidence, however, such as decreasing catch rates and shrinking age structure that seemed to indicate natural mortality had increased in recent years. As a result, the 2009 stock assessment included several analyses to investigate time varying M for weakfish, including:

- Inverse correlations between the rise in abundance of striped bass and spiny dogfish with the decline in abundance of weakfish for possible increased predation effects on weakfish M.
- Competitive interactions between striped bass and weakfish over the consumption of forage fish such as menhaden to analyze the potential for negative effects on weakfish survival.
- Age-varying M estimator, which employs a negative linear relationship between M and the mean fish weight-at-age, to calculate estimates of M-at-age for weakfish by year from 1982 through 2007 for all natural systems and latitudes, natural systems in temperate latitudes and oceanic natural systems in all latitudes respectively. These estimates ranged from a maximum of 1.06 at age 1 in oceanic systems of all latitudes in 1990 to a minimum of 0.22 at age 6+ for natural systems in temperate regions for 2006.
- Patterns in weakfish food habits, as well as correlations between historical weakfish landings and mean sea surface water temperature shifts coincident with the Atlantic Multidecadal Oscillation index to investigate potential explanatory variables for mortality.

Although many of these factors provide correlations to support the concept of a variable M, and the 2009 peer review panel agreed with the WTC's findings, it was not possible to describe relationships that could be used to model time varying M.

For the current assessment, both constant and time varying natural mortality have been revisited. The WTC prefers the use of a time varying M, so several of the past analyses have been updated, and new methods attempted to model M. However, in the event that a time varying M cannot be modeled accurately, the fall back was to include a constant M value.

2.5.1 Constant M

Several estimator methods were evaluated to calculate new estimates for constant M, including the rule-of-thumb (in the form of $\ln(P)/t_{max}$), used previously. The initial set of estimators include both life history based and longevity based estimators; however, due to difficulties deriving reliable von Bertalanffy growth parameters for coastwide or regional stock definitions (See Section 2.3 Age and Growth), only the t_{max} natural mortality estimators were used. Several age-constant estimators (including variants of estimators) were examined and evaluated for a coastwide constant estimate of M. Maximum age values were obtained from weakfish length and age data submitted by all states from Florida, to Rhode Island as well as from the ChesMMAP and NEAMAP surveys. The maximum observed age was 15 from the coastwide data, pooled over all years, as well as from each of the South (North Carolina – Florida) and North (Massachusetts – Virginia) regional data sets, rendering the regional M estimates identical to those coast-wide.

These t_{max}-based methods provided a range of M estimates from 0.11 to 0.41 (Table 2.5.1). Of the methods evaluated, three were eliminated based on several factors. Charnov and Berrigan 1990 and Jensen's 1996 yielded estimates considered unrealistically low (0.15 and 0.11 respectively) based on first principles (life history) and analyses performed in previous assessments and updates (ASMFC 2006, ASMFC 2009a). Hewitt and Hoenig (2005) did not recommend using the rule- of- thumb approach due to its reliance on an arbitrary constant (P) for the proportion of the stock remaining at maximum age, as little data exist to support the assignment of P to any particular quantile of the stock.

Coast-wide estimates from the remaining, non-eliminated estimators ranged from 0.28 to 0.41. The recommended coast-wide value of constant M for this stock assessment is 0.41, the estimate calculated from the updated Hoenig non-linear least-squares method. Then et al (2015) recommend this method as the single best estimator of M, when the t_{max} value is known, since it performed better and displayed more desirable residuals than the other estimators studied in their analysis, which included two of the other four estimators considered in this assessment. Then et al. (2015) also advocated against using the average of multiple M estimates due to concerns over equal reliability of, and possible lack of independence between, the estimators. They further indicated a single value of M can be a useful representation of mortality over the exploitable lifespan of a species, and concluded that t_{max}-based estimators performed better than estimators using other life history and environmental variables since the observed t_{max} was evaluated to be "the best and a sufficient predictor of M" when M is assumed to be constant over time.

2.5.2 Time Varying M

Longevity Based Estimates

In consideration of discussions in previous assessments regarding the possibility of time varying M, estimates of natural mortality were calculated using the preferred t_{max}-based estimators on the observed maximum age within discrete five year blocks of time from 2014 back through 1995, with the years 1982 through 1994 grouped together due to the relative scarcity of age data for that time. Average estimates were calculated for each region and time block for ease in displaying possible trends over time (Table 2.5.2). The average of estimates coastwide ranged from 0.32 to 0.62 (range of individual estimates 0.28 – 0.73) with the higher estimates occurring in the earliest time spans (peaking at 0.62 for the years 1995 through 1999). The average M dropped to 0.34 in the five years from 2005 through 2009 then climbed slightly to 0.36 during the most recent five years. The average M estimates for the Southern region ranged from 0.34 to 0.99 with the highest value seen for the most recent time period of 2010 through 2014. Individual estimates ranged from 0.28 to 1.12. The Southern region results were very similar to the coastwide estimates through 2009, then climbed significantly in the subsequent time period due to the decline in t_{max} to just 5 years. The M estimates for the Northern region were identical with the coastwide with the exception of the earliest time period (1982 -1994) for which there were no age records from this region. There were fewer age samples recorded from 2010 through 2014, but the total number was only 26% less than the number aged in the previous 5 years which yielded a maximum observed age of 15. The pattern of decreasing M over time is contradictory to the expected pattern of increasing M. Although this is unexpected, one possible explanation is that the age distribution is an artifact of the exploitation history (few old ages in the 1980s) and/or expansion of the age structure during the 1990s (persistence of fish at older ages in recent times).

Food Habits

The 2009 stock assessment used data from the NEFSC food habits database, collected during the seasonal trawl surveys, to show a strong correlation between the prevalence of weakfish 5”-12” with empty stomachs in the fall and total mortality estimated from the ADAPT VPA. The terminal year of that analysis was 2002 due to the retrospective pattern in the VPA. For the current assessment, the prevalence of empty stomachs was updated through 2008 (the terminal year of the NEFSC inshore trawl survey). Results indicate the three year average prevalence of empty stomachs was relatively constant around 20% during the early 1990s, increased steadily during the late 1990s to a peak of over 33% in 2001, and had declined back to roughly 20% by 2005 (Figure 2.5.1).

Although NEFSC survey no longer samples inshore stations, this area has been sampled by the Northeast Area Monitoring and Assessment Program (NEAMAP) trawl survey since 2007. Food habits data from the NEAMAP survey were analyzed similarly to the NEFSC data to see if the signal persists. Results are generally higher than those from the NEFSC survey (Figure 2.5.1), which may support the hypothesis of increased natural mortality, but may also be due to other factors such as sampling methodology. Additional work should be done on both datasets to investigate the effects of factors such as time of day, depth/distance from shore, and sample size.

Environmental

The Atlantic Multidecadal Oscillation produces cyclical patterns in sea surface temperature over a 65-70 year period. For the 2009 assessment, the WTC showed a strong negative correlation between the AMO (smoothed and detrended) and reconstructed commercial weakfish harvest (as proxy for abundance) back to 1929. This pattern was qualitatively extended back to the late 19th century based on anecdotal accounts of weakfish abundance. Recent harvest and AMO data also show a continuation of the pattern (Figure 2.5.2), but severe commercial harvest restrictions in the early 2000s may affect the relationship. However, an index of abundance based on recreational catch per unit effort developed for this assessment (See Section 6.2 Fishery Dependent Indices) should not be affected by harvest regulations. Although not as strong as the AMO-commercial relationship, the recreational CPUE index in also negatively correlated with the AMO (Figure 2.5.2).

Modified Catch Survey Analysis

Catch survey analysis (Collie and Sissenwine 1983; Collie and Kruse 1998) is a simple two stage model that combines harvest data and relative abundance of recruit and pre-recruit sized fish to estimate harvest rates. The general model can be written as

$$N_{r,t+1} = \left(N_{r,t} + \frac{N_{p,t}}{\phi}\right) \mathrm{e}^{-M_t} - (q_r * C_t)\mathrm{e}^{-M_t * (1-T)}$$

where N_r and N_p are abundance of recruits and pre-recruits from respective surveys, q_r is survey catchability of recruits, *phi* is the scalar between pre-recruit and recruit catchability, and C is annual harvest in numbers. Catch and annual relative abundance of recruits and pre-recruits are known. For this exercise, estimates of q for each survey were derived from the ASAP model run for this assessment (see Section 7.2, Statistical Catch at Age Model), leaving M as unknown to be solved by the model. The ASAP models used to solve for q assumed a constant M, but this should not be problematic for the following reason. Although ASAP does not accurately depict trends in weakfish F over time using a constant M, population trends are not affected by the mis-specification of mortality between M and F. Therefore, the relationships between survey data and true population size (*i.e.* q values) are considered accurate.

Prior to 1994, management measures for weakfish were not mandatory, and length frequency data from the recreational fishery suggest there was no strict minimum size. As such, identification of distinct pre-recruit and recruit size groups is not possible. By 1995, mandatory size limits of 12" or greater were in place coastwide. This analysis therefore uses harvest and abundance data for 1995 onward. Weakfish grow quickly, and are assumed to be 90% recruited to the fishery by age 2. Most indices of abundance are from fall surveys, so were lagged forward to represent abundance of the next age group (*e.g.* YOY as index of age 1). An index of pre-recruit abundance was derived by combining all of the young of year indices as well as the age zero components of the aged indices into a single composite index using the method of Conn (2010). Abundance of recruited fish was estimated by age 1+ components of the New Jersey, Delaware, NEFSC, NEAMAP, and SEAMAP trawl surveys, the NC gill net survey, and the recreational fishery dependent index (see Section 6.0 Indices of Abundance). Each recruit index was run against the composite pre-recruit index to estimate annual M. Due to high interannual variability in the indices, some year/index combinations resulted in an estimate of $M < 0$. These values were reset to $M = 0$ to maintain biological credibility.

Results of the analysis for individual surveys show high interannual variability, and often implausibly low mortality, but all indices indicate an increase in M over time (Table 2.5.3). When averaged across surveys, the pattern in M exhibited a general increase over time but still exhibited interannual variability (Figure 2.5.3). Natural mortality averaged approximately 0.29 during 1995-1997 but began to increase by the end of the decade. M exceeded 0.5 for the first time in 2001 and continued to increase to nearly 1.25 by 2007. From 2007 to 2012, M varied without trend around a mean of 0.98 before increasing dramatically in 2013 to 1.78.

Bayesian Age Structured Model

Jiao et al (2012) investigated a range of hypotheses regarding weakfish natural mortality using a Bayesian age structured population model. Results indicated that, of the hypotheses investigated, a model that incorporated time varying M had the greatest statistical support. An update of that model for this assessment (See Section 7.1 Bayesian Age Structured Model), continues to support this hypothesis. Natural mortality is estimated to be below 0.20 from 1982 to the mid-1990s (Figure 2.5.4). Beginning in the late 1990s, M increases five-fold from 0.19 in 1997 to 0.95 in 2008. Natural mortality is relatively constant around this level through 2012, but appears to have declined slightly in recent years. The terminal year estimate is M = 0.84.

Based on the correlation between harvest and the AMO presented in the 2009 stock assessment, Jiao et al (2012) attempted to model natural mortality as a function of the AMO (Figure 2.5.5). Although the relationship was significant, the relationship did not explain all of the variation in M estimated by the population model. The authors caution that correlation does not mean causality, and that the relationship between M and AMO may vary over time.

Summary

Several of the methods investigated in this assessment appear to hold some promise to be able to estimate natural mortality over time. There was insufficient information in the growth data for this to be a useful method, and the termination of the NEFSC inshore survey rules out the utility of the NEFSC food habits data. Data from the NEAMAP survey may eventually fill this void, but the time series is currently too short to identify patterns and further analysis is needed in order to link the NEFSC and NEAMAP results. Trends in abundance seem to correspond well with the AMO, and Jiao et al (2012) have shown a significant relationship between model estimated M and the AMO, but confirmation of the relationship is still unknown due to the long period of the AMO (not even one full cycle). However, if the relationship is found to be true, this would allow at least short term projections of M into the future for management purposes. The Collie-Sissenwine method does not allow projections, but is easily developed using harvest and survey data. Modeling M internally with the Bayesian age structured model provides estimates of M over the entire time series and incorporates all of the data and assumptions regarding the population, but the effort requirement to build and run the model is substantial. Although all of the methods have drawbacks, the general pattern coming out of many of them is consistent, which lends credibility to the results of time varying M.

2.6 Hybridization

In the 2000s, Tringali et al. (2011) discovered that what was recorded as weakfish (*Cynoscion regalis*) on Florida's Atlantic coast was a mixture of weakfish, sand seatrout (*C. arenarius*) and their hybrids. They found that there was an active zone of introgressive hybridization between the two species centered in the Nassau and St. Johns Rivers, with the genome proportions of "pure" weakfish estimated at 48% in Nassau County and 17% in Duval County, and that "pure" weakfish were rare southward. Since then, reference was made to the Cynoscion complex or to weakfish-like fish.

An analysis of genetic samples from SEAMAP data found a *Cynoscion arenarius* hybrid as far north as Winyah Bay, South Carolina (Jamison 2015). This work also found small percentages of hybridization among other Cynoscion species. Although sampling found the most frequent hybrid was sand seatrout with weakfish, there were also weakfish-silver seatrout hybrids, and weakfish-spotted seatrout hybrids. Overall low occurrence of hybrids led Jamison to conclude that using the current management strategy for weakfish is appropriate with continued monitoring.

Estimates of commercial and recreational landings of weakfish in Florida were adjusted to account for the presence of hybrids, using the proportions observed by Tringali et al (2011). This proportion was assumed to be constant through time and applied to the entire time-series. Additional sampling is necessary to determine if this assumption is valid or if the proportions change over time.

3.0 HABITAT DESCRIPTION

Weakfish are found in shallow marine and estuarine waters along the Atlantic coast. They can be found in salinities as low as 6 ppt (Dahlberg 1972) and temperatures ranging from 17^o to 26.5^o C (Merriner 1976).

Like many other North Atlantic species, weakfish exhibit a north-inshore/south-offshore migration pattern, although in the southern part of their range they are considered resident. Shepherd and Grimes (1983) observed that migrations occur in conjunction with movements of the $16\text{-}24^o$ isotherms. Warming of coastal waters during springtime triggers a northward and inshore migration of adults from their wintering grounds in the Mid-Atlantic. The spring migration brings fish to nearshore coastal waters, coastal bays, and estuaries where spawning occurs. Adults and juveniles exhibit seasonal residence in the Mid-Atlantic bight (Manderson et al., 2014). Turnure et al. (2014) found that adult weakfish establish relatively small areas of localized movement in estuaries during summer months. Juvenile weakfish exhibit tolerance to low dissolved oxygen and high water temperatures showing no significant changes in growth, or avoidance behaviors (until about 1 mg O_2 L^{-10}) in a laboratory setting when exposed to these conditions (Stierhoff et al., 2009).

3.1 Spawning, Egg, and Larval Habitat

Weakfish spawn in estuarine and nearshore habitats throughout their range. Principal spawning areas are from North Carolina to Montauk, NY, although spawning and presence of juveniles has been observed in the bays and inlets of Georgia, South Carolina (Lunz and Schwartz 1969, Mahood 1974, and Powles and Stender 1978, all as cited in Mercer 1985) and Massachusetts (M. Bednarski, Massachusetts Division of Marine Fisheries, pers. comm.). Larval and juvenile weakfish generally inhabit estuarine rivers, bays, and sounds, but have been taken in freshwater (Thomas 1971) and as far as 70 km offshore (Berrien et al 1978). Mercer (1983) found that juveniles are most prevalent in shallow bays and navigation channels and are commonly associated with sand or sand/grass bottoms.

3.2 Juvenile and Adult Habitats

Weakfish form multiple aggregations and move southward and offshore in waves as temperatures decline in the fall (Manderson et al. 2014, Turnure et al. 2015). Important wintering grounds for the stock are located on the continental shelf from Chesapeake Bay to Cape Lookout, North Carolina (Merriner 1973, as cited in Mercer 1985). There is evidence that some fish may be overwintering further north than previously recorded (Weinstein et al. 2009). Stable isotope signatures of juvenile weakfish captured in the mouth of the Delaware Bay suggest that the fish stayed in the upper portion of the Delaware Bay to overwinter (Weinstein et al. 2009). This contradicts the belief that juveniles do not overwinter north of Pamlico-Albemarle sound in North Carolina. There has also been increasing evidence of the importance of the inner continental shelf in addition to estuarine habitats for YOY fish, including weakfish (Woodland et al. 2012). For example, the density of age-0 weakfish in the late summer can be higher on the inner continental shelf near the Middle Atlantic Bight than in the adjacent Chesapeake Bay estuary (Woodland et al. 2012). This suggests that, throughout the summer, larger juveniles continuously leave the estuary for the inner continental shelf (Woodland et al. 2012).

4.0 FISHERY DESCRIPTION

4.1 Commercial Fishery

Records of commercial weakfish landings are available back to 1950 through the National Marine Fisheries Service (NMFS) website. From 1950 through the 1960s commercial landings ranged from about 2,000 to 4,000 metric tons (MT) per year (Figure 4.1.1). Beginning in 1970, reported landings exhibited a dramatic increase to a record high of more than 16,000 MT in 1980. From 1982 to 1988, landings fluctuated between approximately 8,000 and 10,000 MT. Since 1989, landings have declined continuously, except for a brief increase to about 4,000 MT in the mid- to late-1990s. Estimated commercial harvest reached its lowest level in 2011 at approximately 60 MT. Commercial landings in 2014 were roughly 89 MT.

Fishing occurs on the migrating fish along the coast and then concentrates on estuaries for the remainder of spring and summer, from Pamlico Sound in North Carolina through Peconic Bay on eastern Long Island, New York. In mid-summer, some larger fish arrive in southern New England, including Connecticut, Rhode Island, and Massachusetts. With fall, weakfish leave estuaries and begin their fall migration south to the overwintering grounds, and are targeted as they move down the coast.

Three states - North Carolina, Virginia, and New Jersey - have consistently accounted for 70 to 90% of the coastwide commercial harvest since 1950 (Table 4.1.1, Figure 4.1.2). North Carolina has predominated with nearly 34% of the coastwide harvest over the last ten years, while Virginia and New Jersey have averaged 28% and 14% respectively. In 2009, commercial harvest in New York surpassed that in New Jersey. In 2014, New York accounted for 16% of commercial catch (Table 4.1.2).

From the mid-1950s to the early 1980s, landings from the trawl fishery generally accounted for 50 to 70% of commercial landings (Figure 4.1.3). Beginning in the early 1980s, harvest from trawlers began a gradual decline and recently have accounted for approximately 15% of total harvest. Conversely, between 1979 and 1987, landings from gillnets increased from around 10% of annual harvest to 45% of annual harvest. In 2014, gillnets accounted for 55% of commercial catch. Over the entire time period, pound nets and haul seines have each averaged between 10 and 20% of total harvest annually, despite declining trends.

Discarding of weakfish by commercial fishermen is known to occur, and discard mortality is assumed to be 100%. Discards were estimated using a different method than previous assessments (see Section 5.1.12 NEFSC Northeast Fishery Observer Program) which resulted in somewhat lower estimates of weakfish discards (Figure 4.1.4), but addresses a concern of double counting raised by the WTC. Estimates for the current assessment indicate discards varied between 156 and 264 MT per year during the 1980s before nearly tripling in magnitude, increasing from 156 MT in 1989 to the time series peak of 510 MT in 1990 (Table 4.1.3). Discards generally remained above 275 MT per year through 1996, but subsequently exhibited a gradual decline to 124 MT in 2003. In 2004, discards dropped sharply to less than 40 MT and have varied without trend (mean 52 MT, range 20 – 96 MT) through the end of the time series. Although length samples from commercial discards are limited, the discards are dominated by age-0 and age-1 fish in most years.

Commercial weakfish discards are primarily attributed to the northern region trawl fishery during the second half of the year (Figure 4.1.5). This sector accounts for more than 40% of total discards in most years of the time series (28 out of 33), and more than 60% in ten of the years. During the first decade of the time series, northern otter trawls in the early part of the year were the second largest contributor to discards, but this switched to northern gill nets in the early season for 1992 to 2002, and then to southern otter trawl in the early season for 2002 to 2009, before switching back to northern otter trawls in 2011. Other significant contributors include northern spring season gill nets during the late 1990s and early 2000s, and the southern fall trawl fishery from 2003 to 2010, each accounting for 10-20% of annual discards.

Commercial CPUE was analyzed in depth during the 2009 benchmark stock assessment (NEFSC 2009) (Figures 4.1.6, 4.1.7, 4.1.8, and 4.1.9). Although there is some regional and temporal variability, commercial CPUE generally present a consistent pattern of recovery during the late 1990s and then a severe decline in the early 2000s. Commercial CPUE since the mid to late 1990s corresponds well with model estimates of population trends, fishery independent and fishery dependent abundance indices, and observed size and age structure.

4.2 Recreational Fishery

Recreational harvest statistics for the weakfish fishery are available on the NMFS Marine Recreational Fishery Information Program (MRIP) website for the period 1981 to 2014 (www.st.nmfs.noaa.gov/recreational-fisheries). From 1981 to 1988, the number of weakfish caught and the number harvested fluctuated without trend between 2 million and around 11 million fish; however, during this same time period, harvested weight generally declined from around 7,259 MT to 2,722 MT (Figure 4.2.1). Nearly 90% of all fish caught were retained during these years.

From 1989 to 1993, catch (numbers) and harvest (numbers and weight) remained relatively stable. Catch fluctuated between 1.6 and 2.2 million fish, while harvest ranged between 0.95 and 1.8 million fish and 499 to 998 MT. The proportion of fish released alive increased over this period, with the percentage of total catch that was harvested during this period decreasing from around 90% to less than 50% (Figure 4.2.2).

In 1994, weakfish catches increased and averaged around 6 million fish until 2000. Harvest numbers increased to a lesser extent and fluctuated between approximately 1.5 and 2.5 million fish. Harvest weight also increased to 1,814 MT during this period. In 2003, harvest sharply declined to 462,000 fish but rose to 1.4 million in 2005. Since 2006, harvest has declined to a time series low of roughly 27,000 in 2011. In 2014, harvest was 62,000 fish and total catch was 616,000 fish.

Recreational harvest has been dominated by the five Mid-Atlantic states between North Carolina and New Jersey (Table 4.2.1; Figure 4.2.3). New Jersey dominated landings in most years, averaging 35% of coastwide harvest across the time series (Table 4.2.2). Virginia consistently produced greater than 20% of coastwide landings from 1981 to 1992 but has since declined, averaging about 10% from 2002 and 2007. Since 1995, several states have each had periods of substantial landings, with Delaware contributing 20-30% of total harvest for 1995-1998, Maryland accounting for approximately 25% from 1999 to 2001, and North Carolina averaging 22.5% from 2003 to 2007. Between 2009 and 2011, North Carolina accounted for nearly 60% of recreational landings but this dropped to 33% in 2014. New Jersey accounted for 22% of recreational harvest in 2014.

Recreational discard mortality is assumed to be 10% of all discarded fish based on catch-and- release experiments with weakfish and the closely related spotted seatrout (*Cynoscion nebulosis;* (*e.g.* Murphy et al 1995, Malchoff and Heins 1997, Swihart et al 2000, Duffy 2002, Gearhart 2002). Weakfish hook-and-release experiments produced dichotomous mean mortality estimates, either near 3% or 15%, and 10% release mortality was adopted by the WTC. From 1981 to 1989, harvested weakfish averaged 89% of total catch (numbers). Even with high landings, discard losses during this period were the lowest of the time series, with all but one year having fewer than 100,000 fish discarded coastwide (Figure 4.2.4). Between 1989 and 1995, harvest fell to 27% of catch, and discard losses increased to more than 400,000 fish in 1995. Harvest rebounded slightly to 41% of catch in 1997 and 1998, but dropped back to between 20-40% since 1999. Despite relatively stable release rates since 1995, discard losses have varied greatly due to large interannual fluctuations in catch. Discard losses peaked at approximately 500,000 fish in 1996 and 2000, but have since decreased along with catch. Between 2002 and 2007, discard losses have ranged between 135,000 and 225,000 fish.

4.3 Total Removals

Throughout the time series, total removals have been dominated by the commercial fishery (Table 4.3.1, Figure 4.3.1). Removals were greatest during the early portion of the time series, averaging 13,500 MT between 1981 and 1988. Between 1989 and 1993, removals dropped off quickly to 4,000 MT. The next few years showed a slight rebound to a peak of 6,500 MT in 1998. Since then, removals have declined continuously to the time series minimum of only 72 MT in 2011. In 2014, total removals increased only slightly to 124 MT. On average, commercial harvest has accounted for 70% of the landings over the time series.

5.0 FISHERY-DEPENDENT DATA SOURCES

5.1 Commercial Harvest and Discards

Commercial landings data were taken from two sources. Where available, state-specific harvest records collected through a mandatory reporting system were considered the most reliable source for landings. Unfortunately, not all states require mandatory reporting of weakfish harvest. In such cases, landings estimates were obtained from the NMFS commercial landings database, available through the NMFS Office of Science and Technology, Fisheries Statistics Division website (http://www.st.nmfs.noaa.gov/commercial-fisheries/index). Although estimates are available from NMFS, it is not mandatory to report weakfish harvest to NMFS, so these records (like those of most species) may be incomplete. Discrepancies between NMFS reported harvest and state reported harvest under mandatory reporting suggest that NMFS harvest estimates for weakfish are a potential source of uncertainty. An analysis conducted for the 2009 stock assessment (NEFSC 2009) showed that the discrepancy between federal and state reports of weakfish harvest was generally less than 10% when evaluated across gear types.

Addendum I to the Weakfish FMP establishes fishery dependent monitoring requirements for states to achieve in the weakfish commercial fishery. Specifically, it requires states collect 6 individual fish lengths for each metric ton of weakfish landed commercially and the collection of 3 individual fish ages for each metric ton of total weakfish landed. *De minimis* states, as defined in Amendment 4, are states whose combined average commercial and recreational landings (by weight) over the last two years constitute less than 1% of the coastwide commercial and recreational landings. *De minimis* states are not required to conduct fishery dependent monitoring. Since 2002, Georgia and Florida have been *de minimis* while Connecticut has been *de minimis* since 2004 and Massachusetts has been *de minimis* since 2006. South Carolina was granted *de minimis* status between 2000 and 2008.

5.1.1 Florida

Data Collection

During 1950 through 1984, Florida's commercial landings data were collected from seafood dealers on a monthly basis by the NMFS. In late 1984, Florida agencies involved in the management of natural resources, including fisheries, established a trip-ticket (TTK) reporting system, known as the Marine Fisheries Information System, designed to monitor the fisheries productions. When the program first started, data were collected by both NMFS and the TTK system to enable a comparison of the new data collection system. In 1986, the TTK system became the official commercial fisheries landings data collection system in Florida after it was determined that the monthly dealer summaries and the detailed TTK information were comparable. The TTK program requires all wholesale and retail seafood dealers to report their purchase of saltwater products from commercial fishermen on a trip-level basis. Dealers report the Saltwater Products License number, the wholesale dealer license number, the date of the sale, the gear used (since 1991), trip duration (time away from the dock), area fished (since 1986, but was mandatory from 1994), depth fished, number of traps or number of sets (where applicable), species landed, quantity landed, and price paid per pound for each trip.

Landings of weakfish on Florida's Atlantic coast for the period 1978–1985 were from the NMFS database. Those after 1986 were from the FWC's TTK database. Florida's reported commercial landings were adjusted to account for hybridization (Table 5.1.1). The commercial landings from Nassau and Duval counties were adjusted using the genetic proportions of "pure" weakfish within the *Cynoscion* complex (Tringali et al. 2011) as determined for these counties, i.e. about 48% and 17%, respectively. The proportion of "pure" weakfish in the landings south of Duval County was assumed to be negligible, and those landings were not included.

Biological Sampling

Florida usually collects length data from the commercial fishery and, when opportunity allows, collects weights of fish intercepted through a Trip Interview Program (TIP) at fish houses. While weakfish is included on the list of species to be sampled, commercial fishing has been nearly nonexistent and collecting adequate length measurements problematic. No "pure" weakfish landed by the commercial fishery were sampled for ageing structures.

5.1.2 Georgia

Data Collection

Commercial fishermen, or harvesters, in Georgia have been required by law to participate in a trip-ticket reporting system since 2000. Per Rule 391-2-4-.09, all seafood dealers are required to report fishing trip level records on a monthly basis directly to the Georgia Department of Natural Resources (GADNR). Furthermore, all commercial seafood harvesters shall submit fishing trip level records to the seafood dealer when sale transactions occur. Information collected on trip tickets is to be written on GADNR approved forms and must include the following information: trip date, vessel ID, individual ID, trip number, species, quantity, units of measurement, disposition, ex-vessel value or price, county or port landed, state landed, dealer ID, unloading date, market, grade, gear, quantity of gear, days at sea, number of crew, fishing time, area fished, and number of sets. Landings reports are due to the GADNR by the 10th of each month. Prior to 2000, NMFS dealer reports were used to estimate harvest.

Biological Sampling

Georgia does not have a directed commercial fishery for weakfish, and any weakfish landed are caught as bycatch in the pursuit of other species. The only fishery in which the GADNR currently provides observer coverage on commercial fishing vessels is the cannonball jellyfish fishery, and there is no known harvest of weakfish in this fishery. There are no other monitoring programs to determine the discards/bycatch of weakfish from commercial fishing gears (e.g. shrimp trawl, etc.) operating along Georgia's coast. Consequently, no biological sampling or aging of weakfish via commercial fishing efforts occurs in Georgia.

5.1.3 South Carolina

Data Collection

Commercially-licensed fishermen in South Carolina are required by law to participate in a trip-ticket reporting system. He or she must provide a valid ID number, Commercial Saltwater License number or Customer ID to the wholesale dealer to complete the trip ticket. He/she must also provide complete and accurate information about species landed, quantity, harvest methods, area of catch and other information required by SCDNR [Sec. 50-5-300 (A); Sec. 50-5-380 (A), SC Code of Laws]. The Fisheries Statistics Section of SCDNR must receive completed trip tickets by the 10th of the following month. Currently under South Carolina law, "It is unlawful for a person to take or have in possession more than one weakfish (Cynoscion regalis) in any one day," [Sec. 50-5-1705 (H), SC Code of Laws] and the weakfish must be at least 12-inches in total length [Sec. 50-5-1710 (B), SC Code of Laws]. Therefore, even if weakfish are encountered during the course of commercial fishery operations, fishermen are not permitted to land more than one weakfish per day effectively eliminating any chance of encountering weakfish through the trip ticket system.

Biological Sampling

South Carolina does not have a directed commercial fishery for weakfish and there are no observer or other monitoring programs to determine the discards/bycatch of weakfish from commercial fishing gears (e.g. shrimp trawl, etc.) operating along South Carolina's coast. There is no available biological sampling data of weakfish through commercial fisheries in South Carolina.

5.1.4 North Carolina

Data Collection

Prior to 1978, North Carolina's commercial landings data were collected by NMFS. In 1978, the North Carolina Division of Marine Fisheries (NCDMF) entered into a cooperative program with the NMFS to maintain and expand the monthly surveys of North Carolina's major commercial seafood dealers. Beginning in 1994, NCDMF instituted a mandatory trip-ticket system to track commercial landings.

On January 1, 1994, the NCDMF initiated a TTK program to obtain more complete and accurate trip-level commercial landings statistics (Lupton and Phalen 1996). Trip ticket forms are used by state-licensed fish dealers to document all transfers of fish sold from coastal waters from the fishermen to the dealer. The data reported on these forms include transaction date, area fished, gear used, and landed species as well as fishermen and dealer information.

The majority of trips reported to NCDMF TTK only record one gear per trip; however, as many as three gears can be reported on a trip ticket and are entered by the program's data clerks in no particular order. When multiple gears are listed on a trip ticket, the first gear may not be the gear used to catch a specific species if multiple species were listed on the same ticket but caught with different gears. In 2004, electronic reporting of trip tickets became available to commercial dealers and made it possible to associate a specific gear for each species reported. This increased the accuracy of reporting by documenting the correct relationship between gear and species. North Carolina dealers are required to record each transaction with a fisherman and report trip-level data to NCDMF on a monthly basis.

Biological Sampling

Commercial length-frequency data were obtained by the NCDMF commercial fisheries-dependent sampling program. Weakfish lengths are collected at local fish houses by gear, market grade, and area fished. Random samples of culled catches are taken to ensure adequate coverage of all species in the catches. Length frequencies obtained from a sample were expanded to the total catch using the total weights from the trip ticket. All expanded catches were then combined to describe a given commercial gear for a specified time period. Gears identified were: beach seine, estuarine gill nets, long haul, ocean gill net, ocean trawl, pound net, and other.

In cases where the weight of particular species' market grades were included on the trip ticket but were not sampled, an estimate of the number of fish landed for the grade was made by using the mean weight per individual from samples of that species and grade from the same year. Species numerical abundance was calculated by determining the number of individuals/market grade and then summing all the market grades for each species. Catches were analyzed by gear type, year and semi-annually by "fishing season" (i.e., January through June and July through December).

Collection and aging of weakfish scales began in 1978 and continued through 1996. Otoliths and scales were collected starting in May 1995. A scale-otolith comparison study was conducted using the 1995 and 1996 collections. As a result, otoliths are the preferred aging structure for weakfish. Starting in 1997, only otoliths were used to age weakfish.

NCDMF collects weakfish age samples monthly beginning January 1st of each year and continuing through the end of December. A target of 10 age samples per 50-mm size bin is set for each month. Samples are collected through both fishery-independent and fishery-dependent sampling. If fish are not able to be sampled at a fish house, funds have been intermittently available to purchase fish from seafood dealers for later processing. Sectioned otoliths were each read by two independent readers to improve precision and accuracy. Discrepancies between the two age estimates were reviewed by the readers to reach consensus, or discarded if consensus could not be reached.

Commercial catch at length were calculated by expanding the size class frequency (20 mm fork length bins) collected from fish house samples to the trip ticket harvest by market grade. This was completed for all marketed fish, the same analysis was completed for non-marketed fish or bait. Gears reported were beach seine, estuarine gill net, long haul, ocean gill net, ocean trawl, pound net, and other for two periods: January-June and July-December. Commercial average weights were calculated by gear and market grade for January - June and July-December for each year.

Because TTKs are only submitted when fish are transferred from fishermen to dealers, records of unsuccessful fishing trips are not available to NCDMF. As such, there is no direct information regarding trips where a species was targeted but not caught. Information on these unsuccessful trips is necessary for calculating a reliable index of relative abundance for use in stock assessments. Another potential bias for NCDMF data relates to the reporting of multiple gears on a single trip ticket. It is not always possible to identify the gear used to catch a particular species on a trip ticket that lists multiple gears and species.

5.1.4 Virginia

Data Collection

All vessels landing seafood in Virginia for commercial purposes must possess a Seafood Landing License, unless the vessel owner is a registered Virginia commercial fisherman. All registered commercial fishermen and holders of seafood landing licenses are required to report daily harvest from Virginia tidal and federal waters to the Virginia Marine Resources Commission (VMRC) on a monthly basis. Daily harvest reporting includes information on number of crew, the amount of hours from leaving port to landing, gear soak time, gear amount, water body fished, and amount of pounds landed by species.

Biological Sampling

Field sampling at fish processing houses or dealers involves multi-stage random sampling. Targets are set based on mandatory reporting of harvest data, by harvesters, from the previous years. A three year moving average of landings by gear and month (or other temporal segment) provides a preliminary goal for the number of length and weight samples to be collected. Real time landings are used to adjust the preliminary targets. Targets for aging samples (see below for criteria) are tracked and collection updates are done weekly. Sampling data are recorded on electronic measuring boards. Weights of individual fish are recorded on electronic scales and downloaded directly to the electronic boards. A fish identification number unique to each specimen is created as well as a batch number for a subsample from a specific trip.

Subsamples of a catch or batch are processed for sex information (gender and gonadal maturity or spawning condition index). Such subsamples are indexed by visual inspection (macroscopic) of the gonads. Females are indexed as gonadal stage I-V and males stage 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, in terms of spawning condition, are not assigned a gonadal maturity stage.

The goal of otolith collection is to correspond to the length frequency distribution 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. Sampled fish are 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).

Ancillary data, for fish sampled at dealers, are collected and include: date harvested, harvest area, gear type used, and total catch (recorded if only 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 the Virginia Marine Resources Commission on a monthly basis by harvesters, sometime after a sampling event.

5.1.5 Maryland

Data Collection

Maryland DNR has a mandatory reporting system for commercial fishermen. Catch in pounds, days fished, area fished and amount and type of gear used were reported by month prior to 2006. A daily trip log was phased in from 2002 to 2005 with all fishermen using the daily log beginning in 2006. Effort data is only available for 1980-1984, 1990 and 1992 to the present. Landings prior to 1981 are from NOAA. Changes in reporting method and sources, as well as the reliance of fishermen reporting their effort consistently and correctly, make the effort data unreliable for calculating CPUEs, particularly prior to 2006.

Biological Sampling

Commercial pound nets were sampled in the Chesapeake Bay and in the lower reaches of its major tributaries from the Patuxent River south to the Potomac River. Sampling locations varied each year depending on where the cooperating fishermen's nets were set. The survey has been conducted every year from 1993 to 2014. Each site was generally sampled once every two weeks, weather and fisherman's schedule permitting. Net soak time and manner in which they were fished were consistent with the fishermen's day-to-day operations. All weakfish, regardless of whether they were legal to harvest, were measured to the nearest mm total length from each net when possible, and a subsample was retained to be weighed, sexed and have otoliths extracted. Weakfish were frequently encountered in the survey through the 1990s, but fewer have been encountered in the past decade. Weakfish from the trawl and gill net fisheries were also obtained from fish houses along the Atlantic coast. Fish house sampling was opportunistic in nature, with random boxes of harvested fish selected for sampling. Sample size, area of capture and gear type vary by year, with most sampling occurring in late fall and early winter.

Sampled fish were measured to the nearest mm total length, weighed to the nearest gram, sexed and had otoliths removed for aging. All otoliths were processed and aged by South Carolina DNR prior to 2011. From 2011 to 2014, weakfish otoliths were processed and aged by Maryland DNR. Both labs cut a thin cross section of the otoliths, which were subsequently aged.

5.1.6 Delaware

Data Collection

Commercial fishermen licensed in Delaware are required to submit monthly logbook reports. Total harvest, effort as trip days and net yards, port landed and location fished are required data elements in monthly reports. Annual commercial landings are also collected by the NMFS. No weakfish commercial discard data are collected in Delaware.

Biological Sampling

From 1993 - 2004, sampling of the commercial gill net fishery was conducted at commercial fish houses as fishermen would unload their fish. As the abundance of weakfish declined and landings were less abundant, sampling effort shifted to the purchasing of boxed weakfish. All fish were measured for fork length to the nearest half centimeter. Total weight (kg) and sex were also recorded. Sagittal otoliths were removed and placed in envelopes with sample number, location, date and gear type. One otolith was chosen randomly from each pair and processed for age determination.

5.1.7 New Jersey

Data Collection

New Jersey does not have mandatory harvest reporting for most gears or species, so the majority of weakfish harvest comes from the NMFS landings database. One exception is the small mesh gill net fishery which has been required to report under the small mesh gill net exemption in Delaware Bay since 1997.

Biological Sampling

New Jersey has collected biological data on weakfish specimens collected from various sources and gear types during the years 1995 through 1998 and, continuously, since 2003. These data include total length in millimeters, sex and age (derived from reading otolith samples).

Weight data for individual fish were collected in pounds from 1995, 1996, 1998, and 2003 through 2007. Kilogram weights for each specimen were recorded beginning in 2008. No weight data were available for 1997 and 2014. Length data (in inches) are obtained from harvest reports submitted by commercial fishermen participating in New Jersey's Gill Net Mesh Exemption Program which allows a non-directed harvest of weakfish in a traditional multi-species fishery using small mesh gill nets from March through December. Harvested weakfish lengths have been collected since 1997, with released fish lengths being recorded since 2008.

Fisheries dependent samples have dwindled in recent years due to difficulties arising from the extremely low level of landings, with 2012 being the last year of samples from the commercial sector, and only 2 samples in 2014 from the recreational fishery. New Jersey does not currently have a program for purchasing weakfish specimens from dealers or fish houses.

5.1.8 New York

Data Collection

New York collects weakfish length and age samples from its commercial fishery through fish observed at seafood dealer locations. Samples targets are stratified by season (spring, summer and fall) as well as by gear. Seasonal sampling targets were based on monthly distributions of the pervious years New York State commercial weakfish landings. The percentage of weakfish landings that occurred from January through March, which were minimal, was added to the spring target. No attempt was made to sample weakfish during the winter time period. Additionally, recreational samples were obtained when possible.

Biological Sampling

All weakfish are measured in total length. Weakfish otoliths are remove and processed for age determination. All ageing and processing protocols used are in accordance with guidelines established in the SCDNR weakfish aging manual.

5.1.9 Connecticut

Since the mid-1970's, Connecticut has require mandatory commercial fishery reporting including monthly logbooks of daily fishing activity and sales from fishermen and monthly reports of individual purchase transactions from dealers. The weakfish commercial fishery in Connecticut has been *de minimis* status since 2003 and therefore, no fishery dependent biological sampling has been conducted by the state.

5.1.10 Rhode Island

Data Collection

Beginning in 2006, all seafood dealers making primary purchases directly from fisherman in Rhode Island, have been required to report all purchases bi-weekly to the Atlantic Coastal Cooperative Statistics Program (ACCSP) Standard Atlantic Fisheries Information System (SAFIS).

Catch and effort data from commercial fisherman has been collected through a logbook program in RI since 2007. Commercial fisherman are required to submit catch and effort reports to the RI DEM Office of Marine Fisheries on a quarterly basis.

SAFIS reports are routinely checked against fisherman reports to identify errors and missing reports. Dealers who fail to comply with the reporting requirements may have their dealer's license suspended or revoked. Fisherman who fail to comply with reporting requirements are prohibited from renewing their commercial fishing license the following year until all of their reports have been submitted (RIMF 2013, RIMF 2015).

Biological Sampling

Each year the state of RI is required to collect 3 ages and 6 lengths per metric ton of weakfish landed the previous year. To satisfy this requirement, weakfish are purchased from licensed seafood dealers and/or collected on the Rhode Island Department of Environmental Management (RIDEM) seasonal trawl survey. Whole fish are processed fresh when possible; otherwise fish are frozen and stored for later processing.

Whole weakfish are weighed in grams and measured for total length to the nearest millimeter. Otoliths are removed and stored in vials for later processing. Beginning in 2013, fish are dissected and information on sex, maturity and stomach contents are collected. In the laboratory, otoliths are mounted to microscope slides with crystal bond and sectioned using a Buehler IsoMet low speed saw. Sectioned otoliths are viewed with a microscope for quality and may be baked after sectioning to more clearly define annuli. Sectioned otoliths are mounted to microscope slides with Flo-Texx mounting medium, labeled and stored in a microscope slide box. Sectioned otoliths are viewed with a digital stereomicroscope with transmitted light for age determination. Weakfish are assumed to have a birthdate of January 1 with annuli deposition occurring in May and June. The number of visible annuli is recorded as well as the final age. The final age is equal to the annuli count for fish that have already laid down an annulus for the year and for fish that have yet to lay down an annulus, the final age is the annulus count plus one (known as bumping).

5.1.11 Massachusetts

Massachusetts has historically accounted for <1% of coastwide commercial weakfish landings and operates under *de minimis* status. Accordingly, Massachusetts does not perform any targeted sampling of lengths or ages on commercially landed weakfish.

5.1.12 NEFSC Northeast Fishery Observer Program (NEFOP)

Discard mortality of weakfish by commercial fisheries was assumed to be 100%. Most discarding occurs in conjunction with two gears (trawls and gillnets) and a limited number of target species. The first quantitative analysis of weakfish commercial discards was provided by de Silva (2004). That reports investigates several methods to estimate discards, including effort based estimates, regression analysis, and ratio extrapolation. It was determined that multi-year ratios provided the most reliable estimates of discards from the methods investigated, and this methodology was applied for the 2006 and 2009 stock assessments. Ratios were developed for key species-gear combinations, expanded to total catch of that species-gear combination, and then summed across all combinations to estimate total weakfish discards. A major concern with this methodology is the chance for "double counting" because some of the target species co-occur. In an attempt to address this concern, several alternative discard estimation methods were investigated for the current assessment. All methods are based on data from the NEFSC Northeast Fishery Observer Program (NEFOP).

The first method the WTC investigated was the NMFS Standard Bycatch Reporting Method (SBRM; Wigley et al 2007, Wigley et al 2014). Wigley et al (2007) evaluate several methods of discard estimation and determined that a combined ratio method based on target species discards to all species kept (d_{target} / k_{all}) provided the most reliable estimates of discards of the methods investigated. When this method is applied to weakfish, however, ratios were found to be extremely small, resulting in unrealistically low estimates of discards. This was attributed to the sampling strategy employed by the Observer Program which focuses on federal fisheries, many of which are unlikely to ever encounter a weakfish.

The next method investigated by the WTC, and the one selected for use in the current assessment, could be considered a combination of the SBRM and de Silva (2004). Like de Silva (2004) the analysis includes only species that are likely to co-occur with weakfish. But to minimize the potential for double counting associated with the de Silva method, ratios were developed using a combined ratio method similar to the SBRM. The suite of indicator species associated with weakfish discards was identified using the Jaccard index of similarity (Jaccard 1912; see Section 6.2.1 for more details on this method).

Another difference between the current assessment and previous assessments was the stratification used. Previous assessments developed an "all years combined" ratio by season, region, and gear. For the current assessment, preliminary runs indicate that seasonal variability was generally small compared to temporal variability. As a result, the WTC combined across seasons but partitioned the years into explicit management time blocks (pre-1995, 1995-1996, 1997-2002, 2003-2009, 2010+). The one exception was the northern region otter trawl fishery which showed seasonal differences and had sufficient samples to develop separate seasonal ratios by time block. Sample sizes for observed hauls and observed hauls that had weakfish discards are shown in Tables 5.1.2 and 5.1.3, respectively. Species guilds were developed using the Jaccard method for each region-gear combination (Table 5.1.4).

Discard ratios were estimated for each stratum (Table 5.1.5) as the sum of weakfish discards divided by combined harvest of all guild species in observed hauls (d_{target} / k_{guild}). Prior to 1994 (the first year in the NEFOP database), there were few commercial regulations for weakfish, so it was assumed that all discards were for non-regulatory reasons. A ratio of non-regulatory discards was developed for each stratum for the years 1994-2000 and applied to landings for 1982-1993 to estimate discards in the years prior to the observer program. Variance of the ratios was estimated using equation 6.13 of Cochran (1977)

$$v(\hat{R}) = \frac{1-f}{n\bar{x}^2}\left(s_y^2 + \hat{R}^2 s_x^2 - 2\hat{R}s_{yx}\right)$$

with the assumption that the sampling fraction *f* (*i.e.* n/N) approached zero. Ratios were expanded to estimates of total discards using combined harvest of the appropriate guild species pulled from the ACCSP commercial landings database. Although most ratios were for combined seasons, ratios were applied to landings at the season level for use in the regional-seasonal age-length keys.

5.1.13 SEFSC Shrimp Trawl Observer Program

Juvenile weakfish are caught as bycatch in the south Atlantic shrimp trawl fishery. Scott-Denton *et al.* (2012) found that weakfish made up 0.9% of the total catch (shrimp, bycatch, and debris) by weight on observed trips from 2008-2010 in the south Atlantic.

To quantify potential removals from this fishery, the Weakfish TC obtained data from the SEFSC Galveston's lab observer program. The observer program conducts bycatch monitoring on shrimp vessels targeting either penaeid or rock shrimp in the south Atlantic and the Gulf of Mexico. Observer coverage goes back to 1998, but did not become mandatory until 2008 in the south Atlantic. Prior to that, the database includes both voluntary bycatch monitoring trips and BRD/TED testing trips.
The dataset was subset to include only bycatch monitoring trips (both voluntary and mandatory) that occurred in the south Atlantic. This resulted in 516 trips that conducted 2,464 tows from 2005-2014 (Table 5.1.6). Of those trips, 167 observed bycatch of weakfish. Additional trips observed "*Cynoscion* spp." bycatch, but did not record the catch to the individual species level; "*Cynoscion* spp." likely included weakfish and silver, spotted, and sand seatrout.

There was only a weak relationship between the weight of weakfish in a sample and the weight of shrimp (Figure 5.1.1) so the WTC chose to use a bycatch-per-unit-effort approach. The annual BCPUE (Table 5.1.7) was multiplied by the estimates of shrimping effort in the south Atlantic from the South Atlantic Shrimp system and state trip-ticket programs as was done for recent south Atlantic Spanish mackerel and red snapper assessments (SEDAR 2012). To extend the BCPUE time-series past 2005, the relationship between BCPUE and the SEAMAP index of abundance was used to estimate BCPUE from the SEAMAP index from 1990 – 2004. The intent of this approach was to avoid applying a constant BCPUE when BCPUE is most likely driven by changes in abundance, particularly of young-of-year weakfish. However, the relationship between the SEAMAP index and the BCPUE was not strong, introducing additional error into the calculations.

The final estimates of weakfish bycatch were very small relative to total commercial removals (Figure 5.1.2). In addition, the length distribution of the weakfish samples indicated the catch was predominantly composed of age-0 fish, which were not included in the population model (Figure 5.1.3). For these reasons, as well as the high uncertainty in the data set coming from the low sample size, the lack of mandatory coverage prior to 2008, and the uncertainty in extrapolating the BCPUE further into the past, the estimates of shrimp trawl bycatch were not included in the assessment.

The WTC also explored the NC DMF shrimp observer dataset, which had much better sample size for the years in which it was active, but only covered one year of inshore sampling and one year of offshore sampling, as well as only covering the waters of NC. They found similar rates of weakfish in their sample, with about 2% of the total catch by weight made up of weakfish in the inshore samples. Because of the limited temporal and spatial range of this dataset, estimates of total bycatch were not developed from it.

5.2 Recreational

5.2.1 Data Sources

The main source of information on recreational fishing for weakfish is the MRIP which was formerly the Marine Recreational Fisheries Statistical Survey (MRFSS). In 2005, the National Academy of Sciences' Natural Research Council (NRC) was commissioned to review the MRFSS and provide recommendations for improving recreational fishing estimates. A major finding of the NRC was that intercept methods resulted in a non-representative sample of recreational anglers and their catch-per-trip was not accounted for in the estimation methodology, resulting in potentially biased catch estimates and overestimated precision (MRIP website, http://www.st.nmfs.noaa.gov/recreational-fisheries/index). Interviewers were instructed to maximize the number of intercepts made and site selection was at the interviewer's discretion. Interviewers were more likely to obtain intercepts from high pressure sites and disregard low pressure sites and the catch-per-trip at the low pressure sites was not adequately represented. The NRC's review contributed to the implementation of a new estimation methodology. MRIP uses the same basic data as MRFSS but implements a new catch estimate methodology that better matches the sampling design used in the dockside intercept survey. The MRIP methodology is intended to account for possible differences in catch rates due to factors such as activity at fishing sites and time of day.

MRFSS/MRIP provides estimates for the number of trips anglers are taking, the total amount of fish harvested (numbers or weight), total number discarded, catch rates, and biological information. The survey is conducted coastwide and usually by state agency employees or contractors. In MRFSS/MRIP, anglers that fish from private boats and from shore are sampled using random dockside intercepts and telephone calls. During a dockside intercept, anglers are interviewed about their trip and the catch is counted, measured, and weighed. Angler access points are randomly selected in proportion to their expected fishing activity. To estimate effort, coastal households are randomly called and anglers are interviewed about the fishing trips taken during the previous 2 months. Similarly, a for-hire telephone survey is used to collect trip information directly from for-hire operators. Angler participation in MRIP surveys is voluntary. For details in addition to the description provided here, visit the NOAA recreational fisheries statistics website (www.st.nmfs.noaa.gov/recreational-fisheries).

5.2.2 Catch Estimates

MRIP provides estimates for three subcategories of catch, including observed harvest (Type A), unobserved harvest (e.g. filleted before observation, discarded dead; Type B1) and released alive (Type B2). Estimates of harvest were developed for each region/year/season combination as a sum of observed and unobserved harvest (Type A + B1). Because sand seatrout and weakfish are indiscernible except through genetic analysis, MRFSS/MRIP estimates in Florida are for the *Cynoscion* complex of weakfish, sand seatrout, and their hybrids. Florida catches were corrected for hybridization before combining with other southern region states. Estimates for true weakfish in Florida (Table 5.2.1) were calculated by subsetting total catch from the Atlantic coast of Florida into total catch from Nassau and Duval counties, based on the ratios of Nassau and Duval counties' intercepts relative to all Type A intercepts on the Atlantic coast of Florida, and applying the genome proportions of 48% for Nassau County and 17% for Duval County (Tringali et al, 2011). The proportion of true weakfish in catches from counties south of Duval County was assumed to be negligible and those removals were not included in the assessment.

In addition, MRFSS/MRIP also records catch of "sea trout, unidentified" which may be weakfish or the closely related sand or silver sea trout. As a sensitivity run, a proportion of the catch of "sea trout, unidentified" was included in the total removals. The proportion was based on the annual ratio of identified weakfish to the sum of identified weakfish, sand, and silver sea trout catch. Although weakfish made up most of the catch of identified sea trout, the catch of unidentified sea trout was small relative to weakfish catch, and the total additional removals were low.

5.2.3 MRIP/MRFSS Calibration

In 2012, MRIP changed how it calculated estimates of recreational catch and the associated 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 of MRFSS estimates falling within the confidence intervals of the MRIP estimates (Figure 5.2.1). In addition, there was no evidence of bias in the differences between the two methods (i.e., one method was not consistently higher or lower than the other). Because of this, the TC chose not to calibrate older estimates of recreational catch.

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 5.2.2). 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 5.2.2). MRIP PSEs were approximately 29% higher for harvest estimates and 37% higher for total catch.

5.2.4 Biological Samples

Biological samples collected by MRFSS/MRIP include lengths and weights of a subsample of Type A fish. Starting in 2004, MRIP also sampled catch on-board headboat vessels, allowing observers to measure both harvested and released alive fish, referred to as Type 9 lengths (Figure 5.2.2). No ages are collected by MRFSS/MRIP. MRFSS/MRIP develops estimates of total harvest in weight and harvest-at-length from these data. In addition, some states collect length and age information from recreational fisheries. Recreational length-weight data were combined with similar data from commercial and fishery independent sources to develop region- and season-specific length-weight relationships.

The number of length samples collected by MRFSS/MRIP is above the criterion of 100 lengths per 200 MT of landings (Burns et al 1983).

Length frequencies of released alive fish from MRFSS/MRIP were only available from 2004 onward. Assessments for other recreationally important species have used American Littoral Society (ALS) volunteer tagging data to infer the lengths of released alive fish, and the WTC investigated this dataset. However, a comparison of the length frequency from ALS data and the length frequency from MRIP Type 9 and Type A data in the years where both data sets were available showed the

ALS length frequency included more larger fish than the Type 9 data and were similar to the Type A fish (Figure 5.2.3).

5.2.5 Discards

Estimates of the number of recreational weakfish released alive (Type B2 fish) were obtained from the MRIP database. Estimates in Florida were corrected for weakfish-sand seatrout hybridization using ratios reported by Tringali et al. (2011). In previous assessments, release mortality was assumed to equal 20%. However, based on a review of available data, the WTC has decreased the release mortality to 10% (e.g. Murphy et al 1995, Malchoff and Heins 1997, Swihart et al 2000, Duffy 2002, Gearhart 2002).

5.3 Catch-at-Age Development

Due to the fast growth of weakfish, age-0 fish were present in both recreational and commercial catches in the late season (Jun-Dec), but the proportions were small. The age-0 component of the catch was dropped from the catch-at-age, and only ages 1-6+ were modeled.

5.3.1 Age-Length Keys

Age data was used to develop age length keys (ALK). Sample sizes of ages by year, season, and source from 2004-2014 are given in Table 5.3.1. Ages from the 1980s were from scale samples. In the 1990s, otoliths became the principal method for aging weakfish. In the 1998 stock assessment, scale-based ages from previous years were converted to otolith-based ages using a scale-otolith conversion matrix that was based on the direct comparison of approximately 2300 samples (Daniel and Vaughan 1997; NEFSC 1998). During the 2000 SARC review, an error was discovered in the scale-otolith conversion matrix and an updated CAA, corrected during the review, was accepted by the reviewers.

All ALKs were constructed by pooling age-length data from fisheries independent and fisheries dependent data sets in half year increments (Jan-June, Jul-Dec). Prior to 1990, data from all states was pooled together in two year increments for 1982-1983, 1985-1986, and 1988-1989. As no data were available from 1984 and 1987, these years used the 1982-1983 and 1985-1986 ALKs, respectively. From 1990 onward, keys were constructed for two regions, the northern (FL-NC) and southern (VA-MA) region. Region and seasonal ALKs were constructed in 2 year increments for 1990-1991 through 1994-1995. Annual keys were constructed from 1996 onwards. For more information on sample sizes and ALK construction, see NEFSC 2000, ASMFC 2006, and NEFSC 2009.

Although previous ALKs were constructed using the method of Fridriksson (1934), the WSASC decided to use multinomial logistic regression (Gerritsen et al. 2006; Stari et al. 2010) to construct keys from 2004-onwards. Multinomial keys objectively fill length gaps in sampling, which are particularly problematic for weakfish in recent years, due to low sample sizes. Keys were constructed separately for the southern and northern regions as before, but separate ALKs were also constructed for the ChesMMAP, SEAMAP, and NEAMAP surveys (see Section 6.0 Indices of Abundance). The southern and northern ALKs include data from these surveys, but the survey specific keys only included data from those specific surveys. To test for potential differences in assessment results caused by the shift in the method of ALK construction, traditional ALKs were constructed for the period 2004-2014 and considered as a model sensitivity run.

5.3.2 Commercial Catch-at-Age

5.3.2.1 Commercial Harvest-at-Age

Previous assessments for weakfish developed annual gear-, region-, and season-specific length frequencies for weakfish from commercial sampling data and used the appropriate age-length key (see Section 5.3.1 Age-Length Keys) to convert catch-at-length to catch-at-age (CAA). The commercial catch-at-age was added to the recreational and commercial discard catch-at-age matrices to create a single catch-at-age. Because the raw data used to develop the catch-at-age were missing for the earliest part of the time series, the 2009 assessment was not able to update the discard mortality rate to 10%. In addition, the WSASC was interested in separating the commercial and recreational removals into separate fleets for this benchmark assessment. This required that the historic weakfish CAA data be re-created and updated.

Although the raw data are still missing, the TC was able to recover length frequencies, ALKs, gear-specific landings, and working papers describing how the commercial catch-at-age was developed. These data were used to recreate the commercial catch-at-age from 1982-1999. Original catch-at-age files from 2000-2004 were available and did not need to be recreated. Data from the previous assessment was used to calculate new CAAs from 2004-2007 to allow for the use of multinomial ALKs. For a full discussion of the recreation process and a comparison of the new and old CAAs from 1982-1999, please see Appendix A1.

For 2008-2014, North Carolina gear- and season-specific length frequencies (expanded to total catch-at-length by gear and season) were used to develop the NC directed commercial catch-at-age. NC also collects data on fish landed as bait or scrap, developing length frequencies and total catch estimates for that source of removals, which were used to develop bait catch-at-age matrices by year and season. The NC directed commercial length frequency data were pooled across gears and used as a proxy for South Carolina, Georgia, and Florida commercial landings.

Sample size in the northern region was not adequate to develop gear-specific length frequencies. State-specific length frequencies were used to characterize the commercial harvest when the seasonal sample size was greater than 25 lengths. If the sample size was less than that, states were pooled with neighboring states with similar size regulations. Virginia and New Jersey sample sizes were adequate for all years/season. Where necessary, Maryland and Delaware were pooled with Virginia, who share the same 12 inch minimum size. New York, Connecticut, Rhode Island, and Massachusetts were pooled together, but sample size was still inadequate in some years. Length frequencies from NJ and VA were borrowed for those states; however, the states of MA through NY have a minimum size of 16 inches, while NJ has a 13 inch minimum size limit and VA has a 12 inch commercial minimum size limit. Where length frequencies were borrowed from those states, they were truncated below the minimum observed size in the MA-NY data, to allow the possibility of non-compliance in the MA-NY landings.

Length frequencies and commercial landings in weight were converted to catch-at-age in numbers using region- and season-specific length-weight relationships and ALKs (see Section 5.3.1 Age-Length Keys).

5.3.2.2 Commercial Discards-at-Age

The catch-at-age for the commercial discards was developed separately and then added to the commercial harvest catch-at-age. In order to convert discard weight (see Section 5.1.12 NEFSC

Northeast Fishery Observer Program) to discard numbers at size, a minimum of 25 length samples was established. This required substantial filling of holes (Table 5.3.2), so a hierarchical data pooling strategy was employed, collapsing first across years in a management time block, then seasons for that management block, and finally adjacent time blocks if necessary. For the years 1982-1993, data were collapsed across all years for a region, season, and gear since no observer data was available between 1982 and 1989. Samples from 1989 to 1993 were used back through 1982.

Region-year-season-gear specific length frequency distributions were combined with region-year-season specific length-weight equations to convert discard weight to discard numbers at size. Frequency at size in the sample was converted to proportion of sample weight at size. The proportions at size were multiplied by total discard weight to determine total weight at size. Finally, total weight at size was divided by average weight at size to estimate numbers at size by region-year-season-gear. To convert to numbers at age, numbers at size were summed across gears and applied to region-year-season age-length keys.

5.3.2.3 Total Commercial Catch-at-Age

The total commercial catch-at-age is shown in Table 5.3.3 and Figure 5.3.1. The catch-at-age is dominated by age-1 and age-2 fish. The age-structure of the catch expanded in the mid-to-late 1990s, but has contracted significantly since the early 2000s, with very few age-5 and age-6+ present in the catch.

5.3.3 Recreational Catch-at-Age

MRFSS/MRIP total harvest length frequency data were queried by state and season for each year from 1982-2014, and pooled to region and season. Florida lengths were excluded from the length frequencies in the South Atlantic region for 2000-2014 due to the hybridization issue. Length frequencies were converted to numbers at age using the appropriate region/year/season age-length key (See Section 5.3.1 Age-Length Keys).

For the length frequency of recreational discards, the TC used the MRFSS/MRIP harvest length frequencies for released alive fish from 1982-1999, the average MRIP Type 9 (released alive) length frequency from 2004-2008 for 2000-2003, and the annual MRIP Type 9 length frequencies for 2004-2014 to develop the catch-at-age for the release mortality component of the recreational catch-at-age (assumed to be 10% of the total released alive fish).

The proportion of total catch that was released alive was relatively low at the beginning of the time-series and prior to 1996 and the implementation of a consistent coastwide size limit, this assumption is reasonable. The years between 1996 and 2004 have the most uncertainty in the release mortality component of the catch-at-age, due to the lack of length samples from fish released alive.

The total recreational catch-at-age is shown in Table 5.3.4 and Figure 5.3.2. The catch-at-age is made up of primarily age-2 and age-3 fish. The recreational age structure shows the same expansion in the mid-to-late 1990s followed by a significant contraction. The proportion of age-5 and age-6+ fish in the recreational catch is nearly zero since 2010.

5.4 Sources of Uncertainty

Development of commercial and recreational removals at age estimates identified a number of potential sources of uncertainty. Commercial harvest estimates provided by NMFS may be misreported since weakfish are not a federal species and therefore do not need to go through a federal dealer. NEFSC (2009) compared harvest estimates from states with mandatory reporting with federal estimates from those same states. While there was significant discrepancy in estimates for individual gears, differences in harvest combined across gears were generally less than 10% by state and year. The current assessment estimates commercial harvest at age aggregated across gears, which should minimize the amount of error in the CAA estimates. In addition, the majority of weakfish commercial landings come from NC and VA, which have robust harvest reporting and biological sampling programs from the commercial fisheries.

Commercial discard estimates are hindered by low sample sizes due to the observer program focusing on federally managed fisheries In addition, length frequency sampling of weakfish discards was very poor for many of the strata used. Combining length samples across years or strata may smear any signal in size or age distribution of discards. Currently, commercial discards account for a relatively small proportion of total removals, which should minimize the impact of any size/age error. In the future increasing the sample size of both the number of observed trips from inshore fisheries and the number of lengths samples of weakfish is required to improve estimates of commercial weakfish discards. The discard estimation method has changed for this assessment, but the WTC concluded that the new methodology provides more realistic estimates than previous methods.

A recent review of the MRFSS program identified several potential biases and inadequacies of the sampling and estimation methodologies (NRC 2006).

Many of these issues have been addressed through reimplementation of the survey as MRIP in 2012. Harvest and discard estimates have been adjusted using the new MRIP estimation methodology back to 2004. Prior to 2004, adjustments were not made to weakfish harvest or discard estimates, as a comparison of MRFSS and MRIP estimates showed only minor difference with no consistent directional bias, but the PSE of estimates were adjusted to account for the new sampling methodology. PSEs are strongly influenced by sample size, and in years of low weakfish abundance, when fewer weakfish trips are intercepted, the PSE of the catch estimates are higher. However, even the adjusted PSE values are below the ACCSP recommend threshold of 40% (ACCSP 2016).

In addition to sampling methodology concerns listed above, recreational discard estimates will be affected by the recreational discard mortality rate. A thorough literature review prior to the 2009 stock assessment found dichotomous estimates of discard mortality of either 3% or 15%. A value of 10% was selected as a slightly conservative representative of this dichotomy.

Length frequency data for recreational harvest are generally sufficient. Sampling of recreational discard length frequency has generally been adequate since 2004, although the southern region samples were pooled across seasons. Size distributions for 2000-2003 were taken from the average of 2004-2014 samples, which may not be representative of the time period. Prior to 2000, length frequencies are based on harvest length frequencies. This may contribute substantial error to the size/age distribution, particularly from the mid to late 1990s once discarding increased following implementation of regulations. Recreational discards, while increasing in relative importance, are still generally less than 10% of total removals.

Conversion of total catch to catch at age is dependent on the available biological samples, which are a function of sampling intensity and gear selectivity. Borrowing of length frequency data across years, areas, or seasons may not be representative of the catch to which they are being applied. Similarly, age-length keys made from combined fishery independent and fishery dependent data may produce error in catch at age estimates. In addition, error in the scale:otolith age conversion may propagate through the catch at age. In recent years, the decline in abundance of weakfish and regulatory restrictions make collection of samples difficult.

The WTC is aware that there are several potential sources of uncertainty in the overall catch at age estimates. Attempts have been made to identify, and in some cases quantify, these error sources; however, the extent of uncertainty associated with each of these sources, and their cumulative effect, remains largely unknown. The use of statistical catch at age models (see section 7.0 Methods) which can account for error in the catch matrix are a significant improvement over previous assessments which assumed catch was known without error. Regardless, a persistent cumulative trend in either direction would result in inaccurate catch at age estimates and may influence assessment results.

6.0 INDICES OF ABUNDANCE

6.1 Fishery-Independent Surveys

The WTC reviewed and evaluated 45 fishery independent surveys for inclusion in the stock assessment, including trawl surveys, gill net surveys, and recreational surveys (Table 6.1.1). Each of these datasets was evaluated against a set of criteria the WTC assembled to determine which surveys were suitable for describing weakfish population trends. A survey was removed if

1. It had an insufficient time series to identify trends (<10 years).
2. It used inconsistent sampling methodology that couldn't be accounted for through standardization.
3. It had intermittent or rare catch of weakfish.
4. It covered a small geographic area that is not representative of the regional stock unit.
5. It didn't use a statistical base survey unless they have spatial persistence.

Thirty-one indices were considered not suitable for the assessment because they did not meet one or more of the criteria (Table 6.1.1). The remaining 14 datasets were retained for use in the assessment and are described in more detail below.

Previous assessments had aged indices into age-0 – 5+ and then lagged them forward one year in the model. For this assessment, non-YOY surveys were aged into age-0 –6+ age classes using survey-specific ALKs if available, or the appropriate region and season key. The age-0 component of the age-0+ indices were removed and indices were not lagged in the models.

Please see Appendix 2 for descriptions of fishery independent surveys considered but not used in the assessment.

6.1.1 North Carolina Gill Net Survey (NC PSIGN)

The Fisheries-Independent Gill-Net Survey, also known as Program 915, began on March 1, 2001 and includes Hyde and Dare counties (Figure 6.1.1). In July 2003, sampling was expanded to include the Neuse, Pamlico, and Pungo Rivers, and additional areas in the Southern District were added in April 2008 (Figure 6.1.1).

Floating gill nets are used to sample shallow strata while sink gill nets are fished in deep strata. Each net gang consists of 27.4 m segments of 7.6-, 8.9-, 10.2-, 11.4-, 12.7-, 14.0-, 15.2-, and 16.5 cm stretched mesh, for a total of 219.5 yards of nets combined. Catches from an array of gill nets comprise a single sample; two samples (one shallow, one deep)—totaling 438.9 yards of gill net—are completed each trip. Gill nets are typically deployed within an hour of sunset and fished the following morning. Efforts are made to keep all soak times within 12 hours. All gill nets are constructed with a hanging ratio of 2:1. Nets constructed for shallow strata have a vertical height between 1.8 and 2.1 m. Prior to 2005, nets constructed for deep and shallow strata were made with the same configurations. Beginning in 2005, all deep water nets were constructed with a vertical height of approximately 3.0m. With this configuration, all gill nets were floating and fished the entire water column.

A stratified random sampling design is used, based on area and water depth. Each region is overlaid with a one-minute by one-minute grid system (equivalent to one square nautical mile) and delineated into shallow (<1.8 m) and deep (>1.8 m) strata using bathymetric data from NOAA navigational charts and field observations. Beginning in 2005, deep sets have been made along the 1.8 m contour. Sampling in Pamlico Sound is divided into two regions: Region 1, which includes areas of eastern Pamlico Sound adjacent to the Outer Banks from southern Roanoke Island to the northern end of Portsmouth Island; and Region 2, which includes Hyde County bays from Stumpy Point Bay to Abel's Bay and adjacent areas of western Pamlico Sound. Each of the two regions is further segregated into four similar sized areas to ensure that samples are evenly distributed throughout each region. These are denoted by either Hyde or Dare and numbers 1 through 4. The Hyde areas are numbered south to north, while the Dare areas are numbered north to south. The rivers are divided into four areas in the Neuse River (Upper, Upper-Middle, Lower-Middle, and Lower), three areas in the Pamlico River (Upper, Middle, and Lower), and only one area for the Pungo River. The upper Neuse area was reduced to avoid damage to gear from obstructions, and the lower Neuse was expanded to increase coverage in the downstream area.

Initially, sampling occurred during all 12 months of the year. In 2002, sampling during December 15 to February 14 was eliminated due to extremely low catches and unsafe working conditions. Sampling delays were extensive in 2003, so this year was excluded from analysis because of the lack of temporal completeness. Sampling in the Pamlico, Pungo, and Neuse Rivers did not begin until July 2003. Each of the sampling areas within each region is sampled twice a month. Within a month, a total of 32 samples are completed (eight areas × twice a month × two samples) in both the Pamlico Sound and the river systems. The weighting factors by region and strata were:

Region 1: Shallow water - 461.3 square kilometers
Region 1: Deep water - 186.9 square kilometers
Region 2: Shallow water - 283.0 square kilometers
Region 2: Deep water – 241.8 square kilometers

In order to prevent bias due to unequal sampling across areas and time, only the core samples taken each month (n=32) were used in the calculations of the annual weighted CPUE index.

All fish are sorted by species. A count and a total weight to the nearest 0.01 kg, including damaged (partially eaten or decayed) specimens, are recorded. Length, sex, age, and reproductive samples are taken from selected target species, including weakfish. All age samples are collected and processed as described in Section 5.1.4.

One annual index of relative abundance was developed from the NC PSIGNS data. The index was based on all core samples collected during the calendar year that occurred within the Pamlico Sound portion of the survey only. Data for the rivers and ocean portion of the survey were reviewed but deemed not useable due to high numbers of zero catches. The Cape Fear River portion was also reviewed, however it was also not selected due to a limited time series. The Cape Fear River portion may be useful when a significant time series is obtained.

Available variables for standardization included year, depth, area, surface temperature, surface salinity, dissolved oxygen, pH, wind direction, and wind speed. The best-fitting generalized linear model (GLM) for NC PSIGNS used a negative binomial distribution and included year, depth, and area as significant covariates.

The NC PSIGNS index shows a declining trend over the time series (Table 6.1.2, Figure 6.1.2), and the age structure has contracted since the beginning of the time-series, with almost no age-5 and age-6+ observed since 2010 (Figure 6.1.2). Weakfish are a target species in NC PSIGNS. The survey is designed to collect data of fish using estuarine habitats but nearshore ocean areas, which may be utilized by weakfish, are not sampled. While sample design has been largely consistent, some adjustments have been made with the goal of reducing sea turtle interactions. In 2005, some deep water grids were dropped in Pamlico Sound, and in 2011, one area stratum in eastern Pamlico Sound was not sampled for a three-month period from June–August to reduce sea turtle interactions.

6.1.2 North Carolina Pamlico Sound Survey (NC P195)

Program 195 was instituted in March 1987 to provide a long-term, fishery-independent database for the waters of the Pamlico Sound, eastern Albemarle Sound, and the lower Neuse and Pamlico Rivers. The survey follows a stratified random design. Data collected from the survey have been used to calculate juvenile abundance indices and estimate population parameters for interstate and statewide stock assessments of recreationally and commercially important fish stocks.

The survey samples 52–54 randomly selected stations based on a grid system (one-minute by one-minute grid system equivalent to one square nautical mile) during the months of June and September. Sampling is stratified by depth and geographic area. Shallow water is considered water between 1.8 to 3.7 feet in depth and deep water is considered water >3.7 feet in depth. The seven designated strata are: Neuse River; Pamlico River; Pungo River; Pamlico Sound east of Bluff Shoal, shallow and deep; and Pamlico Sound west of Bluff Shoal, shallow and deep. As of March 1989, the randomly selected stations have been optimally allocated among the strata based upon all the previous sampling in order to provide the most accurate abundance estimates (PSE < 20) for selected species. A minimum of three stations (replicates) are maintained in each strata. A minimum of 104 stations are sampled each year to ensure maximum spatial coverage. Since 1991, sampling has occurred in Pamlico Sound and the Neuse, Pamlico, and Pungo rivers.

Sampling is conducted aboard the R/V *Carolina Coast*, equipped with double-rigged demersal mongoose trawls. The R/V *Carolina Coast* is a 44-ft fiberglass hulled double-rigged trawler. The trawl consists of a body made of #9 twine with 47.6-mm stretch mesh, a codend of #30 twine with 38.1-mm stretch mesh, and a 3.05-m tailbag. A 36.6-m three-lead bridle is attached to each of a pair of wooden chain doors that measure 1.22 m by 0.61 m and a tongue centered on the headrope. A 4.76-mm thick, 9.26-m tickler chain is connected to the door next to the 10.4-m footrope. Tow duration is 20 minutes at 2.5 knots.

The sampling season and number of strata sampled have undergone some changes since the survey's inception. In 1990, December sampling was stopped, all Albemarle Sound strata were eliminated, and the Pungo River stratum was added. In 1991, March sampling was eliminated. Sampling now occurs only in Pamlico Sound and the Pamlico, Pungo, and Neuse rivers and bays during June and September. Time delays also occurred in some years. In 1999, samples were collected during the month of July and the end of September and October because vessel repairs and hurricanes prevented following the normal schedule. In September 2003, Hurricane Isabel caused a delay and sampling was completed during two days in October.

Environmental and habitat data are recorded during the haul back of each trawl. Parameters measured include: weather description, light phase, surface and bottom temperature (°C), surface and bottom salinity (ppt), surface and bottom dissolved oxygen (DO; mg/L), start time, secchi depth (cm; added 2008), sediment size, wind speed (knots), wind direction, precipitation, start and end latitude, and start and end longitude.

The entire catch is sorted by species; each species is enumerated and a total weight is taken for each species. Individuals of each target species are measured. If present in large numbers, a sub-sample of 30–60 individuals of each target species is measured and a total weight of the measured individuals for each species is taken. If not on the target species list, the species is enumerated and a total weight taken. Weakfish are on the target species list and measured to the nearest millimeter fork length and an aggregate weight of all individuals is taken to the nearest 0.1 kg.

An index of relative abundance of age-0 weakfish was calculated using the GLM approach. In order to provide the most relevant index, data were limited to those collected during September, when age-0 weakfish are most prevalent in the survey, and all weakfish 200 mm fork length or less were considered age-0.

Available covariates for standardization of the age-0 index were year, depth, surface temperature, surface salinity, dissolved oxygen, and wind speed. The best-fitting GLM for the P195 index of age-0 weakfish abundance included year, depth, surface temperature, and surface salinity as significant covariates and had a negative binomial distribution. The index varied without trend over the time series.

An index of relative abundance of age-1 weakfish was calculated using the GLM approach. In order to provide the most relevant index, data were limited to those collected during June, when age-1 weakfish are most prevalent in the survey, and all weakfish 140mm fork length or greater were considered age-1.

Available covariates for standardization of the age-1 index were year, depth, surface temperature, surface salinity, dissolved oxygen, and wind speed. The best-fitting GLM for the P195 index of age-1 weakfish abundance included year, depth, surface temperature, and surface salinity as significant covariates and had a negative binomial distribution. The index varied without trend over the time series.

Although weakfish are a target species, this survey was not specifically designed to target weakfish. Sampling is limited to the months of June and September and may not capture the peak recruitment period in some years.

The NC P195 were highly variable and did not exhibit a significant trend over the time-series (Table 6.1.3, Figure 6.1.3).

6.1.3 Southeast Area Monitoring and Assessment Program (SEAMAP)

Catches from the Georgia, South Carolina and North Carolina portions of the Southeast Area Monitoring and Assessment Program (SEAMAP) were used to create an age aggregate index. Florida catches were omitted due to issues of hybridization and overall catches accounting for a small portion of the total survey catch. Dates used for this assessment were 1990-2014.

Sampling cruises were conducted seasonally: spring (mid-April – May), summer (July-August) and fall (October-November), in established strata between Cape Canaveral, Florida (28^o 30.0'N) and Cape Hatteras, North Carolina (35^o 13.2'N). Stations were allocated to strata according to results of an Optimal Allocation Analysis. Sampling was conducted during daylight hours. Operations at each site used paired 22.9 m mongoose-type Falcon trawls (designed and constructed by Beaufort Marine Supply) with tickler chains. These were towed for 20 minutes bottom time from the R/V *Lady Lisa*, a 22.9 m St. Augustine shrimp trawler. Nets did not contain TEDs or BRDs so that density estimates for all sizes of each species could be calculated, and to maintain comparability with previous survey data. Contents of each net were processed independently. Weakfish were measured to the nearest centimeter. Large or complex samples were subsampled by weight with a randomly selected subsample from each net processed. Large numbers of individuals of a species were subsampled and only 30 to 60 individuals measured, when appropriate.

Following trawl collections, hydrographic and meteorological data (air and water temperature, salinity, wind speed and direction, wave height, and barometric pressure) were recorded. Water temperature and salinity was measured and recorded with a SEABIRD Conductivity, Temperature, and Depth (CTD). Abundance, biomass, and length-frequency data was recorded on a computer utilizing electronic measuring boards. The SEAMAP catch data was spatially (North Carolina to Georgia) and temporally (only fall collections) restricted to provide a comparable index to the other coastwide indices. The SEAMAP Weakfish index (catch per tow) was standardized using a zero-inflated negative binomial generalized linear model and the final model selected was:

Number of Fish Caught ~ Year + Bottom Temperature (°C) + Surface Salinity (ppt) + Average Depth + Air Temperature (°C) + offset (LogEffort) | Bottom Temperature (°C) + Surface Salinity

The SEAMAP index is dominated by age-0 and age-1 fish. The age-1+ index has been quite variable over the time-series, with a time-series high in 2014 (Table 6.1.2, Figure 6.1.4). The contraction of the age-structure since the mid-2000s is not as dramatic as in the catch and other inshore age-1+ indices, possibly due to the lower catchability of older fish in this survey.

6.1.4 Virginia Institute of Marine Science Chesapeake Bay Trawl Survey

The Virginia Institute of Marine Science (VIMS) has conducted a trawl survey in lower Chesapeake Bay since 1955. Over time there have been several changes to sampling strategy and survey area. Currently, sampling is conducted using a 9.1 m semi-balloon otter trawl with a 6.4 mm codend liner. Sampling occurs monthly throughout the year using stratified random sampling in the mainstem Bay and fixed stations in tributaries. Young of year are identified through examination of length frequencies (monthly ranges), and an index of recruitment is computed as the geometric mean catch per tow during August to October from the three major tributaries.

The geographic region covered by the survey includes the Virginia portion of the Chesapeake Bay and lower portions of its three main tributaries (James, York, and Rappahannock Rivers). Although sampling does occur in the main stem, catches of weakfish are generally minimal in the Bay, so the index is limited to the three tributaries. Few large weakfish are present year round, but the estuaries provide suitable nursery grounds for juveniles.

Recruitment varies widely over the time series, ranging from less than 5 fish per tow to more than 35 fish per tow (Table 6.1.3, Figure 6.1.5). Interannual variability is often large, particularly in the early portion of the time series, with the maximum and minimum indices occurring in consecutive years (1985, 1986). From 1986 to 1990, the survey shows a rapid increase from 4.7 to 30.0 fish per tow, followed by a sharp drop back to 7.0 fish per tow by 1994. Recruitment rebounded slightly through 1999, but generally has been declining since.

No estimates of survey variability are available for the current index; however, 95% CIs for an index that includes Bay and River stations (data not shown) indicate good precision which has improved as the survey progressed. Since 1989, CIs have generally been within 25 to 40% of the observed mean value. It could be expected that precision of the “river only” index would be greater, as catches of weakfish are less variable in the rivers than the Chesapeake Bay.

The VIMS trawl survey occurs within the core region of weakfish abundance during months when weakfish would be present. Precision is uncertain, but proxy data indicate low to moderate variability. The VIMS young-of-year trawl survey caught 232,351 weakfish in tows from 1988 to 2014. Available variables for standardization included year, trawl depth, temperature, dissolved oxygen, salinity, and, as a categorical variable, the stratum the sample was taken from. The data set had less than 25% zeros, so a negative binomial model was chosen over a zero-inflated negative binomial model. The best fitting generalized linear model (GLM) for this survey was the negative binomial model including year, depth, temperature, and stratum as significant covariates. The WTC has determined that this survey is suitable for use in the assessment.

6.1.5 Maryland Coastal Bays Juvenile Trawl Survey

The Maryland Department of Natural Resources (MDDNR) has conducted the Coastal Bays Fisheries trawl survey in Maryland’s Coastal Bays since 1972, sampling with a standardized protocol since 1989. Trawl sampling was conducted at 20 fixed sites throughout Maryland’s Coastal Bays on a monthly basis from April through October. The boat operator took into account wind and tide (speed and direction) when determining trawl direction. A standard 4.9 m semi-balloon trawl net was used in areas with a depth of greater than 1.1 m. Each trawl was a standard 6-minute (0.1 hr) tow at a speed of approximately 2.8 knots. Speed was monitored during the tow using the GPS. Waypoints marking the sample start (gear fully deployed) and stop (point of gear retrieval) locations were taken using the GPS to determine the area swept (hectares). Time was tracked using a stop watch which was started at full gear deployment. Fishes and invertebrates were identified, counted, and measured for total length in millimeters. At each site, a sub-sample of the first 20 fish (when applicable) was measured and the remainder counted.

Due to low weakfish catches, only tows from July-October were used to calculate the index. As this was a fixed site survey, persistence (Warren 1994) was analyzed. After correcting for false discovery rate due to multiple comparisons, this survey was found to have relatively high persistence with 47% of the pairwise year comparisons significant. The index (catch per tow) was standardized using a negative binomial GLM with the following significant covariates: year, surface water temperature (°C), starting depth (ft), and surface salinity (ppt). The index shows some increase in number of weakfish/tow through the 1990s and a generally declining trend since 2001 (Table 6.1.3, Figure 6.1.6).

6.1.6 Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP)

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) Trawl Survey has been sampling the mainstem of the Chesapeake Bay, from Poole's Island, MD to the Virginian Capes at the mouth of the Bay since 2002. ChesMMAP conducts 5 cruises annually, during the months of March, May, July, September, and November. This survey is designed to sample the late juvenile and adult stages of the living marine resources in Chesapeake Bay, and as such the timing of sampling is meant to coincide with the seasonal residency of juvenile and adult life stages in the estuary.

The ChesMMAP survey area is stratified into five latitudinal regions, and each region is comprised of three depth strata. Depth strata bounds are consistent across regions, and correspond to shallow (3.0m to 9.1m), middle (9.1m to 15.2m), and deep (>15.2m) waters in the bay. Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A total of 80 sites are sampled per cruise, and a four-seam, two-bridle, semi-balloon bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.5kts. The trawl has a 13.7m headline length, and is made of 15.2cm stretch mesh webbing in the body of the net and 7.6cm stretch mesh in the codend. The codend is not outfitted with a liner which enables the net to be towed effectively at relatively high speeds, facilitating the capture of the target late juvenile and adult stages. Trawl wingspread and headline height are measured during each tow. A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation), atmospheric data, and station identification information are recorded at each sampling site.

Following each tow, the catch is sorted by species and, if appropriate, by size group within a species. Size groups are not predetermined for each species, but rather are defined relative to the size composition of that species for that tow. As such, size designations and ranges of small, medium, and large for a species may vary somewhat among tows. Such an approach facilitates representative subsampling, and therefore proper catch characterization, for each tow.

A subsample of five weakfish is selected from each size group from each tow for full processing. Specifically, individual total length (TL - mm), whole and eviscerated weight (kg), sex, and maturity stage are recorded. Stomachs are removed for diet analysis and otoliths are removed for age determination. For specimens not taken for full processing, aggregate weight and individual total length measurements (mm) are recorded by size group.

Encounter rates of weakfish on the ChesMMAP Survey were moderate and reflected spatial and temporal trends in the migratory patterns of this species. Overall, weakfish have been collected on 27.8% of tows conducted between March and November since the inception of the survey. The percentage of tows with weakfish ranged from 10.0% to 38.5% per year, 1.3% and 41.7% by month, and 7.9% to 40.7% by latitudinal region over the time series. Weakfish encounter rates exhibited an increasing trend with increasing survey month and decreasing latitude. This species was encountered most frequently during the September (38.9%) and November (41.7%) cruises, and capture rates were greatest in the southernmost latitudinal regions (Region 4 – 40.0%, Region 5 – 40.7%). Weakfish collected by ChesMMAP ranged between 15 mm TL to 616 mm TL and from age-0 to age-6. Catches ranged from 0 to 366 weakfish per tow, while the mean was 13.6 fish per tow (s.e. 0.6). Approximately 70.0% of tows where weakfish were caught were comprised of five or fewer specimens.

In this survey dataset, eight explanatory variables were recorded. Among these recorded variables, seven are continuous (depth, water temperature, salinity, dissolved oxygen, latitude, and longitude) and two are categorical (year and month). According to the discussion among weakfish SAS and TC, only data collected during fall season were used to conduct catch rate standardization. Two models were compared: 1) delta model comprising two generalized linear models (Delta_GLM); 2) delta model comprising two generalized additive models (Delta_GAM). Based on multicollinearity analysis, delta-AIC and cross validation, 4 variables (latitude, longitude, water temperature and year) were selected for Delta-GAM and Delta-GLM. The models were compared based on AIC and 3-fold cross-validation, and the results indicated that the Delta-GAM yielded much smaller AIC and smallest training error and testing error.

The ChesMMAP age-1+ index has decline nearly continuously over the entire time-series, reaching a time-series low in 2014 (Table 6.1.2, Figure 6.1.7). The age-structure of the index is dominated by age-0 and age-1 fish, and the proportion of age-4, 5, and 6+ fish in the index has been near zero since the mid-2000s (Figure 6.1.7).

6.1.7 Delaware Fish and Wildlife Delaware Bay Trawl Survey

The Delaware Division of Fish and Wildlife (DEDFW) has conducted a trawl survey within the Delaware Bay since 1966 (1966-1971, 1979-1984, and 1990 – present). The Delaware Bay trawl survey occurs in one of the major weakfish spawning areas and historically has been shown to capture a wide size and age range of weakfish throughout the year. Trends in abundance correspond well with observed information from commercial and recreational fisheries; and are coherent with other indicators of weakfish abundance. The WTC has historically determined that the Delaware 30-foot trawl survey provides a reliable age-structure index of weakfish abundance.

The survey collects monthly samples from March through December at nine fixed stations throughout the Delaware portion of the Bay. The net used has a 30.5 foot headrope and 2” stretch mesh codend. A Yellow Springs Instrument Co. Model 85 oxygen, conductivity, salinity and temperature meter was used to measure surface and bottom temperature (°C), dissolved oxygen (ppm) and salinity (ppt) at the conclusion of each tow. Upon completion of each tow, the sample was emptied on the deck and sorted by species. Aggregate weights are taken for each species. Species represented by less than 50 individuals were measured for fork length to the nearest half-centimeter. Species with more than fifty individuals were randomly sub-sampled (50 measurements) for length with the remainder being enumerated.

The Delaware Weakfish index (catch per tow) was standardized using a zero-inflated negative binomial generalized linear model:

Number of Fish Caught ~ Year + Depth + Month + offset(LogEffort) | Depth + Month

with data from May-September, as this temporal period largely encapsulated when weakfish were present in Delaware Bay.

Since 1991, length frequencies have been aged using survey specific age-length keys.

The geographic range of this survey is limited to Delaware Bay, a small portion of the range of the weakfish stock. However, Delaware Bay is known to be a major weakfish spawning ground along the Atlantic coast (Nye et al 2008). Fish from a wide size and age distribution have been historically available to the survey due to the temporal and spatial coverage of the survey design, including young of year to larger, mature individuals.

Weakfish abundance was moderate in the early 1980s and early 1990s, ranging from 15-30 fish/nm (Table 6.1.2, Figure 6.1.8). Beginning in 1992, abundance increased sharply to a time series high of over 230 fish in 1996. Abundance decreased by more than half in 1997, and has exhibited a generally declining trend since that time.

Age structure (Figure 6.1.8) advanced from primarily age 1 and 2 fish in the early 1990s to include ages 7 and 8 in 1998-2000. Abundance of age 4+ fish accounted for 30 to 35% of the total index in 1997 and 1998 as the large 1993 year class moved through. Abundance of older ages has since declined to levels observed in the early 1990s, with 3+ fish accounting for less than 3% of the total number caught.

6.1.8 Delaware Fish and Wildlife Delaware Bay Juvenile Trawl Survey

In addition to the 30-foot trawl survey, the DEDFW has conducted a fixed station trawl survey in Delaware Bay targeting juvenile finfish from 1980-present. The Delaware young of year survey occurs within the core area of weakfish abundance and encompasses a major spawning/nursery area for the species during months when weakfish are present. The survey has captured the occurrence of several strong year classes with good precision. The WTC has used this survey in previous stock assessments as an index of recruitment.

Sampling is conducted monthly from April through October using a semi-balloon otter trawl. The net has a 5.2 m headrope and a 12.7 mm stretch mesh codend liner. Weakfish are a significant component of the catch, with the greatest majority of these weakfish (more than 99% in some years) being young of the year. The DE Juvenile Weakfish index (catch per tow) was standardized using a zero-inflated negative binomial generalized linear model:

Number of Fish Caught ~ Year + Month + offset(LogEffort) | Depth + Month

with data from May-September, as this temporal period largely encapsulated when weakfish were present in Delaware Bay.

Throughout the time series, the annual average recruitment index has ranged from 13.5 to 86.5 fish per tow (Table 6.1.3, Figure 6.1.9). Weak recruitment occurred in 1980, 1983 and 2006, with annual averages less than 17.5 fish per tow, while the two strongest recruitment events of 84.4 and 86.5 fish per tow occurred in 1997 and 2005, respectively. Average recruitment over the time series has been approximately 40.8 fish per tow with twelve annual peaks at or greater than 40.8 fish per tow, including 2014 at 79.9 fish per tow.

6.1.9 New Jersey Ocean Trawl Program

The New Jersey Department of Environmental Protection'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 originated as bi-monthly cruises, but since 1991, the survey has been conducted five times per year (January, April, June, August and October) in the coastal waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay. The survey 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. The boundaries for these strata are nearly identical to those used by the NEFSC in this region, although the northern- and southern-most strata for New Jersey are truncated at the state boundaries. The sampling gear is a two-seam trawl with a 25m head rope, 30.5m footrope, forward netting of 4.7 inch stretch mesh, rear netting of 3.1 inch stretch mesh, cod end of 3.0 inch stretch mesh, and a cod end liner of 0.25 inch bar mesh. All fish and most macro-invertebrates taken during these surveys are counted and weighed to obtain abundance and biomass totals per species by tow, with individual lengths measured to the nearest centimeter. This program has consistently contributed weakfish specimens for growth and age analysis since 2007.

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 were recorded with a thermistor. Beginning with the January 2011 survey and for all subsequent trawl cruises, water chemistry data are collected via a YSI 6820 multi-parameter water quality Sonde which records depth, temperature, dissolved oxygen and specific conductance. Water samples readings have usually been collected prior to each sampling tow, although they are occasionally collected immediately following a tow.

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 trawl samples collected per year. For each sample, the net is towed for 20 minutes at a target speed of 3 knots, timed from the moment the winch brakes are set to stop the deployment of the 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, though in shallow (<10m) water this ratio is often much greater, to ensure adequate separation between the vessel and the net.

Weakfish specimens are collected from this survey (5 fish per length bin per day) for alter processing. Data collected include total length (m), whole damp weight (kg), and sex. Otoliths are extracted for age determination.

The majority of weakfish in this survey are observed during the June, August and October cruises, although the June catches are inconsistent. Previous assessments have used abundance data from the combined August and October cruises as well as a proportion of positive tows index from the August survey cruise alone to develop an index of weakfish abundance. Experienced samplers from this survey have observed that the use of either the August or the October cruise data alone does not fully encompass the occurrence or abundance of the weakfish in New Jersey's coastal waters. Variability in the timing of the survey cruises relative to the movement of the weakfish out of the bays into the ocean waters will influence this species' appearance in the survey samples. Length frequency distributions are dominated by the older, larger fish in the August cruises while the October samples show a dominance of the young-of-the-year and yearling weakfish. The length frequencies from the combined August and October trawl cruises, while still showing a higher peak for the older fish, present a more balanced representation of the composition of the weakfish in New Jersey's nearshore waters. For the current assessment, a GLM-based index was derived using a negative binomial distribution of the August and October abundance data with mean depth and bottom salinity as the covariates (Table 6.1.2, Figure 6.1.10). This index fluctuated without a general trend (range 0.35 to 439.82) with a surge in numbers for 1994 (time series high) and 1995, followed by smaller peaks in 2000, 2004 and 2011. New Jersey's age length keys were applied to this survey's mean catch at length indices to derive an index-at-age (Figure 6.1.10). Consistent with many of the other surveys, there has been a truncation of the age structure of the weakfish catch in recent years with no age-6+ fish seen since 2002.

6.1.10 NYSDEC Peconic Bay Juvenile Trawl Survey

The New York Division of Fish, Wildlife and Marine Resources has conducted a juvenile trawl survey in the Peconic Bay estuary of Long Island since 1985. Weakfish was the primary target species when the survey was initiated, and Peconic Bay was selected for the survey area because of its importance as a weakfish spawning ground. Random sampling occurs weekly between May and October using a semi-balloon shrimp trawl with a 4.9 m headrope and 12.7 mm stretch mesh codend liner. The survey samples mainly young of year weakfish, and a YOY index has historically been calculated using all sampling months. In 2005 and 2006, technical difficulties constrained sampling to May – July (2005) and July – October (2006), so a revised index using only July and August has been calculated. The two indices (all months and July-August) show a similar increasing trend and are well correlated (r = 0.96).

The July-August index ranges from less than one to more than 30 fish per tow (Table 6.1.3, Figure 6.1.11). Despite large interannual variations, there appears to be a gradual increase in recruitment over the time series through the late 2000s. In 2009, however, abundance dropped dramatically to less than 2 fish per tow where it has remained relatively stable through the end of the time series. Strong year classes occurred in 1991, 1996, and 2005 (time series high).

Because this survey is conducted outside the apparent core area, NEFSC (2000) recommended that this survey not be used as an index of abundance. However, the survey was developed specifically to monitor trends in weakfish populations on an important spawning ground, and some strong year classes have been observed. Precision of the survey is acceptable. For these reasons, the WTC used the Peconic Bay YOY survey in the assessment.

6.1.11 Connecticut Department of Energy and Environmental Protection Long Island Sound Trawl Survey (CT LISTS)

Since 1984, the Connecticut Department of Energy and Environmental Protection has conducted spring and fall trawl surveys in the Connecticut portion of Long Island Sound between the New York/Connecticut border in the west and New London, CT in the east. Survey effort consists of three spring cruises conducted during April, May and June, and three fall cruises during September/October. Stratified random sampling is employed based on four depth zones and three bottom types. Survey gear consists of a 14 x 9.1 m high-rise otter trawl with 5 mm codend mesh. The survey catches mostly YOY and age 1 weakfish as defined by examination of length frequencies. For the fall survey, a 30 cm length cutoff is used to separate YOY and age 1 fish. Indices of abundance for age 0 and age 1+ are developed as geometric mean catch per tow. The age 0 index was used in the composite YOY index and the age 1+ index was incorporated as a sensitivity run.

Sampling is limited to Long Island Sound. The Sound encompasses a very small portion of the weakfish range, but may serve as a primary nursery habitat in this region.

From 1984 to 1998, the YOY index varied without trend, and generally ranged from approximately 3 to 10 fish per tow, with relatively strong year classes (10-15 fish per tow) occurring in five years (Table 6.1.4, Figure 6.1.12). In 1999, recruitment increased sharply and has remained above 30 fish per tow in all years except 2005, 2006, and 2008-2013. However, the index was 41 in 2014. Time series highs of more than 63 fish per tow occurred in 2000 and 2007, while minimum catches of approximately 1 fish or less occurred in 1984, 1986, and 2006. The CV of the YOY index has exhibited a generally negative trend over the time series.

NEFSC (2000) recommended that this survey not be used as an index of abundance because it occurs outside the core area of weakfish abundance. However, large recruitment events have been observed in this area over the last ten years, suggesting it may provide prime nursery habitat. In addition, precision of the YOY catches is strong. For these reasons, the WTC concluded that the Long Island Sound YOY index was suitable for use in the assessment.

Like the other surveys, this survey was standardized using a GLM approach. However, environmental covariates were not consistently collected until 1992 and seven years of the early part of the time series would be lost with GLM standardization. As this survey is one of the few with data back into the early 1980s and the standardized index was very similar to the geometric mean catch/tow, the WSASC decided not to use GLM standardization and continue use of the geometric mean index.

6.1.12 Rhode Island Seasonal Trawl Survey

2014 marked the 36th year of Rhode Island Department of Environmental Management's (RIDEM) seasonal trawl survey. The survey was initiated in 1979 to monitor recreationally important finfish stocks in Narragansett Bay, Rhode Island Sound, and Block Island Sound. The survey aims to monitor trends in abundance and distribution, to determine population size/age composition, and to evaluate the biology and ecology of estuarine and marine finfish and invertebrate species occurring in RI waters. Over the years, this survey has become an important component of fisheries resource assessment and management at the state and regional levels.

The survey employs a stratified random and fixed design defined by 12 fixed stations in Narragansett Bay, 14 random stations in Narragansett Bay, 6 fixed stations in Rhode Island Sound, and 12 fixed stations in Block Island Sound.

In 2005, RIDEM replaced the research vessel and survey gear that has been utilized by the survey since its inception. The R/V *Thomas J. Wright* was replaced with a 50' research vessel, the R/V *John H. Chafee*. During the spring and summer of 2005, a series of paired tow trials were conducted using modern acoustic equipment and new nets designed to match the trawl net used by the NMFS. The results of this experiment were used to calibrate the old and new vessels in order to maintain the continuity of the survey time series. Unfortunately, the new net design was too large for the new research vessel and could not be successfully towed in many of the areas required by the trawl survey. Because of this, a new net was designed in the same dimensions as the net previously used for the survey and is used for the trawl survey. By using a similar net design to the previous survey net, the continuity of the survey is able to be maintained, though analysis to confirm this is still pending.

In 2012, new doors were installed on the R/V *John H. Chafee.* A rigorous calibration experiment was done to calibrate the new trawl configuration with the new doors to the old trawl configuration with the old doors. The analysis has been conducted, but is unpublished at this point.

The following is a description of the net used in the survey:
Fishing Circle: 533.4x11.4 cm 2 seam
Head Rope: 12.2 m'
Foot Rope: 16.8 m
Chain Sweep with 0.8 cm links – hung 30.5 cm spacing with 13 links per space
Wings all the way back to codend: 11.4 cm mesh - #42 thread
Codend: 5.1 cm mesh – Euro Web 3mm thread
Codend liner: 6.4 mm

At each station a standard 20 minute tow is conducted at 2.5 knots. Catch is sorted by species. Length (cm/mm) is recorded for all finfish, skates, squid, scallops, whelk, lobster, blue crabs and horseshoe crabs. Similarly, weights (gm/kg) and number are recorded as well. Data on wind direction and speed, sea condition, air temperature and cloud cover as well as surface and bottom water temperatures, are recorded at each station.

Sampling at each random and fixed station during the fall component of the survey typically occurs in September and October of each year; however, sampling has in the past also occurred in November.

Weakfish are rarely observed in the spring component of the RIDEM seasonal trawl survey, but are not uncommon in the fall. The fall component of the Rhode Island seasonal trawl survey is predominantly comprised of YOY weakfish which are present in at least 10% of all tows in any given year of the survey. The RI YOY weakfish index was standardized using a negative binomial GLM and the covariates considered included year, depth, bottom temperature, and stratum. Of the considered covariates, year and bottom temperature were found to be significant and included in the final model.

The index varied without trend over the time-series, with extreme highs in 1997 and 2004 (Table 6.1.3, Figure 6.1.13).

6.1.13 Northeast Fisheries Science Center Bottom Trawl Survey

The National Marine Fisheries Service (NMFS) Northeast Fishery Science Center (NEFSC) conducts seasonal trawl surveys between Nova Scotia and Cape Hatteras. Stratified random sampling is conducted using a #36 Yankee otter trawl equipped with roller gear and a 1.25 cm mesh codend liner. The survey covers a large portion of the geographic range of weakfish, including their "core" distribution area (NEFSC 2000) of New Jersey to North Carolina. Despite the extended latitudinal range, the survey is not capable of sampling in shallow waters, and few sites are conducted in waters less than 9 m. In addition, the survey does not sample the South Atlantic portion of the range.

Weakfish are infrequent in the winter, spring, and summer surveys, but are commonly intercepted in the fall during their offshore migration. Index at age composition was developed by applying annual survey specific length frequency data to the annual mean catch per tow and then applying either survey specific ALKs (when available) or the pooled Mid-Atlantic region late season ALK (see section 5.3.1).

The NEFSC index is generally stable at low numbers (< 20 fish per tow) during the 1980s and 1990s (Table 6.1.2, Figure 6.1.14). Two notable exceptions are 1984 and 1994, with peaks of 116 and 60 fish per tow, respectively. Evaluation of the index at age data does not indicate that these peaks were the result of strong year classes. Between 1998 and 2003, the index rose sharply, from less than 5 fish to more than 170 fish per tow, before declining rapidly back to previous levels by 2007.

In 2009, the NEFSC changed survey vessels. The new R/V Bigelow is larger and cannot sample the inner-most inshore strata that the previous vessel did. Instead, those strata are now sampled by the Northeast Area Monitoring and Assessment Program (NEAMP), described in Section 6.1.14. As few weakfish were ever observed in the offshore strata, 2008 is the terminal year of the NEFSC index for weakfish.

6.1.14 Northeast Area Monitoring and Assessment Program (NEAMAP)

The Northeast Area Monitoring and Assessment Program, Mid-Atlantic/Southern New England Nearshore Trawl Survey (NEAMAP) has been sampling the coastal ocean from Martha's Vineyard, MA to Cape Hatteras, NC since the fall of 2007. NEAMAP conducts two cruises per year, one in the spring and one in the fall, mirroring the efforts of the Northeast Fisheries Science Center (NEFSC) Bottom Trawl Surveys offshore. Spring cruises begin during the third week in April and conclude around the end of May, while the fall surveys span from the third week in September until the beginning of November. Sampling progresses from south to north in the spring and in the opposite direction in the fall, so as to follow the general migratory pattern of the living marine resources of these regions.

The survey area is stratified by both latitudinal/longitudinal region and depth. Depth strata between Montauk, NY and Cape Hatteras are 6.1m-12.2m and 12.2m-18.3m, while those in Block Island Sound and Rhode Island Sound are 18.3m-27.4m and 27.4m-36.6m. It is worth noting that, between Montauk and Hatteras, the outer boundary of the NEAMAP Survey and the inner boundary of the NEFSC Survey align. Both programs sample in Block Island Sound and Rhode Island Sound.

Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A total of 150 sites are sampled per cruise, except 160 sites were sampled in the spring and fall of 2009 as part of an investigation into the adequacy of the program's stratification approach. A four-seam, three-bridle, 400x12cm bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.0kts. The gear is of the same size as and nearly identical in design to that used by the NEFSC survey, only sweep configuration and trawl door type differ between the two programs. Tow times and tow speeds are consistent between the two programs. The net is outfitted with a 2.54cm knotless nylon liner to retain the early life stages of the various fishes and invertebrates sampled by the trawl. Trawl wingspread, doorspread, headline height, and bottom contact are measured during each tow, and those in which net performance falls outside of defined acceptable ranges are either re-towed or excluded from analyses in an effort to maintain sampling consistency. A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation), atmospheric data, and station identification information are recorded at each sampling site.

Following each tow, the catch is sorted by species and, if appropriate, by size group within a species. Size groups are not predetermined for each species, but rather are defined relative to the size composition of that species for that tow. As such, size designations and ranges of small, medium, and large for a species may vary somewhat between tows. Such an approach facilitates representative subsampling, and therefore proper catch characterization, for each tow.

A subsample of five weakfish is selected from each size group from each tow for full processing. Specifically, individual total length (mm), whole and eviscerated weight (kg), sex, and maturity stage are recorded. Stomachs are removed for diet analysis and otoliths are removed for age determination. For specimens not taken for full processing, aggregate weight and individual total length measurements (mm) are recorded by size group.

While weakfish were sampled during both spring and fall cruises, catches were somewhat less frequent during the spring surveys. Specifically, weakfish have been encountered on 40.0% of tows on average for the spring cruises, with cruise-specific encounter rates ranging from 22.7% to 58.0%. Although a relatively broad size range (75 mm TL to 565 mm TL; age-1 to age-4) of weakfish has been sampled over the course of the NEAMAP spring surveys, individual catches were typically smaller than those in the fall. An average of 300.2 weakfish (s.e. 65.8) were collected per tow in the spring, with 41.2% of tows comprised of five or fewer weakfish. In contrast, weakfish have been encountered on 60.0% of fall tows overall, and this rate has ranged from 49.3% to 71.3% among cruises. The size and age ranges sampled during fall cruises were similar to those seen on spring surveys (44 mm TL to 640 mm TL; age-0 to age-4, respectively), but the fall cruises typically yielded a greater number of weakfish per tow than did the spring surveys, with a mean of 768.3 fish per tow (s.e. 56.8). While 58.8% of spring tows were comprised of greater than five weakfish, 79.8% of fall tows yielded more than 5 specimens, by comparison. Spatially, the percentage of tows in which weakfish were collected by survey region generally increased from north to south for both seasons.

In this survey dataset, nine explanatory variables were recorded. Among these recorded variables, seven are continuous (depth, water temperature, percentage of oxygen saturation, salinity, dissolved oxygen, latitude, and longitude) and two are categorical (year and month). According to the discussion among weakfish SAS and TC, only data collected during fall season were used to conduct catch rate standardization. Because NEAMAP survey crosses a long latitude and alternative habitat types, spatial autocorrelation and nonlinearity can be important, five models that could be used to explore linearity, nonlineariy and spatial autocorrelation were developed and compared to conduct catch rate standardization (details on the methodology can be found in Zhang 2016). These five models were: 1) delta model comprising two generalized linear models (Delta_GLM); 2) delta model comprising two generalized additive models (Delta_GAM); 3) simultaneous autoregressive (SAR) error model combined with auto covariate model; 4) SAR lag model combined with auto covariate model; 5) SAR mixed model combined with auto covariate model. Based on multicollinearity analysis, delta-AIC and cross validation, 6 variables (depth, water temperature, percentage of oxygen saturation, dissolved oxygen, latitude, and year) were selected for Delta-GAM. The models were compared based on AIC and 3-fold cross-validation, and the results indicated that the Delta-GAM yielded much smaller AIC and smallest training error and testing error.

The age-1+ index varies without trend over the time-series (Table 6.1.2, Figure 6.1.15). The age-structure of the index is dominated by age-0 and age-1, with almost no age-4 -6+ fish present in the catch (Figure 6.1.15). The time-series is short for this index, but the WTC felt it was important to include this index in the benchmark, so that it could be used in future updates as the time-series gets longer and it provides important information in areas formerly covered by the NEFSC survey.

6.1.15 Composite Young-of-Year Index

States from Rhode Island through North Carolina conduct trawl surveys for juvenile finfish that capture YOY weakfish, as described above. These surveys are noisy and cover small geographical areas compared to the population range of weakfish. Bayesian hierarchical modeling was used to combine these indices into a single composite index, using the method developed by Conn (2010), that represents the coastwise recruitment dynamics of weakfish.

Conn's (2010) method assumes that all indices are tracking the abundance of recruits, but are also influenced by sampling error and process error (e.g., sampling different components of the coastwide recruit population).

$$\log(U_t) = Normal(\log(\mu_t) + \log(q_{it}), (\sigma_{it}^{p})^2 + (\sigma_{it}^{p})^2)$$

A Bayesian analysis was performed to estimate the true trend in relative abundance of recruits as well as the process error and catchability associated with each survey. The input parameters and priors were chosen to be the same as Conn (2010) and the Atlantic Menhaden assessment (2015) used.

A Normal(log(100), 1) distribution was chosen for $\nu_t = \log(\mu_t)$ The mean of this distribution, log(100), was chosen so that the mean of the relative abundance time series would be approximately 100. This number is arbitrary, since we are interested in the trends in relative abundance, not the actual number.

For catchability, which is assumed constant and estimated in log-space, χ_i was set as χ_i = Normal(log(0.01), 0.5), which gives reasonable support to plausible parameter values.

Finally, for process error, Gelman (2006) suggests that a Uniform(0,m) distribution may outperform other choices when there is a small number of group effects. We specified a Uniform(0, 5) prior distribution for σ^p, which gives equal weight to all plausible precision values.

The observed CVs from the surveys were used as the input sampling error.

The composite YOY generally varied without a strong trend, being below average in the 1980s and most recent years, and above average from 1992-2006 (Table 6.1.3, Figure 6.1.16).

6.2 Fishery Dependent Indices

6.2.1 MRFSS/MRIP Harvest per Unit Effort

In addition to fishery independent survey indices of abundance, the WTC again developed a fishery dependent index from the Marine Recreational Fisheries Statistics Survey (MRFSS). In the past, a MRFSS index was developed based on weakfish catch divided by all private/rental boat trips in state waters of the Mid-Atlantic region (Uphoff 2005). To address a concern that this estimate of effort was too broad, including many trips that had a very low chance of catching weakfish, Brust (2004) refined the analysis by using trips that caught weakfish or any of a suite of five species most commonly caught when weakfish are caught. A comparison of these two methods showed very high correlation between the two methods (Pearson r = 0.96), and the simpler method was retained over the more time intensive method of Brust (2004). A fishery dependent index developed with this methodology was used in several of the models in the 2009 stock assessment.

For the current assessment, the WTC again discussed the need for a more statistically based approach to determine effort (potential weakfish trips) for the calculation of CPUE, such as Stephens and MacCall (2004) and Jaccard (1912). Both methods identify species guilds where observation of any one of those species might signify the presence of the target species, but unlike the method used by Brust (2004), the associations are based on statistical criteria rather than just frequency of occurrence. Species to include in the final weakfish recreational CPUE were identified using the Jaccard index of similarity (Jaccard 1912). Estimation of the similarity coefficient can be summarized as follows.

1) Determine the number of trips (MRFSS intercepts) that caught the target species.
2) Determine which non-target species were caught on trips when the target species was caught.
3) Determine the number of trips (MRFSS intercepts) that caught a given non-target species.
4) Divide the number of trips that caught both the target and non-target species by the number of trips that caught either the target species or the non-target species.

Mathematically, this can be expressed as

$$J = \frac{N_{11}}{N_{10} + N_{01} + N_{11}}$$

where N is the number of trips and the subscripts of 0 and 1 are binary for observation of the target and non-target species. High values of J suggest high correlation between the target and non-target species (*e.g.* habitat utilization), so observation of the non-target species implies presence of the target species even if it is not observed. For the current analysis, species guilds were composed of the target species and the five species with the highest similarity coefficients. Any trip that caught any one of the guild species was considered a potential weakfish trip. Species guilds, and therefore effort estimates, were developed for each state individually to allow development of state-specific CPUE indices. It was assumed that there was no temporal variation in species associations (guild composition) over time for a given state. State specific species guilds and effort (# of intercepts of potential trips) time series are shown in Table 6.2.1 and 6.2.2, respectively. Massachusetts, Rhode Island, and Connecticut had no strong species associations and were dropped from the remainder of the analysis.

For each potential weakfish trip identified through the guild analysis, trip level CPUE was estimated as the weakfish catch divided by the number of anglers contributing to the catch. Because observed (Type A) and unobserved (Type B1 and B2) catch are handled separately by MRFSS and do not necessarily have the same number of anglers associated with the two types of catch on a given trip, it was necessary to develop separate CPUE estimates for observed and unobserved fish and sum them (CPUE = CPUE_A + CPUE_B). Admittedly, this is not ideal, but should not have an overall large effect on the results. Florida was not included in the analysis due to hybridization issues.

Because limited information was available to describe the length frequency (and therefore age distribution) of discarded fish prior to 2004, the WTC decided to use an index of harvested fish only (HPUE) coupled with a selectivity curve as input for the population model. Trip level HPUE was calculated like CPUE above, but using only the A type catch.

Trip specific CPUE (or HPUE) was then modeled in R using a negative binomial GLM. Full models for the positive and binomial components are as follows.

lnCPUE ~ YEAR + AREA + WAVE + STATE + MODE + HRSF
success ~ YEAR + AREA + WAVE + STATE + MODE + HRSF

For each component, the final model included only the factors that explained greater than 5% of the total deviance. For the coastwide model, these were Year, Area, Wave, and State for the positive model, and Year, State, and Mode for the binomial component.

The resulting coastwide index shows a sharp increase in HPUE during the early 1980s, from approximately 0.11 fish per trip in 1982 to 0.70 fish per trip in 1987, followed by a sharp decline in HPUE during the late 1980s into the early 1990s back to around 0.10 fish per trip (Figure 6.2.1). Harvest rates increased again between 1992 and 1997, reaching a peak of 0.30 in 1997, but then began a steady decline for over a decade. By 2009, harvest rates had fallen to below 0.03 fish per trip and have fluctuated without trend around these levels since then.

Recreational CPUE follows a similar pattern to HPUE (Figure 6.2.1). During the 1980s the two trends were nearly identical as there were few management measures and therefore few discarded fish. Implementation of management measures in the early 1990s caused the trends to diverge in scale, but not pattern. CPUE rose to 0.45 fish per trip in 1996 before declining to approximately 0.05 by 2007, remaining relatively steady through the terminal year.

To investigate the spike in CPUE in the mid-1980s, a state-level analysis was conducted using the same methods. State-specific CPUE were then standardized to the time series mean and then a constant added to facilitate juxtaposition (Figure 6.2.2). Results show that the spike in CPUE was driven mainly by the Chesapeake Bay states. Possible causes of the sharp increase could be actual changes in abundance or availability, random error from low sample size, or sampling intensity (*e.g.* targeted add-on interviews). Records of sampling intensity were not available, and there are no other known sources of abundance information for this region and period, so it is unsure whether the spike is real or artifact.

7.0 METHODS

7.1 Bayesian Age-Structured Model

7.1.1 Assessment Model Description

Based on the data available (Figures 7.1.1 and 7.1.2; Tables 7.1.1 and 7.1.2) and questions or concerns on the Atlantic weakfish (*Cynoscion regalis*) fishery (ASMFC 2006; NEFSC 2009), several statistical catch-at-age models to assess the population dynamics were constructed and compared. Four models were used. Among these models, 2 fleets, commercial and recreational catch were separated, selectivies of the 2 fleets were assumed to be age specific, and recreational fishery selectivity was assumed to change in 1996 because of the change in management policy on fishable size. Recreational discards are assumed to have a release mortality of 10%, whereas commercial discards are assumed to have a 100% mortality rate. Because the commercial catch includes both harvest and discards, it was assumed that the implementation of size limits would not have a significant effect on the size composition of total commercial removals, as fish are simply transferred from one disposition to another. The 4 models focused on testing different hypotheses on natural mortality and spatial asynchrony/synchrony reflected in the abundance indices (Jiao et al. 2012; 2016). More specifically: M1) a statistical catch-at-age model (SCA), with constant natural mortality and a stationary catchability equation; M2) a SCA with time-varying natural mortality, following a random walk process that implies a non-stationary population; M3) a SCA, with varying population spatial asynchrony and synchrony over time, with the spatial heterogeneity modeled as a random effect; and M4) a SCA that was a hybrid of models 2 and 3 listed above. The last three models assume that the population dynamics are not stationary. A Bayesian approach was used to estimate parameters, while performance of the models was compared by goodness-of-fit and the retrospective patterns of the models.

7.1.2 Reference Point Model Description

$F_{0.1}$, $F_{40\%}$, F_{MSY}, $SSB_{40\%}$, F_{limit} and SSB_{limit} used in Amendment IV, were assessed and corresponding risks of the population being overfished and overfishing occurring were evaluated.

7.1.3 Assessment Model Configuration

7.1.3.1 Spatial and Temporal Coverage

The model included data from the US Atlantic coast from Massachusetts through Florida, including three offshore surveys and 11 inshore surveys. Data from 1982-2014 were used.

7.1.3.2. Parameterization

Details of the four models including equations are described below.

M1 is a commonly used statistical catch-at-age model. Based on the data structure of weakfish it is written as

$$
\begin{aligned}
& Ln(N_{a+1,y+1}) = Ln(N_{a,y} e^{-\sum_i F_{i,a,y} - M}) \\
& Ln(C_{i,a,y}) = Ln[\frac{F_{i,a,y}}{\sum_i F_{i,a,y} + M} N_{a,y} (1 - e^{-\sum_i F_{i,a,y} - M})] + \varepsilon_{Ci,a,y} \\
& F_{i,a,y} = F_{i,y} S_{i,a} \\
& Ln(I_{j,a,y}) = Ln(q_{j,a} N_{a,y}) + \varepsilon_{j,a,y} \\
& N_{a=1,y} = R_y
\end{aligned}
\quad , \qquad (1)
$$

where a is age; y is year; i is the type of fishery (i=1 indicates commercial fishery; i=2 indicates recreational fishery); j is the jth type of fishery dependent or independent CPUE data I_j; N is population abundance; R is recruitment and is age 1 fish in this case; M is natural mortality which is assumed to be constant, C is observed catch; F is fishing mortality; S is the selectivity which follows a constant vector instead of an equation such as $S_a = \frac{1}{1 - e^{-m(a - s_{50})}}$. Both catch and abundance indices are assumed to follow a lognormal distribution with log-transformed residuals following a normal distributions $\varepsilon_{c,a,y} \sim N(0, \sigma_c^2)$; $\varepsilon_{j,a,y} \sim N(0, \sigma_j^2)$. In this model, M is assumed to be known and fixed at 0.25, for all age groups and years (ASMFC 2006; NEFSC 2009). A constant vector was used to model selectivity, instead of a logistic curve, because the catch-at-age matrix is composed of several types of catch composition, so the selectivity can be less regular than that of a logistic curve or a dome shaped smooth curve. R_y has been found to be highly variable and spawning stock size can often only explain a limited amount of variation of recruitment. So it is assumed that recruitment in year y, R_y, are parameters to be estimated instead of modeled using regulated curves such as Cushing and Beverton-Holt (Ricker 1975; Quinn and Deriso 1999). This approach also avoided the influence of recruitment modeling choices on the nonstationary M models and spatial synchrony/asynchrony in this study.

M2 used a random walk process to model changes in M among years,

$$
\begin{aligned}
& Ln(M_y) = Ln(M_{y-1}) + \varepsilon_{m_y} \\
& Ln(M_{y=1}) = Ln(\bar{M}) + \varepsilon_M \\
& \bar{M} \sim U(b_1, b_2)
\end{aligned}
\quad , \qquad (2)
$$

where M_y is M at year y and M_y follows a random walk process. Log transformed $M_{y=1}$ follows a 2 level distribution with mean $Ln(\bar{M})$ and variance σ_M^2 and $\bar{M}$ further follows a uniform distribution between b1 and b2.

M3, a hierarchical model, is similar to model M1, except that the population size being sampled by the various surveys, $N_{j,a,y}$ was assumed to be different for different survey locations, i.e., $N_{j,a,y}$ was treated as a random effect and was modeled hierarchically, as shown below:

$$\begin{aligned} &Ln(I_{j,a,y}) = Ln(q_{j,a}N_{j,a,y}) + \varepsilon_{j,a,y,2} \\ &N_{j,a,y} \sim Log\text{-}N(Ln(N_{a,y}), \sigma^2_{y,a,N}) \end{aligned} \quad , \qquad (3)$$

where $Log\text{-}N$ refers to the lognormal distribution; variance $\sigma^2_{y,a,N}$ is the variance of log-transformed $N_{a,y}$; $\varepsilon_{j,a,y,2} \sim N(0,\sigma^2_{j,2})$. By modeling $N_{j,a,y}$ using a distribution with median $N_{a,y}$, the possible heterogeneity of the population density in each survey location, $\varepsilon_{j,a,y,N} \sim MVN(0,\sigma^2_{y,a,N})$, is modeled.

M4 is a hybrid of M2 and M3. It uses a random walk process to model the changes of M over time. Also, the population size being sampled by the various surveys, $N_{j,a,y}$ was assumed to be different for different survey locations, i.e., were treated as random effects, and modeled hierarchically. The full model equations can be written as

$$\begin{aligned} &Ln(N_{a+1,y+1}) = Ln(N_{a,y}e^{-\sum_i F_{i,a,y}-M}) \\ &Ln(C_{i,a,y}) = Ln[\frac{F_{i,a,y}}{\sum_i F_{i,a,y}+M}N_{a,y}(1-e^{-\sum_i F_{i,a,y}-M})] + \varepsilon_{Ci,a,y} \\ &F_{i,a,y} = F_{i,y}S_{i,a} \\ &Ln(I_{j,a,y}) = Ln(q_{j,a}N_{j,a,y}) + \varepsilon_{j,a,y,2} \\ &N_{j,a,y} \sim Log\text{-}N(Ln(N_{a,y}), \sigma^2_{y,a,N}) \\ &Ln(M_y) = Ln(M_{y-1}) + \varepsilon_{m_y} \\ &Ln(M_{y=1}) = Ln(\bar{M}) + \varepsilon_M \\ &\bar{M} \sim U(b_1, b_2) \\ &N_{a=1,y} = R_y \end{aligned} \quad . \qquad (4)$$

A Bayesian approach was used to fit the models to data collected from different sources. The Bayesian methods are computationally possible for nonstationary time series models (Calder et al. 2003; Carroll et al. 2006). The Bayesian approach uses a probability rule (Bayes' theorem) to calculate a "posterior distribution" from the observed data and a "prior distribution", which summarizes the prior knowledge of the parameters (Gelman et al. 2004). Because M2, M3 and M4 model either M or $N_{j,a,y}$ hierarchically, the posterior density distribution for parameters also needs hyperpriors (Jiao et al. 2012).

Two types of prior distributions are commonly used in a Bayesian stock assessment: non-informative and informative (Berger 1985; Gelman et al. 2004; Gelman 2006). The choice of a non-informative or informative prior for a parameter was determined by the reliability and details of prior knowledge about the parameter. Prior knowledge of fishery parameters were from different sources, including weakfish fishermen's experience, results derived from previous studies on the weakfish fishery, and knowledge of similar species and fisheries. Most of the priors were consistent with the most recent stock assessment, except parameters on the hypotheses that were tested. Priors on the mean of M that were used in some of the proposed models were based on a literature search, maximum age, life history parameters, empirical equations, knowledge of similar species and other fisheries (Pauly 1980; Hoenig 1983; Peterson and Wroblewski 1984; Roff 1984; Chen and Watanabe 1989; Lorenzen 2005). That is, an informative prior for hyperparameter $\bar{M}$ was used in the hierarchically structured M in the Bayesian estimator. Details of the priors are listed in Table 7.1.2.

Models were compared based on their goodness-of-fits and retrospective patterns. Deviance Information Criterion (DIC) was used which is more appropriate when Bayesian hierarchical modes are used (Spiegelhalter et al. 2002, 2004; Jiao et al. 2008, 2009).

7.1.3.3. Weighting of Likelihoods

The indices were weighted equally once selected based on the discussion during the data workshop and the criteria agreed by the data workshop participants.

7.1.3.4. Sensitivity Analyses

Sensitivity analyses were conducted both to the data scenarios and the model configuration. Sensitivity to prior selection was also analyzed based on previous studies (Jiao et al. 2012).

Six scenarios were selected to explore the sensitivity of the model to input data (Table 7.1.3). This included the base model run, a run with unconverted scale ages, a run with the original, unreconstructed catch-at-age (not split by fleet for 1982-1989), a run using traditional ALKs instead of multinomial keys in the most recent years, a 15% mortality rate on recreational releases, and the inclusion of "unidentified trout" in the catch stream.

Sensitivity to model structure was evaluated through the development of four models to compare hypotheses on natural mortality and spatial asynchrony and synchrony. Jiao et al (2012) compared 4 hypotheses on natural mortality, here we selected the one that was recommended by Jiao et al. (2012) based on the weakfish data through 2007.

7.1.3.5 Retrospective Analyses

Retrospective error has been one of the important issues in fisheries stock assessments (Mohn 1999; Legault 2009). Here, an extra 3-year retrospective analysis was carried out for each model, and the retrospective error was treated as one of the criteria to compare models, with two measurements of retrospective error being used. The first one measures

$$E1_t = (N_t \big|_{\text{data to year } t} - N_t \big|_{\text{data to year } t+1}) / (N_t \big|_{\text{data to year } t+1}),$$

where $N_t \big|_{\text{data to year } t}$ is the estimated population abundance in year *t* when data up to year *t* were used in the model. The second one is based on Mohn (1999), and it is calculated as below when the 3-year retrospective analysis was carried out:

$$E2 = \sum_{t=2014-3}^{2014} \frac{N_t \big|_{\text{data to year } t} - N_t \big|_{\text{data to year 2014}}}{N_t \big|_{\text{data to year } t}}.$$

7.2 Statistical Catch-at-Age Model (ASAP)

7.2.1 Assessment Model Description

As a complement to the Bayesian model, the WSASC also explored the use of a statistical catch-at-age model, ASAP. ASAP is a forward-projecting catch-at-age model programmed in ADMB and developed by NOAA's Northeast Fisheries Science Center. 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 3: ASAP Technical Documentation for more detailed descriptions of model structure and code. ASAP is available for download at http://nft.nefsc.noaa.gov/.

7.2.2 Assessment Model Configuration

7.2.2.1 Spatial and Temporal Coverage

The ASAP model runs used the same catch and index data as the Bayesian model from Massachusetts through Florida, covering the years 1982-2014.

7.2.2.2 Parameterization

The ASAP model was configured similarly to the Bayesian model. The base run used two fleets, commercial and recreational with two selectivity blocks each: 1982-1995, and 1996-2014, split corresponding to when consistent coastwide regulations were implemented. The commercial fleet was assumed to have a dome-shaped selectivity, given the consistent high proportion of catch from gillnets, while the recreational fleet was assumed to have a flat-top selectivity. Both fleets' selectivity patterns were estimated at-age (as opposed to fitting a logistic or double-logistic curve), with selectivity fixed at one for age-4+ in the recreational fleet and at age-3 in the commercial fleet.

Index selectivity was also estimated at-age, and fixed at one for age-1 for indices where the catch was dominated by age-0 and age-1 fish. This was all indices except the MRIP HPUE and the NC Pamlico Sound Gillnet Survey.

7.2.2.3 Weighting of Likelihoods

For total catch and index values, ASAP allows users to specify weights in the form of lambdas (a single multiplier per data set that is applied to the likelihood component) and CVs (annual estimates of precision that are included in the calculation of the likelihood component for a data). Effective sample size is used to provide weight in the calculation of the multinomial likelihood for the catch-at-age and index-at-age values. For the base run, all lambdas were set to one (equal weighting of the datasets).

Additional weighting was provided through the CVs. The calibrated MRIP PSEs were used as CVs on the recreational catch, and the average MRIP PSE for the time-series was used as the CV on commercial catch (CV=0.12).

Annual index CVs were based on the estimated CVs from the data sets, and scaled to average ~0.24-0.30, with less weight being put on the offshore indices to reflect the higher proportion of catch coming from inshore areas.

7.2.2.4 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.

7.2.2.5 Sensitivity Runs

The same set of input data sensitivity runs were used for ASAP as for the Bayesian model. This included the base model run, a run with unconverted scale ages, a run with the original, unreconstructed catch-at-age (not split by fleet for 1982-1989), a run using traditional ALKs instead of multinomial keys in the most recent years, a 15% mortality rate on recreational releases, and the inclusion of “unidentified trout” in the catch stream.

In addition, the effects of individual indices were examined by removing one index at a time, and by subsetting to inshore or offshore indices. The ASAP model was also run with the age-constant time-series of M estimated by the Bayesian model and by the catch-survey analysis as a comparison to the time-constant base model run.

7.2.2.6 Retrospective Analyses

The base model and sensitivity runs were subject to a retrospective analysis that removed successive years of data from the model for 6 years.

7.2.2.7 Projections

Short-term (3 year) and long-term (100 year) projections were run using the NEFSC Toolbox program AGEPRO (v. 4.2) to evaluate the effects of fishing at current F under constant and time-varying M scenarios. The results of the Bayesian model and historical patterns in the AMO were used to develop a hypothetical time-series for time-varying M into the future (Figure 7.2.1), and a hypothetical time-series where the current high M as estimated by the model remains constant in the future (a regime shift scenario).

7.3 Depletion-Based Stock Reduction Analysis (DBSRA)

Modeling of weakfish populations was also investigated using Depletion Based Stock Reduction Analysis (DBSRA) and extended DBSRA (xDBSRA). DBSRA (Dick and MacCall 2011) is a production model used to estimate population parameters and management reference points for data poor stocks. To circumvent the lack of data, the population model is parameterized with distributions of assumed population parameters. The results are distributions of population and management parameters that result from valid combinations of input parameter draws. The extended model (Dick et al in prep) incorporates survey index data, and by doing so is capable of updating the assumed distributions (*i.e.* produces posterior distributions) of both population and management parameters. Both models have been approved for management use by, and are currently being used by, the Pacific Fisheries Management Council (AFSC 2010).

Although the base model was able to converge, it did not appear to be able to adequately characterize the rebuilding period during the 1990s. As a result, population biomass was estimated to start high and decline nearly continuously to low levels by the early 2000s. Incorporation of index data in the extended model was not able to improve the estimates, likely due to the high variability and lack of clear trends among the indices.

By this point, it was evident that we were getting credible runs from both ASAP and the Bayesian model, so further investigation with xDBSRA was discontinued. Future attempts to employ xDBSRA for weakfish should investigate the age at recruitment to the fishery, stricter constraints on input parameter distributions, time varying natural mortality, and the selection of indices to incorporate into the extended model.

7.4 Continuity Run

In addition to the suite of new models explored for this assessment, the WTC updated the model used in the previous assessment. The Virtual Population Analysis (VPA) was conducted with only updates to the data used in the previous assessment (i.e., no new or recalculated indices), and those results were compared to the ASAP run using the same input dataset as well as the preferred Bayesian age-structured model and the base ASAP model run.

7.4.1 Relative F

The modeling approach approved during the 2009 stock assessment is a rescaled relative analysis, so a continuity run of this method was conducted for the current assessment. Full details of the method are provided in Section 8.0 of NEFSC (2009) and summarized here. Three abundance indices (NJ proportion positive, DE geometric mean, and recreational fishery dependent CPUE) were scaled to the recreational index using the time series mean CPUE of each index. The scaled indices were then averaged to develop a single blended abundance index. Relative F was then found as

$$RelF_t = \frac{Catch_t}{\frac{1}{2}(RelN_t + RelN_{t+1})}$$

Relative F values were then rescaled to instantaneous rates of F using an average scalar between the relative F estimates and F values from a converged portion of the 2009 ADAPT VPA (1982-1985).

Although the overall methodology remained the same for the continuity run, two changes to the input data were necessary. First, it was not possible to replicate the values of the DE or NJ indices used in the 2009 assessment (Figure 7.4.1), although the pattern and scale were generally similar for each respective index. Second, changes were made to how total removals were calculated, which resulted in slightly different trends in removals between the 2009 and 2016 model runs (Figure 7.4.2). The remaining steps of the analysis were consistent with the 2009 run. In particular, the indices were scaled to the recreational index using the years 1982-2007, and the scalar value used to convert relative F to instantaneous F was the same as used in 2009.

7.4.2 Virtual Population Analysis (VPA) Continuity Run

The VPA used in the 2009 assessment was updated with data through 2014. The same indices were used, as were the methods of calculating those indices. The same set of data was also read into ASAP to compare the effects of using ASAP on the 2009 data set.

7.5 Biological Reference Points

The NEFSC Toolbox program Yield-Per-Recruit (v. 3.3) was used to develop SPR reference points ($F_{20\%}$, $F_{30\%}$, and $F_{40\%}$), based on the observed maturity schedule used in the model, the average weight-at-age from the last five years, and a composite selectivity pattern developed from the geometric mean of the last five years of total F-at-age scaled to one. Natural mortality was set equal to the time-series average of the estimates from the Bayesian model (M=0.43).

The SAS considered MSY-based reference points that would require a stock-recruitment relationship. However, since young-of-year indices have not shown the same strong decline that the adult population has, the SAS did not believe a reliable stock-recruitment relationship could be developed. The SAS calculated updated versions of the $SSB_{threshold}$ by using the NEFSC Toolbox program AgePro (v. 4.2.2) to project the population forward under 3 different constant M scenarios (high M = average of the most recent 5 years = 0.93; average M = 0.43, and low M = average of the first 10 years of the time-series = 0.15), as well as a time-varying M scenario. Time-varying M was assumed to be a function of the AMO (based on the fitted relationship between estimated M and the AMO from 1982-2014), and historical patterns in the AMO were used to project M into the future (Figure 7.5.1). Recruitment was assumed independent of SSB and drawn from an empirical distribution of the time-series of model-estimated recruitment.

8.0 RESULTS

8.1 Bayesian Age-Structured Model

8.1.1 Goodness of Fit

Among the 4 models compared, the M4 performed better in both DIC and retrospective errors (Table 8.1.1) for the base case, and also had the lowest DIC across a range of data sensitivity runs (Table 8.1.2). The DIC value of M4 is much lower than the other 3 models, and the retrospective error, both one year retro and Mohn's retrospective error are much smaller than the other 3 models. This suggested that M4 is the most appropriate model and the weakfish population is nonstationary as reflected in M variation over time, and spatial asynchrony.

See Appendix 4 for diagnostic plots and tables for this model.

8.1.2 Selectivity and catchability

According to the age-specific selectivity estimation, commercial fishery selectivity reaches high (near 1) in M1 and remains high across ages 2+ (Figure 8.1.1A). Selectivity estimation of ages 2 and 3 in models 2 and 4 are lower than in M1. Selectivity in the first block of the recreational fishery reaches a high at age 4 in model M1 and remains high, but peaks later for models M2 and M4; all models show a pattern of a decrease in selectivity from age 4 to age 5, followed by an increase or flattening for age 6+ in the second block (Figure 8.1.1B).

8.1.3 Mortality Rates

The estimated fishing mortality rate in 2010s were low in all 4 models. The relative magnitude of F over time among the 4 models were not the same although similar patterns were observed (Table 8.1.3, Figures 8.1.2 A and B).

The natural mortality rates estimated by the preferred model (M4) are shown in Table 8.1.4. The estimated M over time from M2 and M4 showed a similar trend (Figure 8.1.3). M was low in 1980s but increased in mid-1990s and kept high after mid-2000s. The recent 2 years' M tended to decrease slightly.

8.1.4 Population Size

The estimated population size of Atlantic weakfish is low in recent year (Tables 8.1.5 and 8.1.6, Figure 8.1.4). The 4 models all showed a recent decrease but explained the history trend differently. M1 and M2, assuming constant M and a random walk M, showed a large decrease in 1985-1990 but recovered in mid-1990s. M3 and M4, assuming spatial heterogeneity and spatial heterogeneity with a random walk M, also showed a decrease in 1985-1990 but the recovery in mid-1990s is not as significant as in models 1 and 2.

Recruitment in recent years was lower in all model scenarios, but the models with spatial heterogeneity (M3 and M4) showed a more pronounced declining trend over the entire time series (Table 8.1.7, Figure 8.1.5).

8.1.5 Sensitivity Analyses

All the models showed robustness with data scenarios and the results can be seen in Figures 8.1.6 - 8.1.11 and Table 8.1.2. Model 4 always yielded the lowest DIC values among the 6 data scenarios. The estimated population trend/size, F, S and M (if treated as unknown) are consistent among data scenarios (Table 8.1.2). The most noticeable difference in the data sensitivity runs was the difference between the use of multinomial keys (S1) and traditional age-length keys (S4) in the most recent years, with S4 tending to yield lower population size, lower recruitment and higher fishing mortality especially when M3 and M4 were used.

M4 yielded lower DIC value, and lower retrospective errors.

8.1.6 Retrospective Analyses

Retrospective analyses results are in Figures 8.1.12 – 8.1.16 and Table 8.1.1. Model 4 is more robust to retrospective analysis.

8.2 Statistical Catch-at-Age Model (ASAP)

8.2.1 Goodness of Fit

ASAP showed strong patterning in some of the residuals for total catch and index values (Figures 8.2.1 – 8.2.10). ASAP estimated lower catch in the beginning of the time series and higher catch in the later years, especially for the commercial fleet. It also predicted higher index values than observed in the early part of the time-series and lower index values in later years for several indices, most notably the composite young-of-year index.

8.2.2 Selectivity

The selectivity patterns estimated by ASAP for each selectivity block are shown in Figure 8.2.11. The commercial fleet had a slightly higher selectivity on the younger ages and a younger age of full selectivity (age-3 vs. age-4) than the recreational fleet. The model estimated selectivity decreased for both fleets on the younger ages in the second regulatory period, i.e., after the introduction of coastwide minimum size limits, as would be expected.

8.2.3 Fishing Mortality Rates

The fishing mortality rates by fleet estimated by ASAP with constant M are shown in Table 8.2.1 and Figure 8.2.12. Full F averaged 0.68 for the commercial fleet over the first 10 years of the time-series, then declined during the mid to late-1990s. The recreational fleet was relatively steady over that time-period, averaging a full F of 0.22. Model-estimated F began to increase for both fleets in 2000 and showed extreme spikes from 2006-2010 (F=2.43-3.47), despite low catches. Estimated F dropped after 2010.

8.2.4 Population Size

Both total abundance and spawning stock biomass have declined to very low levels since the beginning of the time-series (Tables 8.2.2 and 8.2.3; Figures 8.2.3 and 8.2.14).

Total abundance was approximately 50 million fish at the beginning of the time-series, increased to a high of 81.6 million fish in 1986, and then declined until the early 1990s. Total abundance increased during the mid-1990s but not to the time-series high, reaching 56.2 million fish in 1994, before declining steadily to a time-series low of 3.7 million fish in 2010. Abundance has increased slightly in recent years, and total abundance in 2014 was 6.7 million fish.

Spawning stock biomass followed a similar trend, with declines in the early part of the time-series, from a high of 15,359 MT, followed by a partial recovery in the early 1990s to 10,417 MT in 1997, and then a steady decline to a time-series low of 456 MT in 2010. SSB has also increased slightly since 2010, to 1,436 MT in 2014.

8.2.5 Recruitment

Recruitment estimated by the model has declined steadily since the beginning of the time-series (Table 8.2.4, Figure 8.2.15) and replicates the trends in N and SSB. Recruitment peaked in 1986 at 48.2 million age-1 fish then declined. Recruitment in recent years has been variable but low, ranging from 4.1 million age-1 fish in 2008 to a time-series low of 1.9 million fish in 2013. Recruitment in 2014 was estimated at 2.9 million age-1 fish.

Young-of-year indices in contrast have been variable but relatively steady, and the model shows strong patterning in the residuals for the composite YOY index, with the model overestimating the index in the early part of the time-series and underestimating it in the later years.

8.2.6 Sensitivity Analyses

ASAP was somewhat sensitive to whether the scale ages were converted or not, with unconverted scales resulting in lower SSB and higher F and recruitment estimates at the beginning of the time series. However, these differences disappeared by the early 1990s and recent population parameter estimates were very similar (Figure 8.2.16). ASAP was also sensitive to the use of the composite YOY index, producing higher abundance, recruitment, and F estimates at the beginning of the time series and lower estimates at the end of the time series when the composite index was used, instead of all individual YOY indices; estimates of SSB were more similar across the runs, with the exception of the most recent years when the individual YOY indices were more optimistic about the increasing trend in SSB (Figure 8.2.16).

ASAP was not especially sensitive to one index over any other (Figure 8.2.17), but was more sensitive to whether the suite of inshore or offshore indices was used. The offshore index run showed a more optimistic trend than the inshore index run and the base run, with the offshore index run suggesting abundance and SSB were at levels comparable to the period of stock recovery observed in the mid-1990s (Figure 8.2.18).

When ASAP was run with the time-varying estimate of M from the Bayesian model and the modified CSA method, it showed the peak of abundance and biomass in the late 1990s/early 2000s instead of at the beginning of the time series, which is not consistent with the fishery history and the perception of the stock during this time period. Dropping all the offshore indices (NEFSC, NEAMAP, NJ Otter Trawl, and SEAMAP) and changing the MRIP HPUE back into a single time-series with the selectivity linked to the recreational fleet resulted in patterns in the ASAP estimates of N, SSB, and recruitment that were much closer to the trends in the constant M scenario (Figure 8.2.19). The estimates from the constant M model run are not as sensitive to these changes.

The major difference remaining was the trend in F (Figure 8.2.19). The constant M model predicted an increasing trend in F from 1996 forward, with large peaks in the late 2000s, while the time-varying M model showed some peaks in those years but not as extreme and still lower than the beginning of the time-series.

8.2.7 Retrospective Analyses

The constant M runs of ASAP showed a strong retrospective pattern of overestimating SSB and underestimating F since 2008 (Figure 8.2.20). This is consistent with a retrospective bias caused by significantly underestimating M in these years, and the ASAP run with time-varying M showed a less severe pattern (Figure 8.2.21) with a Mohn's rho that was closer to zero, but did not completely resolve the problem.

8.3 Depletion-Based Stock Reduction Analysis (DBSRA)

This model failed to produce credible results. See Section 7.3 Depletion-Based Stock Reduction Analysis for more discussion of the approach.

8.4 Continuity Run

8.4.1 Relative F

Despite the revised input data, the trend in rescaled F is very similar to that estimated in the 2009 stock assessment (Figure 8.4.1). Fishing mortality varies between approximately 0.4 and 0.9 during the 1980s, but declines quickly during the 1990s, dropping below F = 0.2 by 1994. Between 1994 and 2009, F declined slowly from approximately 0.15 to 0.05. A much larger decline occurred between 2009 (F = 0.056) and 2010 (F = 0.022), coincident with implementation of Addendum 4, and has varied without trend around F = 0.025 since then. Rescaled fishing mortality in the terminal years is estimated at F = 0.036.

8.4.2 Virtual Population Analysis (VPA)

The VPA model appeared to struggle with the updated data, resulting in F estimates that were at the bounds. The VPA model estimated higher total abundance, recruitment, and SSB at the beginning of the time-series than the ASAP model with either the 2009 base data or the 2016 base data (Figure 8.4.2). The VPA also showed the peak of abundance, recruitment, and SSB in the mid-1990s, instead of at the beginning of the time-series as the ASAP runs do. However, all three models showed more similar estimates in the last ten years. The VPA and the ASAP with the 2009 base data were slightly more optimistic about trends in N, SSB, and F than the 2016 base model, but all agree that the population is at very low levels compared to the early part of the time-series.

8.5 Biological Reference Points

Attempting to account for changing M simply by changing the M in the reference point calculations leads to the conclusion that under conditions of high M, the target and threshold F values should also be high (Table 8.5.1). This is counterintuitive to conservation-oriented management, which would suggest that when the stock is experiencing high natural mortality, SSB should be protected by reducing fishing pressure.

As a result, the TC chose to use SPR calculations based on the average M observed over the time series, M=0.43. This results in an $F_{target}=F_{30\%SPR}=0.55$ and a $Z_{target}=Z_{30\%SPR}=0.98$. The threshold values were based on 20% SPR, resulting in $F_{threshold}=F_{20\%SPR}=0.93$ and a $Z_{threshold}=Z_{20\%SPR}=1.36$.

The SSB projections indicated that the population will not stabilize at an equilibrium population size under time-varying natural mortality even without fishing pressure (Figure 8.5.1). In addition, the highs the population reaches under low levels of M will not be as high as the level the population reaches under a constant M regime at those same low levels (Figure 8.5.1, Table 8.5.2).

An SSB target does not make sense under these conditions, so the TC recommended only a SSB threshold corresponding to 30% of the SSB attained by the population in the long term under constant average M (M=0.43), resulting in $SSB_{threshold}$ = 6,880 MT.

The difference between the long-term equilibrium SSB assuming a constant, low M=0.15 (the early average of the estimated time-series) and the peak SSB reached by the time-varying M suggests that the range of productivity the stock experiences is a function of both the magnitude and the periodicity of fluctuations in M. However, the time-series of the model is short relative to the AMO, and the current relationship may not hold into the future. This is an important source of uncertainty in the projections used to establish SSB reference points. Similarly, F and Z SPR reference points are sensitive to assumptions about natural mortality and fishery selectivity. Z reference points are also sensitivity to the assumption about whether additional mortality is applied to all ages equally or in a differential pattern. If future patterns in M are different from historical patterns, the reference points calculated here may not be appropriate.

9.0 STOCK STATUS

9.1 Current Overfishing, Overfished/Depleted Definitions

Currently, there is no overfishing definition for weakfish. The SSB target and threshold were set at SSB30% and SSB20%, respectively, such that the target represents a level of SSB that is 30% of an unfished stock. If the stock were to be below the SSB threshold, it would be considered depleted.

9.2 Stock Status Determination

As a result of this assessment, the Weakfish TC recommends new Z and SSB reference points along with a two-stage control rule for evaluating weakfish stock status and management response.

9.2.1 Depleted Status

Under conditions of time-varying natural mortality, there is no long-term stable equilibrium population size, so an SSB target is not informative for management. The Weakfish TC recommends an SSB threshold of $SSB_{30\%}$ = 6,880 MT that is equivalent to 30% of the projected SSB under average natural mortality and no fishing. When SSB is below that threshold, the stock is considered depleted.

SSB in 2014 was 2,548 MT, below the SSB threshold, indicating the stock is depleted (Table 9.2.1, Figure 9.2.1). SSB has been below the threshold for the last 13 years.

9.2.2 Overfishing/Total Mortality Status

The TC recommends the use of total mortality benchmarks to prevent an increase in fishing pressure when F is low but M is high. When Z is below the Z target, F reference points can be used to assess overfishing status.

Z in 2014 was 1.11, above the Z target, but below the Z threshold, indicating total mortality is still high but within acceptable limits (Table 9.2.1, Figure 9.2.2). Z was above the threshold from 2002-2013.

9.2.3 Control Rule for Stock Status and Management Response

The TC recommends a two-stage control rule to evaluate stock status and management response.

When SSB is below that threshold, the stock is considered depleted and management should act to minimize fishing pressure.

When SSB is above the SSB threshold, management should evaluate total mortality rates by comparing current Z relative to the Z target and threshold, $Z_{SPR30\%} = 0.98$ and $Z_{SPR20\%} = 1.36$, respectively. If Z is above the $Z_{SPR20\%}$ threshold, then management should continue to minimize F. If Z is above the $Z_{SPR30\%}$ target but below $Z_{SPR20\%}$, then a limited increased fishing pressure would be allowed, assuming the stock is in a period of rebuilding. If Z is below $Z_{SPR30\%}$ target, then fishing will be managed with standard F reference points ($F_{SPR30\%} = 0.55$ and $F_{SPR20\%} = 0.93$ with M=0.43). Overfishing status will be determined relative to the F reference points when SSB is above the threshold and Z is below the threshold.

The TC recommends that SSB be above the threshold and Z be below the threshold for more than one year before management changes are implemented.

9.3 Uncertainty

The preferred model indicates some positive signs in the weakfish stock in the most recent year, with an increase in SSB and a decrease in Z and M. However, the stock is still well below the SSB threshold, and Z has only been below the threshold for one year. Given the retrospective pattern observed, which is not severe but is in a negative direction, with SSB being overestimated and F and Z being underestimated in the terminal year, the most recent positive trends may be overly optimistic. Caution should be used when interpreting the status of the stock.

Additionally, there is uncertainty in the calculation of the reference points, due to uncertainty in the inputs, but also uncertainty in the future patterns of natural mortality in the stock.

10.0 RESEARCH RECOMMENDATIONS

Fishery-Dependent Priorities

High

- Increase observer coverage to identify the magnitude of discards for all commercial gear types from both directed and non-directed fisheries.[1]

Moderate

- Continue studies on temperature, size, and depth specific recreational hook and release mortality rates, particularly catches from warm, deep waters. Investigate methods to increase survival of released fish.
- Continue studies on mesh size selectivity, particularly trawl fisheries.[2]
- Improve methods to estimate commercial bycatch. Refine estimates of discard mortality based on factors such as distance from shore and other geographical differences for all sizes including below minimum size.

Low

- Determine the onshore versus offshore components of the weakfish fishery.
- Collect catch and effort data including size and age composition of the catch, determine stock mortality throughout the range, and define gear characteristics. In particular, increase length frequency sampling in fisheries from Maryland and further north.
- Develop latitudinal, seasonal, and gear specific age length keys coast wide. Increase sample sizes for gear specific keys.

Modeling / Quantitative Priorities

High

- Evaluate predation of weakfish with a more advanced multispecies model (e.g., the ASMFC MSVPA or Ecopath with Ecosim).
- Develop a bioenergetics model that encompasses a broader range of ages than Hartman and Brandt (1995) and use it to evaluate diet and growth data.

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[1] Some Mid-Atlantic trawl fleet observer coverage has been implemented under ACCSP funding.

[2] Gillnet selectivity has been investigated by Swihart et al (2000). Some gear selectivity information in Amendment 3 to the ASMFC Weakfish FMP. Information can also be obtained from the North Carolina Pamlico Sound Independent Gill Net Survey.

- Analyze the spawner-recruit relationship and examine the effects of the relationship between adult stock size and environmental factors on year class strength.
-

Life History, Biological, and Habitat Priorities

High

- Develop a coastwide tagging program to identify stocks and determine migration, stock mixing, and characteristics of stocks in over wintering grounds. Determine the relationship between migratory aspects and the observed trend in weight at age.[3]
- Monitor weakfish diets over a broad regional and spatial scale.
- Continue to investigate the geographical extent of weakfish hybridization.

Moderate

- Identify and delineate weakfish spawning habitat locations and environmental preferences to quantify spawning habitat.
- Compile data on larval and juvenile distribution from existing databases to obtain preliminary indications of spawning and nursery habitat location and extant.
- Examine geographical and temporal differences in growth rate (length and weight at age).
- Determine the impact of power plants and other water intakes on larval, post larval, and juvenile weakfish mortality in spawning and nursery areas. Calculate the resulting impact on adult stock size.[4]
- Monitor predation on weakfish from both fish and marine mammal species.

Management, Law Enforcement, and Socioeconomic Priorities

Moderate

- Assemble socioeconomic data as it becomes available from ACCSP.

Low

- Define restrictions necessary for implementation of projects in spawning and over wintering areas and develop policies on limiting development projects seasonally or spatially.

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[3] Tagging work to evaluate mortality, movement, stock mixing, and weakfish predator information is scheduled to begin in North Carolina in 2013. Otolith samples have been obtained by Old Dominion University, but funding has not been available for processing.

[4] Data are available for power plants in the Delaware Bay area and North Carolina. Also see Heimbuch et al. 2007. Assessing coastwide effects of power plant entrainment and impingement on fish populations: Atlantic menhaden example. *North American Journal of Fisheries Management*. 27: 569-577.

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12.0 TABLES

Table 1.4.1. Summary of the model runs used in the historical retrospective analysis.

Year	Assessment model	Review type	Notes
1998	XSA with shrinkage	Benchmark, SAW 26	F uses age 4-6
2002	ADAPT run	Update, D Kahn	F uses age 4-5
2006 continuity	ADAPT, uses YOY plus DE, NEFSC, NJ, SEAMAP	Benchmark, ASMFC external, did not pass	F uses age 4-5
2006 final	ADAPT, uses only the MRFSS index, no YOY, no trawl	Benchmark, ASMFC external, did not pass	F uses age 4-5
2009	Rescaled relative F model	Benchmark, SAW 48, passed	F is numbers weighted, biomass is all B not just SSB

Table 2.3.1. Annual weight-at-age (kg) of weakfish.Values from 1982-2000 are from the 2009 assessment; the observed weight-at-age from all data sources combined was used for 2001-2014. Years with no age-weight combinations observed (mainly the older ages in the most recent years) used the long-term average weight-at-age.

	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
1982	0.095	0.212	0.307	0.483	1.076	3.033
1983	0.070	0.190	0.368	0.885	1.395	2.862
1984	0.086	0.189	0.379	0.758	1.583	2.536
1985	0.069	0.267	0.579	1.235	1.748	3.055
1986	0.137	0.262	0.758	1.759	2.819	3.173
1987	0.078	0.236	0.524	1.234	2.127	2.536
1988	0.081	0.179	0.398	0.796	1.494	3.026
1989	0.098	0.186	0.383	0.769	1.417	3.348
1990	0.100	0.180	0.540	1.040	1.580	2.390
1991	0.110	0.310	0.680	1.120	1.600	2.330
1992	0.090	0.260	0.600	1.020	1.480	2.190
1993	0.080	0.180	0.360	0.590	0.860	1.330
1994	0.120	0.230	0.410	0.630	0.890	1.320
1995	0.110	0.190	0.310	0.460	0.630	0.940
1996	0.100	0.190	0.320	0.490	0.680	1.020
1997	0.190	0.280	0.410	0.570	0.740	1.030
1998	0.120	0.210	0.350	0.520	0.710	1.040
1999	0.110	0.210	0.390	0.620	0.870	1.310
2000	0.110	0.210	0.390	0.620	0.870	1.310
2001	0.097	0.326	0.484	0.840	1.424	3.193
2002	0.150	0.267	0.460	0.522	1.367	2.894
2003	0.117	0.306	0.506	1.045	2.262	3.250
2004	0.113	0.260	0.469	1.116	2.451	4.304
2005	0.104	0.244	0.421	0.667	2.142	4.126
2006	0.185	0.321	0.548	0.768	0.970	4.463
2007	0.194	0.462	1.264	1.208	1.318	5.171
2008	0.202	0.437	0.669	2.405	2.813	6.516
2009	0.178	0.293	1.324	3.183	4.689	5.900
2010	0.123	0.394	0.670	1.072	1.740	2.843
2011	0.105	0.286	0.563	0.793	1.577	2.843
2012	0.139	0.301	0.582	0.759	1.577	2.843
2013	0.117	0.191	0.339	0.432	1.577	2.843
2014	0.107	0.212	0.341	0.235	1.577	2.843

Table 2.5.1. Constant M coastwide estimator methods evaluating by the Weakfish Technical Committee.

Alverson and Carney 1975	$M = 3K/(\exp[0.38*K*t_{max}) - 1]$
Rikhter and Efanov 1977	$M = [1.521/(a_{50}^{0.720})] - 0.155$
Gunderson 1980	$M = -0.370 + 4.64GI$
Pauly 1980	$M = \exp[-0.0152 + 0.6543*\ln(K) - 0.279*\ln(L_{inf}/10) + 0.4634*\ln(Temp)]$
Hoenig 1983 (regression)	$M = \exp[1.44 - 0.982*\ln(t_{max})]$
Hoenig 1983 (rule of thumb)	$M=-\ln(P)/t_{max}$
Roff 1984	$M = 3*K/[\exp(t_{max}*K) - 1]$
Ralston 1987	$M = 0.0189 + 2.06*K$
Gunderson and Dygert 1988	$M = 0.03 + 1.68*GI$
Charnov and Berrigan 1990	$M = 2.2/t_{max}$
Jensen 1996	$M = 1.65*t_{max}$
Gunderson 1997	$M = 1.79*GI$
Hewitt and Hoenig 2005	$M = 4.22/t_{max}$
Then et al 2015 (Updated Tmax estimator)	$M = 5.109/t_{max}$
Then et al 2015 (Updated Hoenig 1983)	$M = \exp[1.717-1.01*\ln(t_{max})]$

Table 2.5.2. Longevity-based natural mortality estimators examined for this assessment with preferred estimators in bold font. Results based on maximum age (t_{max}) of 15 from 67,011 age records collected during 1982 – 2014.

Coastwide – All Years		
Estimators	M	Equation
Rule-of-thumb (P = 0.05)	0.20	$M = -\ln(P)/t_{max}$
Rule-of-thumb (P = 0.015)	0.28	
Hewitt and Hoenig 2005	**0.28**	**$M = 4.22/t_{max}$**
Updated One Parameter t_{max} estimator (Then et al. 2015)	**0.34**	**$M = 5.109/t_{max}$**
Hoenig 1983 (regression)	**0.30**	**$M = \exp[1.44 - 0.982*\ln(t_{max})]$**
Updated Hoenig 1983 (Then et al. 2015)	**0.36**	**$M = \exp[1.717 - 1.01*\ln(t_{max})]$**
Updated Hoenig Non-linear Least Squares (Then et al. 2015)	**0.41**	**$M = 4.899*t_{max}^{-0.916}$**
Charnov and Berrigan 1990	0.15	$M = 2.2/t_{max}$
Jensen's First 1996	0.11	$M = 1.65/t_{max}$

Table 2.5.3. Estimated annual M from the modified Catch Survey Analysis method.

YEAR	NJ	DE	SEAMAP	REC	PSIGNS	NMFS	NEAMAP	CHESMAP	AVERAGE
1995	0.59	0.00	0.00	0.00	--	0.90	--	--	**0.30**
1996	1.55	0.57	0.00	0.00	--	0.00	--	--	**0.42**
1997	0.18	0.00	0.00	0.00	--	0.50	--	--	**0.14**
1998	0.00	0.00	0.00	0.00	--	0.00	--	--	**0.00**
1999	0.00	0.00	0.77	0.00	--	0.00	--	--	**0.15**
2000	0.00	0.74	0.80	0.38	--	0.00	--	--	**0.38**
2001	1.77	0.00	0.73	0.44	--	0.00	--	--	**0.59**
2002	0.00	0.84	0.00	0.60	0.28	0.00	--	--	**0.29**
2003	0.82	0.72	0.96	0.91	0.93	0.00	--	0.07	**0.63**
2004	0.00	0.85	0.00	0.82	0.65	1.12	--	0.00	**0.49**
2005	0.68	0.00	0.00	1.26	0.91	0.37	--	1.46	**0.67**
2006	1.76	0.90	0.56	0.95	0.54	0.00	--	0.27	**0.71**
2007	0.28	0.65	1.71	1.65	1.74	1.49	--	1.18	**1.24**
2008	0.00	0.61	0.28	1.46	0.86	0.00	0.00	1.00	**0.52**
2009	1.04	0.34	0.15	1.41	1.45	0.00	2.39	1.79	**1.07**
2010	0.00	0.07	0.31	2.35	1.64	--	1.21	2.01	**1.08**
2011	0.00	0.59	1.49	1.63	1.74	--	1.06	1.14	**1.09**
2012	0.86	0.97	0.00	1.76	0.61	--	0.21	1.68	**0.87**
2013	1.92	1.12	1.25	1.91	1.29	--	2.04	2.91	**1.78**
SLOPE	0.02	0.04	0.04	0.13	0.07	0.01	0.10	0.22	**0.07**

Table 4.1.1 Commercial landings (MT) by state, 1950-2014.

Year	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	Grand Total
1950	0.3	1.7	0.4	64.5	491	260.1	268.7	1819.3	711	0.3		4.9	3622.2
1951		0.5	0.8	69	891.3	302.2	105.7	897.5	572.8			36.6	2876.4
1952		0.9	1.6	75.7	987.3	127.5	127.4	684.3	737.4			19.3	2761.4
1953		7.7	3.1	49	980.8	331.9	114.2	922	860.5			9	3278.2
1954		3.7	1.5	57.6	908.4	167.4	119.2	962.6	1080.1			26.7	3327.2
1955	0.1	2.4	2.9	93.2	851.4	716.3	186.8	1737.6	615		0.6	6.8	4213.1
1956		5.2	4.8	95.5	908	434.5	216.3	1478	835.7		0.6	3.1	3981.7
1957		10.5	10	90.4	918.5	581.5	154.3	915.9	1002.6	4.9		8.6	3697.2
1958		4.2	1.1	39.7	247.8	147.2	94.8	710.6	1728.3	2.7		13	2989.4
1959		0.6	0.5	20.3	168.9	82.4	49.6	309.1	1321.2	3		15.2	1970.8
1960		1	0.4	40.3	238.6	3.5	122.9	367.3	1016.2	5.9		24.4	1820.5
1961		0.5	1	24.3	189.6	60.8	126.5	541.3	1046.8	11.2		25.9	2027.9
1962		3	2.2	21.6	294.8	64.6	87.7	675.5	980	5.2		11.6	2146.2
1963		1	0.3	38.9	151	67	42.8	498.1	798.7	2.8	0	32.6	1633.2
1964		0.6	0.1	25.4	247.3	57.8	78	722.5	891.6	3.1		48.7	2075.1
1965		1.6	0.2	33.1	270.5	100.2	112.4	910.3	888.8	10.5	0.8	135	2463.4
1966		0.3		11.8	156.2	40.6	67.9	471.9	860.2	13.2	0.6	83.3	1706
1967		0.9		13.6	206.7	3.4	38.6	272.3	802.3	1.2	0.1	57.9	1397
1968		1.2		28.7	241.3	2	69.5	508.1	1036.7	0.3	0.2	99.3	1987.3
1969		6.1		52.8	844.8	9.7	79.3	394.7	698.1	2.5	0.2	65.1	2153.3
1970		9.7	0.4	134.2	889.6	66.7	146.2	971.5	1107.3	1.8	0.1	132.6	3460.1
1971	0	83	7.8	580.4	1405.7	96.6	185.1	1058	1653.2			65.6	5135.4
1972	1.5	81.6	0.2	829	1441.8	184.3	142.2	1186.6	3344.2	0		79.5	7290.9
1973	1.3	80.6	3.2	575.8	1162.3	151.5	244.8	2313	2822.1	0.9	0.1	93.7	7449.3
1974	22.3	207.7	6.4	647.2	1218.5	127.4	186	1389.5	2747.1	0.8		58.5	6611.4
1975	12.1	211.6		620.4	1982.4	131.5	402.2	1855.2	3050.6	0.9	1	51.2	8319.1
1976	5.9	147.9	5.9	610.3	2589.7	111.6	197.9	1803.4	3952.4	0.5		40.3	9465.8
1977	6.4	148.6	3.3	774.8	1461.3	150.6	100.6	1962.8	3933.4		0.4	43	8585.2
1978	11.2	114.9	8	748.4	1753.4	135.8	237.8	1765.8	4921.2		0.1	54.3	9750.9
1979	15.8	189.4	15.3	685.6	2957	211.8	304.5	2821.9	6694.7	0.6	0.5	49.6	13946.7
1980	14.3	105	4.3	722.9	2220.8	821.8	257.7	2831.3	9228	5.9	0.1	100.3	16312.4
1981	18.1	109.8	12.4	615.9	1701.1	477	153.5	1121.2	7662.9		0.2	86.3	11958.4
1982	10.4	80.2	11.6	570.2	940.5	587.2	113	974.9	5466.9	0.2	0.3	79.9	8835.3
1983	3.1	74.3	19.4	385.6	985.5	409.1	176.9	1176.1	4642		1.2	53.4	7926.6
1984	2.2	76	14.2	219.8	1248.1	354.9	147.4	956.6	5892.6		0.4	57.1	8969.3
1985	1.4	74	12.8	175.2	1374.4	449.4	143.4	944.5	4454.9		0	60	7690
1986	2.6	57.9	6.2	163.2	1455.4	328.2	152.7	904.5	6490.7		0	49.3	9610.7
1987	0.8	35.7	13.4	149.3	949.9	262.1	166.4	890.3	5220.2		0.1	55.8	7744
1988	1.7	8.8	1.1	56.5	1058.2	240.7	377.7	668.2	6845.6			52.2	9310.7
1989	0.9	4.4	1	46.9	661.6	240.5	337.4	465	4588.5	0.1		77.7	6424
1990	0.8	11.2	0.6	9	439.2	278.1	300.4	547.7	2631.8		0	62.2	4281
1991	0.9	11.3	9.7	50.6	532.6	225.6	148.9	480.7	2408			74.8	3943.1
1992	1.4	13.7	1.6	76.2	426.7	164.4	174.8	249.5	2205.6			67.1	3381
1993	0.5	4.5	0.7	40.1	378.5	88.3	82.5	493.5	1954.7			65.5	3108.8
1994		8.2	5	45.1	315.4	118.8	63.9	587.1	1583			81.5	2808
1995	0.2	23.9	2.9	78.2	393.4	127.6	31.5	673.6	1865.8			22.8	3219.9

Table 4.1.1 cont.

1996	0	19.7	3.1	165.7	372.9		60.2	719.9	1804.3			2	3147.8
1997	0	14.1	5	152.7	470.1	253.5	87.4	706.7	1615.3			5.3	3310.1
1998	0.2	35	6.6	225.2	818.6	250.7	110.9	845.5	1521.4			6.8	3820.9
1999	1.2	57.3	10.1	222.2	585.7	199.7	101.4	759.3	1187.3			7.9	3132.1
2000	0.2	85.9	3.6	160	486	149.1	94.5	618.2	847.8			4.3	2449.6
2001	0.1	49.7	3.1	262.5	379.9	85.1	84.3	508.9	889.2			4.9	2267.7
2002	0.4	55.7	4.6	233.1	391.5	78.4	50.5	518.9	829.3			2.6	2165
2003	0.2	28.7	1.4	65.5	154.3	41.5	21.5	208.4	385			1.2	907.7
2004	0	17.4	2.8	80.9	92.8	23.3		161.9	310.9			1.2	691.2
2005		18.9	2.8	49.8	29.2	32.1	16.2	176.9	191.2			3.3	520.4
2006	3.9	20.2	3.2	69.3	93.7	15.6	23.2	85.2	164.6			2.7	481.6
2007	0	9.3	0.9	39.3	74.6	11.2	10.1	183.2	79.7			4.8	413.1
2008	0.2	4.4	0.5	20.1	25.8	4.8	0.8	75	77.3			3.8	212.7
2009	0	2.9	0.2	46.1	14.6	1.3	2	29.8	74			2.9	173.8
2010	0.3	2.4	0.4	5.9	5.5	1	0.3	28	48.2			1.4	93.4
2011	0.3	2.6	1	7.8	6	0.4	0.1	11.9	29.9			6	66
2012	1.5	8.1	2.1	28.6	8.8	13.1	0.1	20.7	41.5			14.9	139.4
2013	0.4	14.4	2.7	49.3	6.7	3.9	0.1	24.8	54.5			5	161.8
2014	2.7	7	1.5	14.9	3.9	1.8	1	10.2	47.7			2.2	92.9

Table 4.1.2. Percent of commercial landings by state.

Year	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL
1950	0.01%	0.05%	0.01%	1.78%	13.56%	7.18%	7.42%	50.23%	19.63%	0.01%	0.00%	0.14%
1951	0.00%	0.02%	0.03%	2.40%	30.99%	10.51%	3.67%	31.20%	19.91%	0.00%	0.00%	1.27%
1952	0.00%	0.03%	0.06%	2.74%	35.75%	4.62%	4.61%	24.78%	26.70%	0.00%	0.00%	0.70%
1953	0.00%	0.23%	0.09%	1.49%	29.92%	10.12%	3.48%	28.13%	26.25%	0.00%	0.00%	0.27%
1954	0.00%	0.11%	0.05%	1.73%	27.30%	5.03%	3.58%	28.93%	32.46%	0.00%	0.00%	0.80%
1955	0.00%	0.06%	0.07%	2.21%	20.21%	17.00%	4.43%	41.24%	14.60%	0.00%	0.01%	0.16%
1956	0.00%	0.13%	0.12%	2.40%	22.80%	10.91%	5.43%	37.12%	20.99%	0.00%	0.02%	0.08%
1957	0.00%	0.28%	0.27%	2.45%	24.84%	15.73%	4.17%	24.77%	27.12%	0.13%	0.00%	0.23%
1958	0.00%	0.14%	0.04%	1.33%	8.29%	4.92%	3.17%	23.77%	57.81%	0.09%	0.00%	0.43%
1959	0.00%	0.03%	0.03%	1.03%	8.57%	4.18%	2.52%	15.68%	67.04%	0.15%	0.00%	0.77%
1960	0.00%	0.05%	0.02%	2.21%	13.11%	0.19%	6.75%	20.18%	55.82%	0.32%	0.00%	1.34%
1961	0.00%	0.02%	0.05%	1.20%	9.35%	3.00%	6.24%	26.69%	51.62%	0.55%	0.00%	1.28%
1962	0.00%	0.14%	0.10%	1.01%	13.74%	3.01%	4.09%	31.47%	45.66%	0.24%	0.00%	0.54%
1963	0.00%	0.06%	0.02%	2.38%	9.25%	4.10%	2.62%	30.50%	48.90%	0.17%	0.00%	2.00%
1964	0.00%	0.03%	0.00%	1.22%	11.92%	2.79%	3.76%	34.82%	42.97%	0.15%	0.00%	2.35%
1965	0.00%	0.06%	0.01%	1.34%	10.98%	4.07%	4.56%	36.95%	36.08%	0.43%	0.03%	5.48%
1966	0.00%	0.02%	0.00%	0.69%	9.16%	2.38%	3.98%	27.66%	50.42%	0.77%	0.04%	4.88%
1967	0.00%	0.06%	0.00%	0.97%	14.80%	0.24%	2.76%	19.49%	57.43%	0.09%	0.01%	4.14%
1968	0.00%	0.06%	0.00%	1.44%	12.14%	0.10%	3.50%	25.57%	52.17%	0.02%	0.01%	5.00%
1969	0.00%	0.28%	0.00%	2.45%	39.23%	0.45%	3.68%	18.33%	32.42%	0.12%	0.01%	3.02%
1970	0.00%	0.28%	0.01%	3.88%	25.71%	1.93%	4.23%	28.08%	32.00%	0.05%	0.00%	3.83%
1971	0.00%	1.62%	0.15%	11.30%	27.37%	1.88%	3.60%	20.60%	32.19%	0.00%	0.00%	1.28%
1972	0.02%	1.12%	0.00%	11.37%	19.78%	2.53%	1.95%	16.28%	45.87%	0.00%	0.00%	1.09%
1973	0.02%	1.08%	0.04%	7.73%	15.60%	2.03%	3.29%	31.05%	37.88%	0.01%	0.00%	1.26%
1974	0.34%	3.14%	0.10%	9.79%	18.43%	1.93%	2.81%	21.02%	41.55%	0.01%	0.00%	0.88%
1975	0.15%	2.54%	0.00%	7.46%	23.83%	1.58%	4.83%	22.30%	36.67%	0.01%	0.01%	0.62%
1976	0.06%	1.56%	0.06%	6.45%	27.36%	1.18%	2.09%	19.05%	41.75%	0.01%	0.00%	0.43%
1977	0.07%	1.73%	0.04%	9.02%	17.02%	1.75%	1.17%	22.86%	45.82%	0.00%	0.00%	0.50%
1978	0.11%	1.18%	0.08%	7.68%	17.98%	1.39%	2.44%	18.11%	50.47%	0.00%	0.00%	0.56%
1979	0.11%	1.36%	0.11%	4.92%	21.20%	1.52%	2.18%	20.23%	48.00%	0.00%	0.00%	0.36%
1980	0.09%	0.64%	0.03%	4.43%	13.61%	5.04%	1.58%	17.36%	56.57%	0.04%	0.00%	0.61%
1981	0.15%	0.92%	0.10%	5.15%	14.23%	3.99%	1.28%	9.38%	64.08%	0.00%	0.00%	0.72%
1982	0.12%	0.91%	0.13%	6.45%	10.64%	6.65%	1.28%	11.03%	61.88%	0.00%	0.00%	0.90%
1983	0.04%	0.94%	0.24%	4.86%	12.43%	5.16%	2.23%	14.84%	58.56%	0.00%	0.02%	0.67%
1984	0.02%	0.85%	0.16%	2.45%	13.92%	3.96%	1.64%	10.67%	65.70%	0.00%	0.00%	0.64%
1985	0.02%	0.96%	0.17%	2.28%	17.87%	5.84%	1.86%	12.28%	57.93%	0.00%	0.00%	0.78%
1986	0.03%	0.60%	0.06%	1.70%	15.14%	3.41%	1.59%	9.41%	67.54%	0.00%	0.00%	0.51%
1987	0.01%	0.46%	0.17%	1.93%	12.27%	3.38%	2.15%	11.50%	67.41%	0.00%	0.00%	0.72%
1988	0.02%	0.09%	0.01%	0.61%	11.37%	2.59%	4.06%	7.18%	73.52%	0.00%	0.00%	0.56%
1989	0.01%	0.07%	0.02%	0.73%	10.30%	3.74%	5.25%	7.24%	71.43%	0.00%	0.00%	1.21%
1990	0.02%	0.26%	0.01%	0.21%	10.26%	6.50%	7.02%	12.79%	61.48%	0.00%	0.00%	1.45%
1991	0.02%	0.29%	0.25%	1.28%	13.51%	5.72%	3.78%	12.19%	61.07%	0.00%	0.00%	1.90%
1992	0.04%	0.41%	0.05%	2.25%	12.62%	4.86%	5.17%	7.38%	65.24%	0.00%	0.00%	1.98%
1993	0.02%	0.14%	0.02%	1.29%	12.18%	2.84%	2.65%	15.87%	62.88%	0.00%	0.00%	2.11%
1994	0.00%	0.29%	0.18%	1.61%	11.23%	4.23%	2.28%	20.91%	56.37%	0.00%	0.00%	2.90%
1995	0.01%	0.74%	0.09%	2.43%	12.22%	3.96%	0.98%	20.92%	57.95%	0.00%	0.00%	0.71%
1996	0.00%	0.63%	0.10%	5.26%	11.85%	0.00%	1.91%	22.87%	57.32%	0.00%	0.00%	0.06%
1997	0.00%	0.43%	0.15%	4.61%	14.20%	7.66%	2.64%	21.35%	48.80%	0.00%	0.00%	0.16%
1998	0.01%	0.92%	0.17%	5.89%	21.42%	6.56%	2.90%	22.13%	39.82%	0.00%	0.00%	0.18%
1999	0.04%	1.83%	0.32%	7.09%	18.70%	6.38%	3.24%	24.24%	37.91%	0.00%	0.00%	0.25%
2000	0.01%	3.51%	0.15%	6.53%	19.84%	6.09%	3.86%	25.24%	34.61%	0.00%	0.00%	0.18%
2001	0.00%	2.19%	0.14%	11.58%	16.75%	3.75%	3.72%	22.44%	39.21%	0.00%	0.00%	0.22%
2002	0.02%	2.57%	0.21%	10.77%	18.08%	3.62%	2.33%	23.97%	38.30%	0.00%	0.00%	0.12%
2003	0.02%	3.16%	0.15%	7.22%	17.00%	4.57%	2.37%	22.96%	42.41%	0.00%	0.00%	0.13%
2004	0.00%	2.52%	0.41%	11.70%	13.43%	3.37%	0.00%	23.42%	44.98%	0.00%	0.00%	0.17%
2005	0.00%	3.63%	0.54%	9.57%	5.61%	6.17%	3.11%	33.99%	36.74%	0.00%	0.00%	0.63%
2006	0.81%	4.19%	0.66%	14.39%	19.46%	3.24%	4.82%	17.69%	34.18%	0.00%	0.00%	0.56%
2007	0.00%	2.25%	0.22%	9.51%	18.06%	2.71%	2.44%	44.35%	19.29%	0.00%	0.00%	1.16%
2008	0.09%	2.07%	0.24%	9.45%	12.13%	2.26%	0.38%	35.26%	36.34%	0.00%	0.00%	1.79%
2009	0.00%	1.67%	0.12%	26.52%	8.40%	0.75%	1.15%	17.15%	42.58%	0.00%	0.00%	1.67%
2010	0.32%	2.57%	0.43%	6.32%	5.89%	1.07%	0.32%	29.98%	51.61%	0.00%	0.00%	1.50%
2011	0.45%	3.94%	1.52%	11.82%	9.09%	0.61%	0.15%	18.03%	45.30%	0.00%	0.00%	9.09%
2012	1.08%	5.81%	1.51%	20.52%	6.31%	9.40%	0.07%	14.85%	29.77%	0.00%	0.00%	10.69%
2013	0.25%	8.90%	1.67%	30.47%	4.14%	2.41%	0.06%	15.33%	33.68%	0.00%	0.00%	3.09%
2014	2.91%	7.53%	1.61%	16.04%	4.20%	1.94%	1.08%	10.98%	51.35%	0.00%	0.00%	2.37%

Table 4.1.3 Annual estimates of commercial discards (MT).

Year	Commercial Discards (MT)
1982	202.1
1983	252.4
1984	211.2
1985	258.7
1986	263.5
1987	177.0
1988	200.5
1989	155.9
1990	509.5
1991	383.6
1992	375.3
1993	294.5
1994	274.7
1995	313.9
1996	450.9
1997	236.0
1998	236.8
1999	182.4
2000	158.6
2001	161.9
2002	151.5
2003	124.3
2004	38.7
2005	30.0
2006	63.9
2007	96.2
2008	62.5
2009	58.7
2010	49.1
2011	53.3
2012	35.3
2013	20.1
2014	50.5

Table 4.2.1. Recreational harvest (in numbers of fish) from 1982-2014.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	RI	MA	Total
1982			17,342	200,045	715,892	440,146	213,937	104,066	88,234	11,769	18,614		1,810,045
1983	11,012	17,209	6,807	387,871	354,846	595,286	996,589	2,857,093	36,934	6,363	74,608	2,732	5,347,350
1984	18,529		7,836	489,468	782,848	104,057	541,392	1,026,043	20,133	1,561	0	2,237	2,994,104
1985	1,364	4,811	61,788	217,671	505,223	305,799	330,854	812,839	89,538	2,874	17,092	0	2,349,853
1986	4,853	18,130	78,315	611,363	2,418,046	1,947,394	732,537	2,500,622	34,582	7,315	4,595	0	8,357,752
1987	2,412	10,802	18,841	624,160	1,015,413	824,883	534,597	1,666,619	7,447	777	0	0	4,705,951
1988	3,586	0	1,834	438,148	2,297,053	1,163,766	771,996	642,032	13,215	0	0	0	5,331,630
1989	5,327	8,245	6,810	190,193	357,864	226,505	215,454	303,289	6,436		0	0	1,320,123
1990	2,778	2,273	8,027	91,300	286,458	370,528	144,132	216,385	3,057		407	0	1,125,345
1991	5,018	4,954	19,616	140,826	351,947	221,242	314,620	545,665	28,072	18,695	0	0	1,650,655
1992	3,693	1,751	23,501	35,490	265,645	137,260	97,314	311,659	5,282	434	9,624	0	891,653
1993	8,944	14,752	7,360	106,737	108,392	238,768	216,213	203,915	12,610	2,460	0	0	920,151
1994	9,994	718	46,858	177,965	169,740	332,846	258,478	591,571	1,872	0	0	0	1,590,042
1995	2,167	22,437	29,897	62,475	226,682	88,695	375,548	671,850	22,310	0	1,568	0	1,503,629
1996	1,576	5,413	5,695	90,704	193,861	183,408	573,706	1,104,251	16,320	0	0	0	2,174,934
1997	4,295	44,202	2,039	184,954	557,809	162,900	603,618	1,028,334	112,986	517	1,415	0	2,703,069
1998	896	718	15,838	191,181	463,525	290,051	429,678	920,558	21,392	2,183	0	618	2,336,638
1999	2,714	1,679	3,941	127,163	229,209	340,096	211,161	583,883	18,347	1,606	2,296	0	1,522,095
2000	3,276	4,181	5,585	71,247	286,752	475,348	253,073	760,279	42,406	7,342	712	0	1,910,201
2001	1,542	3,316		158,605	175,872	302,719	64,086	736,069	28,126	715	2,301	0	1,473,351
2002	1,842	852	90,245	90,170	178,110	100,467	102,405	492,876	24,962	1,796	1,420	0	1,085,145
2003	774	1,573	4,162	153,753	86,112	41,048	13,998	151,101	9,234	443	109	109	462,416
2004	1,114	9,815	153,589	237,395	158,111	15,832	2,524	228,536	7,596	0	0	0	814,512
2005	1,539	5,764	129,575	163,265	44,088	32,243	14,488	1,008,393	359	0	1,473	0	1,401,187
2006	1,578	3,501	7,123	153,696	43,081	754	5,642	489,440	9,123	0	5,948	0	719,886
2007	961	4,712	71,230	114,332	87,470	6,980	3,072	229,755	7,120	0	0	0	525,632
2008	1,470	5,909	25,794	137,564	27,939	2,000	3,607	298,076	30,543	0	0	0	532,902
2009	2,028	8,664	10,952	81,643	15,523	4,169	5,995	11,928	0	0	0	0	140,902
2010	589	3,113	9,672	50,932	4,303	4,787	31	2,261	3,423	0	0	0	79,111
2011	471	973	4,107	13,464	4,374	237	27	3,003	111	0	0	0	26,767
2012	988	4,603	13,593	40,299	21,791	11,401	4,139	114,330	5,055	0	0	0	216,199
2013	2,086	1,080	13,314	142,857	2,246	1,834	5,662	30,697	7,003	0	331	0	207,110
2014	905	3,377	11,065	26,308	9,084	1,062	3,295	6,520	644	0	0	0	62,260

Table 4.2.2: Percent of recreational harvest caught by each state between 1982 and 2014.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	RI	MA
1982	0%	0%	1%	11%	40%	24%	12%	6%	5%	1%	1%	0%
1983	0%	0%	0%	7%	7%	11%	19%	53%	1%	0%	1%	0%
1984	1%	0%	0%	16%	26%	3%	18%	34%	1%	0%	0%	0%
1985	0%	0%	3%	9%	22%	13%	14%	35%	4%	0%	1%	0%
1986	0%	0%	1%	7%	29%	23%	9%	30%	0%	0%	0%	0%
1987	0%	0%	0%	13%	22%	18%	11%	35%	0%	0%	0%	0%
1988	0%	0%	0%	8%	43%	22%	14%	12%	0%	0%	0%	0%
1989	0%	1%	1%	14%	27%	17%	16%	23%	0%	0%	0%	0%
1990	0%	0%	1%	8%	25%	33%	13%	19%	0%	0%	0%	0%
1991	0%	0%	1%	9%	21%	13%	19%	33%	2%	1%	0%	0%
1992	0%	0%	3%	4%	30%	15%	11%	35%	1%	0%	1%	0%
1993	1%	2%	1%	12%	12%	26%	23%	22%	1%	0%	0%	0%
1994	1%	0%	3%	11%	11%	21%	16%	37%	0%	0%	0%	0%
1995	0%	1%	2%	4%	15%	6%	25%	45%	1%	0%	0%	0%
1996	0%	0%	0%	4%	9%	8%	26%	51%	1%	0%	0%	0%
1997	0%	2%	0%	7%	21%	6%	22%	38%	4%	0%	0%	0%
1998	0%	0%	1%	8%	20%	12%	18%	39%	1%	0%	0%	0%
1999	0%	0%	0%	8%	15%	22%	14%	38%	1%	0%	0%	0%
2000	0%	0%	0%	4%	15%	25%	13%	40%	2%	0%	0%	0%
2001	0%	0%	0%	11%	12%	21%	4%	50%	2%	0%	0%	0%
2002	0%	0%	8%	8%	16%	9%	9%	45%	2%	0%	0%	0%
2003	0%	0%	1%	33%	19%	9%	3%	33%	2%	0%	0%	0%
2004	0%	1%	19%	29%	19%	2%	0%	28%	1%	0%	0%	0%
2005	0%	0%	9%	12%	3%	2%	1%	72%	0%	0%	0%	0%
2006	0%	0%	1%	21%	6%	0%	1%	68%	1%	0%	1%	0%
2007	0%	1%	14%	22%	17%	1%	1%	44%	1%	0%	0%	0%
2008	0%	1%	5%	26%	5%	0%	1%	56%	6%	0%	0%	0%
2009	1%	6%	8%	58%	11%	3%	4%	8%	0%	0%	0%	0%
2010	1%	4%	12%	64%	5%	6%	0%	3%	4%	0%	0%	0%
2011	2%	4%	15%	50%	16%	1%	0%	11%	0%	0%	0%	0%
2012	0%	2%	6%	19%	10%	5%	2%	53%	2%	0%	0%	0%
2013	1%	1%	6%	69%	1%	1%	3%	15%	3%	0%	0%	0%
2014	1%	5%	18%	42%	15%	2%	5%	10%	1%	0%	0%	0%

Table 4.3.1. Total removals of weakfish in millions of fish from all sources, 1982-2014.

	Commercial Landings	Commercial Discards	Recreational Landings	Recreational Discards
1982	28.1	1.3	1.82	0.02
1983	22.9	1.3	5.36	0.03
1984	28.5	1.2	3.04	0.02
1985	28.6	1.6	2.38	0.03
1986	31.5	1.2	8.54	0.23
1987	29.4	1.0	4.81	0.08
1988	34.1	0.9	5.53	0.08
1989	14.0	0.9	1.36	0.02
1990	16.0	5.9	1.16	0.04
1991	17.1	2.5	1.70	0.08
1992	12.9	2.1	0.89	0.07
1993	11.9	2.3	0.94	0.11
1994	8.2	1.1	1.63	0.31
1995	9.4	1.9	1.53	0.41
1996	8.7	2.3	2.24	0.50
1997	8.4	0.6	2.75	0.39
1998	8.6	1.0	2.36	0.33
1999	6.7	0.9	1.54	0.27
2000	4.7	0.5	1.97	0.47
2001	3.2	0.6	1.48	0.36
2002	3.4	0.9	1.10	0.20
2003	1.8	0.4	0.47	0.15
2004	1.9	0.2	0.73	0.18
2005	1.4	0.1	1.34	0.22
2006	1.0	0.2	0.72	0.24
2007	0.7	0.2	0.45	0.12
2008	0.6	0.2	0.51	0.22
2009	0.7	0.2	0.13	0.04
2010	0.5	0.2	0.07	0.07
2011	0.2	0.3	0.03	0.06
2012	0.3	0.1	0.22	0.12
2013	0.3	0.1	0.09	0.04
2014	0.2	0.3	0.06	0.06

Table 5.1.1. Estimated commercial landings and numbers of commercial trips for “pure” weakfish on Florida’s Atlantic coast, 1978–2014. The landings were adjusted using the genome proportions of 48% for Nassau County and 17% for Duval County

	Nassau		Duval		Total		
	Landings (lbs)	Trips	Landings (lbs)	Trips	Landings (lbs)	Trips	Source
1978	571		11862		12434		NMFS
1979	337		7660		7997		NMFS
1980	549		18670		19219		NMFS
1981	344		22304		22648		NMFS
1982	2585		22106		24692		NMFS
1983	429		12260		12690		NMFS
1984	1177	1	14350	110	15526		NMFS
1985	183	1	12583	1137	12766	1138	NMFS
1986	61	2	9101	1228	9162	1230	FWC's TTK
1987	5	1	11714	1344	11719	1345	FWC's TTK
1988			13283	1227	13283	1227	FWC's TTK
1989	169	1	21207	1993	21376	1994	FWC's TTK
1990	218	2	17215	2147	17433	2149	FWC's TTK
1991	234	1	21110	2332	21344	2333	FWC's TTK
1992	18	1	24637	2887	24655	2888	FWC's TTK
1993	108	2	19472	1771	19580	1773	FWC's TTK
1994	550	1	27285	2664	27835	2665	FWC's TTK
1995	156	2	5453	883	5609	885	FWC's TTK
1996	13	1	373	134	386	135	FWC's TTK
1997	21	2	854	231	875	233	FWC's TTK
1998			952	164	952	164	FWC's TTK
1999	27	2	752	242	779	244	FWC's TTK
2000	5	2	443	168	448	170	FWC's TTK
2001			1201	188	1201	188	FWC's TTK
2002			394	87	394	87	FWC's TTK
2003			288	71	288	71	FWC's TTK
2004			192	66	192	66	FWC's TTK
2005			553	338	553	338	FWC's TTK
2006			337	192	337	192	FWC's TTK
2007			888	177	888	177	FWC's TTK
2008			996	135	996	135	FWC's TTK
2009	40	1	413	105	453	106	FWC's TTK
2010			73	27	73	27	FWC's TTK
2011			608	105	608	105	FWC's TTK
2012	124	1	1875	329	1999	330	FWC's TTK
2013			1065	303	1065	303	FWC's TTK
2014			557	168	557	168	FWC's TTK

Table 5.1.2**.** Number of hauls observed in the NEFOP database.

	GN				OTB			
	North		South		North		South	
Year	Early	Late	Early	Late	Early	Late	Early	Late
1994	396	1121	281	19	885	363	117	85
1995	1169	1001	374	119	1177	994	166	
1996	803	845	384	168	894	767	52	
1997	764	688	384	13	710	665	8	
1998	916	505	465	252	422	252	19	21
1999	381	438	190	52	410	616	102	
2000	364	425	126	95	946	776	95	
2001	368	314	93	26	1003	1150		
2002	273	390	31	5	752	2867	92	
2003	619	1202	53	15	2799	2649	55	14
2004	1248	2801		15	3444	5358	194	93
2005	945	2423	4	20	11975	10149	149	59
2006	508	342	2		6457	4552	110	13
2007	341	862	28	6	5249	6567	216	114
2008	471	584	31		6417	7792	218	79
2009	773	612	9	4	6972	7146	239	114
2010	580	870	24		5772	3807	373	143
2011	805	979	9	33	4953	5028	290	84
2012	780	789	5		3924	2845	72	22
2013	300	617	8	47	2984	4000		19
2014	641	902	9	28	4925	4182	192	33

Table 5.1.3. Number of observed hauls that were positive for weakfish discards.

	GN				OTB			
	North		South		North		South	
Year	Early	Late	Early	Late	Early	Late	Early	Late
1994	5	90	48	2	15	2	2	2
1995	56	67	28	7	14	124	2	
1996	17	51	30	1	24	113		
1997	18	38	17		11	22		
1998	19	4	29	16	4			1
1999	6	7	13		3	22	4	
2000		8	8	6	5	5	1	
2001	4	8	16	2	7	55		
2002	3	15	1			41	2	
2003		2	1	1	4	44	5	
2004		9			31	88	6	1
2005		5			9	24	2	
2006		3			8	28	5	3
2007	2	5			3	81	7	7
2008		1			8	35	6	12
2009		1			6	70	20	26
2010		8	3		39	64	6	15
2011				2	34	142	8	2
2012					19	80	10	
2013		3		2	61	66		9
2014	1	1			35	75	14	1

Table 5.1.4. Species guilds associated with weakfish discards.

Region	Gear	Species
North	GN	BUTTERFISH
North	GN	CROAKER, ATLANTIC
North	GN	DOGFISH, SMOOTH
North	GN	MENHADEN, ATLANTIC
North	GN	SPOT
North	GN	WEAKFISH (SQUETEAGUE SEA TROUT)
North	OTB	BLUEFISH
North	OTB	CRAB, HORSESHOE
North	OTB	CROAKER, ATLANTIC
North	OTB	SCUP
North	OTB	SPOT
North	OTB	WEAKFISH (SQUETEAGUE SEA TROUT)
South	GN	BLUEFISH
South	GN	BUTTERFISH
South	GN	CROAKER, ATLANTIC
South	GN	DOGFISH, SPINY
South	GN	MENHADEN, ATLANTIC
South	GN	WEAKFISH (SQUETEAGUE SEA TROUT)
South	OTB	BUTTERFISH
South	OTB	CROAKER, ATLANTIC
South	OTB	DOGFISH, SMOOTH
South	OTB	MENHADEN, ATLANTIC
South	OTB	SPOT
South	OTB	WEAKFISH (SQUETEAGUE SEA TROUT)

Table 5.1.5. Weakfish discard ratios by stratum. NR=ratio of non-regulatory discards from the period 1994-2000.

Mgmt block	Years	Region	Gear	Season	Ratio	R.var	LoCI	HiCI
NR	1982-1993	North	GN	All	0.0068	1.29E-06	0.0046	0.0090
T1	1994	North	GN	All	0.0099	1.50E-05	0.0023	0.0174
T2	1995-1996	North	GN	All	0.0034	3.37E-07	0.0023	0.0046
T3	1997-2002	North	GN	All	0.0078	2.90E-06	0.0045	0.0111
T4	2003-2009	North	GN	All	0.0005	2.28E-08	0.0002	0.0008
T5	2010-2014	North	GN	All	0.0002	3.97E-09	0.0000	0.0003
NR	1982-1993	North	OTB	All	0.0603	1.26E-04	0.0384	0.0822
T1	1994	North	OTB	Early	0.0018	2.00E-06	0.0000	0.0046
T1	1994	North	OTB	Late	0.0297	7.69E-05	0.0126	0.0468
T2	1995-1996	North	OTB	Early	0.0155	4.01E-05	0.0031	0.0278
T2	1995-1996	North	OTB	Late	0.0765	3.04E-04	0.0425	0.1105
T3	1997-2002	North	OTB	Early	0.0023	6.31E-07	0.0008	0.0038
T3	1997-2002	North	OTB	Late	0.0208	4.21E-05	0.0082	0.0335
T4	2003-2009	North	OTB	Early	0.0004	6.35E-09	0.0002	0.0005
T4	2003-2009	North	OTB	Late	0.0275	4.26E-05	0.0148	0.0402
T5	2010-2014	North	OTB	Early	0.0025	5.58E-07	0.0011	0.0040
T5	2010-2014	North	OTB	Late	0.0109	7.87E-06	0.0055	0.0164
NR	1982-1993	South	GN	All	0.0007	8.96E-09	0.0005	0.0009
T1	1994	South	GN	All	0.0008	4.71E-08	0.0004	0.0012
T2	1995-1996	South	GN	All	0.0005	1.69E-08	0.0003	0.0008
T3	1997-2002	South	GN	All	0.0009	2.57E-08	0.0006	0.0012
T4	2003-2009	South	GN	All	0.0002	1.77E-08	0.0000	0.0004
T5	2010-2014	South	GN	All	0.0003	4.83E-08	0.0000	0.0008
NR	1982-1993	South	OTB	All	0.0089	4.21E-05	0.0000	0.0215
T1	1994	South	OTB	All	0.0277	4.54E-04	0.0000	0.0692
T2	1995-1996	South	OTB	All	0.0001	2.68E-08	0.0000	0.0005
T3	1997-2002	South	OTB	All	0.0022	2.31E-06	0.0000	0.0051
T4	2003-2009	South	OTB	All	0.0066	3.89E-06	0.0028	0.0105
T5	2010-2014	South	OTB	All	0.0124	1.65E-05	0.0045	0.0203

Table 5.1.6. Sample size of shrimp vessel observer coverage in the south Atlantic.

Year	All Observed Trips	Bycatch Monitoring Trips
1998	78	
1999	2	
2000	5	
2001	5	1
2002	10	1
2003	6	
2004	23	1
2005	102	101
2006	8	
2007	118	118
2008	31	27
2009	69	67
2010	30	29
2011	61	59
2012	52	46
2013	59	54
2014	16	15
Total	**675**	**519**

Table 5.1.7. BCPUE estimates, standard deviations, and sample size from the SEFSC shrimp trawl observer program.

	BCPUE	SD	# Trips Observed
2005	0.59	1.32	89
2006	--	--	0
2007	0.13	0.31	101
2008	5.61	12.43	27
2009	0.20	0.61	67
2010	0.04	0.17	29
2011	0.11	0.78	57
2012	1.99	4.01	43
2013	0.35	1.16	48
2014	12.57	35.08	13

Table 5.2.1 - Estimated recreational harvests (type A+B1 in weight and numbers) and releases (Type B2, numbers) per season for “pure” weakfish on Florida’s Atlantic coast, 1982–2014 The final estimates are shaded.

	FL's coastwide						Nassau						Duval						Total					
	A+B1 (lbs)		A+B1 (#)		B2 (#)		A+B1 (lbs)		A+B1 (#)		B2 (#)		A+B1 (lbs)		A+B1 (#)		B2 (#)		A+B1 (lbs)		A+B1 (#)		B2 (#)	
	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr	1st Half_yr	2nd Half_yr
1982		48138		40161		3387	0	882	0	736	0	62	0	1139	0	950	0	80	0	2021	0	1686	0	142
1983	163499	184676	123351	169951	3456	18025	2274	3383	1716	3113	48	330	3132	4369	2363	4021	66	426	5406	7752	4078	7133	114	757
1984	368237		493521		6719		5122	0	6865	0	93	0	7053	0	9453	0	129	0	12175	0	16318	0	222	0
1985	11187	10718	26687	9653	0	8031	156	196	371	177	0	147	214	254	511	228	0	190	370	450	882	405	0	337
1986	68249	32554	85152	44119	21336	1619	949	596	1184	808	297	30	1307	770	1631	1044	409	38	2257	1366	2815	1852	705	68
1987	21712	23925	32774	31475	1940	12624	302	438	456	576	27	231	416	566	628	745	37	299	718	1004	1084	1321	64	530
1988	20773	68230	26543	68966	0	636	289	1250	369	1263	0	12	398	1614	508	1632	0	15	687	2864	878	2895	0	27
1989	59111	51995	75761	66118	0	0	822	952	1054	1211	0	0	1132	1230	1451	1564	0	0	1954	2182	2505	2775	0	0
1990	23359	32179	42885	31099	2684	0	325	589	597	570	37	0	447	761	821	736	51	0	772	1351	1418	1305	89	0
1991	1579	79593	2722	112488	2593	33138	21	965	36	1364	34	402	33	3133	57	4428	54	1305	54	4099	93	5793	88	1706
1992	12524	38603	16020	52924	16429	23168	260	908	333	1244	341	545	421	1125	539	1543	553	675	682	2033	872	2787	894	1220
1993	32482	77345	43492	105476	23319	33256	889	2248	1190	3065	638	966	923	2654	1235	3619	662	1141	1811	4901	2425	6684	1300	2107
1994	58782	90254	94400	110313	3868	34273	800	2115	1285	2585	53	803	1747	2802	2806	3425	115	1064	2547	4917	4091	6010	168	1867
1995	31306	12106	32681	22755	30870	20467	367	483	383	908	362	817	480	171	501	322	474	289	847	654	884	1229	835	1106
1996	6110	11108	18142	17617	27622	1937	43	429	127	681	193	75	124	238	368	377	560	41	167	667	495	1057	753	116
1997	58775	6916	62479	10491	68076	44000	1293	336	1374	509	1497	2135	1589	139	1689	212	1840	887	2882	475	3063	721	3338	3022
1998	4904	14333	9112	15566	15276	32131	12	194	22	211	37	435	104	448	193	487	324	1005	116	642	215	698	361	1440
1999	37507	60950	41385	77642	39975	83587	69	888	77	1132	74	1218	286	1593	315	2029	304	2185	355	2481	392	3161	378	3403
2000	53174	58036	65230	58568	101651	108098	112	883	137	892	214	1645	797	1265	978	1277	1524	2357	909	2149	1115	2169	1737	4002
2001	22979	16828	27579	18830	41975	34509	208	259	250	290	380	531	298	463	357	518	544	950	506	722	607	808	924	1480
2002	46679	12468	50787	18320	57623	21639	311	109	339	161	384	190	803	254	874	373	991	441	1114	363	1212	534	1375	631
2003	9920	12262	12852	16763	48058	11460	117	109	152	149	568	102	129	235	167	321	625	219	246	344	319	470	1194	321
2004	17730	18360	22234	20683	68765	61990	15	277	19	312	59	934	317	337	398	380	1231	1138	332	614	417	692	1289	2073
2005	44884	12612	43600	12945	50258	23464	900	105	874	107	1008	195	509	179	494	184	570	334	1409	284	1368	291	1577	528
2006	40962	12845	41069	14772	119571	62045	693	120	695	138	2023	579	525	221	526	254	1531	1068	1218	341	1221	392	3554	1646
2007	12334	29081	15582	31472	25648	20804	65	296	82	320	135	211	141	403	179	436	294	288	206	698	260	756	429	499
2008	29421	15246	41758	12728	0	26536	440	140	625	117	0	243	371	258	527	215	0	449	811	397	1152	332	0	692
2009	49070	3177	51504	2787	7624	0	1091	55	1145	49	170	0	773	61	811	54	120	0	1864	117	1956	102	290	0
2010	6172	4786	6700	5095	918	0	183	82	199	87	27	0	87	105	94	112	13	0	270	187	293	199	40	0
2011	9311	1472	7940	1648	0	10568	242	26	207	29	0	187	240	43	205	48	0	308	483	69	411	77	0	495
2012	13591	1833	19149	3006	0	0	379	25	534	42	0	0	262	51	370	83	0	0	641	76	903	125	0	0
2013	7626	14176	14702	33843	13046	0	43	175	83	417	74	0	255	486	491	1161	436	0	298	661	575	1578	510	0
2014	13315	7149	13748	10553	14116	2388	195	126	201	186	207	42	307	138	317	203	325	46	502	263	518	389	532	88

Table 5.2.2. MRFSS vs. MRIP estimates of precision (Percent Standard Error, PSE) for recreational catch estimates.

	Harvest (A+B1) PSE		Rel. Alive (B2) PSE		Total Catch PSE	
	MRIP	MRFSS	MRIP	MRFSS	MRIP	MRFSS
2004	18.5	12.8	14.4	10.3	11.5	8.1
2005	14.8	11.6	15.0	10.7	10.9	8.0
2006	17.5	12.4	16.7	10.9	13.5	8.8
2007	22.8	13.2	16.0	15.2	13.2	11.6
2008	23.6	20.3	23.4	13.2	19.6	11.3
2009	17.6	16.0	21.7	15.4	16.8	11.9
2010	15.1	12.4	16.2	11.1	14.8	9.9
2011	21.2	19.8	20.0	17.5	19.2	16.6
2012	19.2	13.0	16.5	12.8	14.3	11.1
MRIP/MRFSS	1.29		1.37		1.37	

Table 5.3.1 Age samples for ALKs by year and source.

Early Season (Jan - Jun)

Year	SM-GA	SM-SC	SM-NC	NC	NM-NC	VA	CM	MD	DE	NJ	NY	RI	CT	NM
2004	68	47	116	300	0	591	263	12	259	11	0	0	2	0
2005	19	15	100	284	0	399	99	17	145	13	35	1	44	0
2006	23	18	62	396	0	360	75	0	274	185	139	0	26	0
2007	0	0	0	296	0	280	119	0	333	350	118	0	31	0
2008	23	35	35	122	0	207	88	0	307	110	0	0	3	232
2009	40	53	60	45	0	142	0	2	137	67	0	0	2	108
2010	19	8	79	217	0	122	106	0	147	19	0	0	1	190
2011	38	13	55	173	0	134	66	3	163	5	1	1	14	135
2012	23	30	35	275	0	150	128	5	307	12	3	12	100	204
2013	0	0	0	248	0	128	28	1	281	82	47	17	0	292
2014	0	0	0	126	0	158	0	0	152	1	0	15	0	0

Late Season (Jul-Dec)

Year	SM-GA	SM-SC	SM-NC	NC	NM-NC	VA	CM	MD	DE	NJ	NY	CT	RI	NM
2004	75	40	154	289	0	65	814	136	552	46	0	26	4	0
2005	33	37	172	277	0	357	1009	261	618	135	148	14	59	0
2006	35	23	128	356	0	253	642	180	556	351	43	43	54	0
2007	0	0	0	264	72	142	434	276	491	193	8	11	0	493
2008	36	72	110	358	91	159	279	132	441	334	0	7	0	372
2009	55	124	124	218	132	147	477	61	268	181	14	50	0	734
2010	43	91	124	290	55	138	498	160	355	547	0	0	0	534
2011	121	125	138	205	86	137	388	22	493	305	11	155	8	695
2012	100	88	150	222	72	171	200	116	389	134	13	52	0	708
2013	0	0	0	298	88	124	157	84	287	111	7	0	0	510
2014	0	0	0	383	0	137	149	0	259	107	0	0	5	0

SM=SEAMAP; NM=NEAMAP; CM=ChesMMAP

Table 5.3.2. Sample size of weakfish lengths from the NEFSC observer program.

	North				South			
	GN		OTB		GN		OTB	
Year	Early	Late	Early	Late	Early	Late	Early	Late
1989				48				
1990				686				
1991				1026				
1993		22		268				
1994								
1995	89	21		1089				
1996	41	9	78	841				
1997	48	120	1	100	36			
1998	1		2					
1999				35	6			
2000		6		221	6	10		
2001	2	7	11	307	111	7		
2002	7	8		194	1		1	
2003		1	5	508	2	1	1	
2004		6	30	1009				2
2005		6	11	165				
2006		2	5	319				10
2007	2	3		364			3	30
2008		1	5	85			7	204
2009			11	101			134	219
2010		3	43	120			8	65
2011			2	378			2	3
2012			2	62				
2013			76	18				18
2014		1	2	25			29	

Table 5.3.3. Commercial catch-at-age (landings + discards, thousands of fish) used in the assessment models.

Year	Total N	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1982	28,284.4	8,118.1	11,778.6	5,196.0	2,528.3	450.8	212.7
1983	23,429.4	6,171.3	10,334.7	4,298.3	1,938.0	375.7	311.4
1984	28,940.9	7,236.1	12,861.1	5,719.6	2,618.0	377.0	129.0
1985	27,990.1	13,302.4	10,766.4	2,865.6	927.3	113.8	14.5
1986	31,520.5	14,047.7	12,000.6	3,843.1	1,421.4	185.7	22.0
1987	29,023.4	12,904.3	11,309.1	3,504.5	1,192.6	109.5	3.3
1988	33,955.7	6,573.5	13,490.7	8,289.0	4,743.7	812.9	45.8
1989	13,962.2	2,308.5	4,490.3	3,883.2	2,635.8	570.2	74.3
1990	16,976.2	9,392.4	4,145.5	1,760.2	1,057.1	544.4	76.7
1991	18,387.5	9,717.5	5,059.2	2,171.9	1,031.6	369.9	37.4
1992	14,402.5	4,927.8	5,980.9	1,981.9	1,019.0	446.6	46.2
1993	13,718.7	4,584.9	6,051.3	1,805.7	901.1	338.9	36.7
1994	9,185.4	3,278.2	2,572.3	2,157.0	955.0	185.6	37.3
1995	10,735.2	3,853.5	3,185.8	2,582.8	948.8	138.6	25.5
1996	10,335.8	1,915.5	2,122.4	3,315.8	2,079.2	870.4	32.5
1997	9,004.5	1,101.7	1,563.6	2,091.9	3,120.2	923.0	204.0
1998	9,365.3	1,021.9	1,693.1	2,872.8	1,431.3	1,832.2	513.9
1999	7,108.0	910.3	1,072.2	1,798.3	2,165.4	483.2	678.6
2000	5,211.2	983.4	964.0	1,218.7	1,133.6	707.2	204.1
2001	3,550.0	242.2	1,546.8	762.2	487.4	303.2	208.3
2002	3,790.0	614.3	523.4	1,759.9	489.6	241.3	161.6
2003	2,280.6	401.8	837.0	523.7	394.0	64.4	59.6
2004	2,037.4	706.7	917.8	330.4	42.2	23.8	16.6
2005	1,481.3	164.7	783.4	437.5	66.9	3.9	24.8
2006	1,220.3	293.8	341.7	464.1	103.4	7.4	9.9
2007	911.3	244.8	409.8	163.6	70.6	17.7	4.8
2008	754.4	517.2	150.0	65.3	16.5	4.2	1.3
2009	919.4	649.4	237.9	22.3	7.1	1.5	1.3
2010	584.4	315.7	228.9	34.9	4.2	0.2	0.4
2011	443.0	205.2	196.1	38.7	3.0	0.0	0.0
2012	413.0	156.1	130.5	116.2	10.0	0.2	0.0
2013	412.3	77.8	175.8	115.0	42.0	1.2	0.6
2014	487.5	213.7	144.6	103.9	22.5	2.7	0.2

Table 5.3.4 Recreational catch-at-age (landings + release mortality, thousands of fish) used in the assessment models.

Year	Total N	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6
1982	1,834.40	130.7	383.0	336.1	288.3	272.4	423.9
1983	5,406.88	621.5	2,114.8	1,494.8	870.3	194.7	110.7
1984	3,109.71	511.5	1,201.5	742.4	424.8	105.6	123.9
1985	2,406.94	722.4	908.3	451.6	236.3	63.4	24.9
1986	8,507.65	3,475.3	3,499.1	1,071.1	396.3	52.8	13.0
1987	4,840.37	1,621.9	2,035.5	808.4	326.9	40.2	7.4
1988	5,611.11	276.5	1,777.2	2,051.9	1,260.0	223.2	22.3
1989	1,387.61	112.8	445.4	459.3	300.7	59.0	10.4
1990	1,213.33	161.4	550.5	289.6	152.7	46.6	12.5
1991	1,798.51	150.7	643.2	571.0	325.5	88.9	19.2
1992	972.07	89.1	276.3	274.2	230.2	82.7	19.6
1993	1,070.96	97.3	331.0	354.3	218.4	58.6	11.5
1994	1,954.36	173.3	480.3	863.7	418.6	15.6	2.8
1995	1,949.55	75.7	376.1	850.8	574.2	48.8	23.9
1996	2,734.88	20.4	243.6	1,139.7	860.2	415.2	55.8
1997	3,142.51	21.6	151.5	477.0	1,811.4	502.3	178.7
1998	2,695.25	20.5	186.1	772.9	470.3	914.7	330.7
1999	1,828.87	22.6	119.3	276.4	815.3	195.5	399.8
2000	2,452.78	257.3	331.2	411.5	439.5	812.8	200.5
2001	1,828.07	102.4	777.2	421.5	291.7	126.1	109.1
2002	1,314.52	137.7	132.0	601.2	251.2	128.9	63.6
2003	620.49	61.6	139.7	197.2	133.9	41.8	46.2
2004	911.17	179.4	475.3	198.6	38.1	13.0	6.8
2005	1,571.51	131.0	894.9	473.2	67.4	2.0	3.0
2006	961.31	262.0	235.0	346.6	101.5	4.9	11.3
2007	573.06	98.1	293.4	106.4	64.6	8.2	2.3
2008	722.43	452.8	172.9	82.5	12.2	2.1	0.0
2009	169.76	73.5	68.8	22.3	4.1	0.9	0.2
2010	138.22	66.8	53.2	16.1	2.1	0.0	0.0
2011	82.33	36.5	36.8	8.5	0.3	0.0	0.2
2012	335.47	119.8	120.8	85.8	9.0	0.0	0.0
2013	126.40	23.2	52.1	36.0	14.8	0.0	0.3
2014	116.91	44.7	37.5	27.4	6.4	0.7	0.1

Table 6.1.1 Fishery independent surveys considered by the Weakfish SAS during this assessment.

SURVEYS CONSIDERED	USED IN ASSESSMENT
MA Seine	N
MA Trawl	N
RI Trawl	Y (YOY)
RI Seine - NarBay	N
RI Seine - Coastal Ponds & Lagoons	N
URI Trawl	N
CT LIS Seine	N
CT LIS Trawl	Y (YOY)
NY Peconic Trawl	Y (YOY)
NJ DB Trawl	N
NJ Ocean Trawl	Y (Age 1+)
NJ Juv SB Seine	N
Rutgers Trawl	N
Rutgers IP	N
DE DB Adult Trawl (30')	Y (Age 1+)
DE DB Juv Trawl (17')	Y (YOY)
DE IB Juv Trawl (17')	N
MD Juv SB Seine	N
MD Coastal Trawl	Y (YOY)
MD Blue Crab Trawl	N
MD Coastal Seine	N
MD SB Gillnet	N
VA Shad Gillnet	N
VIMS Juv Trawl	Y (YOY)
NC AR Gillnet -Fall/Winter	N
NC AR Gillnet - Spring	N
NC PS Gillnet, P915	Y (Age 1+)
NC Rivers Gillnet, P915	N
NC South Gillnet, P915	N
NC Juv Seine, P100	N
NC PS Trawl P195	Y (YOY)
SCECAP	N
USFWS Bears Bluff	N
SC Crustacean Trawl Survey	N
GA Trawl	N
GA Gillnet	N
GA Trammel	N
GA Seine	N
FL Trawl	N

FL River Seine	N
FL Haul Seine	N
SEAMAP Trawl	Y (Age 1+)
NEFSC Trawl	Y (Age 1+)
NEAMAP	Y (Age 1+)
CHESMAP	Y (Age 1+)

Table 6.1.2. Age-1+ fishery-independent indices of abundance used in the weakfish assessment.

	NC PSIGNS	SEAMAP	ChesMMAP	DE Bay Adult	NJ Ocean	CT LISTS*	NEFSC Trawl	NEAMAP
1982							7.29	
1983							15.37	
1984						0.53	116.00	
1985						0.24	2.40	
1986						0.24	20.51	
1987						0.11	0.42	
1988					0.35	0.06	9.14	
1989					11.32	0.02	3.32	
1990		9.05			7.73	0.08	2.58	
1991		7.40		34.15	8.86	0.31	7.54	
1992		14.48		26.41	13.13	0.18	3.12	
1993		25.21		88.86	12.58	0.12	12.35	
1994		1.65		212.00	439.82	0.06	60.64	
1995		3.42		163.35	224.05	0.70	14.59	
1996		1.73		258.06	34.49	0.56	23.76	
1997		7.08		122.30	19.91	0.89	8.04	
1998		19.47		120.56	3.73	0.28	4.87	
1999		6.31		94.94	22.11	0.39	19.19	
2000		2.09		182.08	131.99	0.30	39.96	
2001	0.69	1.22		83.28	19.47	0.52	84.54	
2002	0.60	12.41	6.47	154.39	77.48	0.16	111.83	
2003	0.50	7.01	6.64	62.87	42.36	0.07	170.27	
2004	0.50	19.55	10.09	48.67	169.17	0.21	57.35	
2005	0.49	35.18	9.37	29.69	96.38	0.12	48.39	
2006	0.41	21.30	5.80	108.30	16.09	0.29	89.84	
2007	0.19	4.90	4.96	47.16	30.20	0.06	22.47	74.48
2008	0.21	6.52	3.57	47.07	74.08	0.08	28.38	122.60
2009	0.14	9.71	1.26	35.30	30.75	0.30		53.57
2010	0.18	13.40	2.86	44.06	77.58			60.18
2011	0.16	4.68	4.35	85.56	270.76	0.68		136.87
2012	0.37	25.42	2.16	69.73	121.15	0.73		201.36
2013	0.28	6.54	0.72	35.99	19.83	0.52		49.71
2014	0.22	49.83	0.13	22.51	33.31	0.08		58.42

*CT LISTS age-1+ was only used as sensitivity analysis.

Table 6.1.3. Young-of-year indices of abundance used in the weakfish assessment

	NC P195	VIMS Juv. Trawl	MD Coastal Bay	DE Bay Juv. Trawl	NY Peconic Bay	CT LISTS Age-0	RI Fall Trawl	Composite YOY
1982				20.32			16.79	
1983				25.25			19.72	0.62
1984				13.03			1.46	0.32
1985				32.89		1.00	4.07	0.71
1986				35.03		6.19	21.84	0.84
1987				43.70		13.16	4.72	1.02
1988	97.30			23.17	0.60	0.63	0.57	0.51
1989	11.54	29.98		32.35	0.11	3.49	1.43	0.81
1990	16.04	22.98	1.44	33.18	1.38	8.69	0.90	0.82
1991	14.70	6.48	1.81	30.95	0.55	5.56	12.44	0.70
1992	2.98	4.81	5.66	46.96	20.64	11.95	13.66	1.07
1993	5.63	16.43	8.32	43.66	3.26	3.05	14.90	1.06
1994	91.81	8.97	9.61	49.53	1.03	4.08	6.42	1.13
1995	32.98	5.54	4.21	56.62	8.33	11.19	31.41	1.20
1996	6.56	7.86	17.35	58.15	1.60	5.22	0.17	1.19
1997	17.02	11.27	5.89	76.25	24.49	15.23	249.91	1.76
1998	37.80	10.41	9.20	78.59	18.75	12.38	83.45	1.81
1999	155.99	12.12	7.50	37.99	1.03	5.02	6.08	0.95
2000	22.44	12.71	23.13	45.10	8.43	30.93	2.44	1.20
2001	84.02	12.64	10.22	52.59	15.88	63.31	24.02	1.42
2002	35.86	12.11	7.92	34.12	16.18	40.09	9.47	1.01
2003	3.31	10.73	1.95	40.21	12.17	41.35	3.19	0.97
2004	79.15	19.62	6.72	43.69	7.01	49.41	150.55	1.25
2005	44.05	9.21	3.81	44.65	5.52	58.98	1.16	1.10
2006	61.57	6.85	5.27	83.31	31.98	25.86	39.66	1.84
2007	53.37	8.14	4.35	20.60	8.70	1.05	0.50	0.55
2008	16.92	8.39	10.27	47.69	12.07	63.93	14.33	1.21
2009	8.50	13.39	0.37	26.85	7.71	9.03	0.08	0.65
2010	2.32	10.12	1.37	41.94	1.97	6.48	1.26	0.88
2011	271.35	16.04	5.30	37.07	2.55		6.43	0.99
2012	9.92	7.22	1.62	34.38	4.00	11.64	27.02	0.81
2013	7.57	7.27	0.31	25.54	2.16	21.96	10.64	0.60
2014	7.64	12.97	1.00	44.43	2.16	7.01	2.05	0.97

Table 6.2.1. State specific guild species based on Jaccard similarity for MRIP HPUE.

Massachusetts		**Rhode Island**		**Connecticut**	
Species	*J*_val	Species	*J*_val	Species	*J*_val
WEAKFISH	1	WEAKFISH	1	WEAKFISH	1
BASS, BLACK SEA	0.0004	BLUEFISH	0.0033	BASS, BLACK SEA	0.0046
SCUP	0.0003	NA	0.0027	DOGFISH, SMOOTH	0.0043
BLUEFISH	0.0001	SEAROBINS, NORTH AMERICAN	0.0021	SCUP	0.0042
SHARKS, DOGFISH	0	SCUP	0.0021	SEAROBIN, STRIPED	0.0038
SKATE, LITTLE	0	BASS, BLACK SEA	0.0014	SEAROBINS, NORTH AMERICAN	0.0036

New York		**New Jersey**		**Delaware**	
Species	*J*_val	Species	*J*_val	Species	*J*_val
WEAKFISH	1	WEAKFISH	1	WEAKFISH	1
PUFFER, NORTHERN	0.0233	CROAKER, ATLANTIC	0.1129	FLOUNDER, SUMMER	0.1883
DOGFISH, SMOOTH	0.0096	TOADFISH, OYSTER	0.0802	DOGFISH, SMOOTH	0.1597
SEAROBIN, STRIPED	0.0074	DOGFISH, SMOOTH	0.0767	TOADFISH, OYSTER	0.1431
SEAROBINS, NORTH AMERICAN	0.0071	BLUEFISH	0.062	CROAKER, ATLANTIC	0.1422
BLUEFISH	0.0071	FLOUNDER, SUMMER	0.0537	BLUEFISH	0.1216

Maryland		**Virginia**		**North Carolina**	
Species	*J*_val	Species	*J*_val	Species	*J*_val
WEAKFISH	1	WEAKFISH	1	WEAKFISH	1
CROAKER, ATLANTIC	0.1297	SPOT	0.1224	PIGFISH	0.06
TOADFISH, OYSTER	0.1068	CROAKER, ATLANTIC	0.1211	KINGFISH, SOUTHERN	0.0577
SPOT	0.1066	FLOUNDER, SUMMER	0.0822	CROAKER, ATLANTIC	0.0534
BLUEFISH	0.0636	BLUEFISH	0.0806	SEATROUT, SPOTTED	0.0438
FLOUNDER, SUMMER	0.0554	TOADFISH, OYSTER	0.0759	FLOUNDER, SUMMER	0.0431

South Carolina		**Georgia**	
Species	*J*_val	Species	*J*_val
WEAKFISH	1	WEAKFISH	1
KINGFISH, SOUTHERN	0.0405	KINGFISH, SOUTHERN	0.0289
CROAKER, ATLANTIC	0.0363	PIGFISH	0.0285
BLUEFISH	0.021	BLUEFISH	0.0268
TOADFISH, OYSTER	0.0194	SHARK, BONNETHEAD	0.0248
PIGFISH	0.019	BASS, BLACK SEA	0.0219

Table 6.2.2. Number of MRFSS/MRIP-intercepted trips that caught one or more of the guild species.

Year	NY	NJ	DE	MD	VA	NC	SC	GA
1982	1,144	967	290	401	283	378	255	116
1983	1,176	615	411	2,193	738	217	95	185
1984	1,019	378	286	476	520	280	222	142
1985	1,289	524	335	2,380	2,280	367	265	367
1986	3,424	618	386	957	2,480	275	223	328
1987	1,295	1,033	430	534	1,002	833	281	454
1988	1,359	1,047	870	340	685	1,173	253	191
1989	4,746	950	974	648	1,883	1,469	348	241
1990	4,996	1,590	1,215	725	656	1,598	206	127
1991	5,605	2,092	1,192	890	826	2,059	68	197
1992	4,862	1,546	1,207	675	1,082	1,290	152	329
1993	4,935	1,056	1,180	404	801	1,651	131	159
1994	3,533	1,155	1,056	437	2,628	2,685	190	148
1995	1,469	1,229	1,040	438	1,396	2,496	240	167
1996	2,222	1,396	1,145	331	1,365	2,661	361	194
1997	1,991	1,463	1,292	781	1,764	2,329	548	192
1998	1,769	1,488	1,494	984	1,865	2,125	487	365
1999	2,078	1,638	1,176	1,282	1,185	1,975	283	393
2000	1,561	1,494	1,096	1,398	1,392	1,836	358	470
2001	2,667	3,034	1,381	973	2,340	1,971	256	523
2002	1,907	2,025	1,419	1,043	2,086	1,454	318	449
2003	2,890	2,604	1,347	966	1,968	1,438	306	550
2004	2,215	2,357	1,273	987	2,139	1,707	373	546
2005	2,264	2,422	1,828	916	1,554	1,448	593	438
2006	2,352	1,670	1,376	806	913	1,952	586	486
2007	2,598	1,832	1,187	908	2,811	1,600	993	569
2008	2,720	1,765	1,196	917	2,643	1,799	648	499
2009	2,240	1,688	1,211	987	2,193	1,885	523	439
2010	2,380	1,779	1,103	1,000	2,118	3,047	429	546
2011	2,253	1,652	872	774	1,510	3,199	682	529
2012	2,152	1,406	855	520	1,257	3,703	459	552
2013	2,043	1,525	1,959	710	1,869	2,964	595	359
2014	1,587	2,069	1,624	834	1,621	2,645	699	572

Table 7.1.1. Indices used in Bayesian age-structured model.

Types of *Is*	Name of *Is*	Age groups to calibrate
From fishery independent surveys and aged	NMFS survey	1-6+
	DEDFW1	1-6+
	NJDEP	1-6+
	SEAFALL	1-6+
	NCGill	1-6+
From fishery dependent surveys and aged	MRFSS	3-6+
From fishery independent surveys for Young of the Year (YOY)	DEDFW2	1
	NCDMF	1
	VIMS	1
	MDDNR1	1
	NYDEC	1
	RI	1
	CT	1

Table 7.1.2. Priors used in the Bayesian age-structured model. Catches are in 10^6 fish in the models. All the parameters are non-informative, except those for natural mortality.

Models	Parameters and their priors
M1	$\sigma_c^2 \sim U(0.001,10)$; $\sigma_j^2 \sim U(0.001,1)$; $N_{a,y=1982} \sim U(1,100) \times C_{a,y=1982}$; $Ln(R_y) \sim U(0,200)$; $F_y \sim U(0.001,2)$; $S_a \sim U(0,1)$; $Ln(q_{j,a}) \sim U(-8,4)$
M2	Same as in M1, but also $\bar{M} \sim U(0.1,0.4)$; $\sigma_{M_1}^2 \sim U(0.001,1)$; $\sigma_{M_y}^2 \sim U(0.001,1)$
M3	Same as in M1, but also $\sigma_{j,2}^2 \sim U(0.001,1)$; $\varepsilon_{j,a,y,N}$ for aged indices ~ $MVN(u_2,V_2)$, $\mu_2 = [0,0,0,0,0,0]$; $1/V_2 = dwish(R,k)$; $k=9$; $R = [\ \ ]_{6\times6}$ with man diagonal values = 0.1; and other values = 0.005; $\varepsilon_{j,a,y,N}$ for non-aged indices ~ $MVN(u_3,V_3)$, $\mu_3 = [0,0,0,0,0,0,0,0]$; $1/V_3 = dwish(R',k')$; $k'=11$; $R' = [\ \ ]_{8\times8}$ with man diagonal values = 0.1; and other values = 0.005
M4	Hybrid M2 andM3. Same as in M1, but also $\bar{M} \sim U(0.1,0.4)$; $\sigma_{M_1}^2 \sim U(0.001,1)$; $\sigma_{M_y}^2 \sim U(0.001,1)$; and but also $\sigma_{j,2}^2 \sim U(0.001,1)$; $\varepsilon_{j,a,y,N}$ for aged indices ~ $MVN(u_2,V_2)$, $\mu_2 = [0,0,0,0,0,0]$; $1/V_2 = dwish(R,k)$; $k=9$; $R = [\ \ ]_{6\times6}$ with man diagonal values = 0.1; and other values = 0.005; $\varepsilon_{j,a,y,N}$ for non-aged indices ~ $MVN(u_3,V_3)$, $\mu_3 = [0,0,0,0,0,0,0,0]$; $1/V_3 = dwish(R',k')$; $k'=11$; $R' = [\ \ ]_{8\times8}$ with man diagonal values = 0.1; and other values = 0.005

Table 7.1.3. Descriptions of data (S1-S6) and model (M1-M4) sensitivity runs in the Bayesian age-structured model.

Models	Description
S1	Base model run: multinomial ALK, 2 fleets, reconstructed historical catch-at-age with scale ages converted to otolith ages
S2	Scale ages unconverted
S3	Original historical CAA data used for 1982-1989 with a single fleet for this time period
S4	Traditional ALKs for all years
S5	15% recreational release mortality
S6	Inclusion of "unidentified trout" landings
M1	Constant M, no spatial heterogeneity
M2	Time-varying M, no spatial heterogeneity
M3	Constant M, spatial heterogeneity in population available to surveys
M4	Time-varying M and spatial heterogeneity

Table 8.1.1 Estimates of *DIC*s, retrospective errors and predictive p-values, when different models are used. The highlighted numbers indicate the lowest DICs (3A), the lowest retrospective errors (3B), the top two models, with predictive p-values closer to 0.5 (3C), and the corresponding models and years. * note: based on data S4.

Models	DIC	E1 (one year)	E2 (two year)	E3 (three year)	E4 (four year)	E2 (based on 4 years in total)
M1	282.2	1.0106	0.7222	0.2872	0.2047	1.9290
M2	-33.0	0.3194	0.2121	0.1141	0.1318	1.2168
M3	-2286.3	2.7405	0.7790	0.3268	1.5984	2.9305
M4	-2386.0	0.3001	0.1919	0.2031	0.8419	1.6897

Table 8.1.2. *DIC* values for sensitivity runs S1-S6 for models M1-M4. See Table 7.1.3 for a description of the sensitivity runs.

Data scenarios	M1	M2	M3	M4
S1	482.89	138.86	-2141.76	-2178.64
S2	482.17	139.15	-2043.93	-2176.24
S3	391.01	107.88	-2116.44	-2234.04
S4	282.16	-33.02	-2286.30	-2385.99
S5	511.96	165.00	-2107.05	-2179.52
S6	491.05	146.07	-2120.77	-2162.84

Table 8.1.3.A. Full fishing mortality rates estimated by the Bayesian age-structured model for run S1.

Year	Commercial	Recreational	Maximum Total F-at-Age
1982	1.17	0.39	1.55
1983	1.26	0.76	2.00
1984	1.74	0.79	2.51
1985	1.37	0.71	2.06
1986	1.55	0.86	2.39
1987	0.78	0.57	1.33
1988	1.67	0.75	2.40
1989	1.62	0.38	1.99
1990	1.42	0.36	1.77
1991	1.37	0.54	1.90
1992	1.51	0.44	1.94
1993	1.27	0.43	1.70
1994	0.62	0.26	0.87
1995	0.42	0.22	0.63
1996	0.41	0.20	0.60
1997	0.45	0.21	0.65
1998	0.59	0.25	0.82
1999	0.59	0.22	0.80
2000	0.60	0.53	1.11
2001	0.51	0.47	0.96
2002	1.03	0.63	1.63
2003	1.18	0.66	1.81
2004	0.69	0.65	1.32
2005	0.53	0.62	1.14
2006	0.81	0.84	1.63
2007	1.76	0.87	2.58
2008	1.36	0.72	2.04
2009	1.82	0.80	2.57
2010	1.85	0.26	2.06
2011	0.11	0.14	0.25
2012	0.14	0.14	0.28
2013	0.25	0.05	0.29
2014	0.10	0.05	0.15

Table 8.1.3.B. Full fishing mortality rates estimated by the Bayesian age-structured model for run S4.

Year	Commercial	Recreational	Maximum Total F-at-Age
1982	1.23	0.38	1.58
1983	1.34	0.76	2.02
1984	1.80	0.80	2.51
1985	1.47	0.73	2.12
1986	1.64	0.87	2.42
1987	0.82	0.57	1.34
1988	1.73	0.76	2.41
1989	1.69	0.38	2.03
1990	1.50	0.36	1.83
1991	1.42	0.55	1.91
1992	1.57	0.44	1.96
1993	1.42	0.44	1.82
1994	0.71	0.28	0.96
1995	0.47	0.24	0.69
1996	0.46	0.18	0.62
1997	0.51	0.19	0.67
1998	0.69	0.23	0.89
1999	0.75	0.22	0.94
2000	0.72	0.52	1.16
2001	0.60	0.45	1.00
2002	1.14	0.61	1.66
2003	1.34	0.66	1.91
2004	0.77	0.60	1.29
2005	0.62	0.58	1.13
2006	0.92	0.84	1.66
2007	1.76	0.89	2.53
2008	1.52	0.67	2.10
2009	1.59	0.82	2.30
2010	1.79	0.42	2.15
2011	0.49	0.10	0.58
2012	0.39	0.41	0.76
2013	0.48	0.06	0.54
2014	0.18	0.11	0.28

Table 8.1.4.A. Natural mortality and total mortality rates estimated by the Bayesian age-structured model for run S1.

Year	M	Maximum Z-at-Age
1982	0.17	1.72
1983	0.16	2.16
1984	0.16	2.66
1985	0.16	2.22
1986	0.16	2.55
1987	0.16	1.49
1988	0.16	2.56
1989	0.16	2.15
1990	0.16	1.93
1991	0.15	2.05
1992	0.14	2.09
1993	0.14	1.84
1994	0.14	1.01
1995	0.15	0.78
1996	0.16	0.76
1997	0.18	0.83
1998	0.21	1.03
1999	0.26	1.06
2000	0.33	1.44
2001	0.43	1.39
2002	0.55	2.18
2003	0.61	2.42
2004	0.68	1.99
2005	0.76	1.89
2006	0.88	2.51
2007	0.93	3.51
2008	0.94	2.98
2009	0.95	3.52
2010	0.96	3.02
2011	0.96	1.21
2012	0.96	1.24
2013	0.93	1.22
2014	0.84	0.99

Table 8.1.4.B. Natural mortality and total mortality rates estimated by the Bayesian age-structured model for run S4.

Year	M	Maximum Z-at-Age
1982	0.17	1.74
1983	0.16	2.18
1984	0.16	2.67
1985	0.16	2.27
1986	0.16	2.57
1987	0.16	1.49
1988	0.16	2.57
1989	0.16	2.19
1990	0.16	1.98
1991	0.15	2.06
1992	0.14	2.10
1993	0.14	1.96
1994	0.14	1.10
1995	0.14	0.83
1996	0.15	0.77
1997	0.17	0.85
1998	0.20	1.09
1999	0.25	1.18
2000	0.30	1.47
2001	0.38	1.38
2002	0.48	2.14
2003	0.55	2.46
2004	0.63	1.92
2005	0.74	1.87
2006	0.87	2.53
2007	0.93	3.46
2008	0.95	3.04
2009	0.95	3.25
2010	0.95	3.10
2011	0.95	1.53
2012	0.95	1.70
2013	0.92	1.45
2014	0.84	1.11

Table 8.1.5.A. Total abundance estimated by the Bayesian age-structured model in millions of fish for run S1.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	Total N
1982	21.6	16.0	7.3	2.9	1.2	1.2	**49.0**
1983	25.1	14.7	7.4	2.5	0.7	0.6	**50.4**
1984	29.9	16.8	6.3	2.2	0.4	0.2	**55.5**
1985	41.2	18.5	5.7	1.3	0.2	0.1	**66.9**
1986	41.4	27.2	7.5	1.6	0.2	0.0	**77.9**
1987	31.9	26.4	10.0	1.8	0.2	0.0	**70.2**
1988	20.0	23.4	14.5	4.3	0.5	0.1	**62.7**
1989	18.4	12.5	8.3	3.2	0.5	0.1	**43.0**
1990	16.3	11.8	4.8	2.1	0.5	0.1	**35.4**
1991	16.8	10.8	4.9	1.4	0.4	0.1	**34.3**
1992	21.9	11.2	4.5	1.4	0.3	0.1	**39.4**
1993	25.2	14.4	4.5	1.3	0.2	0.1	**45.6**
1994	28.6	17.3	6.5	1.5	0.3	0.1	**54.2**
1995	14.1	22.2	10.9	3.5	0.6	0.1	**51.2**
1996	15.9	11.2	15.1	6.3	1.7	0.4	**50.2**
1997	11.1	12.5	7.6	8.7	3.2	1.2	**43.1**
1998	10.0	8.5	8.1	4.2	4.1	2.3	**35.0**
1999	9.8	7.3	5.0	3.8	1.6	2.9	**27.5**
2000	16.0	6.8	4.1	2.3	1.5	2.0	**30.6**
2001	6.5	10.2	3.3	1.4	0.6	1.2	**22.0**
2002	8.6	3.8	4.7	1.2	0.4	0.6	**18.7**
2003	11.4	4.1	1.2	1.0	0.2	0.2	**17.8**
2004	16.6	4.9	1.1	0.2	0.1	0.1	**22.9**
2005	7.5	7.3	1.6	0.2	0.0	0.0	**16.7**
2006	7.3	3.1	2.4	0.4	0.0	0.0	**13.2**
2007	5.0	2.6	0.8	0.3	0.0	0.0	**8.7**
2008	6.3	1.4	0.4	0.1	0.0	0.0	**8.1**
2009	5.0	1.9	0.3	0.0	0.0	0.0	**7.1**
2010	10.1	1.4	0.3	0.0	0.0	0.0	**11.7**
2011	11.5	2.8	0.2	0.0	0.0	0.0	**14.5**
2012	15.2	4.3	1.0	0.1	0.0	0.0	**20.6**
2013	10.4	5.7	1.5	0.3	0.0	0.0	**17.8**
2014	18.7	3.9	2.0	0.5	0.1	0.0	**25.2**

Table 8.1.5.B. Total abundance estimated by the Bayesian age-structured model in millions of fish for run S4.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	Total N
1982	21.8	16.7	8.0	3.4	1.3	1.1	**51.3**
1983	25.2	15.0	8.1	2.8	0.8	0.5	**51.9**
1984	31.1	16.9	6.7	2.4	0.5	0.2	**57.6**
1985	42.0	19.4	6.2	1.4	0.3	0.1	**69.4**
1986	42.1	27.8	8.3	1.7	0.2	0.0	**80.2**
1987	32.3	27.0	10.8	2.0	0.2	0.0	**72.3**
1988	20.6	23.8	15.3	4.7	0.6	0.1	**65.0**
1989	18.1	13.0	9.0	3.5	0.6	0.1	**44.2**
1990	16.4	11.6	5.3	2.4	0.6	0.1	**36.3**
1991	16.6	10.9	5.1	1.6	0.5	0.1	**34.8**
1992	21.4	11.2	4.9	1.5	0.3	0.1	**39.3**
1993	24.7	14.2	4.8	1.4	0.3	0.1	**45.4**
1994	28.2	16.9	6.5	1.5	0.3	0.1	**53.4**
1995	13.6	21.7	10.6	3.3	0.6	0.1	**49.9**
1996	15.4	10.8	14.6	5.8	1.6	0.4	**48.2**
1997	10.5	12.2	7.3	8.3	2.9	1.0	**41.2**
1998	9.1	8.1	7.9	3.9	4.0	1.9	**33.0**
1999	8.6	6.6	4.7	3.6	1.5	2.2	**25.0**
2000	14.9	5.9	3.6	2.0	1.3	1.3	**27.7**
2001	5.9	9.6	2.9	1.2	0.5	0.7	**20.1**
2002	8.2	3.6	4.6	1.0	0.3	0.4	**17.6**
2003	9.9	4.1	1.2	0.9	0.1	0.1	**16.2**
2004	13.4	4.5	1.2	0.2	0.1	0.0	**19.3**
2005	6.3	6.2	1.5	0.3	0.0	0.0	**14.3**
2006	6.7	2.7	2.0	0.3	0.0	0.0	**11.7**
2007	4.4	2.4	0.6	0.3	0.0	0.0	**7.6**
2008	3.8	1.3	0.4	0.0	0.0	0.0	**5.5**
2009	4.2	1.1	0.2	0.0	0.0	0.0	**5.6**
2010	7.2	1.2	0.2	0.0	0.0	0.0	**8.6**
2011	8.0	2.1	0.2	0.0	0.0	0.0	**10.3**
2012	9.3	2.9	0.6	0.1	0.0	0.0	**12.9**
2013	7.6	3.3	0.9	0.1	0.0	0.0	**11.9**
2014	15.2	2.8	1.1	0.2	0.0	0.0	**19.4**

Table 8.1.6.A. Spawning stock biomass (MT) estimated by the Bayesian age-structured model for run S1.

Year	SSB
1982	13,956.6
1983	12,164.5
1984	10,978.2
1985	13,304.5
1986	22,019.9
1987	16,588.6
1988	15,929.9
1989	10,695.3
1990	9,522.5
1991	11,035.6
1992	9,655.6
1993	7,261.4
1994	11,338.6
1995	11,249.1
1996	13,212.5
1997	17,268.1
1998	13,301.9
1999	12,090.6
2000	10,005.7
2001	11,455.5
2002	7,506.8
2003	5,205.3
2004	4,396.7
2005	3,610.4
2006	4,040.3
2007	3,613.4
2008	2,323.1
2009	1,914.1
2010	1,976.7
2011	2,138.7
2012	4,051.9
2013	2,975.4
2014	3,784.9

Table 8.1.6.B. Spawning stock biomass (MT) estimated by the Bayesian age-structured model for run S4.

Year	SSB
1982	14,443.9
1983	12,686.2
1984	11,467.5
1985	14,158.9
1986	23,149.9
1987	17,516.5
1988	16,820.9
1989	11,392.0
1990	10,201.2
1991	11,500.3
1992	9,990.6
1993	7,406.1
1994	11,208.9
1995	10,940.9
1996	12,572.6
1997	16,329.5
1998	12,337.6
1999	10,588.2
2000	8,329.9
2001	9,163.2
2002	6,363.0
2003	4,660.2
2004	3,803.6
2005	3,132.1
2006	3,529.3
2007	3,117.7
2008	1,712.2
2009	1,502.9
2010	1,520.3
2011	1,565.2
2012	2,582.7
2013	1,901.7
2014	2,711.0

Table 8.1.7.A. Recruitment estimated by the Bayesian age-structured model in millions of fish for run S1.

Year	Age 1
1982	21.6
1983	25.1
1984	29.9
1985	41.2
1986	41.4
1987	31.9
1988	20.0
1989	18.4
1990	16.3
1991	16.8
1992	21.9
1993	25.2
1994	28.6
1995	14.1
1996	15.9
1997	11.1
1998	10.0
1999	9.8
2000	16.0
2001	6.5
2002	8.6
2003	11.4
2004	16.6
2005	7.5
2006	7.3
2007	5.0
2008	6.3
2009	5.0
2010	10.1
2011	11.5
2012	15.2
2013	10.4
2014	18.7

Table 8.1.7.B. Recruitment estimated by the Bayesian age-structured model in millions of fish for run S4.

Year	**Age 1**
1982	21.8
1983	25.2
1984	31.1
1985	42.0
1986	42.1
1987	32.3
1988	20.6
1989	18.1
1990	16.4
1991	16.6
1992	21.4
1993	24.7
1994	28.2
1995	13.6
1996	15.4
1997	10.5
1998	9.1
1999	8.6
2000	14.9
2001	5.9
2002	8.2
2003	9.9
2004	13.4
2005	6.3
2006	6.7
2007	4.4
2008	3.8
2009	4.2
2010	7.2
2011	8.0
2012	9.3
2013	7.6
2014	15.2

Table 8.2.1. Fishing mortality rates estimated by the ASAP model.

Year	**Commercial Fleet Full F**	**Recreational Fleet Full F**	**N-Weighted Average F (Ages 2-4)**
1982	0.49	0.15	0.45
1983	0.57	0.24	0.56
1984	0.84	0.22	0.77
1985	0.65	0.17	0.57
1986	0.71	0.38	0.68
1987	0.55	0.21	0.50
1988	1.03	0.40	1.04
1989	0.78	0.16	0.73
1990	0.63	0.13	0.56
1991	0.65	0.26	0.63
1992	0.60	0.18	0.54
1993	0.47	0.15	0.42
1994	0.28	0.18	0.29
1995	0.24	0.14	0.25
1996	0.26	0.19	0.32
1997	0.28	0.24	0.37
1998	0.35	0.27	0.42
1999	0.41	0.27	0.47
2000	0.49	0.48	0.59
2001	0.49	0.37	0.49
2002	0.86	0.47	0.96
2003	1.31	0.48	1.18
2004	0.66	0.49	0.61
2005	0.66	0.95	0.80
2006	0.89	1.25	1.24
2007	2.14	1.32	1.98
2008	1.33	2.43	1.74
2009	3.47	0.81	2.41
2010	1.42	0.51	1.06
2011	0.43	0.13	0.32
2012	0.27	0.48	0.36
2013	0.19	0.07	0.17
2014	0.09	0.03	0.09

Table 8.2.2. Total abundance estimated by the ASAP model.

Year	Total Abundance (millions of fish)
1982	52.4
1983	50.1
1984	51.4
1985	62.3
1986	81.6
1987	70.7
1988	53.7
1989	32.9
1990	27.8
1991	28.9
1992	34.1
1993	42.9
1994	56.2
1995	49.6
1996	44.9
1997	36.2
1998	27.9
1999	22.7
2000	24.0
2001	16.9
2002	14.6
2003	13.6
2004	13.1
2005	10.9
2006	9.7
2007	6.6
2008	5.8
2009	5.0
2010	3.7
2011	4.5
2012	6.0
2013	5.6
2014	6.7

Table 8.2.3. Spawning stock biomass estimated by the ASAP model.

Year	Spawning Stock Biomass (MT)
1982	15,358.8
1983	11,511.4
1984	8,249.6
1985	9,937.3
1986	15,132.6
1987	12,461.1
1988	7,742.1
1989	5,676.2
1990	5,800.6
1991	6,530.9
1992	5,921.7
1993	5,099.2
1994	9,094.7
1995	8,557.7
1996	9,051.9
1997	10,413.4
1998	7,032.7
1999	6,098.7
2000	4,545.7
2001	5,294.5
2002	3,091.6
2003	2,223.5
2004	2,033.6
2005	1,657.7
2006	1,653.8
2007	1,115.6
2008	829.4
2009	467.4
2010	456.5
2011	651.6
2012	1,174.0
2013	1,016.1
2014	1,436.3

Table 8.2.4. Recruitment estimated by the ASAP model.

Year	**Recruitment (Millions of Age-1 Fish)**
1982	22.5
1983	21.5
1984	25.8
1985	39.0
1986	48.2
1987	29.9
1988	15.9
1989	14.3
1990	12.7
1991	14.6
1992	19.5
1993	24.5
1994	31.1
1995	13.6
1996	13.5
1997	8.8
1998	7.0
1999	7.5
2000	11.7
2001	4.0
2002	5.9
2003	7.4
2004	7.5
2005	3.7
2006	4.8
2007	2.6
2008	4.1
2009	2.7
2010	2.6
2011	2.8
2012	3.1
2013	1.9
2014	2.9

Table 8.5.1. F and Z SPR reference points for weakfish. Bolded values indicate TC-recommended values for stock status determination. SPR 20% = threshold; SPR 30% = target.

	F20%	F30%
M=0.15	0.317	0.210
M=0.43	**0.928**	**0.546**
M=0.93	5.851	3.086

	Z40%	Z30%	Z20%
M=0.43	0.794	**0.976**	**1.358**

Table 8.5.2. SSB reference points under different M scenarios. Bolded value indicates the TC recommended value for the SSB threshold.

	High M	Low M	Avg M	Time-varying M (Low M period)	Time-varying M (High M period)
SSB equilibrium	3,840 MT	159,660 MT	22,950 MT	82,110 MT	3,910 MT
30% Equilibrium SSB	1,152 MT	47,900 MT	**6,880 MT**	24,663 MT	1,170 MT
50% Equilibrium SSB	1,920 MT				1,955 MT
20% Equilibrium SSB		31,9230 MT	4,590 MT	16,420 MT	

Table 9.2.1. Recommended reference points for weakfish and 2014 estimates of population parameters.

	Threshold	Target	2014 Value
SSB	6,880 MT	n.a.	2,548 MT
Z	1.36	0.93	1.11
F	0.93	0.55	0.25

13.0 FIGURES

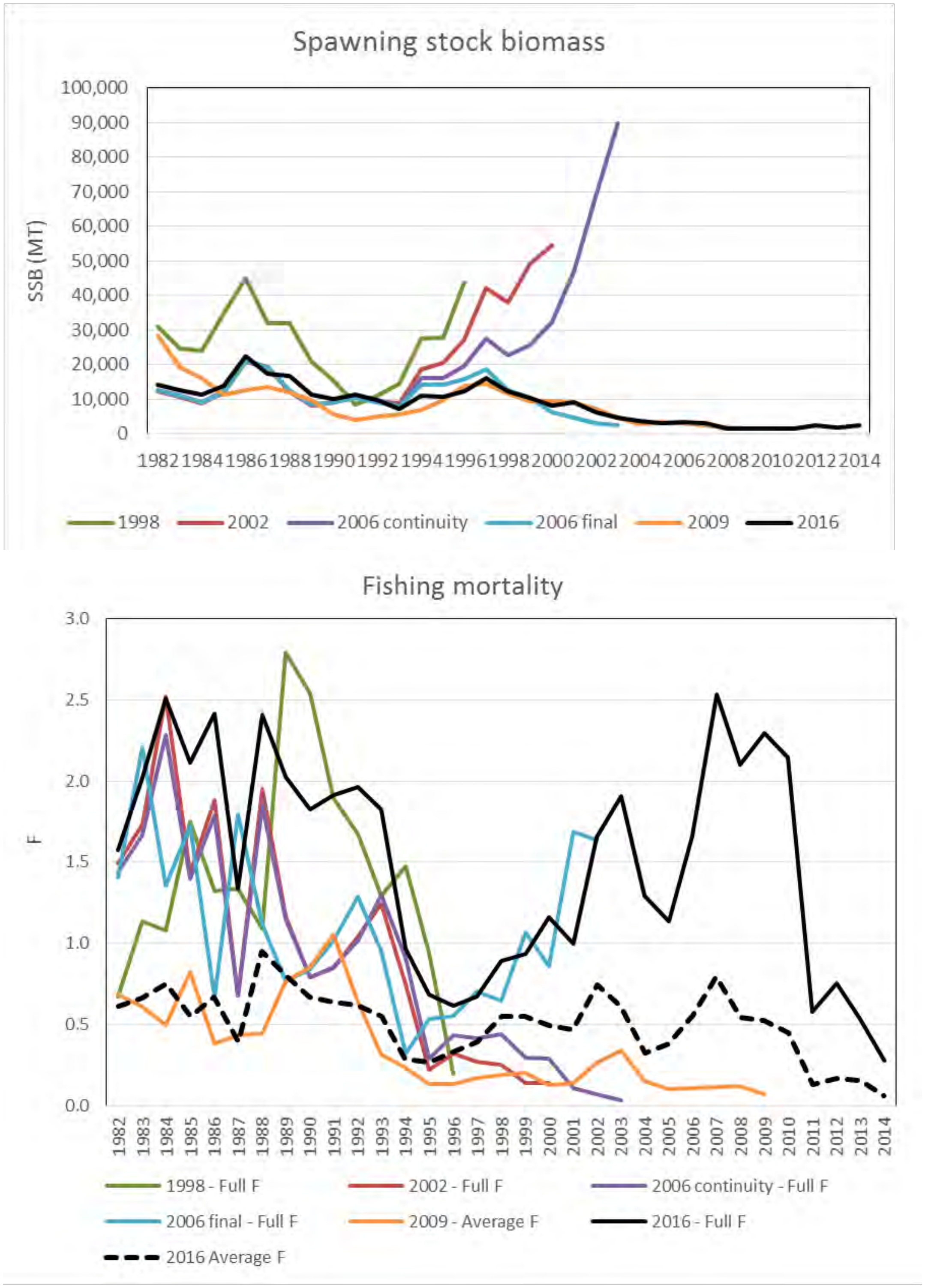


Figure 1.4.1. Historical retrospective analysis of spawning stock biomass (top) and fishing mortality (bottom) for weakfish, 1998 – 2009.

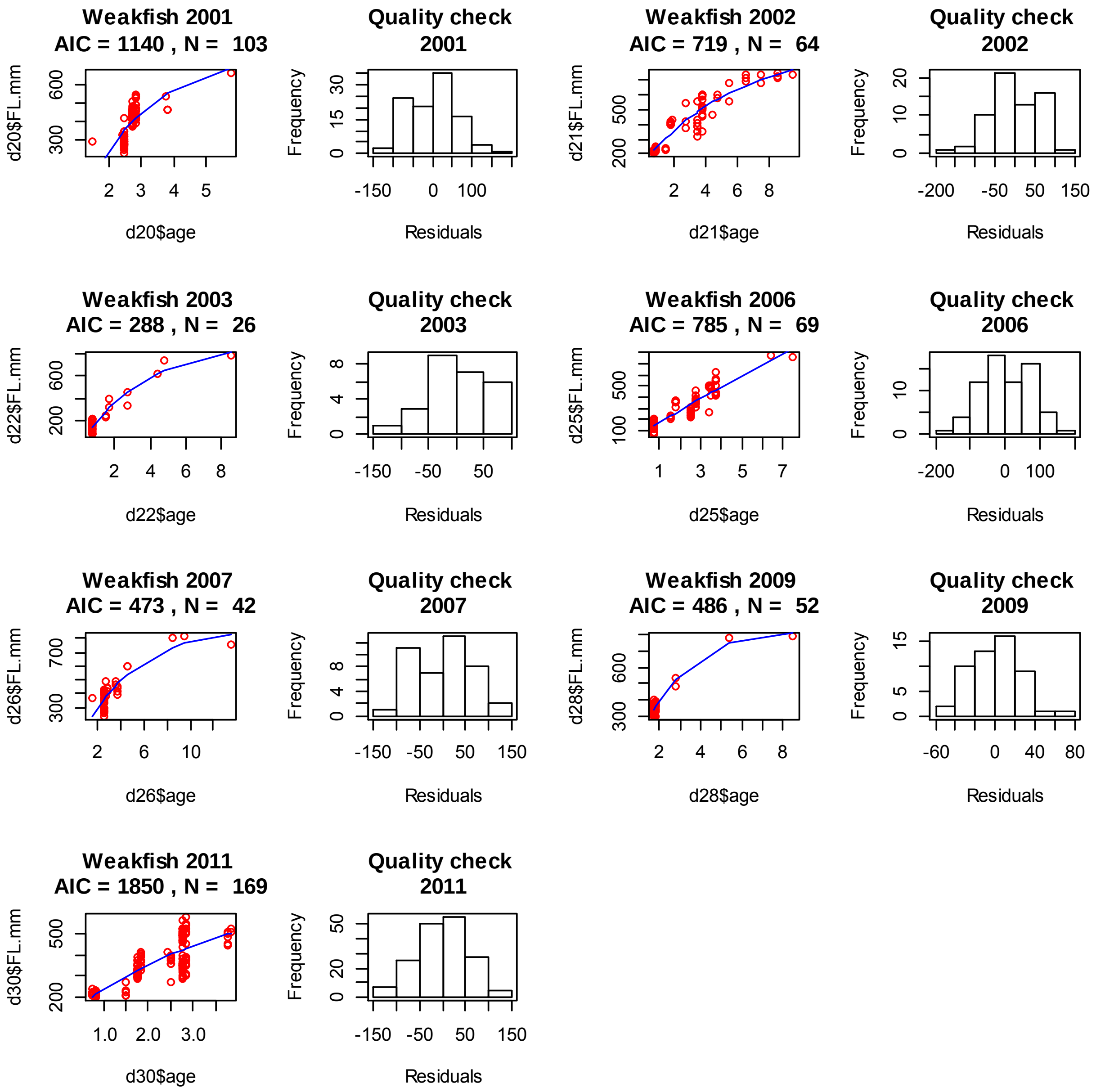


Figure 2.3.1. An example of the total number of VBGM models to converge by year in Delaware and the near linear fit that occurred in 2006.

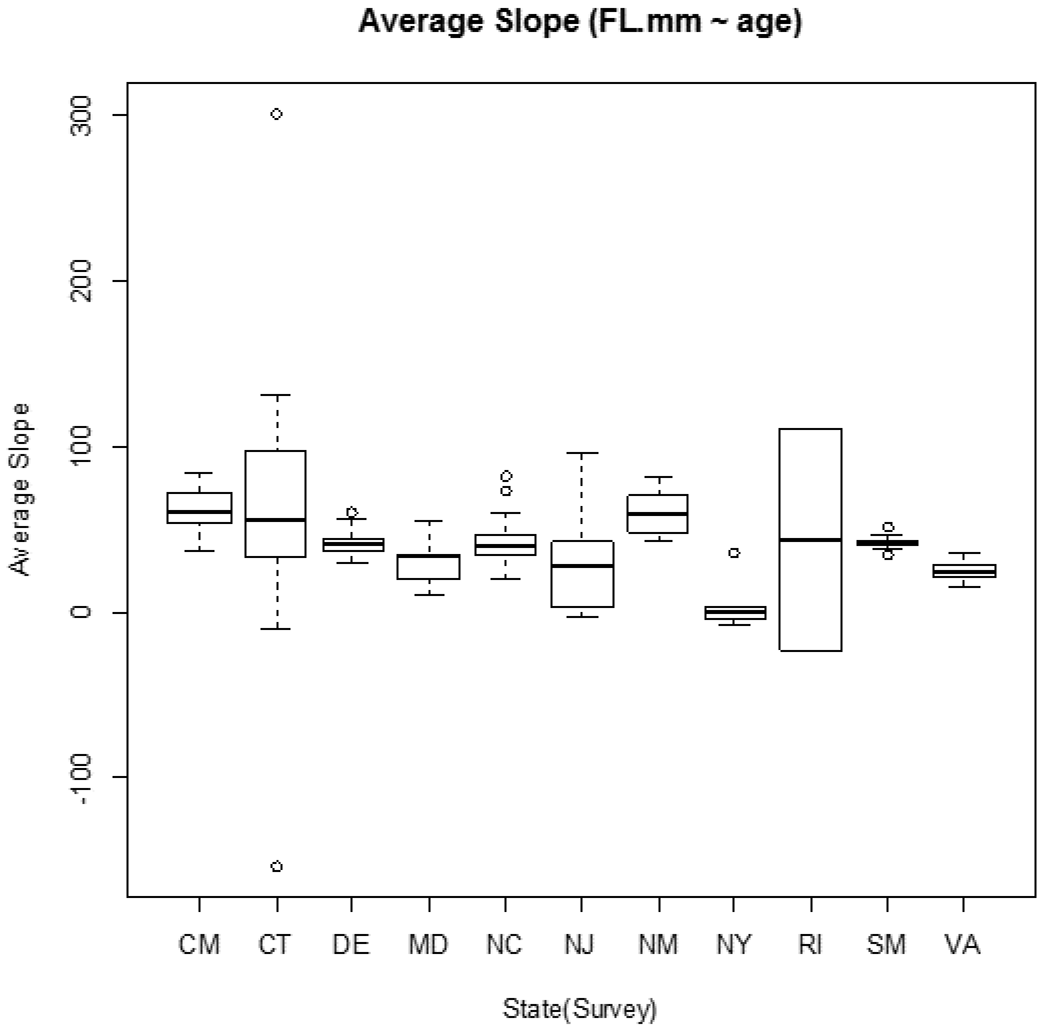


Figure 2.3.2. The average slope of fork length as a function of age by state or survey. CM=ChesMMAP; NM=NEAMAP; SM=SEAMAP.

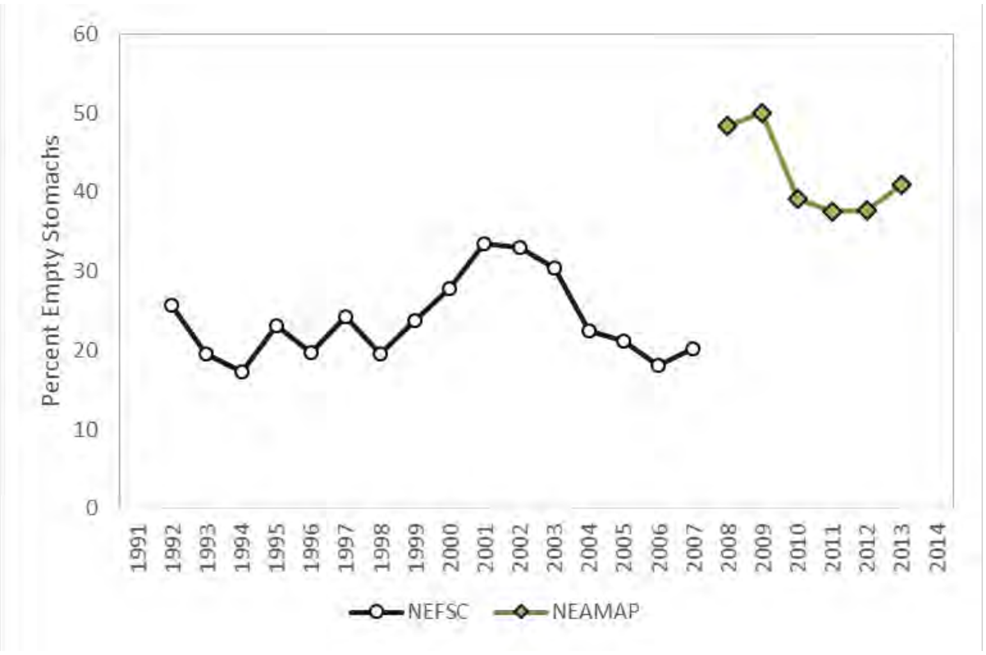


Figure 2.5.1 Three year average prevalence of empty stomachs in 5-12" weakfish in the NEFSC fall cruise food habits database and the NEAMAP database.

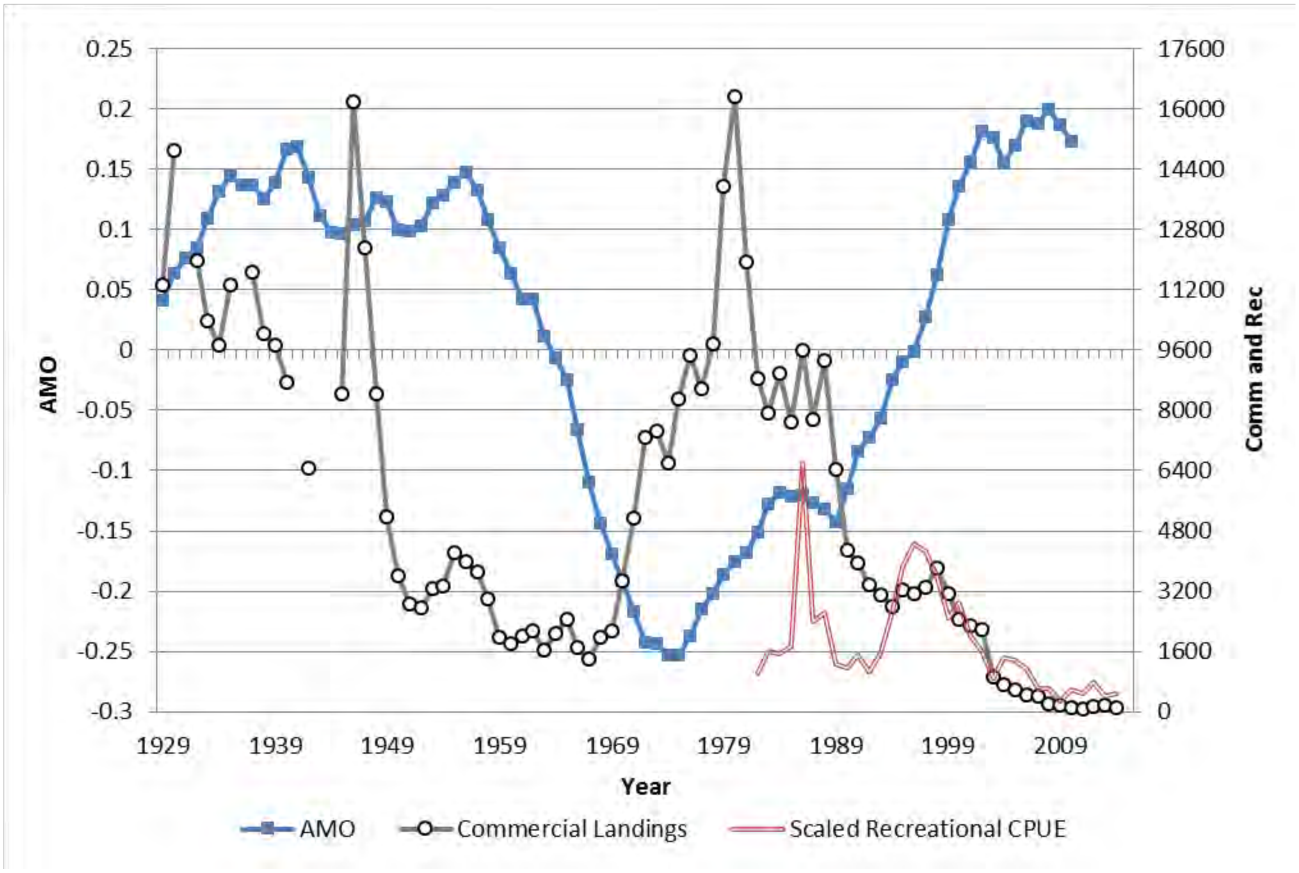


Figure 2.5.2. Commercial landings (MT) and recreational CPUE index (x10,000 to provide similar scale) in relation to the Atlantic Multidecadal Oscillation Index.

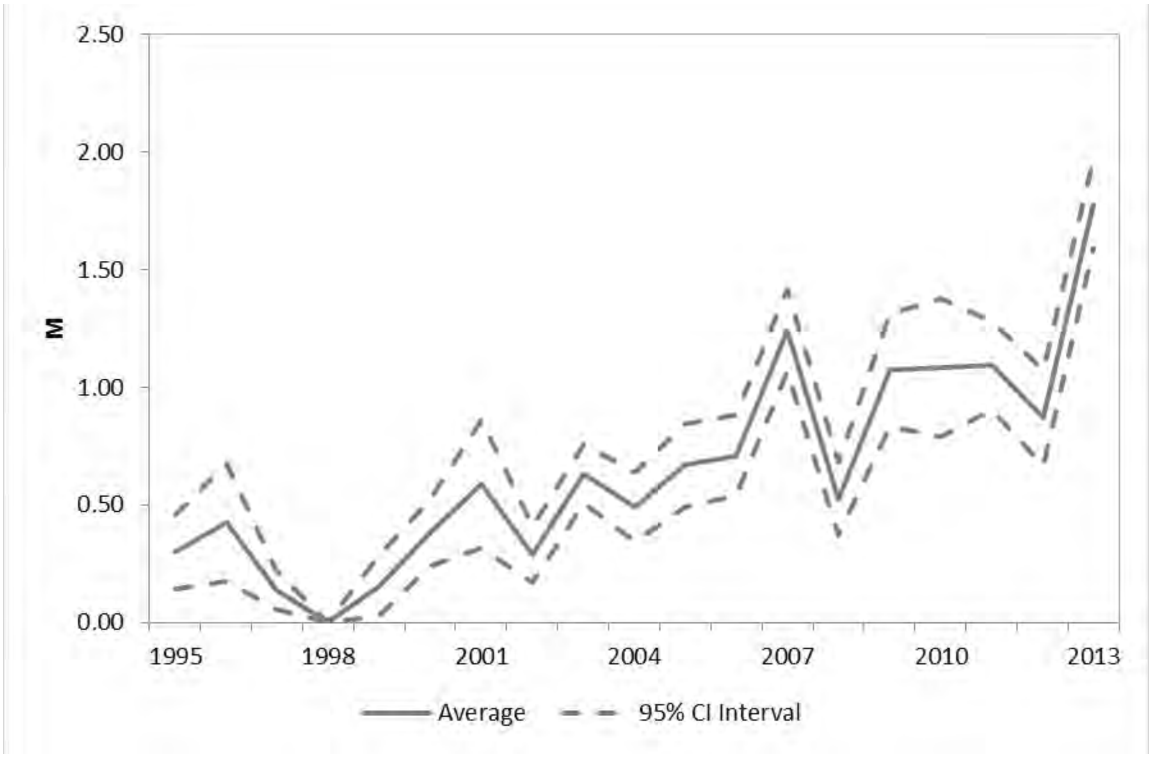


Figure 2.5.3. Estimated annual natural mortality using the modified Catch Survey Analysis method.

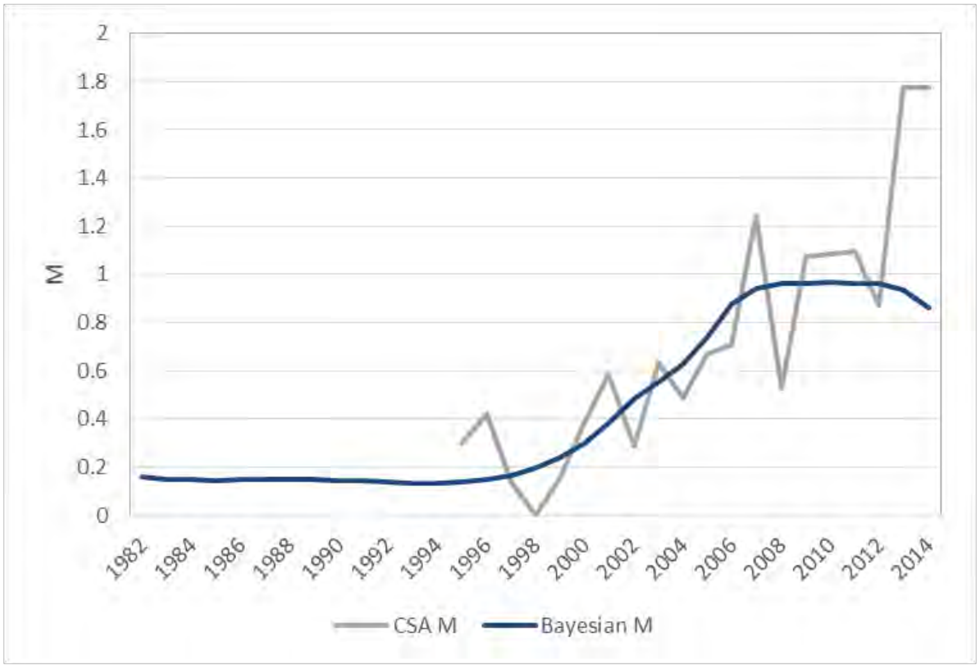


Figure 2.5.4. Comparison of modified CSA M and Bayesian model estimate of M.

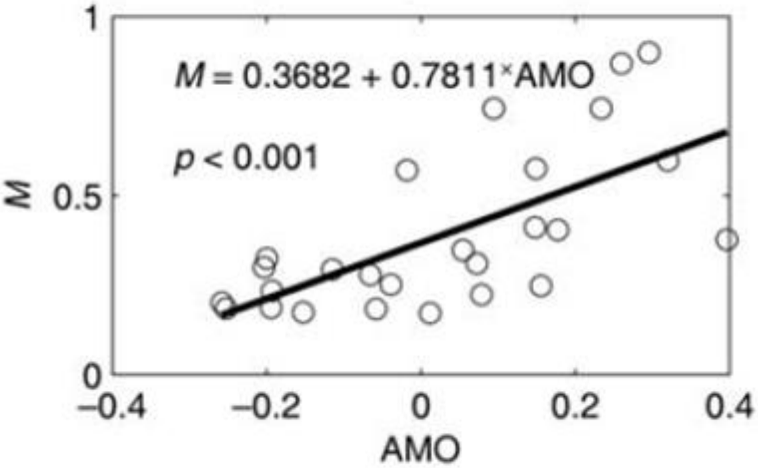


Figure 2.5.5. Relationship between natural mortality and the AMO. Reprinted from Figure 8 of Jiao et al (2012) with permission.

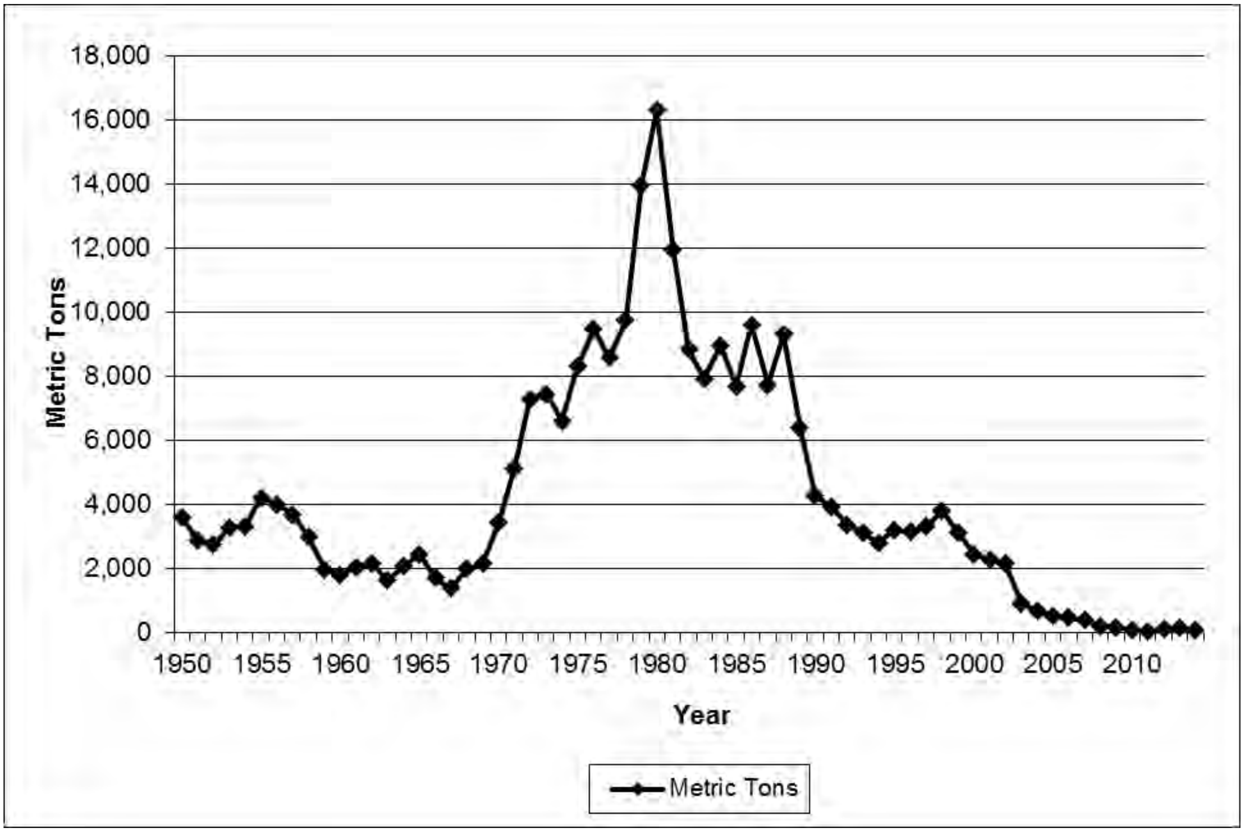


Figure 4.1.1. Commercial harvest of weakfish on the Atlantic coast.

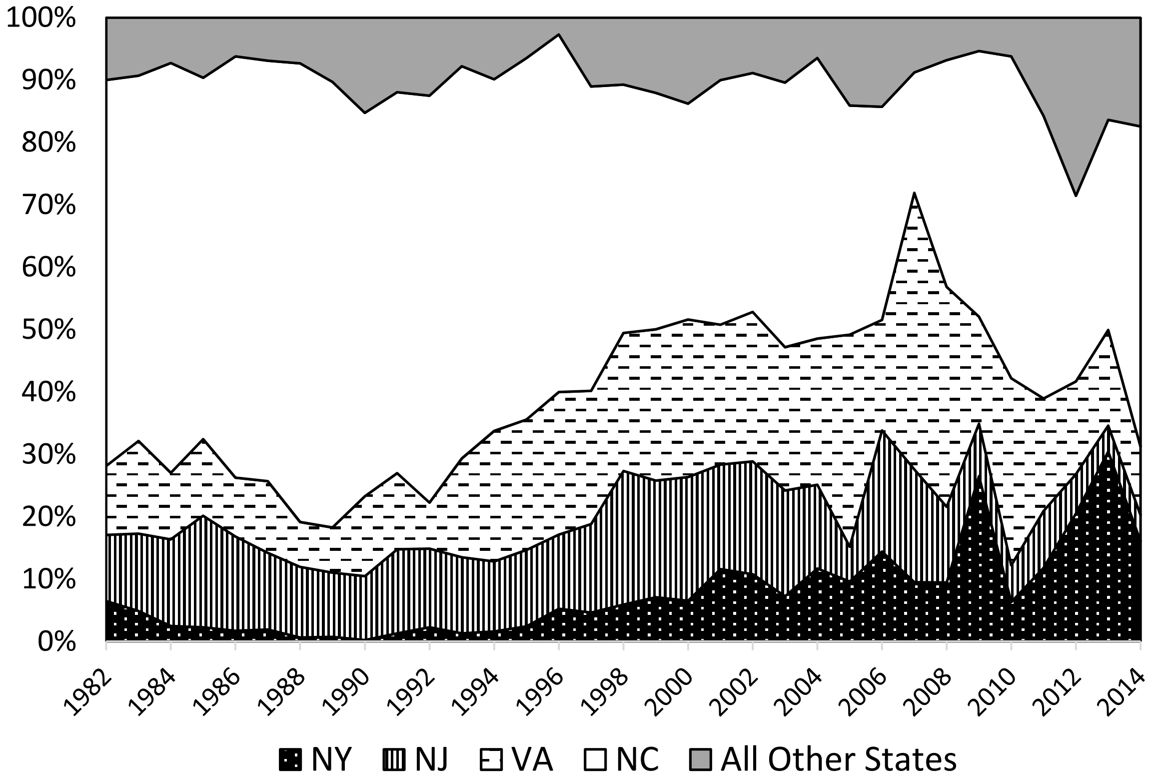


Figure 4.1.2. Percent of annual commercial weakfish landings by state.

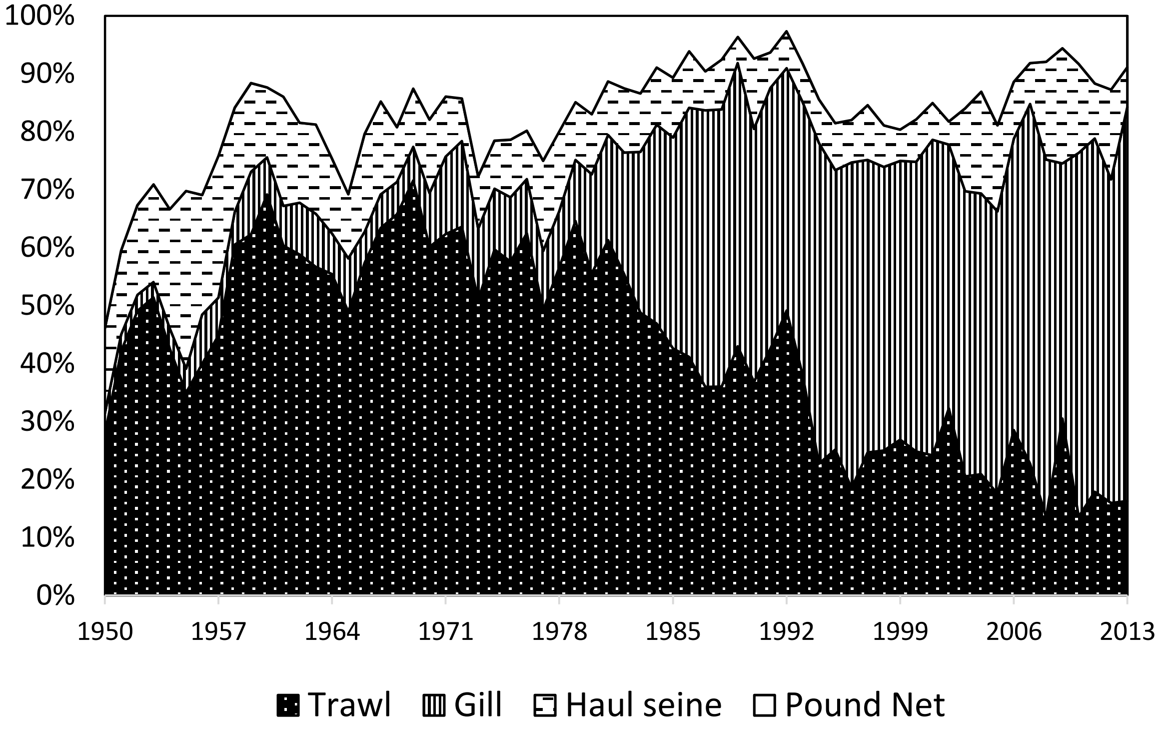


Figure 4.1.3. Percent of annual weakfish landings by major gear.

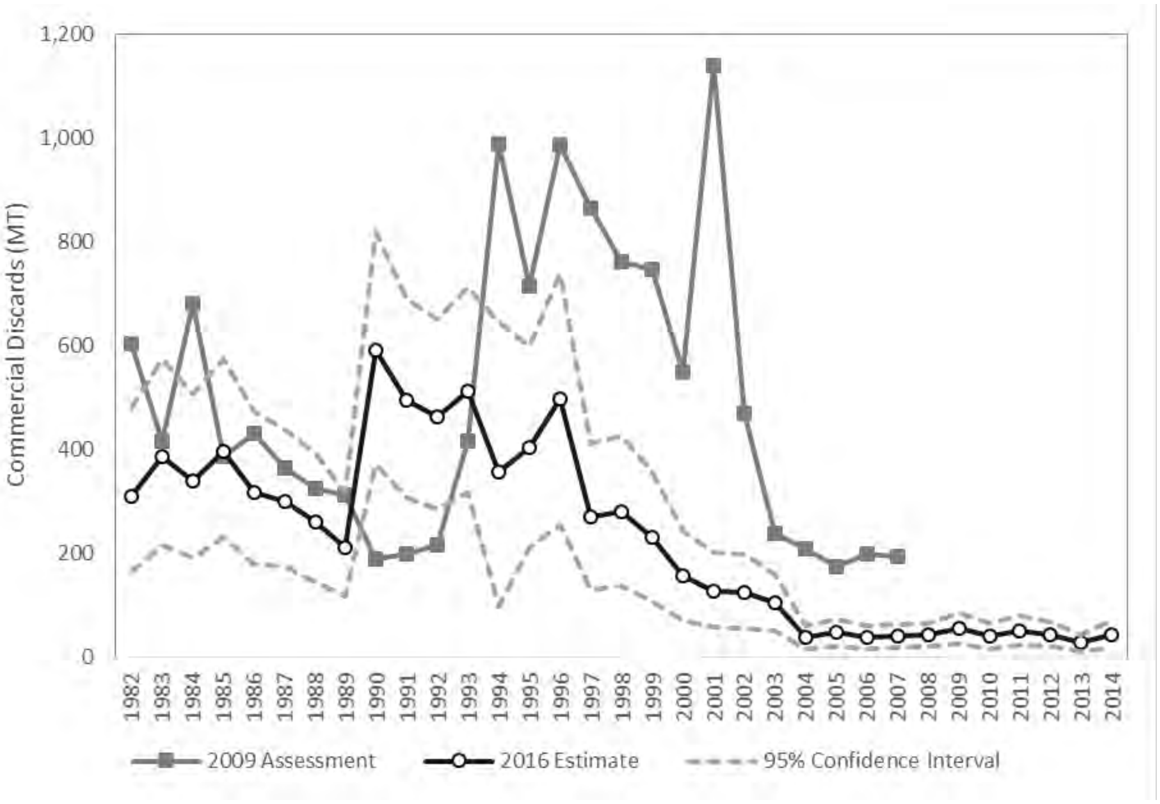


Figure 4.1.4. Comparison of weakfish commercial discard estimates from the 2009 and 2016 stock assessments.

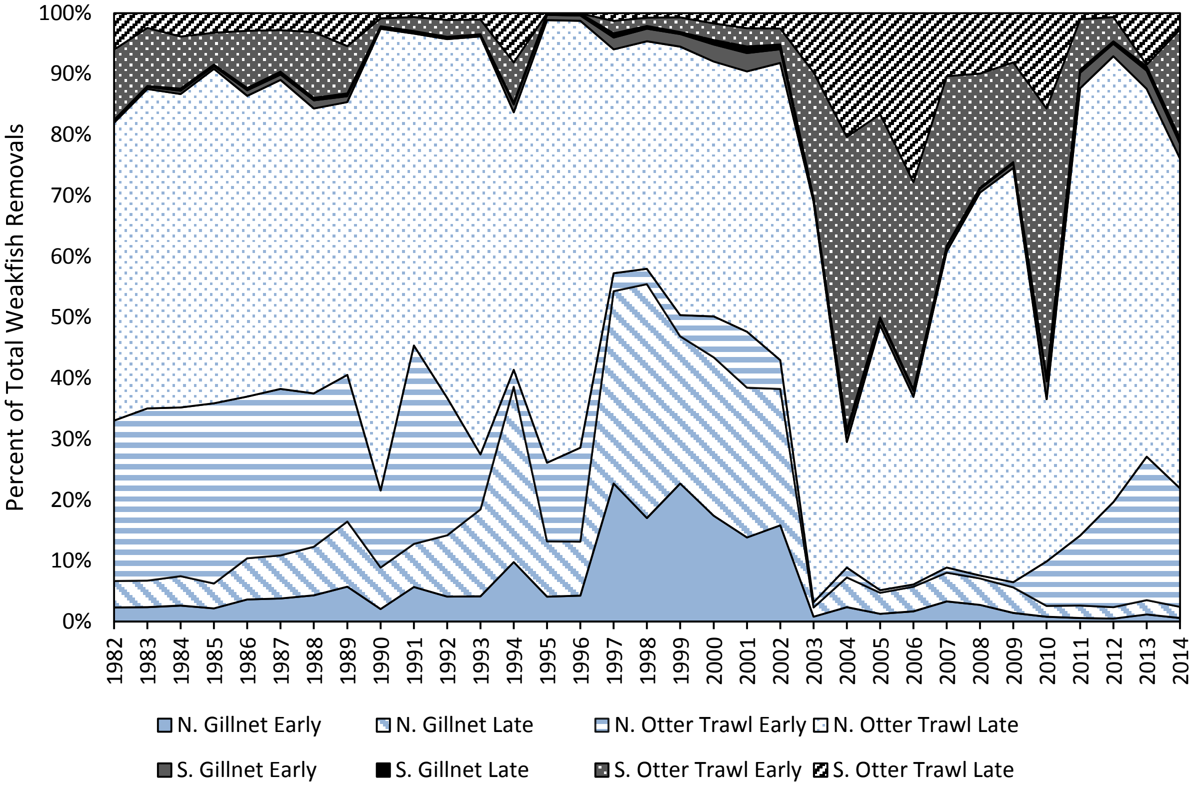


Figure 4.1.5. Proportional distribution of commercial weakfish discards by region, season, and gear.

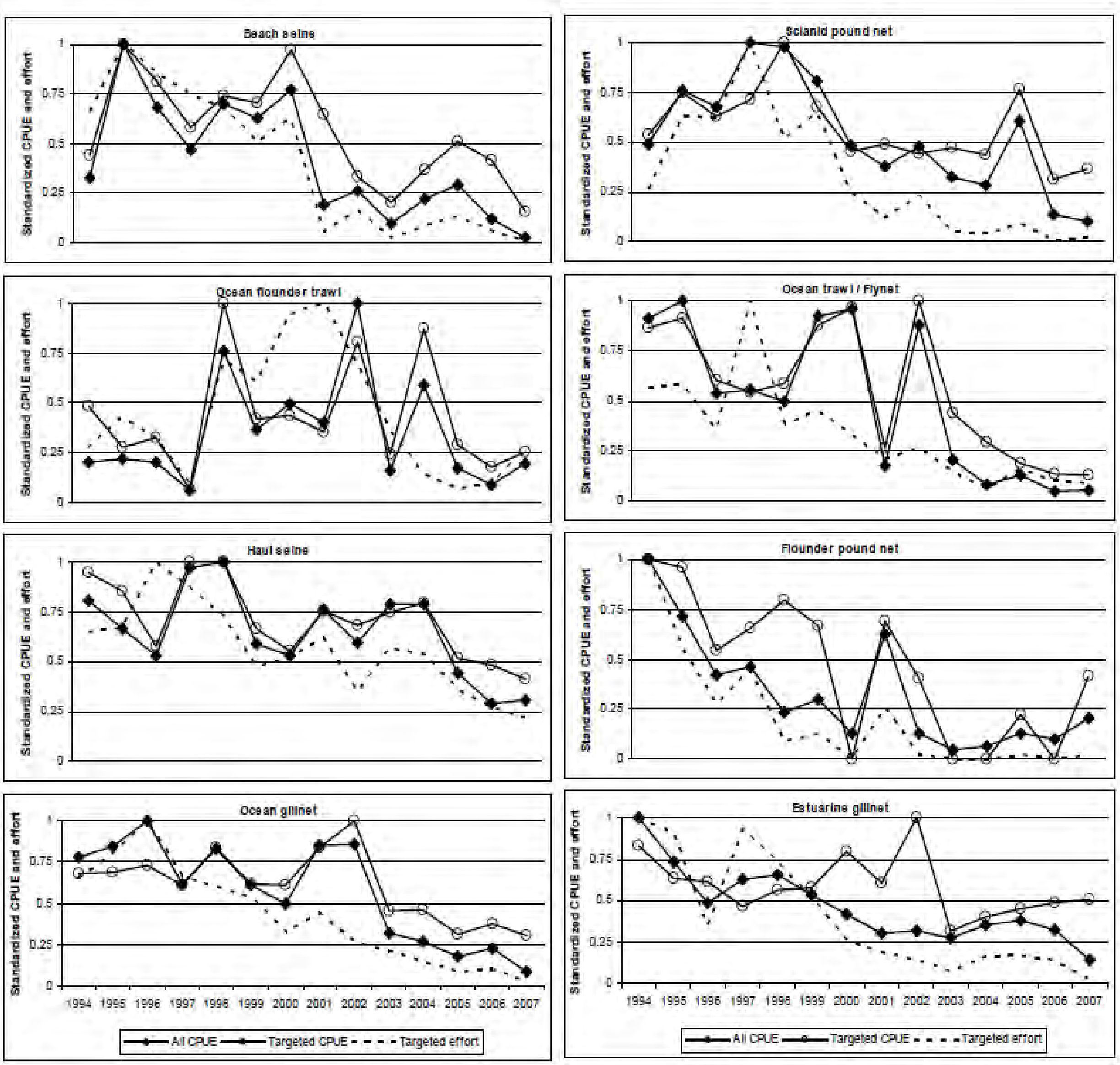


Figure 4.1.6. Standardized commercial CPUE and effort from eight North Carolina Fisheries through 2007. All CPUE=CPUE from all positive trips. “Targeted” = trips with greater than 150 lbs of weakfish.

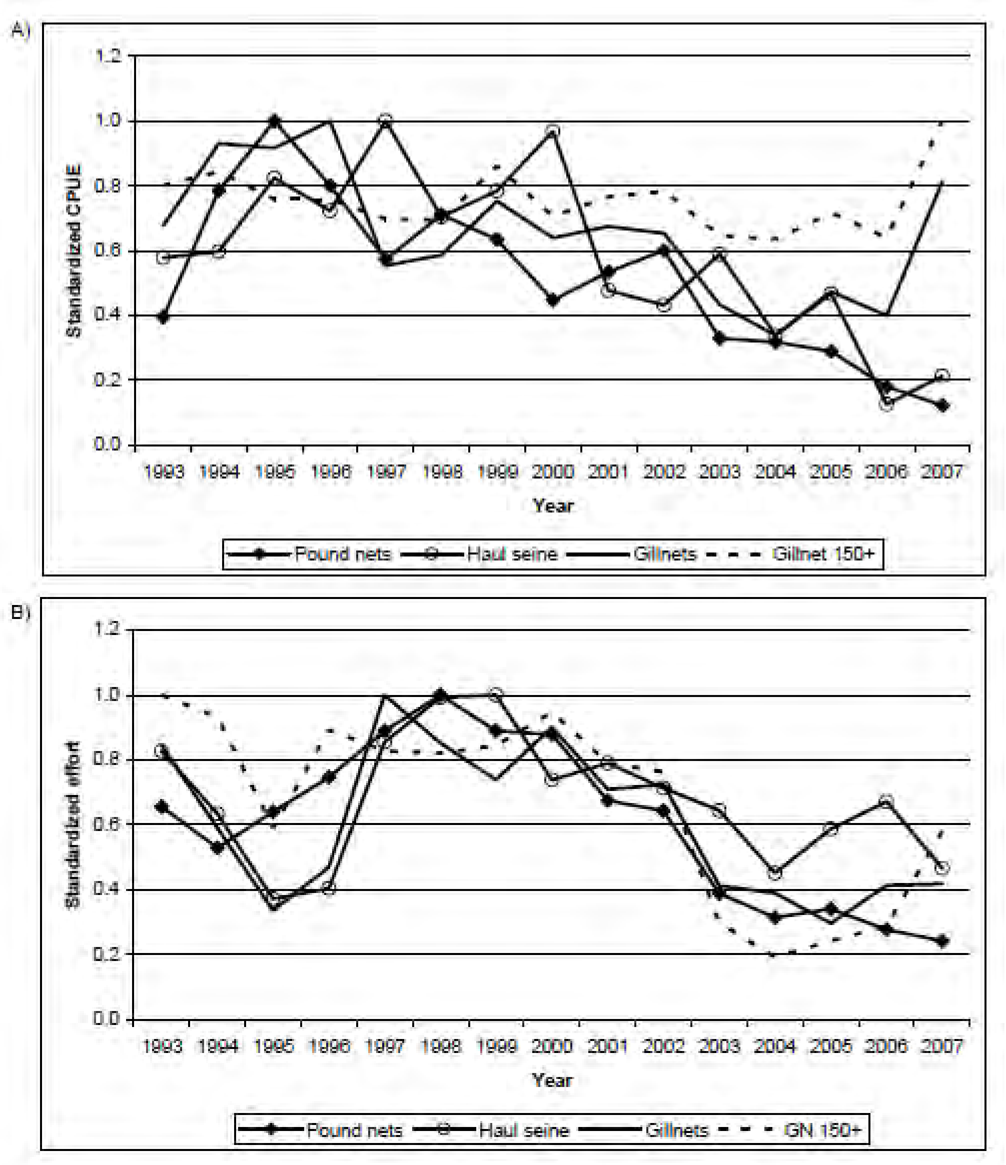


Figure 4.1.7. Standardized commercial CPUE and effort from three Virginia fisheries. A) CPUE. B) Effort. GN 150+ = gillnet trips with 150 pounds or more of weakfish.

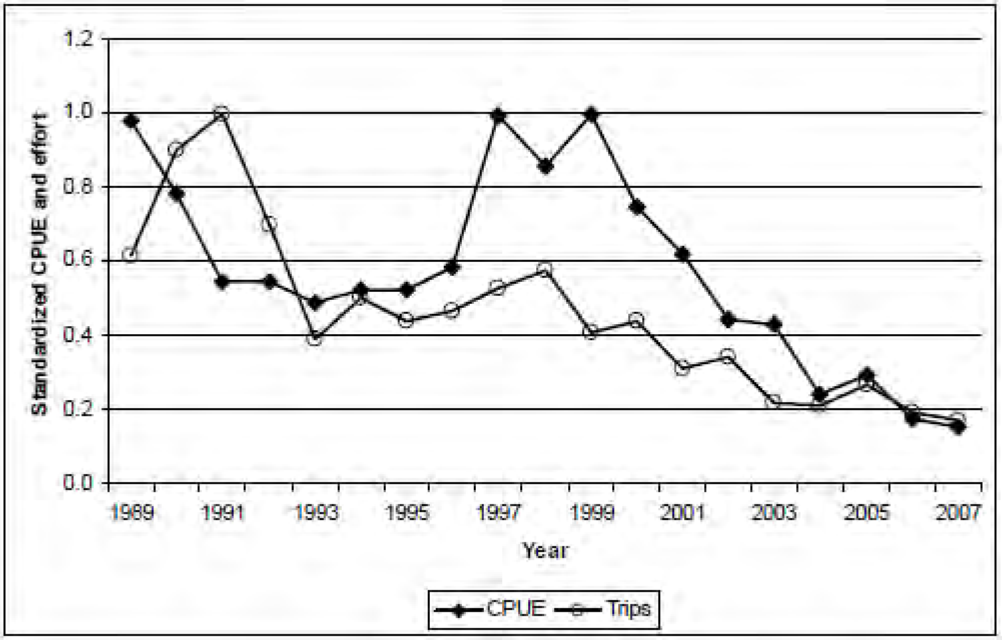


Figure 4.1.8. Standardized commercial CPUE and effort from Delaware's gillnet fishery.

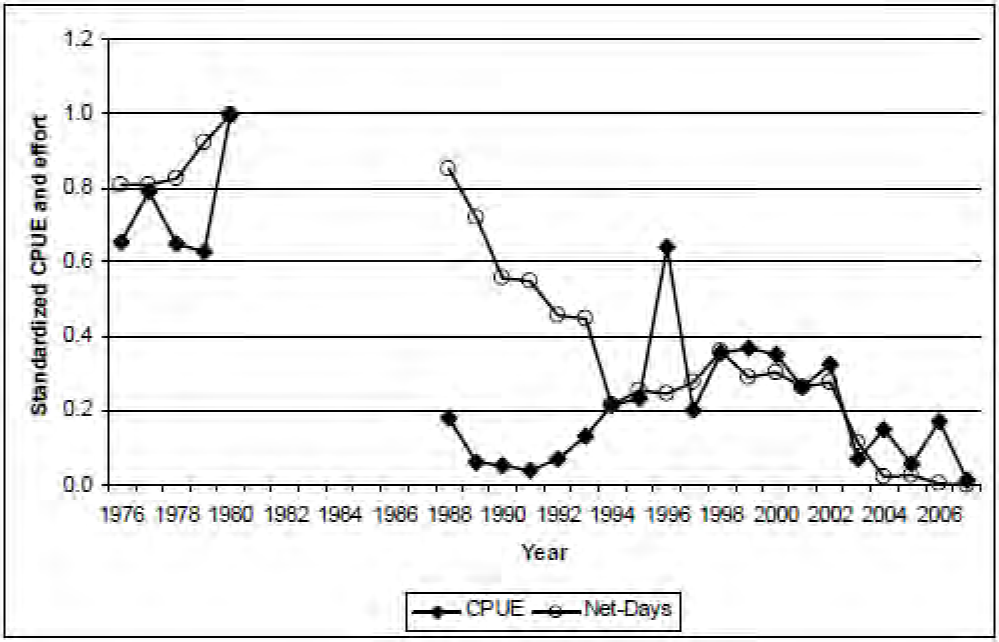
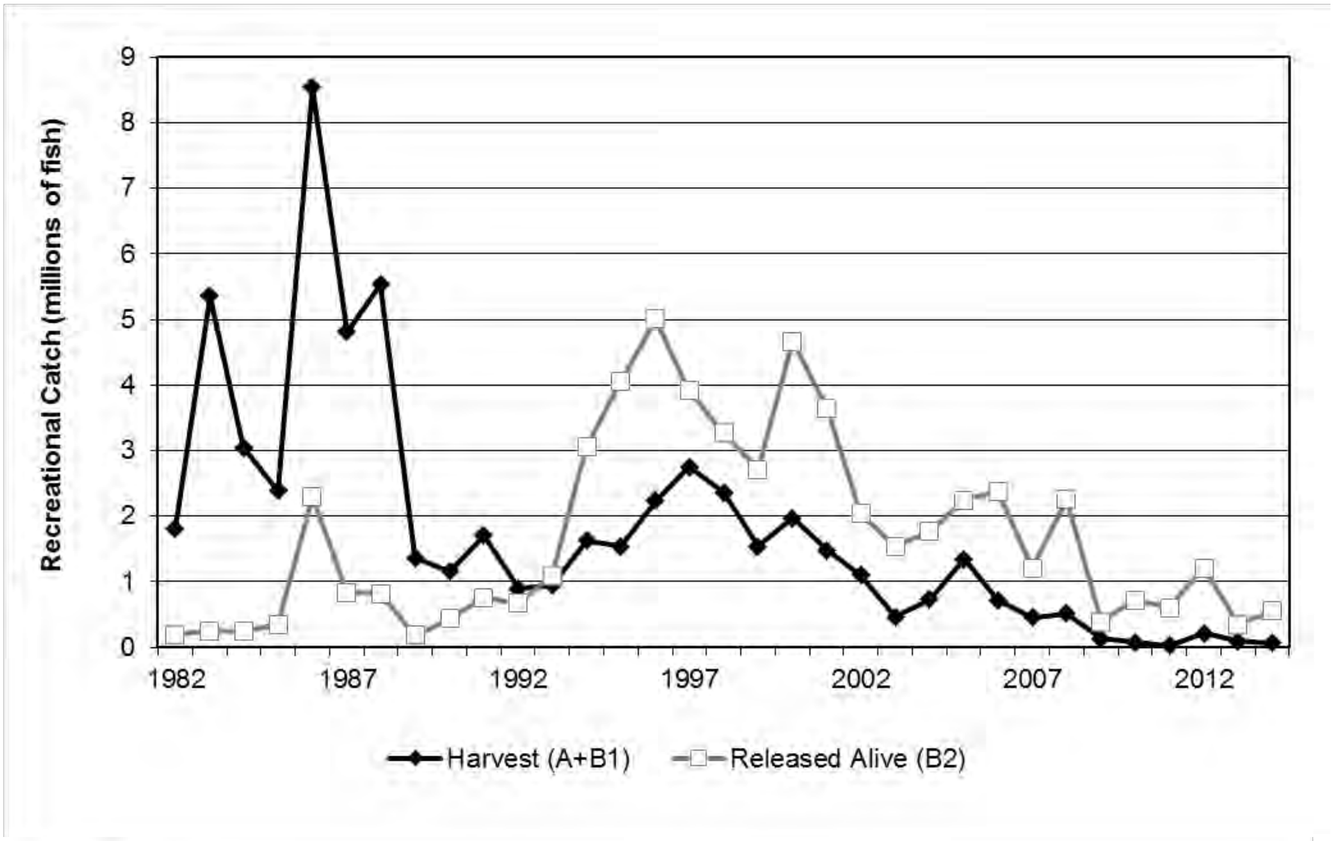


Figure 4.1.9. Standardized commercial CPUE and effort from the Potomac River Pound net fishery.



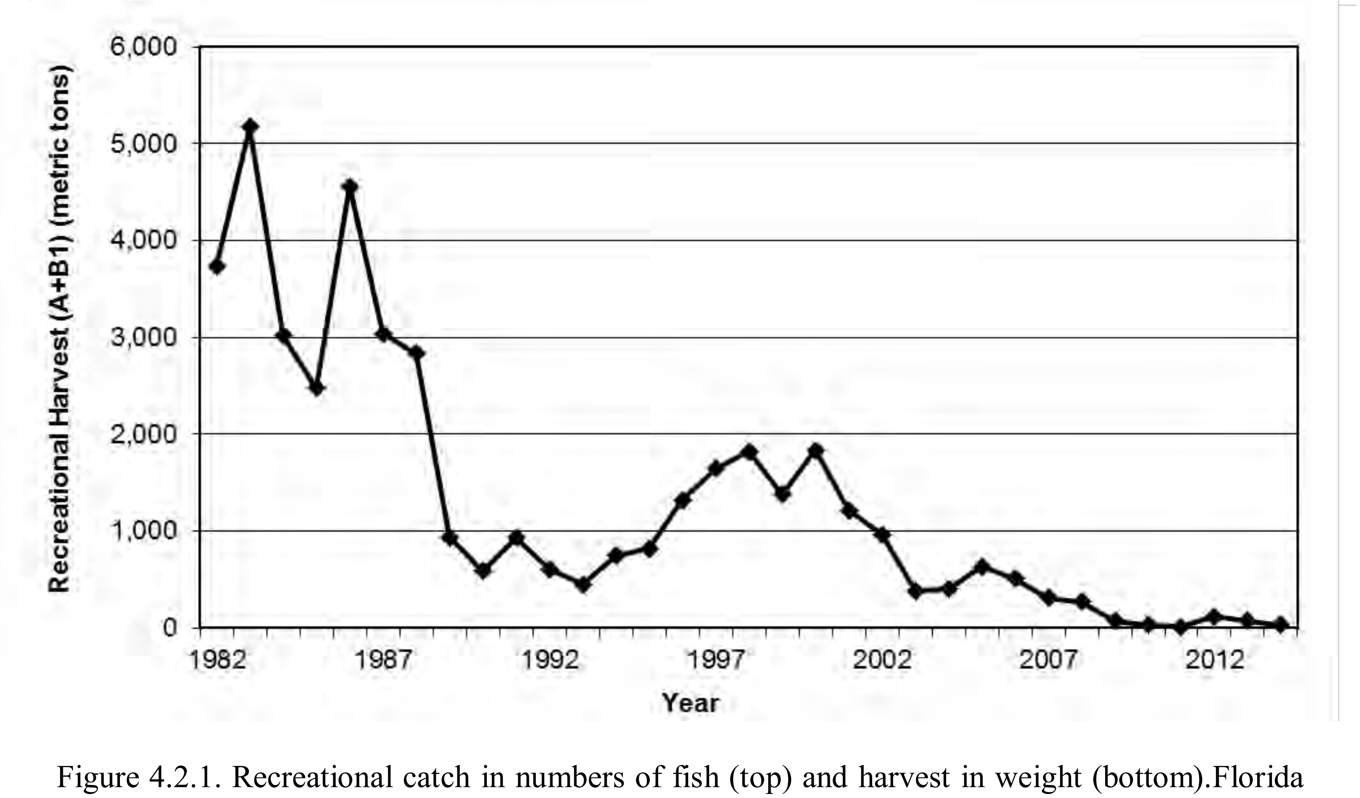


Figure 4.2.1. Recreational catch in numbers of fish (top) and harvest in weight (bottom).Florida catch has been corrected for the presence of hybrids.

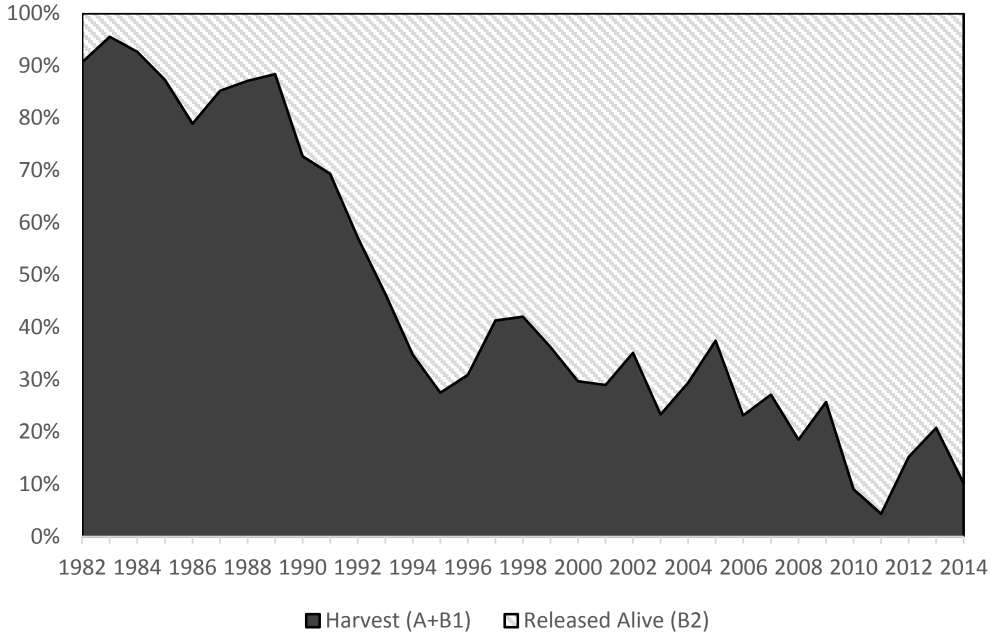
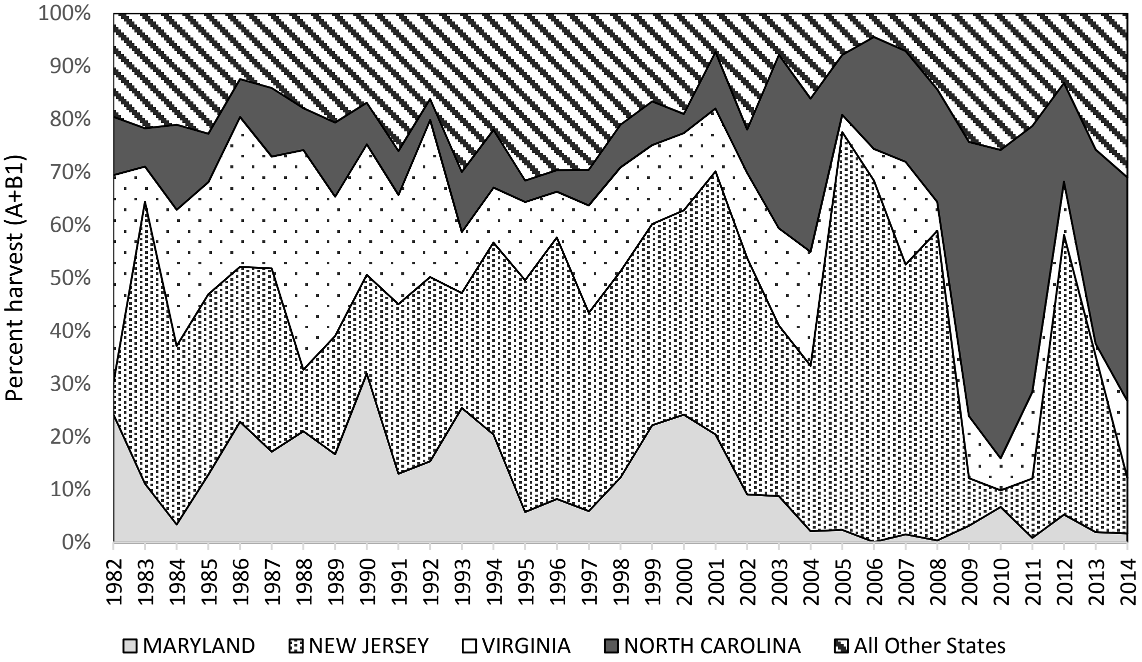


Figure 4.2.2. Percent of recreationally caught weakfish that are harvested vs. released alive.



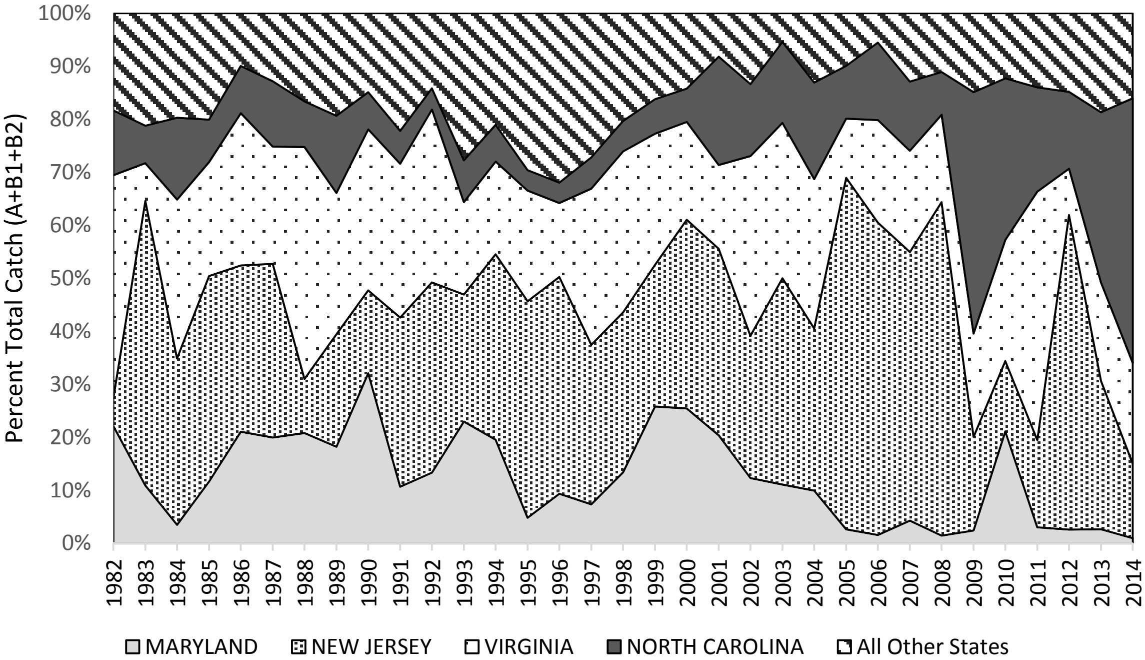


Figure 4.2.3. Percent of recreational harvest (A+B; top) and total catch (A+B1+B2; bottom) by state. Florida catch has been corrected for the presence of hybrids.

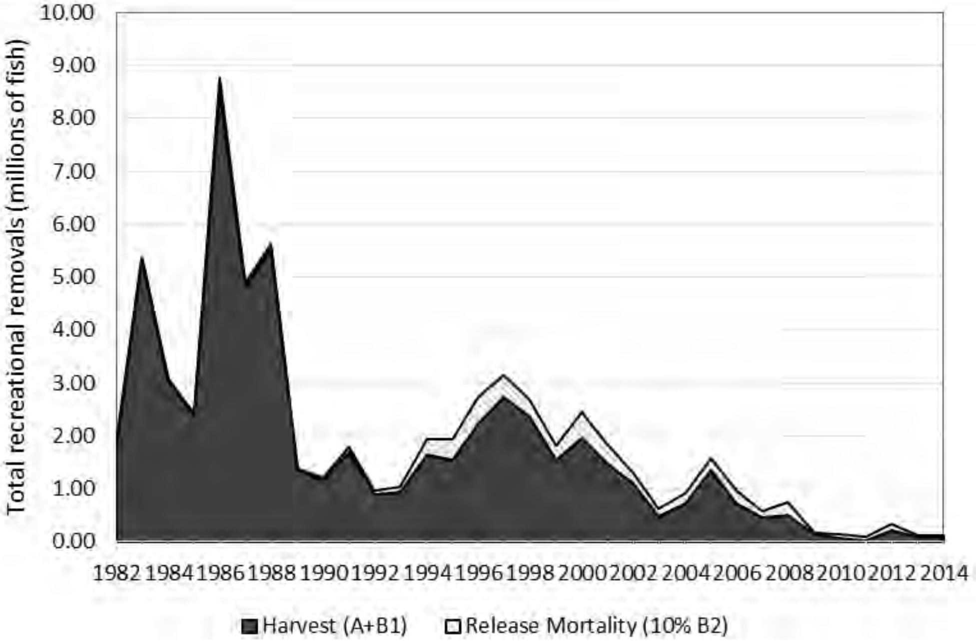


Figure 4.2.4. Total recreational removals by year. Florida catch has been corrected for the presence of hybrids.

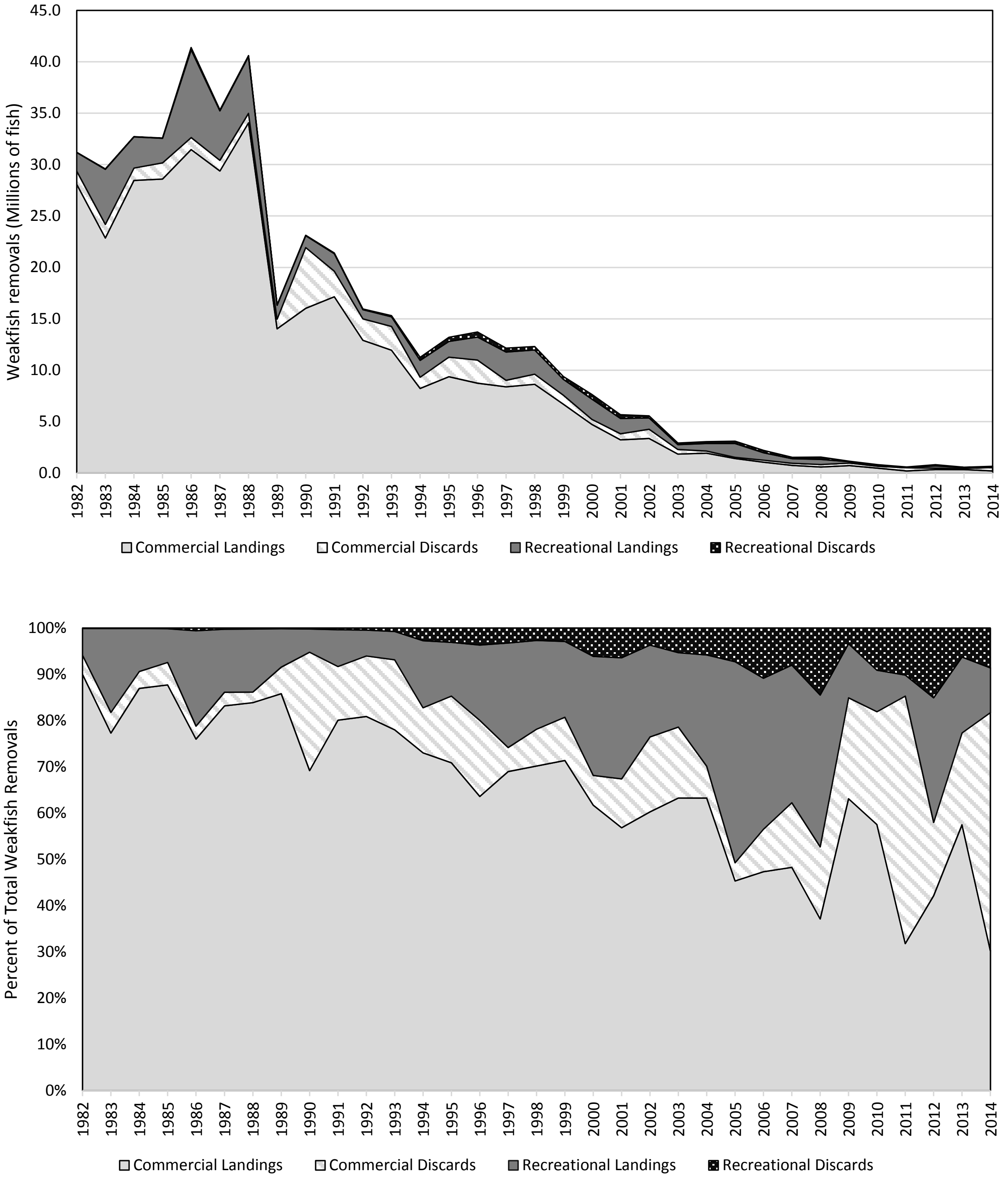


Figure 4.3.1. Total weakfish removals for the Atlantic coast by source, 1982-2014, in millions of fish (top) and in percent (bottom). Florida catch has been corrected for the presence of hybrids.

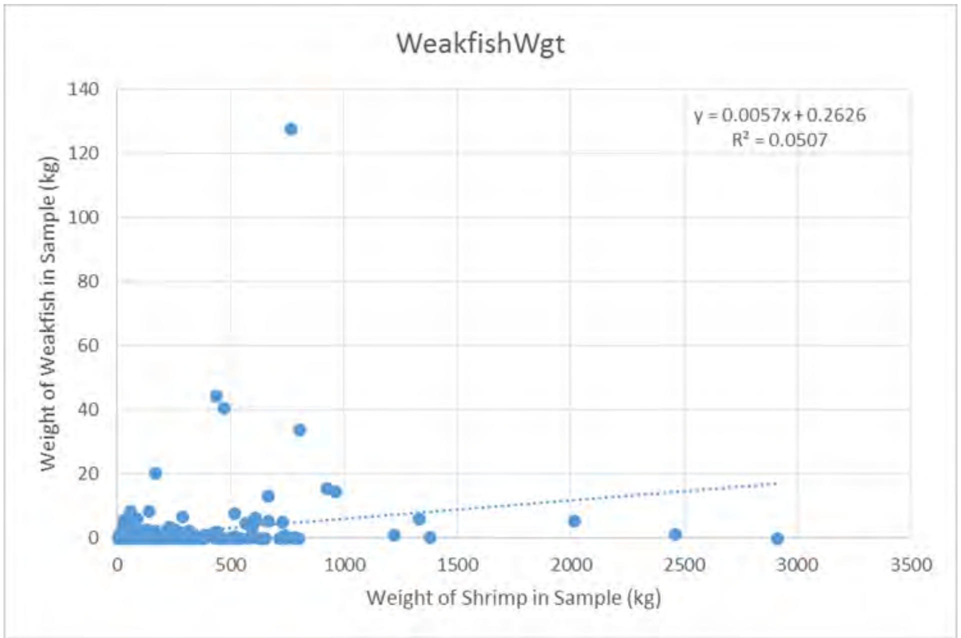


Figure 5.1.1. Relationship between weight of weakfish bycatch in a sample and weight of retained shrimp.

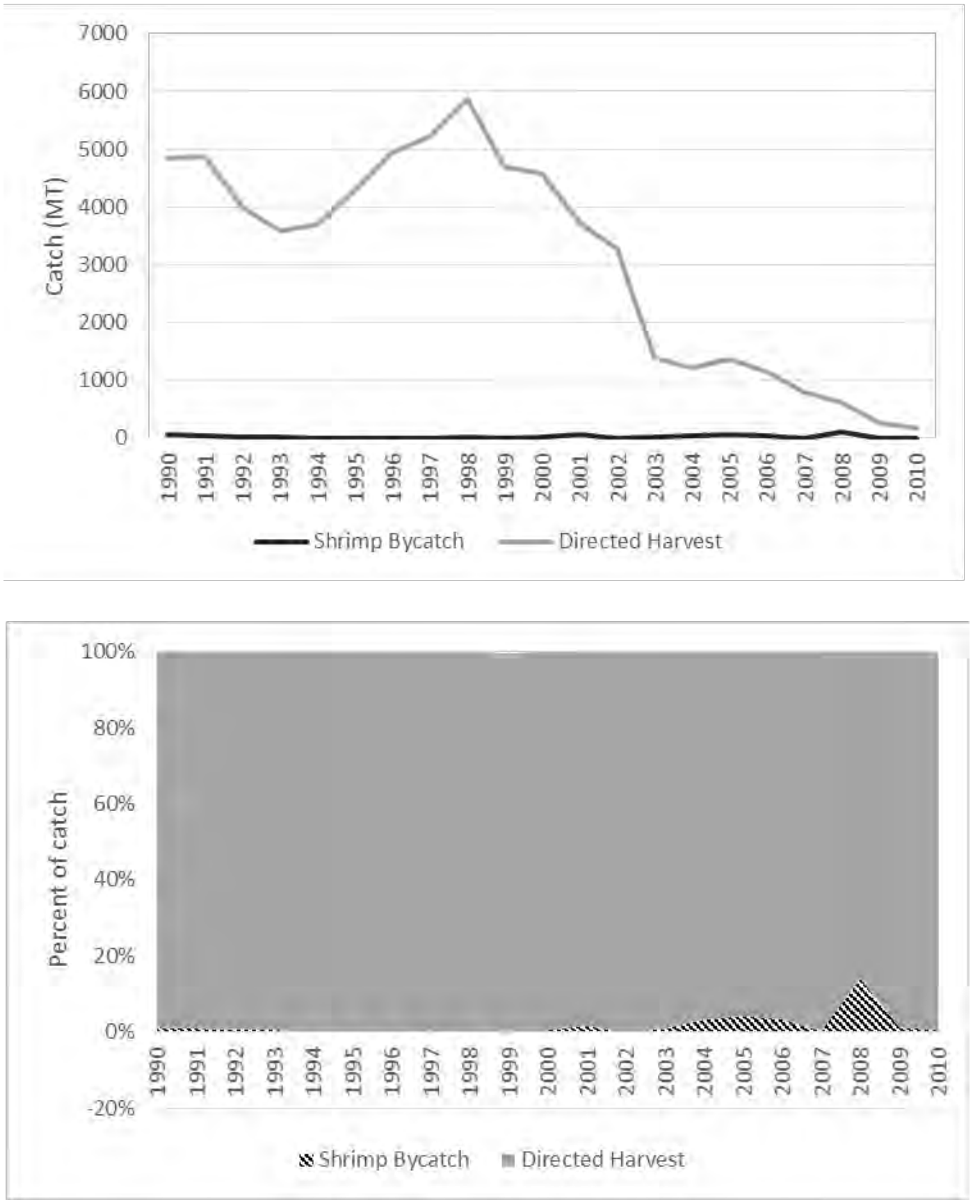


Figure 5.1.2. Estimates of shrimp trawl bycatch compared with total directed removals.

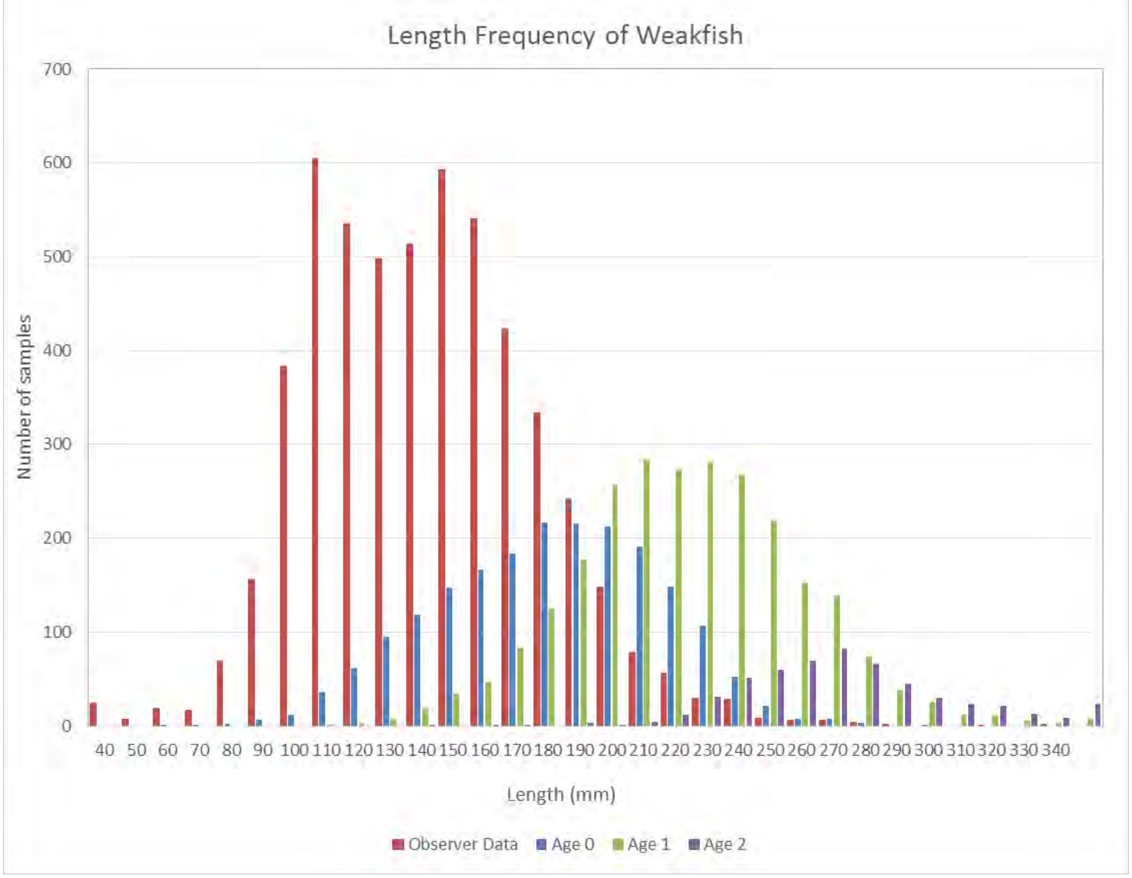


Figure 5.1.3. Length frequency of weakfish from shrimp trawl observer samples compared to length frequencies of aged weakfish from southern region fishery independent and dependent sources.

Figure 5.2.1. Comparison of MRFSS and MRIP estimates of recreational harvest and catch and the associated MRIP 95% confidence intervals.

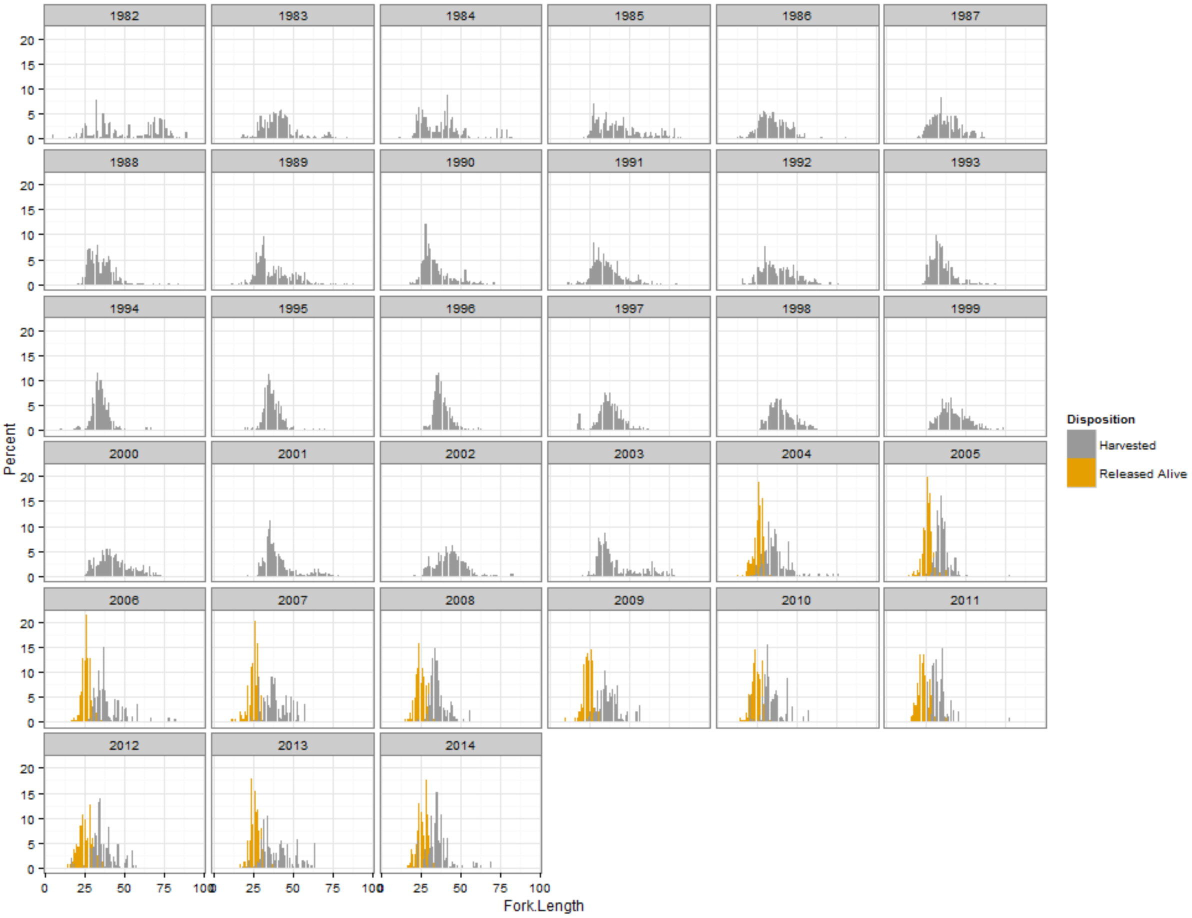


Figure 5.2.2. Length frequencies of MRFSS/MRIP samples of weakfish by disposition. Lengths of released alive fish are not available from MRFSS prior to 2004.

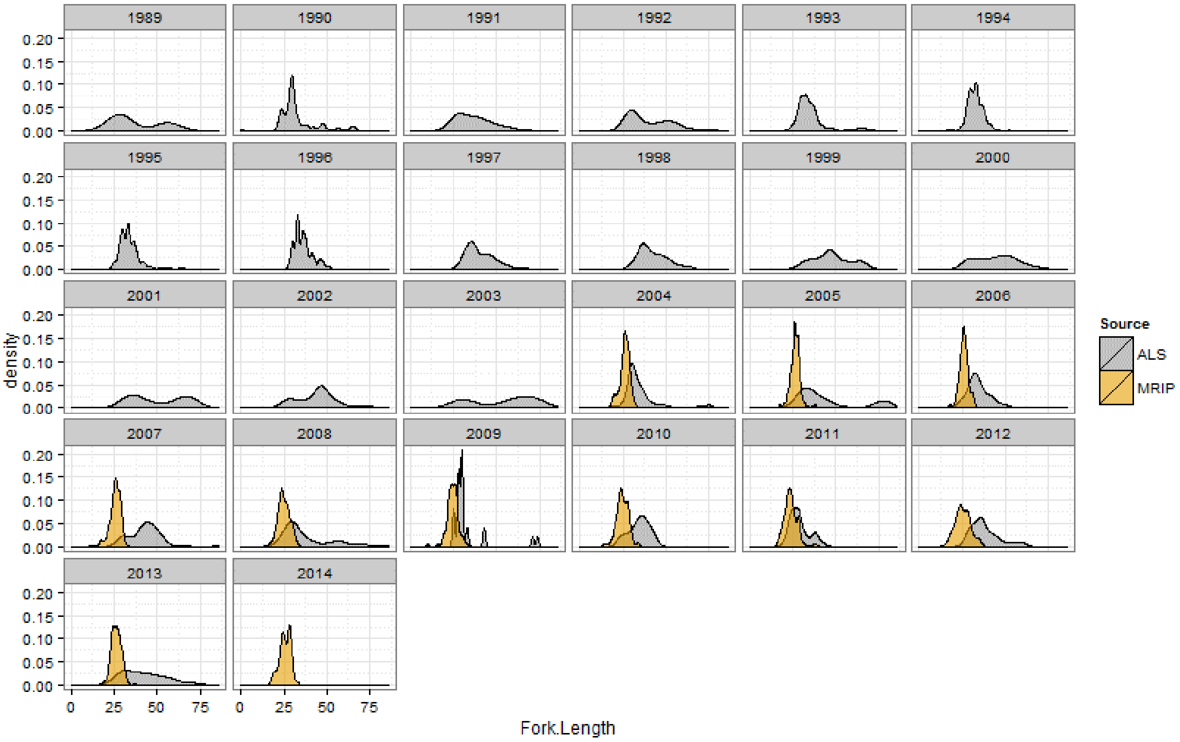


Figure 5.2.3. Comparison of length frequencies from weakfish released alive by ALS volunteer taggers and by headboat anglers as measured by MRIP (Type 9 lengths).

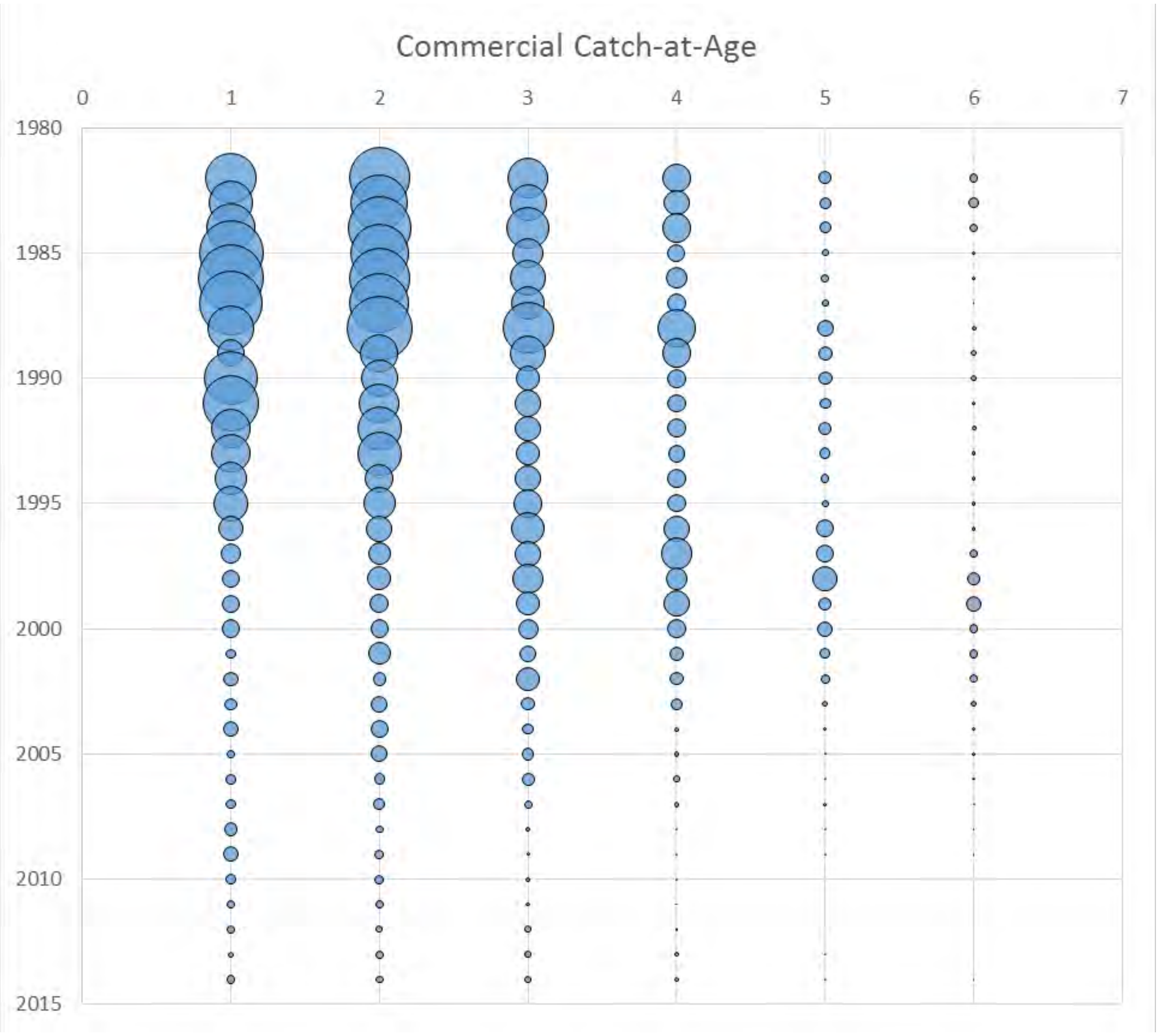


Figure 5.3.1. Commercial catch-at-age input to the age-structured models.

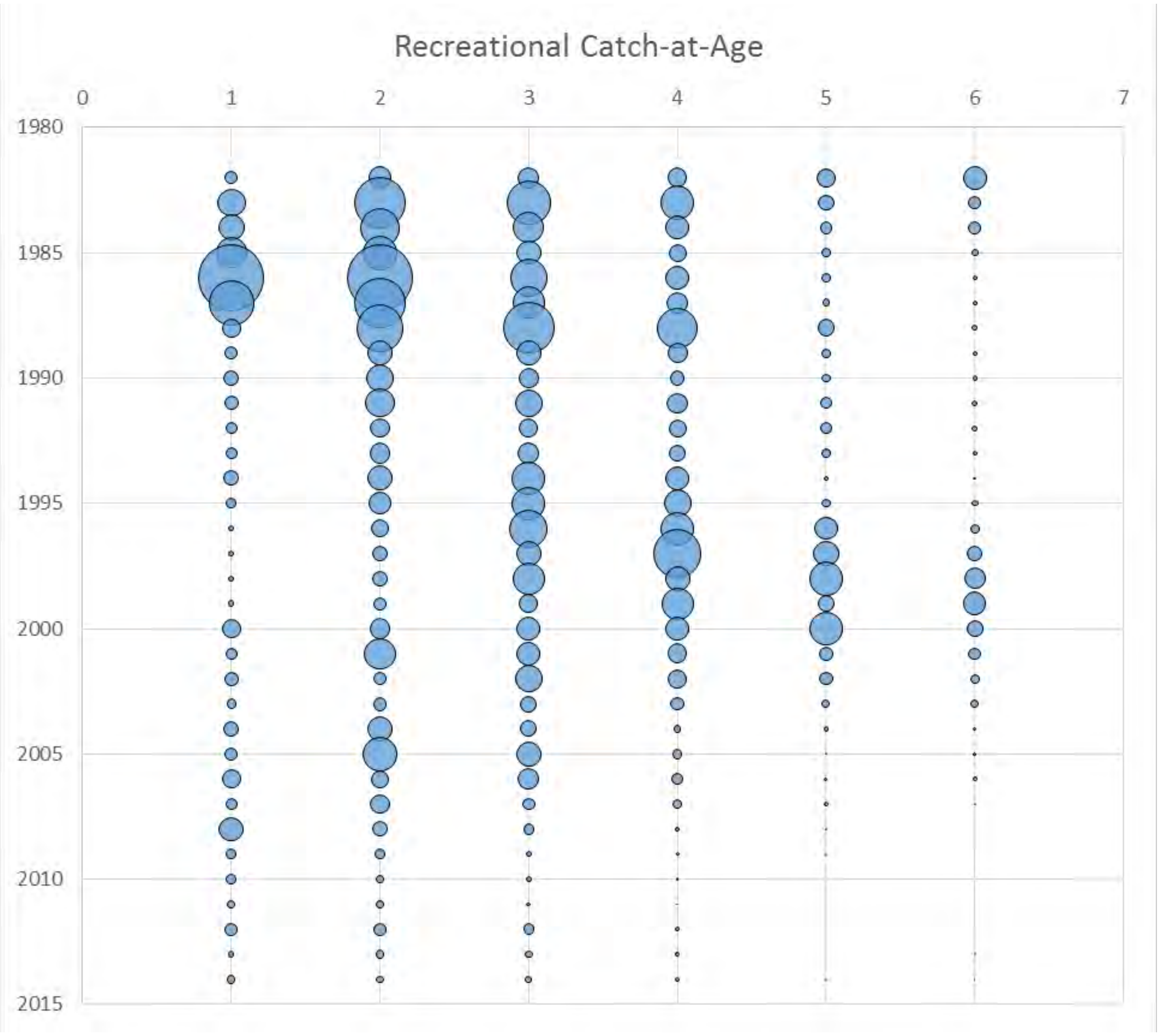


Figure 5.3.2. Recreational catch-at-age used as input to the age-structured models.

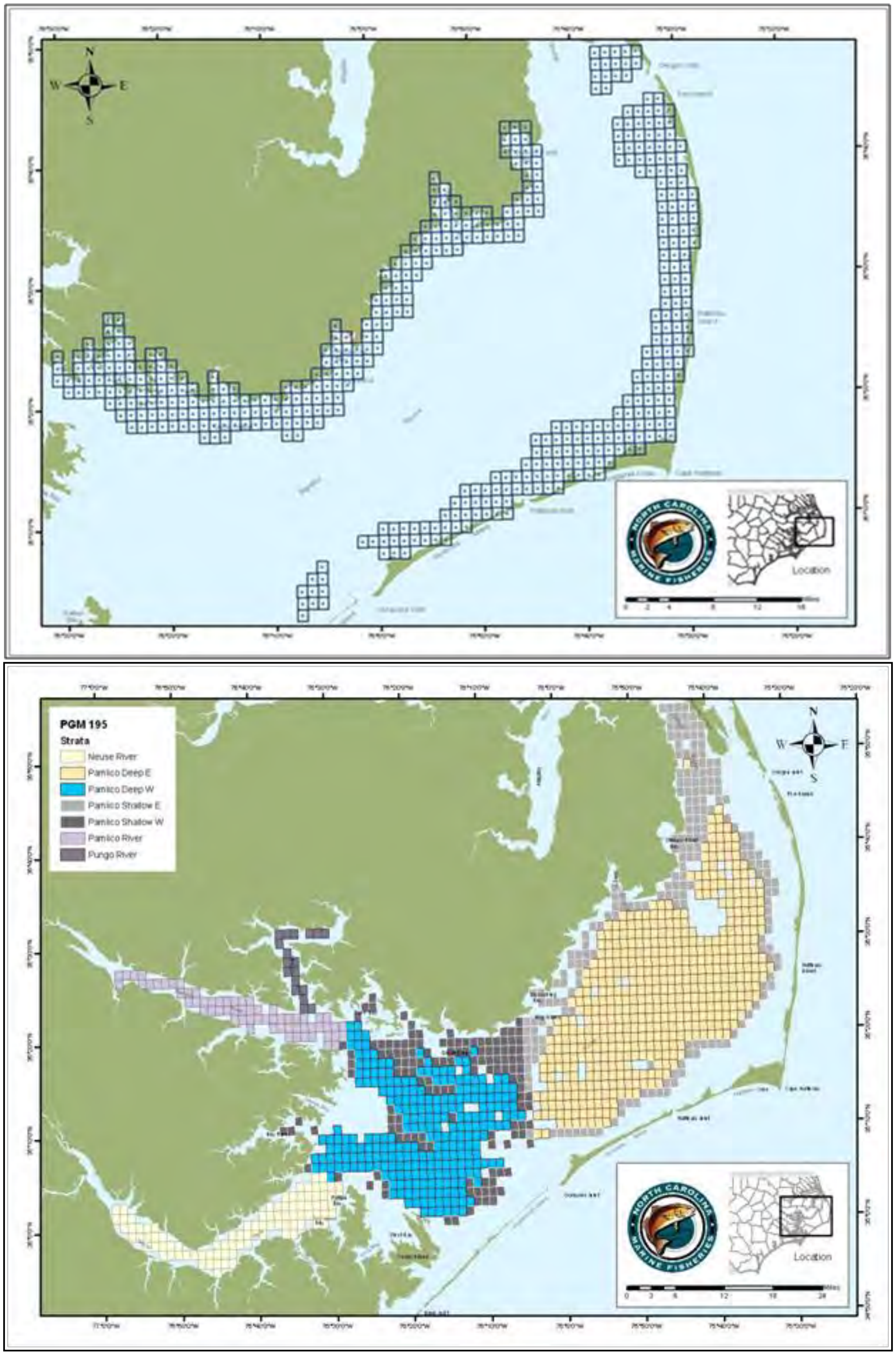


Figure 6.1.1. Sampling location in Hyde and Dare counties at the start of the NC Gill Net Survey in 2001 (top) and expanded sampling by 2008. Sampling in the Neuse, Pamlico, and Pungo rivers was added in 2003. Areas in the Southern District were added in 2008.

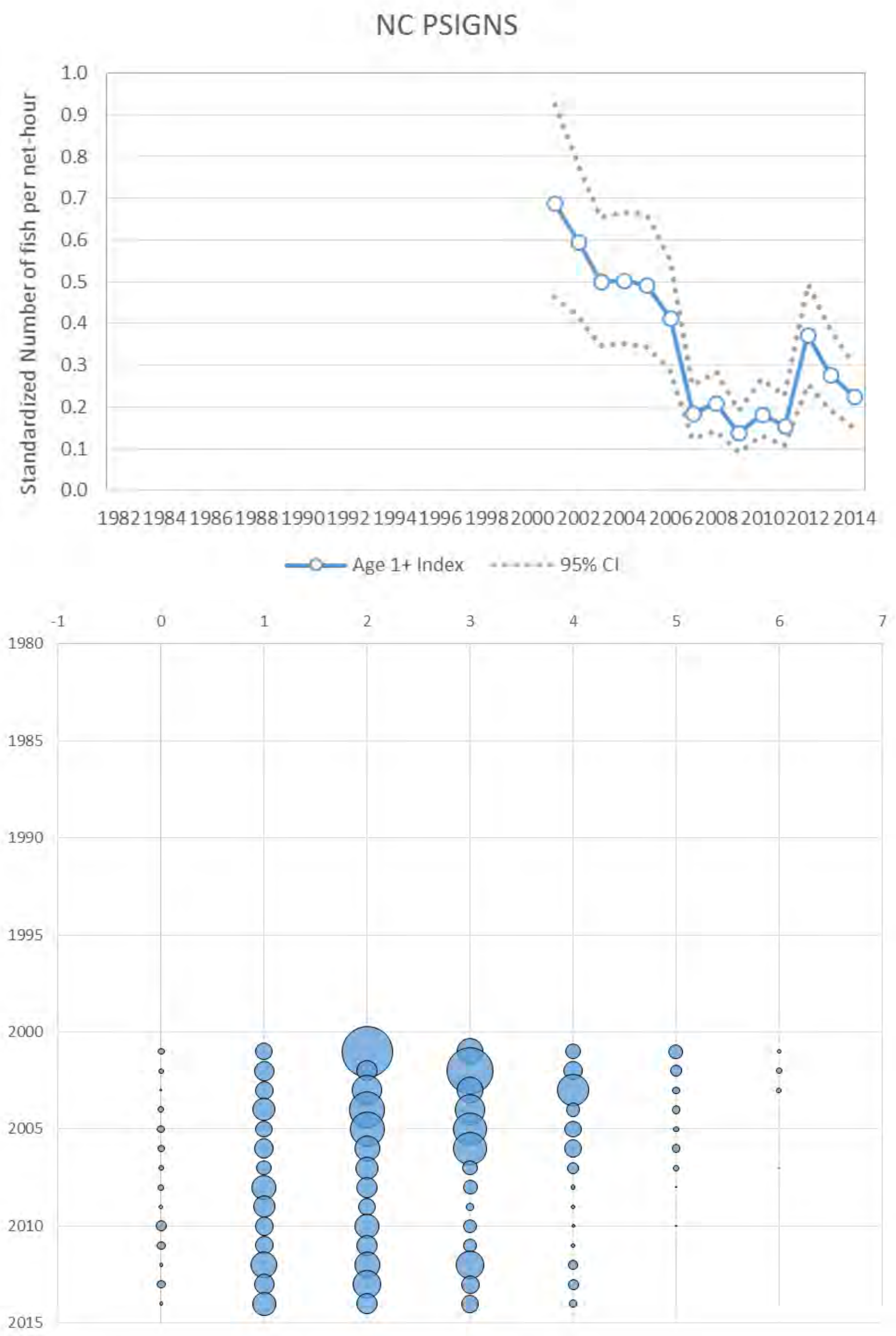


Figure 6.1.2. Total age-1+ index (top) and index-at-age (bottom) from the North Carolina Gillnet Survey.

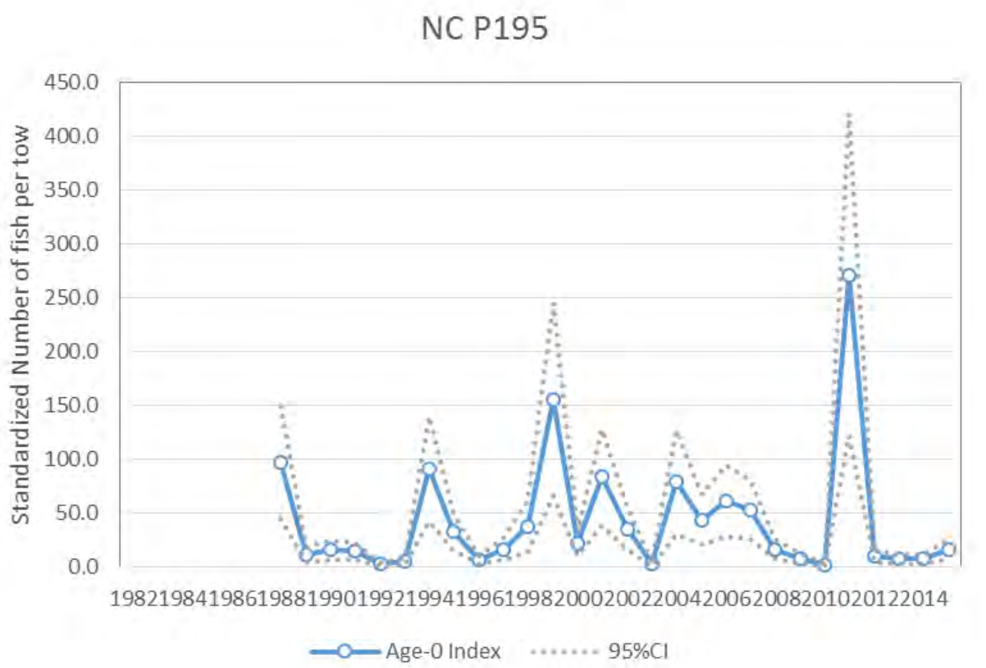
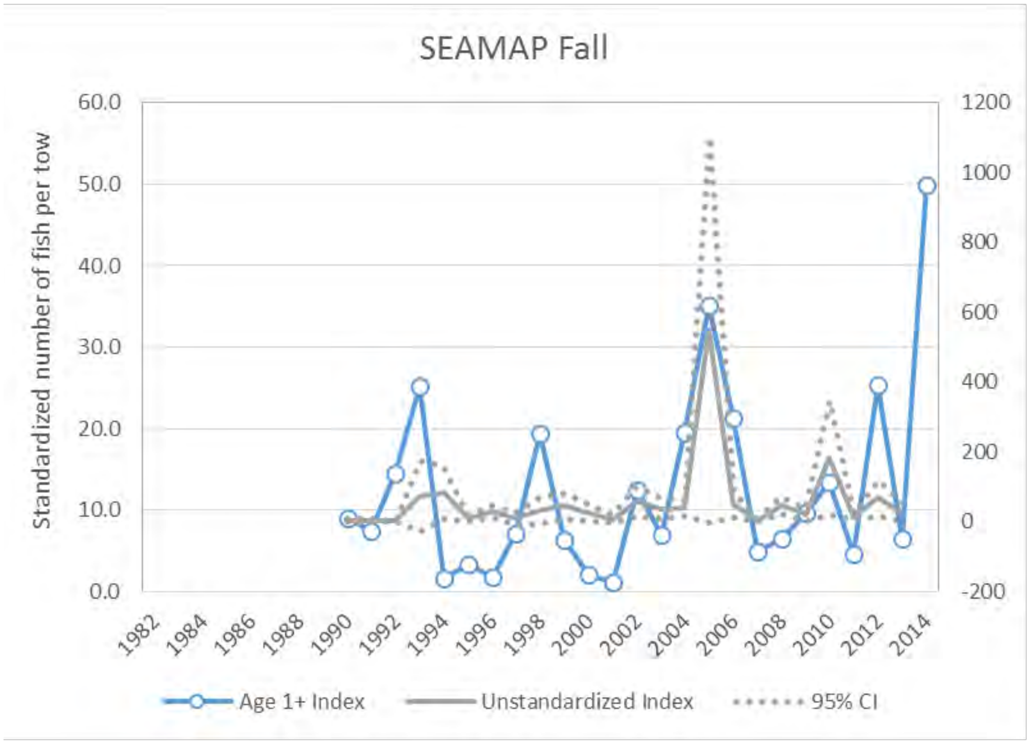


Figure 6.1.3. North Carolina Pamlico Sound (Program 195) YOY index.



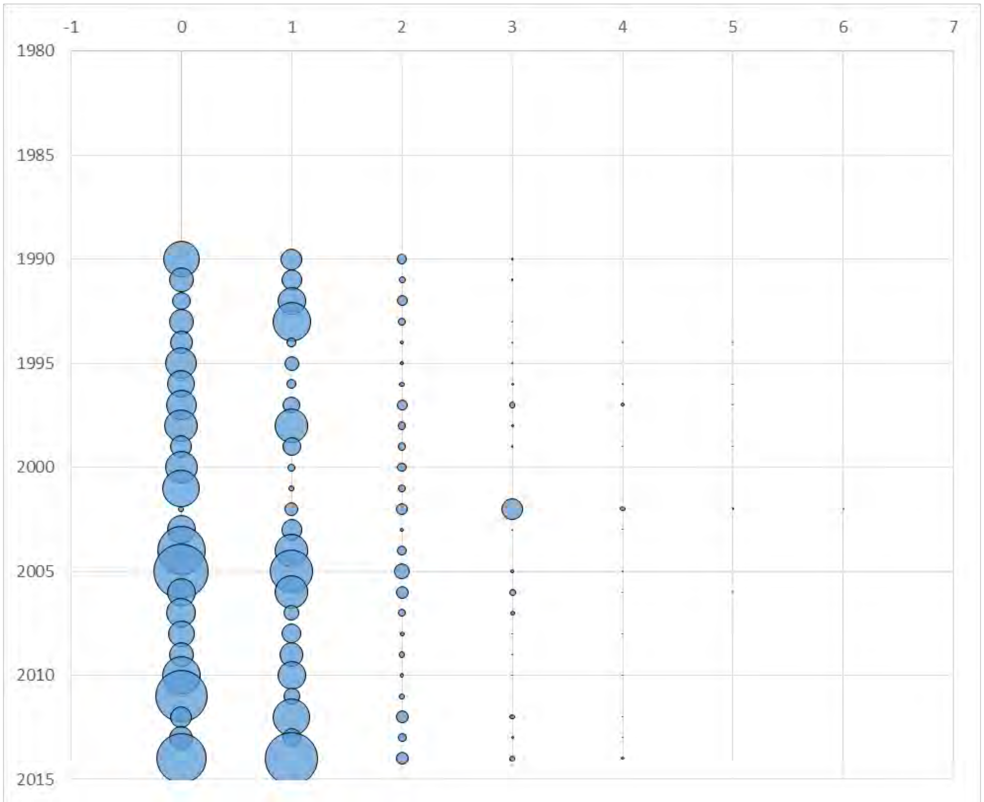


Figure 6.1.4. Total age-1+ index (top) and index-at-age (bottom) from SEAMAP. CIs for indices standardized with a zero-inflated model were not available, so the unstandardized index and CIs are shown for reference.

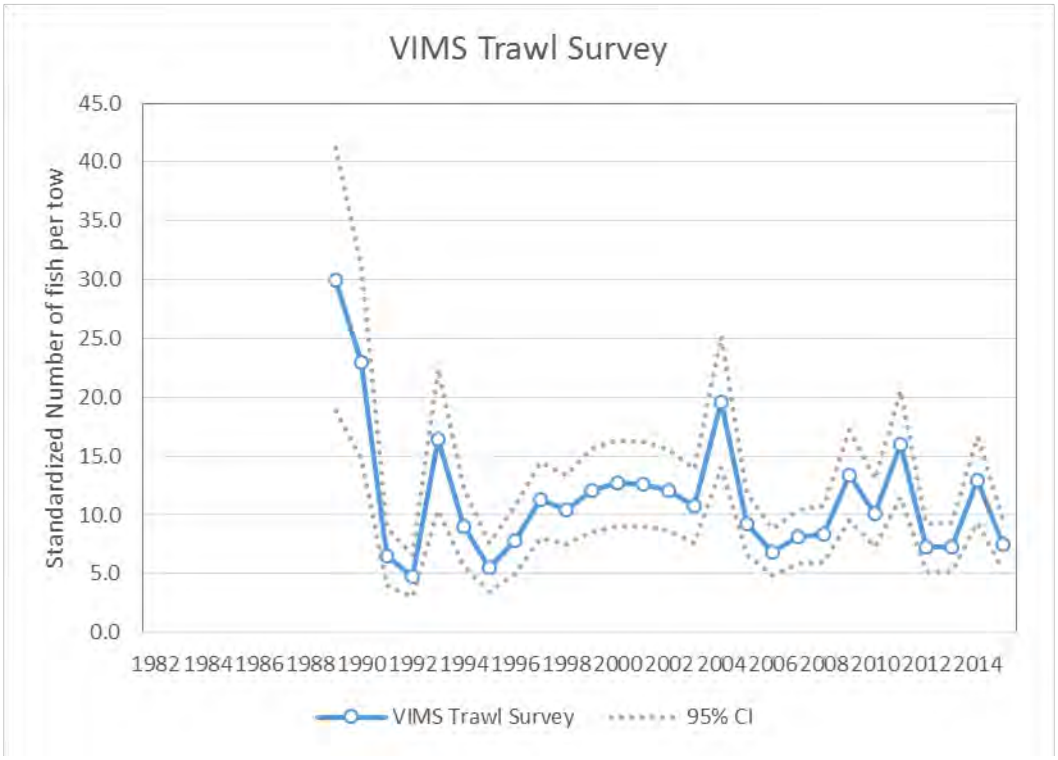


Figure 6.1.5.VIMS Chesapeake Bay Trawl Survey YOY index.

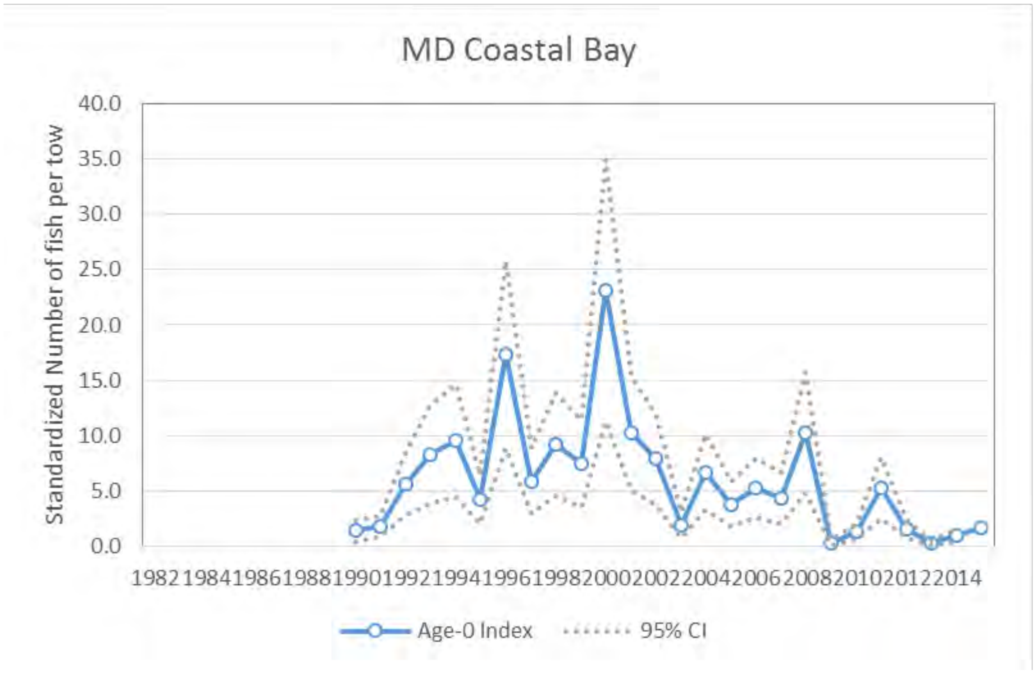


Figure 6.1.6. Maryland Coastal Bay Trawl Survey YOY index.

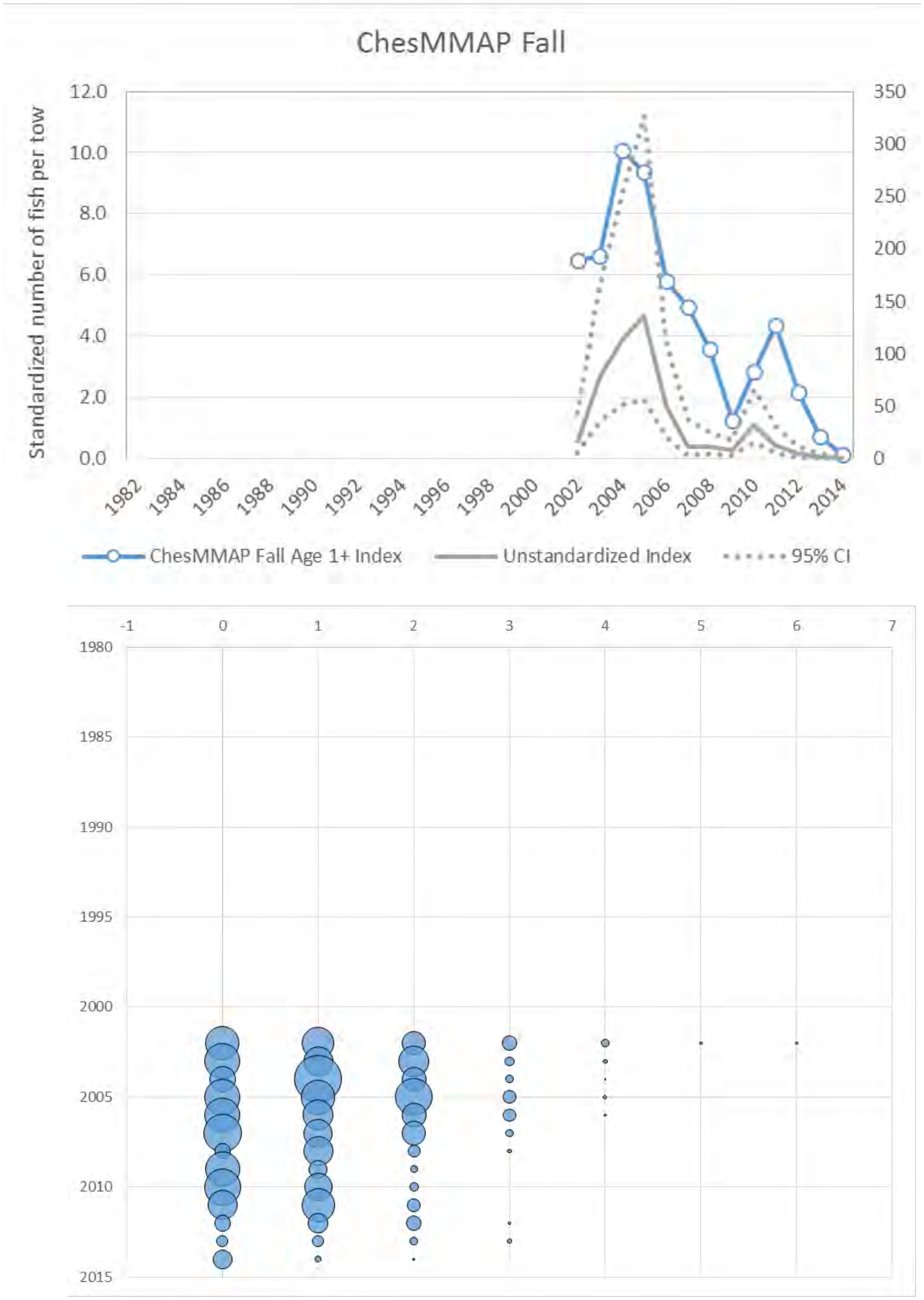
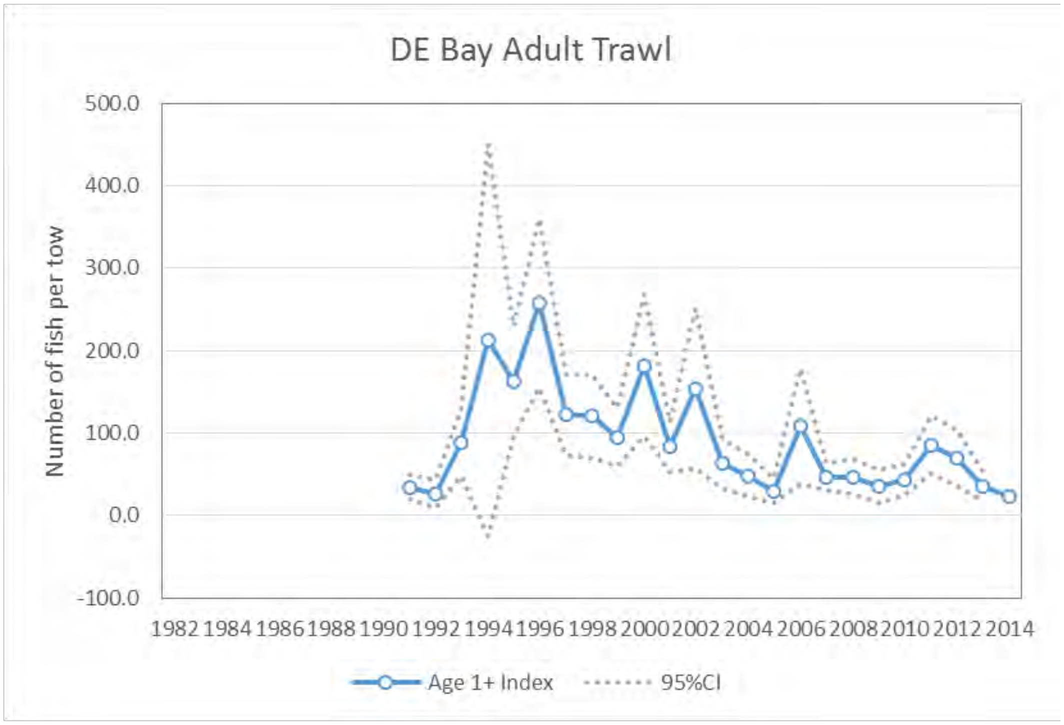


Figure 6.1.7. Total age-1+ index (top) and index-at-age (bottom) from ChesMMAP.CIs for indices standardized with a zero-inflated model were not available, so the unstandardized index and CIs are shown for reference.



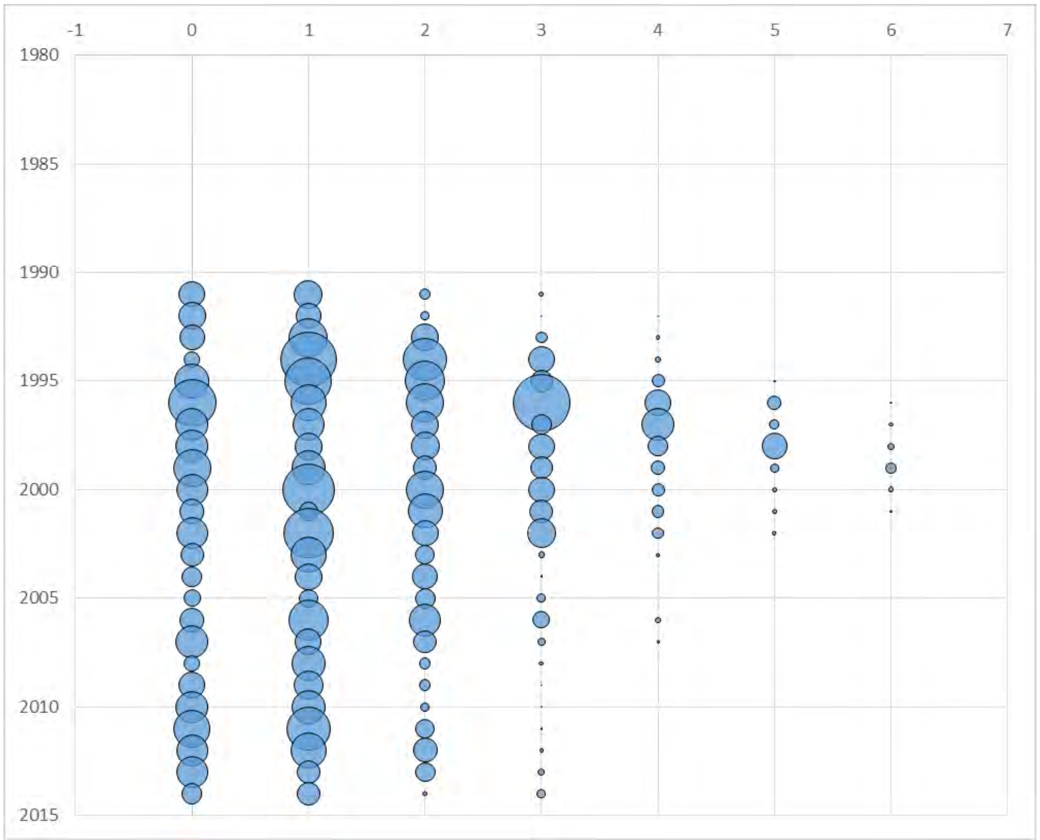


Figure 6.1.8. Total age-1+ index (top) and index-at-age (bottom) from the Delaware Bay Trawl Survey.

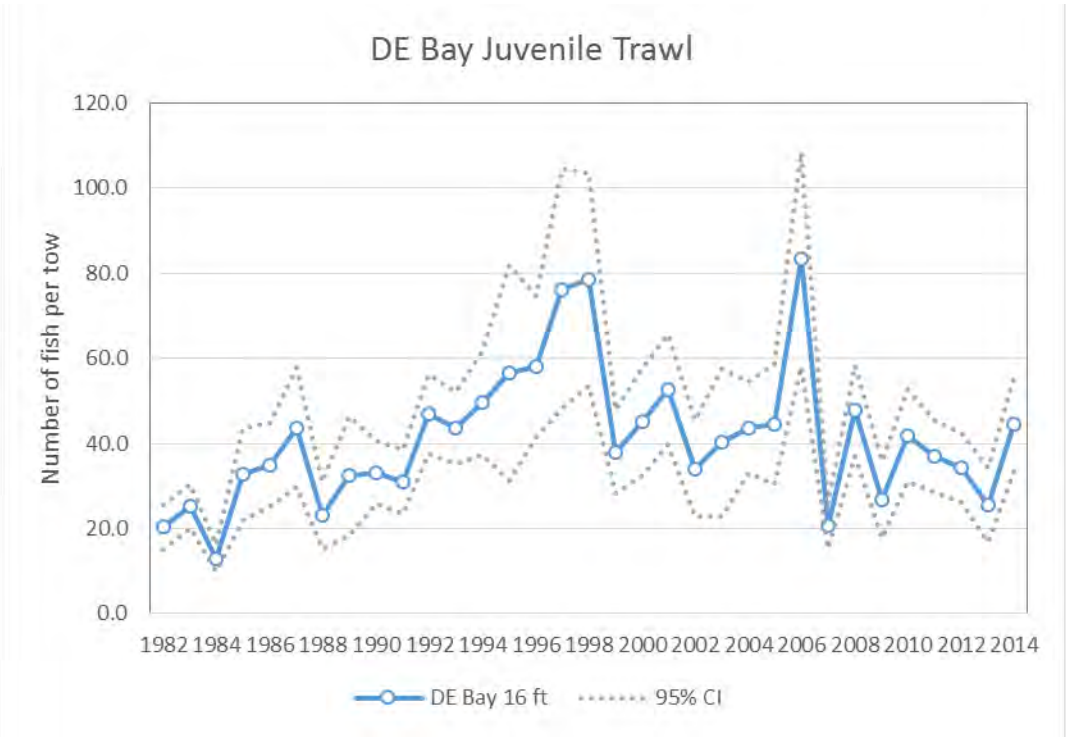


Figure 6.1.9. Delaware Bay Juvenile Trawl Survey YOY index.

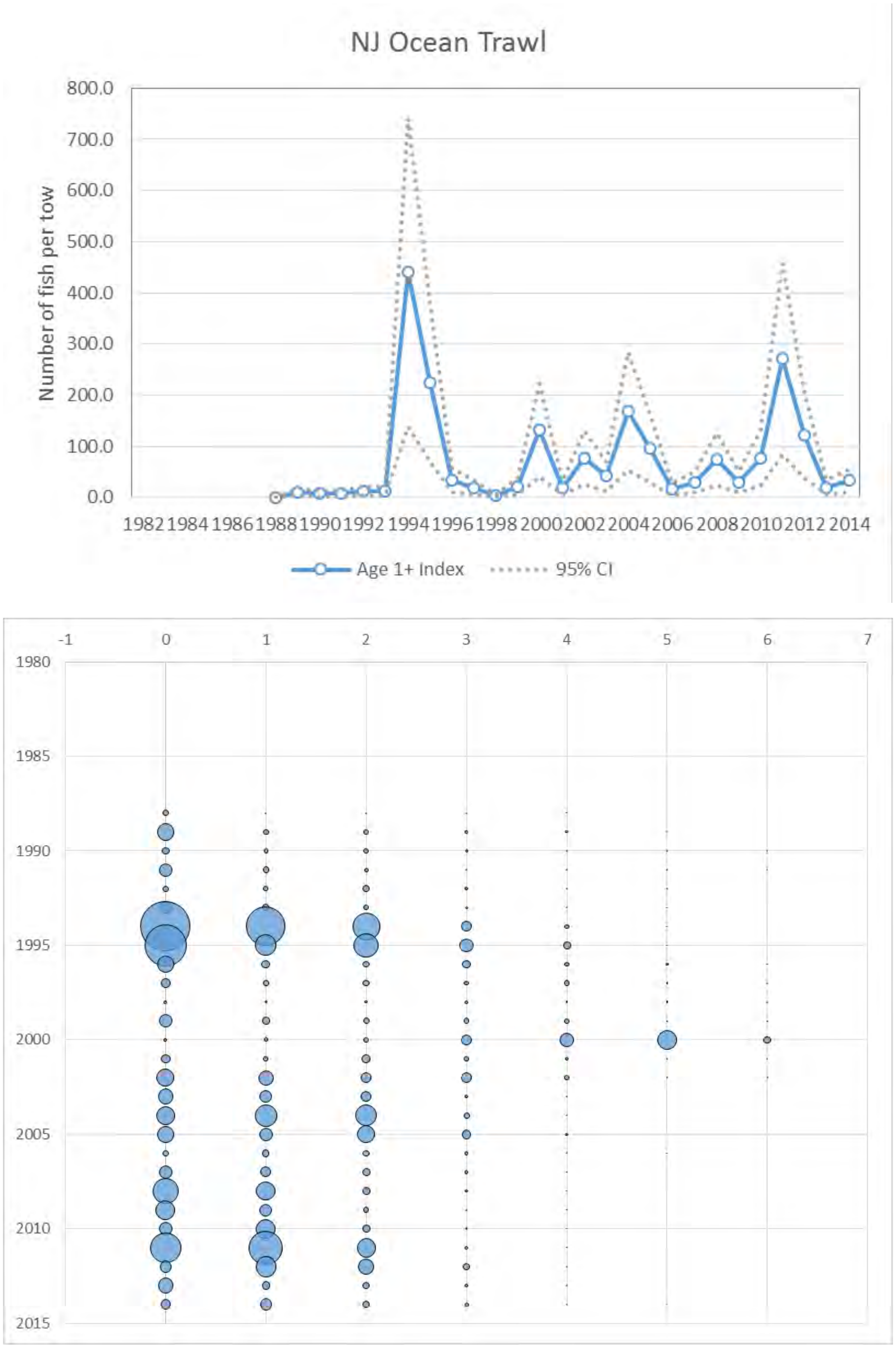


Figure 6.1.10. Total age-1+ index (top) and index-at-age (bottom) from the New Jersey Ocean Trawl Survey.

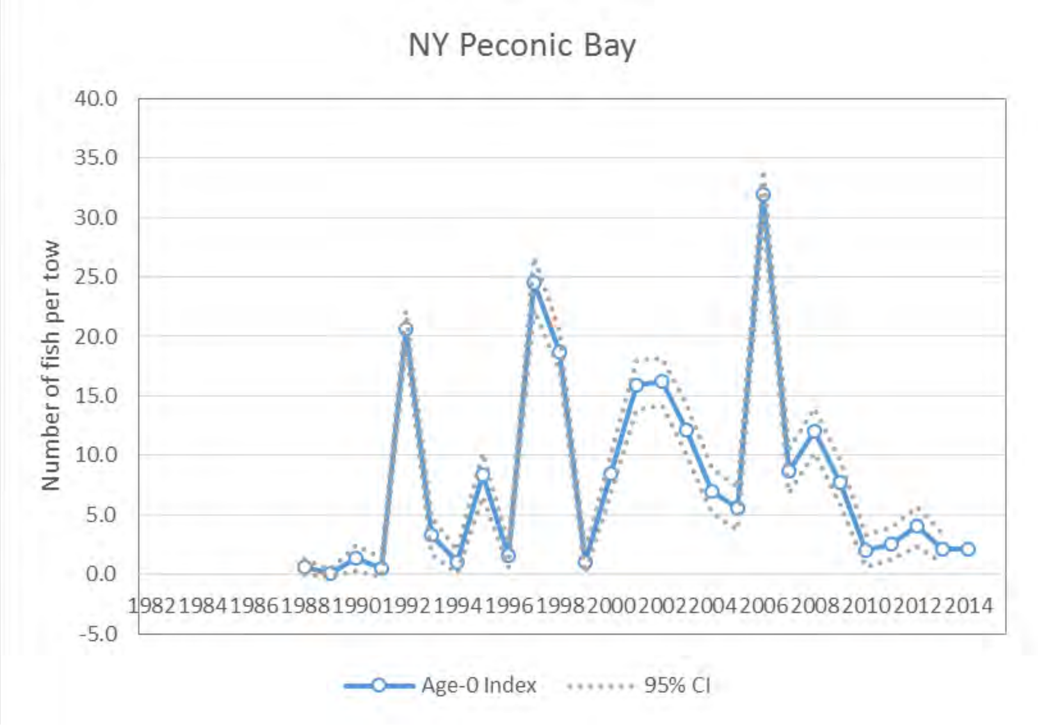


Figure 6.1.11. NY Peconic Bay Trawl Survey YOY index.

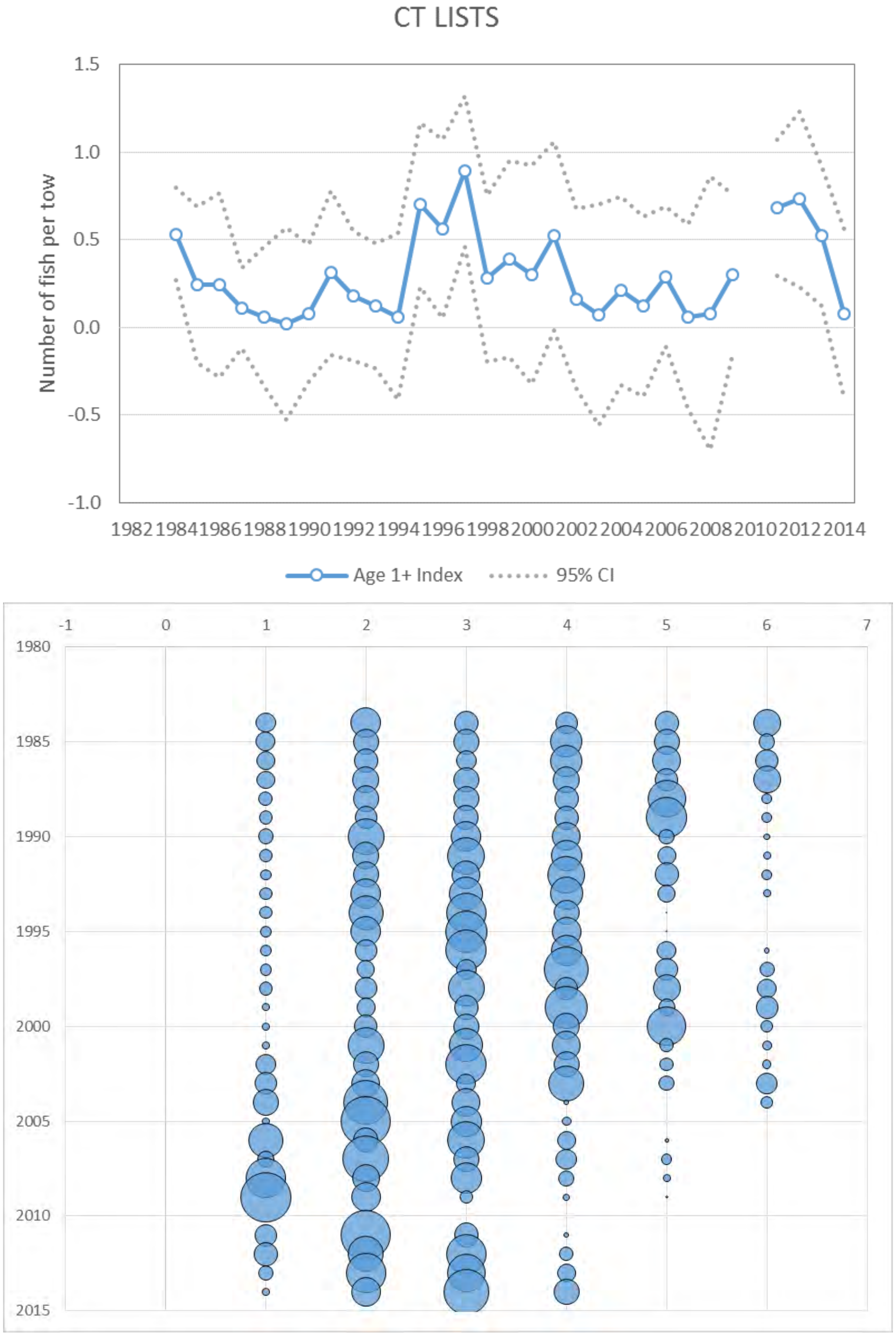


Figure 6.1.12. Total age-1+ index (top) and index-at-age (bottom) from the Connecticut Long Island Sound Trawl Survey. 2010 is missing because of problems with sampling in that year.

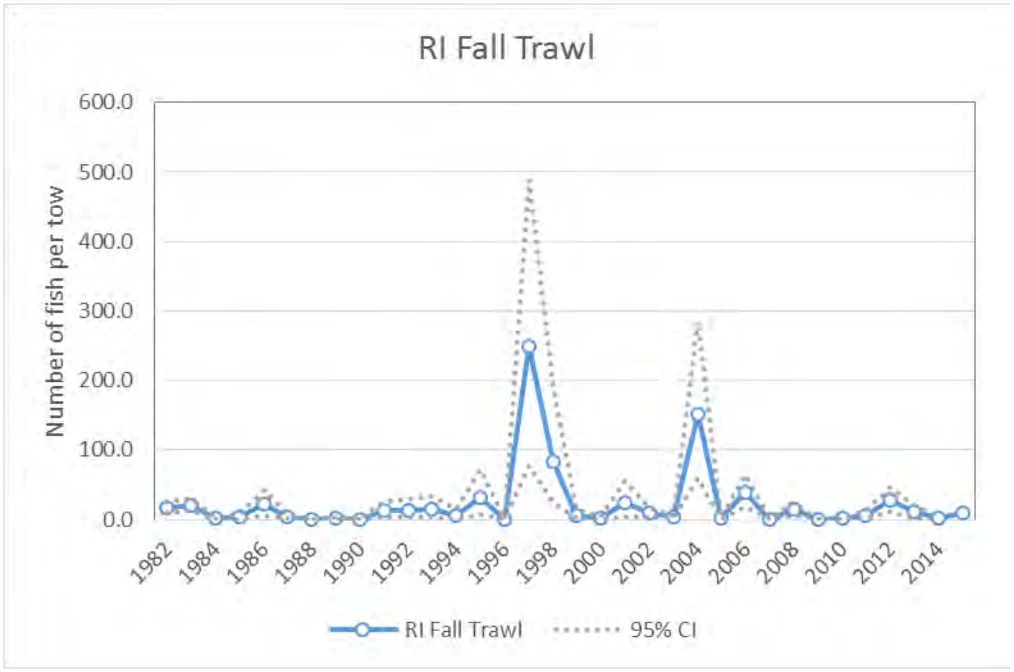
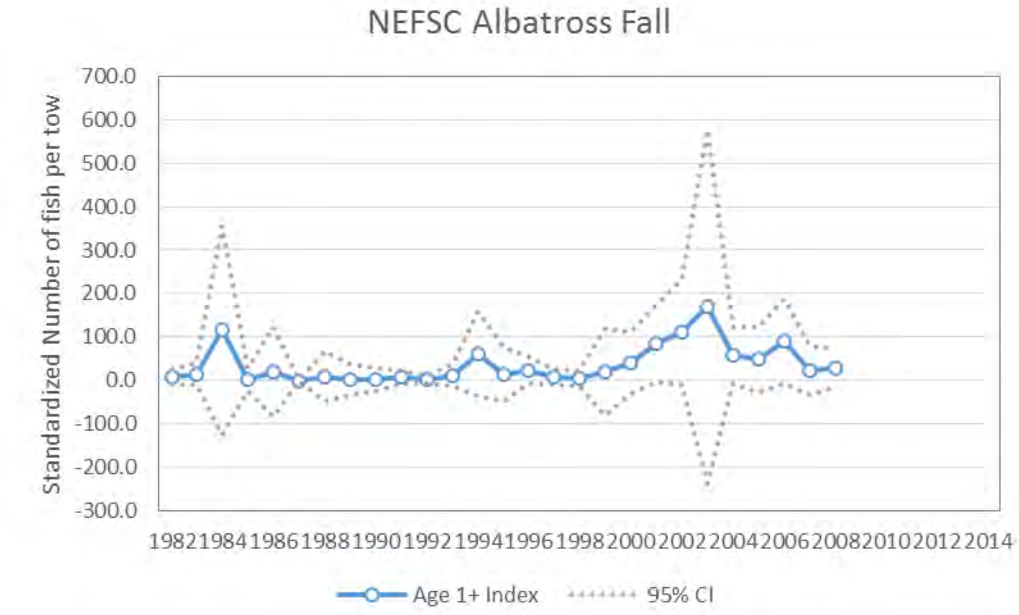


Figure 6.1.13. Rhode Island Seasonal Trawl Survey fall YOY index.



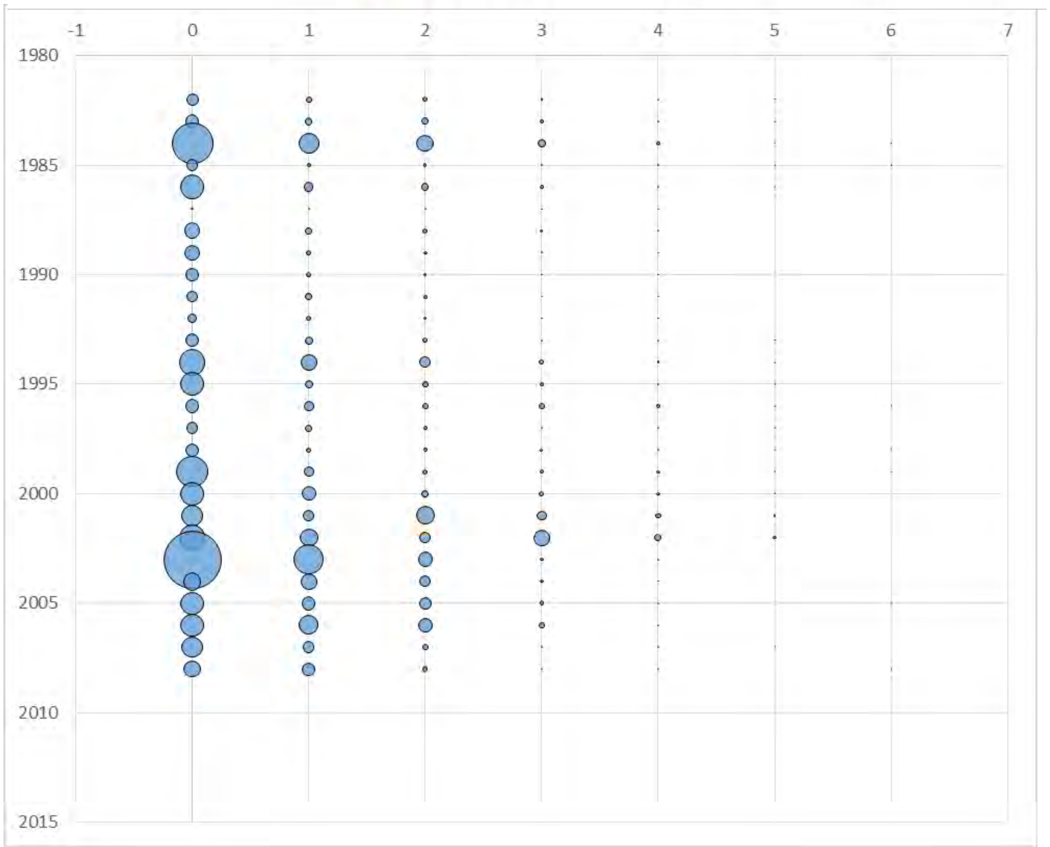


Figure 6.1.14. Total age-1+ index (top) and index-at-age (bottom) from the NEFSC Fall Bottom Trawl Survey.

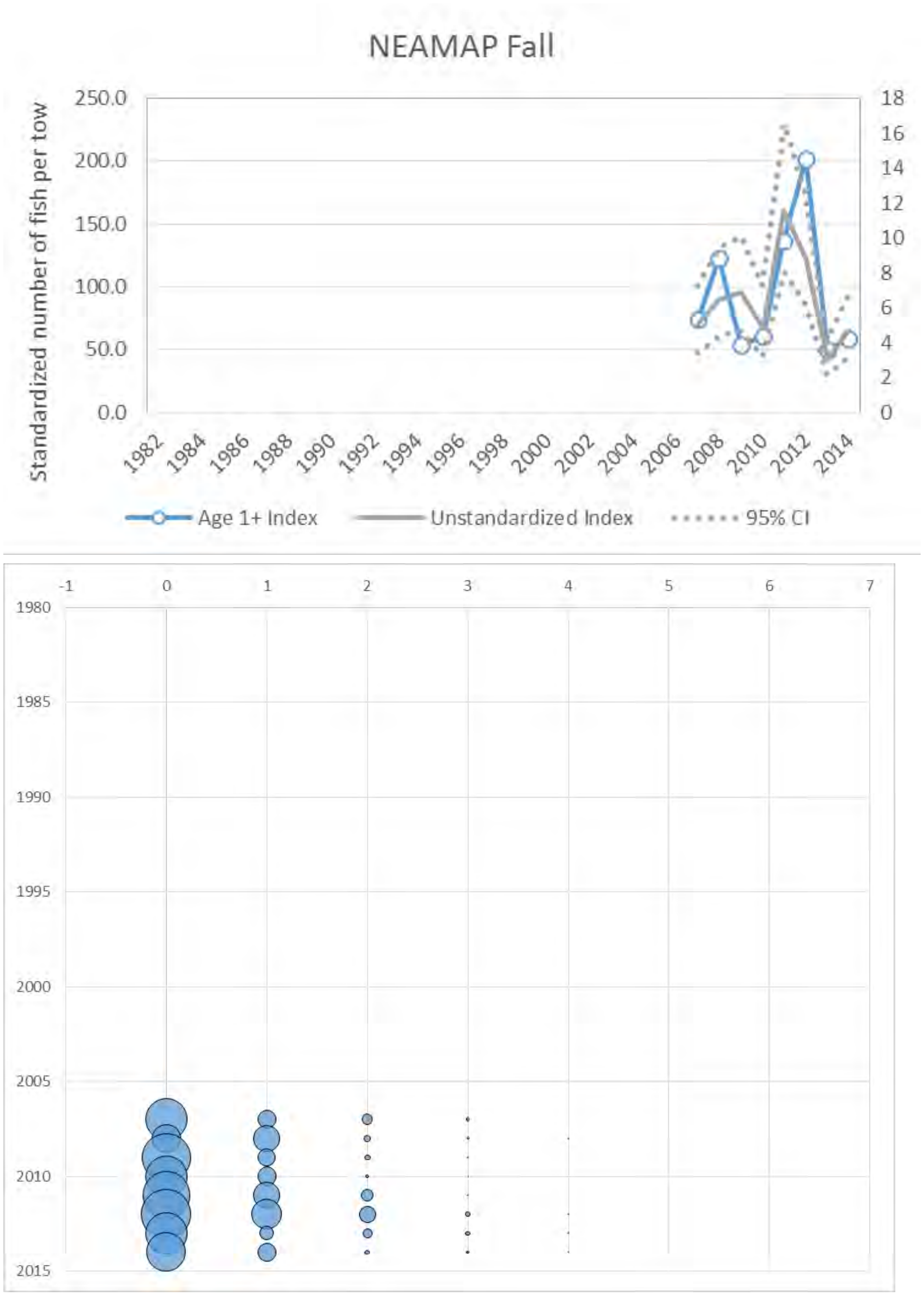


Figure 6.1.15. Total age-1+ index (top) and index-at-age (bottom) from the NEAMAP Fall Trawl Survey.CIs for indices standardized with a zero-inflated model were not available, so the unstandardized index and CIs are shown for reference.

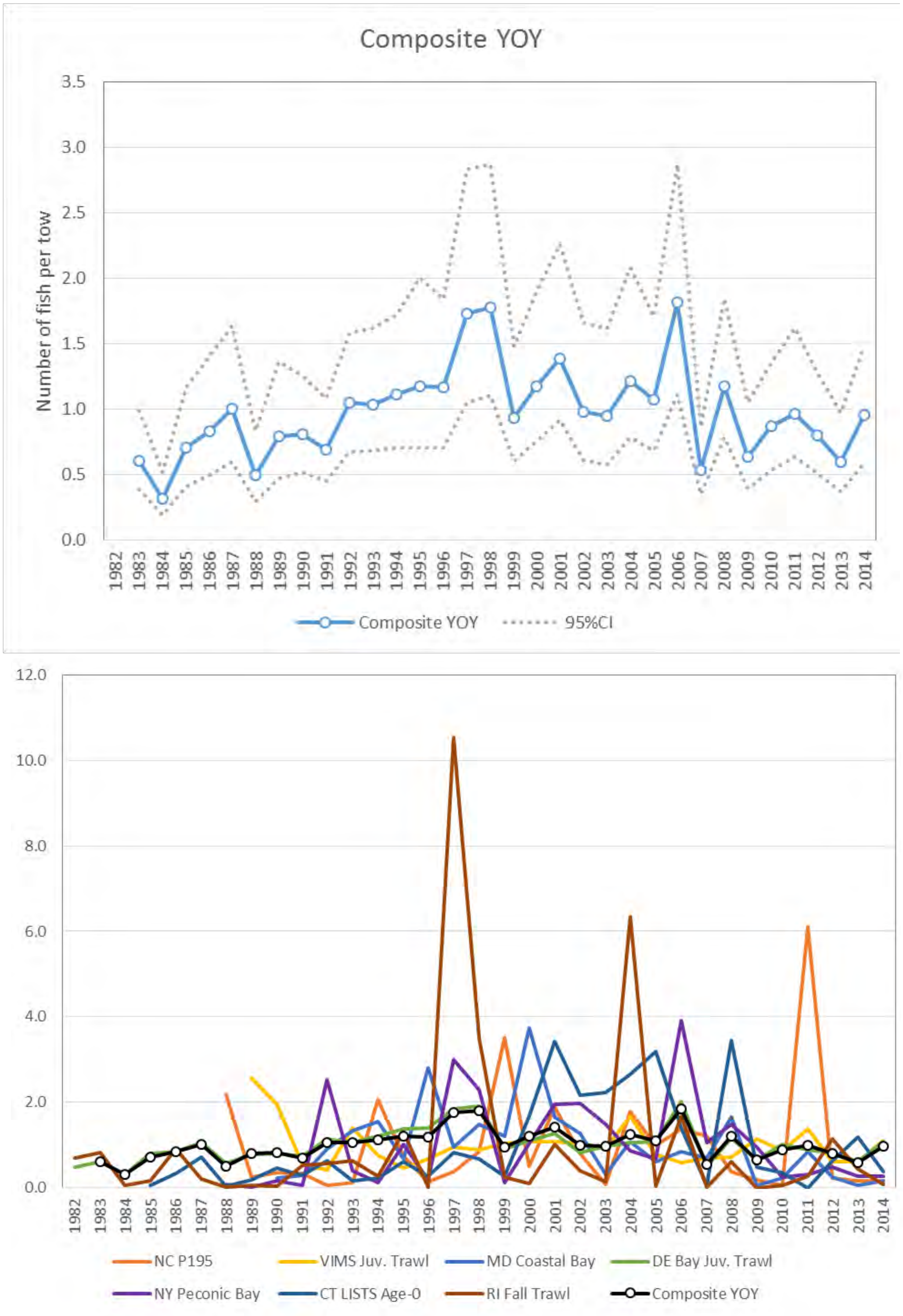
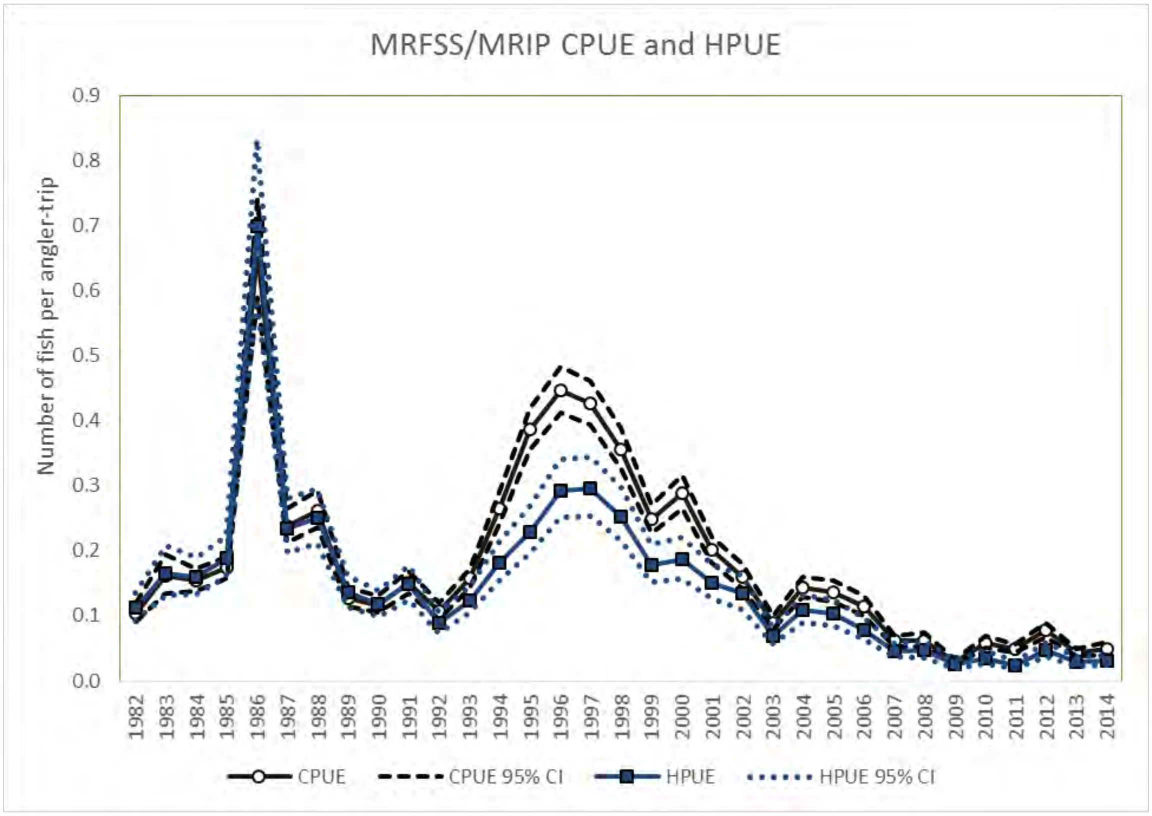


Figure 6.1.16. Final composite YOY index plotted with 95% confidence index (top) and with the component indices scaled to their means (bottom).



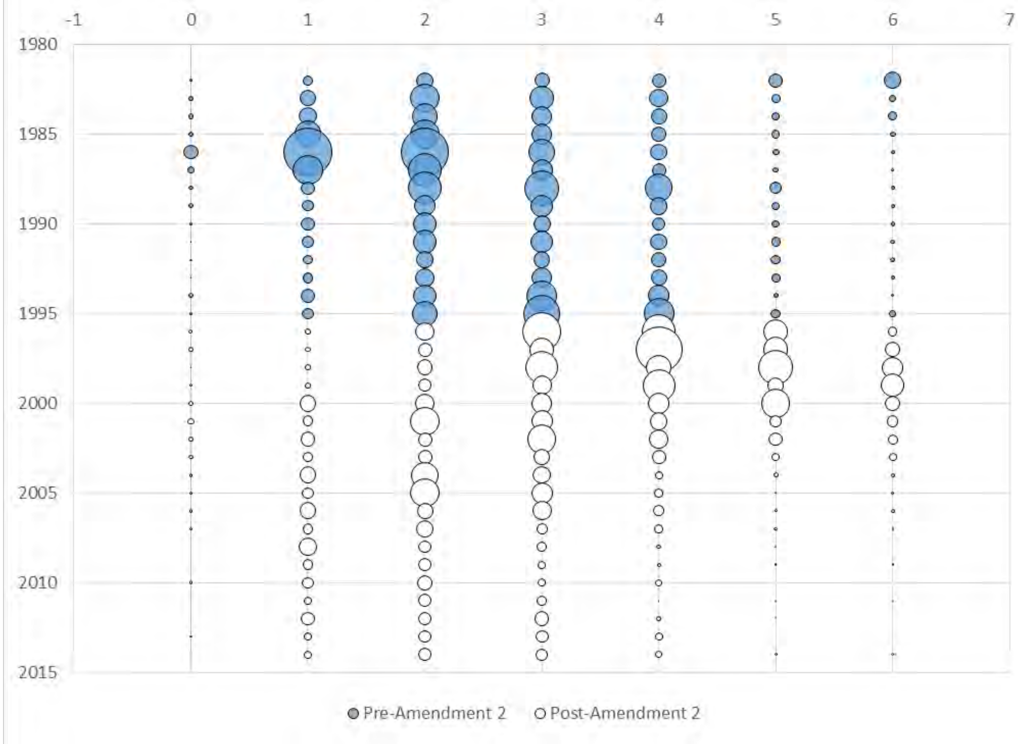


Figure 6.2.1. Weakfish recreational catch per unit effort and harvest per unit effort (top) and age composition of the HPUE index (bottom).

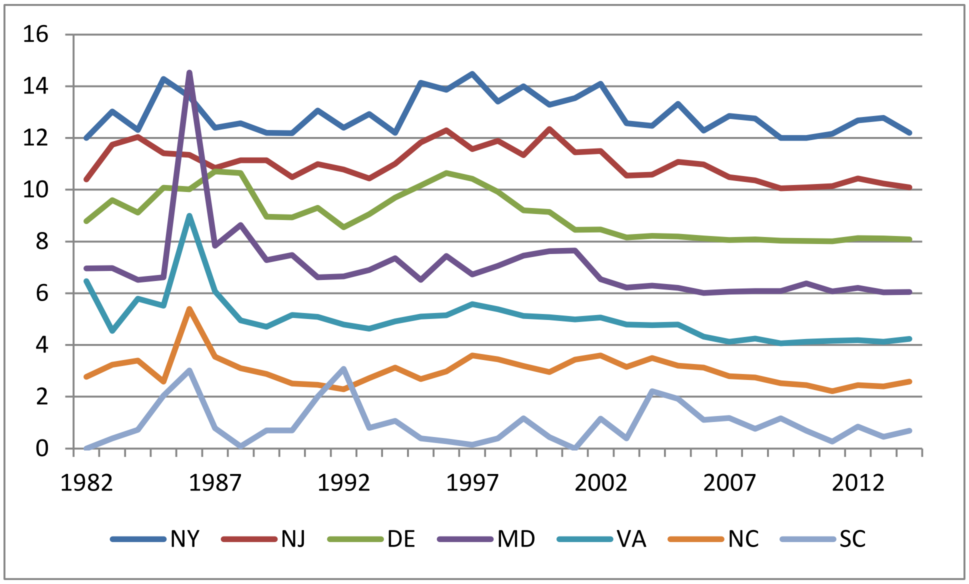


Figure 6.2.2. State specific recreational CPUE.

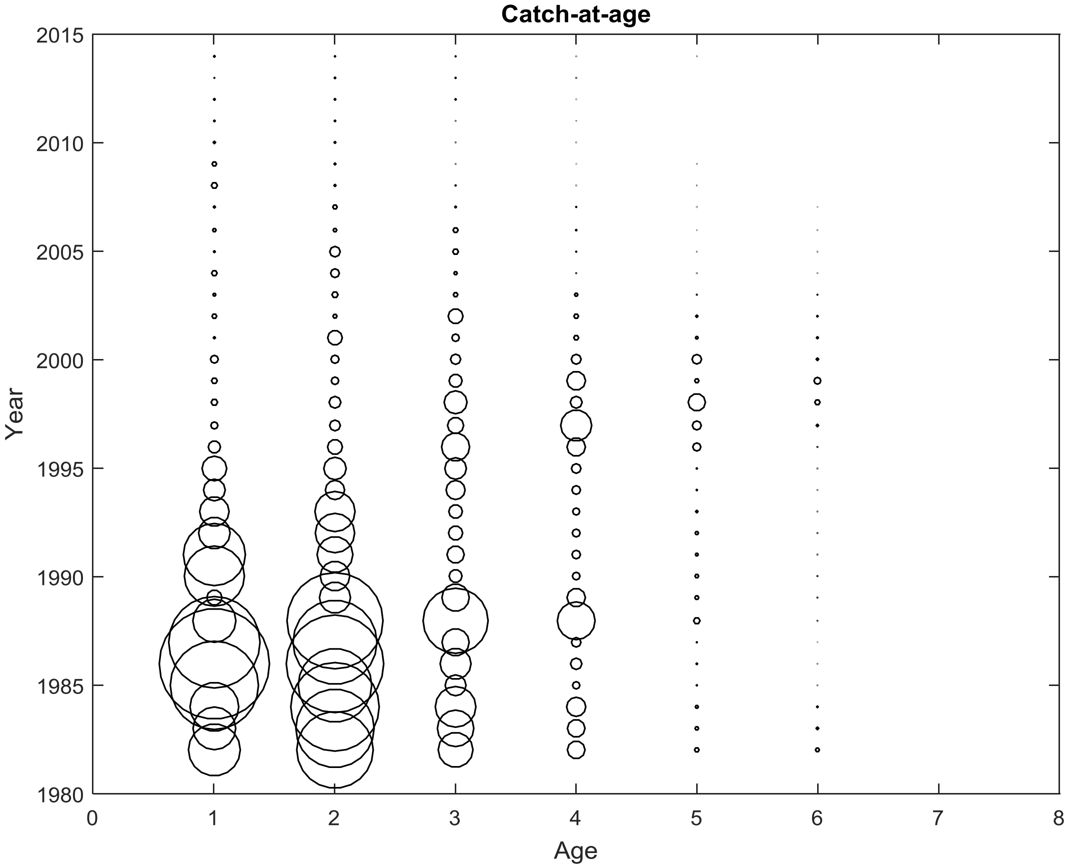


Figure 7.1.1. Total catch-at-age used as input to the age-structured models.

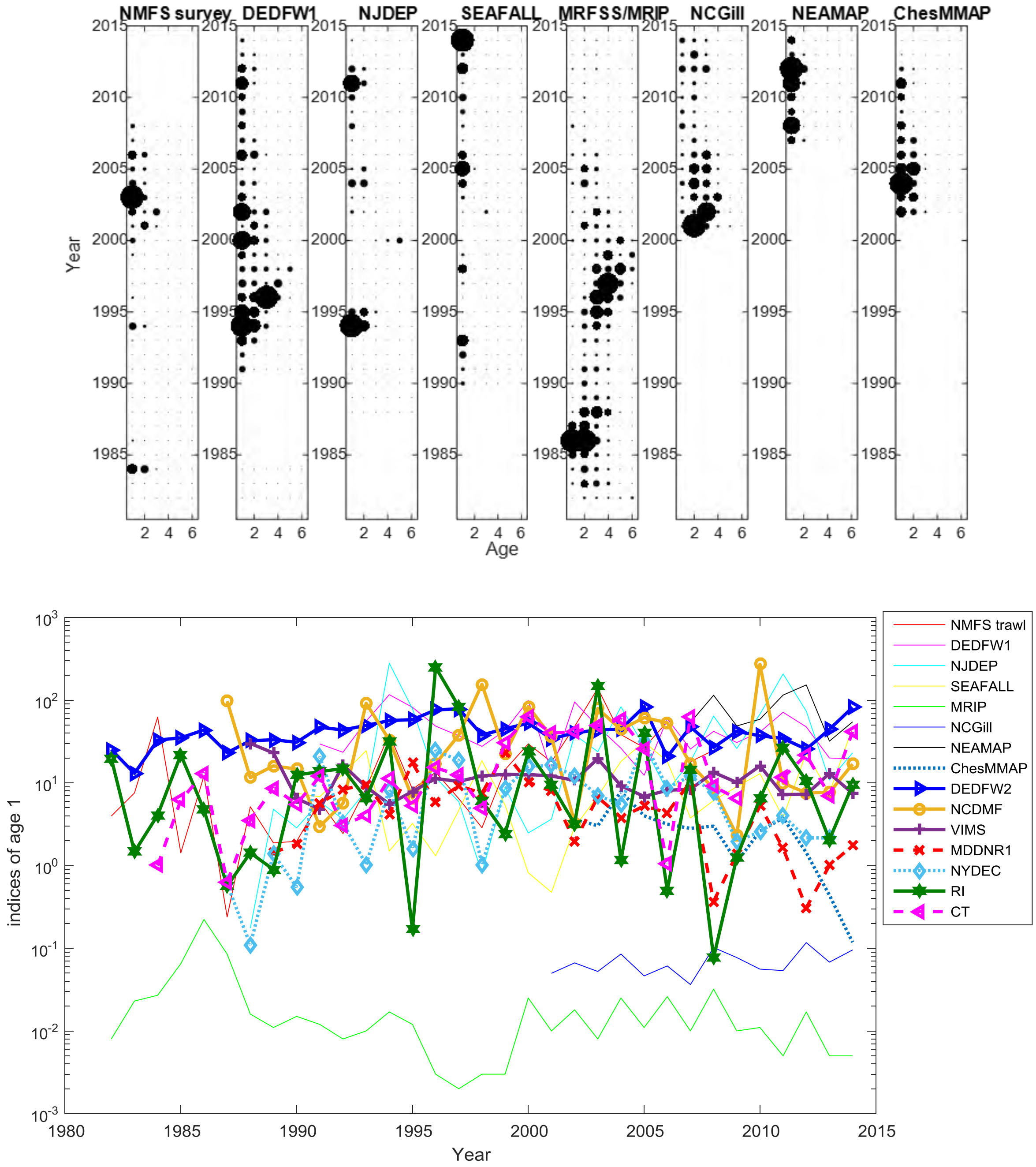


Figure 7.1.2. Relative abundance indices for age-1+ (top) and young-of-year (bottom) used to calibrate the Bayesian model.

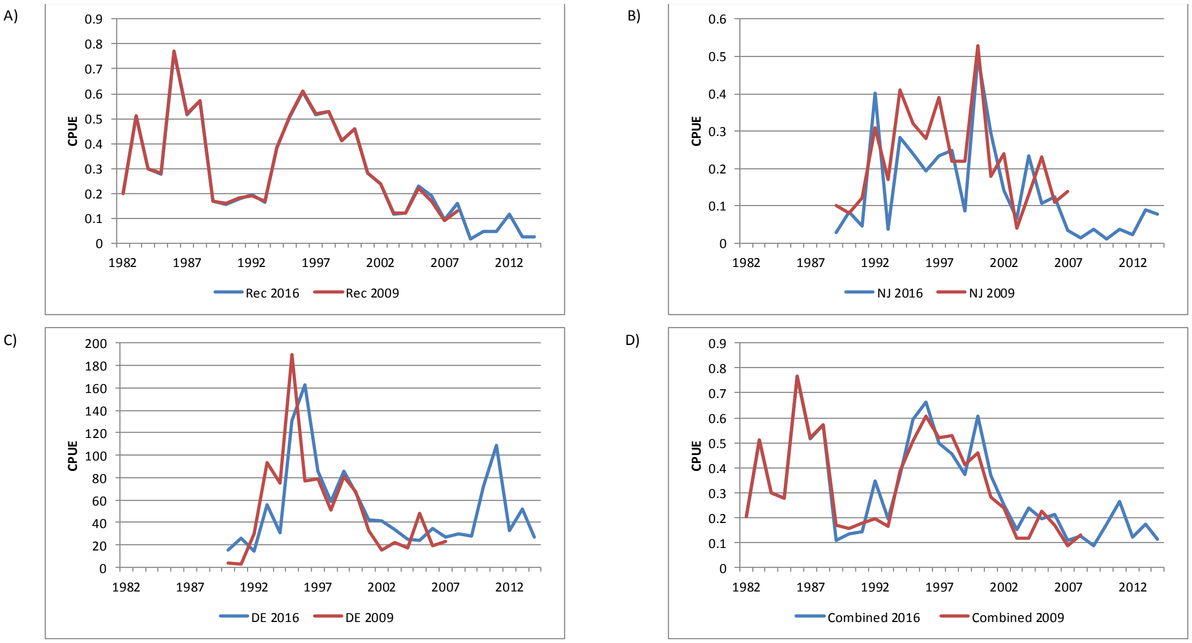


Figure 7.4.1. Comparison of the index trends used in the 2009 and continuity runs of the rescaled relative F analysis.

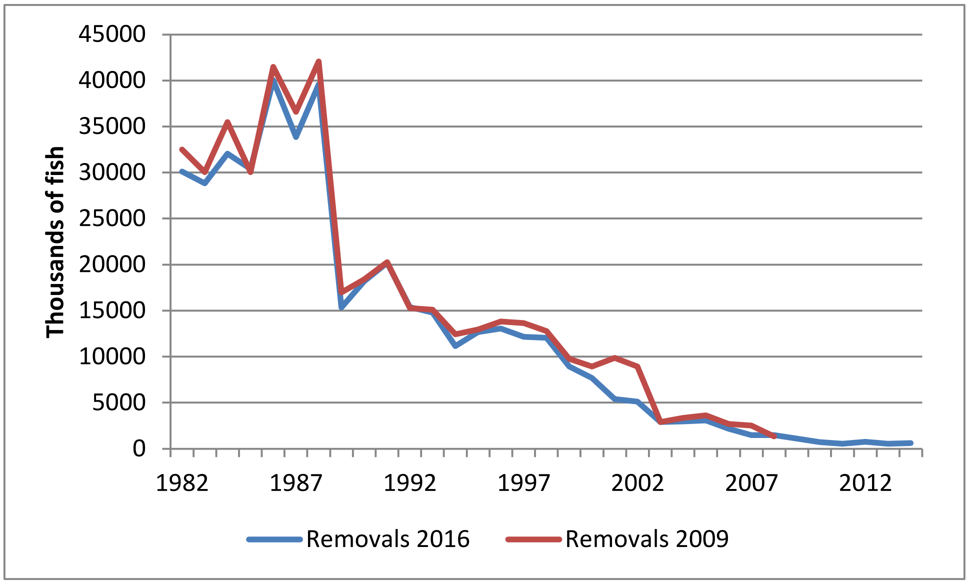


Figure 7.4.2. Comparison of total removals used in the 2009 and continuity runs of the rescaled relative F analysis.

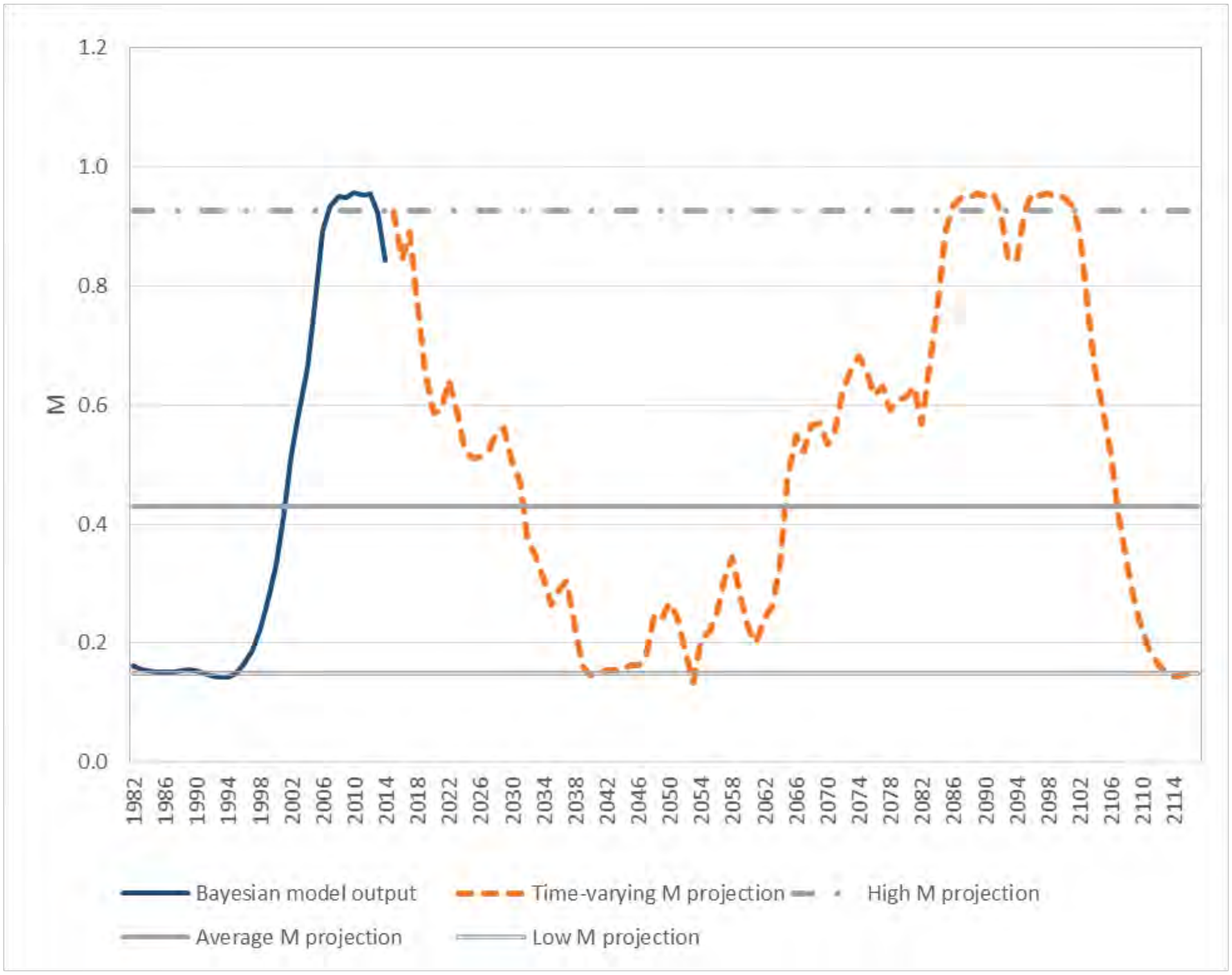


Figure 7.5.1. Hypothetical M scenarios used in reference point projections.

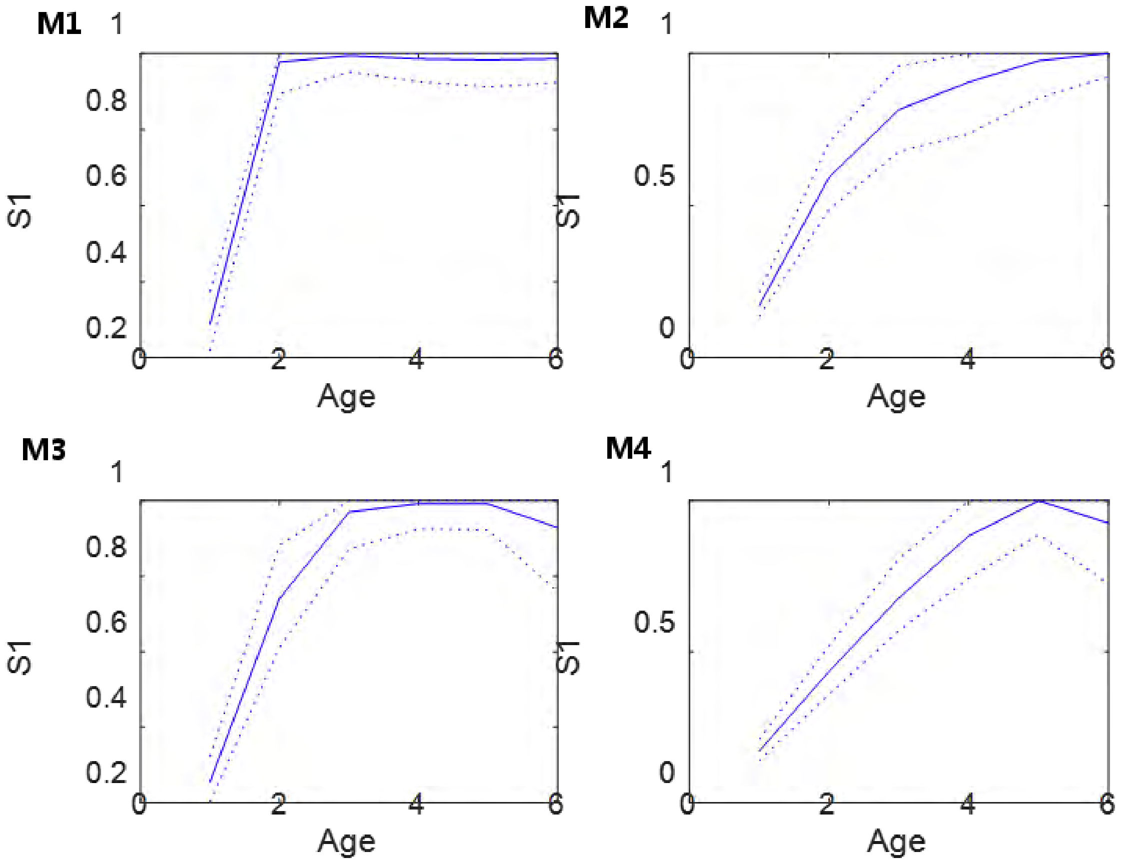


Figure 8.1.1.A. Commercial selectivity estimated by the Bayesian age-structured models. Solid line = posterior mean; dashed lines: 95% credible interval.

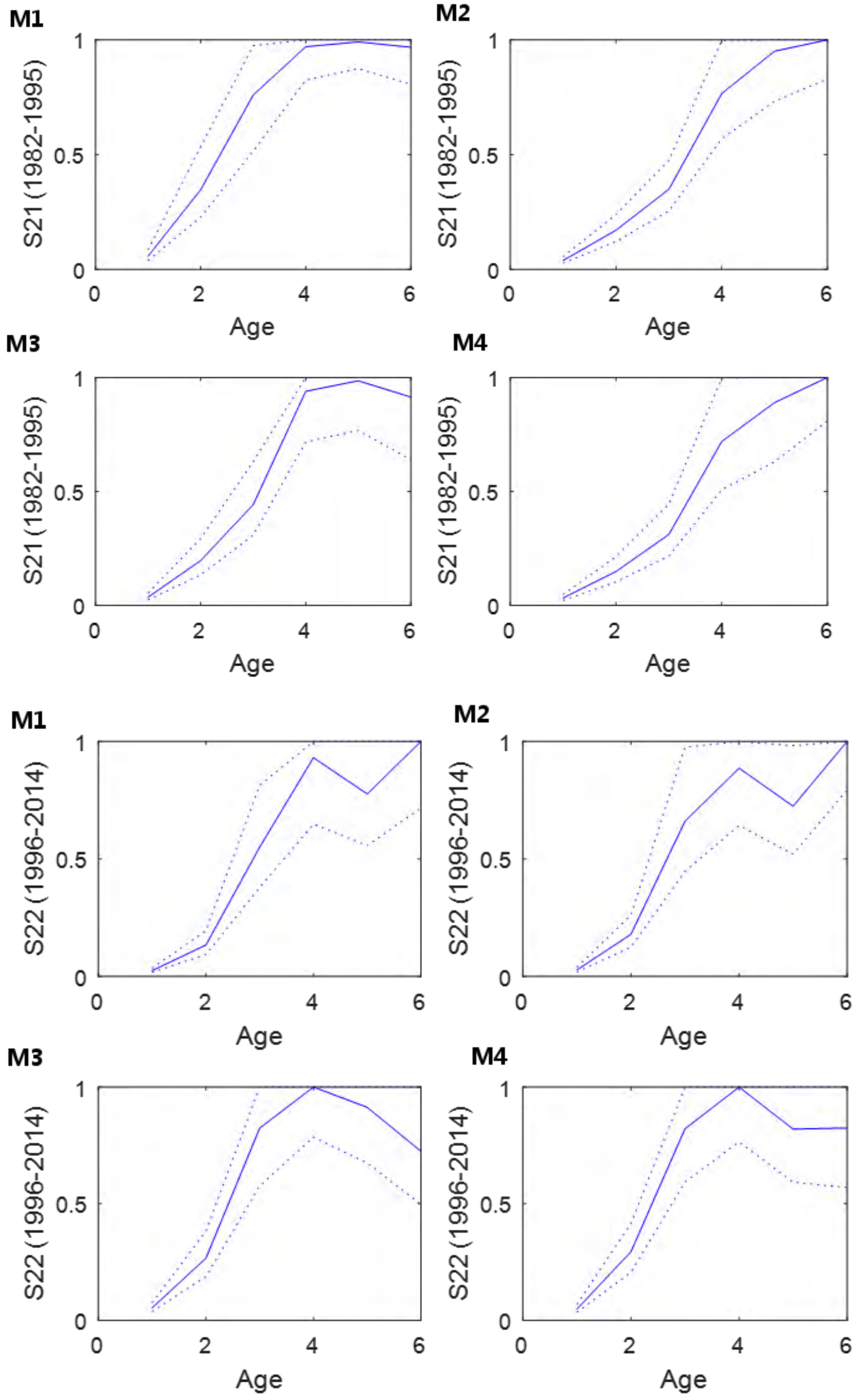


Figure 8.1.1.B. Recreational selectivity by period estimated by the Bayesian age-structured model. Solid line = posterior mean; dashed lines: 95% credible interval..

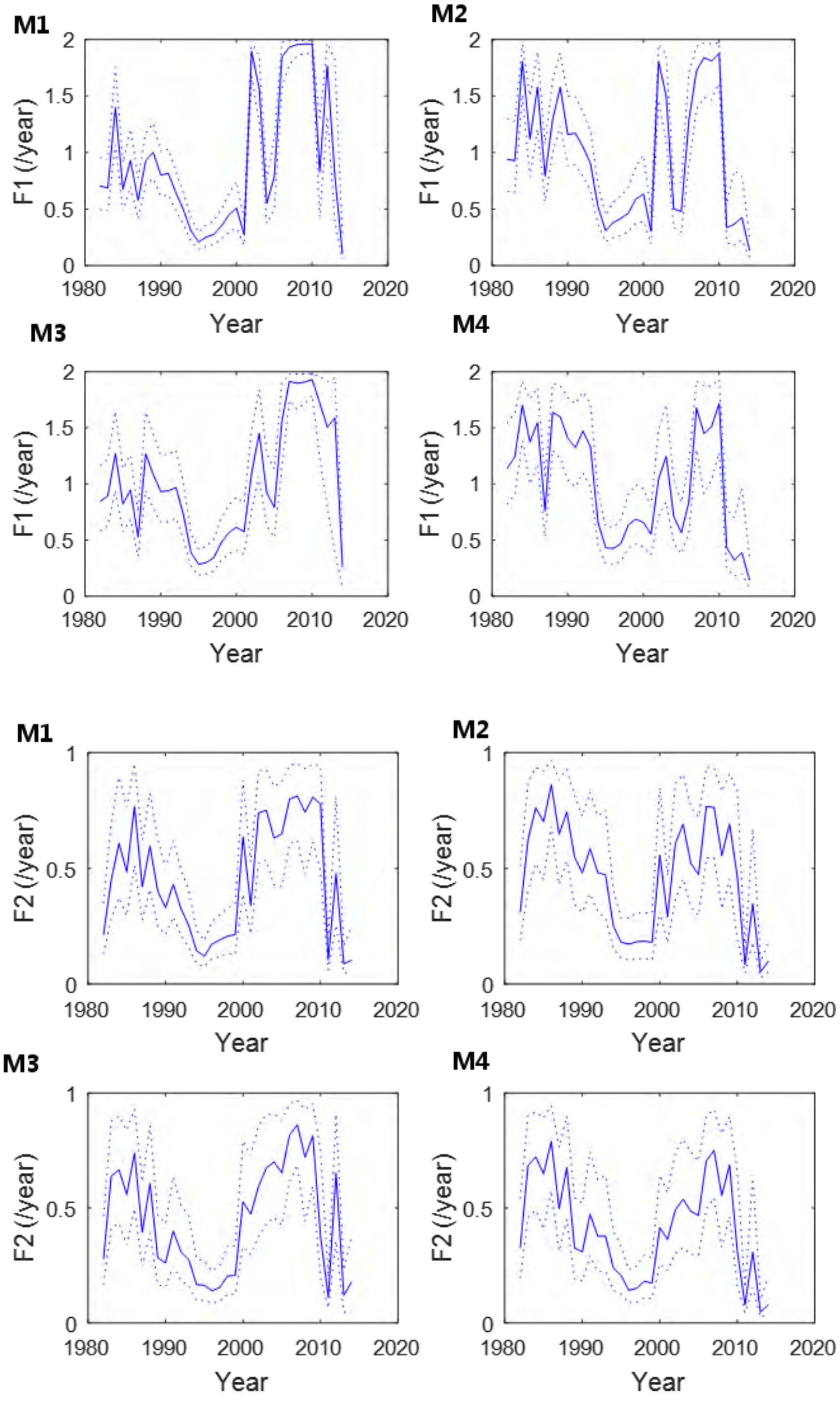


Figure 8.1.2.A. Posterior fishing mortality by fleet estimated by the Bayesian age-structured models.F1 (top 4 panels) is the commercial fleet. F2 (bottom 4 panels) is the recreational fleet. Solid line = posterior mean; dashed lines: 95% credible interval.

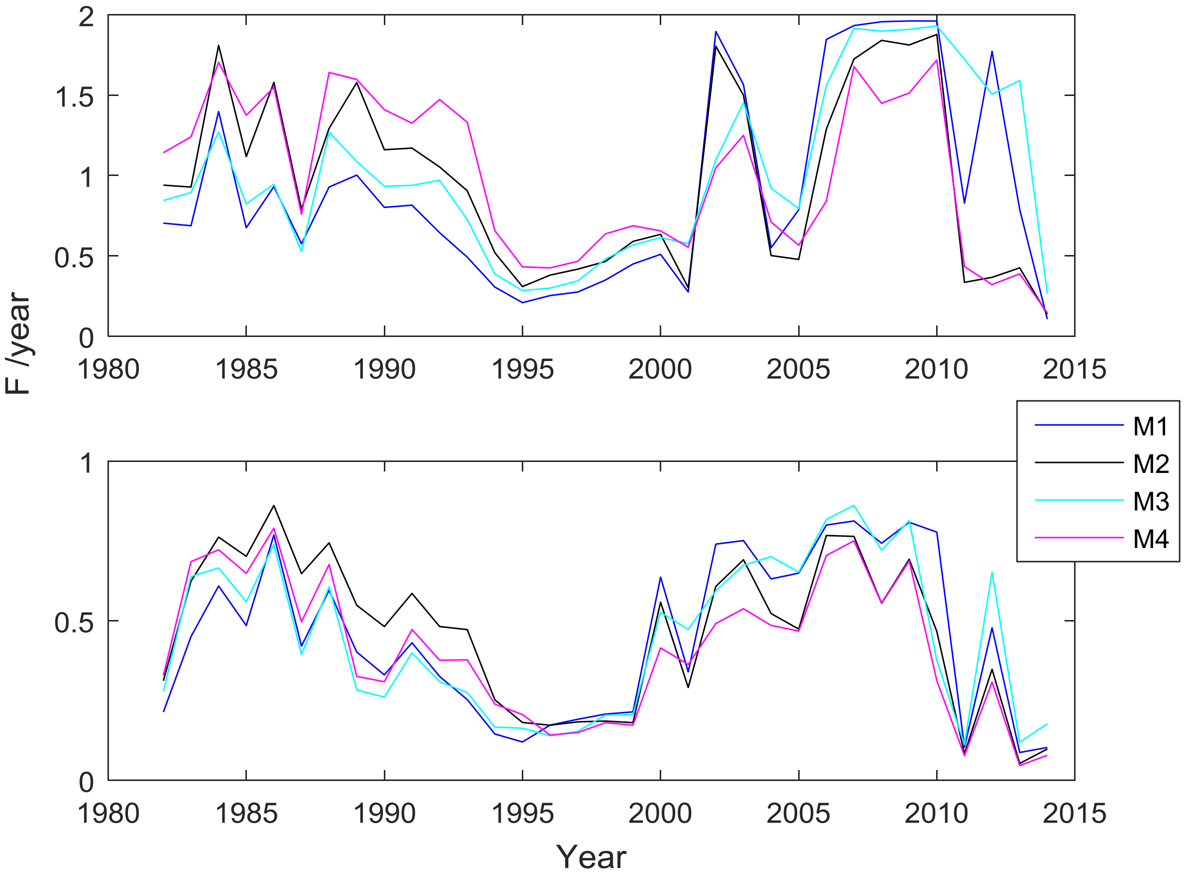


Figure 8.1.2.B. Posterior fishing mortality by fleet estimated by the Bayesian age-structured model, all models plotted together, for the commercial (top) and recreational (bottom) fleets

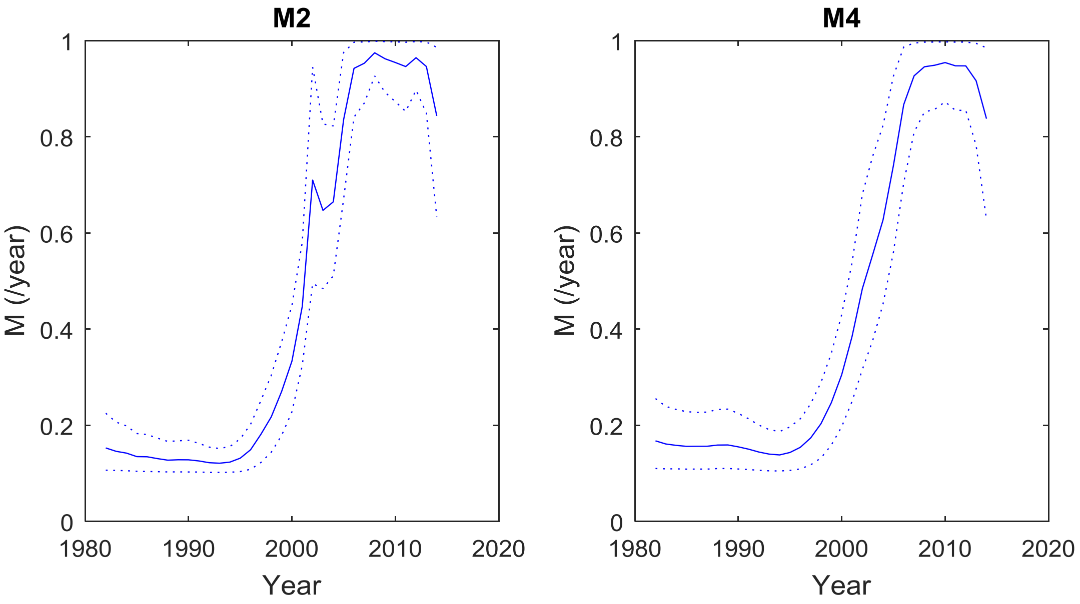


Figure 8.1.3. M estimates from the nonstationary statistical catch-at-age models M2 and M4. Solid line = posterior mean; dashed lines = 95% credible interval.

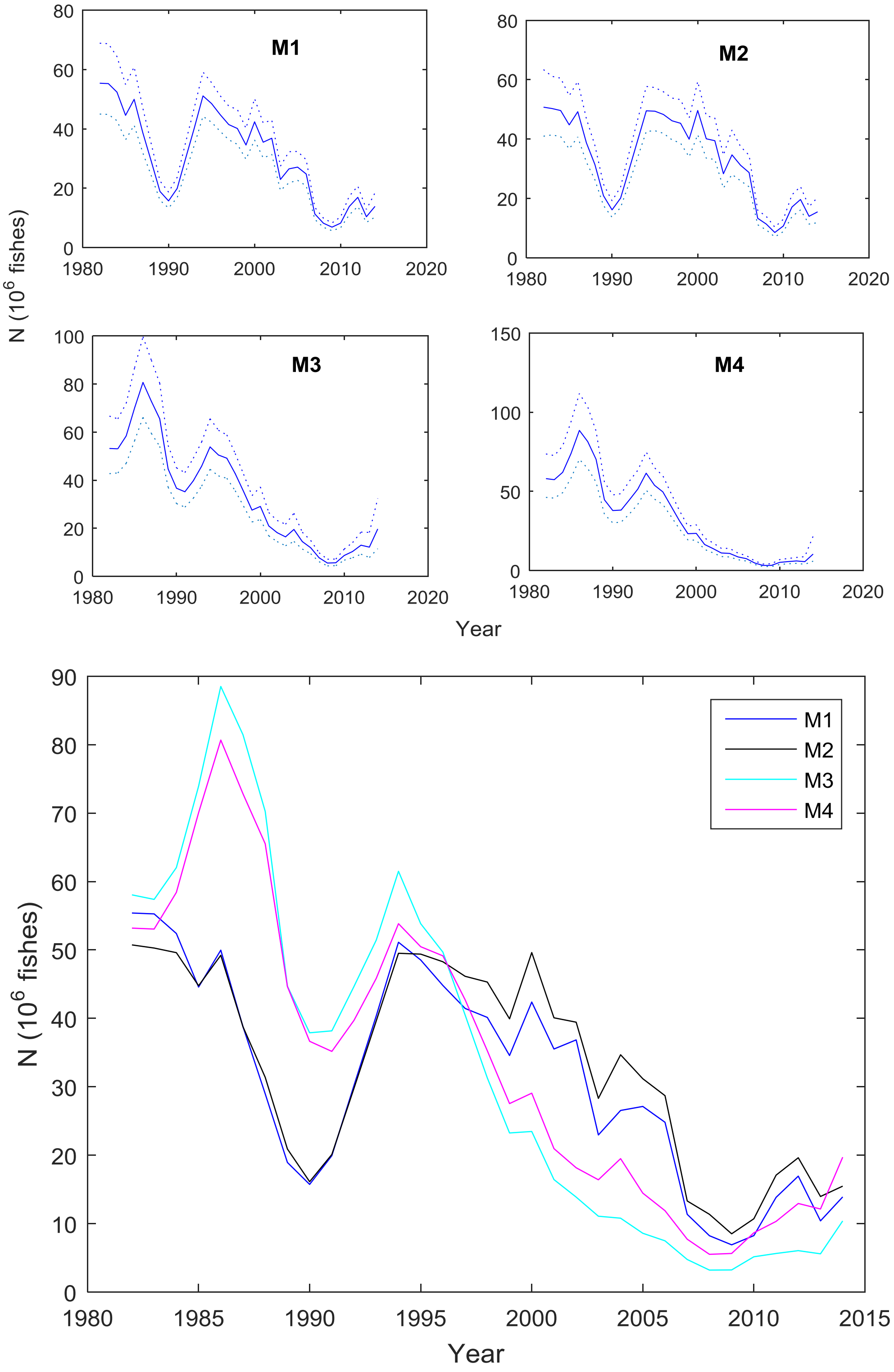


Figure 8.1.4. Posterior population total abundance estimated by the Bayesian age-structured models. Solid line = posterior mean; dashed lines: 95% credible interval.

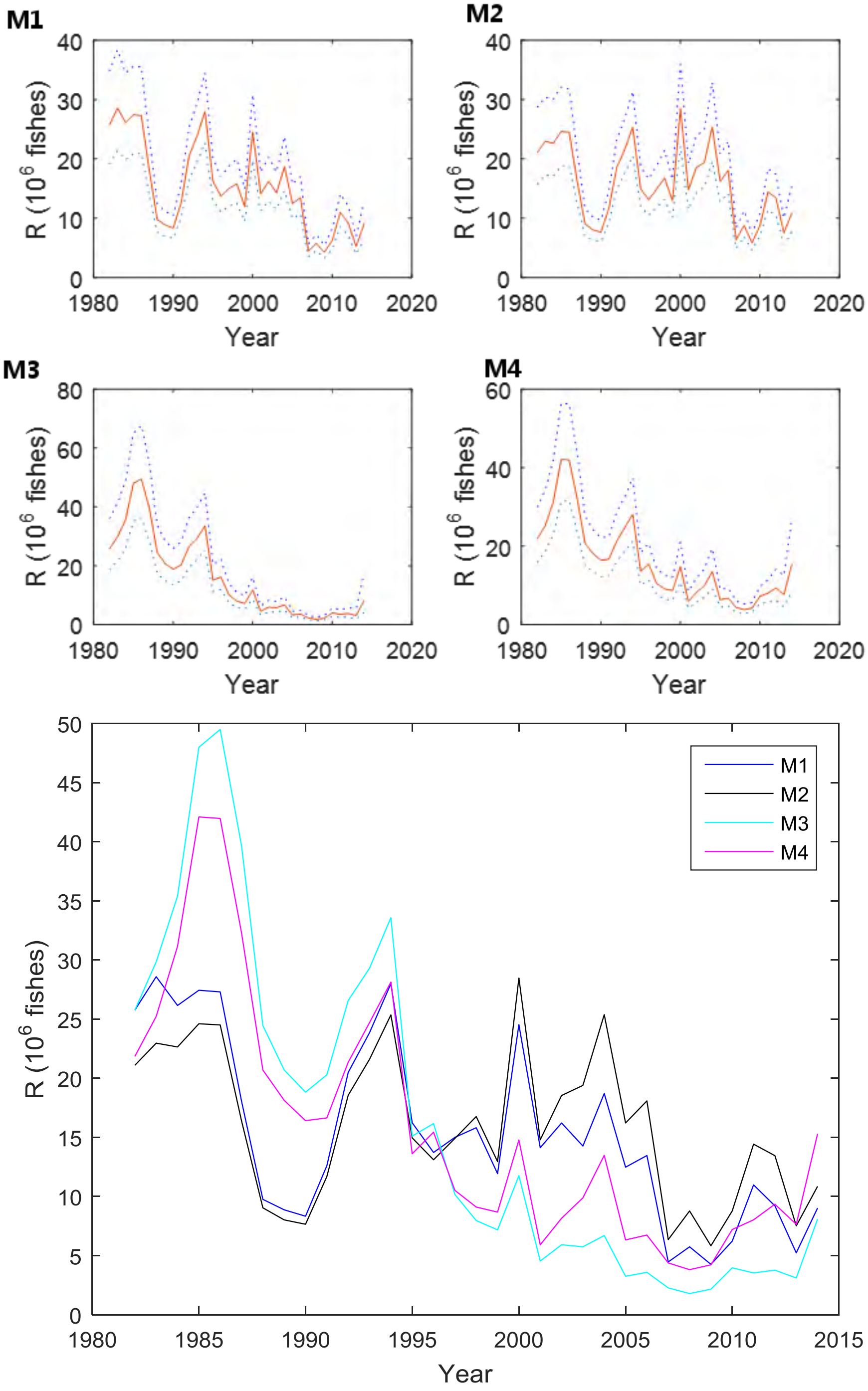


Figure 8.1.5. Posterior recruitment estimated by the Bayesian age-structured models. Solid line = posterior mean; dashed lines: 95% credible interval.

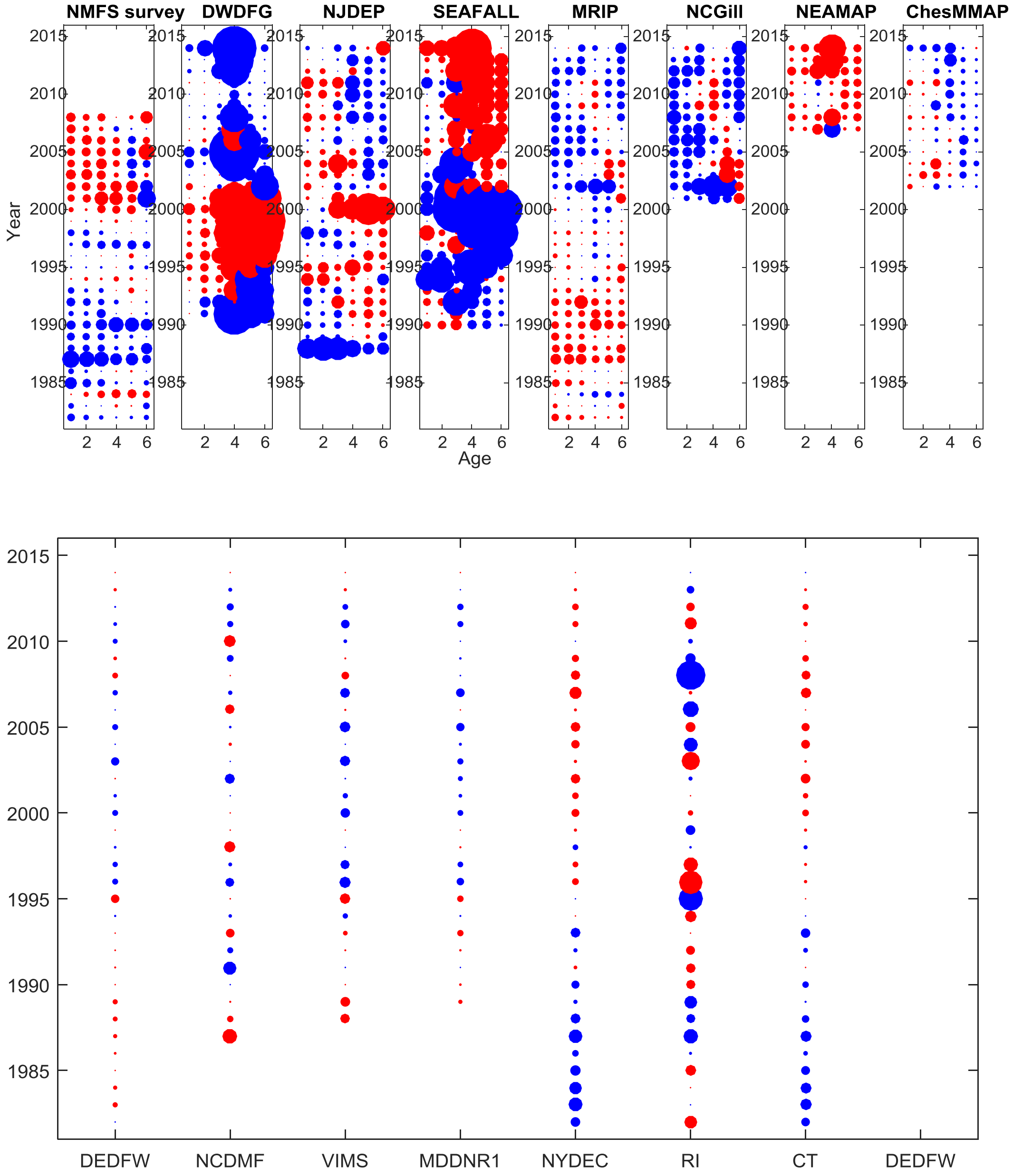


Figure 8.1.6. Spatial heterogeneity reflected from age-1+ (top) and young-of-year (bottom) surveys shown as differences from the mean population size M2. Positive values were plotted in red, while negative values were plotted in blue.

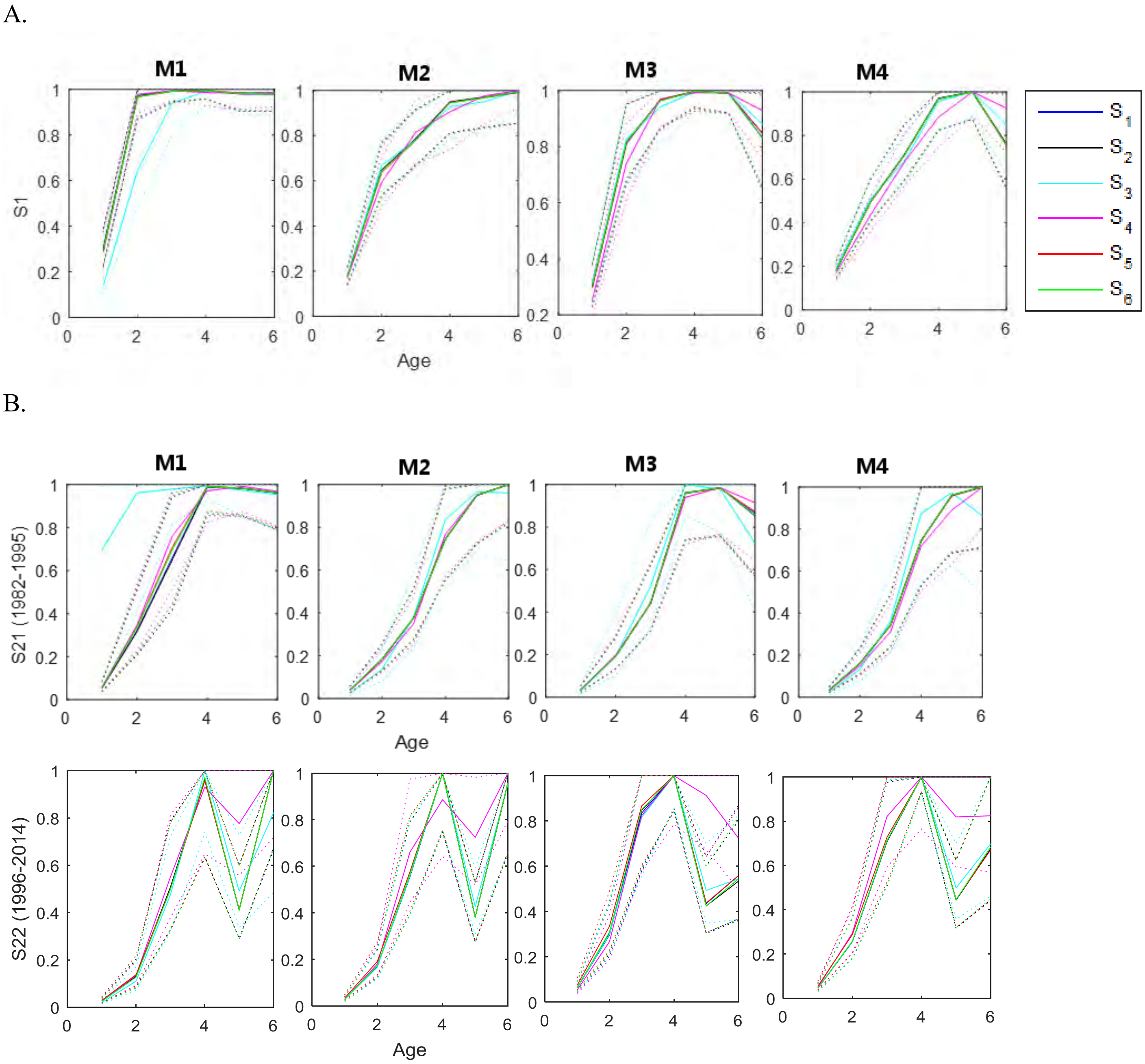


Figure 8.17. Sensitivity results for selectivity estimated by Bayesian age-structured models under different data scenarios for the commercial (A.) and recreational (B.) fleets. See Table 7.1.3 for descriptions of the data scenarios.

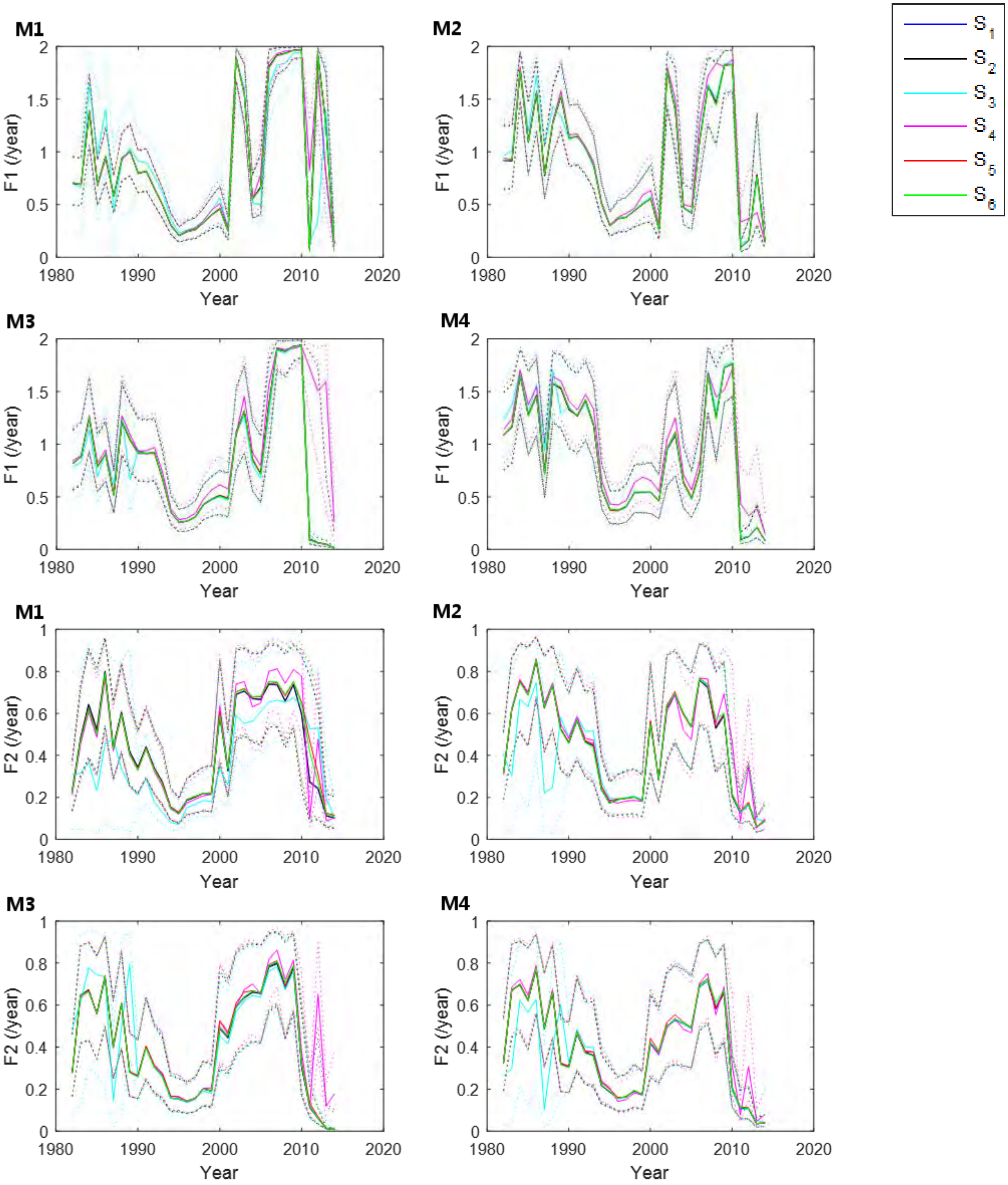


Figure 8.1.8A. Sensitivity results for posterior fishing mortality estimated by Bayesian age-structured model under different data scenarios, for the commercial (top 4 panels) and recreational (bottom 4 panels) fleets. See Table 7.1.3 for descriptions of the data scenarios. Solid line = posterior mean; dashed lines: 95% credible interval.

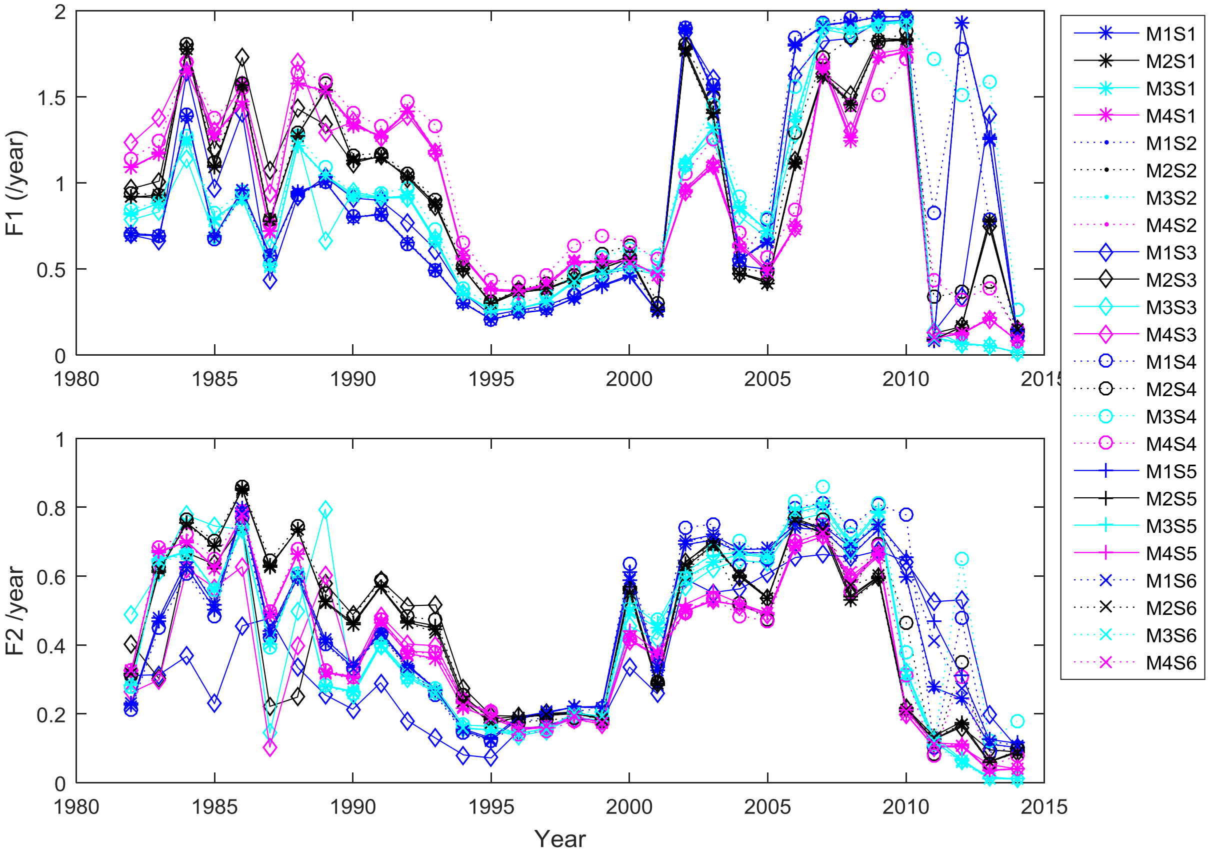


Figure 8.1.8B. Sensitivity results for posterior fishing mortality estimated by Bayesian age-structured model under different data scenarios plotted together for the commercial (top) and recreational (bottom) fleets. See Table 7.1.3 for descriptions of the data scenarios. Solid line = posterior mean; dashed lines: 95% credible interval.

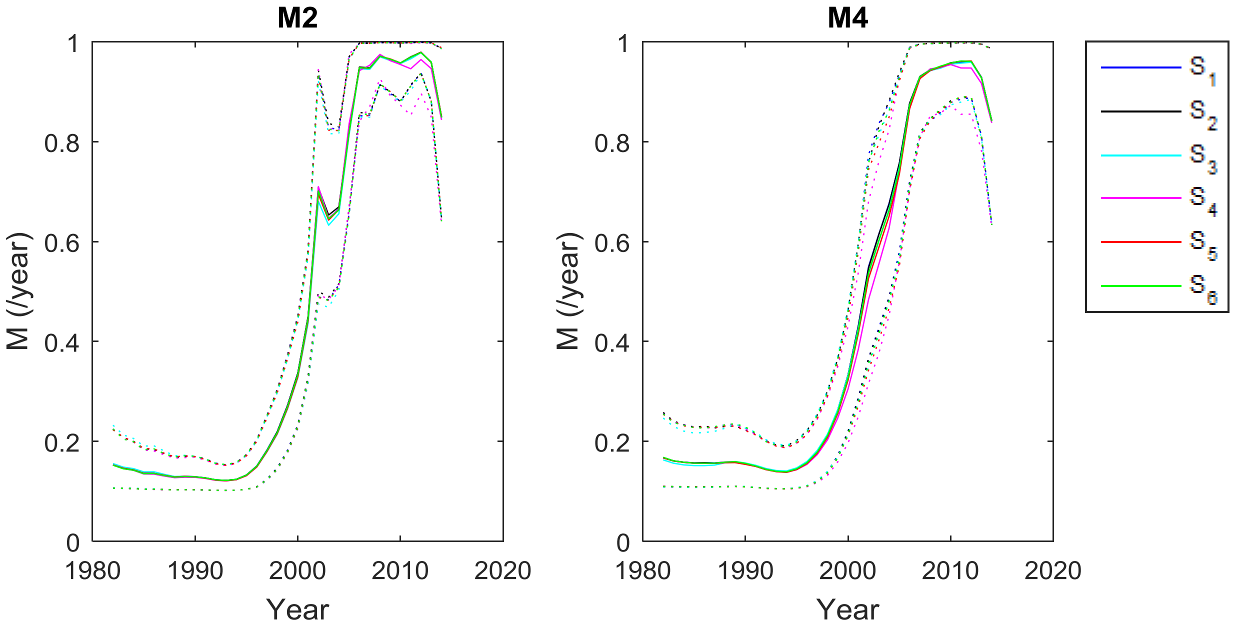


Figure 8.1.9. Sensitivity results of M estimates from the nonstationary statistical catch-at-age models M2 and M4 under different data scenarios. See Table 7.1.3 for descriptions of the data scenarios. Solid line = posterior mean; dashed lines = 95% credible interval.

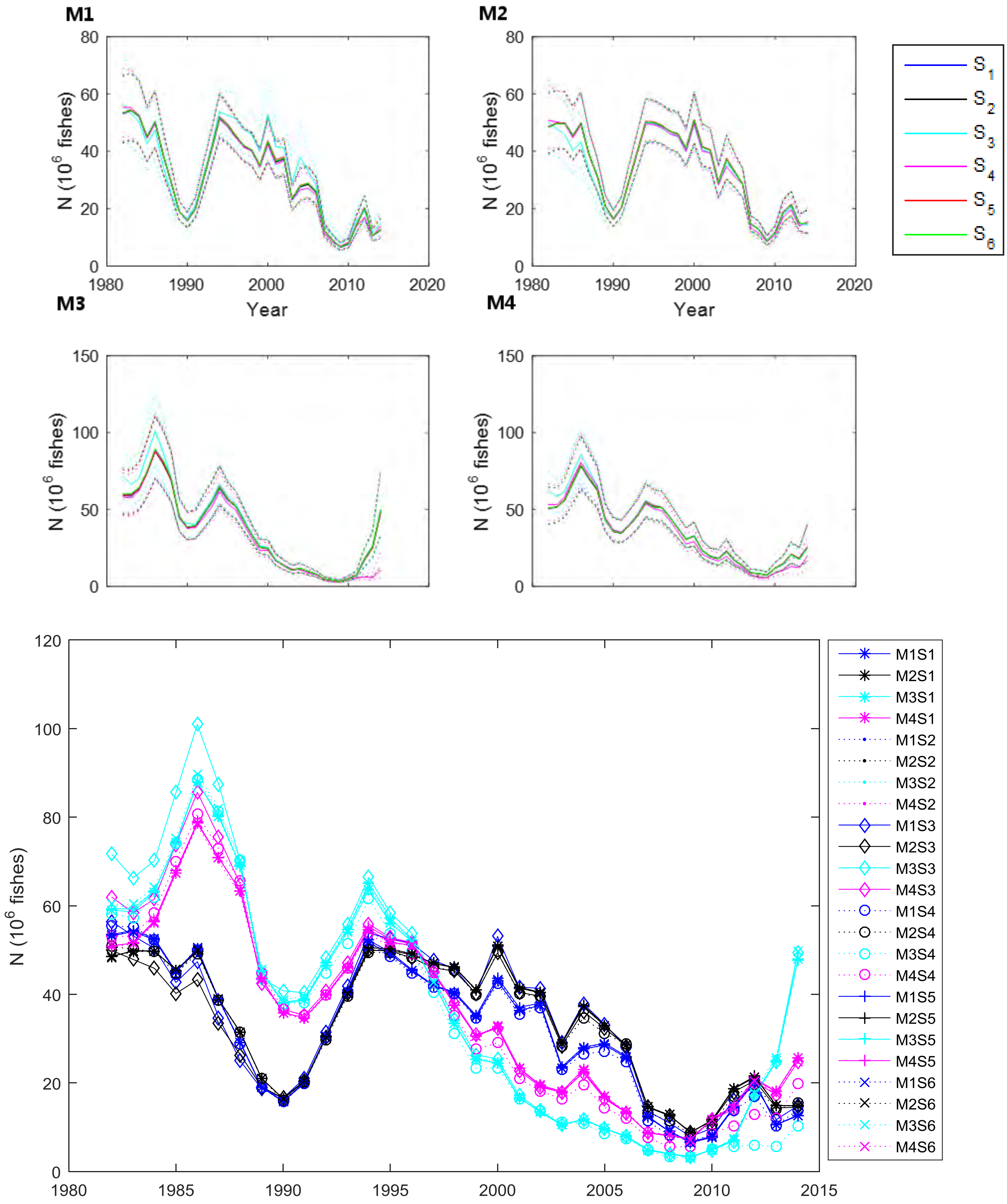


Figure 8.1.10. Sensitivity results for posterior total abundance estimated by Bayesian age-structured model under different data scenarios. See Table 7.1.3 for descriptions of the data scenarios. Solid line = posterior mean; dashed lines: 95% credible interval.

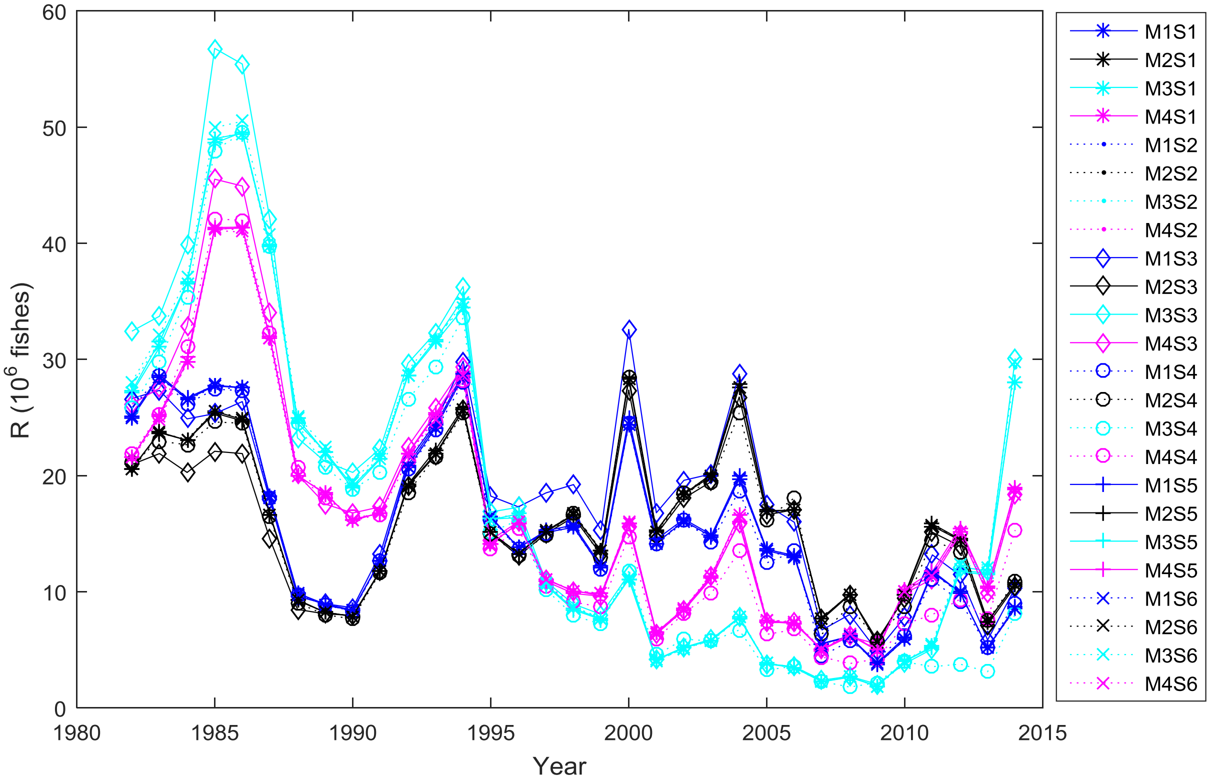


Figure 8.1.11. Posterior recruitment estimated by the age-structured Bayesian models under different data scenarios. See Table 7.1.3 for descriptions of the model and data scenarios.

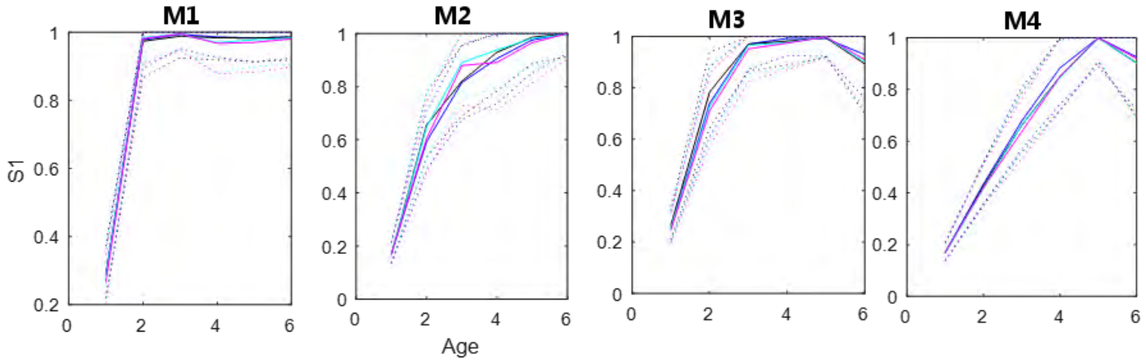


Figure 8.1.12.A. Retrospective analysis results for commercial selectivity pattern estimated by the Bayesian age-structured models. Solid line = posterior mean; dashed lines: 95% credible interval.

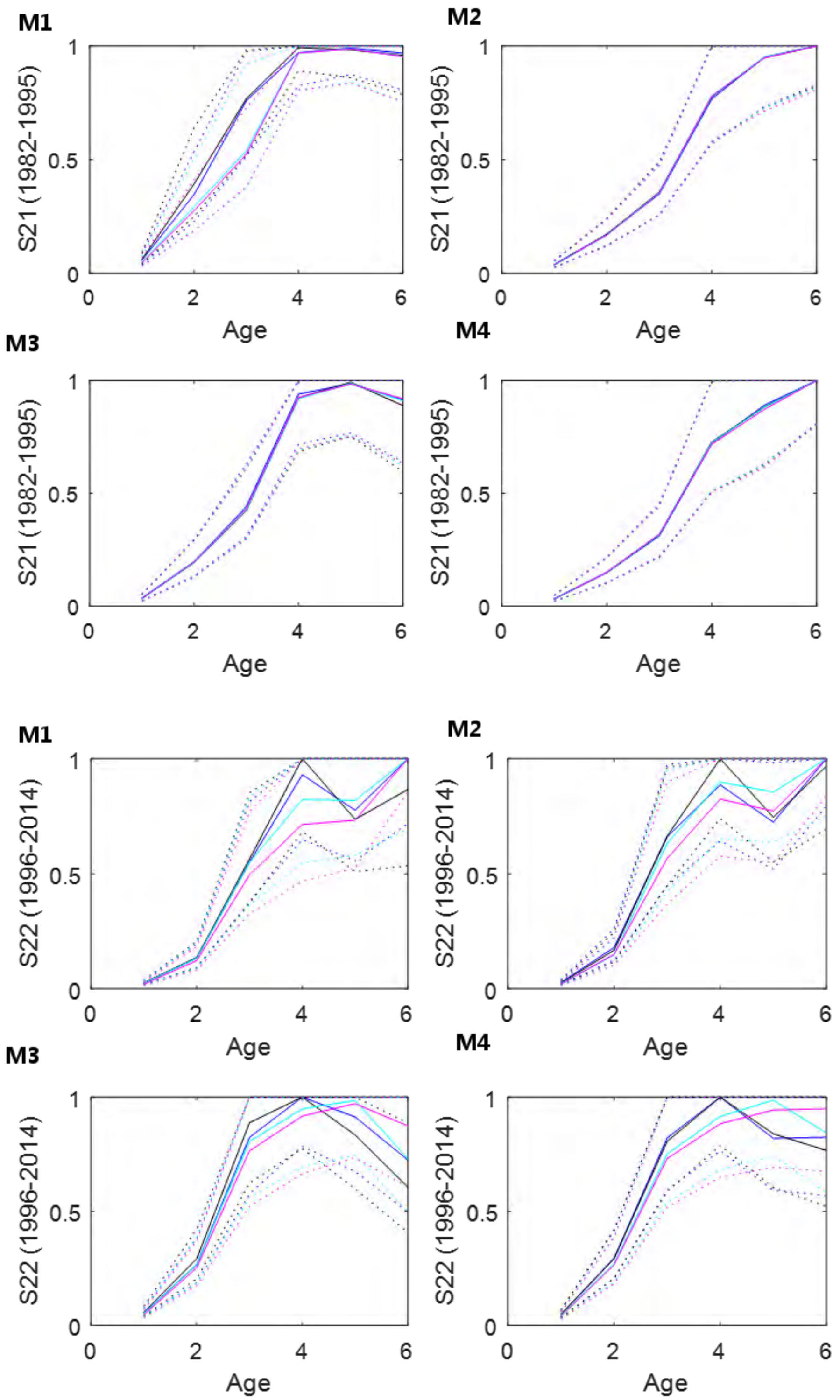


Figure 8.1.12.B. Retrospective analysis results for recreational selectivity patterns estimated by the Bayesian age-structured models. Solid line = posterior mean; dashed lines: 95% credible interval.

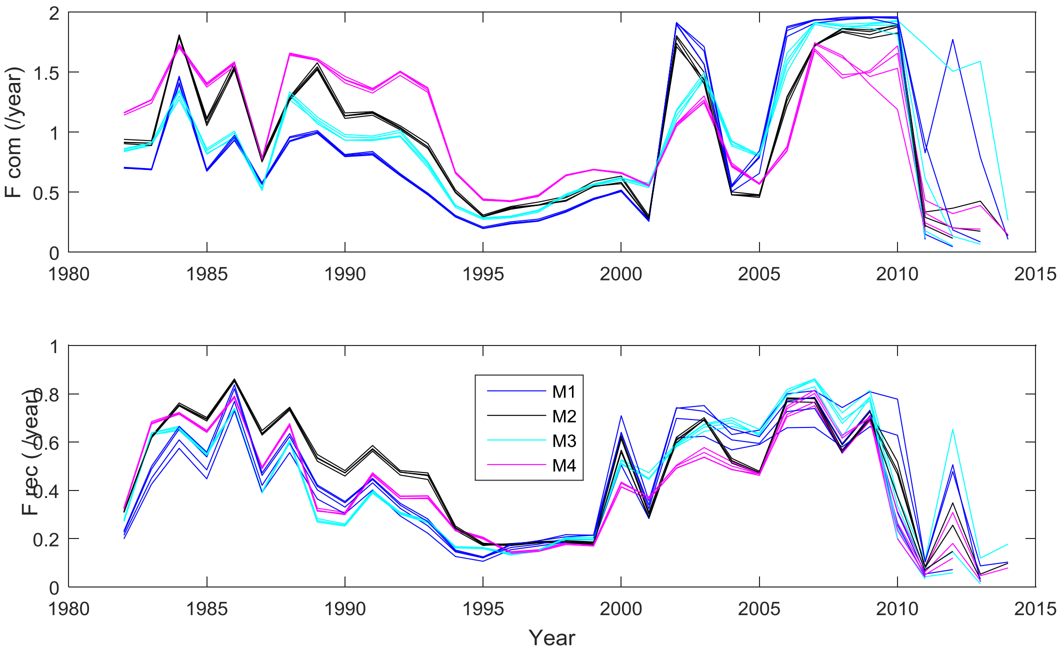


Figure 8.1.13. Retrospective analysis results for posterior fishing mortality estimated by the Bayesian age-structured models.

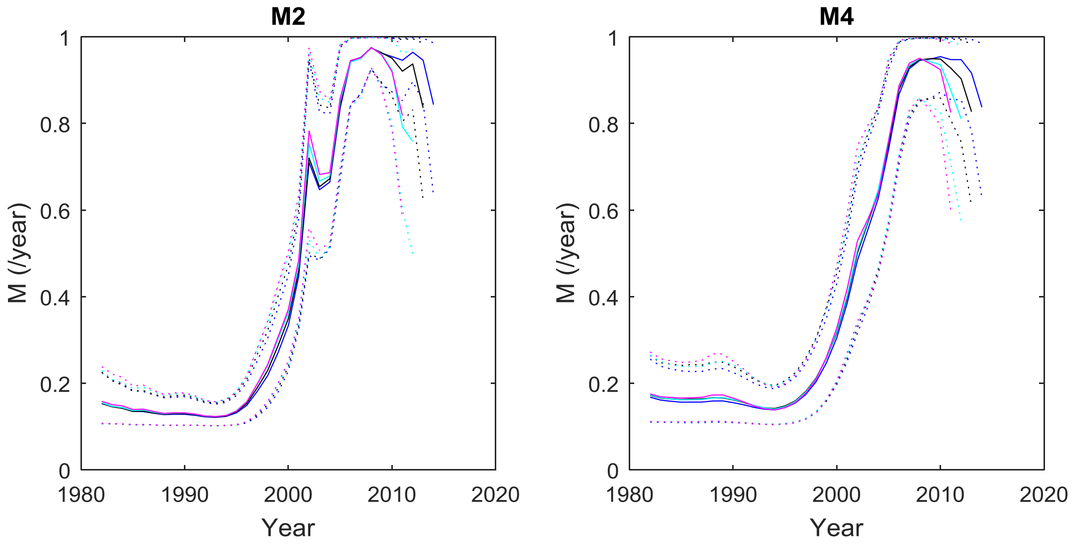


Figure 8.1.14. Retrospective analysis results of M estimates from the nonstationary statistical catch-at-age models M2 and M4. Solid line = posterior mean; dashed lines = 95% credible interval.

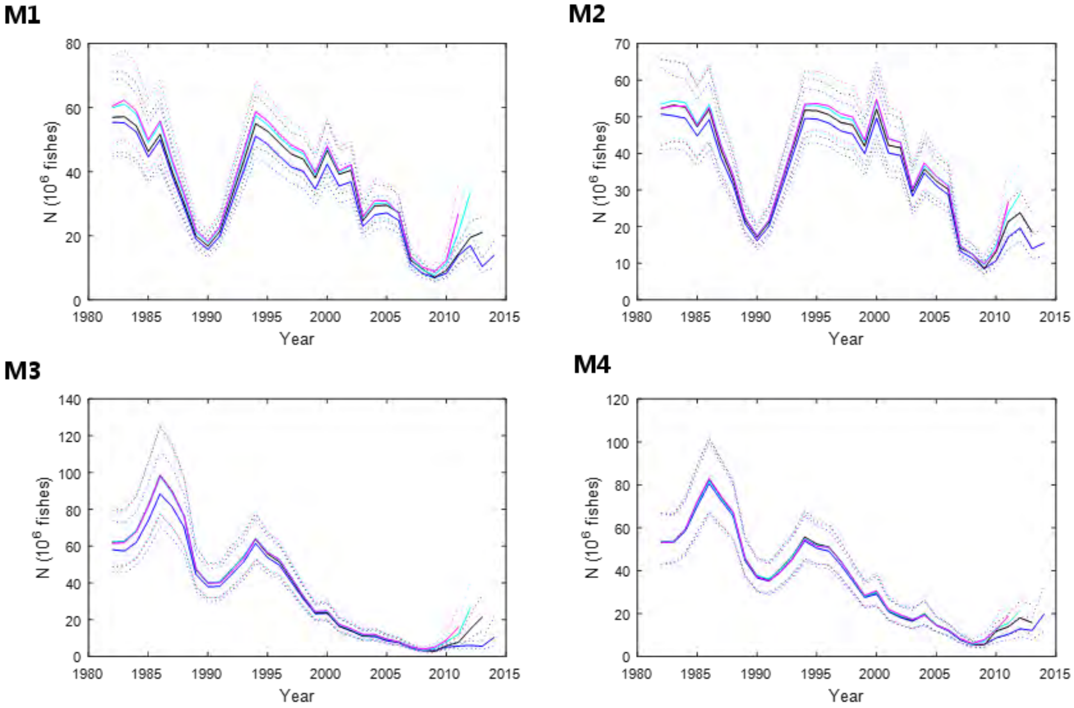


Figure 8.1.15. Retrospective analysis results for posterior population abundance estimated by the Bayesian age-structured model. Solid line = posterior mean; dashed lines = 95% credible interval.

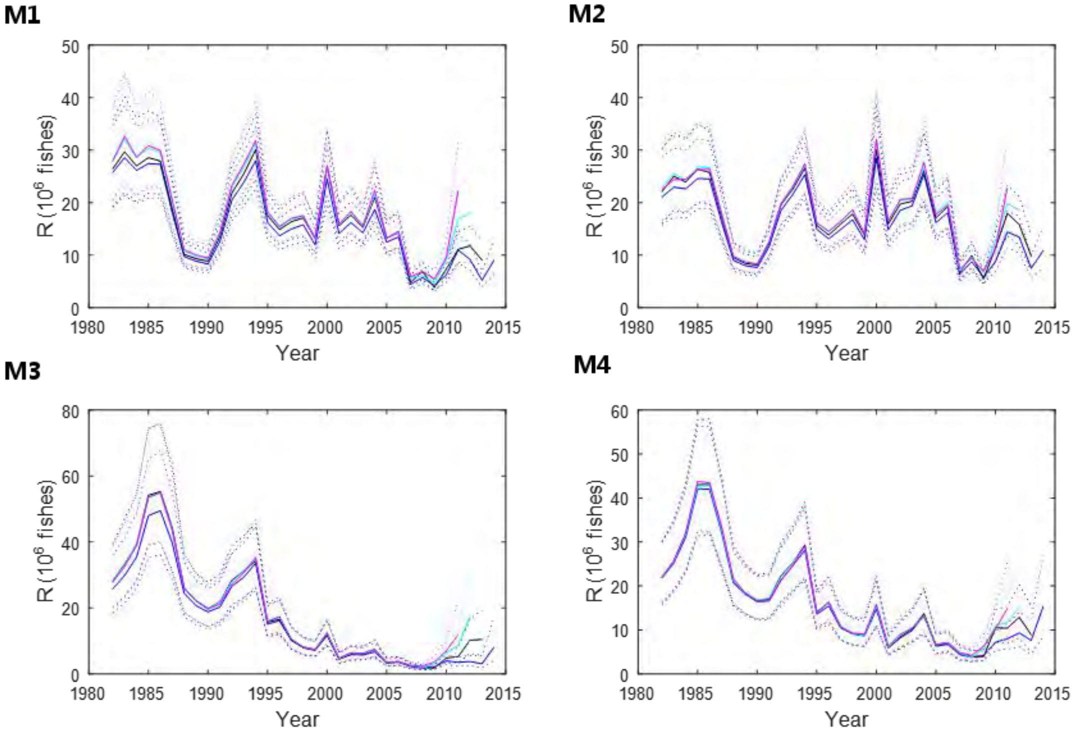


Figure 8.1.16. Retrospective analysis results of posterior recruitment estimated by the Bayesian age-structured models. Solid line = posterior mean; dashed lines = 95% credible interval.

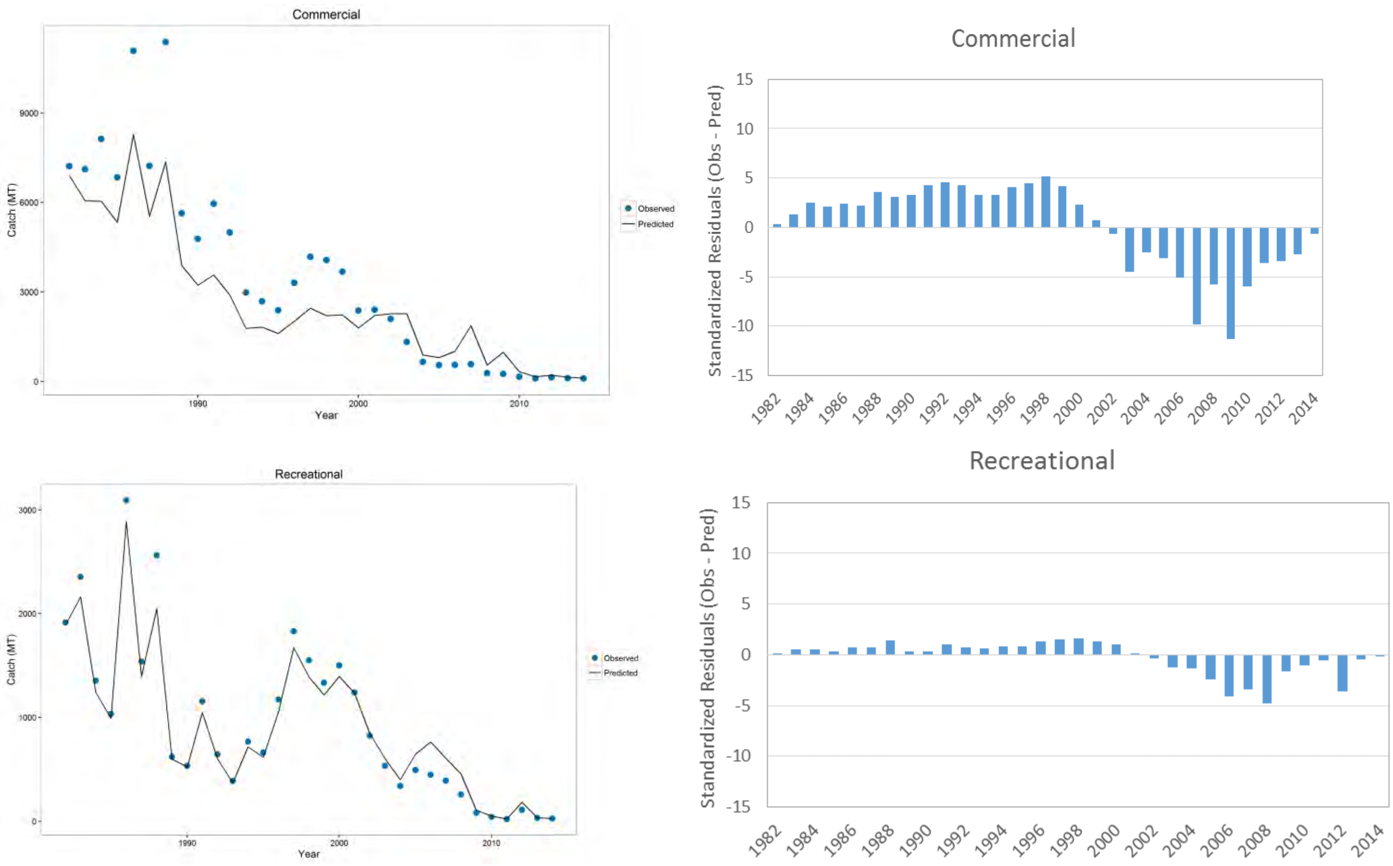


Figure 8.2.1A. Observed and predicted total catch and standardized residuals for the commercial (top) and recreational (bottom) fleet from the ASAP model.

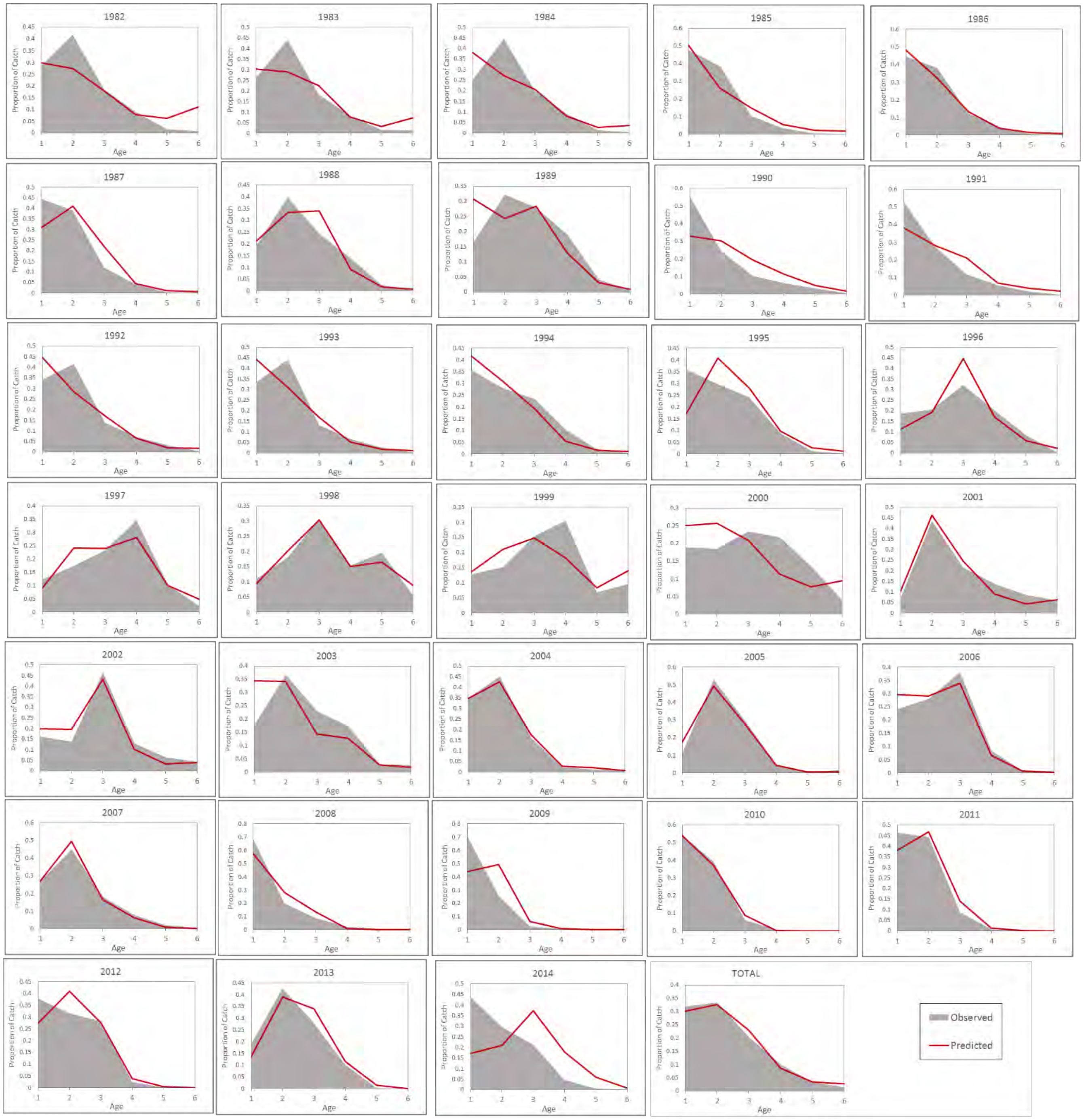


Figure 8.2.1.B. Observed and predicted catch-at-age for the commercial fleet from the ASAP model.

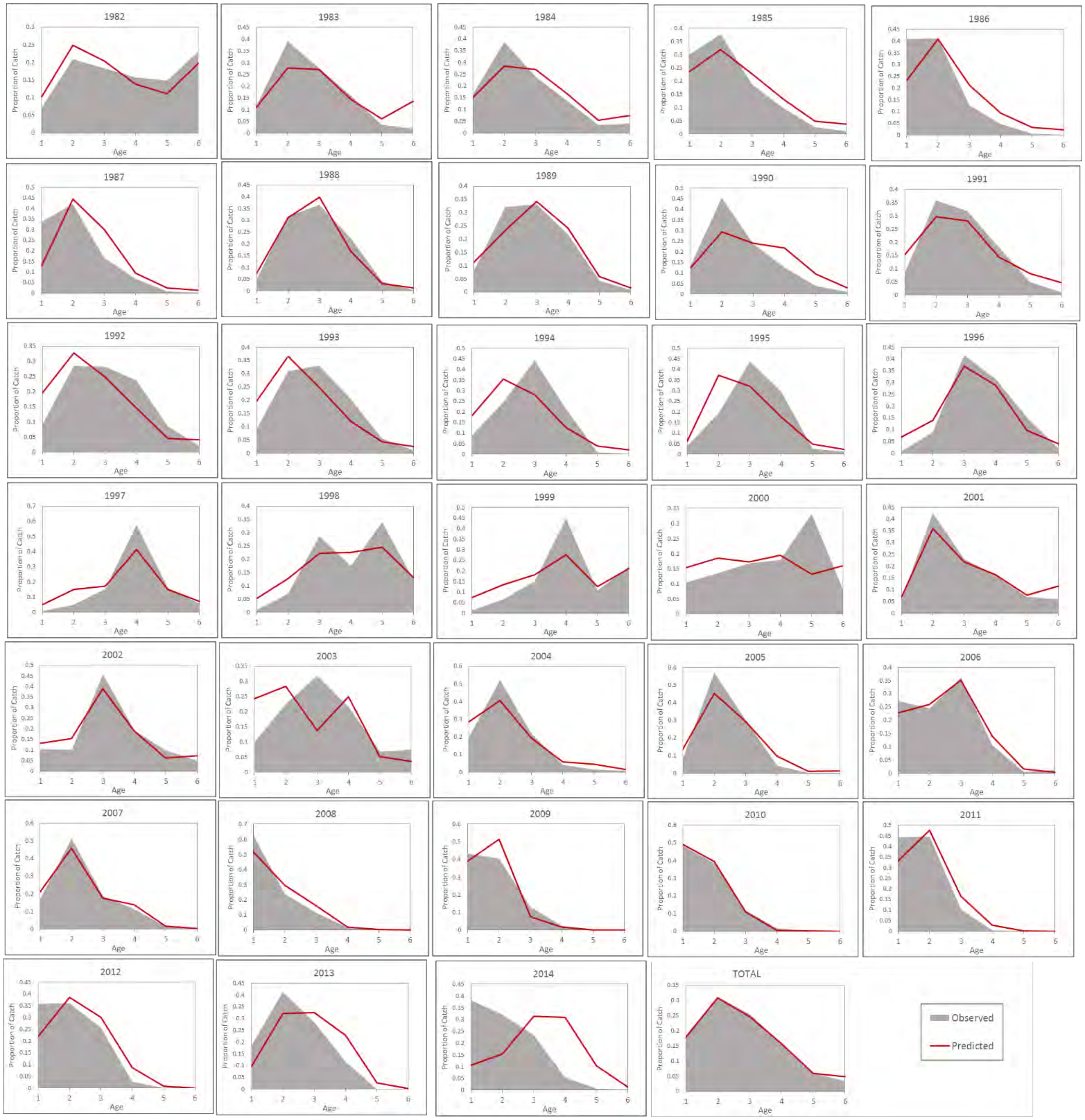


Figure 8.2.1.C. Observed and predicted catch-at-age for the recreational fleet from the ASAP model.

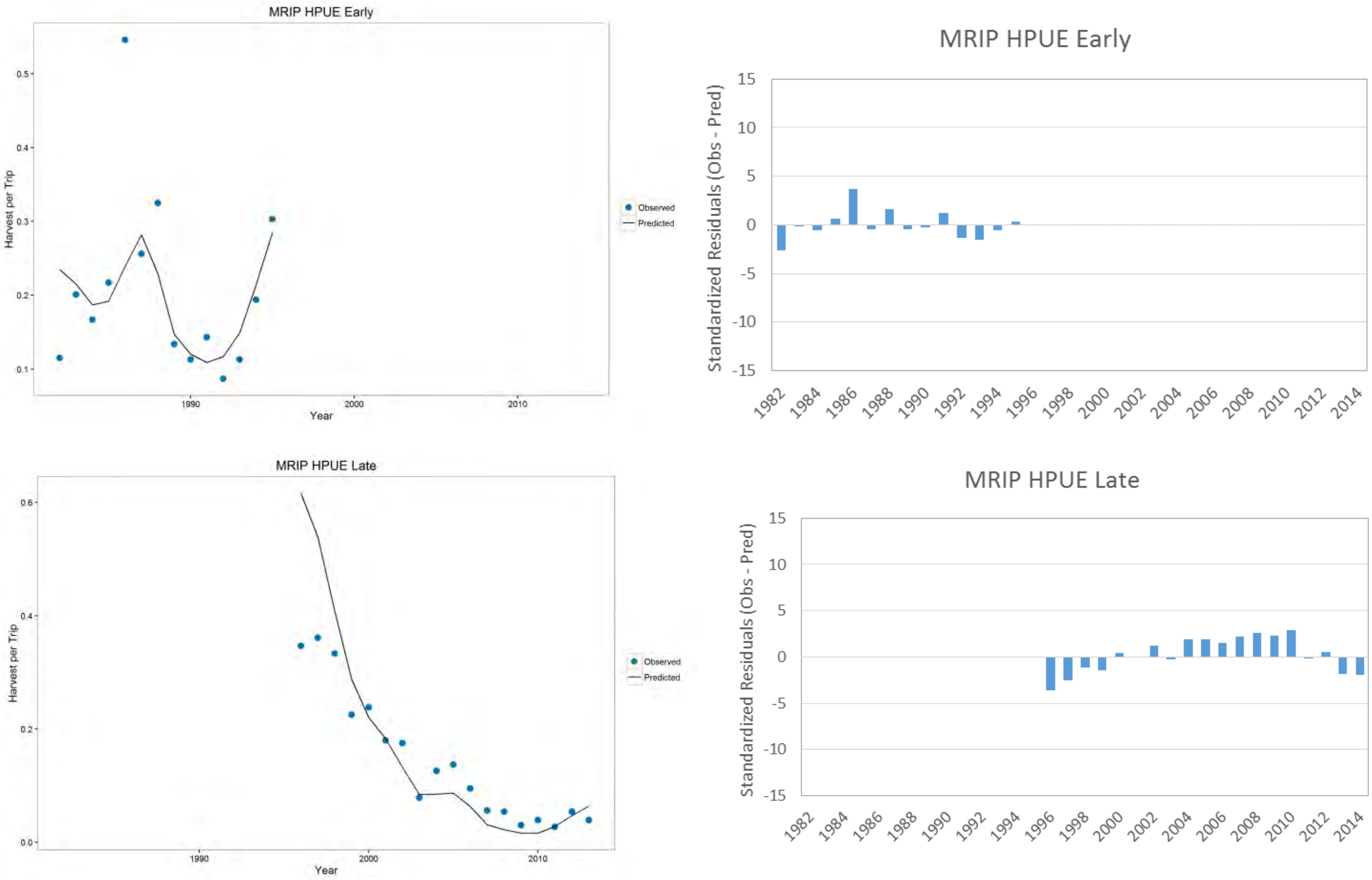


Figure 8.2.2. Observed and predicted values and standardized residuals for the MRIP HPUE index from the ASAP model.

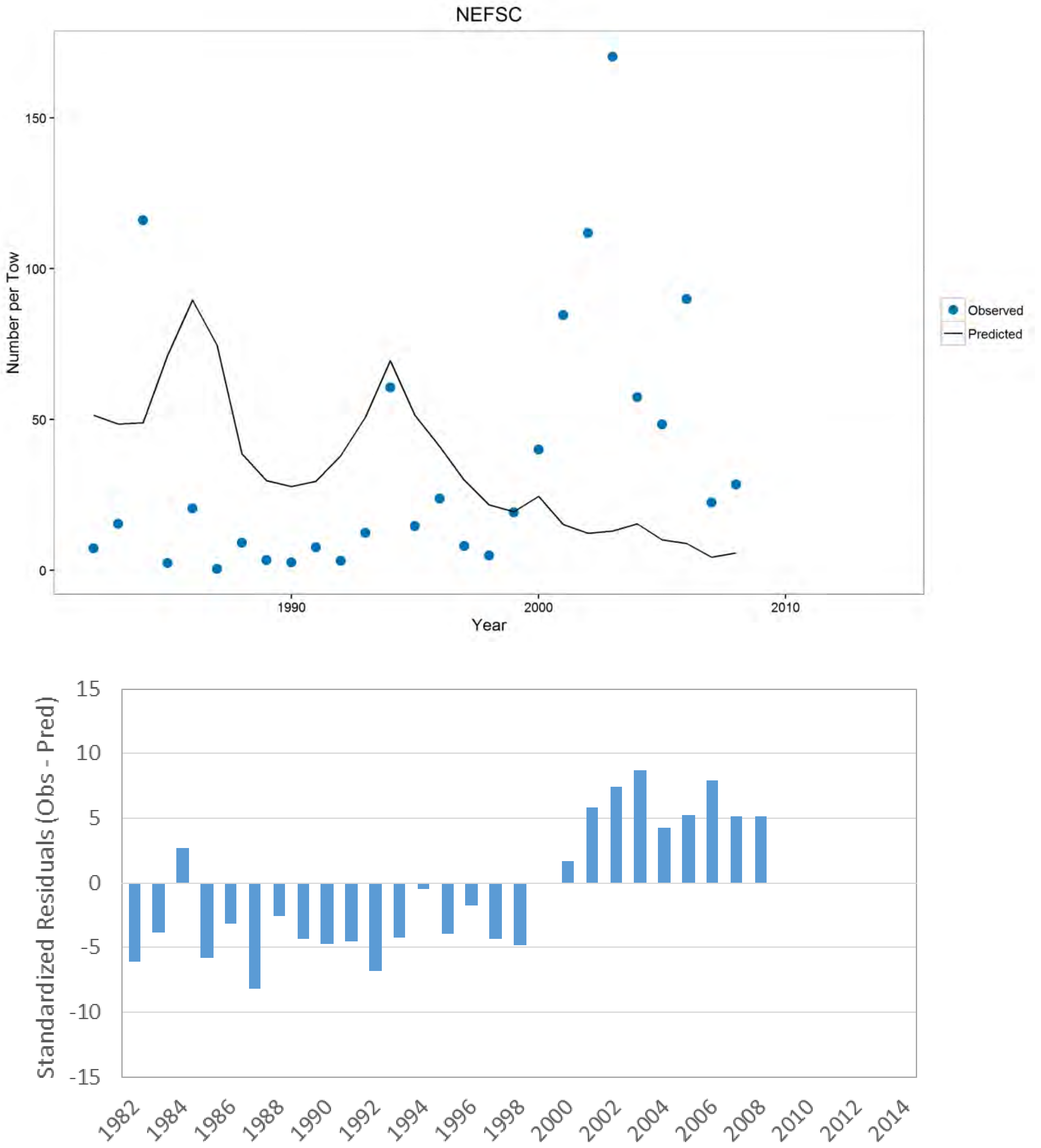


Figure 8.2.3. Observed and predicted values and standardized residuals for the NEFSC Bottom Trawl from the ASAP model.

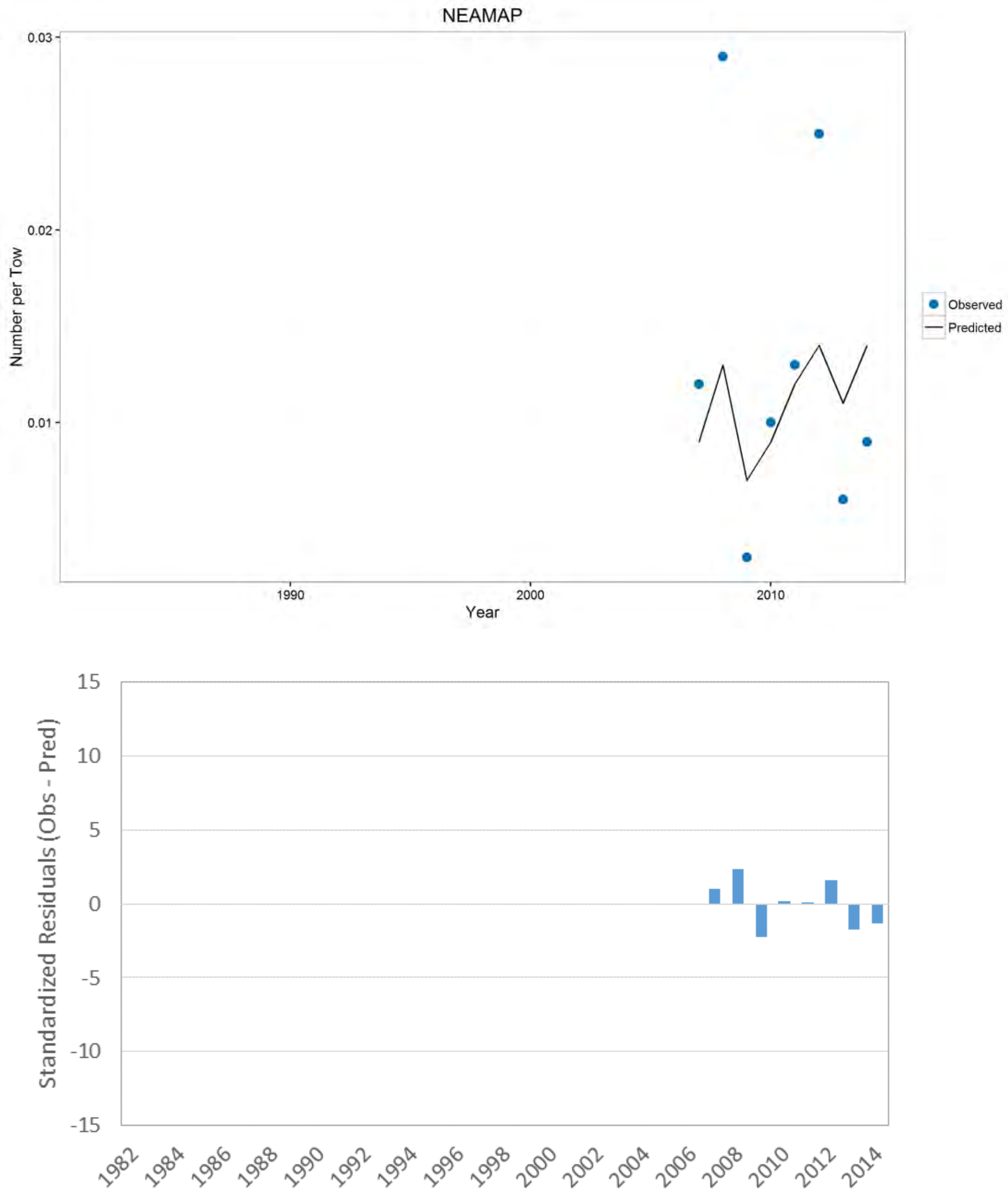


Figure 8.2.4. Observed and predicted values and standardized residuals for the NEAMAP survey from the ASAP model.

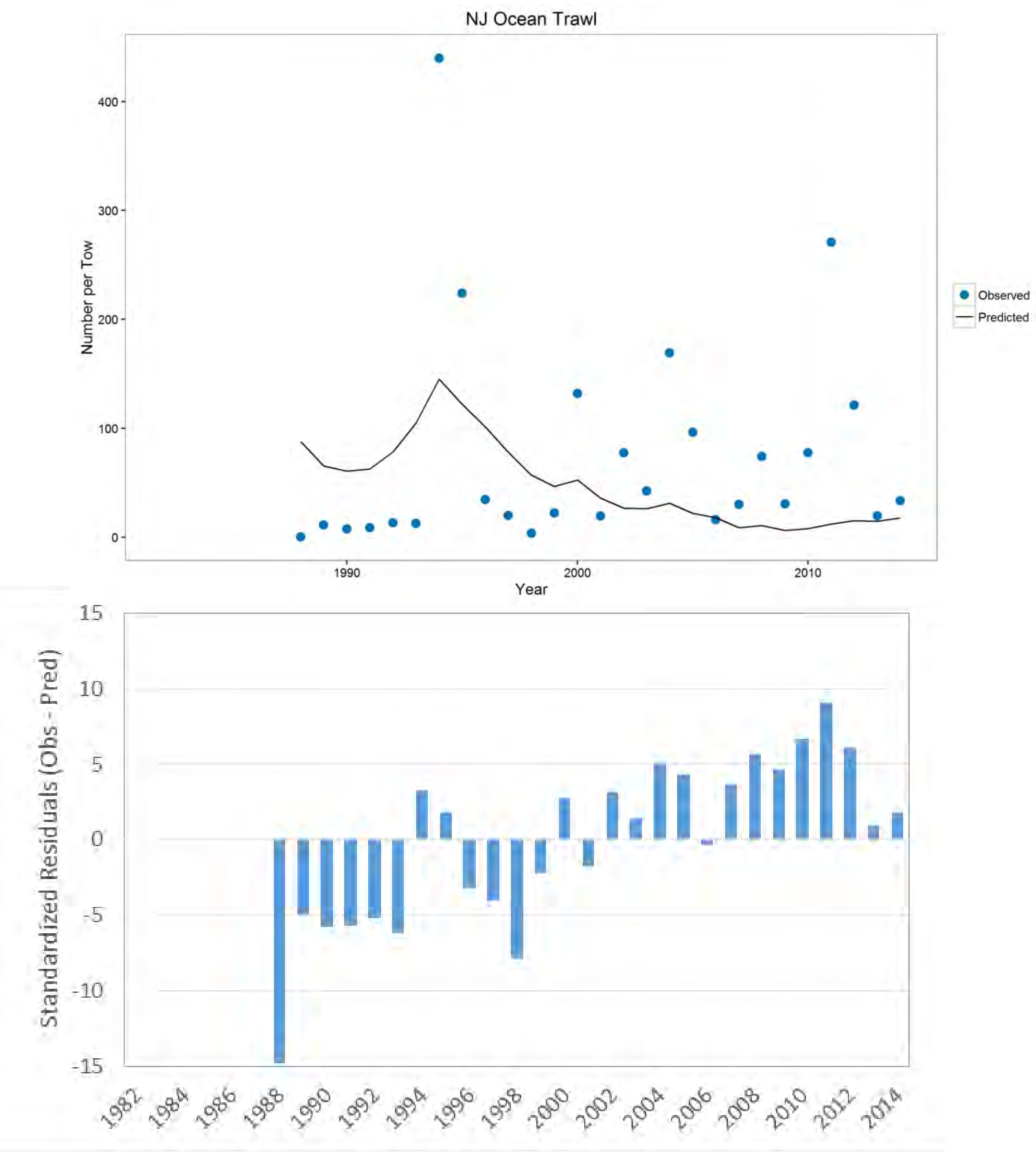


Figure 8.2.5. Observed and predicted values and standardized residuals for the New Jersey Ocean Trawl Survey from the ASAP model.

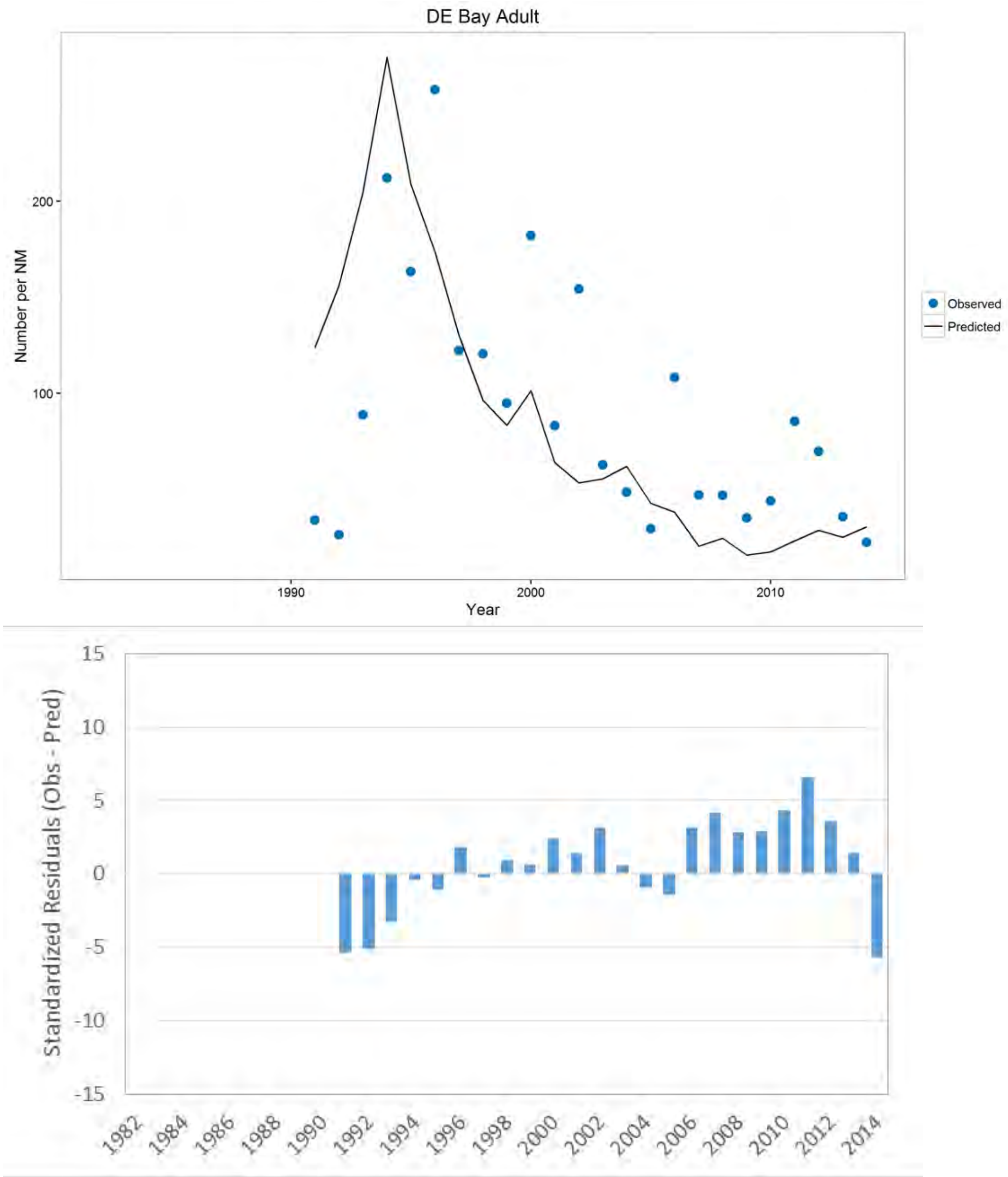


Figure 8.2.6. Observed and predicted values and standardized residuals for the DE Bay Adult Trawl Survey from the ASAP model.

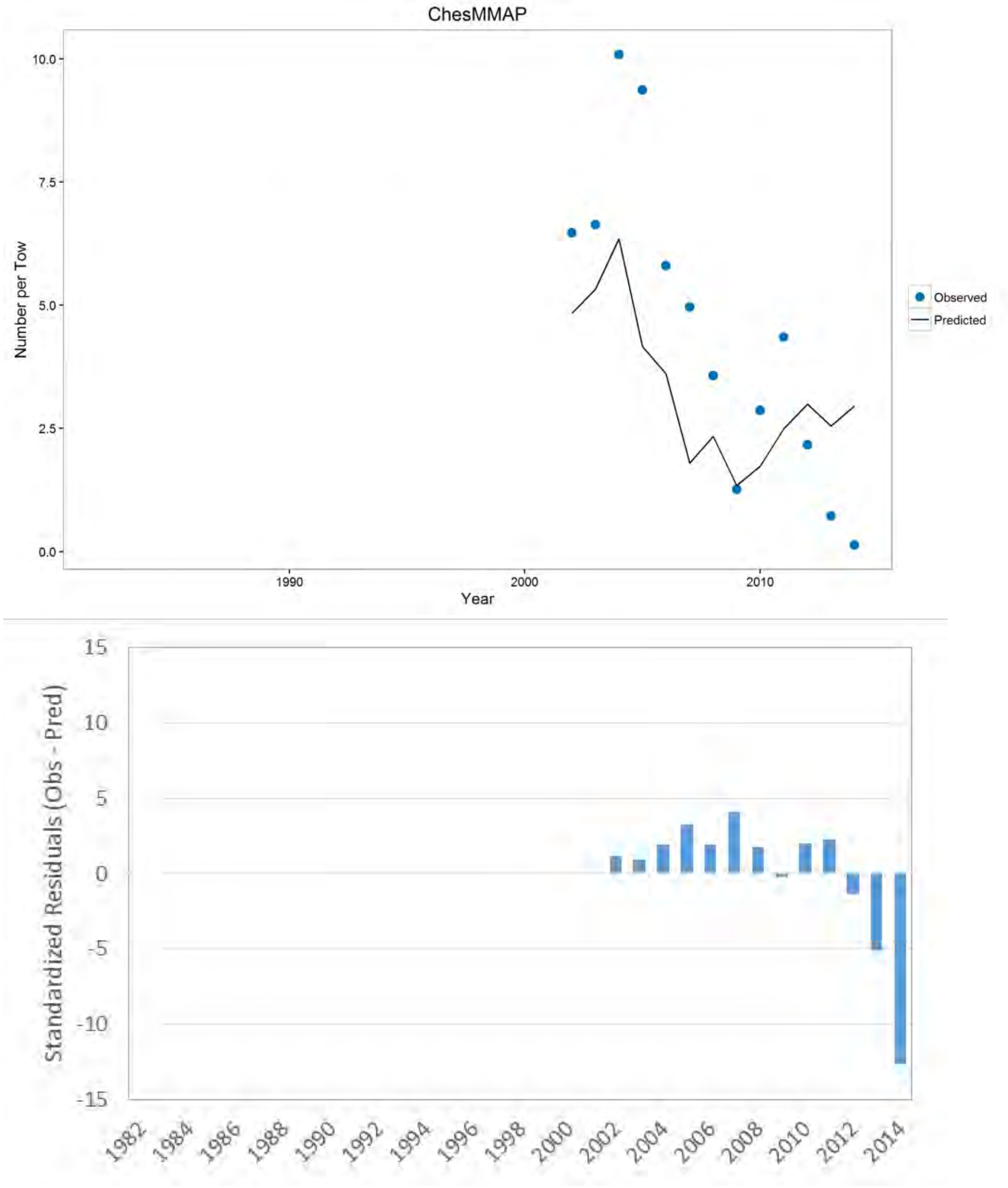


Figure 8.2.7. Observed and predicted values and standardized residuals for the ChesMMAP survey from the ASAP model.

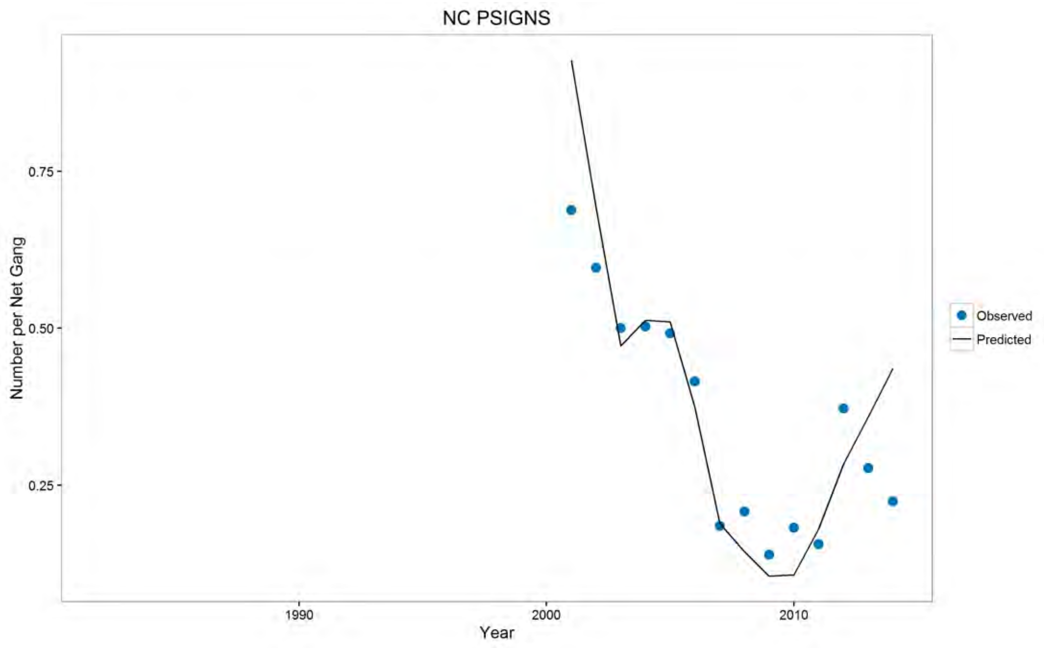


Figure 8.2.8. Observed and predicted values and standardized residuals from the North Carolina Pamlico Sound Independent Gillnet Survey from the ASAP model.

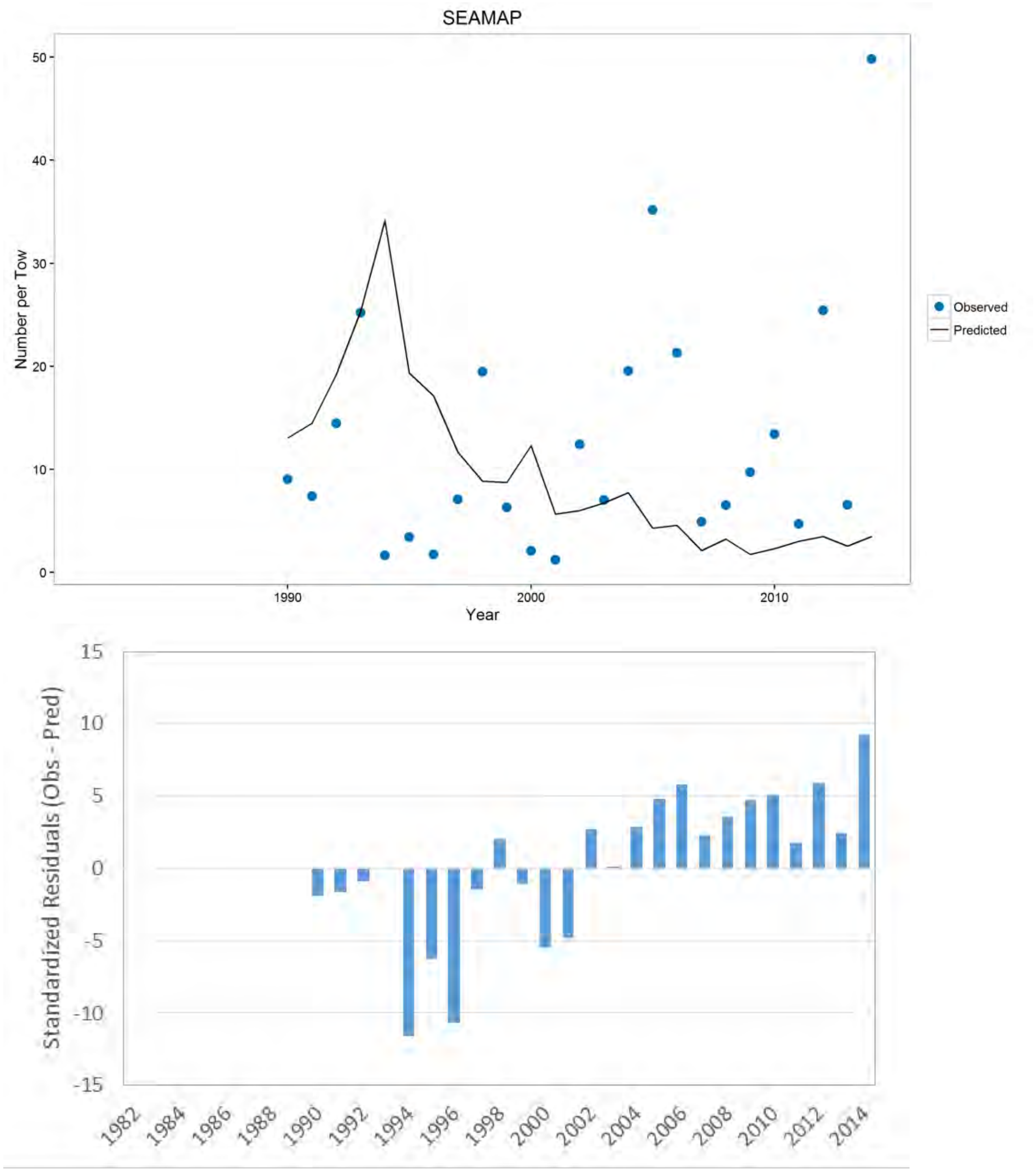


Figure 8.2.9. Observed and predicted values and standardized residuals for the SEAMAP survey from the ASAP model.

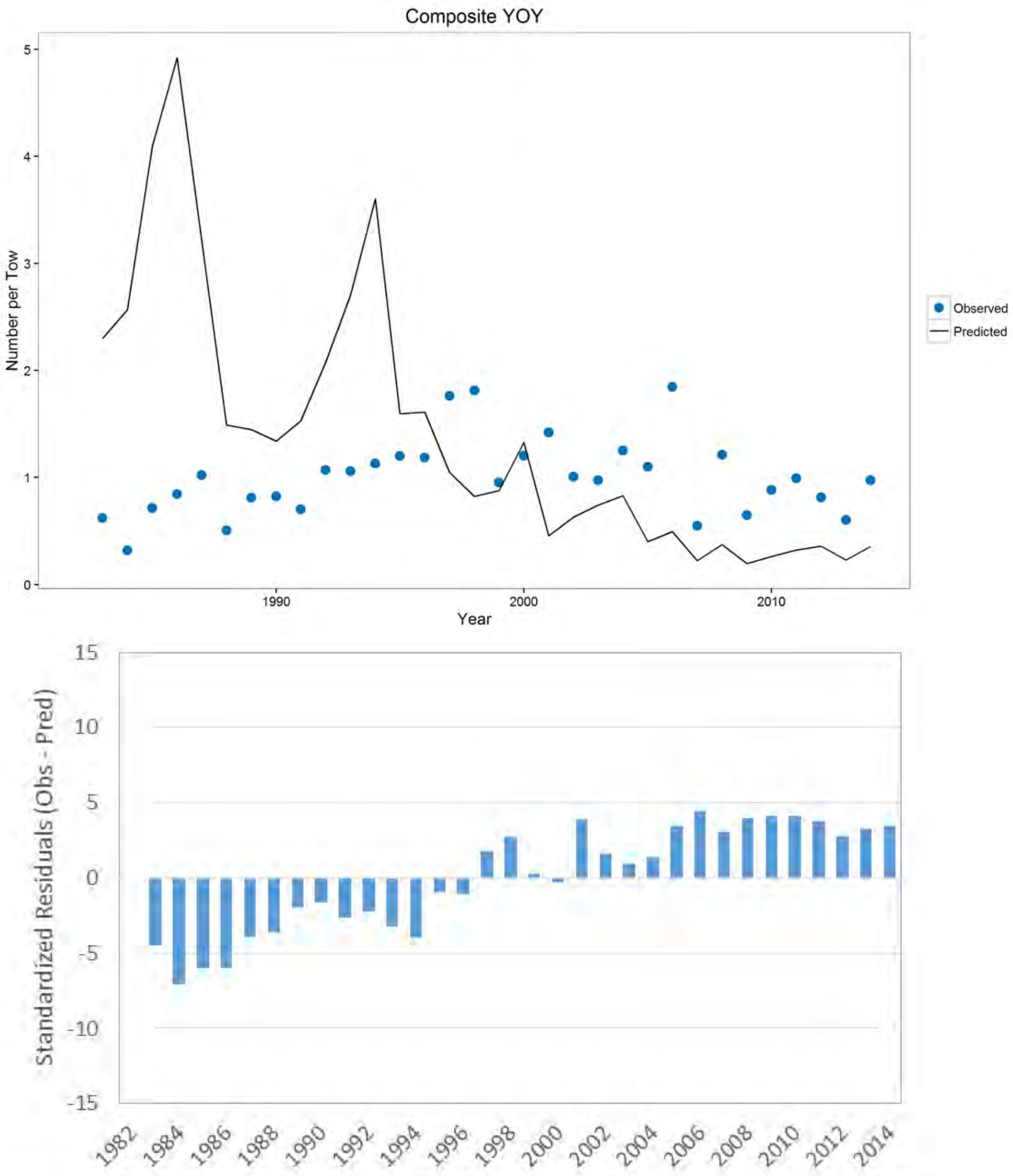


Figure 8.2.10. Observed and predicted values and standardized residuals for the composite young-of-year index from the ASAP model.

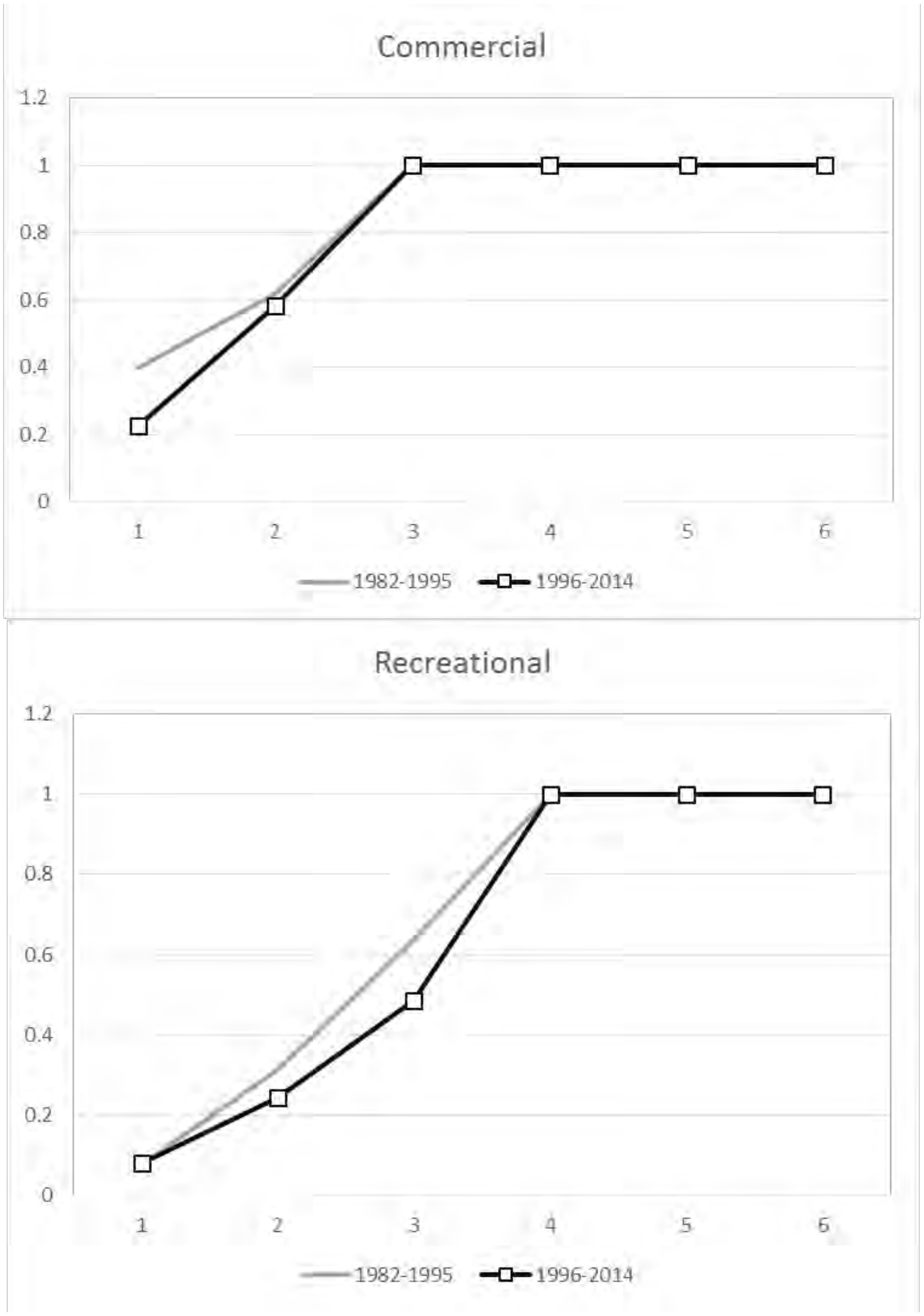


Figure 8.2.11. Selectivity patterns estimated by the ASAP model.

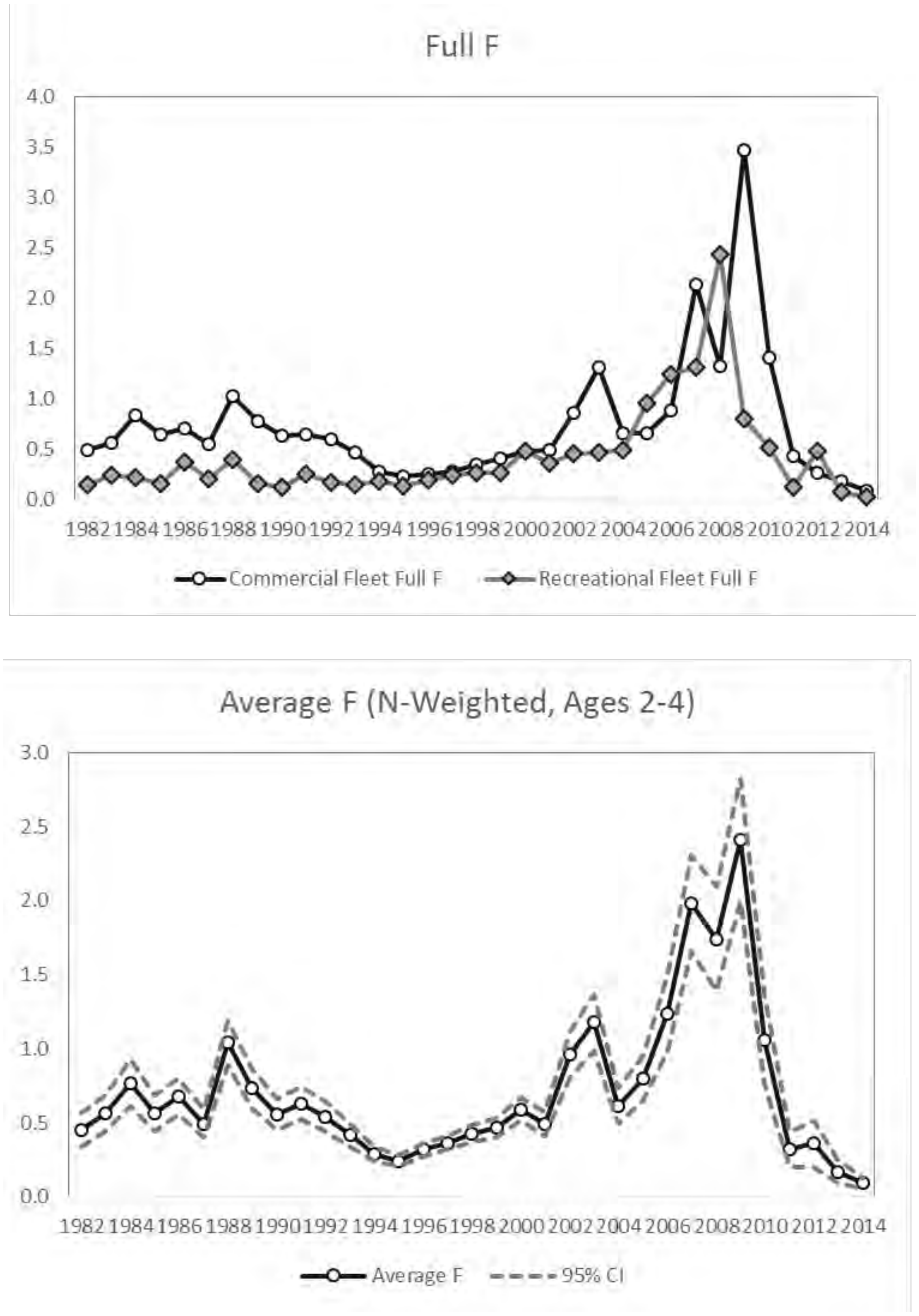


Figure 8.2.12. Fishing mortality estimated by the ASAP model.

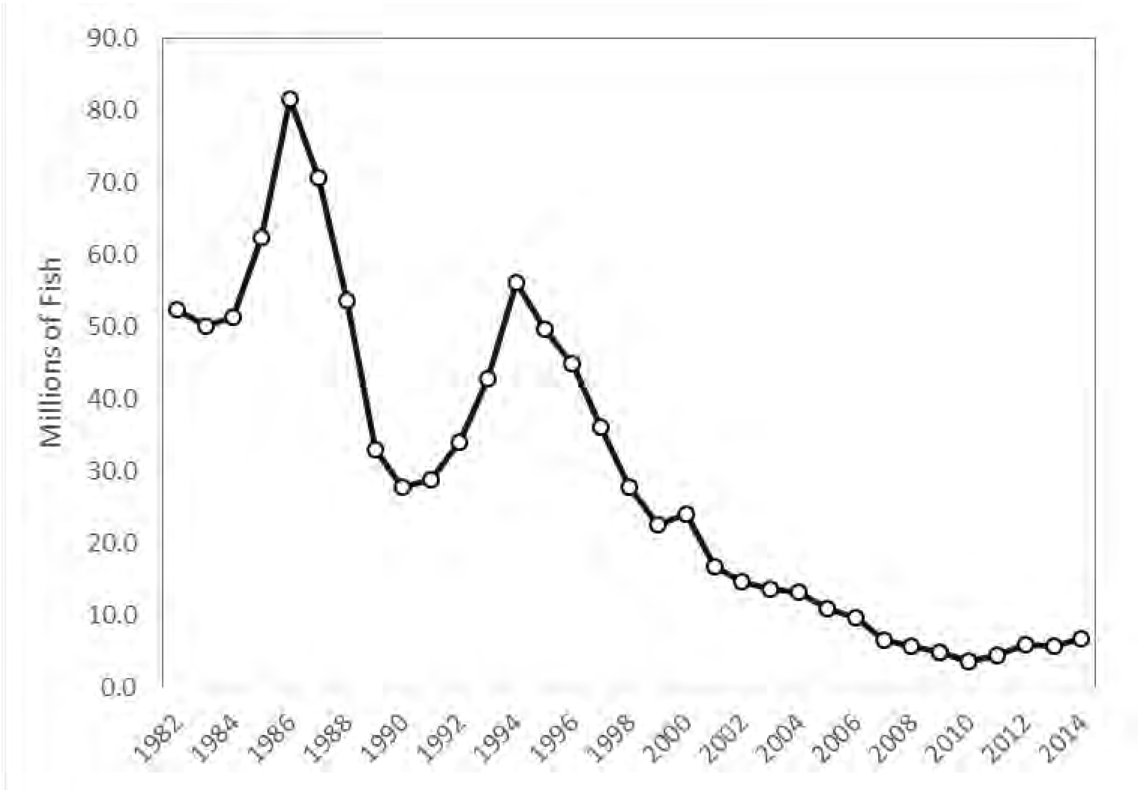


Figure 8.2.13. Total abundance estimated by the ASAP model.

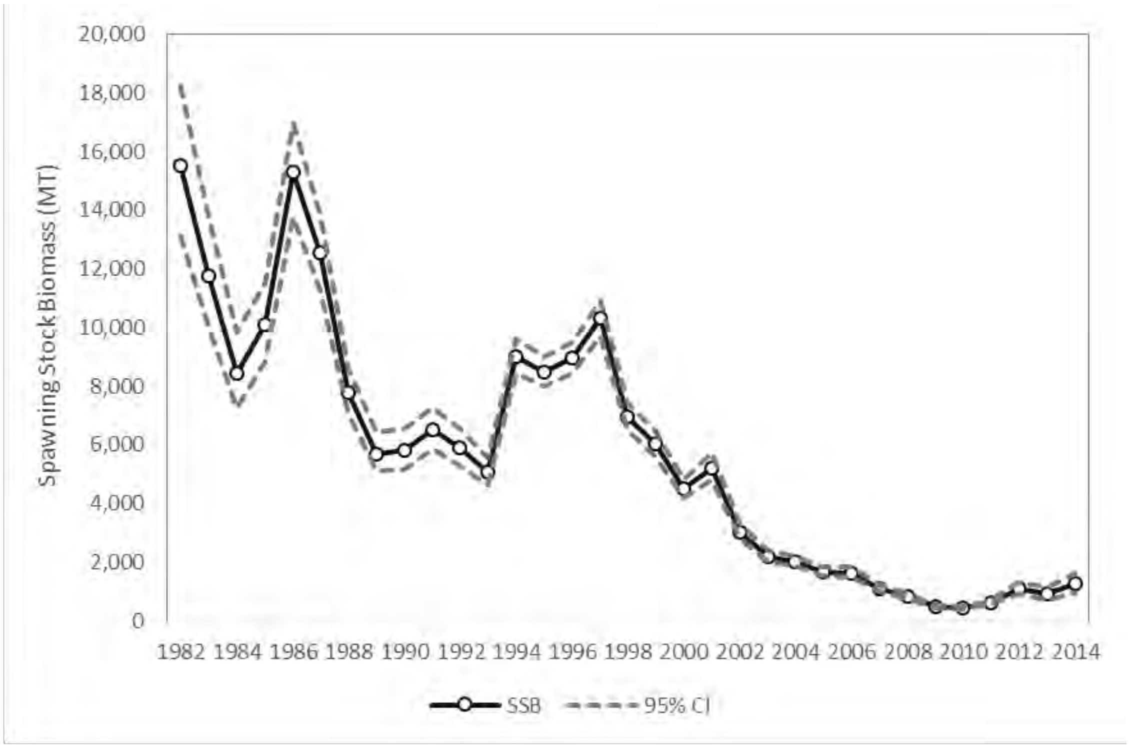


Figure 8.2.14. Spawning stock biomass estimated by the ASAP model.Median and 95% confidence intervals.

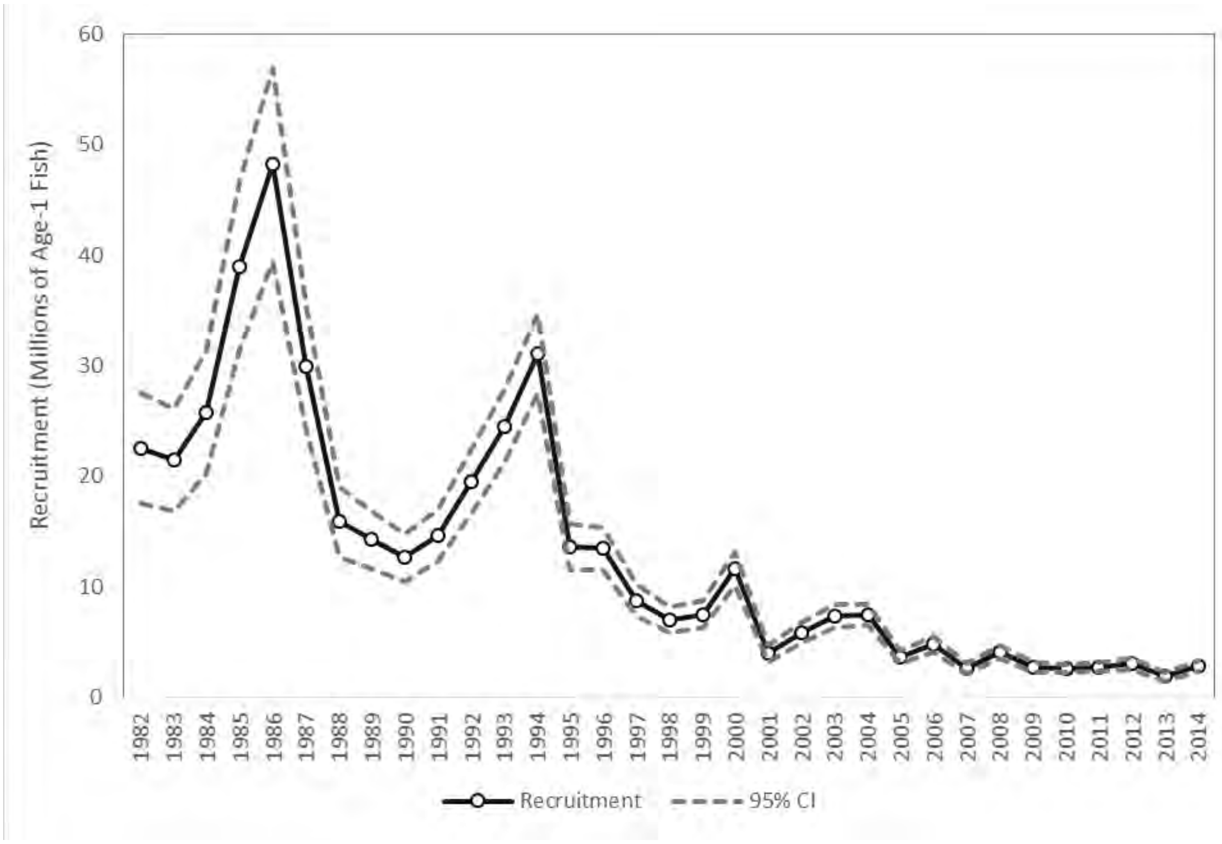


Figure 8.2.15. Recruitment of Age-1 fish estimated by the ASAP model.

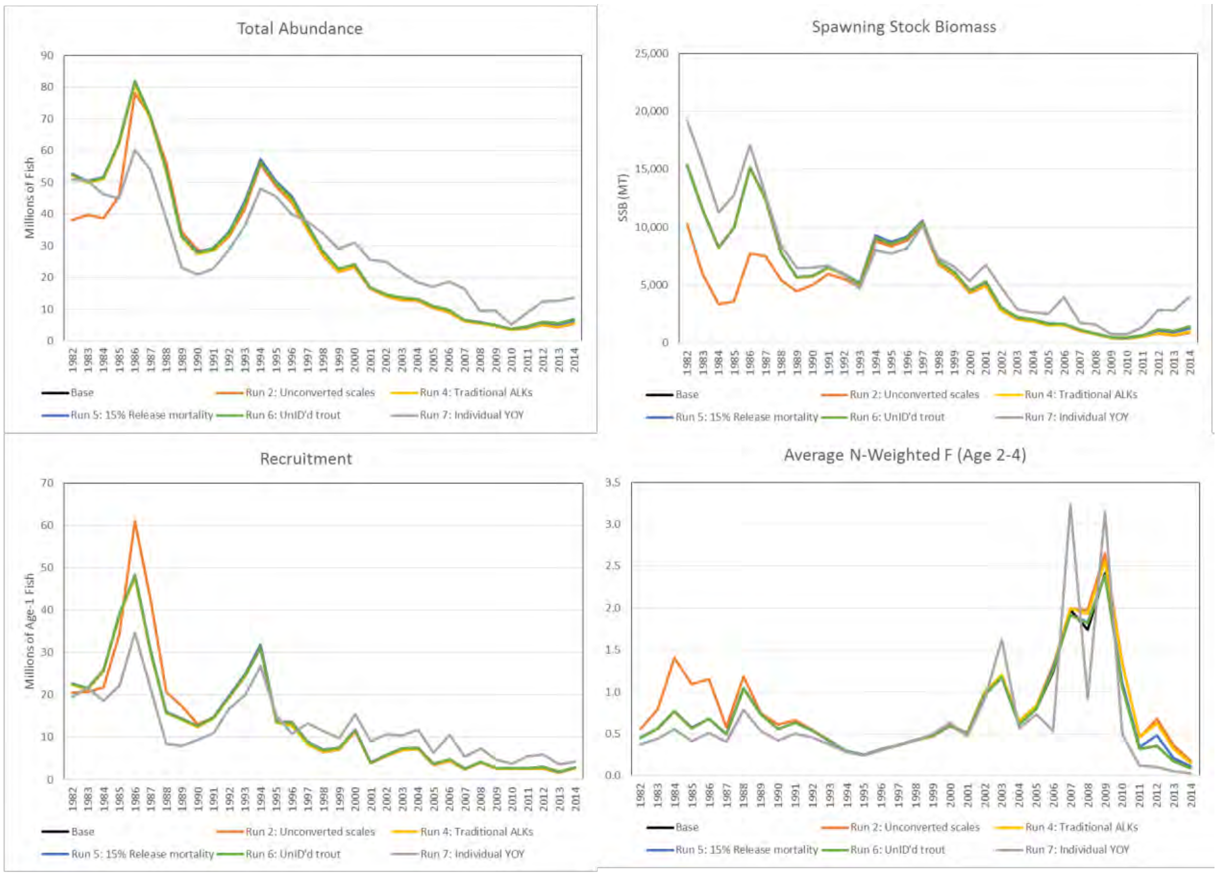


Figure 8.2.16. Sensitivity of the ASAP model to changes in input data.

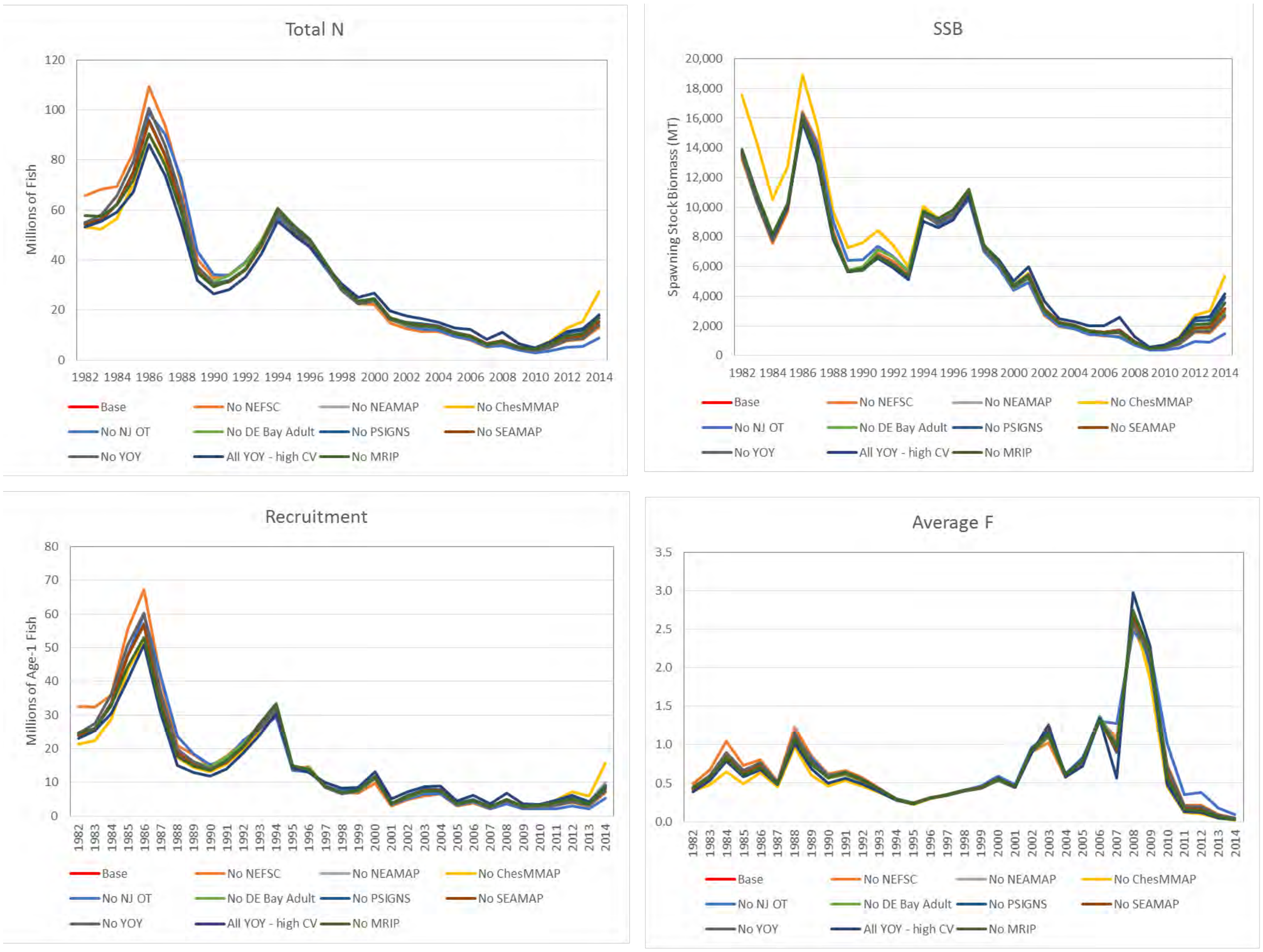


Figure 8.2.17. Sensitivity of the ASAP model to individual indices.

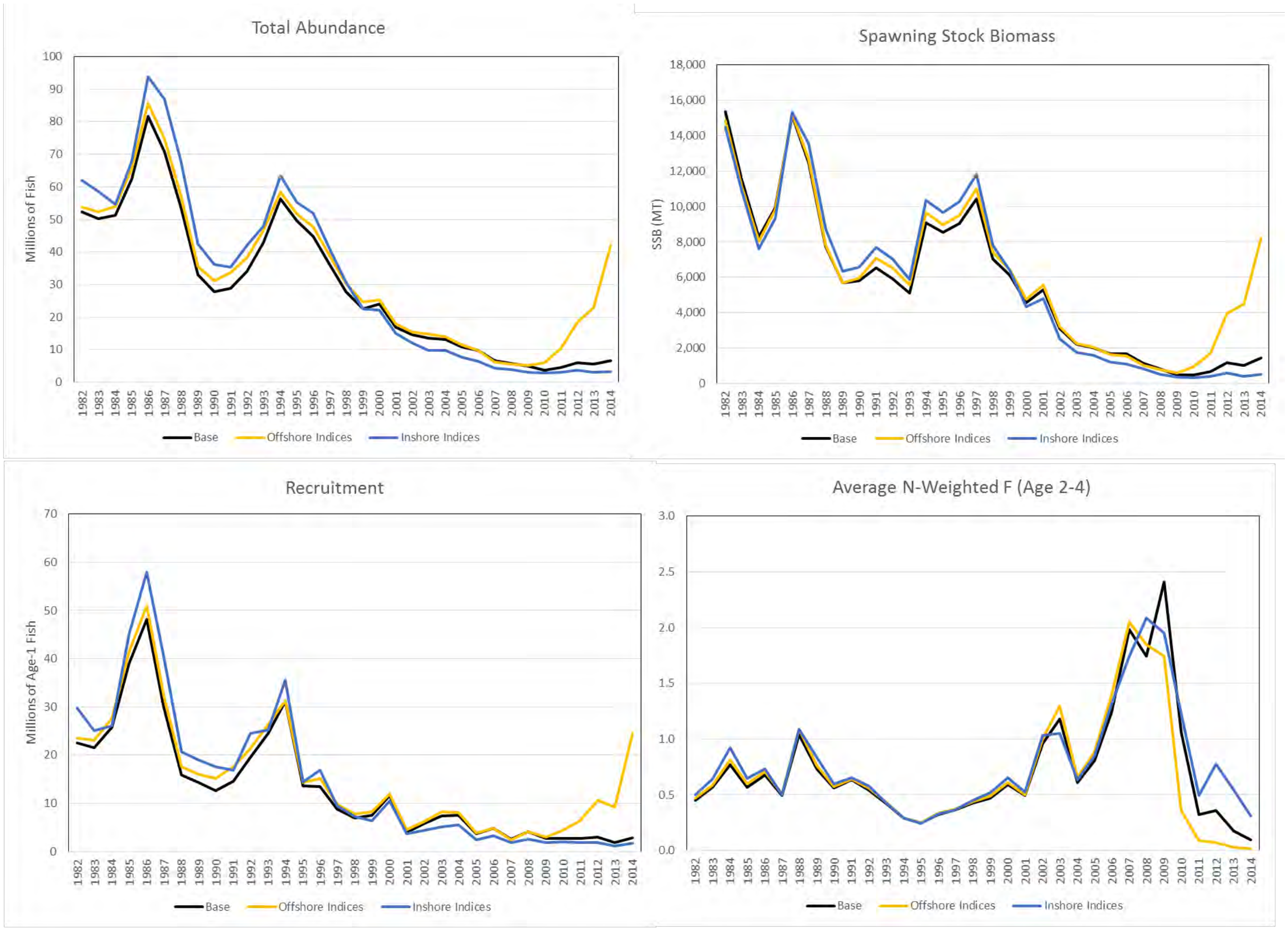


Figure 8.2.18. Sensitivity of the ASAP model to inshore and offshore indices.

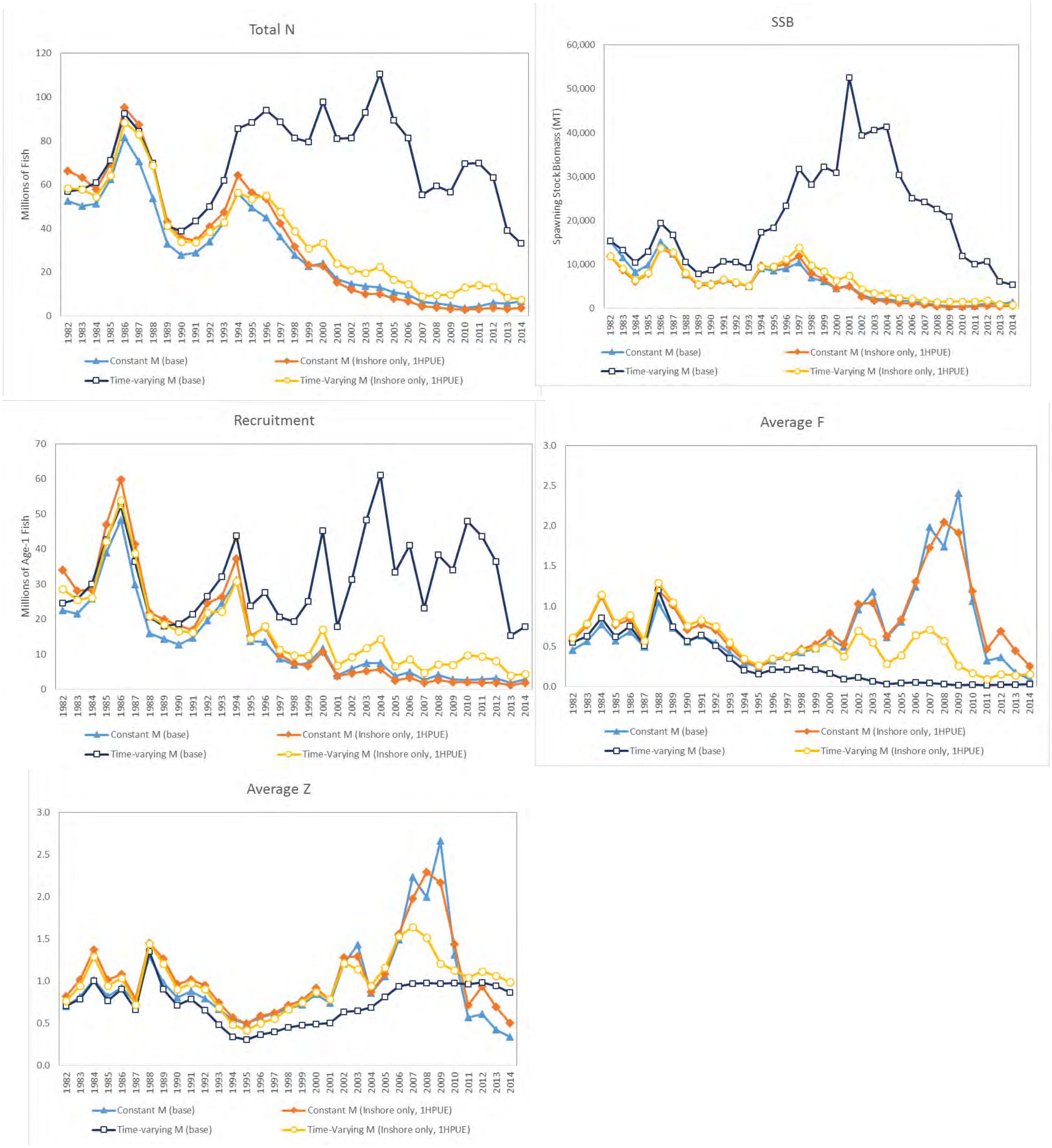


Figure 8.2.19. Comparison of ASAP model results under time-constant and time-varying M.

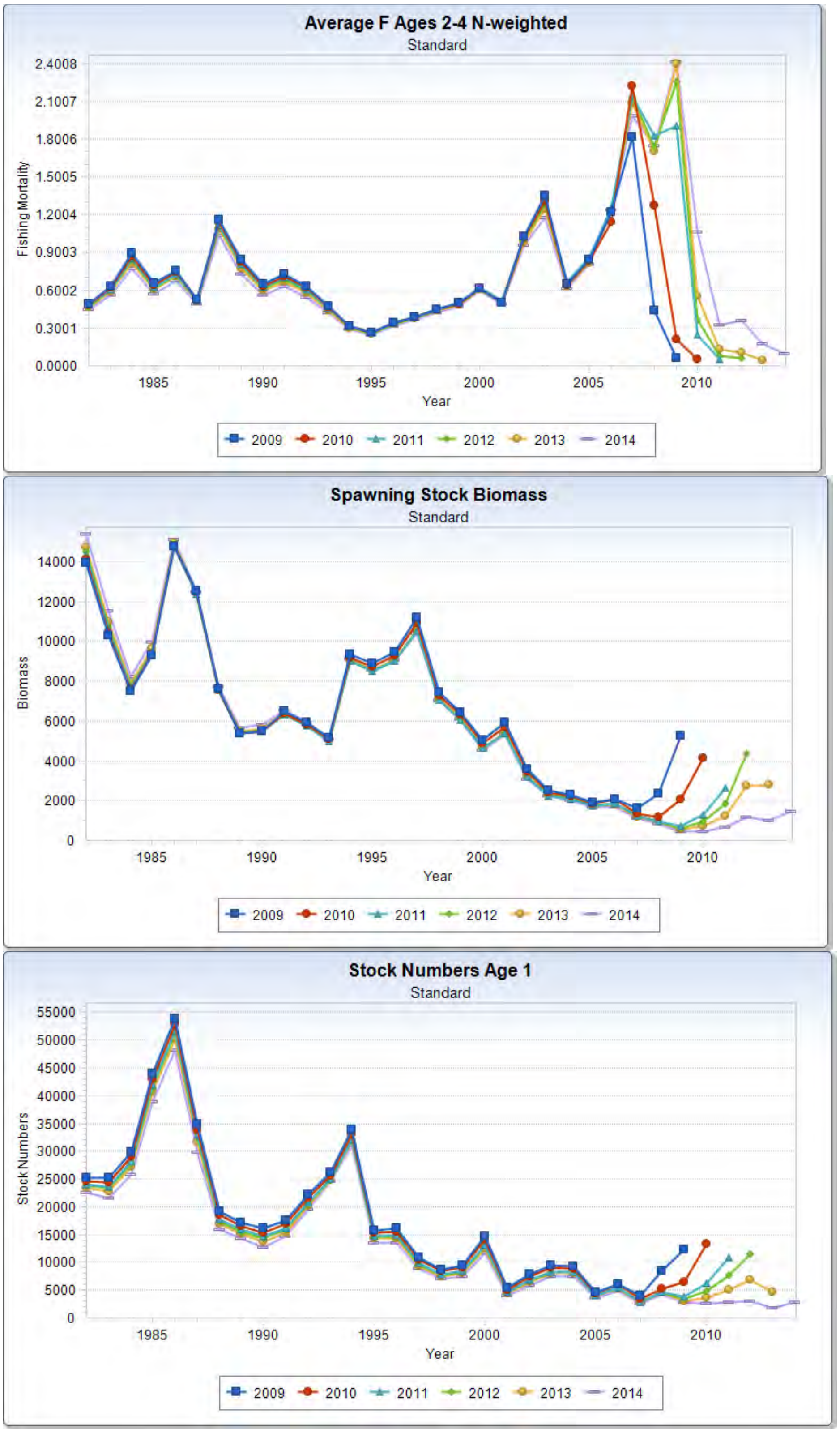


Figure 8.2.20. Retrospective patterns for base model of ASAP model.

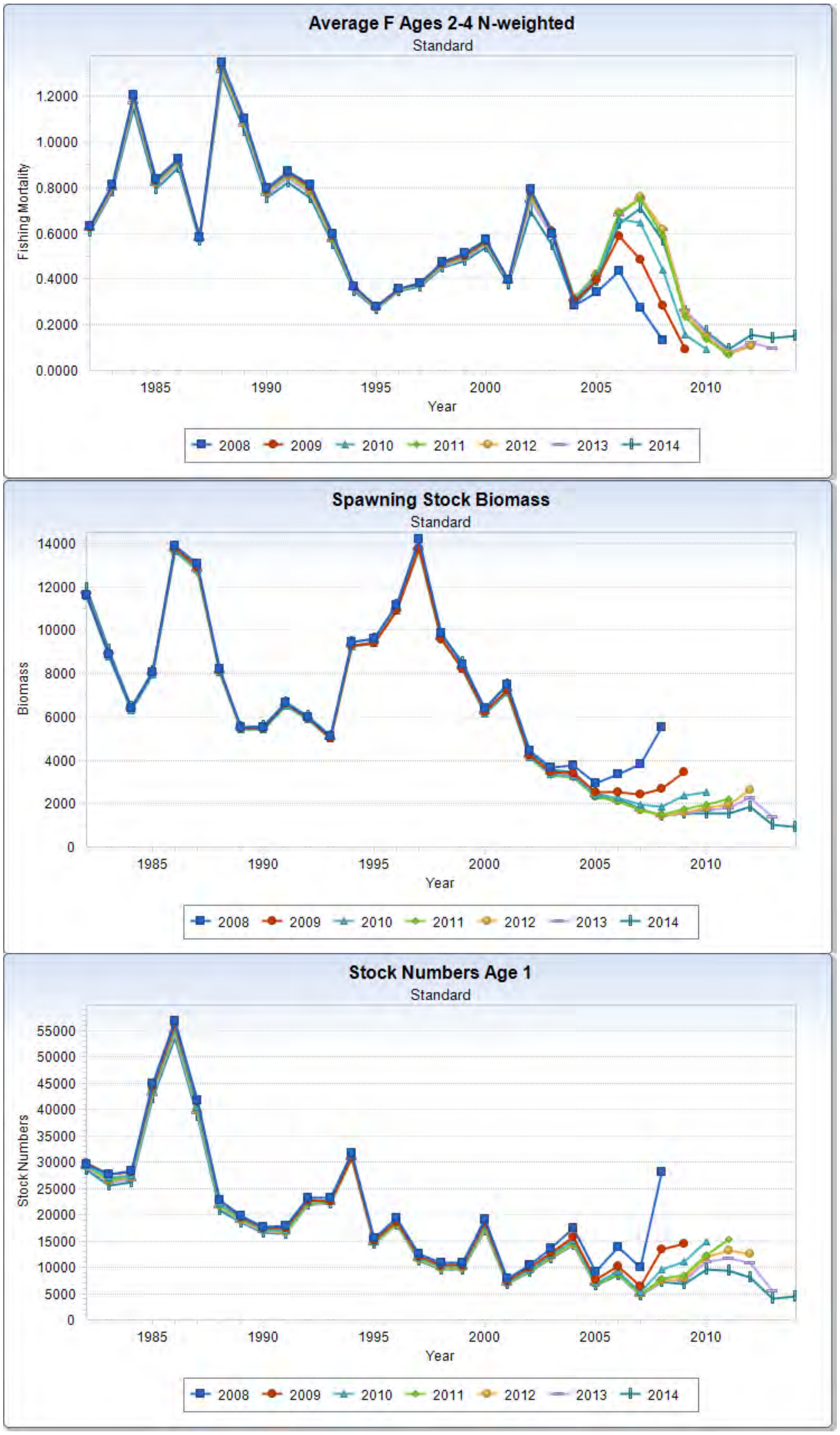


Figure 8.2.21. Retrospective patterns for time-varying M run of ASAP model.

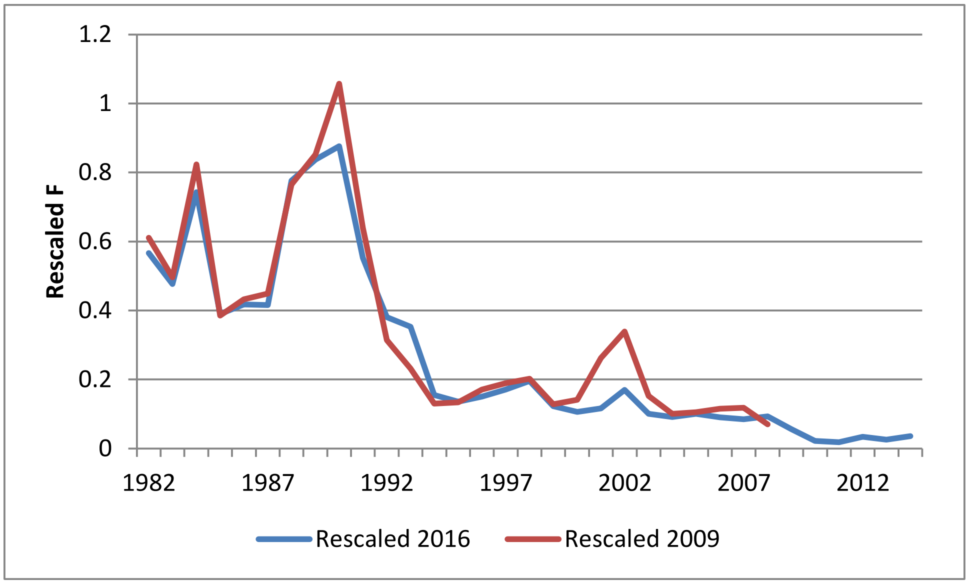


Figure 8.4.1. Rescaled relative F estimates from the 2009 assessment and 2016 continuity runs.

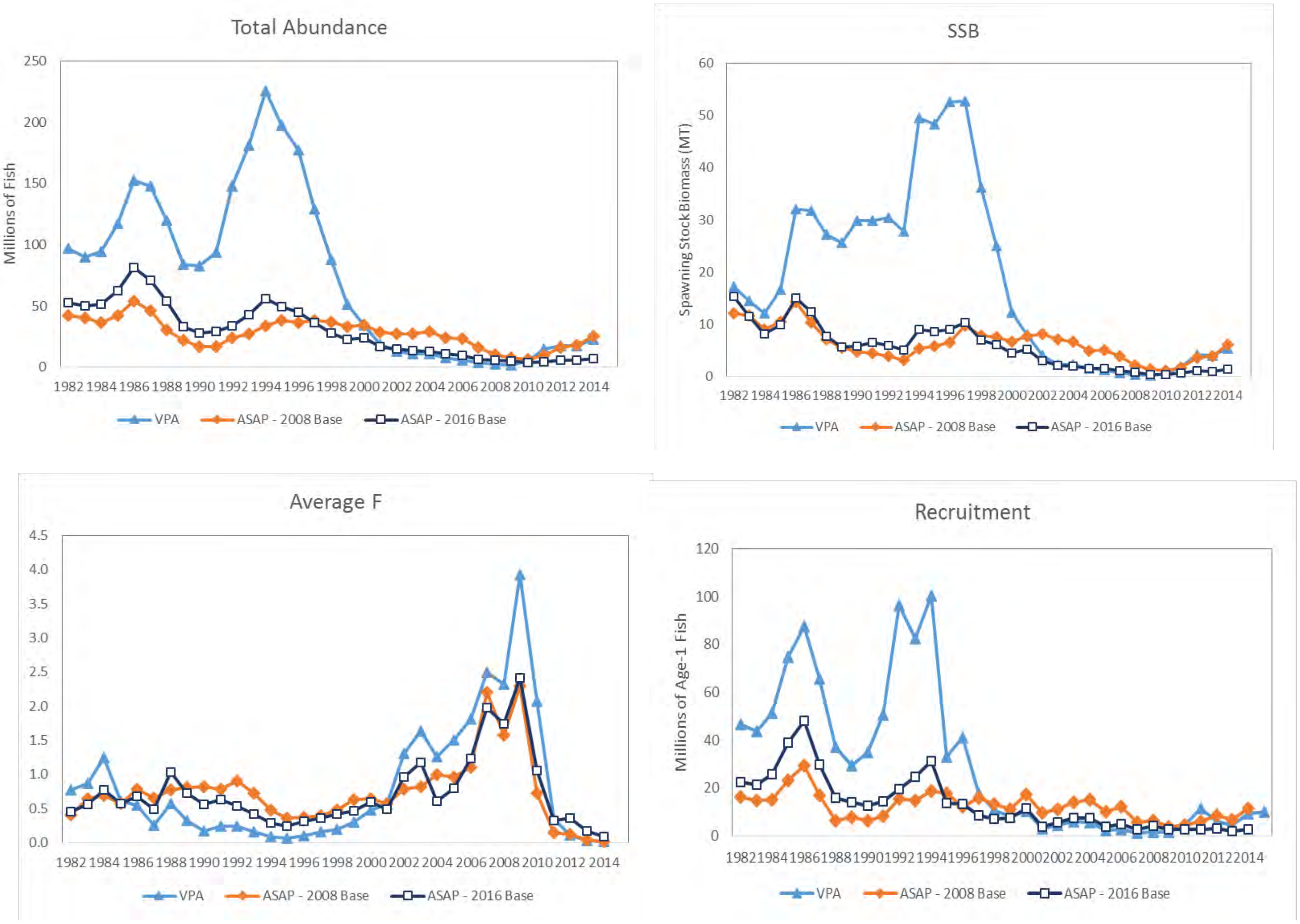


Figure 8.4.2. Comparison of continuity runs from VPA and ASAP models with the 2016 base model ASAP run.

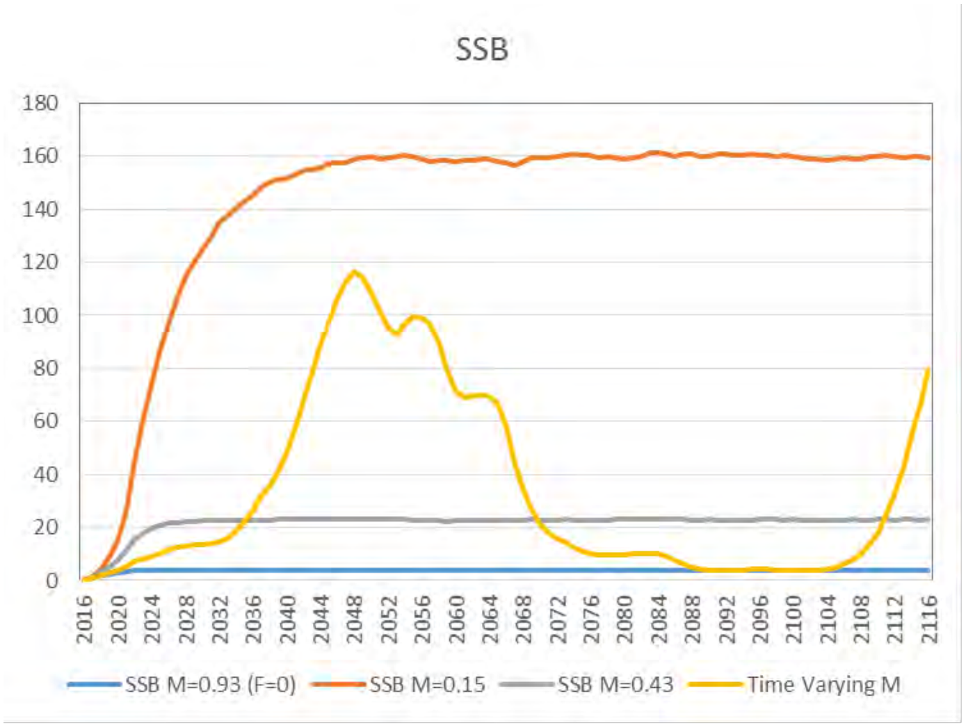


Figure 8.5.1. Long-term projections of SSB under different M scenarios.

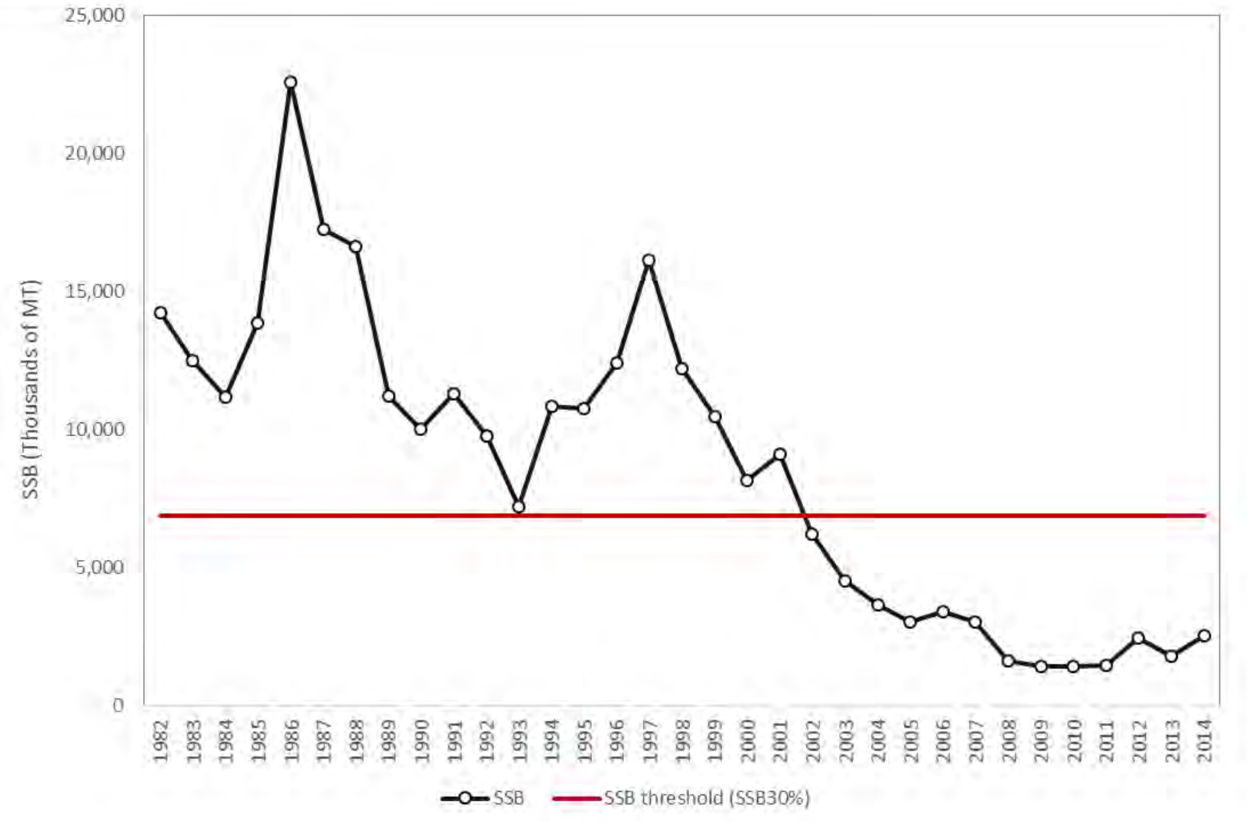


Figure 9.2.1. SSB from the preferred run of the Bayesian model and the SSB threshold.

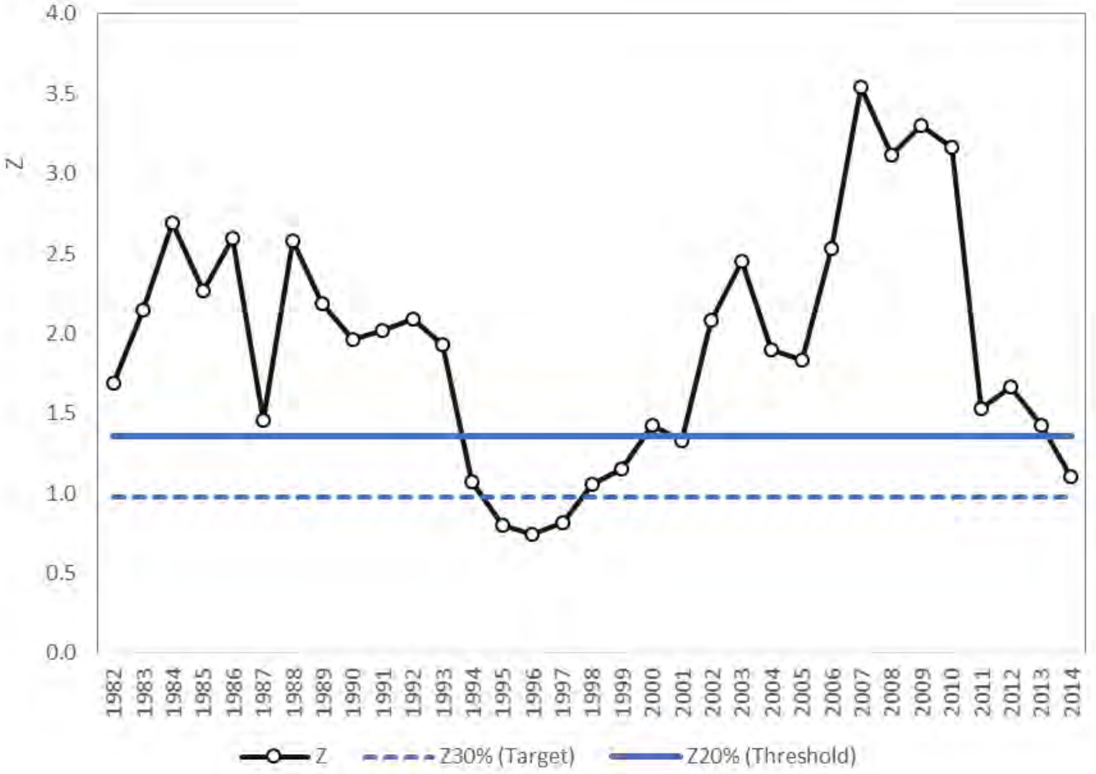


Figure 9.2.2. Total mortality from the preferred run of the Bayesian model and Z target (dashed line) and threshold (solid line).

APPENDICES TO THE 2016 WEAKFISH STOCK ASSESSMENT REPORT

Appendix 1: Re-Creation of Historic Weakfish Catch-at-Age Data
Appendix 2: Fishery Independent Surveys Considered in the Assessment
Appendix 3: ASAP Technical Documentation
Appendix 4: Diagnostics for the Bayesian Age-Structured Model
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APPENDIX 1: RE-CREATION OF HISTORIC WEAKFISH CATCH-AT-AGE DATA

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Maryland Department of Natural Resources
February 2016

2016 Weakfish Benchmark Stock Assessment

In previous stock assessments, a single catch-at-age (CAA) was constructed that included commercial harvest, recreational harvest, and recreational discards, assuming 20% discard mortality. Because data were missing for the earlier part of the time series, previous assessments had not been able to update the discard mortality rate to 10% when it was changed in 2009. In addition, the Weakfish stock assessment subcommittee (SASC) was interested in separating the commercial and recreational removals into separate fleets for this benchmark assessment. This required that the historic weakfish CAA data be re-created and updated.

According to the 2000 Stock Assessment Review Committee (SARC) report, only scale-based ages were available for 1982-1989 and otolith-derived age-length keys (ALKs) were used in developing the 1990-1999 CAA. The scale-based ages from the 1980s were transformed to otolith ages using a scale-otolith conversion matrix. During the 2000 SARC review, an error was discovered in the scale-otolith conversion matrix and an updated CAA, corrected during the review, was accepted by the reviewers. Because of this, it was important that the correct scale-otolith conversion matrix was found.

Similar to previous assessments, landings, ALKs, and length frequencies were split into early (January-June) and late (July-December) seasons for each year and starting in the 1990s, area (mid-Atlantic=Virginia north and south Atlantic=North Carolina south). On an old ASMFC server, files were found that seemed to include the necessary data to re-create the CAA matrices, including length frequencies and ALKs. These files, as well as various reports, were the basis of reconstructing the weakfish CAA.

1982-1989 CAA

Landings

Landings data for 1982-1989 were found in a report to the Weakfish Technical Committee (Vaughan 1999). Landings, in pounds, by year, season, area, fishery, and gear are reproduced here in Tables 1a and 1b.

Length Frequencies

Length frequency data for each year, season, area, and gear were found in the files on the ASMFC server. Data were summarized as the proportion at length for each year, season, area, and gear by 2 inch, total length groups. Sampling was not adequate for all seasons/area/gear combinations, particularly in the early part of the time series, and length frequencies were borrowed across areas. Specifically, mid-Atlantic gill net lengths were not collected until 1986 for the early season and 1988 for the late season and mid-Atlantic haul seine lengths were not collected until 1989. Additionally, there was concern over the representativeness of the samples (Vaughan 1999) for the mid-Atlantic pound net and gill net gears and the following substitutions were agreed upon: the south Atlantic gill net and haul seine length frequencies were used for the mid-Atlantic gill net and haul seine length frequencies for 1982-1988. In addition, the south Atlantic pound net length frequencies were used for the mid-Atlantic pound net length frequencies for 1982-1985 and late season 1986. Length frequencies from the Marine Recreational Fisheries Statistics Survey (MRFSS) were used for the mid-Atlantic and south Atlantic hook and line fisheries for all years. All length frequencies used can be found in Tables 2 and 3.

Mean Weights

Mean weights, in pounds, by season, area, and gear for 1982-1989 were also found in Vaughan (1999). These data are reproduced here in Tables 4a and 4b. Mean weights were used to convert the commercial and scrap landings, in pounds, to number. While the mean weight is provided for recreational landings, these values were not used for the recreational fishery as the MRFSS survey already estimated the landings in number.

Similar to the length sampling above, sampling for all gears was not occurring, particularly in the early part of this time period, and there was concern over the representativeness of the samples for particular area/gear combinations. Vaughan (1999) substituted south Atlantic gill net and haul seine mean weights for mid-Atlantic gill net and haul seine mean weights for 1982-1988. South Atlantic pound net mean weights were also substituted for mid-Atlantic pound net mean weights for 1982-1985 and 1986 late season. The mean weight from the MRFSS survey was used for commercial hook and line mean weights in all years.

Age-Length Keys

Age-length keys were also found on the ASMFC server. Keys for 1982-1989 were developed by season (early and late) but not areas (north/south). However, due to data limitations, years in many cases were pooled. No aging data were available for 1984 and 1987 so these years were based on 1982-1983 and 1985-1986, respectively. The final seasonal ALKs were for 1982-1984, 1985-1987, and 1988-1989, resulting in six keys total (Vaughan 1999, Table 5).

Scale-Otolith Conversion

The weakfish SASC decided to convert the scale-based CAA matrix to an otolith-based CAA using a conversion matrix (Vaughan 1999). According to the 2000 stock assessment report (NEFSC 2000), "the SARC determined that the catch-at-age matrix was corrupted by incorrect transformation of scale ages to otolith ages. A revised catch-at-age matrix was accepted by the SARC." Specifically, members of the Weakfish Technical committee remembered that the conversion matrix had originally been incorrectly transposed.

A table containing the scale-otolith conversion matrix supposedly used in the 2000 assessment was found in a white paper submitted to the Technical Committee (Kahn) and is shown here in Table 6. However, the 2000 assessment claims that two scale-otolith conversion matrices were used, one for each season (NEFSC 2000). Using Vaughan (1997), a seasonal scale-otolith conversion matrix was created and scale ages were transformed using both single and seasonal conversion matrices. Based on comparisons of these results to the CAA from the 2002 assessment (Figure 1; Kahn 2002), it seems that a single scale-otolith conversion matrix was actually used. In addition, after summing and transposing the seasonal tables found in Vaughan (1997), the resulting single scale-otolith conversion matrix matched that found in the white paper, confirming it was the correct transformation matrix.

Comparison to Previously Published CAA

While the absolute numbers at age were different (Table 7), the general trends and proportions of number at age were similar between the 2002 stock assessment document and the re-created CAA (Figure 2). Differences in overall landings were small, between 3.3% and 5.0%, overall. While the exact reason for these discrepancies is unknown, there are two likely causes. First, landings numbers could have been updated between the 1999 Vaughan report and the 2002 assessment. If this did occur, it was not well documented in the reports and newer, updated data files have not been located. Second, Vaughan (2000) describes updates being made to the length-weight equations used to calculate the mean weights for each fishery but provides updated mean weight and landings data only for the 1990s, not the 1980s. As the mean weights are used to convert the pounds landed into numbers landed for the CAA calculations, any changes to these values would affect the total numbers of fish landed. Unfortunately, it does not seem that these values can be updated as some length-weight equations are specific to one state's fishery (i.e. North Carolina) and the only data found has the harvest data already summed by area and gear, not separated out by state. Without this additional information, an updated weighted mean weight for each area and gear combination cannot be calculated.

However, as the trends in the data were consistent and the overall landings numbers were similar, the SASC decided to use this reconstructed data. The benefits of being able to update the discard mortality rate, separate the data into commercial and recreational fleets, and include updated information on Florida harvest given recent evidence of hybridization were greater than matching the original CAA exactly. In addition, a sensitivity run will be done using the original combined recreational and commercial CAA from the 2002 assessment to insure that these differences do not affect the stock assessment results.

1990-1999 CAA

A SAS file used to create the CAA published in Vaughan (2000) was used to recreate the 1990s data. The output of this SAS code recreates the CAA found in Vaughan (2000) exactly but there are a few discrepancies for specific year-age combinations when it's compared to the CAA from the 2002 stock assessment. This is likely due to updated landings but those changes have not been documented in the stock assessment reports and cannot be recreated.

Landings

Input files of the total landings were found on the ASMFC file server. These match the landings data for 1990-1999 that were found in a report to the Weakfish Technical Committee (Vaughan 2000). Landings, in pounds, by year, season, area, fishery, and gear are reproduced here in Tables 1a and 1b.

Length Frequencies

Length frequency data for each year, season, area, and gear were found in the files on the ASMFC server. Data were summarized as the proportion at length for each year, season, area, and gear by 2 inch, total length groups (Tables 2 and 3). Sampling was conducted for each year, region, season, and gear and was deemed adequate for most gears (Vaughan 2000, NEFSC 2000). As in the 1980s, MRFSS length frequencies were used for the commercial hook and line fisheries for all years, seasons, and areas.

Mean Weights

Mean weights, in pounds, by season, area, and gear for 1990-1999 were also found in Vaughan (2000). These data are reproduced here in Tables 4a and 4b. Mean weights were used to convert the commercial and scrap landings, in pounds, to number. While the mean weight is provided for recreational landings, these values were not used to convert MRFSS landings from pounds to numbers as the MRFSS survey already estimated the landings in number. They were, however, used as the mean weights for the commercial hook and line fisheries for all years, seasons, and areas.

Age-Length Keys

Age-length keys for 1990-1999 were all based on otolith ages (Vaughan 2000). As in previous assessments, separate keys were made for each season (early and late) and each region (mid-Atlantic and south Atlantic). According to Vaughan (2000), "region-seasonal keys were pooled in 2-year increments for 1990-1991 through 1994-1995 to reduce the need to fill in for missing area/season combinations, but these keys were annual for 1996-1999. . . when sample size for a given length interval fell below 10, pooled data for the 1990-1998 time periods (area x season) were used." The keys used can be found in Tables 8 and 9 for the mid Atlantic and south Atlantic, respectively.

Comparison to Previously Published CAA

The re-created CAA matches the one in Vaughan (2000) exactly, however, there are four specific year-age discrepancies between the re-calculated CAA and the one published in the 2002 stock assessment report (Kahn 2002). Kahn (2002) mentions no updates to the data through 1999 and it has not been possible to track what was changed. A comparison of the re-created CAA and the one from the 2002 assessment is in Table 7. As most years were exact matches and the differences were small (<1,350 fish in any given year), the SASC decided to use the re-created CAA for this assessment. This allowed for discard mortality to be updated, Florida harvest to be adjusted due to hybridization, and for the fleets to be separated. As with the 1980s data, a sensitivity run will be done using the original combined recreational and commercial CAA from the 2002 assessment to insure that these differences do not affect the stock assessment results.

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Vaughan, D. 1997. Addendum to Scale-Otolith Comparison. Memo to the Weakfish Stock Assessment Subcommittee. June 9, 1997.

Vaughan, D. 1999. Catch-at-age matrix for the Atlantic Weakfish stock, 1982-1998. Report to the Weakfish Technical Committee, Atlantic States Marine Fisheries Commission. August 15, 1999. 20 pp.

Vaughan, D. 2000. Catch-at-age matrix for the Atlantic Weakfish stock, 1990-1999. Report to the Weakfish Technical Committee, Atlantic States Marine Fisheries Commission. October 26, 2000. 16 pp.

Appendix 1 Table 1a. Weakfish landings (1000 pounds) by gear for early (Jan.-Jun.) 1982-1999.

	Recreational[a]		**Commercial (SA)**					**Commercial (MA)**					**Scrap**		
Gear	**SA**	**MA**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Trwl**	**Pnd**	**Haul**
1982	168.1	337.7	1168.5	6298.7	88.3	325.2	11.5	1165.8	948.4	882.0	170.5	45.7	1189.9	61.7	59.1
1983	166.0	217.7	1891.9	4938.3	66.3	464.0	8.5	659.6	608.3	716.6	44.8	40.2	252.8	46.7	101.4
1984	502.0	578.8	3336.8	5401.1	123.1	503.2	5.1	412.0	286.1	434.4	36.6	18.8	282.9	50.4	101.5
1985	223.5	466.3	2878.5	2891.7	135.6	737.4	4.8	514.6	510.7	386.0	57.1	45.8	474.7	46.6	76.2
1986	547.5	1160.7	5568.3	4659.9	47.1	1008.0	3.6	505.9	466.0	276.5	17.9	44.0	847.2	27.2	88.6
1987	77.1	622.7	4572.3	3512.6	48.0	299.5	36.7	488.8	407.4	243.4	12.6	57.9	1107.6	43.8	50.5
1988	132.2	2894.8	6414.8	4616.8	71.2	405.9	4.7	571.2	402.9	370.1	52.7	68.5	2032.9	36.9	39.1
1989	156.1	546.6	4397.6	2964.7	27.8	123.6	4.8	496.3	306.9	173.5	26.9	33.8	148.1	19.9	20.6
1990	47.0	92.8	2222.6	1331.6	41.0	344.9	11.8	564.8	50.0	269.6	14.3	6.3	422.3	26.9	93.4
1991	56.6	712.4	1725.2	2134.4	23.2	57.1	10.9	576.7	104.0	197.8	12.4	12.0	392.0	63.4	15.0
1992	50.1	206.7	1532.8	2130.9	5.8	39.1	11.5	669.1	53.8	130.1	29.2	8.5	201.3	3.3	14.3
1993	74.2	104.5	1545.9	1710.9	4.8	68.2	5.8	355.6	22.9	78.0	15.6	7.9	352.3	14.1	1.4
1994	134.1	145.2	1829.8	626.9	14.7	121.6	2.3	418.9	22.9	170.0	37.1	8.9	62.5	11.0	6.0
1995	87.2	546.5	2047.5	688.7	50.1	225.7	3.9	222.8	9.3	260.7	37.9	24.3	0.0	40.0	1.8
1996	47.7	738.0	2646.9	81.3	51.9	236.9	2.1	402.0	44.0	295.6	26.6	26.2	0.2	47.4	75.8
1997	134.0	887.5	1473.8	636.3	75.3	252.1	3.0	797.0	23.8	269.0	73.5	53.1	0.0	41.0	7.2
1998	87.3	1554.4	1934.5	456.5	80.9	245.3	6.1	749.6	62.8	460.2	59.2	85.6	3.1	66.5	9.3
1999	139.8	1188.4	1417.7	644.2	40.5	105.8	4.5	872.6	92.3	447.2	84.5	65.7	12.2	46.3	5.2

[a] Numbers (1000s), rather than weight, representing A+B1+0.20*B2 for South (SA) and Middle (MA) Atlantic regions.

Appendix 1 Table 1b. Weakfish landings (1000 pounds) by gear for late (Jul.-Dec.) 1982-1999.

	Recreational[a]		**Commercial (SA)**					**Commercial (MA)**					**Scrap**		
Gear	**SA**	**MA**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Trwl**	**Pnd**	**Haul**
1982	98.9	1287.4	336.3	2204.1	300.8	1492.2	4.0	1437.0	1116.0	1266.9	164.8	51.7	202.1	92.8	150.5
1983	545.6	4768.2	557.6	1040.5	193.1	1188.2	5.7	1733.8	1796.4	1368.5	58.5	94.1	167.7	90.2	119.2
1984	493.9	1995.7	979.8	1172.0	258.1	1335.9	2.2	1974.1	2211.4	980.9	67.0	60.0	193.2	95.5	133.4
1985	99.8	1701.3	802.8	1360.6	341.5	802.6	2.5	1920.3	2311.6	935.2	143.9	174.6	388.3	86.5	83.0
1986	365.6	7052.3	903.1	1029.8	225.9	971.8	0.7	2035.1	2408.9	761.4	45.0	209.1	306.5	63.2	99.5
1987	658.2	3683.1	1282.5	991.9	462.6	785.1	14.4	1643.3	1443.3	873.8	47.2	222.8	517.4	116.2	109.3
1988	426.2	2337.2	1248.7	705.6	540.7	1196.9	2.1	1356.5	1496.8	543.6	62.9	394.2	135.0	47.3	76.3
1989	198.0	630.5	769.4	1421.4	120.2	452.8	5.5	1166.4	1297.2	186.3	26.1	161.6	160.1	17.3	46.1
1990	86.2	1196.4	373.4	722.2	153.0	734.7	4.3	968.9	1321.4	204.2	23.6	40.7	276.0	24.5	22.0
1991	160.6	1374.1	481.2	501.2	128.4	407.7	4.4	1120.6	876.3	220.3	49.2	49.9	24.1	76.4	136.7
1992	80.8	1242.4	399.5	472.4	42.0	395.0	4.2	**747.4**	946.6	**343.2**	**36.2**	39.1	153.6	5.9	149.8
1993	151.1	986.6	518.1	248.5	29.0	320.3	5.4	776.8	606.6	440.3	53.3	42.0	78.5	12.2	16.1
1994	227.1	1907.0	430.5	296.1	68.2	277.1	4.9	676.4	474.4	613.5	17.4	55.3	24.1	8.9	37.7
1995	108.7	2037.3	540.8	236.1	74.2	295.1	6.8	526.6	797.3	897.7	6.3	94.8	0.0	15.5	0.6
1996	91.0	3165.5	384.9	311.5	47.3	219.4	1.4	648.6	829.5	846.5	15.7	77.3	16.3	33.9	26.8
1997	186.8	3444.3	503.3	250.8	81.2	293.4	3.7	785.6	831.0	675.7	49.5	103.6	0.0	27.0	2.4
1998	167.4	3344.8	349.3	30.7	26.4	235.0	3.1	924.0	1465.0	983.5	37.6	114.8	8.2	36.6	2.0
1999	181.3	2711.2	172.7	41.8	56.1	140.3	4.7	727.6	1014.4	800.8	28.4	113.5	23.0	66.1	12.4

[a] Numbers (1000s), rather than weight, representing A+B1+0.20*B2 for South (SA) and Middle (MA) Atlantic regions.

[b] Purse-seine landings in Mid-Atlantic for 1984 were 174,900 lbs.

Appendix 1 Table 2. Length frequencies for early season, 1982-1999.

1982 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.009	0	0	0.001	0	0	0	0	0	0	0.008	0	0
7	0.018	0.006	0.001	0.001	0	0	0.001	0	0	0	0.255	0.243	0.034
9	0.044	0.038	0.003	0.013	0	0	0.003	0	0	0	0.608	0.757	0.966
11	0.018	0.176	0.067	0.168	0.599	0.67	0.067	0	0.599	0.670	0.128	0	0
13	0	0.007	0.361	0.164	0.272	0.197	0.361	0	0.272	0.197	0.001	0	0
15	0	0.541	0.446	0.264	0.117	0.133	0.446	0	0.117	0.133	0	0	0
17	0	0.232	0.069	0.205	0.012	0	0.069	0	0.012	0	0	0	0
19	0	0	0.009	0.134	0	0	0.009	0	0	0	0	0	0
21	0.009	0	0.002	0.029	0	0	0.002	0.088	0	0	0	0	0
23	0.011	0	0.001	0.003	0	0	0.001	0.219	0	0	0	0	0
25	0.044	0	0.002	0.003	0	0	0.002	0.182	0	0	0	0	0
27	0.252	0	0.009	0.005	0	0	0.009	0.034	0	0	0	0	0
29	0.293	0	0.014	0.001	0	0	0.014	0.266	0	0	0	0	0
31	0.127	0	0.011	0.006	0	0	0.011	0.205	0	0	0	0	0
33	0.140	0	0.004	0.003	0	0	0.004	0.006	0	0	0	0	0
35	0.035	0	0.001	0	0	0	0.001	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1983 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.008	0	0.004
7	0	0	0.001	0.004	0	0	0.001	0	0	0	0.255	0.218	0.230
9	0.003	0.010	0.003	0.182	0	0	0.003	0	0	0	0.608	0.782	0.766
11	0.012	0.025	0.067	0.305	0.915	0.903	0.067	0	0.915	0.903	0.128	0	0
13	0.074	0.644	0.361	0.182	0.064	0.084	0.361	0	0.064	0.084	0.001	0	0
15	0.108	0.283	0.446	0.169	0.014	0.013	0.446	0	0.014	0.013	0	0	0
17	0.171	0.004	0.069	0.065	0.007	0	0.069	0	0.007	0	0	0	0
19	0.123	0	0.009	0.024	0	0	0.009	0	0	0	0	0	0
21	0.077	0	0.002	0.005	0	0	0.002	0	0	0	0	0	0
23	0.036	0	0.001	0.002	0	0	0.001	0	0	0	0	0	0
25	0.050	0	0.002	0.001	0	0	0.002	0	0	0	0	0	0
27	0.120	0.034	0.009	0.013	0	0	0.009	0.046	0	0	0	0	0
29	0.147	0	0.014	0.028	0	0	0.014	0.532	0	0	0	0	0
31	0.055	0	0.011	0.015	0	0	0.011	0.409	0	0	0	0	0
33	0.014	0	0.004	0.004	0	0	0.004	0.013	0	0	0	0	0
35	0.010	0	0.001	0.001	0	0	0.001	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1984 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.004	0	0.003
7	0	0.403	0	0.001	0	0	0	0	0	0	0.383	0.224	0.274
9	0.432	0	0	0.272	0	0	0	0.080	0	0	0.566	0.776	0.723
11	0.290	0.070	0.007	0.338	0.797	0.516	0.007	0.377	0.797	0.516	0.046	0	0
13	0.001	0.355	0.110	0.260	0.048	0.308	0.110	0.043	0.048	0.308	0.001	0	0
15	0.001	0.006	0.378	0.092	0.107	0.112	0.378	0	0.107	0.112	0	0	0
17	0	0.152	0.270	0.024	0.048	0.038	0.270	0	0.048	0.038	0	0	0
19	0.001	0.014	0.103	0.007	0	0.022	0.103	0	0	0.022	0	0	0
21	0	0	0.036	0.004	0	0.002	0.036	0	0	0.002	0	0	0
23	0	0	0.015	0.001	0	0.002	0.015	0	0	0.002	0	0	0
25	0	0	0.003	0.001	0	0	0.003	0	0	0	0	0	0
27	0.057	0	0.006	0	0	0	0.006	0.023	0	0	0	0	0
29	0.058	0	0.032	0	0	0	0.032	0.266	0	0	0	0	0
31	0.073	0	0.029	0	0	0	0.029	0.205	0	0	0	0	0
33	0.087	0	0.010	0	0	0	0.010	0.006	0	0	0	0	0
35	0	0	0.001	0	0	0	0.001	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1985 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.012	0	0.003
7	0	0	0	0.005	0	0	0	0	0	0	0.164	0	0.102
9	0.036	0	0.003	0.212	0	0	0.003	0.160	0	0	0.703	1	0.895
11	0.376	0.941	0.030	0.528	0.666	0.567	0.030	0.755	0.666	0.567	0.121	0	0
13	0.295	0.016	0.216	0.197	0.277	0.287	0.216	0.085	0.277	0.287	0	0	0
15	0.174	0.009	0.375	0.040	0.039	0.093	0.375	0	0.039	0.093	0	0	0
17	0.032	0.004	0.231	0.009	0.018	0.032	0.231	0	0.018	0.032	0	0	0
19	0.027	0.018	0.108	0.003	0	0.013	0.108	0	0	0.013	0	0	0
21	0.004	0	0.020	0.001	0	0.008	0.020	0	0	0.008	0	0	0
23	0.005	0.012	0.002	0.001	0	0	0.002	0	0	0	0	0	0
25	0.002	0	0.001	0.001	0	0	0.001	0	0	0	0	0	0
27	0.013	0	0.001	0	0	0	0.001	0	0	0	0	0	0
29	0.018	0	0.006	0.001	0	0	0.006	0	0	0	0	0	0
31	0.010	0	0.006	0.001	0	0	0.006	0	0	0	0	0	0
33	0.006	0	0.001	0.001	0	0	0.001	0	0	0	0	0	0
35	0.002	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1986 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.091	0	0	0	0	0	0	0	0	0	0.001	0	0
7	0.078	0	0	0.002	0	0	0	0	0.003	0	0.375	0.203	0.200
9	0.259	0.021	0.002	0.17	0	0	0.002	0.146	0.394	0	0.552	0.793	0.800
11	0.335	0.313	0.050	0.533	0.798	0.654	0.050	0.686	0.467	0.654	0.067	0.004	0
13	0.155	0.318	0.253	0.175	0.166	0.220	0.253	0.167	0.057	0.220	0.005	0	0
15	0.041	0.233	0.311	0.039	0.020	0.066	0.311	0.001	0.008	0.066	0	0	0
17	0.009	0.109	0.245	0.019	0.016	0.031	0.245	0	0.011	0.031	0	0	0
19	0.005	0.006	0.110	0.023	0	0.024	0.110	0	0.008	0.024	0	0	0
21	0.005	0	0.024	0.024	0	0.004	0.024	0	0.006	0.004	0	0	0
23	0.001	0	0.004	0.010	0	0.001	0.004	0	0.003	0.001	0	0	0
25	0.004	0	0.001	0.003	0	0	0.001	0	0.006	0	0	0	0
27	0.008	0	0	0.001	0	0	0	0	0.006	0	0	0	0
29	0.006	0	0	0	0	0	0	0	0.011	0	0	0	0
31	0.001	0	0	0	0	0	0	0	0.017	0	0	0	0
33	0.002	0	0	0.001	0	0	0	0	0.003	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1987 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.005	0	0.004
7	0	0	0	0.002	0	0	0	0	0	0	0.465	0.149	0.283
9	0.115	0.152	0.001	0.170	0.002	0	0.001	0.131	0.015	0	0.445	0.848	0.713
11	0.373	0.373	0.030	0.489	0.579	0.616	0.030	0.617	0.275	0.616	0.085	0.003	0
13	0.390	0.357	0.332	0.212	0.301	0.244	0.332	0.248	0.449	0.244	0	0	0
15	0.105	0.093	0.453	0.089	0.086	0.088	0.453	0.004	0.246	0.088	0	0	0
17	0.004	0.018	0.151	0.025	0.024	0.036	0.151	0	0.015	0.036	0	0	0
19	0.004	0	0.027	0.010	0.008	0.009	0.027	0	0	0.009	0	0	0
21	0.001	0.007	0.005	0.002	0	0.003	0.005	0	0	0.003	0	0	0
23	0.002	0	0.001	0.001	0	0.002	0.001	0	0	0.002	0	0	0
25	0.001	0	0	0	0	0	0	0	0	0	0	0	0
27	0.001	0	0	0	0	0	0	0	0	0	0	0	0
29	0.001	0	0	0	0	0	0	0	0	0	0	0	0
31	0.002	0	0	0	0	0.002	0	0	0	0.002	0	0	0
33	0.001	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1988 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.001	0	0
7	0	0	0	0.004	0	0	0	0	0.011	0	0.363	0.027	0.050
9	0.017	0.020	0	0.271	0	0.005	0	0.116	0.115	0.005	0.559	0.973	0.949
11	0.322	0.096	0.005	0.562	0.714	0.536	0.005	0.549	0.294	0.536	0.076	0	0.001
13	0.336	0.515	0.045	0.133	0.198	0.280	0.045	0.330	0.283	0.280	0.001	0	0
15	0.152	0.238	0.274	0.026	0.070	0.131	0.274	0.005	0.141	0.131	0	0	0
17	0.101	0.087	0.333	0.004	0.014	0.038	0.333	0	0.034	0.038	0	0	0
19	0.050	0	0.204	0	0.004	0.002	0.204	0	0.049	0.002	0	0	0
21	0.014	0.044	0.107	0	0	0.006	0.107	0	0.043	0.006	0	0	0
23	0	0	0.027	0	0	0.001	0.027	0	0.019	0.001	0	0	0
25	0.003	0	0.004	0	0	0.001	0.004	0	0.008	0.001	0	0	0
27	0	0	0.001	0	0	0	0.001	0	0.002	0	0	0	0
29	0.001	0	0	0	0	0	0	0	0	0	0	0	0
31	0.001	0	0	0	0	0	0	0	0.001	0	0	0	0
33	0.002	0	0	0	0	0	0	0	0	0	0	0	0
35	0.001	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1989 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.035	0.023	0.008
7	0	0.002	0	0.001	0	0	0.001	0	0.022	0.033	0.426	0.192	0.314
9	0.096	0.151	0	0.082	0	0.005	0	0.116	0.215	0.451	0.512	0.762	0.678
11	0.315	0.360	0.001	0.340	0.745	0.365	0.005	0.549	0.313	0.233	0.026	0.023	0
13	0.252	0.349	0.054	0.218	0.201	0.339	0.096	0.330	0.116	0.033	0.001	0	0
15	0.049	0.122	0.326	0.128	0.054	0.144	0.203	0.005	0.037	0.022	0	0	0
17	0.040	0.012	0.383	0.069	0	0.041	0.203	0	0.053	0.043	0	0	0
19	0.024	0.002	0.158	0.073	0	0.048	0.228	0	0.098	0.091	0	0	0
21	0.137	0	0.054	0.058	0	0.025	0.159	0	0.087	0.076	0	0	0
23	0.047	0	0.019	0.024	0	0.023	0.070	0	0.039	0.018	0	0	0
25	0.024	0.002	0.004	0.006	0	0.010	0.017	0	0.016	0	0	0	0
27	0.011	0	0.001	0.001	0	0	0.004	0	0.003	0	0	0	0
29	0	0	0	0	0	0	0.002	0	0	0	0	0	0
31	0.001	0	0	0	0	0	0.004	0	0.001	0	0	0	0
33	0.001	0	0	0	0	0	0.003	0	0	0	0	0	0
35	0.003	0	0	0	0	0	0.005	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1990 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0.005	0
5	0	0	0	0	0	0	0	0	0	0	0.007	0	0.015
7	0	0.042	0	0.014	0	0.006	0	0	0.007	0.006	0.552	0.19	0.326
9	0.008	0.084	0.002	0.421	0	0.273	0.001	0.116	0.21	0.209	0.441	0.805	0.646
11	0.157	0.456	0.077	0.371	0.726	0.629	0.013	0.549	0.59	0.486	0	0	0.013
13	0.218	0.288	0.207	0.058	0.253	0.081	0.098	0.33	0.072	0.156	0	0	0
15	0.256	0.101	0.321	0.069	0.014	0.01	0.277	0.005	0.032	0.028	0	0	0
17	0.151	0.029	0.161	0.025	0.007	0.001	0.277	0	0.023	0.011	0	0	0
19	0.059	0	0.141	0.006	0	0	0.165	0	0.016	0.031	0	0	0
21	0.067	0	0.067	0.002	0	0	0.071	0	0.01	0.017	0	0	0
23	0.032	0	0.018	0.004	0	0	0.041	0	0.009	0.011	0	0	0
25	0.017	0	0.004	0.013	0	0	0.049	0	0.024	0.034	0	0	0
27	0.02	0	0.001	0.009	0	0	0.007	0	0.005	0.011	0	0	0
29	0.008	0	0	0.004	0	0	0.001	0	0.001	0	0	0	0
31	0.007	0	0	0.001	0	0	0	0	0.001	0	0	0	0
33	0.000	0	0.001	0.002	0	0	0	0	0	0	0	0	0
35	0	0	0	0.001	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1991 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.001	0	0	0	0	0	0	0	0	0	0.013	0	0
7	0.005	0.06	0	0.006	0	0.001	0	0	0.008	0.002	0.538	0.197	0.676
9	0.004	0.096	0.02	0.413	0	0.16	0.003	0.116	0.25	0.068	0.443	0.803	0.321
11	0.167	0.319	0.333	0.489	0.609	0.734	0.017	0.549	0.6	0.373	0.006	0	0.003
13	0.357	0.355	0.541	0.089	0.319	0.093	0.288	0.33	0.067	0.148	0	0	0
15	0.25	0.16	0.095	0.003	0.06	0.005	0.375	0.005	0.039	0.096	0	0	0
17	0.113	0.01	0.01	0	0.012	0.007	0.145	0	0.012	0.076	0	0	0
19	0.036	0	0.001	0	0	0	0.073	0	0.009	0.055	0	0	0
21	0.036	0	0	0	0	0	0.047	0	0.008	0.066	0	0	0
23	0.017	0	0	0	0	0	0.028	0	0.003	0.052	0	0	0
25	0.007	0	0	0	0	0	0.013	0	0.001	0.032	0	0	0
27	0.004	0	0	0	0	0	0.007	0	0.003	0.027	0	0	0
29	0.003	0	0	0	0	0	0.004	0	0	0.005	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0.000	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1992 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0.001	0.002	0	0	0	0	0.001	0	0.42	0.366	0.607
9	0.336	0.039	0.007	0.169	0	0.373	0.009	0.116	0.209	0.045	0.5	0.634	0.393
11	0.378	0.308	0.403	0.597	0.892	0.491	0.052	0.549	0.714	0.509	0.08	0	0
13	0.132	0.238	0.530	0.066	0.07	0.062	0.160	0.33	0.032	0.096	0	0	0
15	0.03	0.292	0.058	0.048	0.032	0.042	0.325	0.005	0.004	0.042	0	0	0
17	0.033	0.055	0.001	0.05	0.006	0.027	0.211	0	0.013	0.046	0	0	0
19	0.041	0.04	0	0.041	0	0.003	0.114	0	0.004	0.059	0	0	0
21	0.015	0.009	0	0.021	0	0.002	0.076	0	0.008	0.089	0	0	0
23	0.028	0.01	0	0.006	0	0	0.032	0	0.003	0.077	0	0	0
25	0.007	0	0	0	0	0	0.015	0	0.006	0.033	0	0	0
27	0	0.009	0	0	0	0	0.003	0	0.003	0.002	0	0	0
29	0	0	0	0	0	0	0.002	0	0.001	0	0	0	0
31	0	0	0	0	0	0	0.001	0	0.001	0.002	0	0	0
33	0	0	0.000	0	0	0	0.000	0	0.001	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1993 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.001	0	0.03	0	0	0	0	0.006	0	0.034
7	0	0	0	0	0	0.196	0	0	0	0	0.121	0.31	0.513
9	0	0	0.012	0.09	0	0.147	0	0.116	0.223	0.159	0.775	0.69	0.453
11	0.16	0.406	0.466	0.689	0.793	0.55	0.033	0.549	0.581	0.46	0.098	0	0
13	0.501	0.493	0.458	0.196	0.207	0.062	0.425	0.33	0.134	0.198	0	0	0
15	0.141	0.082	0.063	0.016	0	0.01	0.221	0.005	0.021	0.054	0	0	0
17	0.037	0.019	0.001	0.001	0	0	0.067	0	0.005	0.02	0	0	0
19	0	0	0	0	0	0	0.021	0	0.001	0.006	0	0	0
21	0.018	0	0.000	0.001	0	0	0.030	0	0.004	0.01	0	0	0
23	0.091	0	0	0.002	0	0	0.067	0	0.01	0.033	0	0	0
25	0.016	0	0	0.003	0	0.005	0.095	0	0.013	0.043	0	0	0
27	0.027	0	0	0.001	0	0	0.03	0	0.007	0.014	0	0	0
29	0.009	0	0	0	0	0	0.009	0	0.001	0.003	0	0	0
31	0.000	0	0	0	0	0	0.002	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1994 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0.001	0	0.032	0	0.012
7	0.005	0.018	0	0.006	0	0.002	0	0	0.061	0	0.422	0.077	0.366
9	0.005	0.002	0.001	0.083	0.001	0.147	0.001	0.116	0.238	0.147	0.507	0.923	0.615
11	0.213	0.203	0.140	0.342	0.534	0.644	0.018	0.549	0.612	0.43	0.039	0	0.007
13	0.552	0.53	0.51	0.054	0.367	0.162	0.262	0.33	0.075	0.220	0	0	0
15	0.119	0.227	0.268	0.17	0.069	0.042	0.354	0.005	0.01	0.122	0	0	0
17	0.081	0.02	0.067	0.194	0.029	0.003	0.171	0	0.003	0.046	0	0	0
19	0.022	0	0.013	0.097	0	0	0.103	0	0	0.025	0	0	0
21	0.003	0	0.001	0.039	0	0	0.044	0	0	0.007	0	0	0
23	0	0	0	0.011	0	0	0.022	0	0	0.002	0	0	0
25	0	0	0	0.003	0	0	0.01	0	0	0	0	0	0
27	0	0	0	0.001	0	0	0.009	0	0	0	0	0	0
29	0	0	0	0	0	0	0.006	0	0	0.001	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1995 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.003	0	0	0	0	0	0	0.026	0	0
7	0	0	0	0.036	0.02	0.126	0	0	0.002	0	0.292	0.367	0.266
9	0.001	0	0.002	0.078	0.028	0.369	0	0.116	0.179	0.051	0.337	0.631	0.734
11	0.033	0.299	0.247	0.585	0.537	0.353	0.005	0.549	0.671	0.284	0.311	0.002	0
13	0.307	0.17	0.464	0.208	0.294	0.106	0.19	0.33	0.126	0.354	0.022	0	0
15	0.494	0.341	0.198	0.076	0.102	0.02	0.216	0.005	0.015	0.163	0.012	0	0
17	0.115	0.104	0.063	0.014	0.016	0.015	0.206	0	0.002	0.051	0	0	0
19	0.016	0.082	0.02	0.000	0.001	0	0.179	0	0	0.04	0	0	0
21	0.034	0.004	0.005	0	0.001	0.004	0.127	0	0.001	0.019	0	0	0
23	0	0	0.001	0	0.001	0.005	0.052	0	0.002	0.027	0	0	0
25	0	0	0	0	0	0.002	0.023	0	0.002	0.008	0	0	0
27	0	0	0	0	0	0	0.002	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0.003	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1996 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.026	0	0
7	0	0	0	0	0	0.014	0	0	0	0	0.292	0.367	0.237
9	0	0.000	0	0	0.021	0.233	0	0.116	0.099	0.196	0.337	0.631	0.763
11	0.017	0.022	0.057	0.002	0.412	0.463	0.02	0.549	0.46	0.478	0.311	0.002	0
13	0.267	0.417	0.438	0.113	0.403	0.198	0.2	0.330	0.311	0.236	0.022	0	0
15	0.495	0.439	0.31	0.402	0.146	0.077	0.39	0.005	0.104	0.074	0.012	0	0
17	0.184	0.114	0.09	0.291	0.017	0.015	0.202	0	0.019	0.003	0	0	0
19	0.023	0.008	0.071	0.153	0.001	0	0.093	0	0.003	0.004	0	0	0
21	0.004	0	0.027	0.018	0	0	0.033	0	0.002	0.002	0	0	0
23	0.002	0	0.005	0.008	0	0	0.017	0	0.001	0.001	0	0	0
25	0	0	0.002	0.007	0	0	0.017	0	0.001	0.002	0	0	0
27	0.003	0	0	0.005	0	0	0.021	0	0	0.001	0	0	0
29	0.005	0	0	0.001	0	0	0.006	0	0	0.002	0	0	0
31	0	0	0	0	0	0	0.001	0	0	0.001	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1997 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.026	0	0
7	0	0	0	0.001	0.001	0	0	0	0	0	0.292	0.367	0.413
9	0.004	0	0.001	0.003	0.001	0.123	0	0.116	0.13	0.097	0.337	0.631	0.32
11	0.13	0.015	0.016	0.054	0.396	0.753	0.016	0.549	0.531	0.595	0.311	0.002	0.267
13	0.247	0.636	0.506	0.35	0.351	0.099	0.341	0.330	0.235	0.144	0.022	0	0
15	0.384	0.255	0.389	0.28	0.198	0.022	0.357	0.005	0.076	0.127	0.012	0	0
17	0.168	0.081	0.07	0.202	0.043	0.003	0.152	0	0.017	0.019	0	0	0
19	0.045	0.01	0.016	0.087	0.01	0	0.069	0	0.005	0.006	0	0	0
21	0.015	0.003	0.002	0.017	0	0	0.034	0	0.003	0.009	0	0	0
23	0.003	0	0	0.004	0	0	0.019	0	0.001	0.001	0	0	0
25	0.002	0	0	0.002	0	0.000	0.009	0	0.001	0	0	0	0
27	0	0	0	0	0	0	0.002	0	0.001	0.001	0	0	0
29	0.002	0	0	0	0	0	0.001	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0.001	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1998 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0.002	0.325	0.367	0.413
9	0.006	0	0	0	0.018	0.018	0	0.116	0.043	0.143	0.006	0.631	0.32
11	0.101	0.018	0	0.002	0.465	0.292	0.013	0.549	0.375	0.453	0.215	0.002	0.267
13	0.243	0.44	0.254	0.063	0.427	0.382	0.253	0.330	0.443	0.188	0.269	0	0
15	0.312	0.409	0.376	0.369	0.082	0.27	0.305	0.005	0.105	0.091	0.159	0	0
17	0.193	0.132	0.306	0.374	0.008	0.033	0.168	0	0.014	0.034	0.026	0	0
19	0.076	0.001	0.053	0.144	0	0.005	0.112	0	0.01	0.026	0	0	0
21	0.027	0	0.007	0.036	0	0	0.063	0	0.007	0.023	0	0	0
23	0.025	0	0.003	0.009	0	0	0.045	0	0.003	0.019	0	0	0
25	0.012	0	0.001	0.003	0	0.000	0.033	0	0	0.014	0	0	0
27	0.002	0	0	0	0	0	0.006	0	0	0.005	0	0	0
29	0.003	0	0	0	0	0	0.002	0	0	0.001	0	0	0
31	0	0	0	0	0	0	0	0	0	0.001	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 2. Continued.

1999 Early Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.042	0	0
7	0	0	0	0	0	0.008	0	0	0	0	0.249	0.278	0.693
9	0	0	0	0	0.037	0.111	0	0.116	0.001	0.015	0.284	0.657	0.167
11	0.008	0.006	0.006	0.024	0.6	0.6	0.002	0.549	0.212	0.241	0.183	0.057	0.14
13	0.112	0.388	0.274	0.302	0.233	0.226	0.183	0.330	0.398	0.301	0.152	0.008	0
15	0.224	0.414	0.329	0.389	0.117	0.048	0.292	0.005	0.151	0.108	0.049	0	0
17	0.273	0.151	0.185	0.209	0.011	0.006	0.184	0	0.092	0.118	0.029	0	0
19	0.139	0.031	0.15	0.065	0.001	0.001	0.147	0	0.04	0.103	0.004	0	0
21	0.103	0.007	0.029	0.009	0.001	0	0.085	0	0.057	0.074	0	0	0
23	0.081	0	0.009	0.002	0	0	0.056	0	0.029	0.02	0	0	0
25	0.041	0.003	0.006	0	0	0.000	0.039	0	0.011	0.02	0.008	0	0
27	0.011	0	0.008	0	0	0	0.01	0	0.007	0	0	0	0
29	0.007	0	0.004	0	0	0	0.002	0	0.002	0	0	0	0
31	0.001	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Length frequencies for late season, 1982-1999.

1982 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0.003	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.048	0	0.002
7	0.001	0	0	0	0	0	0	0	0	0	0.385	0.036	0.037
9	0.021	0.065	0	0.290	0	0	0	0	0	0	0.521	0.964	0.961
11	0.044	0.266	0.042	0.631	0.609	0.764	0.042	0.066	0.609	0.764	0.046	0	0
13	0.098	0.183	0.459	0.053	0.179	0.132	0.459	0.351	0.179	0.132	0	0	0
15	0.104	0.130	0.378	0.018	0.124	0.037	0.378	0.368	0.124	0.037	0	0	0
17	0.119	0	0.023	0.005	0.068	0.029	0.023	0.173	0.068	0.029	0	0	0
19	0.095	0.032	0.001	0.001	0.017	0.024	0.001	0.007	0.017	0.024	0	0	0
21	0.070	0.259	0	0.001	0	0.013	0	0.003	0	0.013	0	0	0
23	0.004	0.065	0.003	0	0.003	0.001	0.003	0	0.003	0.001	0	0	0
25	0.010	0	0.009	0	0	0	0.009	0.001	0	0	0	0	0
27	0.109	0	0.015	0	0	0	0.015	0.007	0	0	0	0	0
29	0.123	0	0.031	0.001	0	0	0.031	0.013	0	0	0	0	0
31	0.148	0	0.034	0	0	0	0.034	0.011	0	0	0	0	0
33	0.030	0	0.005	0	0	0	0.005	0	0	0	0	0	0
35	0.001	0	0	0	0	0	0	0	0	0	0	0	0
37	0.020	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1983 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0.002
5	0	0	0	0	0	0	0	0	0	0	0.046	0	0
7	0.003	0	0	0.006	0	0	0	0	0	0	0.346	0.075	0.031
9	0.004	0.125	0	0.221	0	0	0	0.011	0	0	0.438	0.925	0.967
11	0.042	0.141	0.043	0.717	0.746	0.817	0.043	0.218	0.746	0.817	0.164	0	0
13	0.167	0.526	0.466	0.038	0.102	0.123	0.466	0.479	0.102	0.123	0.006	0	0
15	0.258	0.139	0.385	0.004	0.095	0.034	0.385	0.243	0.095	0.034	0	0	0
17	0.260	0.045	0.022	0.005	0.035	0.015	0.022	0.037	0.035	0.015	0	0	0
19	0.161	0.020	0	0.003	0.022	0.007	0	0.011	0.022	0.007	0	0	0
21	0.045	0	0	0.001	0	0.003	0	0.001	0	0.003	0	0	0
23	0.014	0	0.003	0	0	0.001	0.003	0	0	0.001	0	0	0
25	0.017	0.002	0.008	0	0	0	0.008	0	0	0	0	0	0
27	0.005	0.002	0.013	0.001	0	0	0.013	0	0	0	0	0	0
29	0.014	0	0.027	0.002	0	0	0.027	0	0	0	0	0	0
31	0.010	0	0.030	0.002	0	0	0.030	0	0	0	0	0	0
33	0	0	0.003	0	0	0	0.003	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1984 Late Season

	Recreational		Commercial SA				Commercial MA					Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Purse	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0
5	0.001	0.017	0	0	0	0	0	0	0	0	0	0.003	0.002	0.001
7	0.004	0.020	0	0	0	0	0	0	0	0	0	0.065	0.038	0.055
9	0.016	0.246	0.004	0.245	0	0	0.004	0.022	0	0	0	0.637	0.958	0.944
11	0.032	0.560	0.049	0.552	0.828	0.782	0.049	0.218	0.828	0.782	0	0.269	0	0
13	0.062	0.141	0.432	0.165	0.073	0.155	0.432	0.305	0.073	0.155	0	0.025	0	0
15	0.201	0.008	0.462	0.022	0.049	0.038	0.462	0.288	0.049	0.038	0	0.001	0	0
17	0.375	0.004	0.045	0.006	0.036	0.017	0.045	0.107	0.036	0.017	0	0	0	0
19	0.217	0.004	0.008	0.004	0.013	0.007	0.008	0.029	0.013	0.007	0	0	0	0
21	0.065	0	0	0.004	0	0.001	0	0.019	0	0.001	0	0	0	0
23	0.014	0	0	0	0.001	0	0	0.007	0.001	0	0	0	0	0
25	0	0	0	0.001	0	0	0	0.003	0	0	0.082	0	0	0
27	0.001	0	0	0	0	0	0	0	0	0	0.398	0	0	0
29	0.003	0	0	0	0	0	0	0.001	0	0	0.367	0	0	0
31	0.006	0	0	0.001	0	0	0	0	0	0	0.153	0	0	0
33	0.003	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0.001	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1985 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.006	0	0.004
7	0	0	0	0.001	0	0	0	0	0	0	0.491	0.167	0.261
9	0.022	0	0.018	0.195	0	0	0.018	0	0	0	0.485	0.833	0.735
11	0.103	0.043	0.256	0.727	0.579	0.775	0.256	0.200	0.579	0.775	0.018	0	0
13	0.189	0.344	0.446	0.065	0.254	0.167	0.446	0.398	0.254	0.167	0	0	0
15	0.201	0.102	0.227	0.006	0.131	0.049	0.227	0.229	0.131	0.049	0	0	0
17	0.117	0	0.048	0.002	0.033	0.007	0.048	0.106	0.033	0.007	0	0	0
19	0.137	0	0.005	0.002	0.003	0.001	0.005	0.049	0.003	0.001	0	0	0
21	0.074	0.441	0	0.001	0	0.001	0	0.018	0	0.001	0	0	0
23	0.046	0.070	0	0	0	0	0	0	0	0	0	0	0
25	0.031	0	0	0	0	0	0	0	0	0	0	0	0
27	0.034	0	0	0	0	0	0	0	0	0	0	0	0
29	0.021	0	0	0.001	0	0	0	0	0	0	0	0	0
31	0.016	0	0	0	0	0	0	0	0	0	0	0	0
33	0.007	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0.002	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1986 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.003	0	0	0	0	0	0	0	0	0	0.031	0.001	0.007
7	0.016	0	0	0	0	0	0	0	0	0	0.289	0.053	0.095
9	0.092	0.091	0.001	0.191	0.001	0	0.001	0.001	0.001	0	0.470	0.942	0.898
11	0.255	0.347	0.047	0.451	0.767	0.773	0.047	0.089	0.767	0.773	0.206	0.004	0
13	0.238	0.381	0.405	0.204	0.151	0.180	0.405	0.230	0.151	0.180	0.003	0	0
15	0.162	0.130	0.450	0.114	0.066	0.035	0.450	0.437	0.066	0.035	0.001	0	0
17	0.138	0.020	0.082	0.032	0.012	0.005	0.082	0.180	0.012	0.005	0	0	0
19	0.065	0.015	0.013	0.006	0.003	0.005	0.013	0.063	0.003	0.005	0	0	0
21	0.020	0.012	0.002	0.001	0	0.002	0.002	0	0	0.002	0	0	0
23	0.004	0.003	0	0	0	0	0	0	0	0	0	0	0
25	0.002	0.001	0	0.001	0	0	0	0	0	0	0	0	0
27	0.001	0	0	0	0	0	0	0	0	0	0	0	0
29	0.002	0	0	0	0	0	0	0	0	0	0	0	0
31	0.001	0	0	0	0	0	0	0	0	0	0	0	0
33	0.001	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1987 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.005	0	0.004
7	0	0	0	0.002	0	0	0	0	0	0	0.465	0.149	0.283
9	0.115	0.152	0.001	0.170	0.002	0	0.001	0.131	0.015	0	0.445	0.848	0.713
11	0.373	0.373	0.030	0.489	0.579	0.616	0.030	0.617	0.275	0.616	0.085	0.003	0
13	0.390	0.357	0.332	0.212	0.301	0.244	0.332	0.248	0.449	0.244	0	0	0
15	0.105	0.093	0.453	0.089	0.086	0.088	0.453	0.004	0.246	0.088	0	0	0
17	0.004	0.018	0.151	0.025	0.024	0.036	0.151	0	0.015	0.036	0	0	0
19	0.004	0	0.027	0.010	0.008	0.009	0.027	0	0	0.009	0	0	0
21	0.001	0.007	0.005	0.002	0	0.003	0.005	0	0	0.003	0	0	0
23	0.002	0	0.001	0.001	0	0.002	0.001	0	0	0.002	0	0	0
25	0.001	0	0	0	0	0	0	0	0	0	0	0	0
27	0.001	0	0	0	0	0	0	0	0	0	0	0	0
29	0.001	0	0	0	0	0	0	0	0	0	0	0	0
31	0.002	0	0	0	0	0.002	0	0	0	0.002	0	0	0
33	0.001	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1988 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0.001	0.003
7	0	0	0	0.002	0	0	0	0	0.002	0	0.585	0.102	0.165
9	0.001	0.081	0	0.150	0	0	0	0.003	0.247	0	0.374	0.884	0.832
11	0.024	0.424	0.006	0.560	0.678	0.663	0.006	0.033	0.336	0.663	0.041	0.013	0
13	0.114	0.212	0.093	0.229	0.179	0.220	0.093	0.100	0.315	0.220	0	0	0
15	0.343	0.187	0.287	0.041	0.085	0.073	0.287	0.421	0.070	0.073	0	0	0
17	0.373	0.075	0.235	0.004	0.047	0.030	0.235	0.257	0.013	0.030	0	0	0
19	0.116	0.015	0.163	0.005	0.010	0.010	0.163	0.128	0.003	0.010	0	0	0
21	0.014	0.006	0.140	0.006	0.001	0.004	0.140	0.054	0.006	0.004	0	0	0
23	0.006	0	0.067	0.002	0	0	0.067	0.004	0.003	0	0	0	0
25	0.006	0	0.009	0.001	0	0	0.009	0	0.002	0	0	0	0
27	0.001	0	0	0	0	0	0	0	0.002	0	0	0	0
29	0.001	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0.001	0	0	0	0
33	0.001	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1989 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.010	0.015	0.008
7	0.001	0.052	0	0	0	0	0	0	0.004	0	0.301	0.222	0.109
9	0.005	0.042	0.002	0.276	0	0.061	0.001	0.029	0.475	0.132	0.507	0.759	0.883
11	0.099	0.311	0.067	0.617	0.669	0.569	0.062	0.111	0.369	0.469	0.182	0.002	0
13	0.239	0.328	0.415	0.032	0.220	0.296	0.439	0.301	0.078	0.284	0	0.002	0
15	0.184	0.138	0.387	0.008	0.085	0.043	0.322	0.241	0.030	0.083	0	0	0
17	0.188	0.119	0.118	0.003	0.024	0.021	0.097	0.197	0.008	0.004	0	0	0
19	0.098	0.006	0.011	0.001	0.002	0.010	0.019	0.079	0.007	0	0	0	0
21	0.083	0.004	0	0	0	0	0.011	0.020	0.012	0.012	0	0	0
23	0.053	0	0	0.004	0	0	0.022	0.015	0.007	0.012	0	0	0
25	0.032	0	0	0.017	0	0	0.022	0.007	0.004	0.004	0	0	0
27	0.012	0	0	0.015	0	0	0.005	0	0.004	0	0	0	0
29	0.001	0	0	0.006	0	0	0	0	0.001	0	0	0	0
31	0.003	0	0	0.007	0	0	0	0	0.001	0	0	0	0
33	0	0	0	0.010	0	0	0	0	0	0	0	0	0
35	0.002	0	0	0.004	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1990 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.006	0.003	0.026
7	0.003	0.039	0	0.001	0	0.001	0	0	0.009	0	0.355	0.082	0.064
9	0.02	0.076	0.01	0.288	0	0.215	0.003	0.072	0.624	0.228	0.514	0.913	0.904
11	0.345	0.19	0.448	0.57	0.789	0.56	0.047	0.492	0.286	0.486	0.125	0.002	0.006
13	0.316	0.344	0.326	0.131	0.183	0.132	0.557	0.326	0.041	0.201	0	0	0
15	0.144	0.177	0.19	0.01	0.024	0.063	0.298	0.096	0.014	0.026	0	0	0
17	0.071	0.087	0.026	0	0.004	0.025	0.059	0.012	0.005	0.009	0	0	0
19	0.047	0.071	0	0	0	0.003	0.017	0.002	0.005	0.018	0	0	0
21	0.026	0.008	0	0	0	0.001	0.012	0	0.002	0.027	0	0	0
23	0.01	0.008	0	0	0	0	0.005	0	0.003	0.005	0	0	0
25	0.010	0	0	0	0	0	0.001	0	0.005	0	0	0	0
27	0.003	0	0	0	0	0	0.001	0	0.004	0	0	0	0
29	0.003	0	0	0	0	0	0	0	0.002	0	0	0	0
31	0.001	0	0	0	0	0	0	0	0	0	0	0	0
33	0.001	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0.000	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1991 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.005	0.002	0.03
7	0	0	0	0.001	0	0	0	0	0.008	0	0.321	0.085	0.349
9	0.01	0.003	0.003	0.235	0	0.021	0.012	0.129	0.554	0.31	0.519	0.912	0.621
11	0.152	0.193	0.258	0.586	0.814	0.67	0.064	0.183	0.241	0.417	0.153	0.001	0
13	0.277	0.348	0.655	0.167	0.153	0.267	0.475	0.258	0.132	0.132	0	0	0
15	0.278	0.318	0.083	0.01	0.025	0.038	0.279	0.181	0.045	0.055	0.002	0	0
17	0.159	0.103	0.001	0.001	0.008	0.004	0.104	0.139	0.008	0.04	0	0	0
19	0.062	0.035	0	0	0	0	0.042	0.069	0.005	0.022	0	0	0
21	0.042	0	0	0	0	0	0.017	0.034	0.001	0.009	0	0	0
23	0.014	0	0	0	0	0	0.006	0	0.002	0.009	0	0	0
25	0.002	0	0	0	0	0	0.001	0.007	0.002	0.002	0	0	0
27	0.001	0	0	0	0	0	0	0	0.002	0.004	0	0	0
29	0.002	0	0	0	0	0	0	0	0	0	0	0	0
31	0.000	0	0.000	0	0	0	0.000	0	0	0	0	0	0
33	0.001	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1992 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0.004	0	0
7	0.002	0.002	0.001	0.003	0	0	0	0	0.002	0.001	0.119	0.094	0.007
9	0.001	0	0.007	0.054	0	0.088	0	0	0.266	0.231	0.543	0.906	0.991
11	0.052	0.442	0.239	0.641	0.825	0.638	0.031	0.217	0.649	0.629	0.321	0	0.002
13	0.204	0.298	0.634	0.29	0.139	0.221	0.554	0.42	0.069	0.088	0.001	0	0
15	0.151	0.122	0.112	0.012	0.026	0.049	0.315	0.272	0.008	0.004	0.012	0	0
17	0.189	0.102	0.007	0	0.01	0.004	0.07	0.06	0	0.003	0	0	0
19	0.155	0.031	0	0	0	0	0.018	0.028	0.001	0.011	0	0	0
21	0.128	0.003	0	0	0	0	0.008	0.003	0.001	0.014	0	0	0
23	0.05	0	0	0	0	0	0.004	0	0.002	0.013	0	0	0
25	0.051	0	0	0	0	0	0	0	0.002	0.004	0	0	0
27	0.003	0	0	0	0	0	0	0	0	0.001	0	0	0
29	0.012	0	0	0	0	0	0	0	0	0	0	0	0
31	0.002	0	0.000	0	0	0	0.000	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0.001	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1993 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0.008	0	0
5	0	0	0	0	0	0	0	0	0	0	0.035	0	0
7	0	0	0.001	0	0	0	0	0	0	0	0.162	0.174	0.114
9	0.001	0.002	0.01	0.09	0	0.115	0	0	0.246	0.25	0.57	0.826	0.875
11	0.041	0.339	0.221	0.78	0.774	0.574	0.023	0.231	0.53	0.526	0.22	0	0.011
13	0.335	0.422	0.613	0.094	0.167	0.246	0.365	0.356	0.158	0.12	0.004	0	0
15	0.39	0.21	0.142	0.035	0.052	0.057	0.443	0.186	0.052	0.03	0.001	0	0
17	0.179	0.027	0.013	0.001	0.007	0.006	0.144	0.157	0	0.023	0	0	0
19	0.027	0	0	0	0	0.002	0.02	0.061	0.001	0.019	0	0	0
21	0.012	0	0	0	0	0	0.005	0.009	0	0.007	0	0	0
23	0.006	0.000	0	0	0	0	0	0	0.001	0.014	0	0	0
25	0.004	0	0	0	0	0	0	0	0.008	0.007	0	0	0
27	0.004	0	0	0	0	0	0	0	0.002	0.001	0	0	0
29	0.001	0	0	0	0	0	0	0	0.002	0.003	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1994 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.002	0	0	0	0	0	0	0	0	0	0	0.042	0.028
7	0.005	0.001	0.001	0	0	0	0	0	0	0	0.005	0.055	0.079
9	0.015	0.013	0.01	0.031	0	0	0	0	0.227	0.163	0.180	0.903	0.848
11	0.032	0.175	0.222	0.724	0.568	0.525	0.014	0.049	0.65	0.756	0.672	0	0.045
13	0.331	0.412	0.613	0.221	0.268	0.298	0.225	0.550	0.088	0.077	0.111	0	0
15	0.44	0.276	0.140	0.022	0.149	0.129	0.436	0.226	0.019	0	0.032	0	0
17	0.134	0.098	0.014	0.001	0.015	0.029	0.251	0.133	0.008	0	0	0	0
19	0.026	0.02	0	0.001	0	0.019	0.065	0.036	0.004	0.002	0	0	0
21	0.005	0.005	0	0	0	0	0.007	0.003	0.002	0	0	0	0
23	0.001	0	0	0	0	0	0.002	0	0.001	0.002	0	0	0
25	0.001	0	0	0	0	0	0	0.003	0	0	0	0	0
27	0.008	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0.001	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1995 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.004	0.004	0.007	0	0	0	0	0	0.173	0.03
7	0	0.001	0	0.002	0	0.011	0	0	0	0	0.005	0.05	0.046
9	0.003	0.001	0	0.017	0.024	0.231	0	0	0.106	0.07	0.18	0.69	0.871
11	0.004	0.071	0.237	0.56	0.546	0.426	0.007	0.069	0.593	0.689	0.672	0.087	0.053
13	0.310	0.196	0.631	0.263	0.279	0.213	0.141	0.303	0.195	0.223	0.111	0	0
15	0.438	0.35	0.112	0.088	0.129	0.076	0.467	0.365	0.081	0.015	0.032	0	0
17	0.171	0.288	0.02	0.045	0.017	0.034	0.223	0.211	0.019	0.003	0	0	0
19	0.046	0.079	0	0.018	0.001	0.002	0.08	0.046	0.005	0	0	0	0
21	0.012	0.014	0	0.003	0	0	0.061	0	0.001	0	0	0	0
23	0.003	0	0	0	0	0	0.007	0.006	0	0	0	0	0
25	0.004	0	0	0	0	0	0.007	0	0	0	0	0	0
27	0.006	0	0	0	0	0	0.005	0	0	0	0	0	0
29	0.003	0	0	0	0	0	0.002	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1996 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.003	0	0	0	0	0	0	0.02	0	0	0	0.173	0
7	0	0	0	0	0.001	0.072	0	0.05	0	0	0.04	0.05	0.092
9	0	0.002	0	0.002	0.096	0.179	0	0.054	0.174	0.215	0.181	0.69	0.832
11	0.001	0.029	0.022	0.111	0.486	0.517	0.032	0.173	0.511	0.603	0.56	0.087	0.076
13	0.187	0.41	0.273	0.667	0.258	0.170	0.332	0.477	0.218	0.125	0.219	0	0
15	0.462	0.429	0.313	0.162	0.13	0.044	0.35	0.145	0.079	0.039	0	0	0
17	0.221	0.108	0.208	0.049	0.028	0.015	0.17	0.049	0.016	0.007	0	0	0
19	0.081	0.022	0.165	0.006	0.001	0.002	0.07	0.018	0.001	0.004	0	0	0
21	0.019	0	0.018	0.002	0	0.001	0.038	0.014	0.001	0.007	0	0	0
23	0.008	0	0.001	0.001	0	0	0.007	0	0	0	0	0	0
25	0.014	0	0	0	0	0	0.001	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0.002	0	0	0	0	0	0	0	0	0	0	0	0
31	0.002	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1997 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.007	0	0	0	0.02	0	0	0.029	0.173	0
7	0.005	0	0	0.059	0	0.018	0	0.05	0	0	0.246	0.05	0.1
9	0.004	0.016	0	0.045	0.02	0.354	0	0.054	0.034	0.215	0.191	0.69	0.884
11	0.003	0.041	0.018	0.16	0.621	0.484	0.017	0.173	0.254	0.603	0.434	0.087	0.016
13	0.192	0.548	0.216	0.536	0.244	0.124	0.333	0.477	0.576	0.125	0.094	0	0
15	0.379	0.325	0.468	0.155	0.095	0.017	0.385	0.145	0.102	0.039	0.006	0	0
17	0.24	0.059	0.205	0.032	0.016	0.003	0.171	0.049	0	0.007	0	0	0
19	0.112	0.01	0.081	0.005	0.002	0.000	0.073	0.018	0.017	0.004	0	0	0
21	0.035	0.001	0.011	0.001	0.001	0	0.019	0.014	0.017	0.007	0	0	0
23	0.02	0	0.001	0	0	0	0.002	0	0	0	0	0	0
25	0.009	0	0	0	0.001	0	0	0	0	0	0	0	0
27	0.001	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0.000	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1998 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0.02	0	0	0.000	0.173	0
7	0	0	0	0	0	0	0	0.05	0	0	0.018	0.05	0.1
9	0.001	0	0	0.001	0.175	0.054	0	0.054	0.046	0.133	0.006	0.69	0.884
11	0.013	0.028	0	0.124	0.598	0.624	0.004	0.173	0.482	0.416	0.813	0.087	0.016
13	0.112	0.439	0.151	0.542	0.175	0.258	0.17	0.477	0.293	0.271	0.16	0	0
15	0.336	0.392	0.335	0.227	0.045	0.056	0.296	0.145	0.116	0.122	0.003	0	0
17	0.217	0.104	0.355	0.079	0.007	0.006	0.273	0.049	0.032	0.042	0	0	0
19	0.148	0.032	0.13	0.023	0	0.002	0.13	0.018	0.017	0.016	0	0	0
21	0.089	0.004	0.024	0.004	0	0	0.075	0.014	0.007	0	0	0	0
23	0.056	0	0.005	0	0	0	0.038	0	0.005	0	0	0	0
25	0.023	0	0	0	0	0	0.013	0	0.001	0	0	0	0
27	0.004	0.001	0	0	0	0	0.001	0	0.001	0	0	0	0
29	0.001	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0.000	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 3. Continued.

1999 Late Season

	Recreational		Commercial SA				Commercial MA				Scrap		
TL (in)	MA	SA	Gill	Trwl	Pnd	Haul	Gill	Trwl	Pnd	Haul	Trwl	Pnd	Haul
3	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0.02	0	0	0.015	0.056	0.008
7	0	0	0	0	0	0.029	0	0.05	0	0	0.266	0.019	0.472
9	0.002	0	0	0	0.073	0.085	0	0.054	0.081	0	0.302	0.697	0.484
11	0.046	0.084	0.012	0.271	0.66	0.56	0.017	0.173	0.434	0.402	0.324	0.228	0.025
13	0.108	0.331	0.442	0.671	0.216	0.219	0.232	0.477	0.26	0.315	0.07	0	0.011
15	0.202	0.391	0.425	0.034	0.043	0.075	0.403	0.145	0.122	0.169	0.023	0	0
17	0.245	0.145	0.092	0.015	0.007	0.027	0.166	0.049	0.072	0.067	0	0	0
19	0.172	0.038	0.027	0.008	0.001	0.004	0.092	0.018	0.016	0.035	0	0	0
21	0.138	0.007	0.001	0.001	0	0.001	0.049	0.014	0.002	0.008	0	0	0
23	0.035	0	0	0	0	0	0.025	0	0.005	0.004	0	0	0
25	0.038	0	0	0	0	0	0.003	0	0.006	0	0	0	0
27	0.012	0.004	0	0	0	0	0.009	0	0.002	0	0	0	0
29	0.001	0	0.001	0	0	0	0.002	0	0	0	0	0	0
31	0.001	0	0	0	0	0	0.002	0	0	0	0	0	0
33	0	0	0	0.000	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 1 Table 4a. Weakfish mean weight (pounds) by gear for early (Jan.-Jun.) 1982-1999.

	Recreational[a]		**Commercial (SA)**					**Commercial (MA)**					**Scrap**		
Gear	**SA**	**MA**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Trwl**	**Pnd**	**Haul**
1982	1.05	6.58	1.32	1.43	0.70	0.59	1.05	1.32	6.58	0.70	0.59	6.58	0.23	0.21	0.26
1983	1.04	3.69	1.32	1.23	0.45	0.46	1.04	1.32	8.79	0.45	0.46	3.69	0.23	0.22	0.23
1984	0.61	2.47	2.15	0.61	0.56	0.71	0.61	2.15	4.62	0.56	0.71	2.47	0.20	0.23	0.20
1985	0.58	1.12	1.45	0.54	0.56	0.68	0.58	1.45	0.45	0.56	0.68	1.12	0.24	0.28	0.26
1986	0.82	0.59	1.33	0.69	0.53	0.65	0.82	1.33	0.47	0.81	0.65	0.59	0.21	0.22	0.21
1987	0.64	0.69	1.12	0.60	0.63	0.67	0.64	1.12	0.49	0.80	0.67	0.69	0.21	0.23	0.20
1988	0.95	0.96	1.87	0.46	0.56	0.70	0.95	1.87	0.52	1.02	0.70	0.96	0.22	0.25	0.28
1989	0.62	1.32	1.70	1.10	0.54	0.98	0.62	2.29	0.52	1.24	0.92	1.32	0.19	0.22	0.20
1990	0.62	1.52	1.49	0.70	0.52	0.42	0.62	2.06	0.52	0.74	0.90	1.52	0.17	0.22	0.20
1991	0.63	1.13	0.69	0.40	0.59	0.45	0.63	1.60	0.52	0.53	1.56	1.13	0.18	0.21	0.16
1992	0.93	0.73	0.65	0.69	0.48	0.48	0.93	1.65	0.52	0.49	1.36	0.73	0.21	0.22	0.16
1993	0.69	1.36	0.64	0.54	0.47	0.38	0.69	1.89	0.52	0.60	0.96	1.36	0.27	0.23	0.18
1994	0.78	0.82	0.90	1.15	0.64	0.50	0.78	1.49	0.52	0.37	0.66	0.82	0.20	0.29	0.20
1995	1.03	1.14	0.86	0.56	0.63	0.64	1.02	1.96	0.52	0.44	0.95	1.14	0.26	0.23	0.21
1996	1.02	1.19	1.15	1.57	0.69	0.52	1.02	1.60	0.52	0.59	0.57	1.19	0.29	0.23	0.22
1997	0.93	1.13	1.00	1.23	0.76	0.47	0.93	1.38	0.52	0.61	0.62	1.12	0.54	0.23	0.27
1998	1.02	1.33	1.31	1.61	0.65	0.80	1.02	1.72	0.52	0.70	0.65	1.33	0.88	0.23	0.27
1999	1.11	1.95	1.49	1.23	0.60	0.54	1.11	1.90	0.52	1.16	1.30	1.95	0.45	0.24	0.20

[a] South (SA) and Middle (MA) Atlantic regions.

Appendix 1 Table 4b. Weakfish mean weight (pounds) by gear for late (Jul.-Dec.) 1982-1999.

	Recreational[a]		**Commercial (SA)**					**Commercial (MA)**					**Scrap**		
Gear	**SA**	**MA**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Gill**	**Trwl**	**Pnd**	**Haul**	**H&L**	**Trwl**	**Pnd**	**Haul**
1982	1.51	4.08	1.66	0.44	0.68	0.61	1.51	1.66	1.31	0.68	0.61	4.08	0.21	0.26	0.28
1983	0.81	1.68	1.66	0.47	0.60	0.54	0.81	1.66	0.85	0.60	0.54	1.68	0.23	0.25	0.26
1984	0.46	1.69	0.98	0.50	0.55	0.54	0.46	0.98	1.04	0.55	0.54	1.69	0.31	0.27	0.25
1985	2.01	2.00	0.82	0.45	0.65	0.53	2.01	0.82	1.01	0.65	0.53	2.00	0.19	0.27	0.24
1986	0.75	0.99	1.02	0.61	0.54	0.52	0.75	1.02	1.18	0.54	0.52	0.99	0.25	0.25	0.25
1987	1.16	1.35	1.52	0.59	0.53	0.54	1.16	1.52	1.16	0.74	0.54	1.35	0.26	0.26	0.26
1988	0.77	1.43	1.95	0.56	0.63	0.62	0.77	1.95	1.51	0.66	0.62	1.43	0.19	0.26	0.25
1989	0.77	1.65	1.02	0.88	0.59	0.59	0.77	1.42	1.25	0.58	0.70	1.65	0.24	0.24	0.26
1990	0.92	0.99	0.72	0.44	0.52	0.53	0.92	1.09	0.62	0.47	0.63	0.99	0.23	0.25	0.25
1991	0.96	1.20	0.69	0.47	0.51	0.54	0.96	1.15	1.08	0.50	0.61	1.20	0.24	0.25	0.20
1992	0.83	1.90	1.02	0.58	0.50	0.54	0.83	1.07	0.93	0.41	0.51	1.90	0.31	0.25	0.27
1993	0.77	1.15	0.75	0.47	0.53	0.55	0.77	1.14	1.03	0.53	0.59	1.15	0.25	0.24	0.25
1994	0.93	1.11	0.75	0.53	0.64	0.72	0.93	1.32	1.03	0.43	0.38	1.11	0.47	0.27	0.26
1995	1.26	1.23	0.74	0.70	0.64	0.56	1.26	1.50	1.17	0.54	0.45	1.23	0.47	0.25	0.27
1996	1.03	1.38	1.38	0.84	0.63	0.49	1.03	1.31	0.79	0.53	0.46	1.38	0.49	0.25	0.27
1997	0.93	1.42	1.29	0.74	0.61	0.43	0.93	1.28	0.74	0.76	0.46	1.42	0.36	0.25	0.23
1998	1.05	1.73	1.50	0.92	0.51	0.57	1.05	1.70	0.74	0.71	0.60	1.73	0.51	0.25	0.24
1999	1.08	1.88	1.06	0.69	0.54	0.59	1.08	1.57	0.74	0.75	0.85	1.88	0.33	0.29	0.20

[a] South (SA) and Middle (MA) Atlantic regions.

[b] Mean weight for purse-seine landings in late 1984 were 7.45 lbs.

Appendix 1 Table 5. Scale based age-length keys for the early and late seasons, 1982-1984, 1985-1987, and 1988-1989.

1982-1984 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	0.943	0.053	0.004	0	0	0
7	0	0.885	0.108	0.007	0	0	0
9	0	0.535	0.419	0.046	0	0	0
11	0	0.037	0.889	0.074	0	0	0
13	0	0.044	0.714	0.231	0	0.011	0
15	0	0	0.564	0.34	0.085	0.011	0
17	0	0	0.342	0.506	0.152	0	0
19	0	0	0.115	0.672	0.213	0	0
21	0	0	0	0.455	0.409	0.136	0
23	0	0	0	0.453	0.427	0.08	0.04
25	0	0	0	0.147	0.677	0.088	0.088
27	0	0	0	0	0.129	0.258	0.613
29	0	0	0	0	0	0.268	0.732
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1982-1984 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.993	0.007	0	0	0	0	0
7	0.942	0.058	0	0	0	0	0
9	0.012	0.964	0.024	0	0	0	0
11	0.006	0.813	0.174	0.007	0	0	0
13	0	0.36	0.6	0.04	0	0	0
15	0	0.103	0.629	0.268	0	0	0
17	0	0.081	0.581	0.23	0.108	0	0
19	0	0	0.463	0.415	0.122	0	0
21	0	0.04	0.2	0.64	0.08	0.04	0
23	0	0	0.312	0.625	0.063	0	0
25	0	0	0.016	0.732	0.203	0.049	0
27	0	0	0	0.5	0.4	0.057	0.043
29	0	0	0	0	0.13	0.305	0.565
31	0	0	0	0	0	0.263	0.737
33	0	0	0	0	0	0.107	0.893
35	0	0	0	0	0	0.025	0.975
37	0	0	0	0	0	0	1

Appendix 1 Table 5. Continued.

1985-1987 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	1	0	0	0	0	0
11	0	0.99	0.01	0	0	0	0
13	0	0.619	0.381	0	0	0	0
15	0	0.035	0.655	0.31	0	0	0
17	0	0.026	0.342	0.632	0	0	0
19	0	0	0.28	0.64	0.04	0.04	0
21	0	0	0	0.603	0.344	0.038	0.015
23	0	0	0	0.453	0.427	0.08	0.04
25	0	0	0	0.147	0.677	0.088	0.088
27	0	0	0	0.013	0.413	0.187	0.387
29	0	0	0	0	0.353	0.588	0.059
31	0	0	0	0.118	0.294	0.529	0.059
33	0	0	0	0	0.009	0.009	0.982
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1985-1987 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.995	0.005	0	0	0	0	0
7	0.963	0.037	0	0	0	0	0
9	0.139	0.848	0.013	0	0	0	0
11	0	0.907	0.093	0	0	0	0
13	0	0.773	0.223	0.004	0	0	0
15	0	0.566	0.421	0.013	0	0	0
17	0	0.252	0.642	0.106	0	0	0
19	0	0.035	0.662	0.282	0.014	0.007	0
21	0	0	0.496	0.477	0.018	0.009	0
23	0	0	0.313	0.663	0.024	0	0
25	0	0	0	0.802	0.177	0.021	0
27	0	0	0	0.66	0.26	0.04	0.04
29	0	0	0	0.07	0.614	0.246	0.07
31	0	0	0	0.029	0.543	0.314	0.114
33	0	0	0	0	0	0.107	0.893
35	0	0	0	0	0	0.025	0.975
37	0	0	0	0	0	0	1

Appendix 1 Table 5. Continued.

1988-1989 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	0.943	0.053	0.004	0	0	0
7	0	0.885	0.108	0.007	0	0	0
9	0	0.421	0.579	0	0	0	0
11	0	0.038	0.705	0.231	0.026	0	0
13	0	0	0.4	0.458	0.132	0.01	0
15	0	0	0.175	0.545	0.25	0.03	0
17	0	0	0.095	0.533	0.324	0.048	0
19	0	0	0.01	0.73	0.19	0.05	0.02
21	0	0	0	0.641	0.32	0.02	0.019
23	0	0	0	0.449	0.435	0.073	0.043
25	0	0	0	0.154	0.731	0.077	0.038
27	0	0	0	0	0.568	0.162	0.27
29	0	0	0	0	0.045	0.137	0.818
31	0	0	0	0	0	0.053	0.947
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1988-1989 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.987	0.013	0	0	0	0	0
7	0.918	0.082	0	0	0	0	0
9	0.231	0.692	0.077	0	0	0	0
11	0	0.641	0.34	0.019	0	0	0
13	0	0.195	0.553	0.219	0.033	0	0
15	0	0.043	0.482	0.451	0.024	0	0
17	0	0	0.506	0.471	0.023	0	0
19	0	0	0.162	0.703	0.135	0	0
21	0	0	0.229	0.6	0.143	0.028	0
23	0	0	0.067	0.633	0.267	0.033	0
25	0	0	0.087	0.522	0.304	0.087	0
27	0	0	0	0.167	0.75	0	0.083
29	0	0	0	0	0.177	0.294	0.529
31	0	0	0	0	0.069	0.172	0.759
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 6. Scale-otolith conversion data and matrix produced from 2,318 weakfish that were ages with both scales and otoliths, first applied in the 1999 stock assessment reviewed by the 30th SARC (NEFSC 2000). Most fish were collected in 1995, but some were from earlier years. To use the conversion matrix, the numbers at age from scale data are arranged in a row across the top of the matrix. The number of fish of each age is then multiplied by the probability in each cell, working down the column to form a new matrix of numbers at otolith age. For examples, if 100 fish were ages as age zero by scales, then 99 would be aged zero and 1 would be aged one year of age. When this is completed for all columns, the rows are summed with each row corresponding to a given age, producing a new age distribution. All fish in the first row of the new matrix would be summed to give the new number aged zero.

Otolith Age	Scale Age						
	0	1	2	3	4	5	6
0	238	4	3	0	0	0	0
1	3	244	21	1	0	0	0
2	0	144	372	32	3	0	0
3	0	20	128	335	21	0	0
4	0	2	54	146	292	13	1
5	0	0	4	13	78	109	5
6	0	0	0	0	2	7	23
Total	241	414	582	527	396	129	29

Transition Matrix						
0.988	0.010	0.005	0.000	0.000	0.000	0.000
0.012	0.589	0.036	0.002	0.000	0.000	0.000
0.000	0.348	0.639	0.061	0.008	0.000	0.000
0.000	0.048	0.220	0.636	0.053	0.000	0.000
0.000	0.005	0.093	0.277	0.737	0.101	0.034
0.000	0.000	0.007	0.025	0.197	0.845	0.172
0.000	0.000	0.000	0.000	0.005	0.054	0.793

Appendix 1 Table 7. Comparison of the 2002 assessment CAA and the re-created CAA, in thousands of fish.

2002 Stock Assessment CAA

	Age						
Year	1	2	3	4	5	6+	Total 1-6+
1982	7,893.4	11,793.7	5,418.6	2,774.0	720.2	639.2	29,239.1
1983	6,430.8	12,099.9	5,702.4	2,775.4	567.1	423.9	27,999.5
1984	7,533.2	13,891.9	6,437.3	3,039.7	483.2	254.2	31,639.5
1985	12,790.2	10,690.1	3,133.5	1,165.4	211.6	54.8	28,045.6
1986	17,032.4	15,000.4	4,815.3	1,816.0	262.3	51.8	38,978.2
1987	14,976.3	13,533.3	4,253.8	1,478.3	143.7	10.6	34,396.0
1988	6,952.0	15,442.8	10,455.5	6,057.7	1,042.3	69.2	40,019.5
1989	2,245.8	4,796.0	4,306.5	2,917.6	625.1	84.4	14,975.4
1990	8,895.0	4,536.5	2,012.2	1,200.2	590.4	88.9	17,323.2
1991	9,103.7	5,460.1	2,685.9	1,354.6	459.0	56.4	19,119.7
1992	4,305.9	5,682.0	2,175.8	1,251.7	527.0	64.8	14,007.2
1993	3,769.4	5,770.2	2,125.9	1,133.1	399.9	48.0	13,246.5
1994	3,165.8	2,876.2	3,000.8	1,362.4	199.4	38.3	10,642.9
1995	3,470.6	3,095.2	3,379.0	1,574.2	196.1	53.6	11,768.7
1996	1,482.4	2,052.7	4,073.4	2,955.9	1,333.7	97.9	11,996.0
1997	970.2	1,553.4	2,562.6	5,036.5	1,469.2	397.1	11,989.0
1998	835.3	1,709.1	3,535.1	1,903.7	2,827.1	870.5	11,680.8
1999	804.9	1,148.4	2,076.0	3,057.8	702.4	1,123.0	8,912.5

Appendix 1 Table 7. Continued.

Re-created CAA

	Age						
Year	1	2	3	4	5	6+	Total 1-6+
1982	7,909.1	11,816.4	5,427.1	2,777.5	720.6	639.2	29,289.9
1983	6,432.6	12,103.6	5,703.7	2,776.0	567.1	423.8	28,006.8
1984	7,550.8	13,905.4	6,436.9	3,037.8	482.7	254.1	31,667.6
1985	13,507.2	11,321.7	3,245.3	1,145.0	175.4	39.6	29,434.2
1986	17,145.8	15,280.3	4,892.2	1,817.9	238.9	35.2	39,410.3
1987	14,210.0	13,129.8	4,269.1	1,508.4	148.6	10.7	33,276.6
1988	6,635.3	15,008.6	10,263.6	5,971.4	1,032.5	68.2	38,979.6
1989	2,245.8	4,795.8	4,306.3	2,917.4	625.1	84.4	14,974.7
1990	8,895.0	4,536.5	2,012.2	1,200.2	590.4	88.9	17,323.2
1991	9,103.7	5,460.0	2,685.9	1,354.6	459.0	56.4	19,119.6
1992	4,305.4	5,682.0	2,175.0	1,251.7	527.0	64.8	14,005.9
1993	3,769.4	5,770.2	2,125.9	1,133.1	399.9	48.0	13,246.4
1994	3,165.8	2,876.9	3,000.8	1,362.4	199.4	38.3	10,643.5
1995	3,470.6	3,095.2	3,379.0	1,574.2	196.1	53.6	11,768.7
1996	1,482.4	2,052.7	4,073.4	2,955.9	1,333.7	97.9	11,996.0
1997	970.2	1,553.4	2,562.6	5,036.5	1,469.2	397.1	11,989.1
1998	835.3	1,709.1	3,535.1	1,903.7	2,827.1	870.5	11,680.9
1999	804.9	1,148.4	2,076.0	3,057.8	702.4	1,123.0	8,912.6

Appendix 1 Table 7. Continued.

Differences (in thousands of fish)

	Age						
Year	1	2	3	4	5	6+	Total 1-6+
1982	15.7	22.7	8.5	3.5	0.4	0.0	50.8
1983	1.8	3.7	1.3	0.6	0.0	-0.1	7.3
1984	17.6	13.5	-0.4	-1.9	-0.5	-0.1	28.1
1985	717.0	631.6	111.8	-20.4	-36.2	-15.2	1,388.6
1986	113.4	279.9	76.9	1.9	-23.4	-16.6	432.1
1987	-766.3	-403.5	15.3	30.1	4.9	0.1	-1,119.4
1988	-316.7	-434.2	-191.9	-86.3	-9.8	-1.0	-1,039.9
1989	0.0	-0.2	-0.2	-0.2	0.0	0.0	-0.7
1990	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
1992	-0.5	0.0	-0.8	0.0	0.0	0.0	-1.3
1993	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1994	0.0	0.7	0.0	0.0	0.0	0.0	0.6
1995	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1996	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1997	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1998	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1999	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 1 Table 8. Otolith based age-length keys for the mid Atlantic early and late seasons, 1990-1991, 1992-1993, 1994-1995, 1996, 1997, 1998, and 1999.

1990-1991 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.069	0.931	0	0	0	0
11	0	0.01	0.854	0.136	0	0	0
13	0	0	0.585	0.34	0.064	0.011	0
15	0	0	0.395	0.531	0.074	0	0
17	0	0	0.111	0.571	0.318	0	0
19	0	0	0.011	0.416	0.483	0.09	0
21	0	0	0	0.149	0.689	0.122	0.04
23	0	0	0	0.089	0.6	0.289	0.022
25	0	0	0	0	0.45	0.3	0.25
27	0	0	0	0	0.191	0.617	0.192
29	0	0	0	0	0.074	0.296	0.63
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1990-1991 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
7	0.927	0.07	0.003	0	0	0	0
9	0	0.88	0.12	0	0	0	0
11	0	0.121	0.835	0.044	0	0	0
13	0	0.167	0.5	0.333	0	0	0
15	0	0.005	0.133	0.378	0.38	0.087	0.017
17	0	0.012	0.118	0.41	0.354	0.087	0.019
19	0	0	0.03	0.576	0.303	0.091	0
21	0	0	0.015	0.168	0.48	0.267	0.07
23	0	0	0	0.105	0.4	0.414	0.081
25	0	0	0	0	0.875	0.125	0
27	0	0	0	0	0.75	0.25	0
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 8. Continued.

1992-1993 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.529	0.471	0	0	0	0
11	0	0	0.807	0.181	0.012	0	0
13	0	0	0.463	0.518	0.019	0	0
15	0	0	0.262	0.69	0.048	0	0
17	0	0	0.045	0.711	0.222	0.022	0
19	0	0	0	0.321	0.572	0.107	0
21	0	0	0	0.273	0.636	0.091	0
23	0	0	0	0.143	0.643	0.214	0
25	0	0	0	0.016	0.359	0.438	0.187
27	0	0	0	0	0.177	0.647	0.176
29	0	0	0	0	0.077	0.154	0.769
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1992-1993 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
7	0.927	0.07	0.003	0	0	0	0
9	0	0.88	0.12	0	0	0	0
11	0	0.121	0.835	0.044	0	0	0
13	0	0.167	0.5	0.333	0	0	0
15	0	0.005	0.133	0.378	0.38	0.087	0.017
17	0	0.012	0.118	0.41	0.354	0.087	0.019
19	0	0	0.03	0.576	0.303	0.091	0
21	0	0	0.015	0.168	0.48	0.267	0.07
23	0	0	0	0.105	0.4	0.414	0.081
25	0	0	0	0	0.875	0.125	0
27	0	0	0	0	0.75	0.25	0
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 8. Continued.

1994-1995 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.355	0.524	0.121	0	0	0
11	0	0.005	0.257	0.6	0.138	0	0
13	0	0	0.078	0.444	0.456	0.022	0
15	0	0	0	0.167	0.667	0.083	0.083
17	0	0	0.019	0.193	0.515	0.231	0.042
19	0	0	0.004	0.212	0.506	0.243	0.035
21	0	0	0	0.132	0.54	0.23	0.098
23	0	0	0	0.053	0.447	0.386	0.114
25	0	0	0	0.016	0.359	0.438	0.187
27	0	0	0	0	0.191	0.617	0.192
29	0	0	0	0	0.074	0.296	0.63
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1994-1995 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.985	0	0.015	0	0	0	0
7	0.954	0.042	0.004	0	0	0	0
9	0.397	0.459	0.134	0.01	0	0	0
11	0.007	0.108	0.736	0.13	0.019	0	0
13	0	0.074	0.333	0.405	0.186	0.002	0
15	0	0.01	0.222	0.541	0.227	0	0
17	0	0.028	0.169	0.507	0.296	0	0
19	0	0	0.056	0.722	0.222	0	0
21	0	0	0.015	0.168	0.48	0.267	0.07
23	0	0	0	0.105	0.4	0.414	0.081
25	0	0	0	0	0.867	0.133	0
27	0	0	0	0	0.75	0.25	0
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 8. Continued.

1996 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.624	0.352	0.024	0	0	0
11	0	0.028	0.298	0.519	0.127	0.028	0
13	0	0	0.059	0.52	0.322	0.099	0
15	0	0.008	0	0.282	0.428	0.274	0.008
17	0	0	0	0.319	0.298	0.34	0.043
19	0	0	0	0.083	0.667	0.25	0
21	0	0	0	0	0.461	0.539	0
23	0	0	0	0	0.4	0.4	0.2
25	0	0	0	0	0.2	0.733	0.067
27	0	0	0	0	0.117	0.824	0.059
29	0	0	0	0	0.069	0.276	0.655
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1996 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.992	0	0.008	0	0	0	0
7	0.952	0.048	0	0	0	0	0
9	0.08	0.715	0.179	0.015	0.007	0.004	0
11	0	0.155	0.317	0.466	0.06	0.002	0
13	0.003	0.017	0.058	0.647	0.223	0.052	0
15	0	0.005	0.104	0.43	0.327	0.129	0.005
17	0	0	0.134	0.385	0.327	0.154	0
19	0	0	0.059	0.393	0.226	0.191	0.131
21	0	0	0.021	0.167	0.291	0.292	0.229
23	0	0	0	0.308	0.231	0.461	0
25	0	0	0	0.027	0.514	0.297	0.162
27	0	0	0	0	0.409	0.318	0.273
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 8. Continued.

1997 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.617	0.383	0	0	0	0
11	0	0	0.429	0.393	0.172	0.006	0
13	0	0.002	0.019	0.112	0.789	0.073	0.005
15	0	0	0.002	0.028	0.756	0.181	0.033
17	0	0	0	0.025	0.624	0.294	0.057
19	0	0	0	0.062	0.488	0.38	0.07
21	0	0	0	0.092	0.354	0.339	0.215
23	0	0	0	0	0.245	0.533	0.222
25	0	0	0	0	0.3	0.45	0.25
27	0	0	0	0	0.177	0.581	0.242
29	0	0	0	0	0.069	0.276	0.655
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1997 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
7	0.865	0.135	0	0	0	0	0
9	0.224	0.689	0.087	0	0	0	0
11	0.005	0.279	0.477	0.167	0.072	0	0
13	0	0.004	0.065	0.147	0.715	0.065	0.004
15	0	0	0.022	0.066	0.701	0.153	0.058
17	0	0	0	0.059	0.647	0.206	0.088
19	0	0	0.059	0.393	0.226	0.191	0.131
21	0	0	0.021	0.167	0.291	0.292	0.229
23	0	0	0	0.308	0.231	0.461	0
25	0	0	0	0.027	0.514	0.297	0.162
27	0	0	0	0	0.409	0.318	0.273
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 8. Continued.

1998 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.491	0.463	0.046	0	0	0
11	0	0.008	0.401	0.468	0.117	0.006	0
13	0	0	0	0.163	0.232	0.593	0.012
15	0	0	0.015	0.06	0.12	0.692	0.113
17	0	0	0	0	0.051	0.769	0.18
19	0	0	0	0.087	0.174	0.391	0.348
21	0	0	0	0.028	0.278	0.389	0.305
23	0	0	0	0	0.362	0.425	0.213
25	0	0	0	0	0.184	0.5	0.316
27	0	0	0	0	0.133	0.467	0.4
29	0	0	0	0	0.069	0.276	0.655
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1998 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
7	0.956	0.044	0	0	0	0	0
9	0.083	0.713	0.195	0	0.009	0	0
11	0.009	0.196	0.366	0.357	0.063	0.009	0
13	0	0.034	0.059	0.509	0.203	0.178	0.017
15	0	0	0.04	0.387	0.178	0.282	0.113
17	0	0	0.093	0.381	0.134	0.268	0.124
19	0	0	0.083	0.292	0.146	0.25	0.229
21	0	0	0	0.128	0.257	0.333	0.282
23	0	0	0	0.238	0.238	0.524	0
25	0	0	0	0.048	0.238	0.428	0.286
27	0	0	0	0	0	0.4	0.6
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 8. Continued.

1999 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.491	0.463	0.046	0	0	0
11	0	0	0.241	0.673	0.086	0	0
13	0	0	0.022	0.188	0.428	0.174	0.188
15	0	0	0	0.028	0.227	0.227	0.518
17	0	0	0	0.034	0.153	0.169	0.644
19	0	0	0	0.062	0.25	0.125	0.563
21	0	0	0	0	0.222	0.333	0.445
23	0	0	0	0	0.12	0.24	0.64
25	0	0	0	0	0.045	0.182	0.773
27	0	0	0	0	0.177	0.581	0.242
29	0	0	0	0	0.111	0.333	0.556
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1999 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.978	0.022	0	0	0	0	0
7	0.974	0.026	0	0	0	0	0
9	0.534	0.432	0.023	0.011	0	0	0
11	0.029	0.106	0.388	0.335	0.13	0.012	0
13	0	0.007	0.168	0.348	0.416	0.054	0.007
15	0	0	0.069	0.178	0.673	0.03	0.05
17	0	0	0.08	0.13	0.58	0.1	0.11
19	0	0	0.048	0.107	0.619	0.095	0.131
21	0	0	0	0.104	0.635	0.073	0.188
23	0	0	0	0.133	0.6	0.05	0.217
25	0	0	0	0.022	0.489	0.133	0.356
27	0	0	0	0	0.318	0.136	0.546
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 9. Otolith based age-length keys for the south Atlantic early and late seasons, 1990-1991, 1992-1993, 1994-1995, 1996, 1997, 1998, and 1999.

1990-1991 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.929	0.071	0	0	0	0
11	0	0.256	0.641	0.103	0	0	0
13	0	0.15	0.179	0.313	0.249	0.104	0.005
15	0	0.038	0.103	0.261	0.375	0.207	0.016
17	0	0	0.016	0.186	0.411	0.333	0.054
19	0	0	0.059	0.177	0.353	0.382	0.029
21	0	0	0.034	0.213	0.371	0.36	0.022
23	0	0	0	0.136	0.352	0.466	0.046
25	0	0	0	0.178	0.393	0.393	0.036
27	0	0	0	0.036	0.214	0.714	0.036
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1990-1991 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
7	1	0	0	0	0	0	0
9	0.28	0.72	0	0	0	0	0
11	0	0.902	0.098	0	0	0	0
13	0	0.5	0.333	0.167	0	0	0
15	0	0.034	0.213	0.447	0.254	0.045	0.007
17	0	0	0.138	0.427	0.37	0.065	0
19	0	0	0.019	0.257	0.48	0.217	0.027
21	0	0	0.015	0.168	0.48	0.267	0.07
23	0	0	0	0.105	0.4	0.414	0.081
25	0	0	0	0.098	0.427	0.384	0.091
27	0	0	0	0.011	0.276	0.598	0.115
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 9. Continued.

1992-1993 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	0.998	0.002	0	0	0	0
9	0	0.848	0.152	0	0	0	0
11	0	0.101	0.812	0.087	0	0	0
13	0	0.15	0.179	0.313	0.249	0.104	0.005
15	0	0.038	0.103	0.261	0.375	0.207	0.016
17	0	0	0.016	0.186	0.411	0.333	0.054
19	0	0	0.059	0.177	0.353	0.382	0.029
21	0	0	0.034	0.213	0.371	0.36	0.022
23	0	0	0	0.136	0.352	0.466	0.046
25	0	0	0	0.178	0.393	0.393	0.036
27	0	0	0	0.036	0.214	0.714	0.036
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1992-1993 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.988	0.012	0	0	0	0	0
7	0.594	0.406	0	0	0	0	0
9	0.229	0.758	0.013	0	0	0	0
11	0.009	0.631	0.36	0	0	0	0
13	0	0.278	0.611	0.111	0	0	0
15	0	0.034	0.213	0.447	0.254	0.045	0.007
17	0	0	0.138	0.427	0.37	0.065	0
19	0	0	0.019	0.257	0.48	0.217	0.027
21	0	0	0.015	0.168	0.48	0.267	0.07
23	0	0	0	0.105	0.4	0.414	0.081
25	0	0	0	0.098	0.427	0.384	0.091
27	0	0	0	0.011	0.276	0.598	0.115
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 9. Continued.

1994-1995 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	0.997	0.003	0	0	0	0
9	0	0.909	0.082	0.009	0	0	0
11	0	0.555	0.267	0.178	0	0	0
13	0	0.663	0.184	0.133	0.02	0	0
15	0	0.255	0.383	0.256	0.106	0	0
17	0	0	0.016	0.186	0.411	0.333	0.054
19	0	0	0.059	0.177	0.353	0.382	0.029
21	0	0	0.034	0.213	0.371	0.36	0.022
23	0	0	0	0.136	0.352	0.466	0.046
25	0	0	0	0.178	0.393	0.393	0.036
27	0	0	0	0.036	0.214	0.714	0.036
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1994-1995 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.951	0.049	0	0	0	0	0
7	0.944	0.056	0	0	0	0	0
9	0.244	0.707	0.047	0.002	0	0	0
11	0.011	0.682	0.192	0.107	0.008	0	0
13	0	0.202	0.293	0.383	0.106	0.016	0
15	0	0.061	0.225	0.578	0.136	0	0
17	0	0	0.106	0.66	0.234	0	0
19	0	0	0	0.35	0.65	0	0
21	0	0	0.015	0.168	0.48	0.267	0.07
23	0	0	0	0.105	0.4	0.414	0.081
25	0	0	0	0.098	0.427	0.384	0.091
27	0	0	0	0.011	0.276	0.598	0.115
29	0	0	0	0	0.147	0.294	0.559
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 9. Continued.

1996 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.838	0.142	0.015	0.005	0	0
11	0	0.059	0.642	0.212	0.08	0.007	0
13	0	0.005	0.199	0.325	0.325	0.146	0
15	0	0.005	0.072	0.211	0.47	0.237	0.005
17	0	0	0	0.233	0.484	0.283	0
19	0	0	0.087	0.217	0.348	0.348	0
21	0	0	0.036	0.229	0.386	0.349	0
23	0	0	0	0.138	0.345	0.471	0.046
25	0	0	0	0.194	0.375	0.417	0.014
27	0	0	0	0.039	0.192	0.769	0
29	0	0	0	0	0.333	0.333	0.334
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1996 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.946	0.043	0.011	0	0	0	0
7	0.937	0.063	0	0	0	0	0
9	0.422	0.531	0.043	0.004	0	0	0
11	0.01	0.46	0.49	0.03	0.01	0	0
13	0.005	0.106	0.55	0.175	0.116	0.048	0
15	0	0.032	0.242	0.332	0.363	0.031	0
17	0	0.015	0.209	0.239	0.492	0.045	0
19	0	0	0.263	0.158	0.526	0.053	0
21	0	0	0.019	0.189	0.302	0.283	0.207
23	0	0	0	0.313	0.281	0.406	0
25	0	0	0	0.026	0.526	0.29	0.158
27	0	0	0	0	0.409	0.318	0.273
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 9. Continued.

1997 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	1	0	0	0	0	0
9	0	0.531	0.391	0.078	0	0	0
11	0	0.01	0.431	0.412	0.118	0.029	0
13	0	0	0.129	0.409	0.326	0.121	0.015
15	0	0	0.055	0.336	0.328	0.234	0.047
17	0	0	0.015	0.121	0.364	0.394	0.106
19	0	0	0	0	0.4	0.5	0.1
21	0	0	0.026	0.164	0.328	0.396	0.086
23	0	0	0	0.112	0.365	0.458	0.065
25	0	0	0	0.083	0.5	0.25	0.167
27	0	0	0	0.033	0.233	0.667	0.067
29	0	0	0	0	0.333	0.333	0.334
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1997 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	0.974	0.024	0.002	0	0	0	0
7	0.807	0.193	0	0	0	0	0
9	0.009	0.945	0.046	0	0	0	0
11	0	0.295	0.474	0.21	0.021	0	0
13	0	0.03	0.192	0.657	0.081	0.04	0
15	0	0	0.157	0.482	0.157	0.168	0.036
17	0	0	0.177	0.382	0.265	0.176	0
19	0	0	0	0.545	0.364	0.091	0
21	0	0	0.019	0.189	0.302	0.283	0.207
23	0	0	0	0.313	0.281	0.406	0
25	0	0	0	0.026	0.526	0.29	0.158
27	0	0	0	0	0.409	0.318	0.273
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 9. Continued.

1998 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	0.972	0.028	0	0	0	0
9	0	0.49	0.479	0.021	0.01	0	0
11	0	0.05	0.757	0.164	0.029	0	0
13	0	0	0.284	0.461	0.177	0.078	0
15	0	0	0.059	0.259	0.247	0.317	0.118
17	0	0	0	0.292	0.222	0.375	0.111
19	0	0	0	0.111	0.222	0.371	0.296
21	0	0	0	0	0.185	0.519	0.296
23	0	0	0	0	0.421	0.421	0.158
25	0	0	0	0	0.273	0.273	0.454
27	0	0	0	0.033	0.233	0.667	0.067
29	0	0	0	0	0.333	0.333	0.334
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

1998 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
7	0.908	0.092	0	0	0	0	0
9	0.081	0.779	0.14	0	0	0	0
11	0	0.158	0.675	0.114	0.053	0	0
13	0	0.048	0.314	0.343	0.257	0.038	0
15	0	0.028	0.208	0.403	0.278	0.069	0.014
17	0	0	0.147	0.441	0.265	0.118	0.029
19	0	0	0.1	0.3	0.3	0.1	0.2
21	0	0	0.019	0.189	0.302	0.283	0.207
23	0	0	0	0.313	0.281	0.406	0
25	0	0	0	0.026	0.526	0.29	0.158
27	0	0	0	0	0.409	0.318	0.273
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

Appendix 1 Table 9. Continued.

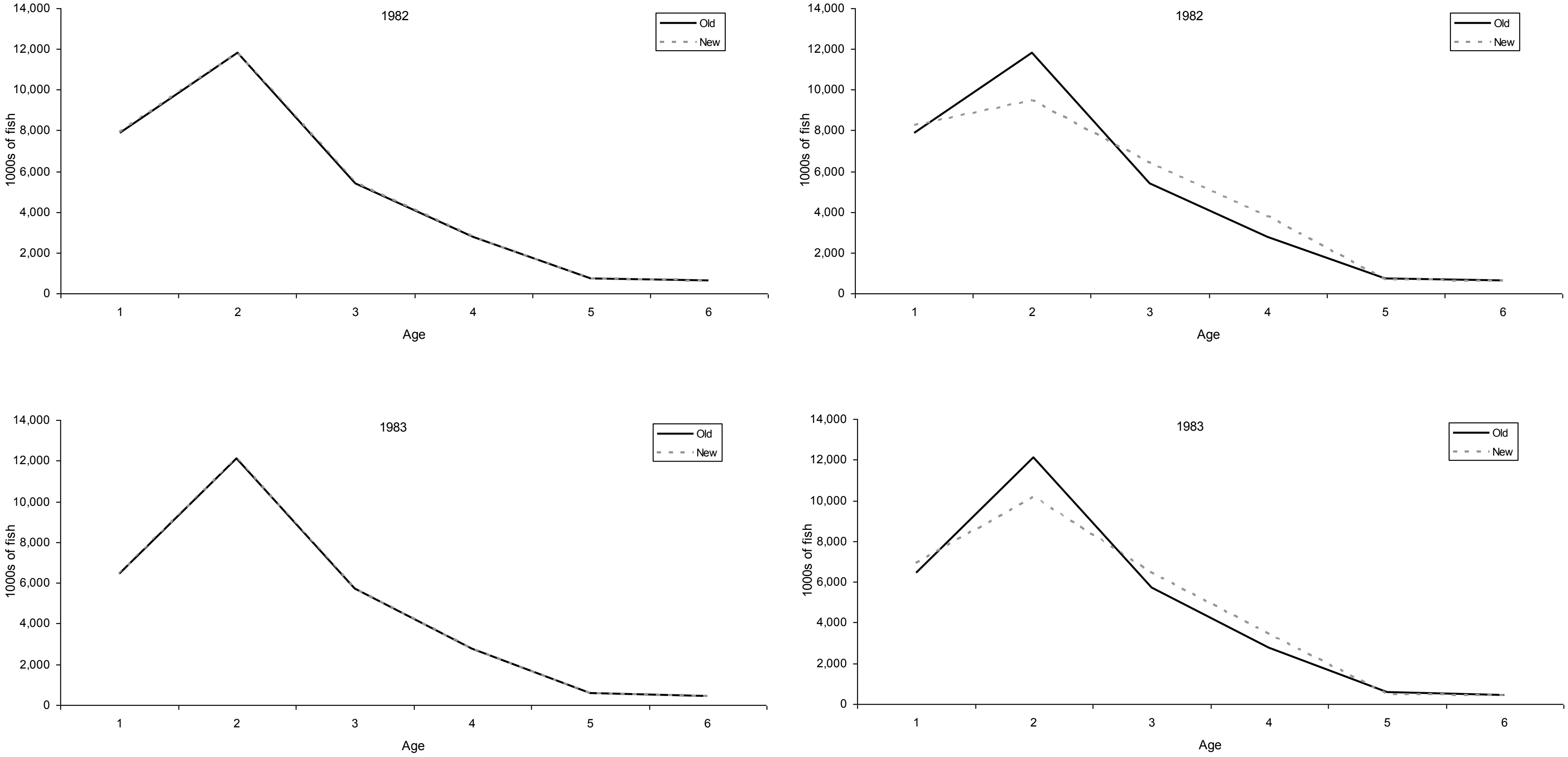
1999 Early Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	0	1	0	0	0	0	0
5	0	1	0	0	0	0	0
7	0	0.993	0.007	0	0	0	0
9	0	0.839	0.146	0.015	0	0	0
11	0	0.156	0.45	0.376	0.018	0	0
13	0	0	0.197	0.454	0.273	0.061	0.015
15	0	0	0.077	0.256	0.487	0.103	0.077
17	0	0	0	0.061	0.636	0.091	0.212
19	0	0	0	0.437	0.188	0.188	0.187
21	0	0	0	0.154	0.308	0.154	0.384
23	0	0	0	0	0.429	0.143	0.428
25	0	0	0	0	0.083	0.333	0.584
27	0	0	0	0	0	0.313	0.687
29	0	0	0	0	0	0.067	0.933
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

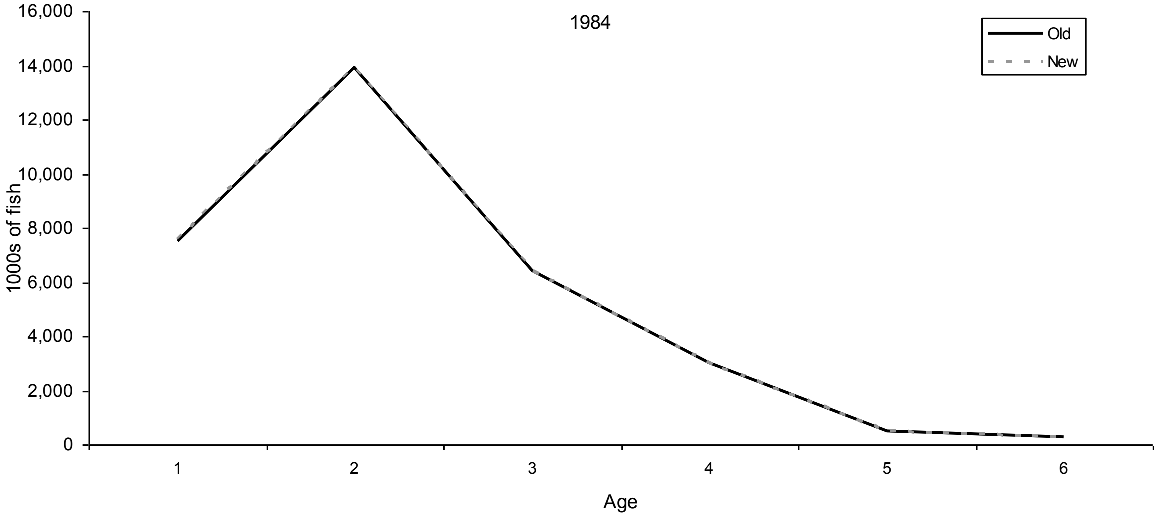
1999 Late Season ALK

TL (in)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+
3	1	0	0	0	0	0	0
5	1	0	0	0	0	0	0
7	0.911	0.089	0	0	0	0	0
9	0.297	0.626	0.077	0	0	0	0
11	0.006	0.5	0.279	0.215	0	0	0
13	0	0.193	0.168	0.504	0.118	0.017	0
15	0	0.131	0.202	0.441	0.143	0.059	0.024
17	0	0.027	0.162	0.433	0.27	0.108	0
19	0	0	0	0.2	0.7	0.1	0
21	0	0	0.019	0.189	0.302	0.283	0.207
23	0	0	0	0.313	0.281	0.406	0
25	0	0	0	0.026	0.526	0.29	0.158
27	0	0	0	0	0.409	0.318	0.273
29	0	0	0	0	0.132	0.263	0.605
31	0	0	0	0	0	0	1
33	0	0	0	0	0	0	1
35	0	0	0	0	0	0	1
37	0	0	0	0	0	0	1

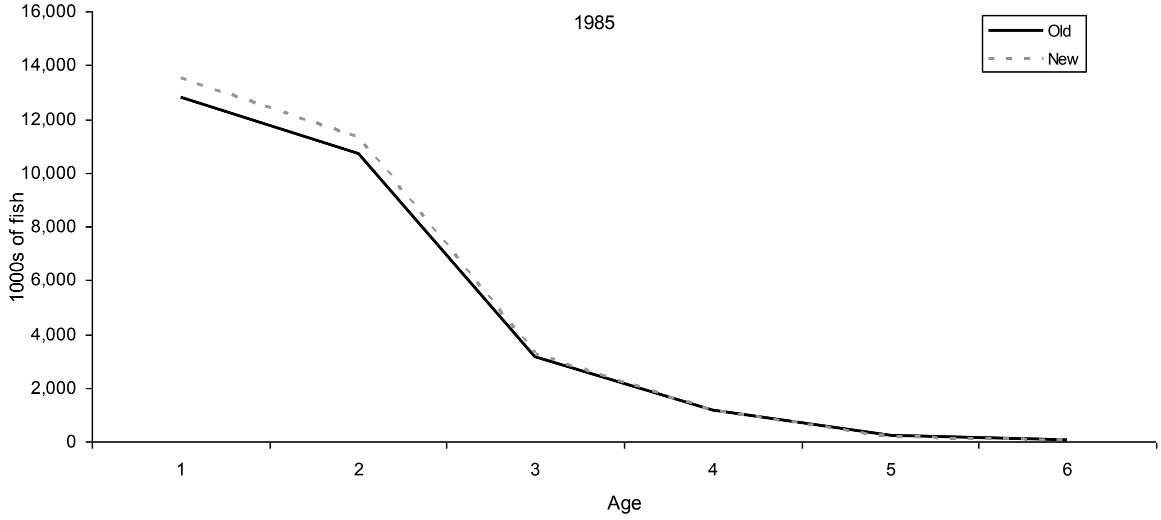
Appendix 1 Figure 1. Results of scale-otolith conversion using a single conversion matrix (left) vs. seasonal conversion matrices (right).

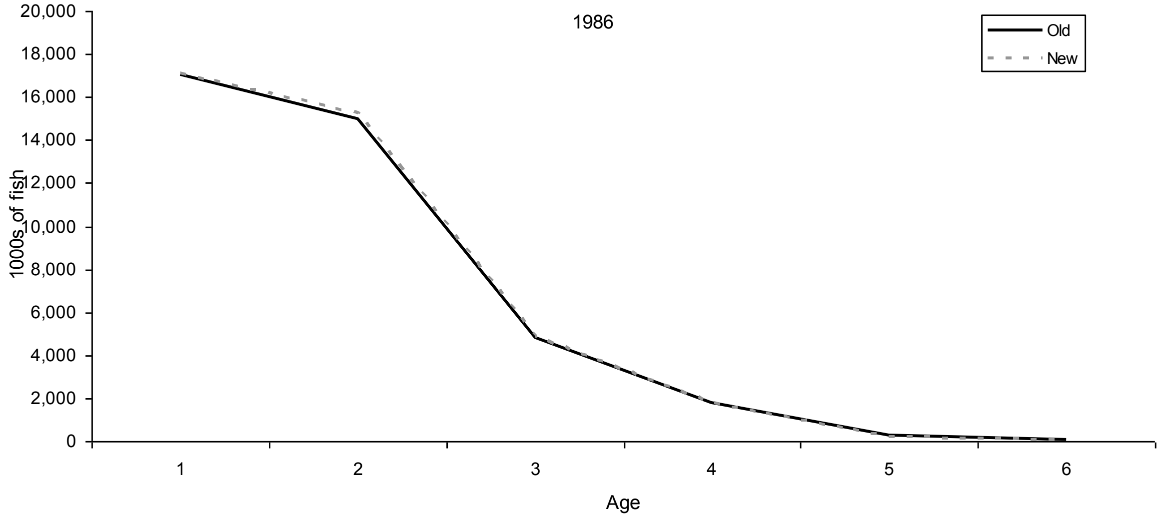


Appendix 1 Figure 2. Comparison of old CAA and re-created CAA for each year, 1982-1989.

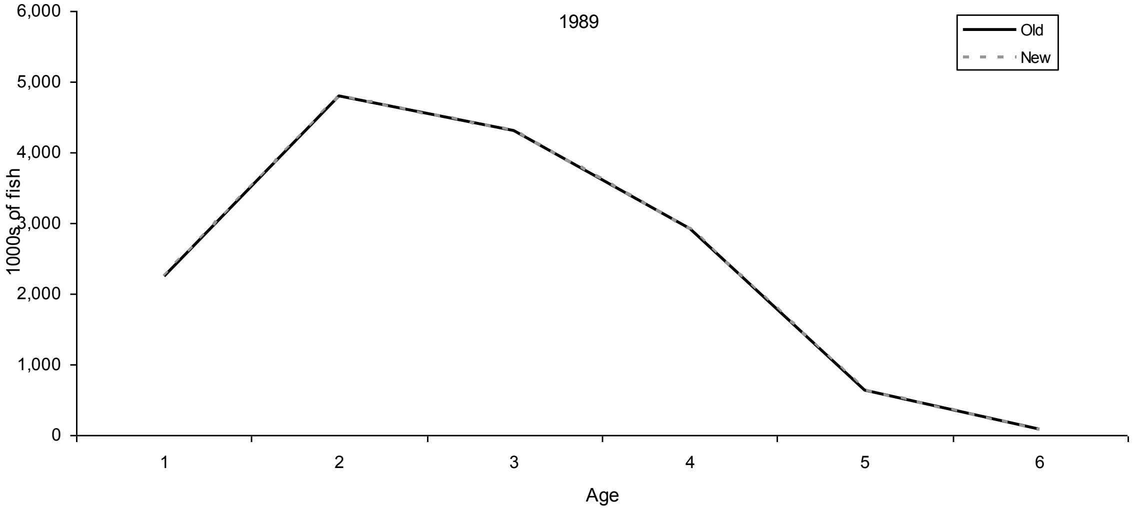


Appendix 1 Figure 2. Continued.





Appendix 1 Figure 2. Continued.



Appendix 3: Technical Documentation for ASAP

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

$$Freport_t = \frac{\sum_{a=a_{rep\min}}^{a_{rep\max}} \omega_{t,a} F_{t,a}}{\sum_{a=a_{rep\min}}^{a_{rep\max}} \omega_{t,a}} \qquad (14)$$

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

$$Lpred_{ifleet,t,a} = N_{ifleet,t,a} Fdir_{ifleet,t,a} (1-e^{-Z_{t,a}}) / Z_{t,a} \qquad (15)$$

$$Dpred_{ifleet,t,a} = N_{ifleet,t,a} Fbycatch_{ifleet,t,a} (1-e^{-Z_{t,a}}) / Z_{t,a} \qquad (16)$$

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 ($Wc_{t,a}$)

$$\hat{L}tot_{ifleet,t} = \sum_{a=fleetstart}^{fleetend} Lpred_{ifleet,t,a} Wc_{t,a} \qquad (17)$$

$$\hat{D}tot_{ifleet,t} = \sum_{a=fleetstart}^{fleetend} Dpred_{ifleet,t,a} Wc_{t,a} \qquad (18)$$

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

$$\hat{L}p_{ifleet,t,a} = \frac{Lpred_{ifleet,t,a}}{\sum_{a=fleetstart}^{fleetend} Lpred_{ifleet,t,a}} \qquad (19)$$

$$\hat{D}p_{ifleet,t,a} = \frac{Dpred_{ifleet,t,a}}{\sum_{a=fleetstart}^{fleetend} Dpred_{ifleet,t,a}} \qquad (20)$$

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 non-directed 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 $1000*(F-Fmax)^2$ for F>Fmax. The second penalty is for F different than M in the early phases, calculated as $100*10^{-phase}$ (ln(avg(F)-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_pred(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_tot_fleet_pred(ifleet,iyear);

Catch_tot_fleet_pred(ifleet,iyear)=CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))*WAAcatchfleet(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))*WAAdiscardfleet(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();
```

Appendix 4: Diagnostics for Bayesian Age-Structured Model

Table A4.1. Gelmen-Rubin statistics for the F and M estimates from the Bayesian age-structured model.

	F1	*F2*	*M*
1982	1.000869	0.999992	1.000527
1983	1.000305	0.999994	1.000496
1984	1.000358	1.000325	1.000699
1985	1.000116	0.999985	1.001088
1986	1.000338	0.999947	1.001317
1987	0.99997	0.999942	1.001239
1988	1.000598	0.999937	1.001813
1989	1.00004	1.000121	1.001379
1990	1.000679	0.999976	1.001559
1991	1.002113	0.999906	1.001477
1992	1.000029	1.000081	1.001105
1993	1.000135	1.000005	1.000854
1994	1.000334	1.000137	1.000515
1995	1.000042	1.000123	1.000621
1996	1.000198	0.999972	1.000687
1997	1.000334	1.000099	1.000594
1998	1.000324	1.000041	1.0009
1999	1.000412	1.000086	1.000725
2000	1.000144	1.000089	1.000276
2001	1.000479	1.00026	1.00073
2002	1.001818	1.000234	1.001559
2003	1.000052	1.000248	1.000673
2004	1.000386	0.999906	1.000373
2005	0.999922	1.000159	1.000001
2006	1.000194	0.999922	0.999913
2007	1.000045	1.000005	0.999934
2008	1.002591	1.00125	1.000147
2009	1.00022	1.000347	0.999948
2010	1.003452	1.002638	1.000004
2011	1.003597	1.001152	0.999948
2012	1.006685	1.004538	1.000018
2013	1.007154	1.00599	1.000115
2014	1.006329	1.006835	1.000065

Table A4.2. Gelmen-Rubin statistics for the age-1+ index q estimates from the Bayesian age-structured model.

Age	*NEFSC q*	*DE Bay q*	*NJ OT q*	*SEAMAP q*	*MRIP q*	*NCPSIGN q*	*NEAMAP q*	*ChesMMAP q*
1	1.00149	1.00071	1.00171	1.00042	1.00093	1.00294	1.01138	1.00430
2	1.00736	1.00070	1.00024	1.00062	1.00017	1.00657	1.00691	1.00546
3	1.00907	1.00150	1.00119	1.00031	1.00041	1.00350	1.00154	1.00561
4	1.00394	1.00068	1.00104	1.00203	1.00185	1.00102	1.02772	1.02724
5	1.00193	1.00465	1.00178	1.01162	1.00657	1.00409	1.00491	1.00724
6	1.00187	1.00004	1.00010	1.00769	1.00245	1.00140	1.00245	1.01342

Table A4.3. Gelmen-Rubin statistics for the YOY index q estimates from the Bayesian age-structured model.

YOY Index	*q*
1	1.00047
2	1.000322
3	1.000362
4	1.001232
5	1.00016
6	0.999989
7	0.999994

Table A4.4. Gelmen-Rubin statistics for the fleet selectivity estimates from the Bayesian age-structured model.

	Commercial	*Recreational Block 1*	*Recreational Block 2*
Age 1	0.999977	1.000123	1.000476
Age 2	1.001108	1.000319	1.000043
Age 3	1.000756	1.000276	1.000577
Age 4	1.003898	1.000116	1.000941
Age 5	1.001495	1.000268	1.003598
Age 6+	1.001585	0.999969	1.001775

Table A4.5 Gelmen-Rubin statistics for the abundance estimates from the Bayesian age-structured model.

	Age 1	*Age 2*	*Age 3*	*Age 4*	*Age 5*	*Age 6*
1982	1.000195	1.000427	1.000205	1.000894	1.00023	1.000058
1983	1.000247	0.999999	1.000156	0.999941	1.000829	1.000171
1984	1.000702	1.000039	0.999942	1.0001	1.000068	1.00009
1985	1.001394	1.000345	1.000013	1.000029	1.000808	1.000082
1986	1.001584	1.000793	1.000218	1.000007	1.000258	1.000726
1987	1.001882	1.000908	1.000724	1.000353	1.00083	1.000445
1988	1.004561	1.001525	1.000741	1.000674	1.000716	1.000818
1989	1.001066	1.003131	1.001212	1.000428	1.001793	1.00053
1990	1.000823	1.000584	1.003134	1.000892	1.002583	1.002481
1991	1.000741	1.00024	1.000158	1.001574	1.00111	1.001544
1992	1.000879	1.000079	0.99993	1.000029	1.000385	0.999925
1993	1.000679	1.000612	1.00029	0.999952	1.00006	1.000286
1994	1.003057	1.000507	1.000329	1.000199	1.000197	0.999995
1995	1.001439	1.002839	1.000749	1.001079	1.000418	1.000156
1996	1.002305	1.001199	1.00249	1.001174	1.001637	1.000783
1997	1.001139	1.001857	1.000928	1.002167	1.001196	1.001498
1998	0.999951	1.000869	1.001484	1.000443	1.002432	1.001958
1999	1.000058	0.999963	1.000477	1.001457	1.000501	1.002475
2000	1.000663	1.000065	1.000491	1.000012	1.000709	1.000727
2001	1.004419	1.000767	1.000173	1.000498	1.000212	1.001285
2002	1.005118	1.004083	1.00038	0.999925	1.000216	1.001915
2003	1.000715	1.00465	1.003423	1.000406	0.999933	1.000735
2004	1.000333	1.000092	1.001875	1.00046	1.000975	1.002479
2005	1.002272	1.000398	0.999998	1.000296	1.000594	1.004174
2006	1.003333	1.002404	1.000445	1.000256	1.000134	1.00354
2007	1.002804	1.003917	1.002238	1.000933	1.001125	1.001393
2008	1.001567	1.002601	1.002064	1.001538	1.00416	1.004792
2009	1.000505	1.001409	1.005705	1.00447	1.007702	1.006219
2010	1.001413	1.000735	1.001535	1.007514	1.007017	1.000083
2011	1.001307	1.002567	1.005636	1.007324	1.010275	1.35E-05
2012	1.004265	1.001829	1.004971	1.009945	1.01018	1.0003
2013	1.006232	1.005494	1.005096	1.010946	1.014438	1.010828
2014	1.001945	1.007301	1.008183	1.008626	1.012695	1.016377

Figure A4.1. Trace plots for Bayesian age-structured model.

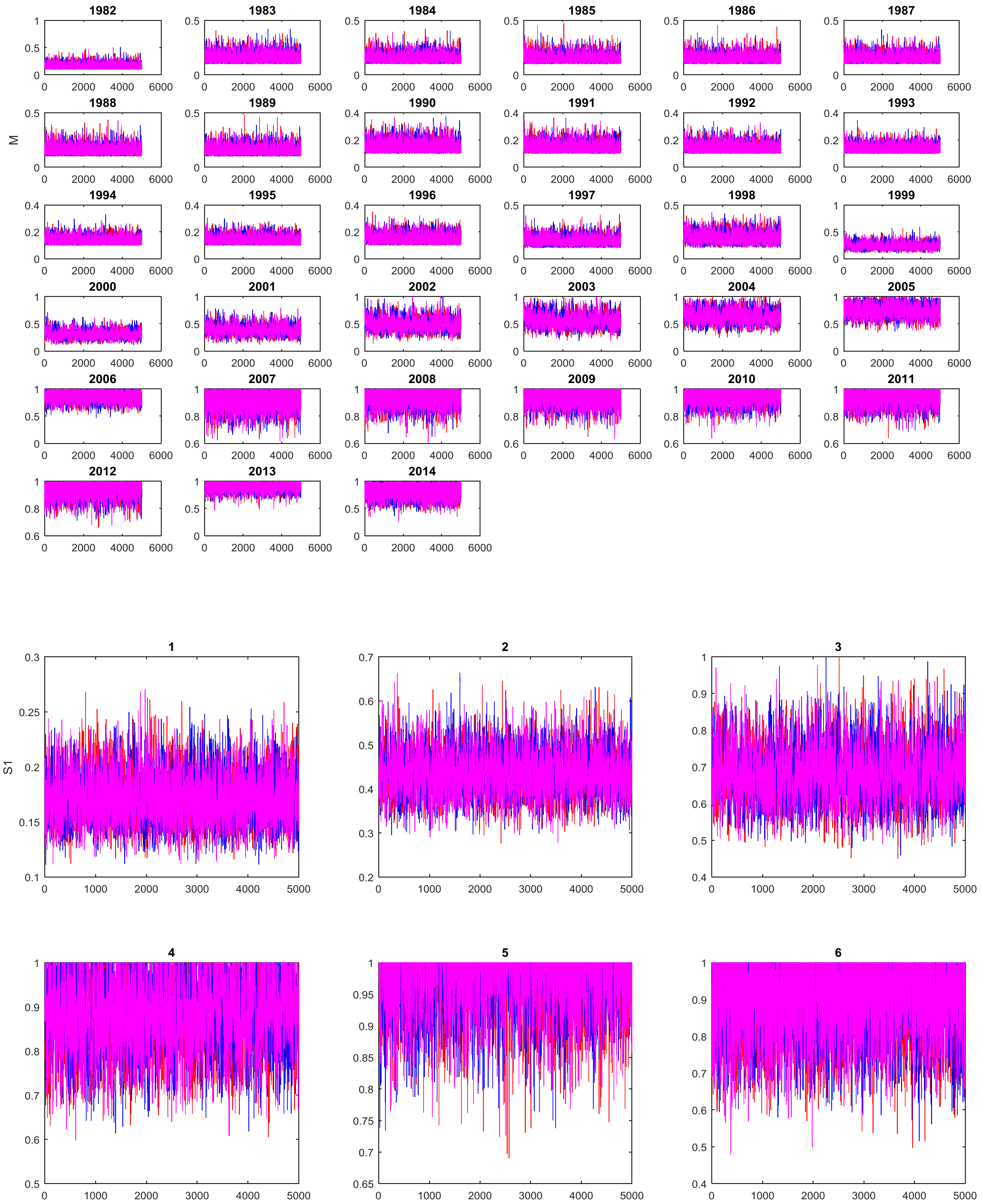


Figure A4.1. (cont.)

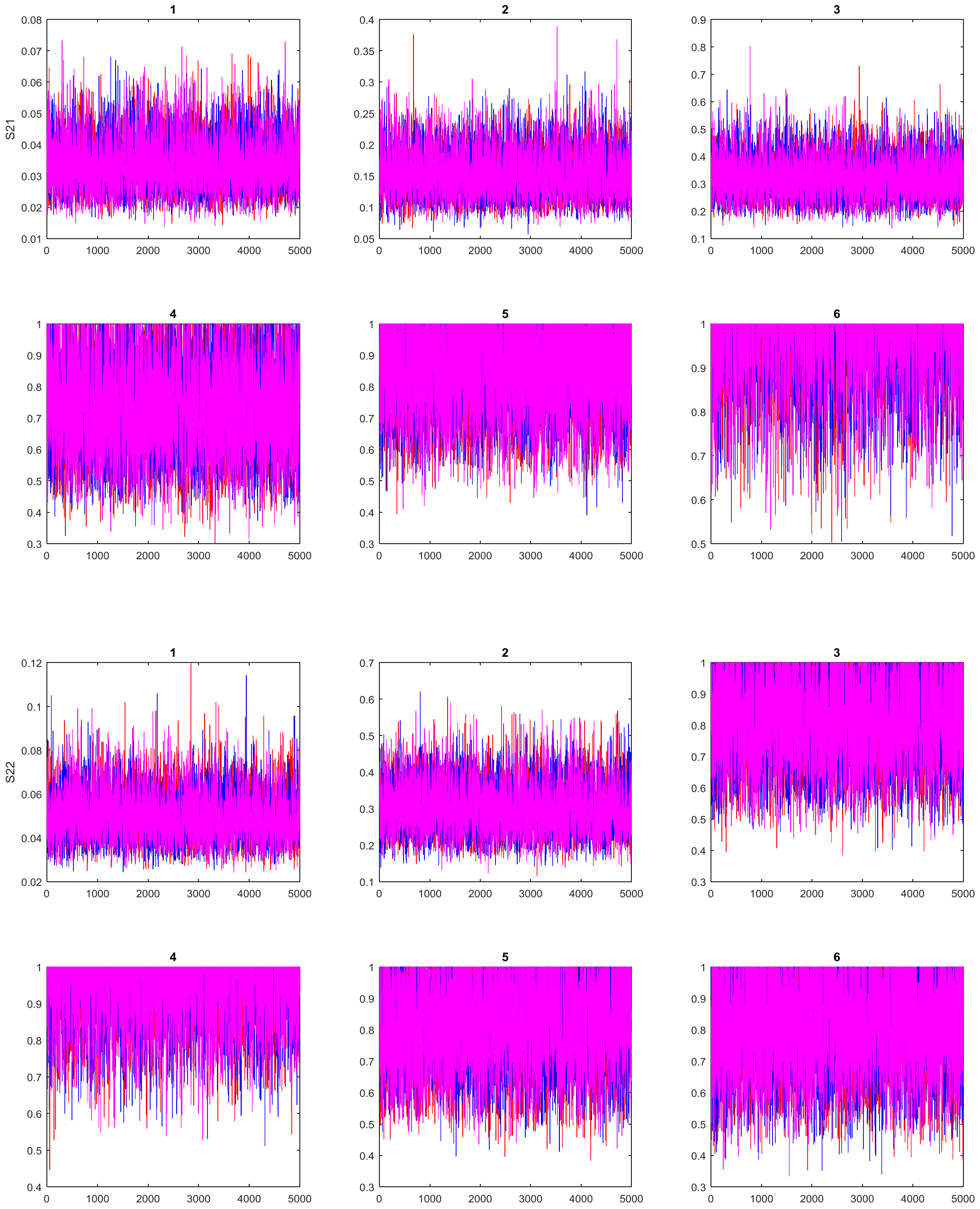


Figure A4.1. (cont.)

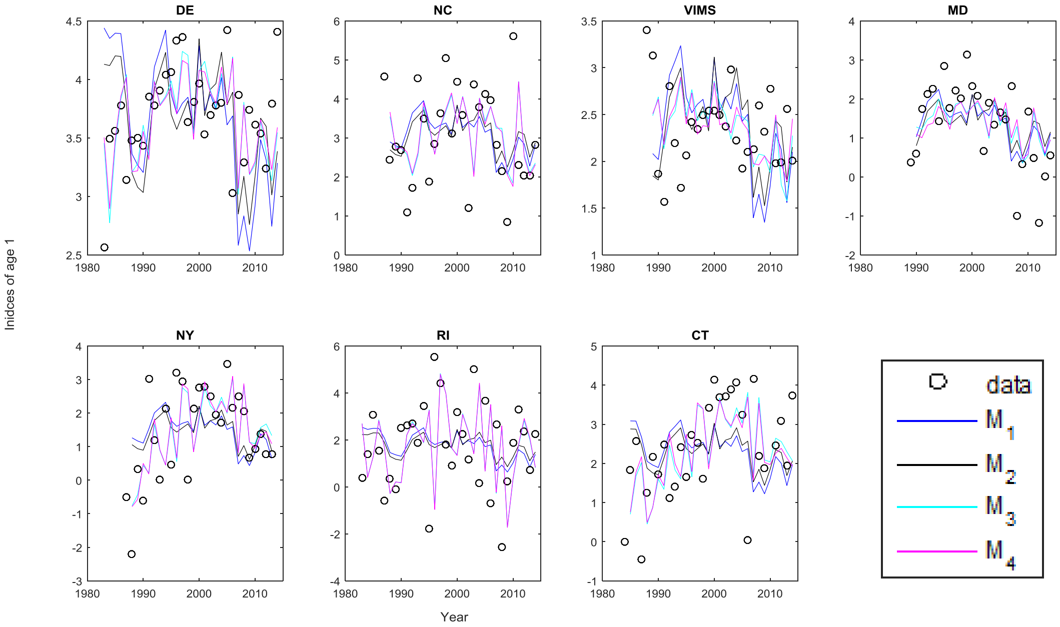


Figure A4.2. Fit to age-0 indices from Bayesian age-structured model.

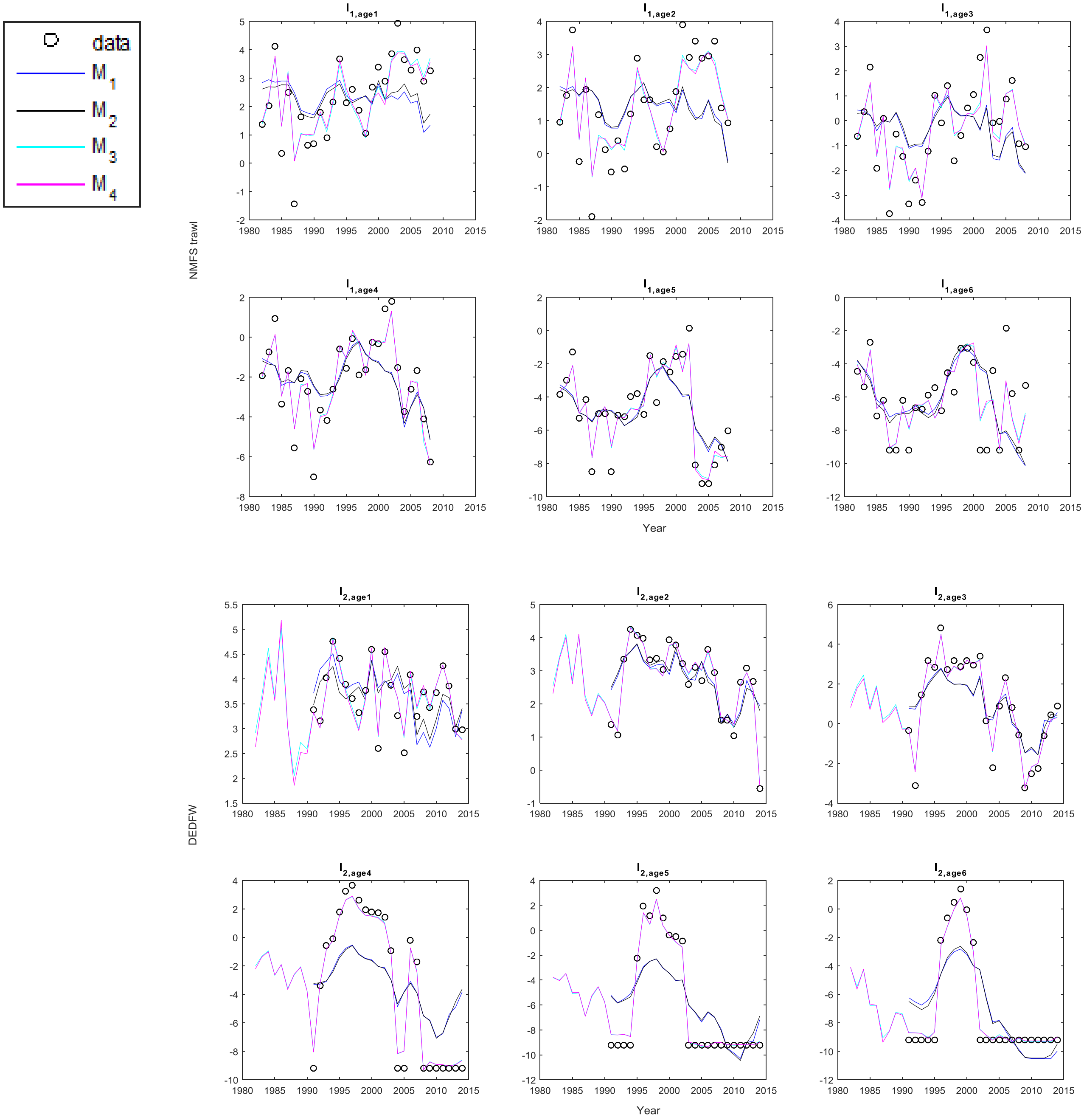


Figure A4.3. Fit to age 1+ indices from the Bayesian age-structured model.

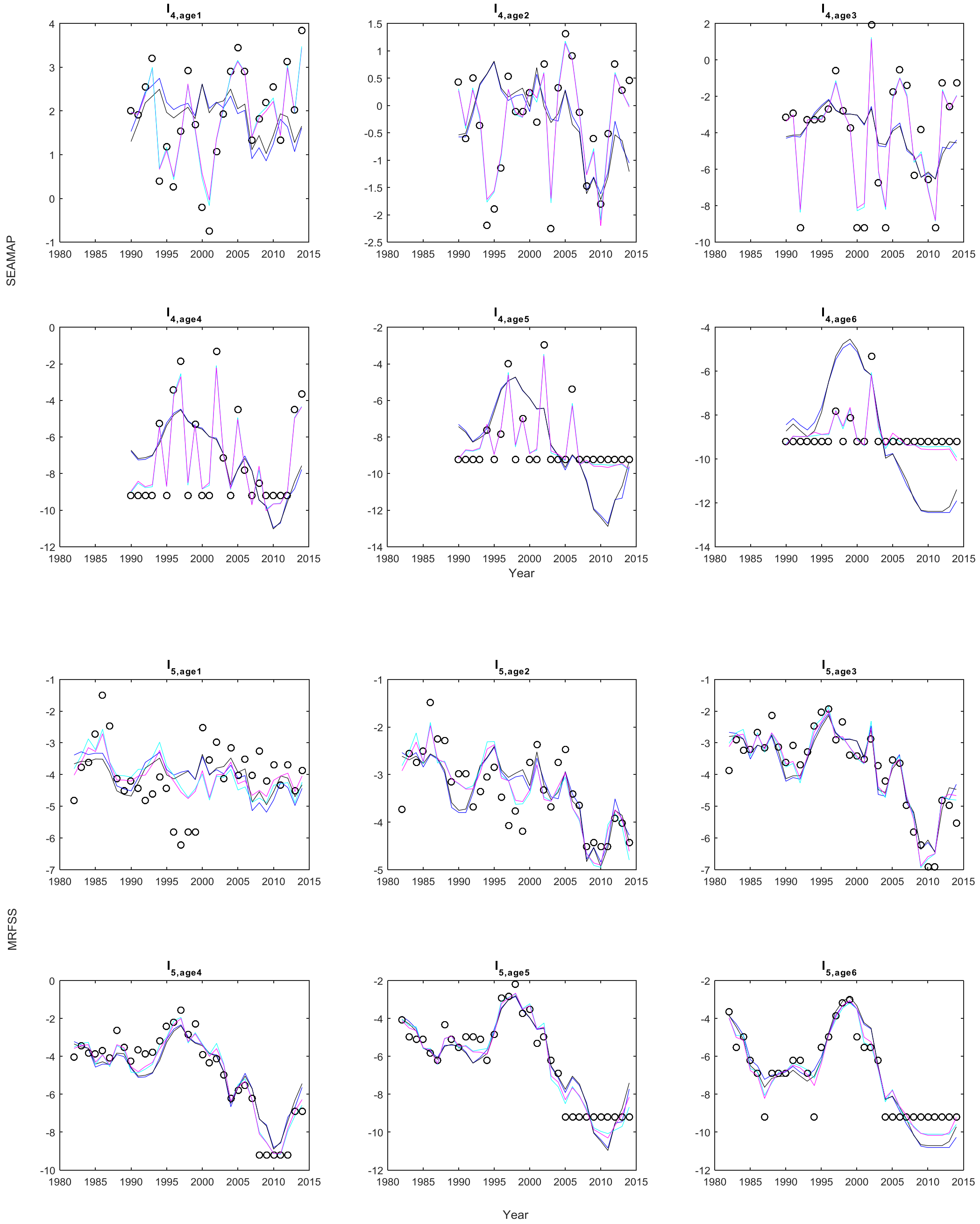


Figure A4.3 (cont.)

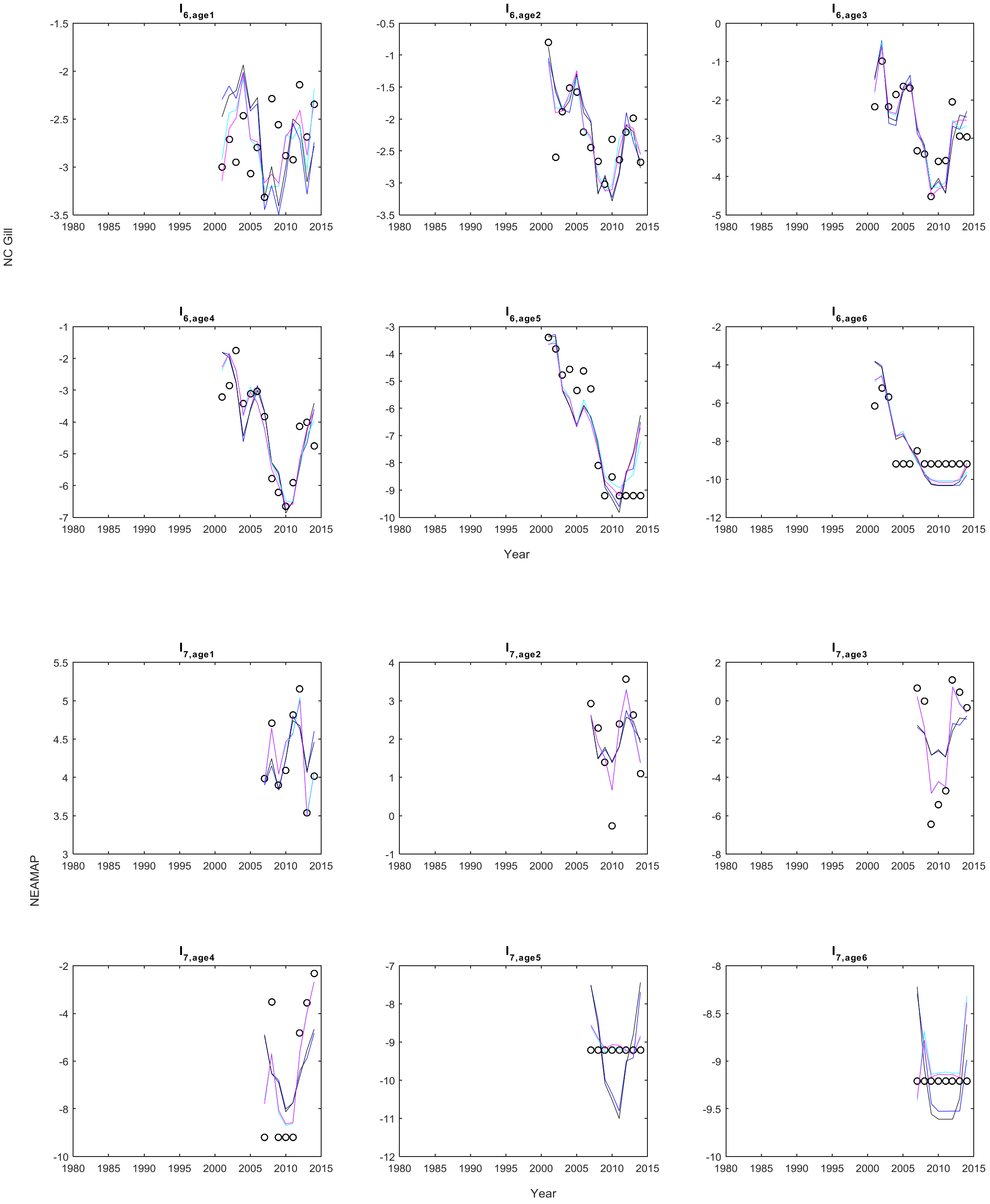


Figure A4.3 (cont.)

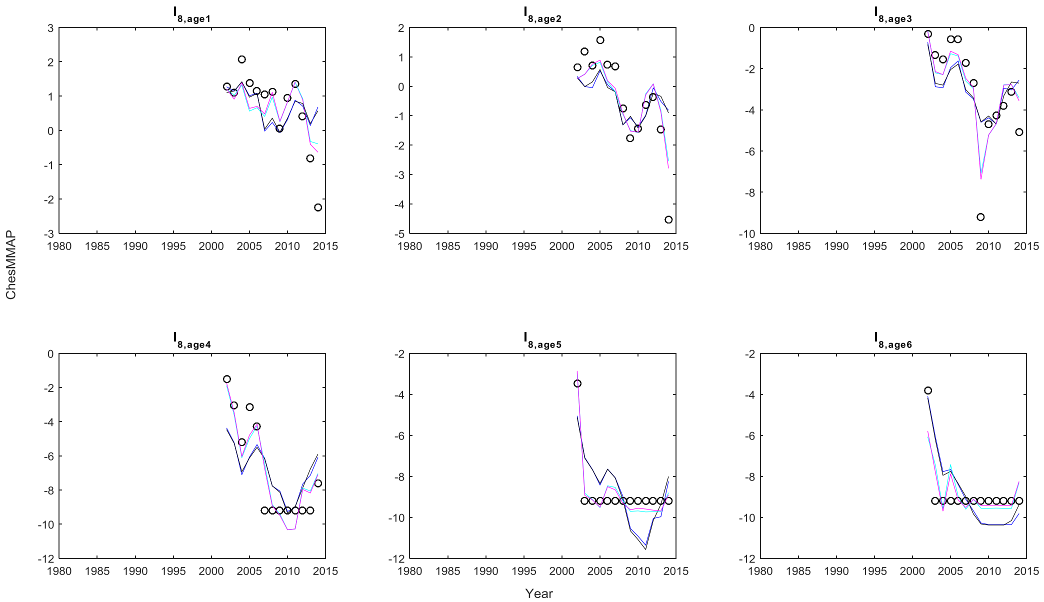


Figure A4.3 (cont.)

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Integrating spatial synchrony/asynchrony of population distribution into stock assessment models: a spatial hierarchical Bayesian statistical catch-at-age approach

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In many marine fisheries assessments, population abundance indices from surveys collected by different states and agencies do not always agree with each other. This phenomenon is often due to the spatial synchrony/asynchrony. Those indices that are asynchronous may result in discrepancies in the assessment of temporal trends. In addition, commonly employed stock assessment models, such as the statistical catch-at-age (SCA) models, do not account for spatial synchrony/asynchrony associated with spatial autocorrelation, dispersal, and environmental noise. This limits the value of statistical inference on key parameters associated with population dynamics and management reference points. To address this problem, a set of geospatial analyses of relative abundance indices is proposed to model the indices from different surveys using spatial hierarchical Bayesian models. This approach allows better integration of different surveys with spatial synchrony and asynchrony. We used Atlantic weakfish (*Cynoscion regalis*) as an example for which there are state-wide surveys and expansive coastal surveys. We further compared the performance of the proposed spatially structured hierarchical Bayesian SCA models with a commonly used Bayesian SCA model that assumes relative abundance indices are spatially independent. Three spatial models were used and compared with mimic different potential spatial patterns. The random effect spatially structured hierarchical Bayesian model was found to be better than the commonly used SCA model and the other two spatial models. A simulation study was conducted to evaluate the uncertainty resulting from model selection and the robustness of the recommended model. The spatially structured hierarchical Bayesian model was shown to be able to integrate different survey indices with/without spatial synchrony. Q3 It is suggested as a useful tool when there are surveys with different spatial characteristics that need to be combined in a fisheries stock assessment.

Keywords: Atlantic weakfish, spatial hierarchical Bayesian model, spatial synchrony/asynchrony, statistical catch-at-age.

Introduction

Many marine fisheries assessments require the modeller to combine survey population abundance indices from different states and agencies. A potentially important problem is that the indices do not always agree with each other and the use of different indices may lead to different decisions (NEFSC, 2008; NDPSWG, 2009). The discrepancy among different survey indices can be attributed to the spatial and temporal aggregation of fish distributions, non-random search behaviour of fishers, fishing power changes, gear selectivity, gear saturation, and other factors (Pope and Garrod, 1975; MacCall, 1976; Rose and Leggett, 1991). Spatial heterogeneity refers to the uneven distribution of observations of interest, such as a trait, event, fish abundance, density, or relationship across a region (Anselin, 2010). Even for well-designed surveys, the indices of abundance can suggest different trends at different locations because of temporal changes in the densities of the population in different locations, shown as spatial asynchronous patterns (Buonaccorsi *et al.*, 2001; Liebhold *et al.*, 2004). Spatial heterogeneity among locations may not change over time but if it does change it would show as spatial asynchrony. Reasons for spatial synchrony/asynchrony include extrinsic environmental stochasticity (Moran effect; Moran, 1953), non-linear density-dependency, and dispersal and species interactions (Heino *et al.*, 1997; Hudson and Cattadori, 1999; Buonaccorsi *et al.*, 2001; Cheal *et al.*, 2007; Vasseur, 2007; Haynes *et al.*, 2009; Massie *et al.*, 2015).

Atlantic weakfish (*Cynoscion regalis*) is used as an example stock in our study. It is very representative of the species along the western coast of the Atlantic Ocean because the surveys available for Atlantic weakfish are also available for most other species distributed in this area. Each state along the North Atlantic has its own localized surveys, and there are also two expansive coastal surveys for this species (Supplementary Table S1; Figure 1). The discrepancy among different survey indices is considerable (NEFSC, 2009). A preliminary analysis based on cross correlation among relative abundance indices that are not standardized, but were reported by each state and agency (NEFSC, 2009), indicated that most of the Q4

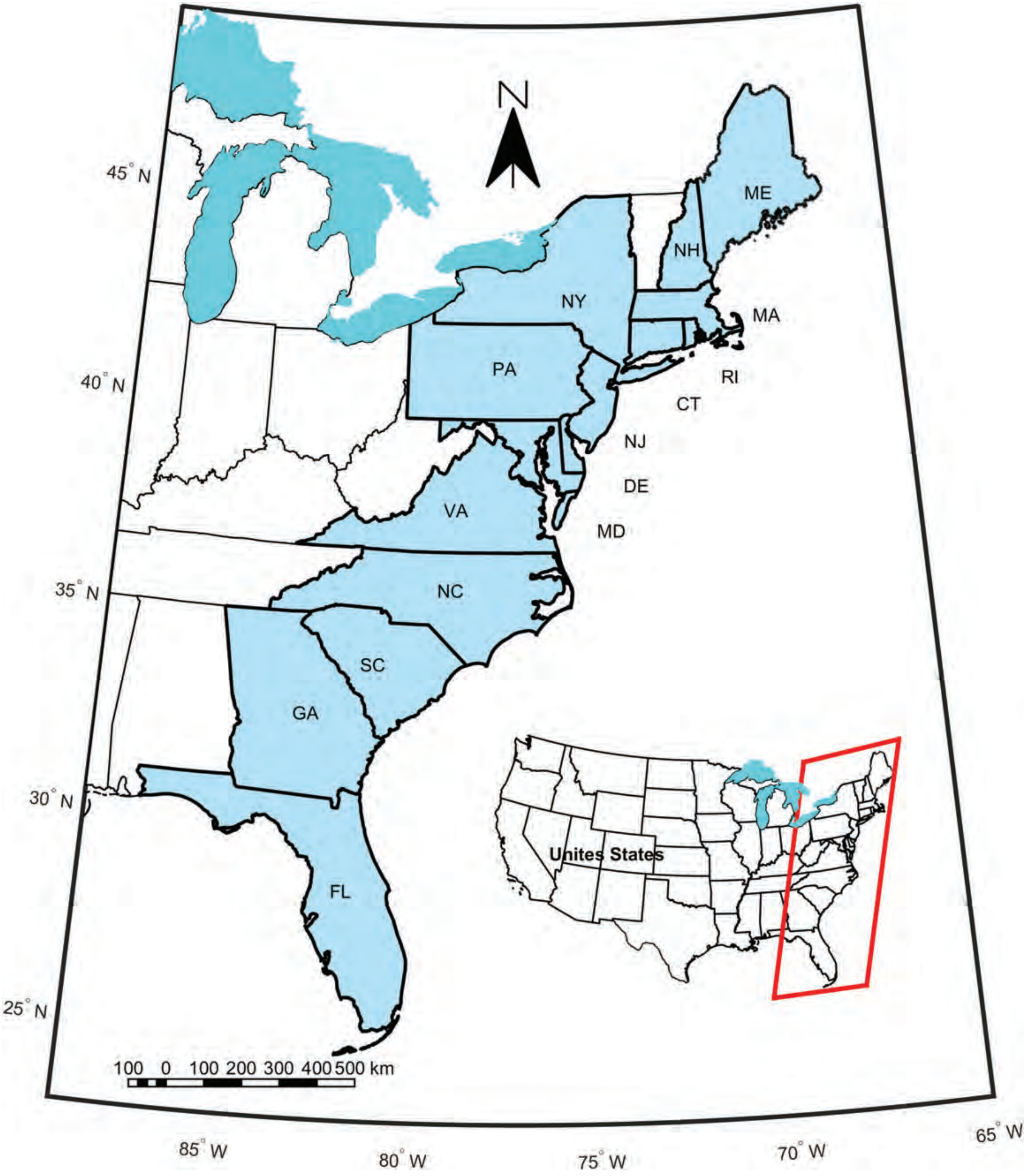

Figure 1. Map of western Atlantic with states that handle Atlantic weakfish surveys indicated. Q8, Q9 Q10

correlations were low and many show no relationship or even have negative relationships (Supplementary Table S2a).

Standardization of the catch rate from the surveys or from the fisheries has been found to potentially eliminate the influence of a variety of factors such as the spatial and temporal aggregation of fish distribution, nonrandom search behaviour of fishers, gear saturation, water temperature, and other possible environmental factors that may influence the distribution and density of the fish (O'Brien and Mayo, 1988; Lo *et al.*, 1992; Maunder and Punt, 2004; Yu *et al.*, 2011). However, standardization itself cannot guarantee that the true overall population size is well represented by each of the localized surveys because of strong changes in fish distributions, habitat types, non-linear response to local population density and dispersal, etc. These similarities and discrepancies among population indices over time are described as spatial synchrony and asynchrony (Vasseur, 2007; Pandit and Kolasa, 2012). Our preliminary analysis based on the standardized relative abundance indices suggested that standardization of weakfish indices did not remove survey index discrepancy (Winter *et al.*, 2009; Supplementary Table S2b).

Spatial autocorrelation, the dependence among observations over geographic space, has been used to model observed spatial heterogeneity or spatial synchrony/asynchrony (Heino *et al.*, 1997; Schabenberger and Gotway, 2005; Vasseur, 2007). Spatial autocorrelation often exists among ecological variables and may cause significant errors in data analyses and population dynamics modelling if neglected (Legendre, 1993; Heino *et al.*, 1997; Lawson *et al.*, 2003; Vasseur, 2007). Commonly employed stock assessment models, such as statistical catch-at-age (SCA) models, do not account for spatial synchrony/asynchrony among these fishery-independent/dependent surveys when relative abundance indices are used to calibrate population size. This limits the statistical inference for resulting key parameters of population dynamics and management reference points.

Our objectives are to account for spatial synchrony/asynchrony caused by spatial autocorrelation, dispersal, and environmental noises and to evaluate the appropriateness of using spatial hierarchical models with SCA models. We modelled relative abundance indices from different surveys, as spatially autocorrelated, through spatial hierarchical Bayesian models. These models of relative abundance indices were then integrated with a statistical catch-at-age model to allow better integration of different surveys. To test the efficiency of the proposed spatial hierarchical Bayesian SCA models in modelling spatial synchrony/asynchrony among survey indices and the uncertainty from model selection, a simulation study was conducted based on the example weakfish stock (Schnute, 1987; Jiao *et al.*, 2009a, b; Toni and Stumpf, 2010). Bayesian estimators were used to estimate parameters, and performance of the models was compared by their goodness-of-fit and the retrospective error evaluation of the models (Calder *et al.*, 2004; Jiao *et al.*, 2009a, b, 2010, 2012). The hierarchical spatially structured Bayesian models developed here, and the framework for modelling population dynamics using age-structured models with different relative abundance indices are applicable to many other species when there are many surveys with different spatial structures and when their relative abundance indices suggest different population trends.

Data and methods

The Atlantic weakfish population was selected as an example and its most recent stock assessment information was used. Data used were from the Atlantic States Marine Fisheries Commission Weakfish Technical Committee (NEFSC, 2009). Detailed information on the catch-at-age matrix and relative abundance surveys are available from the same report. Following the recommendation from the weakfish technical committee, catch data from 1982 to 2007 were used (Supplementary Figure S1). There were 15 relative abundance indices available for this fishery (Supplementary Figure S2). Among them, six provided age-structured relative abundance indices (Supplementary Figure S2a), and eight of them provided age 1 relative abundance that were used in the assessment to calibrate recruitment dynamics (Supplementary Figure S2b and Table S1). Detailed description on the relative abundance indices is given in Supplementary data, Table S1.

A series of stochastic age-structured models was constructed to represent the dynamics of the weakfish stock with different assumptions about spatial heterogeneity over time. The models consist of three submodels including (i) an age-structured process model that describes the dynamics of the population, (ii) an observation model that describes the relationship between estimated catch and observed catch in the fishery, and (iii) a series of observation models that describe the relationship between stock abundance and abundance indices observed in the fishery or fisheries-independent surveys. For the observation models of relative abundance indices, model 1 (M1) is commonly used, which uses a proportional relationship between abundance indices and stock abundance with a lognormal error distribution; model 2 (M2) is based on a random effect model; model 3 (M3) uses a conditional autoregressive model with correlations among neighbouring surveys accounted for; and model 4 (M4) uses a spatially autocorrelated model with correlation modelled as a function of distance between surveys. The four models are described below.

A common statistical catch-at-age model

A commonly used statistical catch-at-age separable model (SCA M1) based on the data structure of weakfish can be written as follows:

$$
\begin{aligned}
&\mathrm{Ln}(N_{a+1,y+1}) = \mathrm{Ln}(N_{a,y}\mathrm{e}^{-F_{a,y}-M})\\
&\mathrm{Ln}(C_{a,y}) = \mathrm{Ln}\left[\frac{F_{a,y}}{F_{a,y}+M}N_{a,y}(1-\mathrm{e}^{-F_{a,y}-M})\right] + \varepsilon_C\\
&F_{a,y} = F_y S_a\\
&\mathrm{Ln}(I_{j,a,y}) = \mathrm{Ln}(q_{j,a}N_{a,y}) + \varepsilon_{j,1}\\
&N_{a=1,y} = R_y \quad \text{and} \quad \ln(R_y) = \ln(\bar{R}) + \varepsilon_R\\
&\ln(N_{a>1,y=1982}) = \ln(\bar{N}_{a>1,y=1982}) + \varepsilon_N\\
&M = \text{known constant},
\end{aligned}
\tag{1}
$$

where a is age, y is year, N is population abundance and $\mathrm{Ln}(N_{a,y})$ means log-transformed $N_{a,y}$, C is observed catch and $\mathrm{Ln}(C_{a,y})$ is assumed to follow a normal distribution with error ε_C, F is fishing mortality and M is natural mortality, R is recruitment and we assumed that $\mathrm{Ln}(R_y)$ followed a normal distribution with mean $\mathrm{Ln}(\bar{R})$ and error ε_R, S is the selectivity, which is treated as age-specific (S_a) and does not change over time, j is the jth type of fishery dependent or independent cpue data. $\mathrm{Ln}(N_{a>1,y=1982})$ is the population size of age a in year 1982, and we assume that it follows a normal distribution with mean $\mathrm{Ln}(\bar{N}_{a>1,y=1982})$ and error ε_N. The errors associated with $\mathrm{Ln}(C_{a,y})$, $\mathrm{Ln}(R_y)$, and $\mathrm{Ln}(N_{a>1,y=1982})$ are assumed to have normal distributions with mean 0 and variance σ_c^2, σ_R^2, and σ_N^2 separately. The error associated with abundance index j, $\varepsilon_{j,1}$, is assumed to have mean 0 and variance σ_j^2. Here because the indices were dealt with in different ways and their variance assumptions are different in different models, we used numbers to represent their variances from models 1 to 4. In this model, M is assumed to be known and fixed at 0.25 and is constant among age groups and years (ASMFC, 2006; NEFSC, 2009). We used a constant vector to model selectivity instead of a logistic curve because the catch-at-age matrix is composed of catches from different fisheries, including trawl, gillnet, poundnet, and recreational fisheries, so the selectivity can be less regular. The initial numbers of population-at-age are estimated, and a uniform prior is used, i.e. $\bar{N}_{a>1,y=1982} \sim U(1, 100) \times C_{a,y=1982}$ with the Bayesian estimation process. The exploitation rate in 1982 was assessed to be >1 from a previous stock assessment, so using the observed $C_{a,y=1982}$ as the lower bound of $\bar{N}_{a>1,y=1982}$, and using $100 \times C_{a,y=1982}$ as the upper bound of $\bar{N}_{a>1,y=1982}$ is biologically reasonable and not restrictive as a prior. The variable R_y has been found to be highly variable and spawning stock size often only explains a limited amount of recruitment variation. So, we assume recruitment in year y,R_y, as a parameter to estimate rather than model using a regulated curve such as the Cushing and Beverton–Holt model (Ricker, 1975; Quinn and Deriso, 1999). Recruitment is assumed to have a two-level hierarchically structured prior (Table 1). If we use $C_{\text{cohort},y}$ to represent the total catch over time from the cohort of year y, then for a vague informative prior, we used $\ln(\bar{R}_y) \sim U\{\min[\ln(C_{1,y=1982:2007})], \max[\ln(100C_{\text{cohort},y})]\}$, for the minimum observed catch of age 1 fish, 1982–2007, we used $\min[\ln(C_{1,y=1982:2007})]$, and for the maximum observed $100 \times C_{\text{cohort},y}$ from 1982 to 2007, we used $\max[\ln(100C_{\text{cohort},y})]$. Given the levels of fishing mortality and natural mortality for Atlantic weakfish, using minimum observed catch as the lower bound of the mean of recruitment, and $\max[\ln(100C_{\text{cohort},y})]$ as the upper bound of the mean of recruitment is biologically reasonable and not restrictive. Recruitment was assumed to follow a lognormal distribution (see Equation 1) and stock recruitment dynamics were analysed outside of the statistical catch-at-age models. This will also avoid the influence of recruitment modelling choices on the hierarchical models of the relative abundance indices. The prior for F_y is assumed to be uniform between 0.001 and 2, that of S_a is uniform between 0 and 1, that of $q_{j,a=1}$ to be between $\min(I_{j,a=1}/\text{upper bound of } \bar{R})$ and $\max(I_{j,a=1}/\text{lower bound of } \bar{R})$, and that of $q_{j,a>1}$ to be between $\min(I_{j,a>1,y}/100C_{a>1,y})$ and $\max(I_{j,a>1,y}/C_{a>1,y})$.

Hierarchical spatial Bayesian statistical catch-at-age models that fit the relative abundance indices as spatially autocorrelated (M2–M4)

The second model is similar to model M1 except that the populations being sampled by the various surveys, $N_{j,a,y}$, are assumed to be different for different survey locations, i.e. are treated as random effects, and were modelled hierarchically (SCA_RE, **M2**),

$$\begin{aligned} &\text{Ln}(I_{j,a,y}) = \text{Ln}(q_{j,a}N_{j,a,y}) + \varepsilon_{j,a,y,2} \\ &N_{j,a,y} \sim \text{Log-}N(\text{Ln}(N_{a,y}), \sigma^2_{y,a,N,2}), \end{aligned} \tag{2}$$

where Log-N means lognormal distribution; variance $\sigma^2_{y,a,N}$ is the variance of log-transformed $N_{a,y}$; $\varepsilon_{j,a,y,2} \sim \text{Normal}(0, \sigma^2_{j,2})$; and the subscript 2 is used to separate the term from the one in M1. We used $\text{Normal}(0, \sigma^2)$ to represent the normal distribution and to avoid confusion with population size N. By modelling $N_{j,a,y}$ using a distribution (with median $N_{a,y}$), the possible heterogeneity of the population density in each survey location, $\varepsilon_{j,a,y,N} \sim MVN(0, \sigma^2_{y,a,N,2})$, is modelled. The subscript 2 in $\sigma^2_{y,a,N,2}$ again is used to separate the term from the one in M1 and MVN means multivariate normal distribution. This model is also called a nested random effect model and it has been applied successfully in many studies (Banerjee *et al.*, 2003; Lawson *et al.*, 2003; Waller and Gotway, 2004); however, the correlation among surveys is rather "all or nothing" as responses on either side of a survey boundary are assumed to be uncorrelated. The random effect model allows the temporal variation of the spatial heterogeneity shown as spatial synchrony/asynchrony to be modelled. The inverse Wishart distributions are used as the conjugate prior for the covariance matrix of the multivariate normal distributions and were used here. Priors used in this model are listed in Table 1.

There have been studies that suggest fish distributions and abundance are spatially autocorrelated because of autocorrelated environmental factors or dispersal (Simard *et al.*, 1992; Cressie, 1993; Petitgas, 1993, 2001; Addis *et al.*, 2009). Modelling spatial autocorrelation has been used to adjust for autocorrelation when standardizing catch rate (Nishida and Chen, 2004). Our third model under consideration is a conditional autoregressive (CAR) model. The CAR provides a method to model the spatial autocorrelation of different surveys by introducing a set of spatially correlated multivariate normal random effects in the model to account for spatial correlation (SCA_CAR **M3**), i.e.

$$\begin{aligned} &\text{Ln}(I_{j,a,y}) = \text{Ln}(q_{j,a}N_{a,y}) + \varepsilon_{j,a,y,3} + \varepsilon_{j,a,y,4} \\ &\varepsilon_{j,a,y,4} \sim N(\bar{\varepsilon}_{j,4}, \sigma^2_{j,4}/n_j) \\ &\bar{\varepsilon}_{j,4} = \sum_{k\in\text{neighbor}(j)} w_{j,k}\varepsilon_k/n_j. \end{aligned} \tag{3}$$

In this model, the $\varepsilon_{j,a,y,3}$ are treated as independent and identically distributed among different surveys, $\varepsilon_{j,a,y,3} \sim \text{Normal}(0, \sigma^2_{j,3})$, and $\varepsilon_{j,a,y,4}$ are viewed as correlated, with the size of the correlation depending on the locations of the surveys and their neighbours. The variable ε_k is the error term of the kth neighbour of survey j. Subscripts 3 and 4 in $\varepsilon_{j,a,y,3}$ and $\varepsilon_{j,a,y,4}$ are used to represent the differences in index uncertainty in this model and to separate them from similar terms in M1 and M2. The variable n_j is the number of neighbours for survey j. Here, the sum of $\varepsilon_{j,a,y,4}$ is always zero; only correlations among neighbouring surveys were counted and neighbours were weighted equally. Priors used in this model are listed in Table 1.

The fourth model that we considered is close to M3, but we modelled the covariance of the correlated surveys according to the distances among them, i.e. both neighbouring surveys and non-neighbouring surveys were considered to be correlated (SCA_Distance **M4**),

$$\begin{aligned} &\text{Ln}(I_{j,a,y}) = \text{Ln}(q_{j,a}N_{a,y}) + \varepsilon_{j,a,y,5} + \varepsilon_{j,a,y,6} \\ &\varepsilon_{j,a,y,6} \sim \text{MVN}(0, V), \end{aligned} \tag{4}$$

where $\varepsilon_{j,a,y,5} \sim \text{Normal}(0, \sigma^2_{j,5})$ and V is the variance–covariance matrix of the normally distributed but spatially correlated $\varepsilon_{j,a,y,6}$. Subscripts 5 and 6 in $\varepsilon_{j,a,y,5}$ and $\varepsilon_{j,a,y,6}$ are used to represent the differences of uncertainty of indices in this model to separate them from similar terms in M1 to M3. If g and h represent two survey locations, then the respective errors should be ε_g and ε_h. The covariance $\text{Cov}(\varepsilon_g, \varepsilon_h)$ between ε_g and ε_h is a function of the distance d_{gh} between g and h, and of the range H (i.e. the maximum distance over which any significant autocorrelation

Table 1. Priors used in the models (catches are in 10^6 fish in the models).

Models	Scenarios	Parameters and their priors
M1 A commonly used SCA model; the abundance indices are independent and proportional to population abundance	S1	$\sigma_c^2 \sim U(0.001, 10)$; $\sigma_j^2 \sim U(0.001, 1)$; $\sigma_R^2 \sim U(0.001, 10)$; $\bar{N}_{a>1,y=1982} \sim U(1, 100) \times C_{a,y=1982}$; $\sigma_N^2 \sim U(0.001, 10)$; $F_y \sim U(0.001, 2)$; $S_a \sim U(0, 1)$; $\mathrm{Ln}(\bar{R}_y) \sim U(\min(\mathrm{Ln}(C_{1,y=1982:2007})), \max(\mathrm{Ln}(100C_{cohort,y})))$; $\mathrm{Ln}(q_{j,a=1}) \sim U(\mathrm{Ln}[\min(I_{j,a=1}/\text{upper bound of } \bar{R})], \mathrm{Ln}[\max(I_{j,a=1}/\text{lower bound of } \bar{R})])$; $\mathrm{Ln}(q_{j,a>1}) \sim U(\mathrm{Ln}[\min(I_{j,a>1,y}/100C_{a>1,y})], Ln[\max(I_{j,a>1,y}/C_{a>1,y})])$
	S2	Same as M1S1 but $\sigma_c^2 \sim U(0.001, 1)$; $\sigma_j^2 \sim U(0.001, 0.5)$; $\sigma_N^2 \sim U(0.001, 5)$; $\mathrm{Ln}(R_y) \sim U(0, 200)$; $\mathrm{Ln}(q_{j,a}) \sim U(-8, 4)$
M2 A spatial SCA model with abundance indices modelled as random effect	S1	Same as in M1S1, but also $\sigma_{j,2}^2 \sim U(0.001, 1)$; $\varepsilon_{j,a,y,N}$ for aged indices $j \sim MVN(u_2, V_2)$, $\mu_2 = [0, 0, 0, 0, 0, 0]$; $1/V_2 = dwish(R, k)$; $k = 9$; $R = [\ ]_{6\times6}$ with main diagonal values = 0.1; and other values = 0.005; $\varepsilon_{j,a,y,N}$ for non-aged indices $j \sim MVN(u_3, V_3)$, $\mu_3 = [0, 0, 0, 0, 0, 0, 0, 0]$; $1/V_3 = d\text{wish}(R', k')$; $k' = 11$; $R' = [\ ]_{8\times8}$ with main diagonal values = 0.1; and other values = 0.005
	S2	Same as in M2S1, but $\sigma_{j,2}^2 \sim U(0.001, 0.5)$ $R = [\ ]_{6\times6}$ with main diagonal values = 0.05; and other values = 0.001; $R' = [\ ]_{8\times8}$ with main diagonal values = 0.05; and other values = 0.001
M3 A spatial SCA model with correlations among neighbouring surveys modelled as conditional autoregressive process	S1	Same as in M1, but also $\sigma_{j,3}^2 \sim U(0.001, 1)$; $\sigma_{j,4}^2 \sim U(0.001, 1)$; $\varepsilon_k \sim U(0.001, 10)$;
	S2	Same as in M1, but also $\sigma_{j,3}^2 \sim U(0.001, 0.5)$; $\sigma_{j,4}^2 \sim U(0.001, 0.5)$; $\varepsilon_k \sim U(0.001, 5)$;
M4 A spatial SCA model with abundance indices assumed to be spatially autocorrelated and correlation modelled as a function of distance between surveys	S1	Same as in M1, but also $\sigma_{j,5}^2 \sim U(0.001, 1)$; $\sigma_{j,6}^2 \sim U(0.001, 1)$; $1/H \sim U(0.2, 2)$;
	S2	Same as in M1, but also $\sigma_{j,5}^2 \sim U(0.001, 0.5)$; $\sigma_{j,6}^2 \sim U(0.001, 0.5)$; $1/H \sim U(0.2, 2)$
	S3	Same as in M1, but also $\sigma_{j,5}^2 \sim U(0.001, 1)$; $\sigma_{j,6}^2 \sim U(0.001, 1)$; $1/H \sim U(0.25, 2)$;

See text for the justification of the priors.

occurs), as specified by the longitude and latitude of the samples, i.e. $\mathrm{Cov}(\varepsilon_g, \varepsilon_h) = {\sigma_6}^2 f\,(d_{gh}, H)$. The variable ${\sigma_6}^2$ is the base covariance when the distance is 0 and the covariance model used is an exponential model, $f\,(d_{gh}, H) = \exp(-d_{gh}/H)$. Here, instead of using the longitude and latitude to determine the distance between surveys, we used the number of states between g and h as the distance. For example, MD and DE are neighbours in Figure 1, and the distance between surveys in these 2 states is defined to be 1; MD and NY are not neighbours since DE and NJ are between them, hence the distance between surveys in MD and NY is 3. Priors used in this model are listed in Table 1.

Both M3 and M4 assume that spatial autocorrelation may cause spatial heterogeneity, but their modelled heterogeneity does not vary over time. M2 allows the modelled spatial heterogeneity to vary over time, i.e. allows for spatial asynchrony (Buonaccorsi *et al.*, 2001; Banerjee *et al.*, 2003).

Bayesian approach and priors

We used a Bayesian approach to fit the spatial hierarchical models to data collected from different sources (Banerjee *et al.*, 2003; Calder *et al.*, 2003). Because models M2 to M4 model I hierarchically, the posterior density distribution for parameters needs to consider hyperpriors related to I. A Bayesian model (M1) defines the posterior density for parameters $(p(\theta = \bar{R}, \bar{N}_{a>1,1982}, F_y, S_a, q_{j,a}, \sigma_j, \sigma_c, \sigma_R, \sigma_N | C, I))$ using Bayes' theorem as

$$p(\theta|C, I) \propto L(I|N, q, \sigma_j)L(C|N, F, S, \sigma_c)\pi(\theta), \tag{5}$$

where $L(I|N, q, \sigma_j)$ equals $\prod_y \prod_a \prod_j g(I_{j,a,y}|N_{a,y}, q_{j,a}, \sigma_j)$, which is the likelihood function of I (all the available relative abundance indices). The variable $L(C|N, F, S, \sigma_c)$ equals $\prod_y \prod_a h(C_{a,y}|N_{a,y}, F_y, S_a, \sigma_c)$, which is the likelihood function of C; and $\pi(\theta)$, the prior of the parameters, equals $\prod_y \prod_a \prod_j \pi(\bar{R})\pi(\bar{N}_{a>1,1982})\pi(F_y)\pi(S_a)\pi(q_{j,a})$ $\pi(\sigma_j)\pi(\sigma_c)\pi(\sigma_R)\pi(\sigma_N)$.

In models M2 to M4, assigning priors for hyperparameters is also needed to calculate the joint posterior. For example when M2 is used, the joint posterior is

$$p(\theta = \bar{R}, \bar{N}_{a>1,1982}, F_y, S_a, q_{j,a}, \sigma_{j,2}, \sigma_c, \sigma_R, \sigma_N, \sigma_{N,2}|C, I) \propto L(I|N, q, \sigma_j)L(C|N, F, S, \sigma_c)\pi(\theta), \tag{6}$$

where $L(I|N, q, \sigma_j)$ is the likelihood function of I (all the available relative abundance indices) and is calculated as $L(I|N, q, \sigma_j) = \prod_y \prod_a \prod_j g(I_{j,a,y}|N_{j,a,y}, q_{j,a}, \sigma_{j,2})$. The variable $L(C|N, F, S, \sigma_c)$ is the likelihood function of C and is calculated as $L(C|N, F, S, \sigma_c) = \prod_y \prod_a h(C_{a,y}|N_{a,y}, F_y, S_a, \sigma_c)$, and $\pi(\theta)$ is $\prod_y \prod_a \prod_j \pi(\bar{R})\pi(\bar{N}_{a>1,1982})\pi(F_y)\pi(S_a)\pi(q_{j,a})\pi(\sigma_{j,2})\pi(\sigma_c)\pi(\sigma_R)$ $\pi(\sigma_N)\pi(\sigma_{N,2})$.

In the equations above, $g(I_{j,a,y}|\ldots)$ is the probability density function for $I_{j,a,y}$ with parameters $N_{a,y}$, $q_{j,a}$, σ_j or $N_{a,y,j}$, $q_{j,a}$, $\sigma_{j,2}$; $h(C_{a,y}|\ldots)$ is the probability density function of $C_{a,y}$ given parameters $N_{a,y}$, F_y, S_a, σ_c; $f(N_{a,y,j}|N_{a,y}, \sigma_{a,y,N,2})$ is the probability density function of $N_{a,y,j}$ with parameters $N_{a,y}$, $\sigma_{a,y,N,2}$. The same algorithm can be used to develop the joint posterior for M3–M4.

Priors need to be specified for all the parameters in a Bayesian analysis. Usually two types of prior distributions are used in a Bayesian analysis: non-informative and informative (Berger, 1985; Gelman *et al.*, 2004; Gelman, 2006). The choice of a non-informative or informative prior for a parameter was determined by the reliability and details of prior knowledge. Priors that are vaguely informative were explained in the model section above. All the priors for the variances for recruitment, catch, and abundance indices are non-informative, and wide uniform distributions were used (Table 1).

A critical issue in using Markov Chain Monte Carlo (MCMC) methods is the convergence diagnostic for the posterior distribution (Cowles and Carlin, 1996). Here, we monitored the trace for key parameters, and also used the Gelman and Rubin statistic (Gelman and Rubin, 1992; Spiegelhalter *et al.*, 2004). Three chains were used. The three chains converged after 20,000 iterations with a thinning interval of 5 based on the convergence criteria. The initial iterations were discarded. The posterior distributions of the key parameters were obtained through a kernel smoothing approach (Bowman and Azzalini, 1997).

Simulation study

After the study based on the example fishery was complete, a simulation study was conducted to test the performance of the proposed models and evaluate the model selection uncertainty when inference was based on a model selection criterion (here Deviance Information Criterion, DIC, see below). Model selection uncertainty increases when the "true" model cannot be found based on the model selection criteria, a phenomenon that has been found to be very common in dealing with ecological and fisheries data (Draper, 1995; Burnham and Anderson, 2002; Jiao *et al.*, 2008). Such a simulation study helps us to understand how robust the recommended model is, how high the model selection uncertainty is, given the example fishery, and allows evaluation of the performance of the recommended model even when the true model cannot be found based on the model selection criteria (Draper, 1995; Jiao *et al.*, 2008). The following simulation algorithm was used to: (i) estimate recruitment, fishing mortality, and all the other parameters from the models (M1—M4) using data of the example fishery and treat these estimates as the "true" population dynamics parameters; (ii) generate population abundance indices data and catch-at-age data from a Monte Carlo simulation based on estimated "true" recruitment, fishing mortality, selectivity and uncertainty levels equivalent to the uncertainties estimated from the original "true" population; (iii) analyse the generated dataset using the four models; and (iv) evaluate the uncertainty arising from model selection and the performance of the "best" model selected by the model goodness of fit (DIC here) based on the relative estimation error (*REE*) and absolute relative estimation error (*AREE*, see Table 2 for the simulation design). Steps (2) through (4) above were repeated 100 times to

Table 2. Relative estimation bias (*REE*) of fishing mortality (*F*), selectivity (*S*) and recruitment (*R*), and the probability of being the best model of 100 simulation runs.

Scenarios	True model used in the simulation	Model used for estimation	Probability of being the best model	Mean of *REE* of *F*	Mean of *REE* of *S*	Mean of *REE* of ln(*R*)	Mean of *AREE* of *F*	Mean of *AREE* of *S*	Mean of *AREE* of ln(*R*)
S1	M1	M1	0	−3.79	2.70	1.21	18.26	11.46	5.37
		M2	100	−3.97	2.28	1.33	17.65	11.67	5.27
		M3	0	−2.76	5.06	1.93	18.54	11.46	5.98
		M4	0	−4.26	2.27	1.20	17.48	11.57	5.15
		Best Model		−3.97	2.28	1.33	17.65	11.67	5.27
S2	M2	M1	0	−5.10	0.72	3.47	15.36	8.60	11.02
		M2	100	−3.89	0.54	2.64	14.23	8.66	7.11
		M3	0	−5.21	2.71	4.12	16.93	8.72	13.68
		M4	0	−4.34	−0.51	3.13	14.25	8.93	9.27
		Best Model		−3.89	0.54	2.64	14.23	8.66	7.11
S3	M3	M1	0	−3.52	4.50	−0.18	25.35	13.64	6.16
		M2	100	−2.53	0.87	−0.35	19.85	11.56	5.46
		M3	0	−4.46	5.62	−0.06	17.99	11.32	4.97
		M4	0	−3.46	2.51	−0.55	22.62	13.66	5.80
		Best Model		−2.53	0.87	−0.35	19.85	11.56	5.46
S4	M4	M1	40	−4.15	3.36	1.57	17.54	10.22	5.55
		M2	60	−3.80	2.84	1.70	17.26	10.16	5.43
		M3	0	−3.14	5.58	2.02	17.26	10.85	6.74
		M4	0	−4.22	2.59	1.49	16.90	10.44	5.19
		Best Model		−3.89	3.02	1.63	17.36	10.20	5.42

yield 100 sets of estimated population growth rates and population densities from each model.

The *REE* and *AREE* statistics which have been widely used in fisheries, are used here to compare the bias accuracy and precision in the corresponding parameter estimates when different models are used (Schnute, 1987; Jiao *et al.*, 2009a, b). The variable $REE(\hat{F}_i)$ for estimated fishing mortality rate in year y, $\hat{F}_y$, was calculated as follows:

$$
\begin{aligned}
REE(\hat{F}_i) &= \frac{1}{n}\sum_{y}\frac{\hat{F}_{y,i} - F'_y}{F'_y} \times 100 \\
AREE(\hat{F}_i) &= \frac{1}{n}\sum_{y}\frac{|\hat{F}_{y,i} - F'_y|}{F'_y} \times 100,
\end{aligned}
\tag{7}
$$

where i indicates the ith simulation run and n is the number of the years. The variable F'_y is the true fishing mortality rate in year y, and $\hat{F}_{y,i}$ is the estimated fishing mortality in year y in the ith simulation. An estimation procedure with small *REE* suggests that it performs well and tends to have smaller bias in estimating *F*. A small AREE suggests that the approach performs better and tends to have better precision in estimating *F*. The same approach was used to estimate *REE* and *AREE* for recruitment and selectivity.

Model selection uncertainty was evaluated through a probability of choosing the "true" model as the best model, based on the lowest DIC value. For example, when the M1 model was used as the true model, in each of these 100 runs, the simulation algorithm would pick the best model based on the DIC values (smallest DIC means the best model); the best model would be recorded in each of the simulation runs. After the 100 runs, the proportion of times each model was chosen as the best model was calculated based on the DICs of each model in the 100 runs. For example, if the M1 model was chosen as the best model in 20 of 100 runs, then the probability is 20%. In this simulation, the results of the *REE*s and *AREE*s, and the probability of being selected as the best model, from the first 50 runs and the second 50 runs were similar. This indicated that the simulation results were stable for *REE* and *AREE*, and for model selection uncertainty estimation. We then decided to use 100 runs considering the long time for computation (Schnute, 1987; Jiao *et al.*, 2008, 2009a, b).

Model goodness of fit

The goodness-of-fit statistics for the hierarchical spatially structured Bayesian statistical catch-at-age (SBSCA) models were compared with the classical, nonspatial SCA model based on the estimates of the DIC:

$$
\begin{aligned}
DIC &= 2\bar{D} - \hat{D}or\bar{D} + p_D \\
D(x, \theta) &= -2\log \mathrm{Likelihood}(x|\theta) \\
p_D &= \bar{D} - \hat{D},
\end{aligned}
\tag{8}
$$

where D is the deviance, a measurement of how well each model fits the observed data, p_D is the effective number of parameters in a Bayesian model, $\bar{D}$ is the posterior mean of the deviance, and $\hat{D}$ is the deviance of the posterior mean. Here, x includes $C_{a,y}$, $I_{j,a,y}$ and θ includes $\bar{R}$, $\bar{N}_{a>1,1982}$, F_y, S_a, $q_{j,a}$, σ_j, σ_c, σ_R, σ_N in the SCA model and also includes hyperparameters used in the distribution of the indices in the other three models, such as parameters in the Wishart (*d*wish, in Table 1) distribution, and *H* in the exponential autocorrelation function. The DIC is a hierarchical modelling generalization of AIC (Akaike information criterion) and BIC (Bayesian information criterion). The lower the DIC value, the better the model. It is particularly useful in hierarchical Bayesian model selection problems (Spiegelhalter *et al.*, 2002 2004; Jiao *et al.*, 2008, 2009a, b, 2010).

Retrospective analysis

Retrospective error has been one of the important issues in fisheries stock assessments (Mohn, 1999; NEFSC, 2008). An extra 3-year retrospective analysis was done for each of the models. The retrospective pattern was treated as one of the two criteria to compare models. Here, 1 year retrospective error was measured as follows:

$$
E1_t = \frac{(N_t|_{\text{data to year } t} - N_t|_{\text{data to year } t+1})}{(N_{\text{data to year } t+1})}, \tag{9}
$$

where $N_t|_{\text{data to year } t}$ is the estimated population abundance in year t when data up to year t was used in the model (Jiao *et al.*, 2012). The second criteria is based on Mohn (1999), and it is calculated as below for the 3-year retrospective analysis:

$$
E2 = \sum_{t=2007-5}^{2007} \frac{N_t|_{\text{data to year } t} - N_t|_{\text{data to year 2007}}}{N_t|_{\text{data to year } t}}. \tag{10}
$$

Sensitivity analysis

In this analysis, non-informative priors were primarily used. Our preliminary analysis found that using an informative prior for parameters tended to decrease the computing time and the Markov Chains converged much faster. This characteristic of an MCMC is very important for models that are as complicated as the ones developed here. We then developed a sensitivity analysis using informative priors for the variance terms, σ^2. The informative prior for σ^2 was based on the modelling analysis from M1 to M4, i.e. two times the variance of model M_i, $\sigma^2|_{M_i}$, was used as the prior of the second scenario of each model. The use of priors from previous analyses has been suggested as valuable in Bayesian analysis (Gelman *et al.*, 2004). This can be a useful way to elicit informative priors. Here we widened the before two times the variance of model M_i, $\sigma^2|_{M_i}$, for the prior of σ^2 in model M_i to make sure that the prior was not too restrictive. For the spatial models we added extra scenarios to test the appropriateness of the priors for the variance–covariance matrix of the spatially correlated residuals. Details of the priors in the sensitivity analysis are presented in Table 1.

Results

Our MCMC convergence diagnostic based on the Gelman and Rubin statistic and the trace plots showed that convergence of the MCMC algorithm for all models are guaranteed. The Gelman and Rubin statistic for all parameters, including all variance terms, ranged from 0.99 to 1.01, indicating convergence of the Markov chains. We also visually observed the trace plots of the major parameters, which showed good mixing of the three chains, also indicative of convergence of the MCMC chains (figures not shown). For the simulation runs, only the Gelman and Rubin statistic was used as the tool to diagnose convergence of the MCMC, and runs with Gelman and Rubin statistic beyond the range of 0.99–1.01 were discarded. Extra simulation runs were added in such cases (only observed in 2 of the 100 runs for M4).

Extending the commonly used SCA model (SCA, M1) to a hierarchical spatial random effect model (SCA_RE, M2) increased the

Table 3. DIC and retrospective error estimates when different models are used.

Models	Scenarios	DIC	E_{2004}	E_{2005}	E_{2006}	$E2$
M1	S1	2437.6	0.24	0.01	0.34	0.57
	S2		0.23	−0.07	0.15	0.33
M2	S1	2140.2	0.12	−0.03	0.34	0.66
	S2		0.06	−0.01	0.26	0.43
M3	S1	2764.5	0.16	−0.01	0.34	0.53
	S2		0.22	0.02	0.36	0.62
M4	S1	2467.6	0.31	0.03	0.44	0.81
	S2		0.28	0.06	0.38	0.73
	S3		0.35	0.05	0.42	0.83

E_{year} is the retrospective error for the given year (see text for explanation), and $E2$ is the retrospective error used in Mohn (1999).

model goodness-of-fit dramatically. The difference between DICs from these two models was 297.4 (Table 3). However, the SCA_CAR model (M3) decreased model goodness-of-fit (Table 3). The spatial hierarchical SCA_Distance model, that assume that covariance among surveys is a function of their distance (M4), also resulted in a relatively higher DIC than when M1 was used but not as high as when M3 was used. The differences between the DIC values indicated that modelling spatial synchrony/asynchrony through hierarchical spatial models is valuable (M2 has the lowest DIC value). Because the fit for M3 and M4 was much worse than M1, spatial autocorrelation among neighbouring areas as modelled in M3 or by M4 (using the distance between locations) seems not evident. Comparison among DICs suggested that M2 was the most appropriate model and that the weakfish population

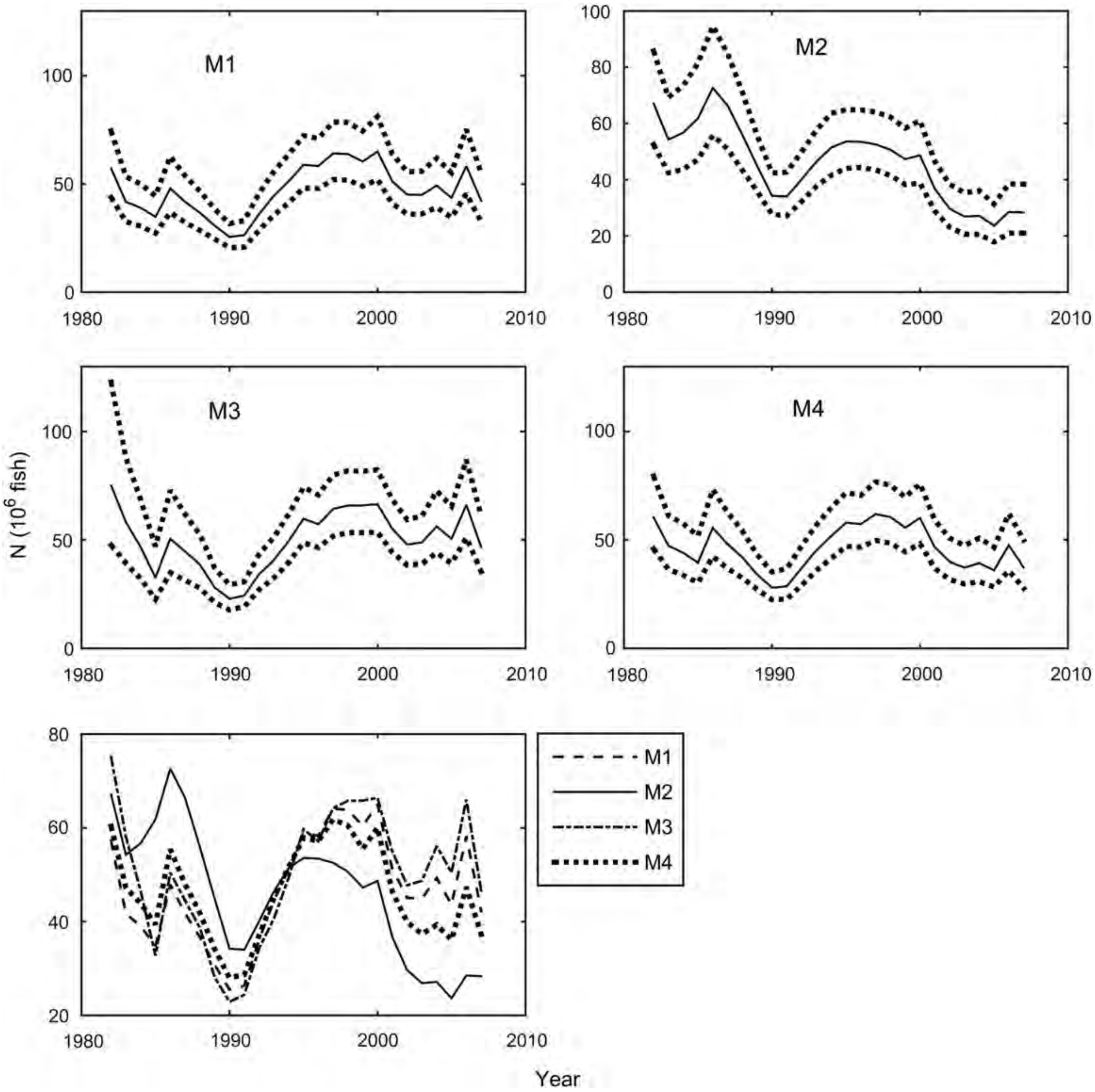

Figure 2. Estimated posterior population abundance. Continuous line represents mean estimates, and dotted lines represent 95% credible intervals.

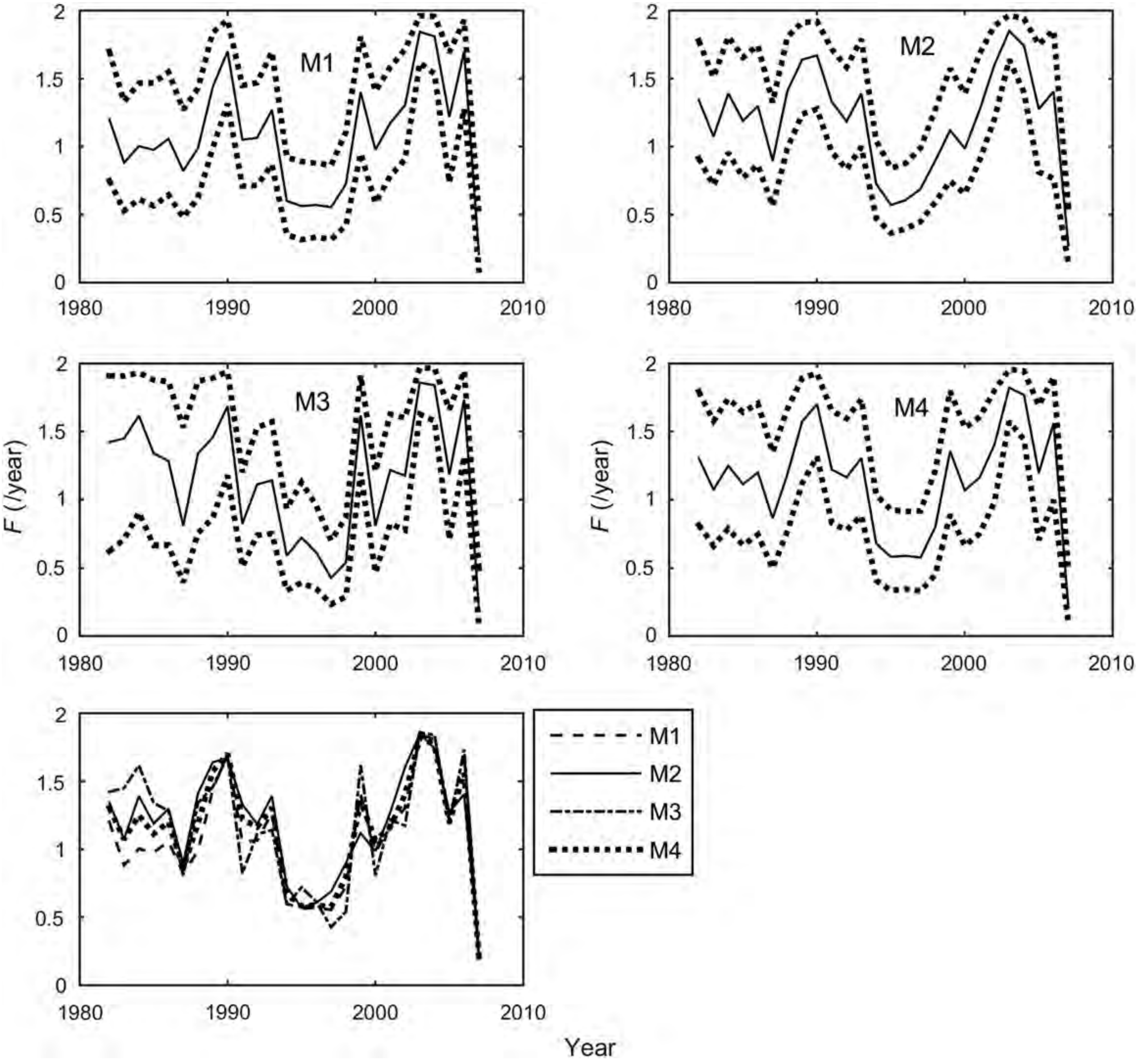

Figure 3. Estimated posterior fishing mortality. Continuous line represents mean estimates, and dotted lines represent 95% credible intervals.

distribution is highly heterogeneous as reflected in the random effect in different surveys and has spatial asynchrony over time.

The estimated population trends from the four models were not the same, with results from M1, M3, and M4 being much closer (Figure 2). M2 resulted in lower population size after the mid-1990s than M1, M3 and M4. Fishing mortality estimation followed similar patterns when different models were used (Figure 3). Here although all the models were calibrated using the same relative abundance indices, expected trends in population size can be different because of the different functions of the abundance indices equations used in the spatial hierarchical models.

The spatial synchrony/asynchrony was modelled as a random effect in the surveys in M2. The estimated $\varepsilon_{j,a,y,2}$ values were plotted to show the spatial heterogeneity and its variation in M2. Bubble plots (Figure 4) were used to represent the spatial variation among surveys with positive $\varepsilon_{j,a,y,2}$ plotted in red and negative values of them plotted in blue. Positive values indicate that the corresponding survey locations tend to have higher population densities than average over time, while negative values indicate that the corresponding locations tend to have lower population densities than average over time. This pattern is associated with synchrony among some surveys/locations and asynchrony with other surveys/locations. The NMFS survey and SEAFALL tended to have a higher than average population densities for ages 2–5 after 2003 although the proportions of ages 2–5 fish are low in both surveys (Figure 4A). DEDFG, NJDEP, and MRFSS surveys tended to have lower than average population densities after 2003. DWDFG and NJDEP tended to have to higher than average population densities from mid-1990s to 2003.

Spatial synchrony/asynchrony of YOY was clearly reflected in the results of M2. The random effects from the YOY surveys indicated that the density of the population was probably changing in different survey locations over time (Figure 4B). The DEDFW, NCDMF, VIMS survey, and RI surveys tended to have higher than average

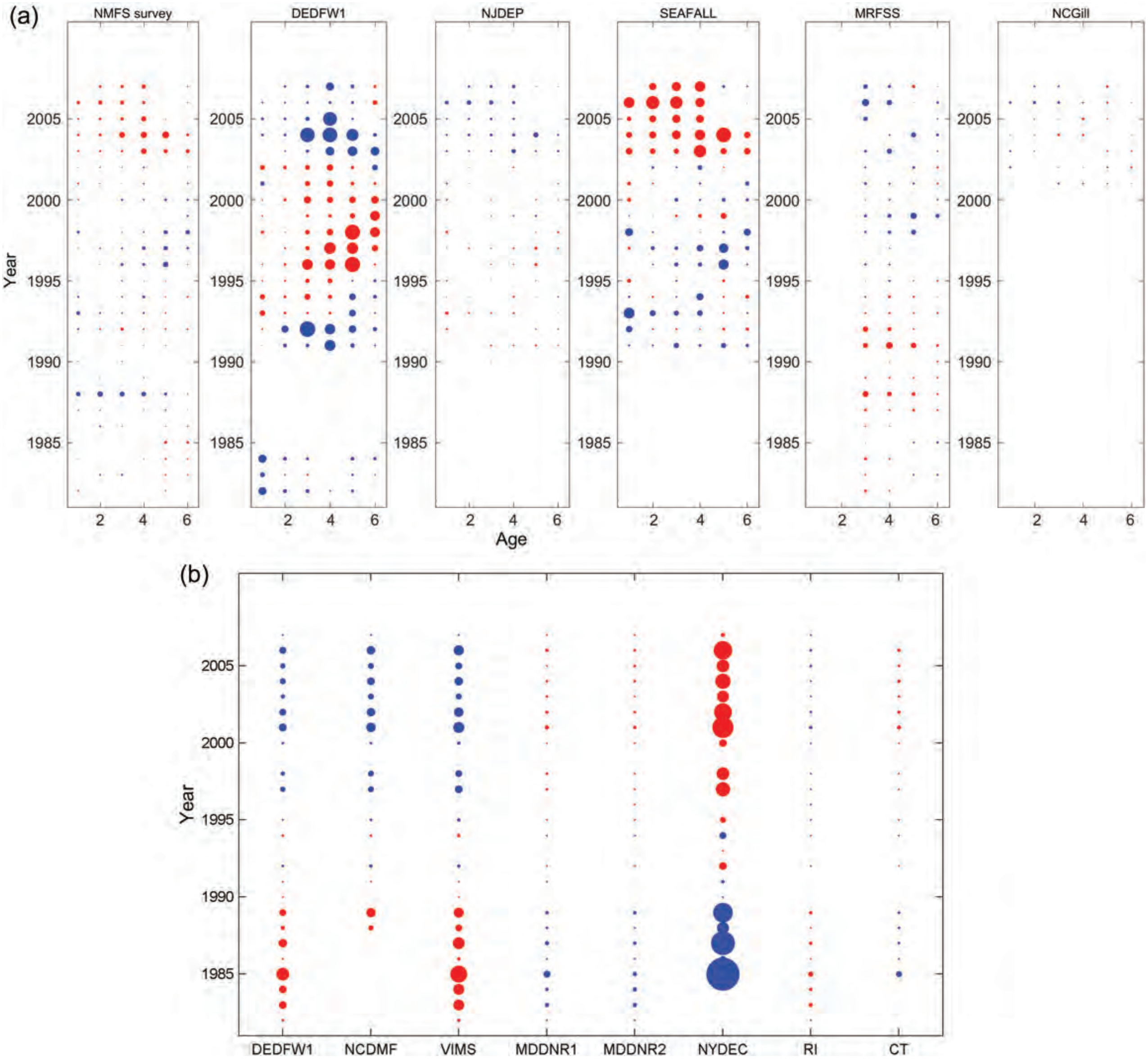

Figure 4. Spatial heterogeneity reflected from different surveys shown as differences from the mean population size M2. Positive values were plotted in red, while negative values were plotted in blue. See text or the explanation of the bubble plot. (a) Spatial-temporal variation of the fish groups shown from 6 age surveys. See Supplementary Table S1 for the explanation of the surveys. See text for the explanation of the bubble plot. (b) Spatial-temporal variation of the age 1 fish groups shown from 8 YOY surveys. See Supplementary Table S1 for the explanation of the surveys.

YOY populations before 1990, but had lower than average YOY population after 1995. The change in the YOY population density was in contrast to the trend for MDDNR1, MDDNR2, and CT surveys, that showed lower than average YOY populations before 1990 but higher than average populations after 1995. The period of 1990–1995 seemed to be the time where the change happened.

The estimated posterior distributions of N_{msy} and F_{msy} from M1 and M3 were similar but different for M2 and M4 (Figure 5). M2 resulted in smaller F_{msy} and larger N_{msy} whereas M4 resulted in larger F_{msy} and smaller N_{msy}.

Model selection uncertainties from the simulation study were high. With the example stock, probabilities of determining the true model were, respectively, 0, 100, 0, and 40% for the M1–M4 models (Table 2). However, the simulation study also showed that the "true" model tended to give the estimate with lower to lowest *REE* and *AREE* values, which means that the parameter estimates are better, but not always the best (Table 2). The *REE* and *AREE* values calculated from the "best model" selected based on DIC, were low and very close to the *REE* and *AREE* calculated when the true models were used (Table 2). This implies that the DIC works well in selecting models among these SCAs (Jiao *et al.*, 2009a, b).

Discussion

Spatial synchrony/asynchrony often exists among species of interest because of autocorrelated ecological variables, species dispersal, species interaction, and collared noises of the environment, and may cause serious errors in data analyses if neglected (Legendre, 1993; Heino *et al.*, 1997; Vasseur, 2007; Pandit *et al.*, 2013). Studies that incorporate spatial processes into fishery data analysis were limited to surveys on either abundance or relative abundance,

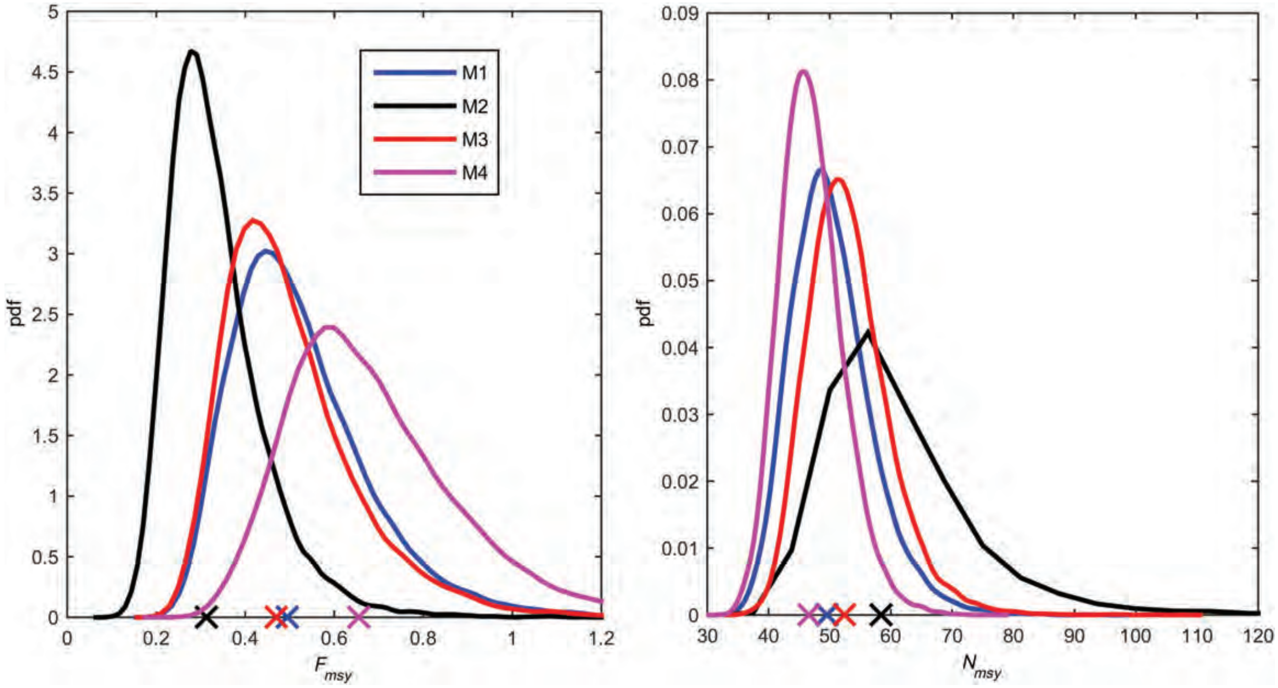

Figure 5. The estimated maximum sustainable population abundance *Nmsy* and maximum sustainable fishing mortality *Fmsy*. Markers x in colours are the median of the posterior distributions.

i.e. the studies either estimate the abundance based on the survey data directly, or use the catch rate standardization to develop relative abundance based on the surveys (Petitgas, 1993, 2001; Nishida and Chen, 2004; Addis *et al.,* 2009). In an age-structured model, the spatial synchrony/asynchrony can be reflected in surveys from different states and regions. The method to integrate different surveys from different locations into a stock assessment model as we propose here is largely needed and has not been developed previously. Our study suggests that our proposed spatial hierarchical Bayesian statistical catch-at-age models can be a very useful and novel method to incorporate spatial synchrony and asynchrony over time into a fisheries stock assessment.

Three hypotheses about the possible spatial dynamics of the population distribution/density were modelled and tested through model comparison. The largely reduced DIC values using the spatial hierarchical model (M2 here) suggested that incorporating spatial variation of the population abundance is worthwhile. It also suggested that spatial asynchrony of Atlantic weakfish is obvious and hence needs to be taken into account by the model. However, the partial correlation structures tested in M3 and M4 did not improve model fit. The increased DIC values using M3 and M4 suggested that spatial heterogeneity of Atlantic weakfish is probably less continuous (M4) and less influenced by the neighbouring regions (M3). This could be derived from the fact that the differences in abundance among location are completely random (M2) or because the real spatial structure is different from those tested in M3 and M4. Other functions, such as spherical and Gaussian models, may be considered in the future (Rossi *et al.,* 1992; Heino *et al.,* 1997).

The spatial hierarchical model that fit the weakfish data the best (M2) suggested that the spatial synchrony and asynchrony among surveys over time was changing around the mid-1990s and early 2000s. After entering the 2000s Atlantic weakfish tended to have a density that was higher during this period than before in the southern area and in the offshore area. According to the time-series surveys on catch of weakfish from private boats by recreational anglers, both the ocean catches and inland catches increased in the South-Atlantic in recent years, but decreased in recent years in the Mid-Atlantic area. The ocean catches in the 1980s in the Mid-Atlantic area are not less than those from inland in the Mid-Atlantic area but are much lower in the South-Atlantic area (Figure 6). These catch observations are consistent with our modelling results on spatial asynchrony.

Results from both prior scenarios when the same models were used were similar, which indicated that the informative priors for variances are appropriate for future stock assessment. The stability of the results might be a result of the hierarchically structured variances (Gelman *et al.,* 2004). Hierarchical models have been found to provide robust estimates of the parameters in models in a variety of areas, such as pharmaceutical, ecological, and fisheries (Gelman *et al.,* 2004; Jiao *et al.,* 2009a, b, 2011).

In our simulation study, we found that the estimated posterior means of the parameters were close to the "true" values in most of the runs. We also found that the *DIC* recommended models resulted in parameter estimates with lower estimation uncertainty that tend to be close to the estimates when the "true" models were used. Schnute (1987) and Jiao *et al.* (2008, 2009a, b) found that the model selection uncertainty can be rather high, and the models recommended by the information based criteria have low probability of being the "true" model. This discrepancy suggested that the model selection uncertainty is probably less when the ΔDIC is higher and $\Delta DIC/DIC$ is larger.

Our study investigated possible spatial hypotheses based on the example fishery and provides potential models that could be used to account for spatial synchrony and asynchrony. We recommend that the preferred model be considered as an operational model for future stock assessment of the example fishery. Other hypotheses on

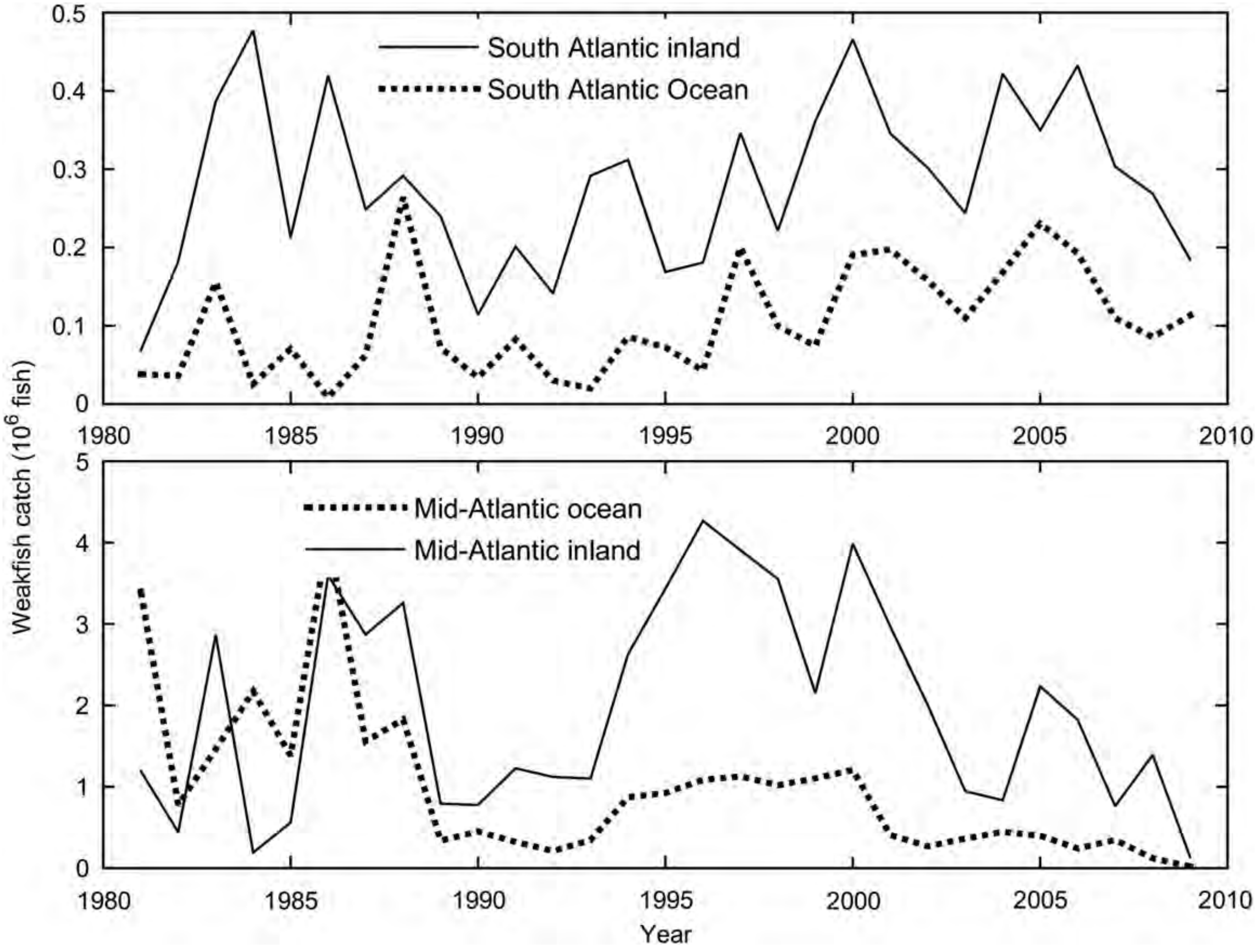

Figure 6. A time-series survey of private boat (only) catch of weakfish by recreational anglers for the Midand South-Atlantic, with a comparison of Inland (for example, Inland VA = the Chesapeake, its tributaries, Potomac tributaries, and seaside bays and inlets) vs. all ocean combined (state ocean + federal ocean).

weakfish stock assessment, such as changes in natural mortality, may need to be considered also when an operational model is considered.

This study provided not only useful spatially dynamic age-structured models but also a framework for fisheries scientists to explore possible ways to incorporate spatial dynamics into fisheries stock assessment models. Fish population dynamic patterns also may affect the performance of different models. Our study reflected characteristics of the example weakfish fishery dynamics across the North Atlantic under harvest, and hence the results are primarily applicable to the weakfish fishery. Results of our research are not intended to supersede results of the 2009 stock assessment for weakfish (NEFSC, 2009). Weakfish was used as a case study to demonstrate the applicability of these models to a wide range of species. Although the conclusion of an optimum model of spatial asynchrony may not be globally true for all southeastern US and Gulf of Mexico fisheries, the model-selection procedure, and the general conclusions on modelling Bayesian SCA with inconsistent or asynchronous relative abundance indices among surveys in different spatial area, have global utility.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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