

# Atlantic States Marine Fisheries Commission

## *Tautog Regional Stock Assessment and Desk Review Report*



**Accepted for Management Use**

**August 2016**



**Vision: Sustainably Managing Atlantic Coastal Fisheries**

## **Overview**

In February 2015, the Commission's Tautog Management Board accepted for management use the 2015 Tautog Benchmark Stock Assessment and Peer Review Report, which assessed tautog stocks on a regional basis. A coastwide approach and two different regional approaches were presented. The regional approaches divided the tautog population into three management units. One regional breakdown included Massachusetts – Connecticut, New York and New Jersey, and Delaware – North Carolina; the alternate regional breakdown included Massachusetts – Rhode Island, Connecticut – New Jersey, and Delaware – North Carolina. The Board was concerned about both splitting Long Island Sound (LIS) into two regions and combining it with New Jersey, and so tasked its Technical Committee and Stock Assessment Subcommittee with conducting two additional regional assessment approaches by dividing the Connecticut – New Jersey region into two smaller units: LIS and the New Jersey – New York Bight. Since these assessments used models previously peer reviewed through the 2015 benchmark stock assessment process, the 2016 Tautog Regional Stock Assessment was desk reviewed through the Commission's peer review process.

### **Tautog Regional Stock Assessment Desk Review Report (PDF Pages 1-28)**

The Desk Review Report provides an evaluation of how each Term of Reference was addressed by the Stock Assessment Subcommittee, including the Panel's findings on stock status and future assessment recommendations.

### **Tautog Regional Stock Assessment Report (PDF Pages 29-175)**

The Stock Assessment Report describes the data and analytical models used in the assessment submitted by the Stock Assessment Subcommittee to the Review Panel.

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## *Tautog Regional Stock Assessment Desk Review Report*



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## *Tautog Regional Stock Assessment Desk Review Report*

Conducted in July 2016

Prepared by the Tautog Stock Assessment Desk Review Panel

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## **Acknowledgements**

The Desk Review Panel thanks members of the Tautog Technical Committee, as well as the staff of the Atlantic States Marine Fisheries Commission for support during this review process and for quickly addressing questions during the review.

## Executive Summary

Mr. Joe O’Hop and Dr. Cynthia M. Jones were contracted to provide a desk review of the most recent tautog stock assessment. The motivation for the update to the 2015 benchmark stock assessment centered on the need to provide uniform management for Long Island Sound (LIS), which was previously under Connecticut regulations for its north shore and New York regulations for its south shore. We attended a two-hour webinar held on July 1, 2016 where two presentations were made. Additional documentation was provided at an FTP site and included: PowerPoint files of the two presentations, the ASAP3 technical manual, The ASAP input files, the AGEPRO reference manual, the Tautog 2016 Regional Assessment Report, the Coastwide Tautog 2015 Benchmark Stock Assessment, the ASMFC tautog desk assessment terms of reference and review timeline.

We commend the Tautog Technical Committee (TTC) for their hard work in developing this new four-region assessment in response to the ASMFC board’s request. We conclude that the terms of reference (TORs) have been met, but that changes to the modeling framework would provide clearer results. The results of the new stock assessment provide different reference point results compared with the 2015 benchmark assessment, with the change from “not overfishing” for the NY-NJ region to “overfishing” for the new NJ-NYB. Why this change occurred is more difficult to explain because the portion of NY LIS which has been incorporated into a LIS region is also estimated as “overfishing.”

The data used in the assessment were the best available. The catch time series relied on the MRFSS/MRIP data, but also the MRFSS/MRIP data as an index of CPUE. This is common practice when there are few other data sources to provide indices in predominantly recreationally-based fisheries, but it should be done with caution because both the time series and the CPUE are based on the same data collection. Other indices were also used, such as the Connecticut Volunteer Angler Survey and a variety of fishery-independent surveys, such as the New York Peconic Trawl Survey, and each was tested to evaluate its effect on model sensitivity. The age data and age-length keys (ALKs) used regionally tested ageing protocols developed from recent tautog ageing workshops. Growth curves were based on fishery-derived lengths and we recommend using bias corrections to alleviate potential length truncation as a result of size limits in the fishery.

Although genetic data support panmixia for tautog along the US east coast, we support the WG interpretation of the growth data that shows some structuring in the coastal population based on limited migration of adults, thus the value in providing regional assessments.

We conclude that the methods used in modeling met the term of reference. We add some additional insights below on improving model inputs: 1) that ASAP will fit weights to age 1 and 2 even though none are provided as input and this should be rectified, 2) some weights were not optimally matched with January 1 age dates.

Uncertainty was characterized using standard methodology and included harvest inputs, steepness and selectivity blocks. We discuss below the use of three versus four selectivity blocks, but find that the TTC working group (WG) use appropriate methods. We do suggest that the plus group weights be re-examined. We also note the severity of retrospective bias spanning selectivity block 3 is worrisome and may influence the F and SSB estimates.

ASAP uses selectivity pattern, weights at age, natural mortality rate and relative fishing intensity in the terminal year to calculate reference points. Input data appear reasonable, but also see our discussions on weights at age below. One concern that arose in the review was the selectivity estimate for the third time block in the NJ-NYB model was counterintuitive and may indicate misspecification in the model. We provide further comments below.

## Evaluation of Terms of Reference (TOR)

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 Tautog Stock Assessment Review Team (TSART) found that this TOR was met. The Tautog Technical Committee (TTC) Work Group (WG) provided a thorough review of all data sources that were considered for the assessment and provided detailed information on data sets used in the regional assessment. These data included both fishery-dependent and fishery-independent data. Fishery-dependent data included both recreational (80% component of fishery) and commercial information.

Recreational data came from MRFSS estimates from 1981-2011, which included re-estimated data for 2004-2011 using MRIP methodology. Over these years, recreational harvest declined from a peak of over one million fish to around 200,000 fish recently, albeit that this data time series was quite variable inter-annually. Fishing occurs in spring and fall depending on state regulations. MRFSS on-site sampling was not based on probability-based site selection, and didn't account for night fishing. Based on recent proper sampling designs, correction factors were applied to this original MRFSS on-site data. However, the calibration has not been tested in a side-by-side comparison so there is no way to evaluate whether the calibration is accurate. Moreover, use of the catch-per-unit effort (CPUE) assumes that fishing from public access points is the same as from private access which is not sampled. This is a strong assumption for fisheries that rely largely on these data as indices and for catch (derived from CPUE). Problems arising from CPUE will depend on the proportion of public/private access to a specific species. This issue was not addressed in the review document. MRIP is also transitioning from a random-digit dialing telephone survey that was used to collect effort information to a mail-based sampling design. The re-calibration of MRFSS data is being evaluated in a three-year side-by-side comparison with the MRIP mail survey. Early evaluation appears to show that MRIP is returning higher effort estimates and because catch is calculated as CPUE x effort, this may cause a jump in catch and a discontinuity in the time series. MRFSS began identifying Long Island Sound as a specific area beginning in 1988. To obtain prior time estimates the mean harvest was used from 1988-1993. The other challenge in using these data was the low sample size of fishing trips that were directed at tautog. Tautog fishing is not widespread and to obtain estimates of fishing trips, the TTCWG used trips that were likely to catch tautog to measure catch-per-unit effort (CPUE). Such trips were defined as those that were directed at a guild of fish that used similar gear and were found in similar habitat.



The strength of using the MRFSS/MRIP time series is based on the predominance of recreational harvest in the fishery, the length of the time series available, and the fact that these data are often the only data available. The weakness of these data are in the inadequacy of the MRFSS sampling design to provide unbiased data, unknown bias even with the MRIP recalibration, and the paucity of tautog intercept interviews which contribute to great variability in the data time series. Moreover, using a guild approach, while it constitutes the best available science, doesn't provide a direct measure of tautog CPUE. Moreover, CPUE and catch are conflated even using the guild approach.

Recreational data for the Connecticut shore of the LIS was also available from the Connecticut Volunteer Angler Survey (CTVAS) since 1970. Although this survey was developed to obtain data on striped bass, trip and catch information are available from all catches that are volunteered by anglers who record their data in logbooks. As with any volunteered data, there is no way to verify that these data reflect the catches of the average angler. Typically, these volunteers are devoted anglers and may have better skill than the average. Thus, this time series could be used as a relative measure of tautog catches, but can't be used to estimate harvest of the entire recreational fishery. Care must be taken when using self-reported data unless there is a way to validate that these data represent the average angler in the fishery. CPUE will potentially be rightward shewed.

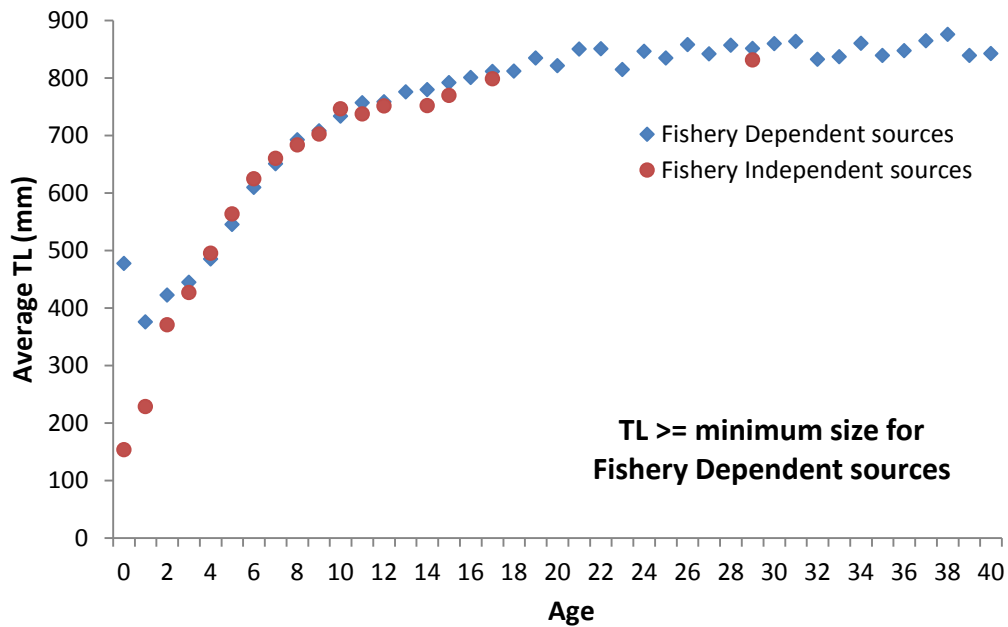
The commercial component of the fishery has declined over decades to approximately 20% of the total harvest. The predominant gear is hand harvest. Landings for the region vary seasonally but occur throughout the year. Although there are federal and state landings records since 1950, it was difficult to split the New York data into LIS and the other New York waters. Because of this, the regional assessment used data from 1988-2014. Other available data for New York was Vessel Trip Reports (VTR) and dealer reports. Prior to 1987, New York commercial landings could not be split into LIS and the south shore. To impute data to LIS, the mean of LIS data from 1986-1989 was attributed to the prior years. Although this extends the time series, it does minimize variance.

Strength of these commercial data is the reliability of mandatory reporting and the length of the time series. However, some years are imputed in the early part of the time series and there is the possibility of under-reporting because of the lack of state reporting programs in some cases. Beyond there, some error is introduced because of the difficulty in splitting the harvest between LIS and the south shore of New York.

Discard data came exclusively from the recreational collection data. This is recorded as the released numbers and dead released are calculated as released by release mortality rate. Released data are obtained from angler self-reporting and there is no way to verify these numbers from anglers using privately-owned vessels. This becomes a problem when releases are proportionally large compared to landed fish. Early in the time series the private/rental sector was 40-60% of harvest, but recently it constitutes 80-90%. Commercial discards were inconsequential and not included.

Fishery-independent data came from the Connecticut LIS Trawl Survey (CLTS), the Millstone Entrainment Sampling (MES), the New York Peconic Trawl Survey (NYPTS), the New York Western Long Island Seine Survey (NYWLISS), and the New Jersey Ocean Trawl Survey (NJOTS). These surveys provided data on relative abundance and biological metrics (sex, length, weight, maturity). However, trawls surveys are not a gear that adequately samples a structure-oriented species such as tautog and result in variable and typically low estimates. Most trawl surveys are statistically designed, employ strict sampling protocols, and provide the best data that are available for the sizes of fish that they are designed to collect.

Fig. 1. Average length of mutton snapper by source of sample.



Length and collection of opercula (in some cases also otoliths) were obtained from both fishery-dependent and fishery-independent surveys. When using length data from fisheries that have size limits, it is advisable to adjust for potential bias (e.g., Fig. 1) prior to comparing growth curves (Schueller et al. 2014 Fish Res 158: 26-39, Diaz et al. 2004). This may have an impact of the growth curve parameterization. Age-length keys were developed from these collections and were used to provide catch-at-age data for the models. Several ageing workshops and age-structure calibrations between laboratories along the US east coast have been conducted and provide consistent ageing results throughout the species range.

The stock-recruitment data are relatively flat. Apparently the growth curves did converge, as VBGF parameter values were obtained with relatively low SE. Comparisons of growth curve parameters and length-weight parameters for the LIS and NJ-NYB regions were presented in the 2016 Regional assessment. According to correspondence from the Tautog

Work Group (WG), the growth curves shown in tables in the Regional assessment were not the growth curves used for the LIS and NJ-NYB models. The growth curves used for input into the LIS and NJ-NYB models originated from analyses used in the 2015 Benchmark assessment.

Fig. 2. Observed and average weights-at-age used for the NJ-NYB model.

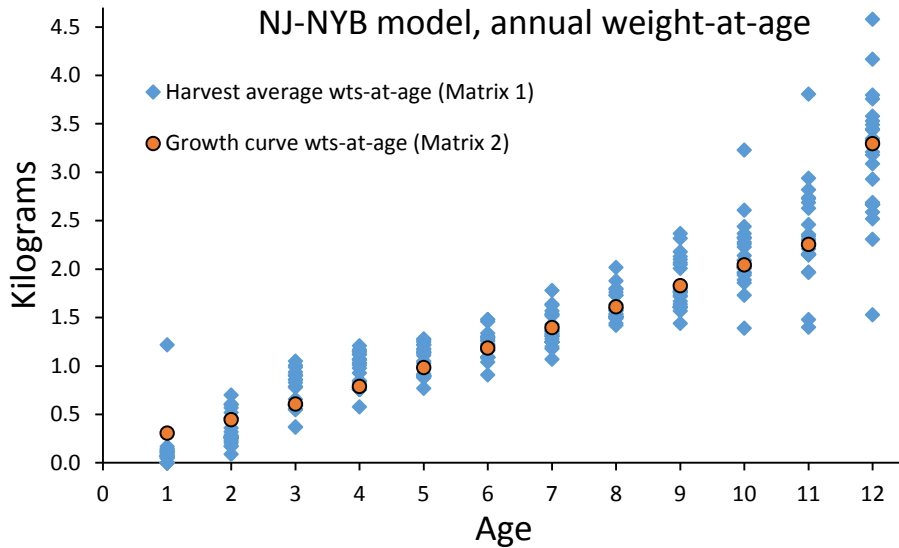
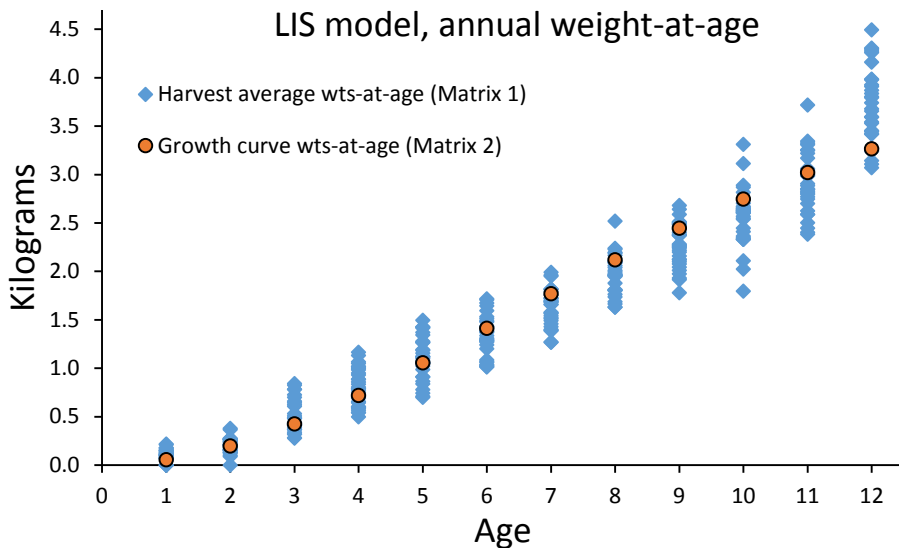


Fig. 3. Observed and average weights-at-age used for the LIS model.



Nonetheless, the growth curve presented for the NJ-NYB region and the growth curve for a somewhat similar regional treatment from the 2015 Benchmark assessment (according to correspondence from the WG) were likely adversely affected by bias (size truncation) introduced through fishery size limits. The estimated NJ-NYB weight-at-age (Fig. 2) calculated from the growth curves in the younger age classes (chiefly ages 1-2) were likely

overstated compared with average weights-at-age observed in catches from the fishery which served as inputs for the harvest for this region. The LIS model was more consistent with the observed weight-at-age (Fig. 3) for the younger ages but may be understating the weight-at-age for the plus group (12+), which might understate SSB for that portion of the population and harvests that would be estimated by the model.

The criteria for data inclusion into the model for this regional assessment followed the same rules as the coast wide 2015 benchmark assessment. Data sets were rejected if the set contained fewer than 10 years of data, inadequate sample size, covered too small a geographic area so that it was not representative of the local subpopulation, or employed inconsistent methodologies. Measures of variance were provided for all input data.

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

This TOR was met. The range of tautog extends from Nova Scotia to South Carolina with greatest abundance from Cape Cod to Chesapeake Bay. Although tautog migrate seasonally, this involved largely offshore and onshore seasonal movements and a high degree of site fidelity. This type of behavior usually restricts the degree of latitudinal mixing and results in a degree of stock structure. Evidence for some structuring is seen in the difference in growth rates from north to south seen in two studies but not in another study. Growth in the Connecticut to New Jersey region showed similar growth trajectories. Similarly, length-weight relationships were similar throughout the region. However, growth parameters for the region differed from growth in the north and in the south of the species range lending credence that analyzing the Connecticut to New Jersey region separately. However, genetic studies have shown no differences between the regions. Often genetic studies will show no differences when there is a small degree of mixing, so that it is a judgment call when growth differences indicate that some structuring exists. Differences in growth will potentially result in different vulnerability to gear in different regions. However, because age-at-maturity is similar throughout the range, one doesn't expect differences in productivity. There is speculation that there could be some contributions of young of the year fish recruiting to the LIS and NJ-NYB regions through oceanographic processes, but the degree to which this may occur is unknown. Depending upon the degree of recruitment to each area, it may be appropriate to treat these two regions as separate sub-stocks as in the current configuration of the 2016 Regional assessment or as two areas with different harvest levels, age compositions, and indices of abundance from a single stock. This issue can only be resolved through future research, and cannot be further addressed at this time.

The current state of knowledge about reproductive strategies of tautog is that they are gonochoristic, but Steimle and Shaheen (1999) note that there are two types of males (one type different from females, the other similar in appearance to females) which may be an indication of protogyny in this species. Other wrasses in this family (Labridae) are known to be protogynous hermaphrodites, but it has not been demonstrated to occur in tautog. This should also be a topic for future research.

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.

The Tautog Stock Assessment Review Team (TSART) found that TOR 3a and b were met, though there were choices made by the analysts that were made for consistency with methods with the 2015 Benchmark assessment that were not well-documented despite an otherwise reasonably thorough presentation. There are always assumptions and choices made by those tasked with assessments, and it is not uncommon for analysts (including those reviewing) to prefer different methods and assumptions. The primary focus for the review is to objectively analyze the work performed and to fairly weigh the impact of the methods and assumptions on the outcomes presented.

The choice Age-Structured Assessment Program (ASAP, version 3.0.17) from the NMFS Northeast Fishery Science Center Toolbox website (<http://nft.nefsc.noaa.gov/>) was reasonable and can accommodate the data sets and life history parameters used as model inputs. Multiple models were not considered, though sensitivity analyses which included removing indices to examine the impact on model estimates were performed.

The configurations for the LIS and NJ-NYB models, constructed from the ASAP input data sets as provided by the WG, are shown in Appendix 1. The two models are similarly configured. The WG provided in their correspondence with the review panel justification for several of the choices made for data inputs (weights at age and SSB, constant M, and maturity) and for their configuration of selectivity parameters (basically, not including fitting criteria for the residuals to use in minimization) for fleets and indices which satisfies TOR 3c. Diagnostics and sensitivity analyses appear adequate to satisfy TOR 3d.

However, there are some conditions in the model inputs that may be improved. The harvest weights at age, in a small number of cases for ages 1 and 2 in both models had zero weight because no fish of these age classes were not observed in the harvest. But, ASAP may predict ages in the population for these age classes, and needs non-zero weights at age to calculate residuals for the harvest weights. Secondly, ASAP computes population numbers and biomass on Jan-1 for each year. The WG explained their reasoning for setting the Jan-1 and SSB weights at age to the same matrix, and that most of the weights at age were drawn from samples during the middle of the year so that the SSB weights at age were appropriate in the two models. While this use of the ASAP weight matrices may represent inconsistent treatment for the biomass at age, the WG argued that because the SSB weights

at age were representative, the reference points for the stock(s) would be properly calculated. Thirdly, the growth curve parameters, derived mainly from fishery dependent sources which are affected by size restrictions on retention, that were used to calculate the SSB weights at age for the NJ-NYB model do not appear reasonable, but the estimated weight at age for spawners may be reasonable despite the misgivings about the growth curve itself (Fig. 2). The weights for age 1 and 2 fish may be overestimated compared to the observed harvest weight at age (Fig. 2), but because tautog do not mature until age 3 the potential overestimation would not impact SSB for the NJ-NYB model. The LIS model growth curve parameters incorporated data from fishery dependent and independent sources, and appears more reasonable for the harvest and SSB data (Fig. 3). However, the weight used for the age 12+ group should be re-examined to make sure that it represents a weighted average for that group. A sensitivity run using an age 15+ group estimated higher SSB, and this may be an indication that weight of 12+ age group was estimated too low. If so, that would potentially impact SSB and reference points in the base run for the LIS model. Lastly, the product of observed numbers at age in the harvest and weight at age in the harvest should equal the total observed harvest weight in the ASAP input file. This was the case for the LIS model but not for the NJ-NYB model. The WG noted that they will resolve this matter.

The WG satisfactorily explained their reasoning for not weighting the estimation of selectivity parameters for the “fleet” and indices for use in fitting the simple logistic selectivity functions by the model. The WG noted that they did not have external information on the selectivity patterns for the fishery or indices that had associated age structures. This was a choice made by the analysts, and opinions may differ on the best approaches for resolving selectivity issues in models.

The assessment document explains that recreational and commercial harvests (which includes landings, fish discarded dead, and that portion of the live releases that are expected to die after release) were grouped into a single harvest matrix by year. The harvests in both areas are primarily from recreational fishing, and the MRFSS/MRIP data was used to determine the number of dead discards and live releases. At-sea sampling and other surveys and voluntary angler programs which provide size information of released fish were used to estimate the sizes and ages (through age-length keys) in the released portion of the recreational catch. Harvests were correctly categorized as the MRFSS/MRIP Type A+B1 fish, but dead discards were incorrectly assumed to be the Type B1 fish which includes fish discarded dead but also a number of other conditions such as fish landed but not seen or not available to be measured (e.g., filleted fish) by the sampler. The Type B1 fish should be re-examined for the proper classification of these fish into dead discards and other harvest. In several species that we have examined in the southeast, very few of the B1 fish are reported as dead discards. The Type B2 fish are fish recorded as released alive, and applying an assumed release mortality rate (2.5% in both models based on tautog being a “hardy” fish) to estimate that fraction of the live releases which suffer mortality due to hook placement, barotrauma, and handling is standard in assessments where no other information on release mortality is available. However, the at-sea sampling often provides

a release condition factor which may be suitable for developing estimates of immediate release mortality of the live releases. Delayed release mortality estimates may be available from tagging studies, though often there is no information of this type and potential impacts are approached through sensitivity runs.

The description of how sample sizes were determined for the fleet harvests and index age compositions for the model inputs were rather brief and not well-documented in the assessment. The WG responded that they will address this issue when the report is updated.

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

This TOR was met. And the approach used to estimate uncertainty followed commonly-used procedures. Uncertainty evaluated the sensitivities to input data, model structure, and retrospectives.

The input data that were tested included 1) individual surveys, 2) the start years for age data, and 3) underestimation of NJ recreational harvest. The Q-Q plot showed that the negative binomial fit the LIS CPUE data well through most of its range, but shows some miss-fitting at the upper range. This MRIP CPUE data also had long runs of negative or positive residuals. In contrast the NYPBTS fit surprisingly well. The CPUE index appears to use tautog catch classed as  $A+B1+(0.025B2)$  where B1 and B2 in the PR/Rental modes are self-reported by anglers. Effort is taken as the number of trips that caught any of the guild species associated with tautog and thus to avoid over-estimating CPUE by underestimating trips from anglers that sought tautog, didn't catch any, but caught something else. While this may not add to bias or variance, it is difficult to say. Uncertainty in the start time of the indices was done to test the effect of estimated NY harvests and discards, to change the ages in the plus group, and to also start the model in 1995 when ALKs were first available. There was a suspected underestimation of recreational harvest in 2005 that was also corrected. This could have been due to poor reporting or to sampling issues in MRFSS.

Uncertainties in the model structure included 1) harvest inputs, 2) steepness and 3) selectivity blocking. To minimize some of the variability present in the MRIP harvest estimates, the TTC used a three-year moving average, thereby smoothing perturbations in the catch record, most likely due to small sample size and infrequent intercepts for anglers targeting tautog. The TTC also chose to use a steepness of one to force the LIS model to fit average recruitment, even though steepness was well estimated in the stock-recruit model. Although this was a test for sensitivity to the SR relation, using  $h=1$  assumes infinite productivity and predetermines the reference points (Mangel et al 2013 CJFAS 70:930-940). The NJ-NYB model estimates  $h=0.9999$  and does not fit the SR relation well. The sensitivity runs did not show any real trends.

Sensitivities comparing the use of three versus four selectivity time blocks in the model structure were evaluated. There is considerable uncertainty in SPR-based F-reference points ( $F_{30\%SPR}$  and  $F_{40\%SPR}$ ) caused by combining the third and fourth time blocks in the model structure. In both models, the F reference points in the 3-block models were lower than in the base run (4-block model).  $F_{MSY}$  in the LIS model was slightly higher in the 3-block model compared with the base run, and this comparison for the NJ-NYB model was not applicable because of the lack of fit (steepness  $\sim 1.0$ ) of the stock-recruitment relationship.

Retrospective analyses for the LIS model spanned two selectivity blocks (1995-2011 and 2012-2014). Three-year (2011-2014) and seven-year (2007-2014) peels were used for the base model with ages 1-12+ and for a model configured with ages 1-15+. The LIS model showed minor retrospective bias in F or SSB for the base run and the model with 15 age groups for the three-year peels, with F for the last year of a time series tending to decline and SSB tending to increase slightly as the next year's data are added. For the seven-year peels, there is no consistent pattern apparent in F or SSB retrospective plots. The magnitudes of the F values cannot be compared between the base run and the 15 age group model, because the basis for the average F was ages 8-12+ for the base run versus ages 8-15+ for the other retrospective. SSB can be compared, and show the base run always below the age 1-15+ model. (This was noted in the assessment report as well, and we recommend [see discussion under TOR 3] that the weight at age of the 12+ group be re-examined.)

For the NJ-NYB model, the retrospective analyses for the base run used a seven-year peel (2007-2014) which spans two selectivity time blocks. The retrospective analyses gave retrospective patterns that appeared to coincide with selectivity breaks. SSB was overstated and F underestimated in the terminal year of the peel compared to the estimates when the next year's data were added for the third time block (2004-2011), and the opposite pattern seems to characterize the 2012-2014 period with SSB being slightly lower and F's higher. SSB for the 2013 peel was underestimated by 25% compared to  $SSB_{2013}$  in the base model through 2014. F is overestimated in the 2012-2013 peels. This is not surprising given that the last selectivity block spans only three years (2012-2014). The severity of the retrospective bias, particularly for years spanning selectivity time block 3, are worrisome and indicate that the F and SSB estimates are highly uncertain in this model.

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.

Given the preceding discussion on the previous TORs, estimates of stock biomass, abundance, and fishing mortality, the LIS model may be relatively robust. The analyses shows relatively little retrospective bias, leading to more confidence in the results from the base run. But, the sensitivity and retrospective run with ages 1-15+ indicate a potential problem with the weight at age in the age 12+ group of the base model. It should be re-

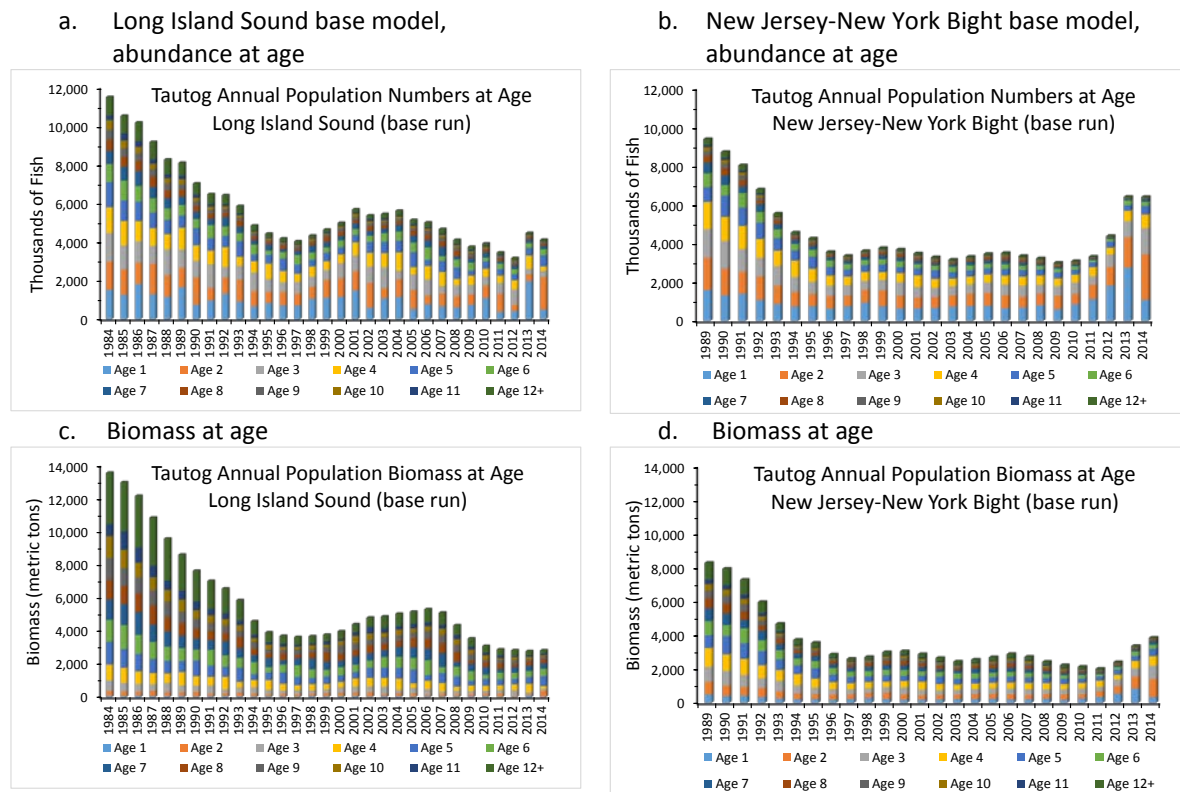


examined to make sure it adequately represents this group. If it does not, the SSB may have been underestimated in the base run.

The NJ-NYB model has much greater uncertainty as shown by the inability of the model to solve for a stock-recruitment relationship and by the bias exhibited in the retrospective analysis. A re-examination of the data inputs (numbers and weights at age, growth curve, age-length keys, etc.) may be warranted.

With the current base model runs, the trends (Fig. 4) in abundance and biomass at age from the LIS and NJ-NYB areas show an erosion of the older age classes which should cause concern to fisheries managers.

Fig. 4. Population trends in abundance and biomass at age from the 2016 Regional Assessment.



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.

ASAP uses the selectivity pattern, weights at age, natural mortality rate, and relative fishing intensity in the terminal year to calculate reference points (ASAP3 reference manual, NMFS 2012a, 2012b). The input data on weights at age, natural mortality, and catch-at-age seemed reasonable. The selectivity estimated for the third time block (2004-2011) in the NJ-

NYB model appears to be counterintuitive. Although size restrictions had increased at that time, the selectivity in the 2004-2011 time block is to the left of all other blocks, indicating that younger fish are caught in greater proportions. This could happen if growth suddenly showed density-dependent effects, a trend not apparent previously. However, this could result from misspecification in the models and is a worrying issue. Changes in selectivity also occur with changes in fish availability or gear, but there are no data to support these as reasons. It could also occur if there were many small fish that were included in the discards. It would be good to review the age-length keys and size-distribution information from the harvests and surveys to ensure that the data used in the analyses are correct. Changes in ageing protocols over time might be suspected, but the assessment document notes that a 2012 workshop was held in 2012 to ensure consistency in ageing methods and that in 2013 there were no consistent differences found in age estimates across states.

When the ASAP model estimates steepness close to one, as in the case for the NJ-NYB model in this assessment, then MSY reference points are inadvisable because the stock-recruit relationship is not well-estimated (Restrepo and Powers, 1999, ICES J Mar Sci 56: 847-852), and SPR reference points are more applicable as done in this assessment. Use of SPR also permits use of F-based reference points (Brooks et al 2010 ICES J Mar Sci 67:165-75). In the case of the reference points for the Long Island Sound where the base runs estimated a stock-recruitment relationship, both MSY-based and SPR-based (MSY proxy) reference points were proposed in the 2016 Regional Assessment. MSY and MSY proxies are affected by any change in fishing practices that affect selectivity (e.g., limits on vessels and gear, hook size/type, size and retention limits, etc.) and availability (e.g., area/depth/season closures) of fish to fishers. The SPR-based MSY proxies are calculated based on yield-per-recruit, so they are equilibrium-based values and are independent of annual recruitment (i.e., the values are “per recruit”). The declining trends in the older age classes seen from the LIS and NJ-NYB base runs (Fig. 4), if these model estimates are reasonable, argues for caution in the choice of reference points.

The review panel has no practical experience with the use of the AgePro software from the NMFS NFT-Toolbox. The SSB SPR-based equilibrium reference points calculated by ASAP and those derived from the use of AgePro and presented in the 2016 Regional Assessment are obviously different (Tables 1 and 2). The ASAP F-reference points are based on an age range specified on the input files. Both the LIS and the NJ-NYB models specified ages 8 to 12+ as the basis for calculating the F-reference points. The SSB estimates are calculated based on the F-reference points, so it is important to specify the basis (age range) for which the F applies. It is also important to state the criteria on which the current F is based, and is not clearly stated in section 7.3 (Stock Status Determination). The current F is defined as the 3-year average value and applies to the arithmetic average of the 2012-2014 fishing mortality rates for the 12+ age group. This is not consistent (but not too different) from the basis (ages 8-12+) for calculating the F-reference points. Other assessments have used n-weighted averages of F over a time period, and ASAP provides a time series for the average F based on ages specified in the input file. Still other assessments have chosen a geometric

average  $F$  over the last years (typically 3) in the time series (see Tables 1 and 2 for examples of different criteria for use as the  $F_{\text{current}}$  in assessments.

For the SPR-based SSB reference points, ASAP (see column with heading “Review Panel” and “base run”) calculates smaller SSB than the corresponding AgePro values (see column with heading “2016 Regional Assessment” and “base run”). The assessment document briefly discusses the use of AgePro for developing the SSB reference points in Section 6.3 (Reference Point Model Description). The rationale for preferring the AgePro estimates to the ASAP estimates, however, is missing and should be provided. It makes quite a difference to the stock status determination.

For the LIS model, the current fishing mortality rate (defined as the average  $F$  over 2012-2014 for age 12+) exceeds the  $F_{\text{target}}$  for both the SPR- and MSY-based  $F$ -reference points (Table 1) which means that overfishing is occurring. For the SSB reference points, the current SSB in 2014 is below the  $SSB_{\text{threshold}}$  from the AgePro estimates and means that the population is overfished. However, the ASAP calculates that  $SSB_{2014}$  is greater than the  $SSB_{\text{threshold}}$ , and the population status would be “not overfished.”

Similar comments apply for the NJ-NYB reference points (Table 2), but all  $F$  and SSB estimates and reference points from the base run result in the population status of overfishing occurring (fishing mortality rate too high) and is overfished (SSB too low).

The Review Panel conducted several exploratory trials of the LIS and NJ-NYB ASAP models with slight variations on the base run configuration (Tables 1 and 2). The first variant explored the impact of assigning a weight ( $\lambda=1$ ) and coefficient of variation ( $CV=0.5$ ) to the selectivity parameters for fleets and indices with more than one associated age class. Differences of reference points,  $F$ , and SSB were slight compared with the base runs, and there was a modest decrease (better fit) in the objective function. Next, this new configuration was modified to link the MRIP index to the “fleet”. Differences in reference points, current  $F$  and SSB, and other values were slightly different and fit was slightly better in the LIS model but not the NJ-NYB model. Lastly, the input configuration was modified to add the stage-2 multipliers to the fleet and index weights on the Lambda-3 tab of ASAP. The rationale for using those weights was to attempt to more equally weight the variances of those components (see Francis 2011a, b) in the objective function. Slightly larger estimates for the SSB reference points and slightly smaller  $F$  rates were obtained for the LIS Model, but the reverse was observed for the NJ-NYB model and the fit was degraded. These runs were not intended to add to the assessment report, only to explore some options in model configuration.

Table 1. List of reference points and other quantities from the 2015 Regional Assessment and from the Review Panel's exploratory ASAP runs using variations on the base model for the Long Island Sound.

definition		2016 Regional Assessment	Review Panel			
		base run	base run	exploratory	exploratory	exploratory
		LIS ASAP (SSB)	LIS ASAP (SSB)	selectivity $\lambda=1$ , CV=0.5	selectivity $\lambda=1$ , CV=0.5, MRIP linked to fleet	selectivity $\lambda=1$ , CV=0.5, MRIP linked to fleet, stage-2 $\lambda$
F at 40%SPR	$F_{target}$	0.27	0.27	0.26	0.23	0.22
F at 30%SPR	$F_{threshold}$	0.47	0.47	0.45	0.38	0.36
Avg. F Age 12+, 2012-2014	3-year avg. F	0.53	0.53	0.51	0.40	0.42
SSB at 40%SPR	$SSB_{target}$	3,757	2,852	2,847	3,056	3,128
SSB at 30%SPR	$SSB_{threshold}$	2,820	1,248	1,245	1,584	1,567
SSB current	SSB 2014	1,956	1,956	1,964	2,184	2,486
Overfishing criteria based on Avg. F for Age 12+ over 2012-2014 exceeding F at 30% SPR, Overfished criteria based on current SSB below SSB at 30%SPR	Stock Status <sup>c</sup>	Overfishing, Overfished	Overfishing, Not Overfished	Overfishing, Not Overfished	Overfishing, Not Overfished	Overfishing <sup>b</sup> , Not Overfished
F 2014, age 12+	F 2014 (age 12+)	0.72	0.72	0.69	0.52	0.42
F 2014, ages 8- 12+ (N-weighted)	F 2014, ages 8- 12+ (N-wgt)		0.69	0.67	0.51	0.41
Avg. F Age 12+ (N-weighted)	Avg. F 12+ (N-wgt)		0.50	0.49	0.39	0.34
N-wgt $F_{geometric}$ 2012-2014, Ages 8- 12+	$F_{geo}$ 2012-2014		0.49	0.48	0.39	0.33
steepness	$h$	0.53	0.53	0.53	0.57	0.56
objective function	objective function <sup>d</sup>	5214	5180	5172	5164	5164
definition		LIS ASAP (MSY)	LIS ASAP (MSY)	selectivity $\lambda=1$ , CV=0.5	selectivity $\lambda=1$ , CV=0.5, MRIP linked to fleet	selectivity $\lambda=1$ , CV=0.5, MRIP linked to fleet, stage-2 $\lambda$
F at 75% MSY	$F_{target}$	0.32	---- <sup>a</sup>	---- <sup>a</sup>	---- <sup>a</sup>	---- <sup>a</sup>
$F_{MSY}$	$F_{threshold}$	0.16	0.16	0.16	0.16	0.15
	3-year avg. F	0.53	0.53	0.51	0.52	0.42
SSB at $F_{MSY}$	$SSB_{target}$	4,576	4,576	4,559	4,196	4,437
SSB at 75% MSY	$SSB_{threshold}$	3,432	3,432	3,419	3,147	3,128
Overfishing criteria based on Avg. F for Age 12+ over 2012-2014 exceeding F at 75% MSY, Overfished criteria based on current SSB below SSB at 75%MSY	SSB 2014	1,956	1,956	1,964	2,184	2,184
	Stock Status	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished

<sup>a</sup> - not calculated

<sup>b</sup> - F geometric criteria would change stock status to "not overfishing"

<sup>c</sup> - Stock Status from the 2016 Regional Assessment used AgePro for calculating SSB targets and thresholds. Calculations by the Review Panel used SSB targets and thresholds calculated by ASAP.

<sup>d</sup> - the contribution of discards (which were not configured in the model) to the objective function were removed for the review panel exploratory runs.

Table 2. List of reference points and other quantities from the 2015 Regional Assessment and from the Review Panel's exploratory ASAP runs using variations on the base model for the New Jersey-New York Bight.					
	2016 Regional Assessment	Review Panel			
	base run	base run	exploratory	exploratory	exploratory
	NJ_NYB ASAP	NJ_NYB ASAP	selectivity $\lambda=1$ , CV=0.5	selectivity $\lambda=1$ , CV=0.5, MRIP linked to fleet	selectivity $\lambda=1$ , CV=0.5, MRIP linked to fleet, stage-2 $\lambda$
$F_{target}$	0.22	0.22	0.21	0.18	0.19
$F_{threshold}$	0.36	0.36	0.36	0.29	0.30
3-year avg. F	0.50	0.50	0.49	0.31	0.41
$SSB_{target}$	2,457	3,136	3,142	3,266	3,224
$SSB_{threshold}$	3,305	2,352	2,356	2,449	2,378
SSB 2014	1,972	1,972	1,986	2,270	1,885
Stock Status <sup>c</sup>	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished
F 2014 (age 12+)	0.66	0.66	0.65	0.39	0.52
F 2014, ages 8-12+		0.65	0.64	0.38	0.51
Avg. F 12+ (N-wgt)		0.50	0.49	0.31	0.41
$F_{geo}$ 2012-2014		0.48	0.47	0.30	0.40
$h$	0.99	0.99	0.99	0.99	0.93
objective function <sup>d</sup>	3660	3631	3624	3685	3693

<sup>a</sup> - not calculated

<sup>b</sup> - F geometric criteria would change stock status to "not overfishing"

<sup>c</sup> - Stock Status from the 2016 Regional Assessment used AgePro for calculating SSB targets and thresholds. Calculations by the Review Panel used SSB targets and thresholds calculated by ASAP.

<sup>d</sup> - the contribution of discards (which were not configured in the model) to the objective function were removed for the review panel exploratory runs.

We did have some concerns with the configurations and data used for the LIS and NJ-NYB models. However, the stock status under this new assessment has the same conclusion. All areas covered by this assessment are overfished and overfishing is occurring as did the benchmark assessment's three region alternative model. The results of the new assessment differ however from the benchmark's preferred three region assessment in that the benchmark assessment did not find the NY-NJ region to be overfished. Because there has been a change in region-specific area inclusion, the LIS southern shore has been separated from NY-NJ, it is not possible to determine if this is the reason for the difference, whether it is sample size, or disaggregation of the MRIP interviews.

## References

- Brooks, E.N., J.E. Powers, and E. Cortex. 2010. Analytical reference points for age-structured models: application to data-poor fisheries. *ICES J. Mar. Sci.* 67: 165-175.
- Diaz, G.A., C.E. Porch, and M. Ortiz. 2004. Growth models of red snapper in U.S. Gulf of Mexico waters estimated from landings with minimum size restrictions. National Marine Fisheries Service, Southeast Fishery Science Center, Sustainable Fisheries Division Contribution SFD-2004-038. 13p.
- Francis, R.I.C.C. 2011a. Data weighting in statistical fisheries stock assessment models. *Can. J. Fish. Aquat. Sci.* 68: 1124-1138.
- Francis, R.I.C.C. 2011b. Corrigendum: Data weighting in statistical fisheries stock assessment models. *Can. J. Fish. Aquat. Sci.* 68: 2228.
- Mangel, M. A.D. MacCall, J. Brodziak, E.J. Dick, R.E. Forrest, R. Pourzand, and S. Ralston. 2013. A perspective on steepness, reference points, and stock assessment. *Can. J. Fish. Aquat. Sci.* 70: 930-940.
- National Marine Fisheries Service. 2012a. Technical Documentation for ASAP Version 3. NMFS Northeast Fishery Science Center. <http://nft.nefsc.noaa.gov/>.
- National Marine Fisheries Service. 2012b. User Manual for ASAP 3. NMFS Northeast Fishery Science Center. <http://nft.nefsc.noaa.gov/>.
- Restrepo, V.R. and J.E. Powers. 1999. Precautionary control rules in US fisheries management: specification and performance. *ICES J. Mar. Sci.* 56: 846-852.
- Schueller, A.M., E.H. Williams, and R.T. Cheshire. 2014. A proposed, tested, and applied adjustment to account for bias in growth parameter estimates due to selectivity. *Fish. Res.* 158: 26-39.
- Steimle, F.W., and P.A. Shaheen. 1999. Tautog (*Tautoga onitis*) Life History and Habitat Requirements. U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-NE-118. 29p.

Appendix 1. Configuration of the 2016 Tautog regional stock assessment models for the Long Island Sound and New Jersey-New York Bight arranged by ASAP interface tab, with footnotes.

Item	LIS (Long Island Sound)	NJ-NYB (New Jersey-New York Bight)
Tab: <b>General Data</b> Model specification <sup>1</sup>	Single fleet (commercial + recreational) 1984-2014 Ages 1-11, 12+ Surveys available: 6 Selectivity blocks: 4 Weight matrices: 2	Single fleet (commercial + recreational) 1989-2014 Ages 1-11, 12+ Surveys available: 3 Selectivity blocks: 4 Weight matrices: 2
Tab: <b>Weights at Age</b> Matrix 1: Catch weight-at-age	kg Harvest = catch-at-age x weight-at-age	kg <sup>2</sup> Harvest ≠ catch-at-age x weight-at-age and Age 1 weight in 2008 anomalous
Tab: <b>Weights at Age</b> Matrix 2: Jan-1 biomass-at-age	kg <sup>3</sup> Age 12+ (plus group) weight may be low. Does it represent a weighted avg. wt. for ages 12-max. age?	kg <sup>3</sup> Ages 1-2 (many, at least) average weights in catch (Matrix 1) much less than Matrix 2.
Tab: <b>Weights at Age</b> Matrix 3: SSB biomass-at-age (set to Matrix 2)	kg <sup>4</sup> Jan-1 biomass and SSB should be different if spawning not on Jan-1.	kg <sup>4</sup> Jan-1 biomass and SSB should be different if spawning not on Jan-1.
Tab: <b>Biological</b> Natural Mortality Maturity Fecundity <sup>7</sup>	<sup>5</sup> Constant M (0.15) <sup>6</sup> - Total (both sexes) Biomass-based, SSB offset=0.42 years	<sup>5</sup> Constant M (0.15) <sup>6</sup> - Total (both sexes) Biomass-based, SSB offset=0.42 years
Tab: <b>Fleets</b> Description Selectivity ages Release mortality <sup>8</sup> Fleet Directed Flag Selectivity blocks  Average F basis:	Rec + Com 1-12+ 0.025 Yes 1984-1986, 1987-1994, 1995-2011, 2012-2014 N-weighted, ages 8-12+	All removals 1-12+ 0.025 Yes 1989-1997, 1998-2003, 2004-2011, 2012-2014 N-weighted, ages 8-12+
Tab: <b>Selectivity</b> <sup>9</sup> Blocks 1-4 Starting values	All single logistic, <b>lambda=0, cv=0</b> A <sub>50</sub> =5, slope=0.6, phase=2 (on)	All single logistic, <b>lambda=0, cv=0</b> A <sub>50</sub> =5, slope=0.6, phase=2 (on)
Tab: <b>Catch</b> Catch at Age Total Weight (Harvest)	(catch + discards combined) Numbers of fish Kilograms	(catch + discards combined) Thousands of fish Metric tons
Tab: <b>Discards</b>	Not used	Not used
Tab: <b>Releases</b>	Not used	Not used
Tab: <b>Index Specification</b> All index and age proportion units in numbers, weight calculations from matrix 2, none linked to fleets, Age 1-12+ indices single logistic Age 1 index age-specific	CT trawl, month=5, Ages 1-12+ NY trawl, month=5, Age 1 index MRIP CPUE, month=6, Ages 1-12+ NY seine, month=5, Age 1 index Millstone Eggs, Age 1 index, not used Millstone Larvae, Age 1 index, not used	NY seine, month=5, Age 1 index NJ trawl, month=6, Ages 1-12+ MRFSS, month=6, Ages 1-12+
Tab: <b>Index Selectivity</b> <sup>10</sup>	All: <b>lambda=0, cv=0 (age 1-12+ indices)</b> <b>lambda=0, cv=0 (age 1 index)</b>  CT trawl A <sub>50</sub> =5, slope=0.6, phase=2 (on) NY trawl, age-specific, phase=-1 (off) MRIP A <sub>50</sub> =5, slope=0.6, phase=2 (on) NY seine, age-specific, phase=-1 (off)	<b>lambda=0, cv=0 (age 1-12+ indices)</b> <b>lambda=0, cv=1 (age 1 index)</b>  NY seine age-specific, phase=-1 (off) NJ trawl A <sub>50</sub> =5, slope=0.6, phase=2 (on) MRFSS A <sub>50</sub> =5, slope=0.6, phase=2 (on)
Tab: <b>Index Data</b> Annual values and CV for indices, age proportions and effective sample sizes if appropriate. Missing annual estimates=-999	Entered, origin of sample sizes for age 1-12+ indices?	Entered, origin of sample sizes for age 1-12+ indices?

Appendix 1. (continued) Configuration of the 2016 Tautog regional stock assessment models for the Long Island Sound and New Jersey-New York Bight arranged by ASAP interface tab.



Item	LIS (Long Island Sound)	NJ-NYB (New Jersey-New York Bight)
<b>Tab: Phases</b>		
F-mult in first year	1	1
F-mult deviations	2	2
Recruitment deviations	2	2
N in first year	2	2
Catchability in first year	3	3
Catchability deviations	-1 (off, i.e., q fixed for block)	-1 (off, i.e., q fixed for block)
Stock Recruitment Scaler	3	3
Steepness	3	3
<b>Tab: Lambdas-1</b>		
Fleet Total Catch (weight) CV and effective sample sizes for fleet age compositions	Origins of CV and ESS not in report	Origins of CV and ESS not in report
<b>Tab: Lambdas-2</b>		
Recruitment CV and lambda for recruitment deviations	CV set to 0.5, lambda set to 0.5	CV set to 0.5, lambda set to 0.5
<b>Tab: Lambdas-3</b>		
Lambda for Total Catch in weight	1	1
Lambda for Total Discards in weight	1	1
Lambda for F-mult in first year	0	0
CV for F-mult in first year	0.5	0.5
Lambda for F-mult deviations	0.5	0.5
CV for F-mult deviations	0.5	0.5
Lambda for Index	All set to 1	All set to 1
Lambda for catchability	All set to 0	All set to 0
CV for catchability	All set to 1	All set to 1
Lambda for catchability deviations	All set to 0	All set to 0
CV for catchability deviations	All set to 1	All set to 1
N in First year deviation	Lambda=0, CV=0.5	Lambda=0, CV=0.5
Deviation from initial steepness	Lambda=0, CV=0.5	Lambda=0, CV=0.5
Deviation from Initial SR scaler	Lambda=0, CV=0.5	Lambda=0, CV=0.5
<b>Tab: Initial Guesses</b>		
Numbers at Age in 1 <sup>st</sup> year	Entered	Entered
Stock Recruitment scaler	10000	1000
Steepness	0.7	0.7
Maximum F	5	100
Catchability for indices	All set to 0.001	All set to 0.001
F-Mult	1	1
<b>Tab: Projection</b>	Not used	Not used
<b>Tab: MCMC<sup>11</sup></b>		
Iterations	1000	1000
Thinning Factor	200	200
Random seed	314156	1126
Age Pro File Option for Age 1	Use Stock Recruitment Relationship	Use Geometric mean of previous years
Start and end year for estimate	1984-2014	1989-2014
MCMC year option	Use Final Year in Stock	Use Final Year in Stock

<sup>11</sup> – ASAP allows the analyst to define multiple fleets, and can be configured to model landings by fleet, total harvest (landings and dead discards) by fleet, or track separately by fleet landings, discards (live and dead), and the portion of the live releases expected to die from release mortality. If the analyst includes only landings or only harvests (landings + dead discards), a single matrix can hold the harvest information. In the case where live releases are estimated to represent a significant portion of the catch (i.e., landings, dead discards, and live releases), then separate matrices are entered to keep track of the ages of the landings, total discards (live and dead), and the proportion of live releases at age in the total catch at age (landings + dead discards + live releases). In this latter case, the estimated release mortality to be applied to the expected live releases is entered as a separate input value. Also in this latter case, that portion of the observed live releases subject to the release mortality should be included in the observed dead discard numbers-at-age and discard weights so that ASAP can calculate the predicted dead discards and residuals from the “observed” dead discards (including the releases expected to die after release). It sounds confusing, but in practice the calculations are usually straight-forward. In the case of the MRFSS/MRIP survey, for most species that we have worked on in the southeast region, there are very few records noting dead releases and in fact most anglers report releasing all their fish alive. So, the A+B1 catch is usually treated as representing landings. The Type B2 catch

(live releases) is examined separately using ancillary information from at-sea studies of released fish. The proportion of released fish scored as “dead”, “struggling at the surface”, and sometimes other categories are assumed to represent the immediate release mortality rate, and the other portion of the released fish are subject to the delayed release mortality rate either assumed from a meta-analysis or from other observational studies (e.g., mark-recapture). Generally, age is inferred from the observed size-at-age of the releases from the at-sea studies either using observed size-at-age proportions (typically fishery independent) or through stochastic ageing techniques (e.g., growth curve, natural mortality rate, and standard deviation of length-at-age). The numbers-at-age (or proportions-at-age) of the dead releases (from immediate release mortality rates) are entered on the discard tab, and the proportions by age of the live releases surviving the encounter with the fishing gear represent the live releases by age divided by the total catch at age and entered on the releases tab. ASAP will use the assumed delayed release mortality rate entered on the Fleet tab to calculate the numbers and weights of released fish that die. To calculate residuals for the weight of total dead discards, the calculated weight of fish dying after release should be included with weight of other dead discards.

Both the LIS and NJ-NYB models were configured as single fleets to contain the landings and discards of the commercial and recreational fishing sectors. The landings were the numbers of fish (LIS) or thousands of fish (NJ-NYB) in the observed catch brought to shore (i.e., landings), and discards (Section 5.1.1.1) appeared to be fish released alive or dead and estimated based on surveys of recreational anglers or commercial fishers. Both models incorrectly defined for the MRFSS/MRIP survey that Type B1 fish as fish released dead, but both models also defined Type B1 fish appropriately as part of the harvest. [This may have been an unfortunate choice of wording in Section 5.1.1.1.] Type B1 fish includes fish discarded dead, but also defines a number of other conditions including fish landed but unavailable for measurement (filleted, etc.) or claimed by the angler and not seen by the sampler.] Harvest weights were the sum of landed weights and estimated dead discards in kilograms (LIS) or metric tons (NJ-NYB). The estimated release mortality for discards was low (2.5%). Using this configuration, both models were treating all landings and discards as harvest, and the release mortality would not operate in the models. ASAP would have no way to calculate the fraction of discards from the total harvest in this calculation, and no way to calculate live and dead releases from the discards.

Separate tables for recreational harvest (A+B1) in numbers of fish were provided for Connecticut, New York, and New Jersey (Table 4.1) and for commercial harvest in metric tons (Table 4.2) for the LIS and NJ-NYB models. However, I did not find separate tables for recreational harvests and releases for the LIS and NJ-NYB models, or for estimated releases for the commercial sector. It is difficult to ascertain the impact of the model configurations without knowing the magnitude and age structure of the live releases. If magnitudes of the estimated live releases were small relative to the harvests, then there would be a negligible impact on predicted harvests in numbers or weight even after release mortality was factored into the equation. However, it could result in residuals in the harvests and age compositions that were inappropriate.

<sup>2</sup> – ASAP allows the user to enter the average weights at age of the landings or harvest (landings + dead discards), and calculates the expected catch (or harvest) based upon the product of the predicted catch-at-age x catch-weight-at-age (Matrix 1). Residuals of the sums of the observed catch (or harvest) weight-at-age and the predicted catch (or harvest) at age are included in the objective function. For calculation consistency, it is advisable to ensure that the observed annual catch equals the sum of the products of the observed annual harvest-at-age (landings, dead discards, and live releases succumbing to release mortality) and annual catch weight-at-age to match the ASAP calculation method for the predicted annual catch weights. The LIS model estimated annual harvest in weight which matched the sum of the product of the catch-at-age and average weight-at-age vectors, but not the NJ-NYB model. The correspondence with the WG indicated that they will re-check these calculations.

In addition, the average weight of Age-1 fish for 2008 in the NJ-NYB model was anomalous and should be examined. However, because few (<1%) Age-1 Tautog are in the catch, the contribution of the weight of Age-1 fish in the year should have only a negligible effect on the output.

A potential situation can arise when there were no weights for specific ages in the observed catch, but for which the model may calculate a predicted catch in numbers for that age. In those cases, it would be advisable to calculate a reasonable weight-at-age for any missing age classes in the observed catch/harvest. Zero weights in a few years were observed in Matrix 1 for both the LIS and NY-NYB models, and overall probably had only a small effect since the total estimated biomass of Age 1 and 2 fish would be a small fraction of the total catch biomass.

See also footnote 7.

<sup>3</sup> – This matrix represents the weights at age that ASAP will use to calculate weight-at-age for the population on January 1. In correspondence with the WG, they elected not to calculate weights-at-age for Jan-1 because most of their growth information probably represented mid-year values. Not calculating Jan-1 biomasses at age may cause some inconsistency with population biomass and catch by ASAP, but the impact on the assessment is probably small.

<sup>4</sup> – This matrix represents the weights at age that ASAP uses to calculate weight-at-age for spawners. ASAP decrements the population numbers at age by natural mortality according to the fraction of the year specified as the spawning offset by the analysts (in this case, spawning is offset by 0.42 years corresponding to June 1 in both models). Even though the weight at age for ages 1-2 in this matrix for the NJ-NYB model are higher than observed for ages 1-2 in harvests, because these young fish are not mature it will not affect the calculated spawning stock biomass (SSB). In the LIS model, the weight of the plus group (ages 12 and older are grouped into a single bin in the base models) appears a little low. The weight at age of the plus group should be calculated as a weighted average of the weight at age in the group, typically offset by natural mortality at age. The LIS model, if the plus group weight is lower than it should be, would potentially be understating SSB if this is the case. The

sensitivity run using the plus group 15+ did estimate a higher SSB than the base run than other sensitivities and the base run using 12+ age group.

<sup>5</sup> – A constant natural mortality of 0.15 over all ages is assumed for both models. This is a choice made by the analysts based on the “rule-of-thumb” method and is within the range (0.12-0.19) for the NJ-NYB region found in the 2015 Benchmark stock assessment for Tautog (ASMFC 2015) and also used in the 2006 stock assessment for this species (ASMFC 2006). There are other natural mortality options like that of Lorenzen (1996, 2005) which observes (and there is experimental and theoretical support from size-selective predation studies) that the rate of predation on the smaller, younger fish is relatively higher than in larger, older fish. Assuming a constant rate of natural mortality in this assessment is a relatively conservative choice than using age-specific natural mortality which has been used in recent assessments in the southeastern U.S. and other areas.

Correspondence with the WG noted that the model estimates using constant M and age-specific M were similar in the 2015 Benchmark assessment. However, Table 6.6.B of the 2015 Benchmark assessment generally shows higher SSB and lower or similar F for the age-specific M configurations at the target and threshold reference points compared to the base run, but do not change the impression of current stock status.

<sup>6</sup> – ASAP can be configured to compute Spawning Stock Biomass and reference points based on mature biomass for both sexes (“total”) or for females only. Both the LIS and NJ-NYB models based these quantities on total maturity as configured. Because the maturity values for this matrix were based on females only, and the sex ratio of females to males is assumed to be 1:1 at all ages, SSB and other reference points could be re-computed to be based upon female SSB by multiplying the maturity values in the current maturity matrix by 0.5. This is a choice to be made by the analysts/stock assessment team/management board and only impacts the magnitude of the SSB reference points. At any rate, the basis for the SSB calculations should be explicitly clear for the managers and future assessments. The correspondence with the WG indicated that this was done to maintain consistency with the 2015 Benchmark assessment.

<sup>7</sup> – Fecundity – based on the product of the maturity-at-age, numbers-at-age decremented by estimated total mortality corresponding to the portion of the year that elapses before spawning occurs, and weight-at-age (spawners). In calculating the biomass of spawners from a growth curve, the weight-at-age should be adjusted for the fraction of the year elapsing before spawning occurs. ASAP will adjust the estimated numbers-at-age by the fraction of the year elapsing before spawning entered on the maturity tab, but does not adjust the spawner weight-at-age. The correspondence from the WG indicated that the weights that they estimated in weight Matrix 2 would be appropriate for mid-year weights-at age and thus appropriate to use for SSB calculations.

<sup>8</sup> – Release mortality and Average F basis ( $F_{\text{report}}$ ) – the current configuration of the model which combines landings and discards into the single catch matrix does not enable ASAP to calculate discards, so this parameter is non-functional in the models as configured. To enable discard calculations, choose the “Include discards in model” option in the General Tab. However, that would also entail estimating the total number of discards (live and dead) at age and the proportions at age of fish released alive to the total numbers of fish at age caught. ASAP enables the analyst to set the basis for fishery reference points based on a range of ages in the model. Both the LIS and NJ-NYB models specified ages 8-12+ as the basis of the reported Fishing Mortality (F) to be used to generate F and SSB reference points.

<sup>9</sup> – Selectivity – ASAP allows fishery selectivity (the proportions at age vulnerable to the fishing gear/fishery for the harvest and for discards if included separately in the model) to be specified as following age-specific patterns, or two function patterns (single logistic or double logistic). Selectivity may be fixed or estimated by the model. Fitting is controlled by whether the minimizer is allowed to solve for the selectivity parameters (phase >0), and whether the residuals are weighted in the objective function that is being minimized (Lambda >0). The bounds around the starting values for selectivity are controlled by specifying the CV for the parameters, and the calculated residuals are assumed to be lognormally distributed by ASAP. The WG chose to maintain consistency with the 2015 Benchmark assessment in the treatment of selectivity parameters (single logistic functions) by setting the phase to a positive value, and set lambdas and CVs to 0 (no contribution to the objective function from fitting). ASAP will replace a CV=0 with 100 to avoid calculation errors, but since the lambda is set to 0, the contribution of the index fit will be zero in the objective function (the AD Model-Builder [ADMB] minimizer attempts to find a minimum for the objective function in the solution space for all active parameters during the fitting process).

Selectivities are arranged in a single or multiple contiguous time blocks in ASAP models, and selectivities and catchabilities (q) will be calculated (or fixed at their starting values if configured that way) for each block.

<sup>10</sup> – Index Selectivity – Each index may be derived from the same or different gears than operate in the fishery, and thus is adjusted for the selectivity of the gear used to sample fish populations. For each index, ASAP will also calculate a catchability (q) relating the index values to the population or harvest numbers (or biomass as appropriate). There is also an option to link indices to fleet harvests if appropriate. Sampling may be appropriate for a portion of the age composition in numbers or weight, and the fitting of the selectivity pattern can be restricted to a single age, a range of ages, or not associated with any part of the age composition. The correspondence with the WG during this review noted that they chose options for the indices consistent with the 2015 Benchmark assessment. Selectivity for age-1 indices were configured appropriately (phase set to -1, lambda set 0, and CV set to 0 or 1 [though setting the CV to 1 is the ASAP convention]). Selectivity (single logistic functions) for indices for wider age ranges (ages 1-12+ in these models) followed the 2015 Benchmark assessment by setting the phase to a positive value and turning off fitting by setting the lambdas and CVs to 0. ASAP will replace a CV=0 with 100 to avoid calculation errors, but since the lambda is set to 0, the contribution of the index fit will be zero in the objective function and will not be used in the ADMB minimization process.

<sup>11</sup> – MCMC – The LIS model estimated a steepness value, so using the stock-recruitment relationship was reasonable to generate recruitment values. The NJ-NYB model estimated steepness essentially at 1.0, so using the geometric mean over at time series to generate recruitment values was reasonable.

#### References

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

Atlantic States Marine Fisheries Commission. 2015. Tautog benchmark stock assessment and peer review reports. February, 2015. ASMFC, Arlington, VA.

# Atlantic States Marine Fisheries Commission

## *Tautog Regional Stock Assessment: Long Island Sound and New Jersey-New York Bight*



June 2016



**Vision: Sustainably Managing Atlantic Coastal Fisheries**

# Atlantic States Marine Fisheries Commission

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June 2016

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## Executive Summary

The Atlantic States Marine Fisheries Commission (ASMFC) manages Tautog (*Tautoga onitis*), under the authority of the Atlantic Coastal Fisheries Cooperative Management Act (ACFMA). The management unit consists of the coastal states from Massachusetts through Virginia. ASMFC has coordinated interstate management of Tautog in state waters (0-3 miles) since 1996.

The 2015 benchmark stock assessment for tautog explored multiple regional definitions for management purposes, including the highly regarded three-region delineation of Massachusetts-Rhode Island, Connecticut-New York-New Jersey, and Delaware-Maryland-Virginia. The ASMFC Tautog Management Board accepted the stock assessment for management use and initiated Draft Amendment 1 in May 2015 to develop regional management alternatives. The Board requested a new assessment to support these management alternatives that would examine the population dynamics in Connecticut-New York-New Jersey in more detail. This regional assessment proposes two additional stock unit boundaries for consideration at a finer regional scale: Long Island Sound (LIS), which consists of Connecticut and New York waters north of Long Island, and New Jersey-New York Bight (NJ-NYB), which consists of New Jersey and New York waters south of Long Island.

Tautog is predominantly a recreationally caught species, with anglers accounting for about 90% of landings coastwide. Tautog are not well-sampled by the MRFSS/MRIP program, resulting in higher percent standard errors (PSEs) and large annual variation in catch estimates, often driven by the small intercept sample size. In the LIS region, recreational landings in the LIS region peaked in 1988 at nearly 700,000 fish. The 2010-2015 average landings in the LIS are 200,000 fish. In the NJ-NYB region, recreational harvest peaked at 1.56 million fish in 1991. Between 2006 and 2014, annual landings in the NJ-NY Bight region have shown high interannual variability without a trend, ranging from approximately 70,000 to 400,000 fish, with an average of 268,000 fish.

The commercial value (dollars per pound) for Tautog has increased fairly steadily since 1990 and has recently surpassed \$3.00 per pound. In the LIS region, commercial landings peaked in 1987 at 159 metric tons. The 2010-2014 average landings in LIS are 37.6 mt. In the NJ-NYB region, commercial harvest during the late 1980s to mid-1990s fluctuated around 70 mt annually. Landings in NJ-NYB since 2009 are 40 mt and below.

The LIS regional stock assessment was led by the University of Connecticut, while the NJ-NYB assessment was led by NJ Division of Fish and Wildlife. The Tautog Technical Committee worked closely with both groups to support these analyses by providing data and technical feedback. New York harvest data, biological samples, and some indices were separated by region (LIS or south shore) and then combined with data from Connecticut or New Jersey to develop regional estimates. The LIS region used data from 1984-2014, while the NJ-NYB region used data from 1989-2014. Population modeling was conducted using the preferred method from the benchmark stock assessment (Age Structured Assessment Program (ASAP) module of the NMFS NEFSC Tool Box).



For the LIS, fishing mortality increased from 1984 to 1995 then declined through the early 2000s, but has been steadily increasing since 2006. The LIS 2012-2014 average full F was 0.53, the highest value in the time series. In NJ-NYB, fishing mortality exhibited a somewhat cyclical trend. Sharp drops in F were observed that generally correspond with implementation of regulations, followed by increases in F in subsequent years. The NJ-NYB 2012-2014 average full F was 0.50.

Spawning stock biomass in the LIS quickly declined from a high of 11,718 mt in 1984 until the early 1990s when the decline slowed. LIS spawning stock biomass (SSB) was 1,956 mt in 2014. In NJ-NYB, SSB was at 5,984 mt in 1989 and declined rapidly during the 1990s. Regulations during the 2000s resulted in minor but temporary rebuilding. SSB declined further during the period 2006-2011, to a low of 1,045 mt in 2011, but has since increased somewhat to 1,972 mt in 2014.

Given the longer time series and the contrast in stock size observed in the LIS region, the Tautog Technical Committee (TC) recommends maximum sustainable yield (MSY)-based benchmarks for the LIS region. Consistent with the benchmark assessment, the SSB target was defined as  $SSB_{MSY}$ , equal to 4,576 mt, and the SSB threshold was defined as 75%  $SSB_{MSY}$ , equal to 3,432 mt. The F target was defined as  $F_{MSY}=0.16$ , and the  $F_{threshold}$  was defined as the long-term equilibrium fishing mortality rate that would produce 75%  $SSB_{MSY}$ , equal to 0.32. Because there was considerable discussion by the TC regarding the utility of the different reference point models, spawner per recruit (SPR)-based reference points are also provided for the LIS region.

**The ASAP model runs indicate the LIS stock is overfished and overfishing is occurring when both the MSY and SPR methods are applied.**

In the NJ-NYB regional model, data were not sufficient to allow credible estimation of the stock-recruit relationship, so the TC considers the MSY-based reference points unreliable. Consistent with the benchmark, the TC is recommending a fishing mortality target of  $F_{40\%SPR}=0.22$  and a threshold of  $F_{30\%SPR}=0.36$ . Recommended SSB reference points are the long term equilibrium biomass associated with the respective fishing mortality rates, with  $SSB_{target} = 3,305$  mt and  $SSB_{threshold} = 2,457$  mt.

**The ASAP model runs indicate the New Jersey and southern New York (NJ-NYB) stock are overfished and overfishing is occurring.**

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## Terms of Reference

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

Tautog are targeted by 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 from 1982 to present. Commercial records indicate low harvest levels from the 1950s-1970s, a similarly low harvest is assumed for the recreational sector. As the popularity of the species increased and technological advancements facilitated the identification of hard bottom habitat, directed recreational and commercial fisheries developed and landings increased rapidly during the late 1970s, peaked in the mid-to late 1980s, and have since declined substantially since.

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 developed from the Northeast Fishery Observer Program were considered too uncertain to include in the model because of the small sample size. Tautog are not well-sampled by the MRFSS/MRIP program, resulting in higher PSEs and large annual variation in catch estimates, often driven by the small intercept sample size.

As a hard structure-associated species, Tautog are also not well-captured by standard trawl-based surveys. The Technical Committee used four previously accepted fishery-independent surveys from Connecticut, New York and New Jersey, two of which are adult and two are young-of-year surveys. Two other indices, (one egg and one larvae) from the entrainment program at the Millstone, CT power plant were included in sensitivity analyses. 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. Under the previous 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 identified three regions, but split Long Island Sound between the Southern New England (SNE) and the NY-NJ regions, so a highly regarded alternative regional scheme was presented that moved CT from the SNE region to the



NY-NJ region. At that time the TC proposed that in a future assessment should split Long Island Sound from New Jersey and the New York Bight, thus creating a four region approach. The LIS and NJ-NYB assessment is presented here.

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

This stock assessment used the Age Structured Assessment Program (ASAP) version 3.0.17, available through the Northeast Fishery Science Center (NEFSC) National Fishery Toolbox (NFT) which is a “data rich,” forward projecting statistical catch at age program to assess Tautog populations. The model incorporated annual harvest estimates, adult fishery-independent and fishery-dependent biomass, available age structure, size-at-age, and juvenile abundance indices. Within each region, the ASAP model assumed a single fleet with three or four selectivity periods based on management time blocks. “Base” models were conducted for each model and region. Sensitivity runs were also conducted for each model to evaluate model sensitivity to input data, model configuration, regional structure, and other assumptions.

Given periodic changes in management for both regions with trends of increased minimum size, the technical committee determined that it was appropriate for both regional assessments to use four selectivity blocks.

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 LIS, fishing mortality spiked in the early 1990s and again exhibited a generally increasing trend since the early 2000s. In NJ-NYB, fishing mortality exhibited a somewhat cyclical trend. Sharp drops in F were observed that generally correspond with implementation of regulations, followed by increases in F in subsequent years.

Trends in biomass are less variable than those for fishing mortality. Consistent with trends in fishing mortality, biomass in the LIS quickly declined from the mid-1980s until the early 1990s and has generally (but slowly) declined since then. In NJ-NYB, SSB declined rapidly during the 1990s. Regulations during the 2000s resulted in minor but temporary rebuilding. SSB declined further during the period 2006-2010, but has since increased back to previous levels. Spawning stock biomass estimates in each region was in the range of 2,000 MT in 2014.

The Technical Committee chose MSY-based reference points for the LIS 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 4,576 MT and an  $SSB_{threshold}$  of 3,432 MT. The  $F_{target}$  was defined as  $F_{MSY}$  (0.16), 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 0.32. SPR estimates are also provided below.

The S-R curve for the NJ-NYB region 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 that region, with  $F_{\text{target}}$  defined as  $F_{40\%SPR}$  and  $F_{\text{threshold}}$  defined as  $F_{30\%SPR}$ . For NJ-NYB, this resulted in  $F_{\text{target}} = 0.22$  and  $F_{\text{threshold}} = 0.36$ . 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.  $SSB_{\text{target}}$  for NJ-NYB was 3,305 MT, and  $SSB_{\text{threshold}}$  was 2,457 MT.

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

Retrospective patterns indicate  $F$  in the terminal year is overestimated in LIS and NJ-NYB. 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 LIS and overestimated relative to the base model in NJ-NYB. 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 LIS region was estimated to be below  $SSB_{\text{threshold}}$  (overfished) with the 2012-2014 average of fishing mortality above the  $F_{\text{threshold}}$  (overfishing occurring). The NJ-NYB region is overfished ( $SSB_{2014}$  below  $SSB_{\text{threshold}}$ ) and the 2012-2014 average of fishing mortality is above  $F_{\text{threshold}}$  (overfishing occurring).

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 TC recommends conducting a Benchmark Stock Assessment in 2021. Update assessments will be conducted for all regions during the fall of 2016 with data through 2015. At that time, the TC will discuss timing of future updates.

## 1. INTRODUCTION

Tautog (*Tautoga onitis*) is a member of the wrasse (Labridae) family inhabiting temperate regions of the U.S. Atlantic coast. The species ranges from the Gulf of Maine through Georgia, with a primary distribution from Cape Cod, Massachusetts to Virginia Beach, Virginia. The species supports important commercial and recreational fisheries throughout the primary range, and has been managed through the Atlantic States Marine Fisheries Commission (ASMFC) since 1996 (ASMFC 1996). The 2015 benchmark stock assessment for tautog delineated the stock into multiple regions for management purposes (ASMFC 2015, Table 1.1). The ASMFC Tautog Management Board (Board) accepted the stock assessment for management use and initiated Draft Amendment 1 in May 2015 to develop regional management alternatives.

To further develop a range of regional alternatives for Draft Amendment 1, the Board requested additional spatial resolution in the Mid-Atlantic region, specifically development of a separate assessment for Long Island Sound (LIS) that includes Connecticut plus New York's north shore of Long Island. The additional region would result in four management units: Massachusetts-Rhode Island (MARI), LIS, New Jersey-New York Bight (NJ-NYB, consisting of NJ plus NY south of Long Island), and Delaware-Maryland-Virginia (DMV, Table 1.2). The purpose of this report is to address the Management Board's request, as well as update the original NYNJ regional assessment without New York's LIS data, yielding an NJ-NYB assessment.

The LIS regional stock assessment was led by the University of Connecticut, while the NJ-NYB assessment was led by NJ Division of Fish and Wildlife. Both received support and advice from the ASMFC Tautog Technical Committee (TC) and Stock Assessment Subcommittee (SAS). New York harvest data, biological samples, and some indices were separated by region (LIS or south shore) and then combined with data from CT or NJ to develop regional estimates. Population modeling was conducted using the preferred method from the benchmark stock assessment (ASAP module of the NMFS NEFSC Tool Box; ASMFC 2015). Subsequent analytical methods, estimation of biological reference points, and stock status determination also employed similar methods to the benchmark.

### 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. All states from Massachusetts through Virginia have a declared interest in the fishery management plan.

## 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](http://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 included only nine months of data under the new regulations (i.e., through 1998). Given the life history of the species, the Tautog Management Board was concerned the assessment provided limited advice on the effects of the new regulations. Addendum II was therefore passed in November 1999, 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  $F_{\text{target}} = F_{40\%SSB} = 0.29$  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  $F_{\text{target}}$  of  $F = M = 0.15$  on the grounds that stock biomass had not responded to previous  $F$  levels. The new  $F_{\text{target}}$  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 recreational management measures for states included in this regional assessment are presented in Table 1.3; regulations for the commercial fishery are in Table 1.4.

### **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, <http://nft.nefsc.noaa.gov/>). In order to incorporate perceived regional differences in biology and fishery characteristics throughout the range of the species, the Technical Committee (TC) 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 stock 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 was 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 TC 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 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, encouraging 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 Addendum IV target of  $F_{target} = 0.20$ . SSB was estimated to be 10,663 MT in 2009, well below Addendum IV’s 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.

A benchmark stock assessment was completed and peer-reviewed in 2014 (ASMFC 2015). The assessment was conducted at a regional level. The TC used life history information, tagging data, fishery characteristics, and data availability considerations to split the coastwide population into three regions. Each region was assessed independently using the statistical catch-at-age model ASAP. All three regions were found to be overfished, with overfishing occurring in the northern one (preferred model) or two (alternate model) regions.

Since 2006, many of the compliance elements of the coastwide FMP have served well to increase the knowledge base regarding this species. In addition, the importance of having a coastwide plan is still high, since recreational and commercial fisheries on the stocks affect the species over broad geographic areas, even if the stock is split into discrete management units. The 2015 benchmark stock assessment proposed regional stock definitions based on localized biological

and socioeconomic trends. This regional assessment proposes additional stock unit boundaries for consideration at a finer regional scale.

## **2. LIFE HISTORY AND STOCK STRUCTURE**

Tautog is one of over 630 wrasse species comprising the family Labridae 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 Cunner (*Tautogolabrus adspersus*) exceptions to the general rule, as they range along the western Atlantic coast from Nova Scotia to South Carolina (Bigelow and Schroeder 1953). Both species are most abundant from the southern Gulf of Maine (lower Massachusetts Bay and southern Cape Cod Bay) to Chesapeake Bay (Steimle and Shaheen 1999).

In a portion of its range, adult tautog seasonally migrate. In northern regions, 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 southernmost part of the range may not undergo seasonal migrations at all (Hostetter and Munroe 1993, Arendt et al 2001). Even further north 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. Studies suggest 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 27°C (Arendt et al 2001).

### **2.1. Age and Growth**

To age Tautog, most states use opercular bones following the techniques of Cooper (1967) and Hostetter 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 annulus, 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. 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 in age estimates arising from use of different hard parts (ASMFC 2012); however, 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. Individuals over 30 years are recorded in Rhode Island, Connecticut, and Virginia. Tautog also grow to large sizes, up to 11.36 kg (25 lbs). Males exhibit faster growth and larger sizes (based on total length) than females (Cooper 1967). Evidence suggests females lifespan is shorter 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). White (1996) developed growth equations that suggested similar growth rates throughout the range, and attributed apparent geographic variability indicated by earlier work to differences in aging techniques.

#### **2.1.1. Analysis of Regional and Temporal Variability in Life History**

Age, length, and weight data were compiled to examine potential differences in growth rates and size-at-age by region and thereby inform stock structure definitions. Data for these analyses were taken from various fishery-dependent and independent surveys (Table 2.1). Analyses excluded Massachusetts samples that were taken in a targeted investigation of stunting, and two likely erroneous data points (Connecticut: a 21 kg fish with a length of 49.1 cm; Delaware: a 36-year old fish with a length of 40 cm). Length, age and weight distributions are positively skewed in all regions (Figure 2.1). Length values are distributed differently among regions in extremes (Figure 2.1A); the MARI region data has the smallest and largest length values, whereas DMV has the largest minimum length and LIS has the smallest maximum length values; mean and median values for length are similar among regions. The MARI sampling program captured the youngest fish (age 0) and also yielded the youngest maximum age, whereas the LIS samples contained the oldest maximum-age fish; mean and median values for age are similar among regions (Figure 2.1B). There is greater disparity among regions in the distribution of weight than in the distribution of length and age (Figure 2.1C), in that the weights of NJ-NYB fish are considerably less than those of other regions: the 75%ile length of NJ-NYB fish is about the same as the median weight of DMV fish, is less than the median weight of LIS fish and is less than the 25%ile of MARI fish.

Analyses of length, weight, and age relationships included nonlinear regression and general linear models. Analysis of Residual Sum of Squares (ARSS) was used to evaluate differences among regions in fitted curves from nonlinear regression (Chen et al. 1992; Haddon 2010):



$$F = \frac{\frac{RSS_p - \sum RSS_i}{df_p - \sum df_i}}{\frac{\sum RSS_i}{\sum df_i}} = \frac{\frac{RSS_p - \sum RSS_i}{m(c-1)}}{\frac{\sum RSS_i}{N - mc}}$$

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,  $m$  is the number of parameters, and  $N$  is the total number of observations. The significance of the result is assessed by calculating the probability of observing  $F$  or greater under the null hypothesis, for numerator degrees of freedom  $m(c-1)$  and denominator degrees of freedom  $N-mc$ . General linear model analysis included analysis of variance (ANOVA) and analysis of covariance (ANCOVA), in which the value of  $F$  is calculated as  $MS_{\text{effect}}/MS_{\text{error}}$ . These approaches permit assessment of how responses vary among levels of each predictor while adjusting or partialling out the effect of other predictors, using least square means (*LSMeans*) estimates. Significance of differences in mean responses among predictor levels is assessed using a multiple-means test (Tukey-Kramer) that is conducted only when the predictor is significant ( $P < 0.05$ ) to control the experimentwise error rate.

Regional differences in life history variables were tested in three sets of comparisons: differences among regions in the four-region scenario (Table 1.2), between CT and the rest of the Southern New England region (i.e. Massachusetts and Rhode Island [MARI]), and between NY data from LIS and the remainder of NYNJ (i.e., New Jersey and the New York Bight [NJ-NYB]). The purpose of the latter two tests is to discern whether LIS represents a source of heterogeneity within the SNE and NYNJ regions in the preferred three-region scenario of the 2015 Benchmark Stock Assessment (Table 1.1)

### 2.1.2. Regional Variability in Growth Curves Estimated via Nonlinear Regression

Von Bertalanffy growth curves were fitted to length-age data. The response for all models was length, and the predictor variable was age. The null hypothesis of no difference in growth curves among regions was tested via ARSS, as described above. Growth curves were fitted using three parameter estimates ( $m=3$ ): asymptotic length ( $L_{inf}$ ), growth rate ( $K$ ), and age at zero size ( $t_0$ ). In the test of difference among regions in the four-region delineation,  $c=4$ ; in the test of difference between CT and MARI, and the test of difference between NY data from LIS and data from NJ-NYB,  $c=2$ . In all regression analyses, initial values of parameters were  $L_{inf}=59$ ,  $K=0.171$ ,  $t_0=0$ ; to check for stability of final estimates, alternate initial values of  $L_{inf}=70$ ,  $K=0.7$ ,  $t_0=-7$  were tested. In all cases the models converged on the same estimates. Diagnostic plots for the regression on all pooled data indicate that residuals are close to normally distributed but that the model overestimates length for the youngest fish and underestimates length for the oldest fish (Figure 2.2).

### **2.1.3. Regional and Temporal Variability in Length-at-Age Estimated by Analysis of Variance**

Growth was also subjected to linear modeling via ANOVA, in which length was the response variable, and age, region, and year were included as categorical predictors. The null hypothesis was that there was no difference in mean length between age, year, and region. Model diagnostics indicated approximate normality of residuals that deviated appreciably only at far tails (Figure 2.4). Levene's test indicated that there was heterogeneity of variance (HOV) for each effect ( $P < 0.0001$ ), but no mean-variance relationship was observed in any case nor were there evidently divergent (high or low variance) levels of any effect. All interactions among main effects were significant but presentation here is limited to a reduced model including only the main effects.

### **2.1.4. Regional Variability in Weight-Length- Relationship Estimated via Nonlinear Regression**

Parameters of the weight-length relationship for Tautog were estimated by nonlinear regression. Data on weight were fewer than data on length, in part because RI and DE rely on intercepts in fishery surveys of specimens that have been filleted. The model for fitting weight to length was the standard power equation for allometric relationships,  $Weight = a * Length^b$ . The null hypothesis of no difference in weight-length curves among regions was tested via ARSS, as described above ( $m=2$ ). In the test of difference among regions in the four-region delineation,  $c=4$ ; in the test of difference between CT and MARI, and the test of difference between LIS and NJ-NYB,  $c=2$ . Because there is scant data on weight of NY fish from LIS, the third hypothesis test used all observations available for weight of LIS fish (i.e., CT and LIS NY) to compare to NJ-NYB. In all regression analyses, initial values of parameters were  $a=0.00001$ ,  $b=3$ ; to check for stability of final estimates, alternate initial values of  $a=0.0001$ ,  $b=2.6$  were tested. In all cases the models converged on the same estimates. Diagnostic plots for the regression on all pooled data indicate that residuals are somewhat leptokurtic and that the model overestimates weight among the longest fish (Figure 2.7). An effort to correct this deviation by restricting the analysis to fish of weight  $< 7$  kg or to fish of length  $\leq 70$  cm did not resolve the deviation so analysis proceeded with the entire dataset.

#### **2.1.4.1. Weight Analysis of Covariance**

Weight-length relationships were also subjected to linear modeling via ANCOVA, in which weight was the response variable, region, and year were included as categorical predictors and length was included as a continuous covariate. Weight and length were  $\log_{10}$ -transformed. The null hypothesis was that there was no difference in weight-at-length between age, year, and region. Model diagnostics indicated approximate normality of residuals that deviated appreciably only at far tails (Figure 2.5). Among-means differences were evaluated as protected Tukey-Kramer tests (conducted only when the treatment was significant at  $P < 0.05$ ) to control the experimentwise error rate, on means adjusted for the other effects (least-squares means [*LSMeans*]). All interactions among main effects were significant but presentation here is limited to a reduced model including only the main effects.

## 2.1.5. Results

### 1.1.1.1. Growth Curves

There is regional heterogeneity in growth curves. The von Bertalanffy assessment of growth revealed that the growth constant ( $K$ ) generally decreased and the maximum size ( $L_{inf}$ ) increased from north to south (Table 2.2). The growth curves for the two northern regions are similar for young fish but the MARI curve asymptotes at a smaller size than that for LIS (Figure 2.6). The growth curve parameters for the two southern regions are similar for young fish, ascending more slowly than the curves for the northern regions, but ultimately ascending to a larger size at age. An F-test via ARSS indicates dissimilarity of growth curves among all regions (Table 2.3). Heterogeneity is also indicated between LIS and MARI, and between LIS and NJ-NYB.

#### 2.1.5.1. Length-at-Age

Mean length varied among ages, years and regions (Table 2.4). Tukey's comparisons of *LSMeans* revealed that differences in mean length between successive ages were significant for younger ages but were not different at greater ages, especially for ages greater than 10. Most (70%) of the 435 inter-year comparisons of mean length-at-age were significant. *LSMean* length adjusted for age and region has increased over time (Figure 2.7; Pearson correlation coefficient  $R = 0.6$ ,  $P = 0.003$ ). Comparing *LSMean* length values that are representative of the trend over time (estimated for the years 1985 and 2014) indicates an increase of 7.3% in length at age over about three decades. In the four-region comparison, as well as in each of the comparisons of LIS and neighboring region, there was a significant difference in mean length-at-age (Table 2.4). *LSMean* length adjusted for age and year does not vary in a north-south gradient: *LSMean* lengths for NJ-NYB and LIS were smallest and the *LSMean* from DMV was largest (Figure 2.8). *LSMean* length of DMV Tautog is 10.4% longer than *LSMean* length of NJ-NYB Tautog.

#### 2.1.5.2. Weight-Length Relationship Estimated via Nonlinear Regression

The parameters of the allometric length-weight function for LIS were estimated. The scaling parameters varied among regions, such that the elevation represented by the coefficient  $a$  decreased and the exponent  $b$  increased in a north to south gradient (Table 2.5). As a result, Tautog of intermediate length are on average heavier in northern regions, but those of greater length are on average heavier in southern regions (Figure 2.9). An F-test via ARSS indicates dissimilarity of growth curves among all regions (Table 2.6). Heterogeneity is also indicated between LIS and MARI, and between LIS and NJ-NYB.

#### 2.1.5.3. Weight Analysis of Covariance

Mean weight-at-length varied among years and regions (Table 2.7). Tukey's comparisons of *LSMeans* revealed that 31% of the 465 inter-year comparisons of mean weight-at-length were significant. Mean weight-at-length, adjusted for region, has decreased over time (Figure 2.10; Pearson correlation coefficient  $R = -0.75$ ,  $P < 0.0001$ ). After simple back transformation, the

heaviest *LSMean* weight (in 1986) is 19.7% greater than the lightest *LSMean* weight (in 2013); comparing values more representative of the general trend (in 1985 and 2012) indicates a decrease of 8.6%. In the four-region comparison, as well as in each of the comparisons of LIS and neighboring region, there was a significant difference in mean weight-at-length (Table 2.7). Weight-at-length did not vary in a north-south gradient; *LSMean* weights for MARI and DMV were smallest and the *LSMean* from LIS was largest (Figure 2.11). The back-transformed *LSMean* for LIS is 5.8% greater than the back-transformed *LSMean* for MARI.

#### **2.1.6. Discussion**

Analyses indicate heterogeneity in growth parameters over space and time. Results of nonlinear regression and general linear models indicated that each region has a biologically distinctive population of Tautog. Specifically, LIS and NJ-NYB parameters are different from those of MARI and DMV, and are different from each other. While the large sample size supporting each analysis contributed to the statistical significance of these differences, the parameters vary to a biologically significant extent. Regional differences in years and collection methods for specimens used in the biological analysis may have contributed to these differences as a confounding effect. In particular, northern states have more data from the earlier years, and DMV states rely exclusively on fishery-dependent sampling thus have limited data on young small 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. An additional caution about the assessment of spatial and temporal variability in growth parameters is that interactions among predictors have not been considered in detail.

Regional and temporal differences in how length changes with age are reflected in von Bertalanffy curves and in estimates of age-adjusted mean length. As indicated in previous stock assessments, Tautog in southern regions achieve a larger final size than those in northern regions (mid-60 cm range vs mid-50 cm range), albeit at an initially slower rate. Predicted age- and year-adjusted length (*LSMean* length) is smallest for the two regions that are subjects of this regional assessment, LIS and NJ-NYB. There has been temporal variability in growth: predicted age- and region-adjusted *LSMean* length has increased over time by about 7%.

Regional and temporal differences in how weight varies with length are reflected in nonlinear regressions using scaling equations and in estimates of length-adjusted mean weight. Weight increases more gradually with length in northern regions but starts out at greater values. The scaling exponent for the weight-length relationship is close to the value of 3 that would be expected on general allometric principles. Analysis of regional differences in adjusted weight (*LSMean* weight adjusted for year and length) indicates that weight-at-length varies in an inverse fashion to length-at-age: mean weight is heaviest for LIS and NJ-NYB, about 6% greater than for the northernmost and southernmost regions. Weight-at-length has decreased over time by about 8% in 30 years.

## **2.2. Maturity**

Unlike most labrids, which are protogynous hermaphrodites, Tautog are gonochoristic. Tautog 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 et al. 2003). Female Tautog begin to mature at age 3, and males begin 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. 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. Males are 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.

## **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 (Olla and Samet, 1977).

### **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 et al. 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 et al. 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. 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**

Natural mortality was long estimated to be  $M = 0.15$  based on the “rule of thumb” method of  $3/T_{max}$  with an assumed max age of 20 years. The TC performed an in-depth analysis during the 2015 Benchmark Stock Assessment using a number of life history- and age-based estimators of  $M$ . Estimates ranged from  $M = 0.14$  to  $0.22$ , with a coastwide average of  $M = 0.16$ , and regional estimates ranging from  $0.15$  in NY-NJ to  $0.23$  in SNE. The regional assessment used the NY-NJ average of  $0.15$  for LIS and for New Jersey-New York Bight. For more information on the analysis of the natural mortality rate, refer to the Benchmark Stock Assessment (ASMFC 2015).

### **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). In the 2015 Benchmark Stock Assessment, the Tautog TC investigated new stock unit definitions based on life history data, fishery and habitat characteristics, and available data sources. While a three-region approach (Table 1.1) in the Benchmark Stock Assessment is still applicable, there was interest in assessing and managing the LIS as a discrete area. This regional assessment analyzes two additional regions (LIS and NJ-NYB) to potentially comprise a four-region management scenario (Table 1.2).

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).

The TC has considered smaller unit stock definitions in the past, but was 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).

In the Benchmark Stock Assessment, the Tautog SAS addressed concerns that hampered regional management during previous assessments. New work included development of fishery dependent abundance indices in areas with no fishery independent data, and the use of a more robust statistical model that better handled uncertainty in the data. These innovations allowed the TC to investigate a regional structure that was not possible in the past.

To help determine appropriate stock units, the Tautog TC considered the following in the 2015 benchmark stock assessment.

- Fishery catch and effort information from NMFS Fishing Vessel Trip Reports (VTRs) was evaluated to identify state-specific fishery characteristics. Results indicate that:
  - MA to CT fisheries remain primarily within local sounds and bays
  - NY and NJ fisheries 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)
  - DE to VA fisheries remain south of Delaware Bay
- 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.
- 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. (MA DMF), Arendt et al. 2001, Cimino pers. comm. (VMRC)).
- Spawning occurs over a widely distributed geographic scope among local aggregations (White et al. 2003, LaPlante and Schultz 2007).

Based on these results, the Tautog TC 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 balance Tautog’s sedentary life history with available data and political boundaries. With these considerations in mind, the Tautog TC determined that the regions of MA-CT, NY-NJ, and DE-VA would be most appropriate. During deliberations, the TC expressed concern that this regionalization splits Long Island Sound across two regions, so a highly regarded alternate regional breakdown moves CT from the southern New England to NY-NJ region.

The Peer Review Panel for the 2015 Benchmark Stock Assessment determined that either the preferred or alternate models were appropriate for management use. However, members of the Board were concerned that splitting LIS between regions (preferred model) could result in inconsistent management measures in a shared body of water, and that combining CT and NJ into a single region (alternate model) could result in regionally inappropriate management measures because of differences in life history and fishery characteristics within the region. The Board tasked the TC with developing a LIS-specific assessment model that would address both of these concerns, allowing regionally consistent and appropriate management measures.

### **3. 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), moving out to deeper water as they grow. Juvenile Tautog 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 in localized areas 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, Tautog range is likely bounded to some degree by available habitat. This may be especially true in the region south of Long Island NY, where relatively little natural rock habitat exists compared to the structure rich northeastern states (Flint 1971).

### **4. FISHERIES DESCRIPTION**

#### **4.1. Recreational Fishery**

Tautog is predominantly a recreationally caught species, with anglers accounting for about 90% of landings coastwide and within the CT-NY-NJ region investigated in this assessment. Information on the coastwide recreational fishery is provided in the Benchmark Stock Assessment (ASMFC 2015). In the LIS region, recreational landings in the LIS region peaked in 1988 at nearly 700,000 fish and fell sharply to about 5% of its peak in 2000 and 2001 (Figure 4.1). Since then landings have approached peak harvest in some years but have mostly varied in the range of 100,000 to 400,000 fish. The 2010-2015 average landings are 200,000 (Table 4.1). In the NJ-NYB region,



recreational harvest exceeded one million fish per year in most years between 1988 and 1993, with a peak of 1.56 million fish in 1991 (Figure 4.1, Table 4.1). Harvest dropped quickly following the peak, however, reaching a time series low of just 24,000 fish in 1998 with an average annual harvest of 415,000 fish between 1994 and 2002. Recreational landings dropped again in 2003, falling below 200,000 fish before recovering slightly by 2006. Between 2006 and 2014, annual landings have shown high interannual variability without a trend, ranging from approximately 70,000 to 400,000 fish, with an average of 268,000 fish.

The majority (nearly 70%) of Tautog recreational harvest coastwide comes from the private/rental boat mode. The remaining 30% is split relatively evenly among the shore mode and for-hire (party/charter boat) mode. Within the CT-NY-NJ region, the proportion of recreational harvest from the private/rental sector has increased from around 50% in the early 1980s to over 80% in recent years (Figure 4.2).

As reported in the Benchmark Stock Assessment (ASMFC 2015), the coastwide 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. 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.

#### **4.2. Commercial Fisheries**

Since 1999, hand harvest has been the primary gear for commercial Tautog harvest, contributing approximately 43% of annual commercial harvest. The value (dollars per pound) for Tautog has increased fairly steadily since 1990 and has recently surpassed \$3.00 per pound. The coastwide history and seasonal pattern of commercial landings and the value (dollars per pound) for Tautog are further described in the Benchmark Stock Assessment.

In the LIS region, commercial landings peaked in 1987 at 159 metric tons, declined to 15 mt in 1999 and 2000 (Figure 4.3, Table 4.2), and since then have stabilized in the range of 40 mt. The 2010-2014 average landings in LIS are 37.6 mt. In the NJ-NYB region, commercial harvest during the late 1980s to mid-1990s fluctuated around 70 mt annually, but declined rapidly to 20 mt by 1999 (Figure 4.3, Table 4.2). Landings rebounded to 60 mt by 2007 and 2008, and since then fell to 40 mt and below.

Commercial landings of Tautog occur throughout the year, but the magnitude of the fishery varies by season. In LIS and NJ-NYB, approximately 35% of the annual harvest occurs during May-July, and again during October-December (Figure 4.4). Harvest is lowest during February and March, when less than 2% of the annual catch occurs.

Since 1984, trawl, pot/trap, and hand gears have accounted for over 75% of coastwide commercial harvest (Figure 4.5). Trawls were most prevalent in the mid-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.

### **4.3. Current Fisheries Status**

As reported in the Benchmark Stock Assessment (ASMFC 2015), regulatory efforts to constrain harvest have had limited effect. Tautog populations coastwide were found to be overfished, regardless of regional structure (Table 1.1). Overfishing status varied by region and regional structure, but overfishing was determined in 6 of the 9 different combinations. Trends in harvest are obscured by high interannual variability in catch and relatively high harvest measurement error. An unquantified illegal live fish market contributes to uncertainty in harvest estimates.

## **5. DATA SOURCES**

This regional assessment uses all of the regionally appropriate data sources used in the 2015 Benchmark Stock Assessment, as well as a few additional data sources that were not available during the benchmark (Table 5.1). Following guidelines set out in the Benchmark Stock Assessment, data sets were rejected in the stock assessment based on the criteria listed below:

- If sampling was intermittent or rare (*e.g.* had fewer than 10 consecutive years of data)
- Contained a small number of samples,
- Covered a small geographic area that was not representative of the regional stock unit, or
- Employed inconsistent methodologies.

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.

### **5.1. Fishery-Dependent Sampling**

#### **5.1.1. Recreational Fishery**

Tautog is predominantly a recreationally caught species, with anglers accounting for about 90% of landings coastwide and within the CT-NY-NJ region investigated in this assessment. Recreational data collection began in 1981 with NOAA's MRFSS program. Data collected from 2004 to 2011 using the MRFSS methodology was re-estimated using the MRIP methodology, which is consistent with the sampling design (see Benchmark Stock Assessment Section 5.1.2.6 for more details).

The MRFSS survey was a two-part survey. Telephone intercepts were made using random digit dialing of households within coastal counties producing effort (two-month sampling 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 marine registry program serves as a comprehensive national directory of recreational anglers 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 nighttime and accounting for zero-catch trips are 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 anglers. MRIP also leverages logbook reporting and tournament sampling to improve quality of data on the distinct for-hire fleet.

The LIS and NJ-NYB stock assessments use MRFSS data from 1984 to 2003, and MRIP data from 2004 to 2014. Starting in 1988, MRFSS identified LIS as a specific fishing area, allowing the development of NY LIS specific harvest estimates. Prior to 1988, NY LIS harvest was estimated using the mean harvest from Long Island Sound 1988-1993. The sum of NY LIS harvest estimates and Connecticut harvest estimates (from all trips landed) produced the total recreational harvest for the LIS region.

The difference between NY total harvest and NY LIS harvest produced the NY south shore harvest estimates. The sum of NY south shore harvest and the NJ estimates (from all trips landed) produced the total recreational harvest in the NJ-NYB region.

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 5.2. Average number of intercepts in LIS was 181 and in NJ-NYB was 296 while in the Benchmark Stock Assessment, all three regions averaged about 300 intercepts a year. Number of intercepted trips peaked in the early-1990s for both LIS and NJ-NYB.

The Benchmark Stock Assessment identifies recreational sampling design, and low sample size in particular, as a source of uncertainty for Tautog harvest estimates. Smaller regional designations (as in this regional assessment) would reduce sample size, which could lead to increased variability and uncertainty.

Another potential source of error is the separation of recreational harvest by area. Errors in the designation of harvest to the different regions would affect the recreational harvest estimates and CAA. The sensitivity of the model to these assumptions was tested with sensitivity runs.

#### **5.1.1.1. Recreational Discards/By-catch**

Recreational discards are estimated by the MRFSS/MRIP survey. Fish that are reported as released dead (Type B1) are included as part of the harvest numbers and weight, while fish released alive (Type B2) are reported only as numbers of fish. Estimates of the total number of Tautog discarded were obtained from queries of the MRFSS/MRIP data, with the NY data being divided based on area fished information. Consistent with the Benchmark Stock Assessment, recreational discard mortality was estimated at 2.5% of all fish released alive.

#### **5.1.1.2. Recreational Catch Rates (CPUE)**

As reported in the Benchmark Stock Assessment (ASMFC 2015), the Tautog TC developed fishery dependent indices of abundance from the recreational survey data. Using only trips positive for Tautog catch or harvest would likely underestimate the true effort, potentially biasing the abundance signal, so the TC investigated a range of methods to better capture trends in recreational Tautog fishing effort. The final method used “logical guilds”. MRFSS raw data were analyzed to determine which species were caught on trips that were positive for Tautog (Table 5.3). A logical guild consisted of Tautog plus the four next most common species. Guilds were developed separately for each state, and all trips that caught any one of the guild species were used as a measure of potential Tautog effort for that state. Data for all states in a region were combined, and a negative binomial GLM was developed to estimate CPUE. The final model used in the benchmark was also used for this regional assessment and was specified as

Total catch ~ Year + State + Wave + Mode, offset =ln(Angler\_Hours).

For this regional assessment, data for CT and NJ were unchanged from the benchmark (other than updating the data through 2014). The NY data were queried using the same logical guild as used in the benchmark, but trips were subset by region based on the area fished code. This allowed development of NJ-NYB- and LIS-specific indices of abundance from the recreational data that were used in the respective regional assessment model. Since the LIS fishing area designation was not collected until 1988, the index prior to 1988 may not be indicative of the region.

Results of the regional fishery-dependent indices based on MRFSS/MRIP data are shown in Table 5.4 and Figures 5.1 to 5.3 for the LIS region and 5.4 to 5.6 for the NJ-NYB region.

#### **5.1.1.3. Biological Sampling from the Recreational Fishery**

Recreational harvest length distributions for the LIS came from three different data sources: MRFSS/MRIP sampling, the Connecticut Volunteer Angler Survey (CTVAS), and the New York Headboat Survey (NYHBS). The NYHBS and MRFSS/MRIP also supplied harvest lengths for the NJ-NYB region, with additional samples collected by NJ DFW biological sampling program. Recreational discard lengths for both regions were obtained from MRIP Type 9 sampling, the

NYHBS sampling, and the American Littoral Society (ALSVAS) Volunteer Angler Program. Additional samples for the LIS region were obtained from the CTVAS.

The MRFSS/MRIP program routinely collects length and weight samples during intercept interviews. For 1988 to 2014, length samples from raw (unweighted) data were identified by state and region to use in the appropriate regional assessment. In 2004, MRIP implemented observers on headboats to collect lengths of fish released alive (Type 9 measurements). No data are available from the MRFSS/MRIP program on size distribution of released fish prior to 2004. MRIP PSEs from 2004-2014 were used as CVs for those years, and the mean PSE from 2004-2014 was used as the CV for 1984-2003 in the LIS region (Table 5.4). For the NJ-NYB region, PSE was calculated as a weighted average of NY and NJ PSE and the respective state proportion of total NJ-NYB harvest. PSEs calculated in this fashion during MRFSS years (1989-2003) were corrected for underestimation by increasing them 30% as in the benchmark assessment.

The Connecticut DEEP Marine Fisheries Division has conducted a Volunteer Angler Survey (CTVAS) since 1970. The survey supplements MRFSS/MRIP by providing additional length measurement data particularly concerning released fish. The survey's objective is to collect marine recreational fishing information concerning finfish species with special emphasis on striped bass. In 1997, the survey design was expanded to include length measurements and to collect information on all species. The CTVAS is designed to collect trip and catch information from marine recreational (hook and line) anglers who volunteer to record their fishing activities by logbook. The logbook format consists of recording fishing effort, target species, fishing mode (boat and shore), area fished (subdivisions of Long Island Sound and adjacent waters), catch information concerning finfish harvested and released. Instructions for volunteers were provided on the inside cover of a postage paid logbook to be returned to the Department. All individual participating angler data is kept confidential. The CTVAS lengths are reported in half-inch increments. As the half-inch measurements are underrepresented in the database, they were split 50/50 and assigned to the whole number above and below. Prior to conversion to centimeters, random a number from -0.50 to 0.49 was added to each measurement.

New York collects length and age samples for the recreational fishery predominantly from the for-hire sector in the NYHBS, and for the commercial fishery from samples obtained opportunistically from fish markets. Samples from the private recreational sector are sometimes obtained although rarely.

#### **5.1.1.4. Recreational Harvest Length Distribution**

For the LIS region, all Long Island Sound MRFSS and MRIP unscaled length measurements contributed to the development of the harvest length distribution. Tautog lengths coded as harvested from the NY headboat survey was included in this distribution. As the CTVAS is considered to not represent the whole fleet (dedicated group of conservation-minded anglers), only fish which are above the year-specific CT minimum size contributed to the harvest length distribution (Table 5.5).

For the NJ-NYB region, recreational harvest length frequency was evaluated separately for NJ and NY south shore. Unweighted MRFSS/MRIP from NJ were the sole source of information used to characterize recreational harvest length distributions in New Jersey, while the south shore harvest was characterized using combined region specific data from MRFSS/MRIP and the NYHBS sampling program (Table 5.6). The sum of the recreational harvest at length for NJ and NY south shore was used to estimate total regional harvest at length.

#### **5.1.1.5. Recreational discard length distribution**

Recreational discards are captured by the MRIP survey. Fish reported as released dead (Type B1) are included as part of the harvest weight, while fish released alive (Type B2) are reported only in numbers (not weight) by MRIP.

Numerous sources contributed to estimate the length frequency of discarded fish (Tables 5.5 and 5.6) in LIS and NJ-NYB. New York data from the ALSVAS (1982-present, discard estimated by state and year-specific regulations) and MRIP Type 9 sampling of fish released alive from headboats (2004-present) was parsed by region based on fishing area into LIS and NY south. Fishery dependent samples were also available from NYHBS sampling (1995-present) and the CTVAS volunteer angler survey (1997-present, discard estimated by state and year-specific regulations).

For LIS as there were no minimum length regulations in year 1984-1987, the discard length distribution from years 1988-1990 was used as a proxy. For the ALSVAS, all CT, NY and RI fish below the CT minimum size requirement from the years 1987-1990 were assigned to CT to fill in low sample size. These data sources provide the length frequency information used to develop the catch-at-age for released fish.

#### **5.1.2. Commercial Fishery**

Tautog commercial landings data from NMFS and state records exist for 1950 to present. The LIS and NJ-NYB assessments use data from the time series 1984-2014. Prior to 1988, the reliability of splitting the NY data (particularly recreational) into regions is uncertain. Commercial harvest estimates used in the Benchmark Stock Assessment were updated through 2014 for all three states, which resulted in minor changes to annual estimates due to standard data auditing procedures. In addition, NY commercial harvest data were updated from the benchmark based on dealer reports adjusted and prorated by Vessel Trip Report (VTR) data (S. Dumais, NYSDEC, pers. comm.). This resulted in substantial changes (increases up to 2x values used in benchmark) to harvest estimates for the years 2004-present. The VTR data were also used to split the NY harvest by region for the years 1988-2014 (LIS and south shore) based on reported statistical area (611 = LIS; 612, 613, 168, 149 = south shore). The location of the NY commercial catch prior to 1987 could not be determined based on reported data. To estimate the NY's LIS commercial harvest prior to those years, the mean from 1986-1989 (83 MT) was used.

Potential biases of commercial harvest estimates discussed in the Benchmark Stock Assessment (ASMFC 2015) include possible under reporting due to lack of state reporting programs and

Tautog not being a NMFS priority species, and the use of recreational length frequency distributions to characterize commercial length frequencies. Both of these concerns are still relevant for this regional assessment. Another source of error is the splitting of NY harvest by region using statistical areas because these areas do not exactly match regional boundaries. In addition, harvesters may fish in multiple areas on a given trip but not complete a separate VTR for each area as instructed. Similarly, all trips from CT were assumed to occur in the LIS region, although this may be inaccurate. Errors in the designation of harvest to the different regions would affect the commercial harvest estimates and CAA. The sensitivity of the model to these assumptions was tested with sensitivity runs.

#### **5.1.2.1. Commercial Discards/By-catch**

As discussed in the Benchmark Stock Assessment, commercial discards were not included in this assessment due to poor observer sample size, high uncertainty in the estimates of commercial discards, and the fact that commercial discards are a small component of total removals.

### **5.2. Fisheries-Independent Surveys and Biological Sampling Programs**

This assessment includes fisheries-independent surveys that encounter Tautog from the state marine fisheries agencies of Connecticut through New Jersey. 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.

#### **5.2.1. 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 5-46 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).

Sampling is divided into spring (April-June) and fall (Sept-Oct) periods, with 40 sites sampled monthly, 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 km<sup>2</sup> (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).

CT DEEP conducts biological sampling during the LISTS. At completion of the tow, the catch is placed onto a sorting table and sorted by species. Tautog, as well as other finfish and crustacean species, are counted and measured (cm).

The number of individuals measured from each tow varies by species, 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).

#### *LISTS abundance index*

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 important factors that affect catchability were not considered in the analysis.

An abundance index for Tautog was created using a negative binomial generalized linear model (glm) with a log link and asymptotic estimates of uncertainty. 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.



A negative binomial glm sub model of year, month, and stratum was selected because the model achieved convergence and had favorable diagnostics (Figures 5.7-5.9, Tables 5.8 and 5.9). One important note is that the continuous variables were not systematically collected until mid-way through the time series, so the final model was constructed using only the categorical variables collected over the entire time series. The index was variable over time, but nonetheless exhibited a marked decrease to low catches beginning in the late-1990s (Figure 5.10, Table 5.7). Model diagnostics indicated an adequate model, given the low and variable catch rate of Tautog in this survey, and underprediction of average annual catch per tow.

### **5.2.2. Millstone Entrainment Sampling**

Samples have been taken since 1976. Sampling frequency varies seasonally; over the period in which Tautog eggs and larvae are collected, samples are taken day and night three times (May) or twice (June through August) a week. A conical plankton net (1.0 x 3.6 m, 335 microns mesh size) collects samples at outflow sites at the Millstone Nuclear Power Plant. Readings from four flowmeters mounted in the mouth of the net account for variations in horizontal and vertical flow. Sample volume is typically about 200 m<sup>3</sup>. All ichthyoplankton collections are immediately fixed in 10% formalin.

Samples are split repeatedly in the laboratory using a NOAA Bourne splitter. Successive splits are sorted and counted until at least 50 larvae (and 50 eggs for samples processed for eggs) are found, or until one half of the sample volume was processed. Tautog eggs are enumerated in all samples collected from April through October. Tautog and Cunner have eggs of similar appearance and were distinguished on the basis of a weekly bimodal distribution of egg diameters (Williams 1967).

#### *Millstone abundance index*

Unlike the other survey data, variables representing factors that affect Tautog catchability were not incorporated into the analysis to standardize the Millstone survey data. The unstandardized survey data are used in sensitivity analysis only (see section 6).

The egg index indicates a high abundance in the mid-1980s, relatively low values through the 1990s, and values comparable to the 1980's from the 2000's to the present (Figure 5.11, Table 5.9). Larval abundance is generally quite low, variable, and has higher values since 2000.

### **5.2.3. NY Peconic Bay Trawl Survey**

NYDEC Peconic Bay trawl survey (NYPBTS) 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 10.7 m lobster-style workboat. At each location, a 4.9 m 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 were recorded at each station. Some gaps in the environmental data exist due to equipment malfunction.

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

NYS DEC collects its Tautog biological samples in the NYPBTS. 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.

#### *Other biological samples*

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.

#### *NYPBTS abundance index*

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.

Fish between 10 and 15 cm in the catch were used for a year-one index. 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. Data are missing for 2005, 2006 and 2008 because the survey was not conducted or incomplete.

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. A model with year, temperature, salinity, station and depth was selected it converged, yielded the lowest AIC value, and had favorable diagnostics (Figures 5.12-5.14, Tables 5.10 and 5.11). Year produced high variance inflation, but this parameter cannot be dropped. All other variables had favorable variance diagnostics. The index indicates a period of high abundance beginning in the 1980s, a decline to

the early 1990s, then a period of variable abundance to the present (Figure 5.15). Model diagnostics indicated an adequate model, given the low and variable catch rate of Tautog, and identified underprediction 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.

#### **5.2.4. NY Western Long Island Seine Survey**

The NY Western Long Island Seine Survey (NYWLISS) operated from 1984-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 for short periods of time. It is a fixed site survey. Environmental information (air and water temperature, salinity, dissolved oxygen, tide stage, wind speed and direction, and wave height) were recorded at each station. Bottom type, vegetation type, and percent cover was recorded qualitatively since 1988.

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.

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

##### *NYWLISS abundance index*

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.

The NYWLI Seine Survey is conducted in three separate embayments: Little Neck and Manhasset Bay in Long Island Sound, and Jamaica Bay on the south shore of Long Island. It was possible to develop region specific indices of abundance for this survey. LIS region data are missing for 1986, 1995 and 2010; data are missing for the NJ-NYB region for 1997. A negative binomial model was used for both regions. 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 LIS region, a model with year and temperature was selected because it converged, yielded the lowest AIC value, and had favorable diagnostics (Figures 5.16-5.18, Tables 5.12 and 5.13). The index was variable, but indicates periodic times of high abundance including the early 1990s and the early 2000s (Figure 5.19). 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.

The NJ-NYB portion (Jamaica Bay) of the seine survey encompasses 19 different stations. As not all stations were sampled continuously, only the eight stations sampled annually in at least 20 years were included in the model. Tows without environmental data were removed from the analysis (213 removed; 1,228 remaining). The full model including Year, Station, Water Temp, DO, and Salinity had a slightly higher AIC (+2) than reduced models and a relatively high collinearity factor (4.5). Dropping salinity resolved the collinearity, but DO was not significant. The model with the lowest AIC value includes Station and Water Temp, and has favorable diagnostics (Figures 5.20 to 5.22, Tables 5.14 and 5.15). The index identifies three periods of recruitment separated by 3-5 years of near zero recruitment (Figure 5.23). The three periods of recruitment show successively higher peaks, with a time series high of 2.7 fish per tow in 2012, and an average catch of 1.5 fish for the period 2012-2014.

#### **5.2.5. NJ Ocean Trawl Survey**

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 five areas north to south, that are further divided into three 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 per year. The sampling gear is a two-seam trawl with a 25 m head rope and 30.5 m footrope. The cod-end has a 6.4 mm 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 kilogram 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 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 were measured with a thermistor. Starting in January, 2011, water chemistry data are collected via a YSI 6820 multi-parameter water quality SONDE from the bottom, mid-point and surface of the water column. Parameters recorded include depth, temperature, dissolved oxygen and specific conductance. Water chemistry data are primarily collected prior to trawling (New Jersey DEP, 2013).

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 ample separation between the vessel and the net (New Jersey DEP, 2013).

#### *Other biological samples*

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 began 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 1993-2003 supplied 20.8% of the samples. Of the rest, 110 fish came from New Jersey's ocean trawl survey, 68 fish from recreational catches confiscated by New Jersey law enforcement and one sample was received from a recreational diver. The majority of the fish were caught using hook and line (95.2%), and some with pots/traps (2.7%), and otter trawls (2.1%). 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 the 4,921 fish 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).

#### **5.2.5.1. NJ Ocean Trawl Survey abundance index**

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 changes through the time series, mainly vessel changes, but it is hoped that the standardization procedure employed accounts for these modifications.

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 full model included year (categorical), month (categorical), station (categorical), depth (continuous), bottom temperature (continuous), and bottom salinity (continuous). A reduced model including year, bottom temperature, depth, and bottom salinity converged, yielded the lowest AIC value, and had favorable diagnostics (Figures 5.24 – 5.26, Tables 5.16 and 5.17). The index was variable, but indicates a period of high abundance at the beginning of the time series, declining through the late 1990s, with a recovery to moderate abundance between 2000-2010. CPUE dropped by more than 50% in 2011-2012, but recovered to previous levels around 0.5 fish per tow in recent years (Figure 5.27). 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.

### **5.3. Development of Age-Length Keys**

The sample size and sources for age-length keys (ALK) by region are shown in Table 5.18.

#### **5.3.1. LIS**

Data sources used to create the Long Island Sound assessment ALKs include LISTS, Rhode Island Trawl Survey (RI) and New York Port Sampling (NY-N). Only fish that were collected from the North Shore of Long Island were included from New York. Rhode Island ages which were collected outside of Long Island Sound were included to ensure the full range of sizes were covered by the key. Additionally, in instances where sizes were still missing in a given year, ages were determined using a pooled key across all years. The length range of the estimated catch is 8 to 83 cm but the length range of the ALK is 15 to 60 cm. Lengths below 16 cm and above 60 cm were accordingly binned into single groups.

#### **5.3.2. NJ-NYB**

Previous assessments created ALKs 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 NY-NJ region could only be created for 1995 forward. This still required pooling across regional boundaries to ensure the full range of sizes were covered by each regional key. As a result, the NY-NJ key includes some data from Long Island Sound and Delaware. The distribution of the NJ-NYB harvest for the years 1989-1994 was assumed to follow the same distribution as the age distribution of the NJ Ocean Trawl survey. Sensitivity of the model to this assumption was evaluated through a sensitivity run of the population model.

## **6. AGE STRUCTURED ASSESSMENT PROGRAM (ASAP) MODEL, METHODS, AND RESULTS**

### **6.1. 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/>

### **6.2. 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 A1: ASAP Technical Documentation* for more detailed descriptions of model structure and code.

### **6.3. Reference Point Model Description**

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 A2: AGEPRO User Guide* for a more detailed description of model structure.

### **6.4. Configuration**

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

#### **6.4.1. Spatial and Temporal Coverage**

The ASAP model was run separately for LIS and NJ-NYB regions considered in this regional assessment. Base models included years 1984 to 2014 for the LIS region and 1989-2014 for the NJ-NYB region.

#### **6.4.2. Selection and Treatment of Indices**

Section 5 provides a detailed description of how indices were selected and standardized.

##### **6.4.2.1. LIS**

The model was fit to both the total standardized index (catch per tow or catch per trip) and index-at-age data, for the LISTS and MRIP CPUE indices. The New York Peconic Bay survey was used as a year one index. The WLISSS and Millstone Entrainment Survey data were treated as a young-of-year index and was lagged forward one year (e.g., the 1985 age-1 predicted index value was fit to the observed 1984 YOY index value).

##### **6.4.2.2. NJ-NYB**

The NJ-NYB regional assessment included the NJ ocean trawl index, the Jamaica Bay portion of the Western Long Island Seine Survey, and the NJ-NYB specific MRFSS recreational CPUE. The WLI seine index was treated as an age-1 index, while the NJ trawl and MRFSS indices were treated as adult indices (ages 1-12+), with age distribution estimated using survey specific length frequency data and the NYNJ ALKs.

### **6.4.3. Parameterization**

#### **6.4.3.1. LIS**

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. Four selectivity blocks were used: 1984-1986, 1987-1994, 1995-2011, and 2012-2014. Breaks were chosen based on implementation of new regulations in Connecticut as New York regulations were implemented in a more step-wise fashion.

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.

#### **6.4.3.2. NJ-NYB**

The NJ-NYB model included year and age specific data from 1989 to 2014, assuming a plus group of ages 12+. Commercial and recreational harvest and discards were combined into a single fleet, with four single logistic selectivity blocks established based on major regulatory and data collection changes that would be expected to alter the size distribution of the catch (pre-FMP = 1995-1997, FMP implementation 1998-2003, collection of Type 9 data 2004-2012, Addendum 6 regulations 2012-2014). Selectivity patterns for the adult indices were also modeled as logistic functions, but were considered to be constant over time.

### **6.4.4. 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. For both regions, 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 adjusted to a target mean CV of 0.3 for model convergence in the LIS region, and to bring RMSEs of the indices close to 1.0 for the NJ-NYB region.

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.



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.

## **6.5. 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. For each region, 200,000 MCMC runs were conducted for the base model, of which 1,000 were kept. Results of the MCMC analyses are presented as the median plus the 5<sup>th</sup> and 95<sup>th</sup> percentiles.

## **6.6. Sensitivity Analyses**

### **6.6.1. Sensitivity to Input Data**

#### **6.6.1.1. LIS**

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
- Different starting values for estimated parameters
- Starting in the year 1988 to avoid estimating New York harvest and discards
- Using a 15-year old plus group
- Excluding all of the estimated New York recreational (1984-1987) and commercial (1984-1985) harvest from (discards were not excluded from this as they account for less than 0.1% of F)
- Including all of New York harvest, north and south of Long Island, recreational (1984-1987) and commercial harvest from 1984:1987-1985

#### **6.6.1.2. NJ-NYB**

Sensitivity runs conducted for the NJ-NYB region to evaluate input data include

- Removal of individual indices to evaluate the influence of each index on model output
- Starting the model in 1995 when region specific ALKs were available
- "Correcting" suspected severe underestimation of recreational harvest in NJ in 2005

## **6.6.2. Sensitivity to Model Configuration**

### **6.6.2.1. LIS**

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 3 selectivity blocks for the catch instead of 4
- Fixing steepness at 1 (i.e., no relationship to SSB and fitting deviations to an average recruitment value)

### **6.6.2.2. NJ-NYB**

One sensitivity analysis was conducted for the NJ-NYB region with respect to model configuration. For this run, the fourth (2012-2014) selectivity block was dropped to address a concern that three years may not be sufficient to estimate selectivity accurately.

## **6.7. Retrospective Analyses**

### **6.7.1. LIS**

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 2014. For the LIS regional model, the terminal years ranged from 2011-2014 and 2007-2014. As a selectivity block ended in 2010, it is important to note that this second retrospective analysis extends into a different selectivity block the catch.

### **6.7.2. NJ-NYB**

A retrospective analysis was conducted in the NJ-NYB region using annual peels from 2014 to 2007. It should be recognized that the last selectivity block for the base model covers years 2012-2014, so the retrospective analysis crosses into the third selectivity block, which makes interpretation of the results difficult.

## **6.8. ASAP Results for LIS**

### **6.8.1. Goodness of Fit**

The total likelihood and index RMSE values are shown in Table 6.1. Total catch residuals were underestimated in 20 out of 30 years in the time series (Figure 6.1). The index residuals showed some patterning (Figure 6.2). LISTS residuals were under estimated in 12 of 30 years, including all of the last three years. NY Trawl was underestimated for the last seven years the survey was conducted and NY Beach Seine survey was overestimated in each of the last 6 years the survey was conducted. MRIP CPUE is underestimated in 5 of the last 6 years and was overestimated for

many of the years in the middle of the time series. The overall fit to the catch-at-age was good (Figure 6.3). Residuals for the index-at-age were good fits to the observed data (Figure 6.4).

## **6.8.2. Parameter Estimates**

### **6.8.2.1. Selectivities, Catchability, and the Stock-Recruitment Relationship**

Recreational minimum sizes were first implemented in CT in 1987 and in NY in 1991 and changes in the CT regulations occurred in 1995, and 2012. NY regulations proceeded in a more step-wise fashion, with minimum size increases in 1994, 1995, 1998 and 2012. Selectivity pattern changes are seen in the model after 1988, 1994, and 2012. With each change in minimum harvest size in CT the selectivity curve shifted to the right (Figure 6.5). Estimates of index catchabilities are shown in Table 6.2. ASAP estimated the steepness of the stock-recruit relationship at  $h=0.5294$  (Figure 6.6).

### **6.8.2.2. Fishing Mortality**

In LIS  $F$  was relatively stable for the years 1984 to 2006, with only one spike in 1993, 1994 and 1995. Since 2006  $F$  has mostly risen and has been over 0.3 in seven of the last eight years. (Table 6.3, Figure 6.7). The median full  $F$  and the 5<sup>th</sup> and 95<sup>th</sup> percentiles from MCMC run are shown in Figure 6.8, and likelihood profiles for terminal year  $F$  are shown in Figure 6.9.

### **6.8.2.3. 6.8.2.3 Abundance and Spawning Stock Biomass Estimates**

Total abundance and spawning stock biomass declined rapidly from 1984 until 1995. Despite a period of slightly increased abundance in the early to mid 2000s, the overall trend has been a slower but consistent decline since 1995 (Table 6.4, Figure 6.10.a). Total abundance decline from a high of 11.5 million fish to the current estimate of 4.1 million fish in 2014. Spawning stock biomass decreased from over 11,700 MT at the beginning of the time-series to the current estimate of 1,900 MT in 2014.

The median SSB and the 5<sup>th</sup> and 95<sup>th</sup> percentiles from MCMC run in shown in Figure 6.10.b, and likelihood profiles for terminal year SSB is shown in Figure 6.11.

Recruitment was generally highest in the early years of the time-series, except for 2013 which had the highest recruitment event on record. Three of the past four years have been the lowest recruitment events on record (Figure 6.10.c).

### **6.8.2.4. Sensitivity Analyses**

Changes to the input data and model assumptions predominantly changed the initial and final estimates of SSB, but overall the trajectories remained the same. The 15-year-old plus group resulted in the highest initial SSB, while using all available indices (including the Millstone data) resulted in the lowest initial SSB. The 15-year-old plus group also resulted in the highest terminal SSB and dropping the MRIP CPUE resulted in the lowest terminal SSB (Table 6.5, Figure 6.12).

Estimates of overfishing status were relatively consistent, with all runs showing overfishing in 1993, 1994, 2007, 2008, 2009, 2010, 2012, 2013 and 2014. Additionally, in 1995 and 2011 eight of nine sensitivity runs show overfishing.

### **6.8.3. 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 2014. As the most recent sensitivity block began in 2011, two retrospective analyses were performed, one with the terminal years ranging from 2011-2014 and one with terminal years ranging from 2007-2014. It is important to note that this second retrospective analysis extends into a different selectivity block.

In the retrospective analysis starting in 2012, the LIS region showed a slight retrospective pattern of overestimating F (Mohn's rho = 0.11, Figure 6.13 a) and underestimating SSB (Mohn's rho = -0.11, Figure 6.14 a). Recruitment tended to be more variable, and was also underestimated in the terminal year (Mohn's rho = -0.18, Figure 6.15 a). For the retrospective analysis ending in 2007, the LIS region showed a slight retrospective pattern of underestimating F (Mohn's rho = -0.01, Figure 6.13 b), SSB (Mohn's rho = -0.04, Figure 6.14 b) and also had variable recruitment which was underestimated in the terminal year (Mohn's rho = -0.14, Figure 6.15 b).

Retrospective analysis was also conducted for the 15 year plus group sensitivity analysis 2012-2014, F was slightly overestimated (Mohn's rho = 0.03, Figure 6.13 c) and), while SSB (Mohn's rho = -0.05, Figure 6.14 c) was slightly underestimated and recruitment in the terminal year (Mohn's rho = -0.31, Figure 6.15 c) was underestimated. For the retrospective analysis ending in 2007, F (Mohn's rho = -0.01, Figure 6.13 d) was near zero and SSB (Mohn's rho = 0.03, Figure 6.14 d) was slightly overestimated. Recruitment in the terminal year was underestimated (Mohn's rho = -0.35, Figure 6.15 d).

### **6.8.4. Reference Point Model**

#### **6.8.4.1. Parameter Estimates**

Estimates of F 30% SPR, F 40% SPR, F MSY, and SSB MSY are shown in Table 6.5. The base model estimated a steepness ( $h=0.529$ ) indicating a strong fit to the S-R model. Steepness for the 15 year plus group model was higher ( $h = 0.662$ ).

F MSY was estimated as 0.164 for the base model and at 0.237 for the 15-year plus group model. The associated SSB MSY values were 4,580 MT and 5,050 MT for these models, respectively.

F 30% SPR was estimated as 0.46 for the 12-year plus group and 0.43 for the 15-year plus group.

F 40% SPR was estimated as 0.29 for the 12-year plus group and 0.25 for the 15-year plus group.

#### **6.8.4.2. Sensitivity Analyses**

In general, estimates of  $F_{30\%SPR}$  and  $F_{40\%SPR}$  were similar across sensitivity runs, while estimates of SSB MSY and MSY-based reference points were variable (Table 6.5).

### **6.9. ASAP Results for NJ-NYB**

#### **6.9.1. Goodness of Fit**

Diagnostics of the base model fit are shown in Table 6.1. The largest components of the overall likelihood are catch and index age comps. Fits to total catch are relatively tight, with the largest discrepancy being a period of underestimation from 1999-2002 (Figure 6.16). Annual catch at age fits show no consistent pattern in over or underestimation at age (Figure 6.17). Fits to survey indices show some patterning in residuals, particularly for the NY seine and MRFSS, but less so for the NJ trawl (Figure 6.18). Overall fit to NJ trawl proportion at age is strong, but the MRFSS index indicates slight overestimation of age 3 and underestimation of age 5.

#### **6.9.2. Parameter Estimates**

##### **6.9.2.1. Selectivities, Catchability, and the Stock-Recruitment Relationship**

The fishery selectivity shifted in the expected direction between the first and second selectivity blocks, but the model estimated an increase in selectivity at age for the third time block despite increased regulation. The reason for this is unknown but may be due to changes in data availability or sampling design. The increased size limit under Addendum 6 in 2012 shifted to the right as expected, with 50% selectivity between ages 5 and 6 (Figure 6.19). Both aged survey indices indicate 50% selectivity by age 3 (Figure 6.19); however, the NJ trawl survey shows slightly higher selectivity at ages 1 and 2, and lower selectivity ages 4 to 6 relative to the MRFSS CPUE.

Estimated catchability for the three surveys ranges from  $1.5e-7$  (NJ trawl) to  $5.0e-7$  (NY seine) (Table 6.2).

Estimated steepness for nearly all model runs was  $h = 0.9999$ , indicating the model was not able to reliably estimate steepness of the spawner-recruit curve.

##### **6.9.2.2. Fishing Mortality**

Consistent with previous assessments, including the 2015 benchmark, a three year moving average  $F$  was used to smooth the time series of  $F$ . Fully exploited fishing mortality ( $F$ -mult) shows high interannual variability, but suggests a cyclical pattern in exploitation over time, with ranges generally between (Table 6.3, Figure 6.20). The declines in  $F$  are generally consistent with changes in regulations which often included increases in minimum size.  $F$  would then increase over the next few years as the fish grew into the new size limit. Terminal year fishing mortality is estimated as  $F_{2014} = 0.658$  or  $F_{3\text{ year}} = 0.50$ . MCMC estimate and confidence limits are relatively wide, with 90% credible intervals ranging from 0.28 to 1.33 (Figure 6.20).

### 6.9.2.3. Abundance and Spawning Stock Biomass Estimates

SSB shows a general decline from approximately 6,000 MT in 1989 to around 1,900 MT by 1996 (Table 6.4, Figure 6.21). Regulations in 1997 and 2003 allowed slight increases in SSB to in subsequent years, but these gains were short lived as F rebounded. From 2006 to 2011, SSB declined from around 2,050 MT to 1,050 MT, but has since recovered to around 1,950 MT in 2014. MCMC estimates of 90% credible intervals on SSB range from 1,490 to 2,860 MT (Figure 6.21).

During the early 1990s, recruitment (age 1) follows a similar pattern as SSB (Table 6.4, Figure 6.22), declining from 1.6 million in 1989 to less than 1 million by 1993. From 1993 to 2010, recruitment varied without trend between approximately 650,000 and 950,000 fish annually. Estimates of recruitment in the last four years of the model were all over one million fish, with an apparent strong year class in 2013, estimated at 2.75 million.

### 6.9.3. Sensitivity Analyses

The sensitivity runs investigating changes to the input data had very little influence on the trends, scale, and terminal year estimates of the model (Table 6.5, Figure 6.23). SSB estimates from all sensitivity runs were within one standard deviation of the base model run, with terminal year estimates ranging from 1,837 to 2,011 MT. Terminal year F estimates ranged from  $F_{2014} = 0.59$  to 0.71 and  $F_{3yr} = 0.47$  to 0.54 relative to the base model estimates of 0.66 and 0.50, respectively.

Recruitment estimates from the different sensitivity runs investigating input data showed only minor variations to the base run for most years in the time series. The largest differences occurred in 2011 for the models that dropped the NJ trawl and MRFSS CPUE indices. Both of these runs underestimated recruitment relative to the base run by approximately 20% (Figure 6.23).

The sensitivity run investigating model configuration (three selectivity blocks) resulted in nearly identical results as the base model for SSB and recruitment, but had a profound effect on fishing mortality rates in recent years (Table 6.5, Figure 6.23). From 2011-2014, the alternate configuration underestimated F relative to the base model, with a terminal year estimate of  $F_{2014} = 0.27$  and a three year average  $F = 0.33$ , approximately 47% and 32% lower than base run estimate, respectively.

### 6.9.4. Retrospective Analyses

The NJ-NYB region retrospective analysis spanned from 2014 to 2007, which extended into the previous selectivity block, making interpretation of the results difficult. With that in mind, SSB is overestimated relative to the base model in all but the penultimate year of the model (Figure 6.24). For the 2013 peel, SSB is underestimated by nearly 25% with respect to the base model. The retrospective pattern in fishing mortality switches at the change in selectivity (Figure 6.24), from overestimated F in recent years to underestimating F during the third selectivity block. Some of the earliest estimates are underestimated by 100% or more. The pattern in recruitment is more

variable, but terminal year estimates during the fourth selectivity period fall below the final base run estimates (Figure 6.24).

## 6.9.5. Reference Point Model

### 6.9.5.1. Parameter Estimates

Estimates of  $F_{30\%SPR}$ ,  $F_{40\%SPR}$ ,  $F_{MSY}$ , and  $SSB_{MSY}$  are shown in Table 6.5. Estimates of  $F_{MSY}$  are not considered reliable due to the model's inability to estimate stock-recruit steepness. 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).

$F_{30\%SPR}$  was estimated as 0.364, with an associated equilibrium SSB estimate of 2,457 MT (90% CI = 1,973 to 3,375 MT).  $F_{40\%SPR}$  was estimated as 0.216, with an associated equilibrium SSB estimate 3,305 MT (90% CI = 2,704 to 4,339 MT).

### 6.9.5.2. Sensitivity Analyses

SPR based fishing mortality benchmarks were similar for all sensitivity runs investigating input data. The sensitivity run investigating model structure estimated lower benchmarks, with  $F_{30\%} = 0.25$  and  $F_{40\%} = 0.16$ . This is to be expected given the higher selectivity at age under the three selectivity block configuration.

## 7. 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.  $B_{targ}$  and  $B_{lim}$  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. These are the current definitions for management use.

In the 2015 Benchmark Stock Assessment's 'highly regarded alternative' three-region approach, the TC proposed an SSB target of  $SSB_{MSY}$  and an SSB threshold of 75%  $SSB_{MSY}$  for MA-RI. 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 CT-NY-NJ and DMV 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.

The Board approved the Benchmark Stock Assessment for management use, but the proposed definitions in the Benchmark Stock Assessment have not been implemented. The Board is awaiting the results of the regional assessment to determine the regional boundaries which will then be included in Draft Amendment 1 and released for public comment.

	SSB target		SSB threshold		F target		F threshold	
	Definition	Value	Definition	Value	Definition	Value	Definition	Value
<b>MA-RI</b>	SSB <sub>MSY</sub>	2,633 MT	75%SSB <sub>MSY</sub>	1,975 MT	F <sub>MSY</sub>	0.16	F associated with 75%SSB <sub>MSY</sub>	0.19
<b>CT-NY-NJ</b>	SSB associated with F <sub>40%SPR</sub>	5,160 MT	SSB associated with F <sub>30%SPR</sub>	3,920 MT	F <sub>40%SPR</sub>	0.17	F <sub>30%SPR</sub>	0.24
<b>DMV</b>	SSB associated with F <sub>40%SPR</sub>	2,090 MT	SSB associated with F <sub>30%SPR</sub>	1,580 MT	F <sub>40%SPR</sub>	0.16	F <sub>30%SPR</sub>	0.24

## 7.2. New Proposed Definitions

Similar to the benchmark, there was inconsistency in ASAP’s ability to estimate steepness of the stock-recruit relationship, resulting in different proposed reference points by region. Estimated steepness of the LIS regional model was deemed credible by the TC, and the TC therefore recommends MSY-based benchmarks for this region. Consistent with the benchmark assessment, threshold values are recommended at 75% SSB<sub>MSY</sub> and the equilibrium fishing mortality rate associated with this biomass. Because there was considerable discussion by the TC regarding the utility of the different reference point models, SPR-based reference points are also provided for the LIS region.

In the NJ-NYB regional model, data were not sufficient to allow credible estimation of the stock-recruit relationship, so the TC considers the MSY-based reference points unreliable. Consistent with the benchmark, the TC is recommending a fishing mortality target of F<sub>40%SPR</sub> and a threshold of F<sub>30%SPR</sub>. Recommended SSB reference points are the long term equilibrium biomass associated with the respective fishing mortality rates.

	SSB target		SSB threshold		F target		F threshold	
	Definition	Value	Definition	Value	Definition	Value	Definition	Value
<b>LIS (MSY)</b>	SSB <sub>MSY</sub>	4,576 MT	75% SSB <sub>MSY</sub>	3,432 MT	F <sub>MSY</sub>	0.16	F <sub>75%SSBMSY</sub>	0.32
<b>LIS (SPR)</b>	SSB associated with F <sub>40%SPR</sub>	3,757 MT	SSB associated with F <sub>30%SPR</sub>	2,820 MT	F <sub>40%SPR</sub>	0.27	F <sub>30%SPR</sub>	0.47
<b>NJ-NYB</b>	SSB associated with F <sub>40%SPR</sub>	3,305 MT	SSB associated with F <sub>30%SPR</sub>	2,547 MT	F <sub>40%SPR</sub>	0.22	F <sub>30%SPR</sub>	0.36



### 7.3. Stock Status Determination

#### 7.3.1. Overfishing Status

##### 7.3.1.1. LIS

The ASAP model runs indicated overfishing was occurring in Long Island Sound in 2014, by using both MSY and SPR methods. For the MSY estimates, both the point estimate of  $F_{2014} = 0.73$  and the 3-year average value of  $F_{3yr} = 0.53$  were above the threshold value of 0.32 (Table 7.1, Figure 7.1). For SPR estimates, both the point estimate of  $F_{2014} = 0.73$  and the 3-year average value of  $F_{3yr} = 0.53$  were above both  $F_{Target} = 0.26$  and  $F_{threshold} = 0.46$  (Table 7.1, Figure 7.2).

##### 7.3.1.2. NJ-NYB

The ASAP model runs indicated overfishing was occurring in New Jersey and southern New York in 2014. Both the point estimate of  $F_{2014} = 0.66$  and the 3-year average value of  $F_{3yr} = 0.50$  were above both  $F_{Target} = 0.22$  and  $F_{threshold} = 0.36$  (Table 7.1, Figure 7.3). Approximately 20% of the MCMC iterations were below the threshold F value in 2014.

#### 7.3.2. Overfished Status

##### 7.3.2.1. LIS

The ASAP model runs indicated the Tautog stock was overfished in Long Island Sound by using both MSY and SPR methods.  $SSB_{MSY}$  (target, 4,576) and  $SSB_{75\%MSY}$  (threshold, 3,432 MT) are above  $SSB_{2014}$  (2,083 MT, Table 7.1, Figure 7.1).  $SSB$  in 2014 was 1,956 MT, below both the  $SSB_{target} = 3,757$  MT and the  $SSB_{threshold} = 2,2820$  MT (Table 7.1, Figure 7.2).

##### 7.3.2.2. NJ-NYB

The ASAP model run indicates that the NJ-NYB Tautog population is overfished.  $SSB_{2014}$  was estimated at 1,972 MT, approximately 20% below the  $SSB_{30\%SPR}$  threshold and 40% below the  $SSB_{40\%SPR}$  target. Estimated terminal year biomass is identical to the MCMC 5<sup>th</sup> percentile estimate (Table 7.1, Figure 7.3).

## 8. 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 Stock Assessment are underlined.

## **8.1. Fishery-Dependent Priorities**

### **8.1.1. 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**

### **8.2.1. 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**

### **8.3.1. 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.

### 8.3.2. 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**

##### **8.4.1. Moderate**

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

##### **8.4.2. 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](http://www.asmfc.org/uploads/file/2012_Tautog_Ageing_Workshop_Report.pdf)*

#### **8.6. Future Stock Assessments**

The TC recommends conducting a Benchmark Stock Assessment in 2021. Update assessments will be conducted for all regions during the fall of 2016 with data through 2015. At that time, the TC will discuss timing of future updates.

## 9. LITERATURE CITED

- Arendt, M., J. Lucy, and T. Munroe. 2001. Seasonal occurrence and site-utilization patterns of adult Tautog, *Tautoga onitis* (Labridae), at manmade and natural structures in Chesapeake Bay. *Fish Bull.* 99:519-527.
- Atlantic States Marine Fisheries Commission. 1996. Fisheries Management Plan for Tautog. ASMFC, Washington, DC.
- Atlantic States Marine Fisheries Commission. 2002. Addendum III to the Fisheries Management Plan for Tautog. ASMFC, Washington, DC.
- Atlantic States Marine Fisheries Commission. 2006. Tautog stock assessment report for peer review. Report No. 06-02. Arlington, VA.
- Atlantic States Marine Fisheries Commission. 2011. Addendum VI to the Fisheries Management Plan for Tautog. ASMFC, Arlington, VA.
- Atlantic States Marine Fisheries Commission. 2012. Proceedings of the Tautog Ageing Workshop. ASMFC, Arlington, VA. Access: [http://www.asmfc.org/uploads/file/2012\\_Tautog\\_Ageing\\_Workshop\\_Report.pdf](http://www.asmfc.org/uploads/file/2012_Tautog_Ageing_Workshop_Report.pdf)
- Atlantic States Marine Fisheries Commission. 2015. Tautog benchmark stock assessment. Arlington, VA.
- Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Service, Fishery Bulletin 74: 223-230 p.
- Briggs, P.T. 1969. The Sport Fisheries for Tautog in the Inshore Waters of Eastern Long Island. *NY Fish & Game J.* Vol. 16(2):238-254.
- Briggs, P.T. 1975. An Evaluation of Artificial Reefs in New York's Marine Waters. *NY Fish & Game J.* Vol. 22(1):51-56.
- Briggs, P.T. 1977. Status of Tautog Populations at Artificial Reefs in New York Waters and Effect of Fishing. *NY Fish & Game J.* Vol. 24(2):154-167.
- Briggs, P.T. and J.S. O'Connor. 1971. Comparison of Shore-Zone Fishes Over Naturally Vegetated and Sand-Filled Bottoms in Great South Bay. *NY Fish & Game J.* Vol. 18(1):15-41.
- Chen, Yi, D. A. Jackson, and H. H. Harvey. 1992. "A comparison of von Bertalanffy and polynomial functions in modelling fish growth data." *Canadian Journal of Fisheries and Aquatic Sciences* 49: 1228-1235.

- Chenoweth, S. 1963. Spawning and fecundity of the Tautog, *Tautoga onitis*. M.S. thesis. University of Rhode Island. North Kingston, RI, 60 p.
- Cooper, R.A. 1966. Migration and Population Estimation of the Tautog *Tautoga onitis* (Linnaeus), from Rhode Island. *Trans. Am. Fish. Soc.* 95(3):239-247.
- Cooper, R.A. 1967. Age and growth of the Tautog, *Tautog onitis* (Linnaeus), from Rhode Island. *Transactions of the American Fisheries Society* 96:134-142.
- Dixon, M.S. 1994. Habitat Selection in Juvenile Tautog, *Tautoga onitis* and Juvenile Cunner, *Tautoglabrus adspersus*. MS. Thesis. UCONN. 77 pp.
- Dorf, B.A. and J.C. Powell. 1997. Distribution, Abundance and Habitat Characteristics of Juvenile Tautog (*Tautoga onitis*, Family Labridae) in Narragansett Bay, Rhode Island, 1988-1992. *Estuaries.* 20(3):589-600.
- Ecklund, A.M. and T.E. Targett. 1990. Reproductive seasonality of fishes inhabiting hard bottom areas in the Middle Atlantic Bight. *Copeia* 1990:1180-1184.
- Flint, R.F. 1971. *Glacial and Quarternary Geology*. John Wiley and Sons, Inc.
- Haddon, Malcolm. 2010. *Modelling and quantitative methods in fisheries*. CRC press.
- Hostetter, E.B. and T.A. Munroe 1993. Age, growth, and reproduction of Tautog *Tautoga onitis* (Labridae: Perciformes) from coastal waters of Virginia. *Fishery Bulletin* 91:45-64.
- LaPlante, L.H. and Eric Schultz. 2007. Annual Fecundity of Tautog in Long Island Sound: Size Effects and Long-Term Changes in a Harvested Population. *American Fisheries Society* 136: 1520-1533.
- Olla, B.L. A. J. Bejda, and A.D. Martin. 1974. Daily activity, movements, feeding and seasonal occurrence of the Tautog, *Tautoga onitis*. *Fishery Bulletin* 72:27-35.
- Olla, B.L., A.J. Bejde, and A.D. Martin. 1975. Activity, Movements and Feeding Behavior of the Cunner, *Tautoglabrus adspersus*, and Comparison of Food Habits with Young Tautog, *Tautoga onitis*, off Long Island, New York. *Fishery Bulletin (U.S.)* Vol. 73(4):895-900.
- Olla, B.L., A.J. Bejde, and A.D. Martin. 1979. Seasonal Dispersal and Habitat Selection of the Cunner, *Tautoglabrus adspersus* and Young Tautog, *Tautoga onitis*, in Fire Island Inlet, Long Island, New York. *Fishery Bulletin (U.S)* Vol. 77(1):255-261.
- Olla, B.L. and C. Samet. 1977. Courtship and spawning behavior of the Tautog, *Tautoga onitis* (Pisces: Labridae), under laboratory conditions. *Fishery Bulletin* 75:585-599.

- Olla, B.L.; Samet, C.; Studholme, A.L. 1981. Correlates between number of mates, shelter availability and reproductive behavior in the Tautog, *Tautoga onitis*. Marine Biology (Berl.) 62:239-248.
- Orbacz, E.A., and P. Gaffney. 2000, Genetic structure of Tautog (*Tautoga onitis*) populations assayed by RFLP and DGGE analysis of mitochondrial and nuclear genes. Fisheries Bulletin 98:336-344
- Orth, R.J. and K.L. Heck Jr. 1980. Structural Components of Eelgrass (*Zostera marina*) Meadows in the Lower Chesapeake Bay-Fishes. Estuaries 3(4):278-288.
- Sogard, S.M., K.W. Able and M.P. Fahay. 1992. Early Life History of the Tautog *Tautoga onitis* in the Mid-Atlantic Bight. Fishery Bulletin, U.S. 90:529-539.
- Steimle, F. W. and P. A. Shaheen. 1999. Tautog (*Tautoga onitis*) life history and habitat requirements. NOAA Technical Memorandum NMFS-NE-118.
- Stolgitis, J.A. 1970. Some aspects of the biology of Tautog, *Tautoga onitis* (Linnaeus), from the Weweantic River Estuary, Massachusetts, 1966. M.S. Thesis, University of Massachusetts, Amherst.
- White, G.G. 1996. Reproductive Biology of Tautog, *Tautoga onitis*, in the Lower Chesapeake Bay and Coastal Waters of Virginia. M.S. Thesis. The College of William and Mary.
- White, G.G., T.A. Munroe, and H.M. Austin. 2003. Reproductive seasonality, fecundity, and spawning frequency of Tautog (*Tautoga onitis*) in the lower Chesapeake Bay and coastal waters of Virginia. Fisheries Bulletin 101: 424-442.

## 10. TABLES

**Table 1.1.** The four stock definitions presented in the 2015 benchmark stock assessment. Includes overfished, overfishing status for sub-regions based on the ASAP model and peer-reviewed methods. In this report, the region comprising MA, RI and CT in Option A is referred to as Southern New England (SNE); that comprising NY and NJ is abbreviated NYNJ, and the region comprising DE, MD and VA in all stock unit definitions options is abbreviated DMV. In Option B, the region comprising MA and RI is abbreviated MARI, and that comprising CT, NY and NJ is abbreviated as CTNYNJ.

Options for Stock Unit Definitions	MA	RI	CT	NY	NJ	DE	MD	VA
A. Three Region (Assessment Preferred)	Overfished Overfishing			Overfished Not Overfishing		Overfished Not Overfishing		
B. Three Region (Highly Regarded Alternative)	Overfished Overfishing		Overfished Overfishing			Overfished Not Overfishing		
C. Two Region	Overfished Overfishing					Overfished Overfishing		
D. Coastwide (status quo)	Overfished Overfishing							

**Table 1.2.** Stock status for Long Island Sound (LIS) and New Jersey-New York Bight (NJ-NYB). Results of analysis of regional assessment presented in this document.

Option for Stock Unit Definition	MARI	LIS	NJ-NYB	DMV
A. Four Region	Overfished Overfishing	Overfished Overfishing	Overfished Overfishing	Overfished Not Overfishing



**Table 1.3.** Recreational regulations for Tautog by state in the two regions covered in this regional stock assessment.

STATE	SIZE LIMIT (inches)	POSSESSION LIMITS (number of fish/ person/ day)	OPEN SEASONS
Connecticut	16"	2 2 4	Apr 1-Apr 30 July 1 – Aug 31 Oct 10 – Dec 6
New York	16"	4	Oct 5 – Dec 14
New Jersey	15"	4 4 1 6	Jan 1 – Feb 28 Apr 1 – Apr 30 Jul 17 – Nov 15 Nov 16 – Dec 31

**Table 1.4.** Commercial regulations for Tautog by state in the two regions covered in this regional stock assessment.

STATE	SIZE LIMIT	POSSESSION LIMITS (number of fish/person/vessel)	OPEN SEASONS	GEAR RESTRICTIONS*
Connecticut	16"	10	Apr 1- Apr 30 Jul 1 - Aug 31 Oct 8 - Dec 24	Mandatory pot requirements.
New York	15"	25 (10 fish w/ lobster gear and when 6 lobsters are in possession)	Jan 1 - Feb 28/29 Apr 8 –Dec 31	Mandatory pot requirements. Pot/trap must have a 3 1/8 inch circular vent
New Jersey	15"	> 100 lbs requires directed fishery permit	Jan 1 - 15 June 11 - 30 Nov 1 - Dec 31	Mandatory pot requirements.

\* FMP regulations: A pot and trap used to catch Tautog shall have hinges or fasteners on one panel or door made of one of the following degradable materials: 1) Untreated hemp or jute string of 3/16 inch in diameter or smaller; 2) Magnesium alloy fasteners; or 3) Ungalvanized or uncoated iron wire of 0.094-inch diameter or smaller.

**Table 2.1.** Survey data used in analyses of length, age and weight.

For each state, separate surveys are identified if known, what type of sample (Fishery Independent [FI], Commercial [C], Recreational [R], or Unknown [U]), the range of years in the survey, and sample size (length and age data [N(L-A)], weight and length data [N(W-L)]). The latter two columns are not exclusive; some fish may have provided both length-age and weight-length data.

State	Survey	Type	Years	N(L-A)	N(W-L)
<b>CT</b>	LISTS	FI	1984-2015	6550	6015
<b>CT</b>	Laplante	FI	2000-2001		111
<b>RI</b>		C, R	1987-2015	4303	
<b>NY (LIS)</b>	NYWLISS	FI	1996	1	2
<b>NY (LIS)</b>		C,R	1995-2015	2039	33
<b>NY (South Shore)</b>		C, R	1995-2015	1474	801
<b>MA</b>	DMF	FI	2009-2015	967	136
<b>MA</b>	By-catch	C	2009-2015	823	155
<b>MA</b>	Rec	R	2011-2015	161	
<b>MA</b>	Unknown		1995-2014	2995	537
<b>NJ</b>	Research	FI	1993-2014	1206	75
<b>NJ</b>	Commercial	C	2004-2014	645	1264
<b>NJ</b>	Recreational	R	2007-2014	206	117
<b>NJ</b>	Party/Charter	R	2005-2014	2830	261
<b>DE</b>		C, R	2003-2014	5051	
<b>MD</b>		C	1996-2012	3179	3270
<b>MD</b>		R, U	1999-2012	669	723

**Table 2.2.** Von Bertalanffy parameter estimates by region, arranged N to S.

	Estimate	SE
<b>MARI</b>		
Linf	55.1	0.3
K	0.201	0.004
t0	-0.883	0.063
<b>LIS</b>		
Linf	57.8	0.3
K	0.174	0.003
t0	-0.409	0.051
<b>NJ-NYB</b>		
Linf	65.6	1.3
K	0.094	0.005
t0	-3.05	0.16
<b>DMV</b>		
Linf	64.6	1.2
K	0.1	0.0
t0	-3.1	0.2

**Table 2.3.** ARSS of regional heterogeneity in growth curves.

The three rows of results represent test of heterogeneity among all four regions, between LIS and MARI, and between NY's data from LIS and NJ-NYB respectively. In each case the F statistic represents the probability that the residual variability as curves are fitted to data by region (four regions, LIS&MARI, LIS&NJ-NYB) is the same as variability as curves are fitted to the pooled data (coastwide, SNE, CTNYNJ). The columns represent the number of curves tested (m), the summed residual sum of squares as curves are fitted by region ( $\sum RSS_i$ ), the residual sum of squares as a curve is fitted to the pooled data (RSSp), the F statistic, and the p value under the null hypothesis of homogeneity among the regions.

	m	$\sum RSS_i$	RSSp	F	p
Four regions vs. coastwide	4	4.9E+05	8.7E+05	3.2E+03	<0.0001
LIS&MARI vs. SNE	2	3.0E+05	3.3E+05	4.0E+02	<0.0001
LIS&NJ-NYB vs. NYNJ	2	1.7E+05	1.8E+05	1.2E+02	<0.0001

**Table 2.4.** ANOVA tests of age, year, region on length. For each listed effect, entries are degrees of freedom (DF), type III sum of squares (SS), F value (F) estimating the difference between variability attributable to the effect and residual variability, and P value under the null hypothesis of no effect. Results are presented testing for differences among the four regions, and between LIS and MARI, finally between LIS and NJ-NYB.

	DF	SS	F	P
All four regions				
Age	29	1.3E+06	2300	<.0001
Year	31	5.0E+04	82	<.0001
Region	3	9.1E+04	1500	<.0001
LIS&MARI				
Age	29	8.0E+05	1400	<.0001
Year	31	1.3E+04	21	<.0001
Region	1	1.0E+04	520	<.0001
LIS&NJ-NYB				
Age	28	7.5E+05	1600	<.0001
Year	31	4.8E+04	94	<.0001
Region	1	1.5E+03	94	<.0001

**Table 2.5.** Parameter estimates for the weight-length scaling relationship. Relationship is (Weight = a\*Length<sup>b</sup>) by region, arranged N to S.

	Estimate	SE
MARI		
a	5.00E-05	3.42E-06
b	2.8	0.0
LIS		
a	3.90E-05	1.74E-06
b	2.8	0.0
NJ-NYB		
a	3.60E-05	1.51E-06
b	2.9	0.0
DMV		
a	2.80E-05	1.24E-06
b	2.9	0.0

**Table 2.6.** ARSS of regional heterogeneity in weight-at-length curves. The three rows of results represent test of heterogeneity among all four regions, between LIS and MARI, and between LIS and NJ-NYB respectively. In each case the F statistic represents the probability that the residual variability as curves are fitted to data by region (four regions, LIS&MARI, LIS&NJ-NYB) is the same as variability as curves are fitted to the pooled data (coastwide, SNE, CTNYNJ). The columns represent the number of curves tested (m), the summed residual sum of squares as curves are fitted by region ( $\Sigma R S S_i$ ), the residual sum of squares as a curve is fitted to the pooled data (RSSp), the F statistic, and the p value under the null hypothesis of homogeneity among the regions.

	m	$\Sigma R S S_i$	RSSp	F	P
Four regions vs. coastwide	4	690	470	1030	<0.0001
LIS&MARI vs. SNE	2	410	394	139	<0.0001
LIS&NJ-NYB vs. NYNJ	2	459	453	55.0	<0.0001

**Table 2.7.** ANCOVA tests of year and region on weight-at-length. For each listed effect, entries are degrees of freedom (DF), type III sum of squares (SS), F value (F) estimating the difference between variability attributable to the effect and residual variability, and P value under the null hypothesis of no effect. Results are presented testing for differences among the four regions, and between LIS and MARI, finally between LIS and NJ-NYB.

	DF	SS	F	P
All four regions				
Length	1	1370	1370	2.80E+05
Year	30	1.88	0.0628	12.9
Region	3	0.591	0.197	40.4
LIS&MARI				
Age	1	907	907	2.23E+05
Year	30	1.98	0.0661	16.2
Region	1	0.396	0.396	97.2
LIS&NJ-NYB				
Age	1	1020	1020	1.96E+05
Year	30	1.64	0.0547	10.5
Region	1	0.0234	0.0234	4.47

**Table 4.1.** Recreational harvest (A+B1) for Tautog in number of fish, 1981-2015 (MRIP).

<b>Year</b>	<b>CT</b>	<b>NY</b>	<b>NJ</b>
1981	100,308	721,062	132,271
1982	231,187	646,693	583,550
1983	200,676	612,163	344,580
1984	287,470	286,077	516,086
1985	182,318	1,105,234	840,627
1986	333,396	1,183,114	2,369,852
1987	312,430	929,887	1,015,123
1988	234,198	828,183	564,286
1989	303,782	562,549	710,958
1990	75,871	953,622	841,770
1991	191,137	871,221	1,067,283
1992	319,221	413,236	1,018,205
1993	180,055	505,632	773,213
1994	150,109	196,937	208,003
1995	120,259	118,006	707,963
1996	72,558	82,826	470,431
1997	32,200	92,907	196,724
1998	66,797	68,887	11,667
1999	15,701	196,564	165,505
2000	10,648	79,245	462,371
2001	16,579	45,913	467,728
2002	100,240	629,772	347,831
2003	167,875	128,729	102,593
2004	16,464	278,749	90,214
2005	35,699	84,280	43,055
2006	200,708	246,882	200,725
2007	352,819	223,798	300,179
2008	167,179	318,899	172,518
2009	85,915	346,276	127,403
2010	116,058	145,663	374,599
2011	25,823	111,406	136,674
2012	194,101	61,508	37,611
2013	104,982	76,797	111,377
2014	289,829	263,962	169,879

**Table 4.2.** Commercial landings for Tautog in metric tons (MT), by region, 1984-2014.  
Source: NOAA Fisheries and ACCSP.

Year	LIS	NJ-NYB
1984	14.8 (CT only)	59
1985	22.7 (CT only)	57
1986	129.4	55
1987	159.1	58
1988	116.9	90
1989	140.4	48
1990	77.9	70
1991	76.2	80
1992	74.4	67
1993	60.0	77
1994	35.5	98
1995	24.1	71
1996	53.0	51
1997	33.9	31
1998	30.3	23
1999	15.3	20
2000	15.5	25
2001	27.2	39
2002	29.9	26
2003	39.2	42
2004	40.8	50
2005	36.0	47
2006	39.3	52
2007	54.6	58
2008	37.3	57
2009	23.9	34
2010	32.2	52
2011	40.1	52
2012	29.8	32
2013	38.7	38
2014	47.3	32

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

Data	Source	Years	Region(s)	Category
Recreational Landings	MRFSS, MRIP	1984 - 2014	LIS/NYB	Fishery-dependent
Recreational CPUE	VTR	1994 - 2012	LIS, NYB	Fishery-dependent
Recreational CPUE	MRFSS/MRIP	1981 - 2014	LIS, NYB	Fishery-dependent
Length distribution of recreational harvested fish	MRFSS/MRIP	1984 - 2014	LIS, NYB	Fishery-dependent
Length distribution of recreational harvested fish	Volunteer Angler Survey	1997 - 2014	LIS (CT)	Fishery-dependent
Length distribution of recreational harvested fish	NY Head Boat Sampling	1995-1999, 2006-2014	LIS/NYB (NY)	Fishery-dependent
Length distribution of recreational released fish	MRIP	2004 - 2014	LIS, NYB	Fishery-dependent
Length distribution of recreational discards	American Littoral Society	1987 - 2014	LIS, NYB	Fishery-dependent
Commercial Landings	ACCSP, NMFS	1970 - 2014	LIS/NYB	Fishery-dependent
Age	Commercial Sampling by Individual States		LIS/NYB	Biological
Abundance	Long Island Sound Trawl Survey	1984 - 2014	LIS	Fishery-independent
Abundance	Millstone Entrainment (sensitivity only)	1984 - 2014	LIS	Fishery-independent
Abundance	Peconic Bay Trawl Survey	1987 - 2012	LIS	Fishery-independent
Abundance	Western Long Island Sound Survey (NYWLI)	1984 - 2014	LIS, NYB	Fishery-independent
Abundance	NJ Ocean Trawl Survey	1988 - 2014	NYB	Fishery-independent



**Table 5.2.** Number of MRFSS/MRIP intercepted trips that were positive for Tautog.

Year	LIS			NYB		
	CT	NY LIS	Total	NY south	NJ	Total
1984	71		71	80	35	115
1985	55		55	109	50	159
1986	80		80	501	54	555
1987	83		83	139	122	261
1988	179	56	235	78	104	182
1989	177	155	332	442	235	677
1990	185	312	497	488	301	789
1991	124	467	591	388	333	721
1992	171	333	504	413	253	666
1993	132	262	394	350	118	468
1994	100	86	186	154	57	211
1995	50	29	79	48	147	195
1996	61	19	80	59	148	207
1997	60	41	101	53	115	168
1998	59	43	102	47	43	90
1999	38	73	111	99	91	190
2000	33	26	59	54	113	167
2001	66	18	84	73	231	304
2002	67	103	170	101	232	333
2003	191	46	237	83	140	223
2004	44	104	148	92	212	304
2005	113	76	189	43	119	162
2006	84	147	231	151	126	277
2007	92	102	194	110	182	292
2008	56	142	198	156	261	417
2009	19	126	145	103	227	330
2010	94	111	205	119	167	286
2011	28	83	111	132	119	251
2012	99	51	150	64	118	182
Grand Total	2611	3011	5622	4729	4453	9182

**Table 5.3.** Species included in guilds for identification of target trips and estimation of CPUE using MRFSS/MRIP data.

Common name	Scientific name	CT	NY	NJ
Black sea bass	<i>Centropristis striata</i>		5	3
Bluefish	<i>Pomatomus saltatrix</i>	6		6
Cunner	<i>Tautoglabrus adspersus</i>	3	2	2
Scup	<i>Stenotomus chrysops</i>	4	3	4
Summer flounder	<i>Paralichthys dentatus</i>	5	6	5
Tautog	<i>Tautoga onitis</i>	1	1	1
Winter flounder	<i>Pseudopleuronectes americanus</i>	2	4	

**Table 5.4.** MRIP CPUE, CV and PSE by region.

Year	LIS			NYB		
	Mean	CV	PSE	Mean	CV	PSE
1984	1.66	0.128	0.370	0.25	0.1	
1985	1.38	0.132	0.370	0.31	0.1	
1986	1.26	0.113	0.370	0.69	0.07	
1987	1.48	0.107	0.370	0.54	0.08	
1988	3.53	0.0726	0.370	0.52	0.08	
1989	2.54	0.0683	0.370	0.69	0.07	0.8970
1990	1.47	0.061	0.370	0.8	0.06	1.0400
1991	1.77	0.0568	0.370	0.69	0.05	0.8970
1992	2.4	0.0594	0.370	0.89	0.06	1.1570
1993	1.85	0.0686	0.370	0.49	0.07	0.6370
1994	1.37	0.0888	0.370	0.29	0.08	0.3770
1995	0.878	0.116	0.370	0.62	0.08	0.8060
1996	1.05	0.111	0.370	0.39	0.08	0.5070
1997	0.717	0.101	0.370	0.31	0.08	0.4030
1998	0.602	0.105	0.370	0.14	0.1	0.1820
1999	0.673	0.0971	0.370	0.24	0.09	0.3120
2000	0.233	0.129	0.370	0.29	0.08	0.3770
2001	0.282	0.106	0.370	0.4	0.06	0.5200
2002	1.01	0.0943	0.370	0.54	0.07	0.7020
2003	0.818	0.0782	0.370	0.18	0.07	0.2340
2004	0.67	0.0943	0.472	0.31	0.07	0.3100
2005	0.84	0.0992	0.492	0.18	0.08	0.1800
2006	1.08	0.0922	0.384	0.32	0.08	0.3200
2007	0.927	0.0922	0.275	0.34	0.08	0.3400
2008	0.902	0.09	0.221	0.33	0.08	0.3300
2009	0.817	0.107	0.267	0.57	0.08	0.5700
2010	0.869	0.0908	0.239	0.3	0.08	0.3000
2011	0.79	0.118	0.499	0.3	0.09	0.3000
2012	0.708	0.0972	0.305	0.23	0.09	0.2300
2013	0.55	0.1	0.521	0.22	0.09	0.2200
2014	1.11	0.0852	0.291	0.26	0.08	0.2600

**Table 5.5.** Sample size from multiple surveys used in estimating size distribution of harvested and discarded fish in LIS.

Year	LIS Harvest length sources			LIS Discard length sources			
	MRFSS/ MRIP	NYHBS	CTVAS	MRIP Type 9	NYHBS	ALSVAS	CTVAS
1984	166						
1985	58						
1986	91						
1987	204					15	
1988	260					25	
1989	428					31	
1990	370					51	
1991	535					100	
1992	515					41	
1993	455					33	
1994	195					39	
1995	37	153			184	36	
1996	55	454			340	54	
1997	51	260	142		348	11	98
1998	45	96	235		95	90	182
1999	26	176	304		134	74	110
2000	1	0	122		0	68	84
2001	64	0	134		0	72	91
2002	72	0	259		0	89	125
2003	229	0	455		0	6	213
2004	56	0	153	57	0	4	45
2005	128	0	345	143	0	41	113
2006	136	267	392	321	0	41	171
2007	99	134	349	166	0	101	123
2008	33	335	263	135	249	36	120
2009	67	150	274	122	244	4	144
2010	180	159	274	148	239	4	141
2011	65	45	375	124	52	11	246
2012	78	56	385	182	145	103	516
2013	52	42	278	40	17	86	206
2014	60	41	161	98	220	174	379

**Table 5.6.** Sample size from multiple surveys used in estimating size distribution of harvested and discarded fish in NJ-NYB

	New Jersey			New York south				
	Harvest	Discards		Harvest		Discards		
	MRFSS	ALS	Type 9	MRFSS	NYHBS	ALS	NYHBS	Type 9
1995	133	85		22	174	19	304	
1996	90	67		16	161	22	226	
1997	43	52		17	179	21	208	
1998	15	26		1	68	34	232	
1999	24	32		28	32	77	147	
2000	112	7		12		74		
2001	249	123		4		47		
2002	261	89		60		135		
2003	78	63		39		11		
2004	162	78	233	67		17		38
2005	40	98	57	18		4		23
2006	71	30	32	49	31	45		165
2007	109	100	87	102	22	9		158
2008	233	266	219	97	136	8	93	134
2009	218	152	147	75	124	18	521	99
2010	101	168	76	58	61	24	66	75
2011	65	219	21	39	73	8	58	32
2012	109	190	219	57	5	23	79	74
2013	54	102	58	21	57	41		19
2014	163	81	106	15	23	26	43	28

**Table 5.7.** Index values for the CT Long Island Sound Trawl Survey (LISTS).

Year	Mean	SE	CV	LCI	UCI	Nominal
1984	1.69741	0.49534	0.29182	0.72654	2.66828	4.62745
1985	0.95593	0.25975	0.27172	0.44683	1.46504	2.56349
1986	1.03314	0.22618	0.21893	0.58982	1.47645	2.88776
1987	0.82925	0.18088	0.21812	0.47473	1.18378	1.81500
1988	0.61670	0.13638	0.22115	0.34938	0.88401	2.27500
1989	0.77127	0.16878	0.21883	0.44046	1.10207	3.00000
1990	0.78684	0.17218	0.21882	0.44937	1.12431	2.77000
1991	1.03916	0.22479	0.21632	0.59856	1.47975	2.50500
1992	0.46545	0.11721	0.25182	0.23572	0.69518	1.65625
1993	0.25742	0.06060	0.23544	0.13863	0.37620	0.78500
1994	0.27695	0.06481	0.23403	0.14991	0.40398	1.03500
1995	0.14207	0.03586	0.25242	0.07178	0.21236	0.30500
1996	0.20613	0.04964	0.24081	0.10884	0.30342	0.68000
1997	0.27780	0.06496	0.23385	0.15047	0.40512	0.95000
1998	0.36466	0.08354	0.22908	0.20093	0.52839	0.97000
1999	0.50516	0.11294	0.22357	0.28380	0.72653	1.08500
2000	0.45355	0.10205	0.22501	0.25353	0.65357	1.43250
2001	0.54338	0.12197	0.22446	0.30433	0.78244	1.59500
2002	0.95501	0.20712	0.21688	0.54905	1.36097	2.82400
2003	0.39317	0.09665	0.24582	0.20374	0.58260	1.31000
2004	0.34850	0.08032	0.23047	0.19108	0.50593	1.16683
2005	0.29382	0.06842	0.23287	0.15972	0.42793	0.89500
2006	0.39619	0.11145	0.28131	0.17774	0.61463	1.54750
2007	0.36585	0.08376	0.22895	0.20168	0.53002	1.39800
2008	0.37876	0.09341	0.24662	0.19568	0.56185	1.11813
2009	0.26356	0.06197	0.23513	0.14210	0.38503	0.81600
2010	0.16958	0.06154	0.36289	0.04896	0.29020	0.68462
2011	0.17694	0.04637	0.26206	0.08606	0.26781	0.61395
2012	0.28546	0.06662	0.23338	0.15489	0.41604	0.67700
2013	0.28608	0.06673	0.23326	0.15529	0.41688	0.80400
2014	0.32831	0.07598	0.23141	0.17940	0.47722	0.97286

**Table 5.8.** Variance Inflation Factors (VIF) for the final model for the Connecticut Long Island Sound Trawl Survey.

	VIF	Df
Year	1.123055	31
Month	1.123446	6
Strata	1.001532	2

**Table 5.9.** Millstone entrainment abundance indices

Year	Millstone egg				Millstone larvae			
	Mean	CV	L95	U95	Mean	CV	L95	U95
1984	1910.2	19.3	1188.9	2631.4	3.1	33.4	1.1	5.1
1985	5167.9	40.8	1038.3	9297.6	13.7	39.9	3.0	24.4
1986	4476.6	37.6	1177.5	7775.8	3.3	30.7	1.3	5.3
1987	3061.9	26.5	1474.4	4649.3	6.8	26.0	3.3	10.2
1988	2630.1	30.0	1085.4	4174.9	16.0	30.2	6.5	25.5
1989	3129.0	33.5	1073.6	5184.4	13.1	27.4	6.1	20.1
1990	2039.5	29.6	854.5	3224.4	34.2	37.1	9.3	59.1
1991	2127.0	32.2	784.7	3469.3	101.5	26.2	49.4	153.6
1992	1188.9	24.4	619.5	1758.3	13.2	15.9	9.1	17.3
1993	1381.8	20.5	826.1	1937.6	6.7	25.3	3.4	9.9
1994	1370.0	24.6	710.8	2029.2	12.4	32.6	4.5	20.4
1995	1847.1	21.7	1062.9	2631.4	8.6	27.5	3.9	13.2
1996	2265.1	56.6	-246.1	4776.2	17.9	46.4	1.6	34.1
1997	627.5	20.4	377.0	877.9	2.4	23.7	1.3	3.5
1998	1015.2	36.0	299.0	1731.5	14.3	25.8	7.1	21.6
1999	1672.0	36.5	475.0	2869.0	64.3	35.8	19.2	109.3
2000	2393.0	34.4	779.5	4006.5	12.9	50.2	0.2	25.6
2001	3028.0	37.8	784.3	5271.8	120.6	61.1	-23.8	264.9
2002	2075.2	30.2	847.4	3303.0	66.7	45.5	7.2	126.1
2003	2172.6	30.7	863.6	3481.6	453.6	82.6	-280.5	1187.6
2004	3824.5	31.3	1479.1	6169.9	100.4	55.3	-8.4	209.2
2005	2307.3	34.4	753.2	3861.3	257.0	70.1	-96.2	610.1
2006	3384.2	38.7	814.3	5954.0	20.8	22.2	11.8	29.9
2007	4360.6	52.2	-102.5	8823.7	623.6	88.1	-452.8	1700.0
2008	4297.7	45.4	476.1	8119.2	13.9	30.4	5.6	22.2
2009	4345.7	45.4	476.5	8215.0	204.4	51.4	-1.5	410.2
2010	2508.5	45.0	294.4	4722.7	55.4	36.5	15.8	95.1
2011	3432.2	54.0	-200.3	7064.6	41.6	49.8	1.0	82.2
2012	3412.9	42.1	597.3	6228.6	133.7	36.5	38.0	229.5
2013	4056.7	46.6	349.2	7764.2	21.8	24.5	11.3	32.3
2014	3236.3	51.1	-3.0	6475.6	218.9	60.4	-40.1	477.8

**Table 5.10.** Index values for the Peconic Bay Trawl Survey.

Year	Mean	SE	CV	LCI	UCI	Nominal
1987	0.20657	0.06112	0.29589	0.08677	0.32637	0.23164
1988	0.21846	0.06185	0.28313	0.09723	0.33969	0.34272
1989	0.90036	0.24125	0.26795	0.42750	1.37321	1.11905
1990	0.35414	0.09650	0.27249	0.16500	0.54327	0.59302
1991	0.28597	0.07847	0.27441	0.13216	0.43978	0.49497
1992	0.13186	0.03792	0.28758	0.05754	0.20619	0.23358
1993	0.22749	0.06338	0.27859	0.10327	0.35171	0.50242
1994	0.07632	0.02237	0.29306	0.03248	0.12016	0.17991
1995	0.08857	0.02608	0.29445	0.03745	0.13969	0.26596
1996	0.23349	0.06497	0.27827	0.10614	0.36083	0.39609
1997	0.17690	0.05073	0.28675	0.07747	0.27632	0.31926
1998	0.24979	0.07006	0.28048	0.11247	0.38711	0.32911
1999	0.16991	0.04818	0.28353	0.07549	0.26434	0.32250
2000	0.08529	0.02528	0.29645	0.03573	0.13484	0.16667
2001	0.32618	0.08996	0.27581	0.14985	0.50250	0.61353
2002	0.13657	0.03909	0.28620	0.05996	0.21318	0.26506
2003	0.20814	0.05931	0.28495	0.09190	0.32439	0.27990
2004	0.14485	0.04160	0.28720	0.06331	0.22638	0.31204
2007	0.21885	0.06097	0.27859	0.09935	0.33836	0.35696
2009	0.92353	0.24671	0.26713	0.43999	1.40708	1.38120
2010	0.42393	0.12885	0.30395	0.17138	0.67648	0.40728
2011	0.10257	0.03106	0.30281	0.04170	0.16345	0.18750
2012	0.16114	0.04568	0.28351	0.07160	0.25068	0.42051
2013	1.13344	0.34762	0.30669	0.45211	1.81477	0.87845
2014	0.40738	0.11385	0.27946	0.18424	0.63051	0.88127

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

	GVI	Df
Year	16.3433	27
Temp	1.42815	1
Depth	4.36575	1
Salinity	3.60431	1
Station	2.68712	76



**Table 5.12.** Index values for the LIS portion of the NYWLISS

Year	Mean	SE	CV	LCI	UCI	Nominal
1984	0.36852	0.21246	0.57654	-0.04791	0.78495	0.54545
1985						
1986	0.05163	0.04351	0.84276	-0.03365	0.13691	0.06522
1987	0.03251	0.02684	0.82577	-0.02011	0.08512	0.05085
1988	1.24364	0.64349	0.51743	-0.01761	2.50489	0.80357
1989	0.02614	0.02714	1.03805	-0.02704	0.07933	0.01887
1990	0.18745	0.12127	0.64696	-0.05024	0.42514	0.27451
1991	2.93227	1.49264	0.50904	0.00669	5.85785	8.35294
1992	0.45012	0.23419	0.52028	-0.00889	0.90913	0.37705
1993	0.00860	0.01128	1.31121	-0.01350	0.03070	0.01852
1994						
1995	0.06486	0.05674	0.87468	-0.04634	0.17607	0.09756
1996	0.04305	0.03598	0.83583	-0.02748	0.11357	0.03571
1997	0.28133	0.18733	0.66587	-0.08584	0.64850	0.20000
1998	0.21457	0.13072	0.60919	-0.04163	0.47078	0.19149
1999	1.00449	0.50959	0.50732	0.00568	2.00329	1.98214
2000	1.77202	0.81508	0.45997	0.17446	3.36958	1.71429
2001	0.03436	0.02700	0.78589	-0.01856	0.08728	0.04918
2002	0.54771	0.25596	0.46733	0.04602	1.04940	1.26761
2003	0.93490	0.39905	0.42683	0.15277	1.71703	0.93750
2004	0.04531	0.02958	0.65292	-0.01267	0.10328	0.06250
2005	0.33096	0.16820	0.50821	0.00129	0.66063	0.65000
2006	0.17247	0.10502	0.60889	-0.03336	0.37830	0.26087
2007	0.06386	0.03726	0.58343	-0.00916	0.13688	0.12821
2008	0.03992	0.02724	0.68247	-0.01348	0.09332	0.03947
2009						
2010	0.00975	0.01079	1.10661	-0.01139	0.03089	0.01449
2011	0.00848	0.00956	1.12647	-0.01025	0.02721	0.01282
2012	0.40178	0.19044	0.47400	0.02851	0.77504	0.89333
2013	0.02519	0.01949	0.77373	-0.01301	0.06340	0.04225
2014	0.44803	0.21138	0.47179	0.03374	0.86233	0.54054

**Table 5.13.** Variance Inflation Factors (VIF) for the final model for the Long Island Sound portion of NYWLISS

	VIF	Df
Year	1.11859	31
Temp	1.11859	1

**Table 5.14.** Index values for the NJ-NYB portion of the NYWLISS

Year	Mean	SE	CV	LCI	UCI
1987	0.083	0.059678	0.717	-0.03375	0.200182
1988	0.234	0.176132	0.751	-0.11084	0.579603
1989	1.280	0.693817	0.542	-0.08005	2.639718
1990	0.994	0.581048	0.584	-0.14452	2.133192
1991	0.407	0.209723	0.516	-0.00443	0.817686
1992	0.421	0.234922	0.558	-0.03933	0.881559
1993	0.013	0.01579	1.193	-0.01771	0.044187
1994	0.121	0.078111	0.647	-0.03235	0.273843
1995	0.090	0.073814	0.819	-0.05455	0.234806
1996	0.052	0.069127	1.336	-0.08374	0.187236
1997	0.000		1.000		
1998	0.052	0.04881	0.931	-0.04323	0.148107
1999	0.853	0.420692	0.493	0.027951	1.677063
2000	0.634	0.294142	0.464	0.05751	1.210545
2001	1.112	0.588553	0.529	-0.04145	2.265676
2002	0.135	0.086421	0.638	-0.03398	0.304792
2003	0.240	0.143782	0.599	-0.04172	0.521909
2004	1.859	0.924936	0.498	0.046195	3.671946
2005	1.477	0.711284	0.481	0.083149	2.871382
2006	0.622	0.322651	0.519	-0.01021	1.254582
2007	1.041	0.516299	0.496	0.02938	2.053271
2008	0.423	0.247174	0.584	-0.06139	0.907531
2009	0.042	0.046707	1.113	-0.04957	0.133522
2010	0.000	2.79E-09	--	-5.5E-09	5.47E-09
2011	0.066	0.06077	0.918	-0.05289	0.185335
2012	2.745	1.280495	0.467	0.234745	5.254287
2013	0.706	0.369792	0.524	-0.01888	1.430707
2014	0.922	0.43125	0.468	0.076319	1.76682
2015	1.829	0.804744	0.440	0.251654	3.406251

**Table 5.15.** Variance Inflation Factors (VIF) for the final model for the NJ-NYB portion of NYWLISS

	GVIF	Df	GVIF <sup>1/(2*Df)</sup>
Year	1.454453	27	1.006962
Station	1.361557	7	1.02229
W_temp	1.134646	1	1.065198

**Table 5.16.** Index values for the NJOT survey

Year	Mean	SE	CV	LCI	UCI
1988	3.9841	2.2887	0.5745	-0.5018	8.4701
1989	1.2686	0.4317	0.3403	0.4224	2.1148
1990	1.5652	0.5640	0.3603	0.4598	2.6705
1991	0.9882	0.3463	0.3504	0.3095	1.6669
1992	1.3242	0.4561	0.3444	0.4302	2.2181
1993	0.6921	0.2435	0.3518	0.2149	1.1694
1994	0.4337	0.1563	0.3603	0.1274	0.7400
1995	0.6013	0.2104	0.3500	0.1888	1.0138
1996	0.2031	0.0762	0.3751	0.0538	0.3525
1997	0.1121	0.0446	0.3982	0.0246	0.1995
1998	0.2965	0.1075	0.3624	0.0859	0.5071
1999	0.6184	0.2180	0.3525	0.1911	1.0457
2000	0.3338	0.1218	0.3649	0.0951	0.5726
2001	0.2867	0.1052	0.3669	0.0805	0.4930
2002	1.4816	0.5071	0.3423	0.4876	2.4756
2003	0.6049	0.2127	0.3516	0.1880	1.0217
2004	0.3528	0.1281	0.3631	0.1018	0.6039
2005	0.6619	0.2373	0.3585	0.1968	1.1269
2006	0.7597	0.2666	0.3509	0.2372	1.2823
2007	0.3571	0.1289	0.3610	0.1044	0.6098
2008	0.8968	0.3125	0.3484	0.2844	1.5092
2009	0.5716	0.2027	0.3546	0.1744	0.9689
2010	0.4351	0.1559	0.3583	0.1295	0.7407
2011	0.1397	0.0561	0.4014	0.0298	0.2496
2012	0.2479	0.0923	0.3723	0.0670	0.4288
2013	0.4244	0.1524	0.3590	0.1258	0.7231
2014	0.7237	0.2528	0.3494	0.2281	1.2192

**Table 5.17.** Variance Inflation Factors (VIF) for the final model for the NJOT survey

	GVIF	Df	GVIF <sup>1/(2*Df)</sup>
Year	1.276978	27	1.004538
Tempbtm	1.202562	1	1.096614
Depthm	1.018976	1	1.009443
Salinitybt	1.359375	1	1.165922

**Table 5.18.** Data for age-length keys by region.

LIS			NYB	
Year	Source(s)	N	Source(s)	N
1984	CT	466		
1985	CT	472		
1986	CT	312		
1987	CT, RI	407		
1988	CT,RI	230		
1989	CT	398		
1990	CT, RI	238		
1991	CT, RI	237		
1992	CT	206		
1993	CT	129		
1994	CT	195		
1995	CT, NY-N	109	NY, NJ + CT	422
1996	CT, NY-N	288	NY, NJ + CT, DE	671
1997	CT,RI, NY-N	422	NY, NJ + CT, DE	1,461
1998	CT,NY-N	300	NY, NJ + CT, DE	1,010
1999	CT,RI, NY-N	323	NY, NJ + CT, DE	930
2000	CT, RI	284	NY, NJ + CT, DE	1,193
2001	CT, RI	249	NY, NJ + CT, DE	867
2002	CT, RI	859	NJ + CT, DE	816
2003	CT, RI	626	NJ + CT, DE	490
2004	CT,RI, NY-N	625	NY, NJ + CT, DE	993
2005	CT, RI	449	NY, NJ + CT, DE	981
2006	CT,RI, NY-N	674	NY, NJ + CT, DE	1,005
2007	CT,RI, NY-N	760	NY, NJ + CT, DE	1,263
2008	CT,RI, NY-N	742	NY, NJ + CT, DE	830
2009	CT,RI, NY-N	585	NY, NJ + CT, DE	982
2010	CT,RI, NY-N	447	NY, NJ + CT, DE	1,119
2011	CT,RI, NY-N	387	NY, NJ + CT, DE	998
2012	RI, NY-N	302	NJ, NY south	310
2013	RI, NY-N	364	NJ, NY south	433
2014	RI, NY-N	312	NJ, NY south	512

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

	Lambda	Obj Func		Resids	RMSE
Obj Func		5214.09	Catch fleet 1	31	0.9576
		-	Total catch	31	0.9576
Catch fleet total	1	18.4282	Disc fleet 1	0	0
Discard fleet total	1	34.4152	Tot disc	0	0
Index fit total	4	271.964	Index 1 - CT trawl	31	0.9215
Catch age comps	see_below	1774.42	Index 2 - NY trawl	25	2.2735
			Index 3 - MRFSS		
Discard age comps	see_below	0	CPUE	31	1.6237
Index age comps	see_below	3155.17	Index 4 - NY seine	27	4.6044
Sel parms total	0	0	Index total	114	2.66506
Index sel parms total	0	0	Stock N year 1	0	0
q year1 total	0	0	Fmult year 1	0	0.0000
q devs total	0	0	Fmult devs fleet 1	30	0.7002
Fmult year 1 fleet total	0	0	Fmult devs total	30	0.7002
Fmult devs fleet total	0.5	3.42489	Recruitment devs	31	0.783471
N year 1	0	0	Fleet selectivity	0	0
		-	Index selectivity	0	0
Recruit devs	0.5	6.86738	q first year	0	0
SR steepness	0	0	q devs	0	0
SR scalar	0	0	SR steepness	0	0
Fmult max penalty	1000	0	SR scalar	0	0
F penalty	0	0			

**Table 6.1** cont'd

	Lambda	Obj Func		Resids	RMSE
Obj Func		3659.94	Catch fleet 1	26	0.7565
		-	Total catch	26	0.7565
Catch fleet total	1	27.1004	Disc fleet 1	0	0
Discard fleet total	1	28.8644	Tot disc	0	0
Index fit total	3	4.65871	Index 1 - NY seine	24	1.0930
Catch age comps	see_below	1993.49	Index 2 - NJ trawl	26	1.0795
			Index 3 - MRFSS		
Discard age comps	see_below	0	CPUE	26	0.9742
Index age comps	see_below	1658.83	Index total	76	1.0491
Sel parms total	0	0	Stock N year 1	0	0
Index sel parms total	0	0	Fmult year 1	0	0
q year1 total	0	0	Fmult devs fleet 1	25	1.0626
q devs total	0	0	Fmult devs total	25	1.0626
Fmult year 1 fleet total	0	0	Recruitment devs	26	0.7819
Fmult devs fleet total	0.5	6.96425	Fleet selectivity	0	0
N year 1	0	0	Index selectivity	0	0
		-	q first year	0	0
Recruit devs	0.5	5.77612	q devs	0	0
SR steepness	0	0	SR steepness	0	0
SR scalar	0	0	SR scalar	0	0
Fmult max penalty	1000	0			
F penalty	0	0			

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

Region	Survey	Q
LIS	CT Trawl	2.30E-07
	NY Trawl	2.73E-07
	MRIP CPUE	6.64E-07
	NY Seine	2.86E-07
	MillEggs	na
	MillLarvae	na
NYB	NY seine	5.49E-04
	NJ trawl	2.71E-04
	MRFSS	4.61E-04

**Table 6.3** Annual and 3-year average fishing mortality for base model

Region	LIS		NJ-NYB	
Year	Annual F	3-year average	Annual F	3-year average
1984	0.1208			
1985	0.1406			
1986	0.1950	0.1522		
1987	0.2243	0.1866		
1988	0.2185	0.2126		
1989	0.2520	0.2316	0.2298	
1990	0.2150	0.2285	0.3029	
1991	0.1987	0.2219	0.4895	0.3407
1992	0.2698	0.2278	0.6025	0.4650
1993	0.4743	0.3142	0.6304	0.5741
1994	0.4071	0.3837	0.3162	0.5164
1995	0.3140	0.3984	0.6107	0.5191
1996	0.2558	0.3256	0.4540	0.4603
1997	0.1897	0.2531	0.2520	0.4389
1998	0.1721	0.2058	0.0925	0.2662
1999	0.1403	0.1674	0.1991	0.1812
2000	0.0735	0.1286	0.3515	0.2144
2001	0.0846	0.0995	0.4283	0.3263
2002	0.1912	0.1164	0.4768	0.4189
2003	0.1510	0.1423	0.2246	0.3766
2004	0.1441	0.1621	0.1774	0.2930
2005	0.1124	0.1358	0.1078	0.1699
2006	0.1879	0.1481	0.3287	0.2046
2007	0.3607	0.2203	0.4977	0.3114
2008	0.4422	0.3303	0.4621	0.4295
2009	0.4027	0.4018	0.5007	0.4869
2010	0.3479	0.3976	0.7485	0.5705
2011	0.2762	0.3422	0.5005	0.5832
2012	0.4378	0.3540	0.3667	0.5386
2013	0.4362	0.3834	0.4765	0.4479
2014	0.7229	0.5323	0.6578	0.5003

**Table 6.4** Estimated total abundance, SSB and recruits for base model

Region	LIS			NJ-NYB		
Year	Abundance	SSB	Recruits	Abundance	SSB	Recruits
1984	11,518,701	11,718,100	1,519,540			
1985	10,543,445	11,174,300	1,273,700			
1986	10,194,721	10,239,500	1,827,140			
1987	9,185,233	8,978,120	1,296,680			
1988	8,274,641	7,963,820	1,158,390			
1989	8,106,008	7,073,470	1,658,320	9,428.92	5,983.97	1,593.85
1990	7,034,777	6,302,510	749,857	8,742.31	5,733.54	1,322.73
1991	6,482,414	5,903,570	968,590	8,067.19	4,959.21	1,397.59
1992	6,424,968	5,365,780	1,314,580	6,799.33	3,845.61	1,088.46
1993	5,865,453	4,386,960	922,205	5,541.85	2,989.26	872.79
1994	4,854,187	3,528,280	663,198	4,549.40	2,623.25	731.64
1995	4,432,446	3,161,490	838,644	4,243.70	2,298.93	751.42
1996	4,185,540	3,027,160	705,845	3,555.80	1,887.17	630.41
1997	4,034,527	3,024,420	707,298	3,370.29	1,791.33	751.23
1998	4,328,810	3,070,470	1,069,170	3,599.79	1,891.37	952.91
1999	4,641,261	3,129,230	1,111,860	3,770.96	2,053.26	747.55
2000	4,989,587	3,355,610	1,157,240	3,683.13	2,098.62	645.11
2001	5,691,107	3,705,720	1,485,820	3,448.90	1,961.75	651.28
2002	5,380,529	3,936,390	592,421	3,255.65	1,746.51	675.14
2003	5,451,439	4,147,160	1,080,960	3,180.42	1,665.76	728.38
2004	5,624,080	4,273,530	1,148,070	3,329.57	1,752.51	764.82
2005	5,142,562	4,415,720	523,207	3,471.42	1,899.40	782.62
2006	5,010,515	4,512,660	769,280	3,507.61	1,953.09	642.72
2007	4,673,589	4,090,010	670,871	3,355.68	1,751.37	693.07
2008	4,106,654	3,367,440	612,999	3,231.98	1,502.56	808.23
2009	3,748,372	2,773,020	750,591	3,002.47	1,342.08	603.36
2010	3,923,661	2,410,670	1,096,260	3,078.12	1,178.53	870.22
2011	3,455,479	2,265,870	375,007	3,283.43	1,045.07	1,125.09
2012	3,165,989	2,275,530	413,328	4,410.59	1,181.18	1,818.49
2013	4,466,604	2,197,510	1,975,820	6,712.63	1,496.73	2,750.39
2014	4,115,365	1,956,350	495,305	6,689.31	1,971.76	1,080.65



**Table 6.5** FMSY and Ftarget and Fthreshold for base and all sensitivity analyses. SSB30% and SSB40% for the base models.

Model		FMSY	FSPR30%	FSPR40%	SSB30%	SSB40%	SSBMSY
LIS	Base Model	0.1639	0.4654	0.2686	2,820	3,757	4,576
	15 year plus	0.2372	0.4277	0.2476	3,993	5,325	5,052
	NYS, NYT, MRIP	0.0833	0.3704	0.2266			
	LISTS, MRIP	1.3026	0.4689	0.2690			
	3 selectivity blocks	0.1827	0.3492	0.2158			
	1988 forward	0.2968	0.4614	0.2666			
	LISTS, NYS, NYT	0.3760	0.5418	0.2986			
	All Indicies	0.4190	0.4544	0.2634			
	Initial values 1000x	0.2233	0.4625	0.2671			
	Steepness to 1	0.2233	0.4625	0.2671			
	CT only to 1988	0.2289	0.4612	0.2665			
	CT and ALL of NY to 1988	0.2289	0.4612	0.2665			
NYB	Base optim	2.9719	0.3645	0.2155	2,457	3,305	841
	No seine	2.9771	0.3561	0.2118			
	No trawl	0.4010	0.3624	0.2150			
	No MRFSS	2.9727	0.3660	0.2161			
	95+	2.9771	0.3543	0.2111			
	fix 05	2.9777	0.3549	0.2113			
	3 blocks	1.5502	0.2531	0.1633			

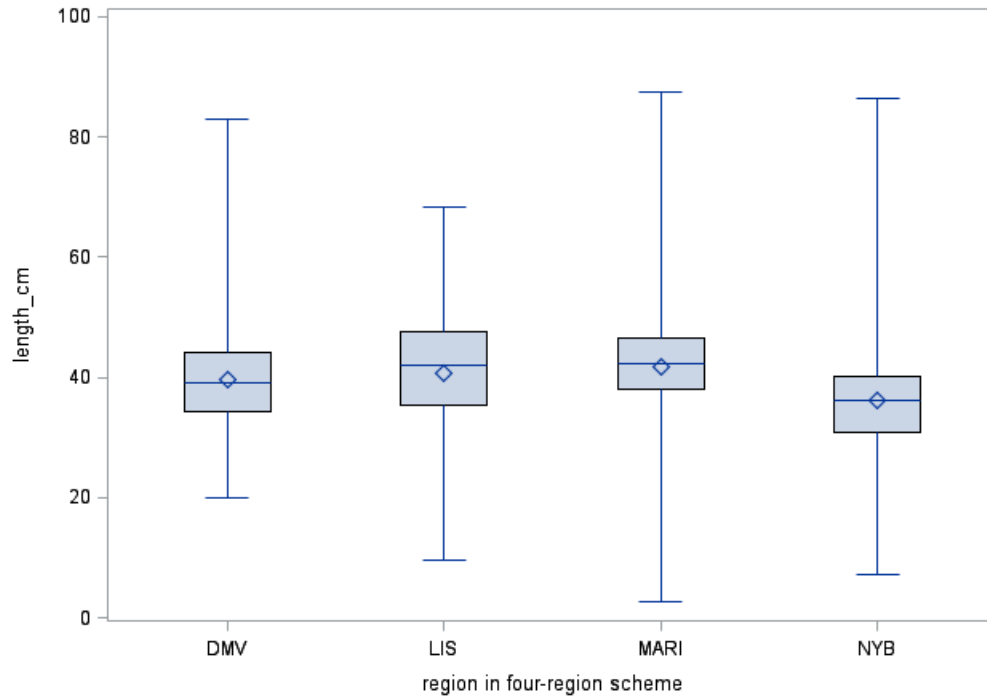
**Table 7.1** Reference points, terminal year estimates, and stock status by region

	LIS (MSY)	LIS (SPR)	NJ-NYB
<b>F<sub>TARGET</sub></b>	0.16	0.27	0.22
<b>F<sub>THRESHOLD</sub></b>	0.32	0.47	0.36
<b>3-YEAR AVG.</b>	0.53	0.53	0.5
<b>SSB<sub>TARGET</sub></b>	4,576 MT	3,757 MT	3,305 MT
<b>SSB<sub>THRESHOLD</sub></b>	3,432 MT	2,820 MT	2,457 MT
<b>SSB 2014</b>	1,956 MT	1,956 MT	1,972 MT
<b>STOCK STATUS</b>	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished

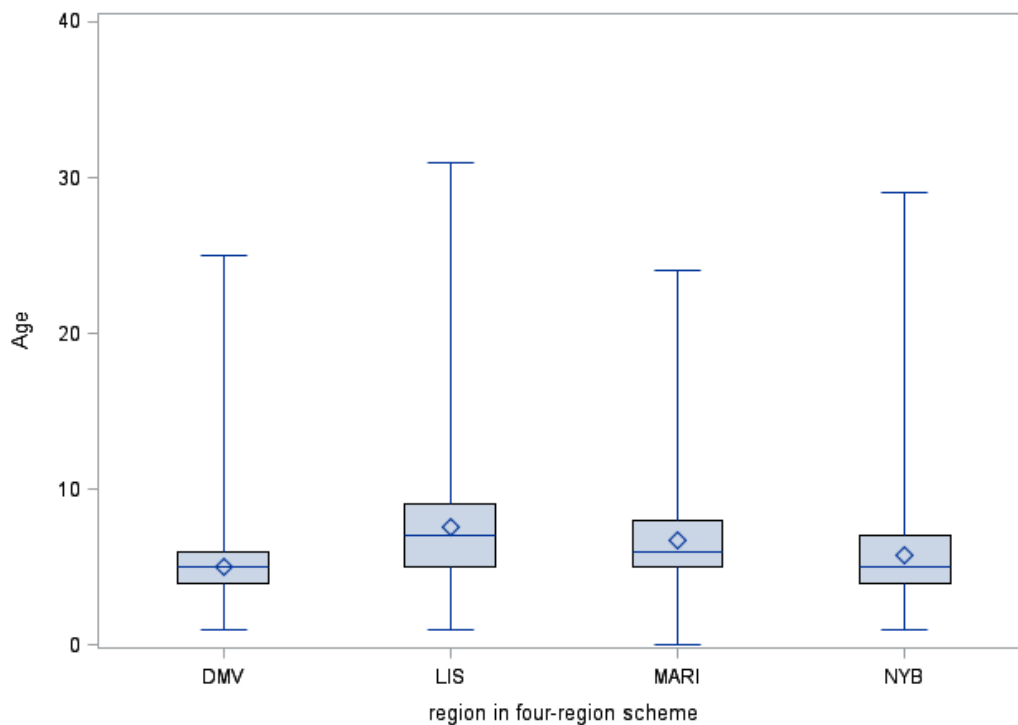
## 11. FIGURES

**Figure 2.1.** Distribution of age, length and weight by region. The lines at the bottom and top of the whiskers represent the minimum and maximum values, the bottom and top of the boxes represent the 25<sup>th</sup> and 75<sup>th</sup> percentiles, the line in the center of each box represents the median, and the diamond symbol represents the mean.

### A) Distribution of length

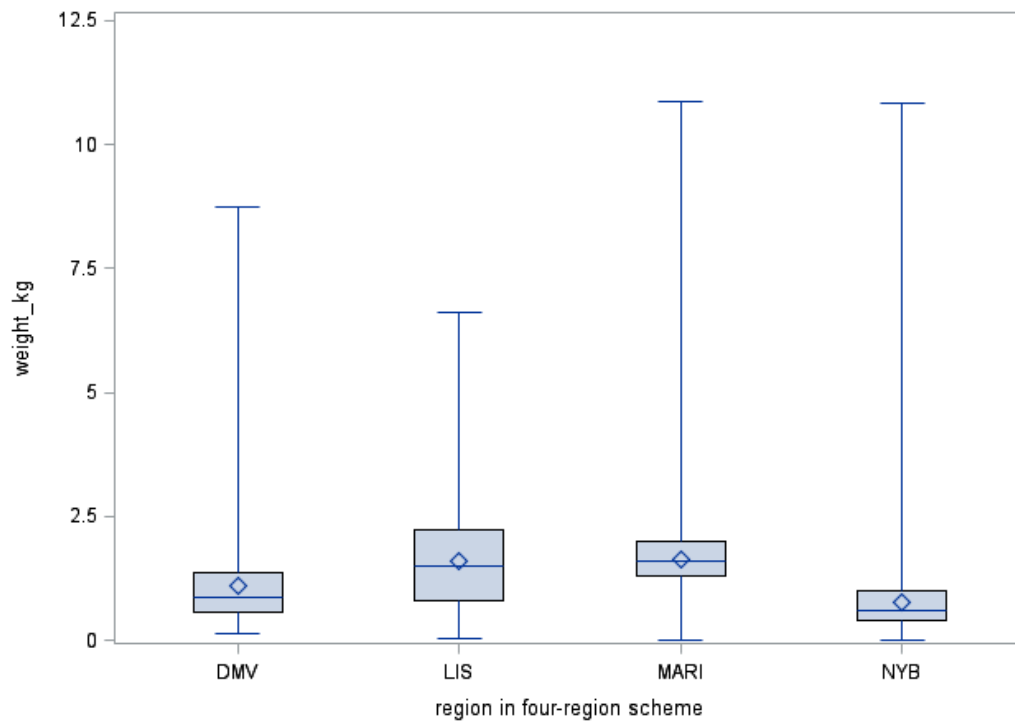


### B) Distribution of age

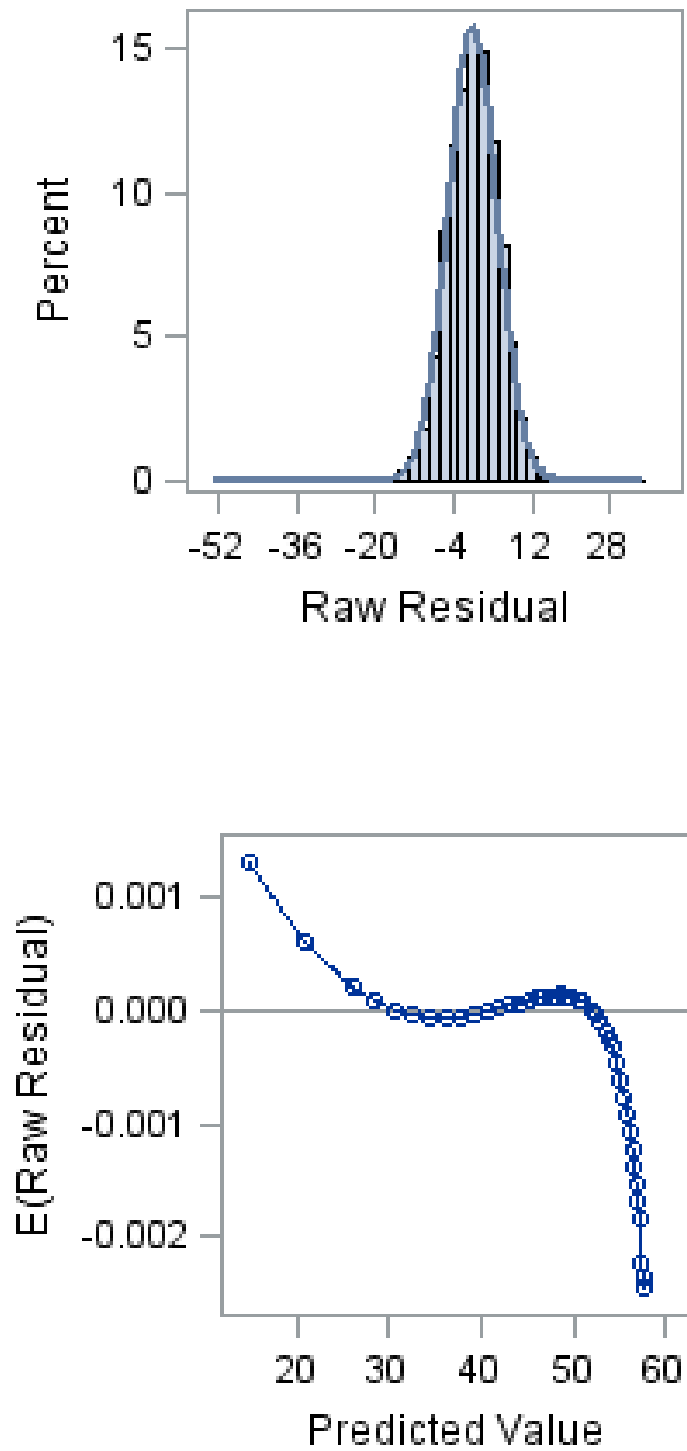


**Fig 2.1 (cont'd)**

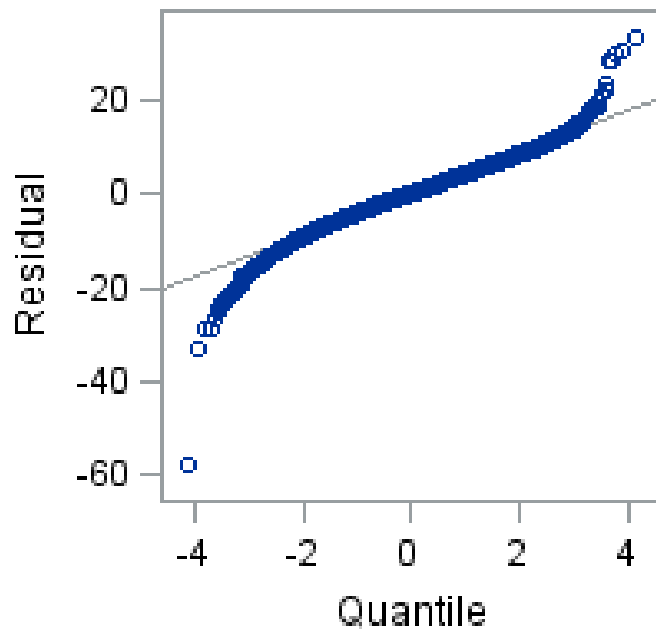
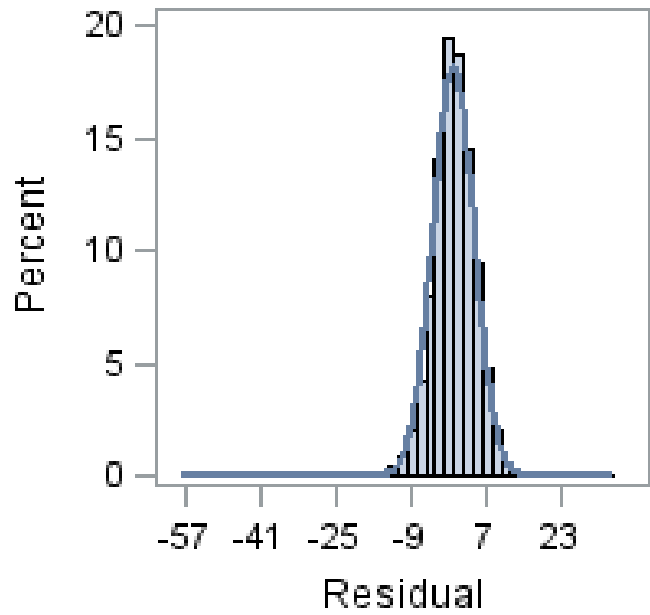
C) Distribution of weight



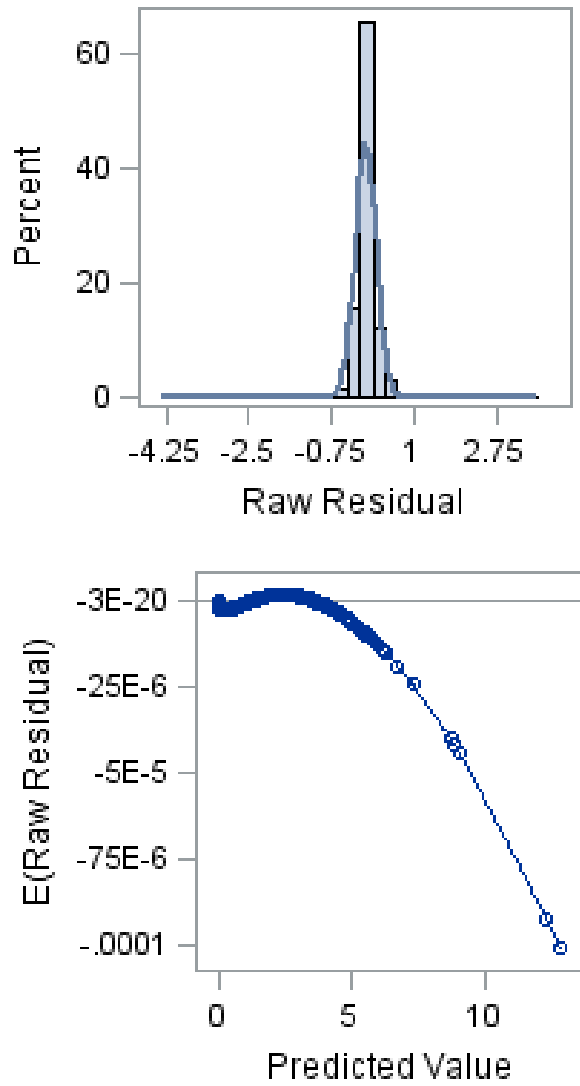
**Figure 2.2.** Diagnostics for nonlinear regression analysis of growth. The upper panel represents a histogram of residuals from expected values, and the lower panel is a plot of mean residuals vs. increments of predicted value.



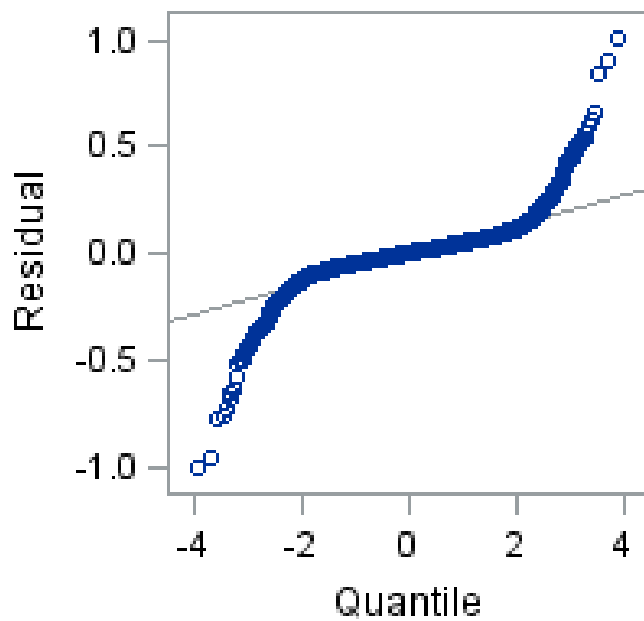
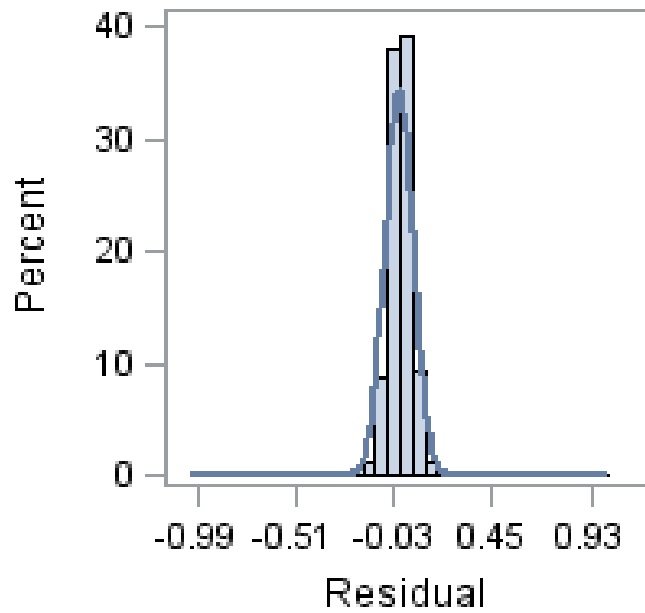
**Figure 2.3.** Diagnostics for length-at-age ANOVA. The upper panel represents a histogram of residuals from expected values, and the lower panel is a quantile-quantile plot of the observed distribution of residuals vs. residuals of the standard normal curve.



**Figure 2.4.** Diagnostics for weight-length nonlinear regression analysis. The upper panel represents a histogram of residuals from expected values, and the lower panel is a plot of mean residuals vs. increments of predicted value.



**Figure 2.5.** Diagnostics for weight-length ANCOVA. The upper panel represents a histogram of residuals from expected values, and the lower panel is a quantile-quantile plot of the observed distribution of residuals vs. residuals of the standard normal curve.



**Figure 2.6.** Von Bertalanffy growth curves by region.

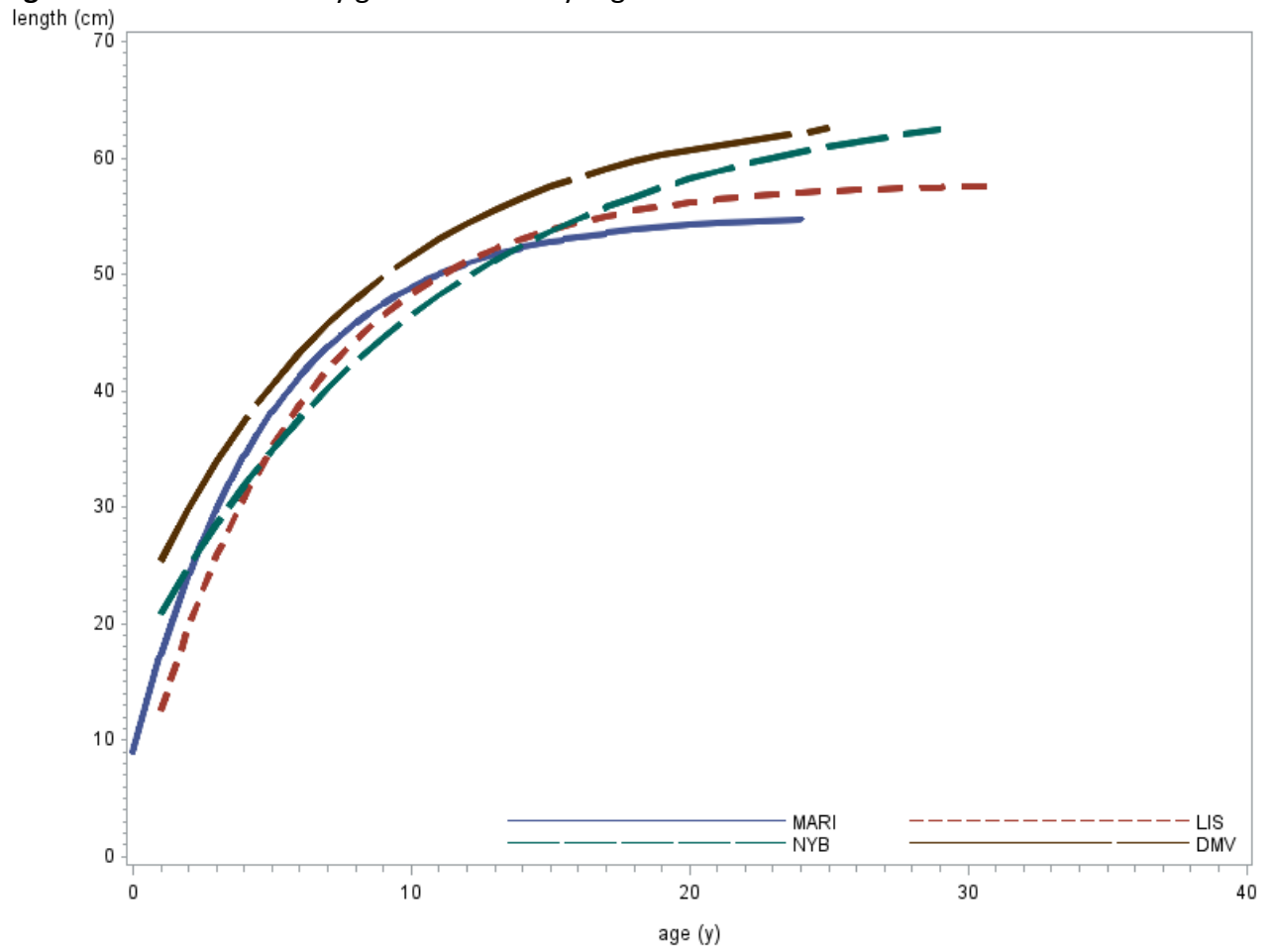
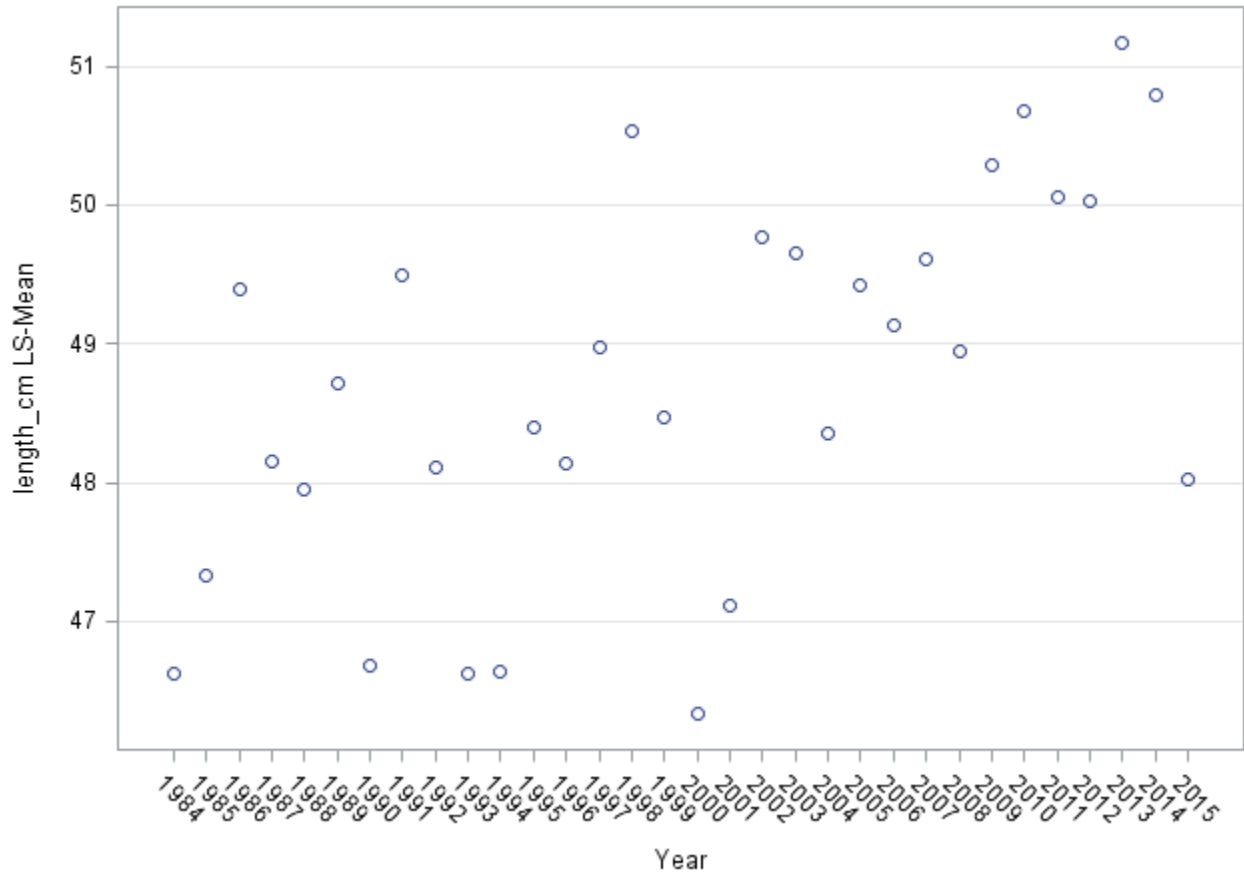
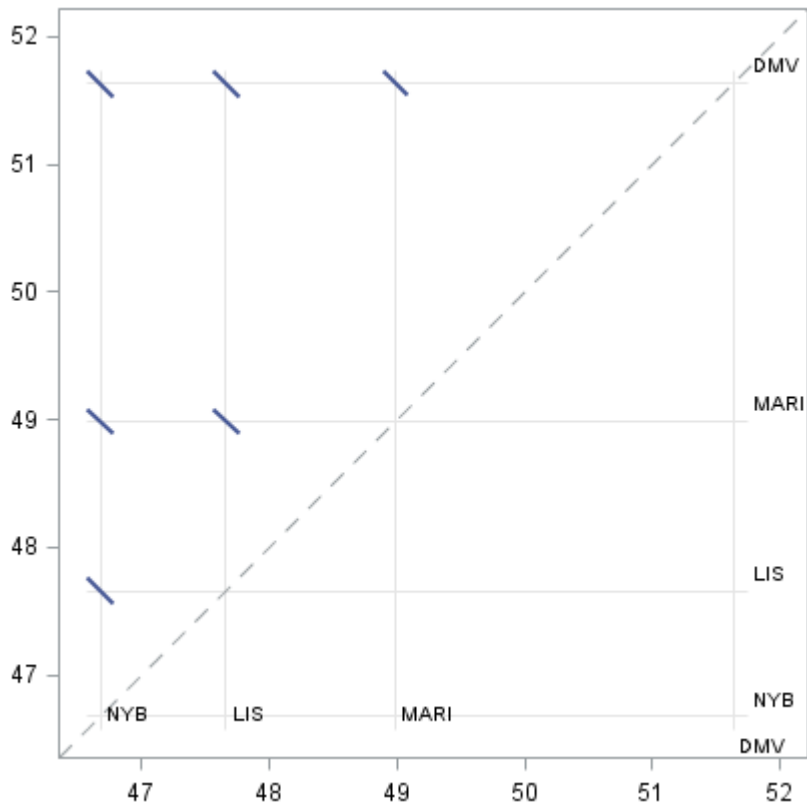




Figure 2.7. LS-Mean length over time.



**Figure 2.8.** LSMeans ( $\pm$ SD) length for each of 4 regions. Values plotted are the difference between LSMeans of each region. Lines represent Tukey-Kramer confidence intervals.



**Figure 2.9.** Length-weight relationships.  
Plotted as regression lines fitted to allometric (power) equations  $\text{weight} = a \cdot \text{length}^b$ .

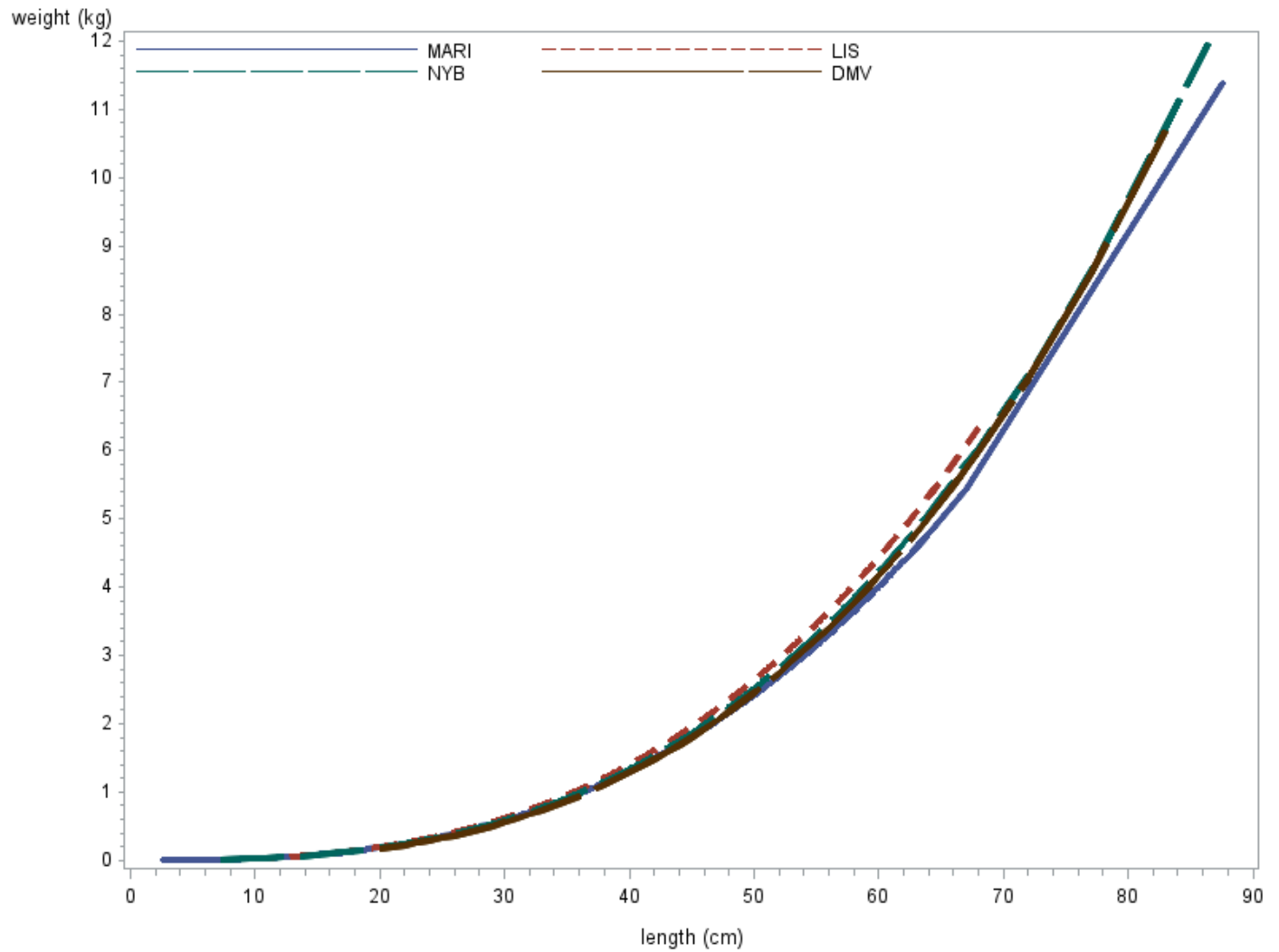
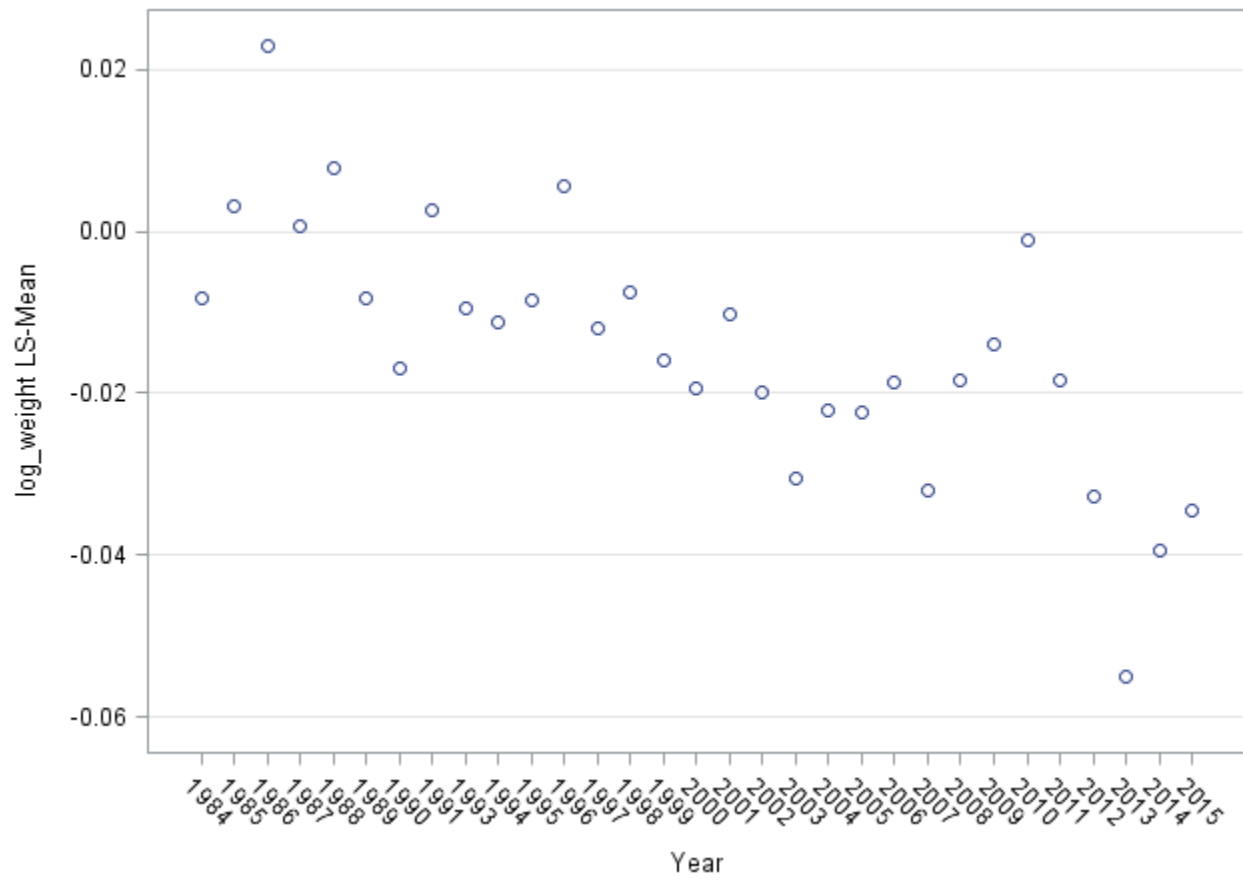
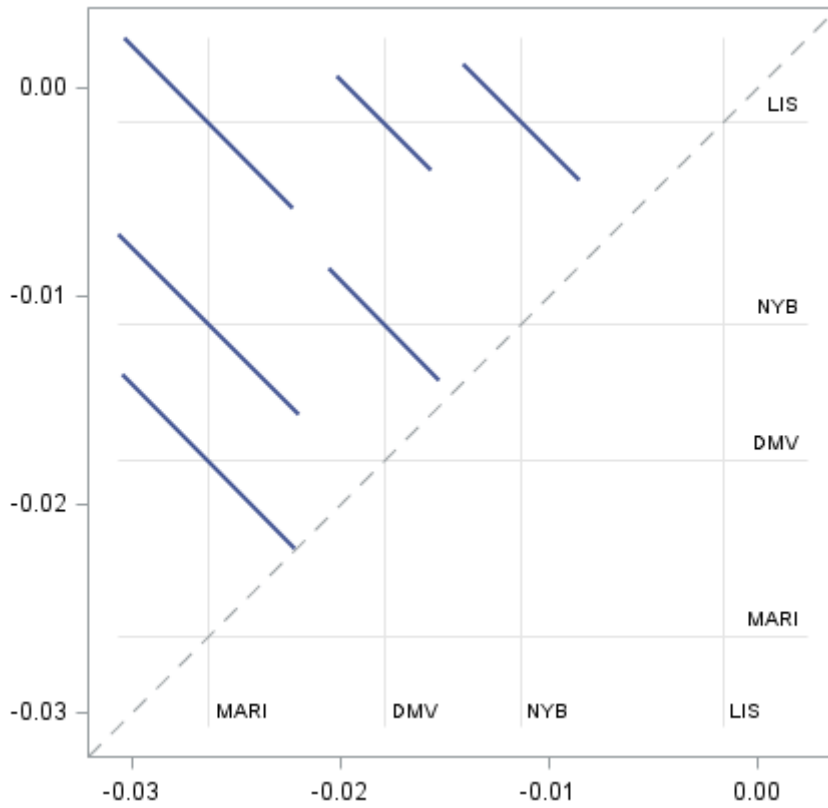


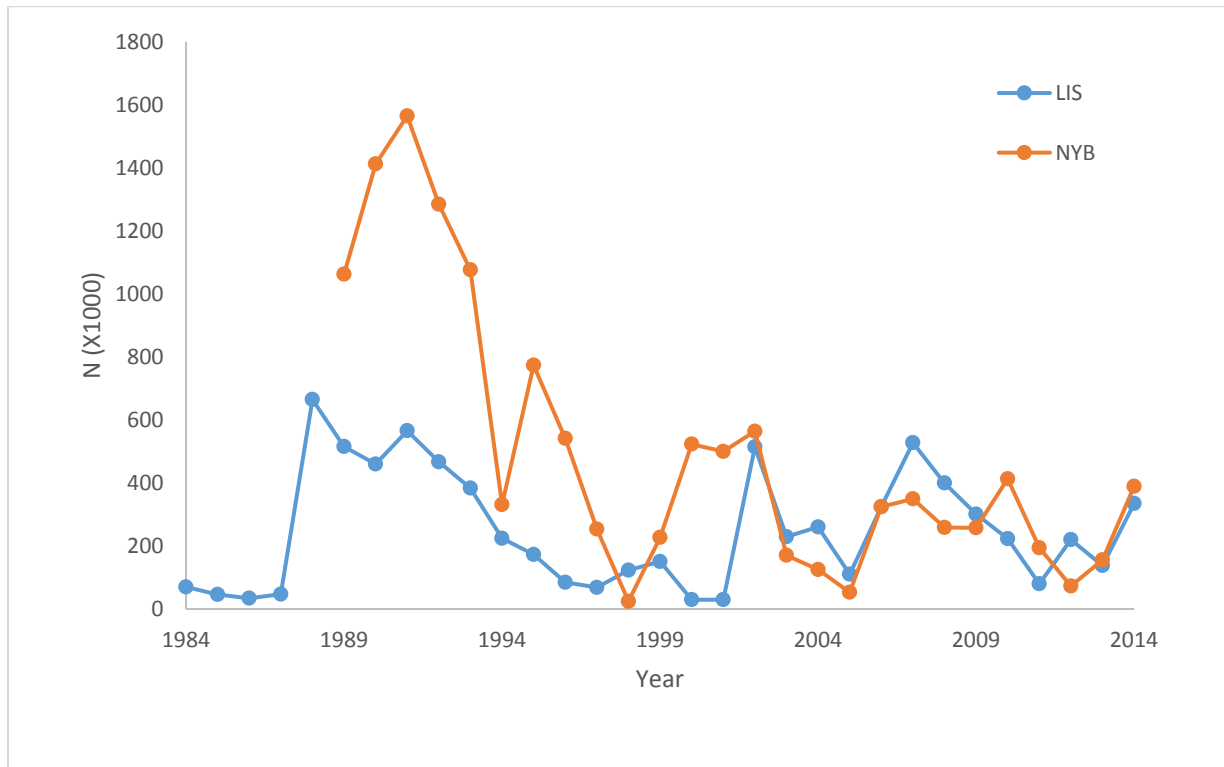
Figure 2.10. LS-Mean weight over time.



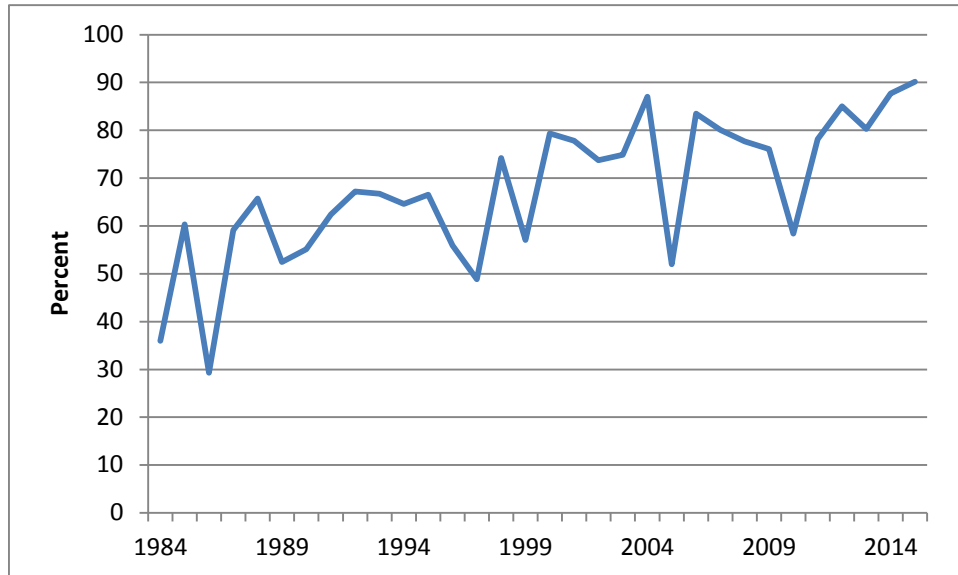
**Figure 2.11.** LSMeans ( $\pm$ SD) weight-at-length for each of 4 regions. Values plotted are the difference between LSMeans of each region. Lines represent Tukey-Kramer confidence intervals.



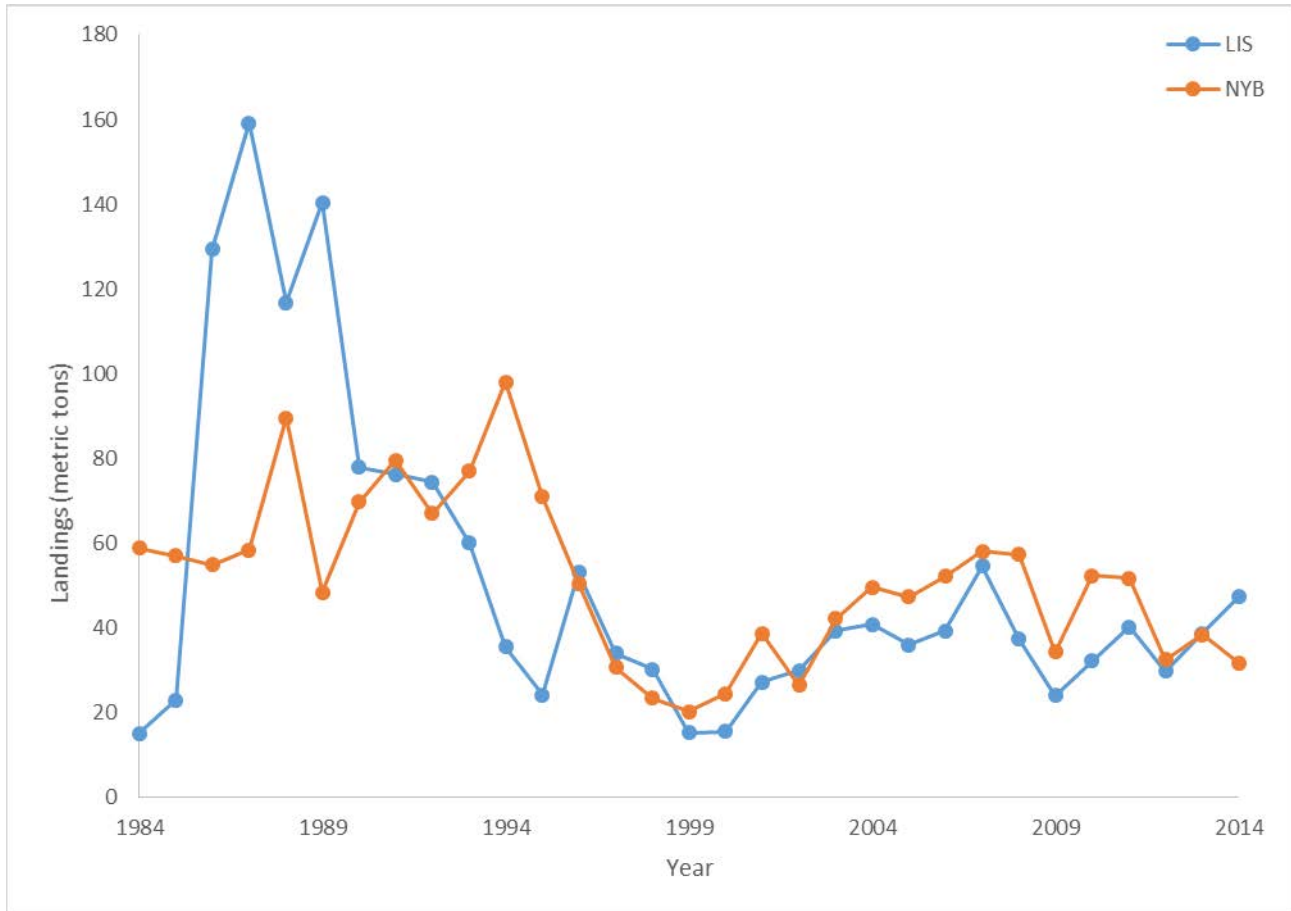
**Figure 4.1.** Recreational landings of Tautog in LIS and NJ-NYB, 1984-2014. LIS data from 1984-1987 are from CT only. Source: NOAA Fisheries Commercial Fisheries Statistics Database, MRFSS, and MRIP.



**Figure 4.2.** Proportion of recreational harvest (CT, NY, NJ combined) from the private/rental sector.

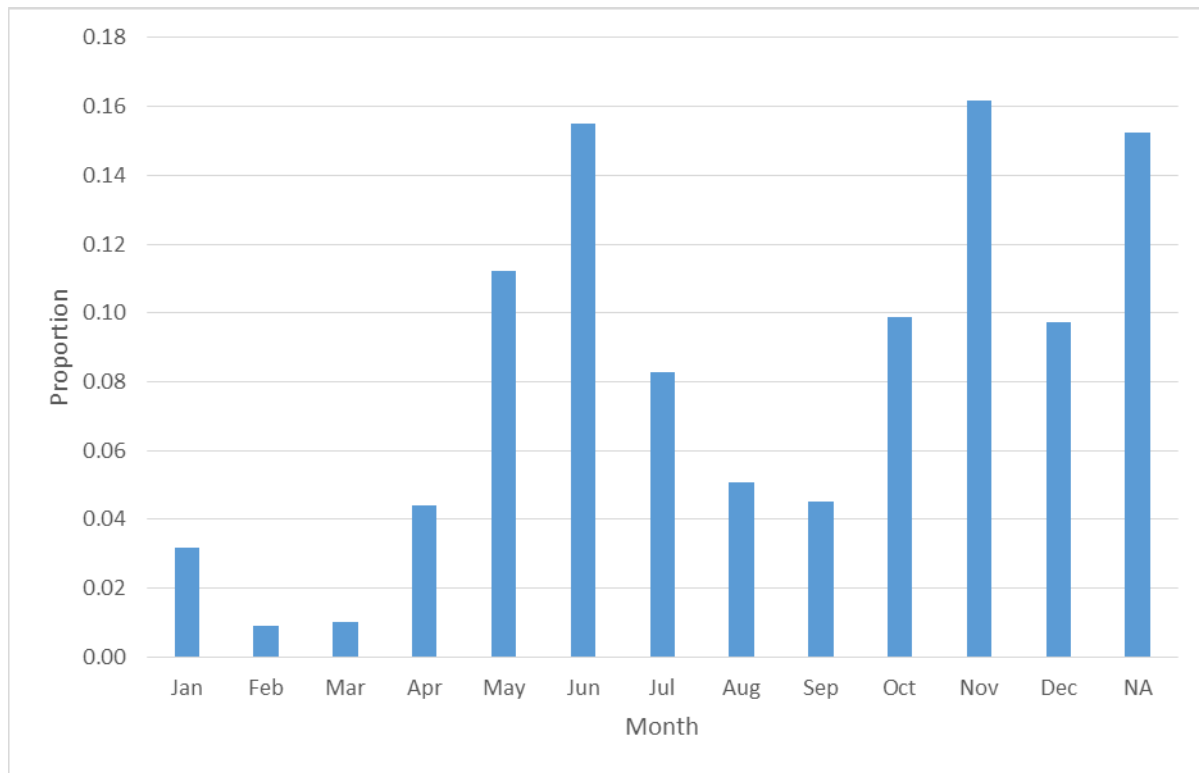


**Figure 4.3.** Commercial landings in LIS and NJ-NYB from 1990-2014. LIS values for 1984 and 1985 are from CT only. Source: NOAA Commercial Fisheries Database <http://www.st.nmfs.noaa.gov/commercial-fisheries/index>.

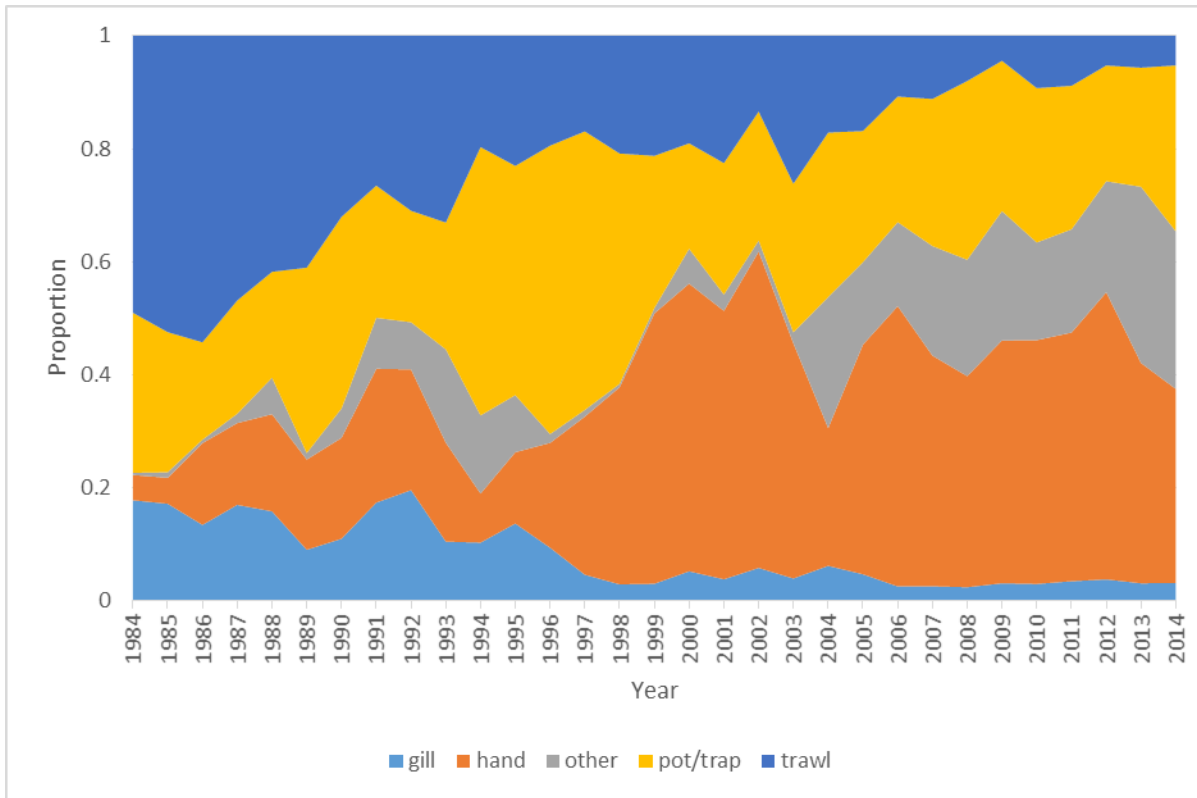




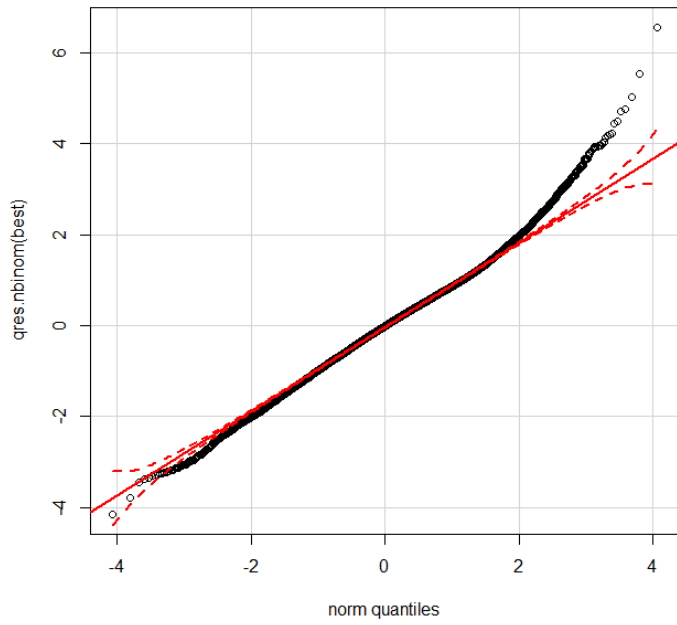
**Figure 4.4.** Relative activity of the commercial tautog fishery by month. Based on CT, NY and NJ commercial landings from 1990-2014.



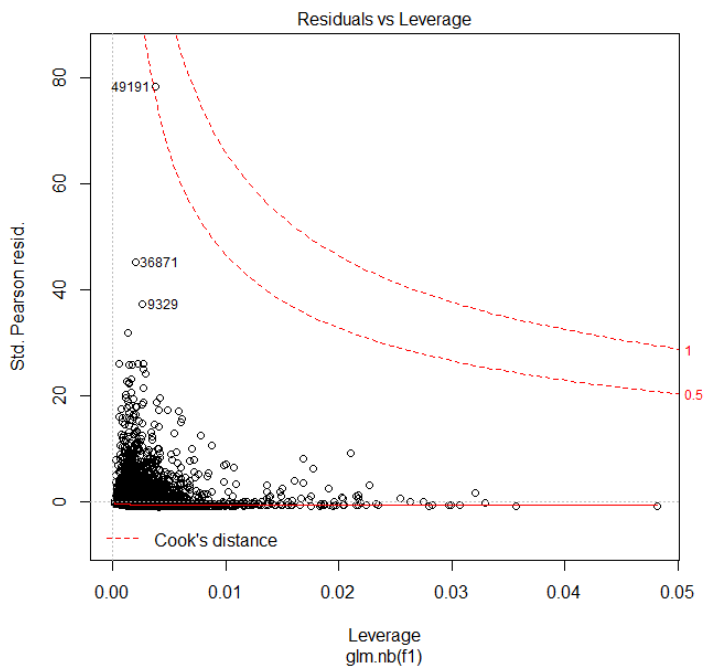
**Figure 4.5.** Relative commercial Tautog landings by fishing gear. Based on based on CT, NY and NJ commercial landings from 1984-2014.



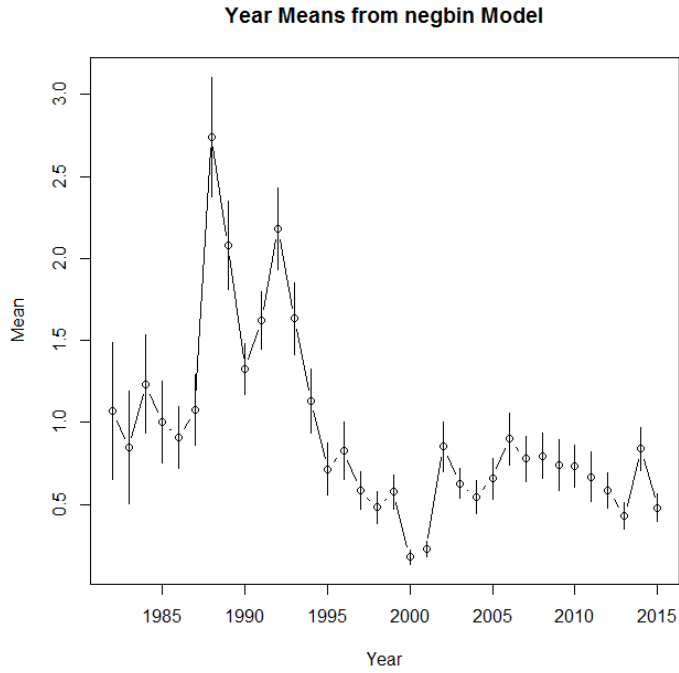
**Figure 5.1.** QQ plot for the negative binomial distribution of the final LIS recreational CPUE index model



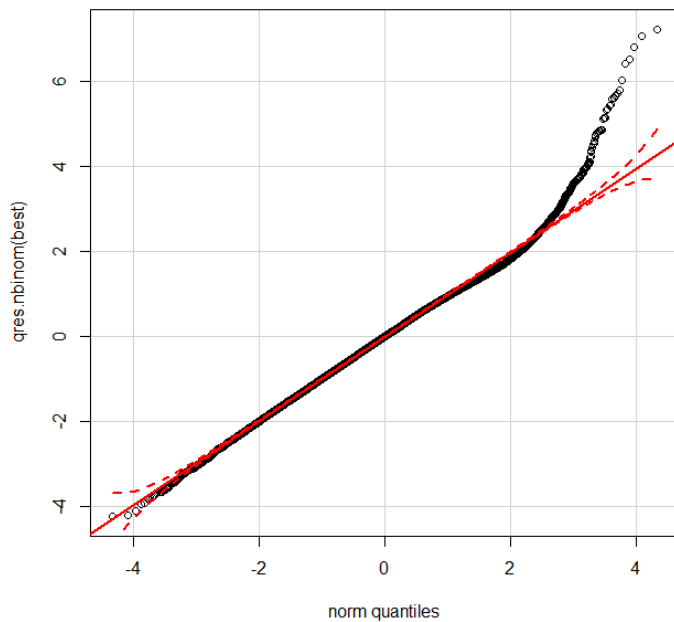
**Figure 5.2.** Cook's distance for the final LIS recreational CPUE index model



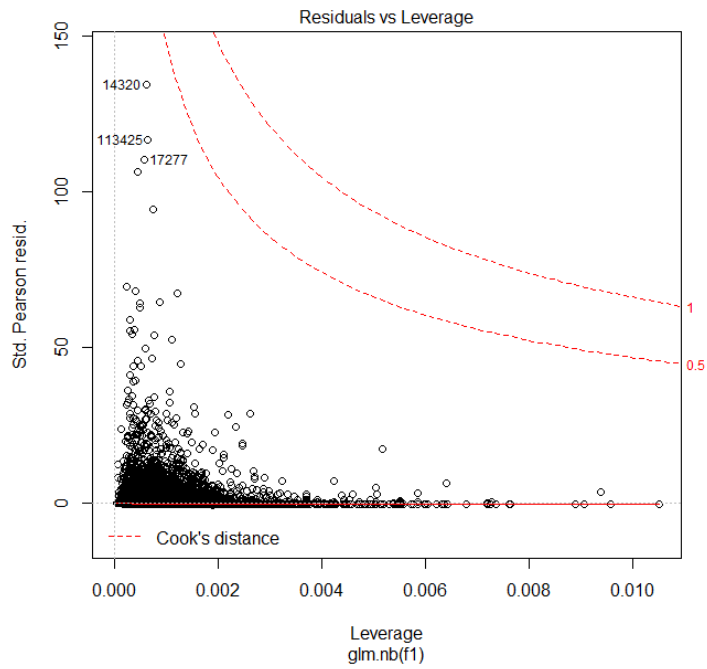
**Figure 5.3.** Final negative binomial distribution estimates of the LIS recreational CPUE index model



**Figure 5.4.** QQ plot for the negative binomial distribution of the final NJ-NYB recreational CPUE index model



**Figure 5.5.** Cook's distance for the final NJ-NYB recreational CPUE index model



**Figure 5.6.** Final negative binomial distribution estimates of the NJ-NYB recreational CPUE index model

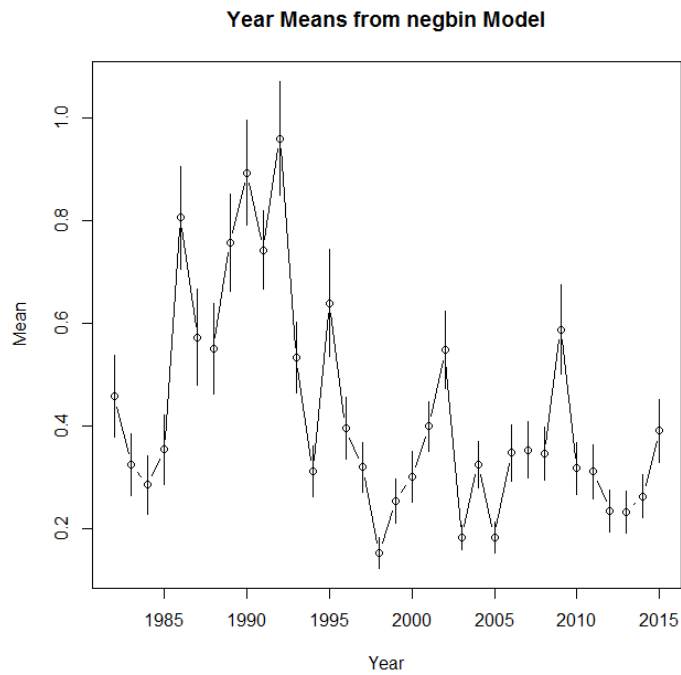


Figure 5.7. Histogram of catch data for the CT LISTS dataset.

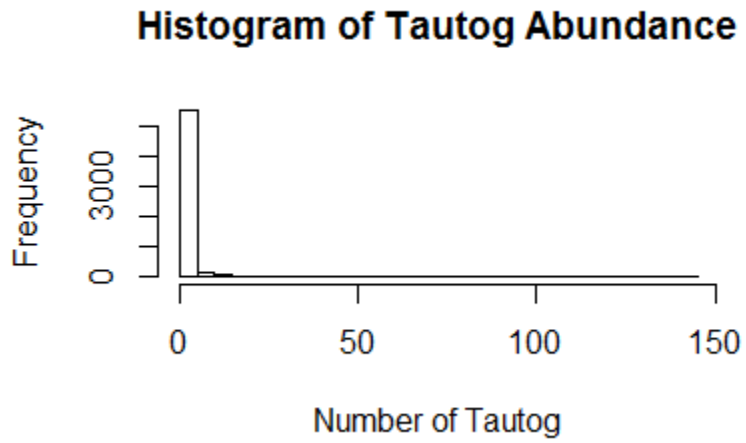


Figure 5.8. QQ Plot for negative binomial distribution for the final model used for the CT LISTS.

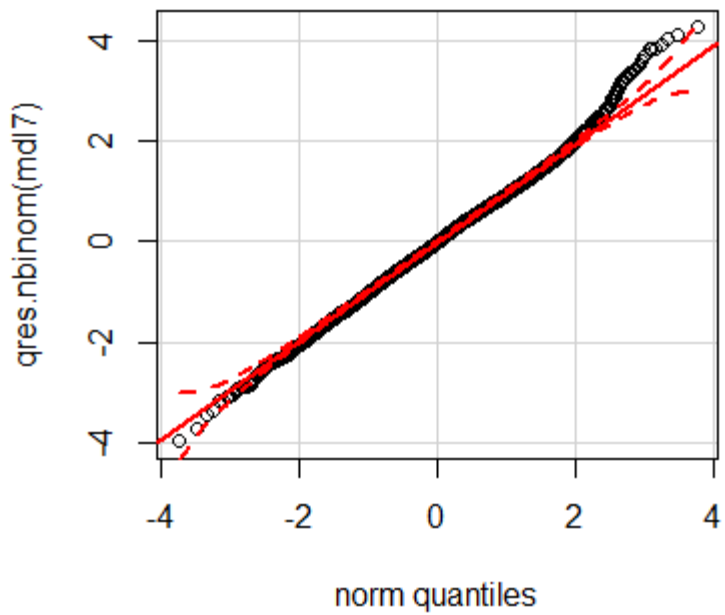


Figure 5.9. Cook's distance plot for the final model used for the CT LISTS.

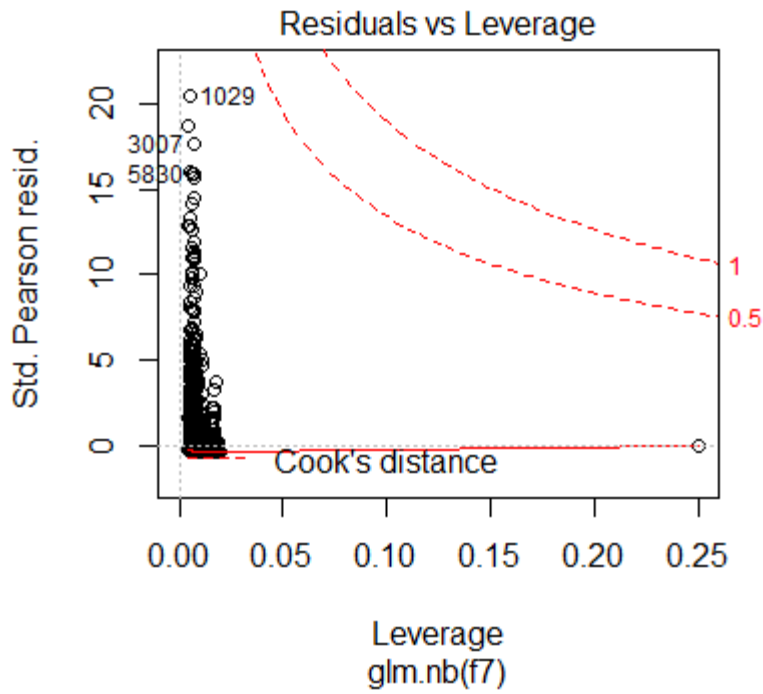
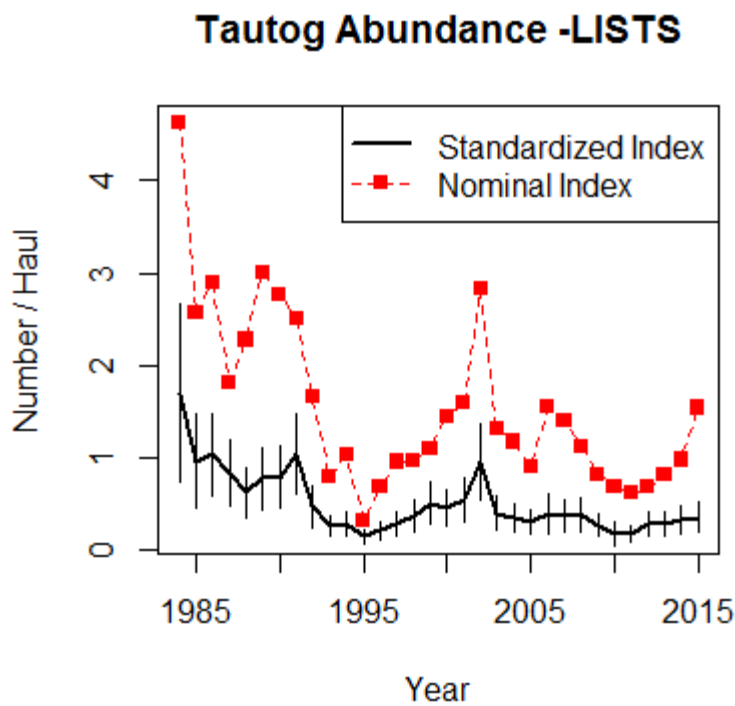


Figure 5.10. Standardized index versus the nominal index for the CT LISTS.



**Figure 5.11.** Annual abundance of Tautog eggs and larvae in the Millstone entrainment samples. Error bars represent confidence interval. For clarity, the interval for eggs is displayed in the positive direction while the interval for larvae is displayed in the negative direction.

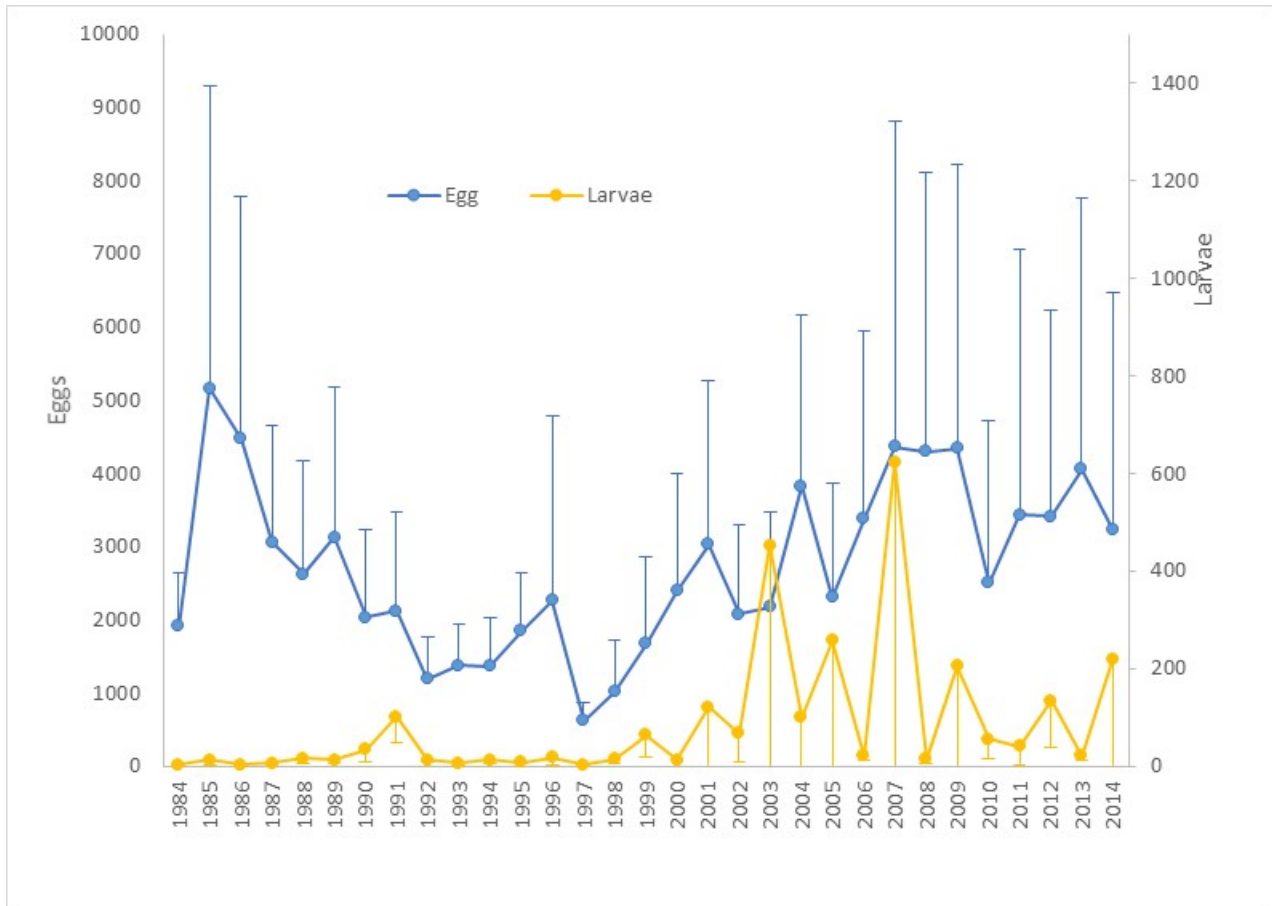




Figure 5.12. Histogram of catch data for the Peconic Bay Trawl Survey dataset.

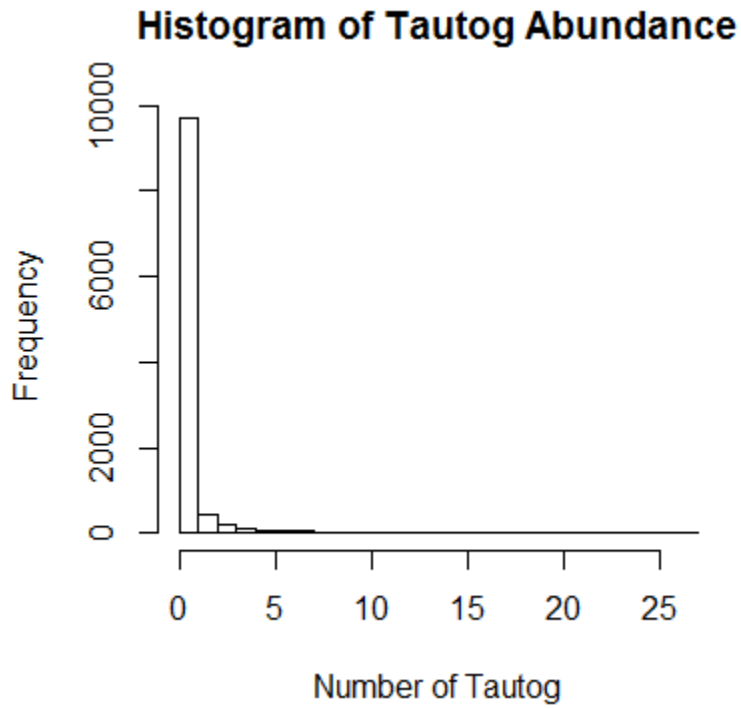


Figure 5.13. QQ Plot for negative binomial distribution for the final model used for the NYPBTS.

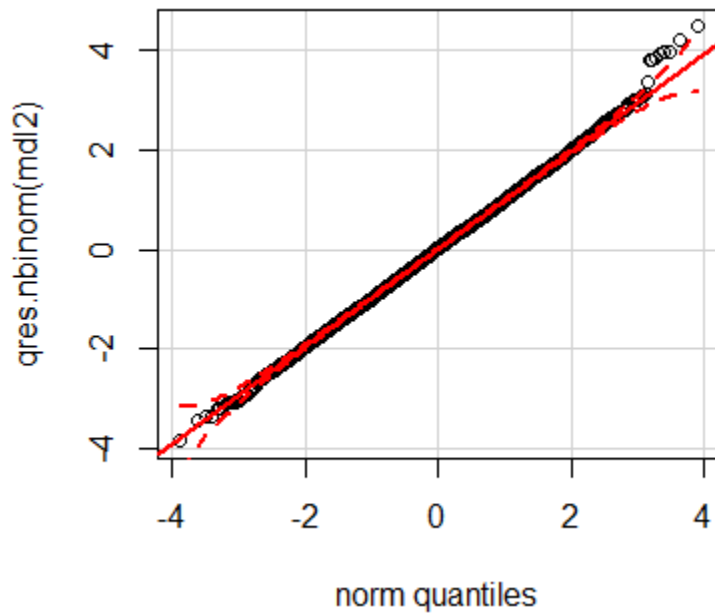


Figure 5.14. Cook's distance plot for the final model used for the NYPBTS.

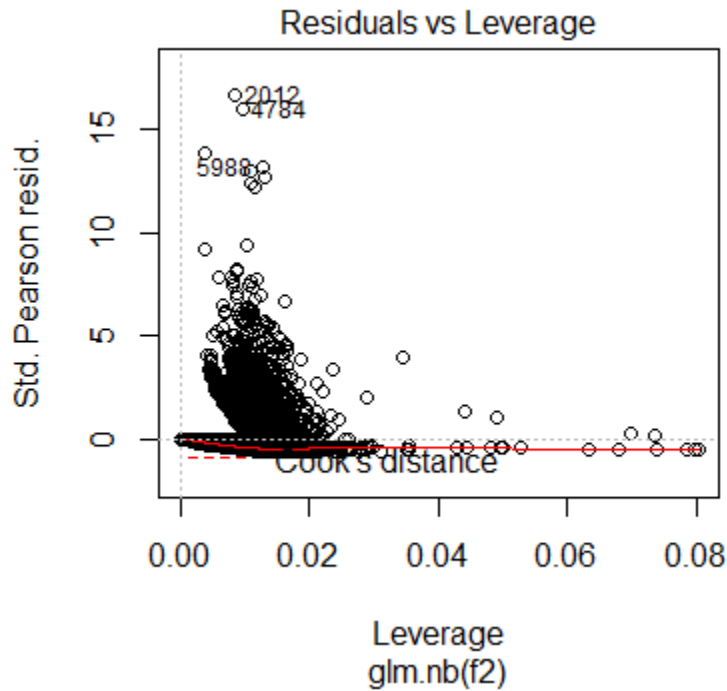
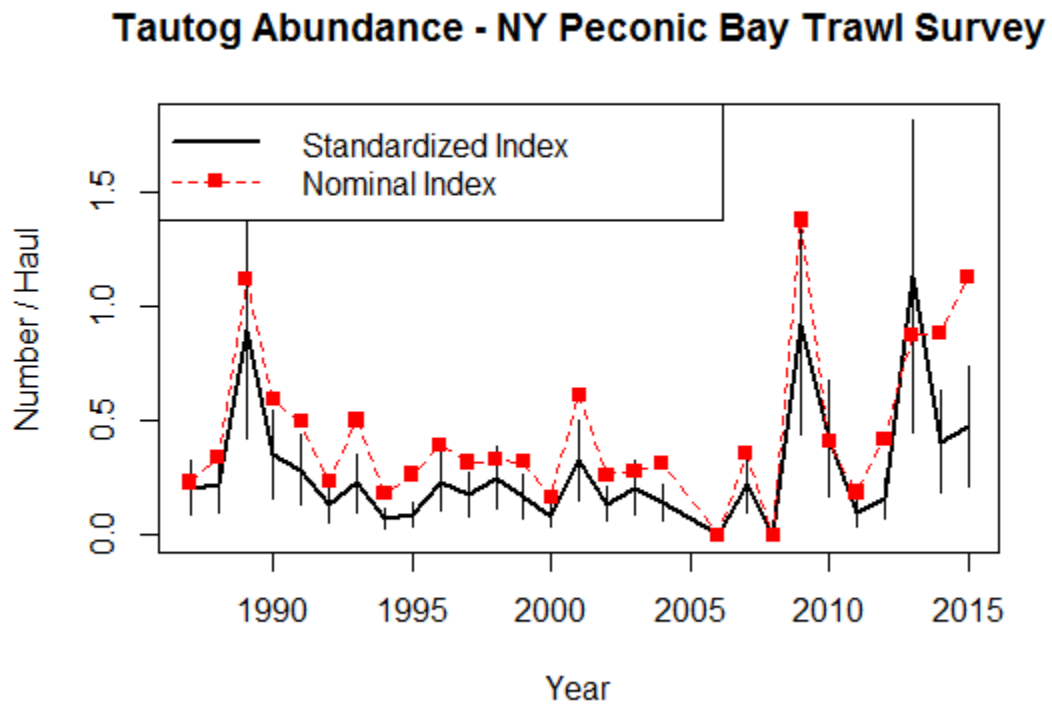
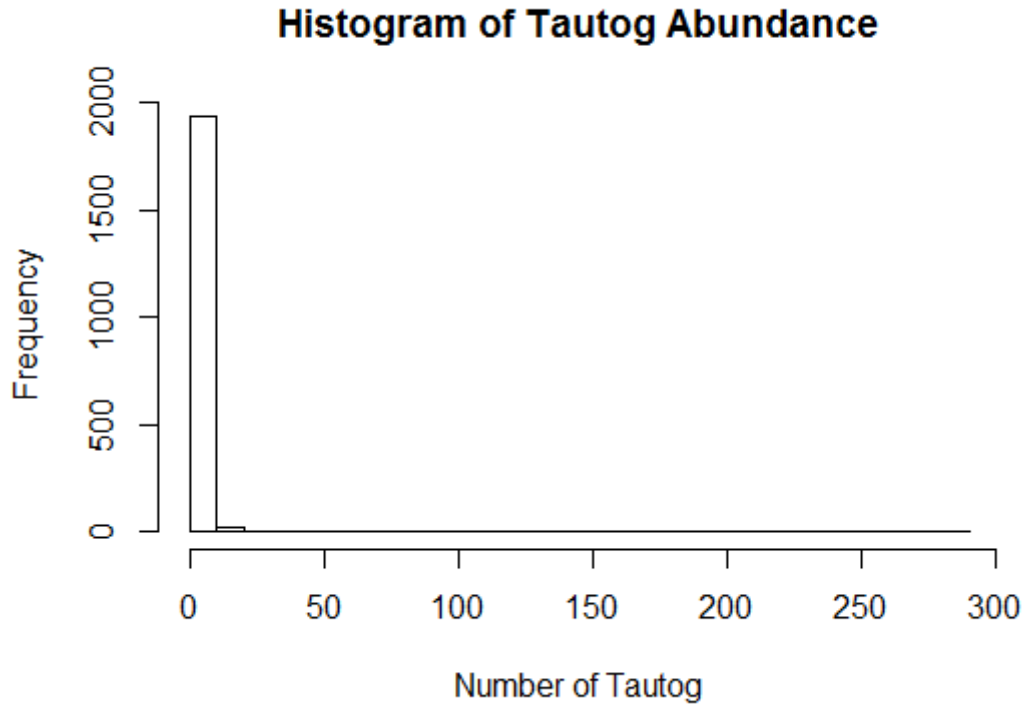


Figure 5.15. Standardized index versus the nominal index for the NYPBTS.



**Figure 5.16.** Histogram of catch data for the LIS portion of the NYWLISS dataset.



**Figure 5.17.** QQ Plot for negative binomial distribution for the final model used for the LIS portion of the NYWLISS.

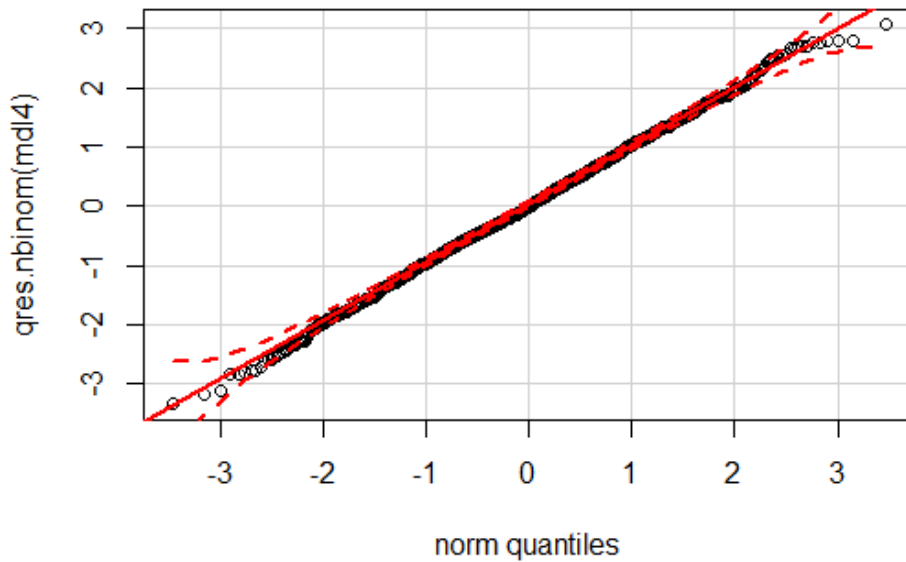


Figure 5.18. Cook's distance plot for the final model used for the LIS portion of the NYWLISS.

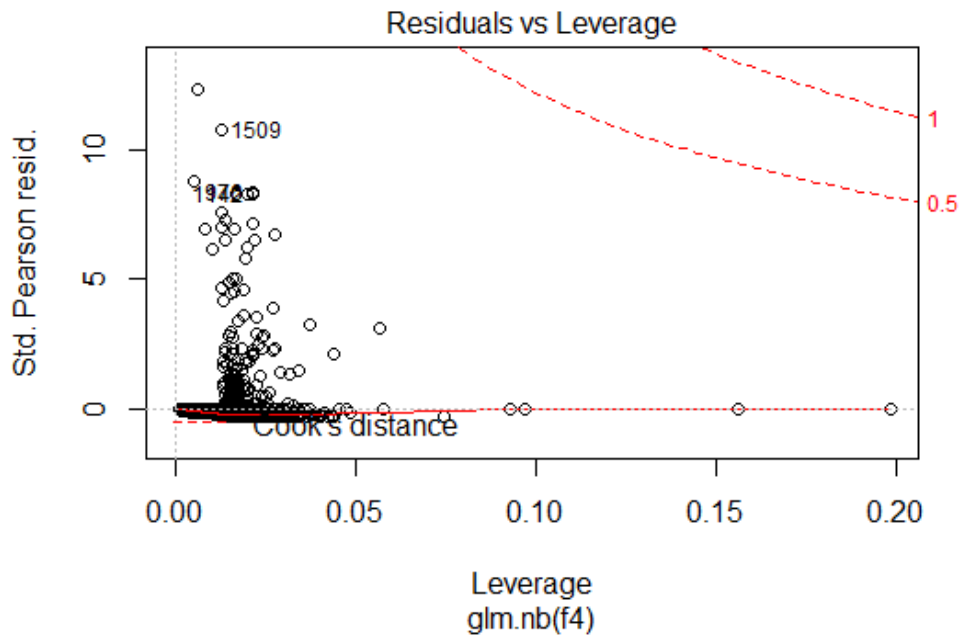
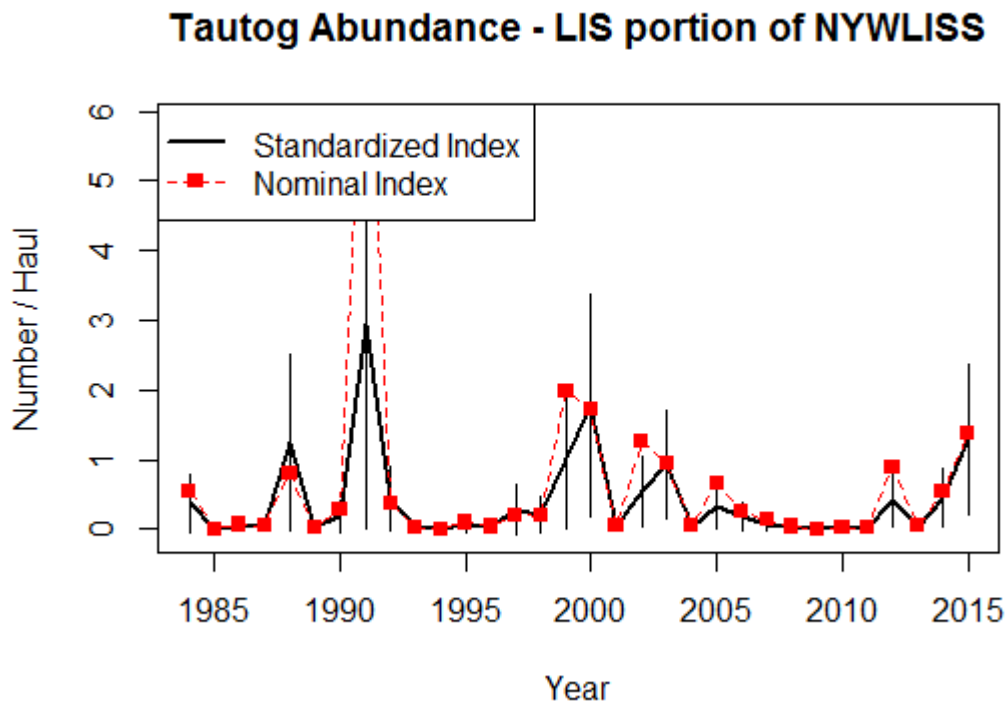
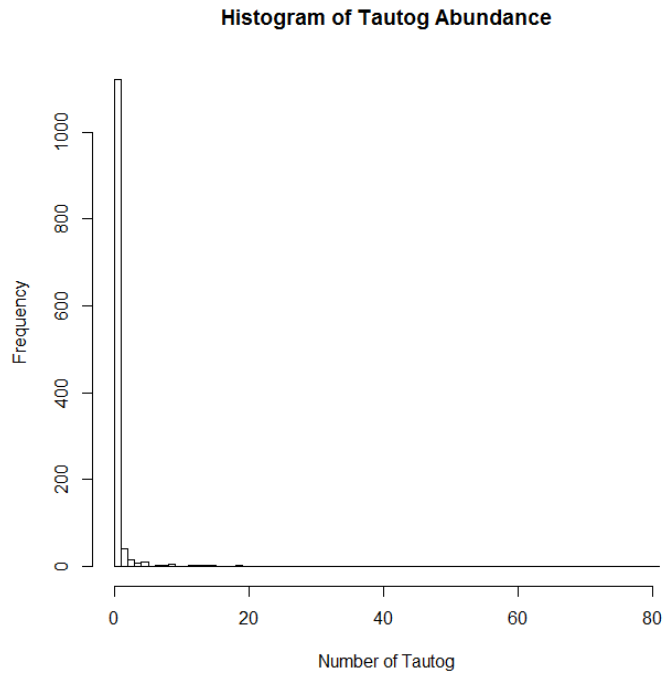


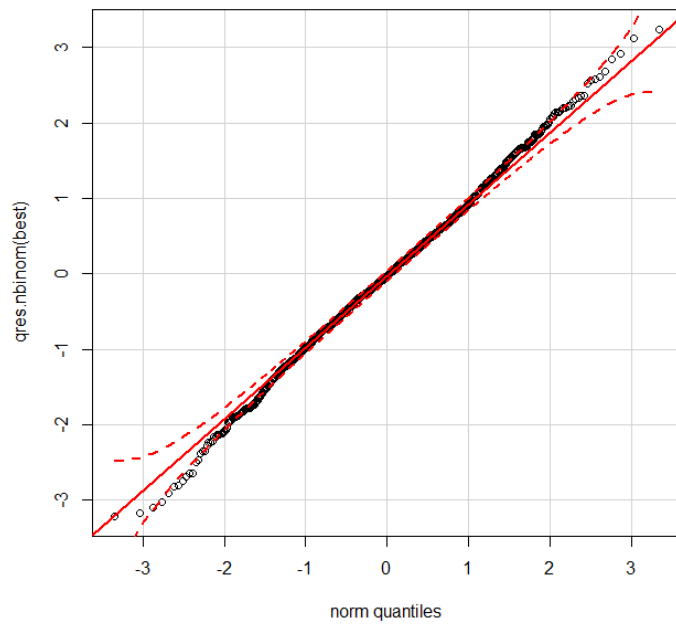
Figure 5.19. Standardized index versus the nominal index for the LIS portion of the NYWLISS.



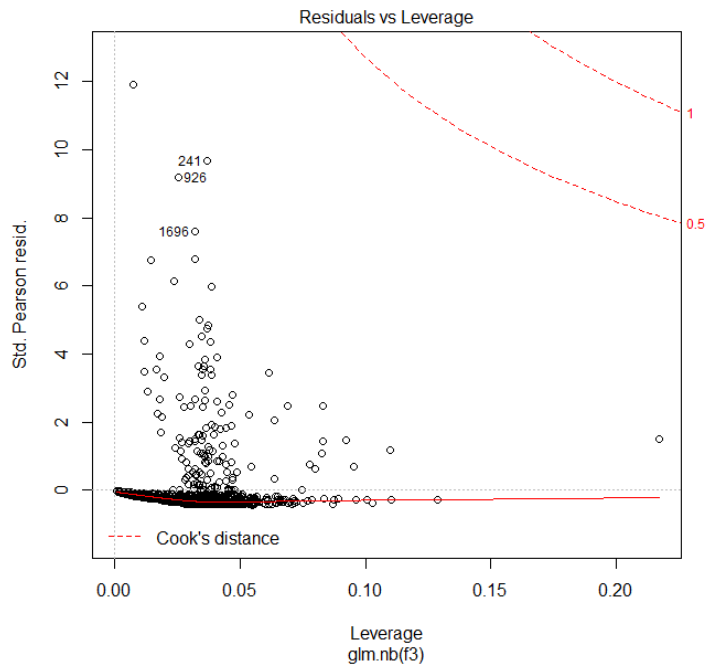
**Figure 5.20.** Histogram of catch data for the NJ-NYB portion of the NYWLISS dataset.



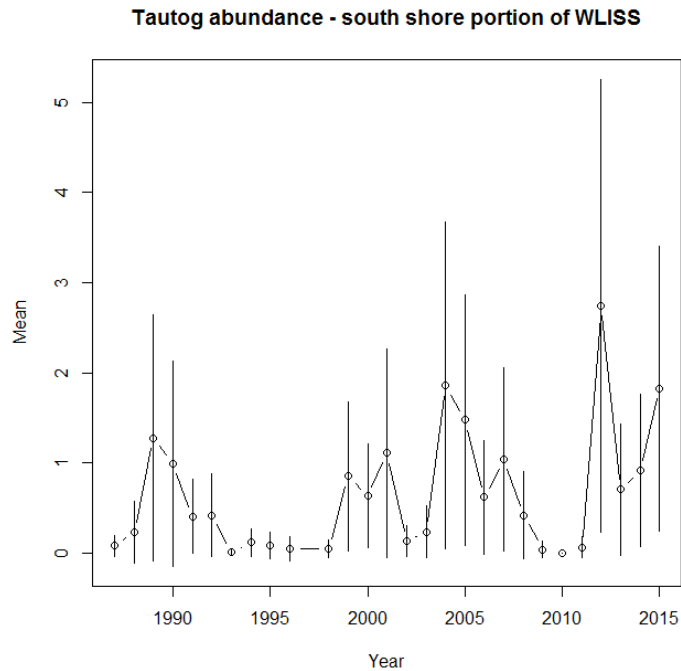
**Figure 5.21.** QQ plot of the negative binomial distribution for the final model of the NJ-NYB portion of the WLISS.



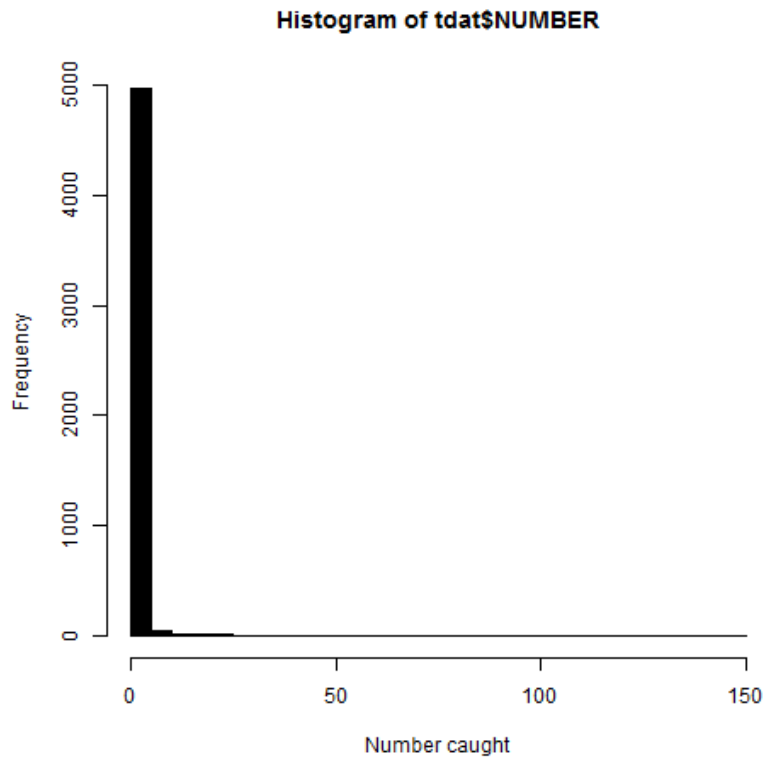
**Figure 5.22.** Cook's distance for the final model of the NJ-NYB portion of the WLISS



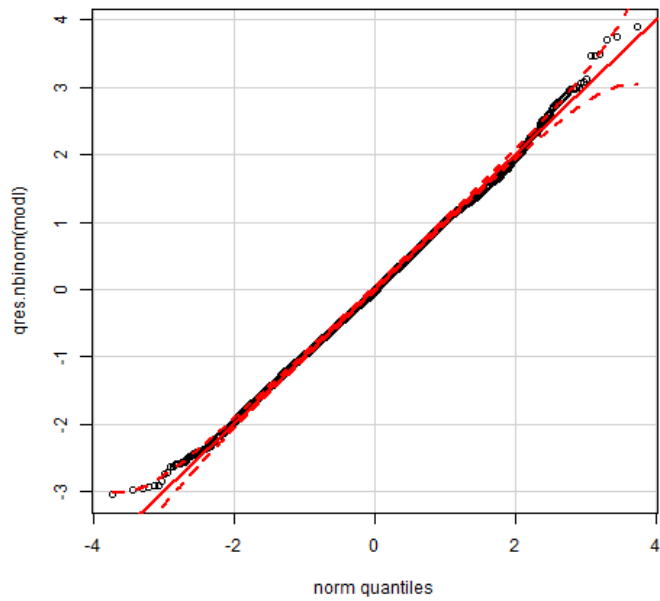
**Figure 5.23.** Final model estimates for the negative binomial GLM of the NJ-NYB portion of the WLISS.



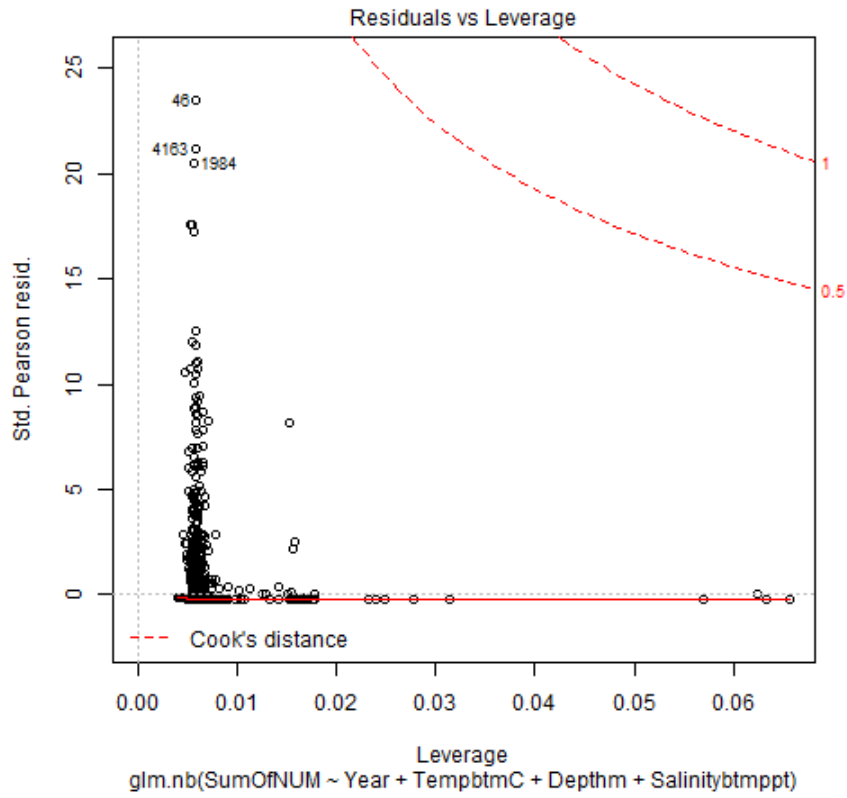
**Figure 5.24.** Catch histogram for the New Jersey Ocean Trawl survey



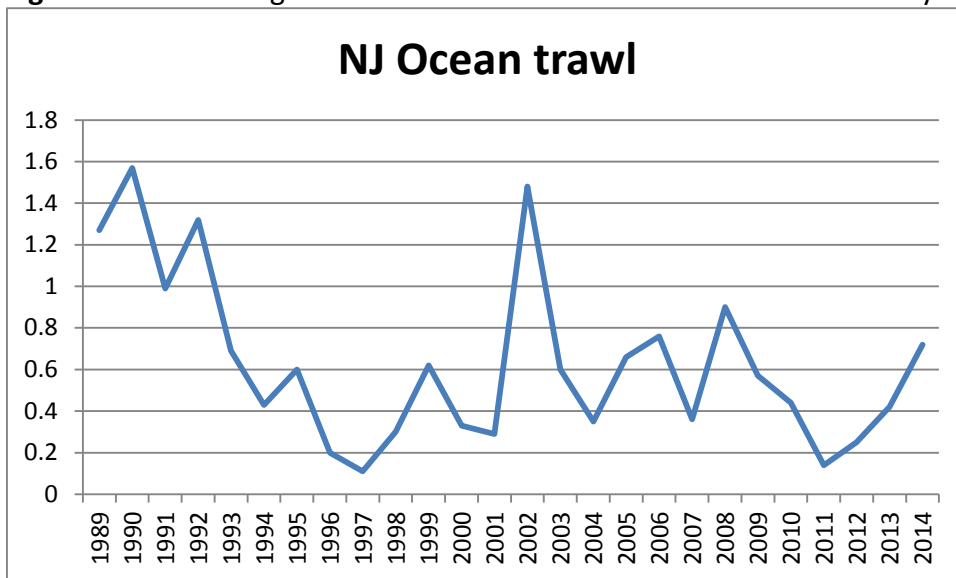
**Figure 5.25.** QQ plot of the negative binomial distribution for the NJ Ocean Trawl survey



**Figure 5.26.** Cook's distance for the final model of the NJ Ocean Trawl survey

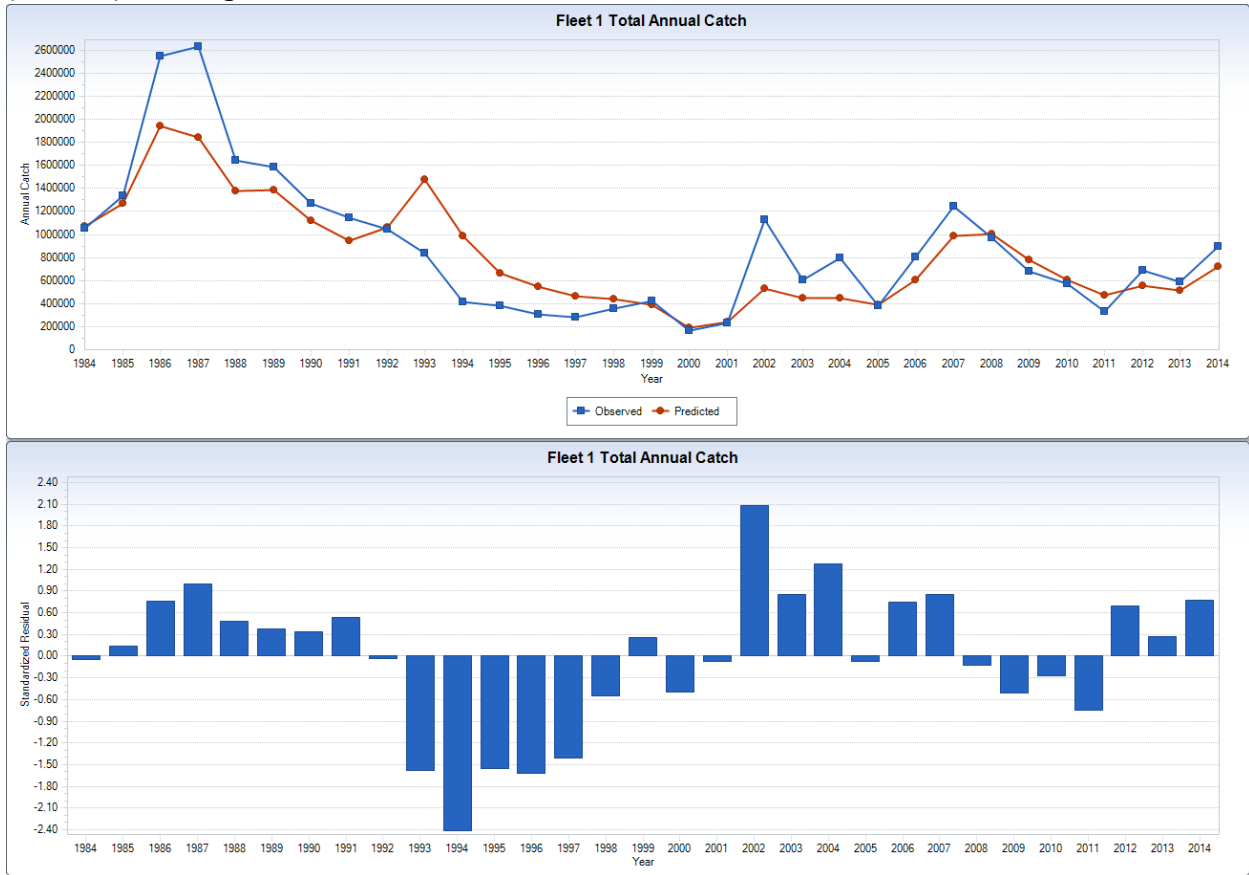


**Figure 5.27.** Final negative binomial model of the NJ ocean trawl survey





**Figure 6.1.** Observed and predicted total catch in weight (top) and standardized residuals (bottom) for Long Island Sound.



**Figure 6.2.** Observed and predicted fishery independent indices (left) and their standardized residuals (right) for Long Island Sound.

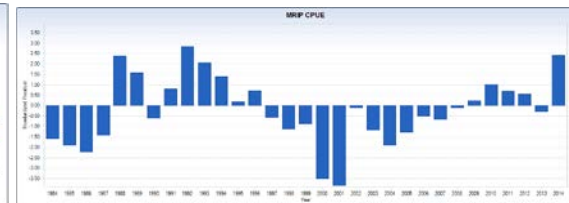
LISTS



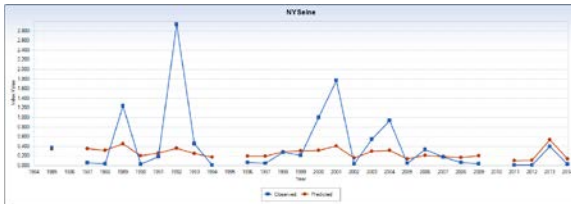
NYTrawl



MRIP CPUE



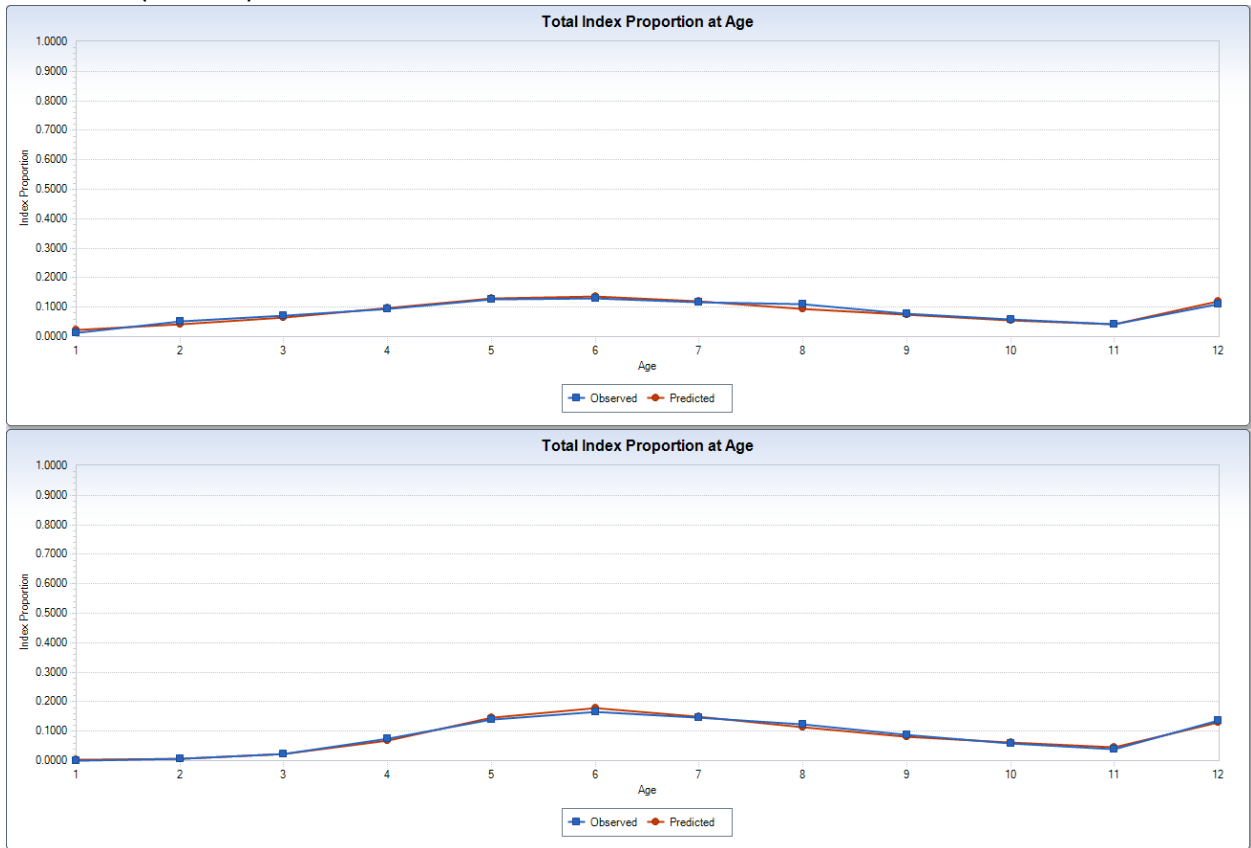
NYSeine



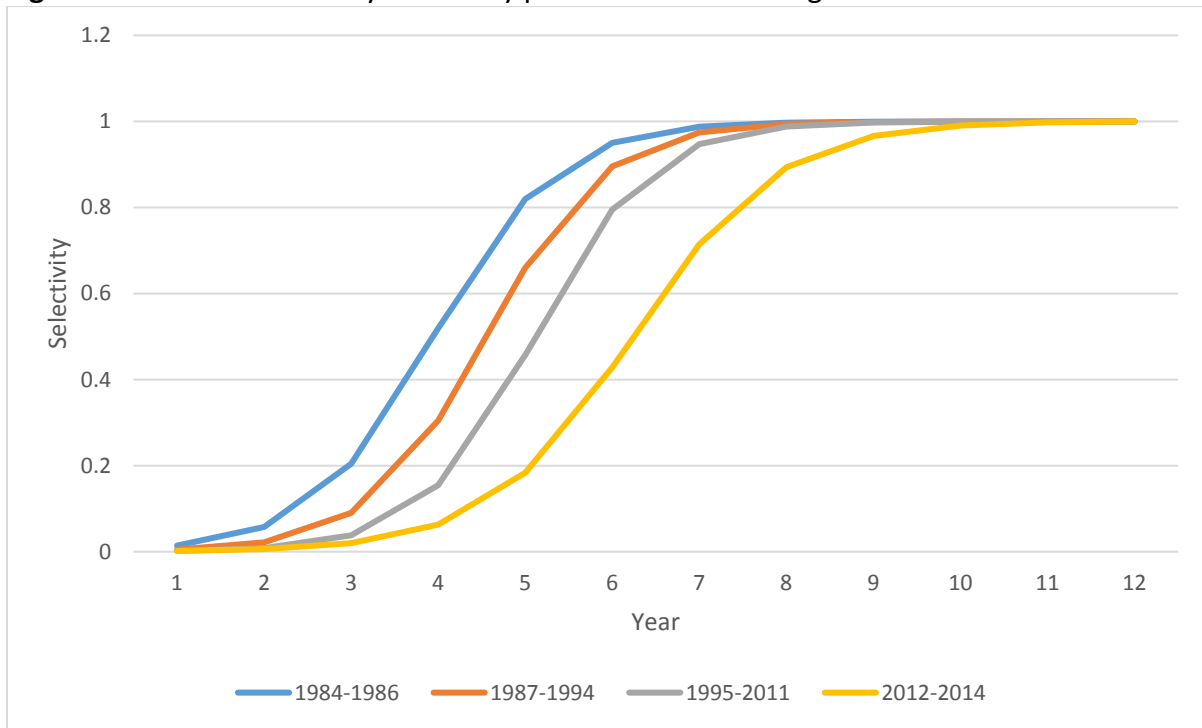
**Figure 6.3.** Total observed and predicted catch-at-age for Long Island Sound.



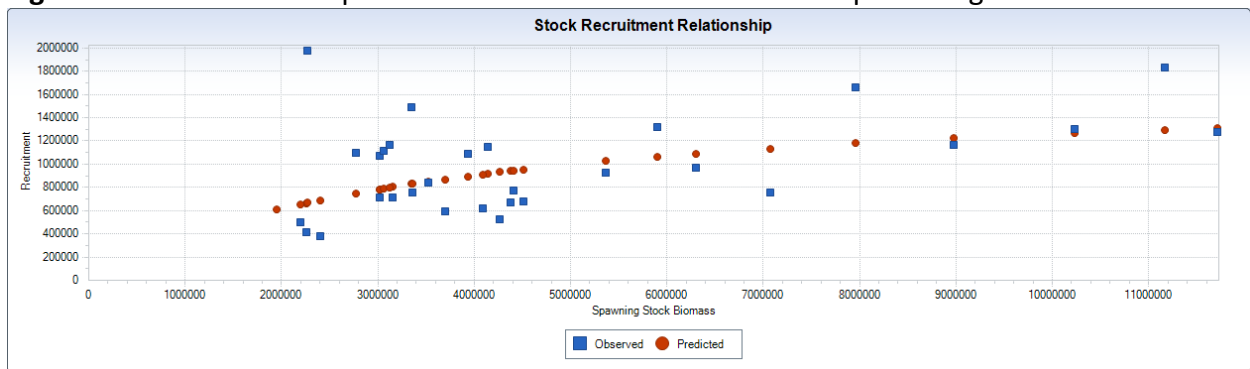
**Figure 6.4.** Total observed and predicted total index-at-age for Long Island Sound, LISTS (top) and MRIP (bottom).



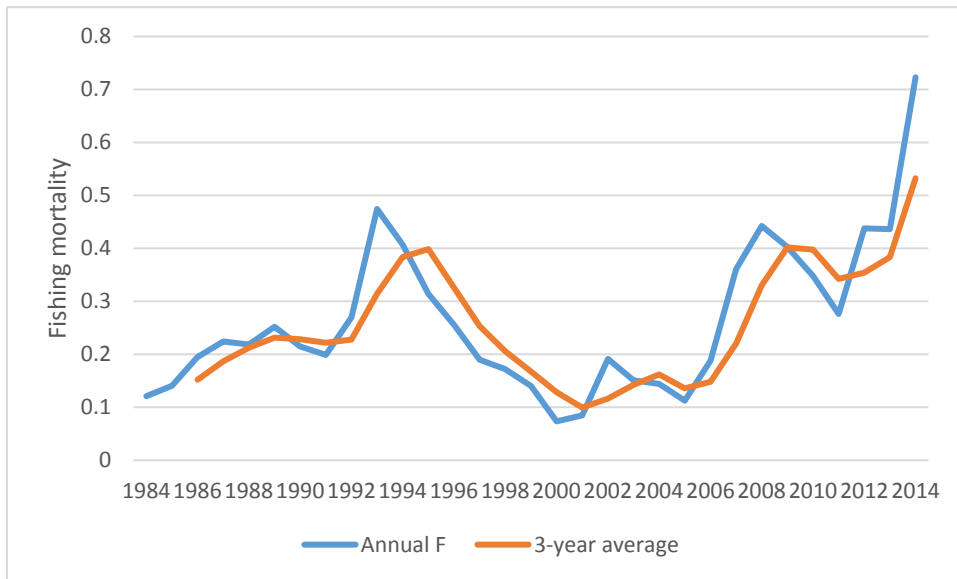
**Figure 6.5.** Estimated fishery selectivity patterns for the LIS regional model.



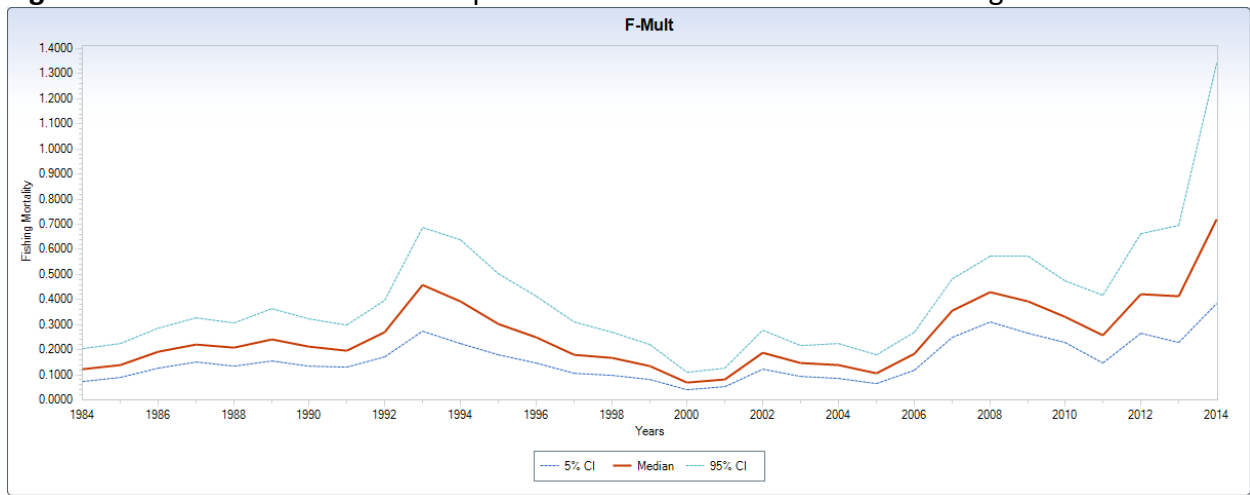
**Figure 6.6.** Observed and predicted stock-recruitment relationship for Long Island Sound



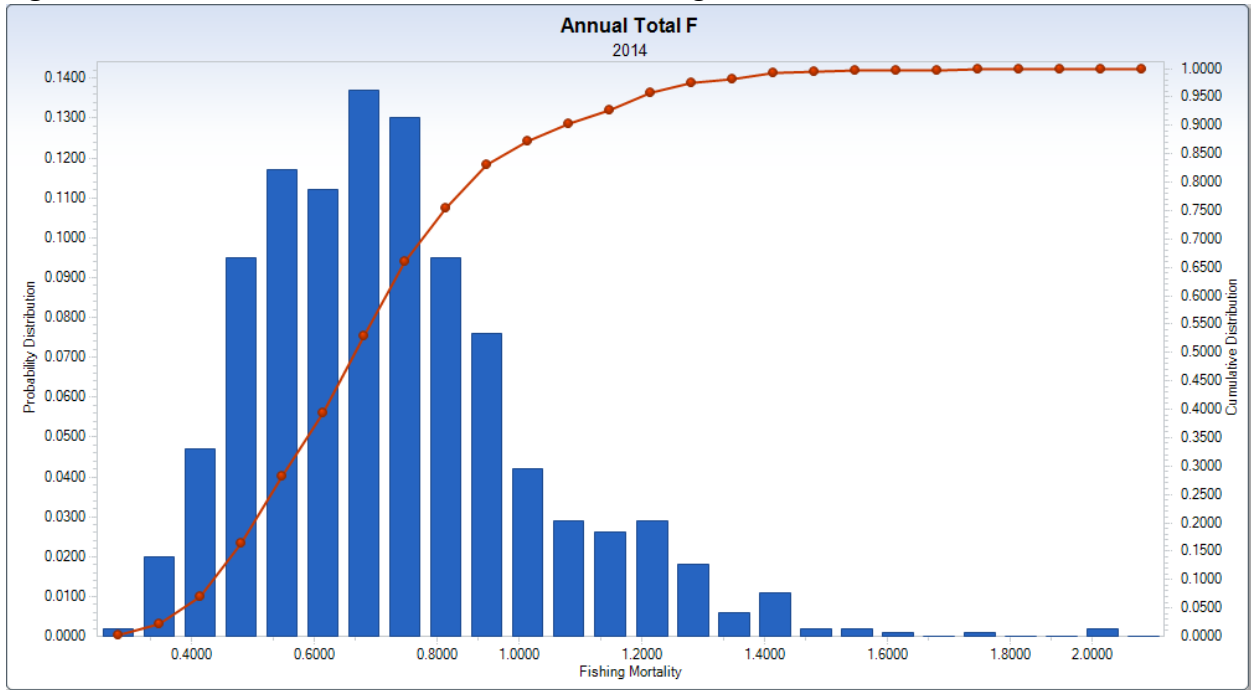
**Figure 6.7.** Annual and three-year average estimates of F for Long Island Sound.



**Figure 6.8.** Median and 5<sup>th</sup> and 95<sup>th</sup> percentile MCMC estimates of F for Long Island Sound.

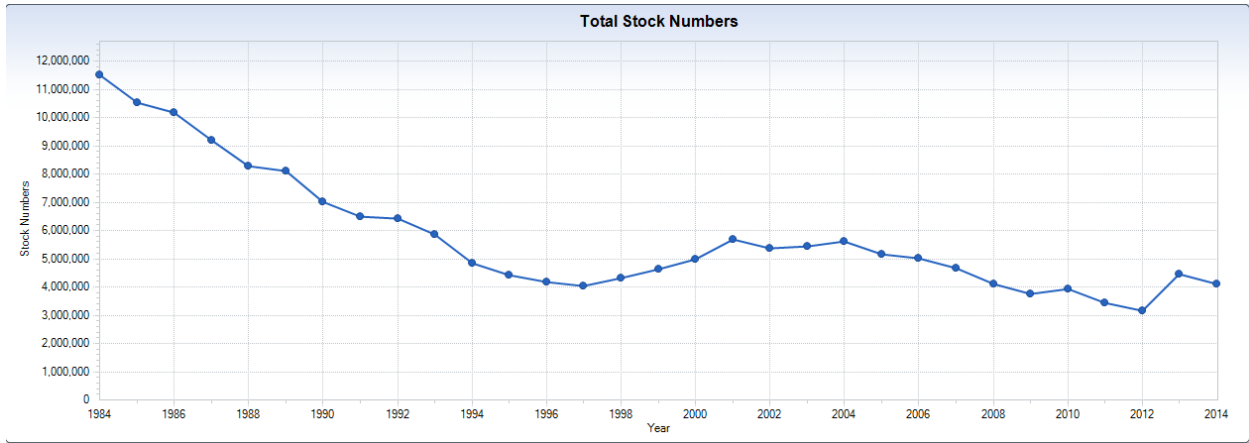


**Figure 6.9.** MCMC distributions on terminal F for Long Island Sound.

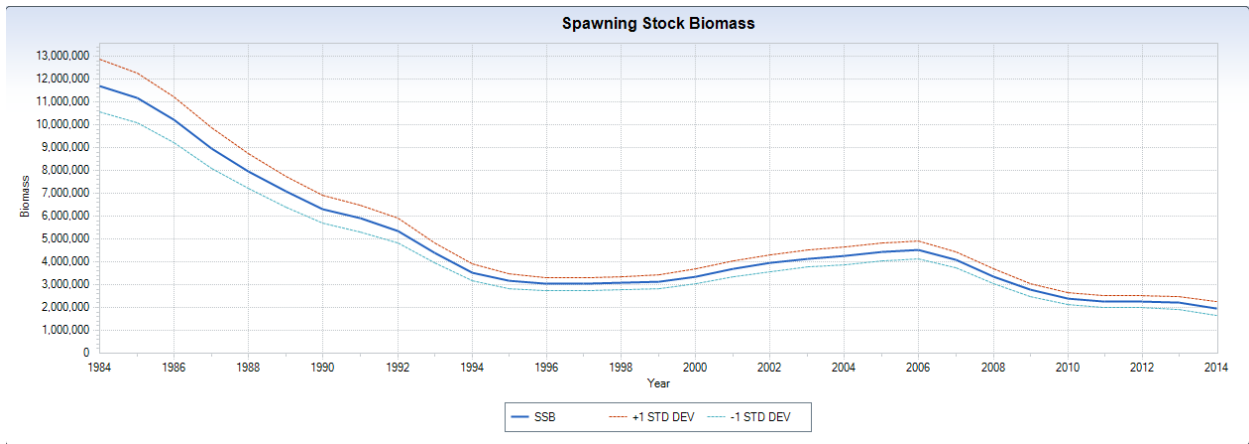


**Figure 6.10.** (a) Total stock numbers, (b) spawning stock biomass and (c) observed recruitment (bottom) for Long Island Sound.

a.



b.

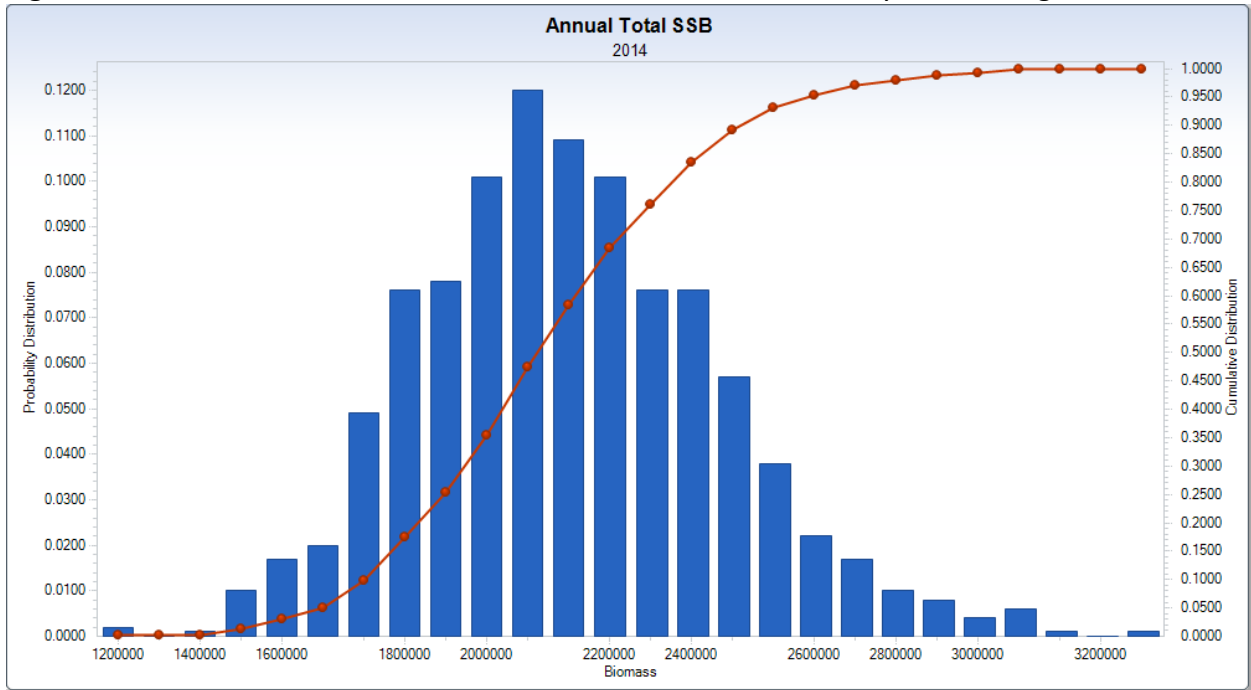


c.





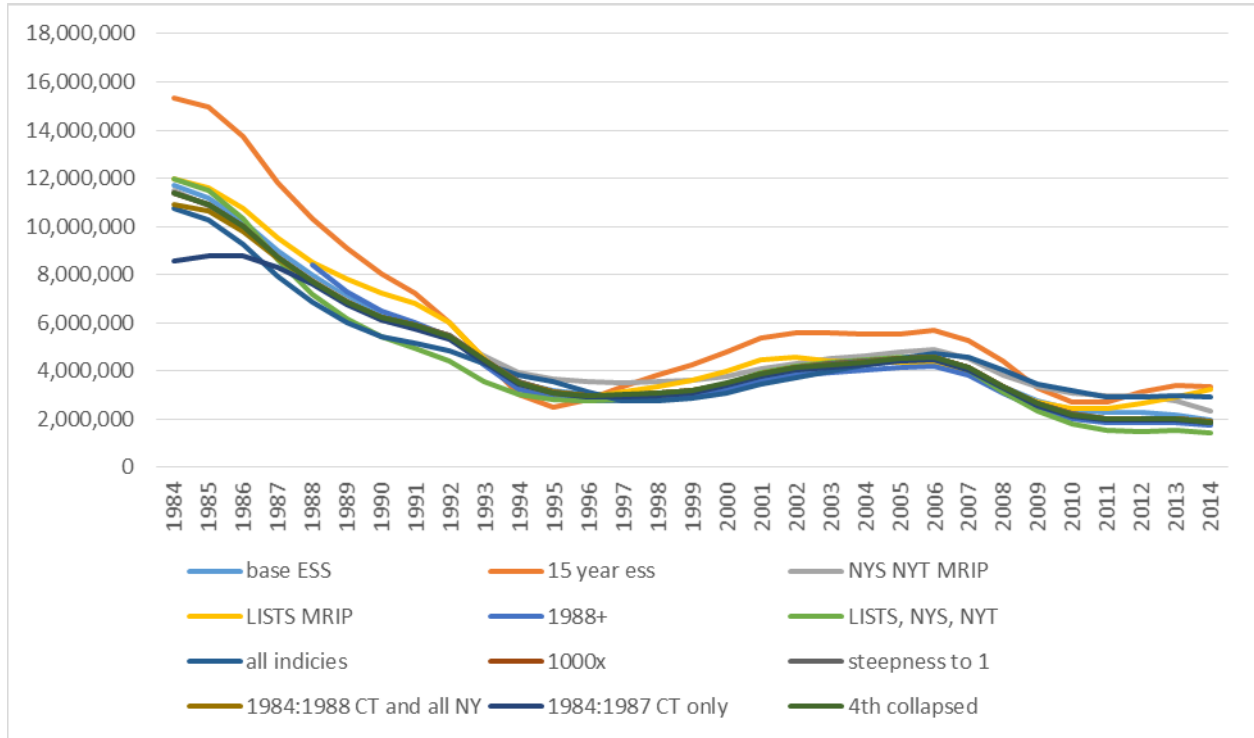
**Figure 6.11.** Distribution of MCMC estimates of SSB in the terminal year for Long Island Sound.



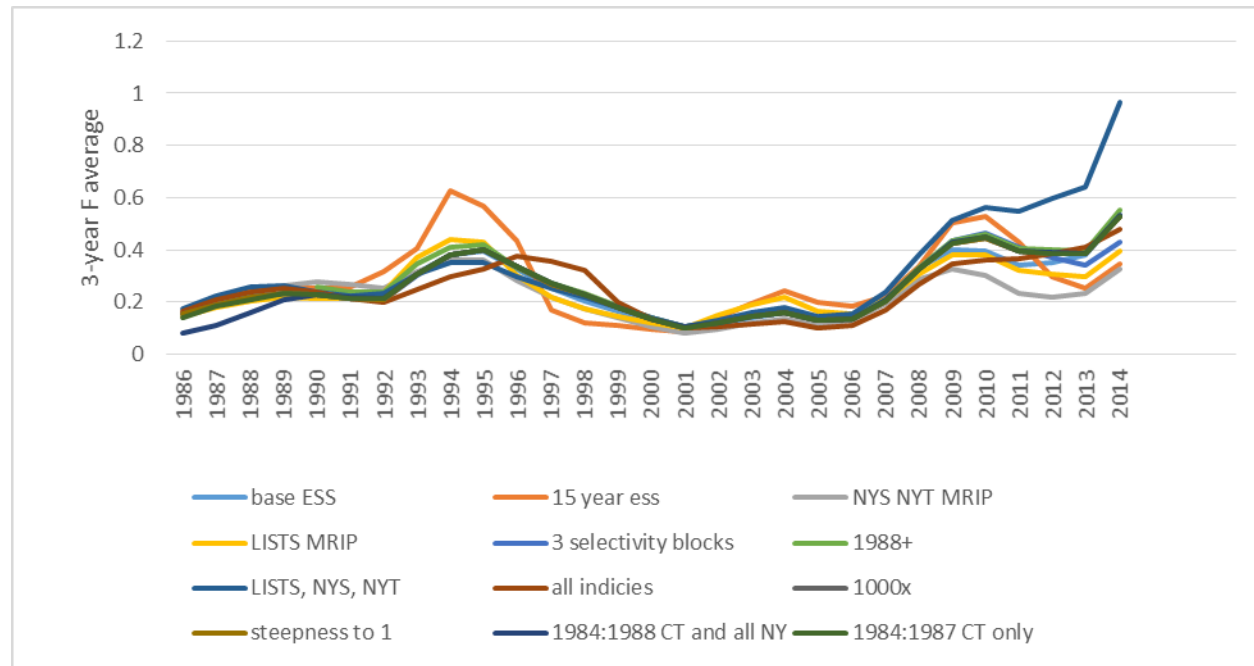
**Figure 6.12.** Sensitivity analyses for LIS

(a) SSB trajectories for different sensitivity runs (b) F 3 year average trajectories for different sensitivity runs, and (c) estimated number of recruits for different sensitivity runs.

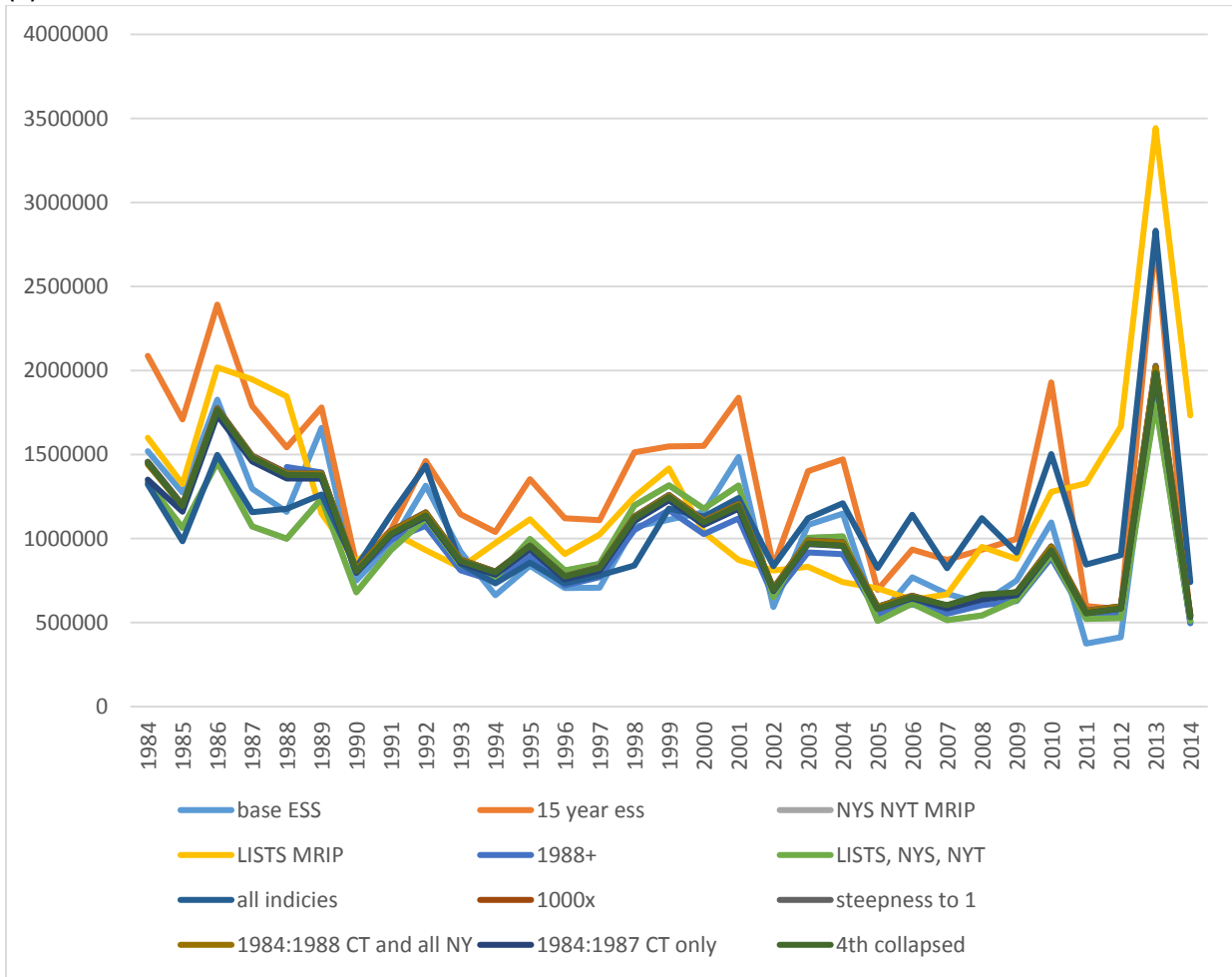
(a)



(b)

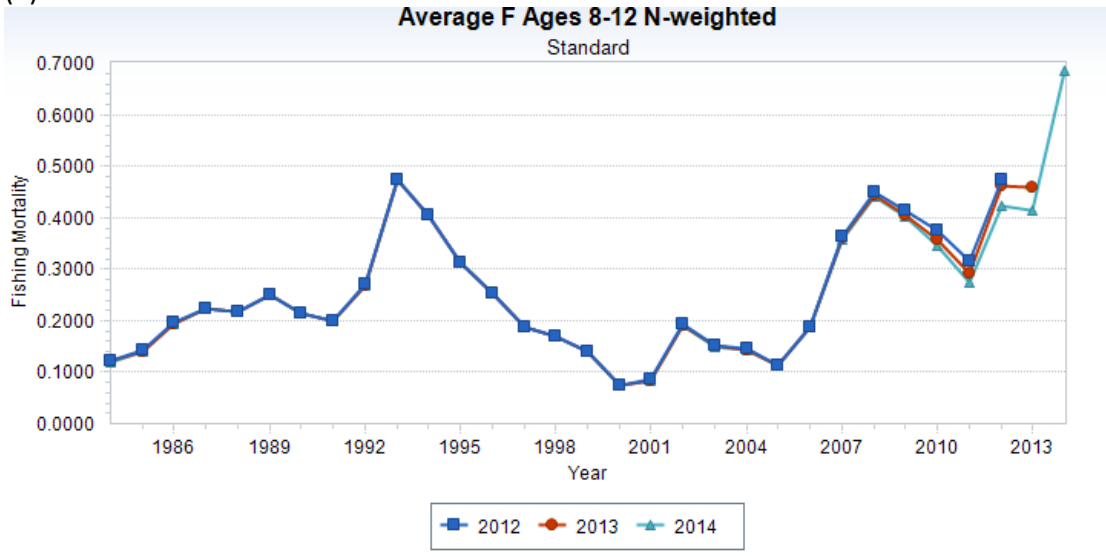


**Figure 6.12. (cont'd)**  
 (c)

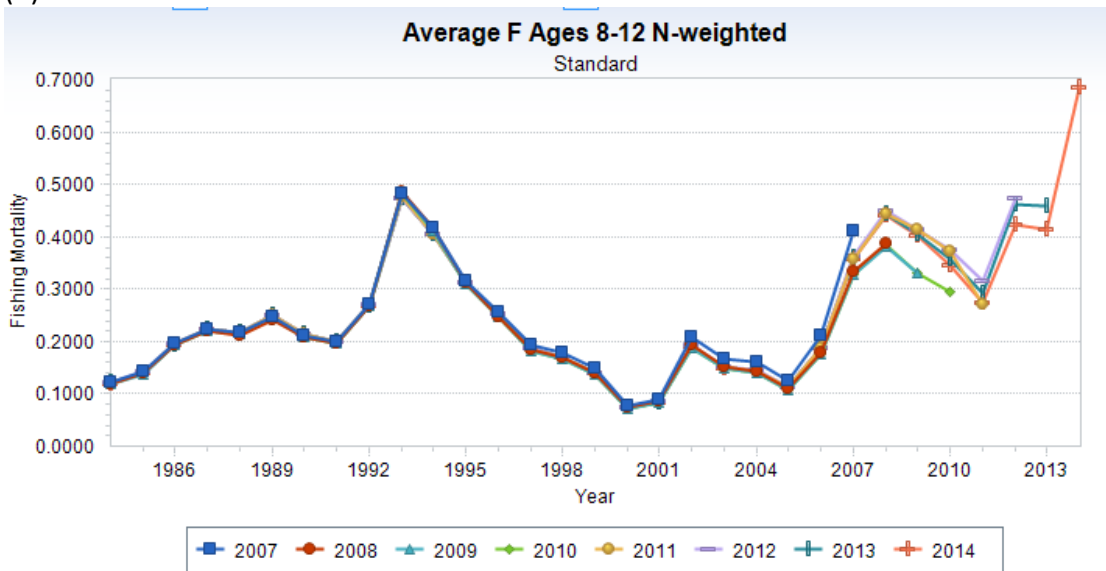


**Figure 6.13.** Retrospective results for F (a) 12-year plus group, start 2012, (b) 12-year plus group start 2007, (c) 15-year plus group, start 2012, (d) 15-year plus group start 2007 the LIS regional models.

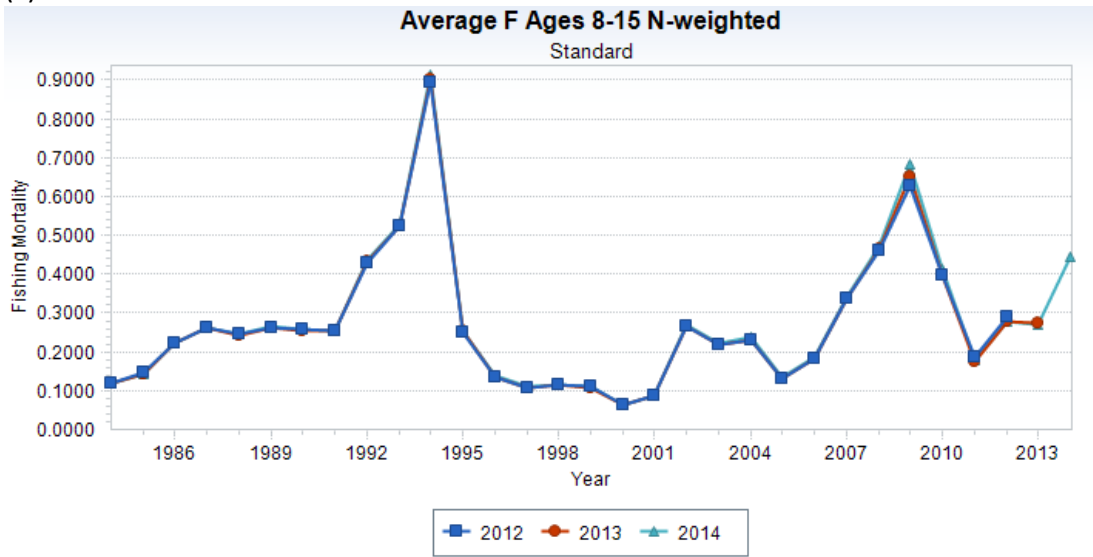
(a)



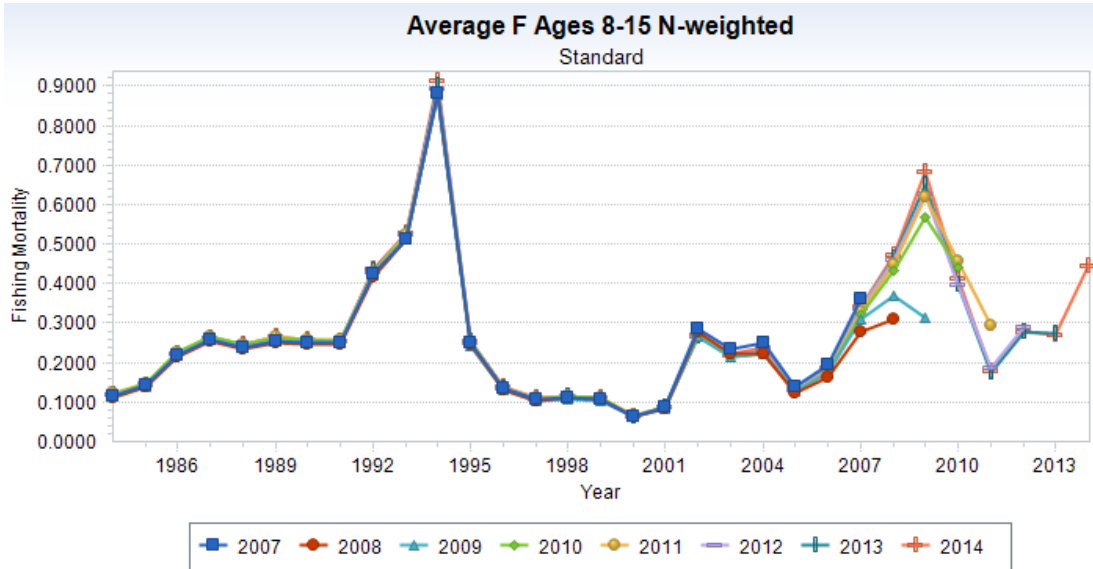
(b)



(c)

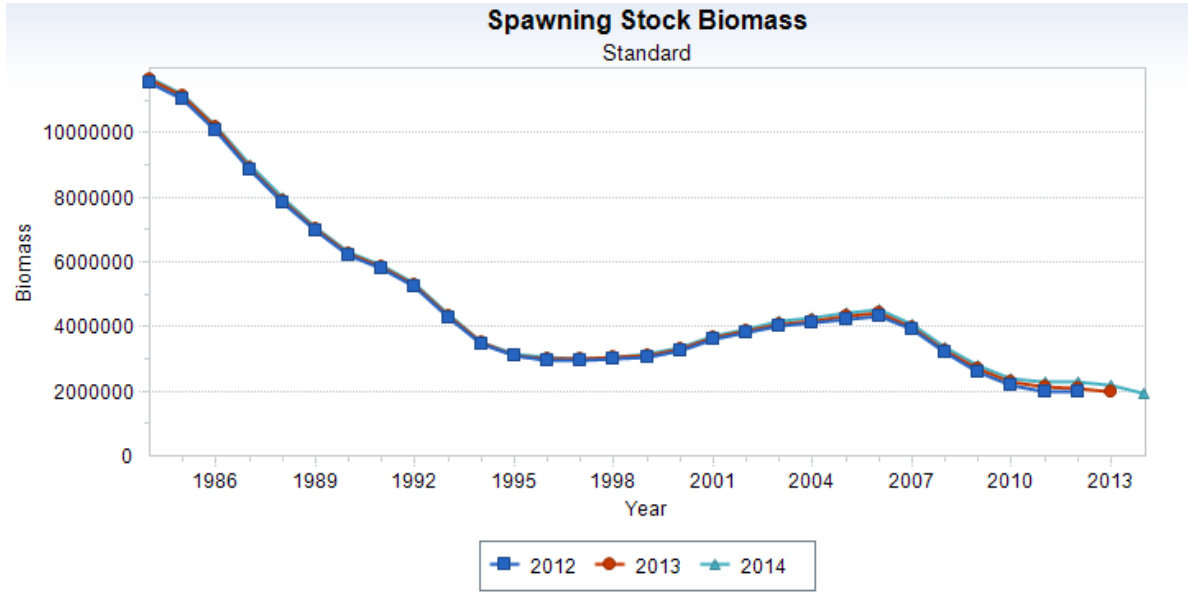


(d)



**Figure 6.14.** Retrospective results for SSB (a) 12-year plus group, start 2012, (b) 12-year plus group start 2007, (c) 15-year plus group, start 2012, (d) 15-year plus group start 2007 the LIS regional models.

(a)



(b)

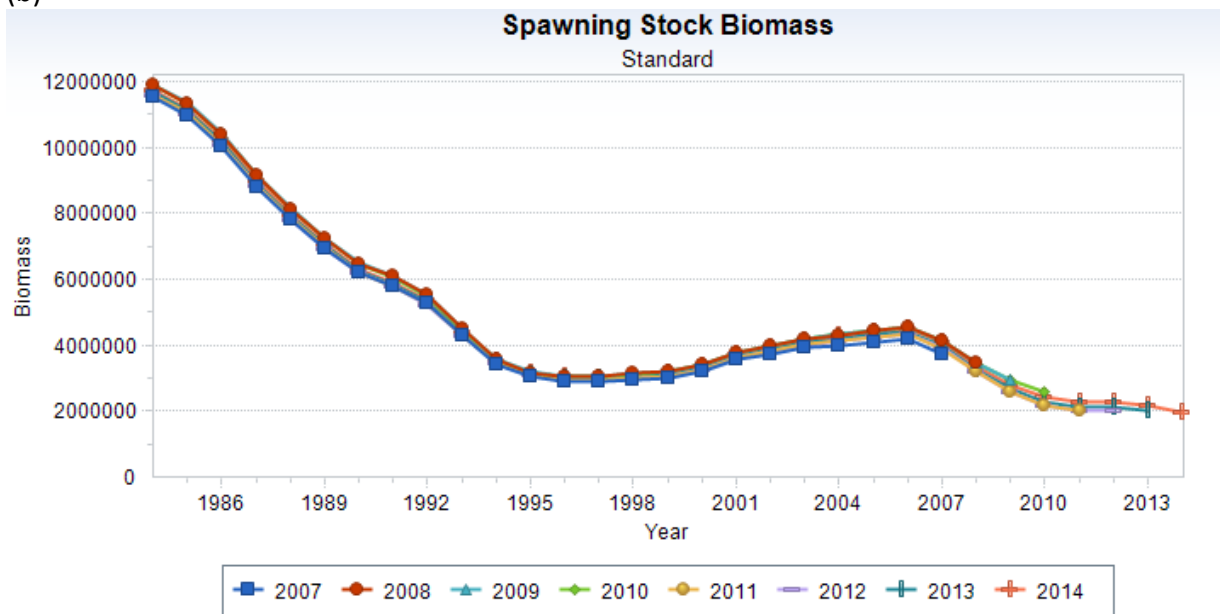
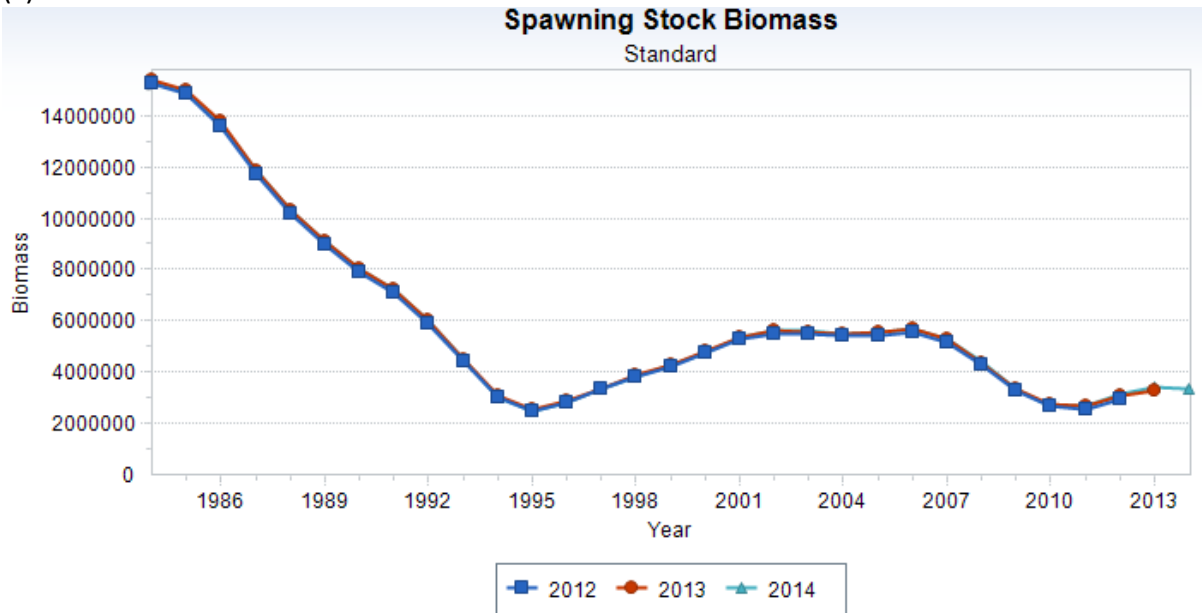
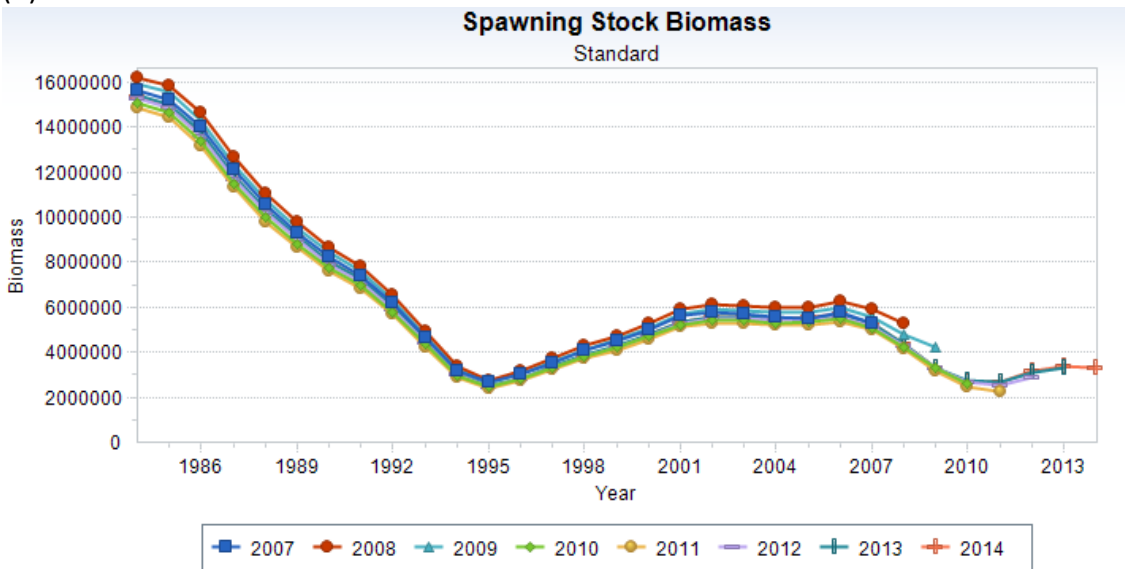


Figure 6.14 (cont.)

(c)

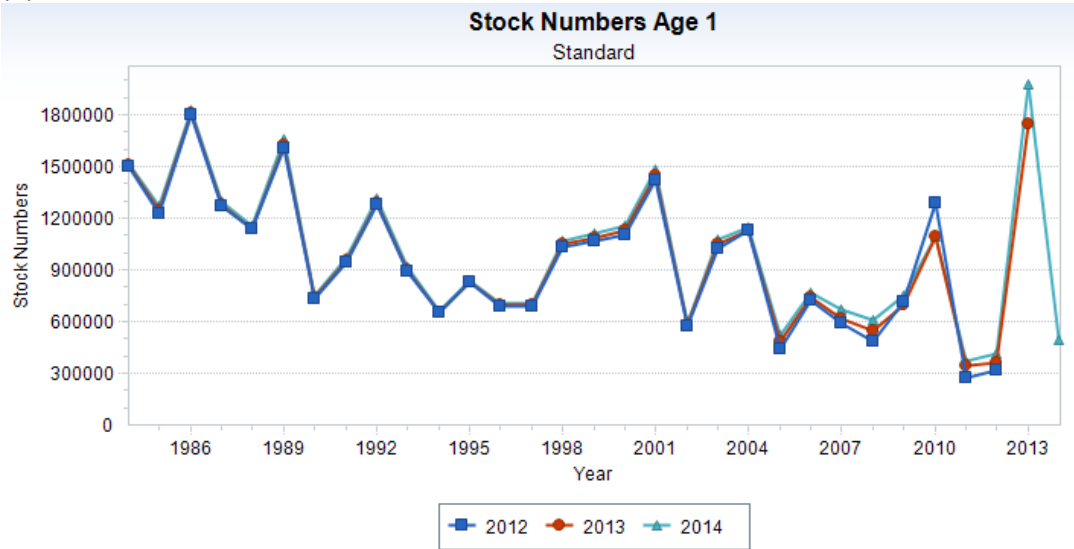


(d)



**Figure 6.15.** Retrospective results for recruits (a) 12-year plus group, start 2012, (b) 12-year plus group start 2007, (c) 15-year plus group, start 2012, (d) 15-year plus group start 2007 the LIS regional models.

(a)



(b)

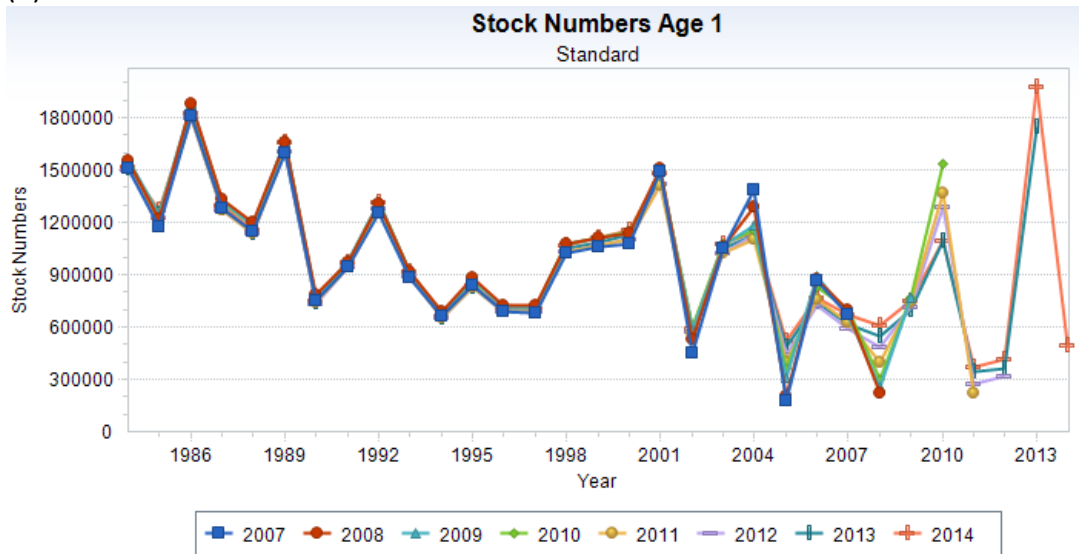
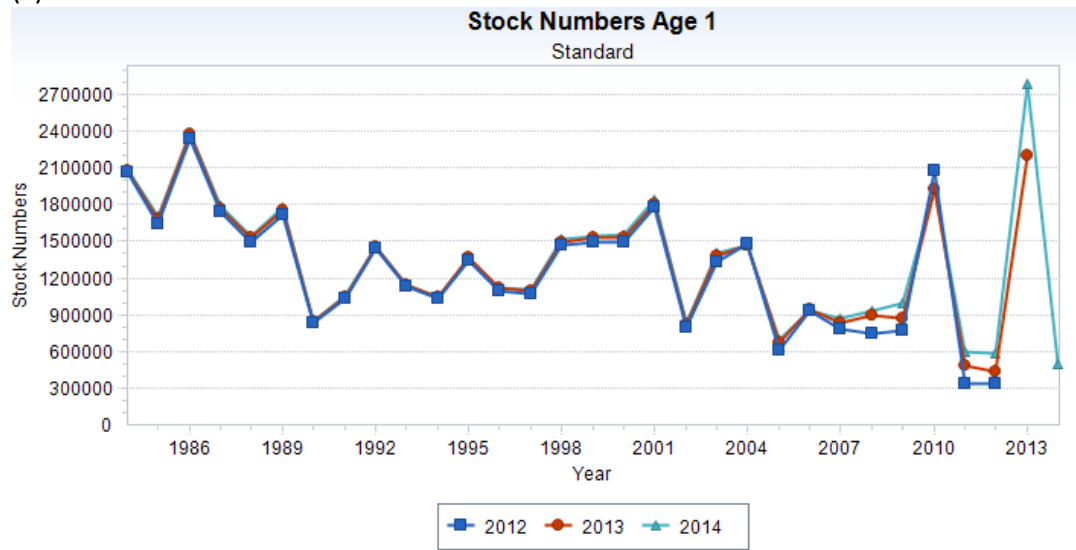


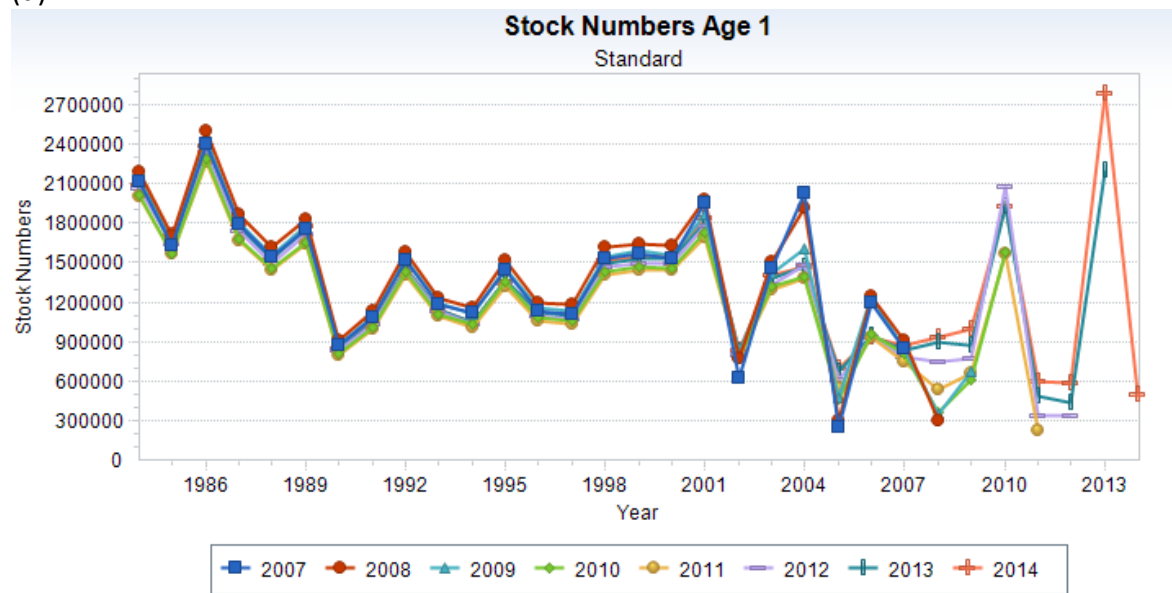


Figure 6.15 (cont.)

(c)



(d)



**Figure 6.16.** NJ-NYB regional model observed and predicted total catch (top) and standardized residuals.

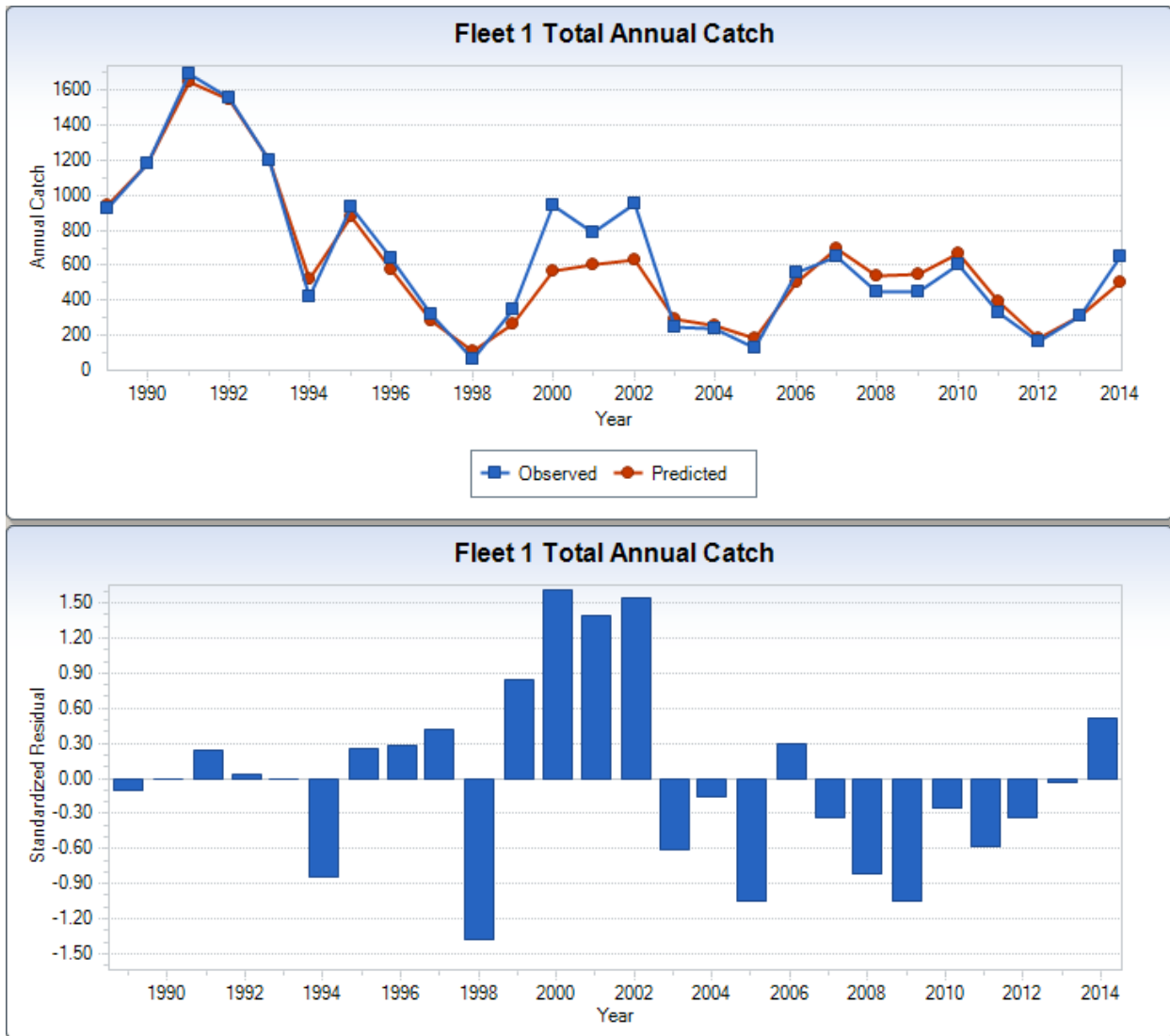


Figure 6.17. Fits to annual catch at age for the NJ-NYB regional model.

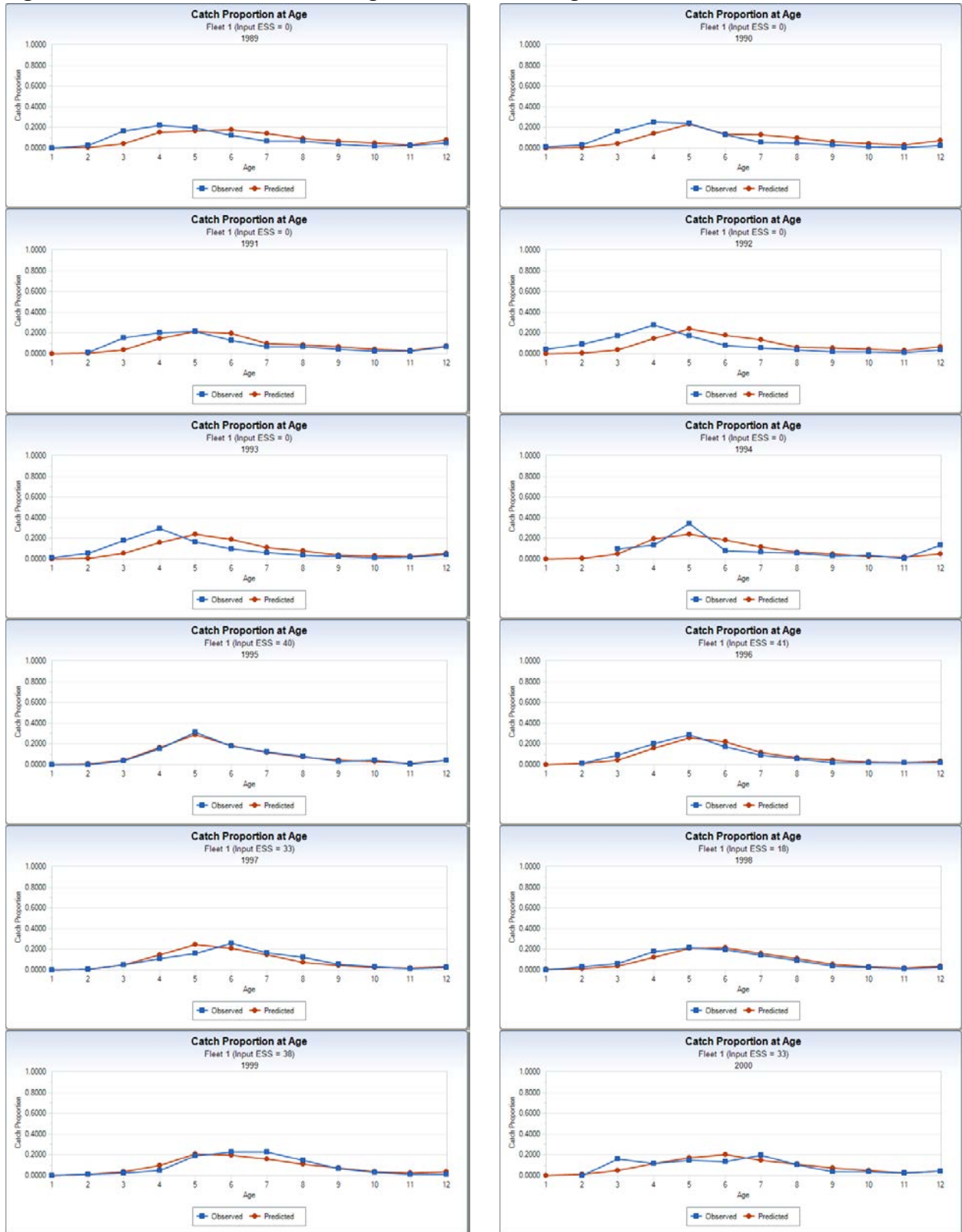


Figure 6.17 (cont.)

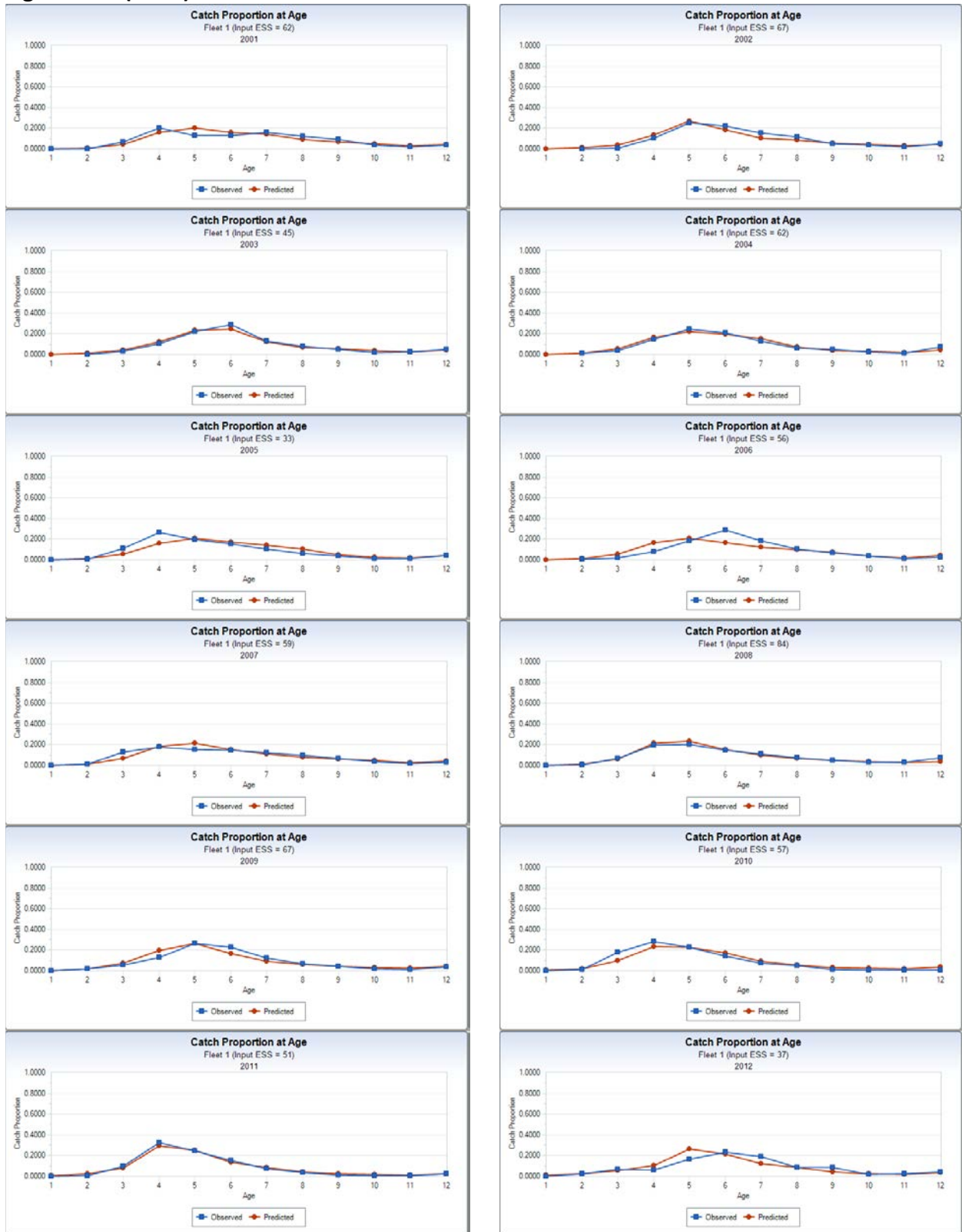
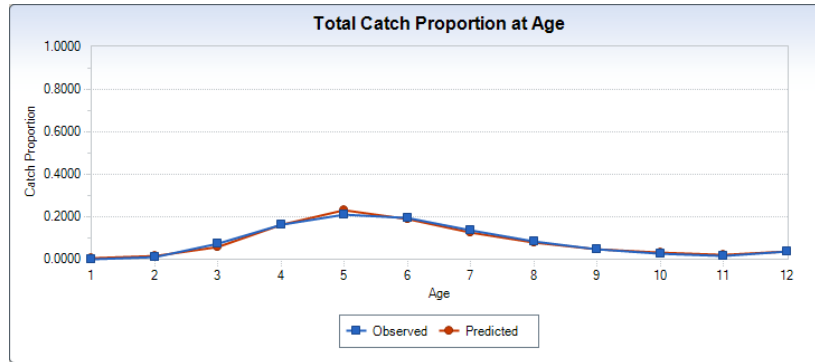
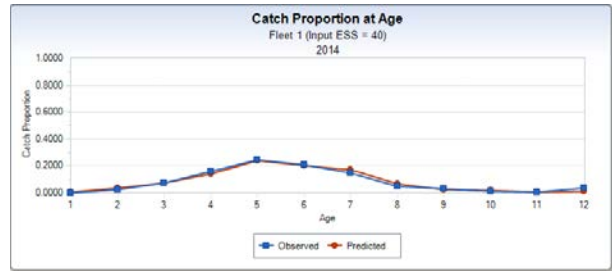
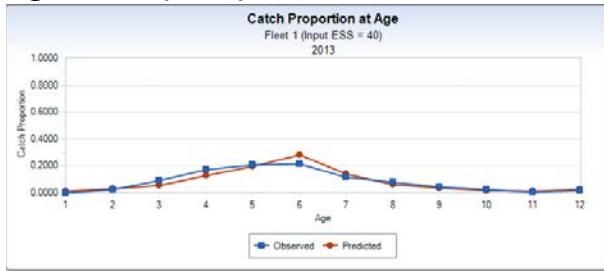
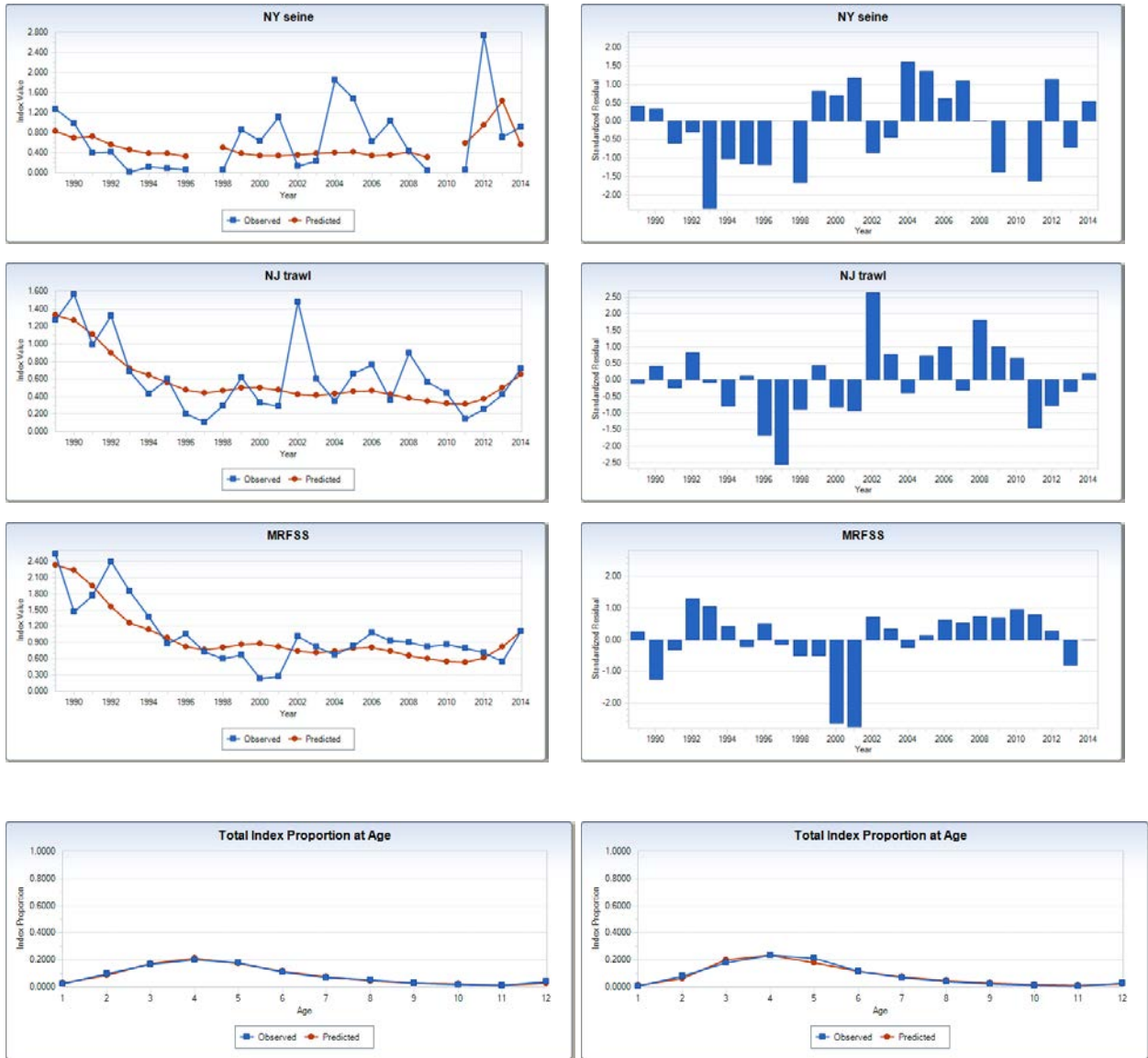


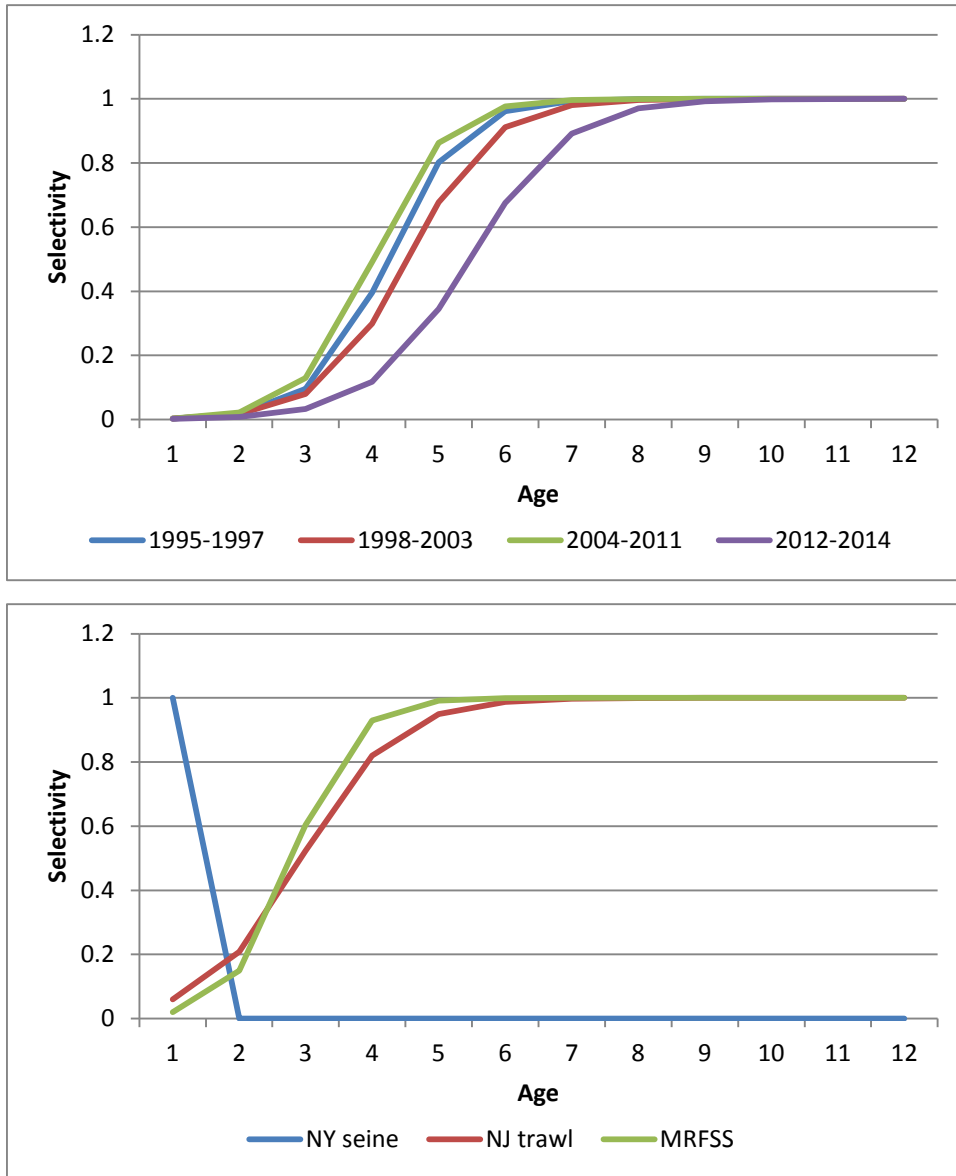
Figure 6.17 (cont.)



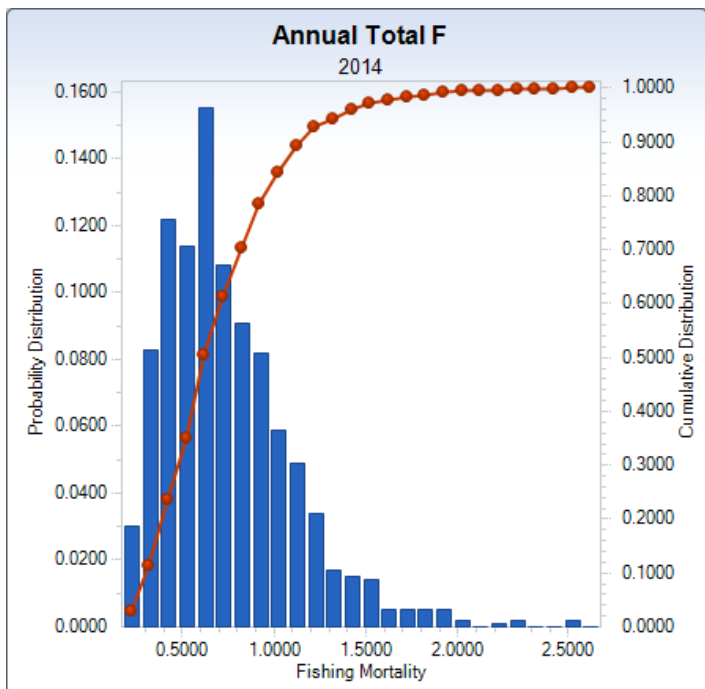
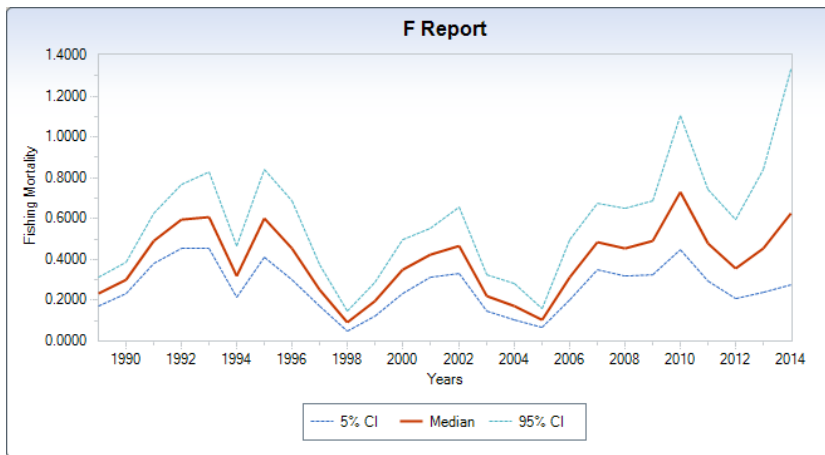
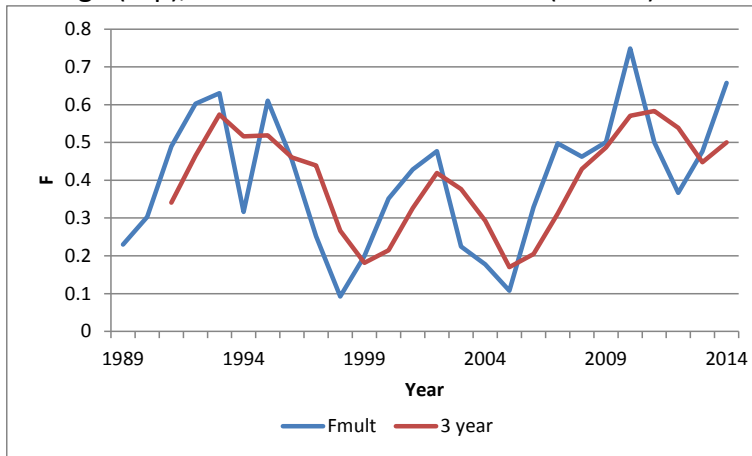
**Figure 6.18.** Fits to annual survey indices and overall index at age (bottom) for the NJ-NYB region.



**Figure 6.19.** Estimated selectivity patterns for the fishery (top) and survey indices for the NJ-NYB regional model.

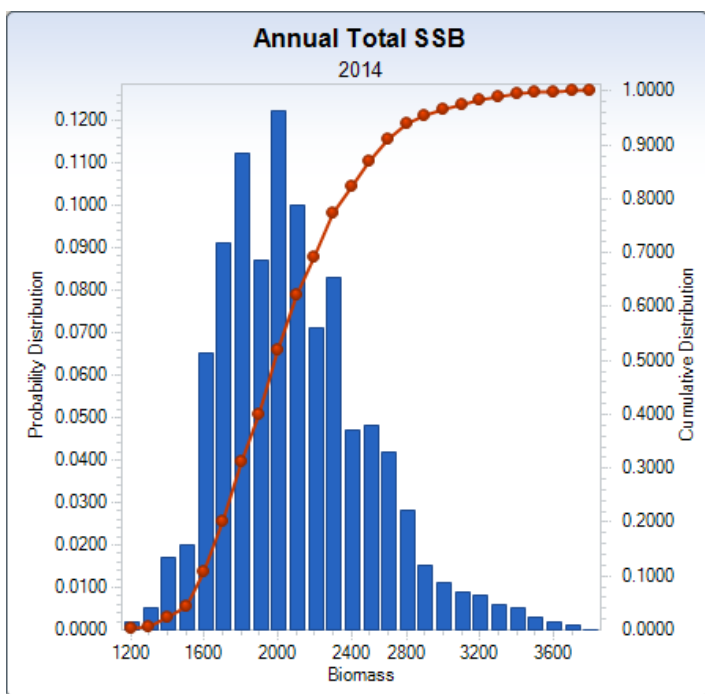
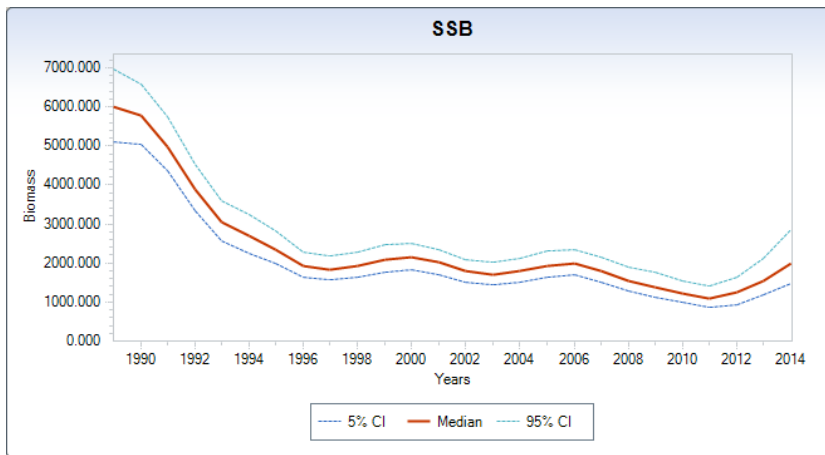
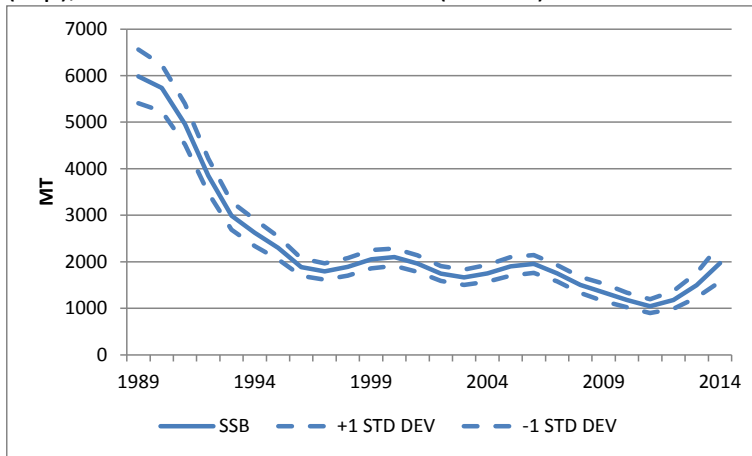


**Figure 6.20.** Fishing mortality estimates for the NJ-NYB regional model. Annual and three year average (top), MCMC median and 90% CI (middle) and MCMC distribution.

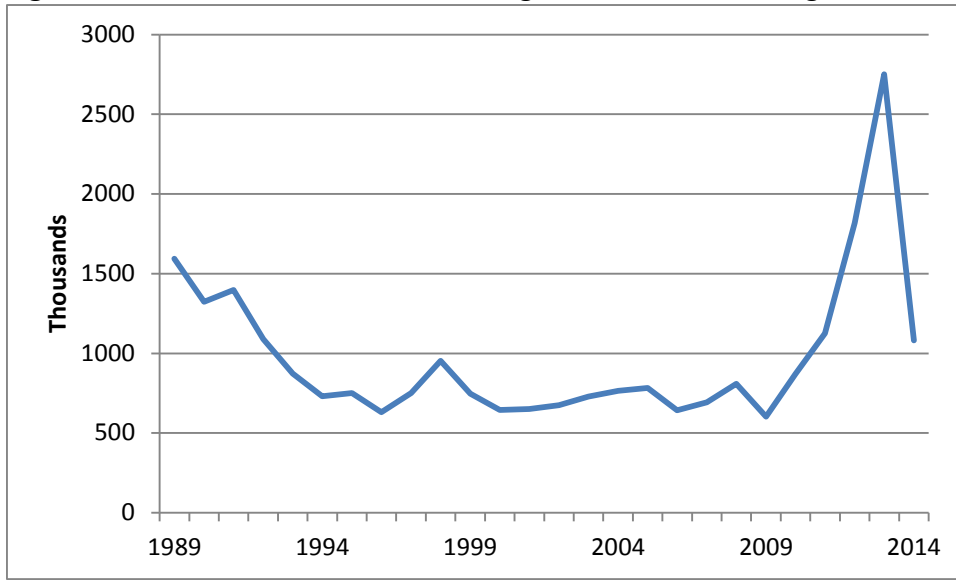




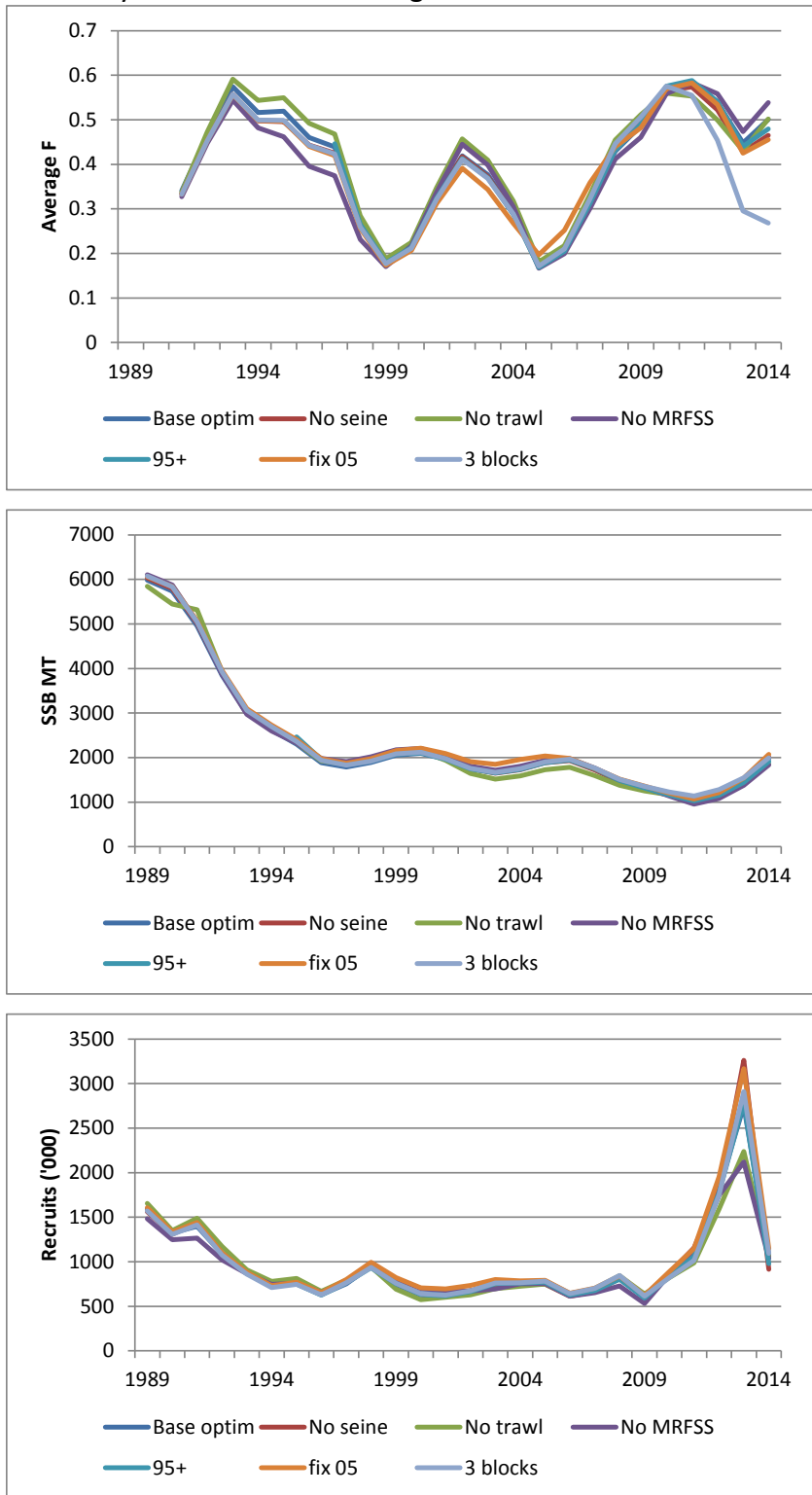
**Figure 6.21.** SSB estimates for the NJ-NYB regional model. Annual with +/- 1 standard deviation (top), MCMC median and 90% CI (middle) and MCMC distribution.



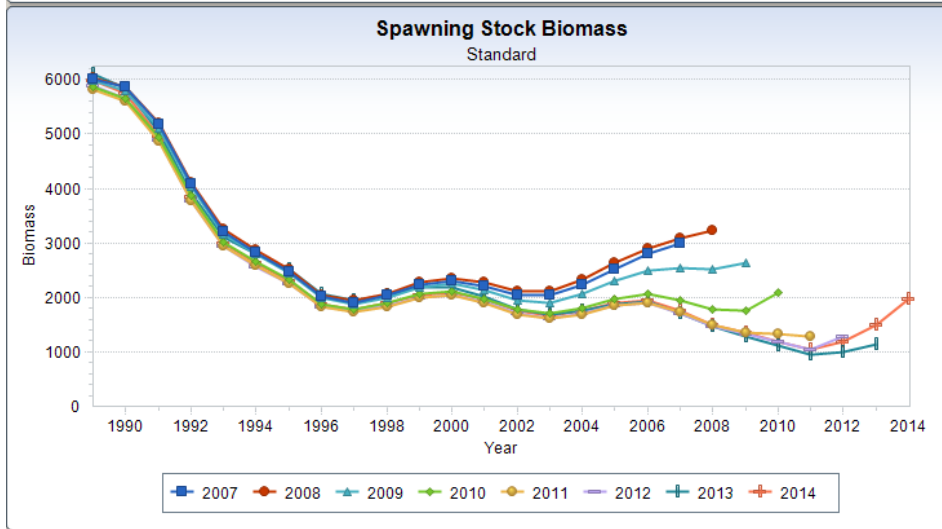
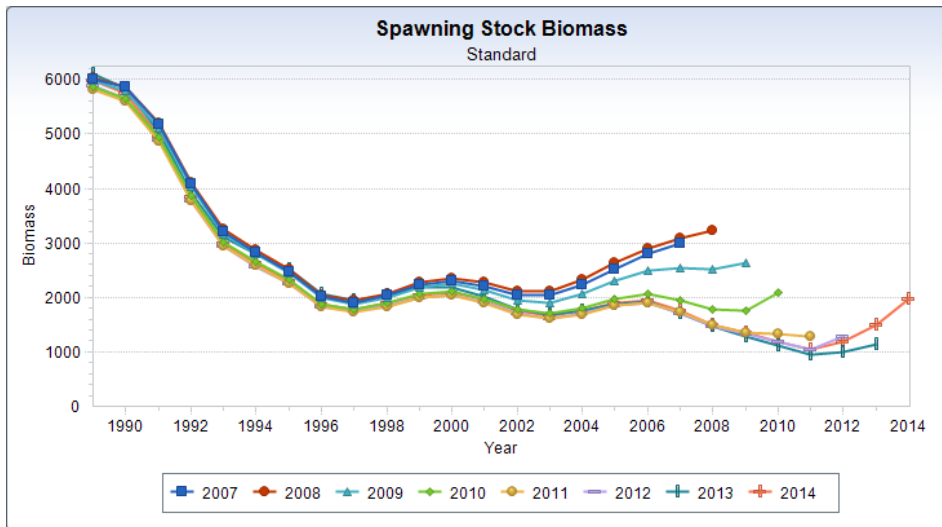
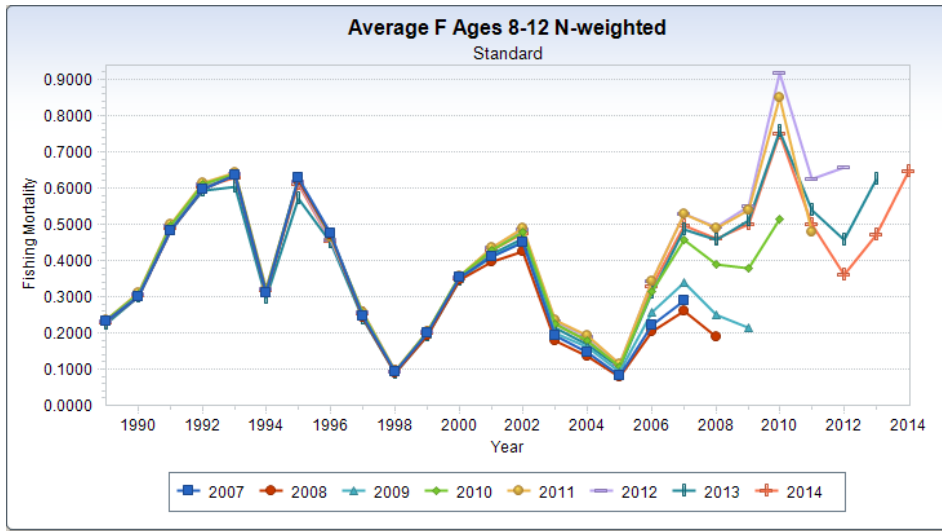
**Figure 6.22.** Estimated recruitment to age 1 for the NJ-NYB regional model



**Figure 6.23** Trajectories of 3 year average F (top) and SSB (middle) and recruits (bottom) for sensitivity runs of the NJ-NYB regional model

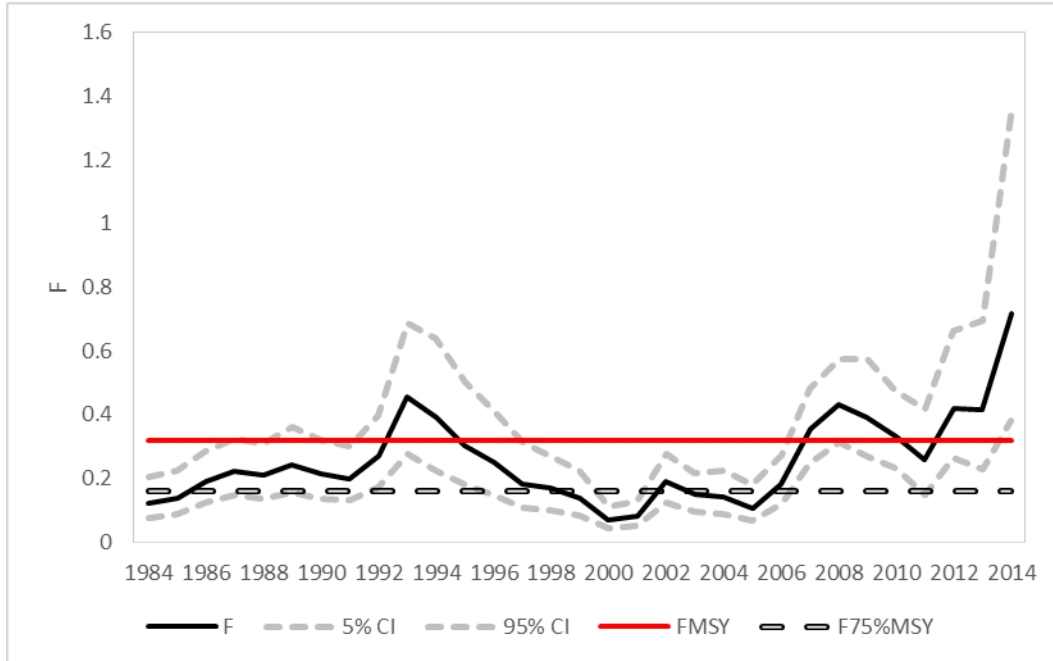


**Figure 6.24.** Retrospective results for F (top), SSB (middle), and recruits in the NJ-NYB regional model.

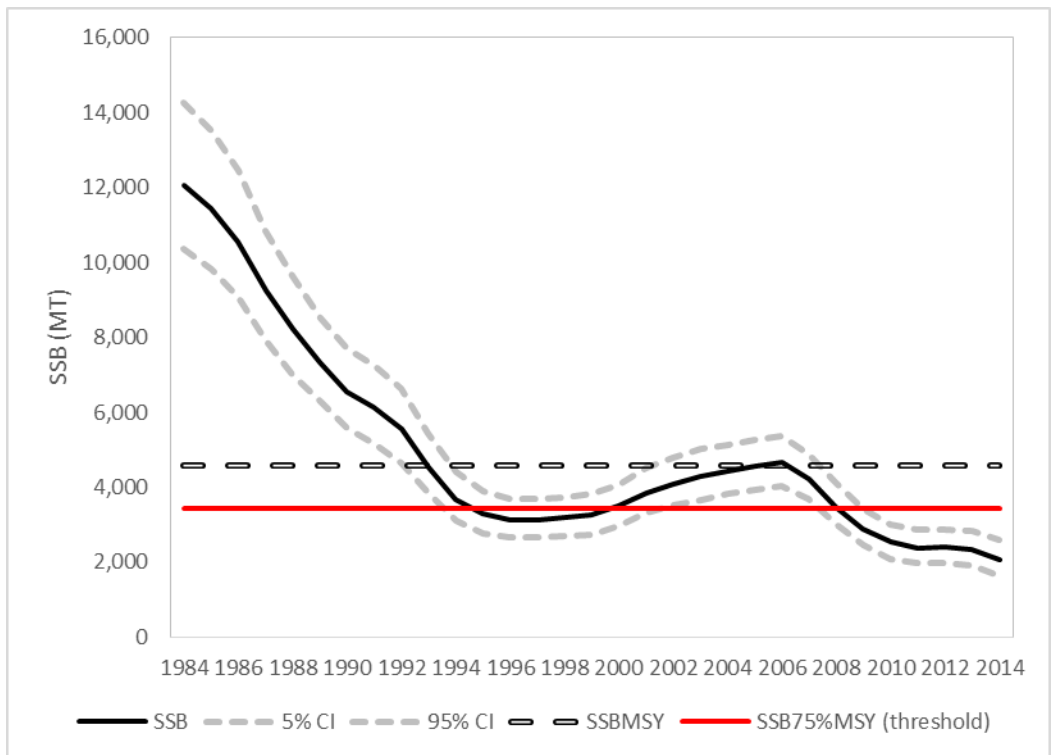


**Figure 7.1** F estimates with MCMC confidence intervals and F target and threshold values (a), and SSB estimates with MCMC confidence intervals and SSB target and threshold values (b) for SPR model in LIS.

(a)

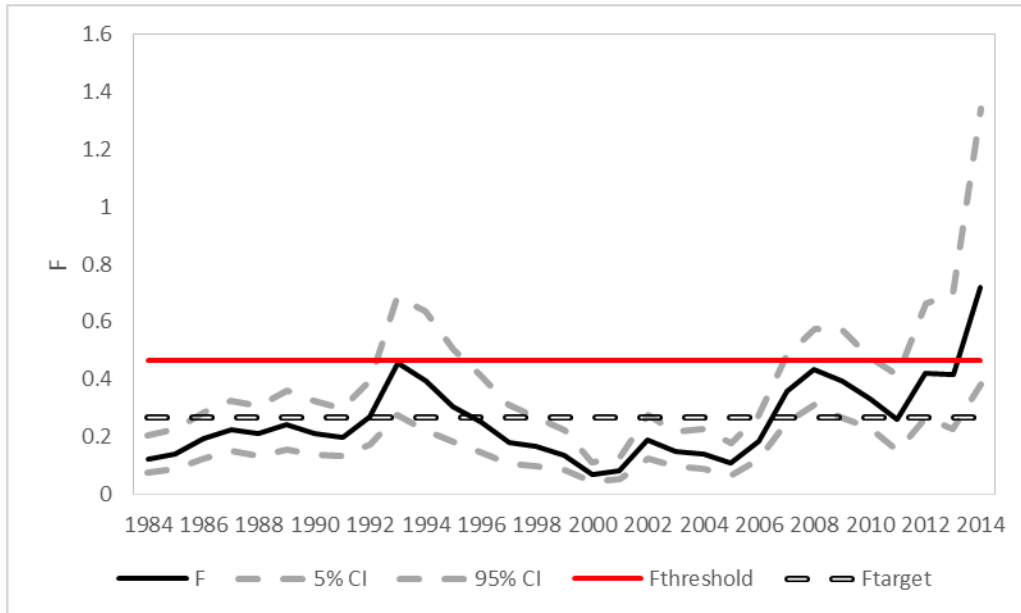


(b)

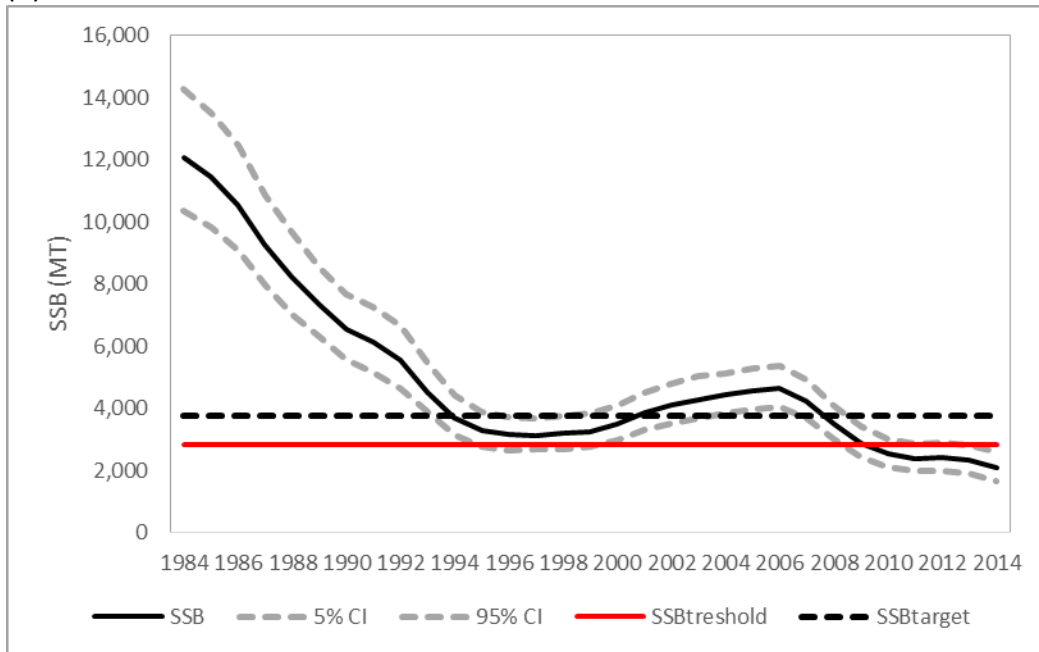


**Figure 7.2** F estimates with MCMC confidence intervals and F target and threshold values (a) and SSB estimates with MCMC confidence intervals and SSB target and threshold values (b) for SPR model in LIS.

(a)



(b)



**Figure 7.3.** Fishing mortality (top) and spawning stock biomass relative to benchmarks for the NJ-NYB region.

