# Atlantic States Marine Fisheries Commission

## *Tautog Benchmark Stock Assessment and Peer Review Reports*

**Accepted for Management Use**
**February 2015**

**Vision: Sustainably Managing Atlantic Coastal Fisheries**

# Overview

The 2015 Tautog Benchmark Stock Assessment occurred through an Atlantic States Marine Fisheries Commission (ASMFC) external peer review process and included an Integrated Peer Reviewer who provided guidance throughout the assessment. ASMFC organized and held a Data Workshop on March 25-29, 2013. Assessment Workshops were held on October 21-24, 2013 and March 10-12, 2014. Participants of the Data and Assessment Workshops included the ASMFC Tautog Stock Assessment Subcommittee and Technical Committee. ASMFC coordinated a joint Peer Review Workshop for the tautog and black drum assessments on November 11-14, 2014. Participants included members of the Tautog Assessment Subcommittee and a Review Panel consisting of four reviewers appointed by ASMFC. The Tautog Management Board accepted the stock assessment and peer review for management use on February 5, 2015.

**Tautog Stock Assessment Peer Review Report** (PDF Pages 1 -17)
The Peer Review Report provides a detailed evaluation of how each Term of Reference was addressed by the Stock Assessment Subcommittee, including the Panel's findings on stock status and future research recommendations.

**Tautog Stock Assessment Report for Peer Review** (PDF Pages 18 - 283)
This report describes the background information, data used, and analysis for the assessment submitted by the Technical Committee to the Review Panel.

# Atlantic States Marine Fisheries Commission

## Tautog Stock Assessment Peer Review Report

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Vision: Sustainably Managing Atlantic Coastal Fisheries

# Atlantic States Marine Fisheries Commission

## Tautog Stock Assessment Peer Review Report

Conducted on
November 11-14, 2014
Virginia Beach, Virginia

Prepared by the
ASMFC Tautog Stock Assessment Review Panel

Dr. Cynthia Jones, Panel Chair, Old Dominion University
Dr. Gary Nelson, Massachusetts Division of Marine Fisheries
Dr. Yan Jiao, Virginia Polytechnic University
Dr. Jason Cope, NMFS Northwest Fisheries Science Center

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# Preface

*Summary of the ASMFC Stock Assessment Review Process*

The Stock Assessment Peer Review Process, adopted in October 1998 and revised in 2002 and 2005 by the Atlantic States Marine Fisheries Commission (ASMFC or Commission), was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal independent review; (2) maintain the quality of Commission stock assessments; (3) ensure the credibility of the scientific basis for management; and (4) provide the public with a clear understanding of fisheries stock assessments. The Commission stock assessment review process includes an evaluation of input data, model development, model assumptions, scientific advice, and a review of broad scientific issues, where appropriate.

The Commission's *Benchmark Stock Assessment Framework* outlines options for conducting an independent review of stock assessments. These options are:

1. The stock assessment review process conducted by the Atlantic States Marine Fisheries Commission.
2. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).
3. The Southeast Data and Assessment Review (SEDAR) conducted by the National Marine Fisheries Service, Southeast Fisheries Science Center (SEFSC).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes stock assessments for all Commission managed species based on species management board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In November 2014, the Commission convened a Stock Assessment Review Panel comprised of scientists with expertise in stock assessment methods, data poor modeling, recreational fisheries data and indices, and tautog life history and ecology. The review of the tautog stock assessment was conducted at the Sheraton Oceanfront Hotel in Virginia Beach from November 11-14, 2014. Prior to the Review Workshop meeting, the Commission provided the Review Panel members with copies of the 2014 Tautog Stock Assessment Report.

The review process consisted of presentations by topic – data inputs, life history analyses, model results, reference points, and stock status – of the completed 2014 stock assessment. Each presentation was followed by general questions from the Panel. The second day involved a closed-door meeting of the Review Panel during which the documents and presentations were discussed and a review report prepared. The report is structured to closely follow the terms of reference provided to the Panel.

# Acknowledgements

The Review Panel thanks members of the Tautog Stock Assessment Subcommittee and Technical Committee, as well as staff of the Atlantic States Marine Fisheries Commission, particularly Patrick Campfield, for support during the review process.

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# Executive Summary

The review panel met in Virginia Beach, VA from November 11-14, 2014. Prior to the review workshop, panel members read the stock assessment report and other relevant documents provided by ASMFC and the tautog (Tautoga onitis) stock assessment subcommittee (SASC). During the workshop, the panel reviewed results of the age structured and data-poor models, and requested additional model explorations, including alternative sensitivity runs to determine the models' robustness to inputs and parameters.

The model the SASC recommended to use for management was the age structured model (ASAP). The ASAP model proved to be relatively robust to estimates of spawning stock biomass, abundance, recruitment, and fishing mortality. Moreover, the Review Panel agreed that the region-level ASAP stock assessment models provided the best available scientific foundation for management. The Review Panel and the SASC team realized that the use of the logistic curve may be causing the selectivity curve to switch to a higher selectivity after increasing the catch size limit in all three regions and may also explain why the catch-at-age data did not fit well in some years.

The ASAP regional model results indicated the population abundance/biomass in the Southern New England (MA-CT) and NY-NJ regions declined (rate: 2.9/14.2; 2078/5500) since the starting year of the model to the present with the most recent two-year biomass increasing slightly. The DMV (DE, MA, VA) region model results show declining abundance, although not as steep as the other two regions, which may be due to the large influence of the MRIP index as the only abundance index used to tune the DMV model. Fishing mortality estimates were also highly variable because of the high variance of recreational harvest statistics. The recent F estimates for the NY-NJ and DMV regions were lower (0.21 versus 0.25 of 3-year average; 0.1 versus 0.17 of 3-year average), than the F estimates from the SNE region (0.59 versus 0.50 of 3-year average).

The Review Panel noted that the $F_{target}$ and $F_{threshold}$ reference points varied among the three regions because they were influenced by the selectivity patterns estimated from each of the regional ASAP models. Variation in growth and maturity among the three regions may also contribute to variations in reference point estimation.

The Review Panel also noted that, by using regional models, the recommended SSB reference point is much smaller than historically recommended SSB reference point. The differences between cumulative SSB reference points from the regional models and the SSB reference point from the coast-wide model changes the stock status to a degree and at the same time increases the risk of the population being overfished. Precaution is needed when using the regional SSB reference point.

*The tautog stock status in each region is overfished.* Through a series of data analyses and modeling, the SASC has documented the overfished status. The following Review Report evaluates the stock assessment findings, comments on strengths and weaknesses, and makes recommendations for future research priorities and assessments.

## Terms of Reference for the Tautog Stock Assessment Review

1. Evaluate the thoroughness of data collection and the presentation and treatment of fishery-dependent and fishery-independent data in the assessment, including the following but not limited to:
    a. Presentation of data source variance (e.g., standard errors).
    b. Justification for inclusion or elimination of available data sources.
    c. Consideration of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, ageing accuracy, sample size).
    d. Calculation and/or standardization of abundance indices.

The 2014 benchmark stock assessment of tautog provides up-to-date information on the biology and life-history of the species, as well as regional stock assessment models that are based on regional biological data and fisheries behavioral patterns in each region.

The Tautog Stock Assessment Subcommittee (SASC) provided a thorough review of all data sources considered for the assessment and provided detailed information on data sets used in the stock assessment. The fishery-dependent and fishery-independent sources of data used primarily by the SASC were the NMFS and state records for commercial landings; Northeast Fisheries Observer Program for commercial discards; state biosampling of commercial and recreational fisheries; the MRFSS/MRIP program for recreational landings, discards, and length frequency; and fishery-independent surveys in the states of MA, RI, CT, NY, NJ, DE, MD, and VA for biological data (lengths, ages, weights) and measures of relative abundance.

The SASC developed four criteria to use to determine if datasets should be retained or excluded in the assessment. A dataset was rejected if it had less than 10 consecutive years of data, or sampling over the 10 years was intermittent; it contained a small number of samples; it covered a small geographic area not representative of the regional stock or coast-wide stock unit; or it employed inconsistent methodologies. However, rejected datasets were used occasionally in a qualitative manner to inform some decisions made by the SASC. The review panel considered the SASC criteria reasonable and agreed with how they were used to include or exclude datasets.

The SASC presented data based on three regions – Southern New England (MA-CT), NY-NJ, and DMV (DE, MA, VA) – developed for management purposes. Commercial landings in weight for each region from 1950 to 2013 were reviewed. These data were considered a census, thus no estimates of error were given. Commercial landings in the earlier years (1950s-1970s) were likely underestimated given that reporting was not required and tautog was considered a ‘trash’ fish during those years. A small live-fish market exists currently along the coast, but there may be under-reporting of the landings. Estimates of commercial discards were poor given the small sample sizes and were not included in the assessment. Since length data from the commercial fishery were unavailable, the use of recreational length data to apportion the commercial catch into age classes may have introduced bias into age compositions. Regardless, the Panel believed these data were adequate for use in the assessment since the commercial landings comprised only a small portion of total landings.

The recreational landings and discards estimates for 1982-2013 from the MRFSS/MRIP program were the primary data used to characterize the recreational fisheries for tautog. The SASC reviewed the magnitudes and trends of the MRFSS/MRIP estimates for the three proposed management regions. When disaggregated by state, PSEs for the MRFSS/MRIP estimates of harvest and releases were generally high (>0.30), indicative of the low number of intercepts obtained by survey interviewers. When aggregated to the proposed regions used in the assessment, PSEs were reasonable (many <0.20). A release mortality of 0.025 was applied to the releases to obtain estimates of dead discards.

Sample sizes of length data collected to characterize the recreational fishery harvest and releases varied over year and among regions. Prior to 1995, sample sizes were reasonable for the number of anglers intercepted by MRFSS/MRIP. However, sample sizes declined in the SNE and NY-NJ regions through 2001. Since then, sample sizes have risen in the NY-NJ and DMV regions, but remain low in SNE. Prior to 2005, limited sampling of released fish occurred and length data from a volunteer tagging program were used. These data may not be representative of the fish being released. Sampling of released fish has increased but sample sizes remain low in the SNE region. However, the Panel believes these data are sufficient for use in the stock assessment.

Opercular bones were used to age tautog. An exchange of structures among states confirmed that opercular bones were aged consistently by state biologists. Annual age-length keys (ALKs) used to apportion catch data into age-classes were not available on a regional basis prior to 1995. Use of pooled data may have biased the age composition if there are regional growth differences among the regions, as purported by the TC/SASC. After 1995, annual ALKs were developed for each region by combining state data. The Panel agreed that the sample sizes of length-age data appeared adequate for the development of annual ALKs.

A number of regional fishery-dependent (2) and fishery-independent (15) indices for use in the stock assessment were reviewed by the SASC. Based on the inclusion/exclusion criteria developed by the SASC, only indices from one fishery-dependent source (MRFSS/MRIP) and four fishery-independent surveys (MA trawl survey, two bottom trawl surveys in RI, and one trawl survey in NY) were used in the stock assessment. The SASC discussed the potential biases of each survey. Recreational CPUE indices were developed for each region from MRFSS/MRIP intercepts of tautog trips (based on logical species guilds) by using a generalized linear modeling approach (assuming a negative binomial error structure) and standardizing by year, state, wave, and mode. Fishery-independent surveys were also standardized for design and environmental variables. Diagnostic plots were reviewed for each index to ensure adequate model fit. Error bounds for all estimates were provided by the SASC. The Panel believed the standardizations were appropriate and the resulting estimates were reasonable. The Panel was concerned that only one index, the recreational CPUE, was available for the DMV.

*Overall, the Panel considers that a credible analysis of the available data was undertaken by the SASC.*

2. Evaluate the assumptions of stock structure and the geographical scale at which the population was assessed.

The SASC presentations and assessment documents provided details on tautog life history supported by the peer-reviewed literature. Tautog is a temperate labrid whose distribution ranges from Nova Scotia to South Carolina with greatest abundance from Cape Cod to Chesapeake Bay. Its habitat is nearshore environments with structure (e.g., rocky reefs). Although it has a seasonal pattern of movement inshore during spring and summer to more offshore during fall and winter, tagging studies have shown recapture within a few miles of release indicating a limited scope of intermixing with other areas. Nonetheless, genetic results do not distinguish separate stocks along its range. However, genetic results do not preclude local stock structure in a 'stepping stone' pattern where some localized adaptation is retained in subareas. Moreover, tautog do not follow a typical labrid reproductive strategy of hermaphrodism, but are gonochoristic and have some sexual dimorphism in coloring and manible structure. Tautog are indeterminate and prolific serial spawners with a protracted spawning season. Eggs and sperm are pelagic and together, this reproductive strategy would permit some mixing with nearby spawners.

In the initial stock assessment and thereafter, tautog have been managed as a unit stock throughout its range. Our current understanding of tautog life history suggests there may be cause to assess and manage using a more regional stock structure. Although not affirmed in genetic studies, the regional basis could be shown with natural tags such as otolith chemistry, as suggested by Dr. Tom Miller during his integrated review of the tautog assessment's development. As Dr. Miller wrote, "Ideally, the spatial structure of the population should be matched by the scale at which the assessment and management are conducted. However, there are numerous examples of successful management of mixed populations within single management units, as well as examples of successful management of arbitrarily divided populations into separate sub-units. Thus, the spatial scale of the population and that of the assessment and management need not match."

The Review Panel also ascertained that there was a paucity of data at a fine spatial scales to support fine-scale models, but recommends that collecting these data could improve model performance and support of such studies would be justified.

3. Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) at the coastwide and regional basis, including but not limited to:
    a. Evaluate the choice and justification of the preferred model(s). Was the most appropriate model (or model averaging approach) chosen given available data and life history of the species?
    b. If multiple models were considered, evaluate the analysts' explanation of any differences in results.
    c. Evaluate model parameterization and specification.

d. Evaluate the diagnostic analyses performed, including sensitivity analyses to determine model stability and potential consequences of major model assumptions.

Three main models that use relative abundance indices were presented by the SASC to describe both area-specific and coastwide tautog population dynamics: 1) the Age Structured Assessment Program (ASAP), 2) extended Depletion-Based Stock Reduction Analysis (xDB-SRA), and 3) Bayesian State Space Surplus Production Model (BSSSP). Each is discussed in turn with regard to its suitability given the data and life history of the species, the parameterization and model specification, and model performance, including sensitivities. Other models using catch only (DCAC and Catch-MSY) were also discussed, but not put forward from the stock assessment team as viable candidates.

Age Structured Assessment Program (ASAP)

The SASC put forward ASAP as the preferred model. This is an age-structured approach using indices of abundance and age compositions to estimate initial age structure, recruitment deviations, index and fishery selectivities, fishing mortality, survey catchability, and stock-recruitment parameters. The underlying catch data are extremely uncertain, but this trait is common to any model that would use a catch time series, thus not a challenge unique to ASAP models. The ASAP model was considered the fullest use of available data in each area, though it was hindered in some respects. ASAP was sometimes restricted, relative to the other models, in its initial year of model estimation. However, comparisons to other models showed this did not cause major deviations in results.

There are at least three major advantages of ASAP over the other two models: 1) more detail in the underlying dynamics (age-structured vs. lumped biomass), 2) indices could be used as numbers rather than biomass only (which required additional assumptions to expand the numbers to biomass) and 3) the estimation of selectivity, rather than assuming selectivity is equal to maturity. Selectivity estimates from ASAP demonstrated significant differences in the assumption that selectivity equals maturity (as used in the other models).

The general parameterization of ASAP shared likelihood components common to other age-structured models, though the need to have an estimate of initial time series age-structure proved a challenge, limiting the capacity of this model to reach back in time to provide initial condition estimates. Likelihood weighting was maintained at 1 for catch and index fits, but downweighted by half for the recruitment and fishing mortality penalty functions. Downweighting the recruitment penalty allowed the model to stray from strict Beverton-Holt recruitment estimates, an assumption the review panel supported. Common data tuning techniques were also applied to make model input consistent with data treatment within the data, including inflation of measurement error on the indices. Selectivities were estimated in three time blocks to address changes in management. Natural mortality was assumed to be constant across ages and through time.

Model fits were adequate, with one or two indices usually dominating the fits. There was an initial concern that index uncertainty may have been underestimated, but subsequent model runs with added variance explored this issue. The recreational-based indices tended to be the most informative, thus much of the model interpretation hinges on the trust in these indices. Fits to the catch-at-age data showed lack of fits in several instances, underscoring the informational weakness in low sample sizes and possible need for additional selectivity blocks. Stock productivity (i.e., steepness) was estimable in two of three areas. The DMV area showed no contrast in the stock-recruitment relationship, thus steepness was not estimable.

Several sensitivities were performed in ASAP across a variety of model specifications. These included removal of indices, the treatment of natural mortality, less selectivity blocks, assumed steepness, and recruitment penalty likelihood weighting. The results were fairly robust to all of these explorations for the SNE model, which was generally the most informed model. Removal of the CT trawl survey and mortality assumptions caused the greatest sensitivities. First year biomass was consistently the most sensitive portion of the biomass estimates. The NY-NJ model showed most sensitivity to the removal of the NJ trawl survey and extension of the model back in time. The DMV model was the least informed model, though it showed the least sensitivity.

Retrospective analyses back to the year 2007 were also examined. SNE showed the least biased patterns, with the two less informed regional models (NY-NJ, DMV) showing more retrospective behavior.

Extended Depletion-Based Stock Reduction Analysis (xDB-SRA)

The xDB-SRA model was offered as another candidate model that shares catch, index, and some life history data with ASAP. The SASC also did some very nice work to incorporate catch uncertainty into the xDB-SRA model, something not traditionally done, and are commended for the creative extension, especially given the poorly informed nature of the catch history and the sensitivity of this method to catch history. Differences from ASAP include: assuming maturity and selectivity are the same function; using a biomass index based on numbers and assumptions on weight; biomass that is not age-structured; productivity based on a more flexible function; and the influence of a prior on relative abundance.

Model diagnostics showed both good post-model, pre-data behavior as well as posterior estimation. The Panel suggested the SASC also include the posterior distributions for yearly catches given those are also randomly drawn inputs to the model. Posteriors on relative stock abundance were highly influenced by the information coming from the indices. Base model runs were very similar to the results found in ASAP, but with much greater uncertainty.

Sensitivities were more limited than those performed in ASAP, and consisted mostly of removing indices and assuming a different production model (Schaefer). There were substantial sensitivities to removal of indices, particularly the MRIP-based indices. No retrospective analyses were conducted.

Bayesian State Space Surplus Production Model (BSSSP)

The state-space model shares in its dynamics a lumped biomass approach rather than the age-structured approach, but it also introduces the capacity to include both process (e.g., biomass) and observation (e.g., index uncertainty) error, an extension not in the xDB-SRA approach. The BSSSP uses a re-parameterization Schaefer model expressed in relative biomass instead of absolute biomass, and thus draws different parameters (i.e, r and K) than in xDB-SRA. Prior distributions used in the model were developed for BSSSP and not used in the other models. It shares the same initial model year with xDB-SRA, which is earlier than the ASAP model. The same indices were used in this model as in the other models, though the BSSSP model also required biomass indices (not as numbers), thus suffering, as xDB-SRA does, from possible issues of expanding numbers to biomass.

Convergence diagnostics were extensive and showed good searching behavior. Model fits to indices were similar in each region to the other models. Despite similar fits, there were very large biomass discrepancies in the NY-NJ and DMV model compared to the other models.

Sensitivities conducted focused on the removal of indices of abundance and different regional configurations. Models demonstrated more sensitivity to removal of indices than the other models. No retrospective analyses were conducted.

The Panel agrees with the SASC that due to model sensitivity to indices and the large discrepancies from the other models (both in trend and absolute biomass), the BSSSP model is not preferred for any of the tautog regional assessments.

*The Panel endorsed the SASC's selection of the ASAP model for use in the stock assessment*. The Panel concluded that the SASC undertook an appropriate model selection process, adequately derived the range of input parameters and undertook innovative model adjustments to addresses issues specific to tautog.

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

Uncertainty was generally characterized in two ways for each model: Uncertainty within the base model specification and sensitivities (discussed in the previous section) to demonstrate uncertainty to model specifications. For base model uncertainty, ASAP used the Markov Chain Monte Carlo (MCMC) algorithm found in the Auto-Differentiating Model Builder (ADMB) programming platform to numerically estimate posterior values for derived quantities. Sampling Importance Resampling (SIR) was used to do the same thing for xDB-SRA. The BSSSP model used Gibbs sampling found in the OpenBUGS program. All methods are appropriate for each respective model.

The overall uncertainty in xDB-SRA and BSSSP was large and expected, but ASAP demonstrated unexpectedly low uncertainty in all base models. Sensitivity analysis also showed relatively low deviations from the base case, thus model specification also had low uncertainty. The largest sources of uncertainty remain the quality of the recreational fishery catch history, the lack of catch information prior to the 1980s, and the low biological sampling effort of tautog.

5. Evaluate the best estimates of stock biomass, abundance, and exploitation from the assessment for use in management, if possible, or specify alternative methods/measures.

The 2014 benchmark stock assessment for tautog provided estimates of stock biomass, abundance, and fishing mortality rate at the level of three regions: SNE, NY-NJ, and DMV. A coast wide ASAP model was run but mainly functioned to bridge the changes from the ADAPT-VPA model, used in the 2005 benchmark stock assessment, to the ASAP age-structured model. Analyses conducted both at the regional level and the coast wide level were reviewed, with greater focus on the regional analyses.

The model that the SASC team recommends to use for management purposes is the ASAP age-structured model. After multiple alternative sensitivity runs of the ASAP model, including additional runs requested by the Panel, the resulting estimates of spawning stock biomass, abundance, recruitment, and fishing mortality are relatively robust. The Panel agreed that the region level ASAP stock assessment models provided the best available scientific foundation for management. The Panel and the SASC realized that the use of the logistic curve may be what caused the selectivity curve to switch to a higher selectivity after increasing catch size limit in all three regions. This may also explain why the model struggled to fit the catch-at-age data in some years. An alternative flexible selectivity curve could be developed and used in the stock assessment model given the tautog fisheries' use of multiple gear types.

The ASAP regional model results indicated that the population abundance/biomass in the SNE and NY-NJ regions declined (rate: 2.9/14.2; 2078/5500) from the starting year of the model to the present with biomass increasing slightly in the two most recent years. The DMV region model results also show a declining trend but it is not as severe as the other regions. The SASC and Panel suggest this is because of the large influence of the MRIP index, the only abundance index used to tune the DMV region model. Fishing mortality estimates have been highly variable because of the highly varied recreational harvest statistics. The recent F estimates for the NY-NJ and DMV regions were lower (0.21 versus 0.25 of 3-year average; 0.1 versus 0.17 of 3-year average), than the F estimates from the SNE region (0.59 versus 0.50 of 3-year average).

The ASAP results are very similar to the results of the DB-SRA and the BSSSP models. There is also a comparison of a coast wide ASAP model run with the ADAPT-VPA model used in past assessments. *In summary, the Panel is very encouraged by the modeling efforts of the SASC and finds they are a significant advance since the previous assessment. The Panel endorses the use of estimates from the ASAP regional models.*

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

**Coast wide F BRP**

| Reference Point | Target | Threshold |
|---|---|---|
| Addendum IV (F=M) | 0.15 | |
| ASAP (Add. IV SSB) | 0.02 | 0.06 |
| $F_{MSY}$ | 0.10 | |
| $F_{SPR}$ | 0.20 | 0.30 |
| | | |
| SNE -- Add. IV | 0.05 | 0.03 |
| SNE new | 0.15 | 0.20 |

**Coast wide SSB BRP**

| Reference Point | Target | Threshold |
|---|---|---|
| Addendum IV | 26,800 | 20,100 |
| VPA updated | 26,700 | 20,015 |
| ASAP | 21,610 | 16,204 |
| SSB MSY | 19,125 | 14,340 |
| SSB SPR | 9,500 | 7,110 |
| SSB $F_{MSY}$ | 13,720 | 10,290 |
| | | |
| SNE -- Add. IV | 8,859 | 6,645 |
| | | |
| SNE new | 3,883 | 2,912 |
| NY-NJ | 3,570 | 2,640 |
| DMV | 2,090 | 1,580 |
| **TOTAL** | **9,543** | **7,132** |

The SASC recommended different models to develop BRPs because of the quality of the stock-recruitment relationships. The Panel found the results of the SNE region model to be reasonable. The $F_{msy}$ (0.15) is recommended as $F_{target}$ and $SSM_{msy}$ (3,883MT) is recommended as $SSB_{target}$. 75%$SSB_{msy}$ is recommended as the $SSB_{threshold}$ and the $F_{threshold}$ based on $SSB_{threshold}$ is 0.20.

The NY-NJ and DMV region models had shorter time series which is reflected in the poor stock-recruitment relationship. $F_{40\%}$ is recommended as the $F_{target}$ and $F_{30\%}$ is recommended as the $F_{threshold}$. See above tables for values.

The Panel noted that the F target and threshold reference points were influenced by the selectivity pattern estimated from the ASAP models, which varied among the 3 regions.

Variation in growth and maturity among the three regions also contributed to variation in the reference point estimates.

The Panel also noted that by using region level models, the recommended $SSB_{BRP}$ is much smaller than $SSB_{BRP}$ recommended historically for management purposes. The differences between cumulative $SSB_{BRP}$ from the regional models and the $SSB_{BRP}$ from the coast wide model changed the stock status to a degree and at the same time increased the risk of the population being overfished. Precaution is needed when using the regional $SSB_{BRP}$ in this case.

Nevertheless, the Panel believes that the new reference points developed by the SASC should be used and, based on the new values, agrees with the stock determinations of the SASC. The Southern New England stock is overfished and overfishing is occurring, the NY-NJ stock is overfished, but overfishing is not occurring, and the DelMarVa stock is overfished, but overfishing is not occurring.

7. Review the research, data collection, and assessment methodology recommendations provided by the TC and make any additional recommendations warranted. Clearly prioritize the activities needed to inform and maintain the current assessment, and provide recommendations to improve the reliability of future assessments.

The recommendations provided by the SASC were comprehensive and the Panel concludes they covered the primary areas needed to improve future assessments. The Review Panel has the following additional research and modeling recommendations:

a. Obtain biological metrics to match the spatial scale of the proposed models, to determine if there is biological justification for such models.
b. Develop an alternative flexible selectivity curve to use in the stock assessment model given the characteristics of multiple gear types in the tautog fisheries.
c. Collect otoliths in addition to opercula from individual fish; invest in otolith microchemical analyses and next-generation sequencing to resolve finer-scale spatial issues.
d. Consider using alternative catch-at-age modeling frameworks (e.g., Stock Synthesis) in order to overcome some constraints of the ASAP model in the NMFS Toolbox. Simpler methods, such as xDB-SRA, can also be performed in Stock Synthesis, providing a common modeling framework to develop and compare different models and their specifications.

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

An assessment update is suggested in another year to check the change of the fishery and population status and the appropriateness of the recommended BRPs from the 3 region-scale models. The next benchmark assessment may be done in 3 years or depend on the results of the update using the current stock assessment models, and the timeframe for developing the models in a new modeling framework.

# Atlantic States Marine Fisheries Commission

## *Tautog Stock Assessment for Peer Review*

**Accepted for Management Use**
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**Vision: Sustainably Managing Atlantic Coastal Fisheries**

# Atlantic States Marine Fisheries Commission

## *Tautog Stock Assessment for Peer Review*

Prepared by the
ASMFC Tautog Stock Assessment Subcommittee:

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

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# DEDICATION

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

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Jeffrey Brust, New Jersey Division of Fish and Wildlife
Paul Caruso, Massachusetts Division of Marine Fisheries
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Linda Barry, New Jersey Division of Fish and Wildlife
Scott Newlin, Delaware Division of Fish and Wildlife
Dr. Alexei Sharov, Maryland Department of Natural Resources
Joe Cimino, Virginia Marine Resources Commission
Tom Wadsworth, North Carolina Division of Marine Fisheries
Dr. Katie Drew, Atlantic States Marine Fisheries Commission
Melissa Yuen, Atlantic States Marine Fisheries Commission

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# EXECUTIVE SUMMARY

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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# TERMS OF REFERENCE

## Approved by the ASMFC Tautog Management Board May 23, 2013

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

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

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

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

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

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

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

## 1.0 INTRODUCTION

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

### 1.1 Management Unit Definition

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

### 1.2 Regulatory History

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

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

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

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

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

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

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

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

### 1.3 Stock Assessment History

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

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

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

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

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

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

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

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

## 2.0 LIFE HISTORY

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

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

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

## 2.1 Age and Growth

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

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

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

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

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

### 2.1.1 Methods

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

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

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

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

*Length-at-Age*

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

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

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

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

### 2.1.2 Results

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

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

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

*Length-Weight Relationship*

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

### 2.1.3 Discussion

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

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

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

## 2.2 Maturity

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

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

### 2.3 Reproduction

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

#### 2.3.1. Female-to-Male Ratio

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

#### 2.3.2. Annual Fecundity

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

#### 2.3.3. Spawning Site Fidelity

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

## 2.4 Natural Mortality

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

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

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

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

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

## 2.5 Stock Definitions

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

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

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

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

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

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

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

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

## 3.0 HABITAT DESCRIPTION

Tautog are attracted to some type of structured habitat in all post larval stages of their life cycle. These habitats include both natural and man-made structures, such as submerged vegetation, shellfish bed, rocks, pilings, accidental shipwrecks and artificial reefs (Olla et al, 1974; Briggs 1975; Briggs and O'Connor 1971; Orth and Heck 1980; Sogard and Able 1991; Dorf and Powell 1997; Steimle and Shaheen 1999).

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

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

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

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

## 4.0 FISHERIES DESCRIPTION

### 4.1 Commercial Fisheries

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

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

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

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

## 4.2 Recreational Fishery

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

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

Recreational catch and effort for tautog are estimated by the NMFS Marine Recreational Fisheries Statistics Survey/Marine Recreational Information Program (MRFSS/MRIP) from 1981 to 2013 (*http://www.st.nmfs.noaa.gov/recreational-fisheries/index*). Since 1981, tautog has been a predominantly recreationally caught species, with the recreational sector accounting for an average of 90% of coastwide total harvest during that time period (Figure 4.5). Coastwide harvest generally ranged between 2.5 million and 3.5 million fish per year between 1982 and

1992, except for one extreme harvest estimate of over 7 million fish in 1987 (Table 4.2, Figure 4.6). Recreational harvest declined steadily to a time series low of just 358,000 fish in 1998, but rebounded quickly and has varied without trend between 750,000 and 1.5 million fish for much of the remainder of the time series. However, recreational harvest has experienced a decline in recent years, with an average harvest in 2011-2013 of approximately 500,000 fish per year. Trends in recreational tautog harvest by weight (MT) follow a similar pattern as numbers (Tables 4.2 and 4.3, Figure 4.6), with an average multiplier of 2.64 lb/fish (range 1.72 – 3.15) from 1981 to 1997, and 3.80 (3.22 – 4.51) since implementation of regulations in 1998.

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

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

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

## 4.3 Current Fisheries Status

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

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

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

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

## 5.0 DATA SOURCES

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

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

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

### 5.1. Fishery-Dependent Sampling

#### 5.1.1. Commercial Fishery

Tautog commercial landings data from NMFS and state records exist for 1950 to present. The time series from 1982-2013 will be used for the stock assessment (Table 4.1) to match the available recreational data time series, because tautog is predominantly recreational species. Commercial catch data used for this assessment is gathered by the NMFS dealer canvass system. In some cases that data is augmented by state obtained data from dealers that may not hold federal permits, since federal requirements do not necessitate the licensing of dealers of tautog.

Catch data is gathered annually as pounds landed. By-catch estimates are unavailable for the commercial fishery since there is limited sea sampling of the directed fisheries that land tautog.

Biases

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

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

#### 5.1.1.1 Commercial Discards/By-catch

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

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

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

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

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

### 5.1.2 Recreational Fishery

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

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

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

Biases

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

#### 5.1.2.1. Recreational Discards/By-catch

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

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

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

#### 5.1.2.2. Recreational Catch Rates (CPUE)

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

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

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

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

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

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

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

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

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

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

### 5.1.2.3. Sampling Intensity

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

### 5.1.2.4. Biological Sampling from the Recreational Fishery

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

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

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

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

### 5.1.2.5. Recreational length frequency distributions

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

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

### 5.1.2.6. MRFSS – MRIP Comparison

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

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

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

## 5.2 Fisheries-Independent Surveys and Biological Sampling Programs

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

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

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

### 5.2.1 Massachusetts Division of Marine Fisheries

#### 5.2.1.1 Survey Design of the Massachusetts Spring Trawl Survey

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

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

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

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

#### 5.2.1.2 Sampling Intensity

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

#### 5.2.1.3 Biological Sampling

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

#### 5.2.1.4 Biases

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

### 5.2.2 Rhode Island Department of Environmental Management

#### 5.2.2.1 Survey Design of the Rhode Island Trawl Survey

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

##### *5.2.2.1.1 Sampling Intensity*

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

##### *5.2.2.1.2 Biological Sampling*

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

##### *5.2.2.1.3 Biases*

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

#### *5.2.2.2 Survey Design of the Rhode Island Seine Survey*

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

##### *5.2.2.2.1 Sampling Intensity*

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

##### *5.2.2.2.2 Biological Sampling*

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

##### *5.2.2.2.3 Biases*

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

### 5.2.3 Connecticut Department of Environmental Conservation

#### 5.2.3.1 Survey Design of the CT Long Island Sound Trawl Survey

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

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

#### 5.2.3.2 Sampling Intensity

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

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

#### 5.2.3.3 Biological Sampling

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

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

#### 5.2.3.4 Biases

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

### 5.2.4 New York Department of Environmental Conservation

#### 5.2.4.1 Survey Design of the NY Peconic Bay Trawl Survey

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

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

##### *5.2.4.1.1 Sampling Intensity*

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

##### *5.2.4.1.2 Biological Sampling*

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

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

##### *5.2.4.1.3 Biases*

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

#### 5.2.4.2 Survey Design of the NY Western Long Island Sound Survey

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

##### *5.2.4.2.1 Sampling Intensity*

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

#### *5.2.4.2.2 Biological Sampling*

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

#### *5.2.4.2.3 Biases*

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

## 5.2.5 New Jersey Department of Environmental Protection

### 5.2.5.1 Survey Design of the NJ Ocean Trawl Survey

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

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

### 5.2.5.2 Sampling Intensity

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

#### 5.2.5.3 Biological Sampling

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

#### 5.2.5.4 Biases

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

### 5.2.6 Delaware Division of Fish and Wildlife

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

#### 5.2.6.2 Biological Sampling

Delaware does not collect tautog biological samples.

### 5.2.7 Maryland Department of Natural Resources

#### 5.2.7.1 Survey Design

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

#### 5.2.7.2 Biological Sampling

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

### 5.2.8 Virginia Marine Resources Commission

#### 5.2.8.1 Survey Design

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

#### 5.2.8.2 Biological Sampling

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

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

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

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

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

### 5.2.9 North Carolina Division of Marine Fisheries

#### 5.2.9.1 Survey Design

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

#### 5.2.9.2 Biological Sampling

NC DMF does not collect tautog biological samples.

## 5.3 Development of Age-Length Keys

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

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

## 5.4 Tagging Data

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

### 5.4.1 Massachusetts Tautog Tagging Methods

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

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

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

### 5.4.2 Maryland Department of Natural Resources

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

### 5.4.3 Virginia Marine Resources Commission

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

### 5.5 Methods for Developing Estimates from State Indices

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

### 5.5.1 Massachusetts

5.5.1.1 Development of Estimates with the Massachusetts Spring Trawl Survey

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

5.5.1.2 Estimates

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

### 5.5.2 Rhode Island

5.5.2.1 Development of Estimates with the Rhode Island Trawl Survey

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

*5.5.2.1.1 Estimates*

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

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

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

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

##### *5.5.2.2.1 Estimates*

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

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

### 5.5.3 Connecticut

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

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

#### 5.5.3.2 Estimates

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

For the data, a negative binomial glm sub model of year, month, and stratum was selected because the model achieved convergence and it produced favorable diagnostics (Figures 5.22 – 5.24, Tables 5.16 and 5.17). One important note is that many of the continuous variables did not begin being collected until mid-way through the dataset, so the final model was constructed with the categorical data fields that spanned the entire time series. The index was variable over time, but exhibited a marked decrease during the time series with low catches beginning in the late-1990s

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

### 5.5.4 New York

#### 5.5.4.1 Development of Estimates with the Peconic Bay Trawl Survey

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

##### *5.5.4.1.2 Estimates*

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

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

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

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

##### *5.5.4.2.1 Estimates*

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

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

### 5.5.5 New Jersey

#### 5.5.5.1 Development of Estimates with the New Jersey Ocean Trawl Survey

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

##### *5.5.5.1.1 Estimates*

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

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

## 6.0 STOCK ASSESSMENT MODELS, METHODS, AND RESULTS

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

### 6.1 Age Structured Assessment Program (ASAP)

### 6.1.1 Background

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

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

### 6.1.2 Assessment Model Description

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

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

### 6.1.3 Reference Point Model Description

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

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

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

### 6.1.4 Configuration

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

#### 6.1.4.1 Spatial and Temporal Coverage

The ASAP model was run for three separate regions:

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

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

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

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

#### 6.1.4.2 Selection and Treatment of Indices

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

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

#### 6.1.4.3 Parameterization

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

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

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

#### 6.1.4.4 Weighting of Likelihoods

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

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

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

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

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

### 6.1.5 Estimating Precision

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

### 6.1.6 Sensitivity Analyses

#### 6.1.6.1 Sensitivity to Input Data

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

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

#### 6.1.6.2 Sensitivity to Model Configuration

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

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

### 6.1.7 Retrospective Analyses

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

### 6.1.8 ASAP Results

#### 6.1.8.1 Goodness of Fit

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

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

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

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

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

#### 6.1.8.2 Parameter Estimates

##### *6.1.8.2.1 Selectivities, Catchability, and the Stock-Recruitment Relationship*

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

Estimates of index catchabilities are shown in Table 6.2.

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

#### *6.1.8.2.2 Fishing Mortality*

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

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

#### *6.1.8.2.3 Abundance and Spawning Stock Biomass Estimates*

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

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

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

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

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

### 6.1.9.3 Sensitivity Analyses

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

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

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

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

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

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

### 6.1.9.4 Retrospective Analyses

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

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

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

#### 6.1.9.5 Reference Point Model

##### *6.1.9.5.1 Parameter Estimates*

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

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

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

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

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

##### *6.1.9.5.2 Sensitivity Analyses*

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

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

### 6.2.1 Background on X-DBSRA

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

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

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

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

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

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

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

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

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

*Recent advancements*

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

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

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

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

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

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

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

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

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

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

*Development of tautog model*

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

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

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

### 6.2.2 Reference Point Model Description

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

### 6.2.3 Configuration

6.2.3.1 Spatial and Temporal Coverage: Input Data

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

6.2.3.2 Selection and Treatment of Indices

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

6.2.3.3 Parameterization

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

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

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

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

### 6.2.4 Estimating Precision

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

### 6.2.5 Sensitivity Analyses

#### 6.2.5.1 Sensitivity to Survey Data

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

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

#### 6.2.5.2 Sensitivity to Model Configuration

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

#### 6.2.5.3 Sensitivity to Regional Structure

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

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

### 6.2.6 Potential Biases

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

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

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

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

### 6.2.7 Results for the Southern New England Region

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

#### 6.2.7.1 Parameter Estimates (include precision of estimates)

##### *6.2.7.1.1 Input parameters*

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

##### *6.2.7.1.2 Exploitation Rates*

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

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

#### *6.2.7.1.3 Biomass Estimates*

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

#### *6.2.7.1.4 Reference Points*

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

### 6.2.7.2 Sensitivity Analyses

#### *6.2.7.2.1 Sensitivity to Survey Data*

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

#### *6.2.7.2.2 Sensitivity to Model Configuration*

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

#### *6.2.7.2.3 Sensitivity to Regional Structure*

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

### 6.2.8 Results for the New York-New Jersey Region

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

#### 6.2.8.1 Parameter Estimates

##### *6.2.8.1.1 Input parameters*

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

##### *6.2.8.1.2 Exploitation Rates*

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

##### *6.2.8.1.3 Biomass Estimates*

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

##### *6.2.8.1.4 Reference Points*

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

6.2.8.2 Sensitivity Analyses

### *6.2.8.2.1 Sensitivity to Survey Data*

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

### *6.2.8.2.2 Sensitivity to Model Configuration*

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

### *6.2.8.2.3 Sensitivity to Regional Structure*

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

## **6.2.9 Results for the DelMarVa Region**

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

6.2.9.1 Parameter Estimates (include precision of estimates)

### *6.2.9.1.1 Input parameters*

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

### *6.2.9.1.2 Exploitation Rates*

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

###### *6.2.9.1.3 Biomass Estimates*

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

###### *6.2.9.1.4 Reference Points*

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

#### 6.2.9.2 Sensitivity Analyses

###### *6.2.9.2.1 Sensitivity to Survey Data*

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

###### *6.2.5.2.2 Sensitivity to Model Configuration*

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

## 6.3 Bayesian State Space Surplus Production (BSSSP)

### 6.3.1 Background

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

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

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

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

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

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

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

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

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

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

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

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

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

### 6.3.2 Configuration

#### 6.3.2.1 Spatial and Temporal Coverage

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

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

### 6.3.2.2 Selection and Treatment of Indices

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

### 6.3.2.3 Parameterization

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

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

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

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

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

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

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

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

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

### 6.3.3 Estimating Precision

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

### 6.3.4 Sensitivity Analyses

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

#### 6.3.4.1 Sensitivity to Input Data

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

#### 6.3.4.2 Sensitivity to Model Configuration

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

### 6.3.5 Results

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

#### 6.3.5.1 Goodness of Fit

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

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

### 6.3.5.2 Parameter Estimates

#### *6.3.5.2.1 r and K.*

*Southern New England (SNE)*

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

*New York – New Jersey (NY-NJ)*

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

*DelMarVa (DMV)*

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

#### *6.3.5.2.2 Exploitation Rates*

*Southern New England (SNE)*

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

*New York – New Jersey (NY-NJ)*

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

*DelMarVa (DMV)*

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

#### *6.3.5.2.3 Abundance or Biomass Estimates*

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

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

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

#### *6.3.5.2.4 Reference Points*

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

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

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

occurring) according to this modeling approach, and harvest is currently below the MSY level in the terminal year (Table 6.21).

### *DelMarVa (DMV)*

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

### 6.3.5.3 Sensitivity Analyses

#### *6.3.5.3.1 Sensitivity to Input Data*

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

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

#### *6.3.5.3.2 Sensitivity to Model Configuration*

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

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

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

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

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

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

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

## 6.4 Virtual Population Analysis (Continuity Run)

### 6.4.1 Background

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

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

### 6.4.2 Reference Point Model Description

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

### 6.4.3 Configuration

#### 6.4.3.1 Spatial and Temporal Coverage

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

#### 6.4.3.2 Selection and Treatment of Indices

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

#### 6.4.2.3 Parameterization

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

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

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

### 6.4.3 Estimating Precision

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

### 6.4.4 Sensitivity Analyses

#### 6.4.4.1 Sensitivity to Input Data

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

### 6.4.5 Retrospective Analyses

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

### 6.4.6 Results

#### 6.4.6.1 Goodness of Fit

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

#### 6.4.6.2 Parameter Estimates

##### *6.4.6.2.1 Selectivities and Catchability*

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

##### *6.4.6.2.2 Exploitation Rates (nlls estimates)*

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

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

#### *6.4.6.2.3 Abundance or Biomass Estimates*

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

### 6.4.6.3 Sensitivity Analyses

#### *6.4.6.3.1 Sensitivity to Input Data*

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

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

### 6.4.6.4 Retrospective Analyses

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

### 6.4.6.7 Results Uncertainty

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

## 6.4.7 ASAP Extension of the VPA Continuity Run

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

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

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

## 6.5 Additional Models Considered

### 6.5.1 Depletion Corrected Average Catch

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

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

### 6.5.2 Catch-MSY Method

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

## 6.6 Comparison of Models and Results

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

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

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

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

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

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

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

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

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

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

## 7.0 STOCK STATUS

### 7.1 Current Overfishing and Overfished Definitions

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

### 7.2 New Proposed Definitions

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

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

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

### 7.3 Stock Status Determination

#### 7.3.1 Overfishing Status

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

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

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

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

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

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

### 7.3.2 Overfished Status

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

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

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

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

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

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

## 8.0 RESEARCH RECOMMENDATIONS

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

### 8.1 Fishery-Dependent Priorities

***High***

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

### 8.2 Fishery-Independent Priorities

***High***

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

### 8.3 Life History, Biological, and Habitat Priorities

***Moderate***

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

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

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

***Low***

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

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

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

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

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

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

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

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

### 8.4 Management, Law Enforcement, and Socioeconomic Priorities

***Moderate***

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

***Low***

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

### 8.5 Research Recommendations That Have Been Met

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

### 8.6 Future Stock Assessments

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

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## 11.0 Tables

**Table 1.1.** Recreational regulations for tautog by state.

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

**Table 1.2.** Commercial regulations for tautog by state.

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

**Table 2.1.** Von Bertalanffy parameter estimates by region scenario.

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

**Table 2.2.** Von Bertalanffy parameter estimates by state.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Table 5.6.** MRIP CPUE by region.

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

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

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

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

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

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

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

**Table 5.10.** Index values for the Massachusetts Trawl Survey.

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

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

| Parameter | VIF | Df |
|---|---|---|
| **Year** | 1.488 | 35 |
| **Temp** | 1.633 | 1 |
| **Depth** | 1.070 | 1 |

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

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

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

| Parameter | VIF | Df |
|---|---|---|
| **Year** | 1.865 | 34 |
| **Temp** | 2.448 | 1 |
| **Depth** | 1.711 | 1 |

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

| **Southern New England** | |
|---|---|
| Total Likelihood | 1933.9 |
| Index RMSE | |
| MA Trawl | 1.19 |
| RI Trawl | 1.18 |
| RI Seine | 1.15 |
| CT Trawl | 0.91 |
| MRIP CPUE | 1.10 |
| N=30, 5%-95% RMSE values for N(0,1) = 0.79 - 1.21 | |
| | |
| **New York-New Jersey** | |
| Total Likelihood | 1090.2 |
| Index RMSE | |
| NY Trawl (YOY) | 1.14 |
| NY Seine (YOY) | 1.40 |
| NJ Trawl | 1.09 |
| MRIP CPUE | 0.82 |
| N=30, 5%-95% RMSE values for N(0,1) = 0.79 - 1.21 | |
| | |
| **DelMarVa** | |
| Total Likelihood | 905.5 |
| Index RMSE | |
| MRIP CPUE | 1.09 |

**Table 6.2.** Index catchability coefficients from the ASAP model.

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

**Table 6.3.** Annual fishing mortality estimates from ASAP model.

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

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

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

**Table 6.5.** Sensitivity Runs

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

| Region | $K_{chain1}$ | $K_{chain2}$ | $r_{chain1}$ | $r_{chain2}$ | $\text{inv}_{\text{chain1}}$ | $\text{inv}_{\text{chain2}}$ |
|---|---|---|---|---|---|---|
| **Southern New England** | 15 | 5 | 0.5 | 0.2 | 900 | 1100 |
| **New York – New Jersey** | 10 | 5 | 0.5 | 0.2 | 900 | 1100 |
| **DelMarVa** | 10 | 5 | 0.5 | 0.2 | 900 | 1100 |

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

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

**Table 6.22.** Back-calculated partial recruitment of tautog.

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

**Table 6.23.** Catchability estimates for tautog.

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

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

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

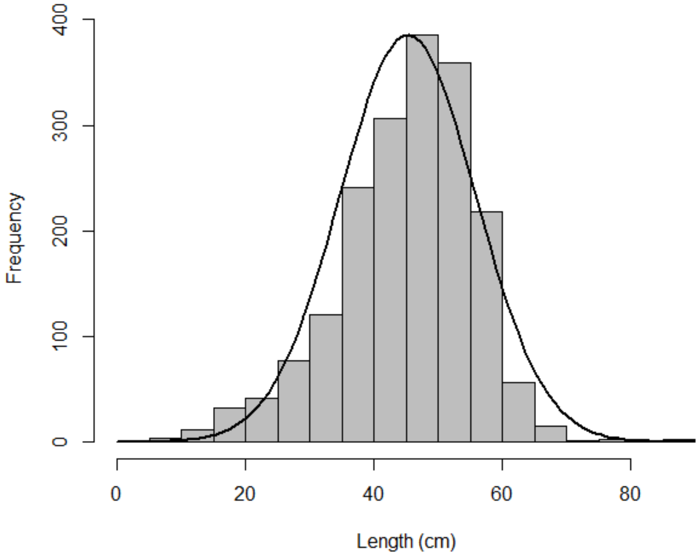
| Age | Maturity | Partial recruitment |
|---|---|---|
| **1** | 0.000 | 0.000 |
| **2** | 0.100 | 0.270 |
| **3** | 0.500 | 0.215 |
| **4** | 0.750 | 0.328 |
| **5** | 1.000 | 0.519 |
| **6** | 1.000 | 0.617 |
| **7** | 1.000 | 0.827 |
| **8** | 1.000 | 0.921 |
| **9** | 1.000 | 1.000 |
| **10** | 1.000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

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

| | SOUTHERN NEW ENGLAND | NEW YORK-NEW JERSEY | DELMARVA |
|---|---|---|---|
| $F_{target}$ | 0.15 | 0.17 | 0.16 |
| $F_{threshold}$ | 0.20 | 0.26 | 0.24 |
| 3-year Avg. F | 0.48 | 0.25 | 0.17 |
| $SSB_{target}$ | 3,883 | 3,570 | 2,090 |
| $SSB_{threshold}$ | 2,912 | 2,640 | 1,580 |
| $SSB_{2013}$ | 1,839 | 2,079 | 1,532 |
| Stock Status | Overfishing, Overfished | Not overfishing, Overfished | Not overfishing, Overfished |

## 12.0 FIGURES

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



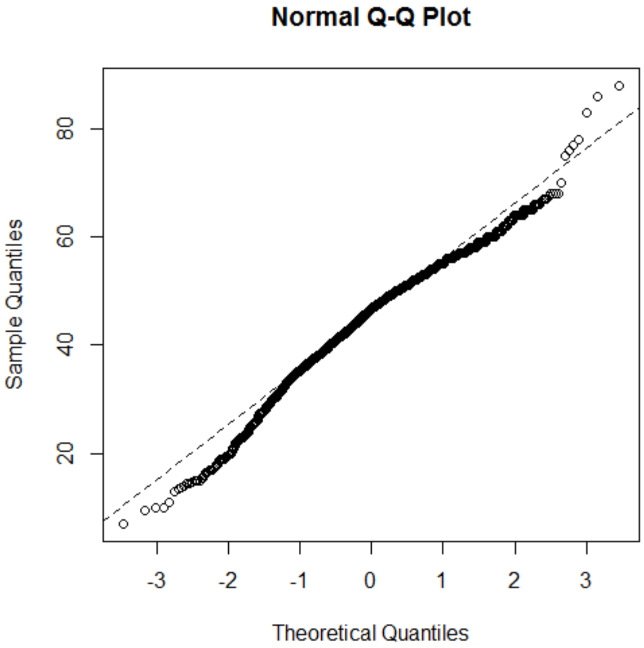


**Figure 2.2.** Von Bertalanffy growth curves by state.

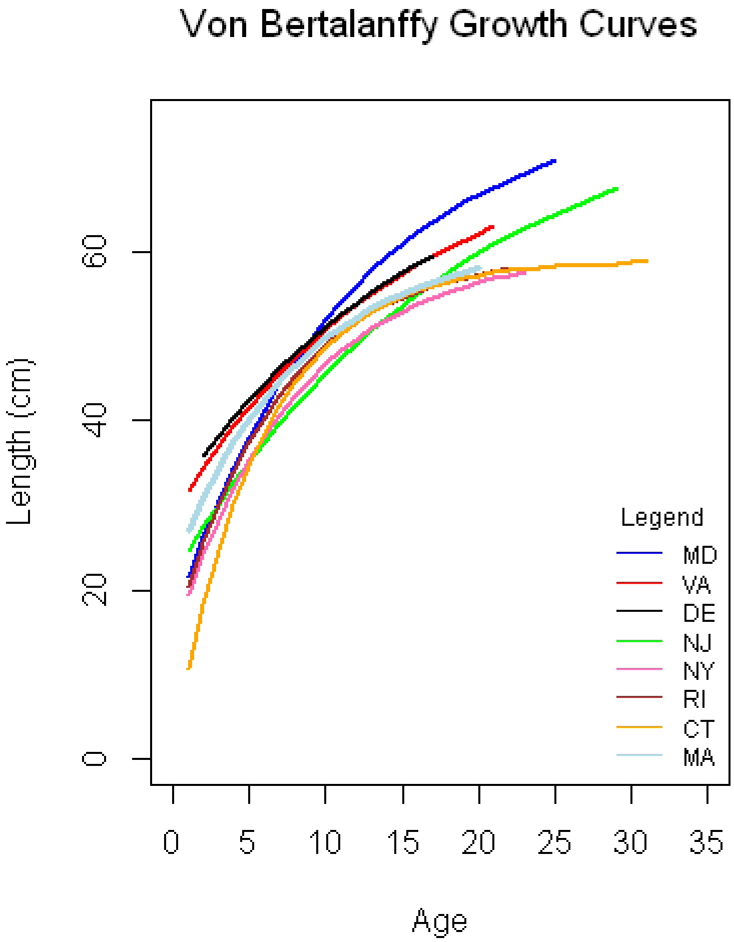
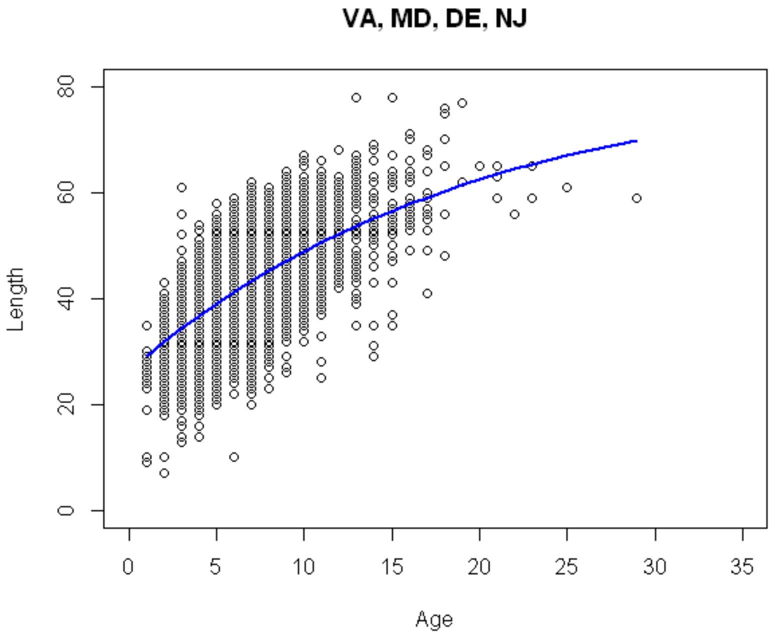


**Figure 2.3.** Von Bertalanffy data and growth curve for southern states and northern states (from 2-region scenario).



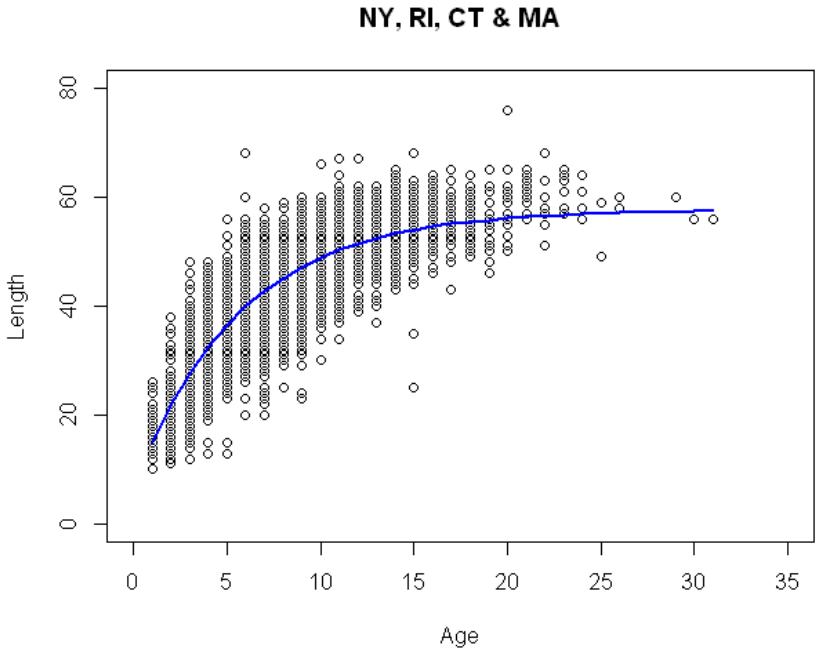


**Figure 2.4.** Mean (±SD) length-at-age for northern (MA, CT, RI, NY) and southern (NJ, DE, MD, VA) regions in Model 1. Error bars are 1 standard deviation.

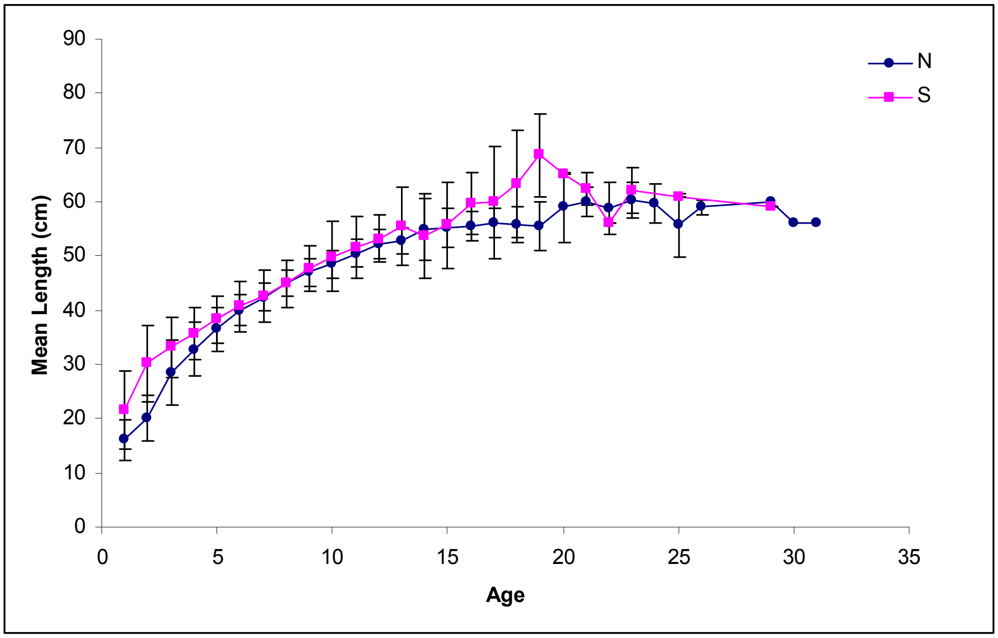


**Figure 2.5.** Mean (±SD) length-at-age for northern (MA, CT, RI), mid-Atlantic (NY, NJ), and southern (DE, MD, VA) regions in Model 2. Error bars are 1 standard deviation.

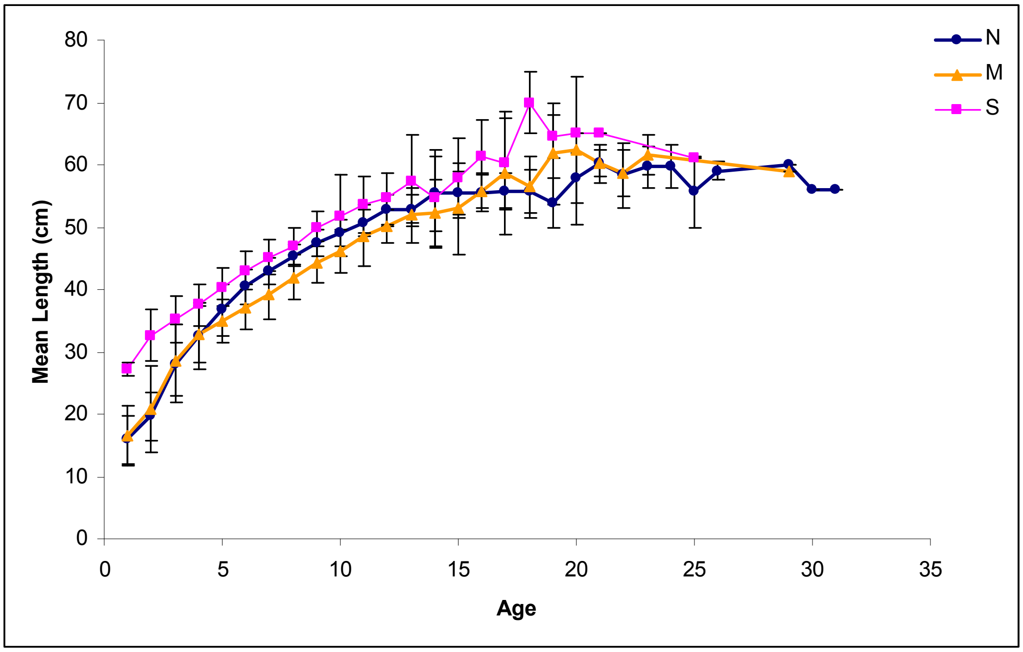


**Figure 2.6.** Mean length-at-age for all states in Model 3. To improve clarity, error bars were not included.

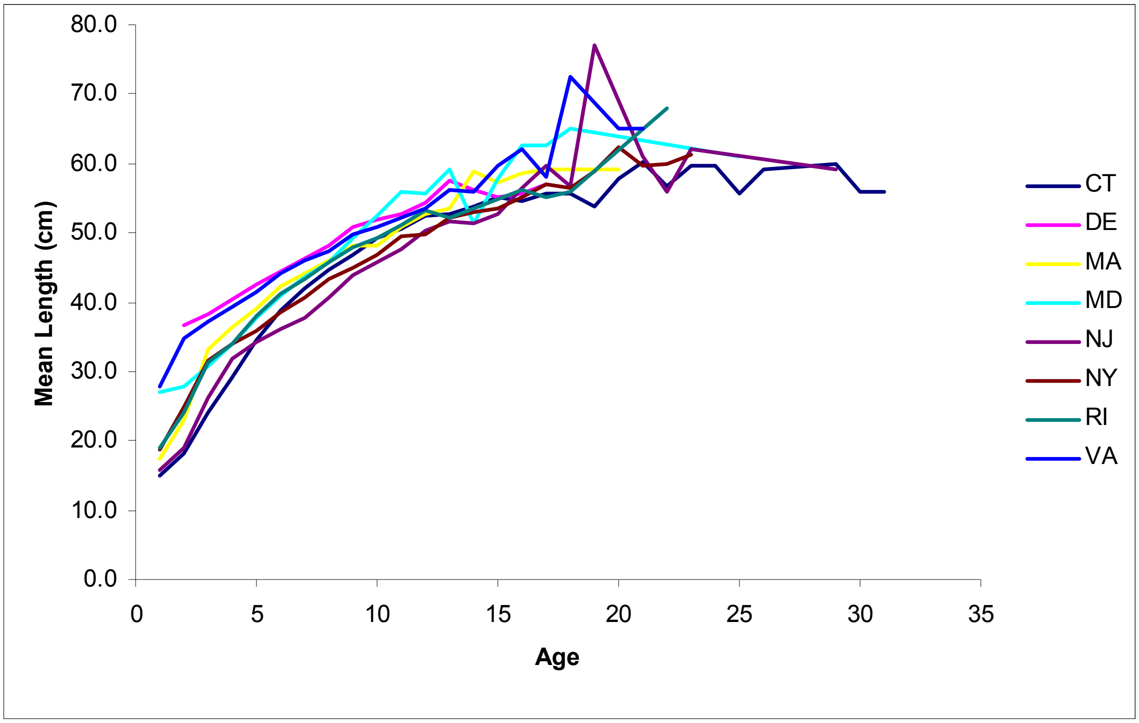


**Figure 2.7.** Length-weight relationships for tautog by state.

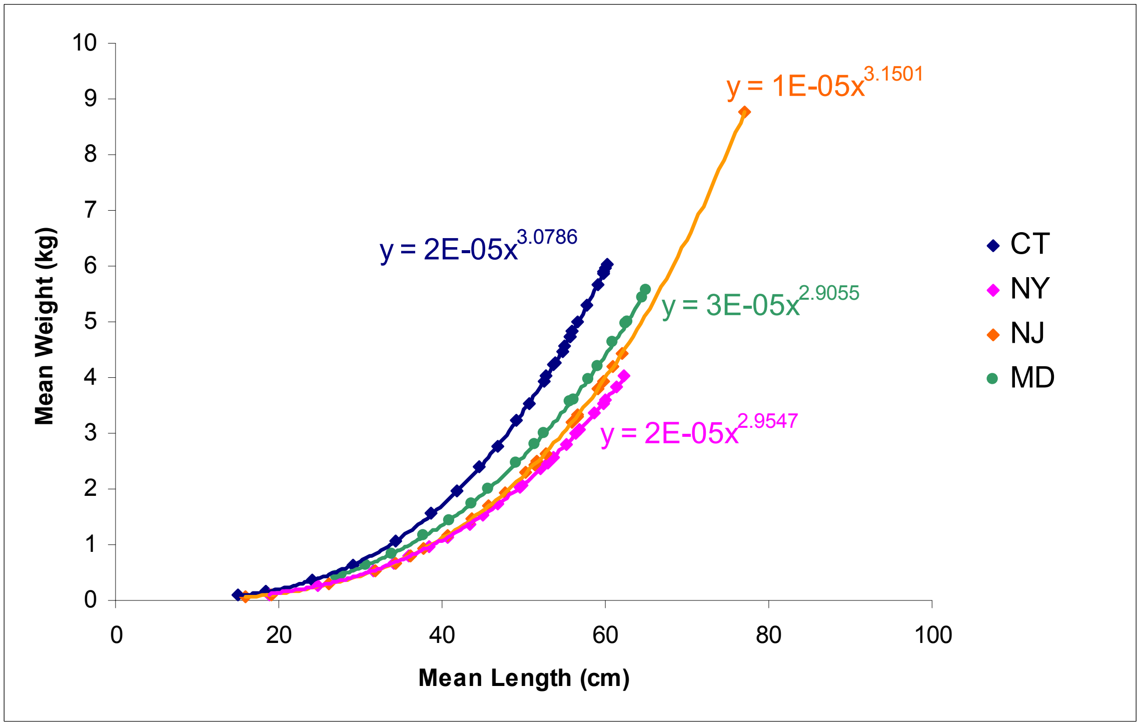


**Figure 2.8.** Mean weight-at-age by state. The length-weight relationship was used to get weight-at-age for states without weight data. Data from CT was applied to MA and RI. Data from NJ was applied to DE, and data from MD was applied to VA.

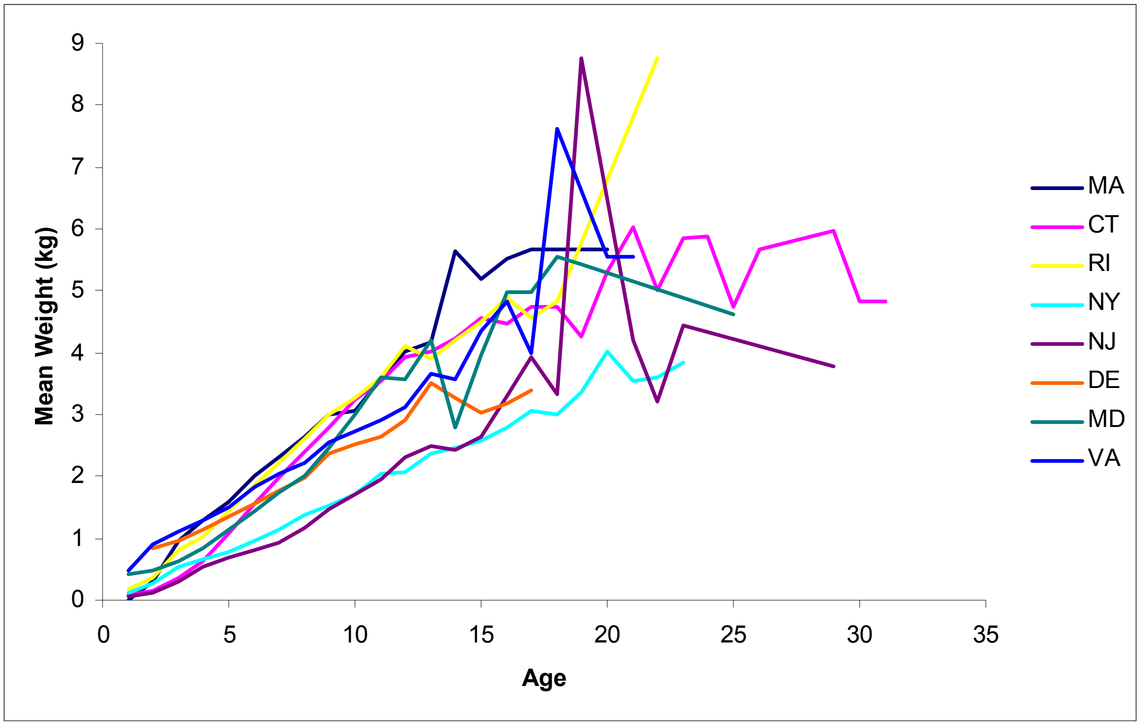


**Figure 4.1.** Coastwide commercial landings and values from 1950-2012. Source: NOAA Commercial Fisheries Database http://www.st.nmfs.noaa.gov/commercial-fisheries/index.

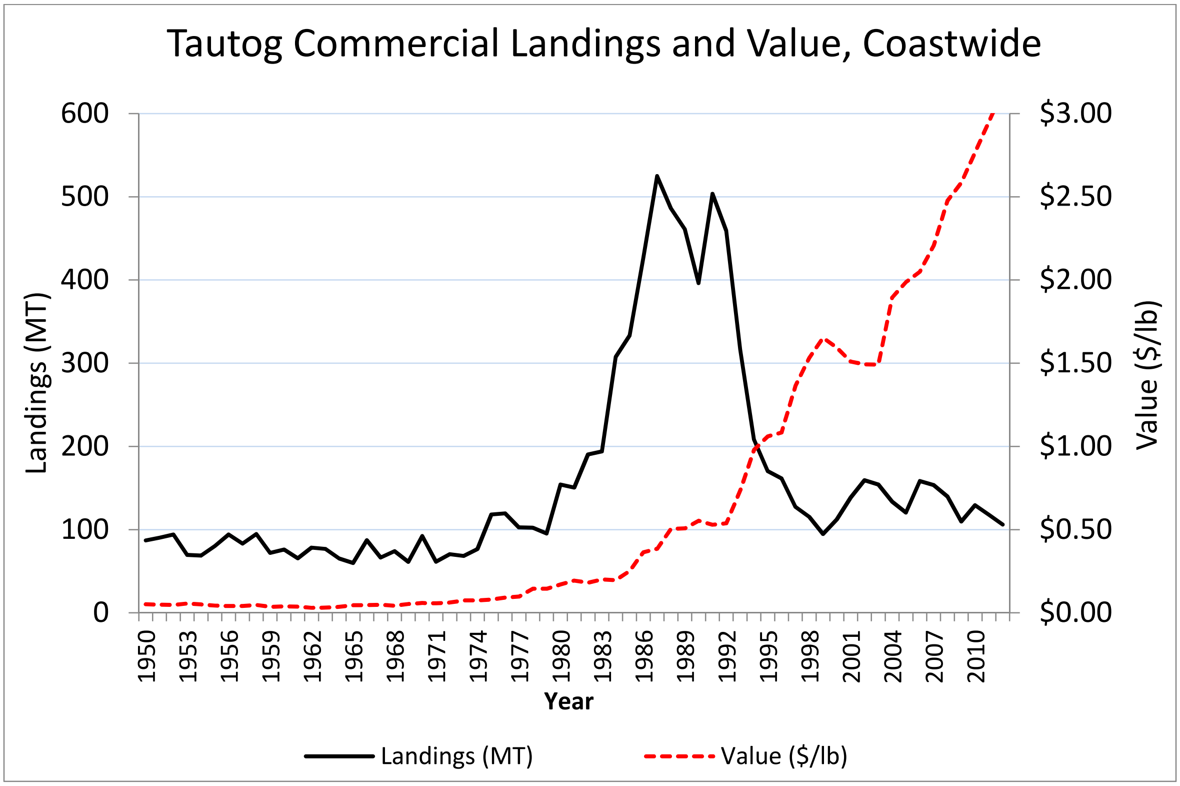


**Figure 4.2.** Relative activity of the commercial tautog fishery by month, based on commercial landings from 1990-2012.

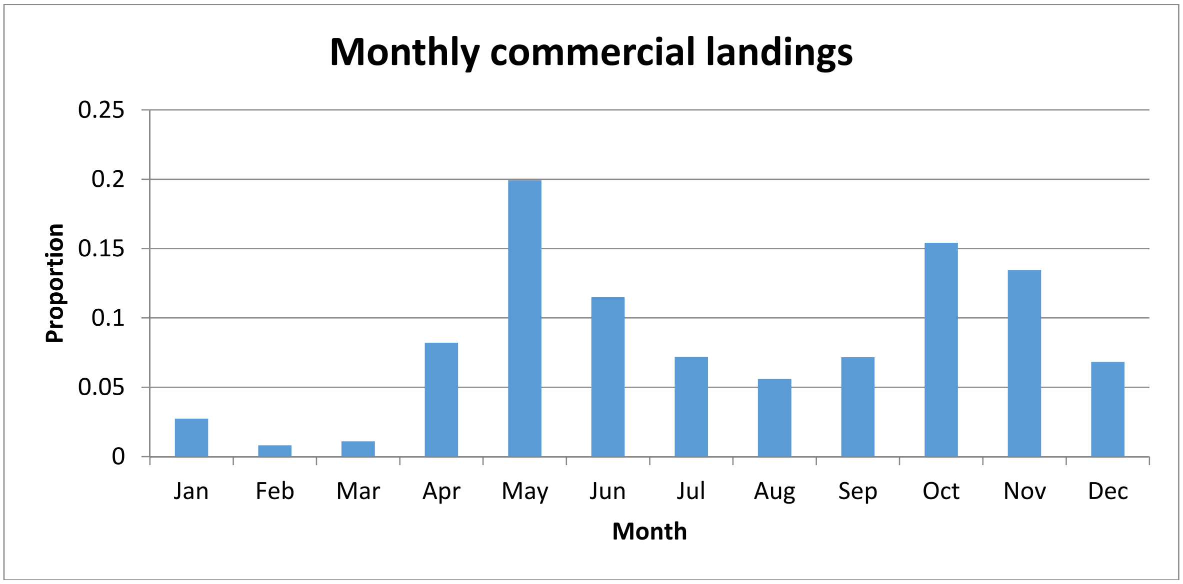


**Figure 4.3.** Relative activity of commercial tautog harvest by state, based on commercial landings from 1982-2012.

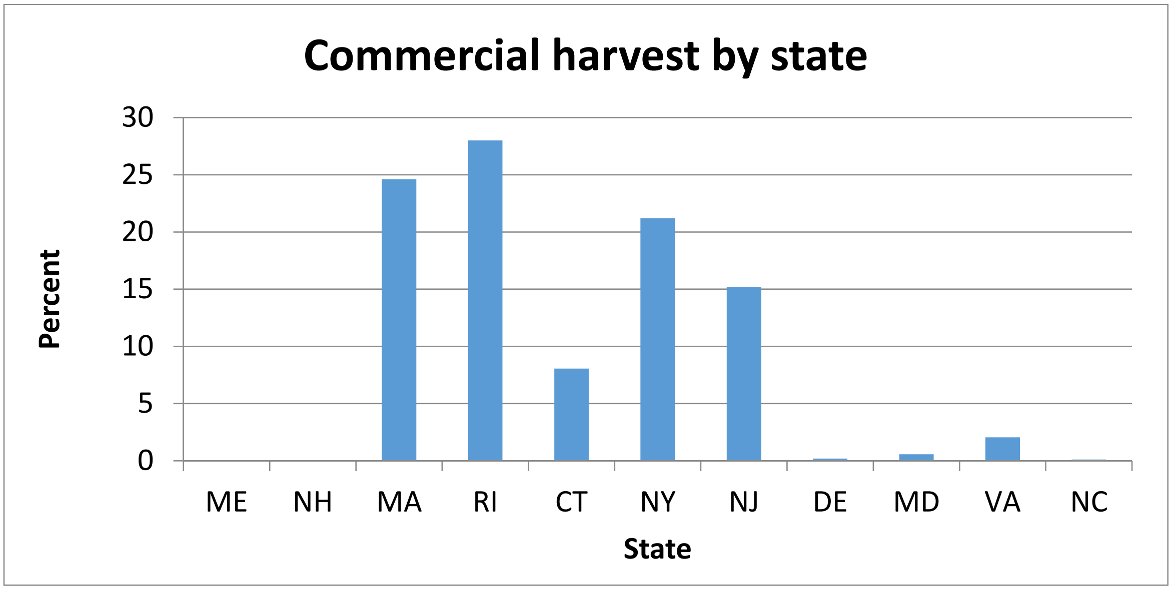


**Figure 4.4.** Relative commercial tautog landings by fishing gear, based on commercial landings from 1982-2012.

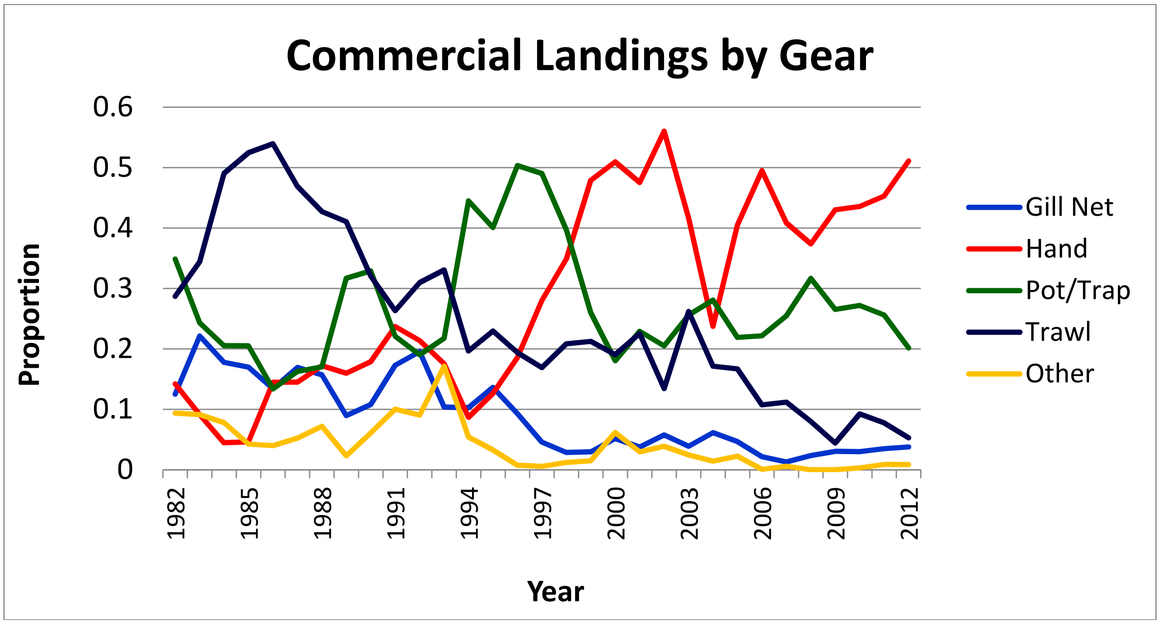


**Figure 4.5.** Total harvest of tautog (recreational and commercial landings) in metric tons. Source: NOAA Fisheries Commercial Fisheries Statistics Database, MRFSS, and MRIP.

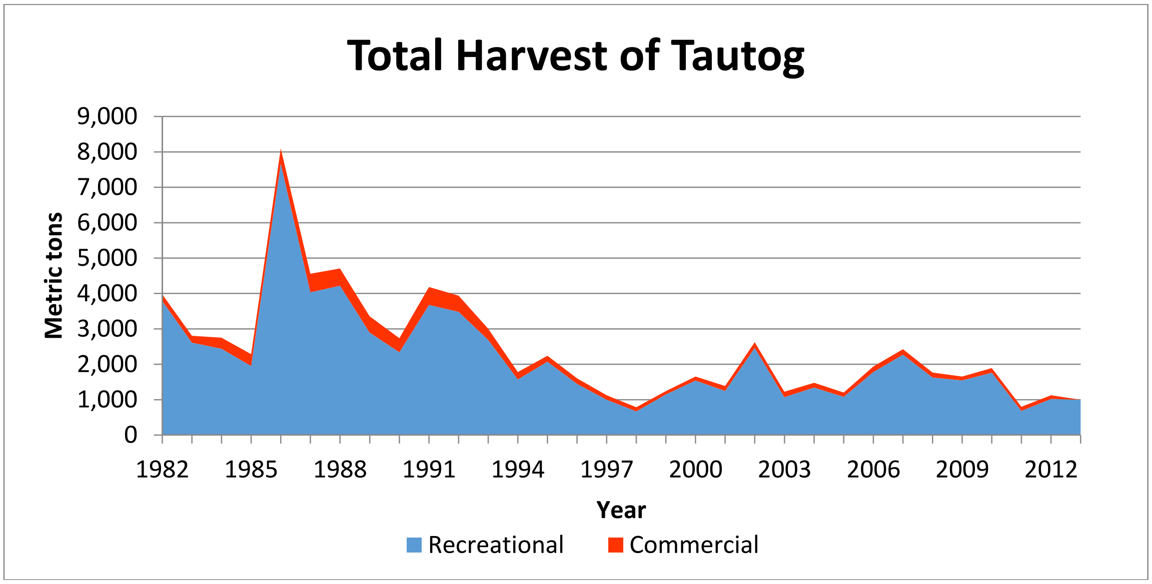


**Figure 4.6.** Coastwide recreational harvest by weight (pounds) and number of fish.

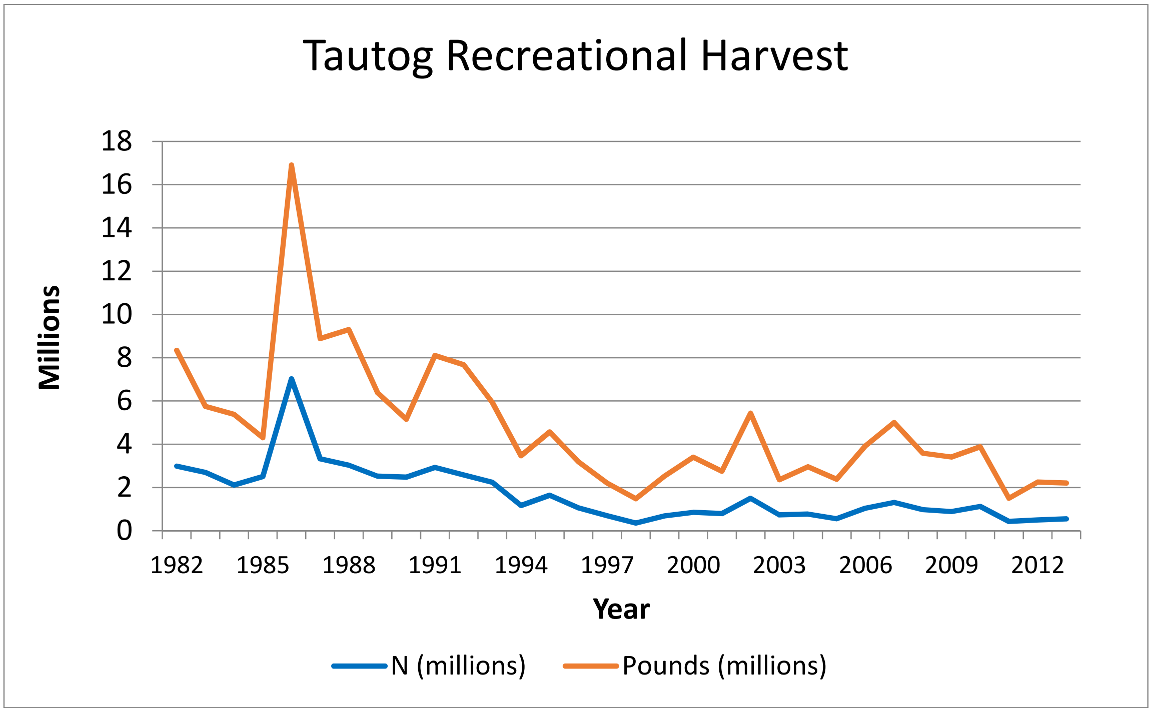


**Figure 4.7.** Coastwide recreational harvest by state. Source: MRIP.

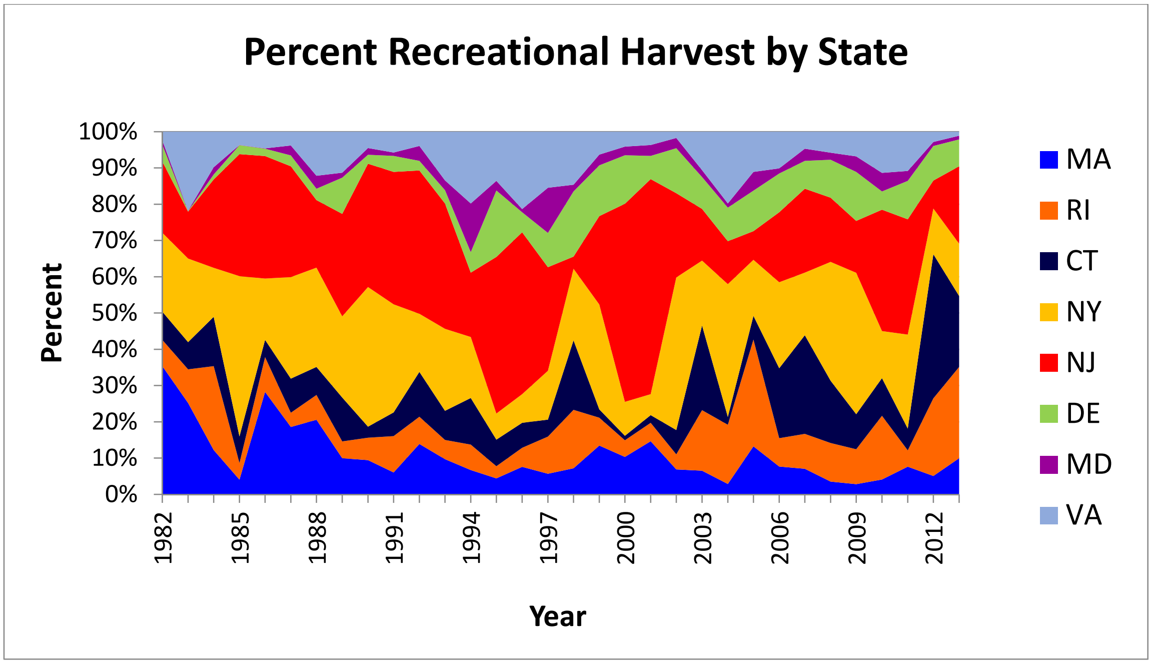


**Figure 4.8.** Coastwide recreational harvest by state. Source: MRIP

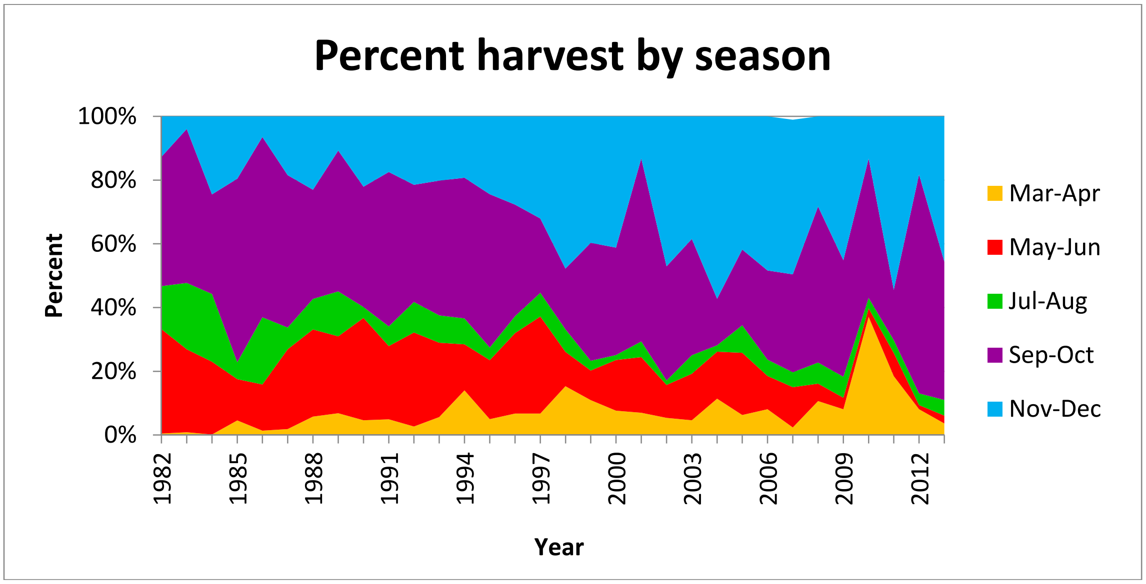


**Figure 4.9.** Coastwide recreational harvest by fishing mode. Source: MRIP

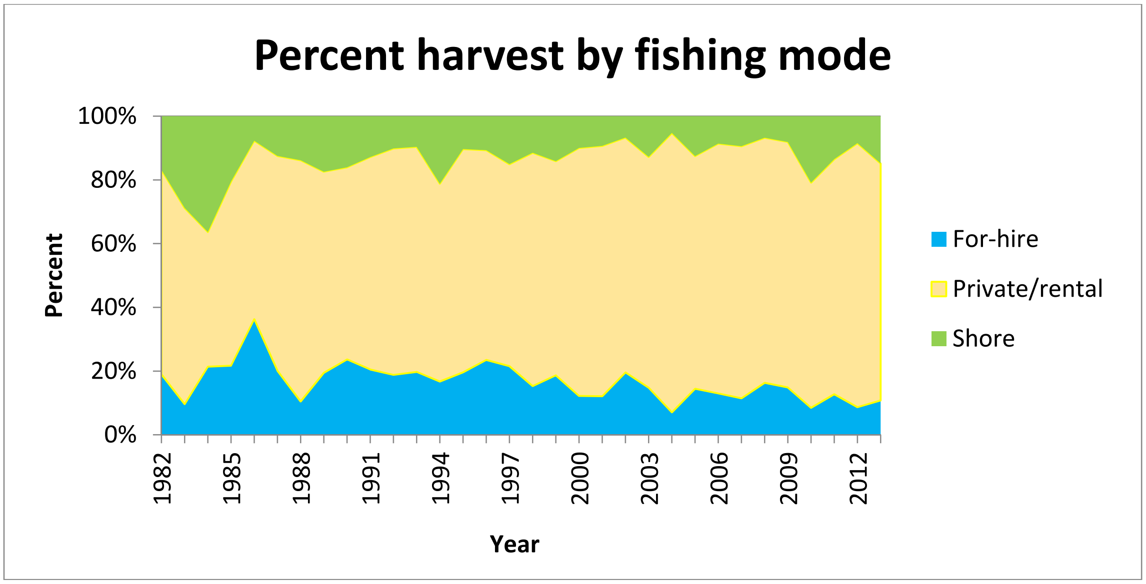


**Figure 5.1.** Number of observed commercial trips by year, region, and gear type that retained or discarded tautog.

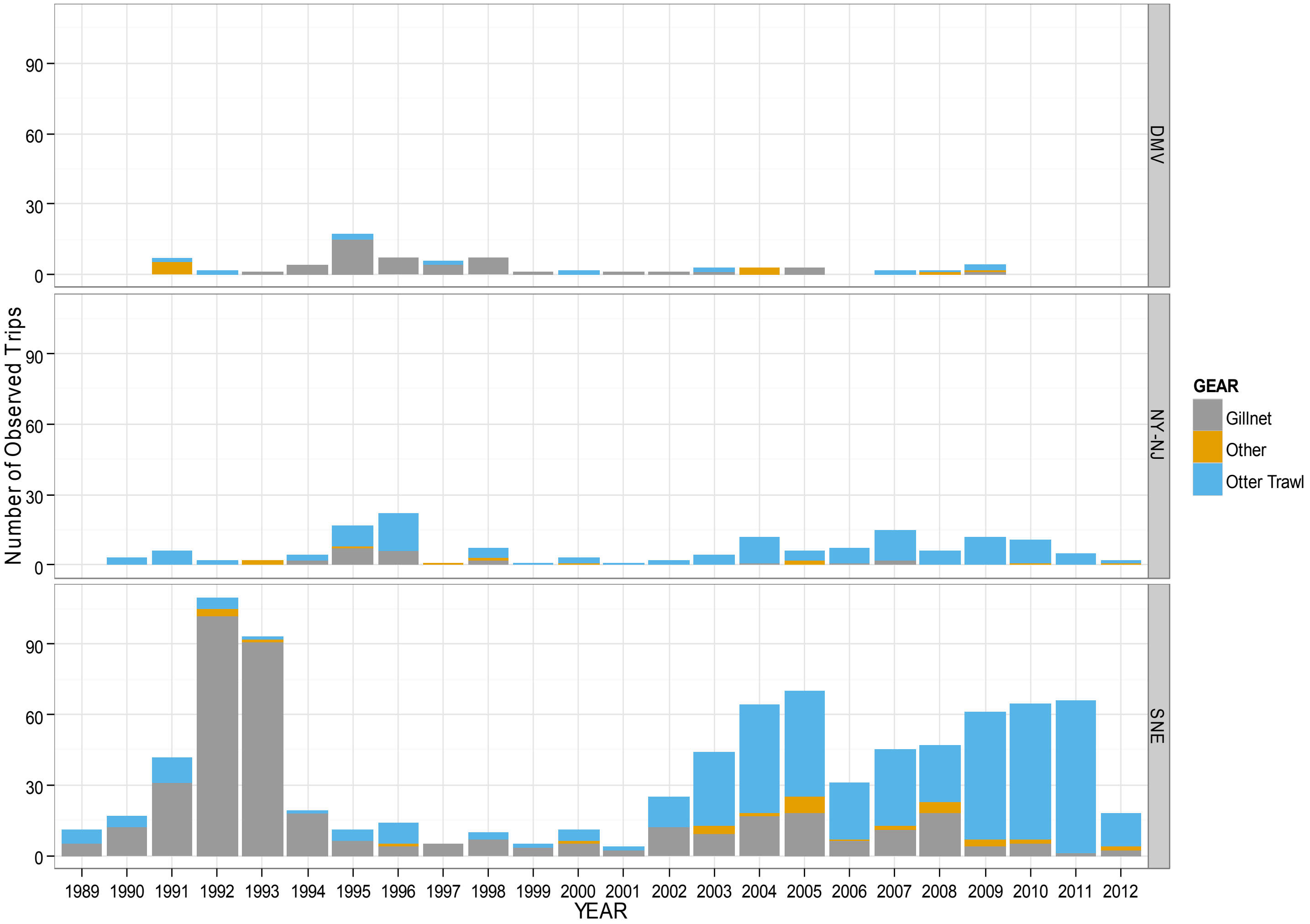


**Figure 5.2.** Length frequencies of commercially retained and discarded tautog by year from observer data.

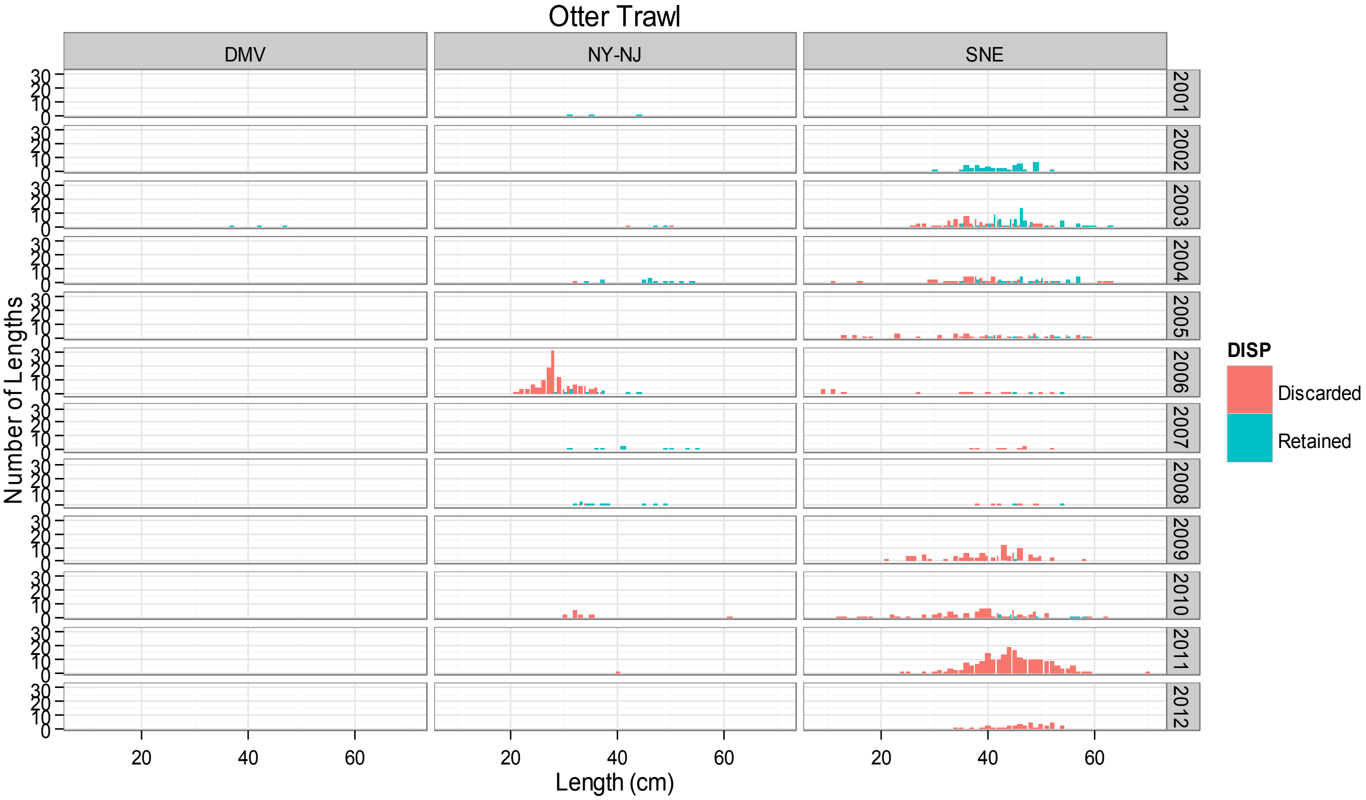
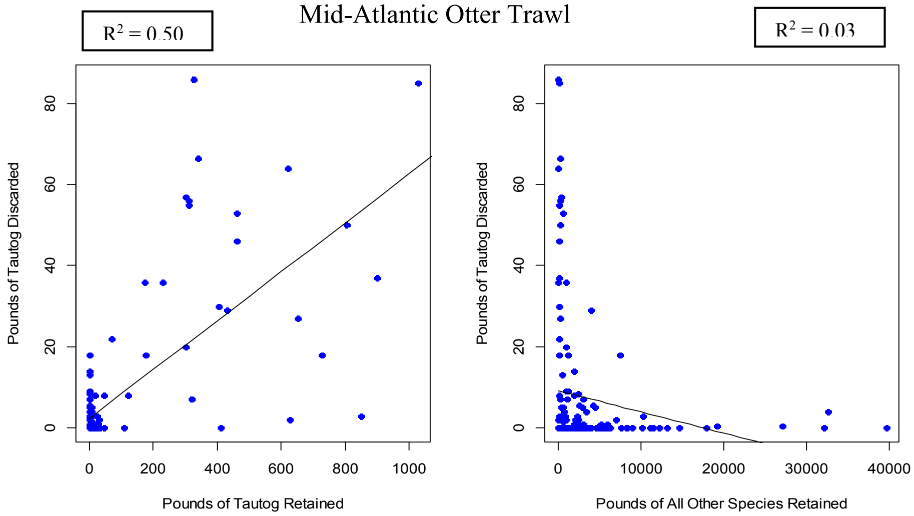
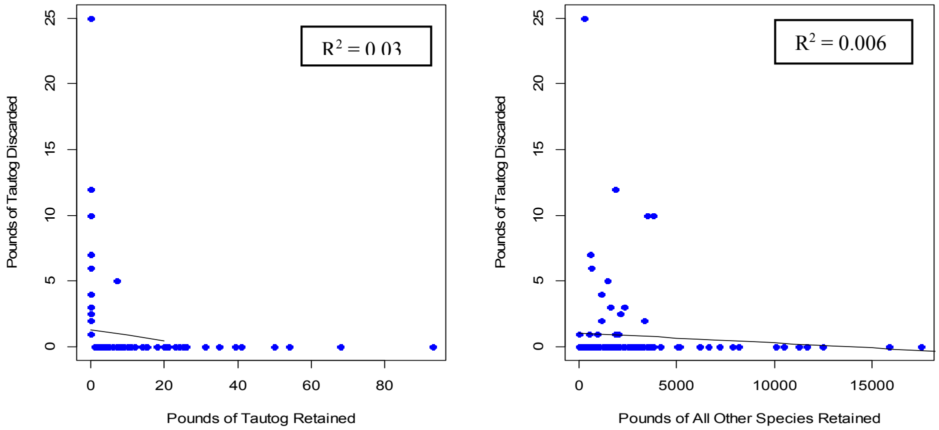


**Figure 5.3.A.** Relationship between pounds of tautog retained and pounds of tautog (left) or other species (right) retained on observed commercial trips in the Mid-Atlantic region.

Mid-Atlantic Otter Trawl



Mid-Atlantic Gillnet



Mid-Atlantic Other Gear

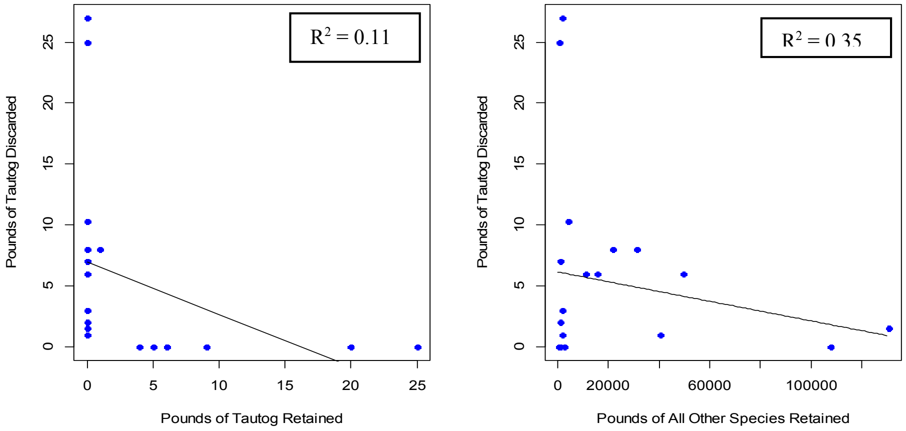
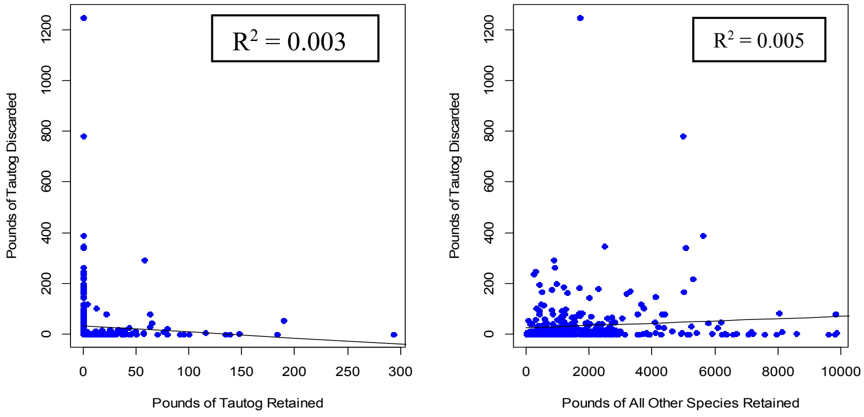
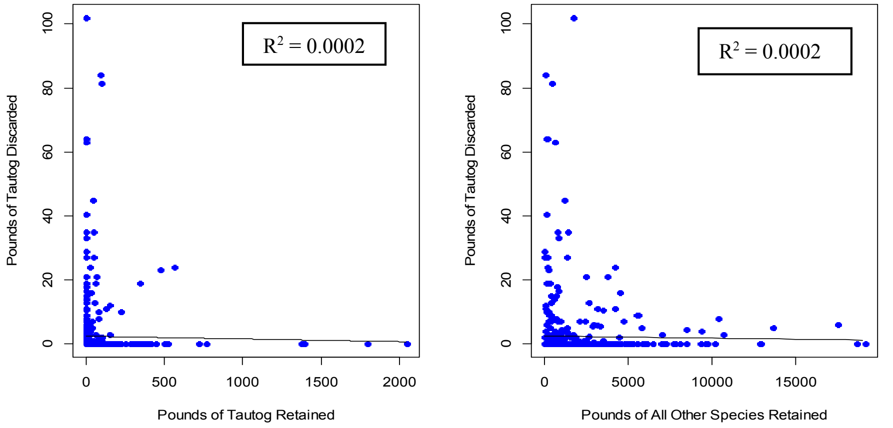


**Figure 5.3.B.** Relationship between pounds of tautog retained and pounds of tautog (left) or other species (right) retained on observed commercial trips in the New England region.

New England Otter Trawls



New England Gillnets



New England Other Gear

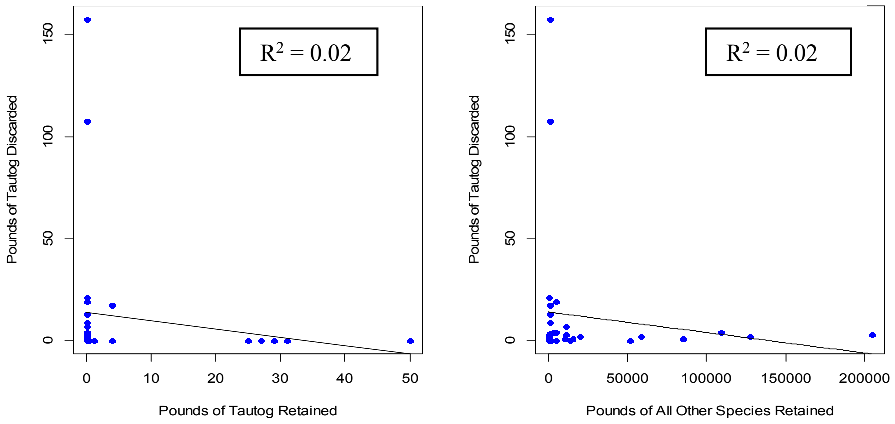


**Figure 5.4.** Total landings of tautog by source for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

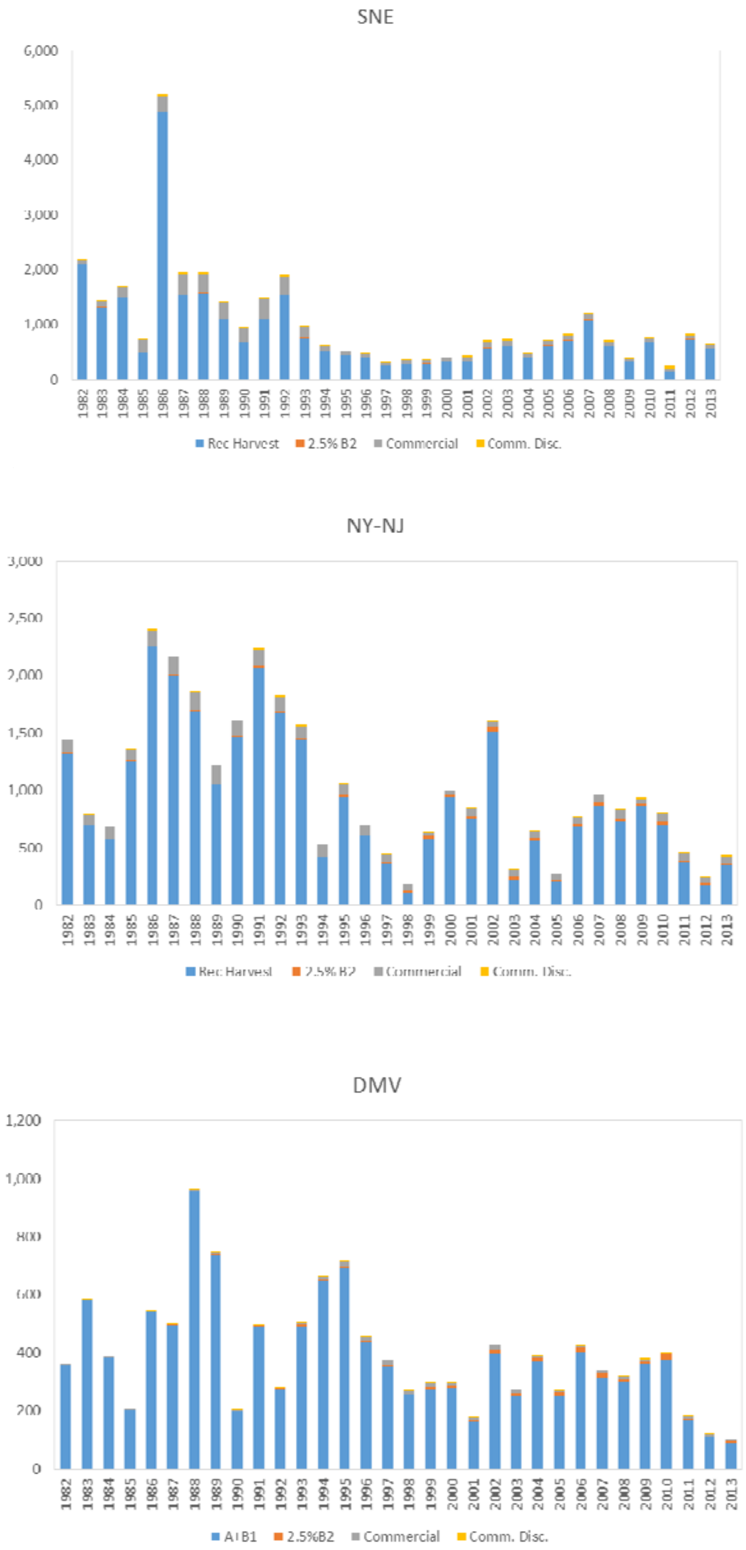
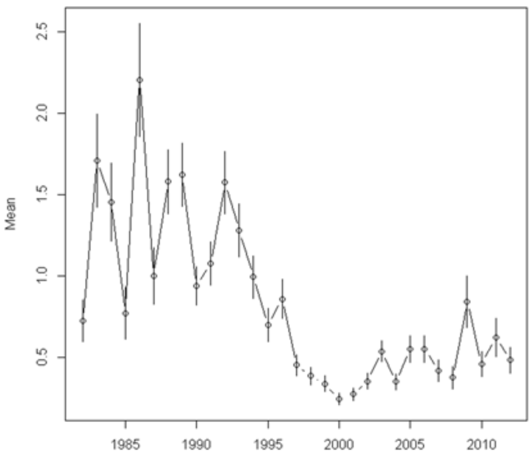
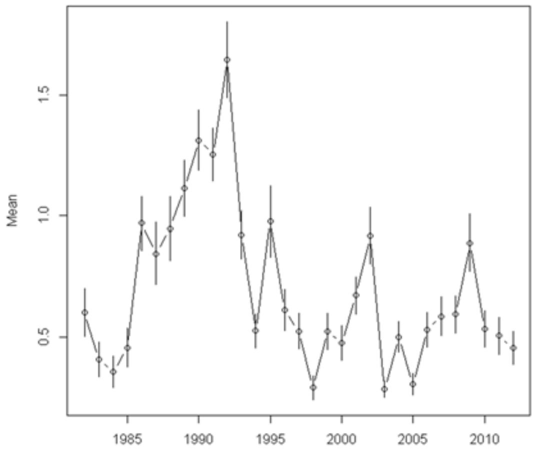


**Figure 5.5.** Standardized MRIP CPUE for the Southern New England (top), NY-NJ (middle), and DelMarVa region (bottom).

SNE



NY-NJ



DMV

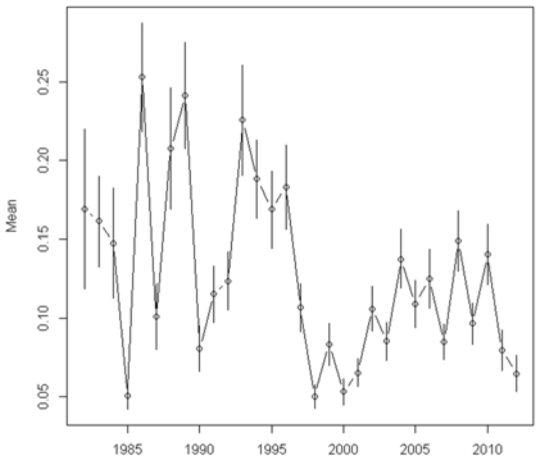


**Figure 5.6.** Recreational vs. commercial length frequencies for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions by regulatory period.

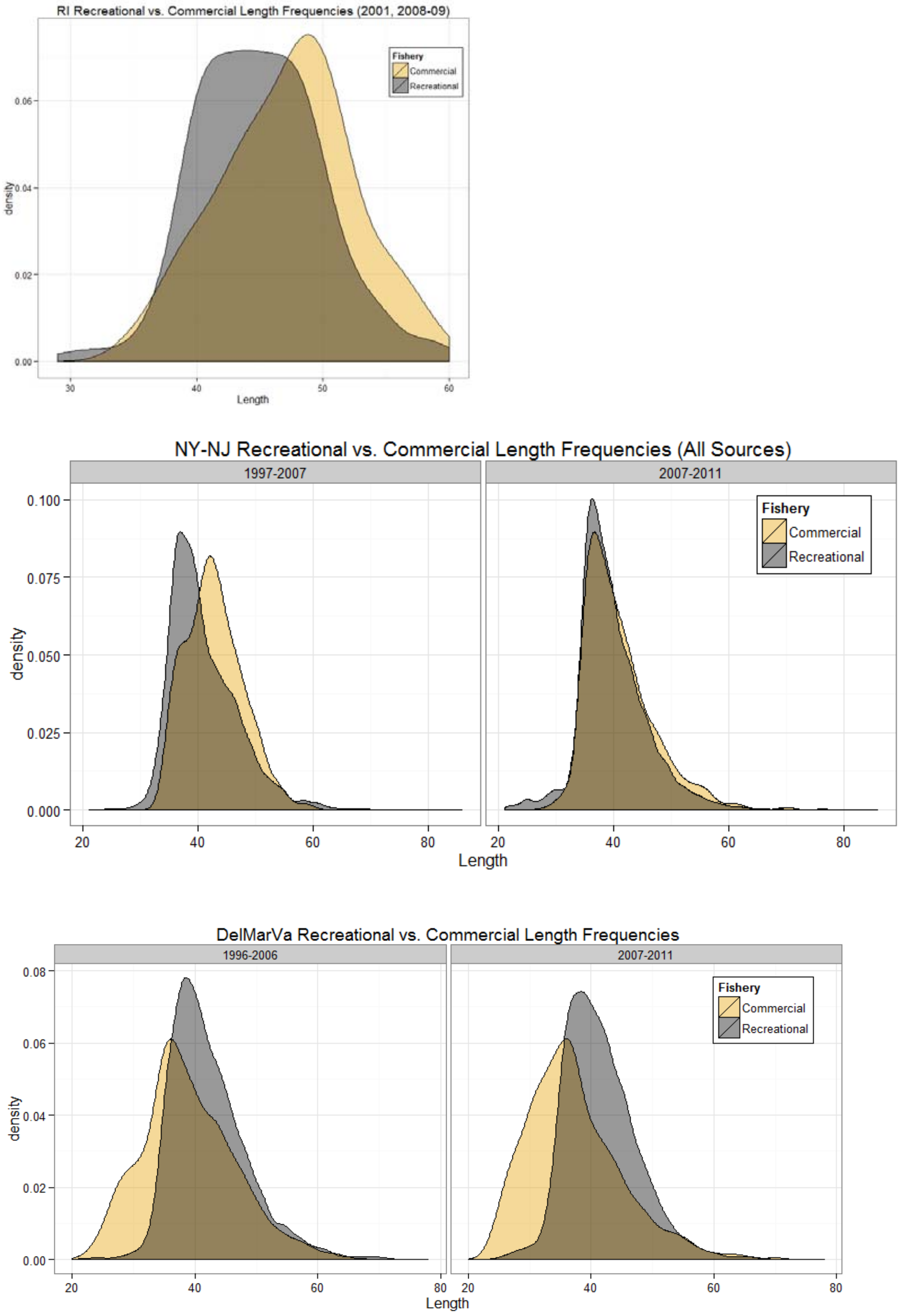


**Figure 5.7.** Recreational harvest vs. released alive length frequencies for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions by regulatory period.

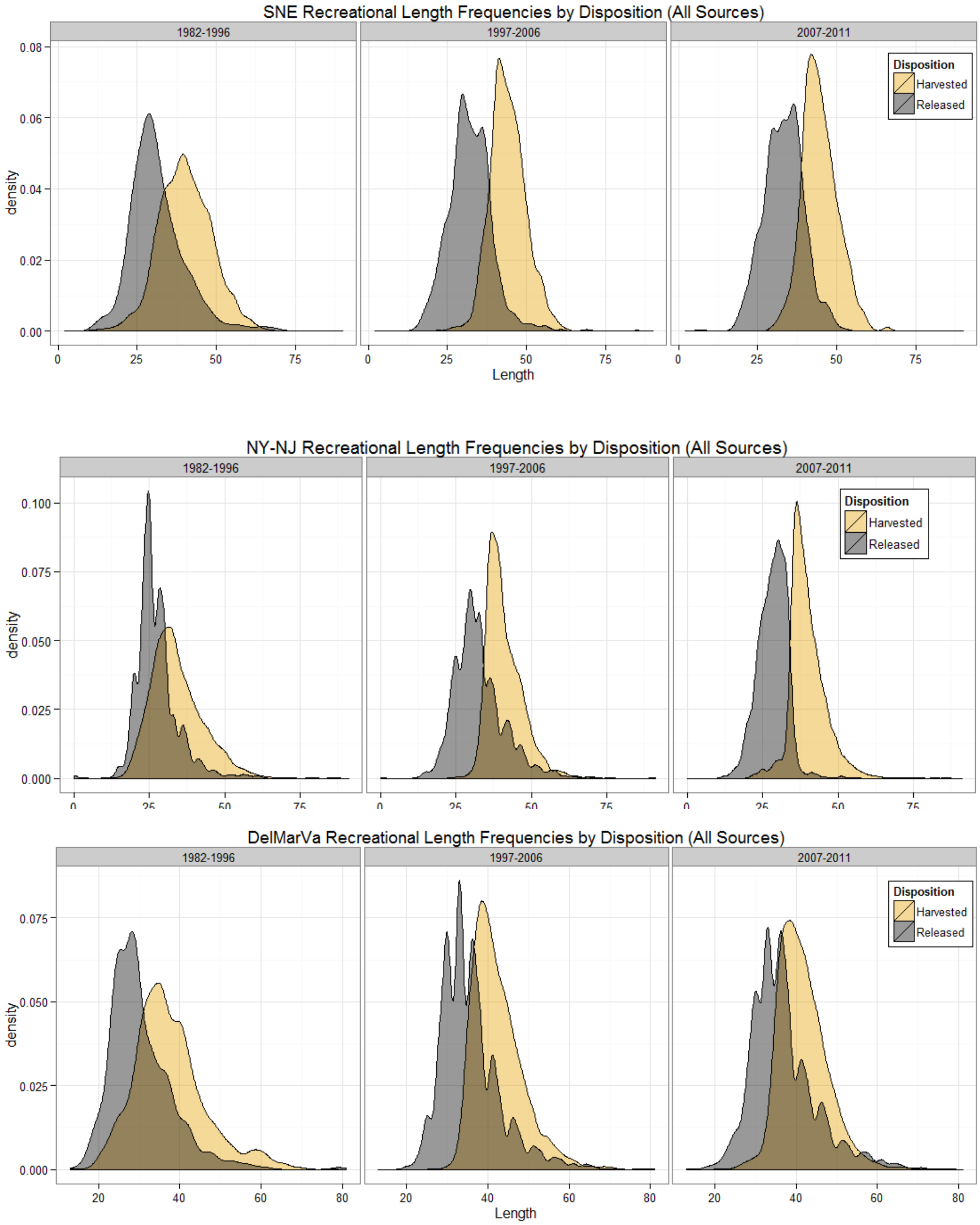


**Figure 5.8.** Recreational released alive length frequencies for the southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions by data source.

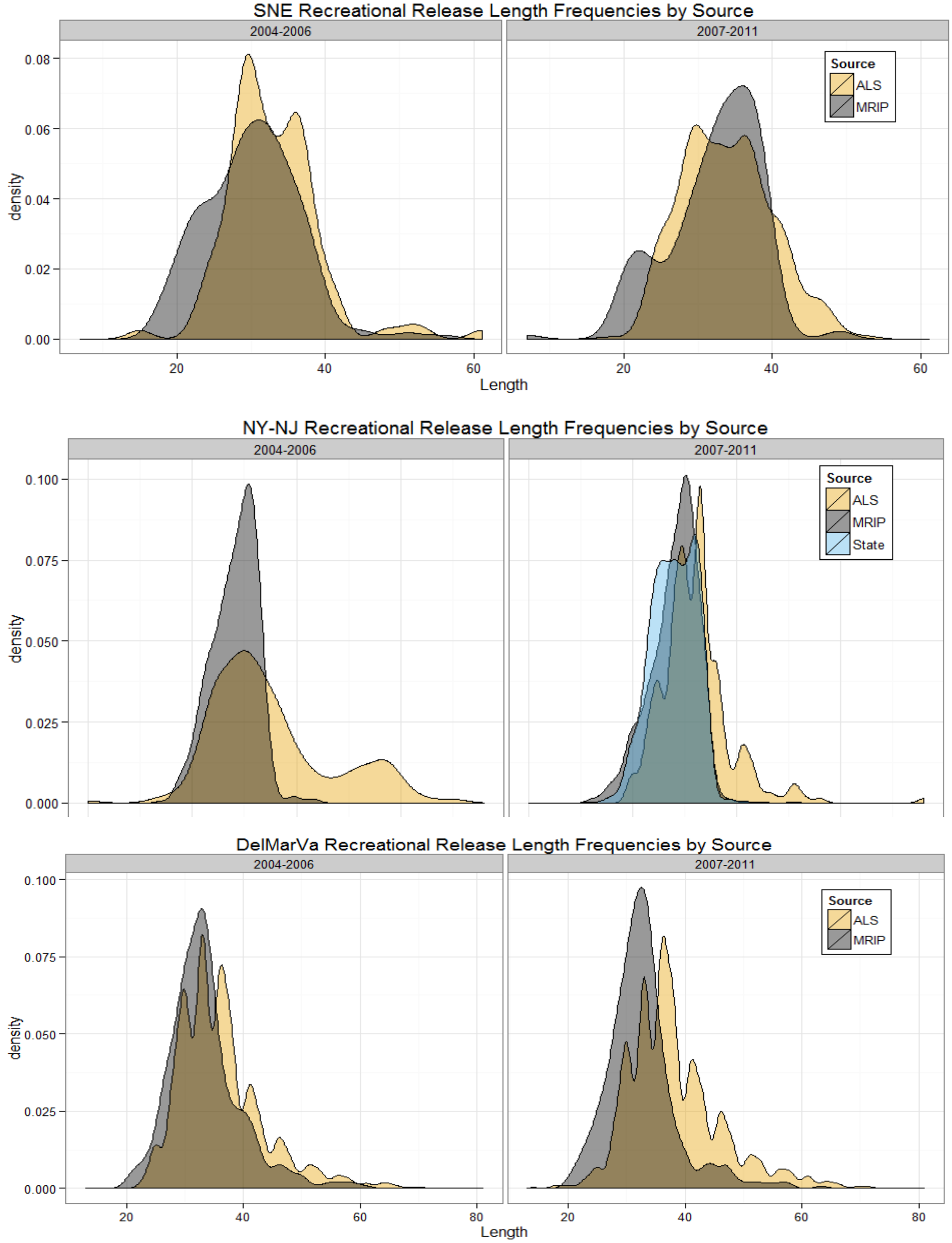


**Figure 5.9.** MRFSS vs. MRIP estimates of recreational harvest in weight by region, plotted with 95% confidence intervals calculated from MRIP estimate of PSE.

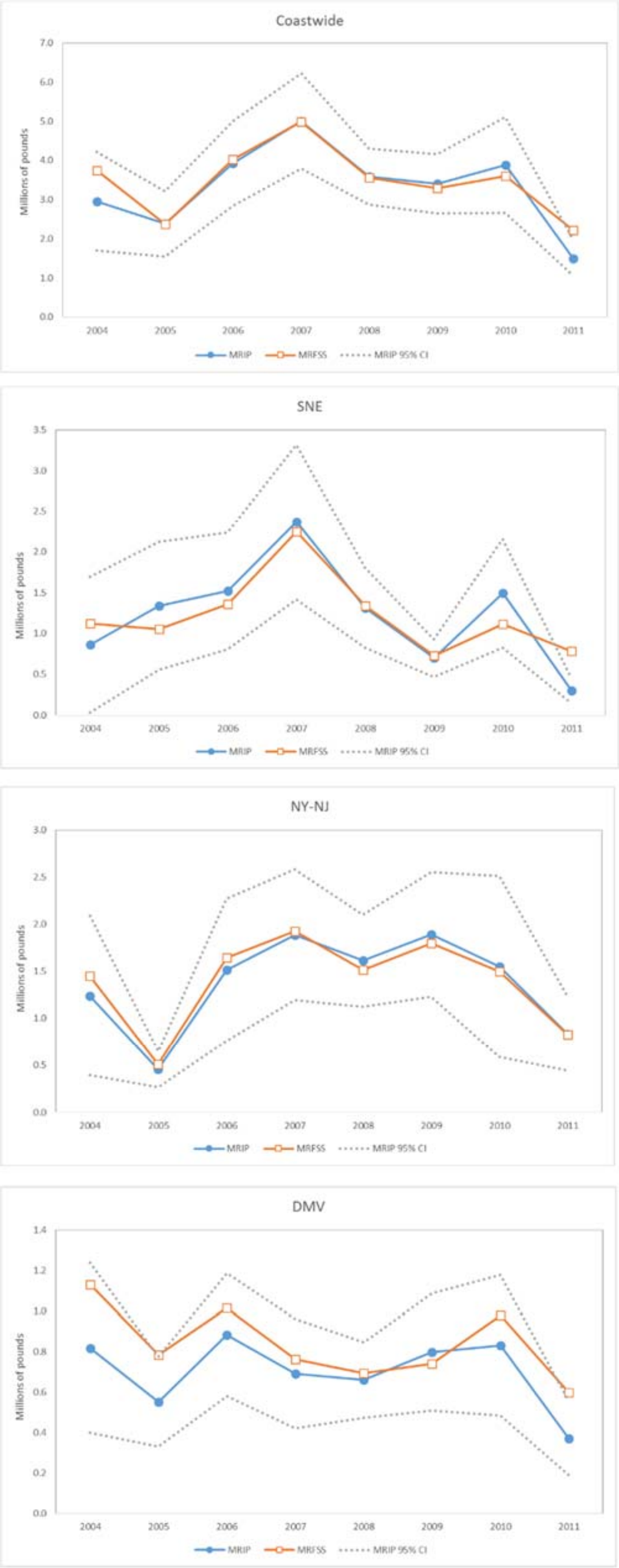


**Figure 5.10.** Histogram of catch data for the Massachusetts Trawl Survey (MATS) dataset**.**

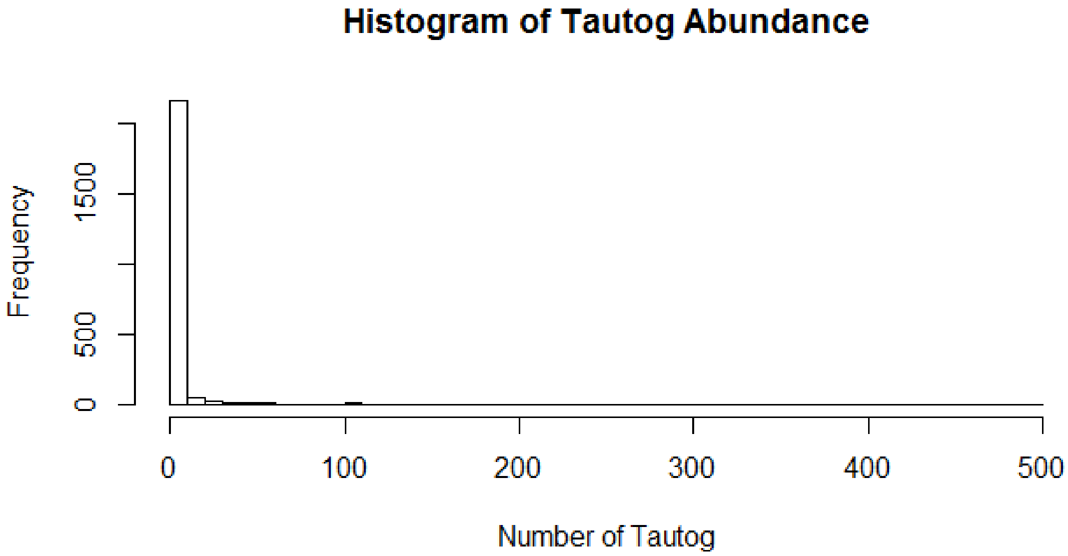


**Figure 5.11.** QQ Plot for negative binomial distribution for the final model used for the MATS.

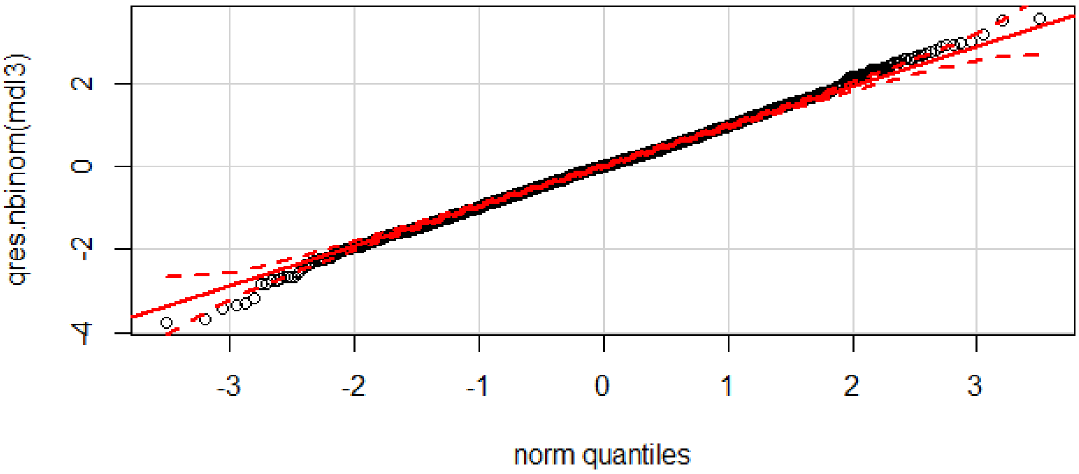


**Figure 5.12.** Cook's distance plot for the final model used for the MATS.

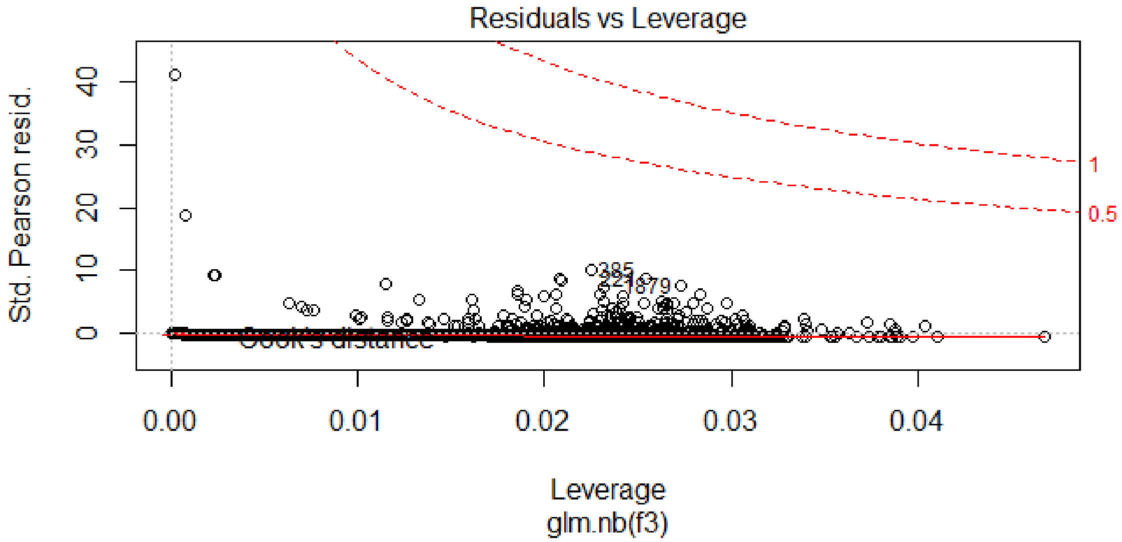


**Figure 5.13.** Standardized index versus the nominal index for the MATS.

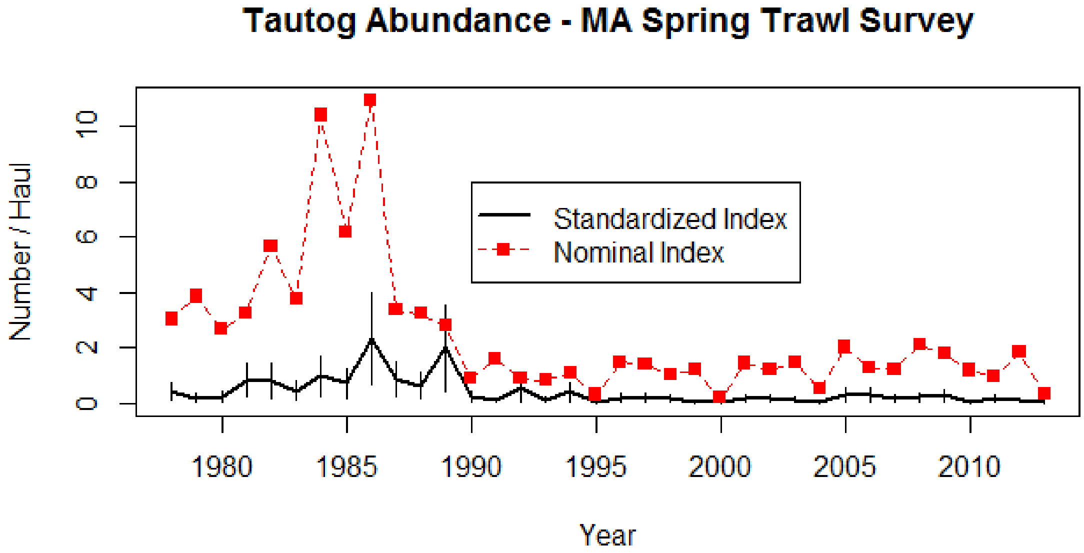


**Figure 5.14.** Histogram of catch data for the RITS dataset.

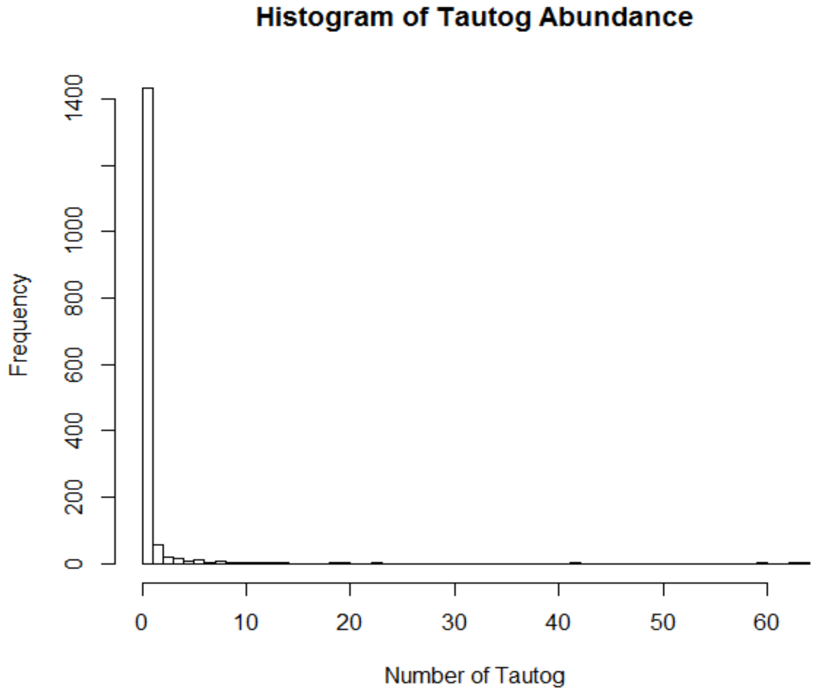


**Figure 5.15.** QQ Plot for negative binomial distribution for the final model used for the RITS.

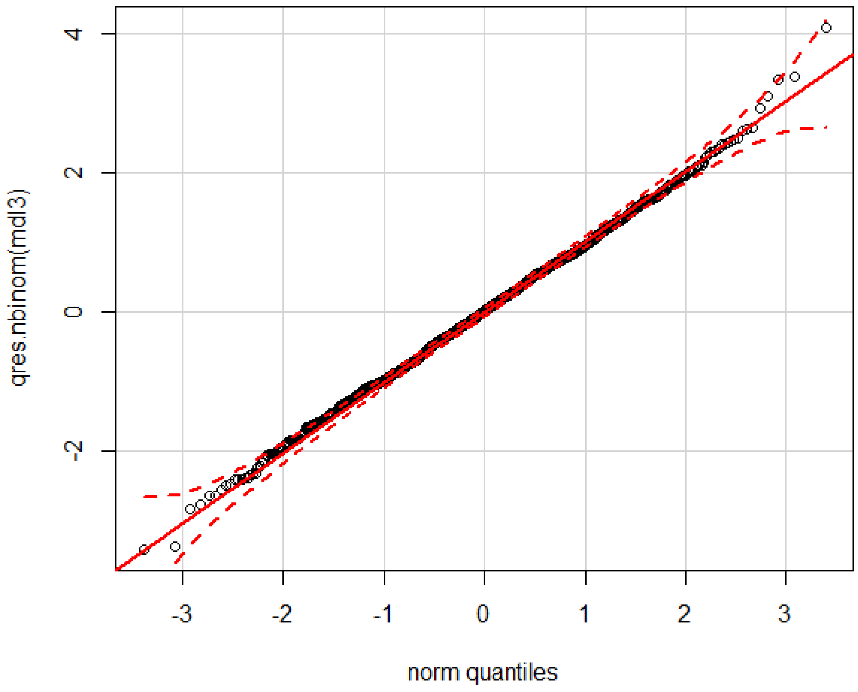


**Figure 5.16.** Cook's distance plot for the final model used for the RITS.

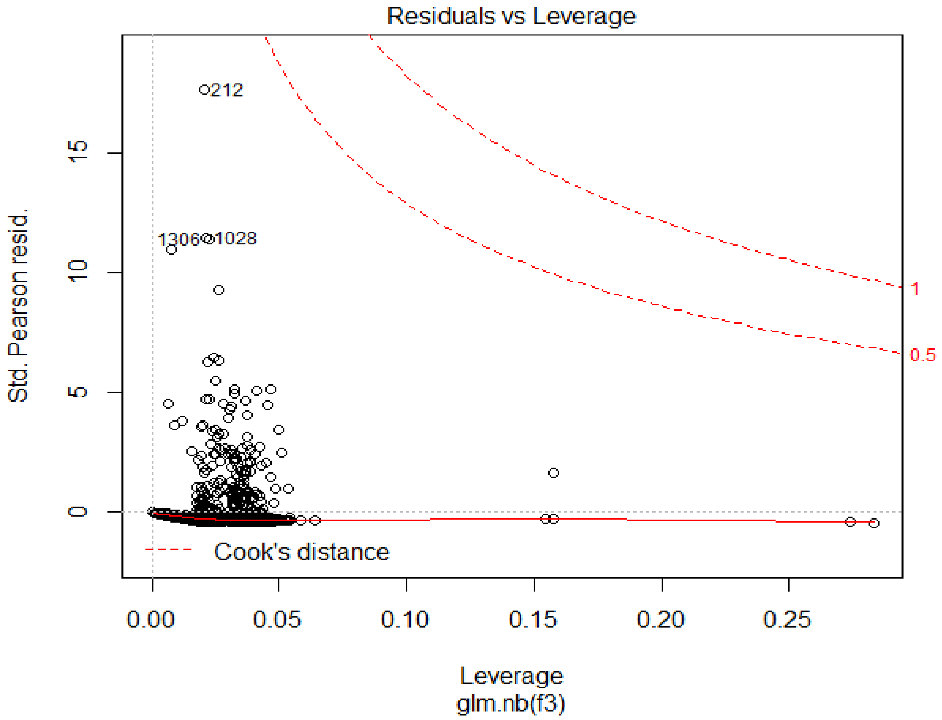


**Figure 5.17.** Standardized index versus the nominal index for the RITS.

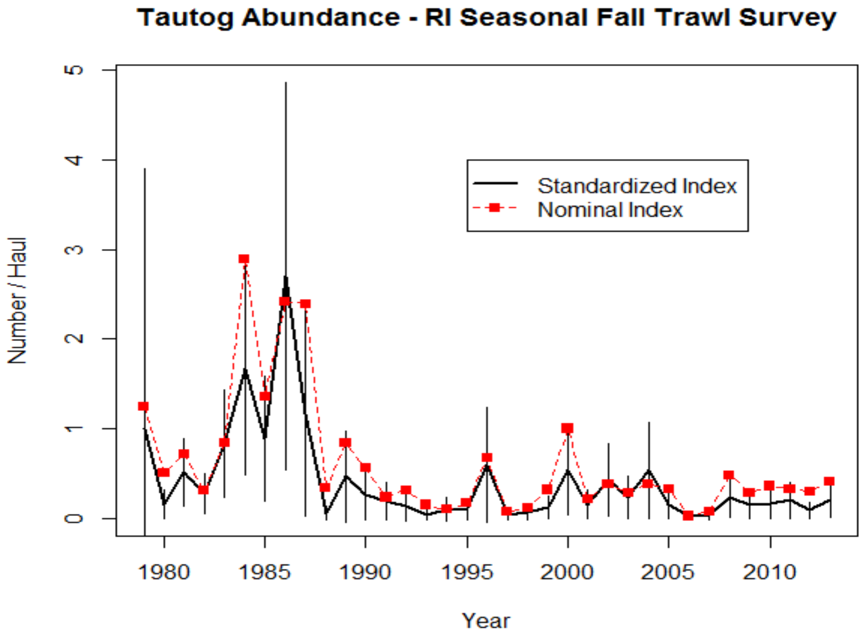


**Figure 5.18.** Histogram of catch data for the RISS dataset.

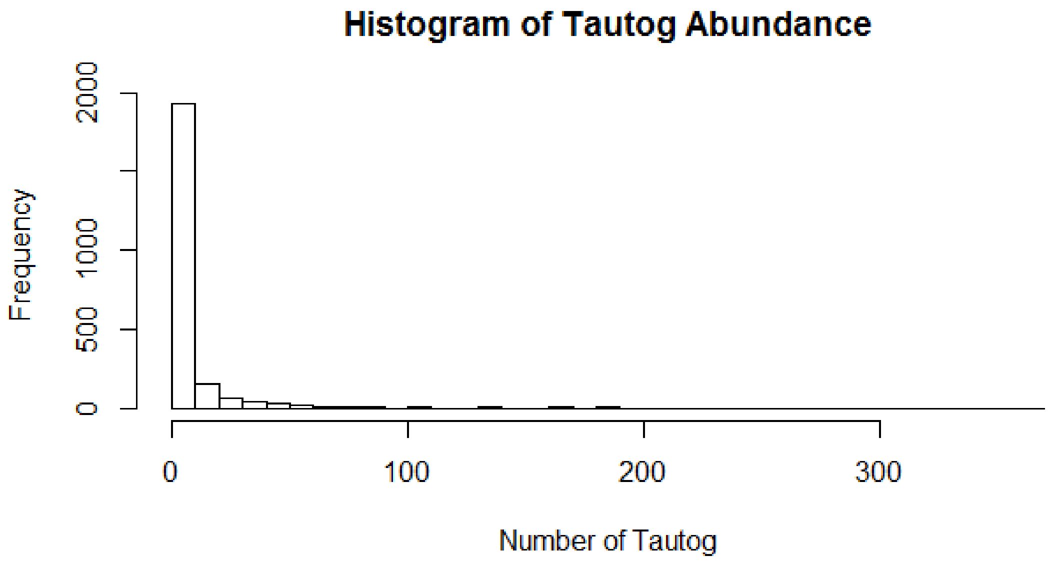


**Figure 5.19.** QQ Plot for negative binomial distribution for the final model used for the RISS.

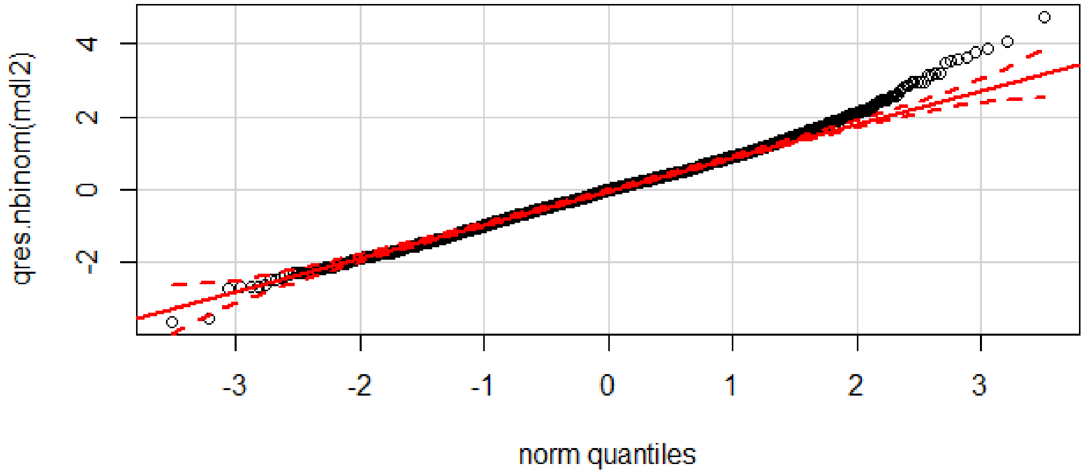


**Figure 5.20.** Cook's distance plot for the final model used for the RISS.

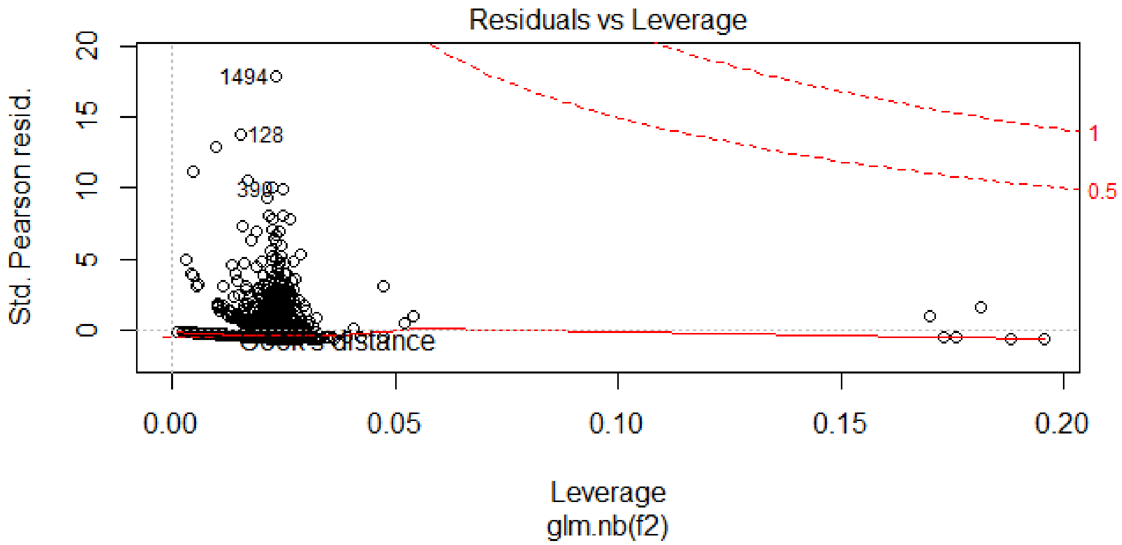


**Figure 5.21.** Standardized index versus the nominal index for the RISS.

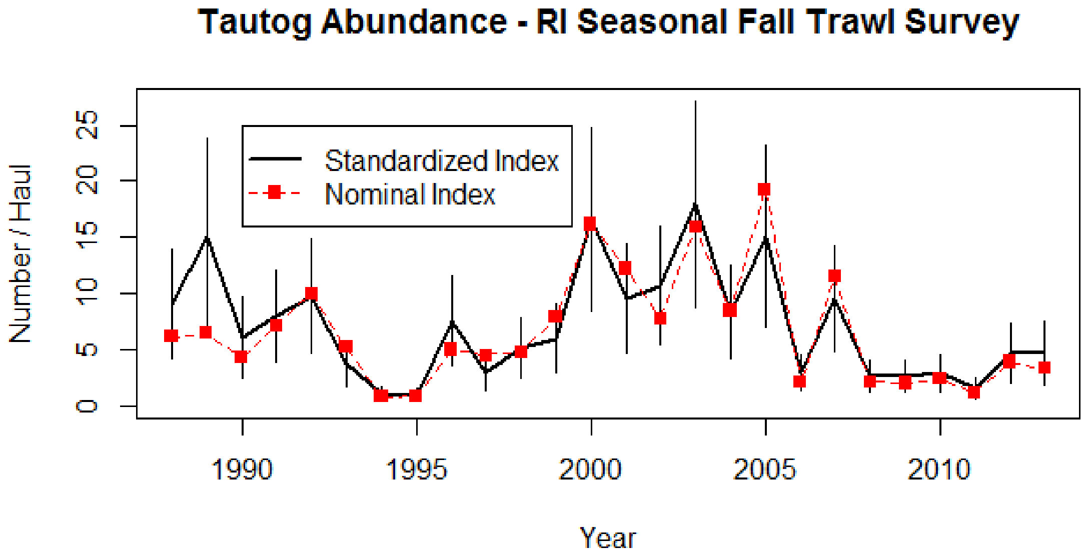


**Figure 5.22.** Histogram of catch data for the CT LISTS dataset.

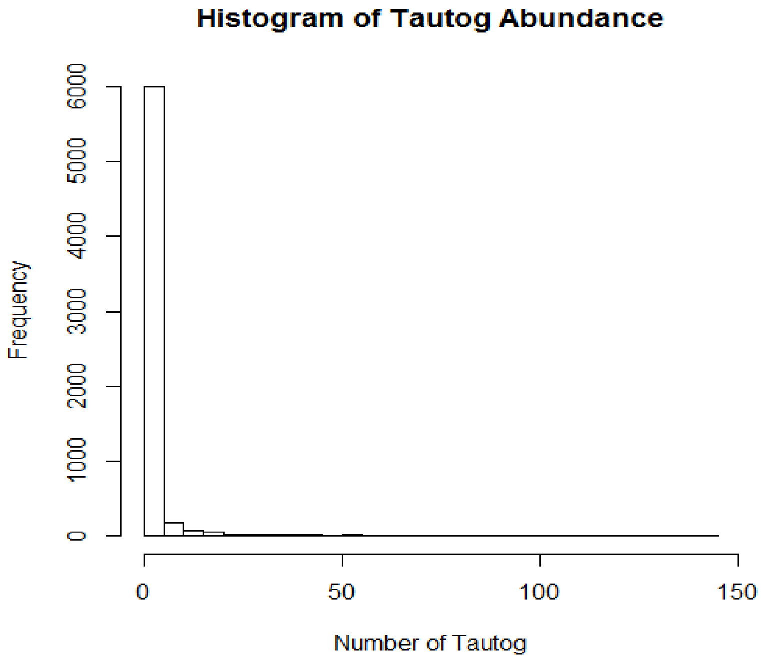


**Figure 5.23.** QQ Plot for negative binomial distribution for the final model used for the CT LISTS.

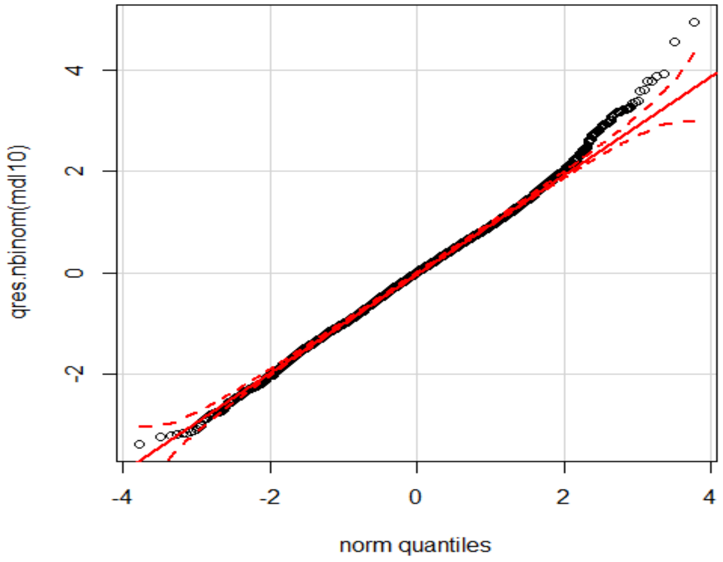


**Figure 5.24.** Cook's distance plot for the final model used for the CT LISTS.

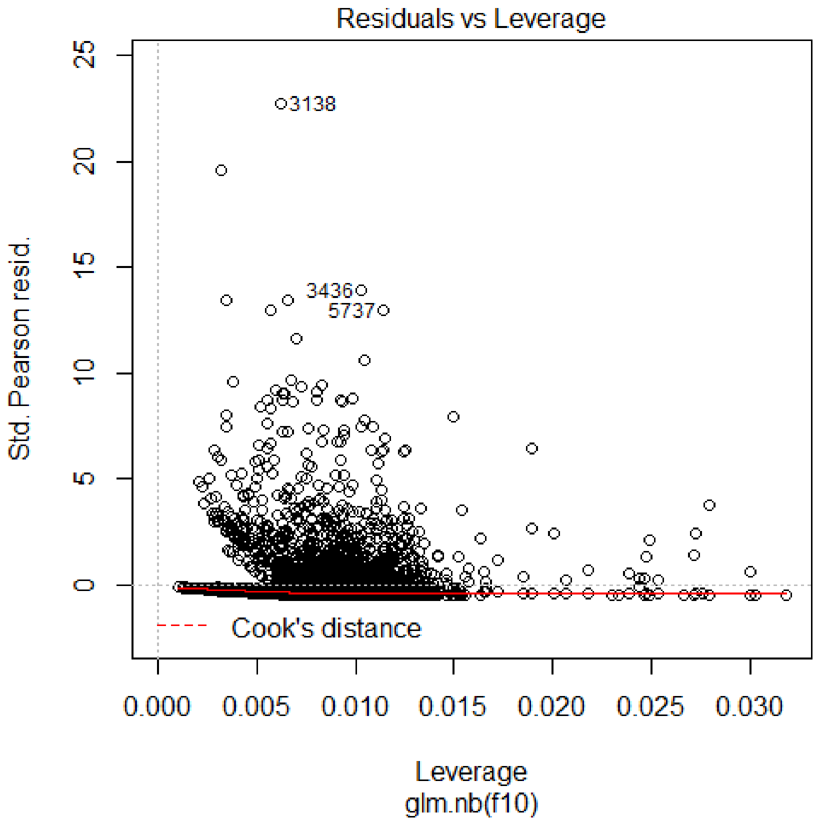


**Figure 5.25.** Standardized index versus the nominal index for the CT LISTS.

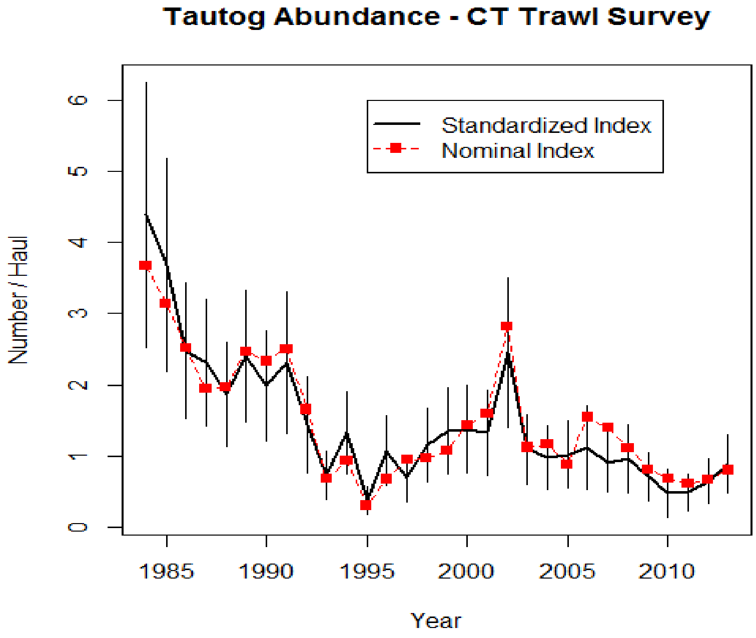


**Figure 5.26.** Histogram of catch data for the NYTS dataset.

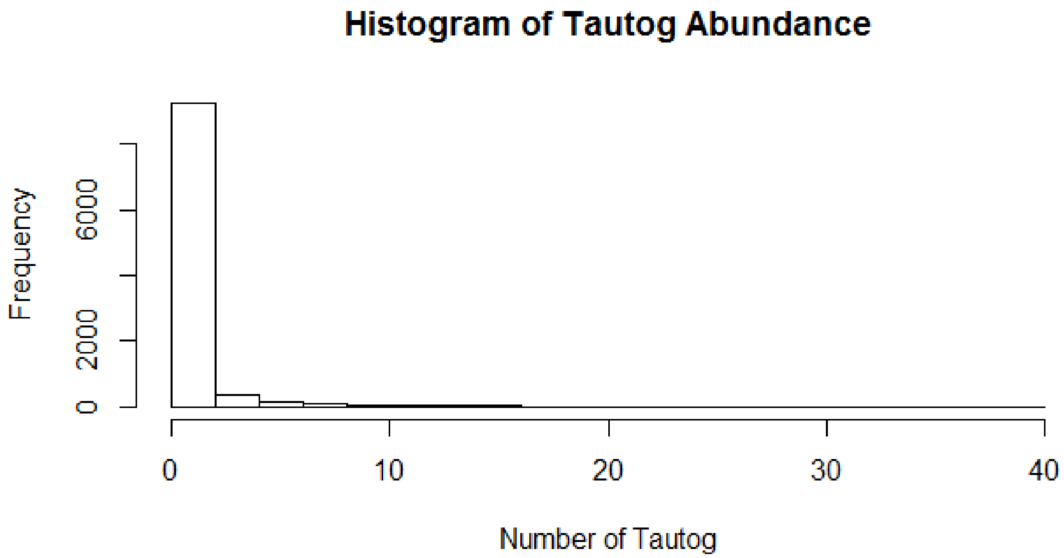


**Figure 5.27.** QQ Plot for negative binomial distribution for the final model used for the NYTS.

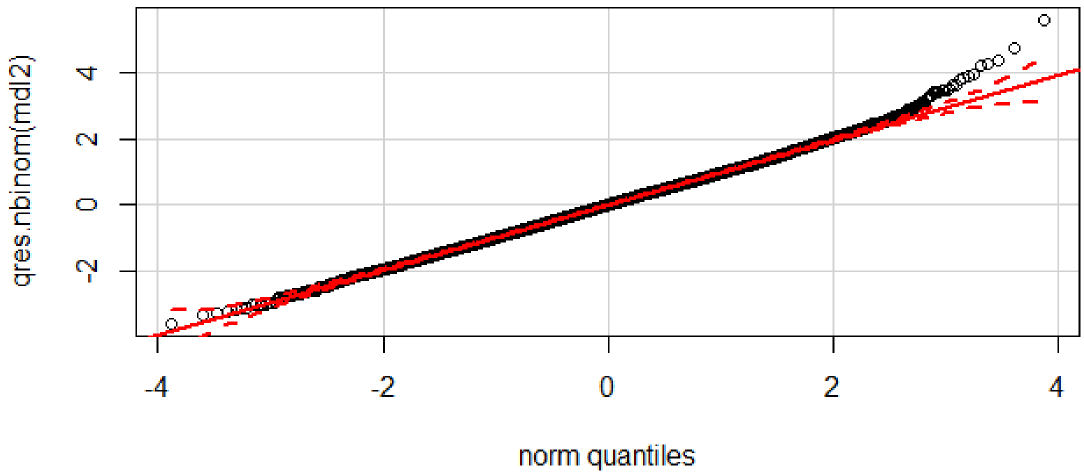


**Figure 5.28.** Cook's distance plot for the final model used for the NYTS.

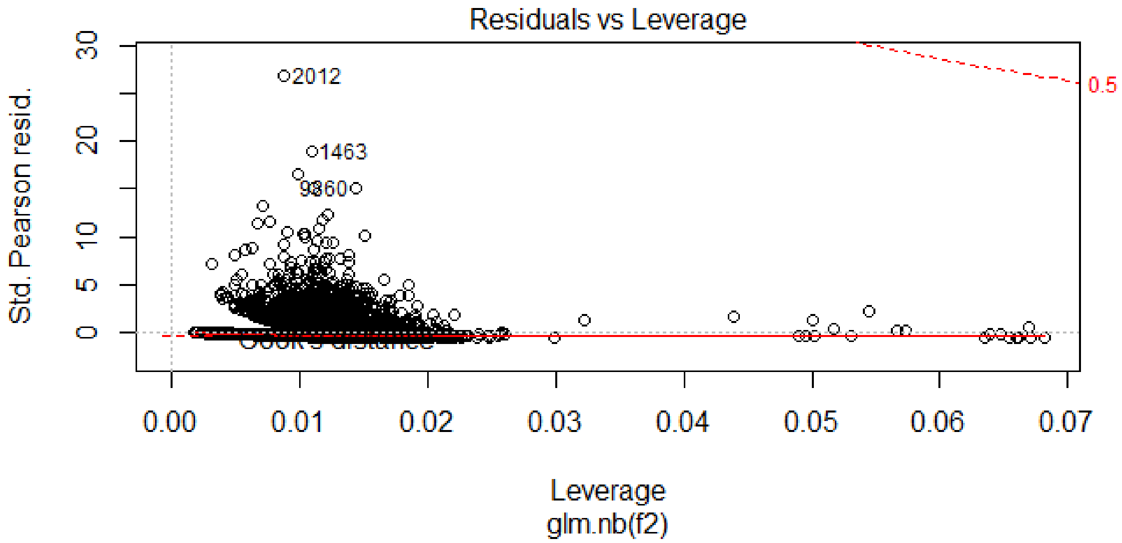


**Figure 5.29.** Standardized index versus the nominal index for the NYTS.

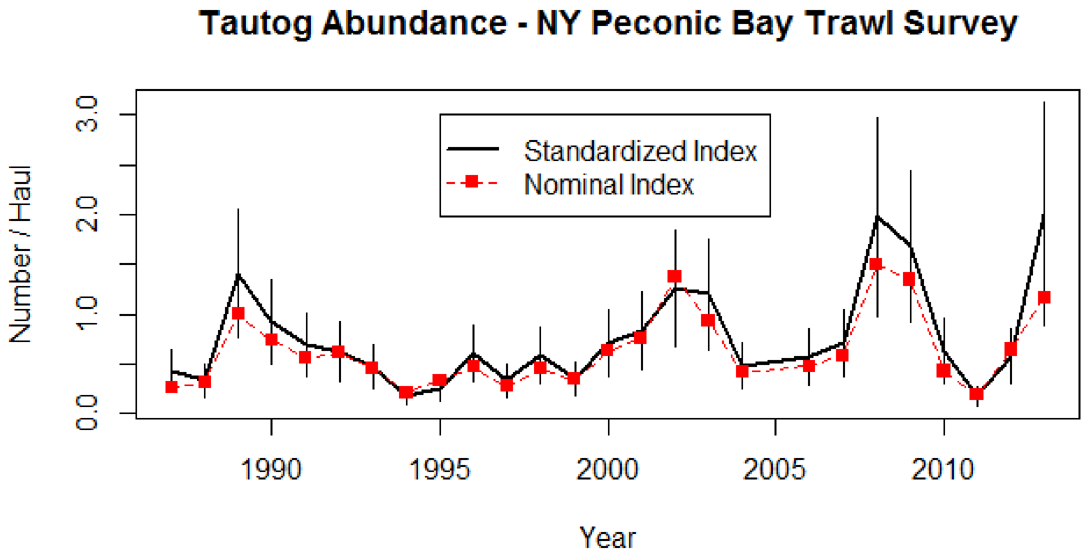


**Figure 5.30.** Histogram of catch data for the NYWLISS dataset.

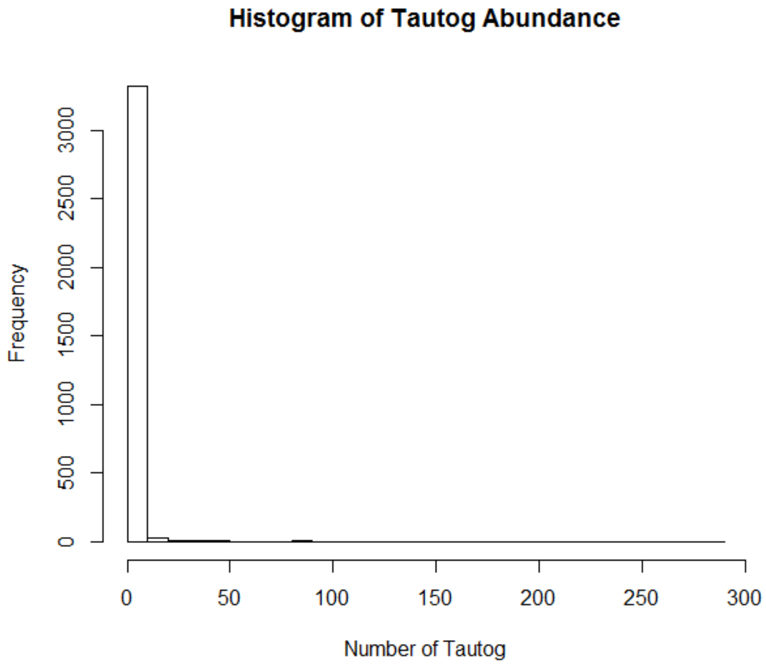


**Figure 5.31.** QQ Plot for negative binomial distribution for the final model used for the NYWLISS.

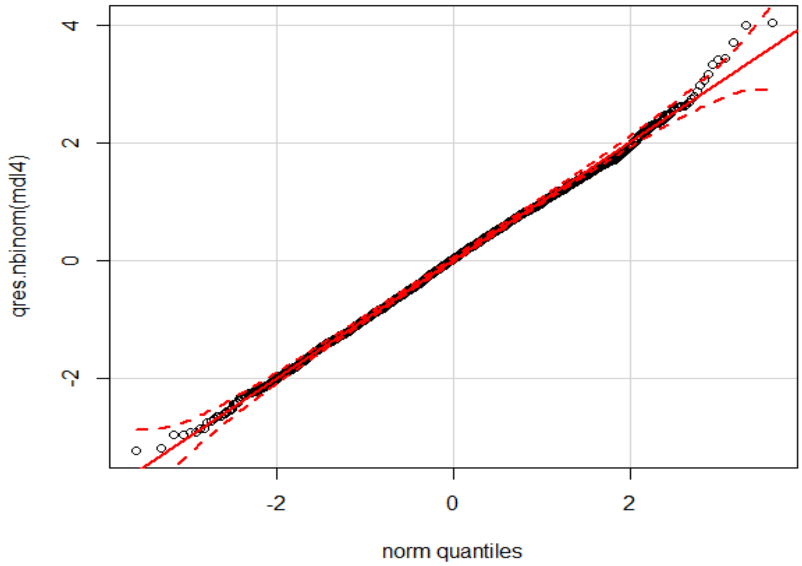


**Figure 5.32.** Cook's distance plot for the final model used for the NYWLISS.

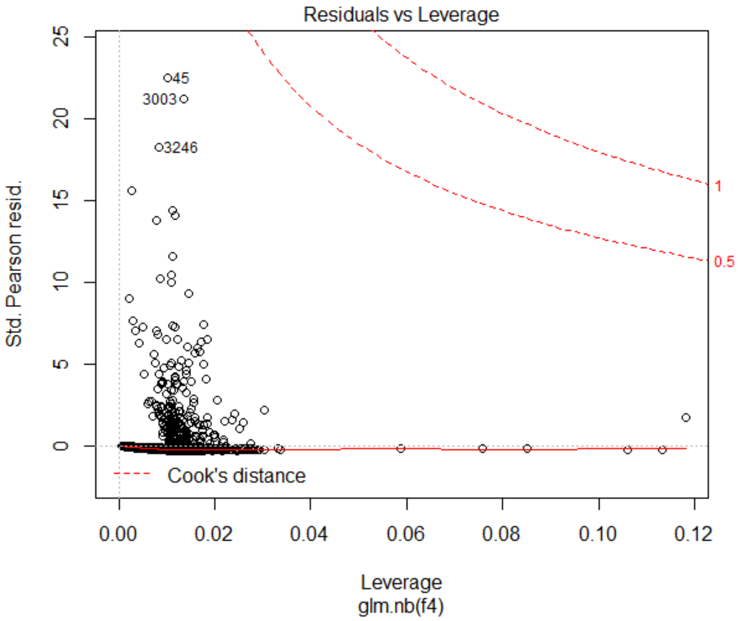


**Figure 5.33.** Standardized index versus the nominal index for the NYWLISS.

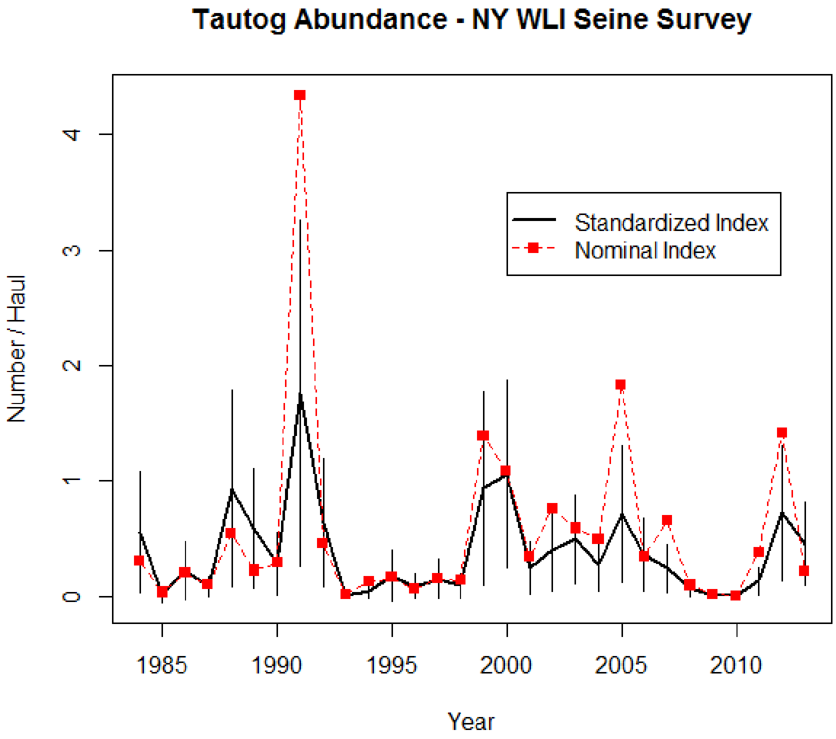


**Figure 5.34.** Histogram of catch data for the NJTS dataset.

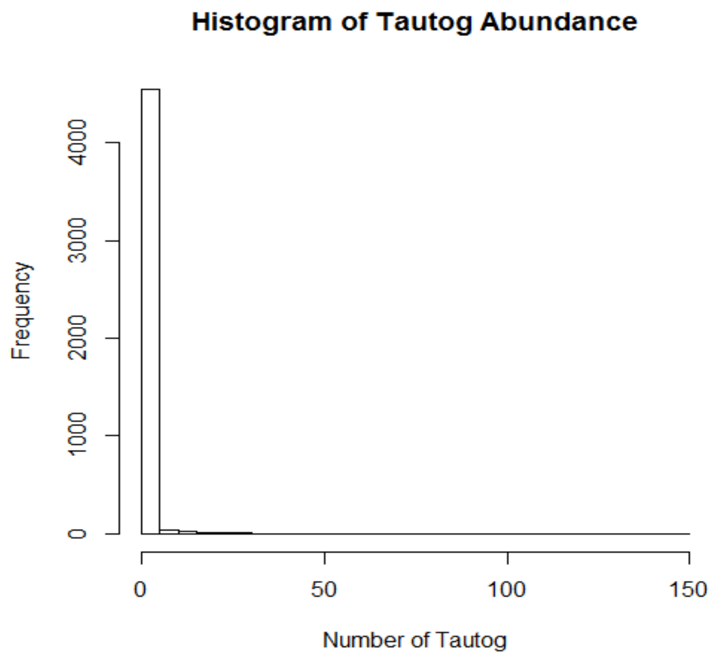


**Figure 5.35.** QQ Plot for negative binomial distribution for the final model used for the NJTS.

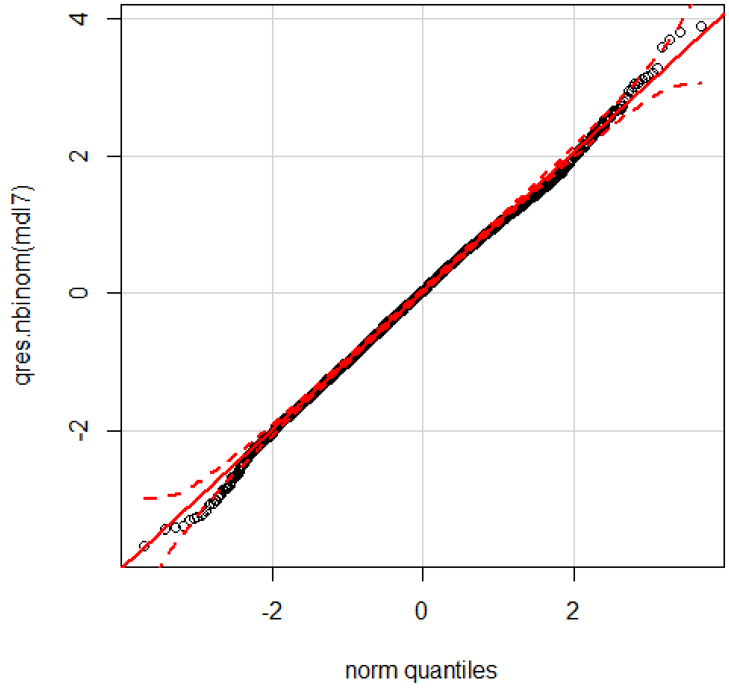


**Figure 5.36.** Cook's distance plot for the final model used for the NJTS.

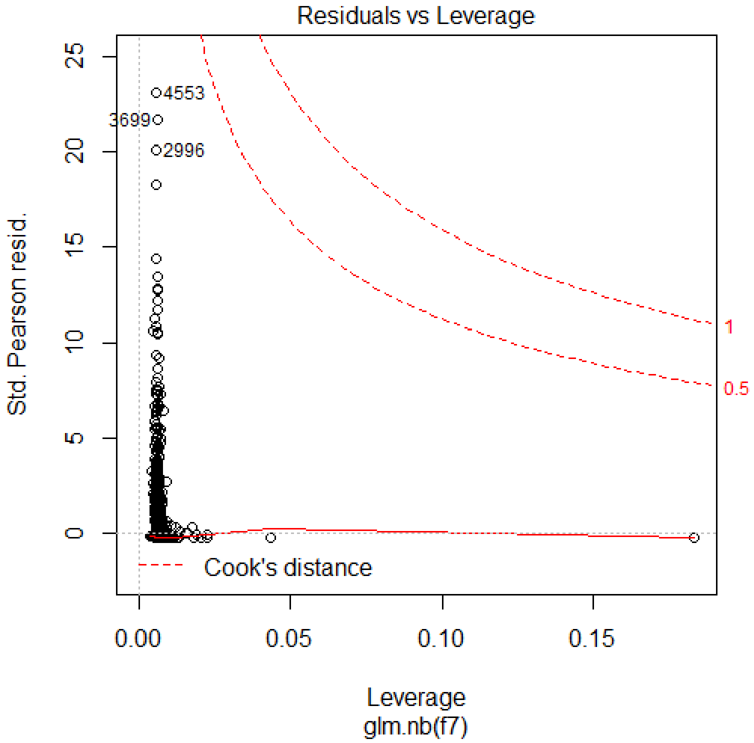


**Figure 5.37.** Standardized index versus the nominal index for the NJTS.

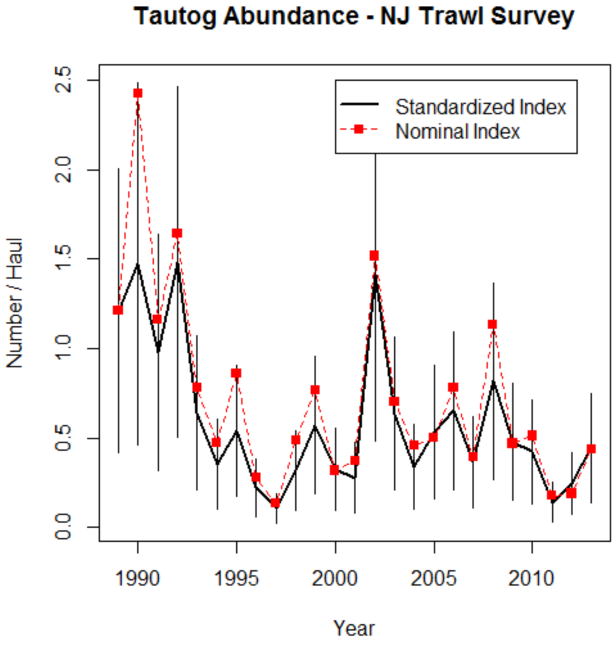


**Figure 6.1.** Observed and predicted total catch in weight (left) and standardized residuals (right) for the Southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

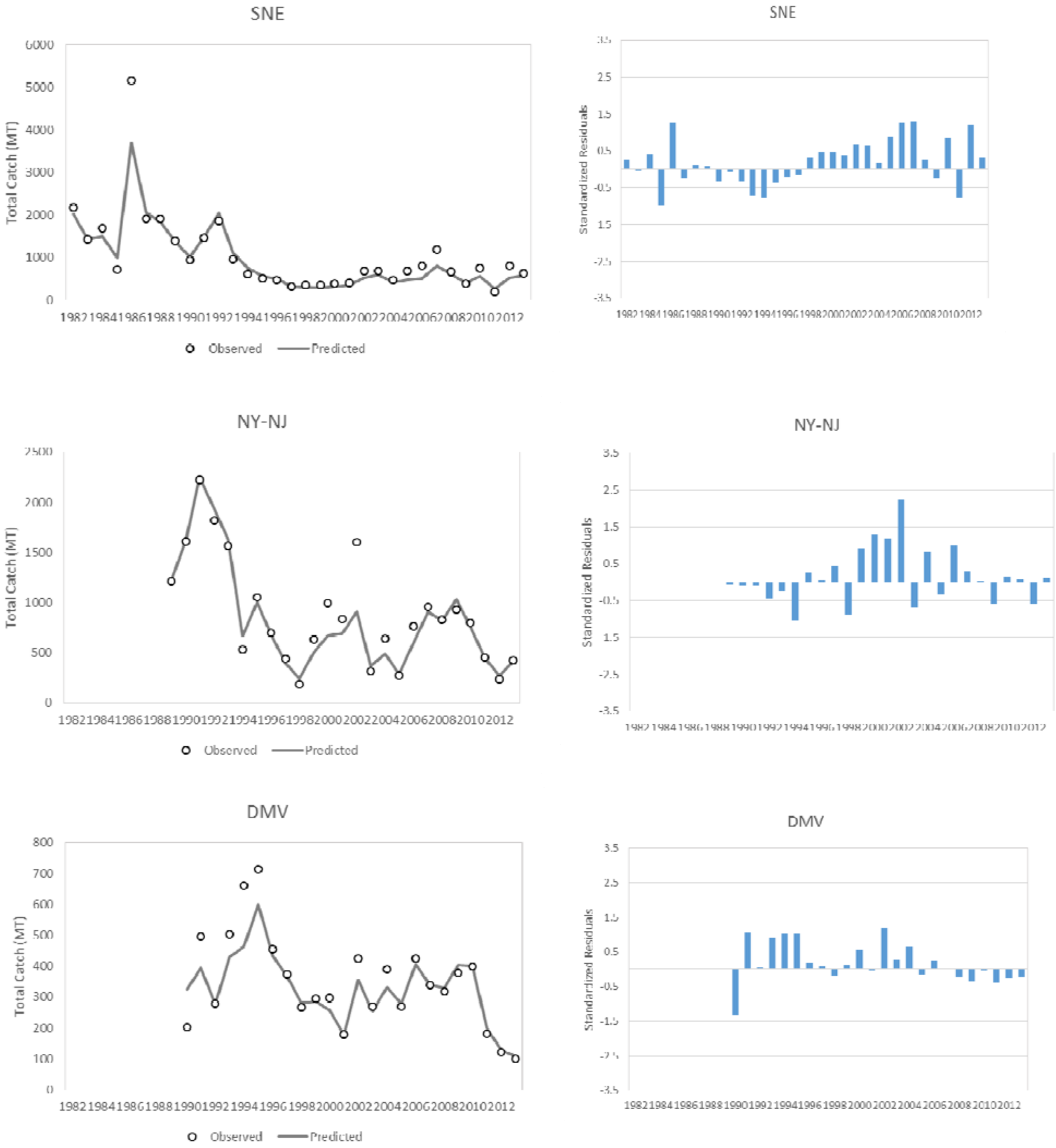


**Figure 6.2.A.** Observed and predicted fishery independent indices (left) and their standardized residuals (right) for the Southern New England region.

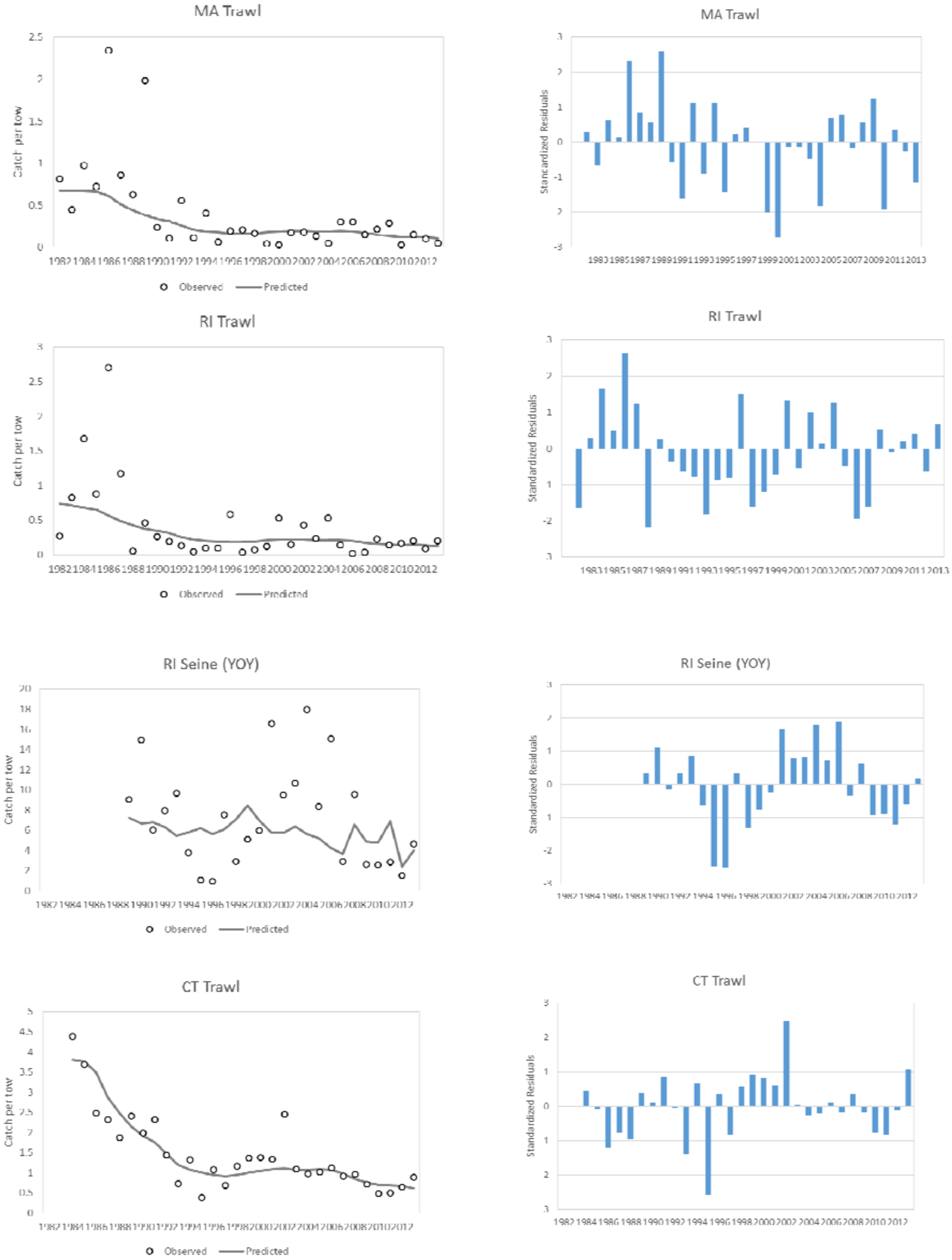


**Figure 6.2.B.** Observed and predicted fishery dependent index (left) and their standardized residuals (right) for the Southern New England region.

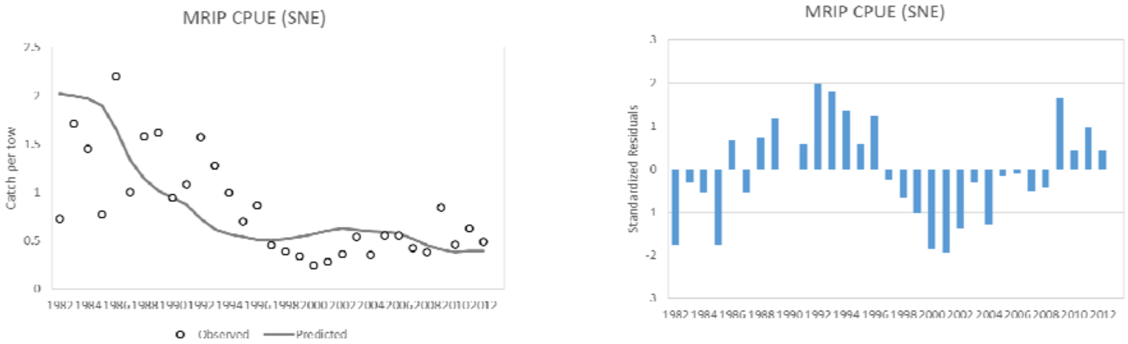


**Figure 6.3.** Observed and predicted indices (left) and their standardized residuals (right) for the NY-NJ region.

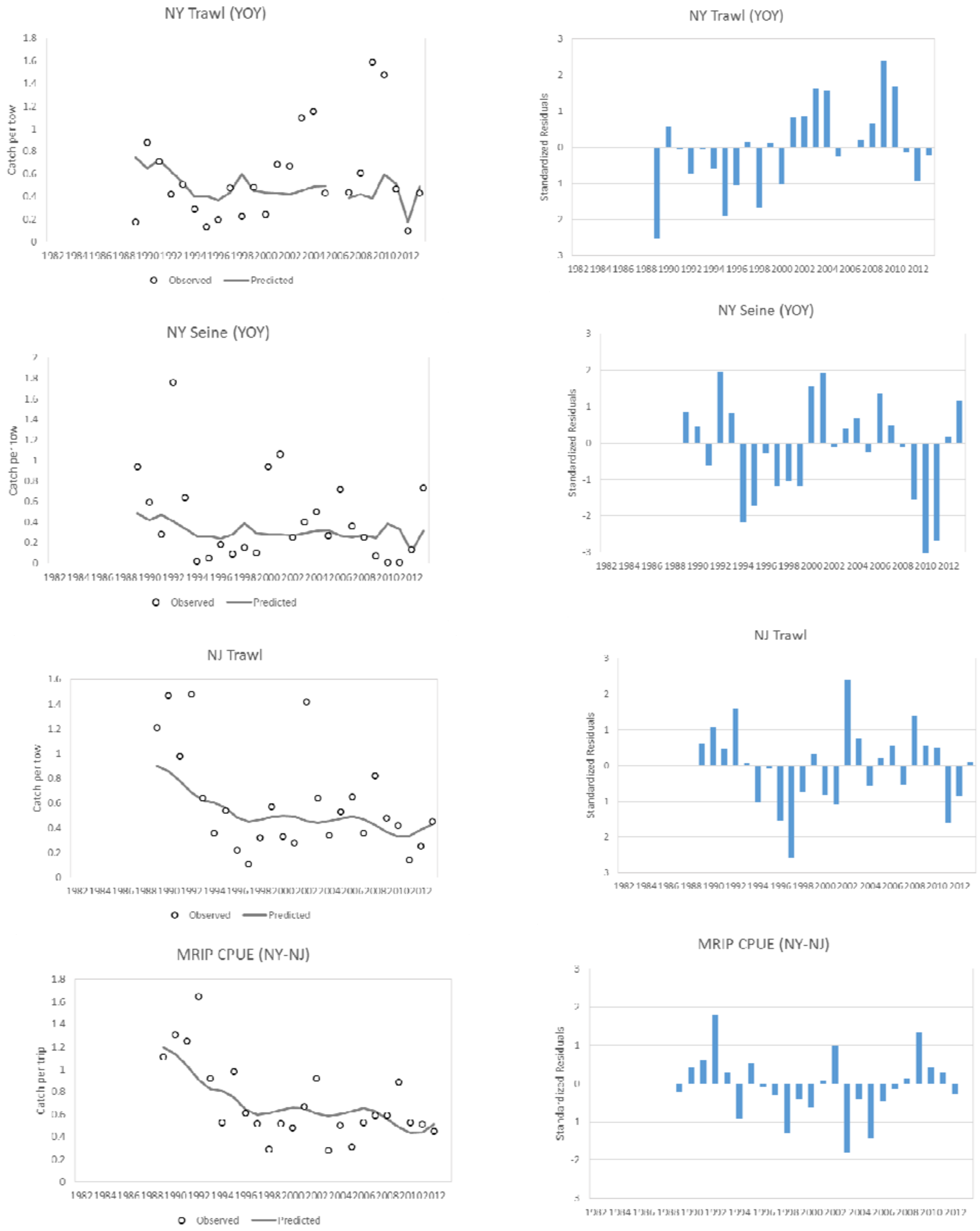
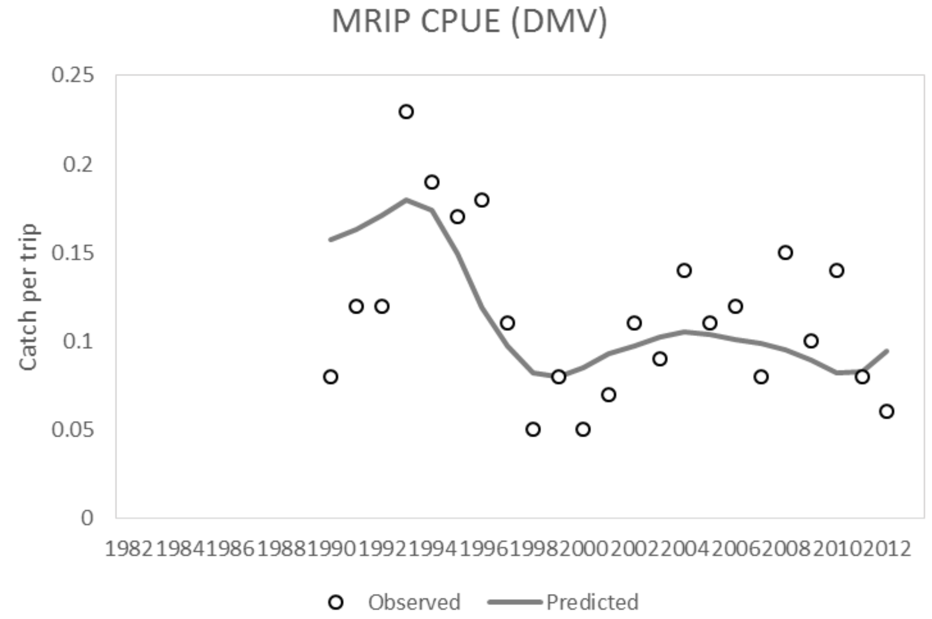


**Figure 6.4.** Observed and predicted index (top) and its standardized residuals (bottom) for the DelMarVa region.



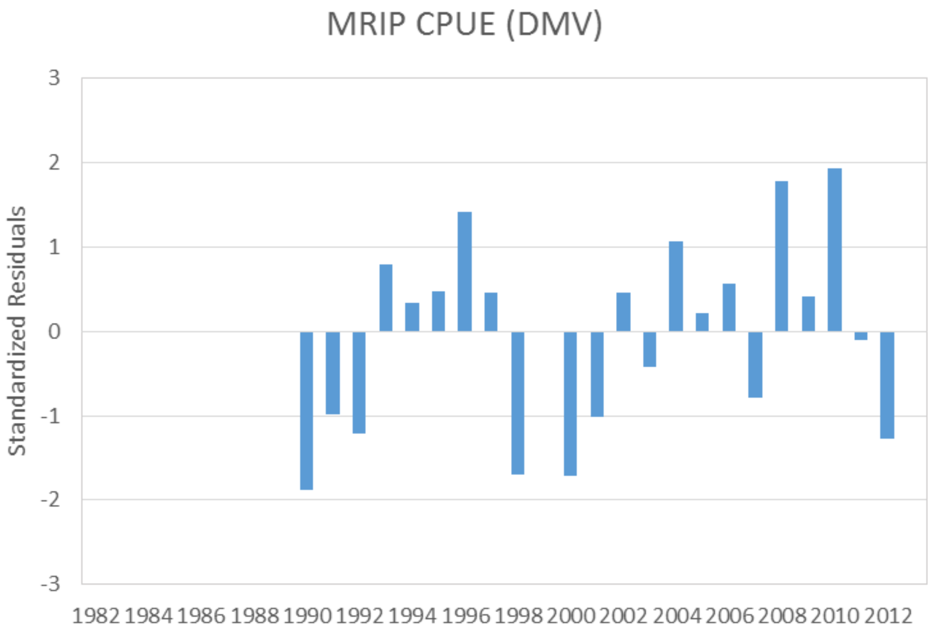


**Figure 6.5.** Total observed and predicted catch-at-age for the southern New England region (top), the NY-NJ region (middle), and the DelMarVa region (bottom).

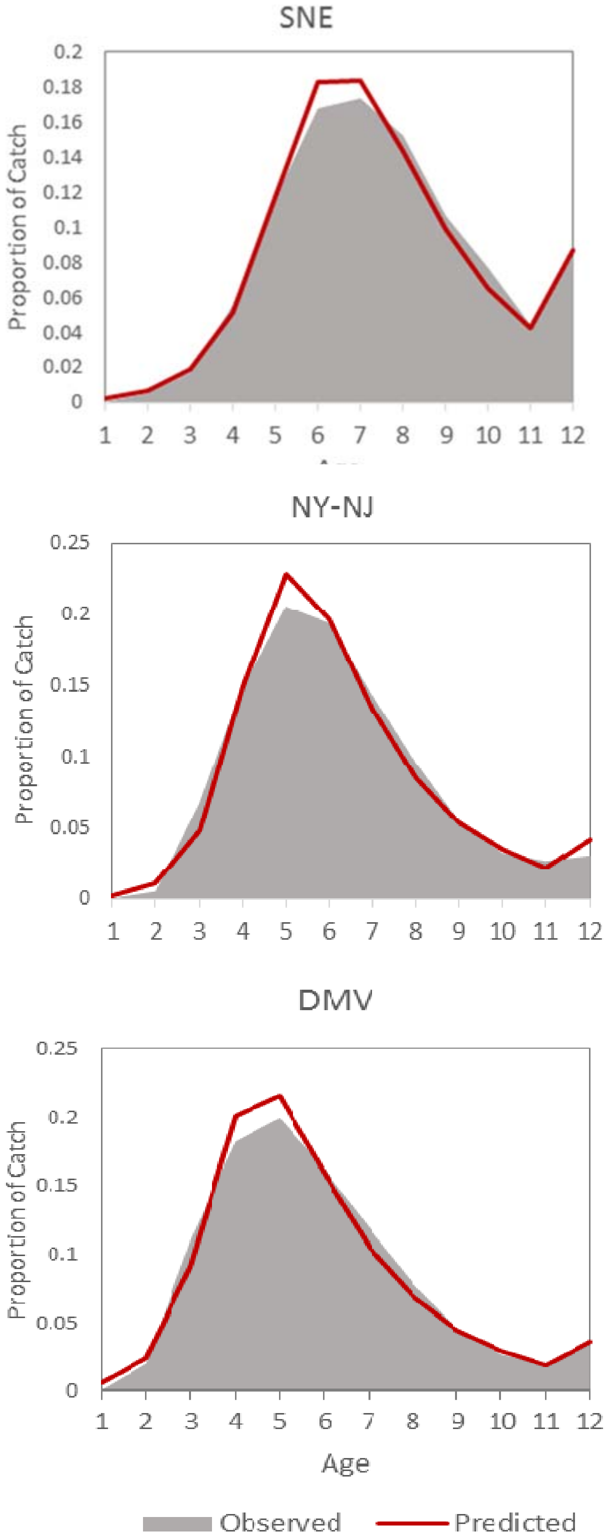


**Figure 6.6.** Annual observed and predicted total catch-at-age for the southern New England region.

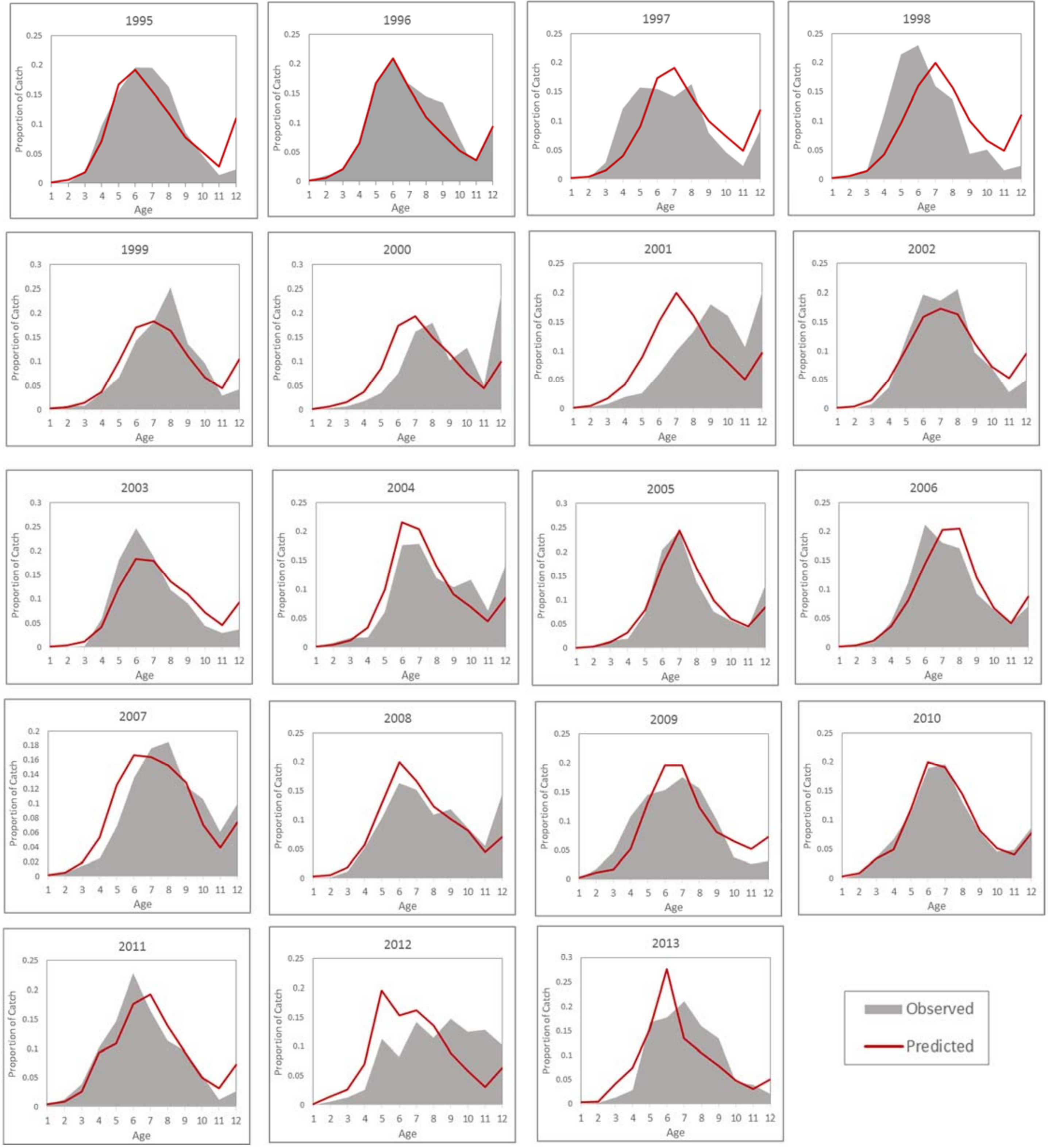


**Figure 6.7.** Annual observed and predicted total catch-at-age for the NY-NJ region.

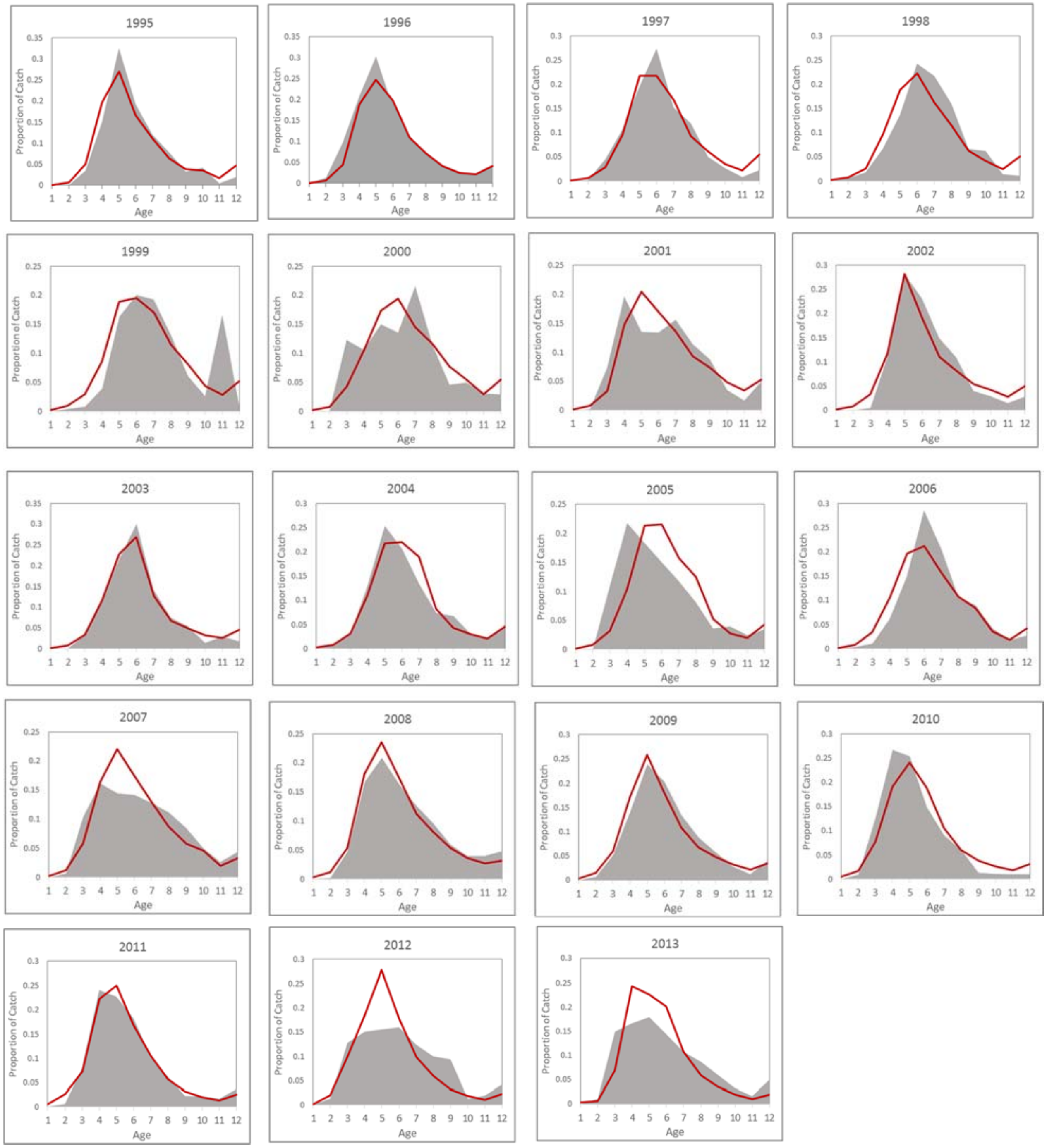


**Figure 6.8.** Annual observed and predicted total catch-at-age for the DelMarVa region.

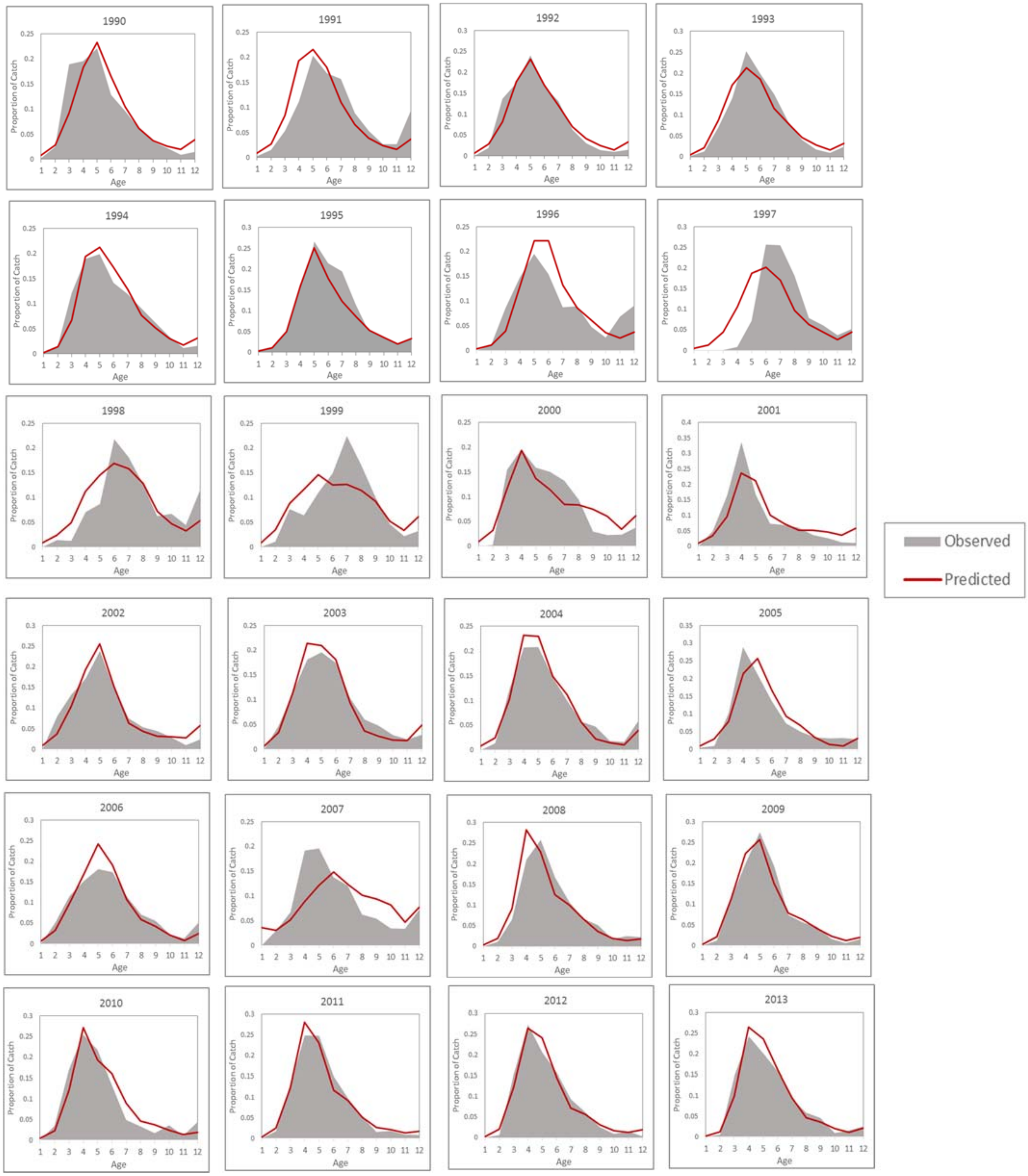


**Figure 6.9.** Total observed and predicted total index-at-age for the southern New England region.

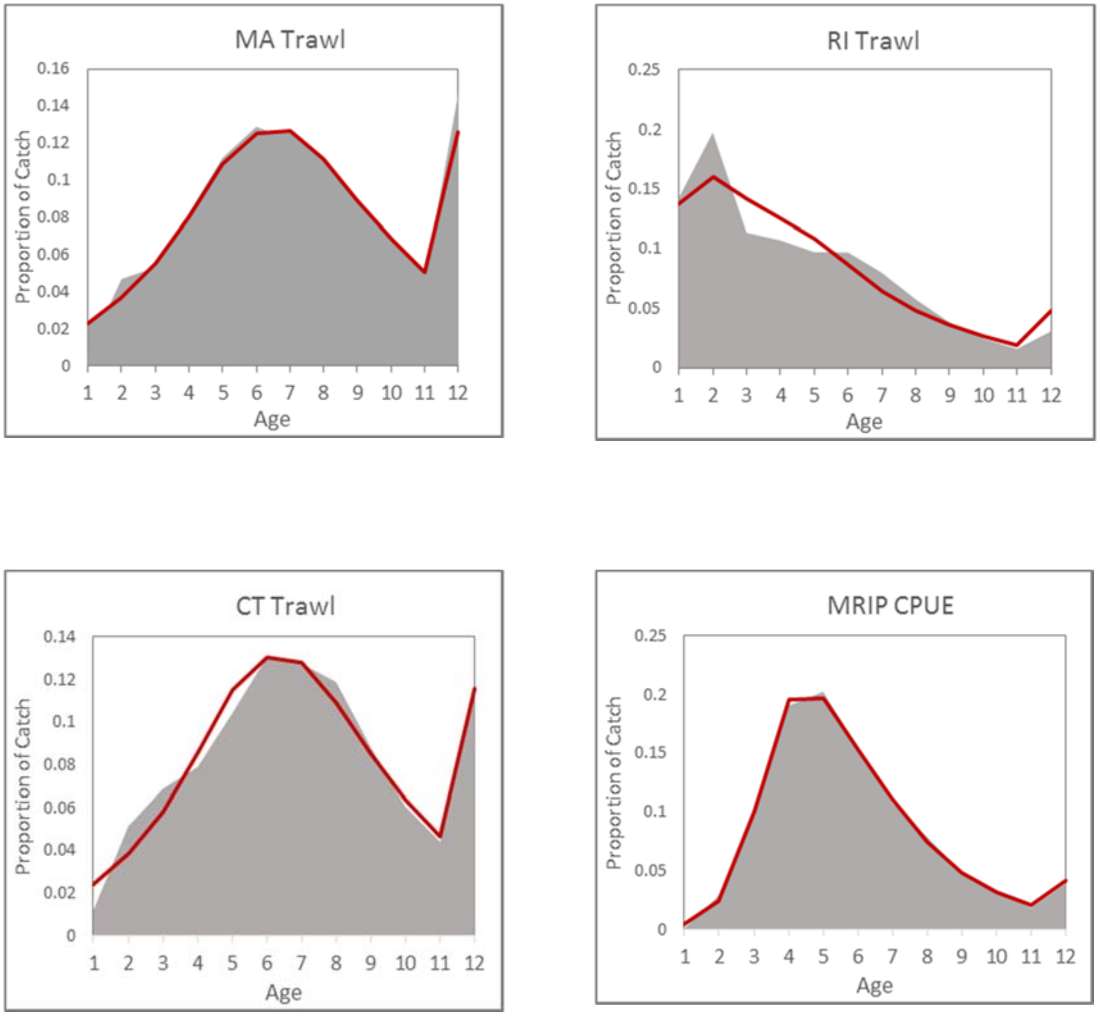


**Figure 6.10.** Total observed and predicted total index-at-age for the NY-NJ region.

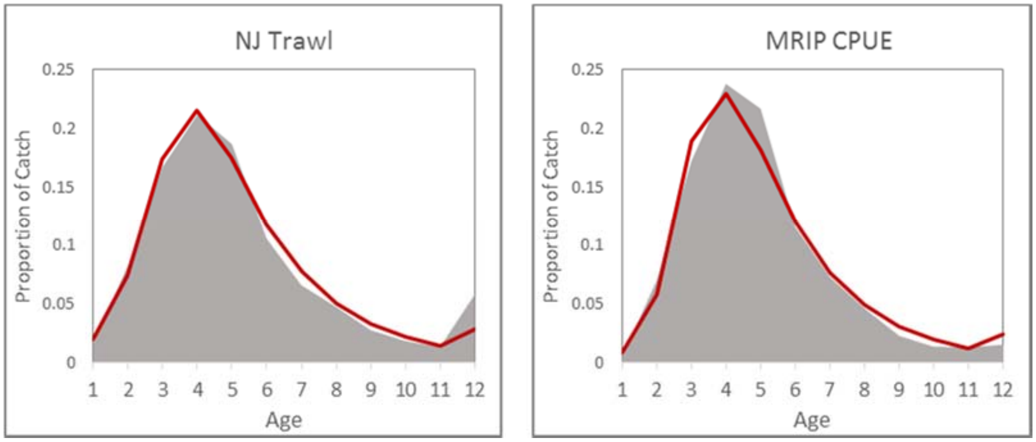


**Figure 6.11.** Total observed and predicted total index-at-age for the DelMarVa region.

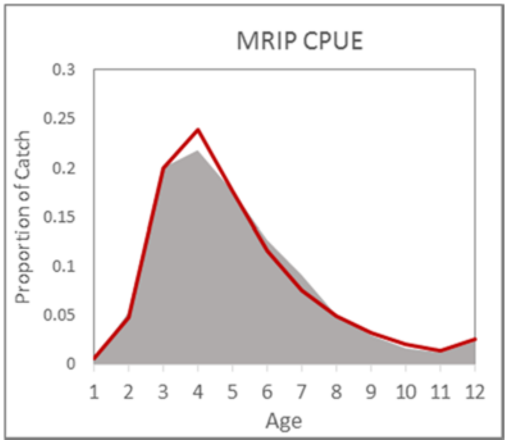


**Figure 6.12.** Selectivity by block for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

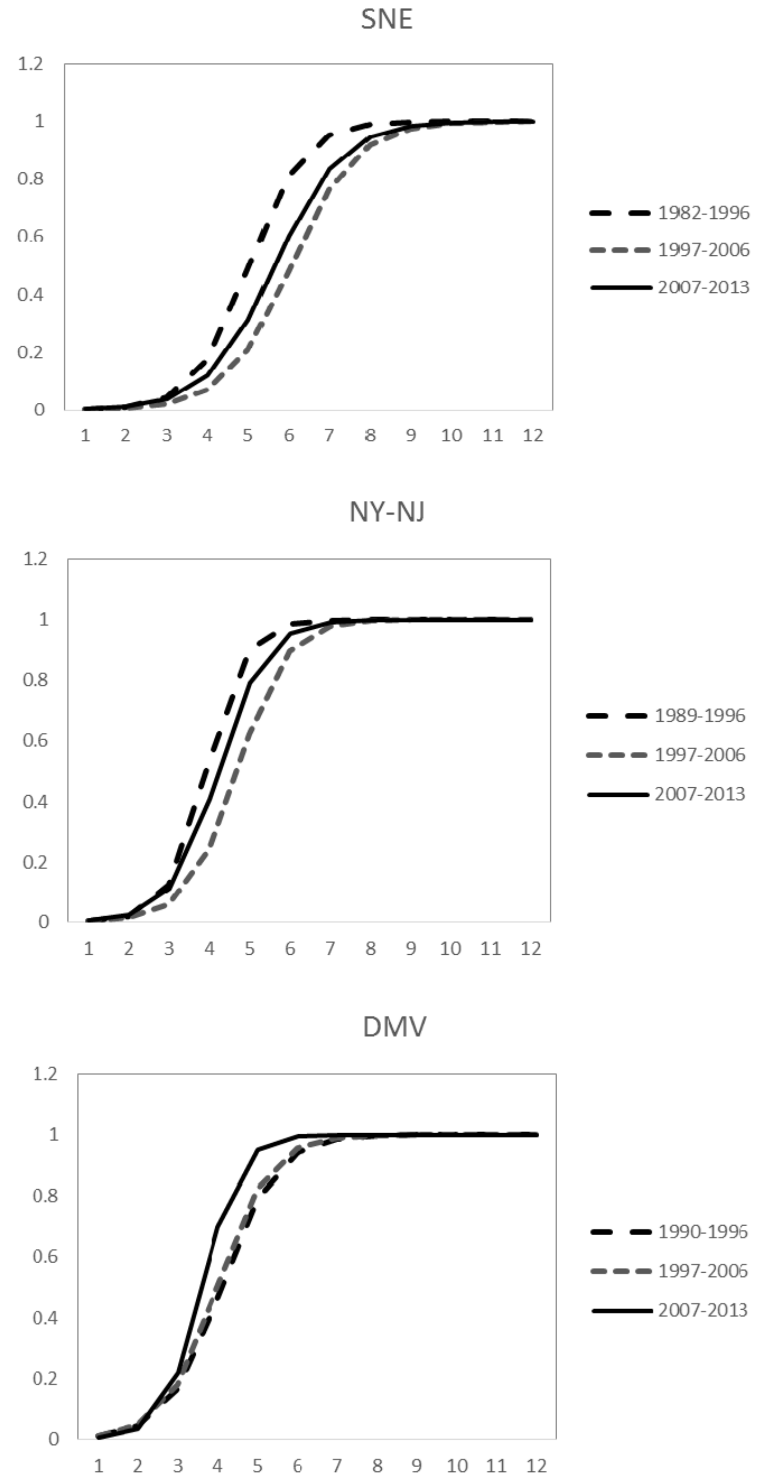


**Figure 6.13.** Observed and predicted stock-recruitment relationship for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

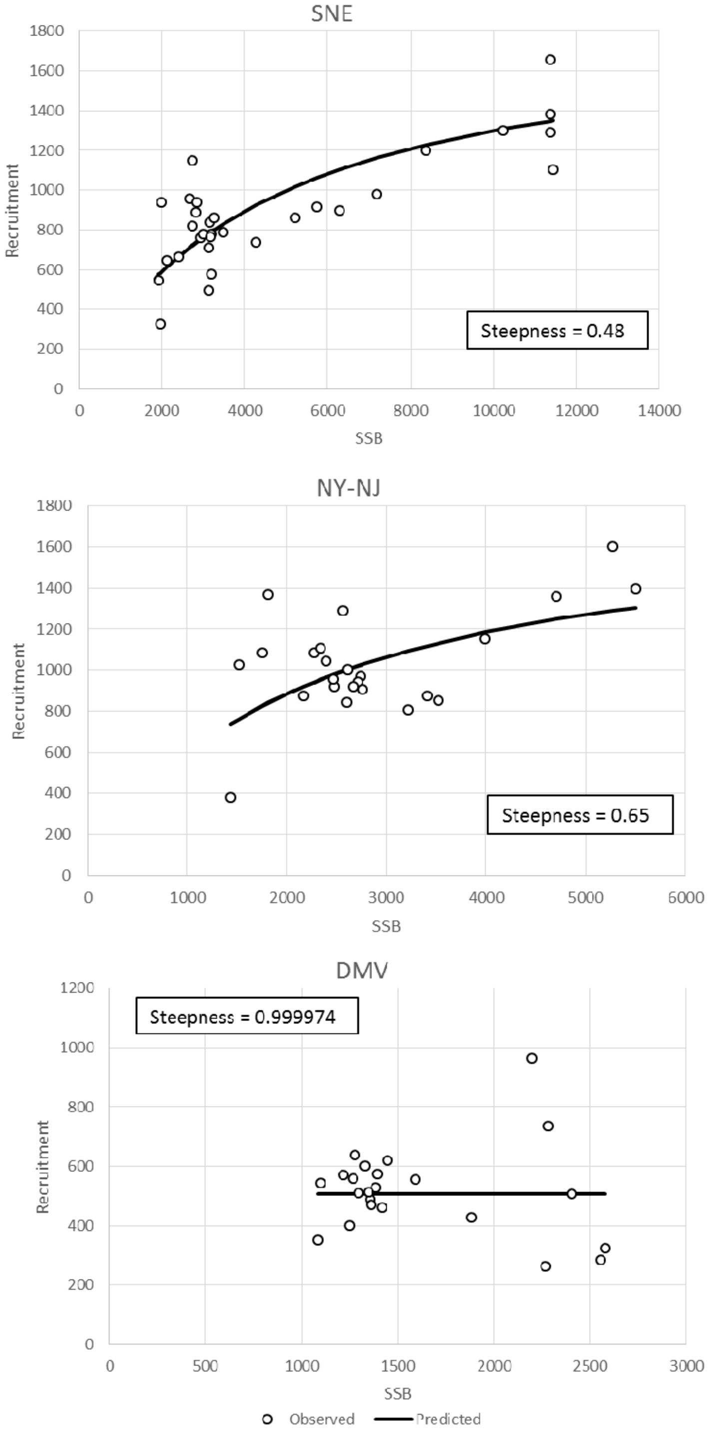


**Figure 6.14.** Annual and three-year average estimates of F for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

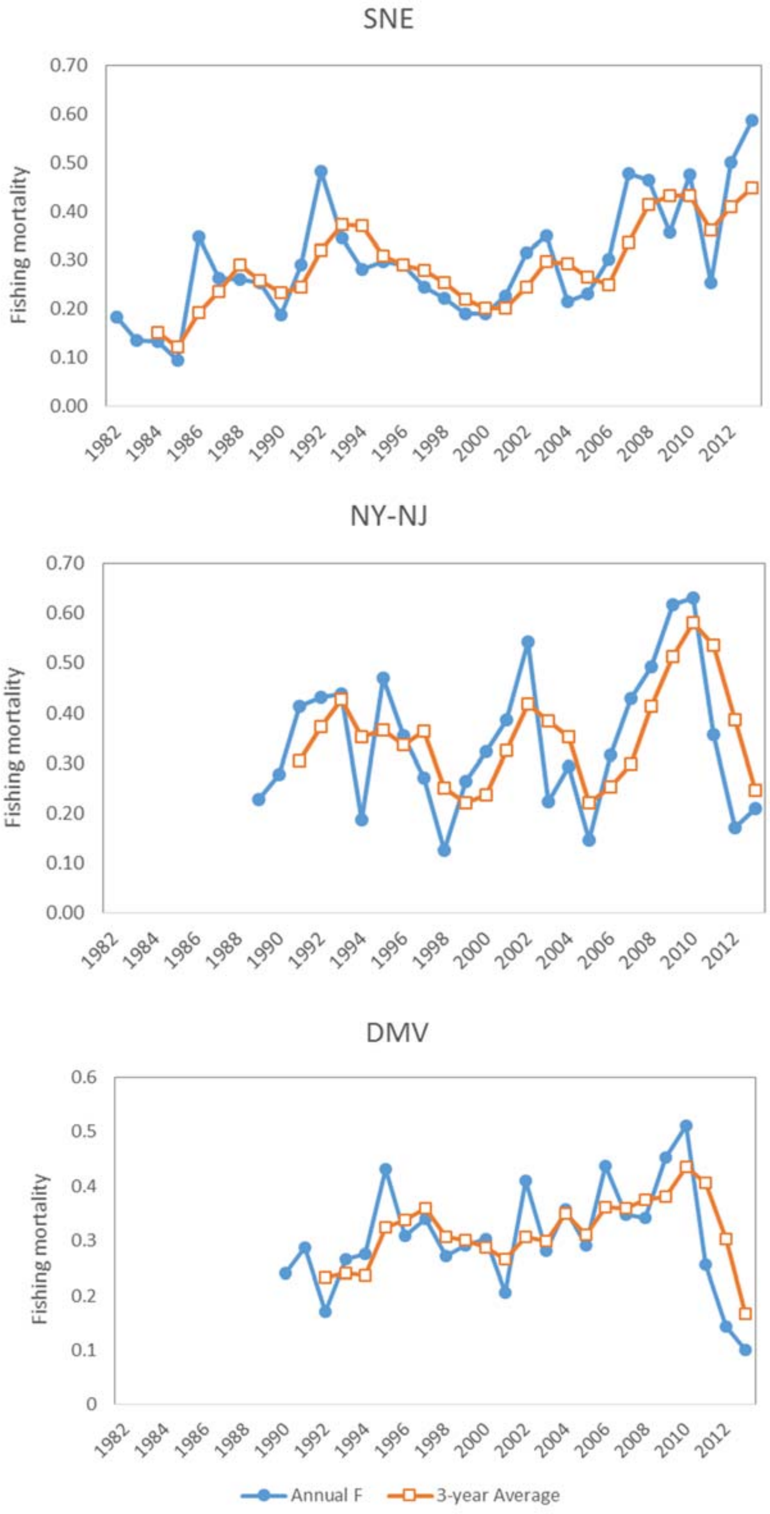


**Figure 6.15.** Median and 5th and 95th percentile MCMC estimates of F for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

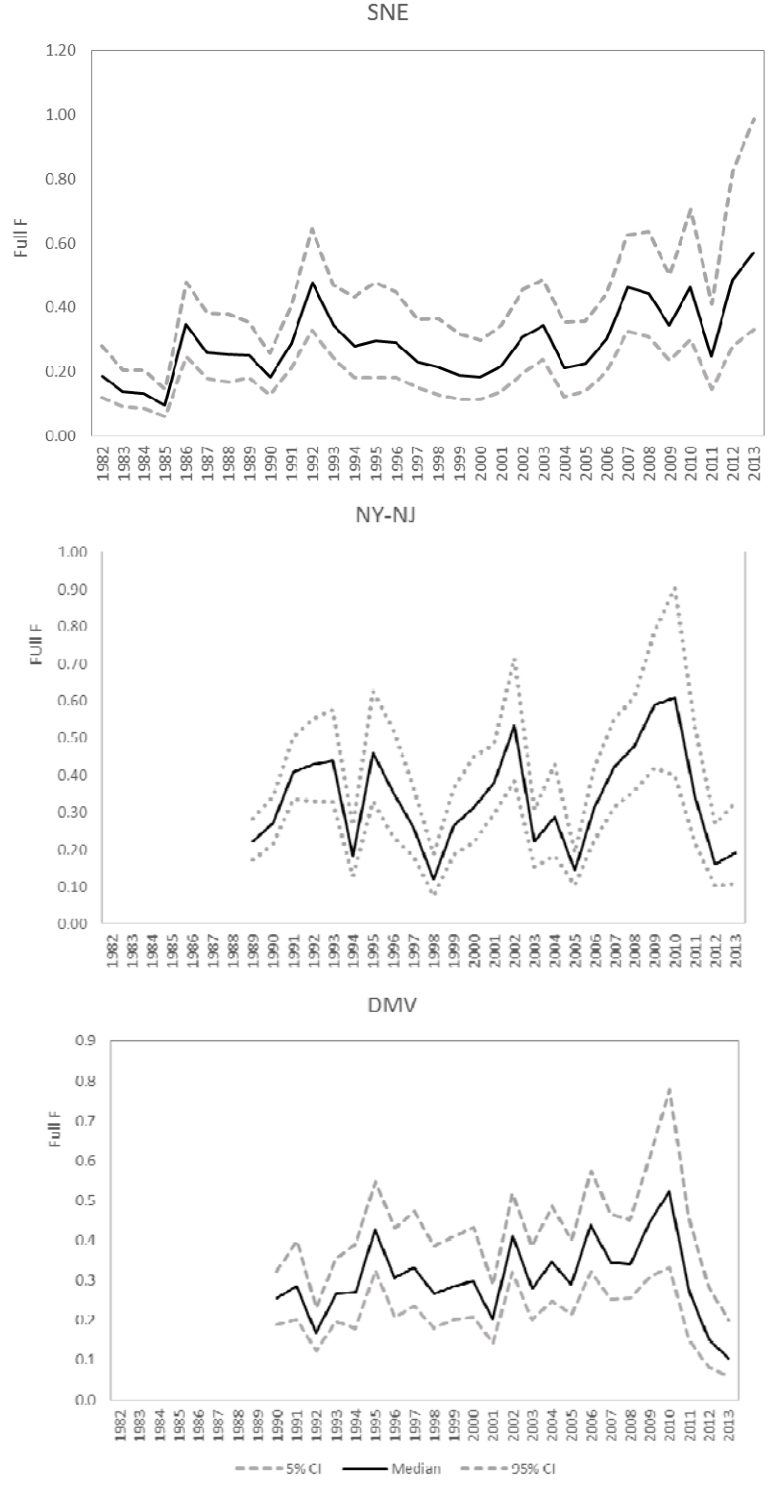


**Figure 6.16.** MCMC distributions on terminal F for southern New England (top left), NY-NJ (top right), and DelMarVa (bottom).

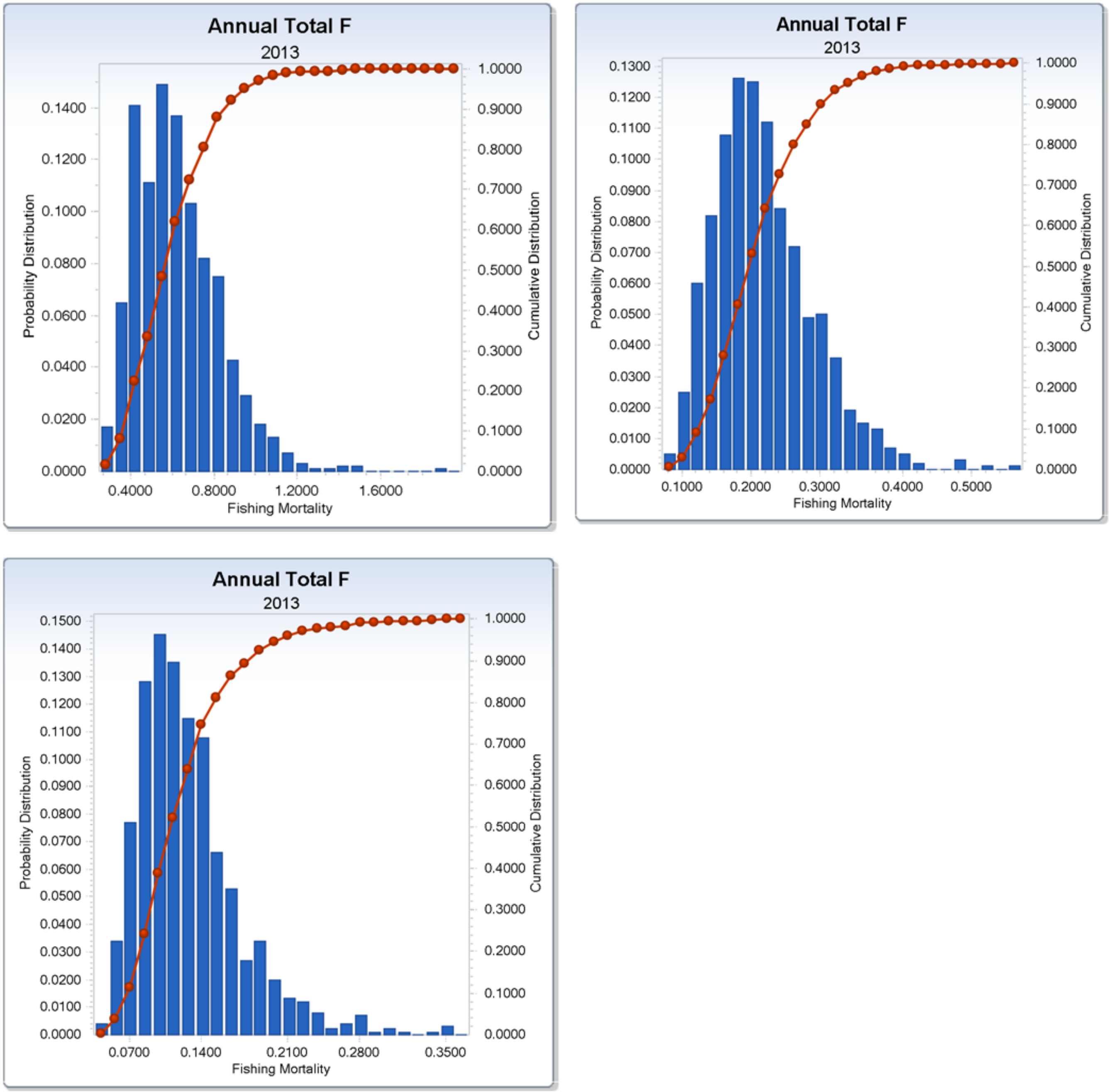


**Figure 6.17.** Median and 5th and 95th percentile MCMC estimates of SSB for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

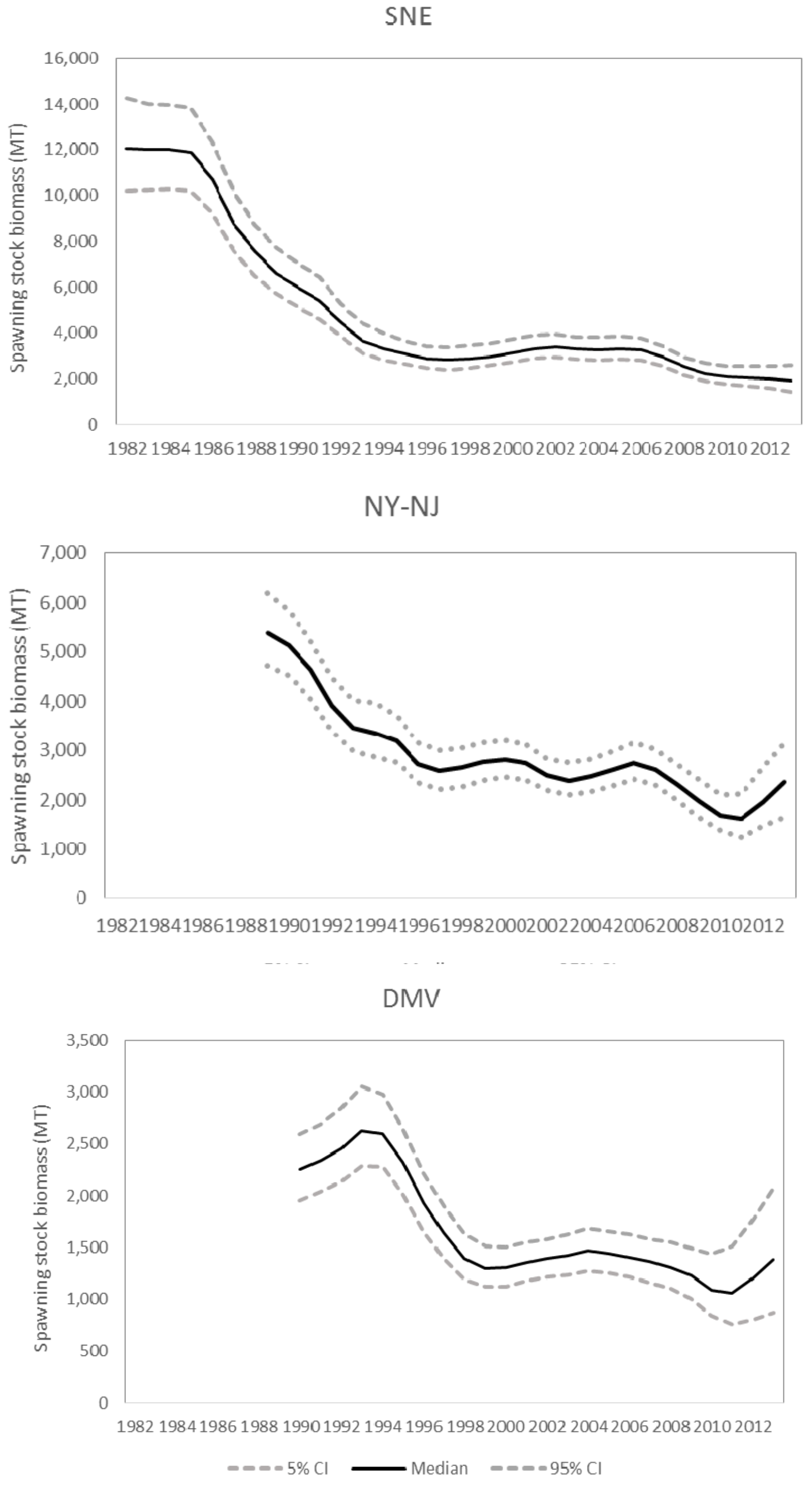


**Figure 6.18.** Distribution of MCMC estimates of SSB in the terminal year for southern New England (top left), NY-NJ (top right), and DelMarVa (bottom).

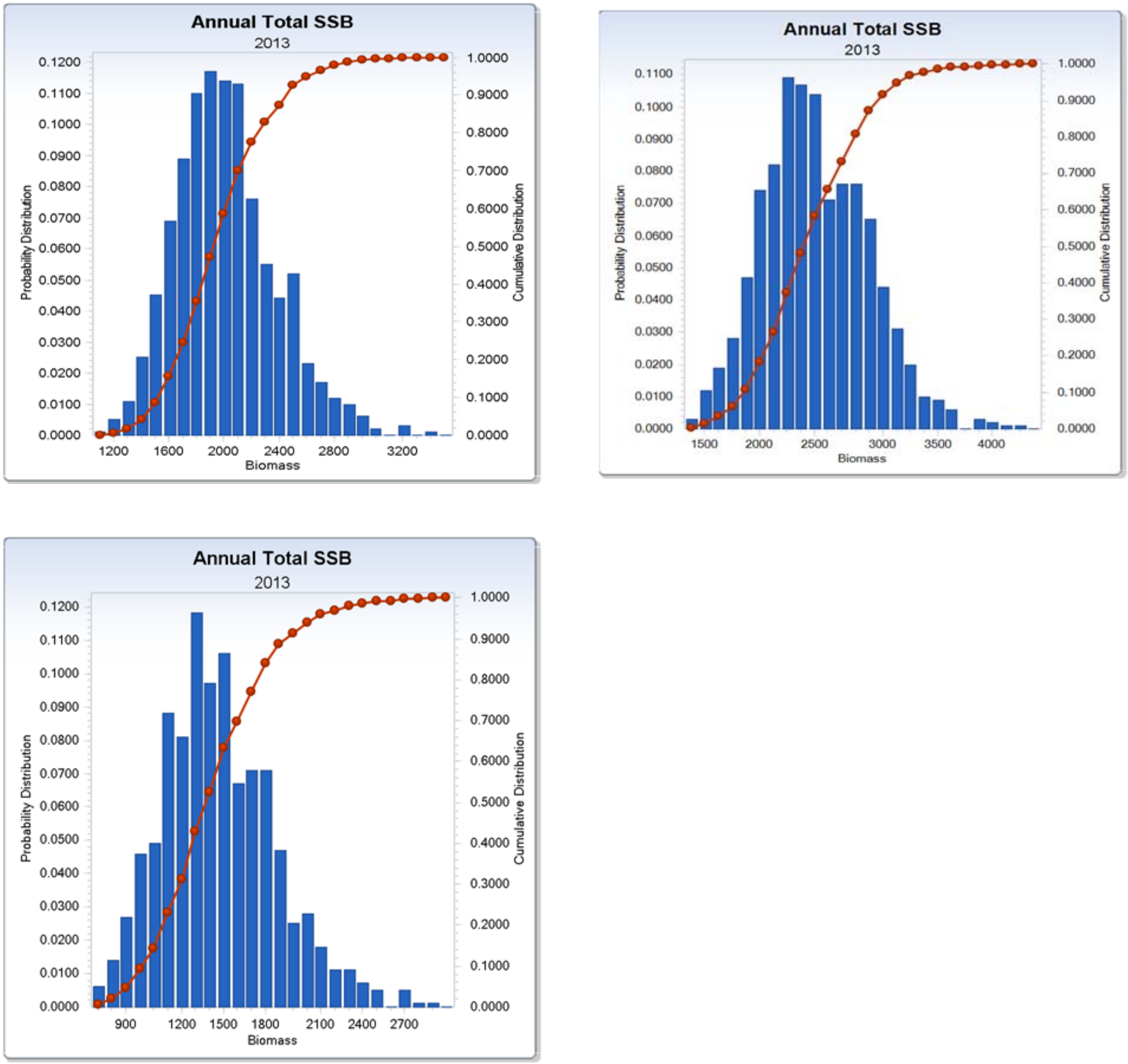


**Figure 6.19.** Estimates of recruitment and their standard deviations for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

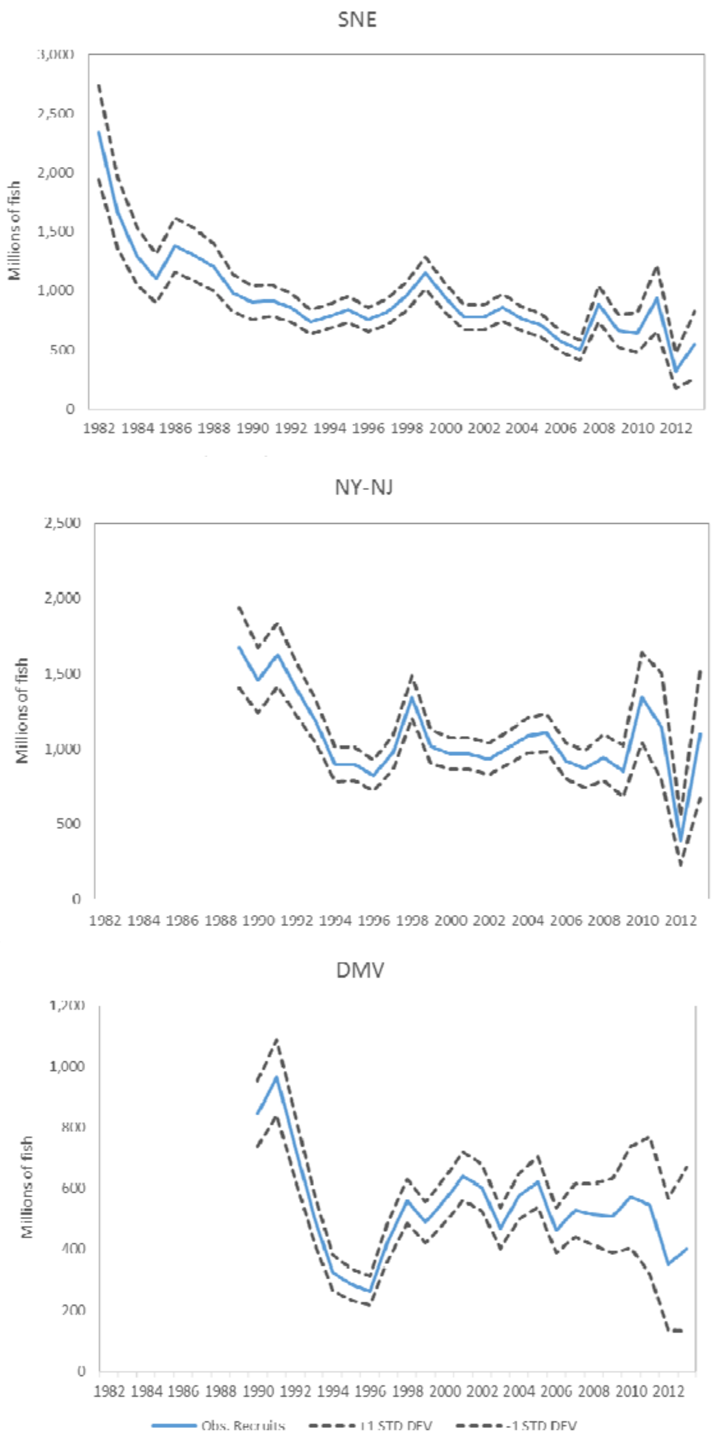


**Figure 6.20.** SSB trajectories for different sensitivity runs for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

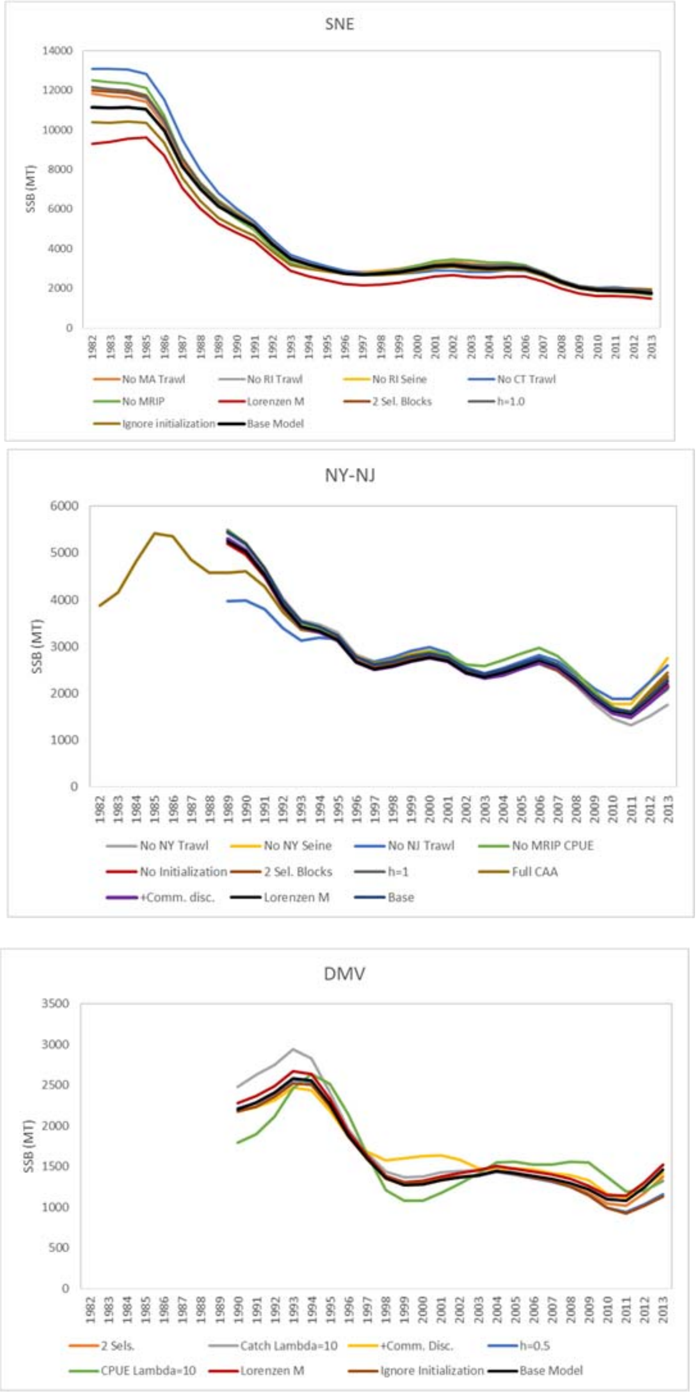


**Figure 6.21.** F trajectories for different sensitivity runs for southern New England (top), NY-NJ (middle), and DelMarVa (bottom).

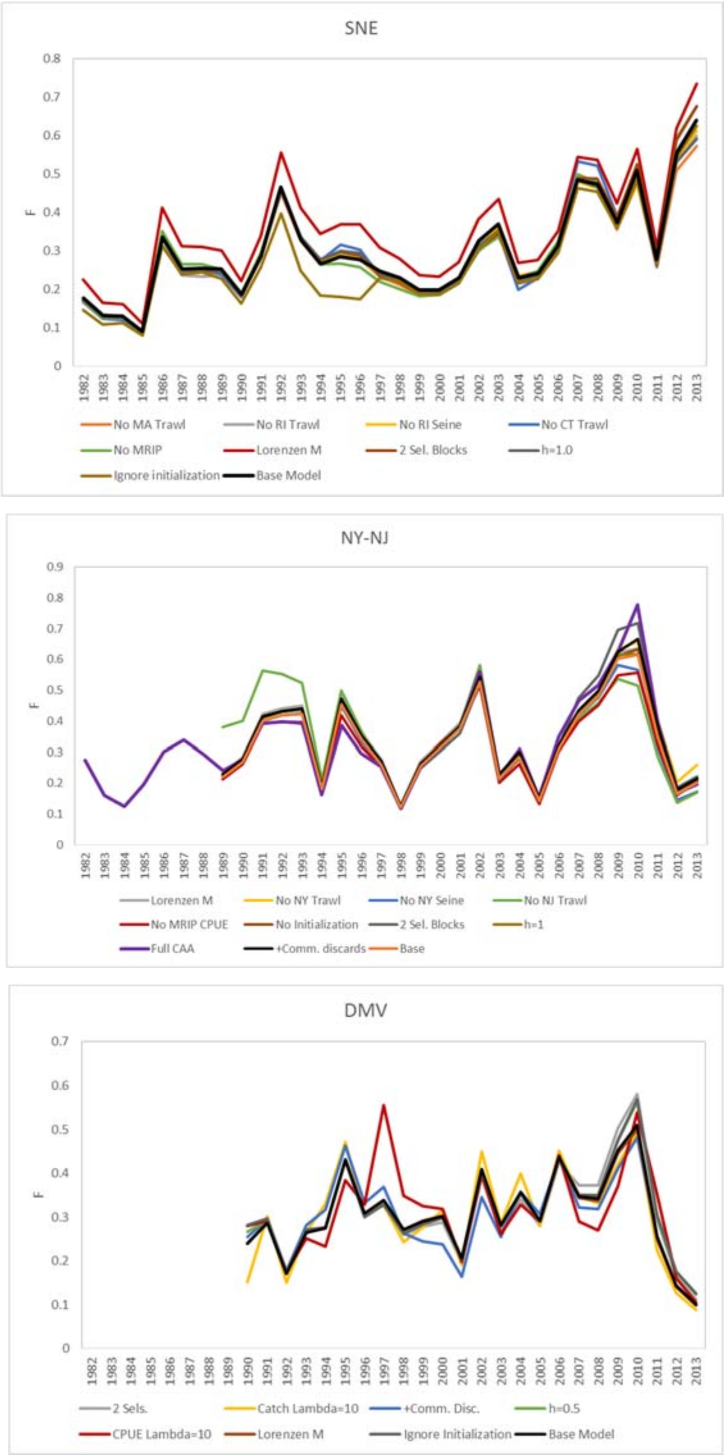


**Figure 6.22A.** Comparison of SSB trends between base model regions (MA-RI-CT/NY-NJ) and Long Island Sound regional split (MA-RI/CT-NY-NJ).

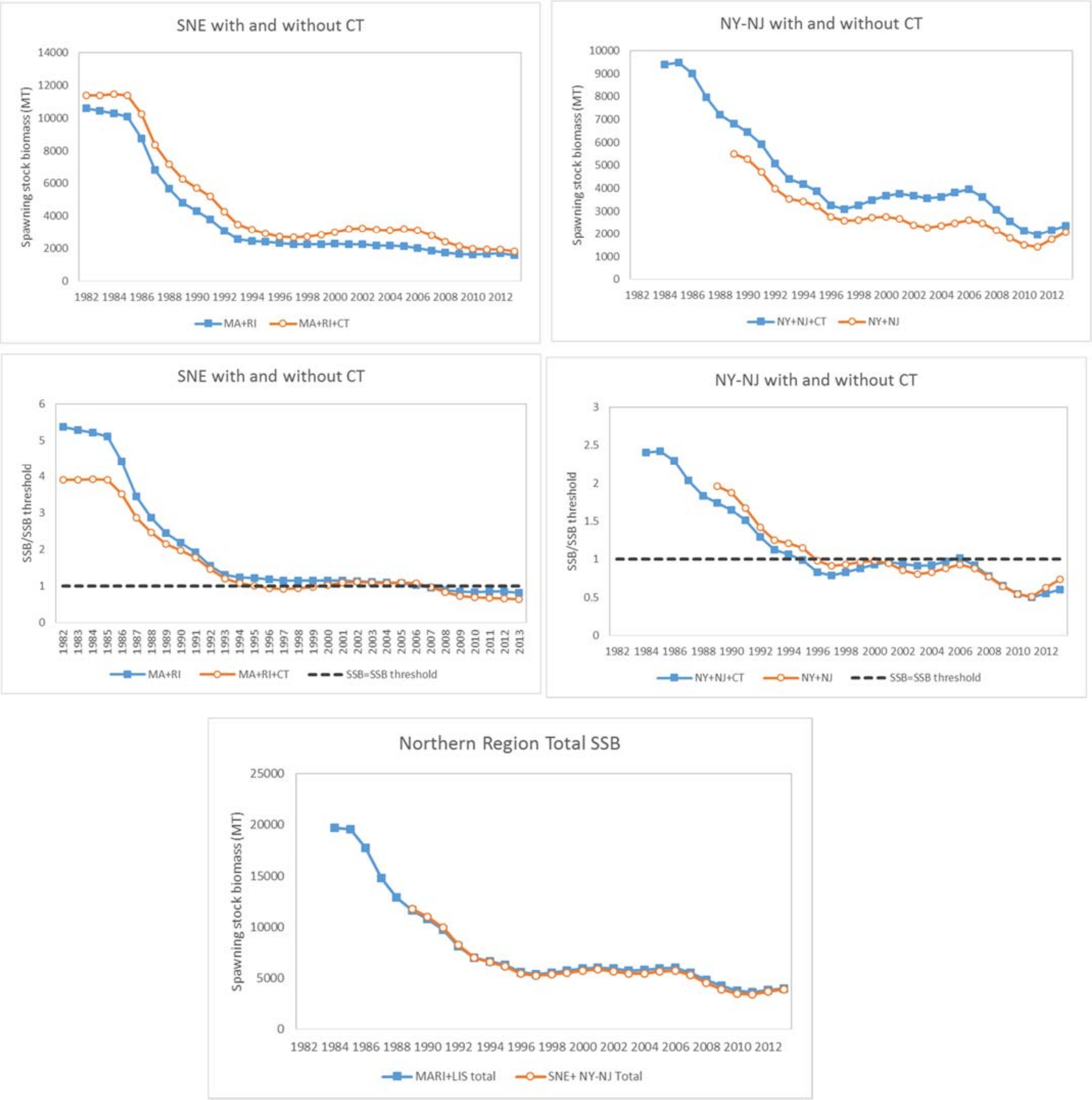


**Figure 6.22B.** Comparison of F trends between base model regions (MA-RI-CT/NY-NJ) and Long Island Sound regional split (MA-RI/CT-NY-NJ).

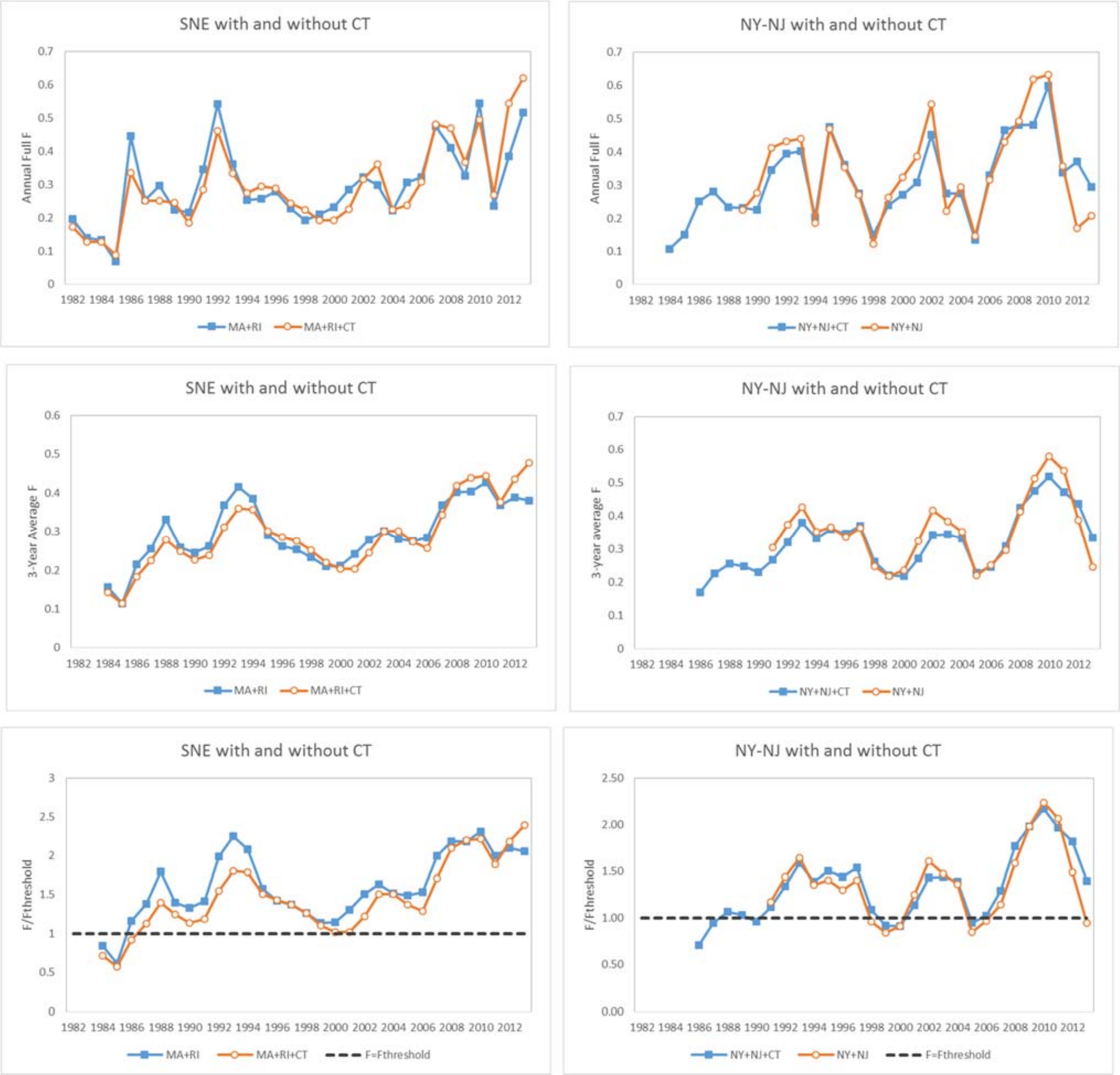


**Figure 6.22C.** Comparison of SSB trends between three-region model (SNE, NY-NJ, DMV) and North (MA-NY) – South (NJ-VA) split.

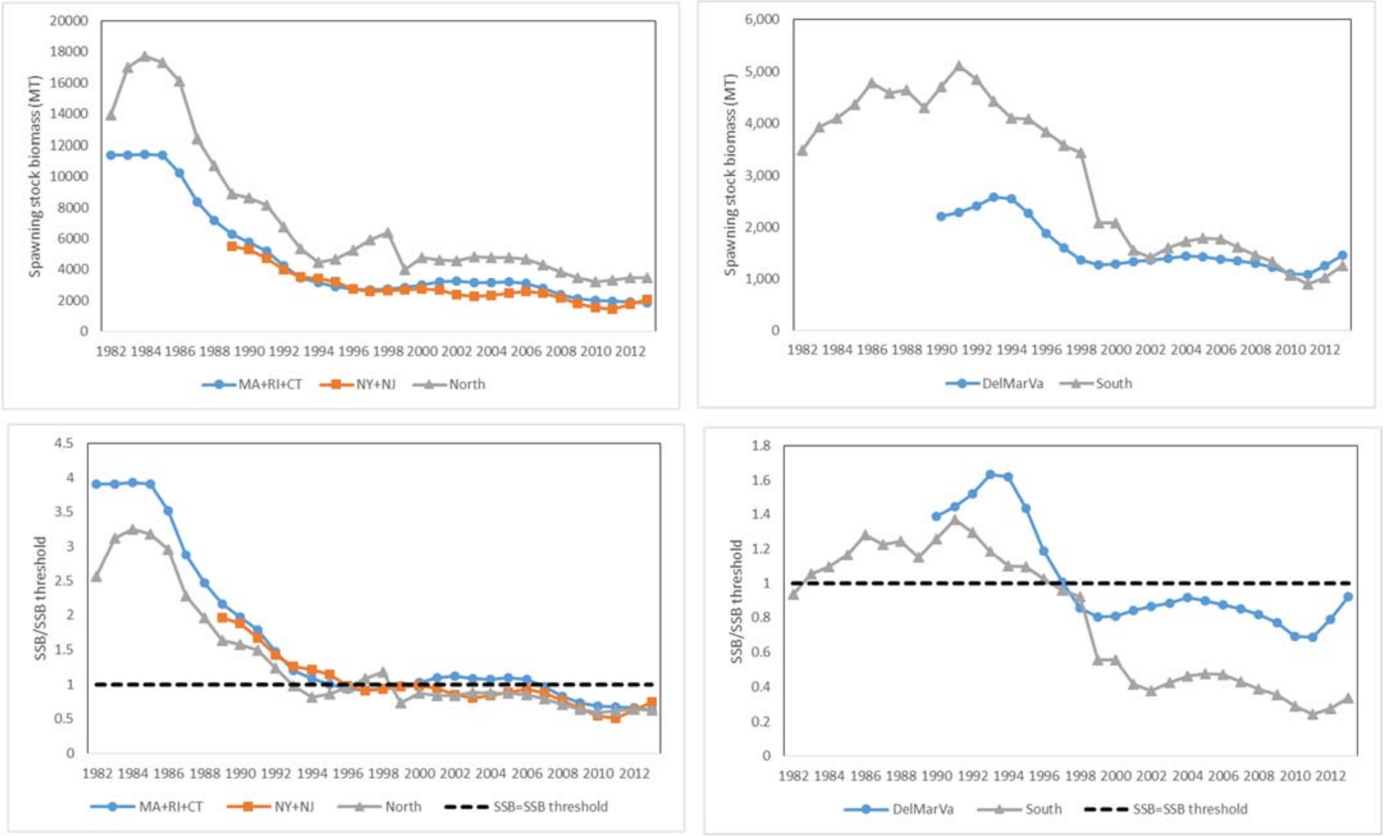
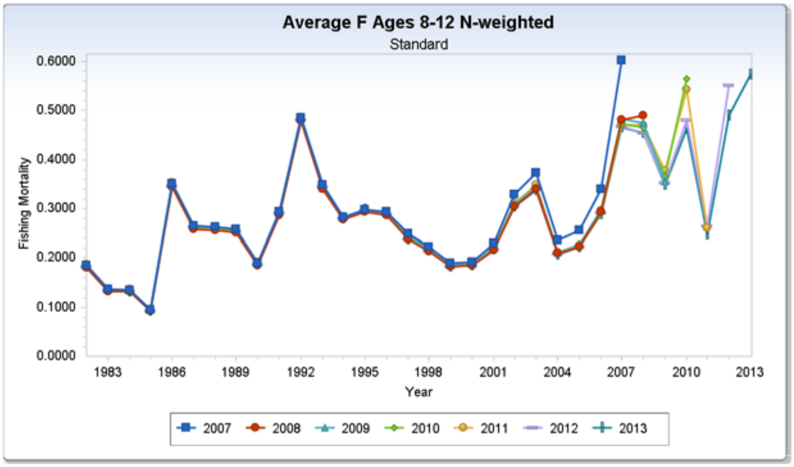
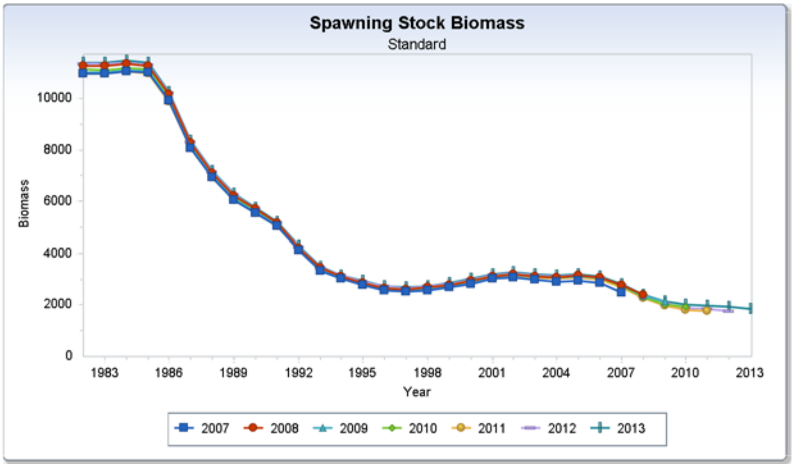


**Figure 6.22D.** Comparison of F trends between three-region model (SNE, NY-NJ, DMV) and North (MA-NY) – South (NJ-VA) split.

**Figure 6.23.** Retrospective patterns for average F (top), SSB (middle), and recruitment (bottom) for southern New England.





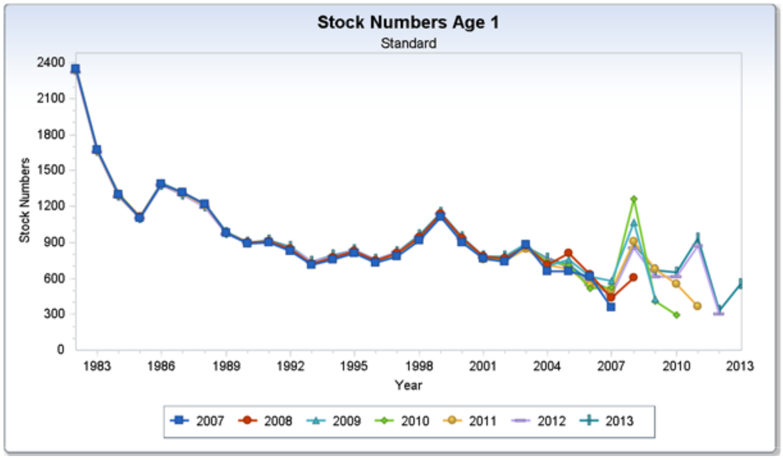


**Figure 6.24.** Retrospective patterns for average F (top), SSB (middle), and recruitment (bottom) for NY-NJ.

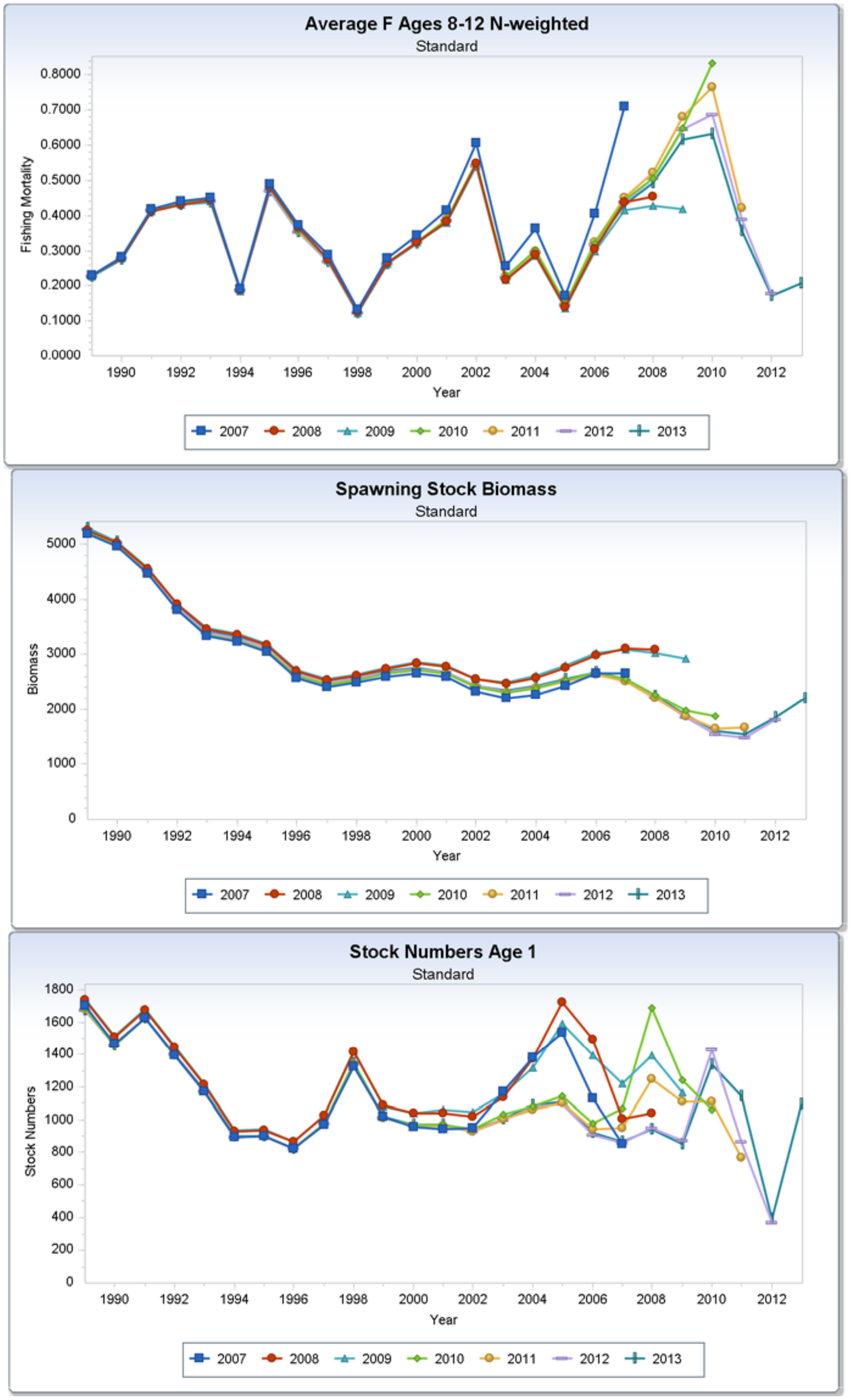


**Figure 6.25.** Retrospective patterns for average F (top), SSB (middle), and recruitment (bottom) for DelMarVa.

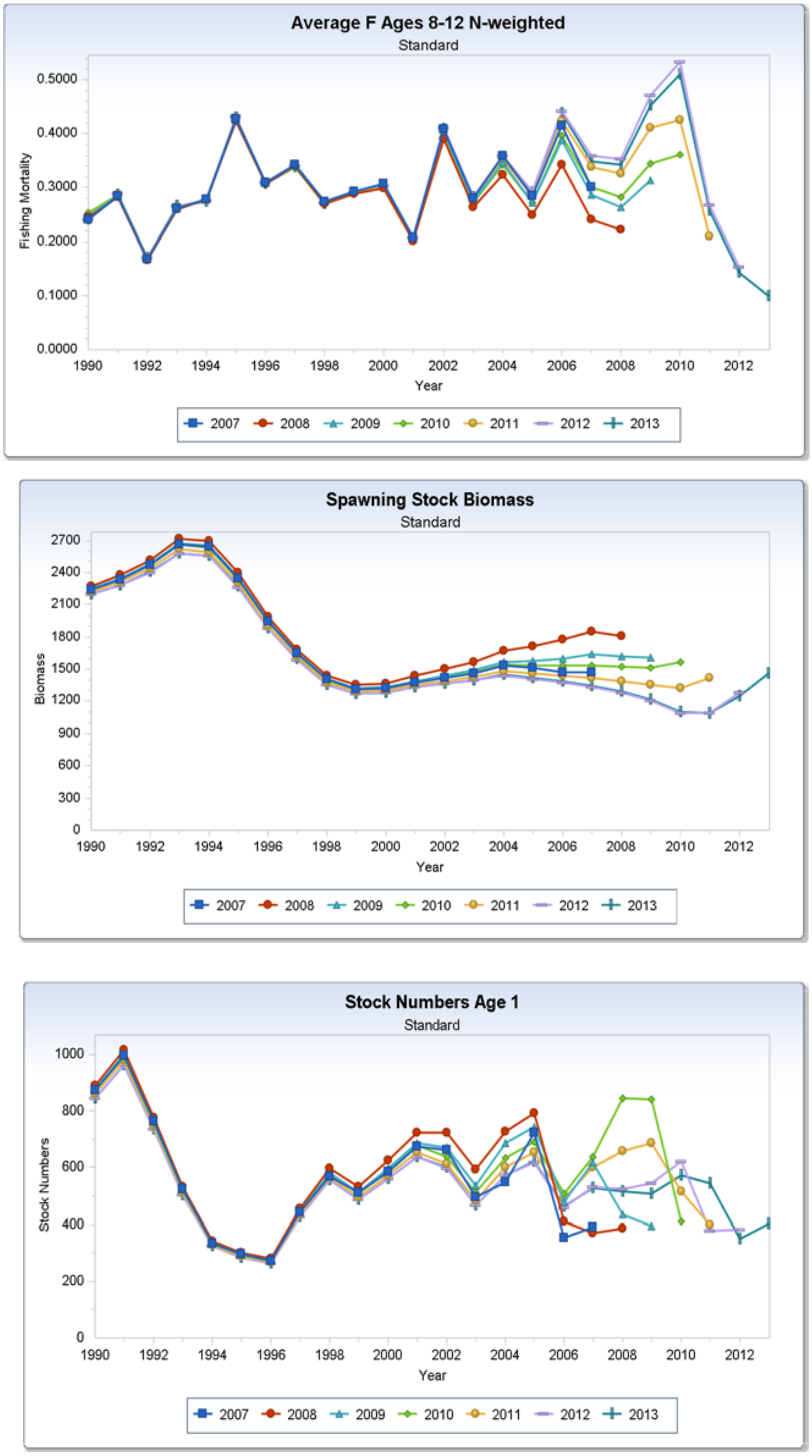


**Figure 6.26.** Valid and invalid draws of base model run of xDB-SRA for SNE region.

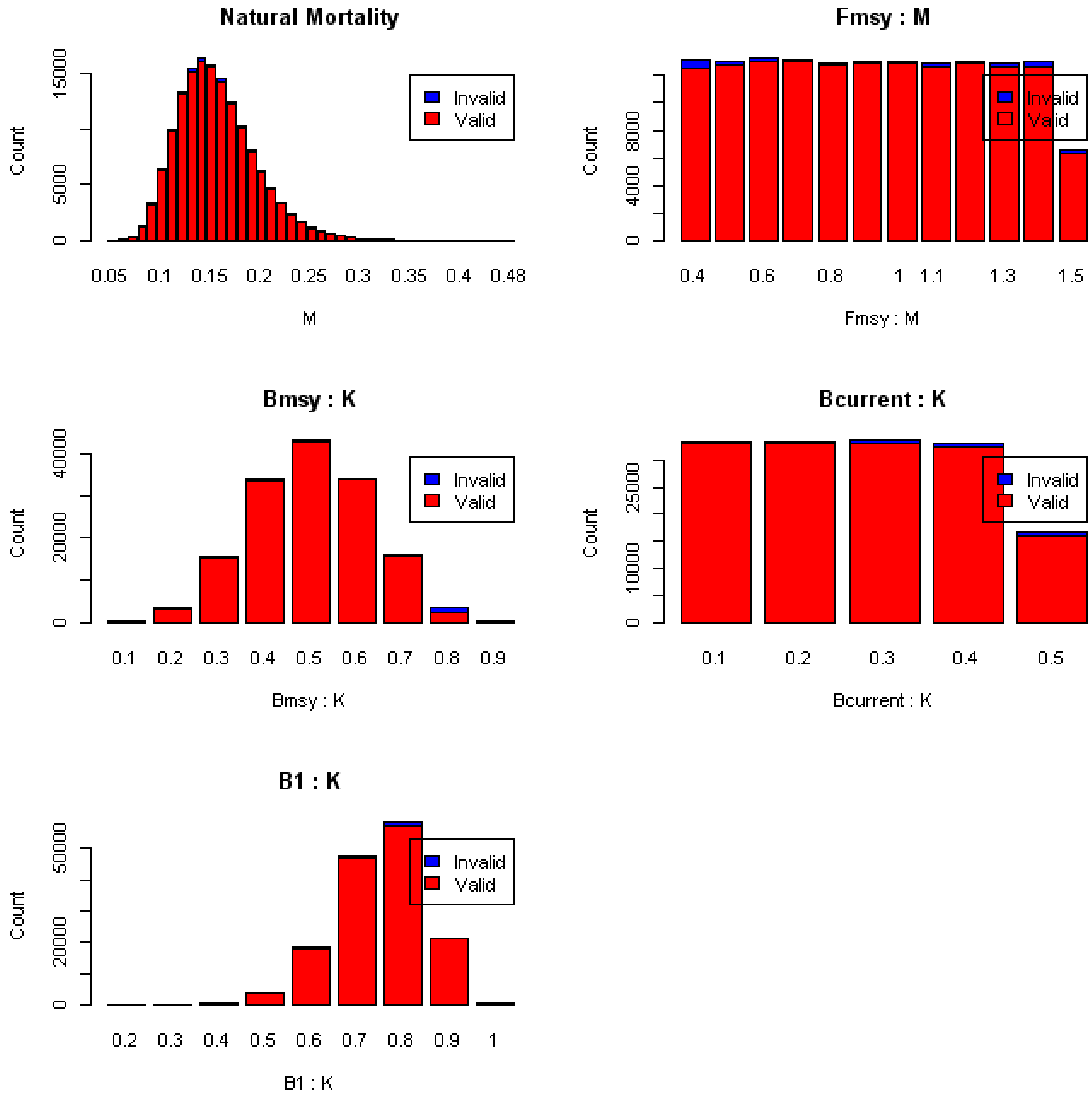


**Figure 6.27.** Distributions of valid and resampled parameter draws of the SNE base model run of xDB-SRA.

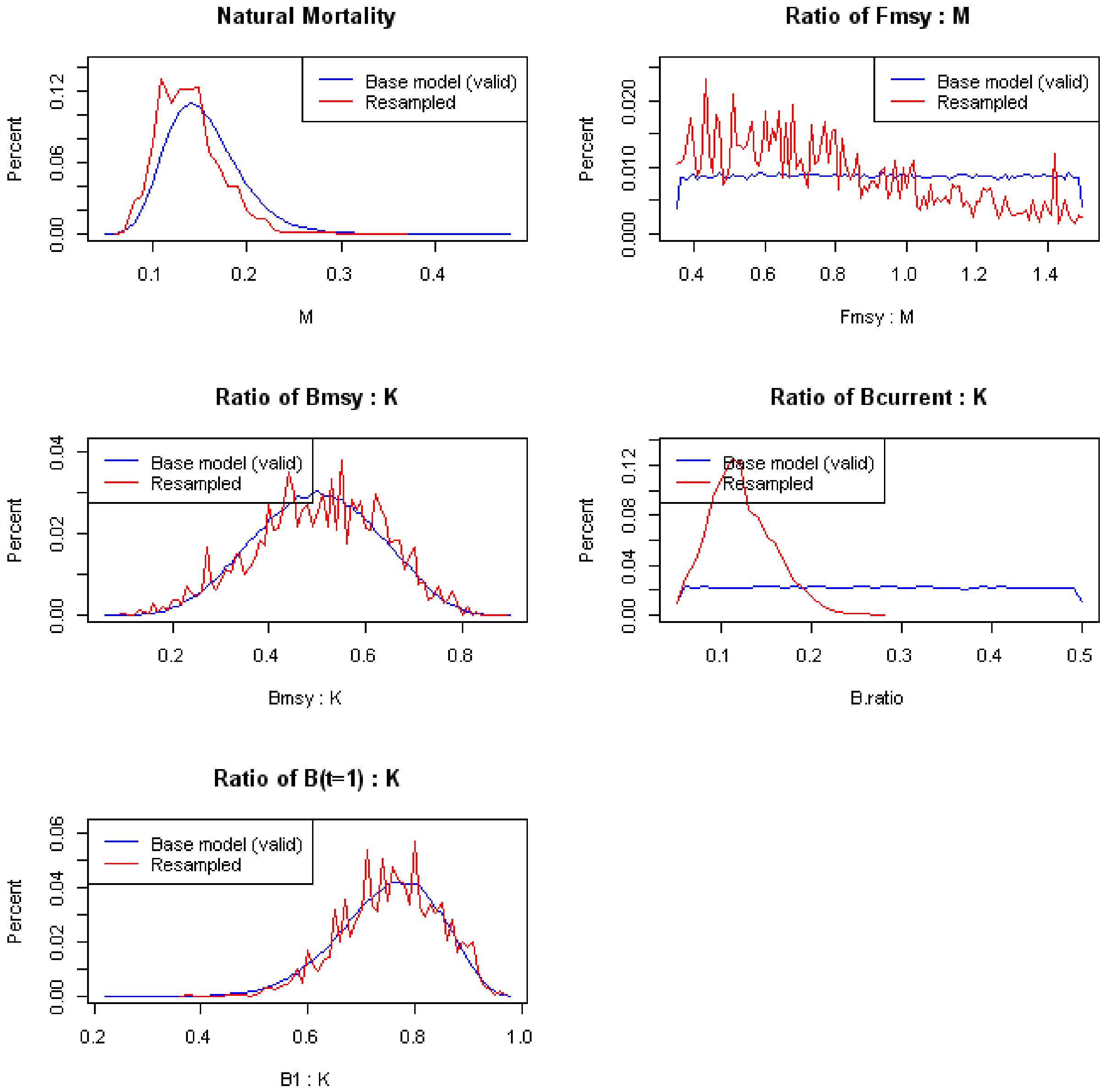


**Figure 6.28.** Biomass and exploitation trajectories for the SNE base model run of xDB-SRA.

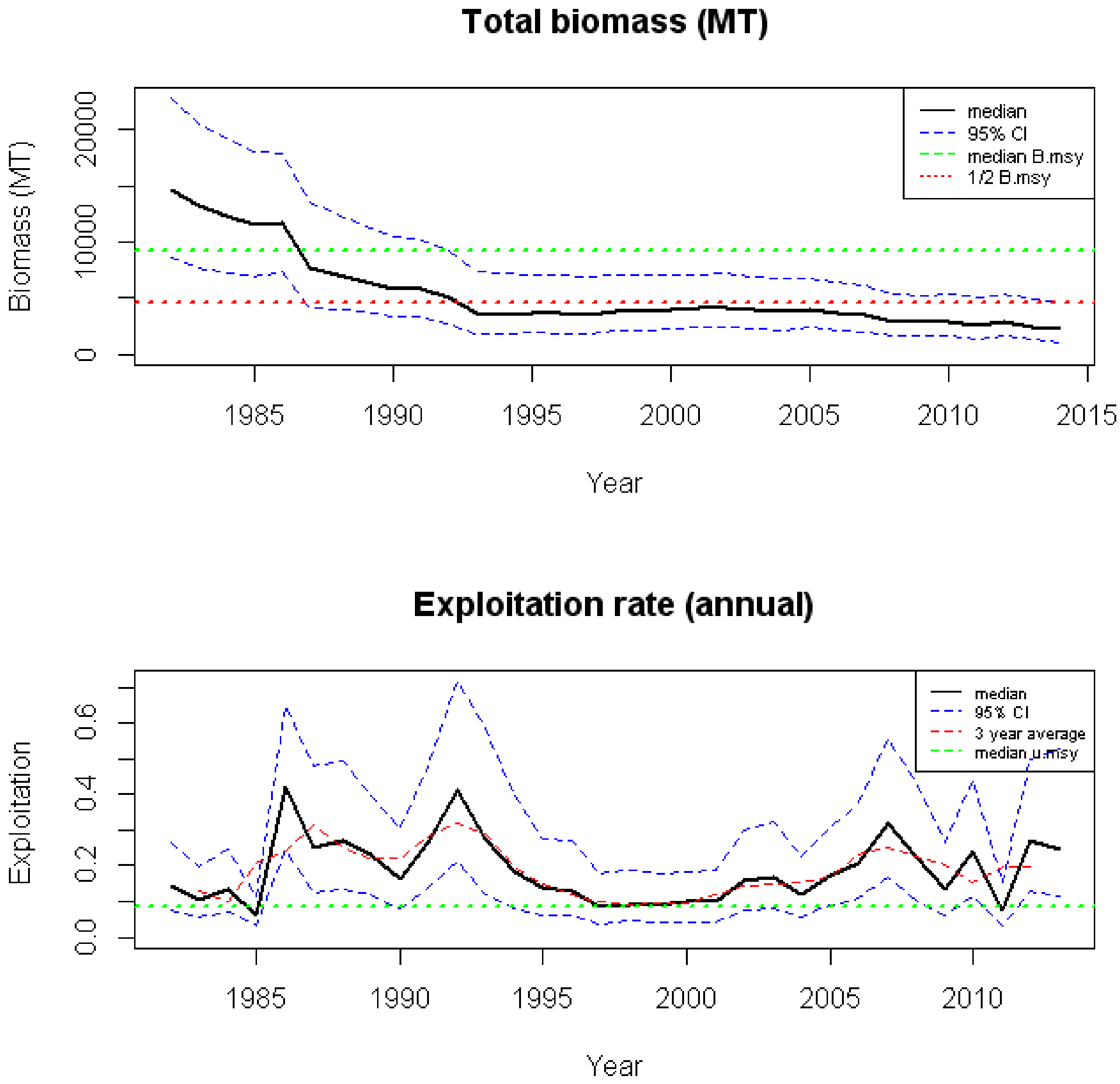


**Figure 6.29.** Distributions of valid and resampled reference point estimates for the SNE base model run of xDB-SRA.

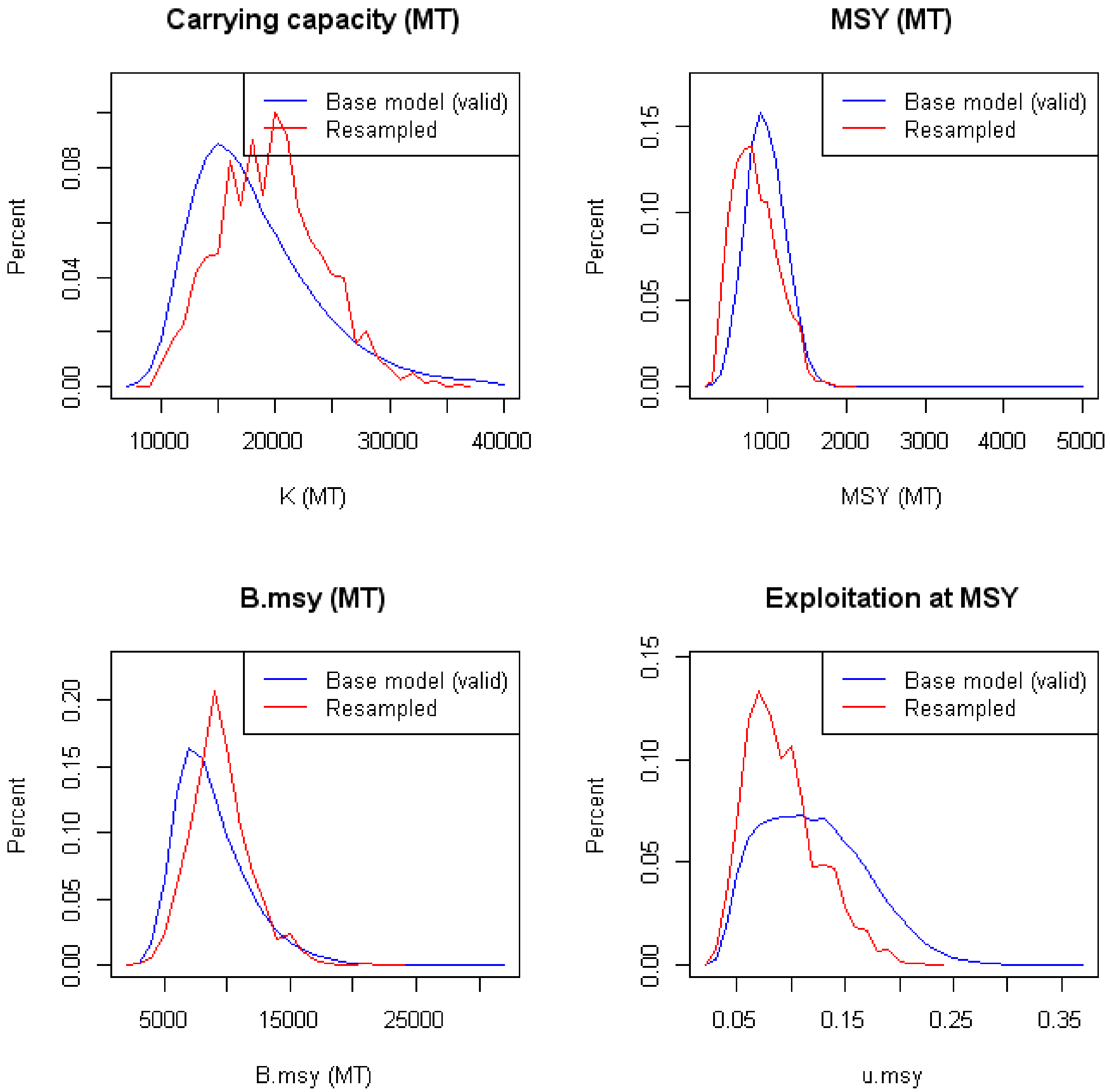


**Figure 6.30.** Results of survey index sensitivity runs for the SNE region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

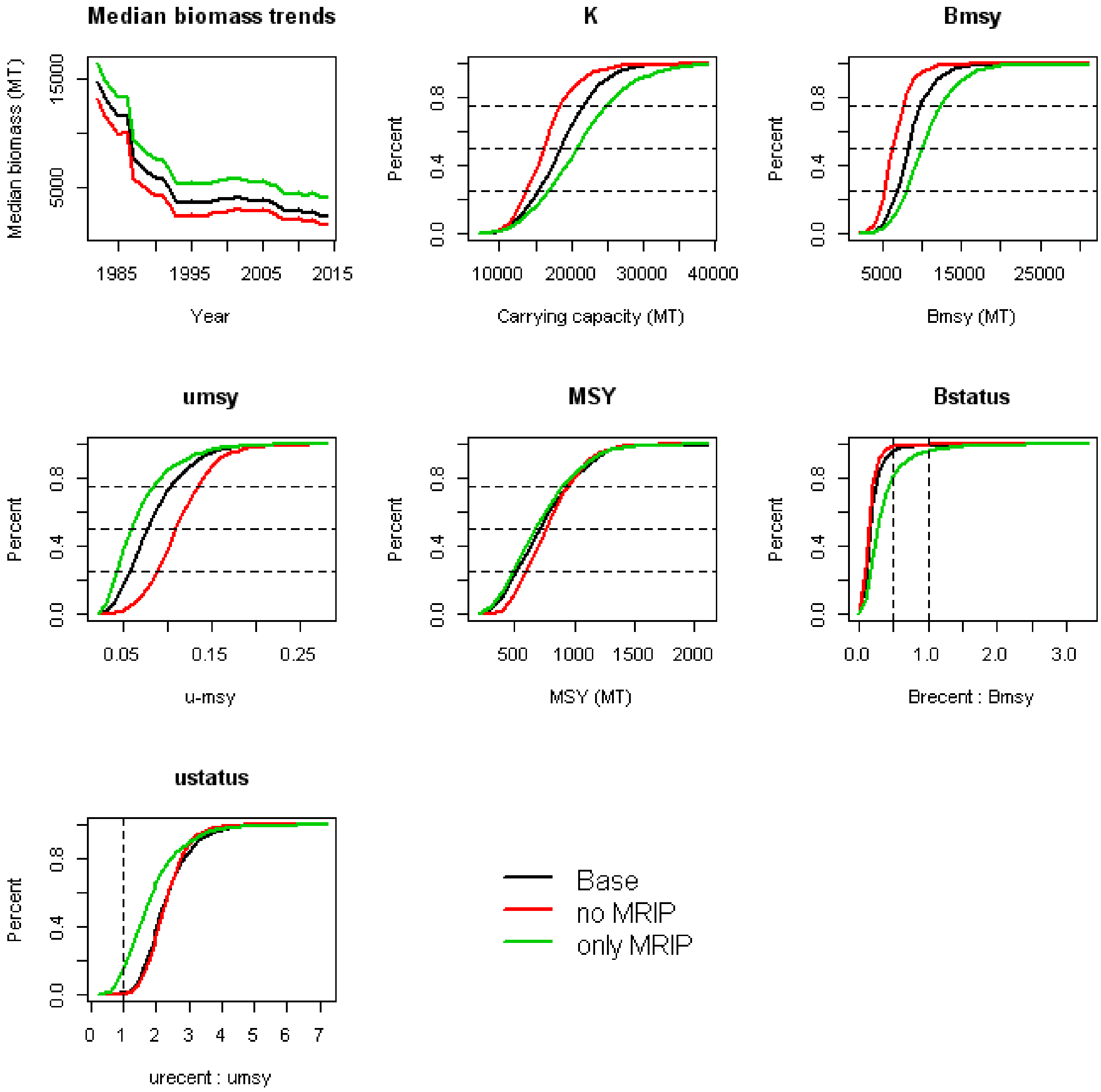


**Figure 6.31.** Results of model configuration sensitivity runs for the SNE region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

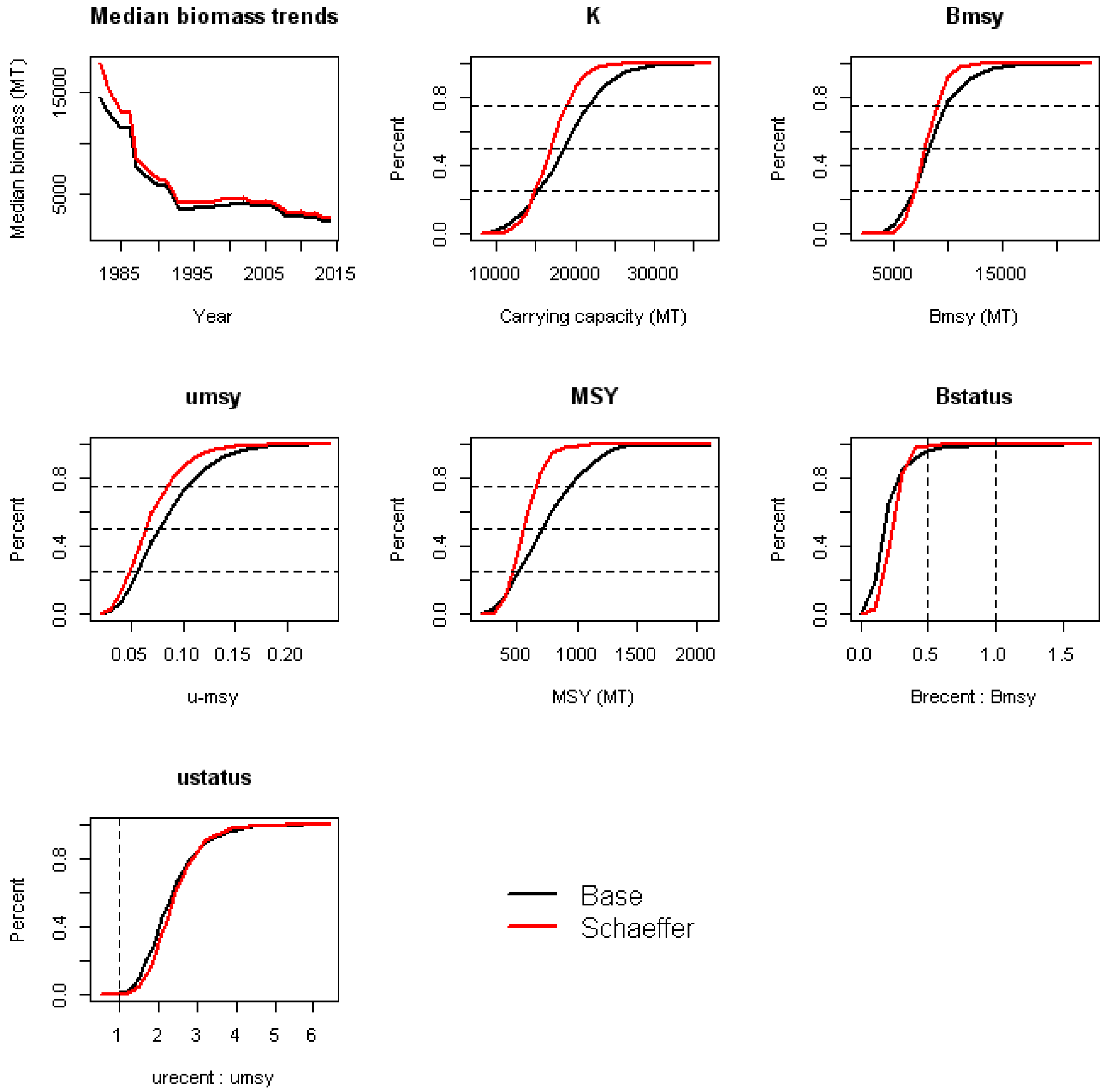


**Figure 6.32.** Results of regional configuration sensitivity runs for the SNE region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

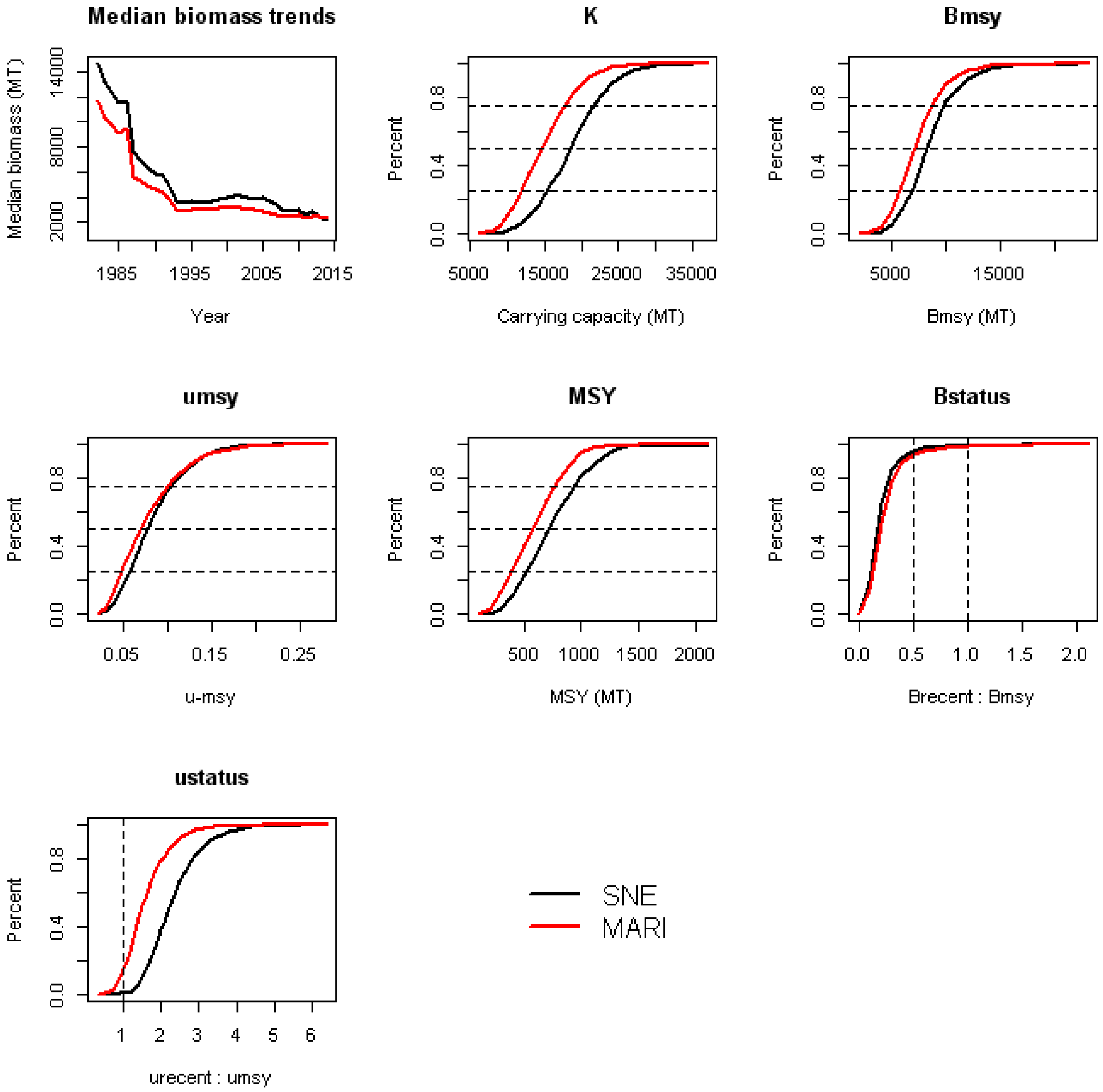


**Figure 6.33.** Valid and invalid draws of base model run of xDB-SRA for NY-NJ region.

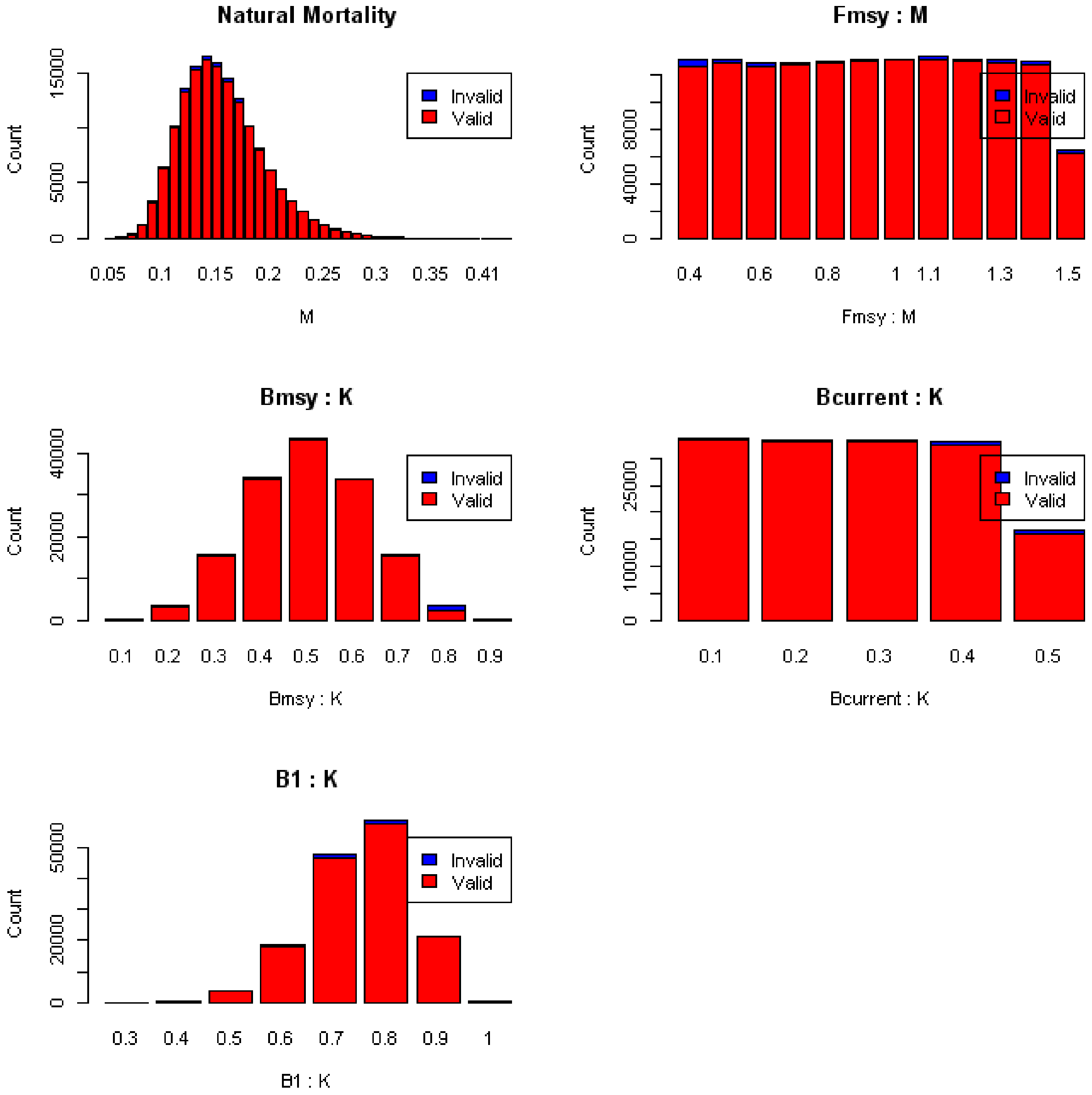


**Figure 6.34.** Distributions of valid and resampled parameter draws of the NY-NJ base model run of xDB-SRA.

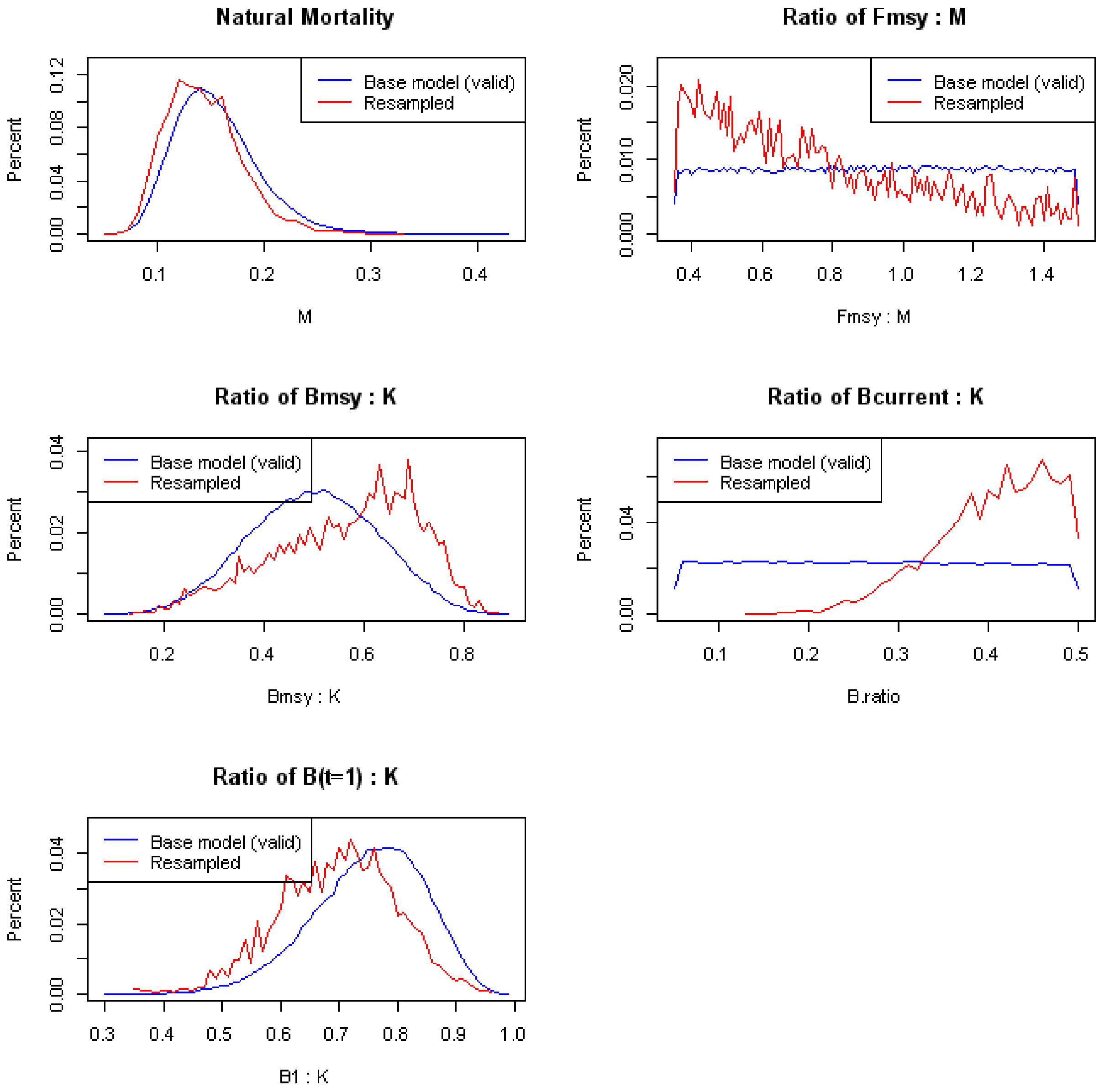
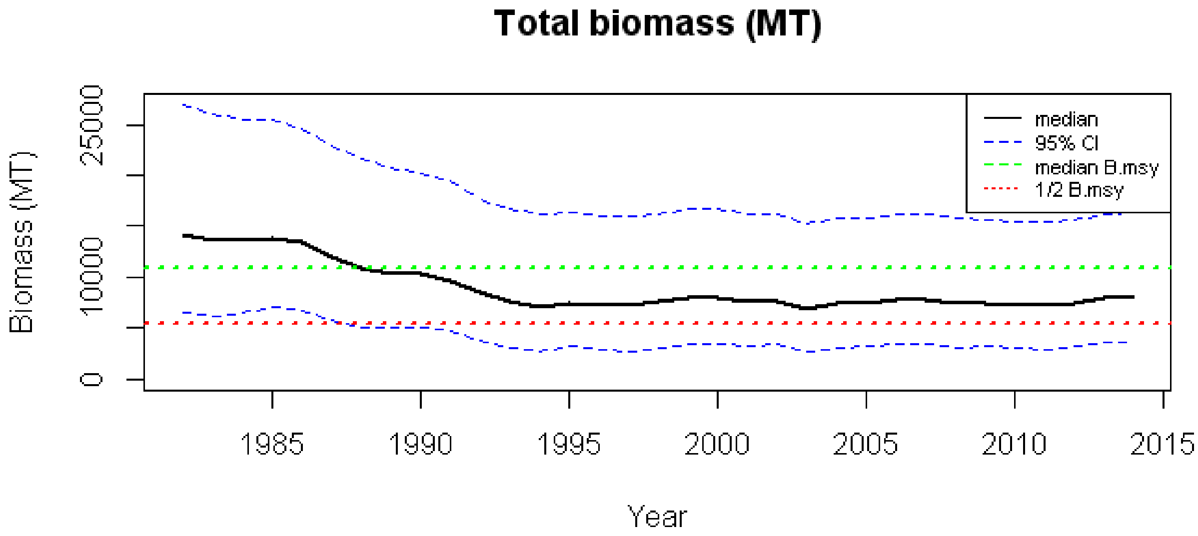


**Figure 6.35.** Biomass and exploitation trajectories for the NY-NJ base model run of xDB-SRA.



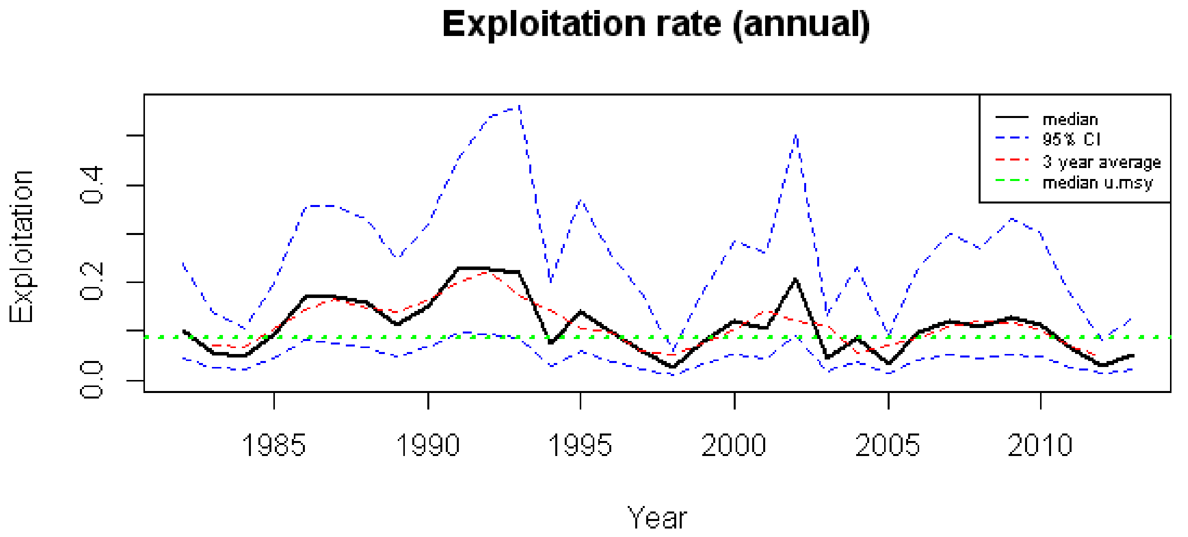


**Figure 6.35.** Distributions of valid and resampled reference point estimates for the NY-NJ base model run of xDB-SRA.

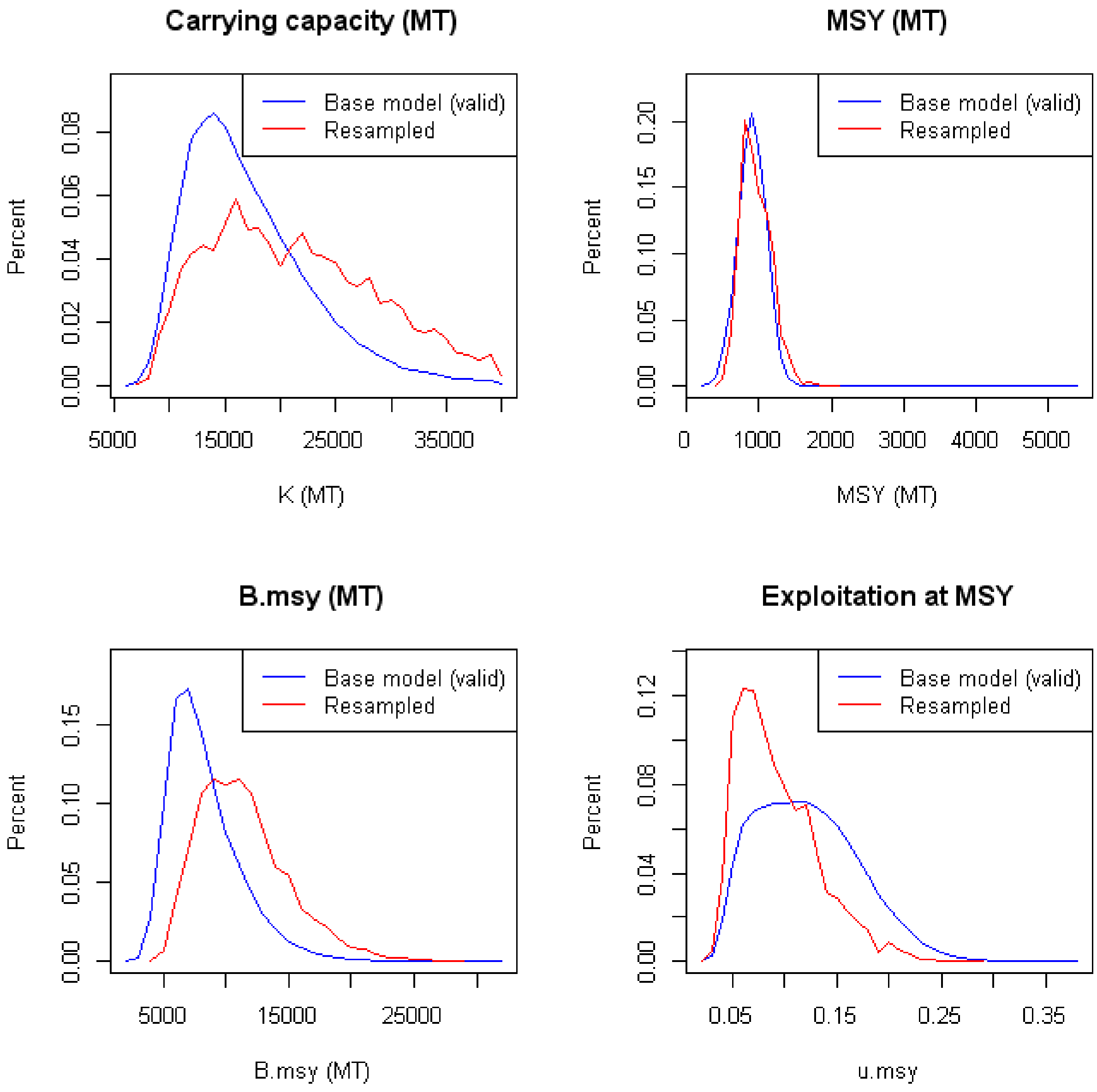


**Figure 6.36.** Results of survey index sensitivity runs for the NY-NJ region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

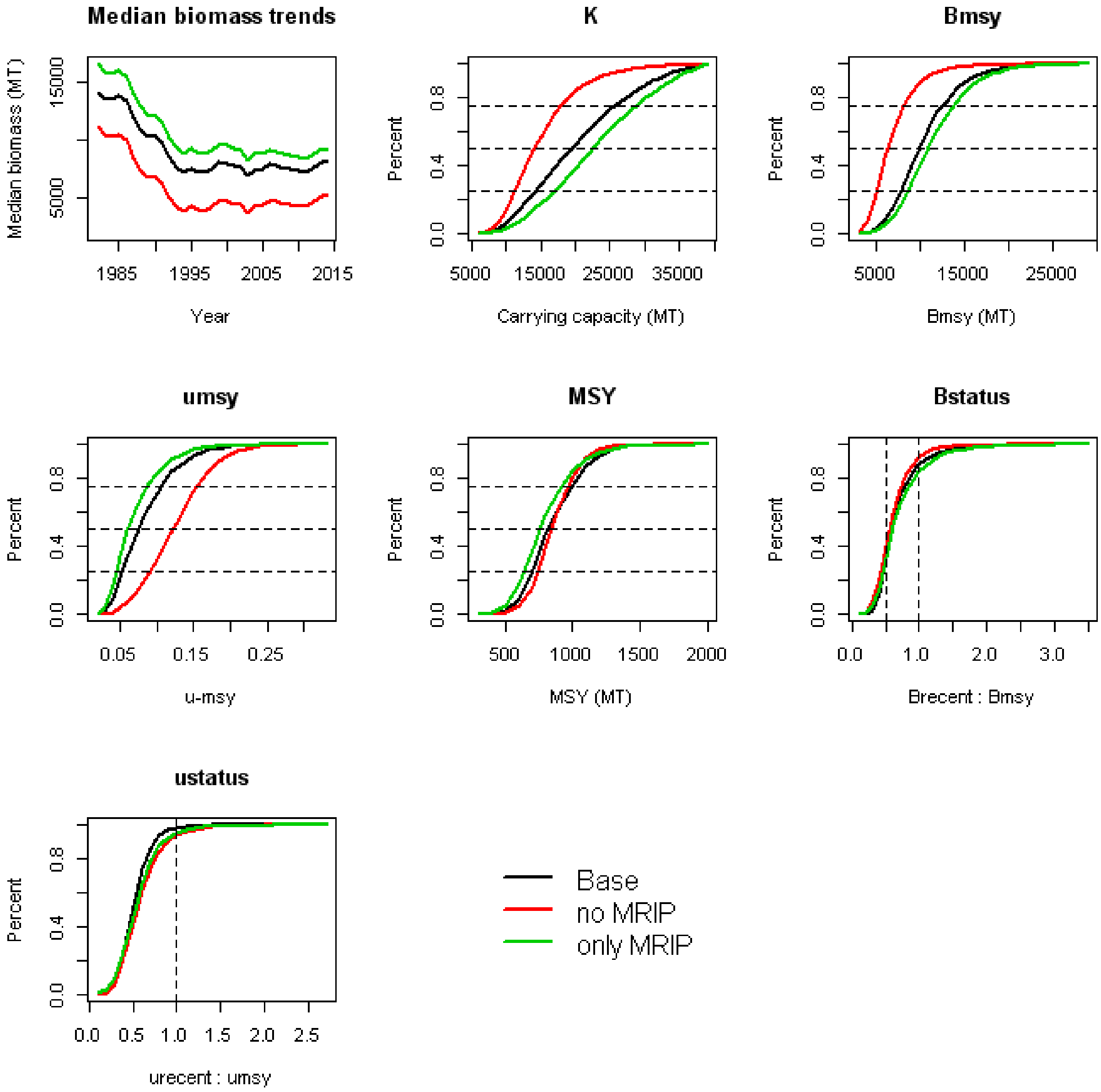


**Figure 6.37.** Results of model configuration sensitivity runs for the NY-NJ region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

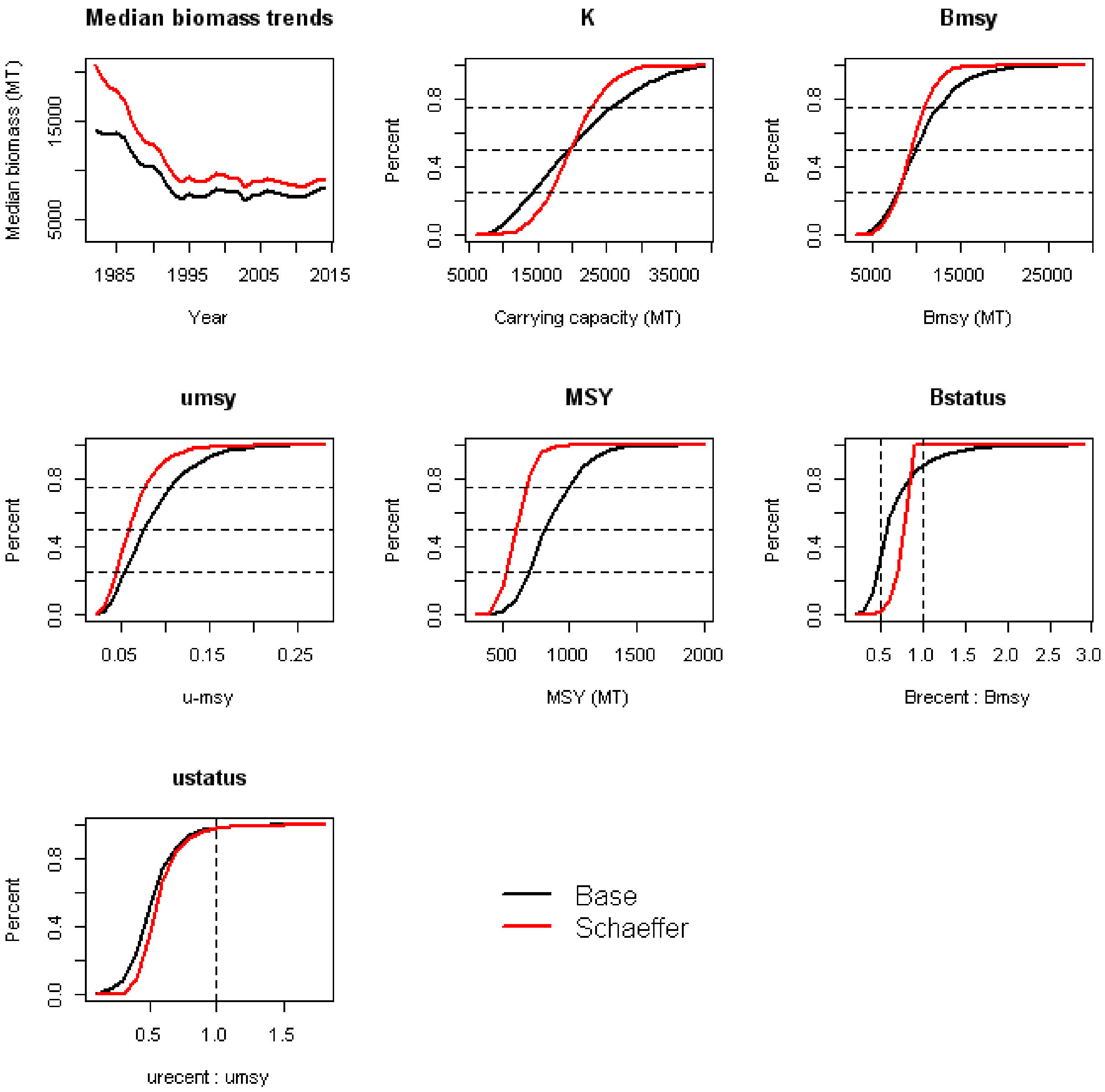


**Figure 6.38.** Results of regional configuration sensitivity runs for the NYNJ region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

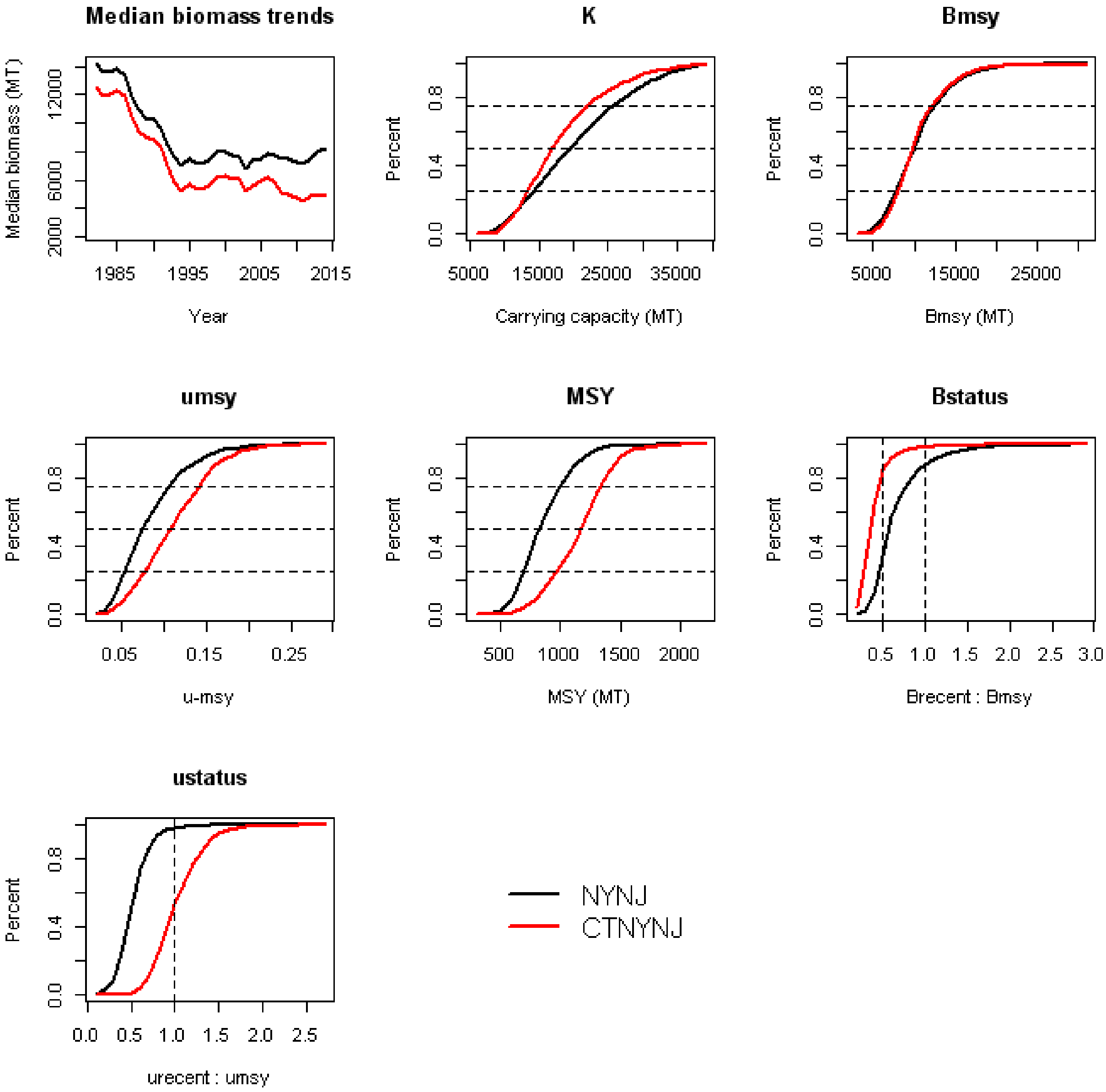


**Figure 6.39.** Valid and invalid draws of base model run of xDB-SRA for DMV region.

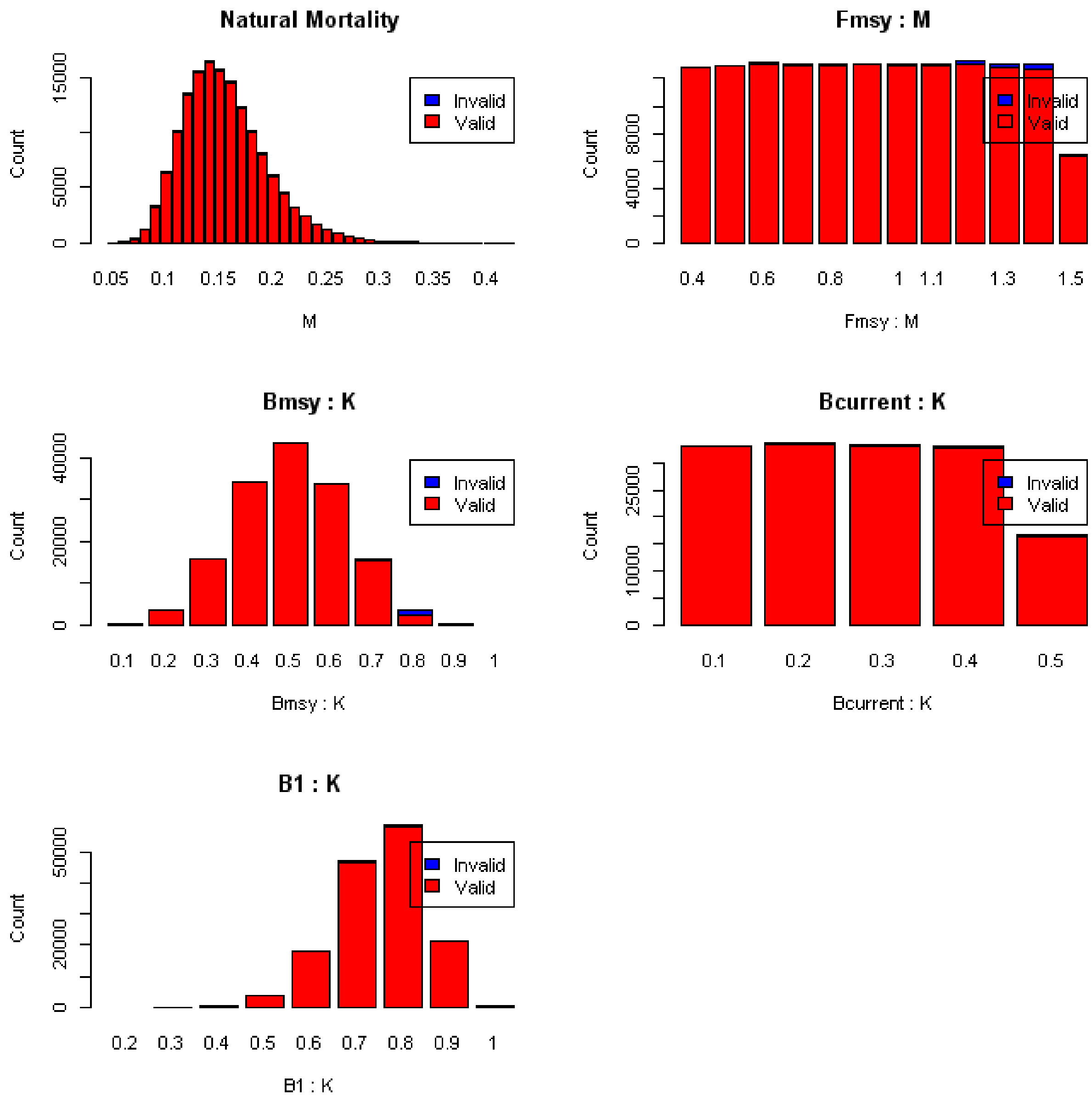


**Figure 6.40.** Distributions of valid and resampled parameter draws of the DMV base model run of xDB-SRA.

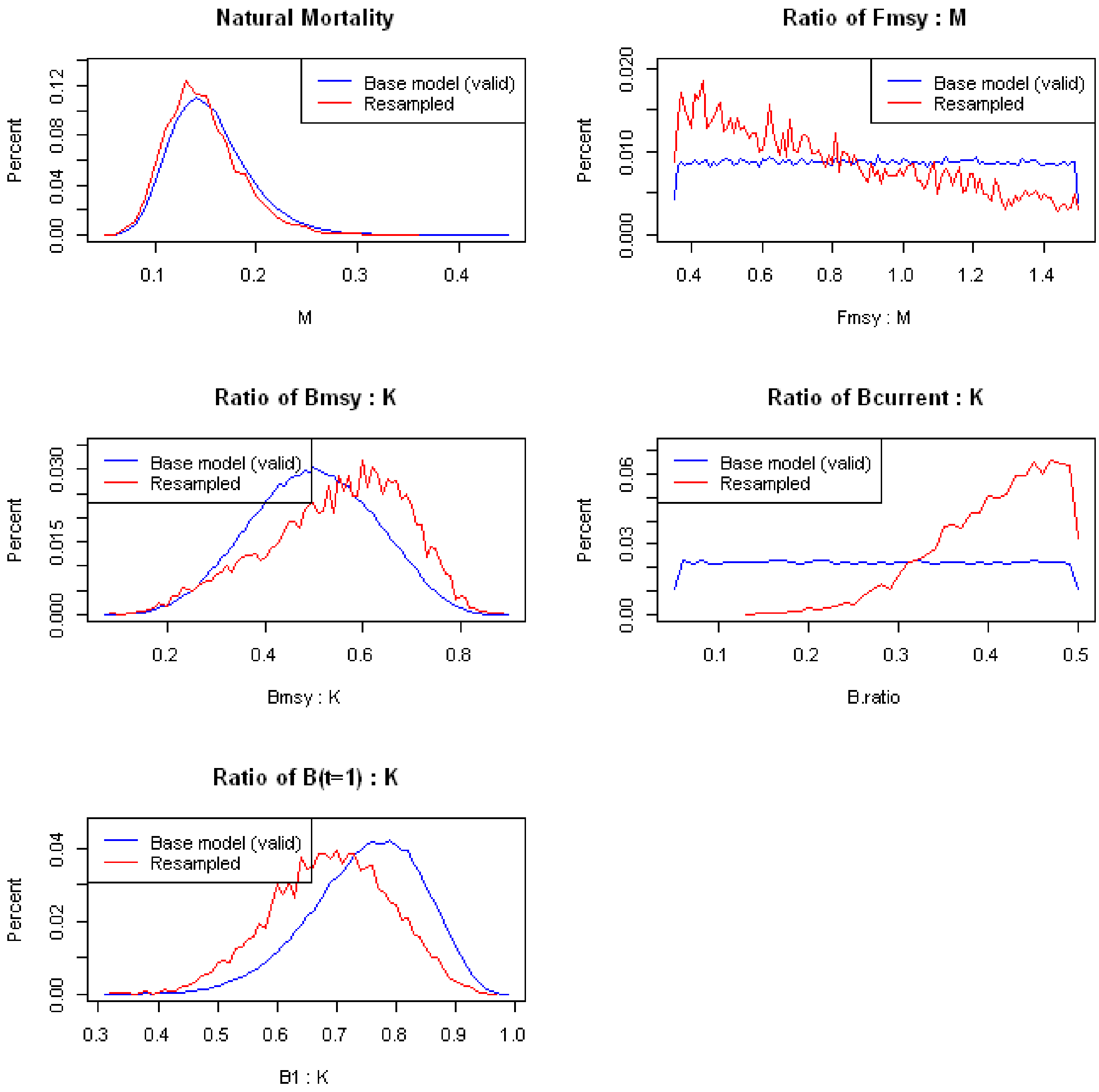


**Figure 6.41.** Biomass and exploitation trajectories for the DMV base model run of xDB-SRA.

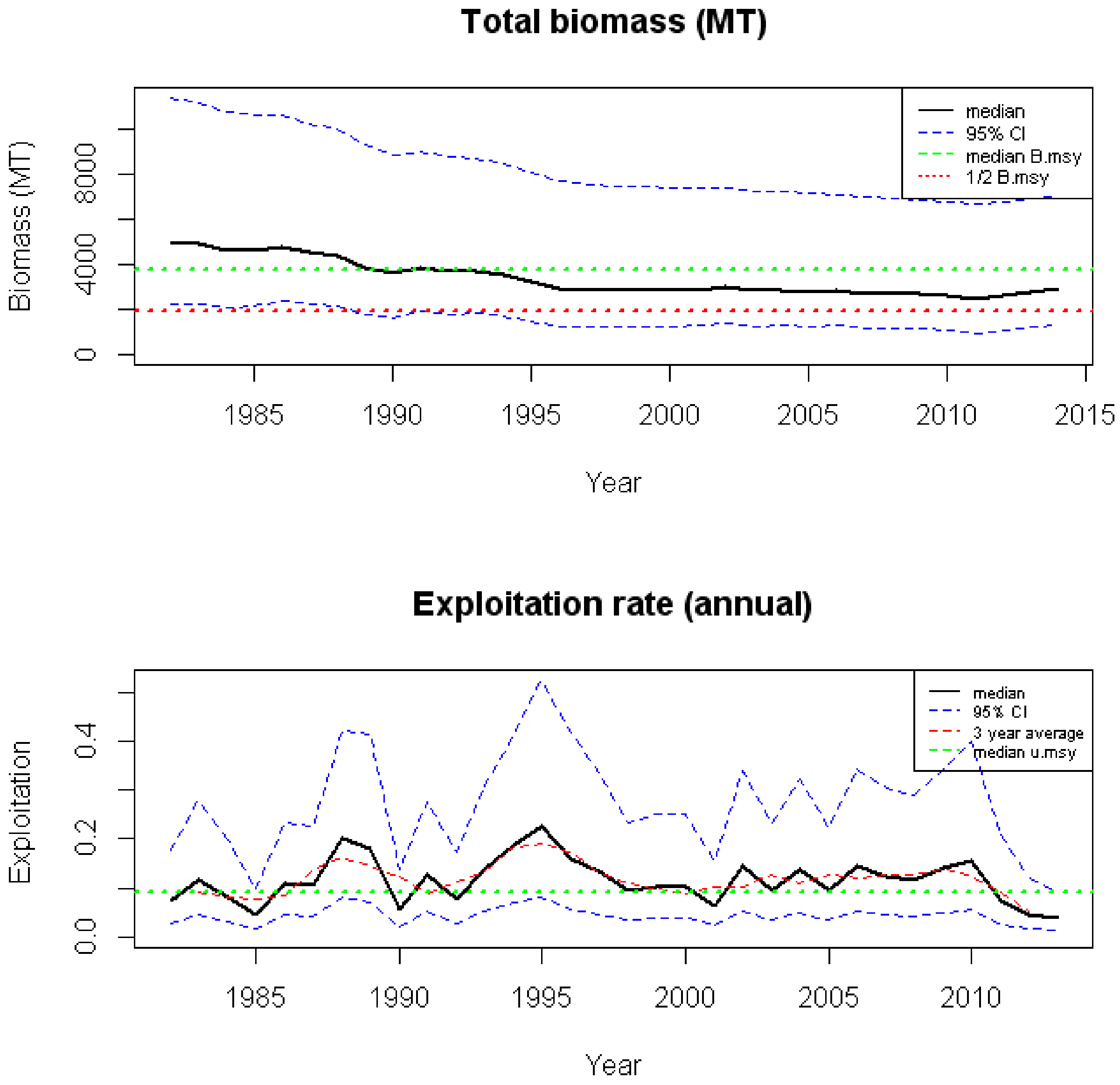


**Figure 6.42.** Distributions of valid and resampled reference point estimates for the DMV base model run of xDB-SRA.

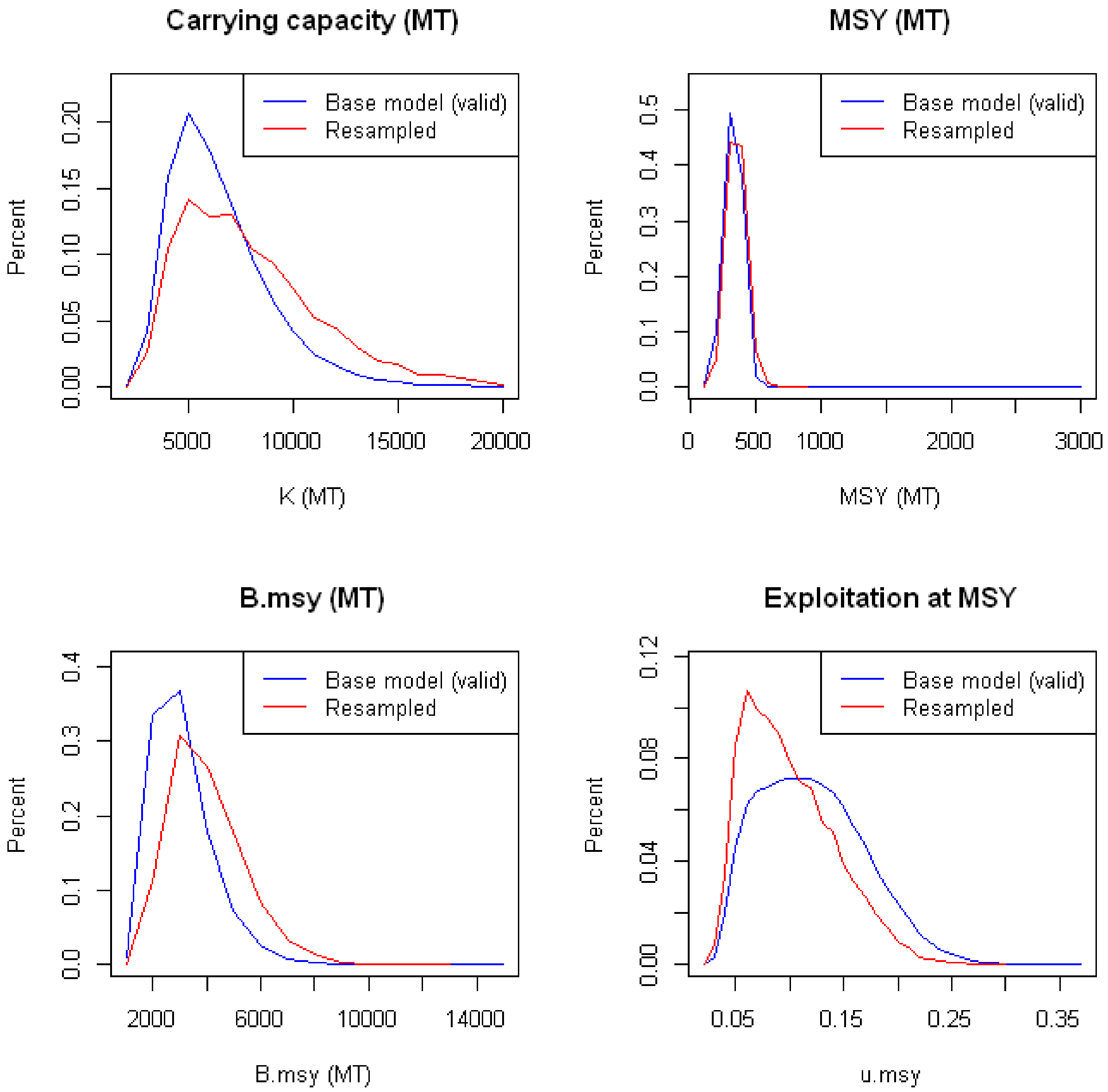


**Figure 6.43.** Results of survey index sensitivity runs for the DMV region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

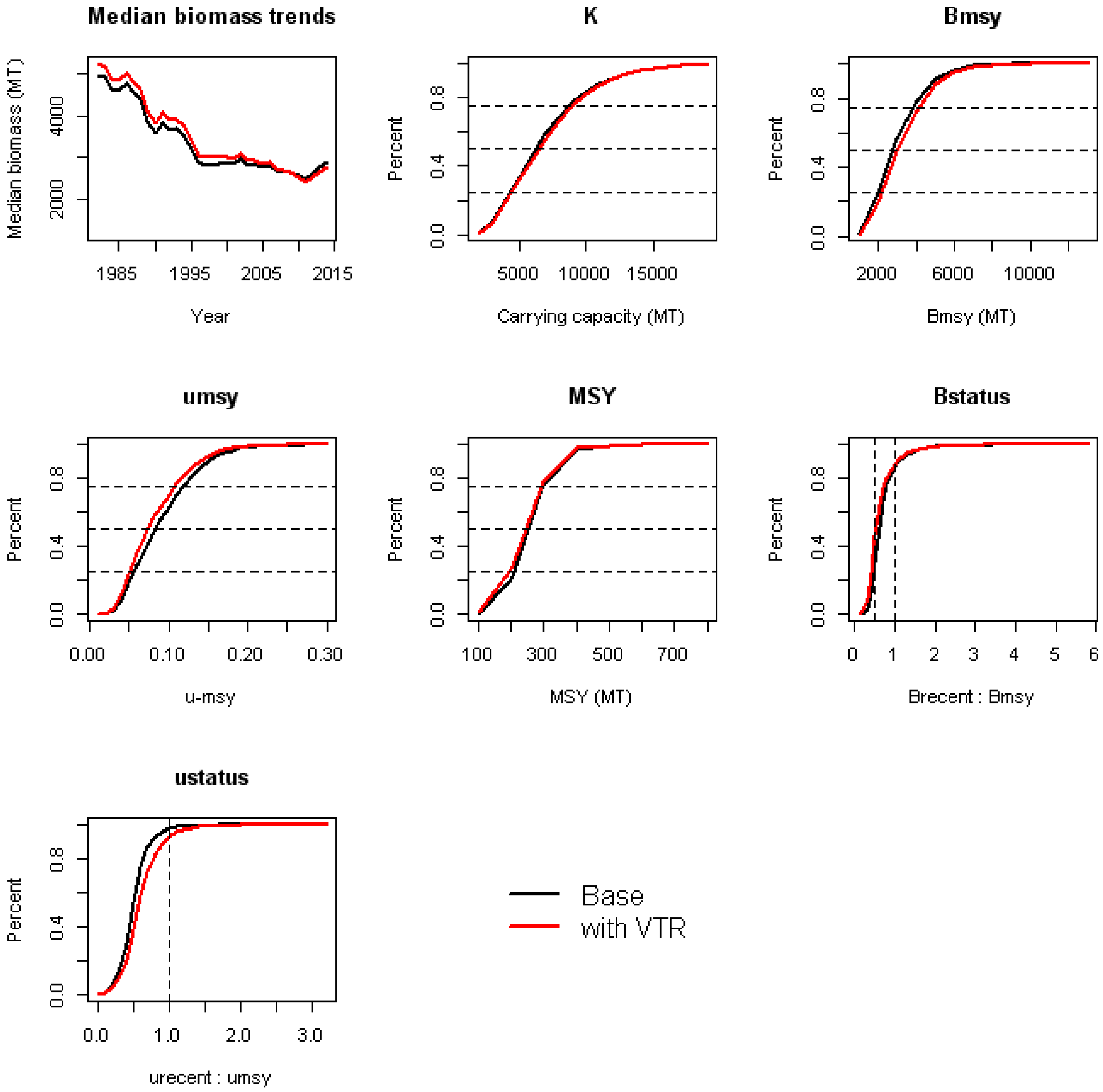


**Figure 6.44.** Results of model configuration sensitivity runs for the DMV region xDB-SRA model. First plot shows median biomass trends over time. All other plots are cumulative parameter distributions.

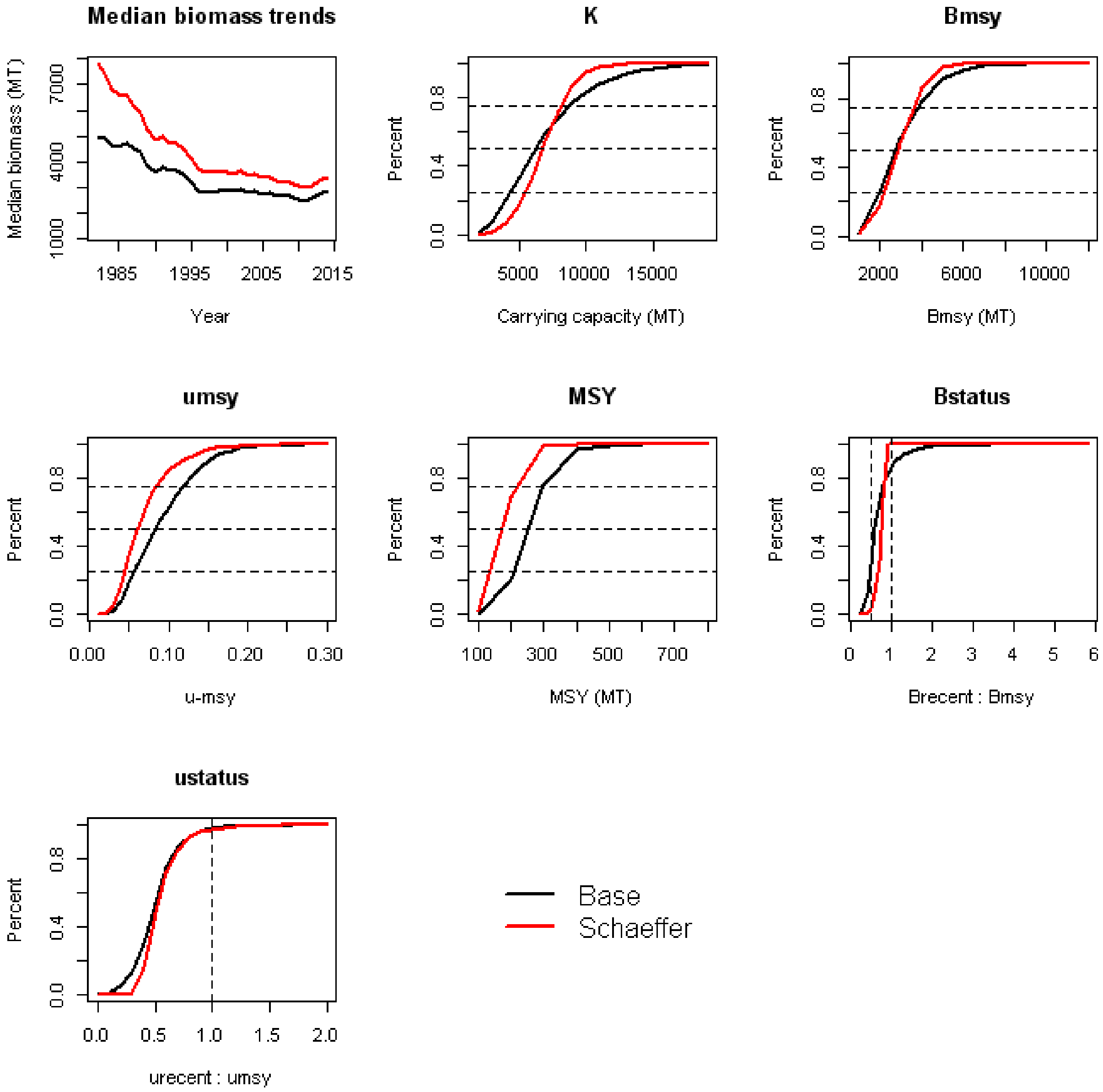


**Figure 6.65.** Biomass estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.

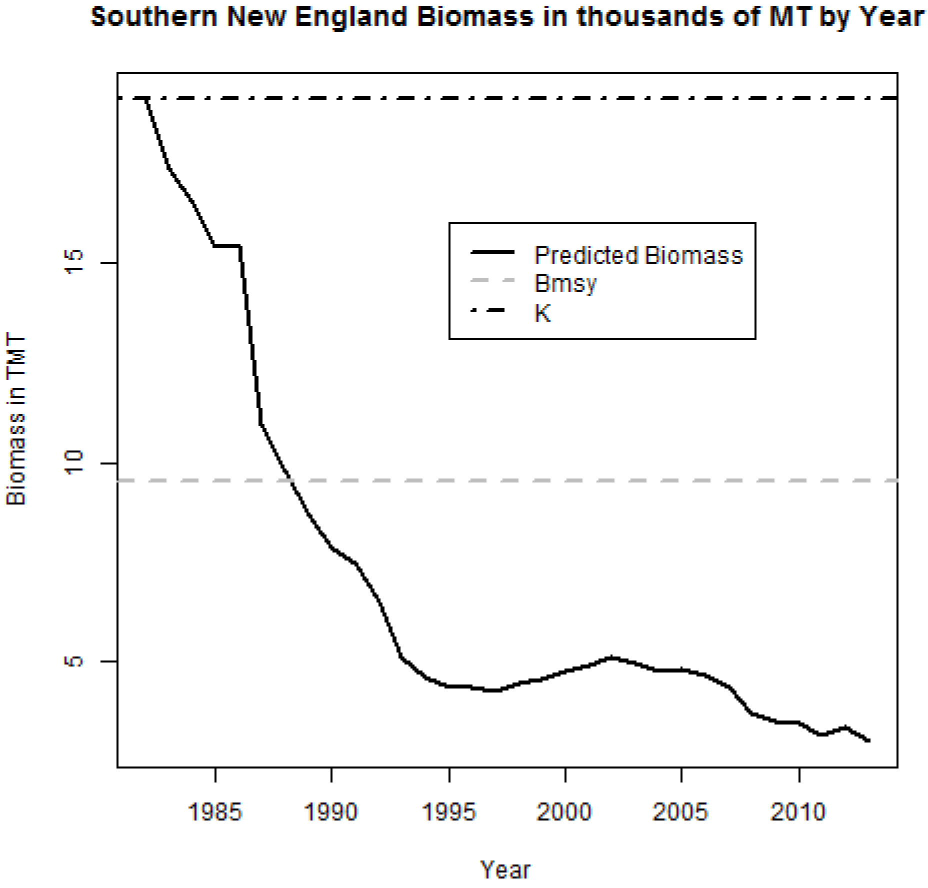


**Figure 6.66.** Predicted versus observed catch estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.

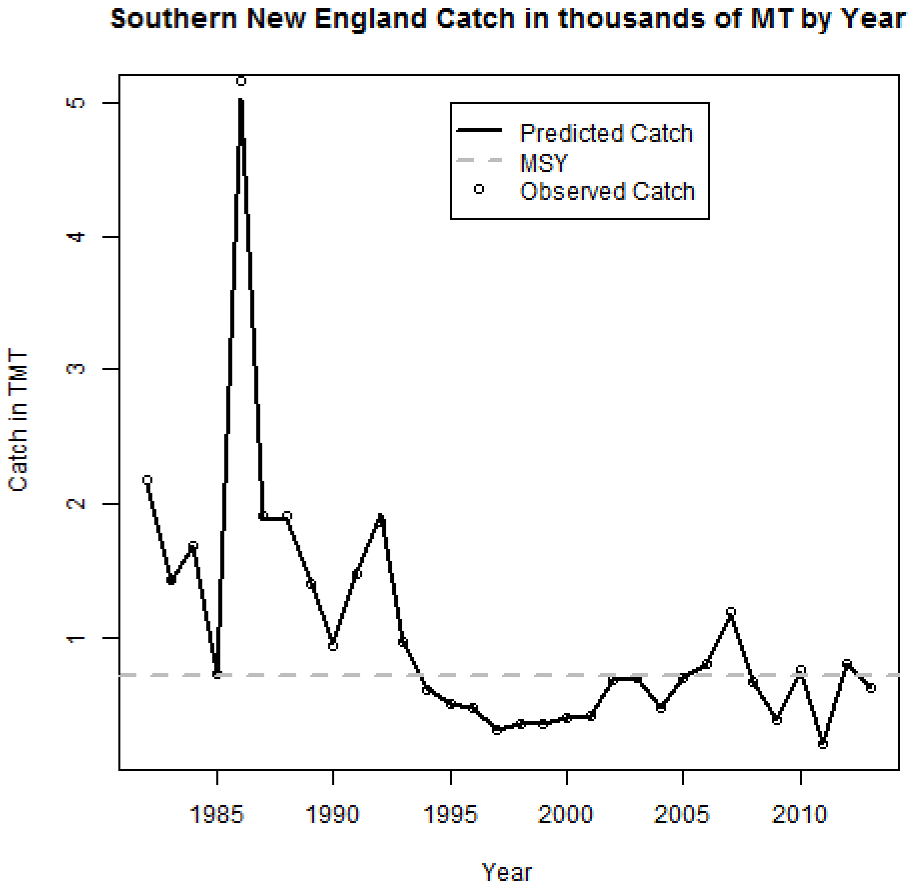


**Figure 6.67.** Index residual estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.

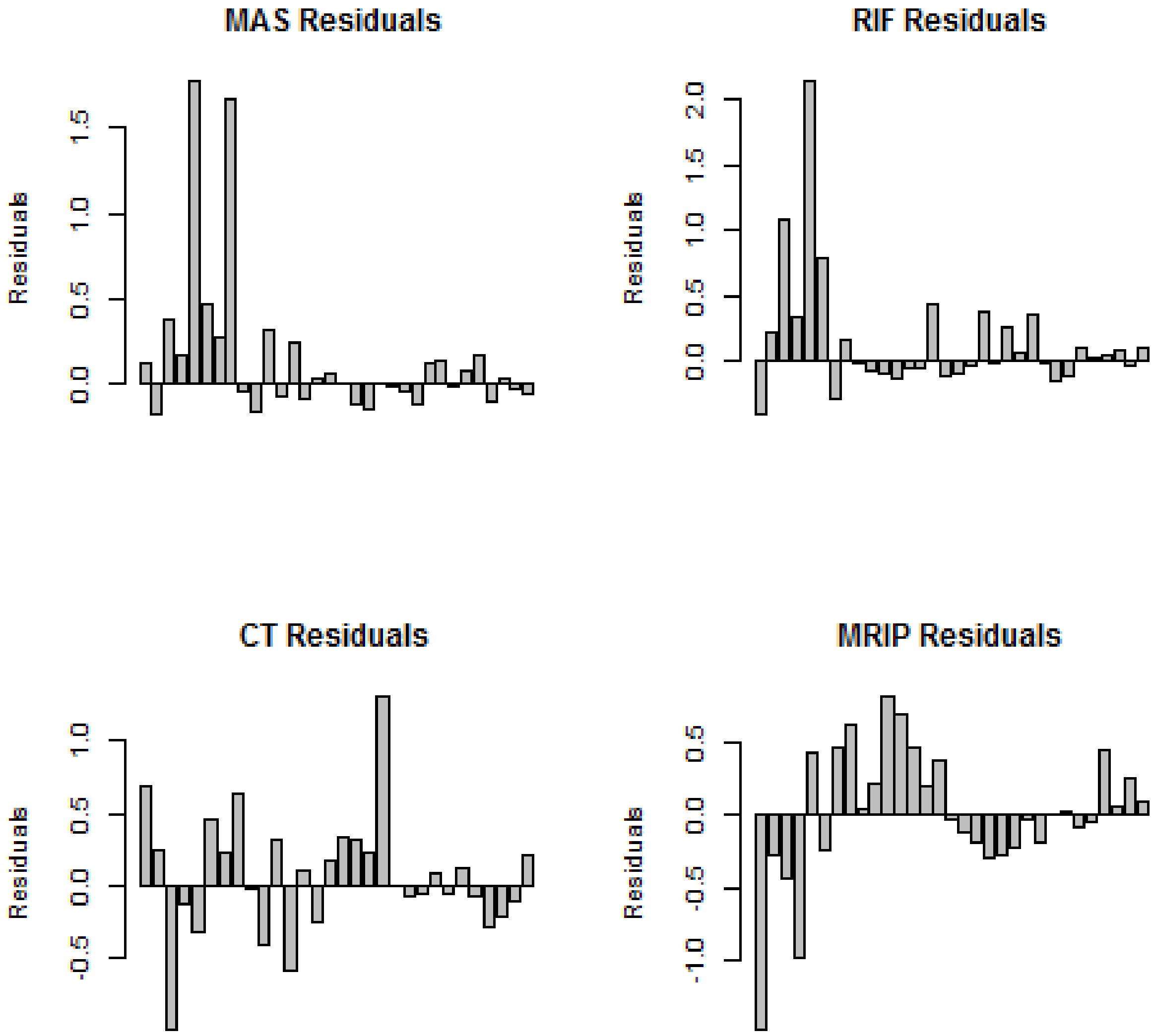


**Figure 6.68.** Exploitation rate estimates through time for the Bayesian State Space Surplus Production Model – Southern New England base configuration.

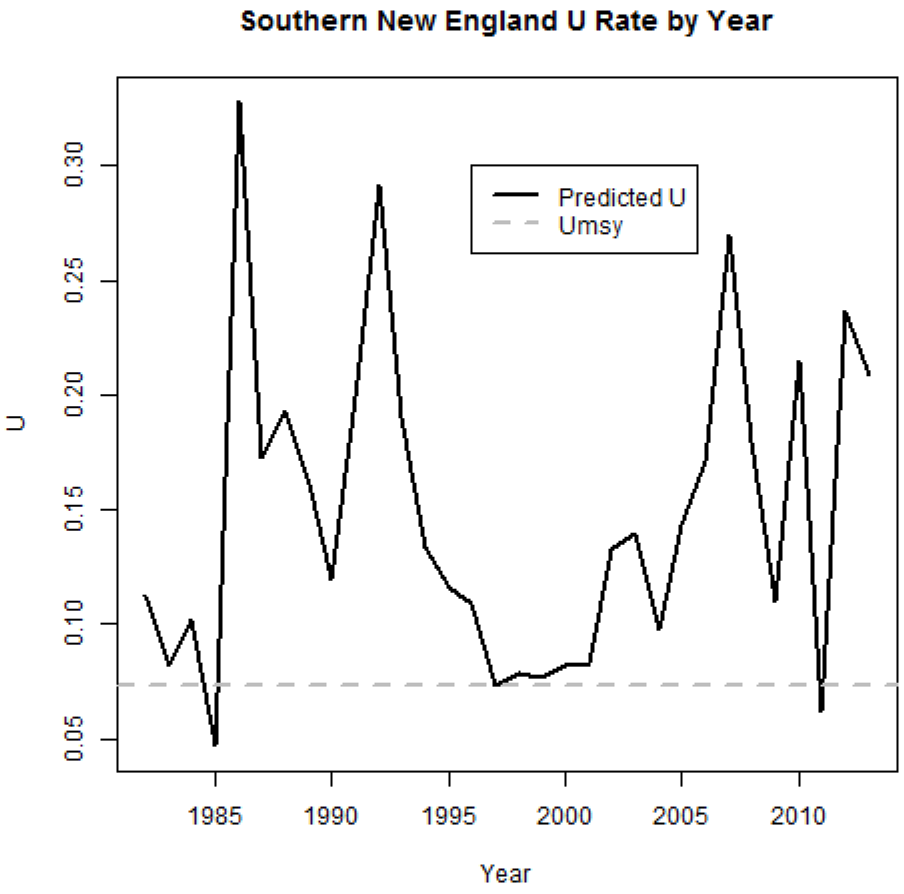


**Figure 6.69.** Biomass estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

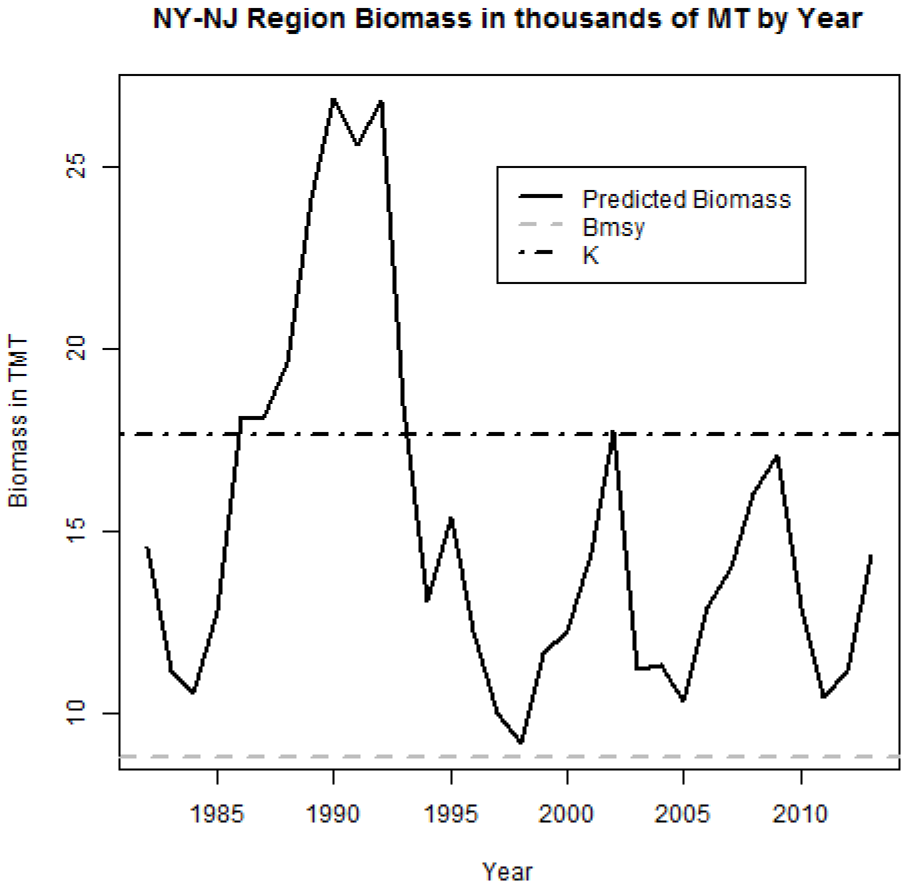


**Figure 6.70.** Predicted versus observed catch estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

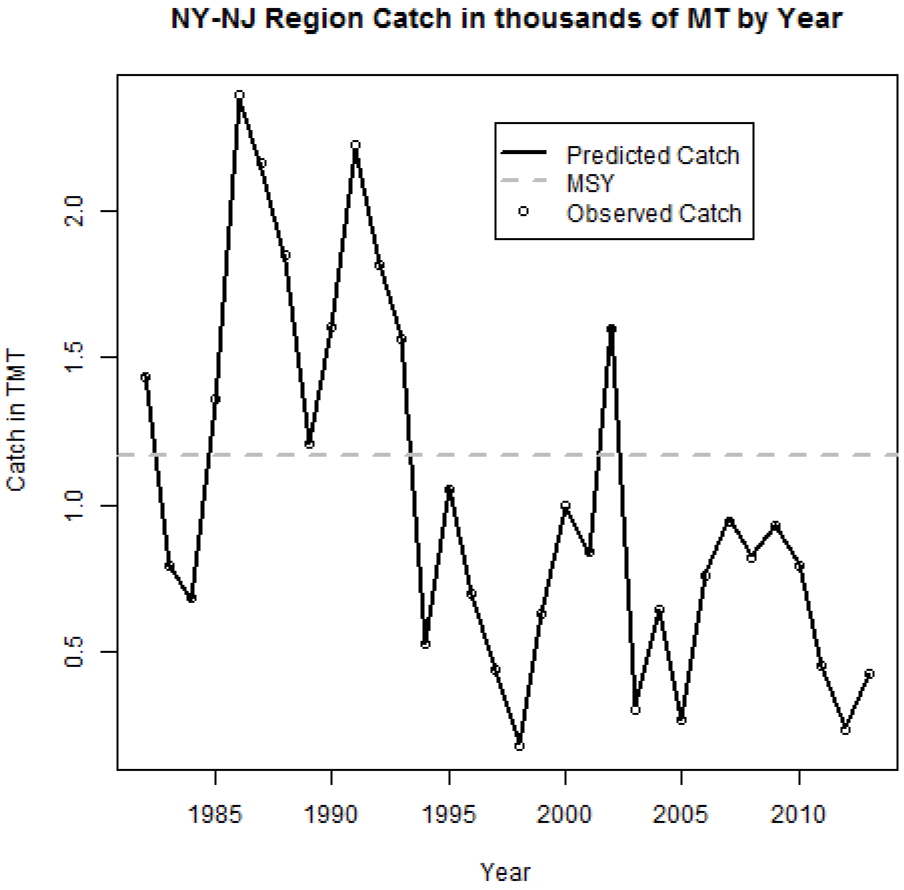


**Figure 6.71.** Index residual estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

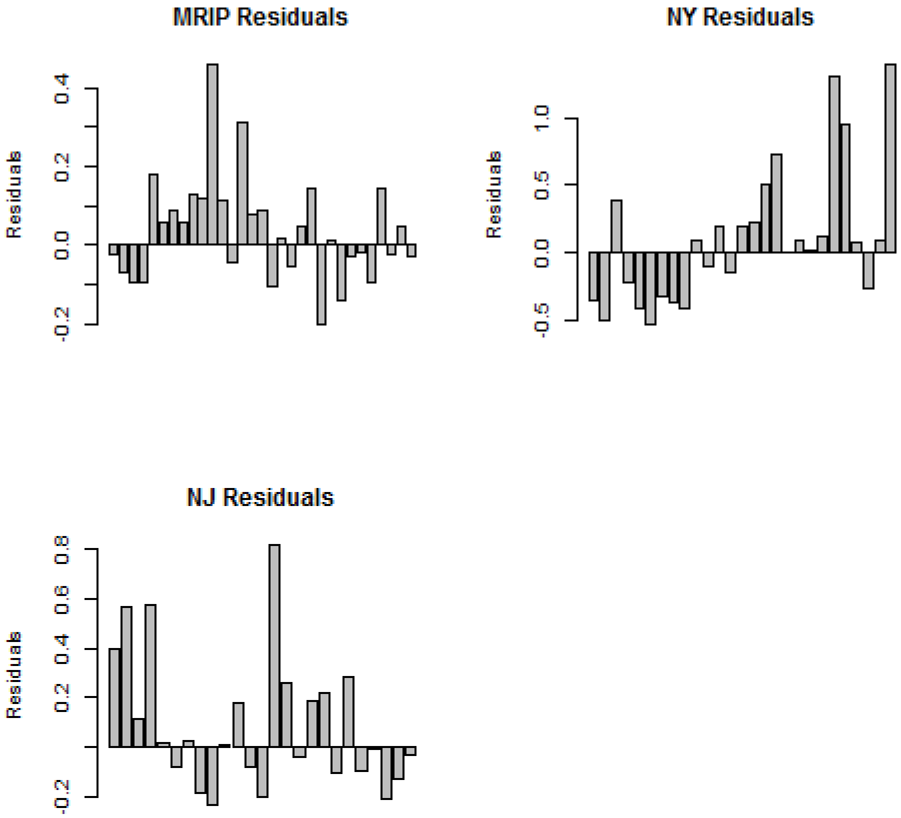


**Figure 6.72.** Exploitation rate estimates through time for the Bayesian State Space Surplus Production Model – New York/New Jersey base configuration.

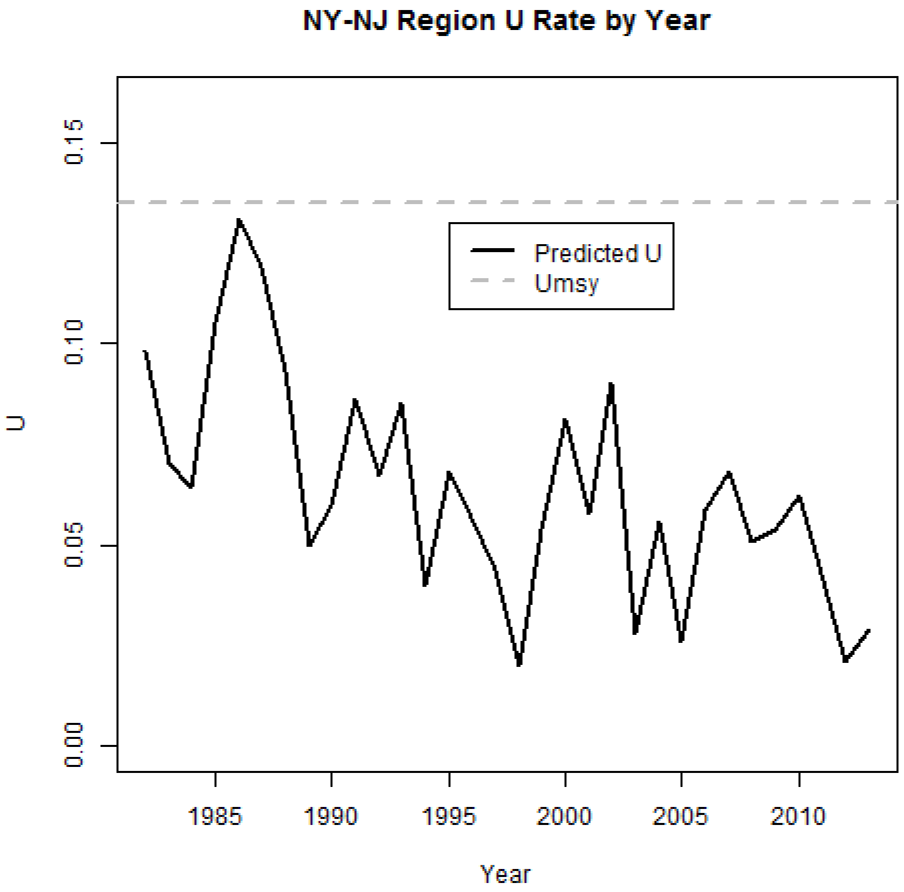


**Figure 6.73.** Biomass estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

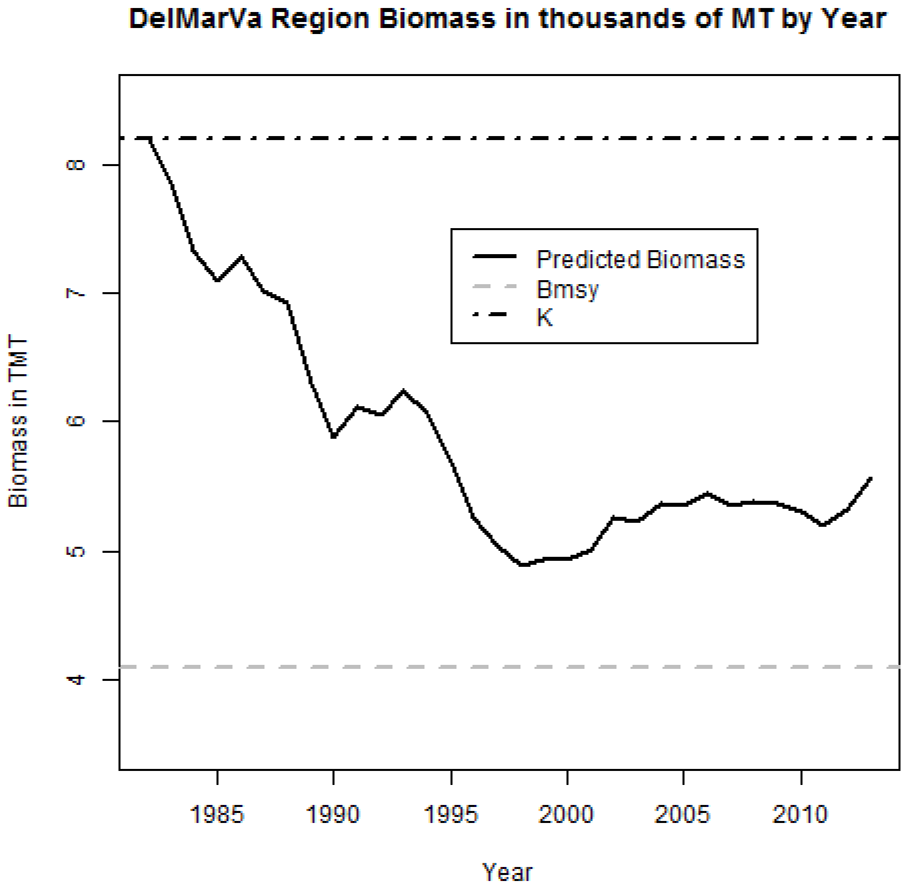


**Figure 6.74.** Predicted versus observed catch estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

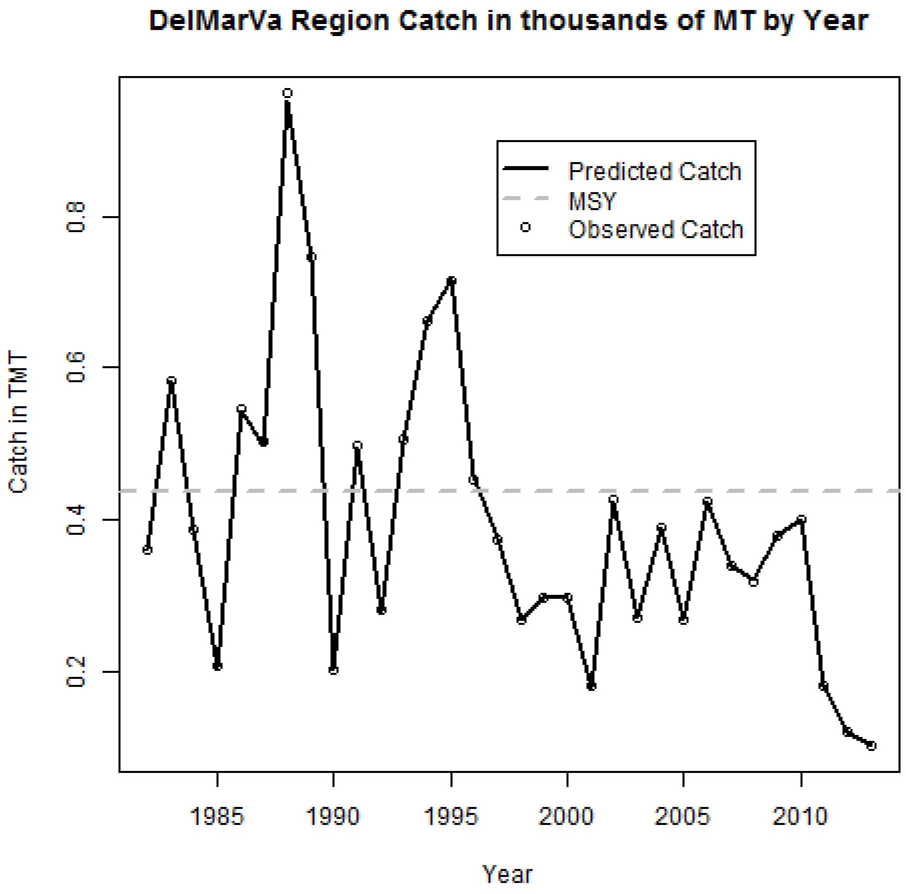


**Figure 6.75.** Index residual estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

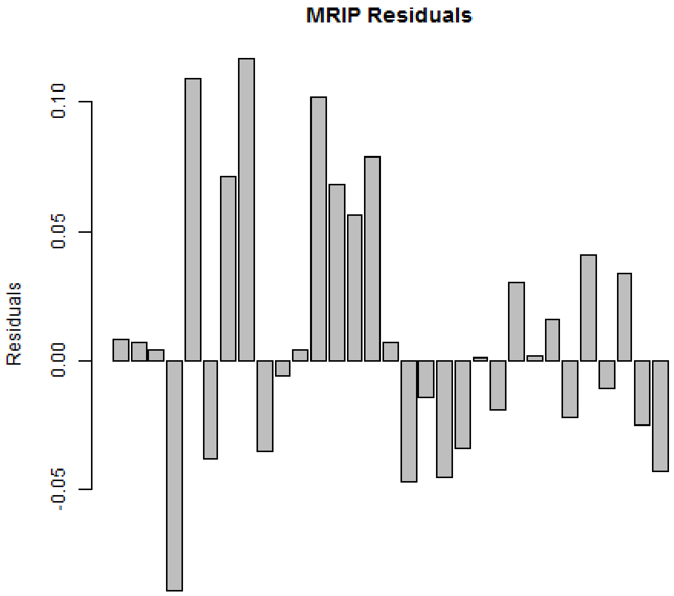


**Figure 6.76.** Exploitation rate estimates through time for the Bayesian State Space Surplus Production Model – DelMarVa base configuration.

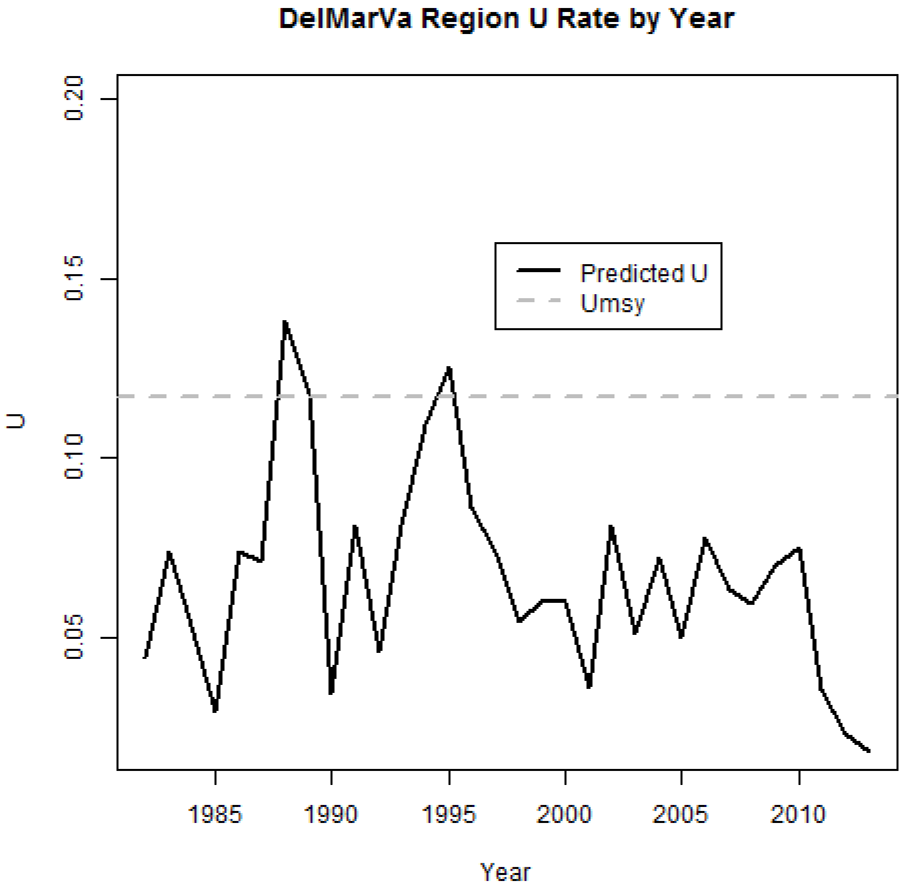


**Figure 6.77.** Biomass trends for different region configurations including a Coastwide region, two region split (Northern Region and Southern Region), and the base three region split (Southern New England, New York – New Jersey, and DelMarVa).

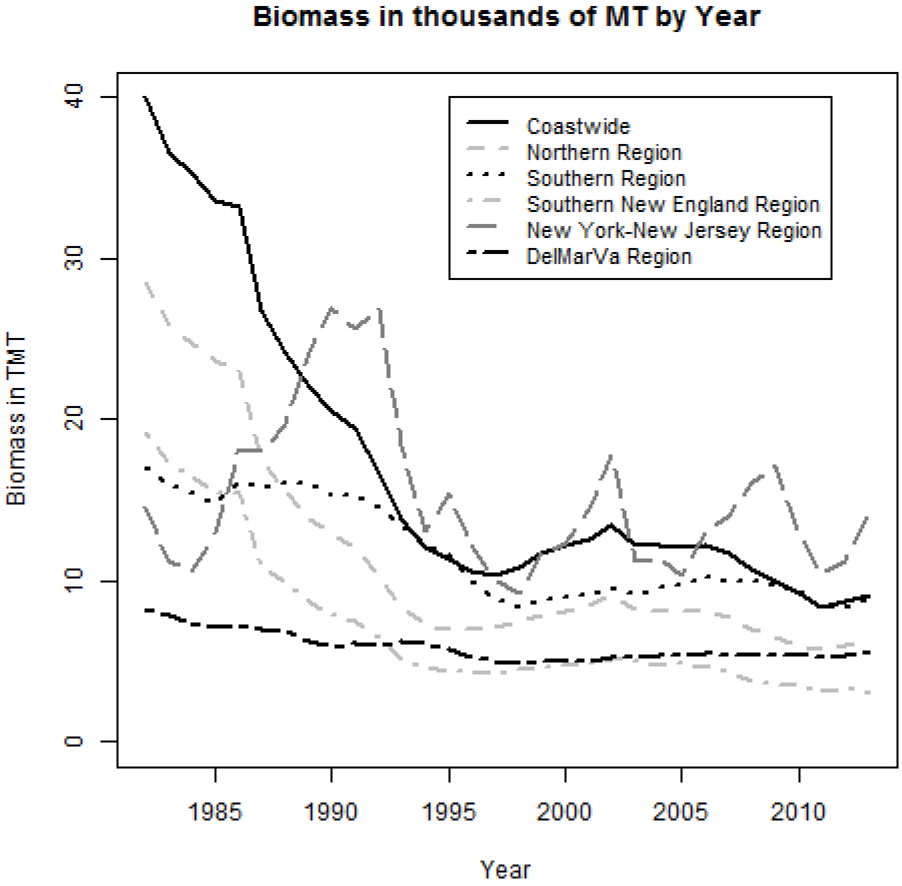


**Figure 6.78.** Exploitation rate trends for different region configurations including a Coastwide region, two region split (Northern Region and Southern Region), and the base three region split (Southern New England, New York – New Jersey, and DelMarVa).

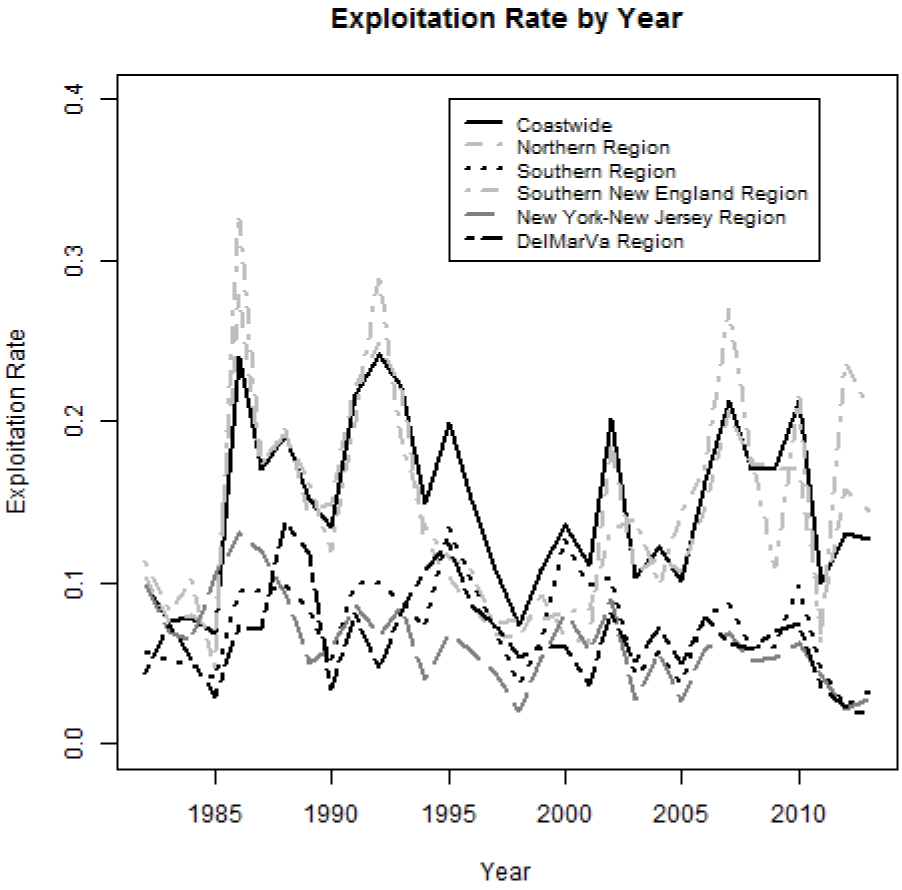


**Figure 6.79.** Biomass trend sensitivity to different index configurations within the New York – New Jersey region.

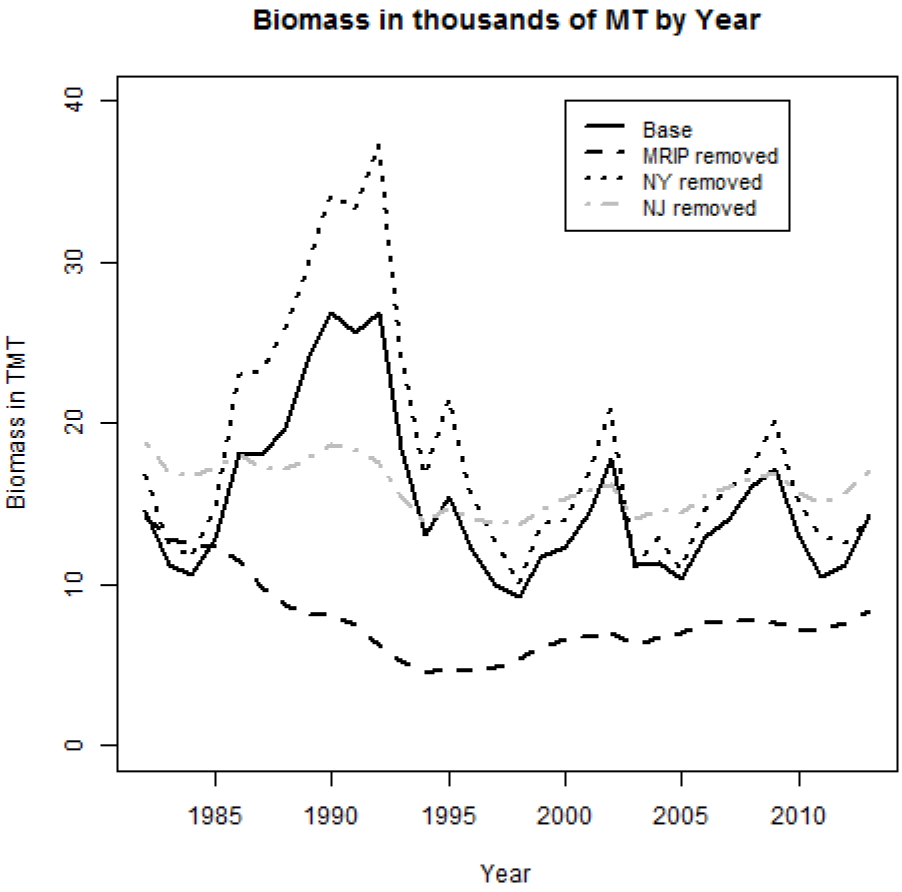


**Figure 6.80.** Exploitation rate trend sensitivity to different index configurations within the New York – New Jersey region.

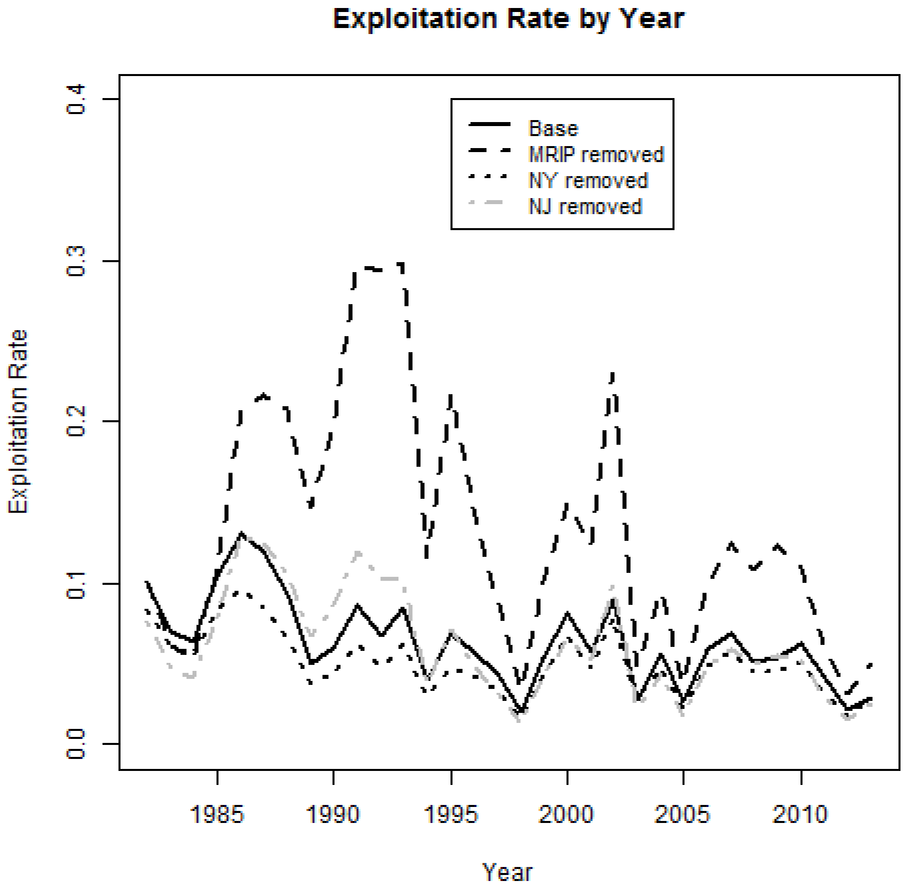


**Figure 6.81.** Biomass trend sensitivity to the alternate region configurations between the New York – New Jersey base configuration and the New York – New Jersey – Connecticut region configurations with calculated $B_{MSY}$ values for each alternate region.

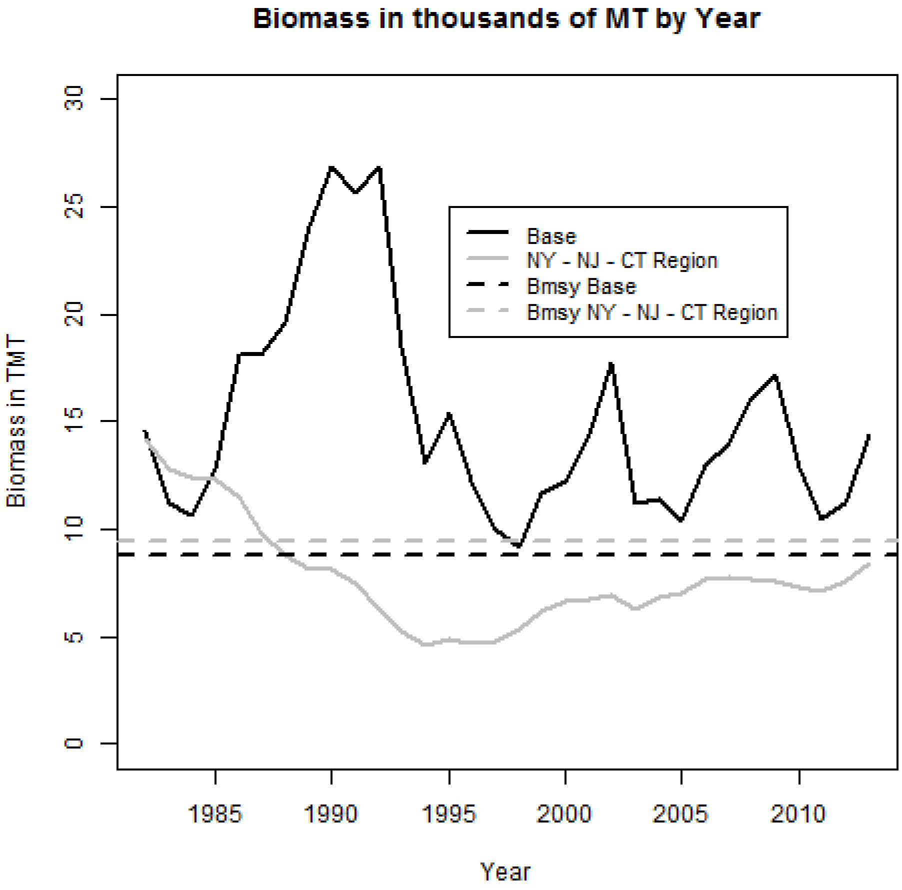


**Figure 6.82.** Exploitation rate sensitivity to the alternate region configurations between the New York – New Jersey base configuration and the New York – New Jersey – Connecticut region configurations with calculated U<sub>MSY</sub> values for each alternate region.

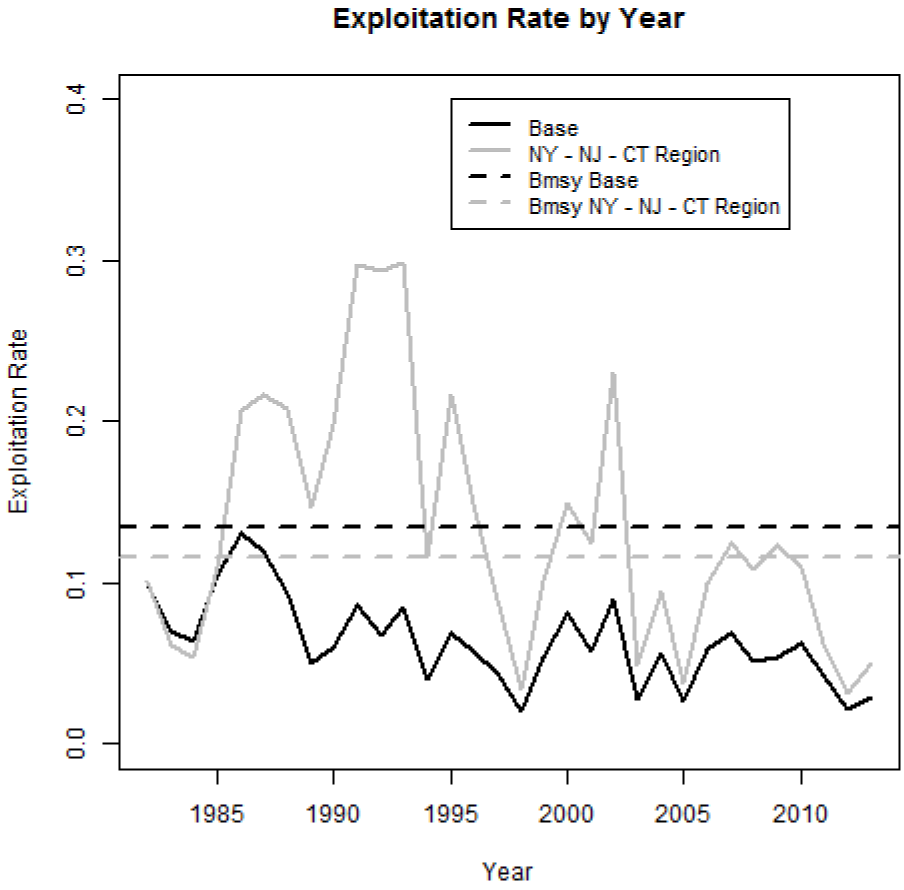


**Figure 6.83.** Biomass trend sensitivity to different index configurations within the Southern New England region.

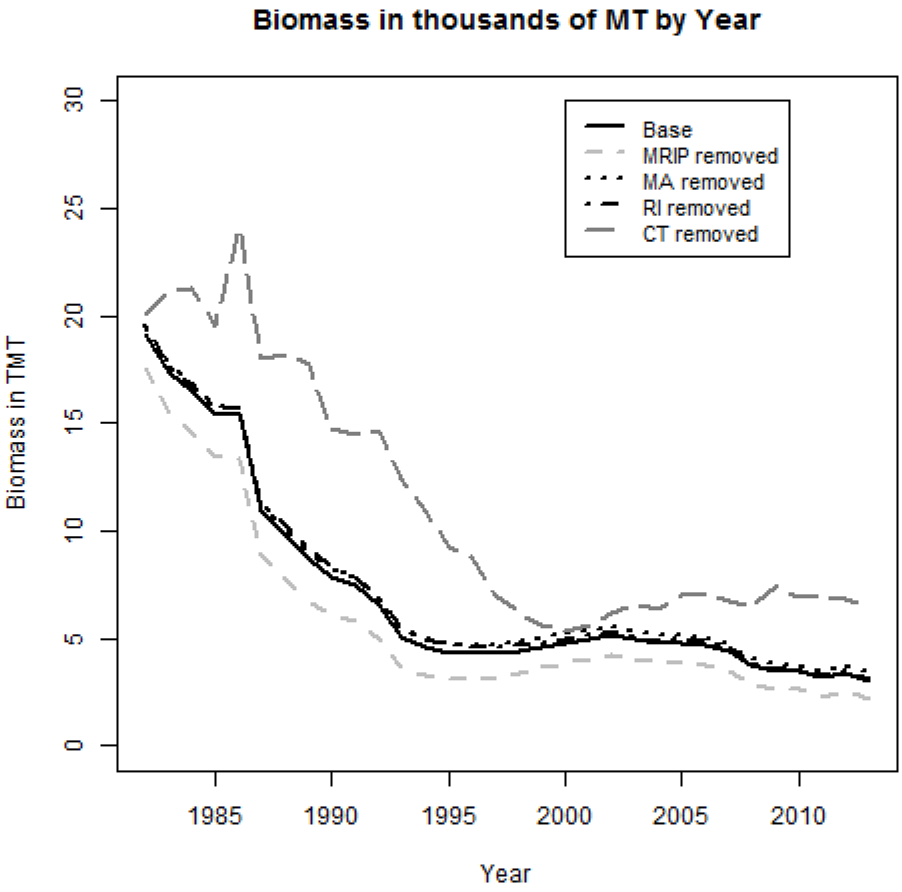


**Figure 6.84.** Exploitation rate trend sensitivity to different index configurations within the Southern New England region.

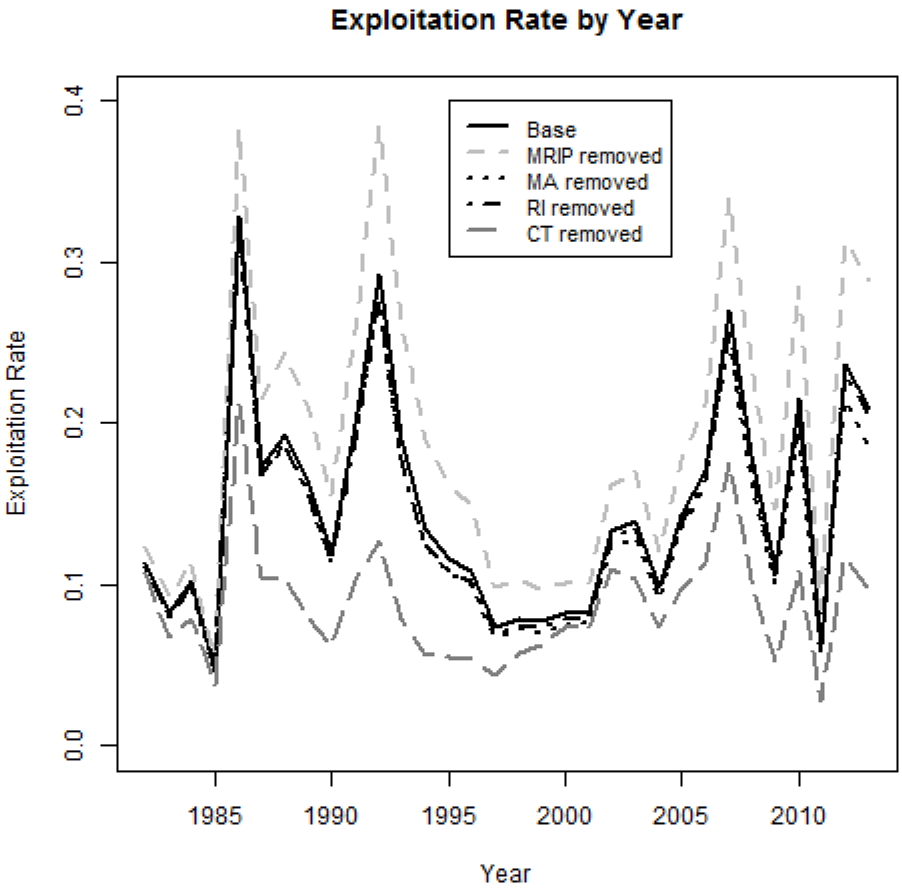


**Figure 6.85.** Biomass trend sensitivity to the alternate region configurations between the Southern New England base configuration and the Southern New England without Connecticut region configurations with calculated $B_{MSY}$ values for each alternate region.

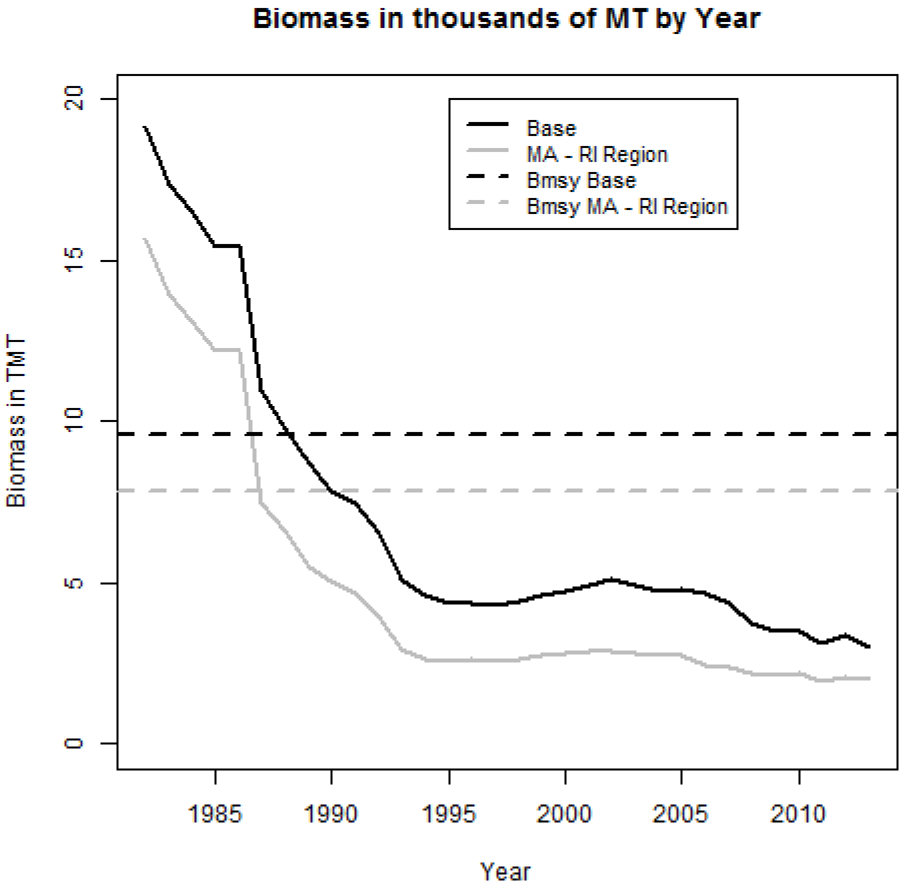


**Figure 6.86.** Exploitation rate sensitivity to the alternate region configurations between the Southern New England base configuration and the Southern New England without Connecticut region configurations with calculated $U_{MSY}$ values for each alternate region.

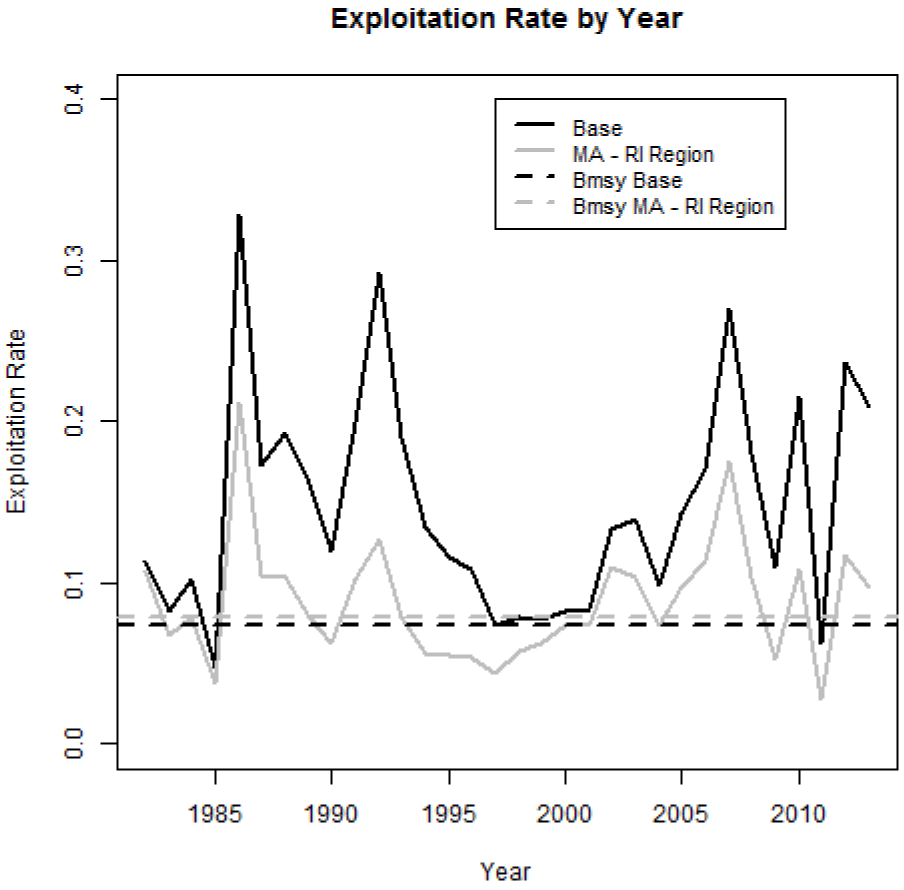


**Figure 6.87** Three year average biomass trends and exploitation rates by region versus MSY reference points.

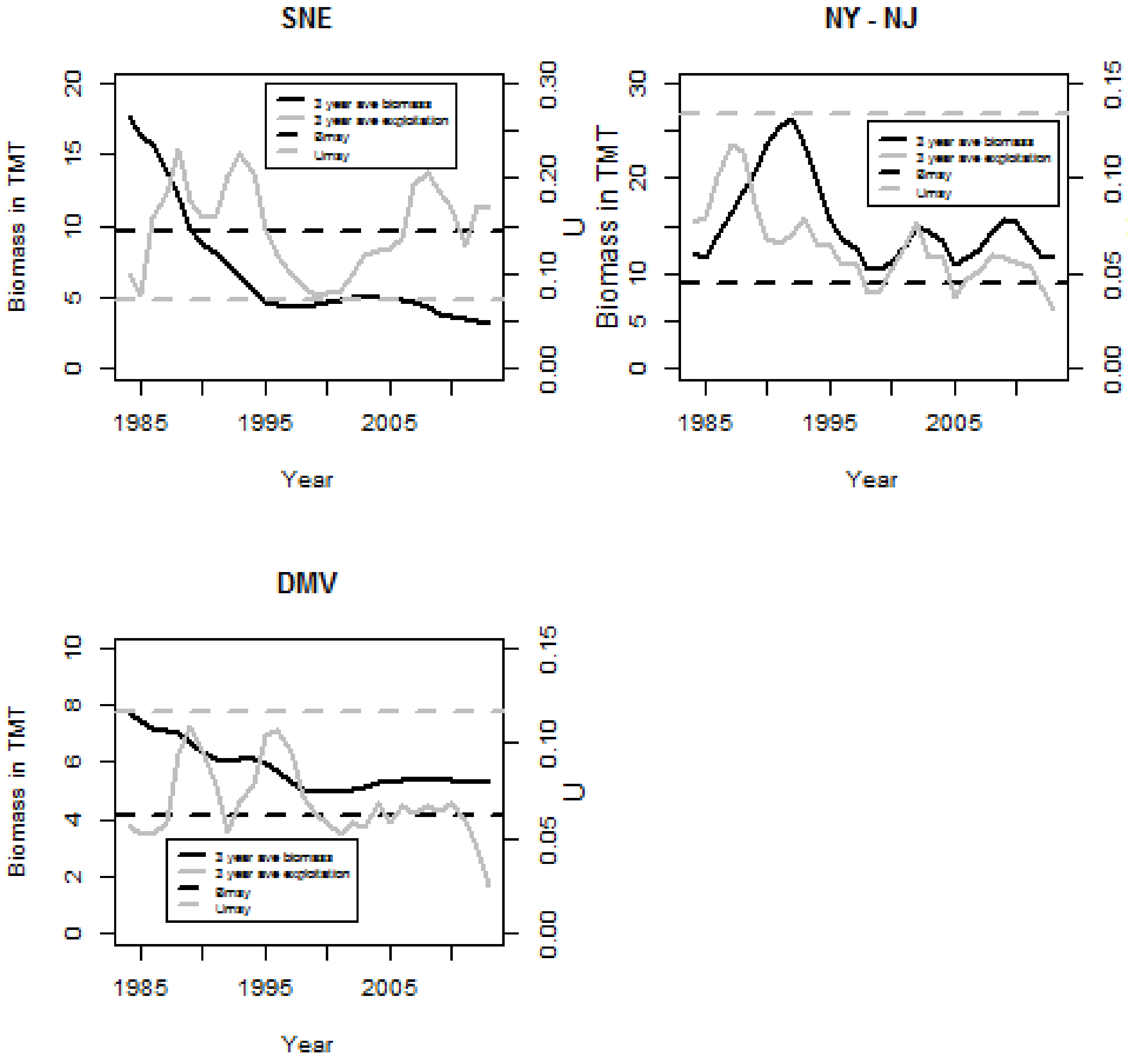


**Figure 6.88.** Index fits for the surveys used in the base configuration of the Southern New England Region.

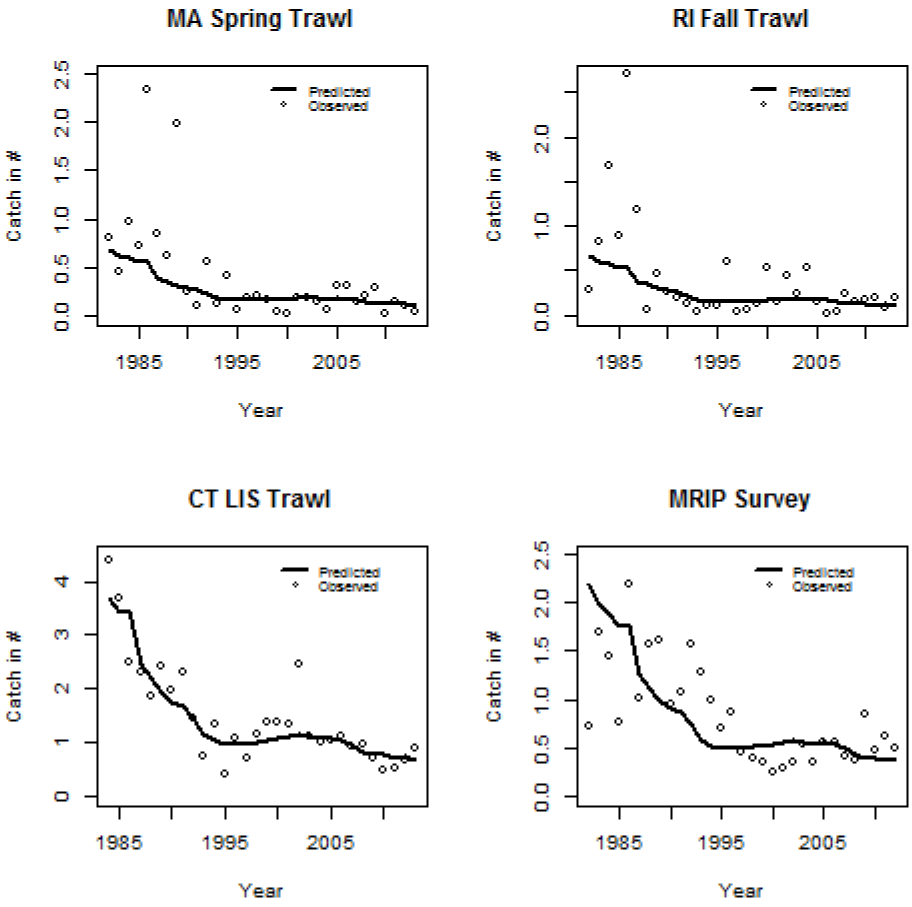


**Figure 6.89.** Index fits for the surveys used in the base configuration of the New York – New Jersey Region.

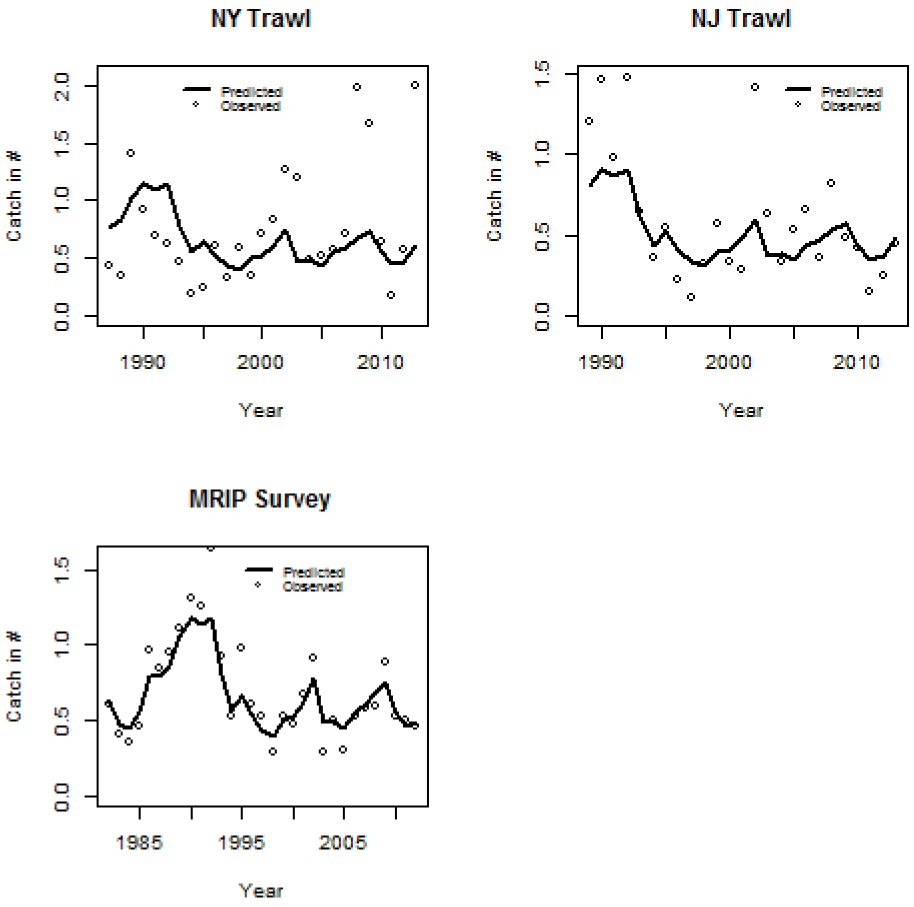


**Figure 6.90.** Index fit for the survey used in the base configuration of the DelMarVa Region.

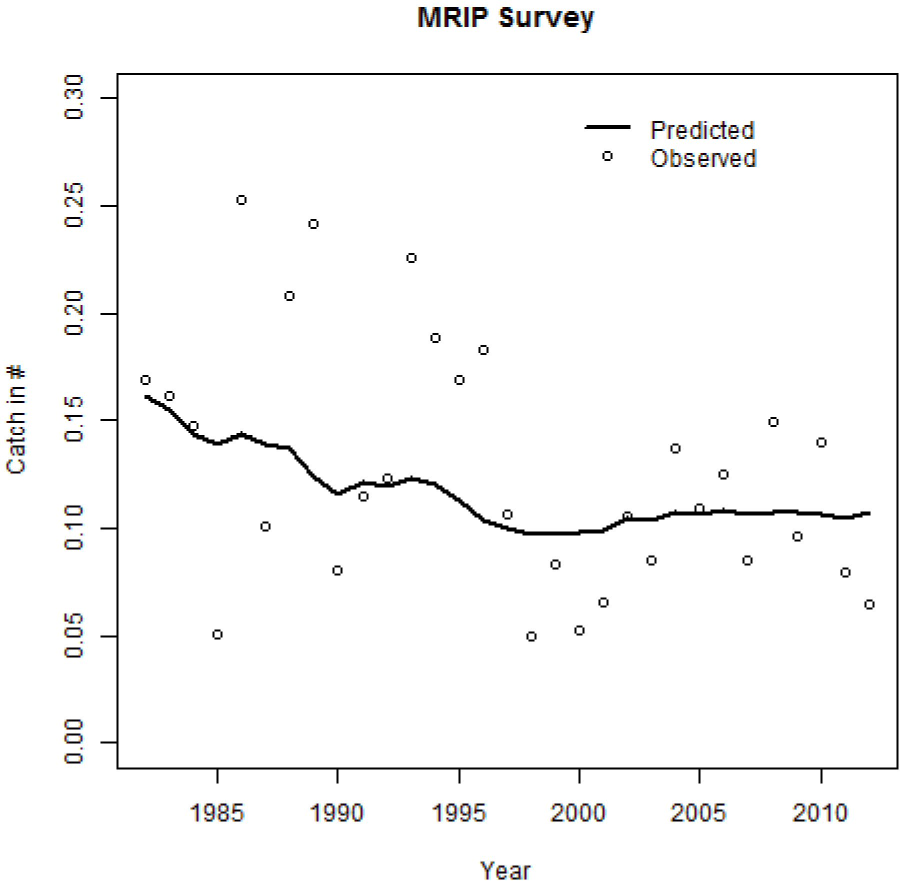
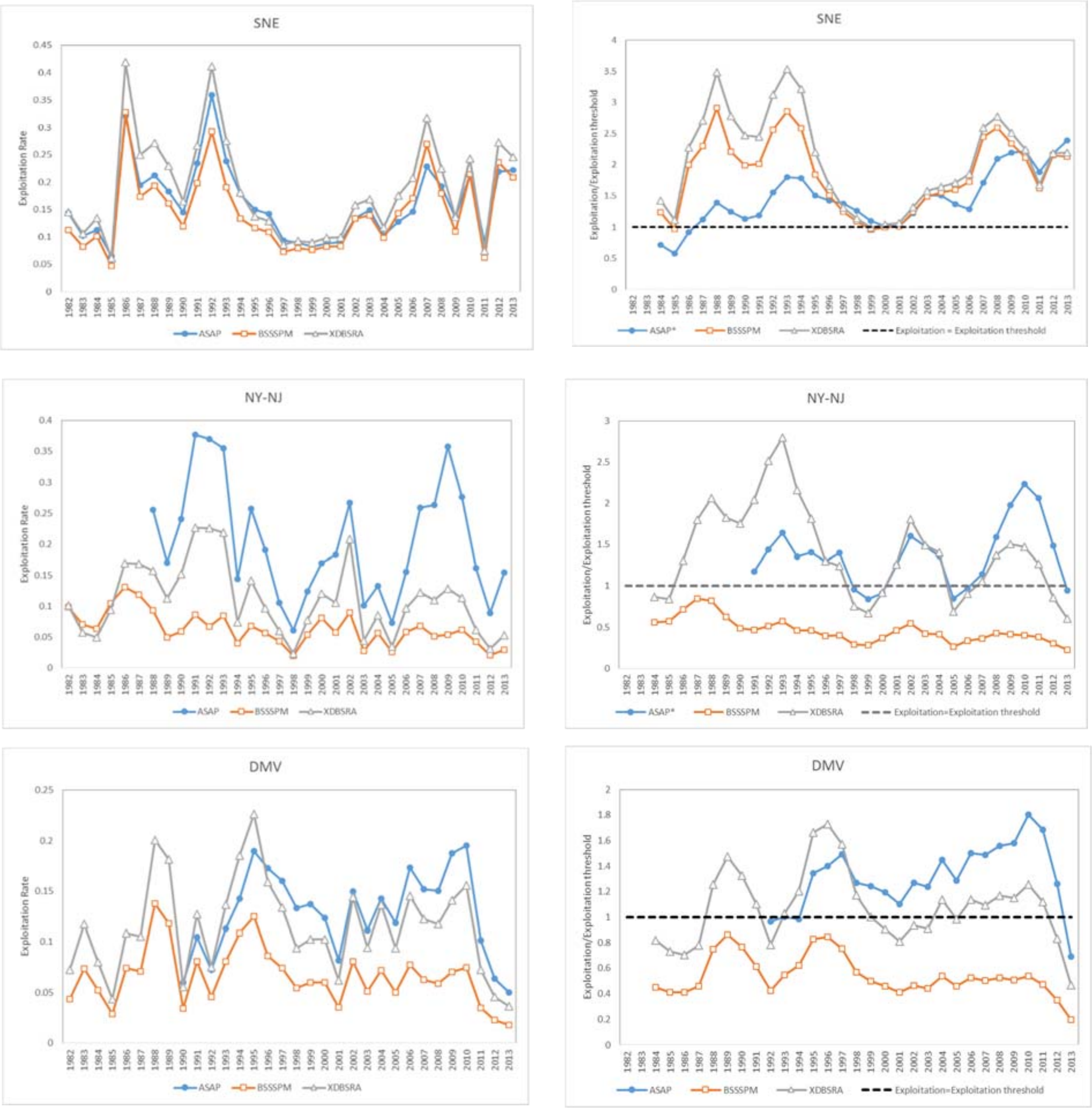
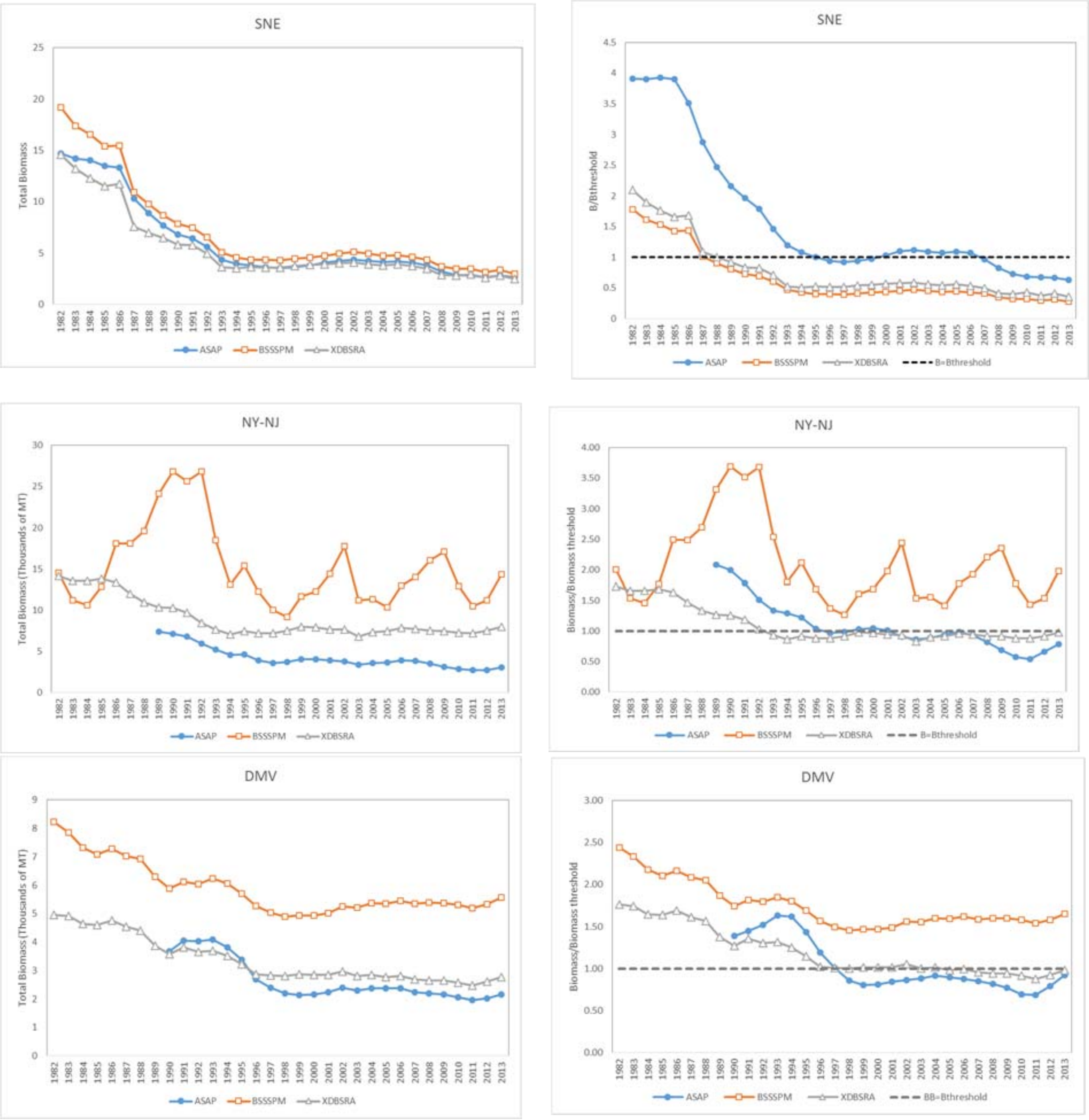


**Figure 6.91.** Annual exploitation rates (left) and 3-year average rates relative to the exploitation threshold (right) by region for the three models considered.



*Exploitation relative to the threshold is calculated as $F/F_{threshold}$ for ASAP, and $\mu/\mu_{threshold}$ for XDBSRA and BSSSPM for the figures on the right, in order to represent overfishing status consistently across models. $F_{threshold}$ was defined as $F_{MSY}$ for ASAP in SNE and $F_{30\%SPR}$ for ASAP in NY-NJ and DMV. $\mu_{threshold}$ was defined as $\mu_{MSY}$ for all three regions for XDBSRA and BSSSPM.

**Figure 6.92.** Total biomass (right) and biomass relative to the biomass threshold (right) across all three models by region.



*Biomass relative to the threshold is calculated as $SSB/SSB_{thershold}$ for ASAP, and $B/B_{threshold}$ for XDBSRA and BSSSPM for the figures on the right, in order to represent overfished status consistently across models. $SSB_{threshold}$ was defined as 75%$SSB_{MSY}$ in SNE and $SSB_{30\%SPR}$ in NY-NJ and DMV for ASAP. $B_{threshold}$ was defined as 75%$B_{MSY}$ for all three regions for XDBSRA and BSSSPM.

**Figure 6.93.** VPA continuity run estimates of N-Weighted average F for ages 8-10.

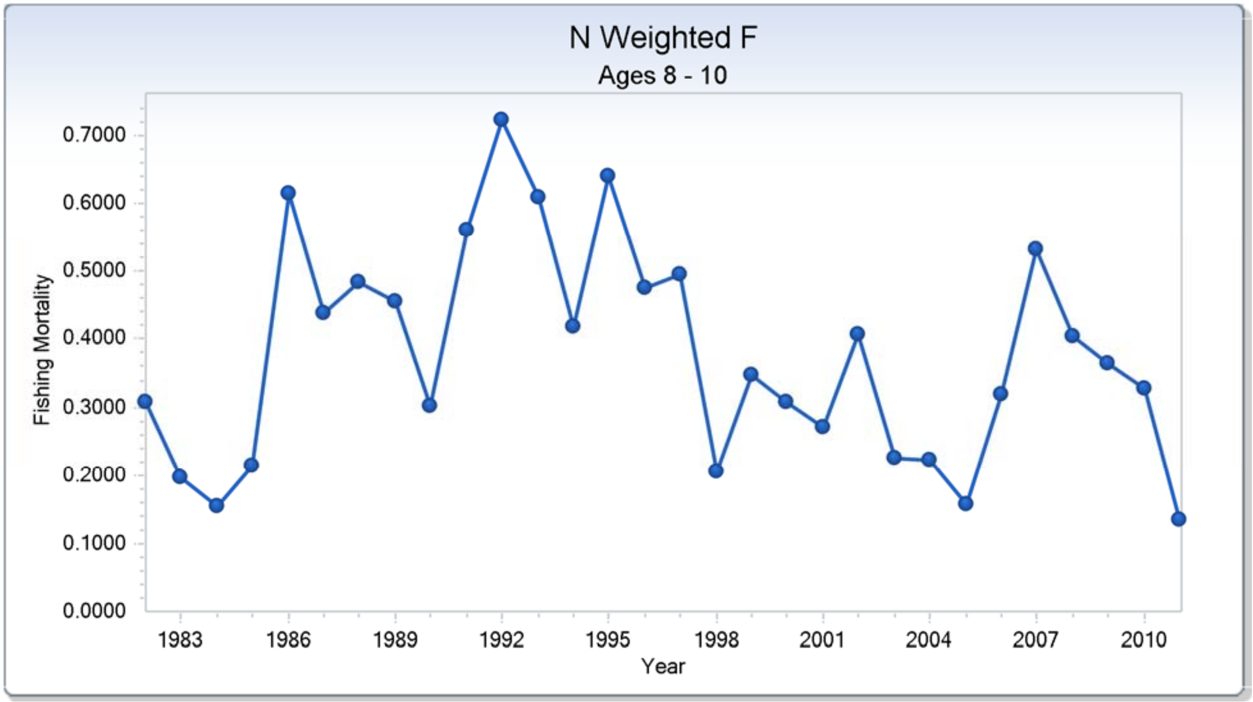
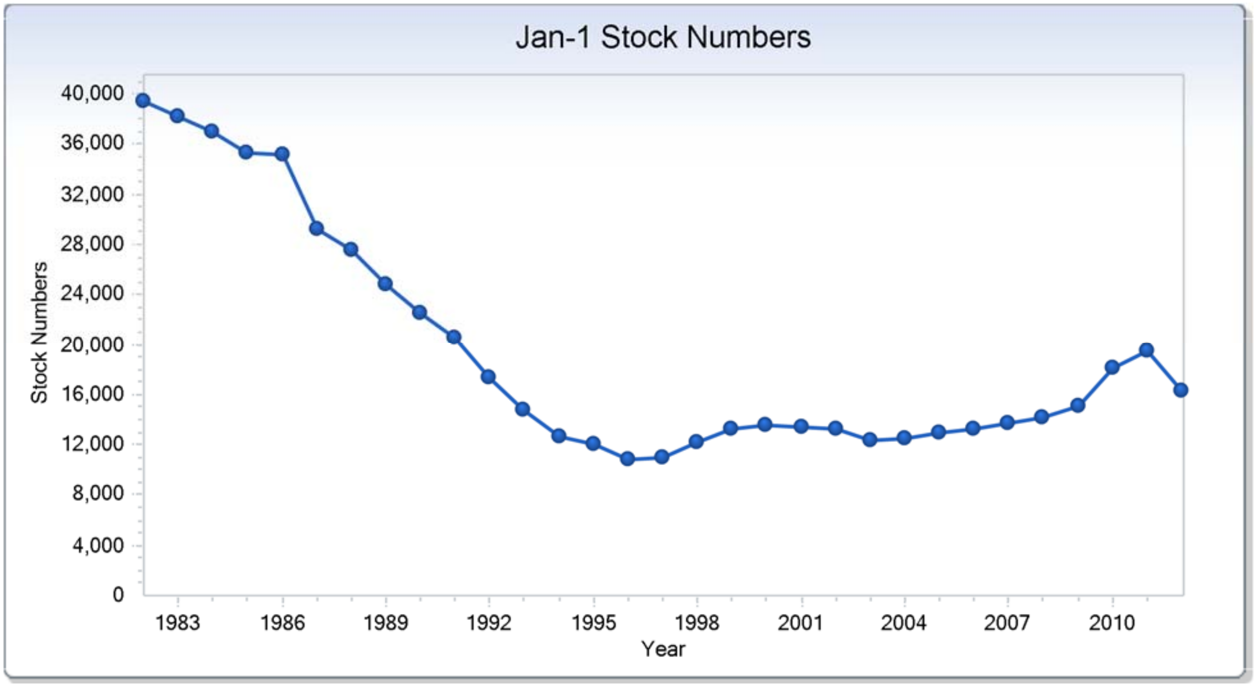


**Figure 6.94.** VPA continuity run estimates of abundance (thousands of fish) and spawning stock biomass (MT).



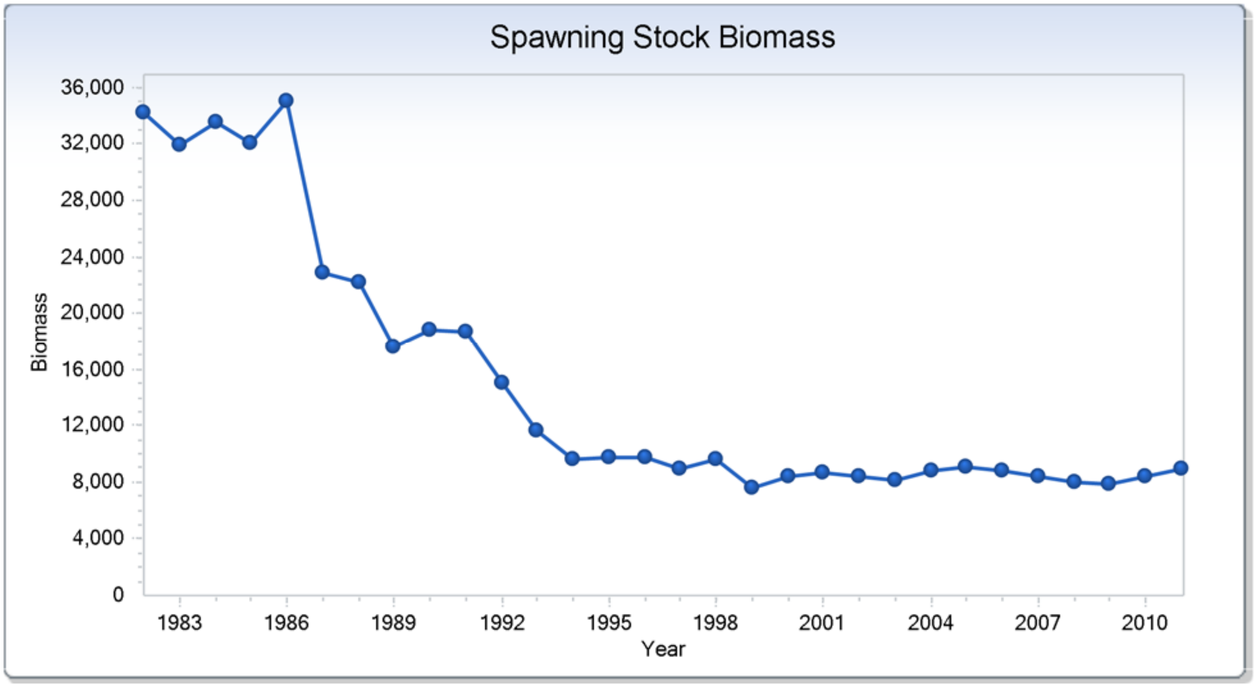
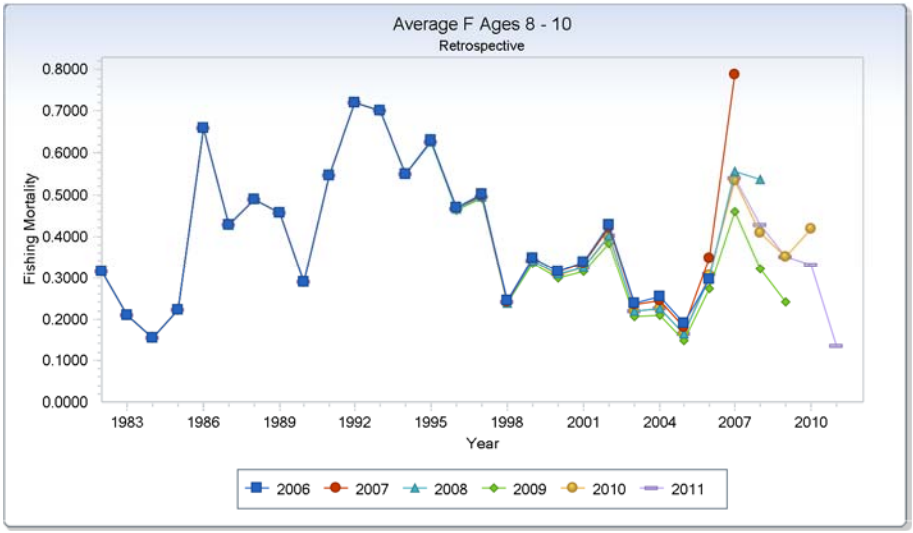
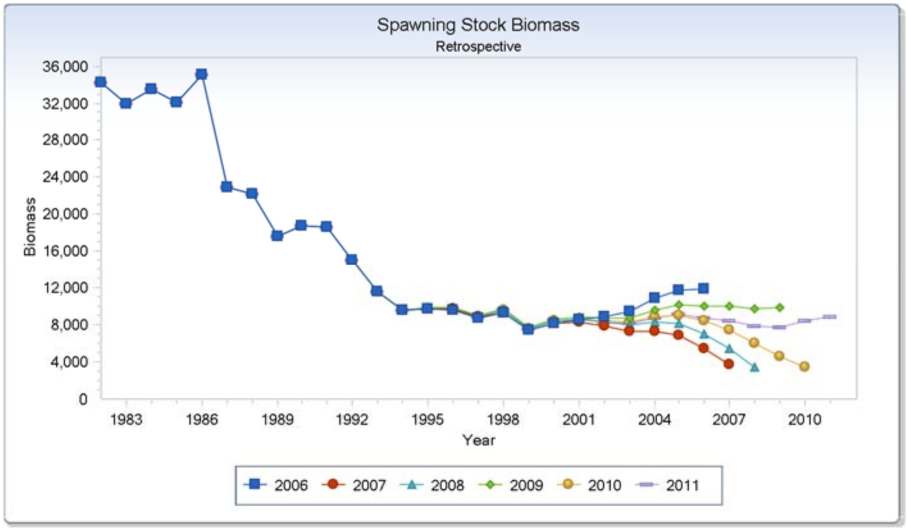


**Figure 6.95.** Retrospective patterns from the VPA continuity run.





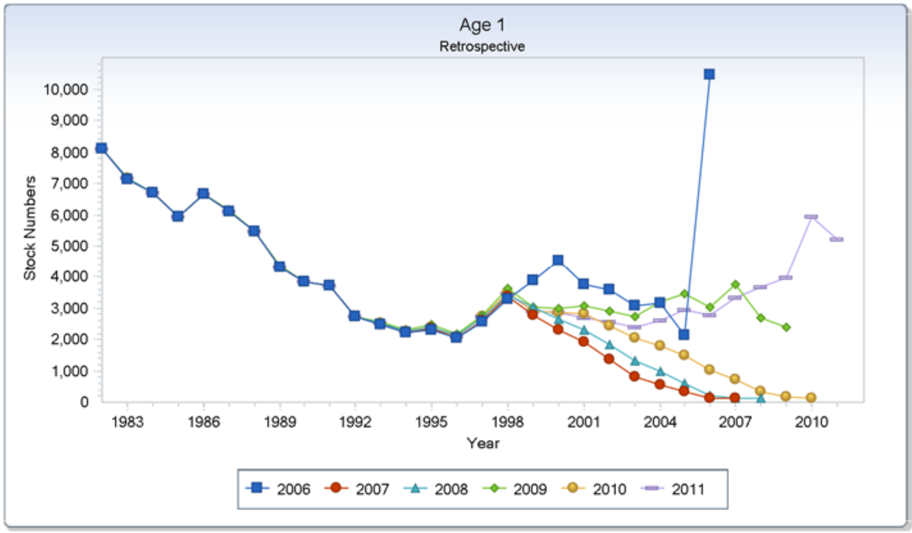
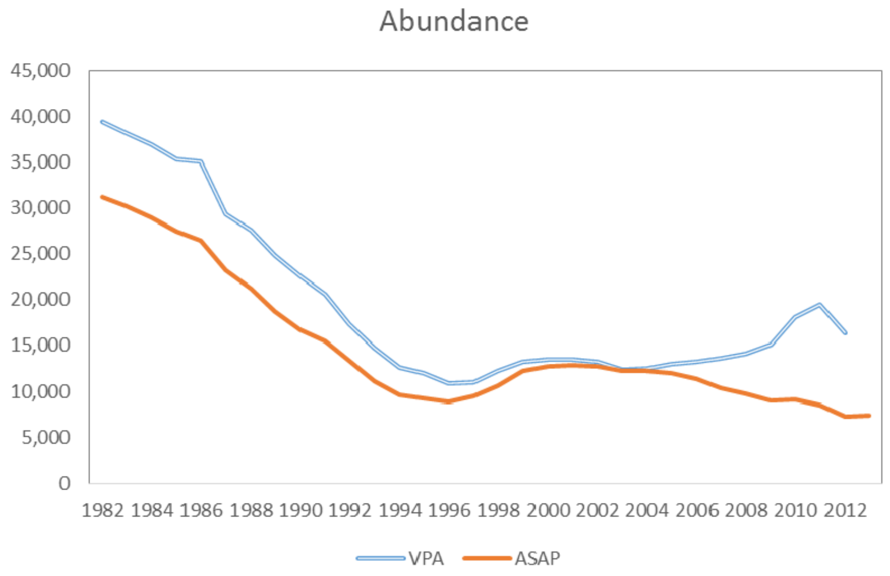


**Figure 6.96.** Comparison of ASAP and VPA estimates of abundance and SSB for the coastwide model.



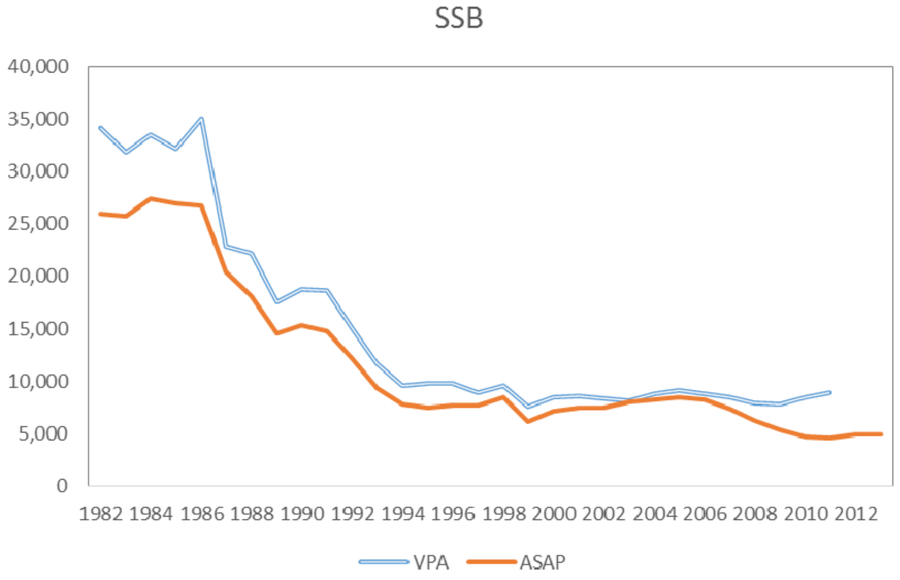
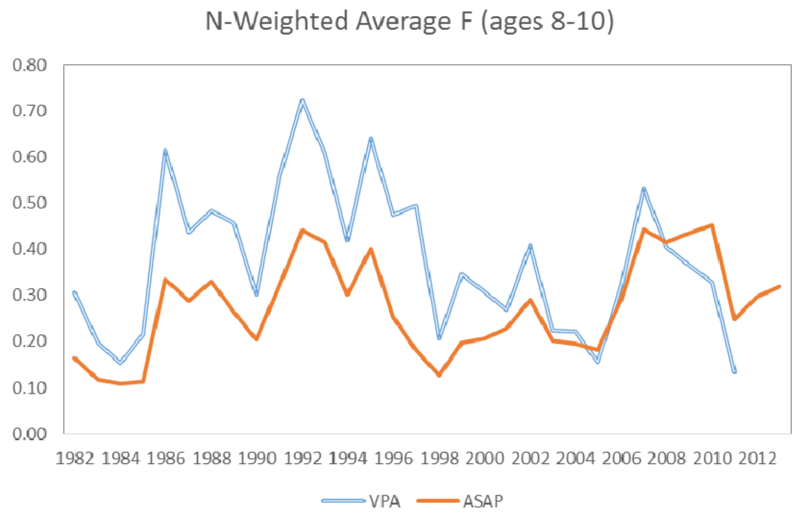


**Figure 6.97.** Comparison of ASAP and VPA estimates of annual N-weighted average F for ages 8-10 and the 3-year average of those values for the coastwide model.


N-Weighted Average F (ages 8-10)

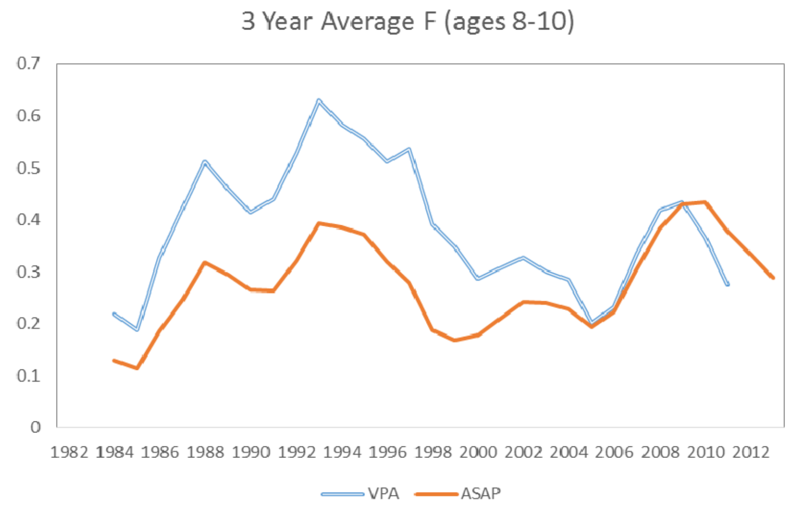

3 Year Average F (ages 8-10)

**Figure 7.1.** F estimates with MCMC confidence intervals and F target and threshold values for the southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.

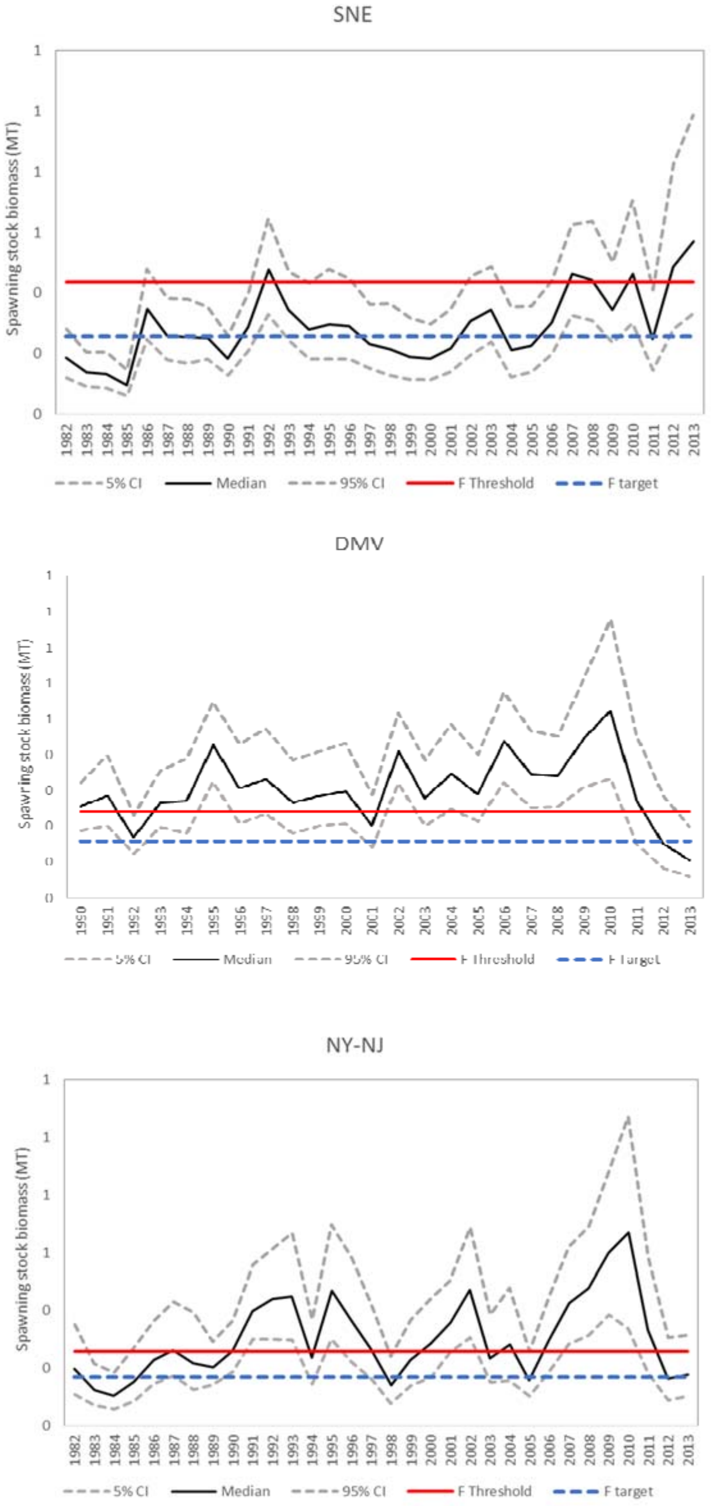


**Figure 7.2.** SSB estimates with MCMC confidence intervals and SSB target and threshold values for the southern New England (top), NY-NJ (middle), and DelMarVa (bottom) regions.