Atlantic States Marine Fisheries Commission

1050 N. Highland Street • Suite 200A-N • Arlington, VA 22201
703.842.0740 • 703.842.0741 (fax) • www.asmfc.org

MEMORANDUM

July 25, 2016

To: **Tautog Management Board**

From: **Toni Kerns, ISFMP Director** TMK

RE: **Tautog LIS and NJNYB Regional Assessments & Desk Review**

The 2015 benchmark stock assessment for tautog explored multiple regional definitions for management purposes, including the three region delineation of Massachusetts-Rhode Island, Connecticut-New York-New Jersey, and Delaware-Maryland- Virginia. The Tautog Management Board accepted the stock assessment for management use and initiated Draft Amendment 1 in May 2015 to develop regional management alternatives.

Additionally, 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 (NJNYB), which consists of New Jersey and New York waters south of Long Island.

The following report contains:

- **Tautog Regional Stock Assessment Desk Review** (PDF pgs 2-32)
- **Tautog Regional Stock Assessments for Long Island Sound and New Jersey-New York Bight** (PDF pgs 33-371; please note the model technical documentation and source codes begin on PDF pg 180)

M16-63

Report to the Atlantic States Marine Fisheries Commission

TAUTOG REGIONAL STOCK ASSESSMENT DESK REVIEW

July 2016

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Acknowledgements

The 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 were 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 2004-2011using 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.

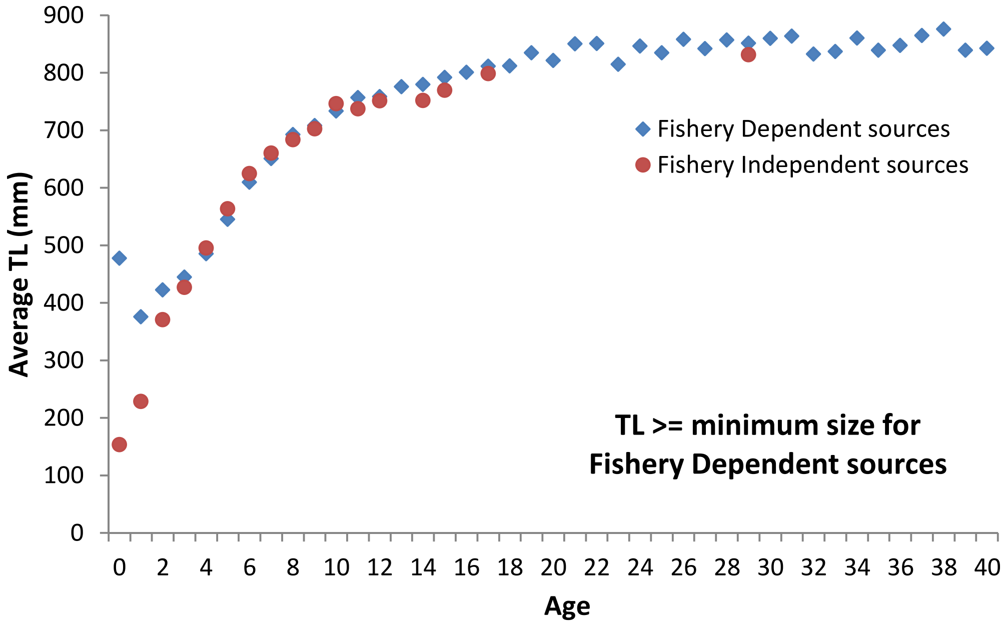
The commercial component of the fishery has declined over decades to approximately 20% of the total harvest. The predominant gear is hand harvest. Landings for the region vary seasonally but occur throughout the year. Although there are federal and state landings records since 1950, it was difficult 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.

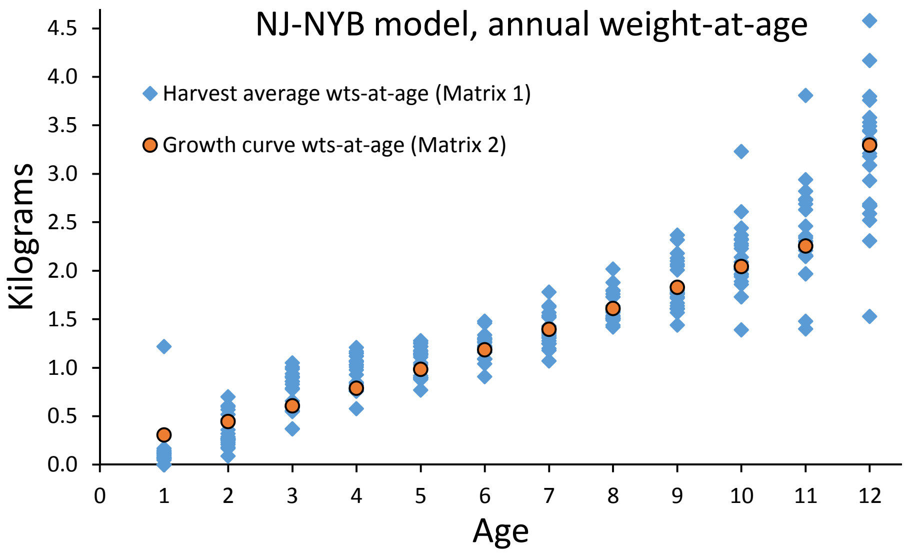
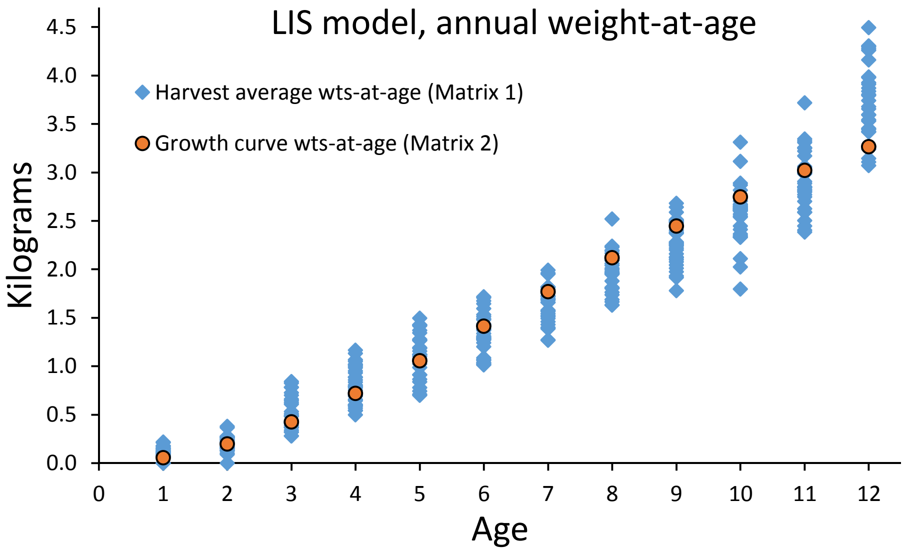


Fig. 3. Observed and average weights-at-age used for the LIS model.



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 ~ 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.

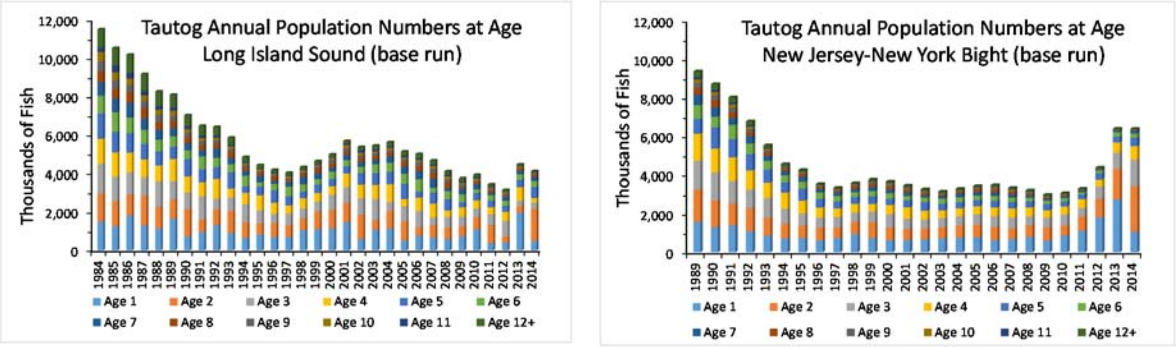
The NJ-NYB model has much greater uncertainty as shown by the inability of the model to solve for a stock-recruitment relationship and by the bias exhibited in the retrospective analysis. A re-examination of the data inputs (numbers and weights at age, growth curve, age-length keys, etc.) may be warranted.

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.

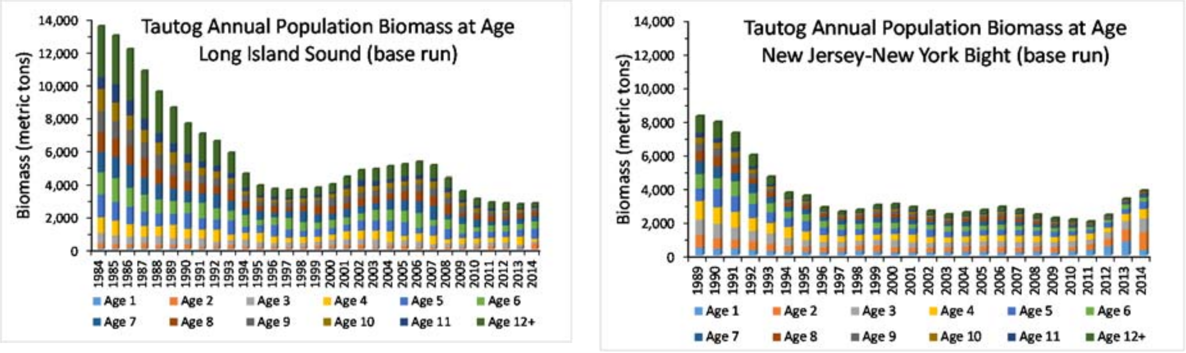
a. Long Island Sound base model, abundance at age

b. New Jersey-New York Bight base model, abundance at age



c. Biomass at age

d. Biomass at age



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 $F_{current}$ 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_{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 below the $SSB_{threshold}$ from the AgePro estimates and means that the population is overfished. However, the ASAP calculates that SSB_{2014} is greater than the $SSB_{threshold}$, 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 (λ=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.

		2016 Regional Assessment	Review Panel			
		base run	base run	exploratory	exploratory	exploratory
definition		LIS ASAP (SSB)	LIS ASAP (SSB)	selectivity λ=1, CV=0.5	selectivity λ=1, CV=0.5, MRIP linked to fleet	selectivity λ=1, CV=0.5, MRIP linked to fleet, stage-2 λ
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[c]	Overfishing, Overfished	Overfishing, Not Overfished	Overfishing, Not Overfished	Overfishing, Not Overfished	Overfishing[b], 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+		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 $F_{geometric\ 2012\text{-}2014,\ Ages\ 8\text{-}12+}$	$F_{geo\ 2012\text{-}2014}$		0.49	0.48	0.39	0.33
steepness	*h*	0.53	0.53	0.53	0.57	0.56
objective function	objective function[d]	5214	5180	5172	5164	5164

definition		LIS ASAP (MSY)	LIS ASAP (MSY)	selectivity λ=1, CV=0.5	selectivity λ=1, CV=0.5, MRIP linked to fleet	selectivity λ=1, CV=0.5, MRIP linked to fleet, stage-2 λ
F at 75% MSY	F_{target}	0.32	----[a]	----[a]	----[a]	----[a]
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
	SSB 2014	1,956	1,956	1,964	2,184	2,184
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	Stock Status	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished	Overfishing, Overfished

[a] - not calculated

[b] - F geometric criteria would change stock status to "not overfishing"

[c] - 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.

[d] - 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 λ=1, CV=0.5	selectivity λ=1, CV=0.5, MRIP linked to fleet	selectivity λ=1, CV=0.5, MRIP linked to fleet, stage-2 λ
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[c]	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
$F_{geo\ 2012\text{-}2014}$		0.48	0.47	0.30	0.40
h	0.99	0.99	0.99	0.99	0.93
objective function[d]	3660	3631	3624	3685	3693

[a] - not calculated

[b] - F geometric criteria would change stock status to "not overfishing"

[c] - 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.

[d] - 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.

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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: **General Data** Model specification[1]	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: **Weights at Age** Matrix 1: Catch weight-at-age	kg Harvest = catch-at-age x weight-at-age	kg [2]*Harvest ≠ catch-at-age x weight-at-age and Age 1 weight in 2008 anomalous*
Tab: **Weights at Age** Matrix 2: Jan-1 biomass-at-age	kg [3]*Age 12+ (plus group) weight may be low. Does it represent a weighted avg. wt. for ages 12-max. age?*	kg [3]*Ages 1-2 (many, at least) average weights in catch (Matrix 1) much less than Matrix 2.*
Tab: **Weights at Age** Matrix 3: SSB biomass-at-age (set to Matrix 2)	kg [4]*Jan-1 biomass and SSB should be different if spawning not on Jan-1.*	kg [4]*Jan-1 biomass and SSB should be different if spawning not on Jan-1.*
Tab: **Biological** Natural Mortality Maturity Fecundity[7]	[5]Constant M (0.15) [6] - Total (both sexes) Biomass-based, SSB offset=0.42 years	[5]Constant M (0.15) [6] - Total (both sexes) Biomass-based, SSB offset=0.42 years
Tab: **Fleets** Description Selectivity ages Release mortality[8] 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: **Selectivity**[9] Blocks 1-4 Starting values	All single logistic, ***lambda=0,cv=0*** A_{50}=5, slope=0.6, phase=2 (on)	All single logistic, ***lambda=0,cv=0*** A_{50}=5, slope=0.6, phase=2 (on)

Item	LIS (Long Island Sound)	NJ-NYB (New Jersey-New York Bight)
Tab: **Catch** Catch at Age Total Weight (Harvest)	(catch + discards combined) Numbers of fish Kilograms	(catch + discards combined) Thousands of fish Metric tons
Tab: **Discards**	Not used	Not used
Tab: **Releases**	Not used	Not used
Tab: **Index Specification** 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: **Index Selectivity**[10]	All: ***lambda=0,cv=0 (age 1-12+ indices)*** ***lambda=0,cv=0 (age 1 index)*** CT trawl A_{50}=5, slope=0.6, phase=2 (on) NY trawl, age-specific, phase=-1 (off) MRIP A_{50}=5, slope=0.6, phase=2 (on) NY seine, age-specific, phase=-1 (off)	***lambda=0,cv=0 (age 1-12+ indices)*** ***lambda=0,cv=1 (age 1 index)*** NY seine age-specific, phase=-1 (off) NJ trawl A_{50}=5, slope=0.6, phase=2 (on) MRFSS A_{50}=5, slope=0.6, phase=2 (on)
Tab: **Index Data** 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)
Tab: **Phases**		
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
Tab: **Lambdas-1**		
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
Tab: **Lambdas-2**		
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
Tab: **Lambdas-3**		
Lambda for Total Catch in weight Lambda for Total Discards in weight Lambda for F-mult in first year CV for F-mult in first year Lambda for F-mult deviations CV for F-mult deviations Lambda for Index Lambda for catchability CV for catchability Lambda for catchability deviations CV for catchability deviations N in First year deviation Deviation from initial steepness Deviation from Initial SR scaler	1 1 0 0.5 0.5 0.5 All set to 1 All set to 0 All set to 1 All set to 0 All set to 1 Lambda=0, CV=0.5 Lambda=0, CV=0.5 Lambda=0, CV=0.5	1 1 0 0.5 0.5 0.5 All set to 1 All set to 0 All set to 1 All set to 0 All set to 1 Lambda=0, CV=0.5 Lambda=0, CV=0.5 Lambda=0, CV=0.5

Tab: **Initial Guesses**		
Numbers at Age in 1st 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
Tab: **Projection**	Not used	Not used
Tab: **MCMC**[11]		
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

[1] – 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.

[2] – 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.

[3] – 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.

[4] – 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.

[5] – 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.

[6] – 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.

[7] – 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.

[8] – Release mortality and Average F basis (F_{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.

[9] – 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 [ADBM] 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.

[10] – 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.

[11] – 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.

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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

Tautog Regional Stock Assessment

Prepared by the Tautog Regional Stock Assessment Working Group
Jacob Kasper, University of Connecticut
Dr. Eric Schultz, University of Connecticut
Jeffrey Brust, New Jersey Division of Fish and Wildlife
Dr. Katie Drew, Atlantic States Marine Fisheries Commission
Ashton Harp, Atlantic States Marine Fisheries Commission

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Jason McNamee, Rhode Island Division of Fish and Wildlife
Michael Bednarski, Massachusetts Division of Marine Fisheries
Deborah Pacileo, Connecticut Department of Energy and Environmental Protection
Sandra Dumais, New York State Department of Environmental Conservation
Linda Barry, New Jersey Division of Fish and Wildlife
Scott Newlin, Delaware Division of Fish and Wildlife
Craig Weedon, Maryland Department of Natural Resources
Dr. Alexei Sharov, Maryland Department of Natural Resources
Joe Cimino, Virginia Marine Resources Commission
Dr. Katie Drew, Atlantic States Marine Fisheries Commission
Ashton Harp, Atlantic States Marine Fisheries Commission

Additional assistance in preparing the regional stock assessment was provided by:

Matthew Gates, Kurt Gottschall, David Simpson, Greg Wojcik, Connecticut Department of Energy and Environmental Protection
Amanda Caskenette, Jason Vokoun, University of Connecticut
Tom Sminkey, National Marine Fisheries Service, Greater Atlantic Regional Fisheries Office

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, peeked 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 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_{target} defined as F40%SPR and $F_{threshold}$ defined as F30%SPR. For NJ-NYB, this resulted in $F_{target} = 0.22$ and $F_{threshold} = 0.36$. 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_{target} for NJ-NYB was 3,305 MT, and $SSB_{threshold}$ 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 $SSB_{threshold}$ (overfished) with the 2012-2014 average of fishing mortality above the $F_{threshold}$ (overfishing occurring). The NJ-NYB region is overfished (SSB_{2014} below $SSB_{threshold}$) and the 2012-2014 average of fishing mortality is above $F_{threshold}$ (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.

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 $F_{target} = F_{40\%SSB} = 0.29$ and mandated that states collect a minimum of 200 age samples per year.

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

In April 2011, Addendum VI to the FMP established a new F_{target} of F = M = 0.15 on the grounds that stock biomass had not responded to previous F levels. The new F_{target} required states to take a 39% reduction in harvest. As in Addendum IV, a regional assessment of Massachusetts and Rhode Island demonstrated a lower regional F using ADAPT VPA, and these states were not required to implement tighter regulations. To achieve the required harvest reduction, all other states adopted higher minimum size limits exceeding the FMP's minimum requirement of 14" in addition to other measures, such as possession limits, seasonal closures, and gear restrictions. Current 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):

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

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_{effect}/MS_{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 (*Linf*), growth rate (*K*), and age at zero size (*t0*). 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 *Linf*=59, *K*=0.171 *t0*=0; to check for stability of final estimates, alternate initial values of *Linf*=70, *K*=0.7, *t0*=-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 (*Linf*) 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 $3/Tmax$ 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^2 (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^3. 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 where 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 5th and 95th 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 5th and 95th 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 5th and 95th 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 teriminal 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 $F_{3\ year}$ = 0.50. MCMC estimate d 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 F2014 = 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. Btarg and Blim were established in Addendum 4 (2007) at 26,800 and 20,100 MT. Results from the 2011 assessment update were F=0.23 and SSB=10,663 MT, indicating the stock is overfished and overfishing is occurring. 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
MA-RI	SSB_{MSY}	2,633 MT	$75\%SSB_{MSY}$	1,975 MT	F_{MSY}	0.16	F associated with $75\%SSB_{MSY}$	0.19
CT-NY-NJ	SSB associated with $F_{40\%SPR}$	5,160 MT	SSB associated with $F_{30\%SPR}$	3,920 MT	$F_{40\%SPR}$	0.17	$F_{30\%SPR}$	0.24
DMV	SSB associated with $F_{40\%SPR}$	2,090 MT	SSB associated with $F_{30\%SPR}$	1,580 MT	$F_{40\%SPR}$	0.16	$F_{30\%SPR}$	0.24

7.2. 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_{MSY} 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 $F_{40\%SPR}$ and a threshold of $F_{30\%SPR}$. 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
LIS (MSY)	SSB_{MSY}	4,576 MT	75% SSB_{MSY}	3,432 MT	F_{MSY}	0.16	$F_{75\%SSBMSY}$	0.32
LIS (SPR)	SSB associated with $F_{40\%SPR}$	3,757 MT	SSB associated with $F_{30\%SPR}$	2,820 MT	$F_{40\%SPR}$	0.27	$F_{30\%SPR}$	0.47
NJ-NYB	SSB associated with $F_{40\%SPR}$	3,305 MT	SSB associated with $F_{30\%SPR}$	2,547 MT	$F_{40\%SPR}$	0.22	$F_{30\%SPR}$	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 SSB40%SPR target. Estimated terminal year biomass is identical to the MCMC 5th 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*

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.

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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.

<table>
<tr><th>Options for Stock Unit Definitions</th><th>MA</th><th>RI</th><th>CT</th><th>NY</th><th>NJ</th><th>DE</th><th>MD</th><th>VA</th></tr>
<tr><td>A. Three Region (Assessment Preferred)</td><td colspan="3">Overfished
Overfishing</td><td colspan="2">Overfished
Not Overfishing</td><td colspan="3">Overfished
Not Overfishing</td></tr>
<tr><td>B. Three Region (Highly Regarded Alternative)</td><td colspan="2">Overfished
Overfishing</td><td colspan="3">Overfished
Overfishing</td><td colspan="3">Overfished
Not Overfishing</td></tr>
<tr><td>C. Two Region</td><td colspan="5">Overfished
Overfishing</td><td colspan="3">Overfished
Overfishing</td></tr>
<tr><td>D. Coastwide (status quo)</td><td colspan="8">Overfished
Overfishing</td></tr>
</table>

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

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

	Estimate	SE
MARI		
Linf	55.1	0.3
K	0.201	0.004
t0	-0.883	0.063
LIS		
Linf	57.8	0.3
K	0.174	0.003
t0	-0.409	0.051
NJ-NYB		
Linf	65.6	1.3
K	0.094	0.005
t0	-3.05	0.16
DMV		
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 (ΣRSSi), 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	ΣRSSi	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^b) 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 (ΣRSSi), 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	ΣRSSi	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).

Year	CT	NY	NJ
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.

	LIS			NYB		
Year	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	*Centropristis striata*		5	3
Bluefish	*Pomatomus saltatrix*	6		6
Cunner	*Tautogolabrus adspersus*	3	2	2
Scup	*Stenotomus chrysops*	4	3	4
Summer flounder	*Paralichthys dentatus*	5	6	5
Tautog	*Tautoga onitis*	1	1	1
Winter flounder	*Pseudopleuronectes americanus*	2	4	

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

	LIS			NYB		
Year	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.

	LIS Harvest length sources			LIS Discard length sources			
Year	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

	Millstone egg				Millstone larvae			
Year	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.

	GVIF	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^(1/(2*Df))
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^(1/(2*Df))
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
Discard age comps	see_below	0		Index 3 - MRFSS 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
Recruit devs	0.5	-6.86738		Index selectivity	0	0
SR steepness	0	0		q first year	0	0
SR scalar	0	0		q devs	0	0
Fmult max penalty	1000	0		SR steepness	0	0
F penalty	0	0		SR scalar	0	0

	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
Discard age comps	see_below	0		Index 3 - MRFSS 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
Recruit devs	0.5	-5.77612		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 6.2. 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 selectivty 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			

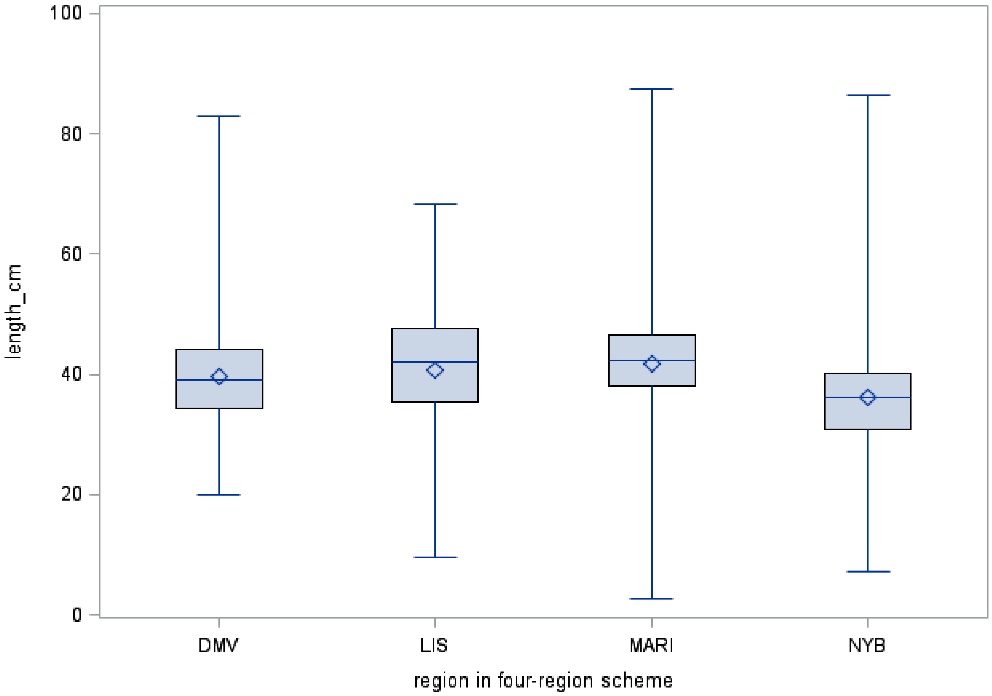
Table 7.1 Reference points, terminal year estimates, and stock status by region

	LIS (MSY)	**LIS (SPR)**	**NJ-NYB**
F_{TARGET}	0.16	0.27	0.22
$F_{THRESHOLD}$	0.32	0.47	0.36
3-YEAR AVG.	0.53	0.53	0.5
SSB_{TARGET}	4,576 MT	3,757 MT	3,305 MT
$SSB_{THRESHOLD}$	3,432 MT	2,820 MT	2,457 MT
SSB 2014	1,956 MT	1,956 MT	1,972 MT
STOCK STATUS	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 25th and 75th 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

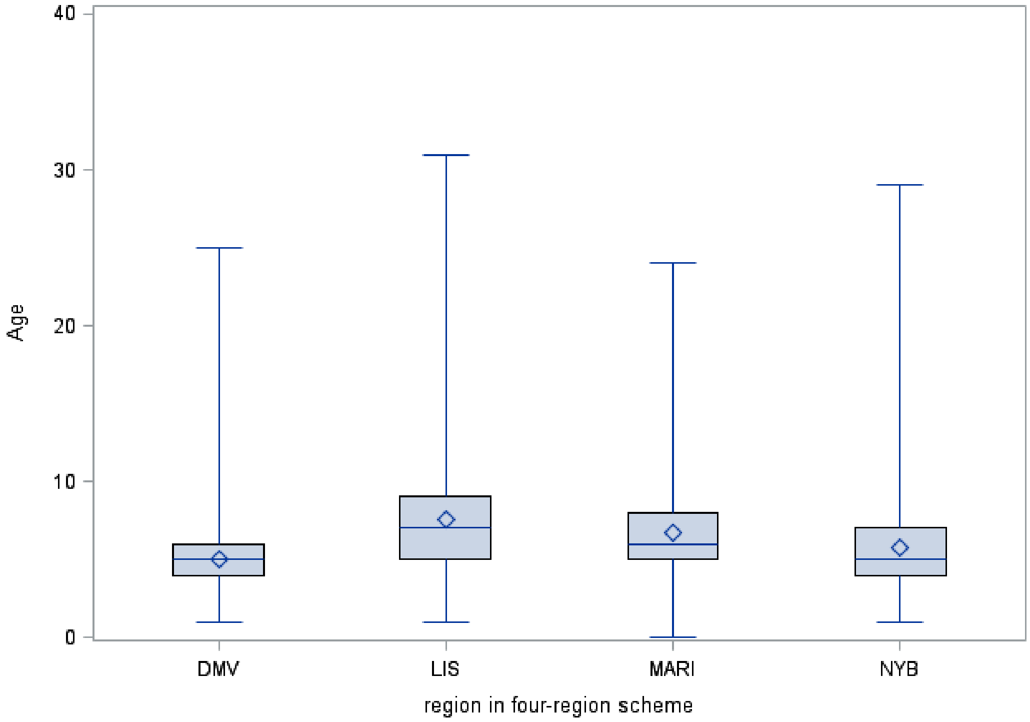


Fig 2.1 (cont'd)

C) Distribution of weight

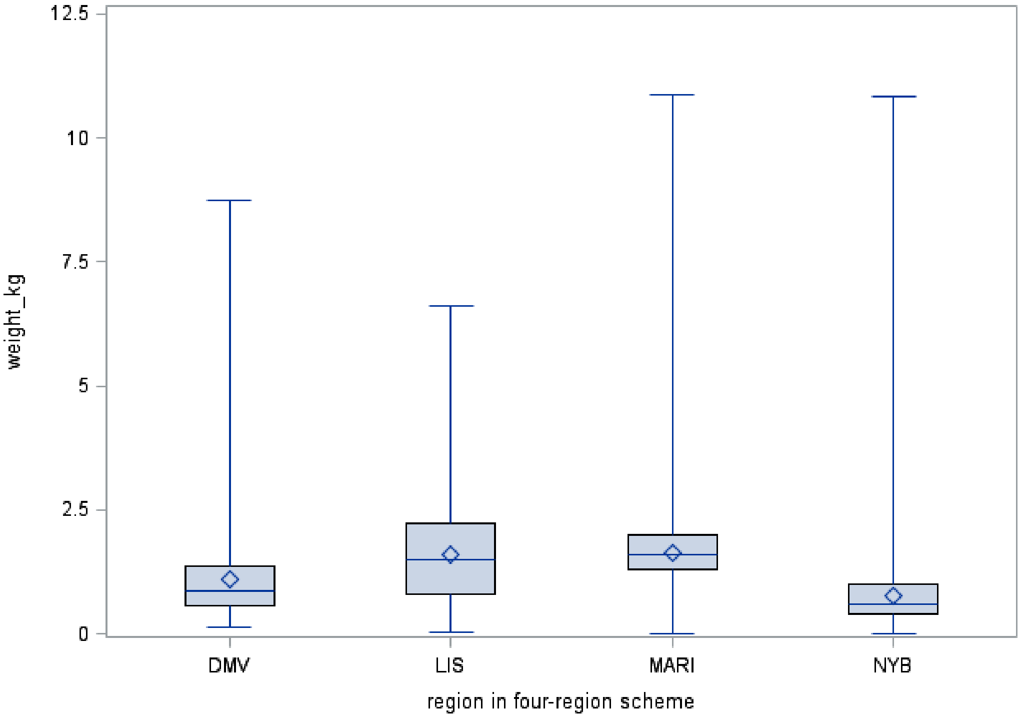


Figure 2.2. Diagnostics for nonlinear regression analysis of growth.
The upper panel represents a histogram of residuals from expected values, and the lower panel is a plot of mean residuals vs. increments of predicted value.

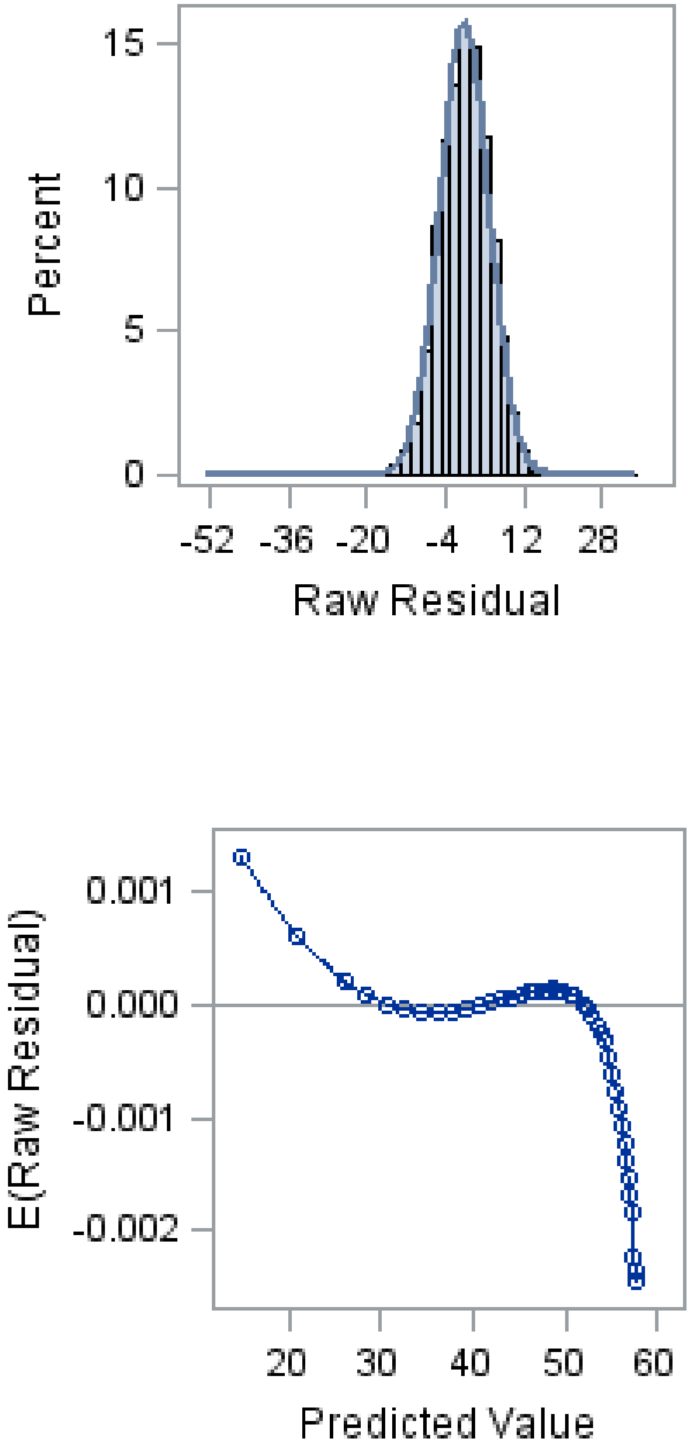


Figure 2.3. Diagnostics for length-at-age ANOVA.
The upper panel represents a histogram of residuals from expected values, and the lower panel is a quantile-quantile plot of the observed distribution of residuals vs. residuals of the standard normal curve.

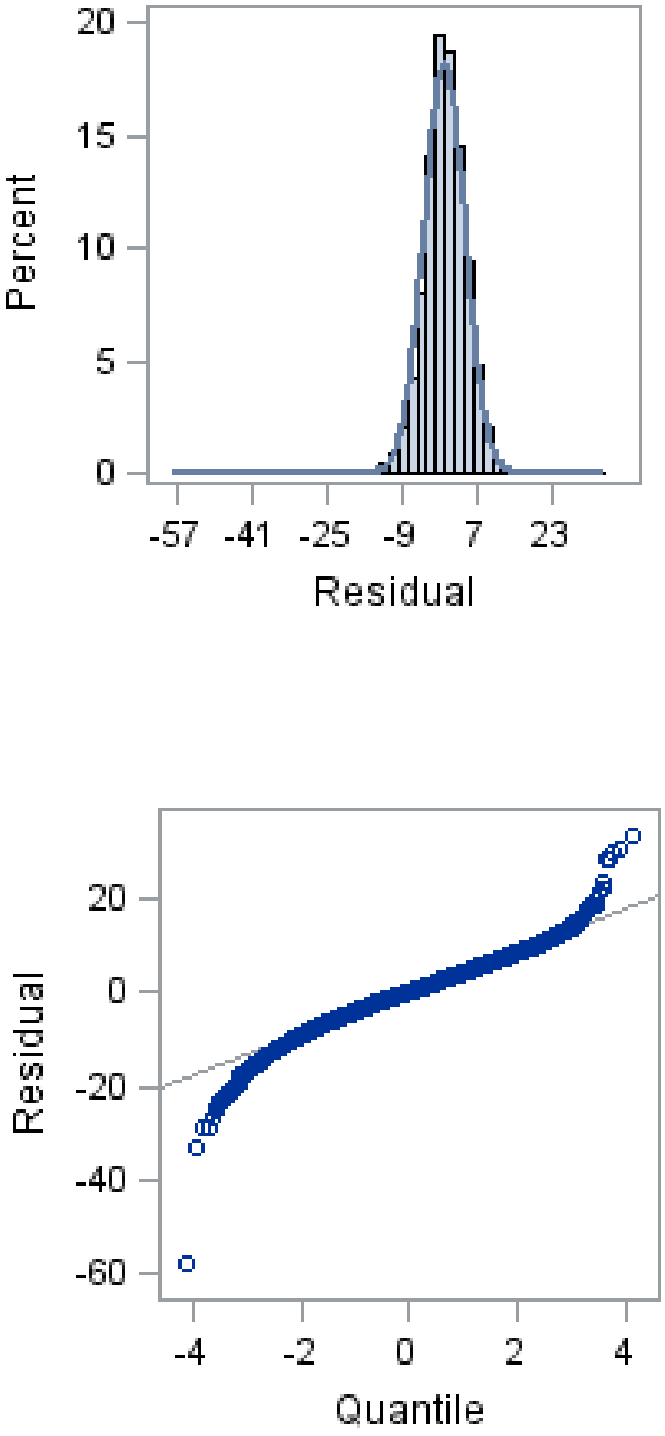


Figure 2.4. Diagnostics for weight-length nonlinear regression analysis.
The upper panel represents a histogram of residuals from expected values, and the lower panel is a plot of mean residuals vs. increments of predicted value.

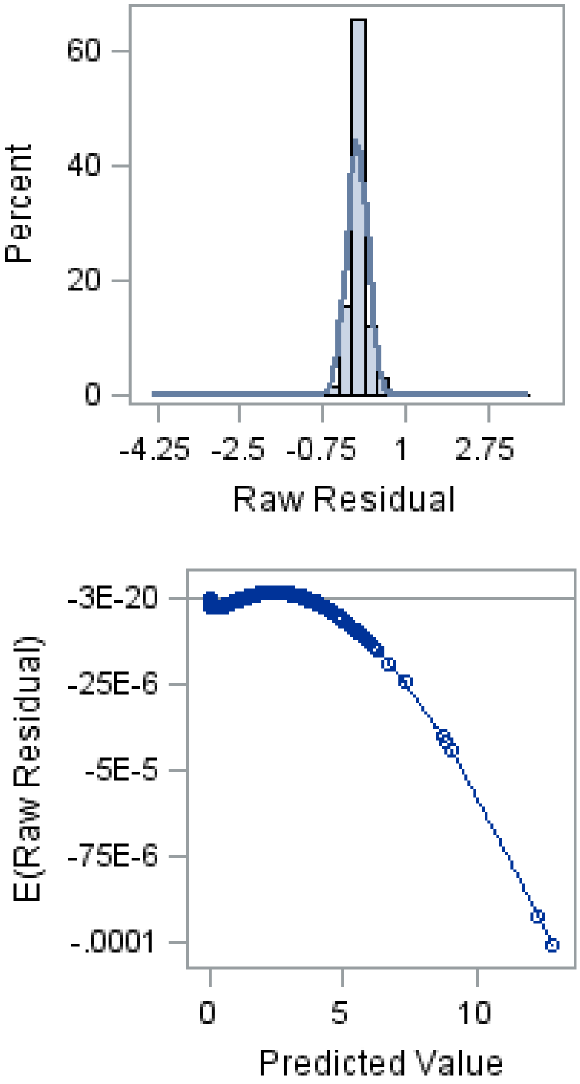


Figure 2.5. Diagnostics for weight-length ANCOVA.

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.

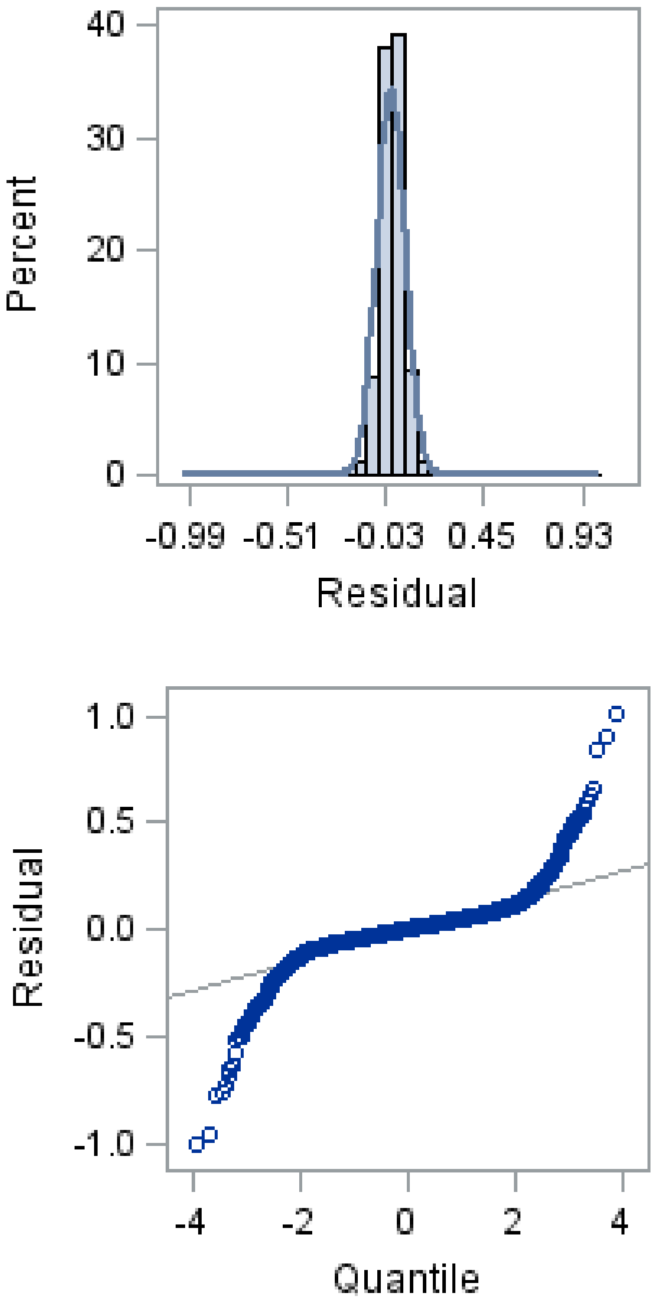


Figure 2.6. Von Bertalanffy growth curves by region.

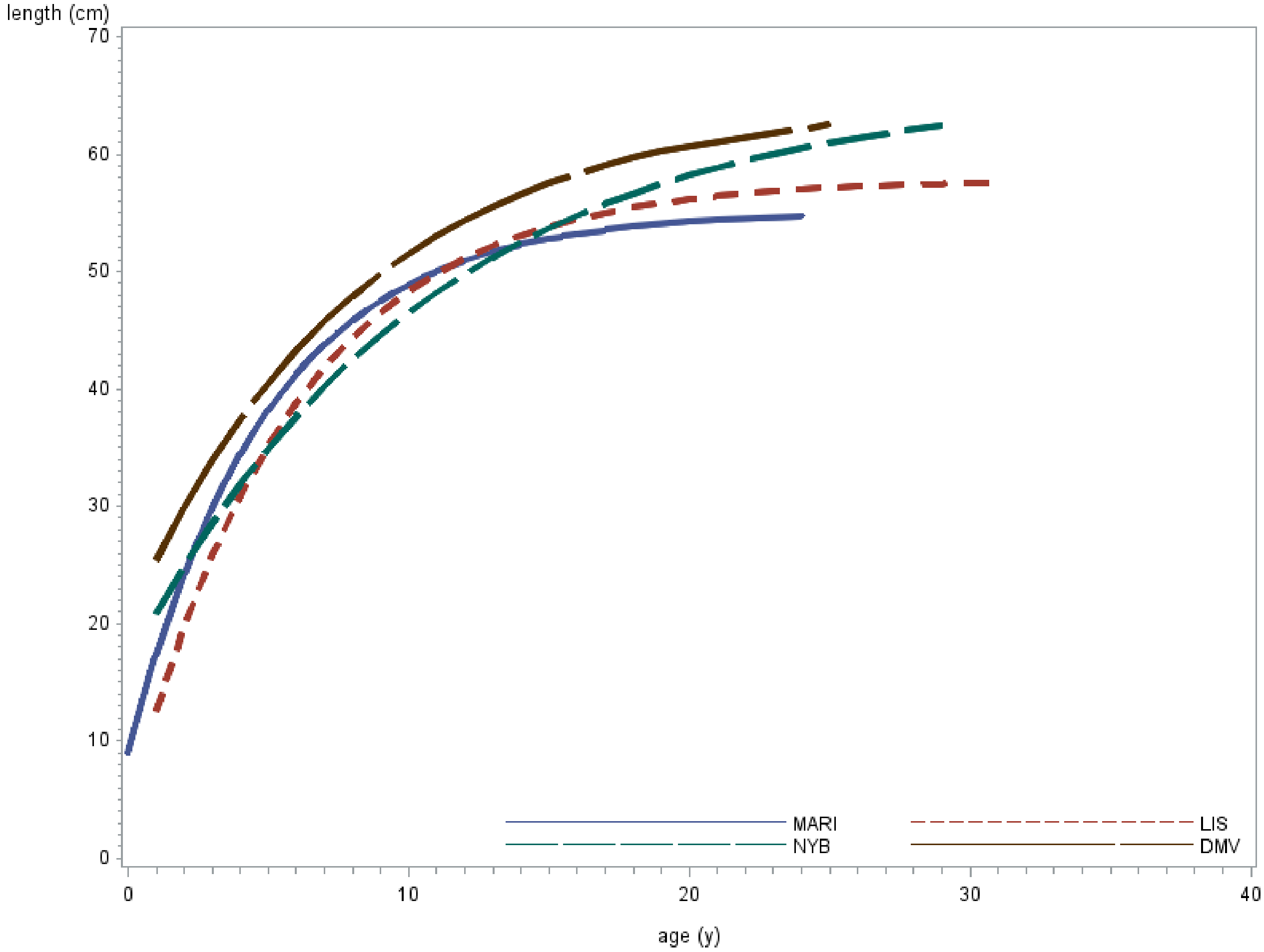


Figure 2.7. LSMean length over time.

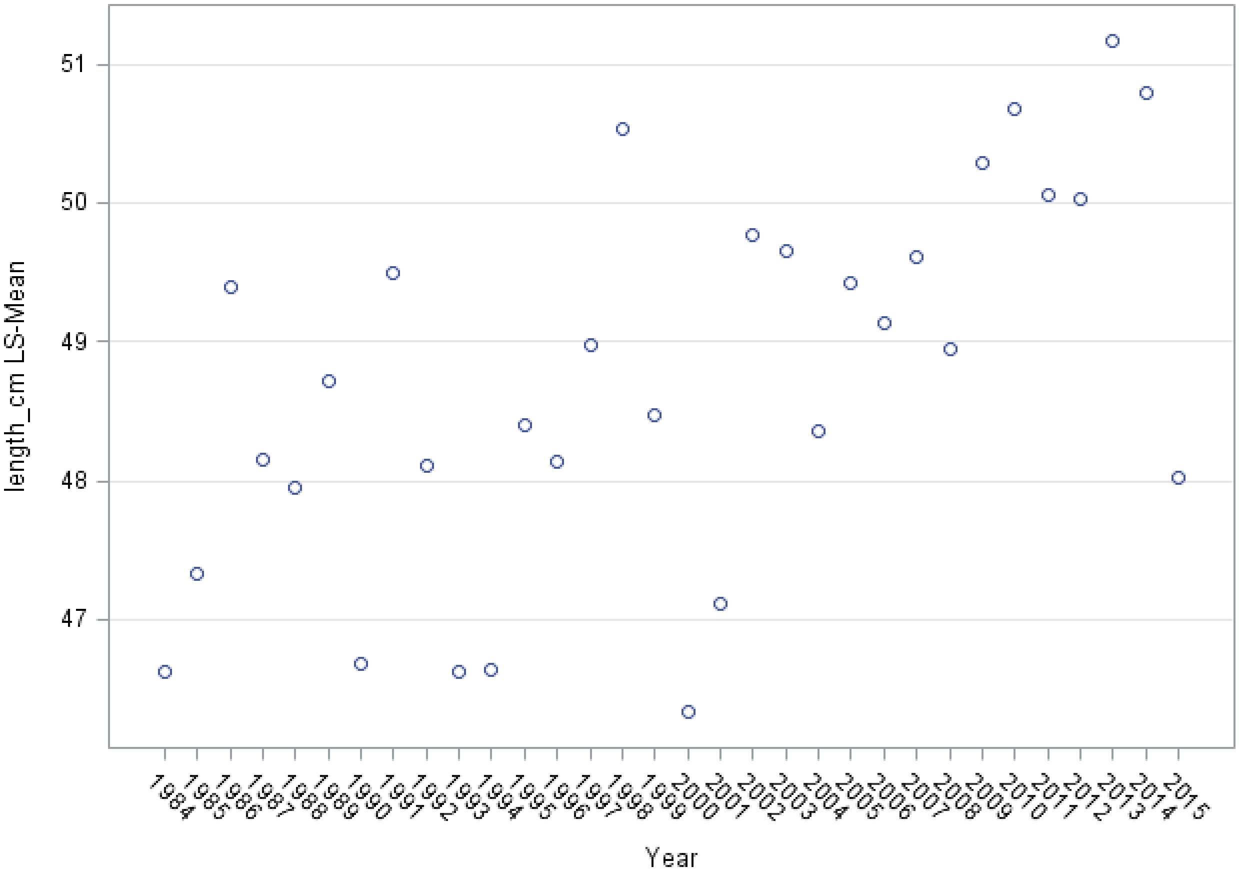


Figure 2.8. LSMean (±SD) length for each of 4 regions.
Values plotted are the difference between LSMeans of each region. Lines represent Tukey-Kramer confidence intervals.

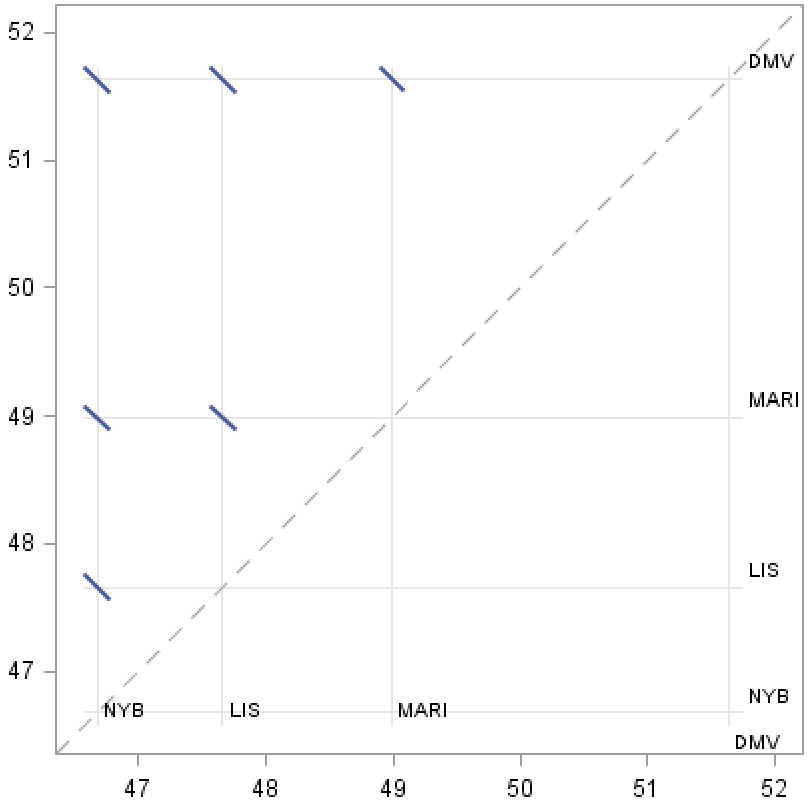


Figure 2.9. Length-weight relationships.
Plotted as regression lines fitted to allometric (power) equations weight = a*length^b.

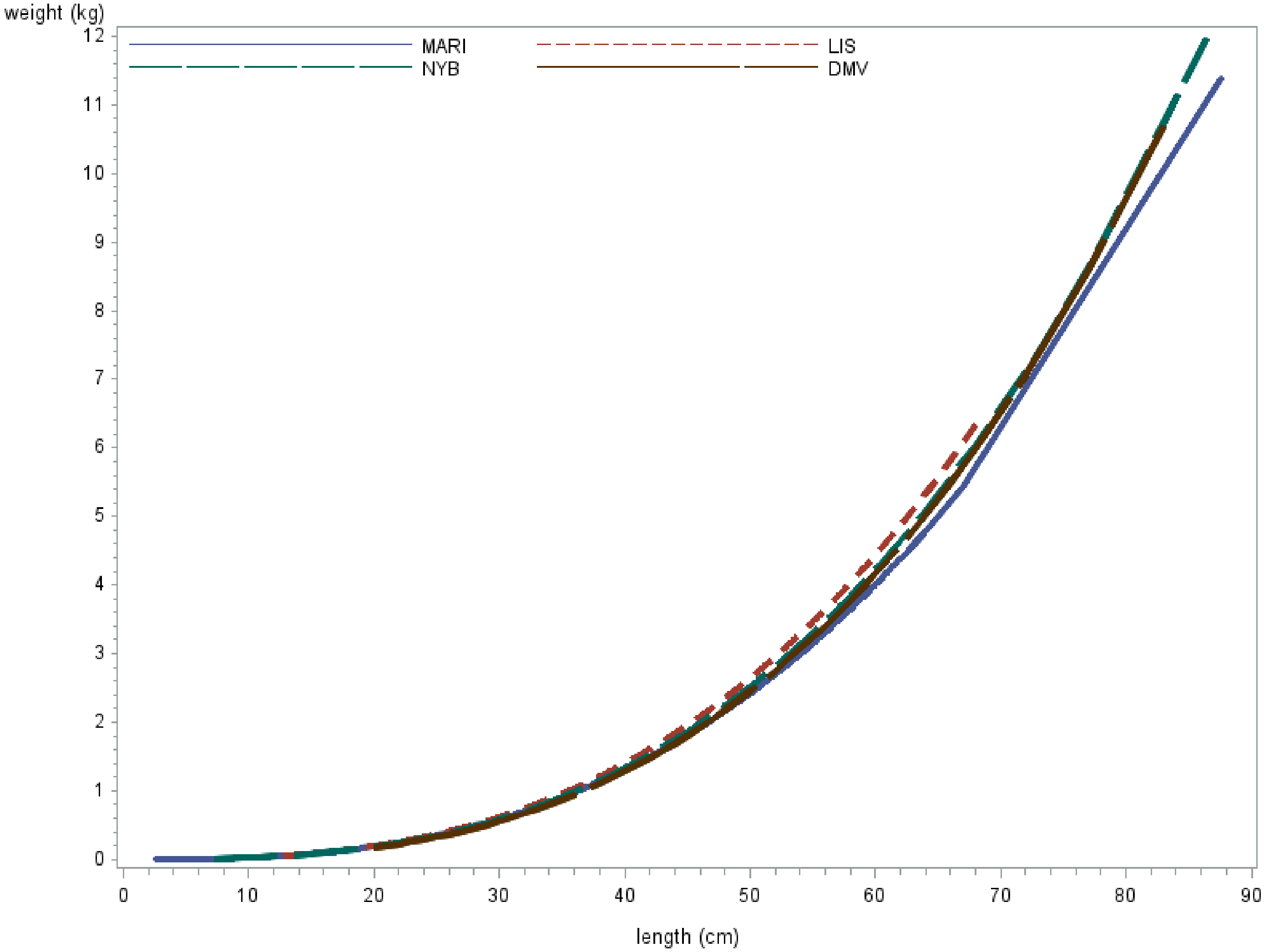


Figure 2.10. LSMean weight over time.

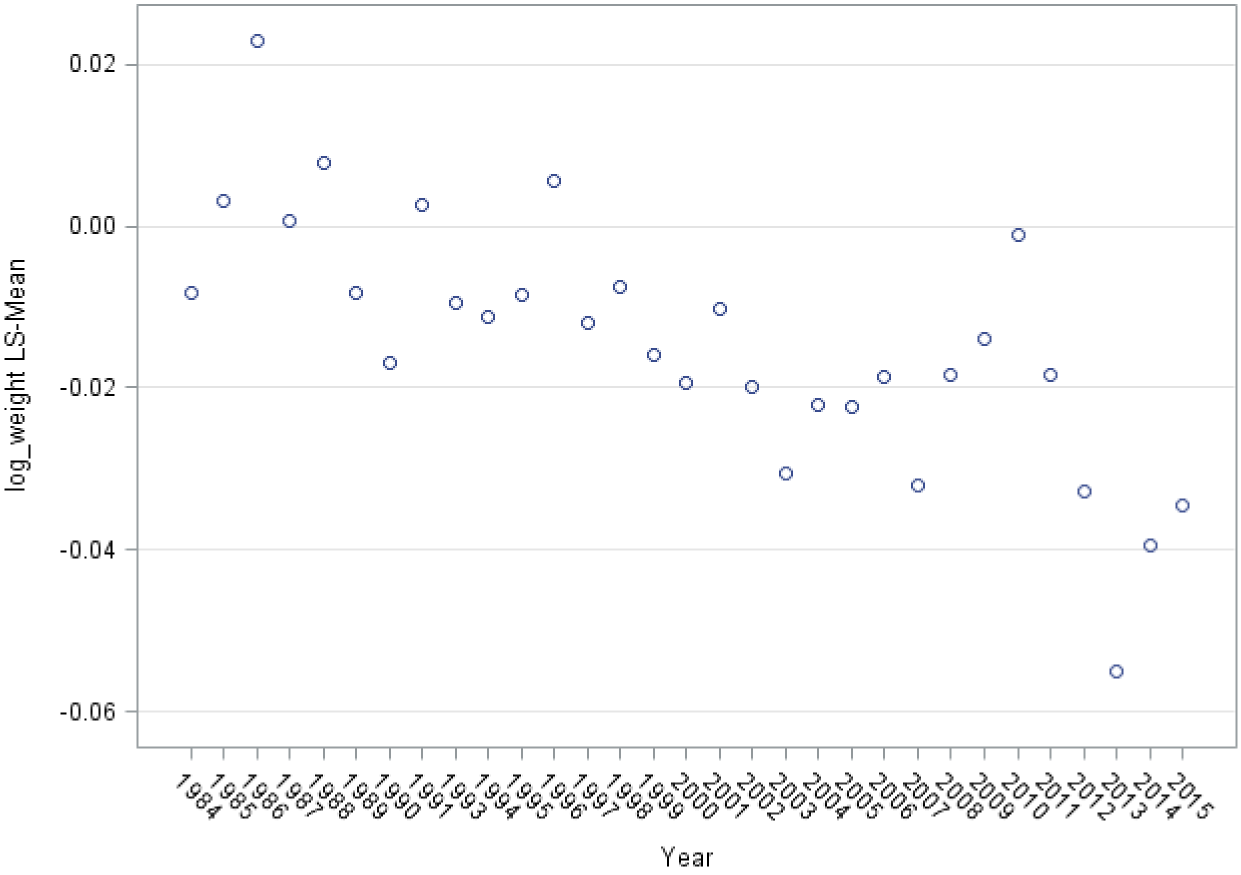


Figure 2.11. LSMean (±SD) weight-at-length for each of 4 regions.
Values plotted are the difference between LSMeans of each region. Lines represent Tukey-Kramer confidence intervals.

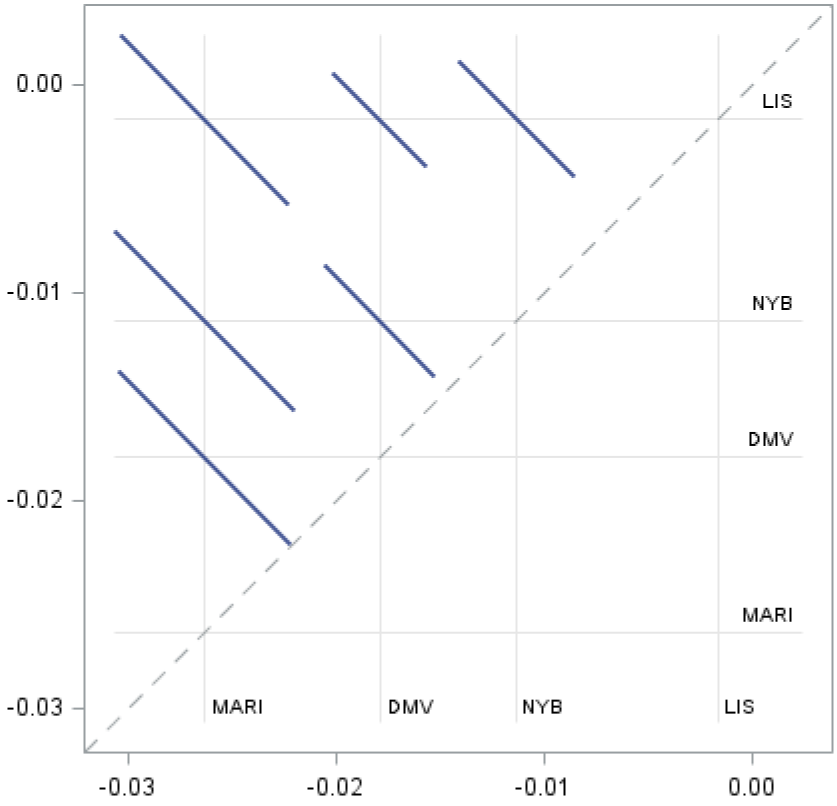


Figure 4.1. Recreational landings of Tautog in LIS and NJ-NYB, 1984-2014.
LIS data from 1984-1987 are from CT only. Source: NOAA Fisheries Commercial Fisheries Statistics Database, MRFSS, and MRIP.

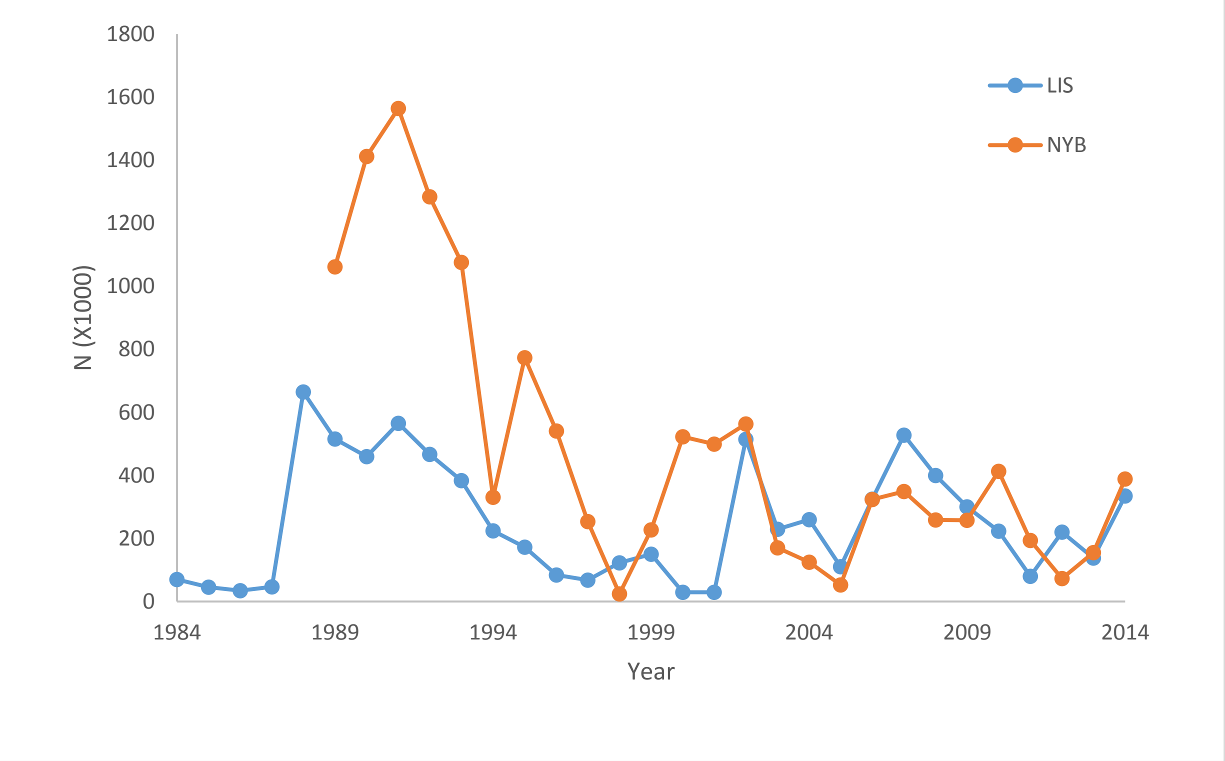


Figure 4.2. Proportion of recreational harvest (CT, NY, NJ combined) from the private/rental sector.

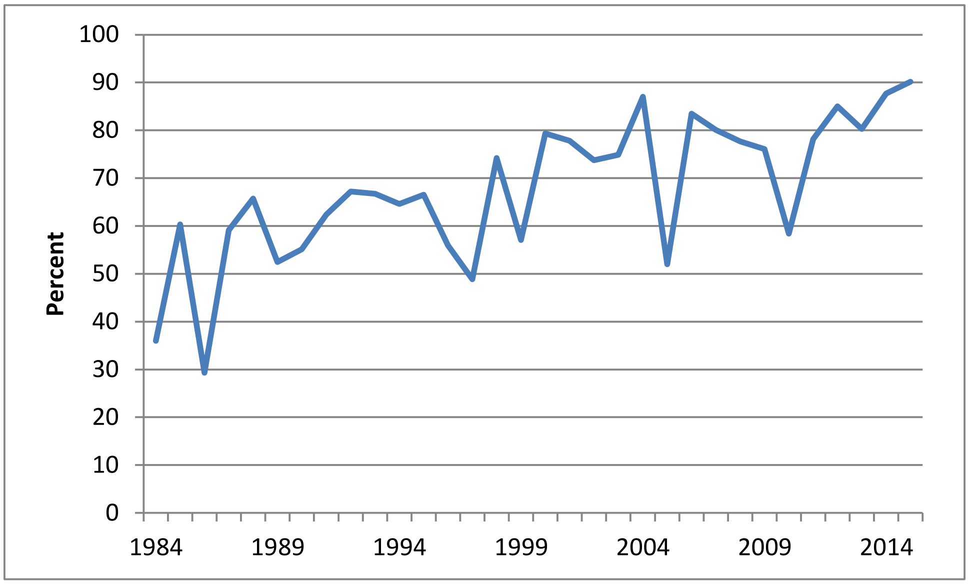


Figure 4.3. Commercial landings in LIS and NJ-NYB from 1990-2014.
LIS values for 1984 and 1985 are from CT only. Source: NOAA Commercial Fisheries Database http://www.st.nmfs.noaa.gov/commercial-fisheries/index.

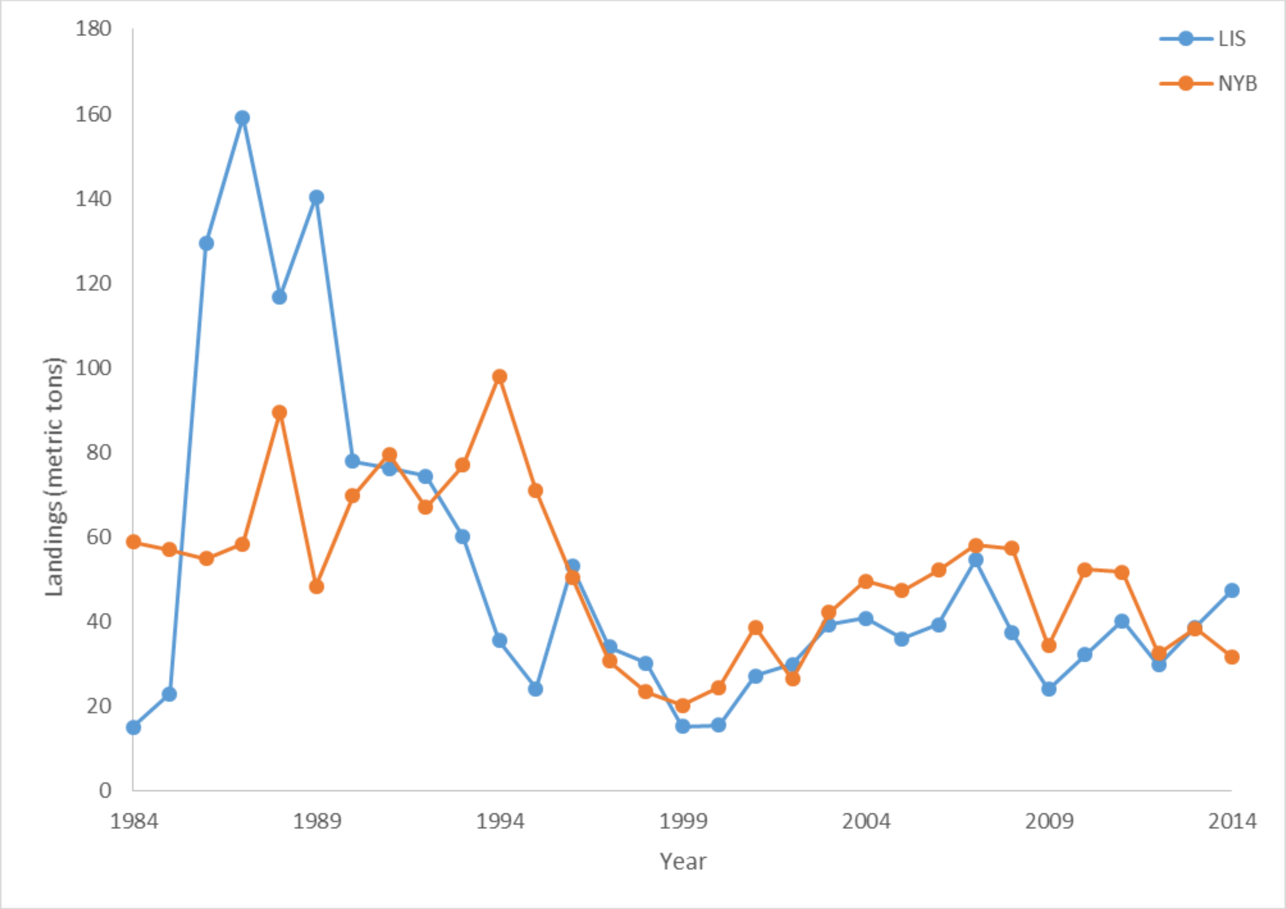


Figure 4.4. Relative activity of the commercial Tautog fishery by month, Based on CT, NY and NJ commercial landings from 1990-2014.

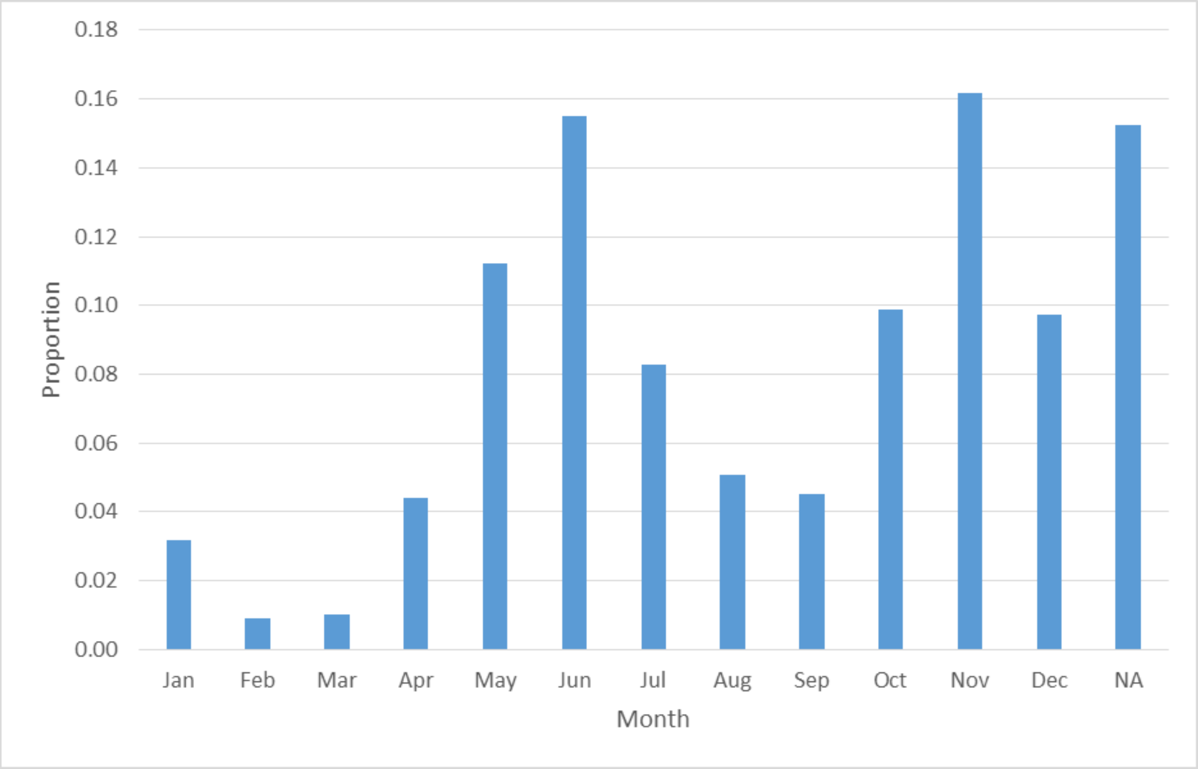


Figure 4.5. Relative commercial Tautog landings by fishing gear
Based on based on CT, NY and NJ commercial landings from 1984-2014.

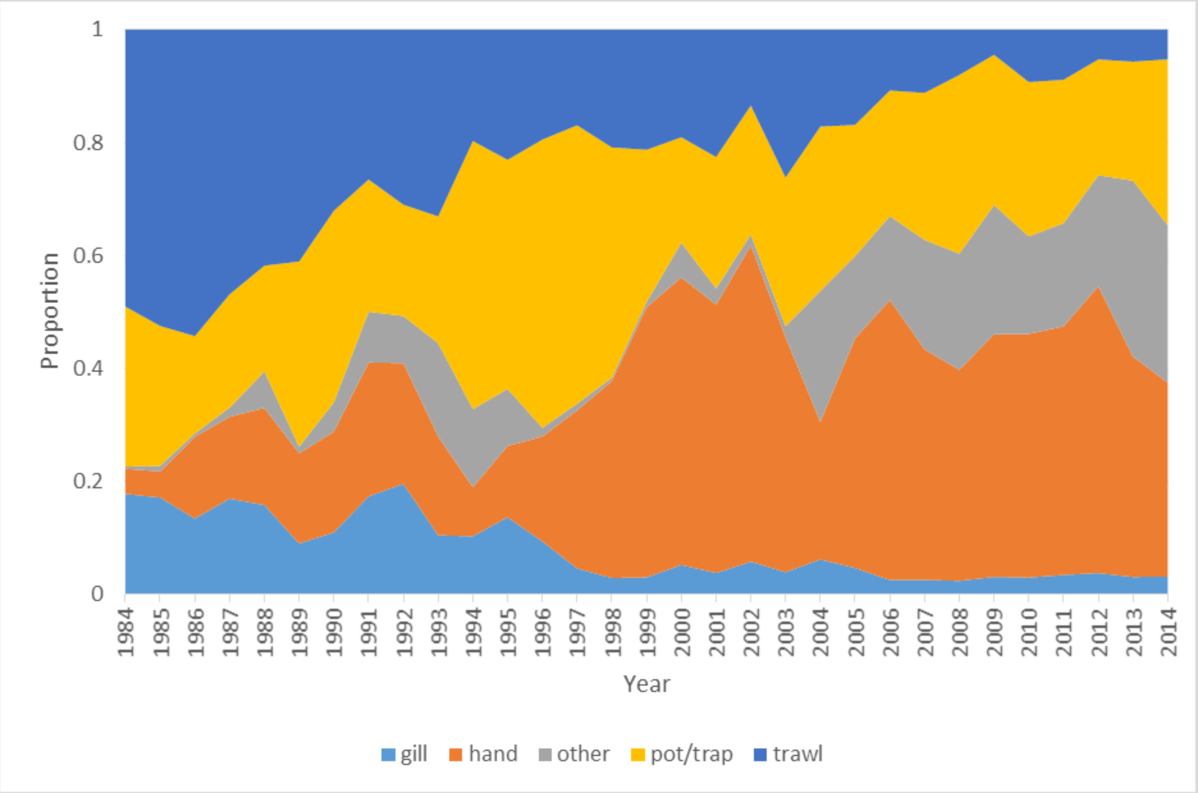


Figure 5.1. QQ plot for the negative binomial distribution of the final LIS recreational CPUE index model

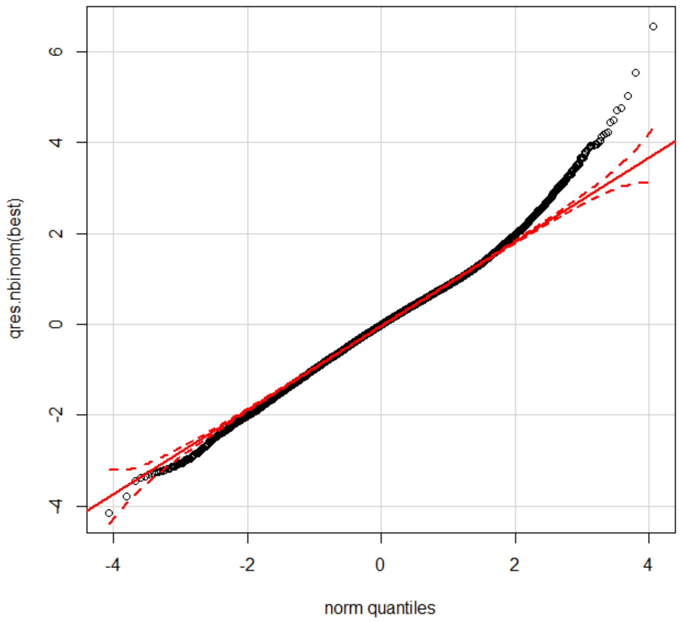


Figure 5.2. Cook’s distance for the final LIS recreational CPUE index model

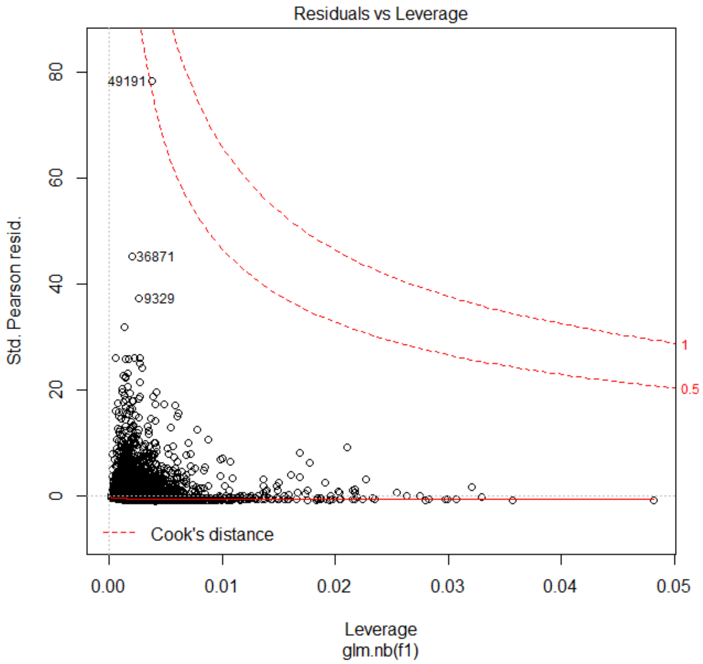


Figure 5.3. Final negative binomial distribution estimates of the LIS recreational CPUE index model

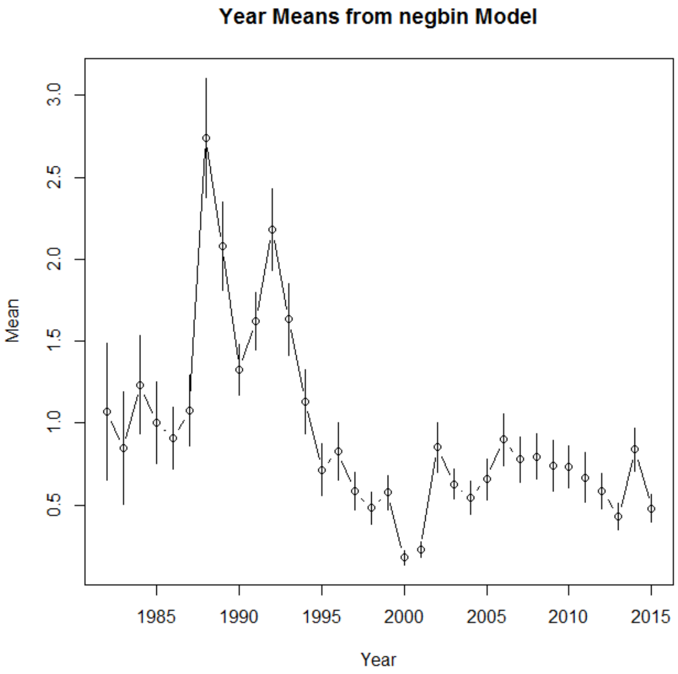


Figure 5.4. QQ plot for the negative binomial distribution of the final NJ-NYB recreational CPUE index model

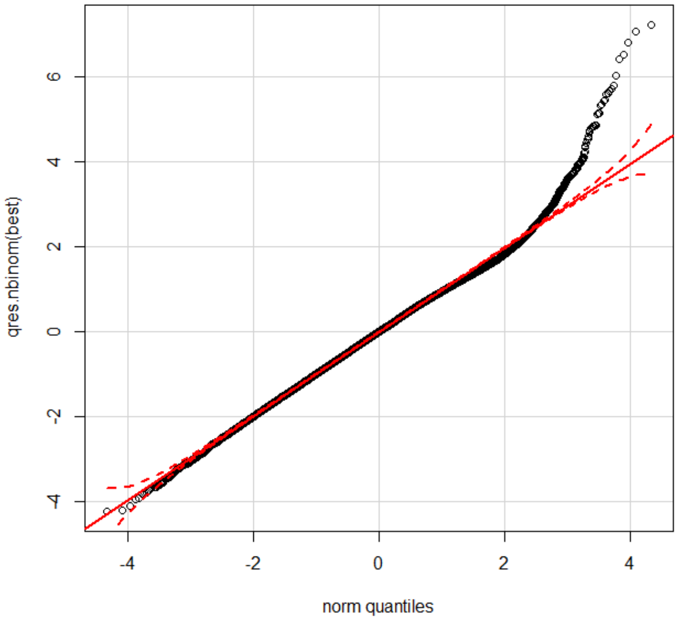


Figure 5.5. Cook's distance for the final NJ-NYB recreational CPUE index model

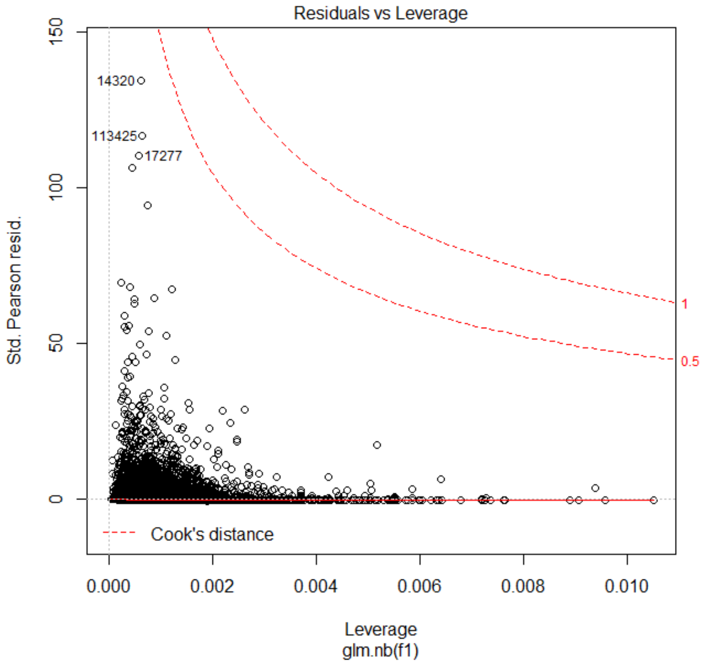


Figure 5.6. Final negative binomial distribution estimates of the NJ-NYB recreational CPUE index model

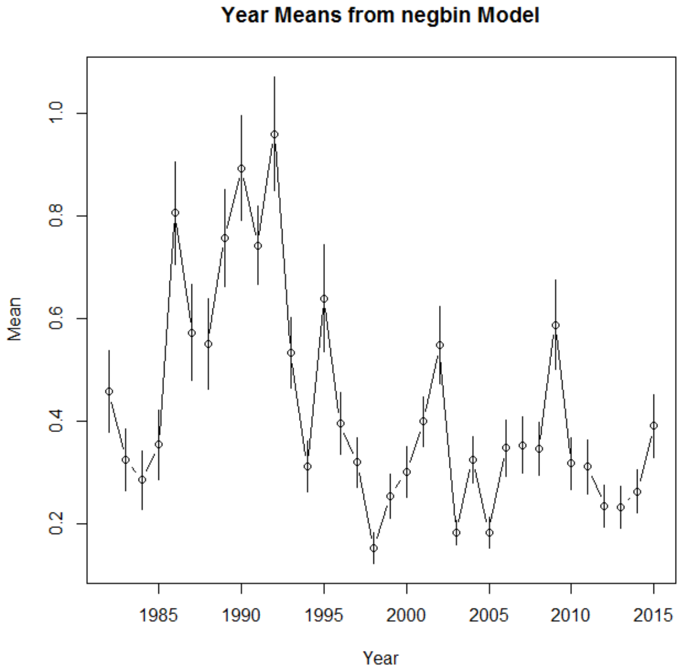


Figure 5.7. Histogram of catch data for the CT LISTS dataset.

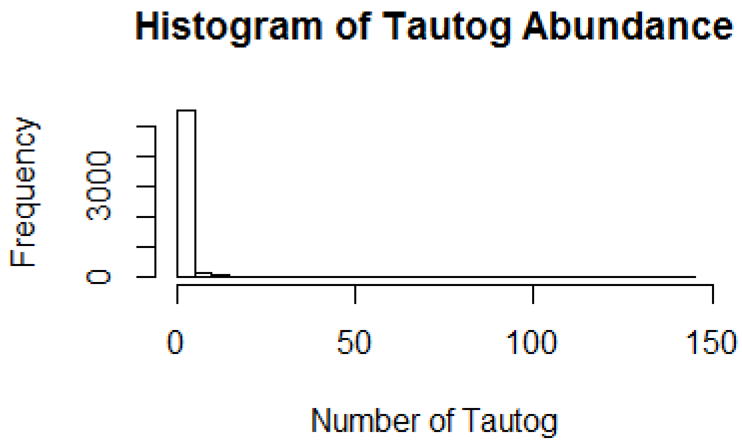


Figure 5.8. QQ Plot for negative binomial distribution for the final model used for the CT LISTS.

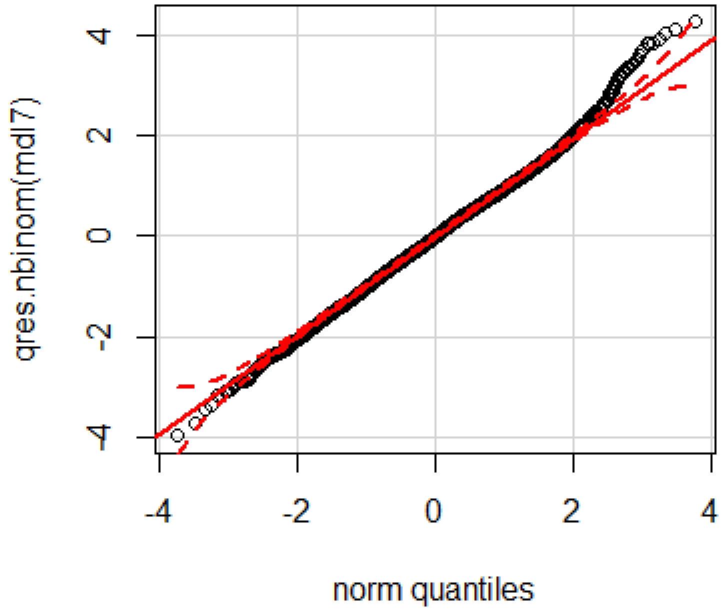


Figure 5.9. Cook's distance plot for the final model used for the CT LISTS.

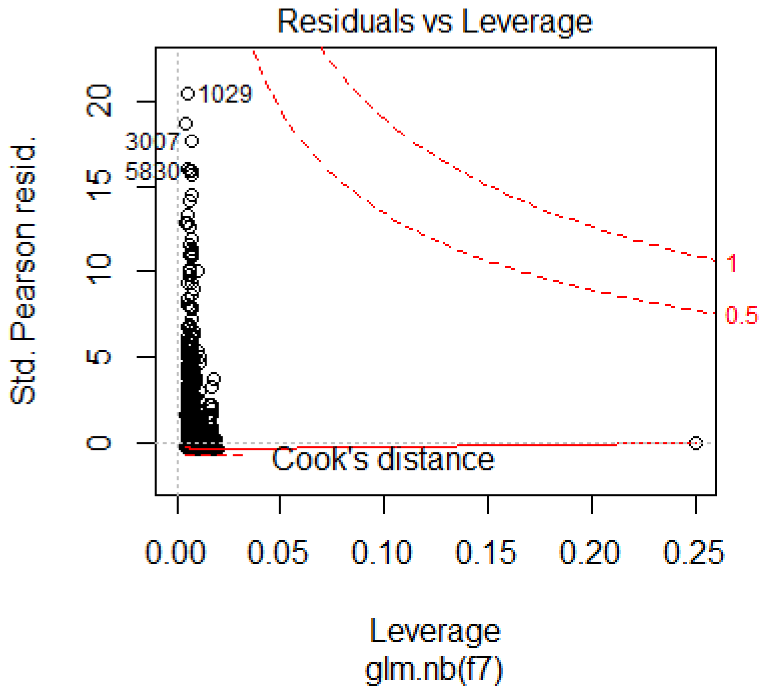


Figure 5.10. Standardized index versus the nominal index for the CT LISTS.

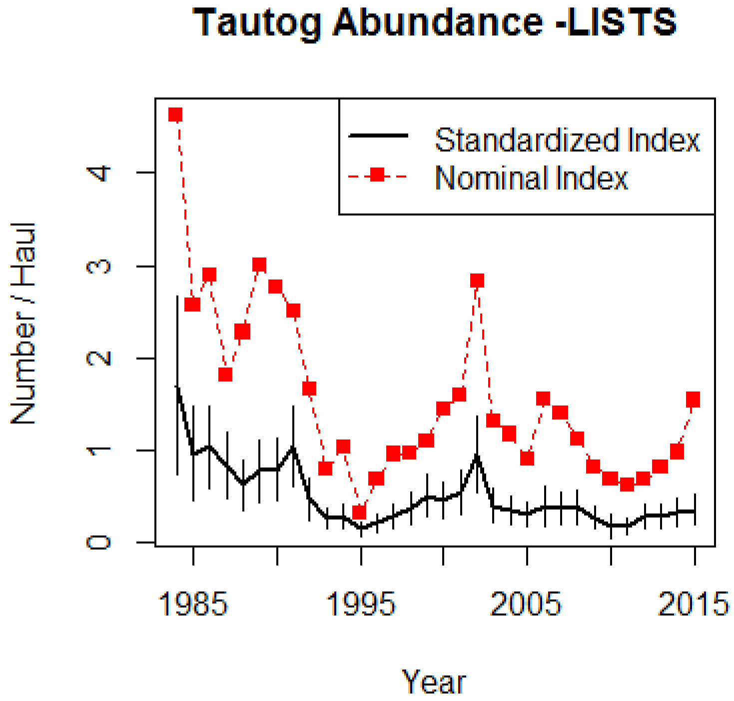


Figure 5.11. Annual abundance of Tautog eggs and larvae in the Millstone entrainment samples.

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.

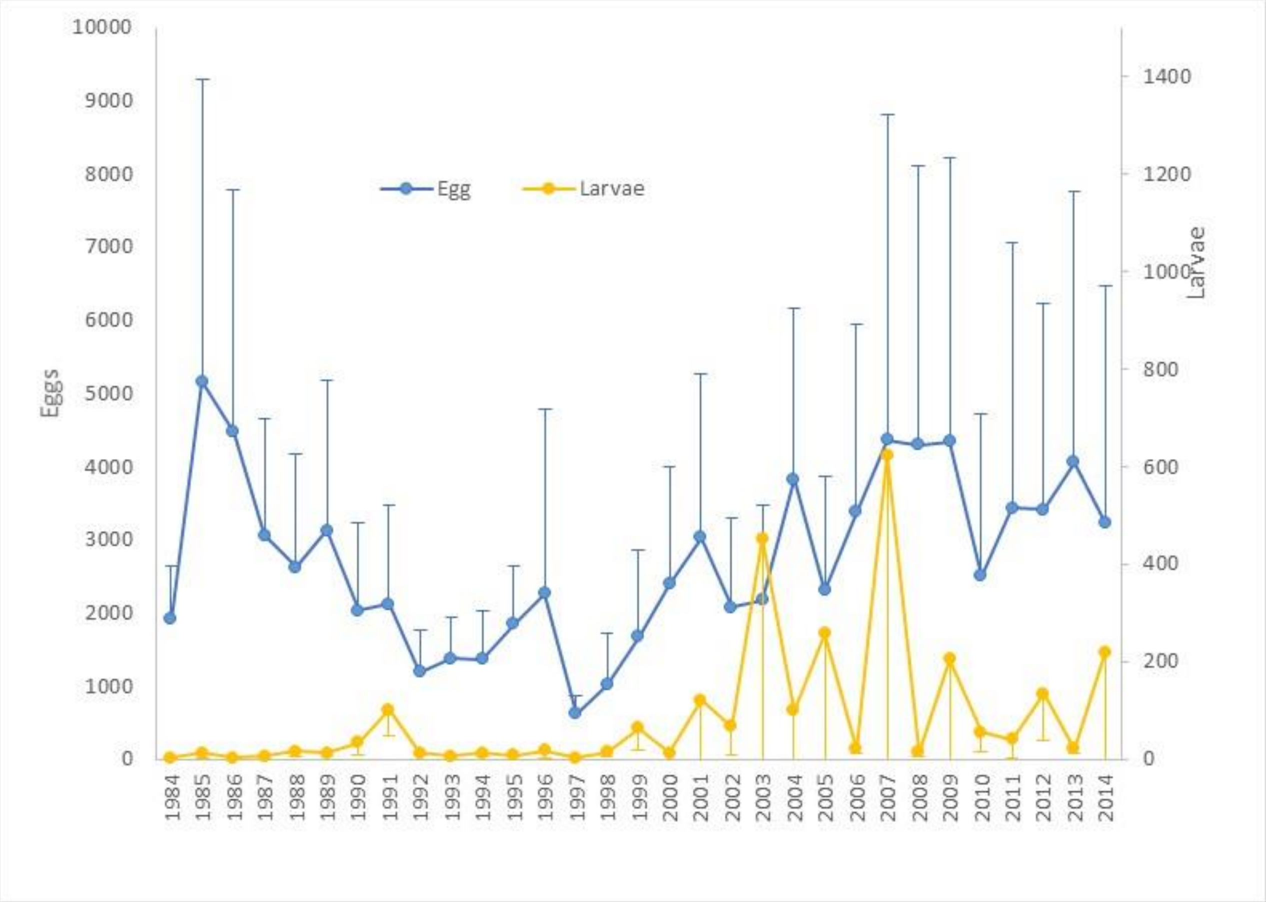


Figure 5.12. Histogram of catch data for the Peconic Bay Trawl Survey dataset.

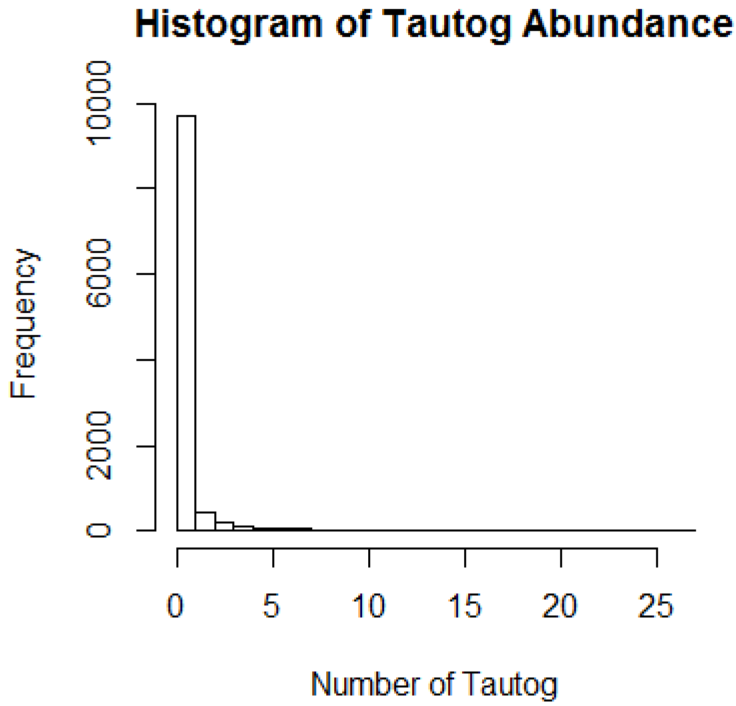


Figure 5.13. QQ Plot for negative binomial distribution for the final model used for the NYPBTS.

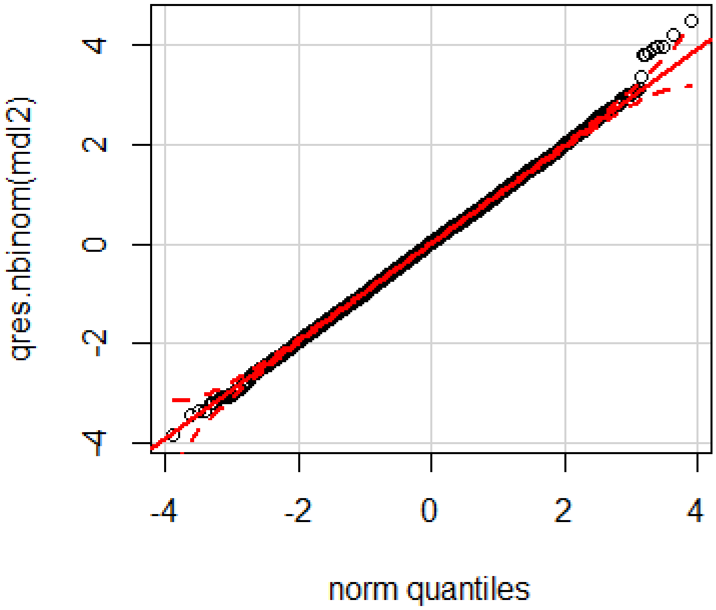


Figure 5.14. Cook's distance plot for the final model used for the NYPBTS.

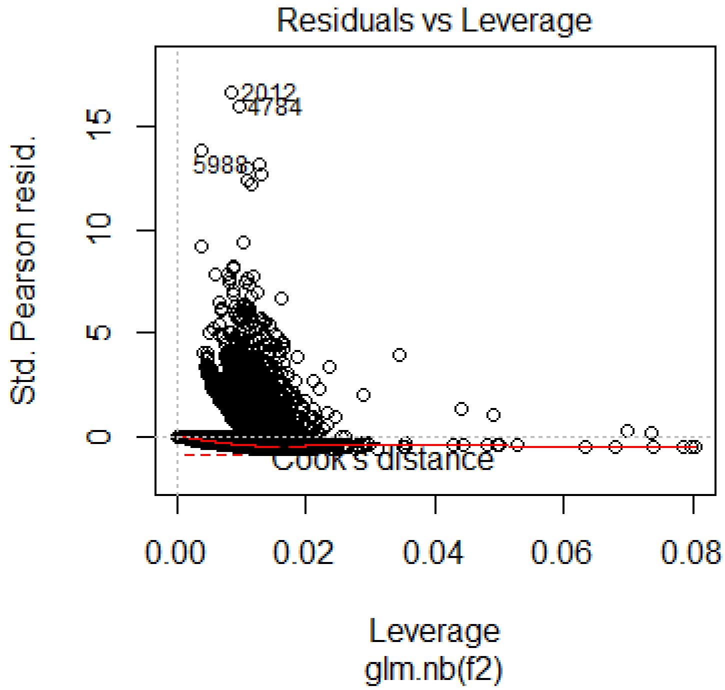


Figure 5.15. Standardized index versus the nominal index for the NYPBTS.

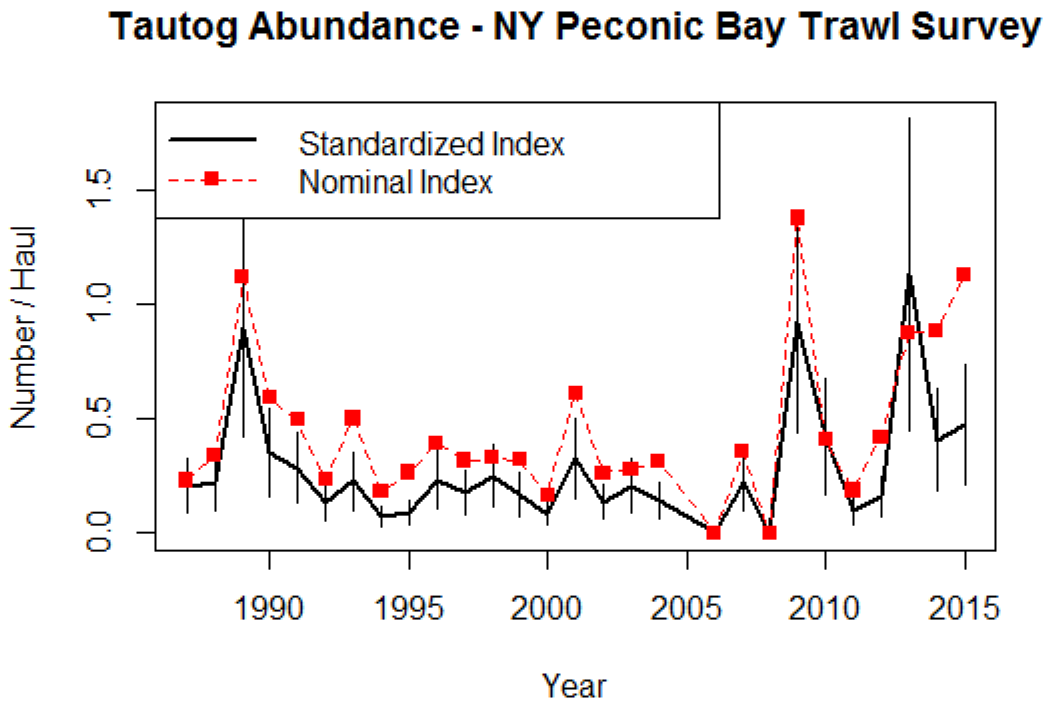


Figure 5.16. Histogram of catch data for the LIS portion of the NYWLISS dataset.

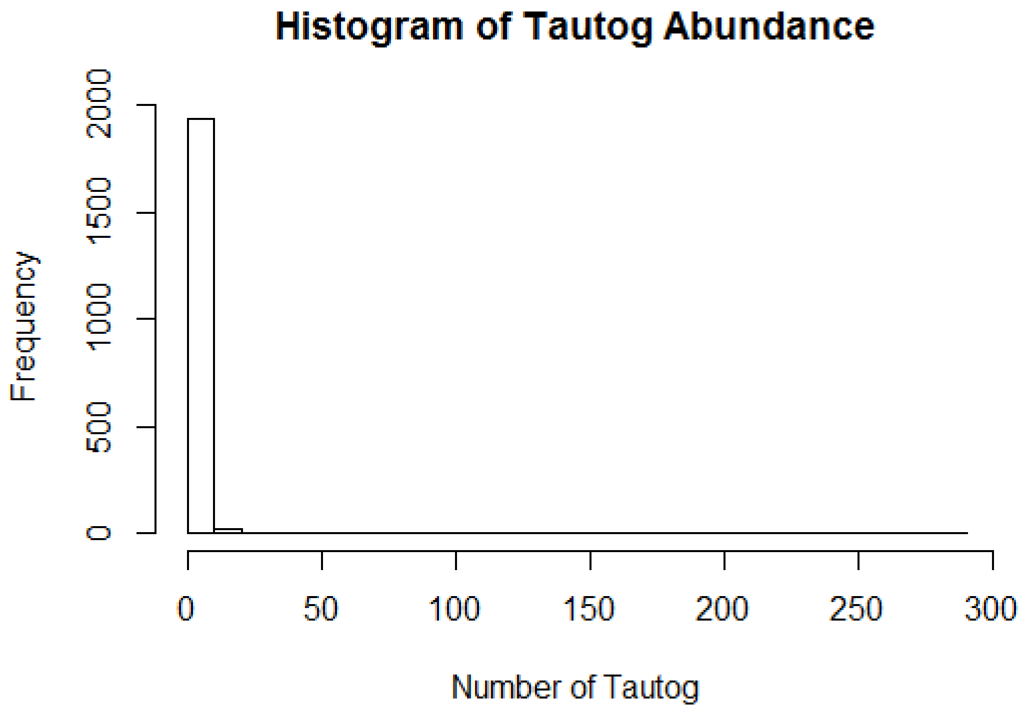


Figure 5.17. QQ Plot for negative binomial distribution for the final model used for the LIS portion of the NYWLISS.

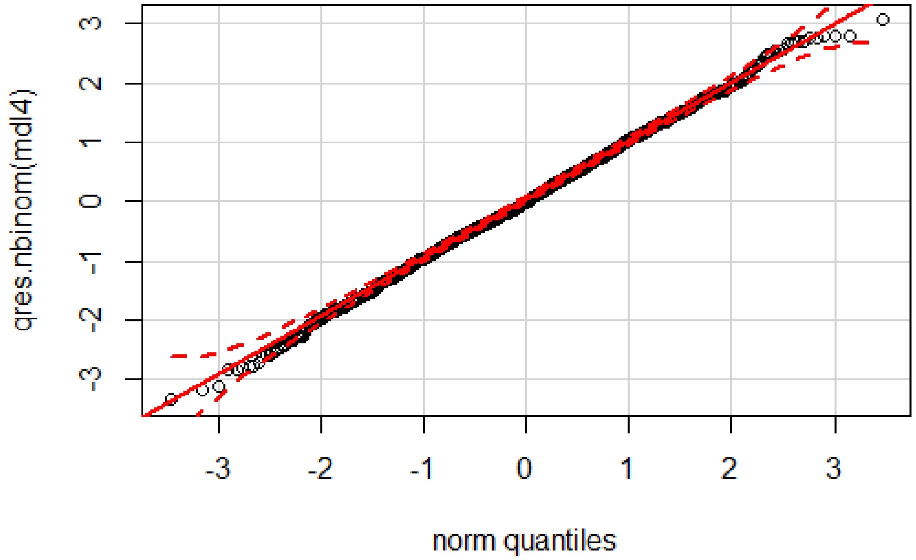


Figure 5.18. Cook's distance plot for the final model used for the LIS portion of the NYWLISS.

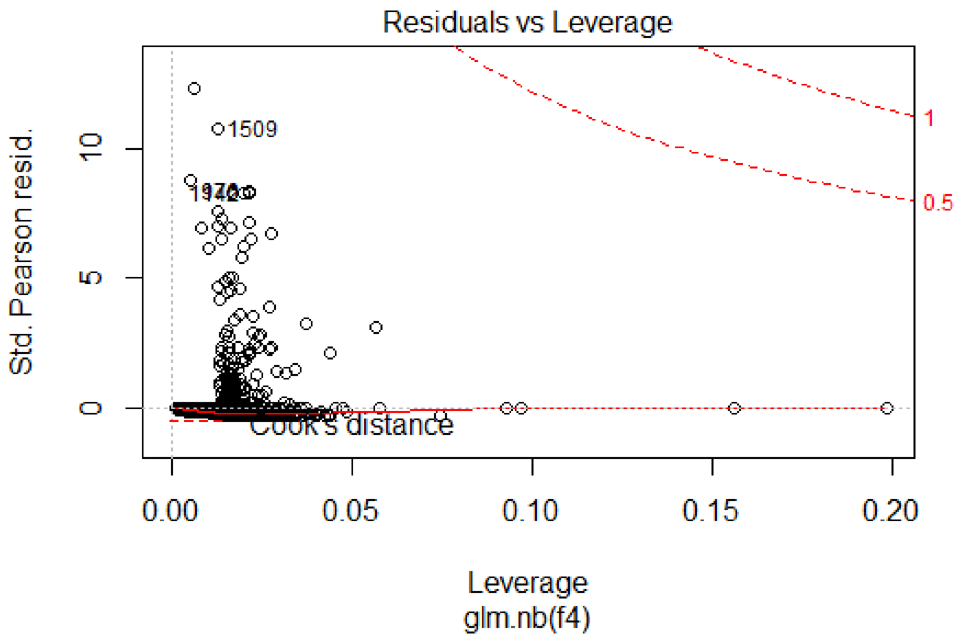


Figure 5.19. Standardized index versus the nominal index for the LIS portion of the NYWLISS.

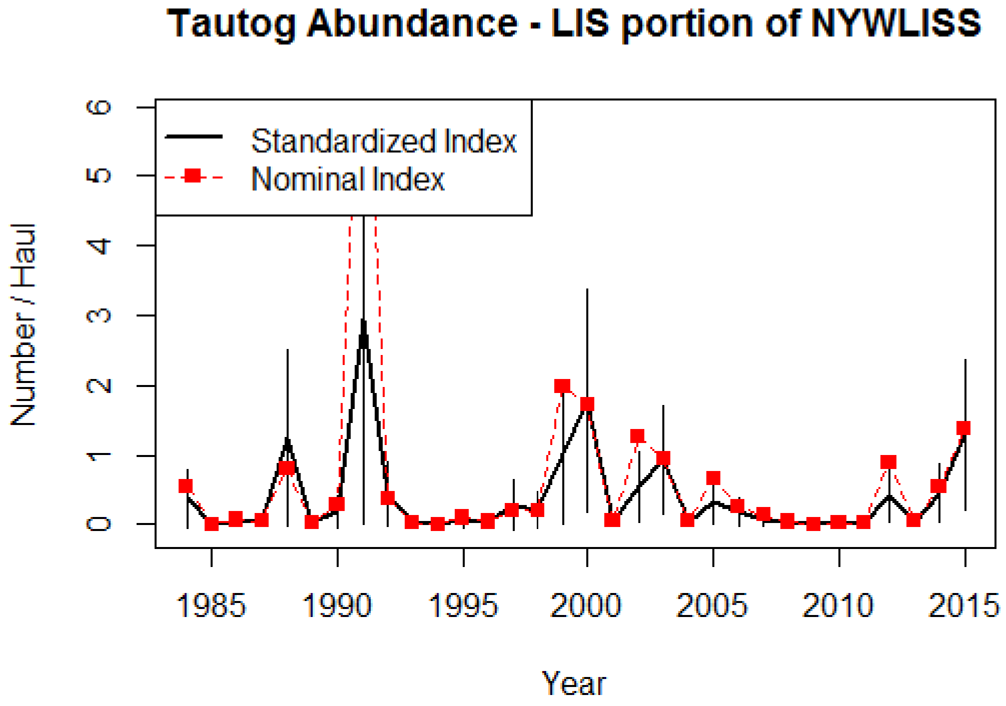


Figure 5.20. Histogram of catch data for the NJ-NYB portion of the NYWLISS dataset.

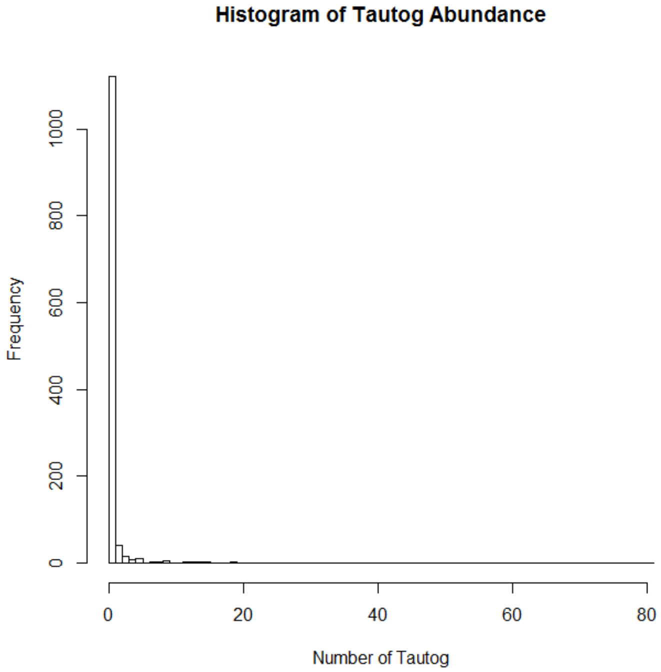


Figure 5.21. QQ plot of the negative binomial distribution for the final model of the NJ-NYB portion of the WLISS.

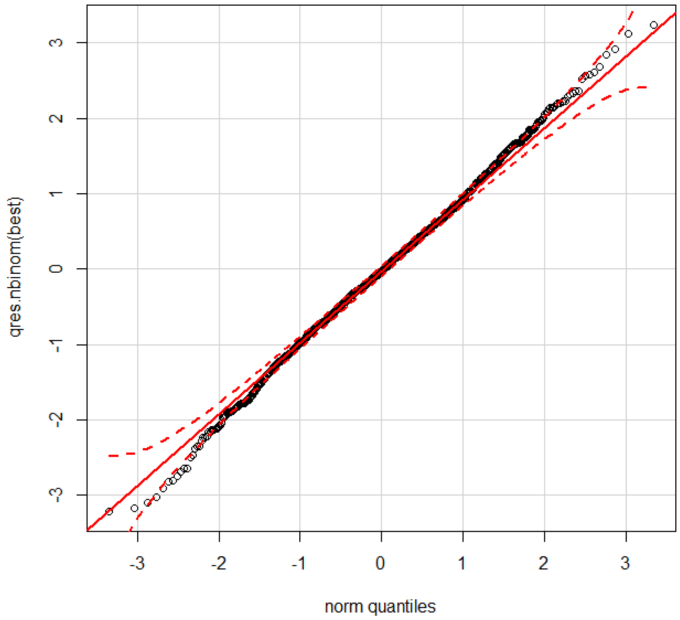


Figure. 5.22. Cook's distance for the final model of the NJ-NYB portion of the WLISS

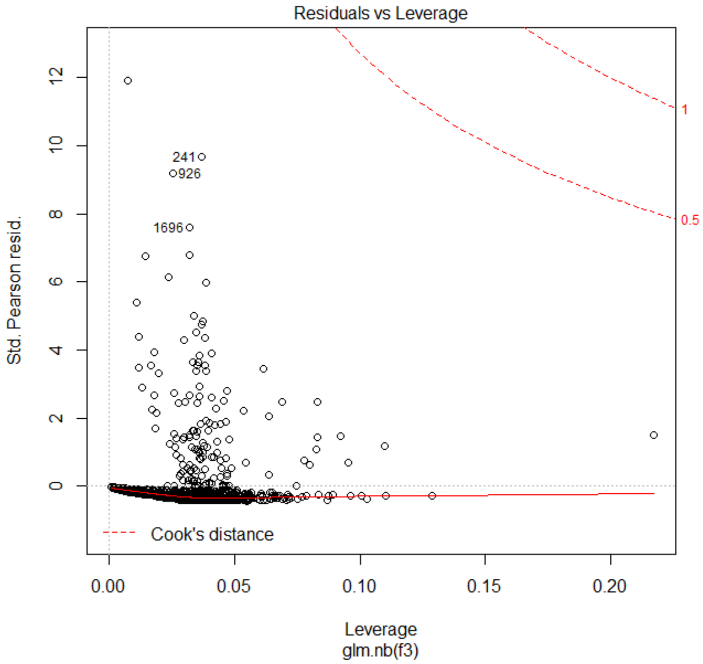


Figure 5.23. Final model estimates for the negative binomial GLM of the NJ-NYB portion of the WLISS.

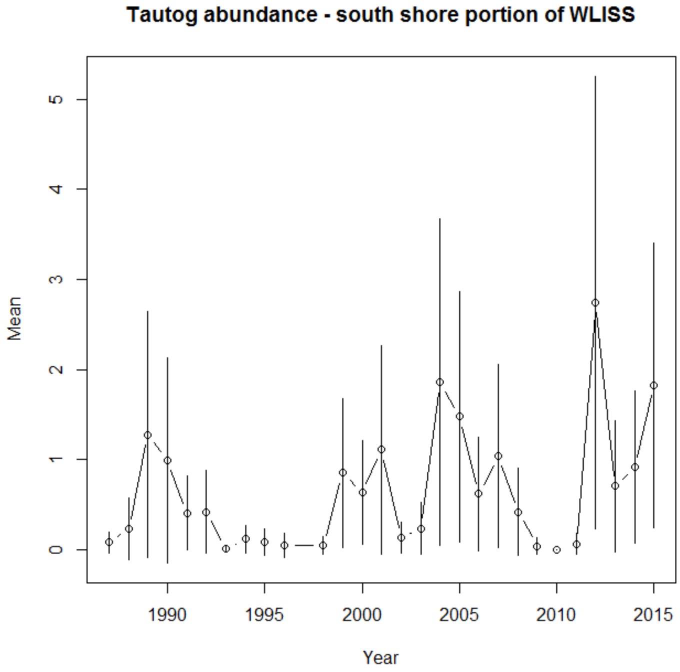


Figure 5.24. Catch histogram for the New Jersey Ocean Trawl survey

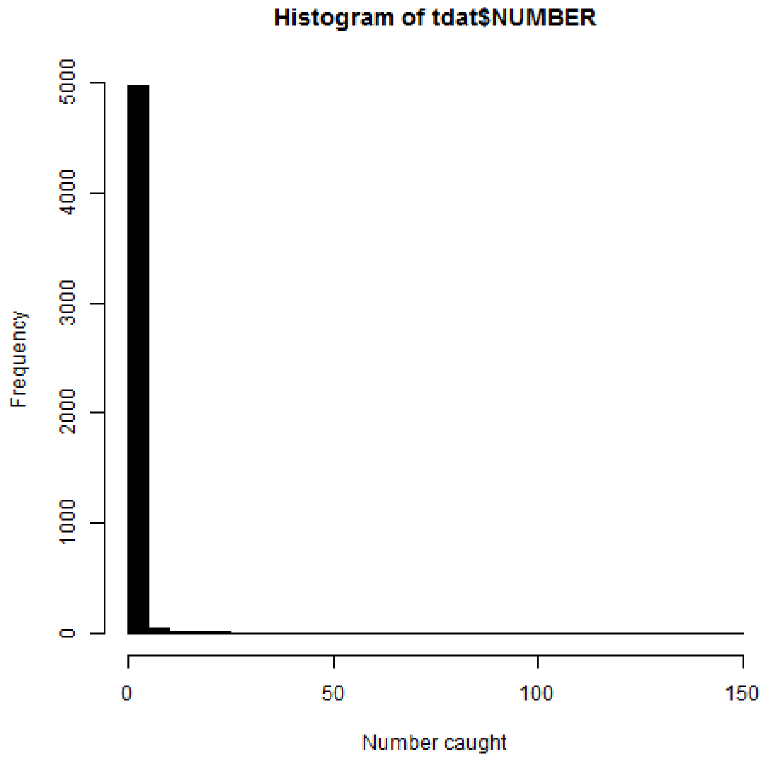


Figure 5.25. QQ plot of the negative binomial distribution for the NJ Ocean Trawl survey

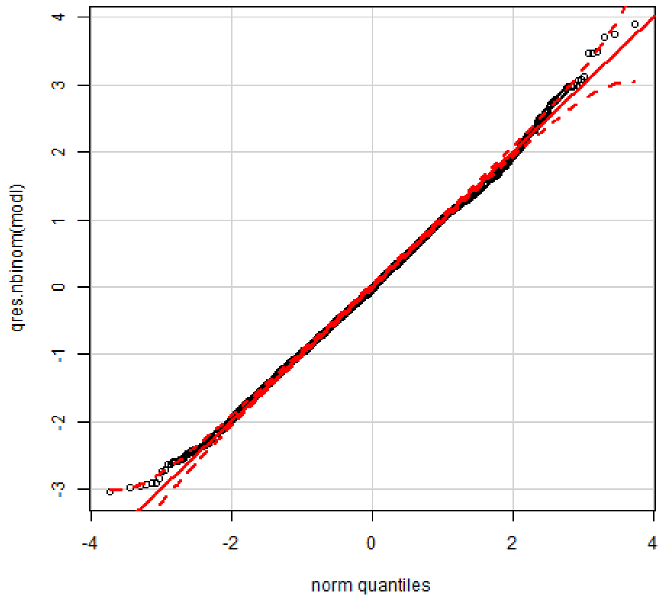


Figure 5.26. Cook's distance for the final model of the NJ Ocean Trawl survey

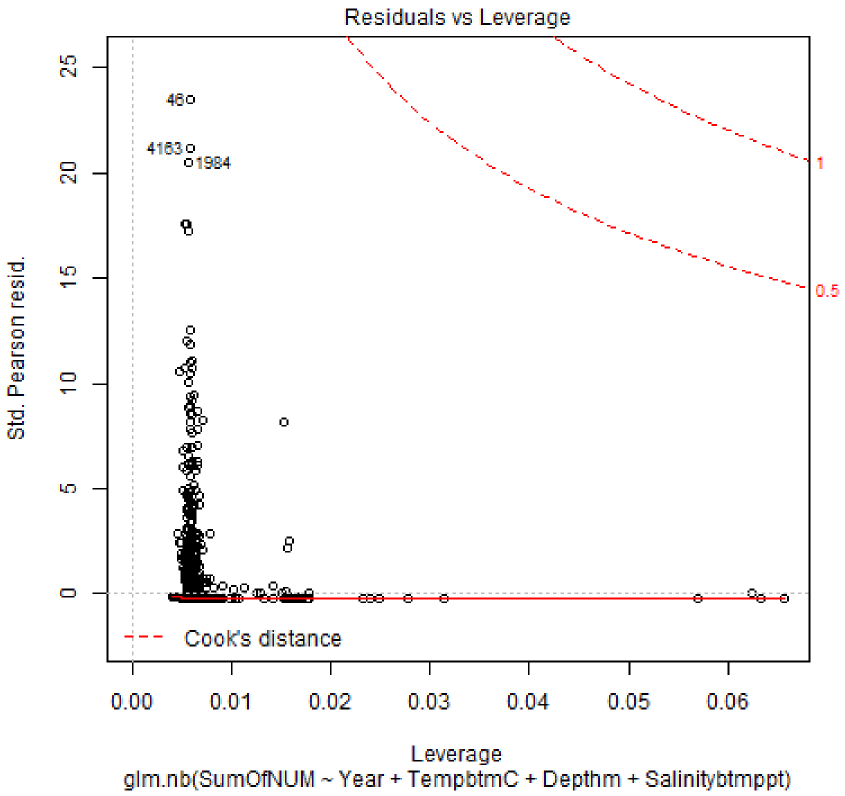


Figure 5.27. Final negative binomial model of the NJ ocean trawl survey

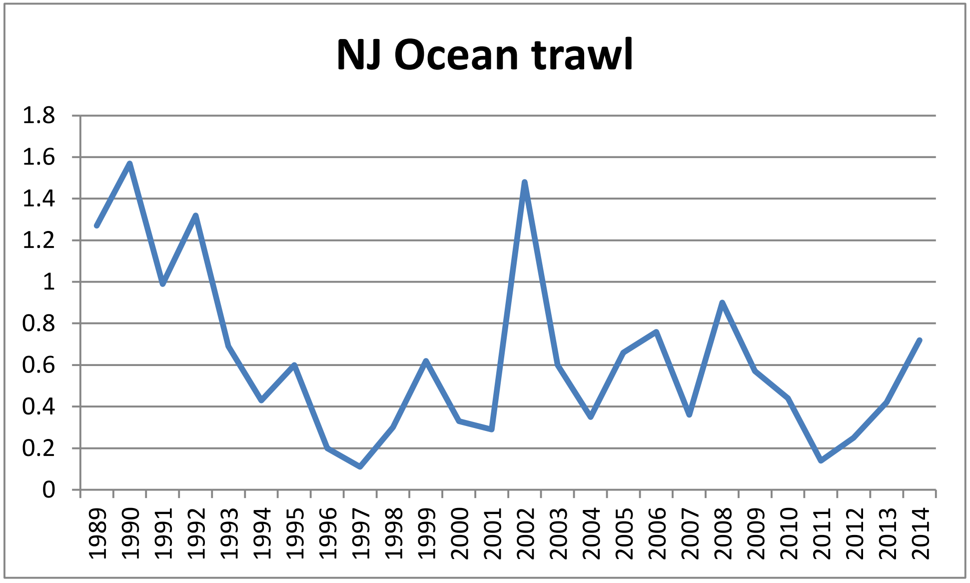


Figure 6.1. Observed and predicted total catch in weight (top) and standardized residuals (bottom) for Long Island Sound.

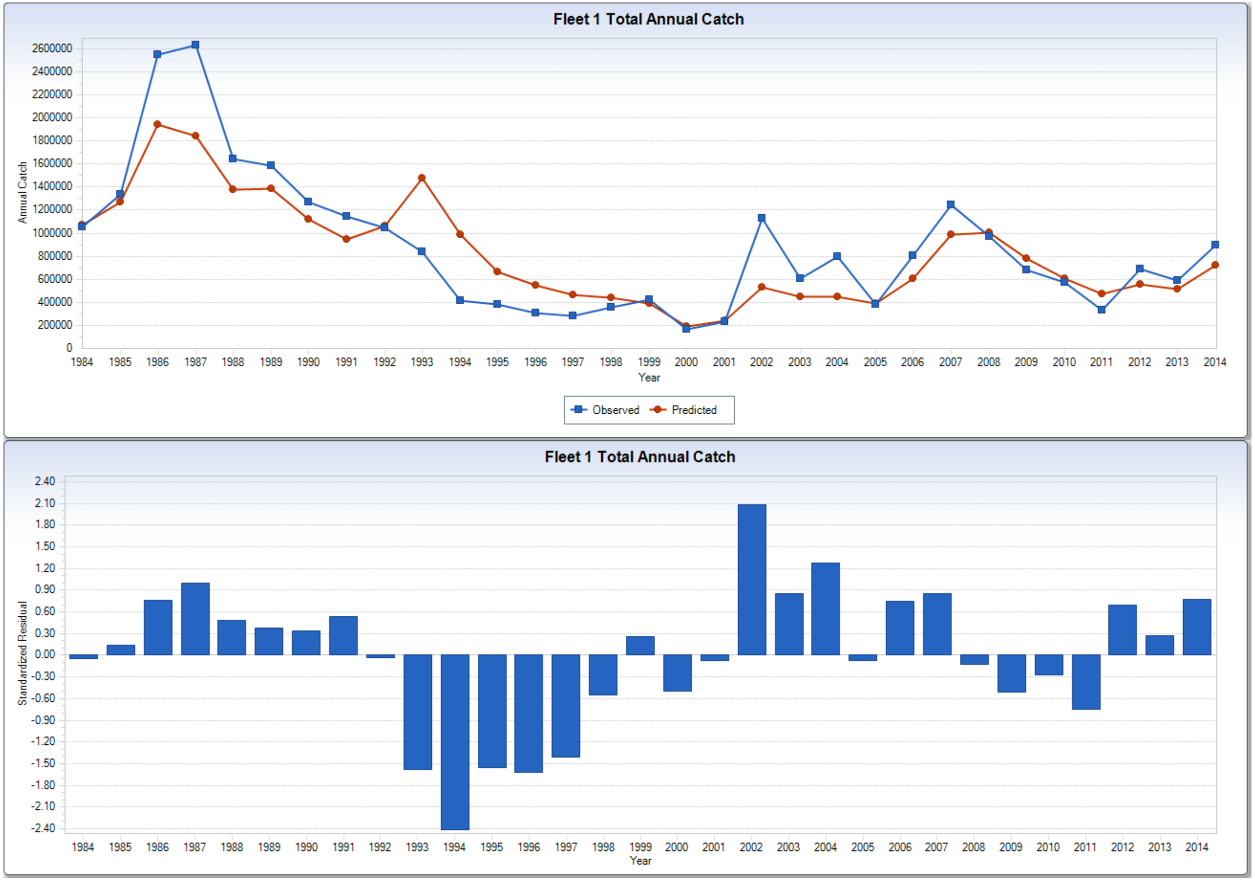
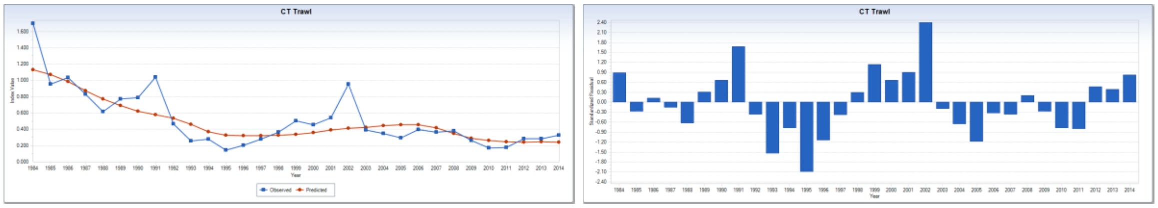
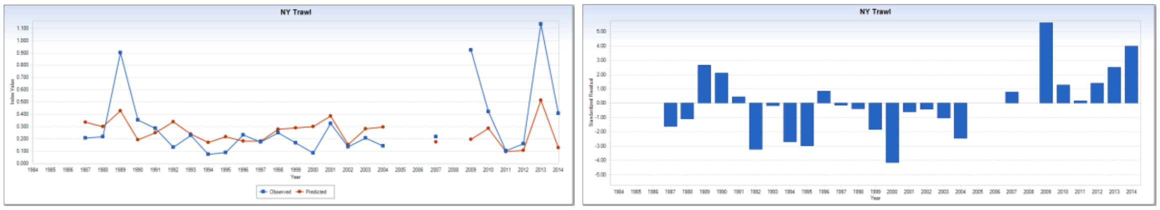


Figure 6.2. Observed and predicted fishery independent indices (left) and their standardized residuals (right) for Long Island Sound.

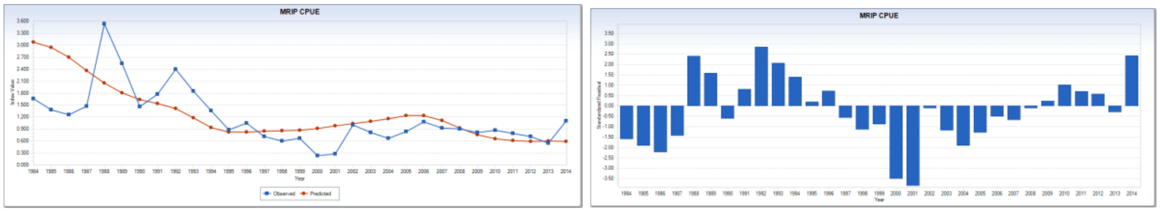
LISTS



NYTrawl



MRIP CPUE



NYSeine

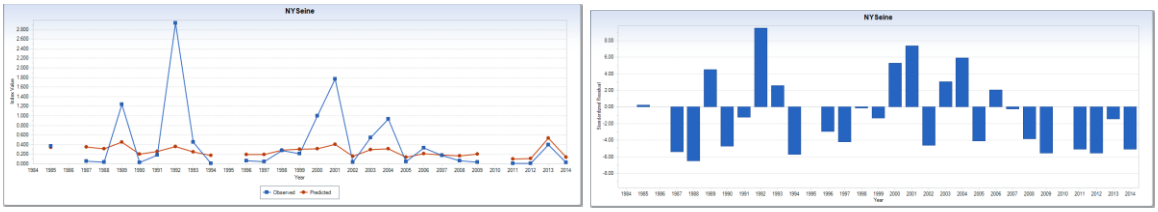


Figure 6.3. Total observed and predicted catch-at-age for Long Island Sound.

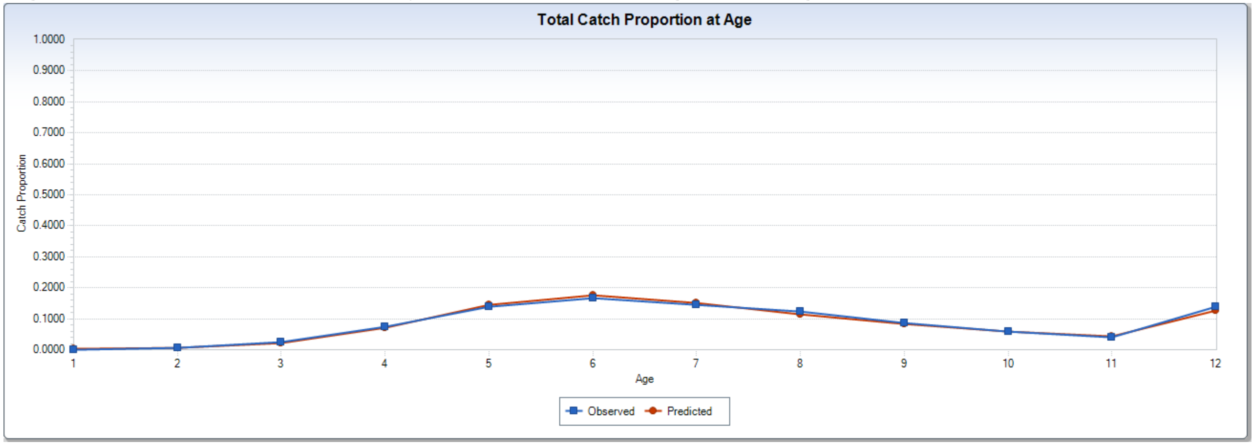
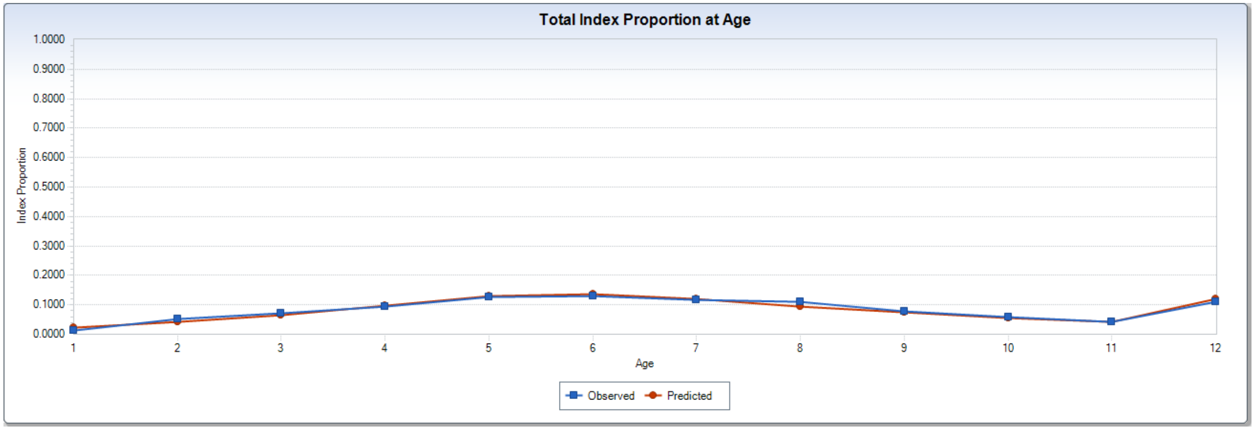


Figure 6.4. Total observed and predicted total index-at-age for Long Island Sound, LISTS (top) and MRIP (bottom).



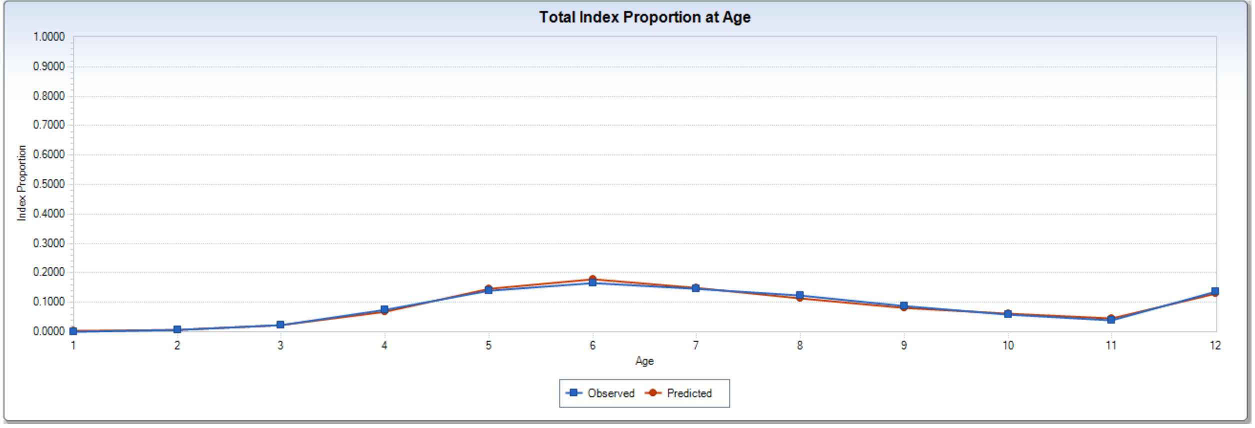


Figure 6.5. Estimated fishery selectivity patterns for the LIS regional model.

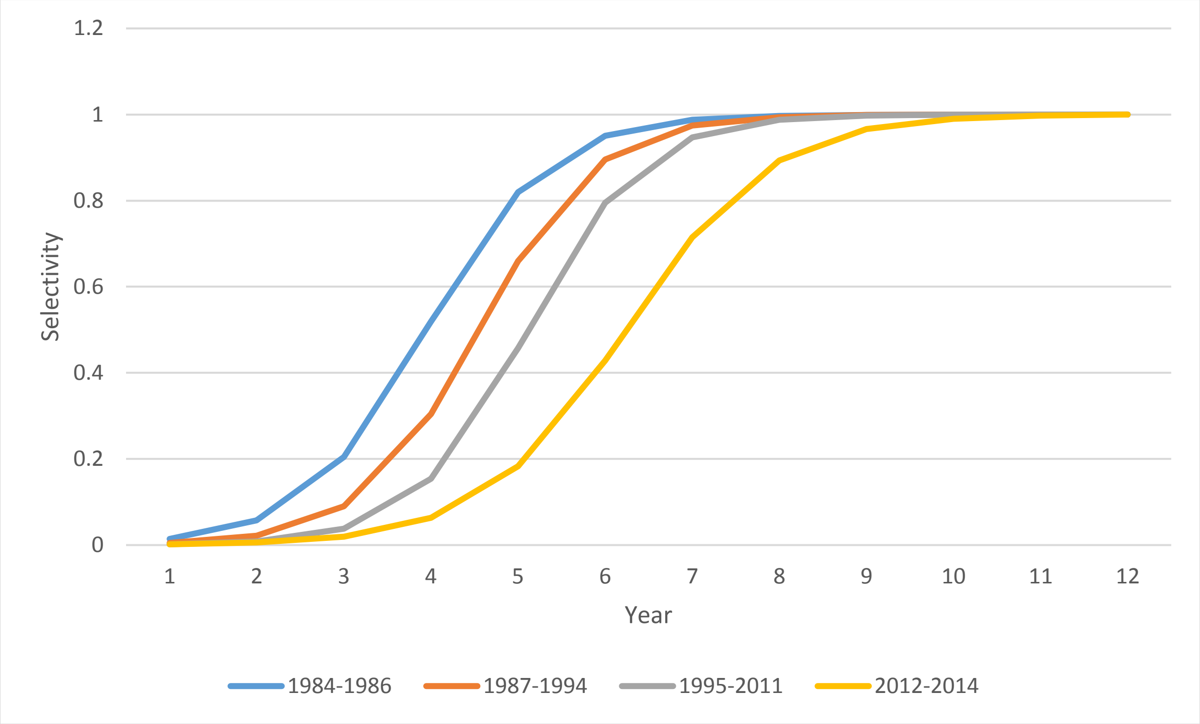


Figure 6.6. Observed and predicted stock-recruitment relationship for Long Island Sound

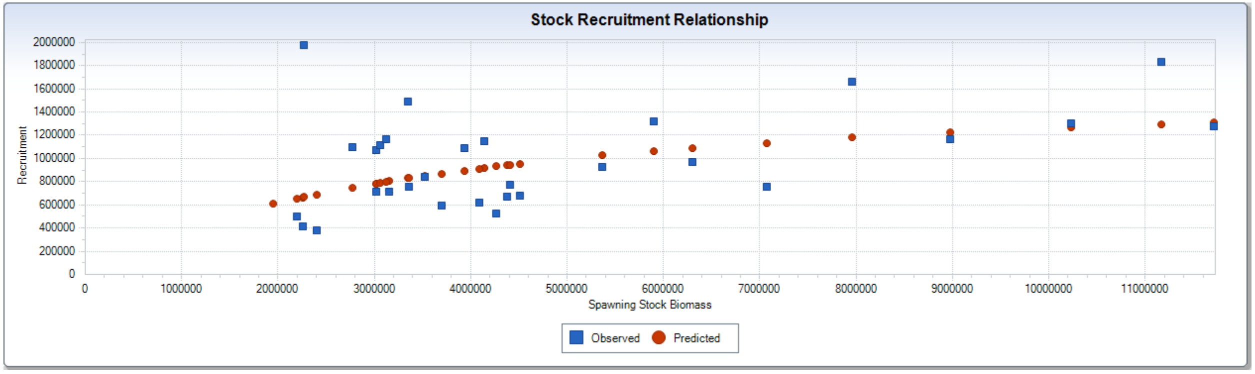


Figure 6.7. Annual and three-year average estimates of F for Long Island Sound.

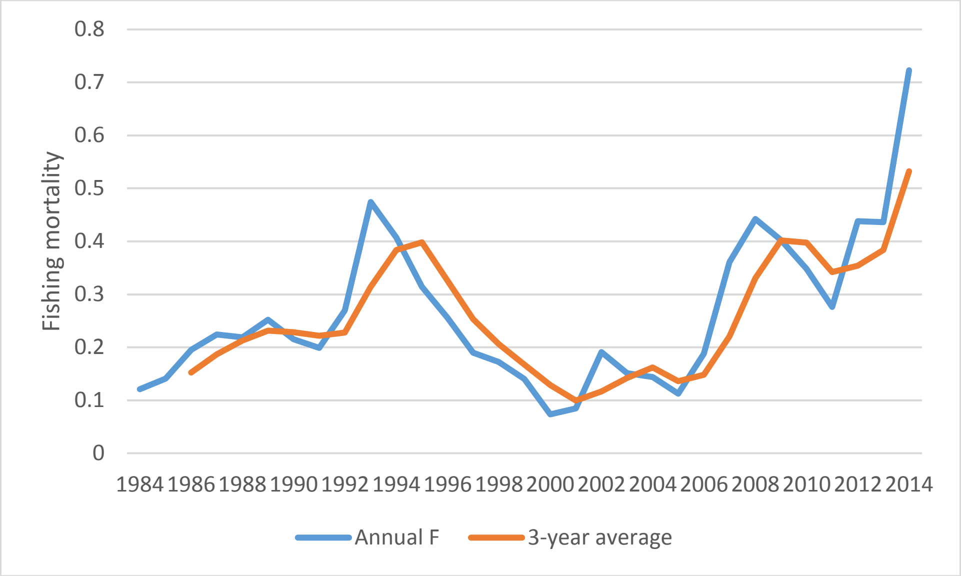


Figure 6.8. Median and 5th and 95th percentile MCMC estimates of F for Long Island Sound.

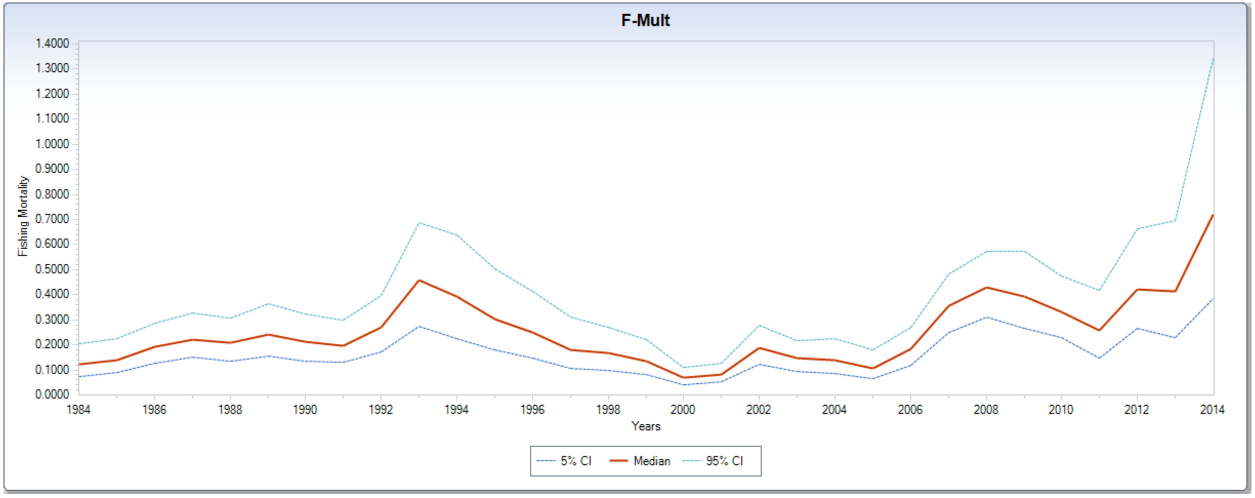


Figure 6.9. MCMC distributions on terminal F for Long Island Sound.

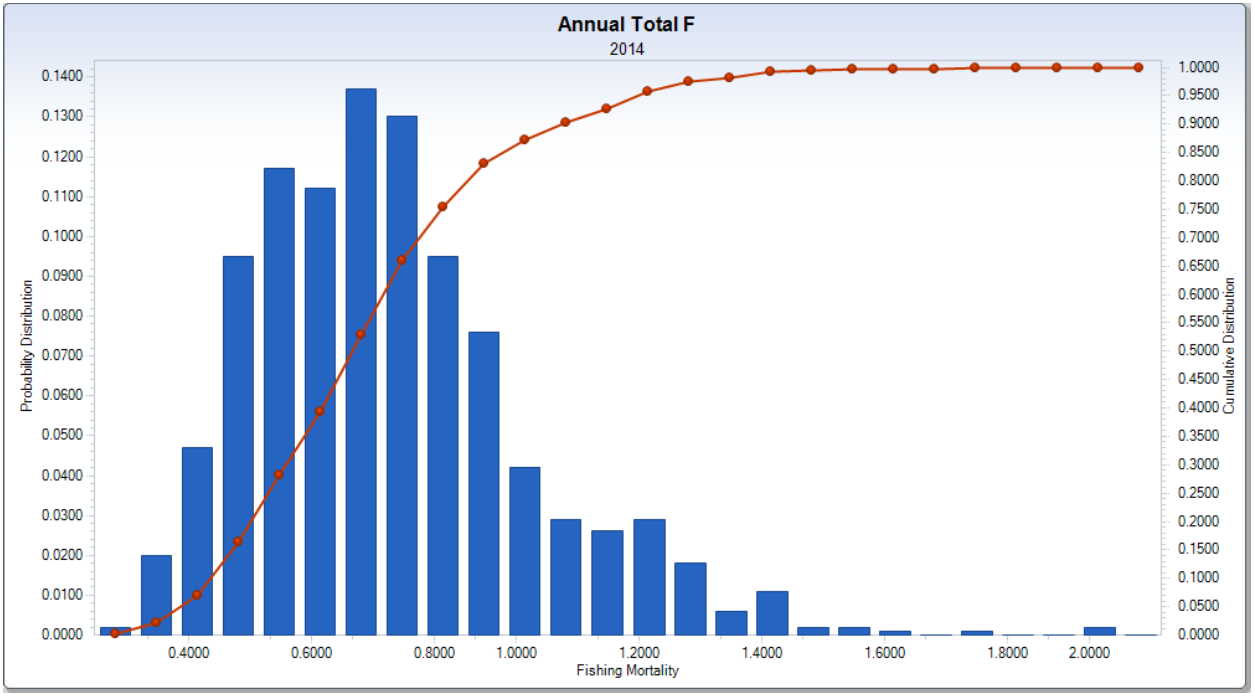
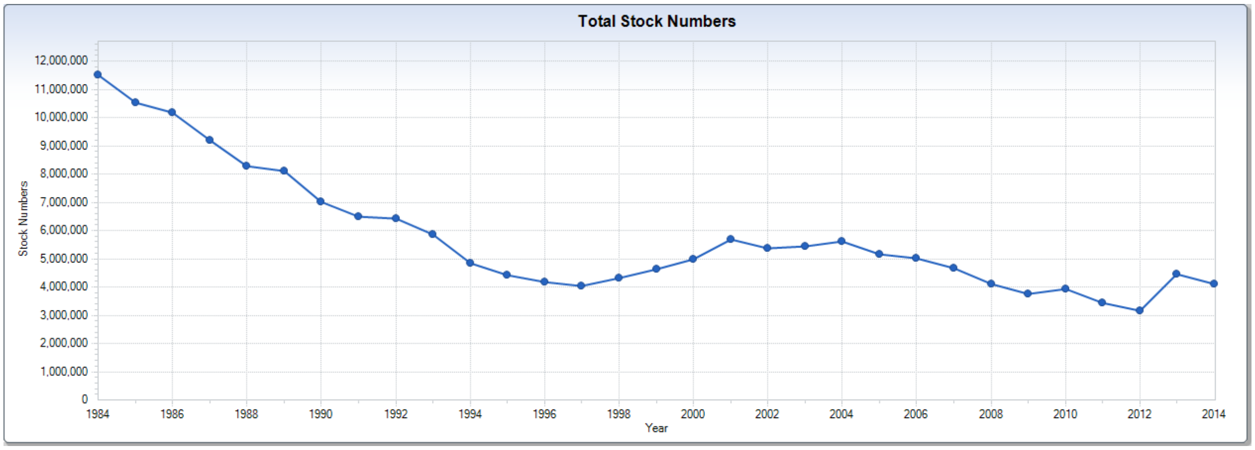
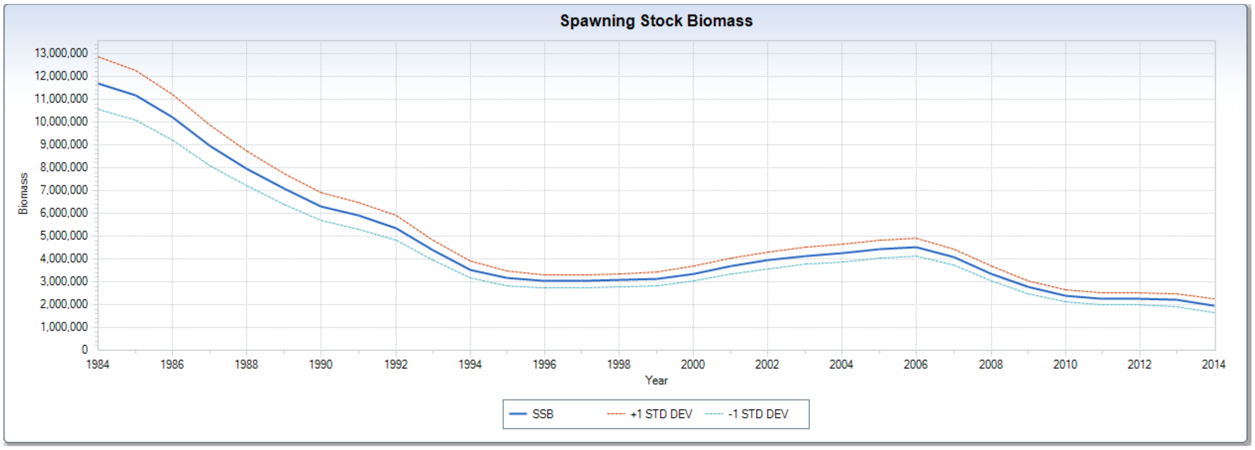


Figure 6.10. (a) Total stock numbers, (b) spawning stock biomass and (c) observed recruitment (bottom) for Long Island Sound.

a.



b.



c.

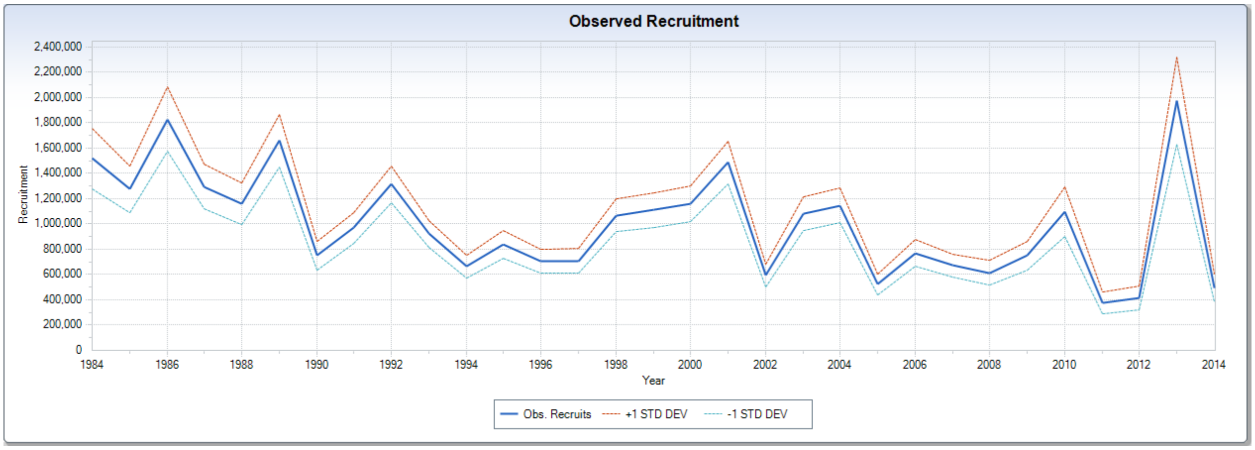


Figure 6.11. Distribution of MCMC estimates of SSB in the terminal year for Long Island Sound.

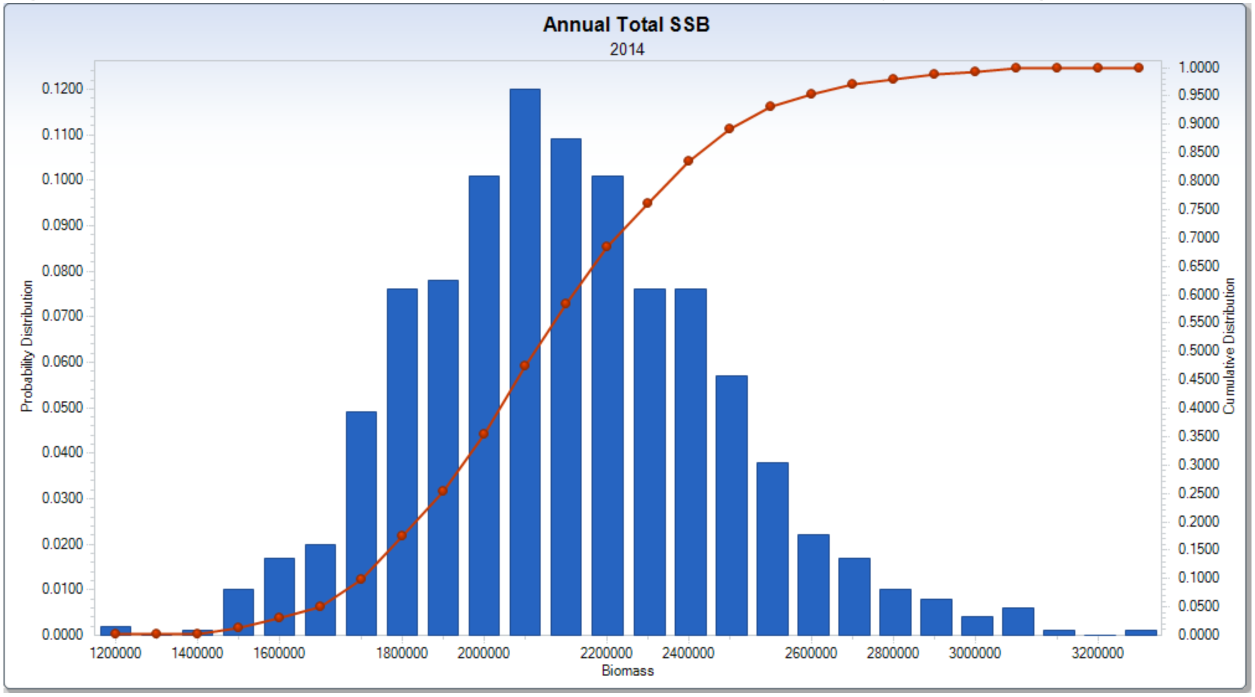
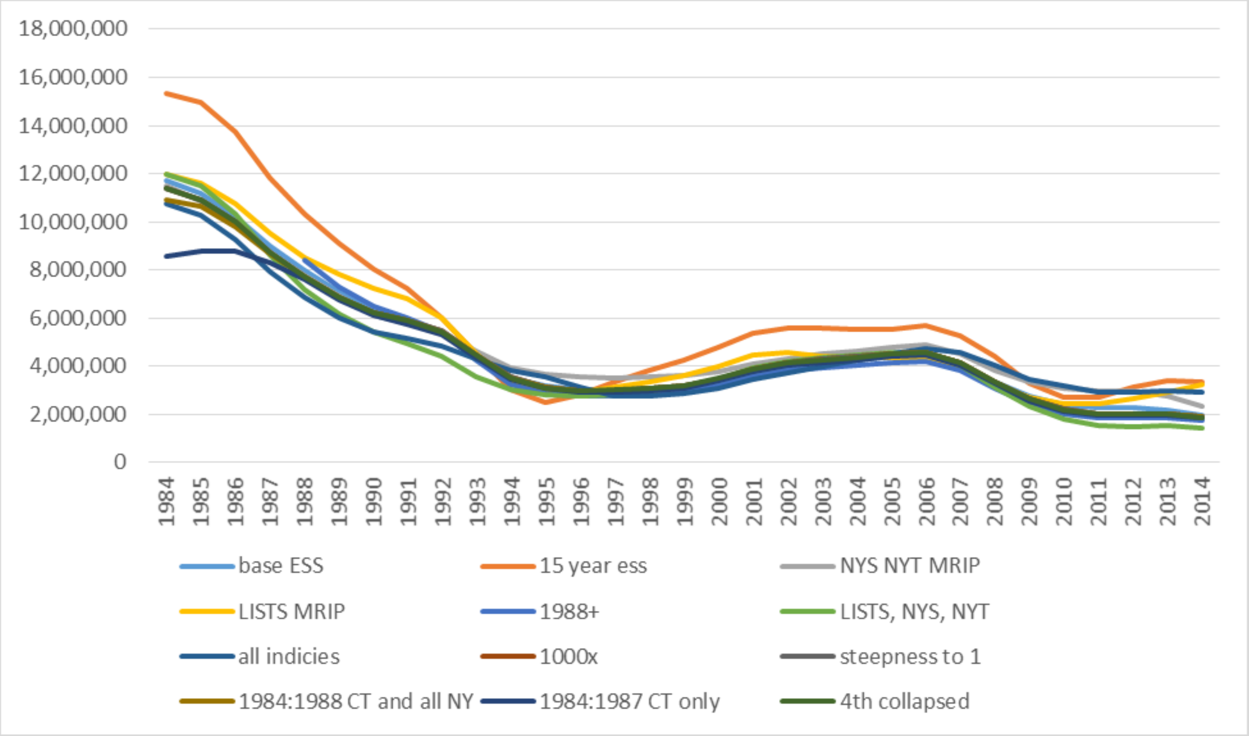


Figure 6.12. Sensitivity analyses for LIS
(a) SSB trajectories for different sensitivity runs (b) F 3 year average trajectories for different sensitivity runs, and (c) estimated number of recruits for different sensitivity runs.

(a)



(b)

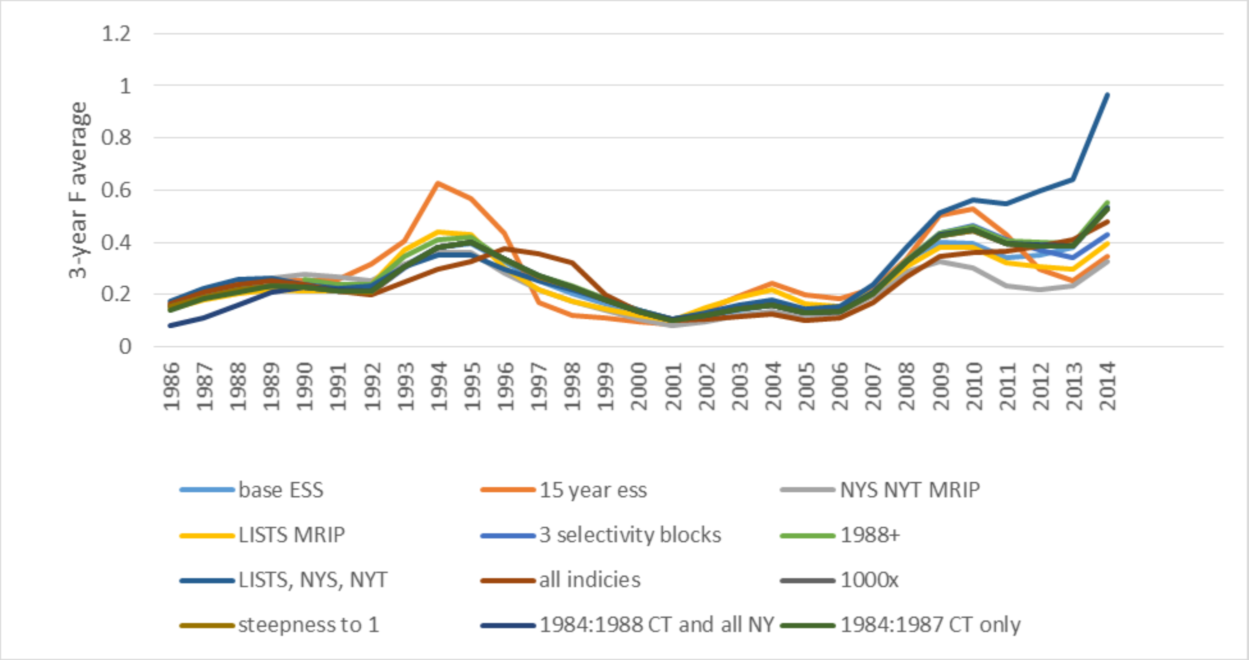


Figure 6.12. (cont'd)

(c)

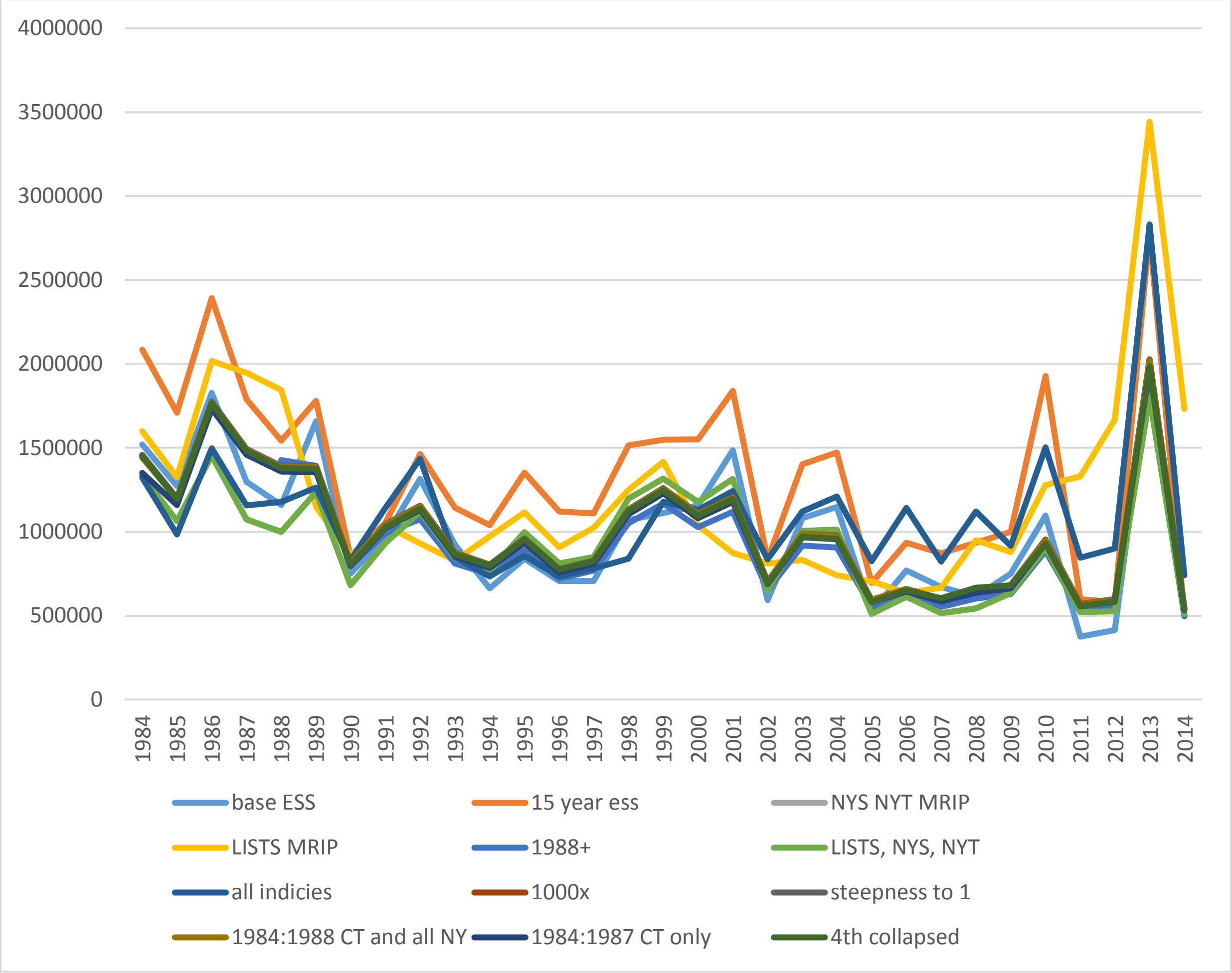
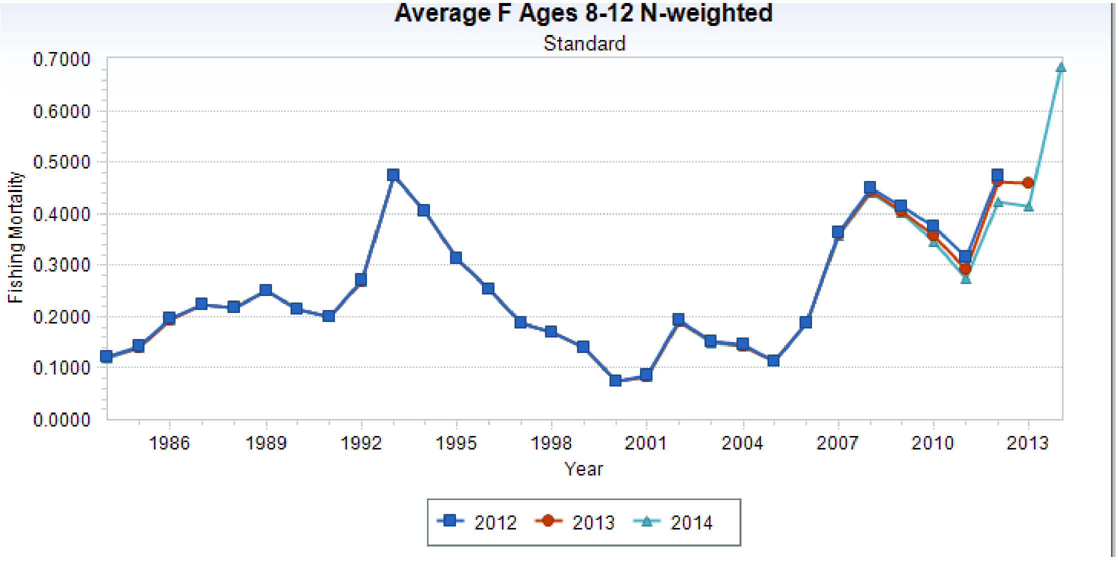
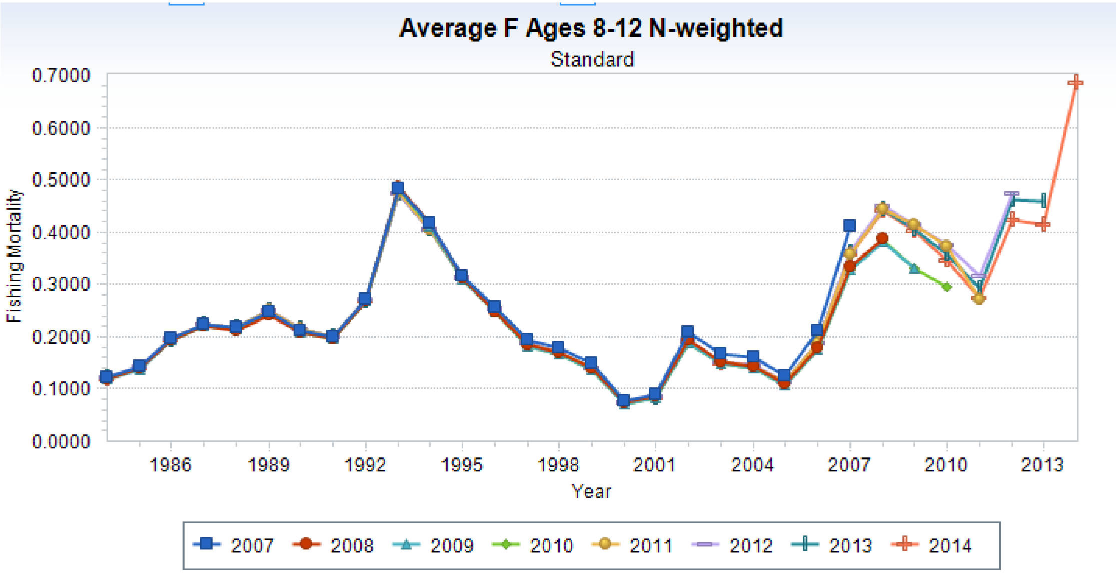


Figure 6.13. Retrospective results for F (a) 12-year plus group, start 2012, (b) 12-year plus group start 2007, (c) 15-year plus group, start 2012, (d) 15-year plus group start 2007 the LIS regional models.

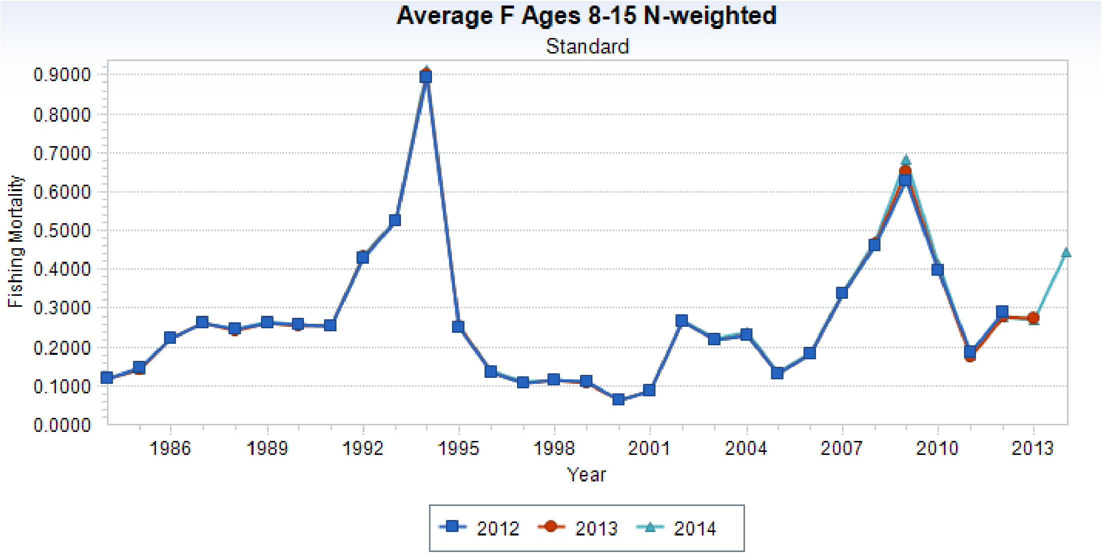
(a)



(b)



(c)


Average F Ages 8-15 N-weighted
Standard
Fishing Mortality
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
Year
2012
2013
2014

(d)

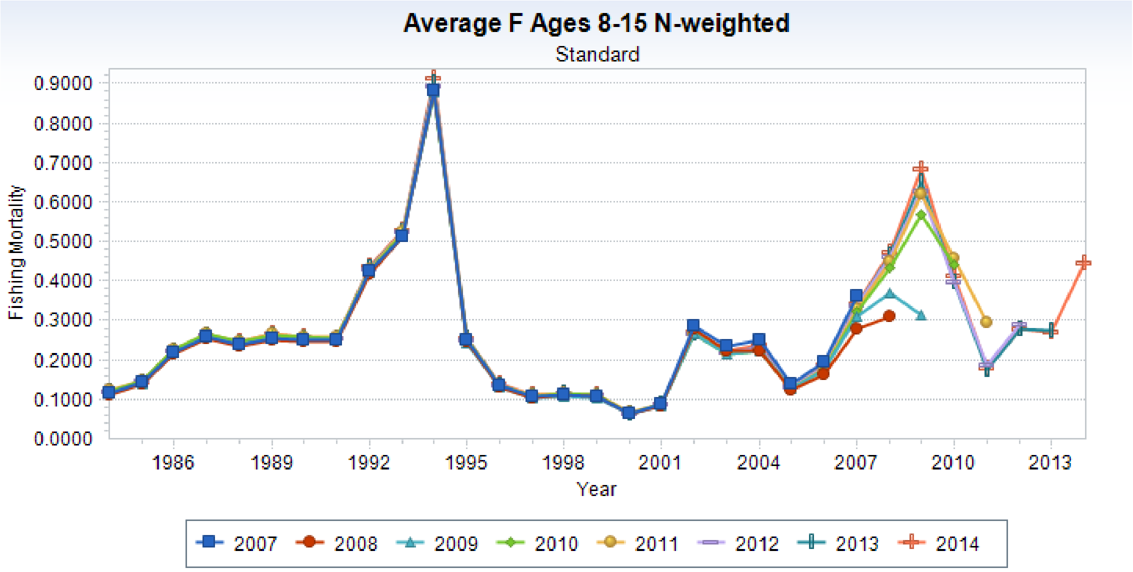
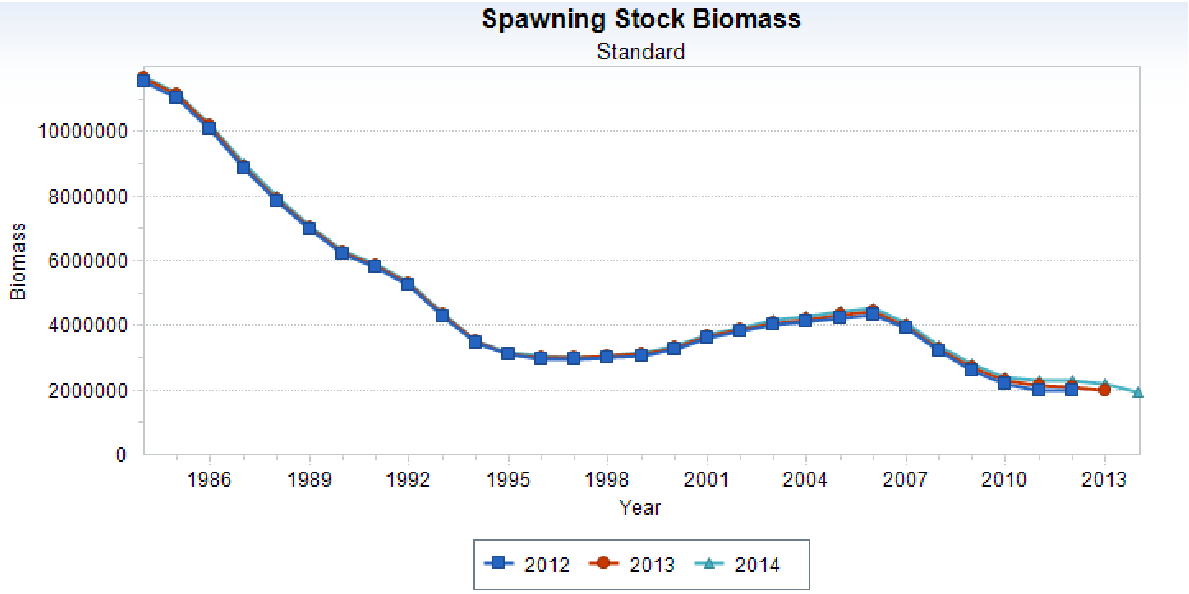

Average F Ages 8-15 N-weighted
Standard
Fishing Mortality
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
Year
2007
2008
2009
2010
2011
2012
2013
2014

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)

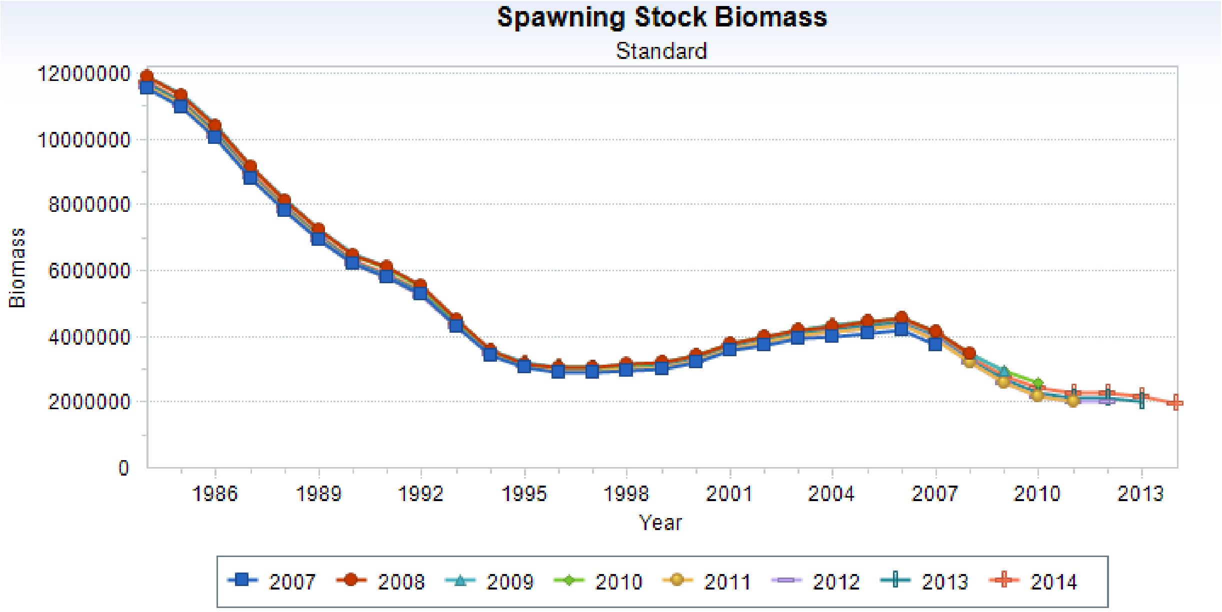
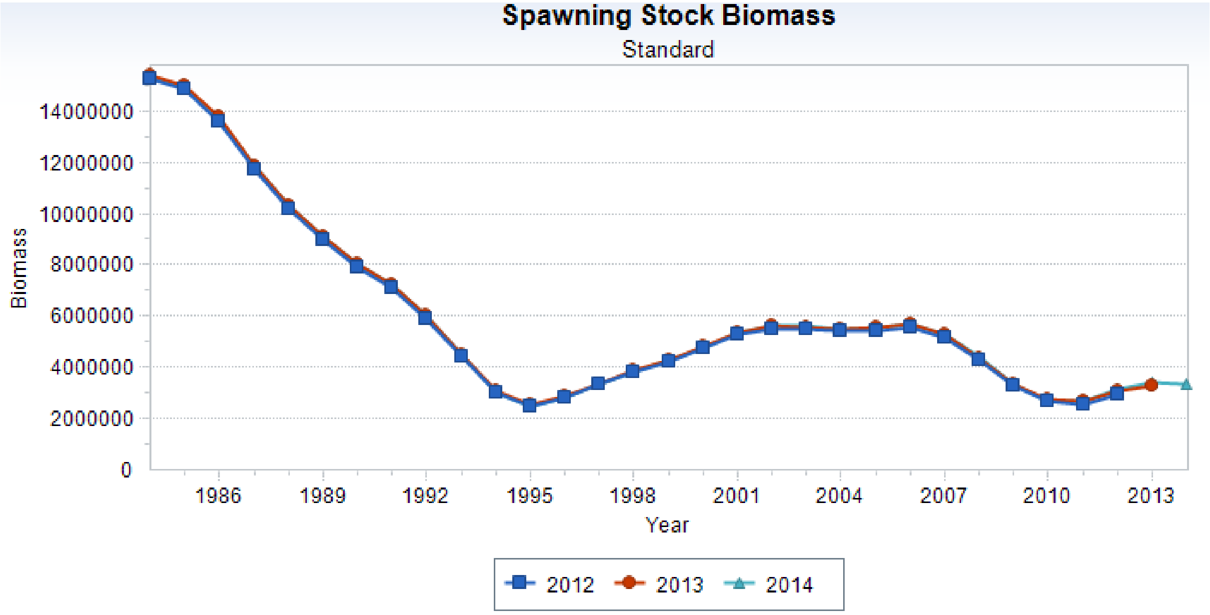


Figure 6.14 (cont.)

(c)



(d)

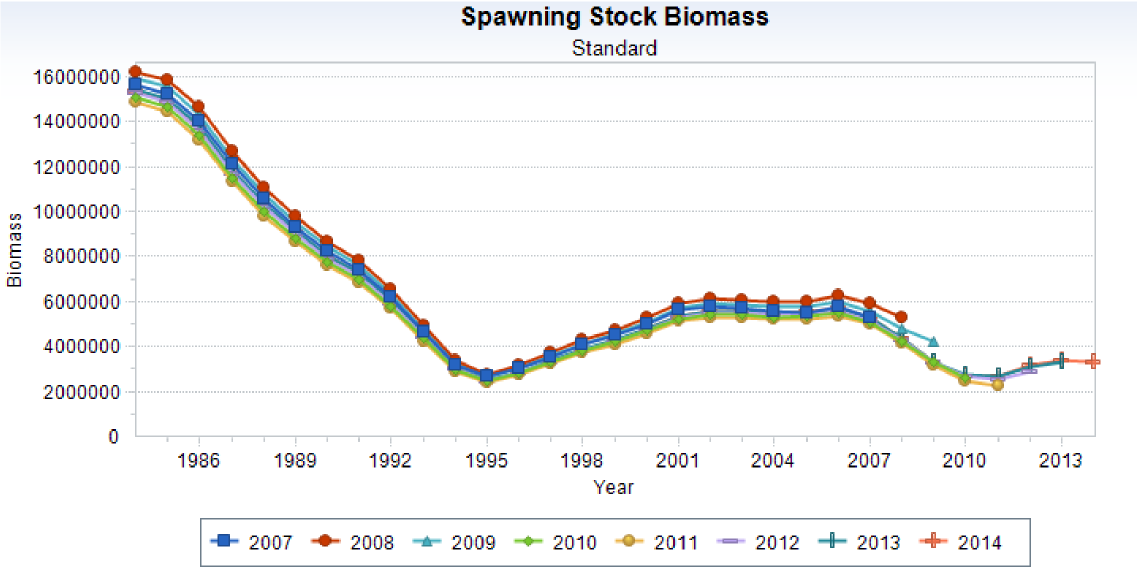
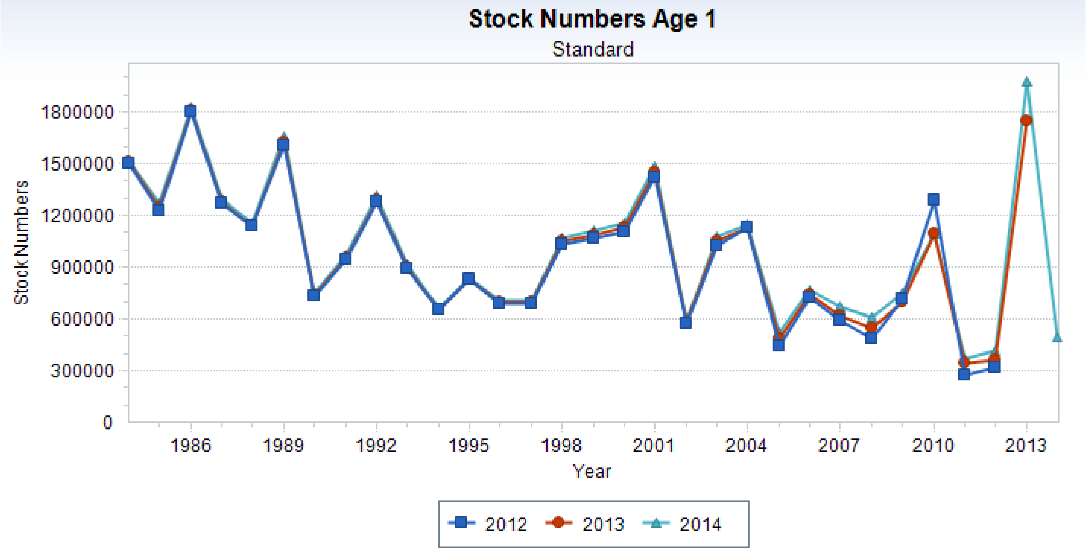


Figure 6.15. Retrospective results for recruits (a) 12-year plus group, start 2012, (b) 12-year plus group start 2007, (c) 15-year plus group, start 2012, (d) 15-year plus group start 2007 the LIS regional models.

(a)



(b)

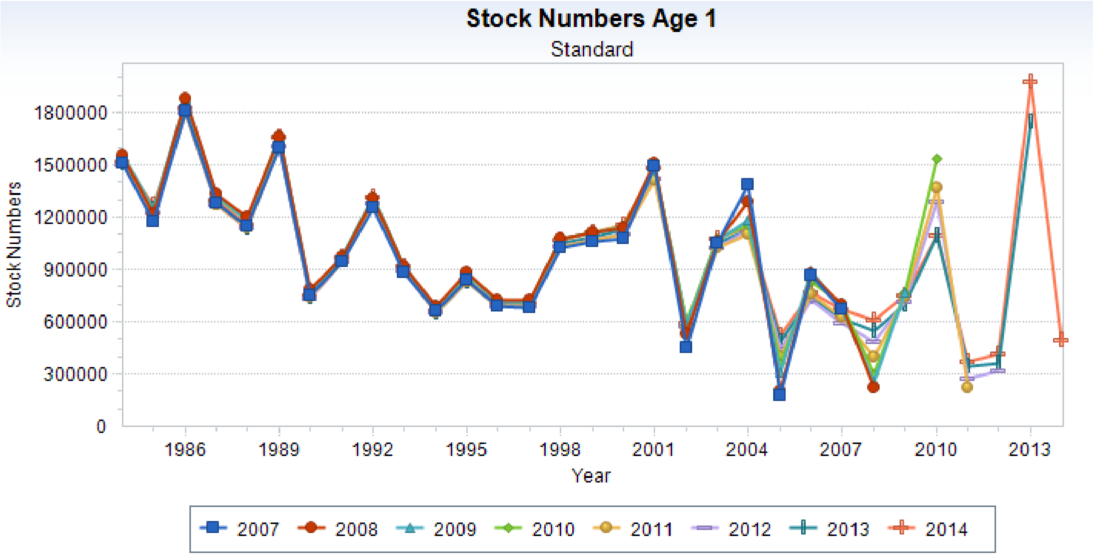
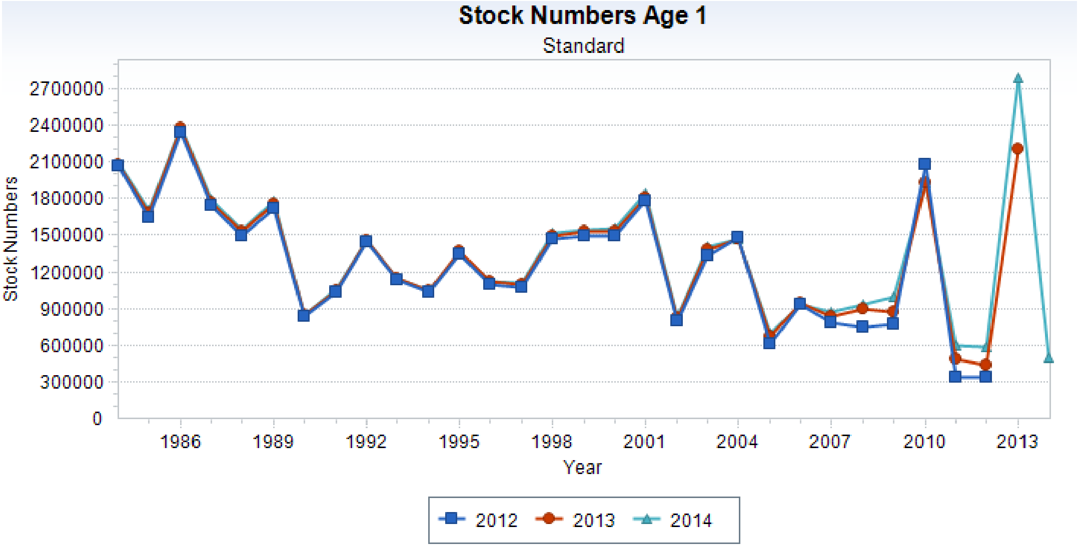


Figure 6.15 (cont.)

(c)



(d)

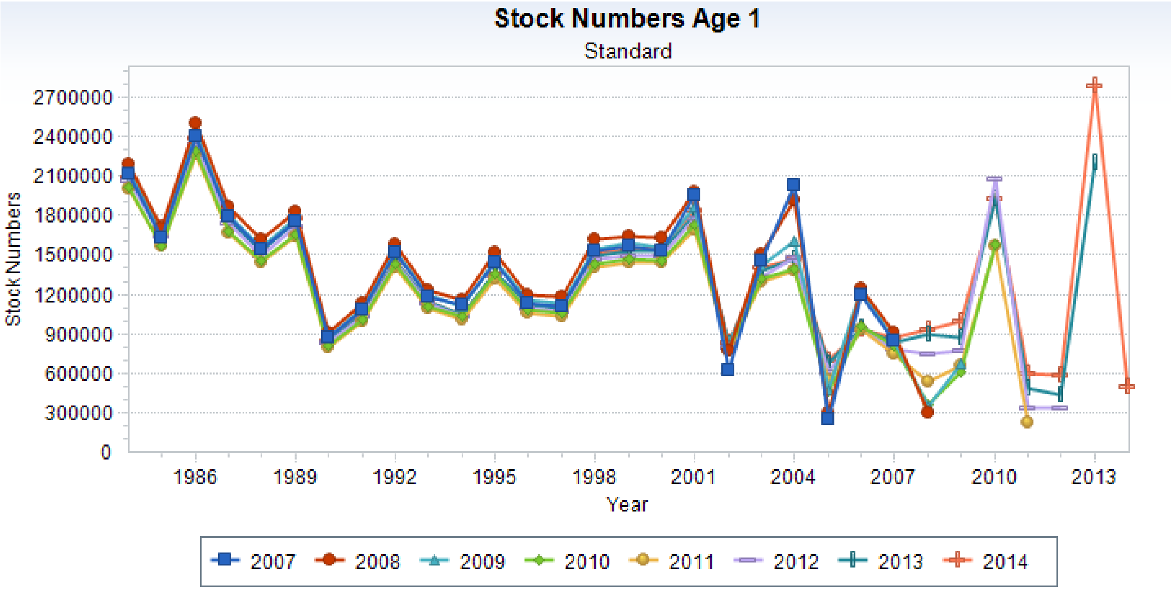


Figure 6.16. NJ-NYB regional model observed and predicted total catch (top) and standardized residuals.

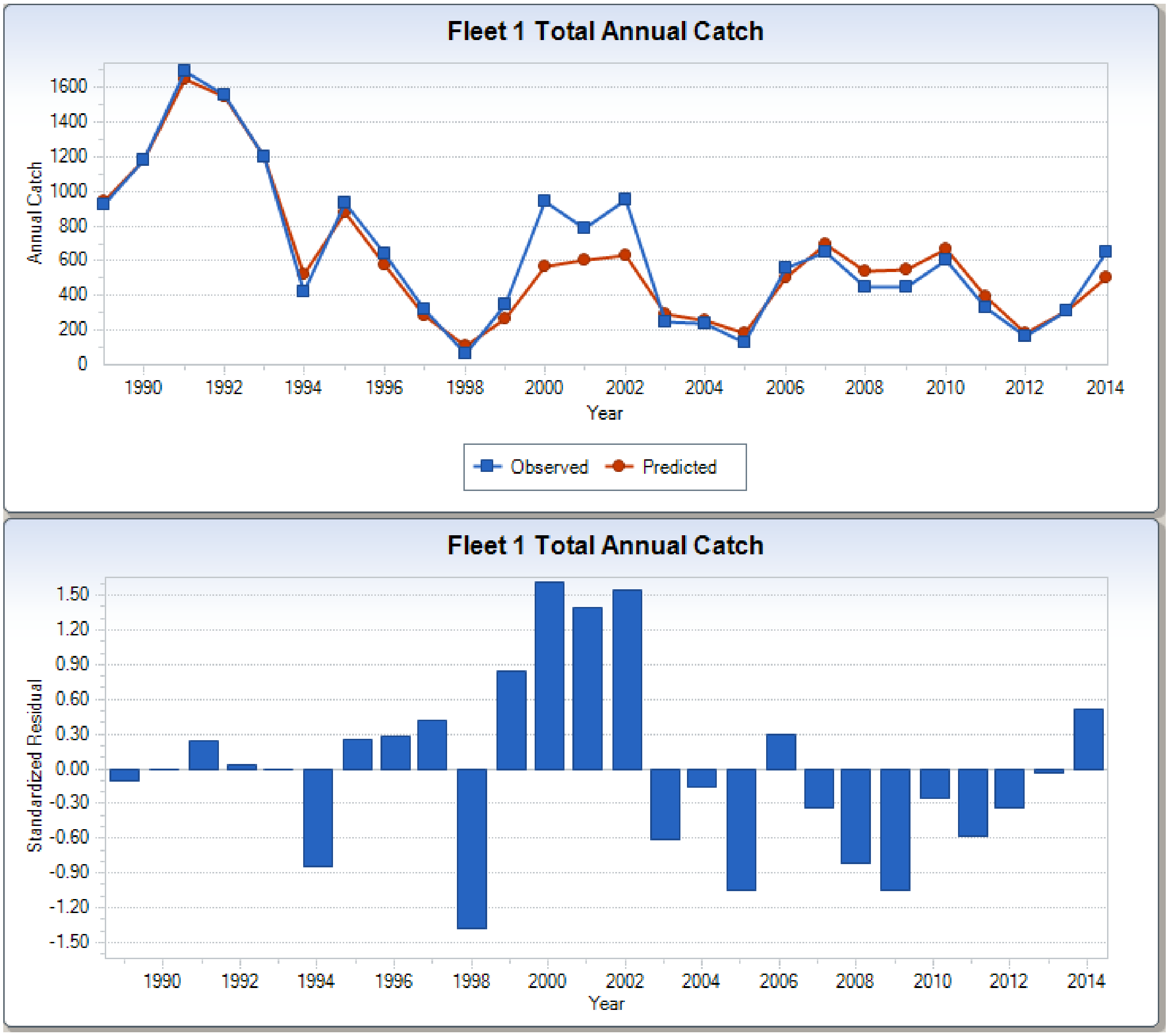


Figure 6.17. Fits to annual catch at age for the NJ-NYB regional model.

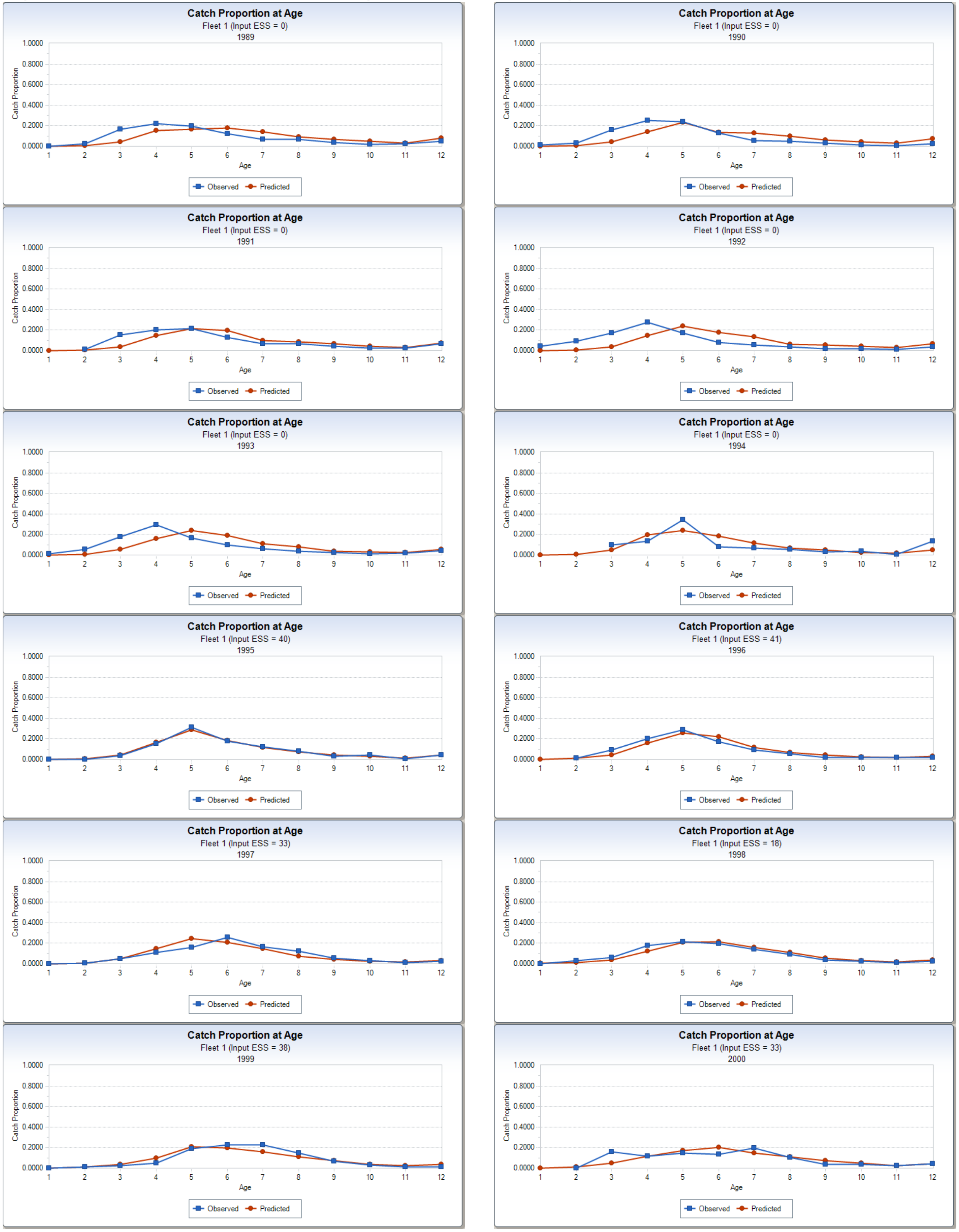


Figure 6.17 (cont.)

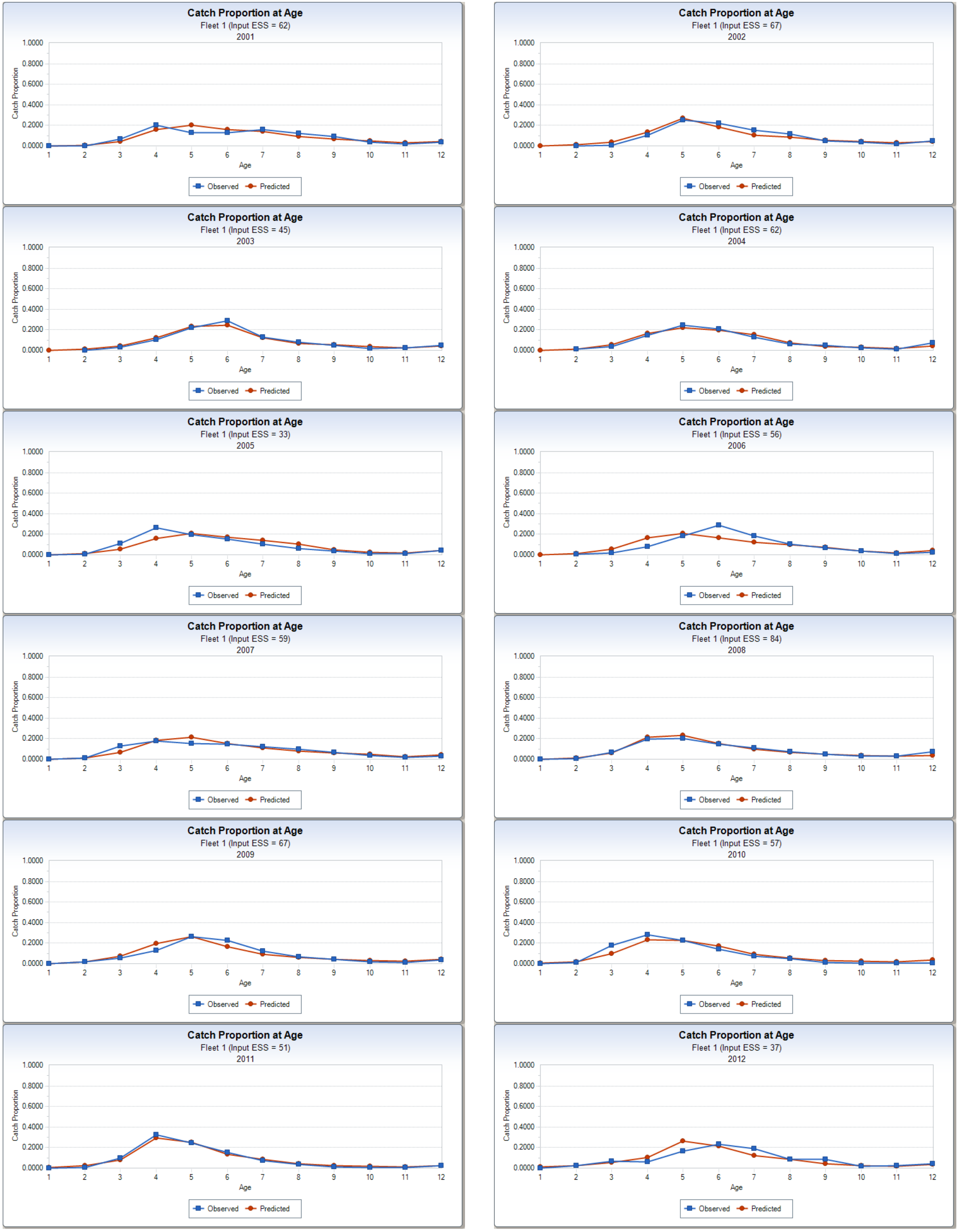


Figure 6.17 (cont.)

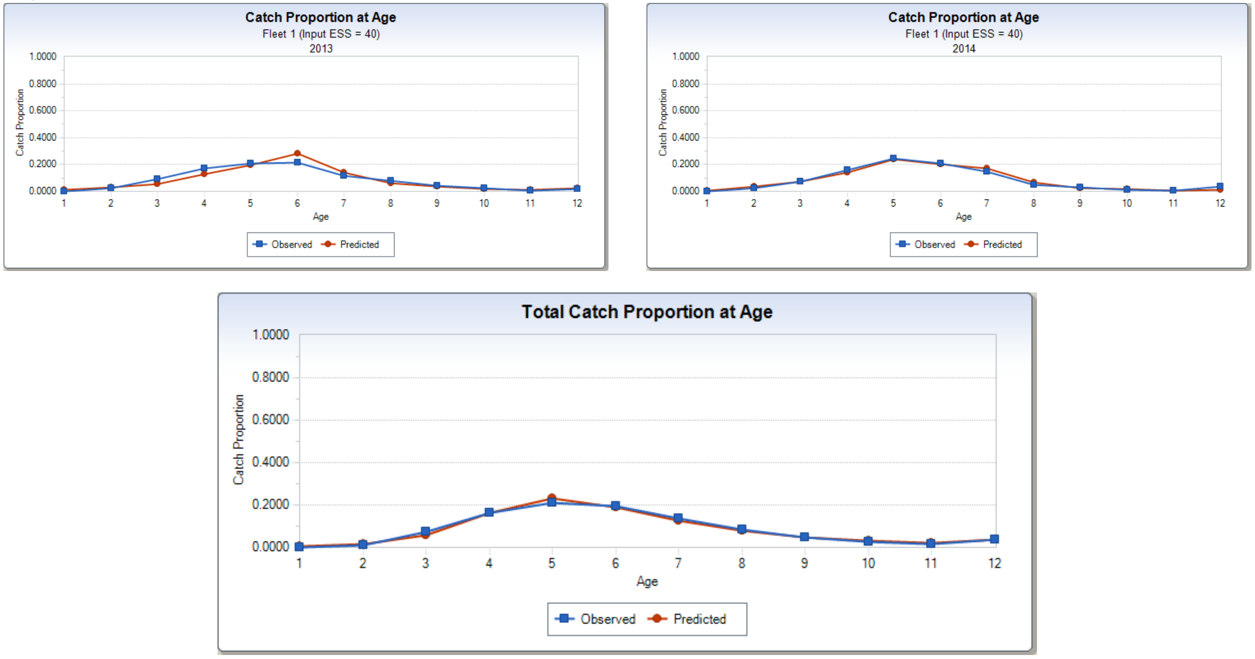


Figure 6.18. Fits to annual survey indices and overall index at age (bottom) for the NJ-NYB region.

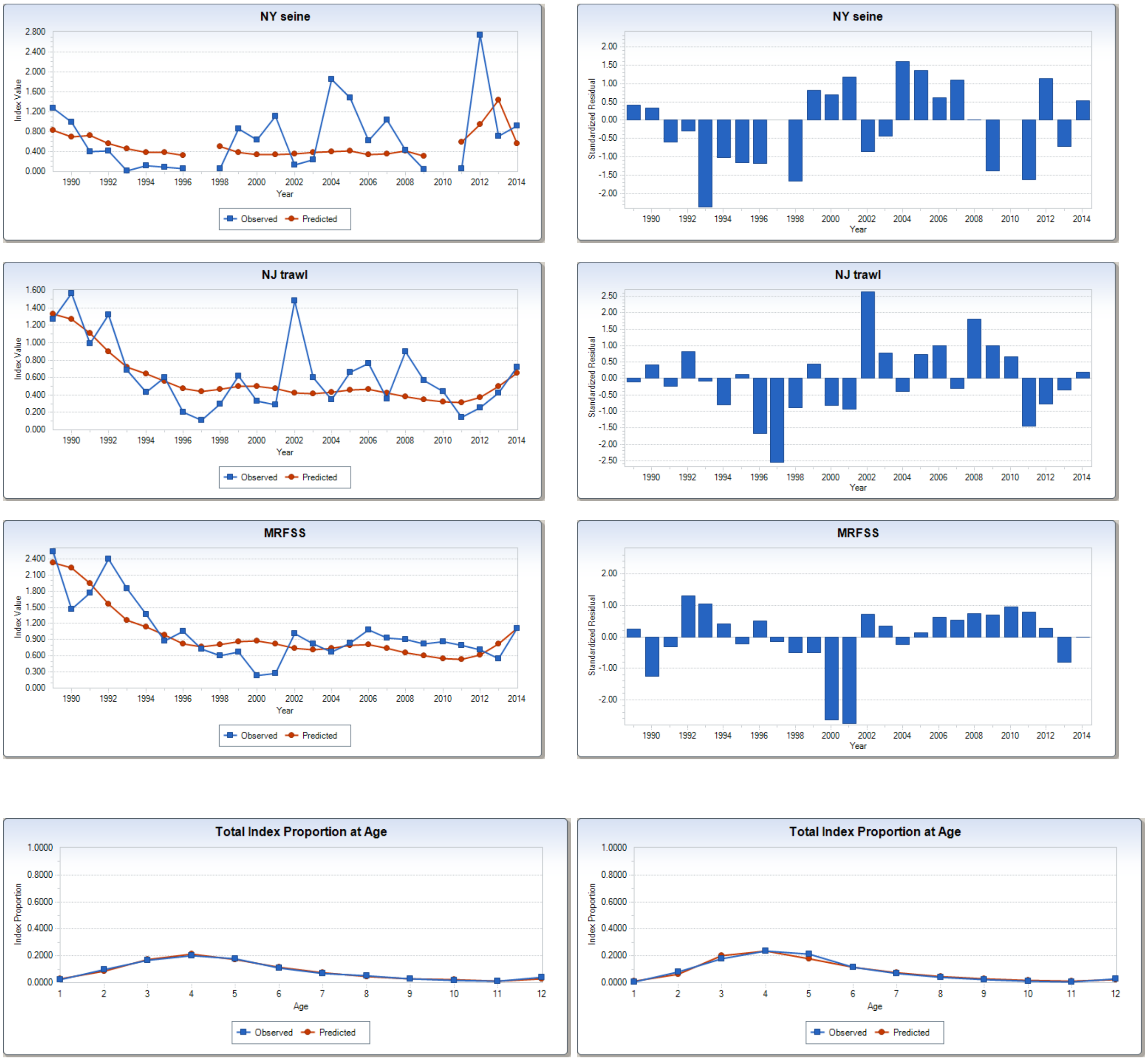
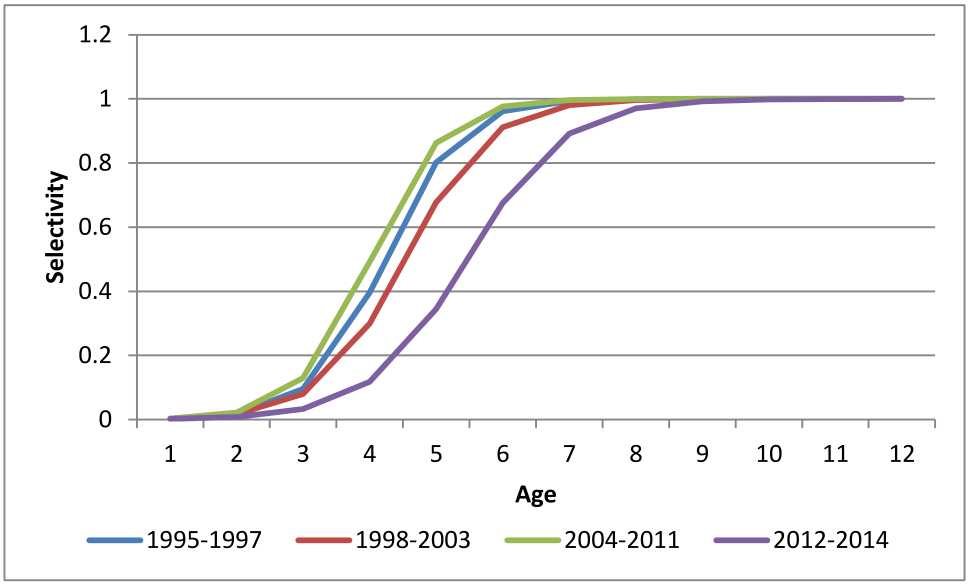


Figure 6.19. Estimated selectivity patterns for the fishery (top) and survey indices for the NJ-NYB regional model.



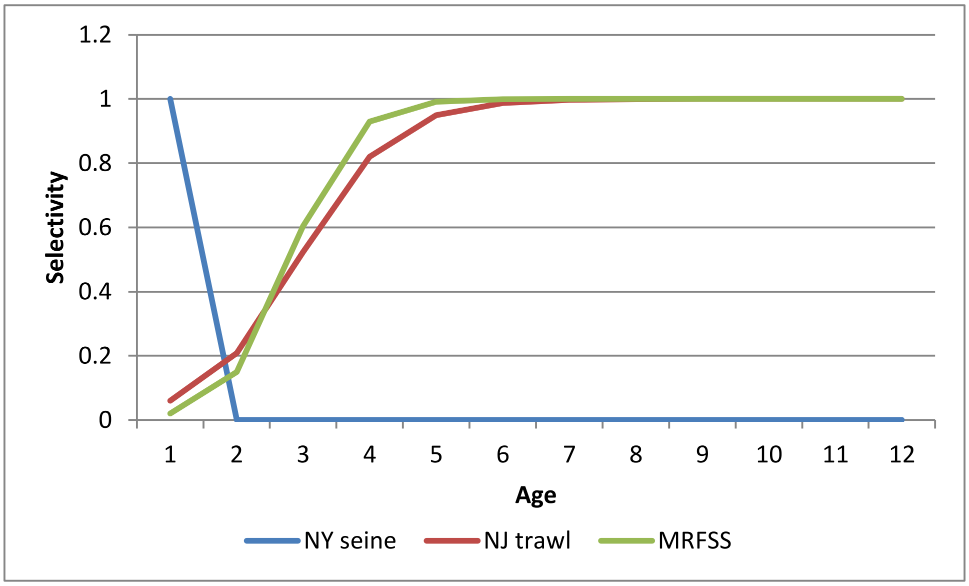
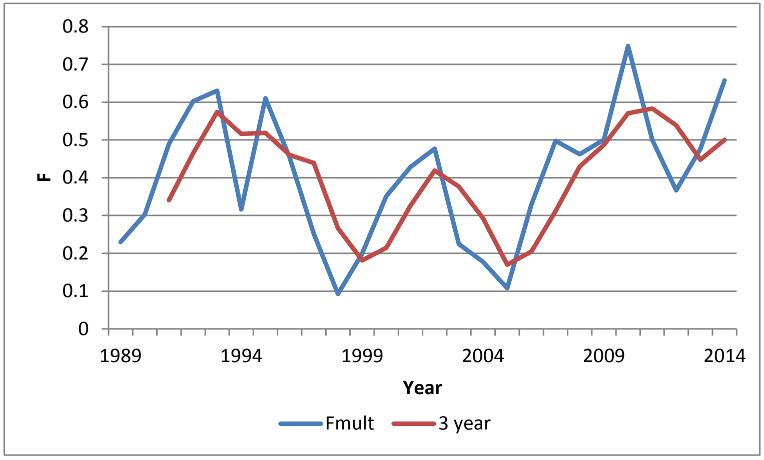
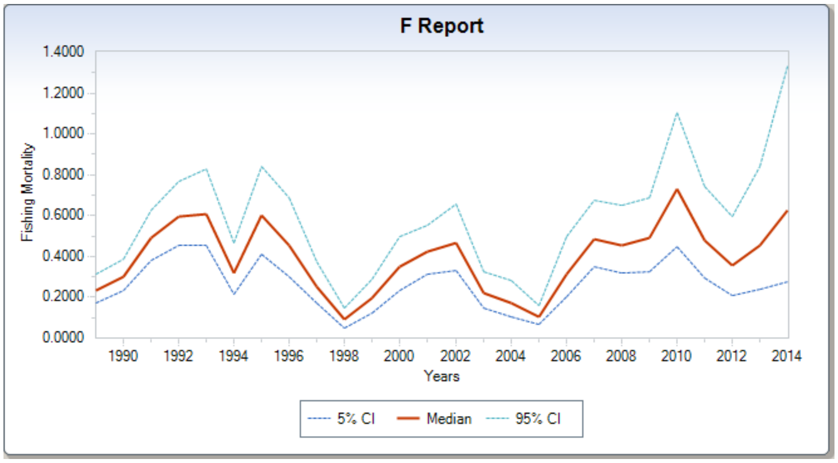


Figure 6.20. Fishing mortality estimates for the NJ-NYB regional model. Annual and three year average (top), MCMC median and 90% CI (middle) and MCMC distribution.





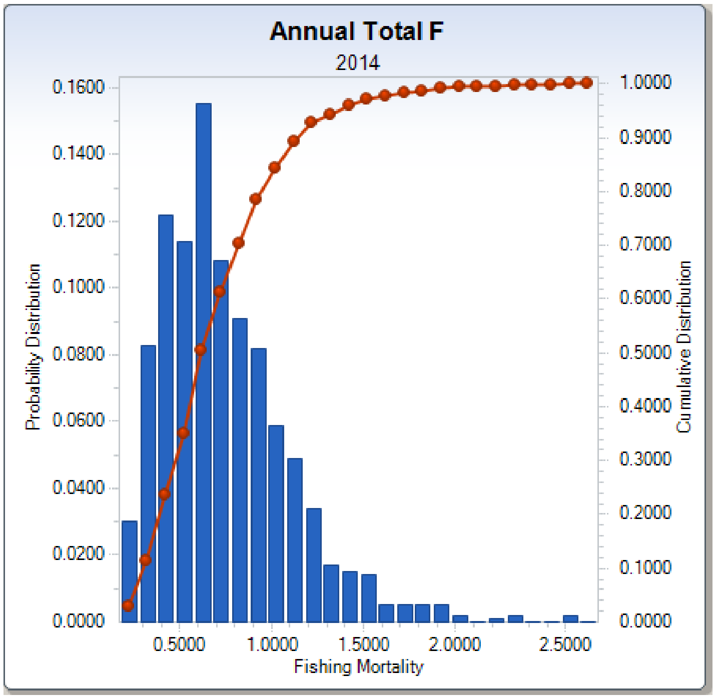


Figure 6.21. SSB estimates for the NJ-NYB regional model. Annual with +/- 1 standard deviation (top), MCMC median and 90% CI (middle) and MCMC distribution.

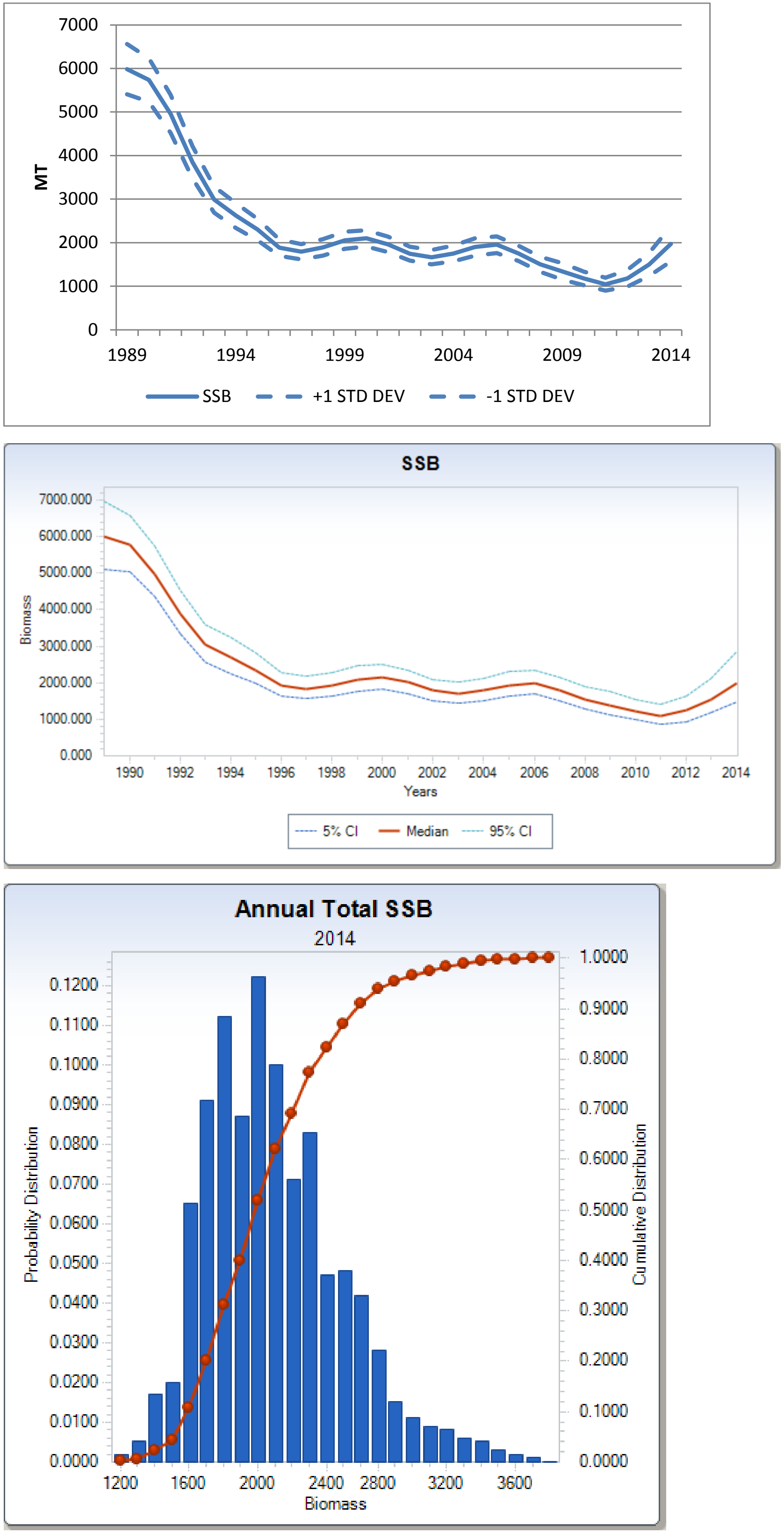


Figure 6.22. Estimated recruitment to age 1 for the NJ-NYB regional model

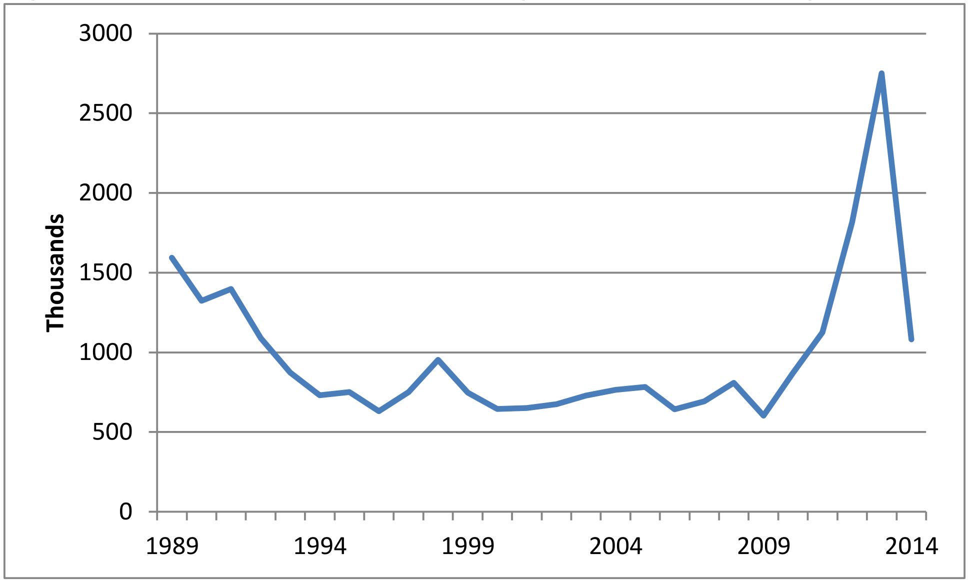


Figure 6.23 Trajectories of 3 year average F (top) and SSB (middle) and recruits (bottom) for sensitivity runs of the NJ-NYB regional model

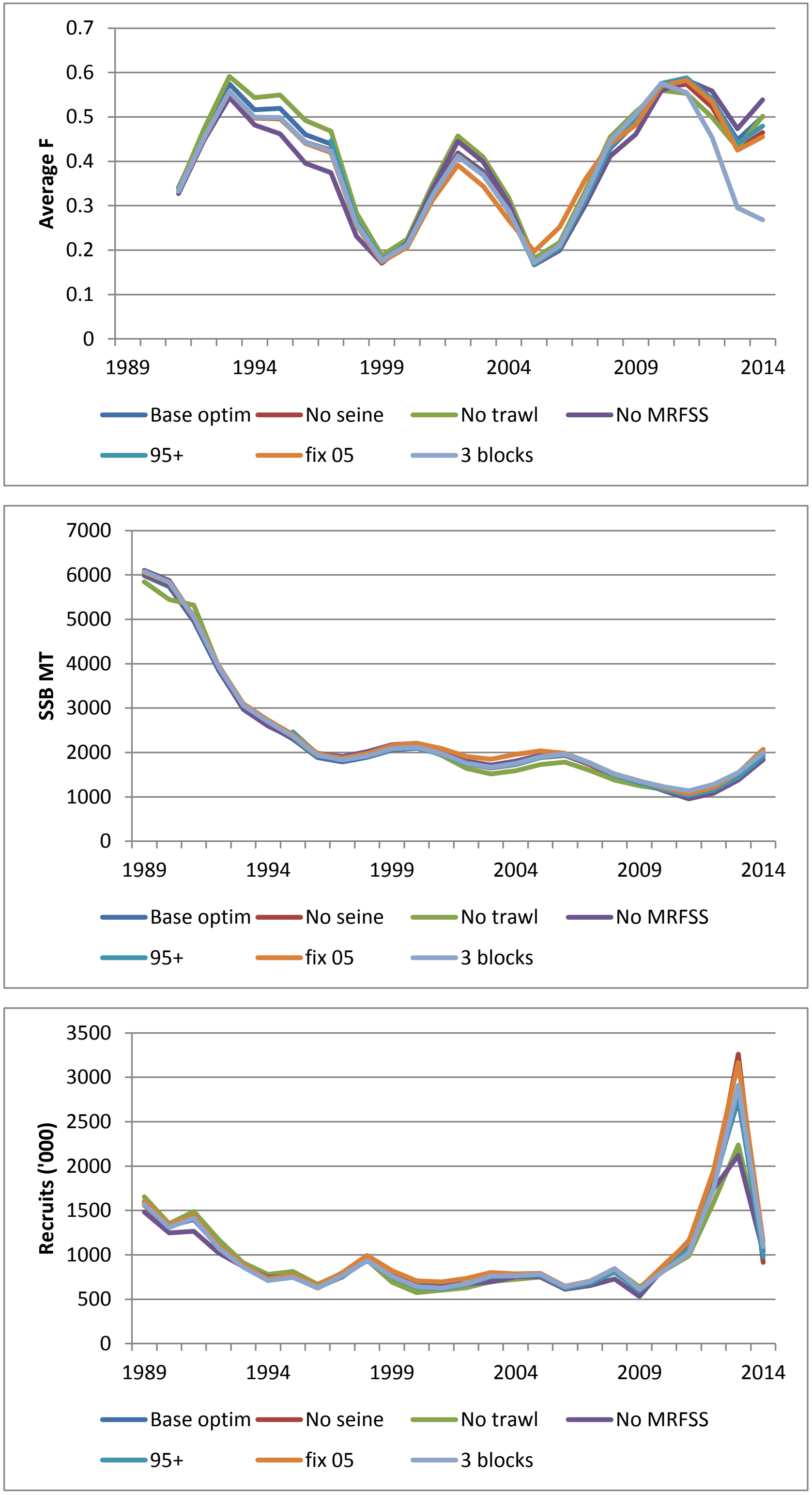
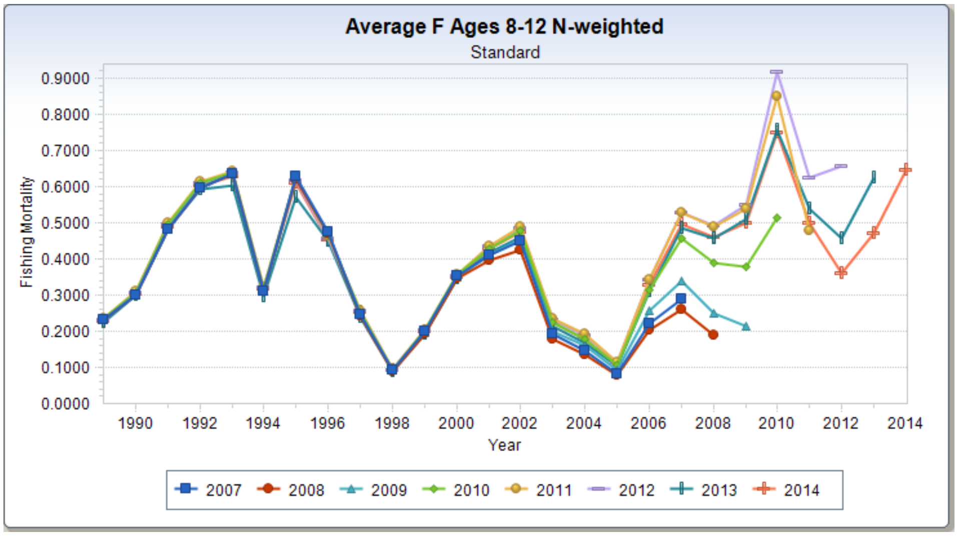
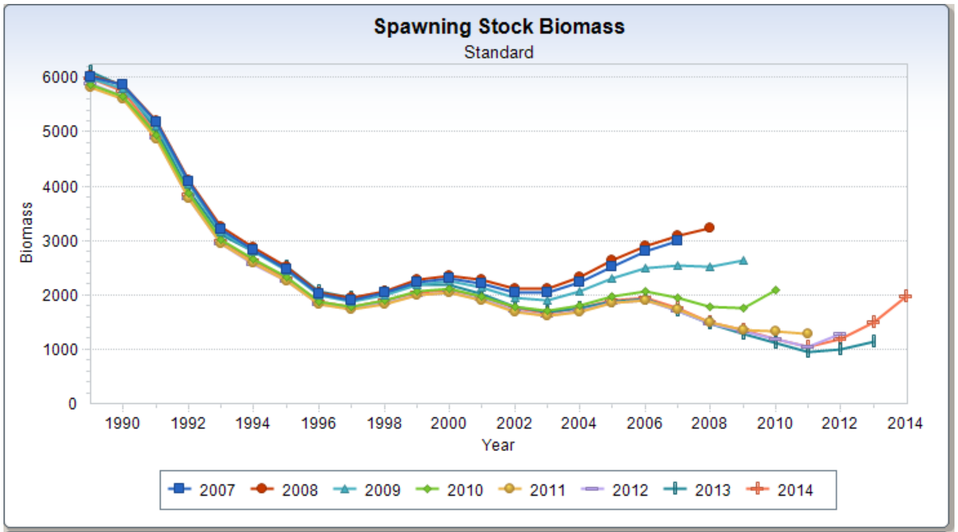


Figure 6.24. Retrospective results for F (top), SSB (middle), and recruits in the NJ-NYB regional model.





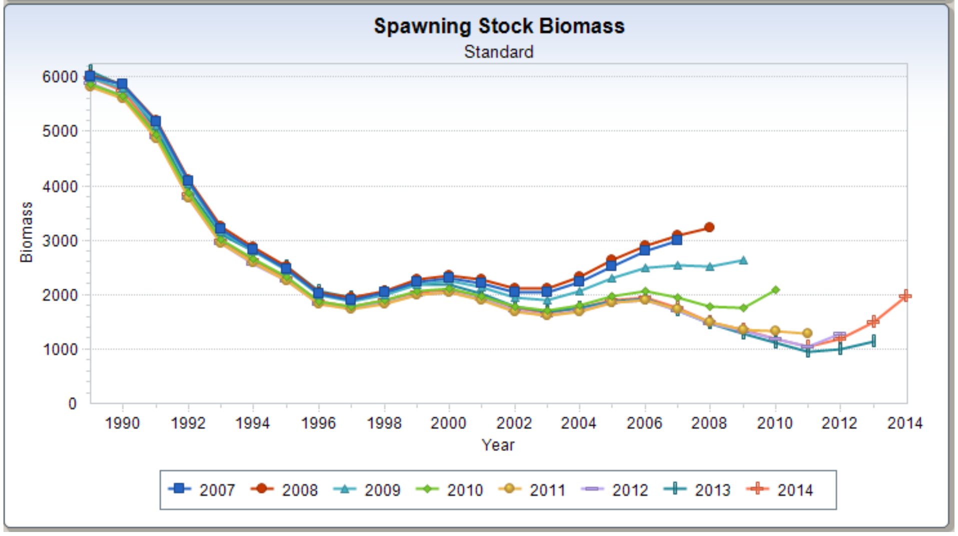
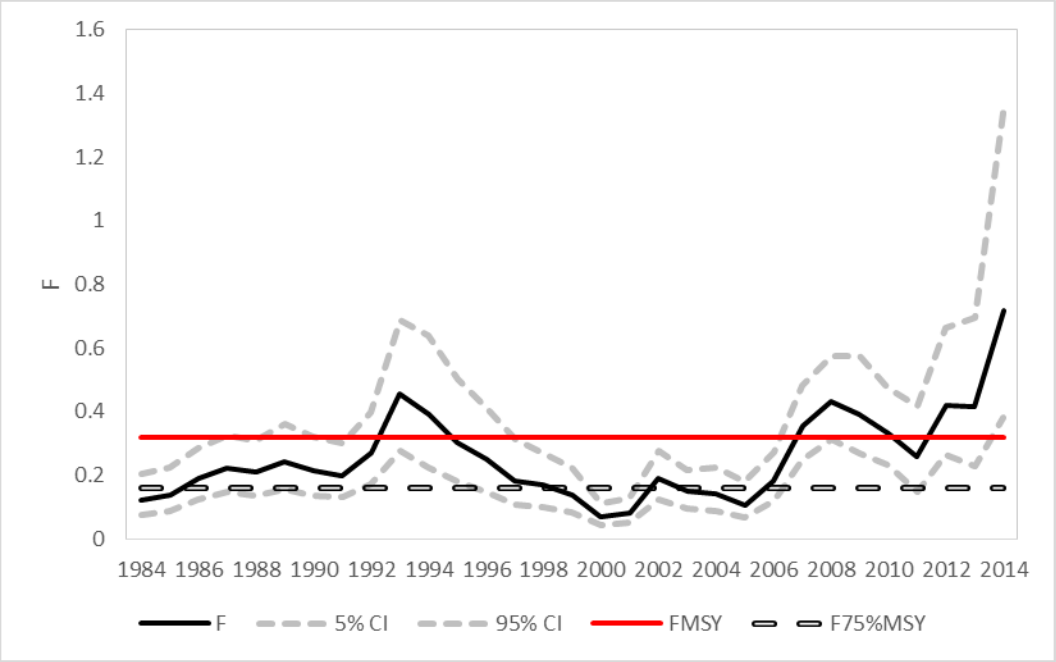


Figure 7.1 F estimates with MCMC confidence intervals and F target and threshold values (a), and SSB estimates with MCMC confidence intervals and SSB target and threshold values (b) for SPR model in LIS.

(a)



(b)

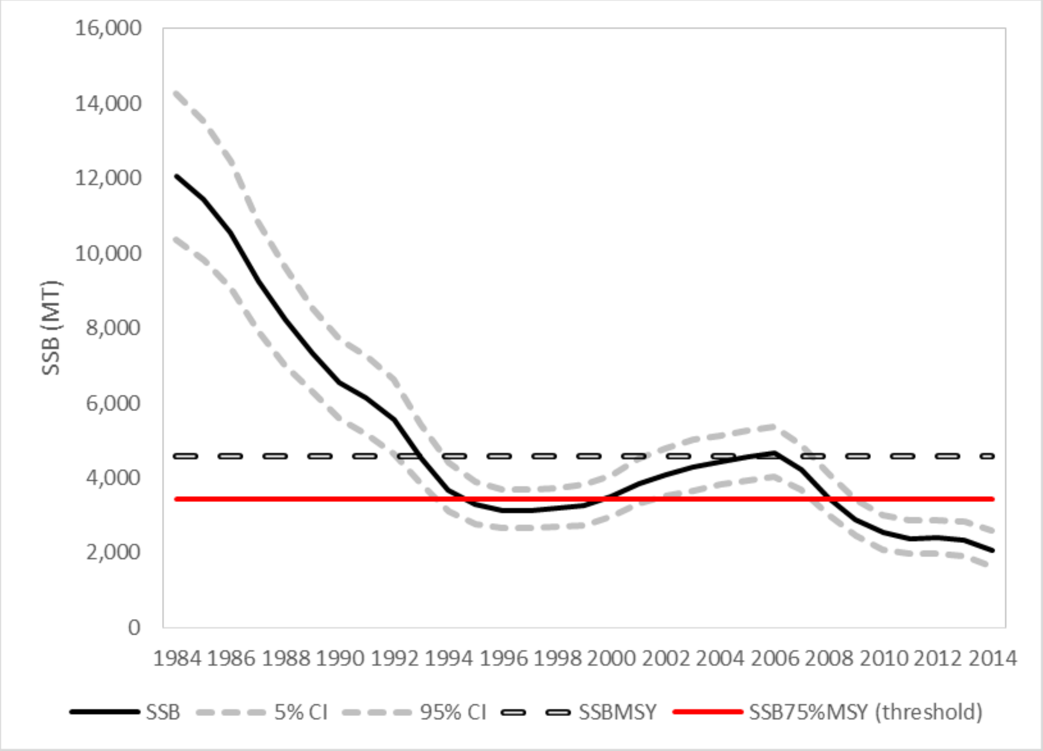
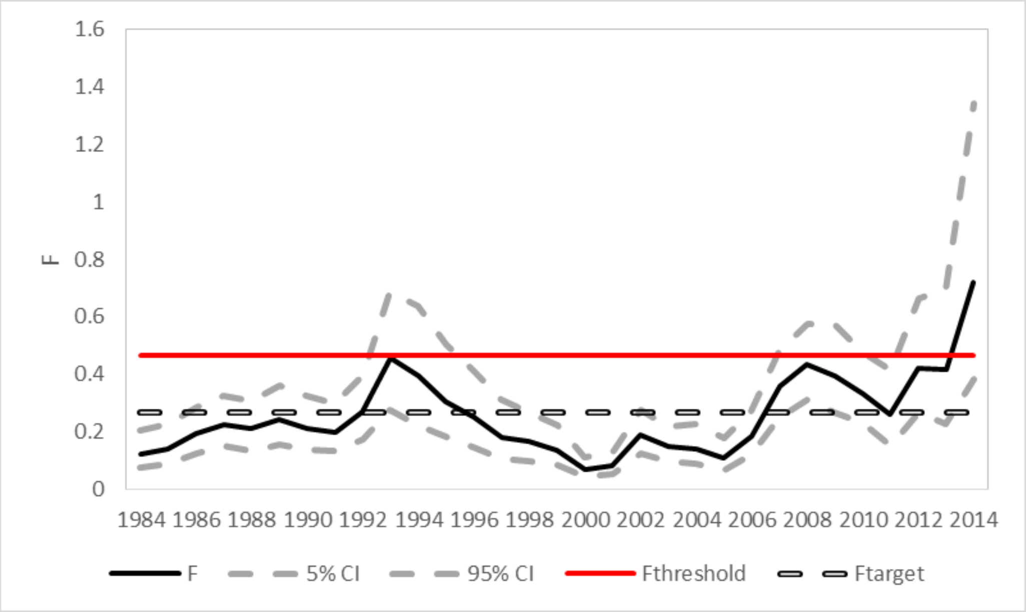


Figure 7.2 F estimates with MCMC confidence intervals and F target and threshold values (a) and SSB estimates with MCMC confidence intervals and SSB target and threshold values (b) for SPR model in LIS.

(a)



(b)

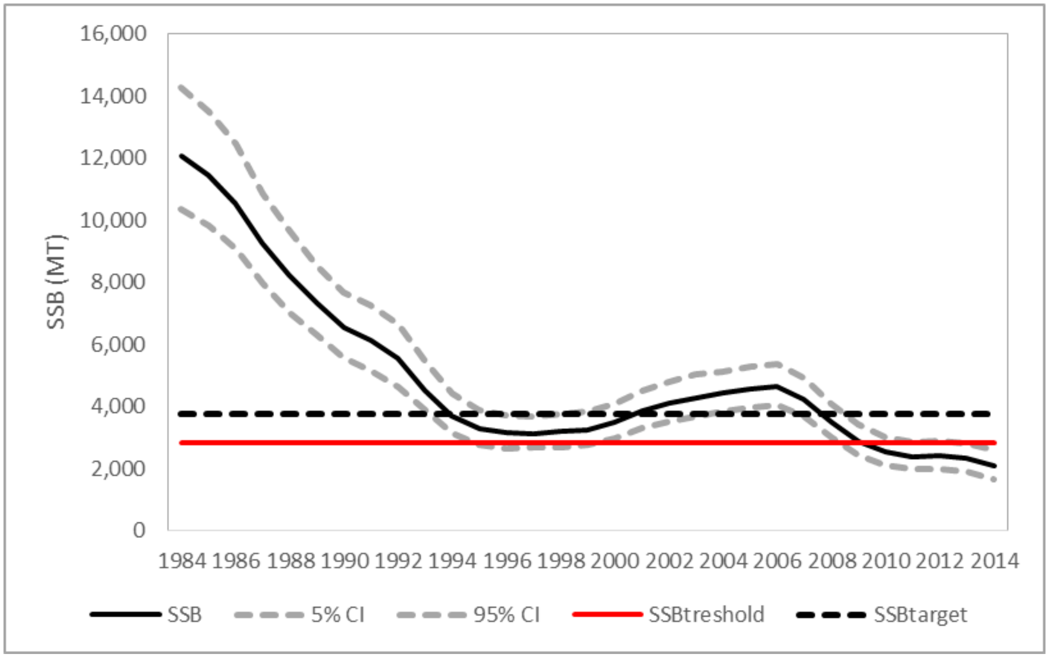
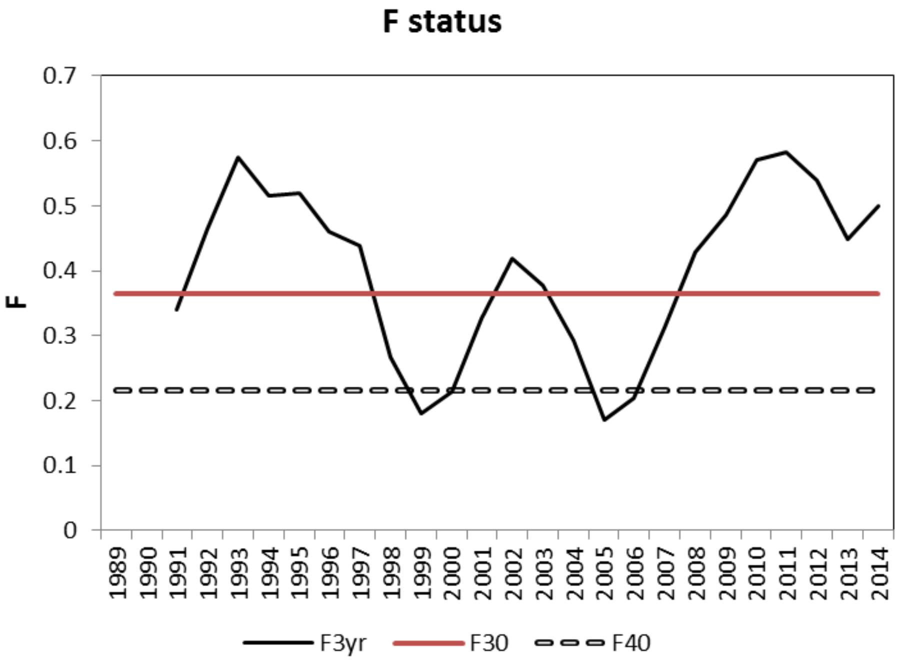
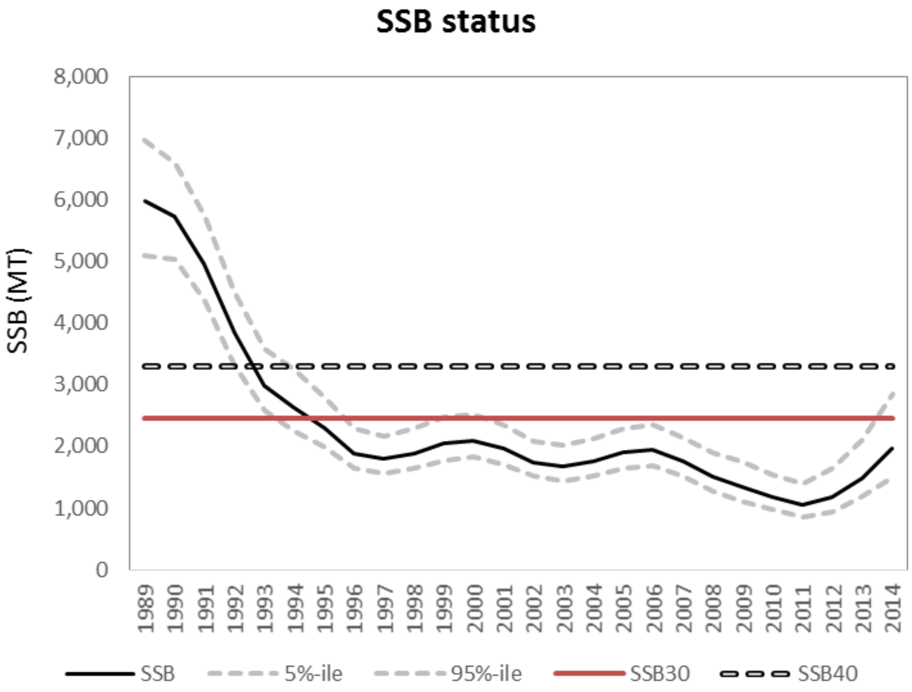


Figure 7.3. Fishing mortality (top) and spawning stock biomass relative to benchmarks for the NJ-NYB region.





Technical Documentation
for
ASAP Version 3.0

NOAA Fisheries Toolbox

September 2012

Table of Contents

Introduction

ASAP3 is an update to the program ASAP (Legault and Restrepo 1998), which was previously updated as ASAP2 in 2008. It contains a number of new features and options that are described in the ASAP3 User's Guide. This document provides the basic equations used in the program along with the approaches used to fit different components of the objective function. More importantly, it contains the actual ADMB code used to generate the executable, so that the exact calculations in the program can be followed. This document uses variable names in a number of places instead of symbols to facilitate understanding of the underlying code.

Basic Equations

The description of the model follows the steps in the code for ease of understanding. Calculation of the objective function is described in the next section.

Spawning Stock Biomass

The spawning stock biomass is calculated based on the population abundance at age (N), the fecundity (Φ), and the proportion of the total mortality (Z, see mortality section below) during the year prior to spawning (p_{SSB}) as

$$SSB_t = \sum_a N_{t,a} \Phi_{t,a} e^{-p_{SSB} Z_{t,a}} \qquad (1)$$

Where the fecundity matrix is either input by the user or else derived as the element by element product of the weight at age matrix and the maturity matrix.

Stock Recruitment Relationship

The Beverton and Holt stock recruitment relationship is used to calculate the expected recruitment in year t+1 from the spawning stock biomass in year t as

$$\hat{R}_{t+1} = \frac{\alpha SSB_t}{\beta + SSB_t} \qquad (2)$$

The equation is reparameterized following Mace and Doonan (ref) to use two parameters: the SR scaler and steepness (τ). The SR scaler can be either unexploited spawning stock biomass (SSB_0) or unexploited recruitment (R_0). These two values are related to each other based on the unexploited spawners per recruit (SPR_0) as $SPR_0 = SSB_0/R_0$. All three of these unexploited values are computed using the natural mortality, weights at age, and maturity (or fecundity) values in the terminal year of the assessment. The stock recruitment relationship is therefor fixed for all years using equation 2 with

$$\alpha = \frac{4\tau(SSB_0 / SPR_0)}{5\tau - 1} \quad and \quad \beta = \frac{SSB_0(1-\tau)}{5\tau - 1} \qquad (3)$$

However, the program also produces the values of unexploited SSB, R, spawners per recruit, and steepness associated with the natural mortality rate, weights at age, and maturity (or fecundity) for each year in the time series. This allows the user to see the influence of these values on the stock recruitment parameters SSB_0, R_0, SPR_0, and τ over time.

Steepness for the Beverton and Holt stock recruitment relationship is only defined between 0.2 and 1.0. Fixing steepness at 1.0 makes expected recruitment constant. The actual recruitment estimated by the model is formed by multiplying the expected recruitment by a recruitment deviation. The recruitment deviations are assumed to follow a lognormal distribution, making the parameters log_Rdev_t. The parameters are estimated as a bounded vector, meaning their sum is zero, so that they are centered on the expected stock recruitment relationship. The population numbers at age 1, recruitment is always assumed to occur at age 1, are

$$N_{t,1} = R_t e^{\log\_Rdev_t} \tag{4}$$

Selectivity

The approach used to estimate fleet selectivity in ASAP3 is quite different from that in ASAP, but the same as in ASAP2. As before, there are selectivity blocks, but now they are defined independently for each fleet. Within each selectivity block, there are three options for estimating selectivity:

1. estimate parameters for each age (one parameter for each age, similar to ASAP in concept, but now each age is bounded by zero and one and at least one age should be fixed at 1.0 instead of estimated)
2. logistic function (2 parameters: α_1, β_1)

   $$Sel_a = \frac{1}{1+e^{-(a-\alpha_1)/\beta_1}} \tag{5}$$

3. double logistic (4 parameters: α_1, β_1, α_2, β_2)

   $$Sel_a = \left(\frac{1}{1+e^{-(a-\alpha_1)/\beta_1}}\right)\left(1-\frac{1}{1+e^{-(a-\alpha_2)/\beta_2}}\right) \tag{6}$$

The selectivity at age is then assigned to all fleet and year combinations within that block. Note that for options 2 and 3, the selectivity at age is divided by the maximum value over all ages, creating the final selectivity vector with maximum of 1.0 for that block.

Mortality

Natural mortality (*M*) is entered as a year by age matrix, as it was in ASAP2, instead of just a vector by age as it was in ASAP.

Fishing mortality (*F*) is assumed to be separable, meaning it is the product of a year effect (*Fmult*) and selectivity at age (described above). The *Fmult* for a fleet and year is determined by two sets of parameters, log_Fmult1_{ifleet}, the parameter for first year for that fleet, and $log\_Fmultdev_{ifleet,t}$, where t=2 to the number of years, the deviation of the parameter from the value in the first year for that fleet. Both sets of parameters are estimated in log space and then exponentiated as

$$Fmult_{ifleet,1} = e^{\log\_Fmult1_{ifleet}}$$

$$Fmult_{ifleet,t} = Fmult_{ifleet,1} e^{\log\_Fmultdev_{ifleet,t}} \quad \forall t \geq 2 \tag{7}$$

Note that the *log_Fmultdev* parameters are not estimated as a dev_vector in the ADMB code, and so fishing intensity can increase continually, decrease continually, or fluctuate throughout the time series. The directed F for a fleet, year, and age, meaning that portion of the F that contributes to landings, is computed using the separable equation along with the proportion of catch released for that fleet, year, and age ($prop\_release_{ifleet,t,a}$) as

$$Fdir_{ifleet,t,a} = Fmult_{ifleet,t,a} Sel_{ifleet,t,a} (1 - prop\_release_{ifleet,t,a}) \tag{8}$$

The bycatch F contains an additional component, the proportion of released fish that die, which is fleet specific ($release\_mort_{ifleet}$)

$$Fbycatch_{ifleet,t,a} = Fmult_{ifleet,t,a} Sel_{ifleet,t,a} prop\_release_{ifleet,t,a} release\_mort_{ifleet} \tag{9}$$

The two parts are then added together to produce the fishing mortality for the fleet, year and age

$$F_{ifleet,t,a} = Fdir_{ifleet,t,a} + Fbycatch_{ifleet,t,a} \tag{10}$$

The total mortality (*Z*) is the sum of natural and fishing mortality at year and age over all fleets

$$Z_{t,a} = M_{t,a} + \sum_{ifleet} F_{ifleet,t,a} \tag{11}$$

Population Abundance

The population abundance in the first year for ages 2 through the maximum age are derived from either the initial guesses ($N1ini_a$) and the parameters $log\_Nyear1dev_a$ as

$$N_{1,a} = N1ini_a e^{\log\_Nyear1dev_a} \tag{12}$$

or as deviations from a population in equilibrium according to the total mortality at age vector in the first year. A partial spawning stock biomass for ages 2 through the maximum age is computed and used in the stock recruitment relationship (Eq. 2) to create an expected recruitment in the first year. The recruitment deviation for the first year is applied to form the population abundance at age 1 in the first year (Eq. 4). The full spawning stock biomass is computed for year 1 using all ages (Eq. 1) now that the first year is completely filled.

The population abundance for years 2 through the end year are then filled by first computing the expected recruitment (Eq. 2) and then applying the recruitment deviation to create the abundance at age 1 (Eq. 4). Ages 2 through the maximum age are filled using the following set of equations

$$\begin{aligned} N_{t,a} &= N_{t-1,a-1} e^{-Z_{t-1,a-1}} \qquad 2 \leq a < A \\ N_{t,A} &= N_{t-1,A-1} e^{-Z_{t-1,A-1}} + N_{t-1,A} e^{-Z_{t-1,A}} \end{aligned} \tag{13}$$

Each year the spawning stock biomass is computed (Eq. 1) and the cycle continued until the end year is reached.

F Report

The original ASAP simply output the Fmult for each fleet and year as an indicator of fishing intensity, along with the full F matrix by fleet and combined over all fleets. This approach for comparing fishing intensity is sufficient if selectivity does not change over time, but can be problematic when selectivity changes. A feature of ASAP2 that is continued in ASAP3 is the use of Freport, which averages the total fishing mortality over an input range of ages (a_{repmin} to a_{repmax}). The averaging is done unweighted ($\omega_{t,a}=1$), weighted by population abundance at age ($\omega_{t,a}=N_{t,a}$), and weighted by population biomass at age ($\omega_{t,a}=N_{t,a}W_{t,a}$ where $W_{t,a}$ denotes the January 1 weight at year and age) as

$$Freport_t = \frac{\sum_{a=a_{rep\min}}^{a_{rep\max}} \omega_{t,a} F_{t,a}}{\sum_{a=a_{rep\min}}^{a_{rep\max}} \omega_{t,a}} \tag{14}$$

Predicted Catch

The predicted landings ($Lpred$) and discards ($Dpred$) in units of numbers of fish for each fleet, year, and age are derived from the Baranov catch equation

$$Lpred_{ifleet,t,a} = N_{ifleet,t,a} Fdir_{ifleet,t,a} (1 - e^{-Z_{t,a}}) / Z_{t,a} \tag{15}$$

$$Dpred_{ifleet,t,a} = N_{ifleet,t,a} Fbycatch_{ifleet,t,a} (1 - e^{-Z_{t,a}}) / Z_{t,a} \tag{16}$$

These predictions are used in two ways, one to form the predicted total weight of landings or discards for a fleet and year, and the other to form the proportions at age for a fleet and year. Both calculations are limited by the starting and ending ages for the fleet. The predicted total catch in weight calculations use the catch weight at year and age ($Wc_{t,a}$)

$$\hat{L}tot_{ifleet,t} = \sum_{a=fleetstart}^{fleetend} Lpred_{ifleet,t,a} Wc_{t,a} \tag{17}$$

$$\hat{D}tot_{ifleet,t} = \sum_{a=fleetstart}^{fleetend} Dpred_{ifleet,t,a} Wc_{t,a} \tag{18}$$

Note that since Fbycatch is derived using the proportion of fish that die after release, the total observed discards in weight ($Dtot$) should only include those fish that die after capture and release.

The predicted landings and discards proportions at age for each fleet and year are only computed for ages within the starting and ending range

$$\hat{L}p_{ifleet,t,a} = \frac{Lpred_{ifleet,t,a}}{\sum_{a=fleetstart}^{fleetend} Lpred_{ifleet,t,a}} \tag{19}$$

$$\hat{D}p_{ifleet,t,a} = \frac{Dpred_{ifleet,t,a}}{\sum_{a=fleetstart}^{fleetend} Dpred_{ifleet,t,a}} \tag{20}$$

Any predicted proportion less than 1e-15 is replaced by the value 1e-15 to avoid division by zero problems in the calculation of the likelihood function.

Catchability

Catchability for each index (*ind*) over time is computed similarly to the Fmult, with one parameter for the catchability in the first year (log_q1_{ind}) and a number of deviation parameters for each additional year of index observations ($log\_q\_dev_{ind,t}$). These parameters are combined and exponentiated to form the catchability value for the fleet and year as

$$q_{ind,t} = e^{\log\_q1_{ind} + \log\_q\_dev_{ind,t}} \qquad (21)$$

where the parameter for the deviation in the first year ($log\_q\_dev_{ind,1}$) is defined as zero.

Predicted Indices

The observed indices have two characteristics that are matched when predicted values are computed, the time of year of the index and the units (numbers or biomass). The estimated population numbers at age are modified to the time of the index according to

$$N*_{ind,t,a} = N_{t,a} \frac{1 - e^{-Z_{t,a}}}{Z_{t,a}} \qquad (22)$$

if the index month is set to -1, corresponding to an average abundance, or

$$N*_{ind,t,a} = N_{t,a} (1 - e^{-(ind\_month/12) Z_{t,a}}) \qquad (23)$$

for index month between 0 and 12. Note that the index month refers to the end of the month, so *ind_month*=0 is January 1 and *ind_month*=12 is December 31. If the units for an index are biomass, then the N* values are multiplied by the user defined weights at age matrix. The selectivity associated with each index is either matched to a fleet or else input. If the selectivity for a fleet is input, it can be either fixed or estimated in the same way as the fleet selectivities (age based, logistic, or double logistic). The final predicted index (*Ipred*) is formed by summing the product of N* and selectivity values over the appropriate ages and multiplying by the catchability for the index

$$Ipred_{ind,t} = q_{ind,t} \sum_{a=indstart}^{indend} N*_{ind,t,a} \, Sel_{ind,t,a} \qquad (24)$$

If the user selects to estimate the proportions at age for an index, then the proportions at age are computed in the same manner as the landings and discards at age (equations 19 and 20). Note that the units used for the aggregate index and proportions at age are set by the user separately, so all four combinations of numbers and biomass are possible.

Reference Points

The program computes a number of common reference points based on the estimated F and biological characteristics of the final year in the assessment. The reference points derive a directed and discard selectivity pattern from all the fleets that were assigned to be directed by summing the F at age and dividing by the maximum directed F. The nondirected F is summed over all fleets that were not assigned as directed, and these F values are fixed during the reference point calculations. The F reference points are computed through a bisection algorithm that is repeated 20 times (producing an accuracy of approximately 1E-05). The reference points computed are $F_{0.1}$, F_{MAX}, $F_{30\%SPR}$, $F_{40\%SPR}$, and F_{MSY}. The associated maximum sustainable yield and spawning stock biomass at F_{MSY} are also provided. The reference point values are averaged in the same manner as the Freport to allow direct comparison. Note, however, that if selectivity or biological characteristics change over time, these comparisons will not be accurate because the reference points are computed assuming the final year values. The program now computes the annual unexploited SSB, unexploited R, unexploited SSB per R, and steepness to demonstrate the potential for change in the F reference points.

Projections

The projections use the same basic calculations as the main assessment program, except that there is no fitting done. The recruitments for each projection year can either be entered by the user or else be derived from the stock recruitment curve (without deviations from the curve). The directed and discard selectivity as well as the bycatch F at age are the same as used in the reference point calculations. There are five options to define what is used to define the fishery in each projections year:

1. match an input directed catch in weight
2. fish at an input F%SPR
3. fish at F_{MSY}
4. fish at the current (terminal year) F
5. fish at an input F

Each year the bycatch F can be modified from the terminal year to examine either increases or decreases in this(these) fishery(ies).

Objective Function Calculation (Fitting the Model)

The objective function in ASAP3 is the sum of a number of model fits and two penalties. There are two types of error distributions in the calculation of the objective function: lognormal and multinomial. Both are converted to negative log likelihoods for use in the minimization conducted by ADMB. Both error distributions contain constant terms that do not change for any value of the parameters. These constants can be either included or excluded from the objective function. Note that since the weights for different components of the objective function multiply the constants, different solutions may result when the constants are included or not.

The lognormal model fits all contain a lambda value that allows emphasis of that particular part of the objective function along with an input coefficient of variation (CV) that is used to measure how strong a particular deviation is. The CV is converted to a variance (σ^2) and associated standard deviation (σ) using the equation

$$\sigma^2 = \ln(CV^2 + 1) \qquad (25)$$

The lognormal distribution has a negative log likelihood, *-ln(L)*, defined by

$$-\ln(L) = 0.5\ln(2\pi) + \sum \ln(obs_i) + \ln(\sigma) + 0.5\sum \frac{(\ln(obs_i) - \ln(pred_i))^2}{\sigma^2} \quad (26)$$

The first two terms on the right side of equation (26) are the constants that are optionally kept or set to zero. The objective function is calculated as

$$obj\ \ fxn = \lambda * (-\ln(L)) \quad (27)$$

So that any component of the objective function can be turned off by setting λ for that component to zero. Standardized residuals for each component are calculated as

$$std\ \ resid_i = \frac{\ln(obs_i) - \ln(pred_i)}{\sigma} \quad (28)$$

In a perfectly fit model, the standardized residuals would have mean zero and standard deviation one.

The multinomial distribution fits employ an input effective sample size to multiply the negative log likelihood when calculating the objective function. This distribution is made up of k bins each containing p_i proportion of the total (sum of p_i=1). The input effective sample size (ESS) is used to create the number of fish in each bin (n_i) as $n_i = ESS * p_i$. The multinomial distribution then has a negative log likelihood defined by

$$-\ln(L) = -\ln(ESS!) + \sum_{i=1}^{k} \ln(n_i!) - ESS\sum_{i=1}^{k} p_i \ln(predp_i) \quad (29)$$

where p_i denotes an observed proportion and $predp_i$ denotes the associated predicted proportion. The first two terms on the right side of equation (29) are the constants that are optionally kept or set to zero. The objective function is simply the negative log likelihood for the multinomial distribution because the effective sample size is an integral part of the calculation of the likelihood.

The lognormal error distribution is assumed for

- Total catch in weight
- Total discards in weight
- Indices
- Stock recruitment relationship
- Selectivity parameters (relative to initial guesses)
- The two stock recruitment parameters (relative to their initial guesses)
- Fmult in year 1 by fleet (relative to initial guesses)
- Fmult deviations
- Catchability in year 1 by fleet (relative to initial guesses)
- Catchability deviations
- Numbers at age in year 1 (relative to either initial guesses or a population in equilibrium)

Multinomial distribution is assumed for

- Catch at age
- Discards at age
- Index proportions at age

The two penalties are formed from estimated total fishing mortality rates. The first is a penalty associated with any total F greater than an input maximum value, calculated as $1000*(F\text{-}Fmax)^2$ for F>Fmax. The second penalty is for F different than M in the early phases, calculated as $100*10^{-phase}$ $(\ln(avg(F)\text{-}\ln(M))^2$. The second penalty is always set to zero in the final estimation phase, regardless of the number of phases.

Appendix 1: Source Code for ASAP3

(Note the code sometimes wraps around to the next line in the presentation here.)

```
// ASAP3 (Age Structured Assessment Program Version 3: August 2012)
//   by Christopher Legault with major contributions from Liz Brooks
//   modified from ASAP2 by Christopher Legault
//   modified from original ASAP by Christopher Legault and Victor Restrepo 1998

// Major changes from ASAP2
// user defines SR curve using steepness and either R0 or S0
// allow user to mix and match biomass and numbers for aggreagate indices and indices proportions at age
// user enters a number of weight at age matrices then defines which are used for catch, discards, SSB, Jan-1 B,
and indices
// compute annual SR curve estimates of R0, S0, steepness, and spawners per recruit to show how changes in M,
fecundity, WAA impact these estimates over time
// expected population at age in year 1 can be either an exponential decline or user initial guesses for
optional deviation calculations
// compute Francis (2011) stage 2 multiplier for multinomial to adjust input Neff

// update April 2012
// fix bug with which inconsistent year for M and WAA used in calculation of unexploited SSB per recruit
// (was first year when all other calculations were last year, now everything last year)
// also added trap for division by zero in Freport calculation to avoid crashes when pop size gets small
// incorporated Liz Brook's make-Rfile.cxx for ADMB2R to optionally create rdat file automatically
// created new output file asap2RMSE.dat for use with R script

// update April 2008
// fixed bug in get_log_factorial function - variable could be i used in two places (thanks to Tim Miller for
finding this one)
//
// Major changes from original ASAP
//
// Enter all available indices and then select which ones to use for tuning
// Change in selectivity estimation to reduce parameter correlations
//   Added option to use logistic or double logistic selectivity patterns
//   Selectivity blocks now independent with own initial starting guesses
// Added CVs and lambdas for many parameters
// Multiple matrices for weights at age at different times of the year
// M matrix instead of vector
// Freport feature to allow easier comparison among years with different selectivity patterns
// Echo input read to file for improved debugging
// MCMC capability added
//   One file for Freport, SSB, and MSY related variables
//   One file for use in AgePro software (.bsn file)
// Full likelihood calculations, including (optionally) constants
// Output of standardized residuals
// Modified year 1 recruitment deviation calculations to reduce probability of extremely large residual

TOP_OF_MAIN_SECTION
// set buffer sizes
  arrmblsize=5000000;
  gradient_structure::set_GRADSTACK_BUFFER_SIZE(10000000);
  gradient_structure::set_MAX_NVAR_OFFSET(50000);
  gradient_structure::set_NUM_DEPENDENT_VARIABLES(10000);
  time(&start); //this is to see how long it takes to run
  cout << endl << "Start time : " << ctime(&start) << endl;

GLOBALS_SECTION
  #include <admodel.h>
  #include <time.h>
  #include <C:\ADMB\admb2r-1.15\admb2r\admb2r.cpp>
  time_t start,finish;
  long hour,minute,second;
  double elapsed_time;
  ofstream ageproMCMC("asap3.bsn");
  ofstream basicMCMC("asap3MCMC.dat");
  ofstream inputlog("asap3input.log");
  //--- preprocessor macro from Larry Jacobson NMFS-Woods Hole
```

```
  #define ICHECK(object) inputlog << "#" #object "\n " << object << endl;

DATA_SECTION
  int debug
  int iyear
  int iage
  int ia
  int ifleet
  int ind
  int i
  int j
  int k
  int iloop
  int io
  number pi
 !!  pi=3.14159265358979;
  number CVfill
 !! CVfill=100.0;
// basic dimensions
  init_int nyears
 !! ICHECK(nyears);
  init_int year1
 !! ICHECK(year1);
  init_int nages
 !! ICHECK(nages);
  init_int nfleets
 !! ICHECK(nfleets);
  init_int nselblocks;
 !! ICHECK(nselblocks);
  init_int navailindices
 !! ICHECK(navailindices);

// biology
  init_matrix M(1,nyears,1,nages)
 !! ICHECK(M);
  init_number isfecund
 !! ICHECK(isfecund);
  init_number fracyearSSB
 !! ICHECK(fracyearSSB);
  init_matrix mature(1,nyears,1,nages)
 !! ICHECK(mature);
  init_int nWAAmatrices
 !! ICHECK(nWAAmatrices);
  int nrowsWAAini
 !! nrowsWAAini=nyears*nWAAmatrices;
  init_matrix WAA_ini(1,nrowsWAAini,1,nages)
 !! ICHECK(WAA_ini);
  int nWAApointbio
 !! nWAApointbio=nfleets*2+2+2;
  init_ivector WAApointbio(1,nWAApointbio) // pointers to WAA matrix for fleet catch and discards, catch all
fleets, discard all fleets, SSB, and Jan1B
 !! ICHECK(WAApointbio);
  matrix fecundity(1,nyears,1,nages)
  3darray WAAcatchfleet(1,nfleets,1,nyears,1,nages)
  3darray WAAdiscardfleet(1,nfleets,1,nyears,1,nages)
  matrix WAAcatchall(1,nyears,1,nages)
  matrix WAAdiscardall(1,nyears,1,nages)
  matrix WAAssb(1,nyears,1,nages)
  matrix WAAjan1b(1,nyears,1,nages)
 LOCAL_CALCS
  if ((max(WAApointbio) > nWAAmatrices) || (min(WAApointbio) < 1))
  {
     cout << "Problem with WAApointbio" << endl;
     ad_exit(1);
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     int ipointcatchfleet=(WAApointbio((ifleet*2)-1)-1)*nyears;
     int ipointdiscardfleet=(WAApointbio(ifleet*2)-1)*nyears;
     for (iyear=1;iyear<=nyears;iyear++)
     {
```

```
        WAAcatchfleet(ifleet,iyear)=WAA_ini((ipointcatchfleet+iyear));
        WAAdiscardfleet(ifleet,iyear)=WAA_ini((ipointdiscardfleet+iyear));
     }
  }
  int ipointcatchall=(WAApointbio((nfleets*2)+1)-1)*nyears;
  int ipointdiscardall=(WAApointbio((nfleets*2)+2)-1)*nyears;
  int ipointssb=(WAApointbio((nfleets*2)+3)-1)*nyears;
  int ipointjan1b=(WAApointbio((nfleets*2)+4)-1)*nyears;
  for (iyear=1;iyear<=nyears;iyear++)
  {
     WAAcatchall(iyear)=WAA_ini((ipointcatchall+iyear));
     WAAdiscardall(iyear)=WAA_ini((ipointdiscardall+iyear));
     WAAssb(iyear)=WAA_ini((ipointssb+iyear));
     WAAjan1b(iyear)=WAA_ini((ipointjan1b+iyear));
  }
  if (isfecund==1)
     fecundity=mature;
  else
     fecundity=elem_prod(WAAssb,mature);
 END_CALCS

// fleet names here with $ in front of label

// Selectivity ****************************************
// need to enter values for all options even though only one will be used for each block
  init_matrix sel_blocks(1,nfleets,1,nyears) // defines blocks for each fleet in successive order
 !! ICHECK(sel_blocks);
  int nsel_ini
 !! nsel_ini=nselblocks*(nages+6);
  init_ivector sel_option(1,nselblocks) // 1=by age, 2=logisitic, 3=double logistic
 !! ICHECK(sel_option);
  init_matrix sel_ini(1,nsel_ini,1,4) // 1st value is initial guess, 2nd is phase, 3rd is lambda, 4th is CV
 !! ICHECK(sel_ini);
  int nselparm
 LOCAL_CALCS
// first count number of selectivity parameters and replace CV=0 with CVfill
  nselparm=0;
  for (i=1;i<=nselblocks;i++)
  {
     if (sel_option(i)==1) nselparm+=nages;
     if (sel_option(i)==2) nselparm+=2;
     if (sel_option(i)==3) nselparm+=4;
  }
  for (i=1;i<=nsel_ini;i++)
  {
     if (sel_ini(i,4) <= 0.0)
         sel_ini(i,4) = CVfill;
  }
 END_CALCS
  vector sel_initial(1,nselparm)
  vector sel_lo(1,nselparm)
  vector sel_hi(1,nselparm)
  ivector sel_phase(1,nselparm)
  vector sel_lambda(1,nselparm)
  vector sel_CV(1,nselparm)
  vector sel_sigma2(1,nselparm)
  vector sel_sigma(1,nselparm)
  vector sel_like_const(1,nselparm)
 LOCAL_CALCS
// now assign bounds and phases for each selectivity parameter
  k=0;
  for (i=1;i<=nselblocks;i++){
     if (sel_option(i)==1) {
        for (iage=1;iage<=nages;iage++) {
           k+=1;
           j=(i-1)*(nages+6)+iage;
           sel_initial(k)=sel_ini(j,1);
           sel_lo(k)=0.0;
           sel_hi(k)=1.0;
           sel_phase(k)=sel_ini(j,2);
           sel_lambda(k)=sel_ini(j,3);
```

```
          sel_CV(k)=sel_ini(j,4);
          sel_sigma2(k)=log(sel_CV(k)*sel_CV(k)+1.0);
          sel_sigma(k)=sqrt(sel_sigma2(k));
       }
    }
    if (sel_option(i)==2) {
       for (ia=1;ia<=2;ia++) {
          k+=1;
          j=(i-1)*(nages+6)+nages+ia;
          sel_initial(k)=sel_ini(j,1);
          sel_lo(k)=0.0;
          sel_hi(k)=nages;
          sel_phase(k)=sel_ini(j,2);
          sel_lambda(k)=sel_ini(j,3);
          sel_CV(k)=sel_ini(j,4);
          sel_sigma2(k)=log(sel_CV(k)*sel_CV(k)+1.0);
          sel_sigma(k)=sqrt(sel_sigma2(k));
       }
    }
    if (sel_option(i)==3) {
       for (ia=1;ia<=4;ia++) {
          k+=1;
          j=(i-1)*(nages+6)+nages+2+ia;
          sel_initial(k)=sel_ini(j,1);
          sel_lo(k)=0.0;
          sel_hi(k)=nages;
          sel_phase(k)=sel_ini(j,2);
          sel_lambda(k)=sel_ini(j,3);
          sel_CV(k)=sel_ini(j,4);
          sel_sigma2(k)=log(sel_CV(k)*sel_CV(k)+1.0);
          sel_sigma(k)=sqrt(sel_sigma2(k));
       }
    }
 }
END_CALCS
 init_ivector sel_start_age(1,nfleets)
!! ICHECK(sel_start_age);
 init_ivector sel_end_age(1,nfleets)
!! ICHECK(sel_end_age);

 init_int Freport_agemin
!! ICHECK(Freport_agemin);
 init_int Freport_agemax
!! ICHECK(Freport_agemax);
 init_int Freport_wtopt
!! ICHECK(Freport_wtopt);

 init_int use_likelihood_constants
!! ICHECK(use_likelihood_constants);
 init_vector release_mort(1,nfleets)
!! ICHECK(release_mort);

// Catch ******************************************
// Includes both landed and discarded components
 init_matrix CAA_ini(1,nyears*nfleets,1,nages+1)
!! ICHECK(CAA_ini);
 init_matrix Discard_ini(1,nyears*nfleets,1,nages+1)
!! ICHECK(Discard_ini);
 init_matrix proportion_release_ini(1,nyears*nfleets,1,nages)
!! ICHECK(proportion_release_ini);
 3darray CAA_obs(1,nfleets,1,nyears,1,nages)
 3darray Discard_obs(1,nfleets,1,nyears,1,nages)
 3darray proportion_release(1,nfleets,1,nyears,1,nages)
 3darray CAA_prop_obs(1,nfleets,1,nyears,sel_start_age,sel_end_age)
 3darray Discard_prop_obs(1,nfleets,1,nyears,sel_start_age,sel_end_age)
 number catch_prop_like_const
 number discard_prop_like_const
 matrix Catch_tot_fleet_obs(1,nfleets,1,nyears)
 matrix Discard_tot_fleet_obs(1,nfleets,1,nyears)
 matrix CAA_prop_obs_sum(1,nfleets,1,nyears)
 matrix Discard_prop_obs_sum(1,nfleets,1,nyears)
```

```
  vector catch_tot_like_const(1,nfleets)
  vector discard_tot_like_const(1,nfleets)
 LOCAL_CALCS
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     catch_tot_like_const(ifleet)=0.0;
     discard_tot_like_const(ifleet)=0.0;
     for (iyear=1;iyear<=nyears;iyear++)
     {
        CAA_obs(ifleet,iyear)(1,nages)=CAA_ini((ifleet-1)*nyears+iyear)(1,nages);
        Discard_obs(ifleet,iyear)(1,nages)=Discard_ini((ifleet-1)*nyears+iyear)(1,nages);
        proportion_release(ifleet,iyear)=proportion_release_ini((ifleet-1)*nyears+iyear)(1,nages);
        Catch_tot_fleet_obs(ifleet,iyear)=CAA_ini((ifleet-1)*nyears+iyear,nages+1);
        Discard_tot_fleet_obs(ifleet,iyear)=Discard_ini((ifleet-1)*nyears+iyear,nages+1);
        if (Catch_tot_fleet_obs(ifleet,iyear)>1.0e-15)
           catch_tot_like_const(ifleet)+=0.5*log(2.0*pi)+log(Catch_tot_fleet_obs(ifleet,iyear));
        if (Discard_tot_fleet_obs(ifleet,iyear)>1.0e-15)
           discard_tot_like_const(ifleet)=0.5*log(2.0*pi)+log(Discard_tot_fleet_obs(ifleet,iyear));
     }
  }
  if (use_likelihood_constants != 1)
  {
     catch_tot_like_const=0.0;
     discard_tot_like_const=0.0;
  }
  CAA_prop_obs=0.0;
  Discard_prop_obs=0.0;
  CAA_prop_obs_sum=0.0;
  Discard_prop_obs_sum=0.0;
  for (iyear=1;iyear<=nyears;iyear++)
  {
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
       if (Catch_tot_fleet_obs(ifleet,iyear)>0.0)
       {
          for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             CAA_prop_obs_sum(ifleet,iyear)+=CAA_obs(ifleet,iyear,iage);
          if (CAA_prop_obs_sum(ifleet,iyear)==0.0)
          {
             CAA_prop_obs(ifleet,iyear)=0.0;
          }
          else
          {

CAA_prop_obs(ifleet,iyear)=CAA_obs(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/CAA_prop_obs_sum(ifl
eet,iyear);
          }
       }
       if (Discard_tot_fleet_obs(ifleet,iyear)>0.0)
       {
          for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             Discard_prop_obs_sum(ifleet,iyear)+=Discard_obs(ifleet,iyear,iage);
          if (Discard_prop_obs_sum(ifleet,iyear)==0.0)
          {
             Discard_prop_obs(ifleet,iyear)=0.0;
          }
          else
          {

Discard_prop_obs(ifleet,iyear)=Discard_obs(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/Discard_prop
_obs_sum(ifleet,iyear);
          }
       }
    }
  }
 END_CALCS

// Indices ******************************
// Enter in all available indices and then pick the ones that are to be used in objective function
// navailindices is the number of indices entered
// nindices is the number of indices used (calculated by program)
```

```
  int indavail
// index names here with $ in front of label
  init_vector index_units_aggregate_ini(1,navailindices) // 1=biomass, 2=numbers
 !! ICHECK(index_units_aggregate_ini);
  init_vector index_units_proportions_ini(1,navailindices) // 1=biomass, 2=numbers
 !! ICHECK(index_units_proportions_ini);
  init_ivector index_WAApoint_ini(1,navailindices) // pointer for which WAA matrix to use for biomass calculations for each index
 !! ICHECK(index_WAApoint_ini);
  init_vector index_month_ini(1,navailindices) // -1=average pop
 !! ICHECK(index_month_ini);
  init_ivector index_sel_choice_ini(1,navailindices) // -1=fixed
 !! ICHECK(index_sel_choice_ini);
  init_ivector index_sel_option_ini(1,navailindices) // 1=by age, 2=logisitic, 3=double logistic
 !! ICHECK(index_sel_option_ini);
  init_ivector index_start_age_ini(1,navailindices)
 !! ICHECK(index_start_age_ini);
  init_ivector index_end_age_ini(1,navailindices)
 !! ICHECK(index_end_age_ini);
  init_ivector index_estimate_proportions_ini(1,navailindices) // 1=yes
 !! ICHECK(index_estimate_proportions_ini);
  init_ivector use_index(1,navailindices) // 1=yes
 !! ICHECK(use_index);
  int nindexsel_ini
 !! nindexsel_ini=navailindices*(nages+6);
  init_matrix index_sel_ini(1,nindexsel_ini,1,4) // 1st value is initial guess, 2nd is phase, 3rd is lambda, 4th is CV
 !! ICHECK(index_sel_ini);
  init_matrix index_ini(1,nyears*navailindices,1,3+nages+1) // year, index value, CV, proportions at age, input effective sample size
 !! ICHECK(index_ini);
  int nindices
 !! nindices=sum(use_index);
  vector index_units_aggregate(1,nindices)
  vector index_units_proportions(1,nindices)
  ivector index_WAApoint(1,nindices)
  vector index_month(1,nindices)
  vector index_sel_option(1,nindices)
  vector index_start_age(1,nindices)
  vector index_end_age(1,nindices)
  vector index_sel_choice(1,nindices)
  ivector index_nobs(1,nindices)
  ivector index_estimate_proportions(1,nindices)
  int nindexselparms
 LOCAL_CALCS
  if ((max(index_WAApoint_ini) > nWAAmatrices) || (min(index_WAApoint_ini) < 1))
  {
     cout << "Problem with index_WAApoint_ini" << endl;
     ad_exit(1);
  }
  for (i=1;i<=nindexsel_ini;i++)
  {
     if (index_sel_ini(i,4) <= 0.0)
         index_sel_ini(i,4) = CVfill;
  }
  for (i=1;i<=nyears*navailindices;i++)
  {
     if (index_ini(i,3) <= 0.0)
         index_ini(i,3) = CVfill;
  }
  ind=0;
  nindexselparms=0;
  for (indavail=1;indavail<=navailindices;indavail++)
  {
     if (use_index(indavail)==1)
     {
       ind+=1;
       index_units_aggregate(ind)=index_units_aggregate_ini(indavail);
       index_units_proportions(ind)=index_units_proportions_ini(indavail);
       index_WAApoint(ind)=index_WAApoint_ini(indavail);
       index_month(ind)=index_month_ini(indavail);
```

```
       index_sel_option(ind)=index_sel_option_ini(indavail);
       if (index_sel_option(ind)==1) nindexselparms+=nages;
       if (index_sel_option(ind)==2) nindexselparms+=2;
       if (index_sel_option(ind)==3) nindexselparms+=4;
       index_start_age(ind)=index_start_age_ini(indavail);
       index_end_age(ind)=index_end_age_ini(indavail);
       index_sel_choice(ind)=index_sel_choice_ini(indavail);
       index_estimate_proportions(ind)=index_estimate_proportions_ini(indavail);
       j=0;
       for (iyear=1;iyear<=nyears;iyear++)
       {
         if (index_ini((indavail-1)*nyears+iyear,2)>0.0)  // zero or negative value for index means not included
             j+=1;
       }
       index_nobs(ind)=j;
     }
  }
 END_CALCS
  matrix index_time(1,nindices,1,index_nobs)
  matrix index_year(1,nindices,1,index_nobs)
  matrix index_obs(1,nindices,1,index_nobs)
  matrix index_cv(1,nindices,1,index_nobs)
  matrix index_sigma2(1,nindices,1,index_nobs)
  matrix index_sigma(1,nindices,1,index_nobs)
  matrix input_eff_samp_size_index(1,nindices,1,index_nobs)
  vector indexsel_initial(1,nindexselparms)
  vector indexsel_lo(1,nindexselparms)
  vector indexsel_hi(1,nindexselparms)
  ivector indexsel_phase(1,nindexselparms)
  vector indexsel_lambda(1,nindexselparms)
  vector indexsel_CV(1,nindexselparms)
  vector indexsel_sigma2(1,nindexselparms)
  vector indexsel_sigma(1,nindexselparms)
  vector indexsel_like_const(1,nindexselparms)
  number index_prop_like_const
  3darray index_sel_input(1,nindices,1,nyears,1,nages)
  3darray index_prop_obs(1,nindices,1,index_nobs,1,nages)
  3darray index_WAA(1,nindices,1,nyears,1,nages)
  vector index_like_const(1,nindices)
  number tempsum
 LOCAL_CALCS
  index_prop_obs=0.0;
  ind=0;
  k=0;
  for (indavail=1;indavail<=navailindices;indavail++)
  {
     if (use_index(indavail)==1)
     {
       ind+=1;
// get the index selectivity information
      if (index_sel_option(ind)==1)
      {
         for (iage=1;iage<=nages;iage++)
         {
            k+=1;
            j=(indavail-1)*(nages+6)+iage;
            indexsel_initial(k)=index_sel_ini(j,1);
            indexsel_lo(k)=0.0;
            indexsel_hi(k)=1.0;
            indexsel_phase(k)=index_sel_ini(j,2);
            indexsel_lambda(k)=index_sel_ini(j,3);
            indexsel_CV(k)=index_sel_ini(j,4);
            indexsel_sigma2(k)=log(indexsel_CV(k)*indexsel_CV(k)+1.0);
            indexsel_sigma(k)=sqrt(indexsel_sigma2(k));
         }
      }
      else if (index_sel_option(ind)==2)
      {
         for (ia=1;ia<=2;ia++)
         {
            k+=1;
```

```
            j=(indavail-1)*(nages+6)+nages+ia;
            indexsel_initial(k)=index_sel_ini(j,1);
            indexsel_lo(k)=0.0;
            indexsel_hi(k)=nages;
            indexsel_phase(k)=index_sel_ini(j,2);
            indexsel_lambda(k)=index_sel_ini(j,3);
            indexsel_CV(k)=index_sel_ini(j,4);
            indexsel_sigma2(k)=log(indexsel_CV(k)*indexsel_CV(k)+1.0);
            indexsel_sigma(k)=sqrt(indexsel_sigma2(k));
         }
      }
      else if (index_sel_option(ind)==3)
      {
         for (ia=1;ia<=4;ia++)
         {
            k+=1;
            j=(indavail-1)*(nages+6)+nages+2+ia;
            indexsel_initial(k)=index_sel_ini(j,1);
            indexsel_lo(k)=0.0;
            indexsel_hi(k)=nages;
            indexsel_phase(k)=index_sel_ini(j,2);
            indexsel_lambda(k)=index_sel_ini(j,3);
            indexsel_CV(k)=index_sel_ini(j,4);
            indexsel_sigma2(k)=log(indexsel_CV(k)*indexsel_CV(k)+1.0);
            indexsel_sigma(k)=sqrt(indexsel_sigma2(k));
         }
      }

// get the index and year specific information
       j=0;
       for (iyear=1;iyear<=nyears;iyear++)
       {
         i=(indavail-1)*nyears+iyear;
         index_sel_input(ind,iyear)=--(--(--index_ini(i)(4,3+nages)));
         if (index_ini(i,2)>0.0)
         {
             j+=1;
             index_time(ind,j)=index_ini(i,1)-year1+1;
             index_year(ind,j)=index_ini(i,1);
             index_obs(ind,j)=index_ini(i,2);
             index_cv(ind,j)=index_ini(i,3);
             index_sigma2(ind,j)=log(index_cv(ind,j)*index_cv(ind,j)+1.0);
             index_sigma(ind,j)=sqrt(index_sigma2(ind,j));
             input_eff_samp_size_index(ind,j)=index_ini(i,nages+4);
             tempsum=sum(index_sel_input(ind,iyear)(index_start_age(ind),index_end_age(ind)));
             if (tempsum > 0.0)
             {
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                     index_prop_obs(ind,j,iage)=index_sel_input(ind,iyear,iage)/tempsum;
                 }
             }
         }
       }
     }
  }
  index_like_const=0.0;
  if (use_likelihood_constants==1)
  {
     for (ind=1;ind<=nindices;ind++)
     {
        index_like_const(ind)=0.5*double(index_nobs(ind))*log(2.0*pi)+sum(log(index_obs(ind)));
     }
  }

// set up the index_WAA matrices (indices in numbers only will have WAA set to 0)
  index_WAA=0.0;
  for (ind=1;ind<=nindices;ind++)
  {
     if (index_units_aggregate(ind)==1 || index_units_proportions(ind)==1)
     {
```

```
        int ipointindex=(index_WAApoint(ind)-1)*nyears;
        for (iyear=1;iyear<=nyears;iyear++)
        {
           index_WAA(ind,iyear)=WAA_ini((ipointindex+iyear));
        }
     }
  }
 END_CALCS

// Phase Controls (other than selectivity)
  init_int phase_Fmult_year1
 !! ICHECK(phase_Fmult_year1);
  init_int phase_Fmult_devs
 !! ICHECK(phase_Fmult_devs);
  init_int phase_recruit_devs
 !! ICHECK(phase_recruit_devs);
  init_int phase_N_year1_devs
 !! ICHECK(phase_N_year1_devs);
  init_int phase_q_year1
 !! ICHECK(phase_q_year1);
  init_int phase_q_devs
 !! ICHECK(phase_q_devs);
  init_int phase_SR_scaler
 !! ICHECK(phase_SR_scaler);
  init_int phase_steepness
 !! ICHECK(phase_steepness);
  init_vector recruit_CV(1,nyears)
 !! ICHECK(recruit_CV);
  vector recruit_sigma2(1,nyears)
  vector recruit_sigma(1,nyears)
  number SR_like_const
 LOCAL_CALCS
  for (iyear=1;iyear<=nyears;iyear++)
  {
    if (recruit_CV(iyear) <= 0.0)
        recruit_CV(iyear) = CVfill;
    recruit_sigma2(iyear)=log(recruit_CV(iyear)*recruit_CV(iyear)+1.0);
    recruit_sigma(iyear)=sqrt(recruit_sigma2(iyear));
  }
  SR_like_const=0.0;
  if (use_likelihood_constants == 1)
     SR_like_const=0.5*double(nyears)*log(2.0*pi);
 END_CALCS
  init_vector lambda_ind_ini(1,navailindices)
 !! ICHECK(lambda_ind_ini);
  init_vector lambda_catch_tot(1,nfleets)
 !! ICHECK(lambda_catch_tot);
  init_vector lambda_Discard_tot(1,nfleets)
 !! ICHECK(lambda_Discard_tot);
  init_matrix catch_tot_CV(1,nyears,1,nfleets)
 !! ICHECK(catch_tot_CV);
  init_matrix discard_tot_CV(1,nyears,1,nfleets)
 !! ICHECK(discard_tot_CV);
  matrix catch_tot_sigma2(1,nfleets,1,nyears)
  matrix catch_tot_sigma(1,nfleets,1,nyears)
  matrix discard_tot_sigma2(1,nfleets,1,nyears)
  matrix discard_tot_sigma(1,nfleets,1,nyears)
  init_matrix input_eff_samp_size_catch_ini(1,nyears,1,nfleets)
 !! ICHECK(input_eff_samp_size_catch_ini);
  init_matrix input_eff_samp_size_discard_ini(1,nyears,1,nfleets)
 !! ICHECK(input_eff_samp_size_discard_ini);
  matrix input_eff_samp_size_catch(1,nfleets,1,nyears)
  matrix input_eff_samp_size_discard(1,nfleets,1,nyears)
  number nfact_in
  number nfact_out
 LOCAL_CALCS
  for(iyear=1;iyear<=nyears;iyear++)
  {
   for(ifleet=1;ifleet<=nfleets;ifleet++)
   {
     if (catch_tot_CV(iyear,ifleet) <= 0.0)
```

```
        catch_tot_CV(iyear,ifleet) = CVfill;
    if (discard_tot_CV(iyear,ifleet) <= 0.0)
        discard_tot_CV(iyear,ifleet) = CVfill;
    catch_tot_sigma2(ifleet,iyear)=log(catch_tot_CV(iyear,ifleet)*catch_tot_CV(iyear,ifleet)+1.0);
    catch_tot_sigma(ifleet,iyear)=sqrt(catch_tot_sigma2(ifleet,iyear));
    discard_tot_sigma2(ifleet,iyear)=log(discard_tot_CV(iyear,ifleet)*discard_tot_CV(iyear,ifleet)+1.0);
    discard_tot_sigma(ifleet,iyear)=sqrt(discard_tot_sigma2(ifleet,iyear));
    input_eff_samp_size_catch(ifleet,iyear)=input_eff_samp_size_catch_ini(iyear,ifleet);
    input_eff_samp_size_discard(ifleet,iyear)=input_eff_samp_size_discard_ini(iyear,ifleet);
  }
 }
END_CALCS
 init_vector lambda_Fmult_year1(1,nfleets)
!! ICHECK(lambda_Fmult_year1);
 init_vector Fmult_year1_CV(1,nfleets)
!! ICHECK(Fmult_year1_CV);
 init_vector lambda_Fmult_devs(1,nfleets)
!! ICHECK(lambda_Fmult_devs);
 init_vector Fmult_devs_CV(1,nfleets)
!! ICHECK(Fmult_devs_CV);
 init_number lambda_N_year1_devs
!! ICHECK(lambda_N_year1_devs);
 init_number N_year1_CV
!! ICHECK(N_year1_CV);
 init_number lambda_recruit_devs
!! ICHECK(lambda_recruit_devs);
 init_vector lambda_q_year1_ini(1,navailindices)
!! ICHECK(lambda_q_year1_ini);
 init_vector q_year1_CV_ini(1,navailindices)
!! ICHECK(q_year1_CV_ini);
 init_vector lambda_q_devs_ini(1,navailindices)
!! ICHECK(lambda_q_devs_ini);
 init_vector q_devs_CV_ini(1,navailindices)
!! ICHECK(q_devs_CV_ini);
 init_number lambda_steepness
!! ICHECK(lambda_steepness);
 init_number steepness_CV
!! ICHECK(steepness_CV);
 init_number lambda_SR_scaler
!! ICHECK(lambda_SR_scaler);
 init_number SR_scaler_CV
!! ICHECK(SR_scaler_CV);
LOCAL_CALCS
 for (i=1;i<=nfleets;i++)
 {
    if (Fmult_year1_CV(i) <= 0.0)
        Fmult_year1_CV(i) = CVfill;
    if (Fmult_devs_CV(i) <= 0.0)
        Fmult_devs_CV(i) = CVfill;
 }
 if (N_year1_CV <= 0.0)
     N_year1_CV = CVfill;
 for (i=1;i<=navailindices;i++)
 {
    if (q_year1_CV_ini(i) <= 0.0)
        q_year1_CV_ini(i) = CVfill;
    if (q_devs_CV_ini(i) <= 0.0)
        q_devs_CV_ini(i) = CVfill;
 }
 if (steepness_CV <= 0.0)
     steepness_CV = CVfill;
 if (SR_scaler_CV <= 0.0)
     SR_scaler_CV = CVfill;
END_CALCS
 vector Fmult_year1_sigma2(1,nfleets)
 vector Fmult_year1_sigma(1,nfleets)
 vector Fmult_year1_like_const(1,nfleets)
 vector Fmult_devs_sigma2(1,nfleets)
 vector Fmult_devs_sigma(1,nfleets)
 vector Fmult_devs_like_const(1,nfleets)
 number N_year1_sigma2
```

```
  number N_year1_sigma
  number N_year1_like_const
  vector lambda_ind(1,nindices)
  vector lambda_q_year1(1,nindices)
  vector q_year1_CV(1,nindices)
  vector q_year1_sigma2(1,nindices)
  vector q_year1_sigma(1,nindices)
  vector q_year1_like_const(1,nindices)
  vector lambda_q_devs(1,nindices)
  vector q_devs_CV(1,nindices)
  vector q_devs_sigma2(1,nindices)
  vector q_devs_sigma(1,nindices)
  vector q_devs_like_const(1,nindices)
  number steepness_sigma2
  number steepness_sigma
  number steepness_like_const
  number SR_scaler_sigma2
  number SR_scaler_sigma
  number SR_scaler_like_const

// starting guesses
  init_int NAA_year1_flag // 1 for devs from exponential decline, 2 for devs from initial guesses
 !! ICHECK(NAA_year1_flag);
  init_vector NAA_year1_ini(1,nages)
 !! ICHECK(NAA_year1_ini);
  init_vector Fmult_year1_ini(1,nfleets)
 !! ICHECK(Fmult_year1_ini);
  init_vector q_year1_iniavail(1,navailindices)
 !! ICHECK(q_year1_iniavail);
  vector q_year1_ini(1,nindices)
  init_number is_SR_scaler_R // 1 for R0, 0 for SSB0
 !! ICHECK(is_SR_scaler_R);
  init_number SR_scaler_ini
 !! ICHECK(SR_scaler_ini);
  init_number SR_steepness_ini
 !! ICHECK(SR_steepness_ini);
  init_number Fmult_max_value
 !! ICHECK(Fmult_max_value);

  init_number ignore_guesses
 !! ICHECK(ignore_guesses);
  number delta

// Projection Info**********************
  init_int do_projections
 !! ICHECK(do_projections);
  init_ivector directed_fleet(1,nfleets)
 !! ICHECK(directed_fleet);
  init_number nfinalyear
 !! ICHECK(nfinalyear);
  int nprojyears
 !! nprojyears=nfinalyear-year1-nyears+1;
  init_matrix project_ini(1,nprojyears,1,5)
 !! ICHECK(project_ini);
  vector proj_recruit(1,nprojyears)
  ivector proj_what(1,nprojyears)
  vector proj_target(1,nprojyears)
  vector proj_F_nondir_mult(1,nprojyears)
 LOCAL_CALCS
  for (iyear=1;iyear<=nprojyears;iyear++)
  {
    proj_recruit(iyear)=project_ini(iyear,2);
    proj_what(iyear)=project_ini(iyear,3);
    proj_target(iyear)=project_ini(iyear,4);
    proj_F_nondir_mult(iyear)=project_ini(iyear,5);
  }
 END_CALCS

// MCMC Info*******************************
  init_int doMCMC
 !! ICHECK(doMCMC);
```

```
 LOCAL_CALCS
  if (doMCMC == 1)
  {
     basicMCMC << " ";
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "F" << iyear+year1-1 << " ";
     }
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "SSB" << iyear+year1-1 << " ";
     }
     // Liz added Fmult_in lastyear and totBjan1
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "Fmult_" << iyear+year1-1 << " ";
          }
     for (iyear=1;iyear<=nyears;iyear++)
     {
        basicMCMC << "totBjan1_" << iyear+year1-1 << " ";
     }

     // end stuff Liz added
     basicMCMC << "MSY  SSBmsy  Fmsy  SSBmsy_ratio  Fmsy_ratio  ";
     basicMCMC << endl; // end of header line
  }
 END_CALCS
  init_int MCMCnyear_opt // 0=output nyear NAA, 1=output nyear+1 NAA
 !! ICHECK(MCMCnyear_opt)
  init_int MCMCnboot  // final number of values for agepro bootstrap file
 !! ICHECK(MCMCnboot);
  init_int MCMCnthin  // thinning rate (1=use every value, 2=use every other value, 3=use every third value,
etc)
 !! ICHECK(MCMCnthin);
  init_int MCMCseed   // large positive integer to seed random number generator
 !! ICHECK(MCMCseed);
// To run MCMC do the following two steps:
// 1st type "asap2 -mcmc N1 -mcsave MCMCnthin -mcseed MCMCseed"
//   where N1 = MCMCnboot * MCMCnthin
// 2nd type "asap2 -mceval"
  init_int fillR_opt // option for filling recruitment in terminal year+1 - used in agepro.bsn file only (1=SR,
2=geomean)
 !! ICHECK(fillR_opt);
  init_int Ravg_start
 !! ICHECK(Ravg_start);
  init_int Ravg_end
 !! ICHECK(Ravg_end);

  init_int make_Rfile // option to create rdat file of input and output values, set to 1 to create the file, 0
to skip this feature
 !! ICHECK(make_Rfile);

  init_int test_value
 !! ICHECK(test_value)
 !! cout << "test value = " << test_value << endl; //CHECK
 !! cout << "input complete" << endl;

  number ntemp0
  number SR_spawners_per_recruit
  vector s_per_r_vec(1,nyears)
 LOCAL_CALCS
  for (iyear=1;iyear<=nyears;iyear++)
  {
    ntemp0=1.0;
    s_per_r_vec(iyear)=0.0;
    for (iage=1;iage<nages;iage++)
    {
      s_per_r_vec(iyear)+=ntemp0*fecundity(iyear,iage)*mfexp(-1.0*fracyearSSB*M(iyear,iage));
      ntemp0*=mfexp(-M(iyear,iage));
    }
    ntemp0/=(1.0-mfexp(-M(iyear,nages)));
```

```
    s_per_r_vec(iyear)+=ntemp0*fecundity(iyear,nages)*mfexp(-1.0*fracyearSSB*M(iyear,nages));
  }
  SR_spawners_per_recruit=s_per_r_vec(nyears); // use last year calculations for SR curve
 END_CALCS

//***********************************************************************
PARAMETER_SECTION
  init_bounded_number_vector sel_params(1,nselparm,sel_lo,sel_hi,sel_phase)
  init_bounded_vector log_Fmult_year1(1,nfleets,-15.,2.,phase_Fmult_year1)
  init_bounded_matrix log_Fmult_devs(1,nfleets,2,nyears,-15.,15.,phase_Fmult_devs)
  init_bounded_dev_vector log_recruit_devs(1,nyears,-15.,15.,phase_recruit_devs)
  init_bounded_vector log_N_year1_devs(2,nages,-15.,15.,phase_N_year1_devs)
  init_bounded_vector log_q_year1(1,nindices,-30,5,phase_q_year1)
  init_bounded_matrix log_q_devs(1,nindices,2,index_nobs,-15.,15.,phase_q_devs)
  init_bounded_number_vector index_sel_params(1,nindexselparms,indexsel_lo,indexsel_hi,indexsel_phase)
  init_bounded_number log_SR_scaler(-1.0,200,phase_SR_scaler)
  init_bounded_number SR_steepness(0.20001,1.0,phase_steepness)
  vector sel_likely(1,nselparm)
  vector sel_stdresid(1,nselparm)
  number sel_rmse
  number sel_rmse_nobs
  number sum_sel_lambda
  number sum_sel_lambda_likely
  matrix indexsel(1,nindices,1,nages)
  vector indexsel_likely(1,nindexselparms)
  vector indexsel_stdresid(1,nindexselparms)
  number indexsel_rmse
  number indexsel_rmse_nobs
  number sum_indexsel_lambda
  number sum_indexsel_lambda_likely
  matrix log_Fmult(1,nfleets,1,nyears)
  matrix Fmult(1,nfleets,1,nyears)
  matrix NAA(1,nyears,1,nages)
  matrix temp_NAA(1,nyears,1,nages)
  matrix temp_BAA(1,nyears,1,nages)
  matrix temp_PAA(1,nyears,1,nages)
  matrix FAA_tot(1,nyears,1,nages)
  matrix Z(1,nyears,1,nages)
  matrix S(1,nyears,1,nages)
  matrix Catch_stdresid(1,nfleets,1,nyears)
  matrix Discard_stdresid(1,nfleets,1,nyears)
  matrix Catch_tot_fleet_pred(1,nfleets,1,nyears)
  matrix Discard_tot_fleet_pred(1,nfleets,1,nyears)
  3darray CAA_pred(1,nfleets,1,nyears,1,nages)
  3darray Discard_pred(1,nfleets,1,nyears,1,nages)
  3darray CAA_prop_pred(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  3darray Discard_prop_pred(1,nfleets,1,nyears,sel_start_age,sel_end_age)
  3darray FAA_by_fleet_dir(1,nfleets,1,nyears,1,nages)
  3darray FAA_by_fleet_Discard(1,nfleets,1,nyears,1,nages)
  matrix sel_by_block(1,nselblocks,1,nages)
  3darray sel_by_fleet(1,nfleets,1,nyears,1,nages)
  vector temp_sel_over_time(1,nyears)
  number temp_sel_fix
  number temp_Fmult_max
  number Fmult_max_pen
  matrix q_by_index(1,nindices,1,index_nobs)
  matrix temp_sel(1,nyears,1,nages)
  vector temp_sel2(1,nages)
  matrix index_pred(1,nindices,1,index_nobs)
  3darray output_index_prop_obs(1,nindices,1,nyears,1,nages)
  3darray output_index_prop_pred(1,nindices,1,nyears,1,nages)
  matrix index_Neff_init(1,nindices,1,nyears)
  matrix index_Neff_est(1,nindices,1,nyears)
  3darray index_prop_pred(1,nindices,1,index_nobs,1,nages)
  number new_Neff_catch
  number new_Neff_discard
  number ntemp
  number SR_S0
  number SR_R0
  number SR_alpha
  number SR_beta
```

```
vector S0_vec(1,nyears)
vector R0_vec(1,nyears)
vector steepness_vec(1,nyears)
vector SR_pred_recruits(1,nyears+1)
number likely_SR_sigma
vector SR_stdresid(1,nyears)
number SR_rmse
number SR_rmse_nobs
vector RSS_sel_devs(1,nfleets)
vector RSS_catch_tot_fleet(1,nfleets)
vector RSS_Discard_tot_fleet(1,nfleets)
vector catch_tot_likely(1,nfleets)
vector discard_tot_likely(1,nfleets)
number likely_catch
number likely_Discard
vector RSS_ind(1,nindices)
vector RSS_ind_sigma(1,nindices)
vector likely_ind(1,nindices)
matrix index_stdresid(1,nindices,1,index_nobs)
number likely_index_age_comp
number fpenalty
number fpenalty_lambda
vector Fmult_year1_stdresid(1,nfleets)
number Fmult_year1_rmse
number Fmult_year1_rmse_nobs
vector Fmult_year1_likely(1,nfleets)
vector Fmult_devs_likely(1,nfleets)
matrix Fmult_devs_stdresid(1,nfleets,1,nyears)
vector Fmult_devs_fleet_rmse(1,nfleets)
vector Fmult_devs_fleet_rmse_nobs(1,nfleets)
number Fmult_devs_rmse
number Fmult_devs_rmse_nobs
number N_year1_likely
vector N_year1_stdresid(2,nages)
number N_year1_rmse
number N_year1_rmse_nobs
vector nyear1temp(1,nages)
vector q_year1_likely(1,nindices)
vector q_year1_stdresid(1,nindices)
number q_year1_rmse
number q_year1_rmse_nobs
vector q_devs_likely(1,nindices)
matrix q_devs_stdresid(1,nindices,1,index_nobs)
number q_devs_rmse
number q_devs_rmse_nobs
number steepness_likely
number steepness_stdresid
number steepness_rmse
number steepness_rmse_nobs
number SR_scaler_likely
number SR_scaler_stdresid
number SR_scaler_rmse
number SR_scaler_rmse_nobs
matrix effective_sample_size(1,nfleets,1,nyears)
matrix effective_Discard_sample_size(1,nfleets,1,nyears)
vector Neff_stage2_mult_catch(1,nfleets)
vector Neff_stage2_mult_discard(1,nfleets)
vector Neff_stage2_mult_index(1,nindices)
vector mean_age_obs(1,nyears)
vector mean_age_pred(1,nyears)
vector mean_age_pred2(1,nyears)
vector mean_age_resid(1,nyears)
vector mean_age_sigma(1,nyears)
number mean_age_x
number mean_age_n
number mean_age_delta
number mean_age_mean
number mean_age_m2
vector temp_Fmult(1,nfleets)
number tempU
number tempN
```

```
number tempB
number tempUd
number tempNd
number tempBd
number trefU
number trefN
number trefB
number trefUd
number trefNd
number trefBd
number Fref_report
number Fref
vector freftemp(1,nages)
vector nreftemp(1,nages)
vector Freport_U(1,nyears)
vector Freport_N(1,nyears)
vector Freport_B(1,nyears)
sdreport_vector Freport(1,nyears)
sdreport_vector TotJan1B(1,nyears)
sdreport_vector SSB(1,nyears)
sdreport_vector ExploitableB(1,nyears)
sdreport_vector recruits(1,nyears)
matrix SSBfracZ(1,nyears,1,nages)
vector final_year_total_sel(1,nages)
vector dir_F(1,nages)
vector Discard_F(1,nages)
vector proj_nondir_F(1,nages)
vector proj_dir_sel(1,nages)
vector proj_Discard_sel(1,nages)
matrix proj_NAA(1,nprojyears,1,nages)
vector proj_Fmult(1,nprojyears)
vector Ftemp(1,nages)
vector Ztemp(1,nages)
vector proj_TotJan1B(1,nprojyears)
vector proj_SSB(1,nprojyears)
number SSBtemp
number denom
matrix proj_F_dir(1,nprojyears,1,nages)
matrix proj_F_Discard(1,nprojyears,1,nages)
matrix proj_F_nondir(1,nprojyears,1,nages)
matrix proj_Z(1,nprojyears,1,nages)
matrix proj_SSBfracZ(1,nprojyears,1,nages)
matrix proj_catch(1,nprojyears,1,nages)
matrix proj_Discard(1,nprojyears,1,nages)
matrix proj_yield(1,nprojyears,1,nages)
vector proj_total_yield(1,nprojyears)
vector proj_total_Discard(1,nprojyears)
vector output_prop_obs(1,nages)
vector output_prop_pred(1,nages)
vector output_Discard_prop_obs(1,nages)
vector output_Discard_prop_pred(1,nages)
vector NAAbsn(1,nages)
number temp_sum
number temp_sum2
number A
number B
number C
number f
number z
number SPR_Fmult
number YPR_Fmult
number SPR
number SPRatio
number YPR
number S_F
number R_F
number slope_origin
number slope
number F30SPR
number F40SPR
number Fmsy
```

```
  number F01
  number Fmax
  number F30SPR_report
  number F40SPR_report
  number F01_report
  number Fmax_report
  number Fcurrent
  number F30SPR_slope
  number F40SPR_slope
  number Fmsy_slope
  number F01_slope
  number Fmax_slope
  number Fcurrent_slope
  number SSmsy
  number tempR
  vector tempFmult(1,nyears) // Liz added
  sdreport_number MSY
  sdreport_number SSBmsy_report
  sdreport_number Fmsy_report
  sdreport_number SSBmsy_ratio
  sdreport_number Fmsy_ratio
  objective_function_value obj_fun

PRELIMINARY_CALCS_SECTION
// subset only used index information
  ind=0;
  for (indavail=1;indavail<=navailindices;indavail++)
  {
     if (use_index(indavail)==1)
     {
       ind+=1;
       lambda_ind(ind)=lambda_ind_ini(indavail);
       lambda_q_year1(ind)=lambda_q_year1_ini(indavail);
       q_year1_CV(ind)=q_year1_CV_ini(indavail);
       lambda_q_devs(ind)=lambda_q_devs_ini(indavail);
       q_devs_CV(ind)=q_devs_CV_ini(indavail);
       q_year1_ini(ind)=q_year1_iniavail(indavail);
     }
  }

  if (ignore_guesses==0)
  {
     NAA(1)=NAA_year1_ini;
     log_Fmult_year1=log(Fmult_year1_ini);
     log_q_year1=log(q_year1_ini);
     log_SR_scaler=log(SR_scaler_ini);
     SR_steepness=SR_steepness_ini;
     for (k=1;k<=nselparm;k++)
     {
        sel_params(k)=sel_initial(k);
     }
     for (k=1;k<=nindexselparms;k++)
     {
        index_sel_params(k)=indexsel_initial(k);
     }
  }

  delta=0.00001;

// convert remaining CVs to variances
  Fmult_year1_sigma2=log(elem_prod(Fmult_year1_CV,Fmult_year1_CV)+1.0);
  Fmult_year1_sigma=sqrt(Fmult_year1_sigma2);
  Fmult_devs_sigma2=log(elem_prod(Fmult_devs_CV,Fmult_devs_CV)+1.0);
  Fmult_devs_sigma=sqrt(Fmult_devs_sigma2);
  N_year1_sigma2=log(N_year1_CV*N_year1_CV+1.0);
  N_year1_sigma=sqrt(N_year1_sigma2);
  q_year1_sigma2=log(elem_prod(q_year1_CV,q_year1_CV)+1.0);
  q_year1_sigma=sqrt(q_year1_sigma2);
  q_devs_sigma2=log(elem_prod(q_devs_CV,q_devs_CV)+1.0);
  q_devs_sigma=sqrt(q_devs_sigma2);
  steepness_sigma2=log(steepness_CV*steepness_CV+1.0);
```

```
  steepness_sigma=sqrt(steepness_sigma2);
  SR_scaler_sigma2=log(SR_scaler_CV*SR_scaler_CV+1.0);
  SR_scaler_sigma=sqrt(SR_scaler_sigma2);

// compute multinomial constants for catch and discards at age, if requested
  catch_prop_like_const=0.0;
  discard_prop_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        for (iyear=1;iyear<=nyears;iyear++)
        {
          if (input_eff_samp_size_catch(ifleet,iyear) > 0)
          {
             nfact_in=input_eff_samp_size_catch(ifleet,iyear);
             get_log_factorial();
             catch_prop_like_const+=-1.0*nfact_out;  // negative for the total
             for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             {
                nfact_in=double(input_eff_samp_size_catch(ifleet,iyear))*CAA_prop_obs(ifleet,iyear,iage)+0.5;
// +0.5 to round instead of truncate nfact_in
                get_log_factorial();
                catch_prop_like_const+=nfact_out;   // positive for the parts
             }
          }
          if (input_eff_samp_size_discard(ifleet,iyear) > 0)
          {
             nfact_in=input_eff_samp_size_discard(ifleet,iyear);
             get_log_factorial();
             discard_prop_like_const+=-1.0*nfact_out; // negative for the total
             for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
             {

nfact_in=double(input_eff_samp_size_discard(ifleet,iyear))*Discard_prop_obs(ifleet,iyear,iage)+0.5;
                get_log_factorial();
                discard_prop_like_const+=nfact_out;   // positive for the parts
             }
          }
        }
     }
  }

// compute multinomial constants for index, if requested
  index_prop_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (ind=1;ind<=nindices;ind++)
     {
        if (index_estimate_proportions(ind)==1)
        {
           for (i=1;i<=index_nobs(ind);i++)
           {
              if (input_eff_samp_size_index(ind,i) > 0)
              {
                 nfact_in=input_eff_samp_size_index(ind,i);
                 get_log_factorial();
                 index_prop_like_const+=-1.0*nfact_out;    // negative for total
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                    nfact_in=double(input_eff_samp_size_index(ind,i))*index_prop_obs(ind,i,iage)+0.5;
                    get_log_factorial();
                    index_prop_like_const+=nfact_out;      // positive for the parts
                 }
              }
           }
        }
     }
  }

// selectivity likelihood constants
```

```
  sel_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (k=1;k<=nselparm;k++)
     {
        if (sel_phase(k) >= 1)
        {
           sel_like_const(k)=0.5*log(2.0*pi)+log(sel_initial(k));
        }
     }
  }

// index selectivity likelihood constants
  indexsel_like_const=0.0;
  if (use_likelihood_constants == 1)
  {
     for (k=1;k<=nindexselparms;k++)
     {
        if (indexsel_phase(k) >= 1)
        {
           indexsel_like_const(k)=0.5*log(2.0*pi)+log(indexsel_initial(k));
        }
     }
  }

// rest of likelihood constants
  if (use_likelihood_constants == 1)
  {
     Fmult_year1_like_const=0.5*log(2.0*pi)+log(Fmult_year1_ini);
     Fmult_devs_like_const=0.5*log(2.0*pi);
     N_year1_like_const=0.5*log(2.0*pi);
     q_year1_like_const=0.5*log(2.0*pi)+log(q_year1_ini);
     q_devs_like_const=0.5*log(2.0*pi);
     steepness_like_const=0.5*log(2.0*pi)+log(SR_steepness_ini);
     SR_scaler_like_const=0.5*log(2.0*pi)+log(SR_scaler_ini);
  }
  else
  {
     Fmult_year1_like_const=0.0;
     Fmult_devs_like_const=0.0;
     N_year1_like_const=0.0;
     q_year1_like_const=0.0;
     q_devs_like_const=0.0;
     steepness_like_const=0.0;
     SR_scaler_like_const=0.0;
  }

// set dev vectors to zero
  log_Fmult_devs.initialize();
  log_recruit_devs.initialize();
  log_N_year1_devs.initialize();
  log_q_devs.initialize();

// initialize MSY related sdreport variables
  MSY.initialize();
  SSBmsy_report.initialize();
  Fmsy_report.initialize();
  SSBmsy_ratio.initialize();
  Fmsy_ratio.initialize();

  debug=0; // debug checks commented out to speed calculations

//***********************************************************************************************
PROCEDURE_SECTION
                                      //  if (debug==1) cout << "starting procedure section" << endl;
  get_SR();                          //  if (debug==1) cout << "got SR" << endl;
  get_selectivity();                  //  if (debug==1) cout << "got selectivity" << endl;
  get_mortality_rates();              //  if (debug==1) cout << "got mortality rates" << endl;
  get_numbers_at_age();               //  if (debug==1) cout << "got numbers at age" << endl;
  get_Freport();                      //  if (debug==1) cout << "got Freport" << endl;
  get_predicted_catch();              //  if (debug==1) cout << "got predicted catch" << endl;
```

```
  get_q();                            //  if (debug==1) cout << "got q" << endl;
  get_predicted_indices();            //  if (debug==1) cout << "got predicted indices" << endl;
  compute_the_objective_function();   //  if (debug==1) cout << "computed objective function" << endl;
  if (last_phase() || mceval_phase())
  {
     get_proj_sel();                  //  if (debug==1) cout <<"got proj sel" << endl;
     get_Fref();                      //  if (debug==1) cout <<"got Fref" << endl;
     get_multinomial_multiplier();    //  if (debug==1) cout <<"got multinomial multiplier" << endl;
  }
  if (mceval_phase())
  {
     write_MCMC();
  }                                   //  if (debug==1) cout << "  . . . end of procedure section" << endl;
//************************************************************************************************

FUNCTION get_SR
// converts stock recruitment scaler and steepness to alpha and beta for Beverton-Holt SR
// note use of is_SR_scaler_R variable to allow user to enter guess for either R0 or SSB0
  if(is_SR_scaler_R==1)
  {
    SR_R0=mfexp(log_SR_scaler);
    SR_S0=SR_spawners_per_recruit*SR_R0;
  }
  else
  {
    SR_S0=mfexp(log_SR_scaler);
    SR_R0=SR_S0/SR_spawners_per_recruit;
  }
  SR_alpha=4.0*SR_steepness*SR_R0/(5.0*SR_steepness-1.0);
  SR_beta=SR_S0*(1.0-SR_steepness)/(5.0*SR_steepness-1.0);
  // now compute year specific vectors of R0, S0, and steepness
  for (iyear=1;iyear<=nyears;iyear++)
  {
    steepness_vec(iyear)=0.2*SR_alpha*s_per_r_vec(iyear)/(0.8*SR_beta+0.2*SR_alpha*s_per_r_vec(iyear));
    R0_vec(iyear)=(SR_alpha*s_per_r_vec(iyear)-SR_beta)/s_per_r_vec(iyear);
    S0_vec(iyear)=s_per_r_vec(iyear)*R0_vec(iyear);
  }

FUNCTION get_selectivity
  dvariable sel_alpha1;
  dvariable sel_beta1;
  dvariable sel_alpha2;
  dvariable sel_beta2;
  dvariable sel_temp;
  dvariable sel1;
  dvariable sel2;
// start by computing selectivity for each block
  k=0;
  for (i=1;i<=nselblocks;i++) {
     if (sel_option(i)==1) {
        for (iage=1;iage<=nages;iage++){
           k+=1;
           sel_by_block(i,iage)=sel_params(k);
        }
     }
     if (sel_option(i)==2) {
        sel_alpha1=sel_params(k+1);
        sel_beta1=sel_params(k+2);
        k+=2;
        for (iage=1;iage<=nages;iage++) {
           sel_by_block(i,iage)=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
        }
        sel_temp=max(sel_by_block(i));
        sel_by_block(i)/=sel_temp;
     }
     if (sel_option(i)==3) {
        sel_alpha1=sel_params(k+1);
        sel_beta1=sel_params(k+2);
        sel_alpha2=sel_params(k+3);
        sel_beta2=sel_params(k+4);
        k+=4;
```

```
        for (iage=1;iage<=nages;iage++) {
           sel1=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
           sel2=1.0-1.0/(1.0+mfexp((sel_alpha2-double(iage))/sel_beta2));
           sel_by_block(i,iage)=sel1*sel2;
        }
        sel_temp=max(sel_by_block(i));
        sel_by_block(i)/=sel_temp;
     }
  }
// now fill in selectivity for each fleet and year according to block
  for (ifleet=1;ifleet<=nfleets;ifleet++) {
     for (iyear=1;iyear<=nyears;iyear++) {
        sel_by_fleet(ifleet,iyear)=sel_by_block(sel_blocks(ifleet,iyear));
     }
  }

FUNCTION get_mortality_rates
// compute directed and discard F by fleet then sum to form total F at age matrix
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     log_Fmult(ifleet,1)=log_Fmult_year1(ifleet);
     if (active(log_Fmult_devs))
     {
         for (iyear=2;iyear<=nyears;iyear++)
             log_Fmult(ifleet,iyear)=log_Fmult(ifleet,iyear-1)+log_Fmult_devs(ifleet,iyear);
     }
     else
     {
         for (iyear=2;iyear<=nyears;iyear++)
             log_Fmult(ifleet,iyear)=log_Fmult_year1(ifleet);
     }
  }
  FAA_tot=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
       for (iage=1;iage<=nages;iage++)
       {

FAA_by_fleet_dir(ifleet,iyear,iage)=(mfexp(log_Fmult(ifleet,iyear))*sel_by_fleet(ifleet,iyear,iage))*(1.0-
proportion_release(ifleet,iyear,iage));

FAA_by_fleet_Discard(ifleet,iyear,iage)=(mfexp(log_Fmult(ifleet,iyear))*sel_by_fleet(ifleet,iyear,iage))*(propor
tion_release(ifleet,iyear,iage)*release_mort(ifleet));
       }
     }
     FAA_tot+=FAA_by_fleet_dir(ifleet)+FAA_by_fleet_Discard(ifleet);
  }
// add fishing and natural mortality to get total mortality
  for (iyear=1;iyear<=nyears;iyear++)
     Z(iyear)=FAA_tot(iyear)+M(iyear);
  S=mfexp(-1.0*Z);
  SSBfracZ=mfexp(-1.0*fracyearSSB*Z); // for use in SSB calcuations

FUNCTION get_numbers_at_age
// get N at age in year 1
  if (phase_N_year1_devs>0)
  {
     for (iage=2;iage<=nages;iage++)
     {
        NAA(1,iage)=NAA_year1_ini(iage)*mfexp(log_N_year1_devs(iage));
     }
  }
// compute initial SSB to derive R in first year
  SSB(1)=0.0;
  for (iage=2;iage<=nages;iage++)
  {
     SSB(1)+=NAA(1,iage)*SSBfracZ(1,iage)*fecundity(1,iage);  // note SSB in year 1 does not include age 1 to
estimate pred_R in year 1
  }
```

```
  SR_pred_recruits(1)=SR_alpha*SSB(1)/(SR_beta+SSB(1));
  NAA(1,1)=SR_pred_recruits(1)*mfexp(log_recruit_devs(1));
  SSB(1)+=NAA(1,1)*SSBfracZ(1,1)*fecundity(1,1);   // now SSB in year 1 is complete and can be used for pred_R
in year 2
// fill out rest of matrix
  for (iyear=2;iyear<=nyears;iyear++)
  {
     SR_pred_recruits(iyear)=SR_alpha*SSB(iyear-1)/(SR_beta+SSB(iyear-1));
     NAA(iyear,1)=SR_pred_recruits(iyear)*mfexp(log_recruit_devs(iyear));
     for (iage=2;iage<=nages;iage++)
         NAA(iyear,iage)=NAA(iyear-1,iage-1)*S(iyear-1,iage-1);
     NAA(iyear,nages)+=NAA(iyear-1,nages)*S(iyear-1,nages);
     SSB(iyear)=elem_prod(NAA(iyear),SSBfracZ(iyear))*fecundity(iyear);
  }
  SR_pred_recruits(nyears+1)=SR_alpha*SSB(nyears)/(SR_beta+SSB(nyears));
  for (iyear=1;iyear<=nyears;iyear++)
  {
     recruits(iyear)=NAA(iyear,1);
  }
// compute two other biomass time series
  for (iyear=1;iyear<=nyears;iyear++)
  {
     TotJan1B(iyear)=NAA(iyear)*WAAjan1b(iyear);
     ExploitableB(iyear)=elem_prod(NAA(iyear),FAA_tot(iyear))*WAAcatchall(iyear)/max(FAA_tot(iyear));
  }

FUNCTION get_Freport
// calculates an average F for a range of ages in each year under three weighting schemes
  for (iyear=1;iyear<=nyears;iyear++){
     tempU=0.0;
     tempN=0.0;
     tempB=0.0;
     tempUd=0.0;
     tempNd=0.0;
     tempBd=0.0;
     for (iage=Freport_agemin;iage<=Freport_agemax;iage++)
     {
       tempU+=FAA_tot(iyear,iage);
       tempN+=FAA_tot(iyear,iage)*NAA(iyear,iage);
       tempB+=FAA_tot(iyear,iage)*NAA(iyear,iage)*WAAjan1b(iyear,iage);
       tempUd+=1.0;
       tempNd+=NAA(iyear,iage);
       tempBd+=NAA(iyear,iage)*WAAjan1b(iyear,iage);
     }
     // April 2012 error trap addition
     if (tempUd <= 0.) Freport_U(iyear)=0.0;
     else Freport_U(iyear)=tempU/tempUd;
     if (tempNd <= 0.) Freport_N(iyear)=Freport_U(iyear);
     else Freport_N(iyear)=tempN/tempNd;
     if (tempBd <= 0.) Freport_B(iyear)=Freport_U(iyear);
     else Freport_B(iyear)=tempB/tempBd;
  }
  if (Freport_wtopt==1) Freport=Freport_U;
  if (Freport_wtopt==2) Freport=Freport_N;
  if (Freport_wtopt==3) Freport=Freport_B;

FUNCTION get_predicted_catch
// assumes continuous F using Baranov equation
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     CAA_pred(ifleet)=elem_prod(elem_div(FAA_by_fleet_dir(ifleet),Z),elem_prod(1.0-S,NAA));
     Discard_pred(ifleet)=elem_prod(elem_div(FAA_by_fleet_Discard(ifleet),Z),elem_prod(1.0-S,NAA));
  }
// now compute proportions at age and total weight of catch
  for (iyear=1;iyear<=nyears;iyear++)
  {
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
       CAA_prop_pred(ifleet,iyear)=0.0;
       Discard_prop_pred(ifleet,iyear)=0.0;
```

```
Catch_tot_fleet_pred(ifleet,iyear)=sum(CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet)));

Discard_tot_fleet_pred(ifleet,iyear)=sum(Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet)));
       if (Catch_tot_fleet_pred(ifleet,iyear)>0.0)

CAA_prop_pred(ifleet,iyear)=CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/Catch_tot_fleet_pr
ed(ifleet,iyear);
       if (Discard_tot_fleet_pred(ifleet,iyear)>0.0)

Discard_prop_pred(ifleet,iyear)=Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))/Discard_to
t_fleet_pred(ifleet,iyear);

Catch_tot_fleet_pred(ifleet,iyear)=CAA_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))*WAAcatchfle
et(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet));

Discard_tot_fleet_pred(ifleet,iyear)=Discard_pred(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet))*WAAdi
scardfleet(ifleet,iyear)(sel_start_age(ifleet),sel_end_age(ifleet));
       for (iage=1;iage<=nages;iage++)
       {
          if (CAA_prop_pred(ifleet,iyear,iage)<1.e-15)
             CAA_prop_pred(ifleet,iyear,iage)=1.0e-15;
          if (Discard_prop_pred(ifleet,iyear,iage)<1.e-15)
             Discard_prop_pred(ifleet,iyear,iage)=1.0e-15;
       }
    }
  }

FUNCTION get_q
// catchability for each index, can be a random walk if q_devs turned on
  for (ind=1;ind<=nindices;ind++)
  {
     q_by_index(ind,1)=mfexp(log_q_year1(ind));
     if (active(log_q_devs))
     {
         for (i=2;i<=index_nobs(ind);i++)
             q_by_index(ind,i)=q_by_index(ind,i-1)*mfexp(log_q_devs(ind,i));
     }
     else
     {
         for (i=2;i<=index_nobs(ind);i++)
             q_by_index(ind,i)=q_by_index(ind,1);
     }
  }

FUNCTION get_predicted_indices
  dvariable sel_alpha1;
  dvariable sel_beta1;
  dvariable sel_alpha2;
  dvariable sel_beta2;
  dvariable sel_temp;
  dvariable sel1;
  dvariable sel2;
// get selectivity for each index
  k=0;
  for (ind=1;ind<=nindices;ind++)
  {
     if (index_sel_choice(ind)>0)
     {
         temp_sel=sel_by_fleet(index_sel_choice(ind));
         if (index_sel_option(ind)==1) k+=nages;
         if (index_sel_option(ind)==2) k+=2;
         if (index_sel_option(ind)==3) k+=4;

     }
     else
     {
         if (index_sel_option(ind)==1)
         {
             for (iage=1;iage<=nages;iage++)
             {
```

```
                k+=1;
                temp_sel2(iage)=index_sel_params(k);
             }
         }
         if (index_sel_option(ind)==2)
         {
             sel_alpha1=index_sel_params(k+1);
             sel_beta1=index_sel_params(k+2);
             k+=2;
             for (iage=1;iage<=nages;iage++)
             {
                temp_sel2(iage)=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
             }
             sel_temp=max(temp_sel2);
             temp_sel2/=sel_temp;
         }
         if (index_sel_option(ind)==3)
         {
             sel_alpha1=index_sel_params(k+1);
             sel_beta1=index_sel_params(k+2);
             sel_alpha2=index_sel_params(k+3);
             sel_beta2=index_sel_params(k+4);
             k+=4;
             for (iage=1;iage<=nages;iage++)
             {
                sel1=1.0/(1.0+mfexp((sel_alpha1-double(iage))/sel_beta1));
                sel2=1.0-1.0/(1.0+mfexp((sel_alpha2-double(iage))/sel_beta2));
                temp_sel2(iage)=sel1*sel2;
             }
             sel_temp=max(temp_sel2);
             temp_sel2/=sel_temp;
         }
         for (iyear=1;iyear<=nyears;iyear++)
         {
             temp_sel(iyear)=temp_sel2;
         }
     }
     indexsel(ind)=temp_sel(1);
// determine when the index should be applied
     if (index_month(ind)==-1)
     {
         temp_NAA=elem_prod(NAA,elem_div(1.0-S,Z));
     }
     else
     {
         temp_NAA=elem_prod(NAA,mfexp(-1.0*((index_month(ind)-1.0)/12.0)*Z));
     }
     temp_BAA=elem_prod(temp_NAA,index_WAA(ind));
// compute the predicted index for each year where observed value > 0
     if (index_units_aggregate(ind)==1)
     {
         temp_PAA=temp_BAA;
     }
     else
     {
         temp_PAA=temp_NAA;
     }
     for (i=1;i<=index_nobs(ind);i++)
     {
         j=index_time(ind,i);
         index_pred(ind,i)=q_by_index(ind,i)*sum(elem_prod(
             temp_PAA(j)(index_start_age(ind),index_end_age(ind)) ,
             temp_sel(j)(index_start_age(ind),index_end_age(ind))));
     }
// compute index proportions at age if necessary
     if (index_units_proportions(ind)==1)
     {
         temp_PAA=temp_BAA;
     }
     else
     {
```

```
         temp_PAA=temp_NAA;
     }
     index_prop_pred(ind)=0.0;
     if (index_estimate_proportions(ind)==1)
     {
         for (i=1;i<=index_nobs(ind);i++)
         {
             j=index_time(ind,i);
             if (index_pred(ind,i)>0.0)
             {
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                     index_prop_pred(ind,i,iage)=q_by_index(ind,i)*temp_PAA(j,iage)*temp_sel(j,iage);
                 }
                 if (sum(index_prop_pred(ind,i)) > 0)
                     index_prop_pred(ind,i)/=sum(index_prop_pred(ind,i));
                 for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                 {
                     if (index_prop_pred(ind,i,iage)<1.e-15)
                        index_prop_pred(ind,i,iage)=1.e-15;
                 }
             }
         }
     }
  }

FUNCTION get_proj_sel
// creates overall directed and discard selectivity patterns and sets bycatch F at age
  dir_F=0.0;
  Discard_F=0.0;
  proj_nondir_F=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if (directed_fleet(ifleet)==1)
     {
        dir_F+=FAA_by_fleet_dir(ifleet,nyears);
        Discard_F+=FAA_by_fleet_Discard(ifleet,nyears);
     }
     else
     {
        proj_nondir_F+=FAA_by_fleet_dir(ifleet,nyears);
     }
  }
  proj_dir_sel=dir_F/max(dir_F);
  proj_Discard_sel=Discard_F/max(dir_F);

FUNCTION get_Fref
// calculates a number of common F reference points using bisection algorithm
  A=0.0;
  B=5.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     SPR_Fmult=C;
     get_SPR();
     if (SPR/SR_spawners_per_recruit<0.30)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F30SPR=C;
  Fref=F30SPR;
  get_Freport_ref();
  F30SPR_report=Fref_report;
  F30SPR_slope=1.0/SPR;
  A=0.0;
  B=5.0;
```

```
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     SPR_Fmult=C;
     get_SPR();
     if (SPR/SR_spawners_per_recruit<0.40)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F40SPR=C;
  Fref=F40SPR;
  get_Freport_ref();
  F40SPR_report=Fref_report;
  F40SPR_slope=1.0/SPR;
  A=0.0;
  B=3.0;
  for (iloop=1;iloop<=20;iloop++)
  {
    C=(A+B)/2.0;
    SPR_Fmult=C+delta;
    get_SPR();
    S_F=SR_alpha*SPR-SR_beta;
    R_F=S_F/SPR;
    YPR_Fmult=C+delta;
    get_YPR();
    slope=R_F*YPR;
    SPR_Fmult=C;
    get_SPR();
    S_F=SR_alpha*SPR-SR_beta;
    R_F=S_F/SPR;
    YPR_Fmult=C;
    get_YPR();
    slope-=R_F*YPR;
//    slope/=delta; only care pos or neg
    if(slope>0.0)
    {
       A=C;
    }
    else
    {
       B=C;
    }
  }
  Fmsy=C;
  Fref=Fmsy;
  get_Freport_ref();
  Fmsy_report=Fref_report;
  SSmsy=S_F;
  SSBmsy_report=SSmsy;
  if (SSmsy>0.0)
    SSBmsy_ratio=SSB(nyears)/SSmsy;
  MSY=YPR*R_F;
  SPR_Fmult=Fmsy;
  get_SPR();
  Fmsy_slope=1.0/SPR;
  YPR_Fmult=delta;
  get_YPR();
  slope_origin=YPR/delta;
  A=0.0;
  B=5.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     YPR_Fmult=C+delta;
     get_YPR();
     slope=YPR;
```

```
     YPR_Fmult=C;
     get_YPR();
     slope-=YPR;
     slope/=delta;
     if (slope<0.10*slope_origin)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  F01=C;
  Fref=F01;
  get_Freport_ref();
  F01_report=Fref_report;
  SPR_Fmult=F01;
  get_SPR();
  F01_slope=1.0/SPR;
  A=0.0;
  B=10.0;
  for (iloop=1;iloop<=20;iloop++)
  {
     C=(A+B)/2.0;
     YPR_Fmult=C+delta;
     get_YPR();
     slope=YPR;
     YPR_Fmult=C;
     get_YPR();
     slope-=YPR;
     slope/=delta;
     if (slope<0.0)
     {
        B=C;
     }
     else
     {
        A=C;
     }
  }
  Fmax=C;
  Fref=Fmax;
  get_Freport_ref();
  Fmax_report=Fref_report;
  SPR_Fmult=Fmax;
  get_SPR();
  Fmax_slope=1.0/SPR;
  Fcurrent=max(FAA_tot(nyears)-proj_nondir_F-Discard_F);
  SPR_Fmult=Fcurrent;
  get_SPR();
  Fcurrent_slope=1.0/SPR;
  if (Fmsy>0.0)
    Fmsy_ratio=Fcurrent/Fmsy;

FUNCTION get_Freport_ref
// Freport calculations for each of the reference points
  trefU=0.0;
  trefN=0.0;
  trefB=0.0;
  trefUd=0.0;
  trefNd=0.0;
  trefBd=0.0;
  nreftemp(1)=1.0;
  for (iage=1;iage<nages;iage++)
  {
     freftemp(iage)=Fref*(proj_dir_sel(iage)+proj_Discard_sel(iage))+proj_nondir_F(iage);
     nreftemp(iage+1)=mfexp(-1.0*(M(nyears,iage)+freftemp(iage)));
  }
  freftemp(nages)=Fref*(proj_dir_sel(nages)+proj_Discard_sel(nages))+proj_nondir_F(nages);
  nreftemp(nages)/=(1.0-mfexp(-1.0*(M(nyears,nages)+freftemp(nages))));
```

```
  for (iage=Freport_agemin;iage<=Freport_agemax;iage++)
  {
     trefU+=freftemp(iage);
     trefN+=freftemp(iage)*nreftemp(iage);
     trefB+=freftemp(iage)*nreftemp(iage)*WAAjan1b(nyears,iage);
     trefUd+=1.0;
     trefNd+=nreftemp(iage);
     trefBd+=nreftemp(iage)*WAAjan1b(nyears,iage);
  }
  if (Freport_wtopt==1) Fref_report=trefU/trefUd;
  if (Freport_wtopt==2) Fref_report=trefN/trefNd;
  if (Freport_wtopt==3) Fref_report=trefB/trefBd;

FUNCTION get_YPR
// simple yield per recruit calculations
  YPR=0.0;
  ntemp=1.0;
  for (iage=1;iage<nages;iage++)
  {
    f=YPR_Fmult*proj_dir_sel(iage);
    z=M(nyears,iage)+f+proj_nondir_F(iage)+YPR_Fmult*proj_Discard_sel(iage);
    YPR+=ntemp*f*WAAcatchall(nyears,iage)*(1.0-mfexp(-1.0*z))/z;
    ntemp*=mfexp(-1.0*z);
  }
  f=YPR_Fmult*proj_dir_sel(nages);
  z=M(nyears,nages)+f+proj_nondir_F(nages)+YPR_Fmult*proj_Discard_sel(nages);
  ntemp/=(1.0-mfexp(-1.0*z));
  YPR+=ntemp*f*WAAcatchall(nyears,nages)*(1.0-mfexp(-1.0*z))/z;

FUNCTION project_into_future
// project population under five possible scenarios for each year
  for (iyear=1;iyear<=nprojyears;iyear++)
  {
    proj_F_nondir(iyear)=proj_nondir_F*proj_F_nondir_mult(iyear);
    if (proj_recruit(iyear)<0.0)  // use stock-recruit relationship
    {
       if (iyear==1)
       {
          proj_NAA(iyear,1)=SR_alpha*SSB(nyears)/(SR_beta+SSB(nyears));
       }
       else
       {
          proj_NAA(iyear,1)=SR_alpha*proj_SSB(iyear-1)/(SR_beta+proj_SSB(iyear-1));
       }
    }
    else
    {
       proj_NAA(iyear,1)=proj_recruit(iyear);
    }
    if (iyear==1)
    {
       for (iage=2;iage<=nages;iage++)
          proj_NAA(1,iage)=NAA(nyears,iage-1)*S(nyears,iage-1);
       proj_NAA(1,nages)+=NAA(nyears,nages)*S(nyears,nages);
    }
    else
    {
       for (iage=2;iage<=nages;iage++)
          proj_NAA(iyear,iage)=proj_NAA(iyear-1,iage-1)*mfexp(-1.0*proj_Z(iyear-1,iage-1));
       proj_NAA(iyear,nages)+=proj_NAA(iyear-1,nages)*mfexp(-1.0*proj_Z(iyear-1,nages));
    }
    if (proj_what(iyear)==1)           // match directed yield
    {
       proj_Fmult(iyear)=3.0;  // first see if catch possible
       proj_F_dir(iyear)=proj_Fmult(iyear)*proj_dir_sel;
       proj_F_Discard(iyear)=proj_Fmult(iyear)*proj_Discard_sel;
       proj_Z(iyear)=M(nyears)+proj_F_nondir(iyear)+proj_F_dir(iyear)+proj_F_Discard(iyear);
       proj_catch(iyear)=elem_prod(elem_div(proj_F_dir(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
       proj_Discard(iyear)=elem_prod(elem_div(proj_F_Discard(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
```

```
       proj_yield(iyear)=elem_prod(proj_catch(iyear),WAAcatchall(nyears));
       proj_total_yield(iyear)=sum(proj_yield(iyear));
       proj_total_Discard(iyear)=sum(elem_prod(proj_Discard(iyear),WAAdiscardall(nyears)));
       if (proj_total_yield(iyear)>proj_target(iyear))  // if catch possible, what F needed
       {
          proj_Fmult(iyear)=0.0;
          for (iloop=1;iloop<=20;iloop++)
          {
             Ftemp=proj_Fmult(iyear)*proj_dir_sel;
             denom=0.0;
             for (iage=1;iage<=nages;iage++)
             {

Ztemp(iage)=M(nyears,iage)+proj_F_nondir(iyear,iage)+proj_Fmult(iyear)*proj_Discard_sel(iage)+Ftemp(iage);
                denom+=proj_NAA(iyear,iage)*WAAcatchall(nyears,iage)*proj_dir_sel(iage)*(1.0-mfexp(-
1.0*Ztemp(iage)))/Ztemp(iage);
             }
             proj_Fmult(iyear)=proj_target(iyear)/denom;
          }
       }
    }
    else if (proj_what(iyear)==2)      // match F%SPR
    {
       A=0.0;
       B=5.0;
       for (iloop=1;iloop<=20;iloop++)
       {
          C=(A+B)/2.0;
          SPR_Fmult=C;
          get_SPR();
          SPRatio=SPR/SR_spawners_per_recruit;
          if (SPRatio<proj_target(iyear))
          {
             B=C;
          }
          else
          {
             A=C;
          }
       }
       proj_Fmult(iyear)=C;
    }
    else if (proj_what(iyear)==3)      // project Fmsy
    {
       proj_Fmult=Fmsy;
    }
    else if (proj_what(iyear)==4)      // project Fcurrent
    {
       proj_Fmult=Fcurrent;
    }
    else if (proj_what(iyear)==5)      // project input F
    {
       proj_Fmult=proj_target(iyear);
    }
    proj_F_dir(iyear)=proj_Fmult(iyear)*proj_dir_sel;
    proj_F_Discard(iyear)=proj_Fmult(iyear)*proj_Discard_sel;
    proj_Z(iyear)=M(nyears)+proj_F_nondir(iyear)+proj_F_dir(iyear)+proj_F_Discard(iyear);
    proj_SSBfracZ(iyear)=mfexp(-1.0*fracyearSSB*proj_Z(iyear));
    proj_catch(iyear)=elem_prod(elem_div(proj_F_dir(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
    proj_Discard(iyear)=elem_prod(elem_div(proj_F_Discard(iyear),proj_Z(iyear)),elem_prod(1.0-mfexp(-
1.0*proj_Z(iyear)),proj_NAA(iyear)));
    proj_yield(iyear)=elem_prod(proj_catch(iyear),WAAcatchall(nyears));
    proj_total_yield(iyear)=sum(proj_yield(iyear));
    proj_total_Discard(iyear)=sum(elem_prod(proj_Discard(iyear),WAAdiscardall(nyears)));
    proj_TotJan1B(iyear)=sum(elem_prod(proj_NAA(iyear),WAAjan1b(nyears)));
    proj_SSB(iyear)=elem_prod(proj_NAA(iyear),proj_SSBfracZ(iyear))*fecundity(nyears);
  }

FUNCTION get_SPR
// simple spawners per recruit calculations
```

```
  ntemp=1.0;
  SPR=0.0;
  for (iage=1;iage<nages;iage++)
  {
    z=M(nyears,iage)+proj_nondir_F(iage)+SPR_Fmult*proj_dir_sel(iage)+SPR_Fmult*proj_Discard_sel(iage);
    SPR+=ntemp*fecundity(nyears,iage)*mfexp(-1.0*fracyearSSB*z);
    ntemp*=mfexp(-1.0*z);
  }
  z=M(nyears,nages)+proj_nondir_F(nages)+SPR_Fmult*proj_dir_sel(nages)+SPR_Fmult*proj_Discard_sel(nages);
  ntemp/=(1.0-mfexp(-1.0*z));
  SPR+=ntemp*fecundity(nyears,nages)*mfexp(-1.0*fracyearSSB*z);

FUNCTION get_multinomial_multiplier
// compute Francis (2011) stage 2 multiplier for multinomial to adjust input Neff
// Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. CJFAS 68: 1124-1138
  Neff_stage2_mult_catch=1;
  Neff_stage2_mult_discard=1;
  Neff_stage2_mult_index=1;
  // Catch
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    mean_age_obs=0.0;
    mean_age_pred=0.0;
    mean_age_pred2=0.0;
    mean_age_resid=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++){
        mean_age_obs(iyear) += CAA_prop_obs(ifleet,iyear,iage)*iage;
        mean_age_pred(iyear) += CAA_prop_pred(ifleet,iyear,iage)*iage;
        mean_age_pred2(iyear) += CAA_prop_pred(ifleet,iyear,iage)*iage*iage;
      }
    }
    mean_age_resid=mean_age_obs-mean_age_pred;
    mean_age_sigma=sqrt(mean_age_pred2-elem_prod(mean_age_pred,mean_age_pred));
    mean_age_n=0.0;
    mean_age_mean=0.0;
    mean_age_m2=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      if (input_eff_samp_size_catch(ifleet,iyear)>0){
        mean_age_x=mean_age_resid(iyear)*sqrt(input_eff_samp_size_catch(ifleet,iyear))/mean_age_sigma(iyear);
        mean_age_n += 1.0;
        mean_age_delta=mean_age_x-mean_age_mean;
        mean_age_mean += mean_age_delta/mean_age_n;
        mean_age_m2 += mean_age_delta*(mean_age_x-mean_age_mean);
      }
    }
    if ((mean_age_n > 0) && (mean_age_m2 > 0)) Neff_stage2_mult_catch(ifleet)=1.0/(mean_age_m2/(mean_age_n-
1.0));
  }

  // Discards
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    mean_age_obs=0.0;
    mean_age_pred=0.0;
    mean_age_pred2=0.0;
    mean_age_resid=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++){
        mean_age_obs(iyear) += Discard_prop_obs(ifleet,iyear,iage)*iage;
        mean_age_pred(iyear) += Discard_prop_pred(ifleet,iyear,iage)*iage;
        mean_age_pred2(iyear) += Discard_prop_pred(ifleet,iyear,iage)*iage*iage;
      }
    }
    mean_age_resid=mean_age_obs-mean_age_pred;
    mean_age_sigma=sqrt(mean_age_pred2-elem_prod(mean_age_pred,mean_age_pred));
    mean_age_n=0.0;
    mean_age_mean=0.0;
    mean_age_m2=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      if (input_eff_samp_size_discard(ifleet,iyear)>0){
        mean_age_x=mean_age_resid(iyear)*sqrt(input_eff_samp_size_discard(ifleet,iyear))/mean_age_sigma(iyear);
        mean_age_n += 1.0;
```

```
        mean_age_delta=mean_age_x-mean_age_mean;
        mean_age_mean += mean_age_delta/mean_age_n;
        mean_age_m2 += mean_age_delta*(mean_age_x-mean_age_mean);
      }
    }
    if ((mean_age_n > 0) && (mean_age_m2 > 0)) Neff_stage2_mult_discard(ifleet)=1.0/(mean_age_m2/(mean_age_n-
1.0));
  }
  // Indices
  for (ind=1;ind<=nindices;ind++){
    mean_age_obs=0.0;
    mean_age_pred=0.0;
    mean_age_pred2=0.0;
    mean_age_resid=0.0;
    for (i=1;i<=index_nobs(ind);i++){
      j=index_time(ind,i);
      for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++){
        mean_age_obs(j) += index_prop_obs(ind,i,iage)*iage;
        mean_age_pred(j) += index_prop_pred(ind,i,iage)*iage;
        mean_age_pred2(j) += index_prop_pred(ind,i,iage)*iage*iage;
      }
    }
    mean_age_resid=mean_age_obs-mean_age_pred;
    mean_age_sigma=sqrt(mean_age_pred2-elem_prod(mean_age_pred,mean_age_pred));
    mean_age_n=0.0;
    mean_age_mean=0.0;
    mean_age_m2=0.0;
    for (iyear=1;iyear<=nyears;iyear++){
      if (index_Neff_init(ind,iyear)>0){
        mean_age_x=mean_age_resid(iyear)*sqrt(index_Neff_init(ind,iyear))/mean_age_sigma(iyear);
        mean_age_n += 1.0;
        mean_age_delta=mean_age_x-mean_age_mean;
        mean_age_mean += mean_age_delta/mean_age_n;
        mean_age_m2 += mean_age_delta*(mean_age_x-mean_age_mean);
      }
    }
    if ((mean_age_n > 0) && (mean_age_m2 > 0)) Neff_stage2_mult_index(ind)=1.0/(mean_age_m2/(mean_age_n-1.0));
  }



FUNCTION get_log_factorial
// compute sum of log factorial, used in multinomial likelihood constant
  nfact_out=0.0;
  if (nfact_in >= 2)
  {
     for (int ilogfact=2;ilogfact<=nfact_in;ilogfact++)
     {
        nfact_out+=log(ilogfact);
     }
  }

FUNCTION compute_the_objective_function
  obj_fun=0.0;
  io=0; // io if statements commented out to speed up program

// indices (lognormal)
  for (ind=1;ind<=nindices;ind++)
  {
     likely_ind(ind)=index_like_const(ind);
     RSS_ind(ind)=norm2(log(index_obs(ind))-log(index_pred(ind)));
     for (i=1;i<=index_nobs(ind);i++)
     {
         likely_ind(ind)+=log(index_sigma(ind,i));
         likely_ind(ind)+=0.5*square(log(index_obs(ind,i))-log(index_pred(ind,i)))/index_sigma2(ind,i);
         index_stdresid(ind,i)=(log(index_obs(ind,i))-log(index_pred(ind,i)))/index_sigma(ind,i);
     }
     obj_fun+=lambda_ind(ind)*likely_ind(ind);
  }
  // if (io==1) cout << "likely_ind " << likely_ind << endl;
```

```
// indices age comp (multinomial)
  likely_index_age_comp=index_prop_like_const;
  for (ind=1;ind<=nindices;ind++)
  {
     if (index_estimate_proportions(ind)==1)
     {
       for (i=1;i<=index_nobs(ind);i++)
       {
         temp_sum=0.0;
         for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
         {
            temp_sum+=index_prop_obs(ind,i,iage)*log(index_prop_pred(ind,i,iage));
         }
         likely_index_age_comp+=-1.0*input_eff_samp_size_index(ind,i)*temp_sum;
       }
     }
  }
  obj_fun+=likely_index_age_comp;
  // if (io==1) cout << "likely_index_age_comp " << likely_index_age_comp << endl;

// total catch (lognormal)
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     catch_tot_likely(ifleet)=catch_tot_like_const(ifleet);
     discard_tot_likely(ifleet)=discard_tot_like_const(ifleet);
     RSS_catch_tot_fleet(ifleet)=norm2(log(Catch_tot_fleet_obs(ifleet)+0.00001)-
log(Catch_tot_fleet_pred(ifleet)+0.00001));
     RSS_Discard_tot_fleet(ifleet)=norm2(log(Discard_tot_fleet_obs(ifleet)+0.00001)-
log(Discard_tot_fleet_pred(ifleet)+0.00001));
     for (iyear=1;iyear<=nyears;iyear++)
     {
        catch_tot_likely(ifleet)+=log(catch_tot_sigma(ifleet,iyear));
        catch_tot_likely(ifleet)+=0.5*square(log(Catch_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Catch_tot_fleet_pred(ifleet,iyear)+0.00001))/catch_tot_sigma2(ifleet,iyear);
        discard_tot_likely(ifleet)+=log(discard_tot_sigma(ifleet,iyear));
        discard_tot_likely(ifleet)+=0.5*square(log(Discard_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Discard_tot_fleet_pred(ifleet,iyear)+0.00001))/discard_tot_sigma2(ifleet,iyear);
     }
     obj_fun+=lambda_catch_tot(ifleet)*catch_tot_likely(ifleet);
     obj_fun+=lambda_Discard_tot(ifleet)*discard_tot_likely(ifleet);
  }
  // if (io==1) cout << "catch_tot_likely " << catch_tot_likely << endl;

// catch age comp (multinomial)
  likely_catch=catch_prop_like_const;
  likely_Discard=discard_prop_like_const;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    for (iyear=1;iyear<=nyears;iyear++)
    {
       temp_sum=0.0;
       temp_sum2=0.0;
       for (iage=sel_start_age(ifleet);iage<=sel_end_age(ifleet);iage++)
       {
          temp_sum+=CAA_prop_obs(ifleet,iyear,iage)*log(CAA_prop_pred(ifleet,iyear,iage));
          if(proportion_release(ifleet,iyear,iage)>0.0)
             temp_sum2+=Discard_prop_obs(ifleet,iyear,iage)*log(Discard_prop_pred(ifleet,iyear,iage));
       }
       likely_catch+=-1.0*input_eff_samp_size_catch(ifleet,iyear)*temp_sum;
       likely_Discard+=-1.0*input_eff_samp_size_discard(ifleet,iyear)*temp_sum2;
    }
  }
  obj_fun+=likely_catch;
  obj_fun+=likely_Discard;
  // if (io==1) cout << "likely_catch " << likely_catch << endl;

// stock-recruitment relationship (lognormal)
  likely_SR_sigma=SR_like_const;
  if (use_likelihood_constants==1)
  {
     likely_SR_sigma+=sum(log(SR_pred_recruits));
```

```
     likely_SR_sigma-=log(SR_pred_recruits(nyears+1));  // pred R in terminal year plus one does not have a
deviation
  }
  SR_stdresid=0.0;
  if (active(log_recruit_devs))
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
        likely_SR_sigma+=log(recruit_sigma(iyear));
        likely_SR_sigma+=0.5*square(log(recruits(iyear))-log(SR_pred_recruits(iyear)))/recruit_sigma2(iyear);
        SR_stdresid(iyear)=(log(recruits(iyear))-log(SR_pred_recruits(iyear)))/recruit_sigma(iyear);
     }
     obj_fun+=lambda_recruit_devs*likely_SR_sigma;
  }
  // if (io==1) cout << "likely_SR_sigma " << likely_SR_sigma << endl;

// selectivity parameters
  sel_likely=0.0;
  sel_stdresid=0.0;
  for (k=1;k<=nselparm;k++)
  {
     if (active(sel_params(k)))
     {
        sel_likely(k)+=sel_like_const(k);
        sel_likely(k)+=log(sel_sigma(k))+0.5*square(log(sel_initial(k))-log(sel_params(k)))/sel_sigma2(k);
        sel_stdresid(k)=(log(sel_initial(k))-log(sel_params(k)))/sel_sigma(k);
        obj_fun+=sel_lambda(k)*sel_likely(k);
     }
  }
  // if (io==1) cout << "sel_likely " << sel_likely << endl;

// index selectivity parameters
  indexsel_likely=0.0;
  indexsel_stdresid=0.0;
  for (k=1;k<=nindexselparms;k++)
  {
     if (active(index_sel_params(k)))
     {
        indexsel_likely(k)+=indexsel_like_const(k);
        indexsel_likely(k)+=log(indexsel_sigma(k))+0.5*square(log(indexsel_initial(k))-
log(index_sel_params(k)))/indexsel_sigma2(k);
        indexsel_stdresid(k)=(log(indexsel_initial(k))-log(index_sel_params(k)))/indexsel_sigma(k);
        obj_fun+=indexsel_lambda(k)*indexsel_likely(k);
     }
  }
  // if (io==1) cout << "indexsel_likely " << indexsel_likely << endl;

  steepness_likely=0.0;
  steepness_stdresid=0.0;
  if (active(SR_steepness))
  {
     steepness_likely=steepness_like_const;
     steepness_likely+=log(steepness_sigma)+0.5*square(log(SR_steepness_ini)-
log(SR_steepness))/steepness_sigma2;
     steepness_stdresid=(log(SR_steepness_ini)-log(SR_steepness))/steepness_sigma;
     obj_fun+=lambda_steepness*steepness_likely;
  }
  // if (io==1) cout << "steepness_likely " << steepness_likely << endl;

  SR_scaler_likely=0.0;
  SR_scaler_stdresid=0.0;
  if (active(log_SR_scaler))
  {
     SR_scaler_likely=SR_scaler_like_const;
     SR_scaler_likely+=log(SR_scaler_sigma)+0.5*(square(log(SR_scaler_ini)-log_SR_scaler))/SR_scaler_sigma2;
     SR_scaler_stdresid=(log(SR_scaler_ini)-log_SR_scaler)/SR_scaler_sigma;
     obj_fun+=lambda_SR_scaler*SR_scaler_likely;
  }
  // if (io==1) cout << "SR_scaler_likely " << SR_scaler_likely << endl;

  Fmult_year1_stdresid=0.0;
```

```
  if (active(log_Fmult_year1))
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        Fmult_year1_likely(ifleet)=Fmult_year1_like_const(ifleet);
        Fmult_year1_likely(ifleet)+=log(Fmult_year1_sigma(ifleet))+0.5*square(log_Fmult_year1(ifleet)-
log(Fmult_year1_ini(ifleet)))/Fmult_year1_sigma2(ifleet);
        Fmult_year1_stdresid(ifleet)=(log_Fmult_year1(ifleet)-
log(Fmult_year1_ini(ifleet)))/Fmult_year1_sigma(ifleet);
     }
     obj_fun+=lambda_Fmult_year1*Fmult_year1_likely;
  }
  // if (io==1) cout << "Fmult_year1_likely " << Fmult_year1_likely << endl;

  Fmult_devs_stdresid=0.0;
  if (active(log_Fmult_devs))
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        Fmult_devs_likely(ifleet)=Fmult_devs_like_const(ifleet);

Fmult_devs_likely(ifleet)+=log(Fmult_devs_sigma(ifleet))+0.5*norm2(log_Fmult_devs(ifleet))/Fmult_devs_sigma2(ifl
eet);
        for (iyear=2;iyear<=nyears;iyear++)
           Fmult_devs_stdresid(ifleet,iyear)=log_Fmult_devs(ifleet,iyear)/Fmult_devs_sigma(ifleet);
     }
     obj_fun+=lambda_Fmult_devs*Fmult_devs_likely;
  }
  // if (io==1) cout << "Fmult_devs_likely " << Fmult_devs_likely << endl;

  q_year1_stdresid=0.0;
  if (active(log_q_year1))
  {
     for (ind=1;ind<=nindices;ind++)
     {
        q_year1_likely(ind)=q_year1_like_const(ind);
        q_year1_likely(ind)+=log(q_year1_sigma(ind))+0.5*square(log_q_year1(ind)-
log(q_year1_ini(ind)))/q_year1_sigma2(ind);
        q_year1_stdresid(ind)=(log_q_year1(ind)-log(q_year1_ini(ind)))/q_year1_sigma(ind);
     }
     obj_fun+=lambda_q_year1*q_year1_likely;
  }
  // if (io==1) cout << "q_year1_likely " << q_year1_likely << endl;

  q_devs_stdresid=0.0;
  if (active(log_q_devs))
  {
     for (ind=1;ind<=nindices;ind++)
     {
       q_devs_likely(ind)=q_devs_like_const(ind);
       q_devs_likely(ind)+=log(q_devs_sigma(ind))+0.5*norm2(log_q_devs(ind))/q_devs_sigma2(ind);
       for (i=2;i<=index_nobs(ind);i++)
          q_devs_stdresid(ind,i)=log_q_devs(ind,i)/q_devs_sigma(ind);
     }
     obj_fun+=lambda_q_devs*q_devs_likely;
  }
  // if (io==1) cout << "q_devs_likely " << q_devs_likely << endl;

  if (NAA_year1_flag==1)
  {
     nyear1temp(1)=SR_pred_recruits(1);
     N_year1_stdresid=0.0;
     for (iage=2;iage<=nages;iage++)
     {
        nyear1temp(iage)=nyear1temp(iage-1)*S(1,iage-1);
     }
     nyear1temp(nages)/=(1.0-S(1,nages));
  }
  else if (NAA_year1_flag==2)
  {
     nyear1temp=NAA_year1_ini;
```

```
  }
  if (active(log_N_year1_devs))
  {
     if (N_year1_sigma>0.0)
     {
        for (iage=2;iage<=nages;iage++)
           N_year1_stdresid(iage)=(log(NAA(1,iage))-log(nyear1temp(iage)))/N_year1_sigma;
     }
     N_year1_likely=N_year1_like_const+sum(log(nyear1temp));
     N_year1_likely+=log(N_year1_sigma)+0.5*norm2(log(NAA(1))-log(nyear1temp))/N_year1_sigma2;
     obj_fun+=lambda_N_year1_devs*N_year1_likely;
  }
  // if (io==1) cout << "N_year1_likely " << N_year1_likely << endl;

  Fmult_max_pen=0.0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    for (iyear=1;iyear<=nyears;iyear++)
    {
       temp_Fmult_max=mfexp(log_Fmult(ifleet,iyear))*max(sel_by_fleet(ifleet,iyear));
       if(temp_Fmult_max>Fmult_max_value)
          Fmult_max_pen+=1000.*(temp_Fmult_max-Fmult_max_value)*(temp_Fmult_max-Fmult_max_value);
    }
  }
  obj_fun+=Fmult_max_pen;
  // if (io==1) cout << "Fmult_max_pen " << Fmult_max_pen << endl;

  fpenalty_lambda=100.0*pow(10.0,(-1.0*current_phase())); // decrease emphasis on F near M as phases increase
  if (last_phase())                                       // no penalty in final solution
     fpenalty_lambda=0.0;
  fpenalty=fpenalty_lambda*square(log(mean(FAA_tot))-log(mean(M)));
  obj_fun+=fpenalty;
  // if (io==1) cout << "fpenalty " << fpenalty << endl;

FUNCTION write_MCMC
// first the output file for AgePro
  if (MCMCnyear_opt == 0)    // use final year
  {
     if (fillR_opt == 0)
     {
        NAAbsn(1)=NAA(nyears,1);
     }
     else if (fillR_opt == 1)
     {
        NAAbsn(1)=SR_pred_recruits(nyears);
     }
     else if (fillR_opt == 2)
     {
        tempR=0.0;
        for (i=Ravg_start;i<=Ravg_end;i++)
        {
           iyear=i-year1+1;
           tempR+=log(NAA(iyear,1));
        }
        NAAbsn(1)=mfexp(tempR/(Ravg_end-Ravg_start+1.0));
     }
     for (iage=2;iage<=nages;iage++)
     {
        NAAbsn(iage)=NAA(nyears,iage);
     }
  }
  else                       // use final year + 1
  {
     if (fillR_opt == 1)
     {
        NAAbsn(1)=SR_pred_recruits(nyears+1);
     }
     else if (fillR_opt == 2)
     {
        tempR=0.0;
        for (i=Ravg_start;i<=Ravg_end;i++)
```

```
        {
           iyear=i-year1+1;
           tempR+=log(NAA(iyear,1));
        }
        NAAbsn(1)=mfexp(tempR/(Ravg_end-Ravg_start+1.0));
     }
     for (iage=2;iage<=nages;iage++)
     {
        NAAbsn(iage)=NAA(nyears,iage-1)*S(nyears,iage-1);
     }
     NAAbsn(nages)+=NAA(nyears,nages)*S(nyears,nages);
  }

  // Liz added
       for (iyear=1;iyear<=nyears;iyear++)
     {
               tempFmult(iyear) = max(extract_row(FAA_tot,iyear));
               }
  // end stuff Liz added


// output the NAAbsn values
  ageproMCMC << NAAbsn << endl;

// now the standard MCMC output file
  basicMCMC << Freport << " " <<
               SSB << " " <<

                ///  Liz added

               tempFmult << " " <<

               rowsum(elem_prod(WAAjan1b, NAA)) << " " <<

               /// end stuff Liz added

               MSY << " " <<
               SSmsy << " " <<
               Fmsy << " " <<
               SSBmsy_ratio << " " <<
               Fmsy_ratio << " " <<
               endl;

REPORT_SECTION
  report << "Age Structured Assessment Program (ASAP) Version 3.0" << endl;
  report << "Start time for run: " << ctime(&start) << endl;
  report << "obj_fun        = " << obj_fun << endl << endl;
  report << "Component                Lambda          obj_fun" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
     report << "__Catch_Fleet_" << ifleet << "               " << lambda_catch_tot(ifleet) << "          " <<
lambda_catch_tot(ifleet)*catch_tot_likely(ifleet) << endl;
  report << "Catch_Fleet_Total             " << sum(lambda_catch_tot) << "          " <<
lambda_catch_tot*catch_tot_likely << endl;
  if (lambda_Discard_tot*discard_tot_likely > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << "__Discard_Fleet_" << ifleet << "             " << lambda_Discard_tot(ifleet) << "          "
<< lambda_Discard_tot(ifleet)*discard_tot_likely(ifleet) << endl;
  }
  report << "Discard_Fleet_Total           " << sum(lambda_Discard_tot) << "          " <<
lambda_Discard_tot*discard_tot_likely << endl;
  for (ind=1;ind<=nindices;ind++)
     report << "__Index_Fit_" << ind << "                 " << lambda_ind(ind) << "          " <<
lambda_ind(ind)*likely_ind(ind) << endl;
  report << "Index_Fit_Total               " << sum(lambda_ind) << "          " << lambda_ind*likely_ind <<
endl;
  report << "Catch_Age_Comps       see_below          " << likely_catch << endl;
  report << "Discard_Age_Comps     see_below          " << likely_Discard << endl;
  report << "Index_Age_Comps       see_below          " << likely_index_age_comp << endl;
  sum_sel_lambda=0;
  sum_sel_lambda_likely=0.0;
```

```
  for (k=1;k<=nselparm;k++)
  {
     if (sel_phase(k) >= 1)
     {
        if      (k < 10  ) report << "__Sel_Param_" << k << "                 " << sel_lambda(k) << "          "
<< sel_lambda(k)*sel_likely(k) << endl;
        else if (k < 100 ) report << "__Sel_Param_" << k << "                " << sel_lambda(k) << "          "
<< sel_lambda(k)*sel_likely(k) << endl;
        else if (k < 1000) report << "__Sel_Param_" << k << "               " << sel_lambda(k) << "          "
<< sel_lambda(k)*sel_likely(k) << endl;
        sum_sel_lambda+=sel_lambda(k);
        sum_sel_lambda_likely+=sel_lambda(k)*sel_likely(k);
     }
  }
  report << "Sel_Params_Total              " << sum_sel_lambda << "          " << sum_sel_lambda_likely << endl;
  sum_indexsel_lambda=0;
  sum_indexsel_lambda_likely=0.0;
  for (k=1;k<=nindexselparms;k++)
  {
     if (indexsel_phase(k) >= 1)
     {
        if      (k <10  ) report << "__Index_Sel_Param_" << k << "           " << indexsel_lambda(k) << "
" << indexsel_lambda(k)*indexsel_likely(k) << endl;
        else if (k <100 ) report << "__Index_Sel_Param_" << k << "          " << indexsel_lambda(k) << "
" << indexsel_lambda(k)*indexsel_likely(k) << endl;
        else if (k <1000) report << "__Index_Sel_Param_" << k << "         " << indexsel_lambda(k) << "
" << indexsel_lambda(k)*indexsel_likely(k) << endl;
        sum_indexsel_lambda+=indexsel_lambda(k);
        sum_indexsel_lambda_likely+=indexsel_lambda(k)*indexsel_likely(k);
     }
  }
  report << "Index_Sel_Params_Total        " << sum_indexsel_lambda << "          " <<
sum_indexsel_lambda_likely << endl;
  if (lambda_q_year1*q_year1_likely > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
        report << "__q_year1_index_" << ind << "             "  << lambda_q_year1(ind) << "          " <<
lambda_q_year1(ind)*q_year1_likely(ind) << endl;
  }
  report << "q_year1_Total                 " << sum(lambda_q_year1) << "          " <<
lambda_q_year1*q_year1_likely << endl;

  if (lambda_q_devs*q_devs_likely > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
        report << "__q_devs_index_" << ind << "              "  << lambda_q_devs(ind) << "          " <<
lambda_q_devs(ind)*q_devs_likely(ind) << endl;
  }
  report << "q_devs_Total                  " << sum(lambda_q_devs) << "          " <<
lambda_q_devs*q_devs_likely << endl;
  if (lambda_Fmult_year1*Fmult_year1_likely > 0.0);
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << "__Fmult_year1_fleet_" << ifleet << "         " << lambda_Fmult_year1(ifleet) << "          "
<< lambda_Fmult_year1(ifleet)*Fmult_year1_likely(ifleet) << endl;
  }
  report << "Fmult_year1_fleet_Total       " << sum(lambda_Fmult_year1) << "          " <<
lambda_Fmult_year1*Fmult_year1_likely << endl;
  if (lambda_Fmult_devs*Fmult_devs_likely > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << "__Fmult_devs_fleet_" << ifleet << "          " << lambda_Fmult_devs(ifleet) << "          "
<< lambda_Fmult_devs(ifleet)*Fmult_devs_likely(ifleet) << endl;
  }
  report << "Fmult_devs_fleet_Total        " << sum(lambda_Fmult_devs) << "          " <<
lambda_Fmult_devs*Fmult_devs_likely << endl;
  report << "N_year_1                      " << lambda_N_year1_devs << "          " <<
lambda_N_year1_devs*N_year1_likely << endl;
  report << "Recruit_devs                  " << lambda_recruit_devs << "          " <<
lambda_recruit_devs*likely_SR_sigma << endl;
```

```
  report << "SR_steepness                  " << lambda_steepness << "          " <<
lambda_steepness*steepness_likely << endl;
  report << "SR_scaler                     " << lambda_SR_scaler << "          " <<
lambda_SR_scaler*SR_scaler_likely << endl;
  report << "Fmult_Max_penalty          1000          " << Fmult_max_pen << endl;
  report << "F_penalty                     " << fpenalty_lambda << "          " << fpenalty << endl;
  report << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
       if (input_eff_samp_size_catch(ifleet,iyear)==0)
       {
         effective_sample_size(ifleet,iyear)=0;
       }
       else
       {
         effective_sample_size(ifleet,iyear)=CAA_prop_pred(ifleet,iyear)*(1.0-
CAA_prop_pred(ifleet,iyear))/norm2(CAA_prop_obs(ifleet,iyear)-CAA_prop_pred(ifleet,iyear));
       }
       if (input_eff_samp_size_discard(ifleet,iyear)==0)
       {
         effective_Discard_sample_size(ifleet,iyear)=0;
       }
       else
       {
         effective_Discard_sample_size(ifleet,iyear)=Discard_prop_pred(ifleet,iyear)*(1.0-
Discard_prop_pred(ifleet,iyear))/norm2(Discard_prop_obs(ifleet,iyear)-Discard_prop_pred(ifleet,iyear));
       }
     }
  }
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " Input and Estimated effective sample sizes for fleet " << ifleet << endl;
     for (iyear=1;iyear<=nyears;iyear++)
        report << iyear+year1-1 << "  " << input_eff_samp_size_catch(ifleet,iyear) << "  " <<
effective_sample_size(ifleet,iyear) << endl;
     report << " Total  " << sum(input_eff_samp_size_catch(ifleet)) << "  " <<
sum(effective_sample_size(ifleet)) << endl;
  }
  report << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " Input and Estimated effective Discard sample sizes for fleet " << ifleet << endl;
     for (iyear=1;iyear<=nyears;iyear++)
        report << iyear+year1-1 << "  " << input_eff_samp_size_discard(ifleet,iyear) << "  " <<
effective_Discard_sample_size(ifleet,iyear) << endl;
     report << " Total  " << sum(input_eff_samp_size_discard(ifleet)) << "  " <<
sum(effective_Discard_sample_size(ifleet)) << endl;
  }
  report << endl;
  report << "Observed and predicted total fleet catch by year and standardized residual" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << " total catches" << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
      Catch_stdresid(ifleet,iyear)=(log(Catch_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Catch_tot_fleet_pred(ifleet,iyear)+0.00001))/catch_tot_sigma(ifleet,iyear);
      report << iyear+year1-1 << "  " << Catch_tot_fleet_obs(ifleet,iyear) << "  " <<
Catch_tot_fleet_pred(ifleet,iyear) << "  " << Catch_stdresid(ifleet,iyear) << endl;
    }
  }
  report << "Observed and predicted total fleet Discards by year and standardized residual" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << " total Discards" << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
      Discard_stdresid(ifleet,iyear)=(log(Discard_tot_fleet_obs(ifleet,iyear)+0.00001)-
log(Discard_tot_fleet_pred(ifleet,iyear)+0.00001))/discard_tot_sigma(ifleet,iyear);
```

```
      report << iyear+year1-1 << "  " << Discard_tot_fleet_obs(ifleet,iyear) << "  " <<
Discard_tot_fleet_pred(ifleet,iyear) << "  " << Discard_stdresid(ifleet,iyear) << endl;
    }
  }
  report << endl << "Index data" << endl;
  for (ind=1;ind<=nindices;ind++) {
     report << "index number " << ind << endl;
     report << "aggregate units = " << index_units_aggregate(ind) << endl;
     report << "proportions units = " << index_units_proportions(ind) << endl;
     report << "month = " << index_month(ind) << endl;
     report << "starting and ending ages for selectivity = " << index_start_age(ind) << "  " <<
index_end_age(ind) << endl;
     report << "selectivity choice = " << index_sel_choice(ind) << endl;
     report << " year, obs index, pred index, standardized residual" << endl;
     for (j=1;j<=index_nobs(ind);j++)
         report << index_year(ind,j) << "  " << index_obs(ind,j) << "  " << index_pred(ind,j) << "  " <<
index_stdresid(ind,j) << endl;
  }
  report << endl;
  index_Neff_init=0.0;
  index_Neff_est=0.0;
  for (ind=1;ind<=nindices;ind++)
  {
     for (iyear=1;iyear<=nyears;iyear++)
     {
         for (i=1;i<=index_nobs(ind);i++)
         {
             if (index_time(ind,i)==iyear)
             {
                 index_Neff_init(ind,iyear)=input_eff_samp_size_index(ind,i);
                 if (input_eff_samp_size_index(ind,i)==0)
                 {
                     index_Neff_est(ind,iyear)=0.0;
                 }
                 else
                 {
                     index_Neff_est(ind,iyear)=index_prop_pred(ind,i)*(1.0-
index_prop_pred(ind,i))/norm2(index_prop_obs(ind,i)-index_prop_pred(ind,i));
                 }
             }
         }
     }
  }
  report << "Input effective sample sizes by index (row=index, column=year)" << endl;
  report << index_Neff_init << endl;
  report << "Estimated effective sample sizes by index (row=index, column=year)" << endl;
  report << index_Neff_est << endl;
  report << endl;
  report << "Index proportions at age by index" << endl;
  for (ind=1;ind<=nindices;ind++)
  {
     output_index_prop_obs(ind)=0.0;
     output_index_prop_pred(ind)=0.0;
     if (index_estimate_proportions(ind)==1)
     {
        report << " Index number " << ind << endl;
        for (iyear=1;iyear<=nyears;iyear++)
        {
           for (i=1;i<=index_nobs(ind);i++)
           {
               if (index_time(ind,i)==iyear)
               {
                   for (iage=index_start_age(ind);iage<=index_end_age(ind);iage++)
                   {
                       output_index_prop_obs(ind,iyear,iage)=index_prop_obs(ind,i,iage);
                       output_index_prop_pred(ind,iyear,iage)=index_prop_pred(ind,i,iage);
                   }
               }
           }
           report << "Year " << iyear+year1-1 << " Obs  = " << output_index_prop_obs(ind,iyear) << endl;
           report << "Year " << iyear+year1-1 << " Pred = " << output_index_prop_pred(ind,iyear) << endl;
```

```
        }
     }
  }
  report << endl;
  report << "Index Selectivity at Age" << endl;
  report << indexsel << endl;
  report << endl;

  report << "Deviations section: only applicable if associated lambda > 0" << endl;
  report << "Nyear1 observed, expected, standardized residual" << endl;
  if (lambda_N_year1_devs > 0.0)
  {
     for (iage=2;iage<=nages;iage++)
     {
        report << iage << "  " << NAA(1,iage) << "  " << nyear1temp(iage) << "  " << N_year1_stdresid(iage) <<
endl;
     }
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Fleet Obs, Initial, and Stadardized Residual for Fmult" << endl;
  if (sum(lambda_Fmult_year1) > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
        report << ifleet << "  " << mfexp(log_Fmult_year1(ifleet)) << "  " << Fmult_year1_ini(ifleet) << "  " <<
Fmult_year1_stdresid(ifleet) << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Standardized Residuals for Fmult_devs by fleet and year" << endl;
  if (sum(lambda_Fmult_devs) > 0.0)
  {
     for (ifleet=1;ifleet<=nfleets;ifleet++)
     {
        report << " fleet " << ifleet << " Fmult_devs standardized residuals" << endl;
        for (iyear=2;iyear<=nyears;iyear++)
           report << iyear << "  " << Fmult_devs_stdresid(ifleet,iyear) << endl;
     }
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Index Obs, Initial, and Standardized Residual for q_year1" << endl;
  if (sum(lambda_q_year1) > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
        report << ind << "  " << mfexp(log_q_year1(ind)) << "  " << q_year1_ini(ind) << "  " <<
              (log_q_year1(ind)-log(q_year1_ini(ind)))/q_year1_sigma(ind) << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Standardized Residuals for catchability deviations by index and year" << endl;
  if (sum(lambda_q_devs) > 0.0)
  {
     for (ind=1;ind<=nindices;ind++)
     {
        report << " index " << ind << " q_devs standardized residuals" << endl;
        for (i=2;i<=index_nobs(ind);i++)
           report << index_year(ind,i) << "  " << log_q_devs(ind,i)/q_devs_sigma(ind) << endl;
     }
```

```
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Obs, Initial, and Stadardized Residual for SR steepness" << endl;
  if (lambda_steepness > 0.0)
  {
     report << SR_steepness << "  " << SR_steepness_ini << "  " << (log(SR_steepness)-
log(SR_steepness_ini))/steepness_sigma << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "Obs, Initial, and Stadardized Residual for SR scaler" << endl;
  if (lambda_SR_scaler > 0.0)
  {
     report << mfexp(log_SR_scaler) << "  " << SR_scaler_ini << "  " << (log_SR_scaler-
log(SR_scaler_ini))/SR_scaler_sigma << endl;
  }
  else
  {
     report << "N/A" << endl;
  }
  report << endl;
  report << "End of Deviations Section" << endl << endl;

  report << "Selectivity by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++) {
     report << " fleet " << ifleet << " selectivity at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
       report << sel_by_fleet(ifleet,iyear) << endl;
  }
  report << endl;
  report << "Fmult by year for each fleet" << endl;
  Fmult=mfexp(log_Fmult);
  for (iyear=1;iyear<=nyears;iyear++) {
     for (ifleet=1;ifleet<=nfleets;ifleet++){
         temp_Fmult(ifleet)=Fmult(ifleet,iyear);
     }
     report << iyear+year1-1 << "  " << temp_Fmult << endl;
  }
  report << endl;
  report << "Directed F by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " fleet " << ifleet << " directed F at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
         report << FAA_by_fleet_dir(ifleet,iyear) << endl;
  }
  report << "Discard F by age and year for each fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << " fleet " << ifleet << " Discard F at age" << endl;
     for (iyear=1;iyear<=nyears;iyear++)
         report << FAA_by_fleet_Discard(ifleet,iyear) << endl;
  }
  report << "Total F" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
     report << FAA_tot(iyear) << endl;
  report << endl;
  report << "Average F for ages " << Freport_agemin << " to " << Freport_agemax << endl;
  if (Freport_wtopt==1) report << "Freport unweighted in .std and MCMC files" << endl;
  if (Freport_wtopt==2) report << "Freport N weighted in .std and MCMC files" << endl;
  if (Freport_wtopt==3) report << "Freport B weighted in .std and MCMC files" << endl;
  report << "year    unweighted   Nweighted    Bweighted" << endl;
  for (iyear=1;iyear<=nyears;iyear++){
```

```
     report << iyear+year1-1 << "  " << Freport_U(iyear) << "  " << Freport_N(iyear) << "  " << Freport_B(iyear)
<< endl;
  }
  report << endl;
  report << "Population Numbers at the Start of the Year" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
     report << NAA(iyear) << endl;
  report << endl;
  report << "Biomass Time Series" << endl;
  report << "Year, TotJan1B, SSB, ExploitableB" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
  {
     report << iyear+year1-1 << "  " << TotJan1B(iyear) << "  " << SSB(iyear) << "  " << ExploitableB(iyear) <<
endl;
  }
  report << endl;
  report << "q by index" << endl;
  for (ind=1;ind<=nindices;ind++)
  {
     report << " index " << ind << " q over time" << endl;
     for (i=1;i<=index_nobs(ind);i++)
     {
         report << index_year(ind,i) << "  " << q_by_index(ind,i) << endl;
     }
  }
  report << endl;
  report << "Proportions of catch at age by fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
       output_prop_obs=0.0;
       output_prop_pred=0.0;
       output_prop_obs(sel_start_age(ifleet),sel_end_age(ifleet))=CAA_prop_obs(ifleet,iyear);
       output_prop_pred(sel_start_age(ifleet),sel_end_age(ifleet))=CAA_prop_pred(ifleet,iyear);
       report << "Year " << iyear << " Obs  = " << output_prop_obs << endl;
       report << "Year " << iyear << " Pred = " << output_prop_pred << endl;
    }
  }
  report << endl;
  report << "Proportions of Discards at age by fleet" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
    report << " fleet " << ifleet << endl;
    for (iyear=1;iyear<=nyears;iyear++)
    {
       output_Discard_prop_obs=0.0;
       output_Discard_prop_pred=0.0;
       output_Discard_prop_obs(sel_start_age(ifleet),sel_end_age(ifleet))=Discard_prop_obs(ifleet,iyear);
       output_Discard_prop_pred(sel_start_age(ifleet),sel_end_age(ifleet))=Discard_prop_pred(ifleet,iyear);
       report << "Year " << iyear << " Obs  = " << output_Discard_prop_obs << endl;
       report << "Year " << iyear << " Pred = " << output_Discard_prop_pred << endl;
    }
  }
  report << endl;
  report << "F Reference Points Using Final Year Selectivity and Freport options" << endl;
  report << " refpt           F       slope to plot on SR" << endl;
  report << "  F0.1     " << F01_report << "     " << F01_slope << endl;
  report << "  Fmax     " << Fmax_report << "     " << Fmax_slope << endl;
  report << "  F30%SPR  " << F30SPR_report << "     " << F30SPR_slope << endl;
  report << "  F40%SPR  " << F40SPR_report << "     " << F40SPR_slope << endl;
  report << "  Fmsy     " << Fmsy_report << "     " << Fmsy_slope << "    SSBmsy    " << SSBmsy_report << "
MSY   " << MSY << endl;
  report << "  Fcurrent " << Freport(nyears) << "     " << Fcurrent_slope << endl;
  report << endl;
  report << "Stock-Recruitment Relationship Parameters" << endl;
  report << " alpha     = " << SR_alpha << endl;
  report << " beta      = " << SR_beta << endl;
  report << " R0        = " << SR_R0 << endl;
  report << " S0        = " << SR_S0 << endl;
```

```
  report << " steepness = " << SR_steepness << endl;
  report << "Spawning Stock, Obs Recruits(year+1), Pred Recruits(year+1), standardized residual" << endl;
  report << "init  xxxx  " << recruits(1) << "  " << SR_pred_recruits(1) << "  " <<
            (log(recruits(1))-log(SR_pred_recruits(1)))/recruit_sigma(1) << endl;
  for (iyear=1;iyear<nyears;iyear++)
    report << iyear+year1-1 << "  " << SSB(iyear) << "  " << recruits(iyear+1) << "  "  <<
SR_pred_recruits(iyear+1) << "  " <<
             (log(recruits(iyear+1))-log(SR_pred_recruits(iyear+1)))/recruit_sigma(iyear+1) << endl;
  report << nyears+year1-1 << "  " << SSB(nyears) << "       xxxx   " << SR_pred_recruits(nyears+1) << endl;
  report << endl;

  report << "Annual stock recruitment parameters" << endl;
  report << "Year, S0_vec, R0_vec, steepness_vec, s_per_r_vec" << endl;
  for (iyear=1;iyear<=nyears;iyear++)
    report << iyear+year1-1 << "  " << S0_vec(iyear) << "  " << R0_vec(iyear) << "  " << steepness_vec(iyear) <<
"  " << s_per_r_vec(iyear) << endl;
  report << endl;

  report << "Root Mean Square Error computed from Standardized Residuals" << endl;
  report << "Component                 #resids         RMSE" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     report << "_Catch_Fleet_" << ifleet << "               " << nyears << "           " <<
sqrt(mean(square(Catch_stdresid(ifleet)))) << endl;
  }
  report << "Catch_Fleet_Total            " << nyears*nfleets << "           " <<
sqrt(mean(square(Catch_stdresid))) << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if (norm2(Discard_stdresid(ifleet)) > 0.0 )
     {
        report << "_Discard_Fleet_" << ifleet << "             " << nyears << "           " <<
sqrt(mean(square(Discard_stdresid(ifleet)))) << endl;
     }
     else
     {
        report << "_Discard_Fleet_" << ifleet << "             " << "0" << "            " << "0" << endl;
     }
  }
  if (norm2(Discard_stdresid) > 0.0)
  {
     report << "Discard_Fleet_Total          " << nyears*nfleets << "           " <<
sqrt(mean(square(Discard_stdresid))) << endl;
  }
  else
  {
     report << "Discard_Fleet_Total          " << "0" << "            " << "0" << endl;
  }
  for (ind=1;ind<=nindices;ind++)
  {
     report << "_Index_" << ind << "                     " << index_nobs(ind) << "           " <<
sqrt(mean(square(index_stdresid(ind)))) << endl;
  }
  report << "Index_Total                  " << sum(index_nobs) << "           " <<
sqrt(mean(square(index_stdresid))) << endl;
  N_year1_rmse=0.0;
  N_year1_rmse_nobs=0;
  if (lambda_N_year1_devs > 0.0 && norm2(N_year1_stdresid) > 0.0)
  {
     N_year1_rmse=sqrt(mean(square(N_year1_stdresid)));
     N_year1_rmse_nobs=nages-1;
  }
  report << "Nyear1                       " << N_year1_rmse_nobs << "           " << N_year1_rmse << endl;
  Fmult_year1_rmse=0.0;
  Fmult_year1_rmse_nobs=0;
  if (sum(lambda_Fmult_year1) > 0.0 && norm2(Fmult_year1_stdresid) > 0.0)
  {
     Fmult_year1_rmse=sqrt(mean(square(Fmult_year1_stdresid)));
     Fmult_year1_rmse_nobs=nfleets;
  }
```

```
  report << "Fmult_Year1                  " << Fmult_year1_rmse_nobs << "           " << Fmult_year1_rmse <<
endl;
  Fmult_devs_fleet_rmse=0.0;
  Fmult_devs_fleet_rmse_nobs=0;
  Fmult_devs_rmse=0.0;
  Fmult_devs_rmse_nobs=0;
  for (ifleet=1;ifleet<=nfleets;ifleet++)
  {
     if (sum(lambda_Fmult_devs) > 0.0 && norm2(Fmult_devs_stdresid(ifleet)) > 0.0)
     {
        Fmult_devs_fleet_rmse(ifleet)=sqrt(mean(square(Fmult_devs_stdresid(ifleet))));
        Fmult_devs_fleet_rmse_nobs(ifleet)=nyears-1;
     }
     report << "_Fmult_devs_Fleet_" << ifleet << "          " << Fmult_devs_fleet_rmse_nobs(ifleet) << "
" << Fmult_devs_fleet_rmse(ifleet) << endl;
  }
  if (sum(lambda_Fmult_devs) > 0.0 && norm2(Fmult_devs_stdresid) > 0.0)
  {
     Fmult_devs_rmse=sqrt(mean(square(Fmult_devs_stdresid)));
     Fmult_devs_rmse_nobs=nfleets*(nyears-1);
  }
  report << "Fmult_devs_Total             " << Fmult_devs_rmse_nobs << "           " << Fmult_devs_rmse << endl;
  SR_rmse=0.0;
  SR_rmse_nobs=0;
  if (lambda_recruit_devs > 0.0 && norm2(SR_stdresid) > 0.0)
  {
     SR_rmse=sqrt(mean(square(SR_stdresid)));
     SR_rmse_nobs=nyears;
  }
  report << "Recruit_devs                 " << SR_rmse_nobs << "           " << SR_rmse << endl;
  sel_rmse=0.0;
  sel_rmse_nobs=0;
  if (sum(sel_lambda) > 0.0 && norm2(sel_stdresid) > 0.0)
  {
     sel_rmse=sqrt(mean(square(sel_stdresid)));
     for (k=1;k<=nselparm;k++)
     {
        if (sel_lambda(k) > 0.0)
           sel_rmse_nobs+=1;
     }
  }
  report << "Fleet_Sel_params             " << sel_rmse_nobs << "           " << sel_rmse << endl;
  indexsel_rmse=0.0;
  indexsel_rmse_nobs=0;
  if (sum(indexsel_lambda) > 0.0 && norm2(indexsel_stdresid) > 0.0)
  {
     indexsel_rmse=sqrt(mean(square(indexsel_stdresid)));
     for (k=1;k<=nindexselparms;k++)
     {
        if (indexsel_lambda(k) > 0.0)
           indexsel_rmse_nobs+=1;
     }
  }
  report << "Index_Sel_params             " << indexsel_rmse_nobs << "           " << indexsel_rmse << endl;
  q_year1_rmse=0.0;
  q_year1_rmse_nobs=0;
  if (sum(lambda_q_year1) > 0.0 && norm2(q_year1_stdresid) > 0.0)
  {
     q_year1_rmse=sqrt(mean(square(q_year1_stdresid)));
     for (ind=1;ind<=nindices;ind++)
     {
        if (lambda_q_year1(ind) > 0.0)
           q_year1_rmse_nobs+=1;
     }
  }
  report << "q_year1                      " << q_year1_rmse_nobs << "           " << q_year1_rmse << endl;
  q_devs_rmse=0.0;
  q_devs_rmse_nobs=0;
  if (sum(lambda_q_devs) > 0.0 && norm2(q_devs_stdresid) > 0.0)
  {
     q_devs_rmse=sqrt(mean(square(q_devs_stdresid)));
```

```
     for (ind=1;ind<=nindices;ind++)
     {
        if (lambda_q_year1(ind) > 0.0)
           q_devs_rmse_nobs+=index_nobs(ind)-1;
     }
  }
  report << "q_devs                       " << q_devs_rmse_nobs << "           " << q_devs_rmse << endl;
  steepness_rmse=0.0;
  steepness_rmse_nobs=0;
  if (lambda_steepness > 0.0)
  {
     steepness_rmse=sfabs(steepness_stdresid);
     steepness_rmse_nobs=1;
  }
  report << "SR_steepness                 " << steepness_rmse_nobs << "           " << steepness_rmse << endl;
  SR_scaler_rmse=0.0;
  SR_scaler_rmse_nobs=0;
  if (lambda_SR_scaler > 0.0)
  {
     SR_scaler_rmse=sfabs(SR_scaler_stdresid);
     SR_scaler_rmse_nobs=1;
  }
  report << "SR_scaler                    " << SR_scaler_rmse_nobs << "           " << SR_scaler_rmse << endl;
  report << endl;

  report << "Stage2 Multipliers for Multinomials (Francis 2011)" << endl;
  report << "Catch by Fleet" << endl;
  report << Neff_stage2_mult_catch << endl;
  report << "Discards by Fleet" << endl;
  report << Neff_stage2_mult_discard << endl;
  report << "Indices" << endl;
  report << Neff_stage2_mult_index << endl;
  report << endl;
  report << "New Input ESS based on applying stage2 multipliers" << endl;
  report << "Catch (rows are fleets, columns are years)" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    report << input_eff_samp_size_catch(ifleet) * Neff_stage2_mult_catch(ifleet) << endl;
  }
  report << "Discards (rows are fleets, columns are years)" << endl;
  for (ifleet=1;ifleet<=nfleets;ifleet++){
    report << input_eff_samp_size_discard(ifleet) * Neff_stage2_mult_discard(ifleet) << endl;
  }
  report << "Indices (rows are indices, columns are years)" << endl;
  for (ind=1;ind<=nindices;ind++){
    report << index_Neff_init(ind) * Neff_stage2_mult_index(ind) << endl;
  }
  report << endl;

  if (do_projections==1 && last_phase())
  {
     project_into_future();
     report << "Projection into Future" << endl;
     report << "Projected NAA" << endl;
     report << proj_NAA << endl;
     report << "Projected Directed FAA" << endl;
     report << proj_F_dir << endl;
     report << "Projected Discard FAA" << endl;
     report << proj_F_Discard << endl;
     report << "Projected Nondirected FAA" << endl;
     report << proj_F_nondir << endl;
     report << "Projected Catch at Age" << endl;
     report << proj_catch << endl;
     report << "Projected Discards at Age (in numbers)" << endl;
     report << proj_Discard << endl;
     report << "Projected Yield at Age" << endl;
     report << proj_yield << endl;
     report << "Year, Total Yield (in weight), Total Discards (in weight), TotJan1B, SSB, proj_what, SS/SSmsy"
<< endl;
     for (iyear=1;iyear<=nprojyears;iyear++)
```

```
       report << year1+nyears-1+iyear << "  " << proj_total_yield(iyear) << "  " << proj_total_Discard(iyear) <<
"  " << proj_TotJan1B(iyear) << "  " << proj_SSB(iyear) << "  " << proj_what(iyear) << "  " <<
proj_SSB(iyear)/SSmsy << endl;
     report << endl;
  }
  else
  {
     report << "Projections not requested" << endl;
     report << endl;
  }
  report << "that's all" << endl;

  if (make_Rfile==1 && last_phase())
  {
    #include "make-Rfile_asap3.cxx"  // ADMB2R code in this file
  }

RUNTIME_SECTION
  convergence_criteria 1.0e-4
  maximum_function_evaluations 1000,1600,10000

FINAL_SECTION
  //Calculates how long is taking to run
  // this code is based on the Widow Rockfish model (from Erik H. Williams, NMFS-Santa Cruz, now Beaufort)
  time(&finish);
  elapsed_time = difftime(finish,start);
  hour = long(elapsed_time)/3600;
  minute = long(elapsed_time)%3600/60;
  second = (long(elapsed_time)%3600)%60;
  cout<<endl<<endl<<"starting time: "<<ctime(&start);
  cout<<"finishing time: "<<ctime(&finish);
  cout<<"This run took: ";
  cout<<hour<<" hours, "<<minute<<" minutes, "<<second<<" seconds."<<endl<<endl<<endl;
```

Appendix 2: make-Rfile_asap3.cxx (to make rdat file)

```
// this is the file that creates the R data object

//===========================================================================
// Open the output file using the AD Model Builder template name, and
// specify 6 digits of precision
// use periods in R variable names instead of underscore

// variables used for naming fleets and indices
adstring ifleetchar;
adstring indchar;
adstring onenum(4);
adstring onednm(4);
adstring twodnm(4);

open_r_file(adprogram_name + ".rdat", 6, -99999);

  // metadata
  open_r_info_list("info", true);
      wrt_r_item("program", "ASAP3");
  close_r_info_list();


  // basic parameter values
  open_r_info_list("parms", false);
      wrt_r_item("styr", year1);
      wrt_r_item("endyr", (year1+nyears-1));
      wrt_r_item("nyears", nyears);
      wrt_r_item("nages", nages);
      wrt_r_item("nfleets", nfleets);
      wrt_r_item("nselblocks", nselblocks);
      wrt_r_item("navailindices", navailindices);
```

```
    wrt_r_item("nindices", nindices);
close_r_info_list();

// run options
open_r_info_list("options", false);
    wrt_r_item("isfecund", isfecund);
    wrt_r_item("frac.yr.spawn", fracyearSSB);
    wrt_r_item("do.projections", do_projections);
    wrt_r_item("ignore.guesses", ignore_guesses);
    wrt_r_item("Freport.agemin", Freport_agemin);
    wrt_r_item("Freport.agemax", Freport_agemax);
    wrt_r_item("Freport.wtopt", Freport_wtopt);
    wrt_r_item("use.likelihood.constants", use_likelihood_constants);
    wrt_r_item("Fmult.max.value", Fmult_max_value);
    wrt_r_item("N.year1.flag",NAA_year1_flag);
    wrt_r_item("do.mcmc",doMCMC);
close_r_info_list();

// Likelihood contributions
open_r_info_list("like", false);
    wrt_r_item("lk.total", obj_fun);
    wrt_r_item("lk.catch.total", (lambda_catch_tot*catch_tot_likely));
    wrt_r_item("lk.discard.total", (lambda_Discard_tot*discard_tot_likely));
    wrt_r_item("lk.index.fit.total", (lambda_ind*likely_ind));
    wrt_r_item("lk.catch.age.comp", likely_catch);
    wrt_r_item("lk.discards.age.comp", likely_Discard);
    wrt_r_item("lk.index.age.comp", likely_index_age_comp);
    wrt_r_item("lk.sel.param.total", sum_sel_lambda_likely);
    wrt_r_item("lk.index.sel.param.total", sum_indexsel_lambda_likely);
    wrt_r_item("lk.q.year1", (lambda_q_year1*q_year1_likely));
    wrt_r_item("lk.q.devs", (lambda_q_devs*q_devs_likely));
    wrt_r_item("lk.Fmult.year1.total", (lambda_Fmult_year1*Fmult_year1_likely));
    wrt_r_item("lk.Fmult.devs.total", (lambda_Fmult_devs*Fmult_devs_likely));
    wrt_r_item("lk.N.year1", (lambda_N_year1_devs*N_year1_likely));
    wrt_r_item("lk.Recruit.devs", (lambda_recruit_devs*likely_SR_sigma));
    wrt_r_item("lk.SR.steepness", (lambda_steepness*steepness_likely));
    wrt_r_item("lk.SR.scaler", (lambda_SR_scaler*SR_scaler_likely));
    wrt_r_item("lk.Fmult.Max.penalty", Fmult_max_pen);
    wrt_r_item("lk.F.penalty", fpenalty);
close_r_info_list();

// fleet, block, and index specific likelihood contributions
open_r_info_list("like.additional", false);
    wrt_r_item("nfleets",nfleets);
    wrt_r_item("nindices",nindices);
    wrt_r_item("nselparms",nselparm);
    wrt_r_item("nindexselparms",nindexselparms);
    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring lk_catch_fleet = adstring("lk.catch.") + ifleetchar;
            wrt_r_item(lk_catch_fleet,(lambda_catch_tot(ifleet)*catch_tot_likely(ifleet)));
        }

        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring lk_discard_fleet = adstring("lk.discard.") + ifleetchar;
            wrt_r_item(lk_discard_fleet,(lambda_Discard_tot(ifleet)*discard_tot_likely(ifleet)));
        }

        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
```

```
        ifleetchar = "fleet" + onenum;
        adstring lk_Fmult_year1_fleet = adstring("lk.Fmult.year1.") + ifleetchar;
        wrt_r_item(lk_Fmult_year1_fleet,(lambda_Fmult_year1(ifleet)*Fmult_year1_likely(ifleet)));
    }

    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring lk_Fmult_devs_fleet = adstring("lk.Fmult.devs.") + ifleetchar;
        wrt_r_item(lk_Fmult_devs_fleet,(lambda_Fmult_devs(ifleet)*Fmult_devs_likely(ifleet)));
    }
}

if (nindices>1)
{
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        adstring lk_index_fit_ind = adstring("lk.index.fit.") + indchar;
        wrt_r_item(lk_index_fit_ind,(lambda_ind(ind)*likely_ind(ind)));
    }

    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        adstring lk_q_year1_ind = adstring("lk.q.year1.") + indchar;
        wrt_r_item(lk_q_year1_ind,(lambda_q_year1(ind)*q_year1_likely(ind)));
    }

    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
```

```
            }
            indchar = "ind" + twodnm;
            adstring lk_q_devs_ind = adstring("lk.q.devs.") + indchar;
            wrt_r_item(lk_q_devs_ind,(lambda_q_devs(ind)*q_devs_likely(ind)));
        }
    }

    for (k=1;k<=nselparm;k++)
    {
        if (sel_phase(k) >=1)
        {
            if (k <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(k, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (k <=99)
            {
                itoa(k, twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            adstring lk_sel_param = adstring("lk.sel.param.") + twodnm;
            wrt_r_item(lk_sel_param,(sel_lambda(k)*sel_likely(k)));

        }
    }

    for (k=1;k<=nindexselparms;k++)
    {
        if (indexsel_phase(k) >=1)
        {
            if (k <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(k, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (k <=99)
            {
                itoa(k, twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            adstring lk_indexsel_param = adstring("lk.indexsel.param.") + twodnm;
            wrt_r_item(lk_indexsel_param,(indexsel_lambda(k)*indexsel_likely(k)));

        }
    }

close_r_info_list();

// initial guesses
open_r_list("initial.guesses");
    open_r_info_list("SR.inits", false);
        wrt_r_item("is.SR.scaler.R",is_SR_scaler_R);
        wrt_r_item("SR.scaler.init",SR_scaler_ini);
        wrt_r_item("SR_steepness.init",SR_steepness_ini);
    close_r_info_list();
    wrt_r_complete_vector("NAA.year1.init",NAA_year1_ini);
    wrt_r_complete_vector("Fmult.year1.init",Fmult_year1_ini);
    wrt_r_complete_vector("q.year1.init",q_year1_ini);
    wrt_r_complete_vector("release.mort", release_mort);
    wrt_r_complete_vector("index.use.flag",use_index);
close_r_list();

// control parameters
open_r_list("control.parms");
```

```
      open_r_info_list("phases", false);
          wrt_r_item("phase.Fmult.year1", phase_Fmult_year1);
          wrt_r_item("phase.Fmult.devs", phase_Fmult_devs);
          wrt_r_item("phase.recruit.devs", phase_recruit_devs);
          wrt_r_item("phase.N.year1.devs", phase_N_year1_devs);
          wrt_r_item("phase.q.year1", phase_q_year1);
          wrt_r_item("phase.q.devs", phase_q_devs);
          wrt_r_item("phase.SR.scaler", phase_SR_scaler);
          wrt_r_item("phase.steepness", phase_steepness);
      close_r_info_list();
      open_r_info_list("singles", false);
          wrt_r_item("lambda.N.year1.devs",lambda_N_year1_devs);
          wrt_r_item("N.year1.cv",N_year1_CV);
          wrt_r_item("lambda.recruit.devs",lambda_recruit_devs);
          wrt_r_item("lambda.steepness",lambda_steepness);
          wrt_r_item("steepness.cv",steepness_CV);
          wrt_r_item("lambda.SR.scaler",lambda_SR_scaler);
          wrt_r_item("SR.scaler.cv", SR_scaler_CV);
      close_r_info_list();
      open_r_info_list("mcmc", false);
          wrt_r_item("mcmc.nyear.opt",MCMCnyear_opt);
          wrt_r_item("mcmc.n.boot",MCMCnboot);
          wrt_r_item("mcmc.n.thin",MCMCnthin);
          wrt_r_item("mcmc.seed",MCMCseed);
          wrt_r_item("fillR.opt",fillR_opt);
          wrt_r_item("Ravg.start",Ravg_start);
          wrt_r_item("Ravg.end",Ravg_end);
      close_r_info_list();
      wrt_r_complete_vector("recruit.cv",recruit_CV);
      wrt_r_complete_vector("lambda.ind",lambda_ind);
      wrt_r_complete_vector("lambda.catch.tot",lambda_catch_tot);
      open_r_matrix("catch.tot.cv");
          wrt_r_matrix(catch_tot_CV, 2, 2);
          wrt_r_namevector(year1, (year1+nyears-1));
          wrt_r_namevector(1, nfleets);
      close_r_matrix();
      wrt_r_complete_vector("lambda.Discard.tot",lambda_Discard_tot);
      open_r_matrix("discard.tot.cv");
          wrt_r_matrix(discard_tot_CV, 2, 2);
          wrt_r_namevector(year1, (year1+nyears-1));
          wrt_r_namevector(1, nfleets);
      close_r_matrix();
      wrt_r_complete_vector("lambda.Fmult.year1",lambda_Fmult_year1);
      wrt_r_complete_vector("Fmult.year1.cv",Fmult_year1_CV);
      wrt_r_complete_vector("lambda.Fmult.devs",lambda_Fmult_devs);
      wrt_r_complete_vector("Fmult.devs.cv",Fmult_devs_CV);
      wrt_r_complete_vector("lambda.q.year1",lambda_q_year1);
      wrt_r_complete_vector("q.year1.cv",q_year1_CV);
      wrt_r_complete_vector("lambda.q.devs",lambda_q_devs);
      wrt_r_complete_vector("q.devs.cv",q_devs_CV);
      wrt_r_complete_vector("directed.fleet",directed_fleet);
      wrt_r_complete_vector("WAA.point.bio",WAApointbio);
      wrt_r_complete_vector("index.units.aggregate", index_units_aggregate);
      wrt_r_complete_vector("index.units.proportions", index_units_proportions);
      wrt_r_complete_vector("index.WAA.point", index_WAApoint);
      wrt_r_complete_vector("index.month", index_month);
      wrt_r_complete_vector("index.sel.start.age",index_start_age);
      wrt_r_complete_vector("index.sel.end.age",index_end_age);
      wrt_r_complete_vector("index.sel.choice",index_sel_choice);
      wrt_r_complete_vector("index.age.comp.flag",index_estimate_proportions);
  close_r_list();

  // selectivity input matrices for fleets and indices
  open_r_list("sel.input.mats");
      // input selectivity matrix, contains combinations of values not used, see fleet_sel_option to determine
which choice was made for each block
      open_r_matrix("fleet.sel.ini");
          wrt_r_matrix(sel_ini, 2, 2);
          wrt_r_namevector(1, (nselblocks*(nages+6)));
          wrt_r_namevector(1, 4);
      close_r_matrix();
```

```
    open_r_matrix("index.sel.ini");
        wrt_r_matrix(index_sel_ini, 2, 2);
        wrt_r_namevector(1, (navailindices*(nages+6)));
        wrt_r_namevector(1, 4);
    close_r_matrix();
close_r_list();

// Weight at Age matrices
open_r_list("WAA.mats");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring WAA_c_fleet = adstring("WAA.catch.") + ifleetchar;
        open_r_matrix(WAA_c_fleet);
            wrt_r_matrix(WAAcatchfleet(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
        adstring WAA_d_fleet = adstring("WAA.discard.") + ifleetchar;
        open_r_matrix(WAA_d_fleet);
            wrt_r_matrix(WAAdiscardfleet(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
    }
    open_r_matrix("WAA.catch.all");
        wrt_r_matrix(WAAcatchall, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    open_r_matrix("WAA.discard.all");
        wrt_r_matrix(WAAdiscardall, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    open_r_matrix("WAA.ssb");
        wrt_r_matrix(WAAssb, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    open_r_matrix("WAA.jan1");
        wrt_r_matrix(WAAjan1b, 2, 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_namevector(1, nages);
    close_r_matrix();

    for (ind=1;ind<=nindices;ind++)
    {
        if (index_units_aggregate(ind)==1 || index_units_proportions(ind)==1)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            adstring index_WAA_name = adstring("index.WAA.") + indchar;
```

```
            open_r_matrix(index_WAA_name);
                wrt_r_matrix(index_WAA(ind), 2, 2);
                wrt_r_namevector(year1, (year1+nyears-1));
                wrt_r_namevector(1,nages);
            close_r_matrix();
        }
    }

  close_r_list();

  // Year by Age Matrices (not fleet specific): M, maturity, fecundity, N, Z, F,
  open_r_matrix("M.age");
      wrt_r_matrix(M, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("maturity");
      wrt_r_matrix(mature, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("fecundity");
      wrt_r_matrix(fecundity, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("N.age");
      wrt_r_matrix(NAA, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("Z.age");
      wrt_r_matrix(Z, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  open_r_matrix("F.age");
      wrt_r_matrix(FAA_tot, 2, 2);
      wrt_r_namevector(year1, (year1+nyears-1));
      wrt_r_namevector(1, nages);
  close_r_matrix();

  // Fleet by Year Matrices: Catch.tot.obs, Catch.tot.pred, Catch.tot.resid), Discard.tot.obs, Discard.tot.pred,
Discard.tot.resid
  open_r_matrix("catch.obs");
      wrt_r_matrix(Catch_tot_fleet_obs, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  open_r_matrix("catch.pred");
      wrt_r_matrix(Catch_tot_fleet_pred, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  open_r_matrix("catch.std.resid");
      wrt_r_matrix(Catch_stdresid, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  open_r_matrix("discard.obs");
      wrt_r_matrix(Discard_tot_fleet_obs, 2, 2);
      wrt_r_namevector(1, nfleets);
      wrt_r_namevector(year1, (year1+nyears-1));
```

```
close_r_matrix();

open_r_matrix("discard.pred");
    wrt_r_matrix(Discard_tot_fleet_pred, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("discard.std.resid");
    wrt_r_matrix(Discard_stdresid, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();


// Age Compositions: Catch and Discards observed and predicted by fleet
open_r_list("catch.comp.mats");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring ccomp_ob = adstring("catch.") + ifleetchar + adstring(".ob");
        open_r_matrix(ccomp_ob);
            wrt_r_matrix(CAA_prop_obs(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();

        adstring ccomp_pr = adstring("catch.") + ifleetchar + adstring(".pr");
        open_r_matrix(ccomp_pr);
            wrt_r_matrix(CAA_prop_pred(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();

        adstring dcomp_ob = adstring("discard.") + ifleetchar + adstring(".ob");
        open_r_matrix(dcomp_ob);
            wrt_r_matrix(Discard_prop_obs(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();

        adstring dcomp_pr = adstring("discard.") + ifleetchar + adstring(".pr");
        open_r_matrix(dcomp_pr);
            wrt_r_matrix(Discard_prop_pred(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(sel_start_age(ifleet), sel_end_age(ifleet));
        close_r_matrix();
    }
close_r_list();


// fleet selectivity blocks
open_r_matrix("fleet.sel.blocks");
    wrt_r_matrix(sel_blocks, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

// vectors of fleet selectivity options
wrt_r_complete_vector("fleet.sel.start.age",sel_start_age);
wrt_r_complete_vector("fleet.sel.end.age",sel_end_age);
wrt_r_complete_vector("fleet.sel.option",sel_option);

// selecivity matrices for each fleet
open_r_list("fleet.sel.mats");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
```

```
        ifleetchar = "fleet" + onenum;
        adstring sel_fleet_char = adstring("sel.m.") + ifleetchar;
        open_r_matrix(sel_fleet_char);
            wrt_r_matrix(sel_by_fleet(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1, nages);
        close_r_matrix();
    }
close_r_list();

// Fmults by fleet
open_r_matrix("fleet.Fmult");
    wrt_r_matrix(Fmult, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

// FAA by fleet directed and discarded
open_r_list("fleet.FAA");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;

        adstring fleet_FAA_dir = adstring("FAA.directed.") + ifleetchar;
        open_r_matrix(fleet_FAA_dir);
            wrt_r_matrix(FAA_by_fleet_dir(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();

        adstring fleet_FAA_discard = adstring("FAA.discarded.") + ifleetchar;
        open_r_matrix(fleet_FAA_discard);
            wrt_r_matrix(FAA_by_fleet_Discard(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
    }
close_r_list();

// proportion release year by age matrices by fleet
open_r_list("fleet.prop.release");
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring fleet_prop_release = adstring("prop.release.") + ifleetchar;
        open_r_matrix(fleet_prop_release);
            wrt_r_matrix(proportion_release(ifleet), 2, 2);
            wrt_r_namevector(year1, (year1+nyears-1));
            wrt_r_namevector(1,nages);
        close_r_matrix();
    }
close_r_list();

// fleet specific annual effective sample sizes input and estimated for catch and discards
open_r_matrix("fleet.catch.Neff.init");
    wrt_r_matrix(input_eff_samp_size_catch, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("fleet.catch.Neff.est");
    wrt_r_matrix(effective_sample_size, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("fleet.discard.Neff.init");
```

```
    wrt_r_matrix(input_eff_samp_size_discard, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

open_r_matrix("fleet.discard.Neff.est");
    wrt_r_matrix(effective_Discard_sample_size, 2, 2);
    wrt_r_namevector(1, nfleets);
    wrt_r_namevector(year1, (year1+nyears-1));
close_r_matrix();

// vector of q for each index if qdevs turned off, otherwise a list with vectors for each index
if (phase_q_devs <= 0)
{
    wrt_r_complete_vector("q.indices",  column(q_by_index,1));
}
else
{
    open_r_list("q.random.walk");
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            adstring q_ind = adstring("q.") + indchar;
            wrt_r_complete_vector(q_ind,q_by_index(ind));
        }
    close_r_list();
}

// vectors for Freport and Biomasses (TotJan1B, SSB, ExploitableB)
wrt_r_complete_vector("F.report",Freport);
wrt_r_complete_vector("tot.jan1.B",TotJan1B);
wrt_r_complete_vector("SSB",SSB);
wrt_r_complete_vector("exploitable.B",ExploitableB);


// F reference values
open_r_info_list("Fref", false);
    wrt_r_item("Fmax", Fmax_report);
    wrt_r_item("F01", F01_report);
    wrt_r_item("F30", F30SPR_report);
    wrt_r_item("F40", F40SPR_report);
    wrt_r_item("Fcurrent", Freport(nyears));
close_r_info_list();

// SR curve parameters
open_r_info_list("SR.parms", false);
    wrt_r_item("SR.alpha", SR_alpha);
    wrt_r_item("SR.beta", SR_beta);
    wrt_r_item("SR.SPR0", SR_spawners_per_recruit);
    wrt_r_item("SR.S0", SR_S0);
    wrt_r_item("SR.R0", SR_R0);
    wrt_r_item("SR.steepness", SR_steepness);
close_r_info_list();

// SR obs, pred, devs, and standardized resids
// note year coresponds to age-1 recruitment, when plot SR curve have to offset SSB and R by one year
open_r_df("SR.resids", year1, (year1+nyears-1), 2);
    wrt_r_namevector(year1, (year1+nyears-1));
```

```
        wrt_r_df_col("year", year1, (year1+nyears-1));
        wrt_r_df_col("recruits", recruits, year1);
        wrt_r_df_col("R.no.devs", SR_pred_recruits, year1);
        wrt_r_df_col("logR.dev", log_recruit_devs, year1);
        wrt_r_df_col("SR.std.resid", SR_stdresid, year1);
    close_r_df();

    // annual values for S0_vec, R0_vec, steepness_vec, s_per_r_vec (last year values should match SR.parms
  values)
    open_r_df("SR.annual.parms", year1, (year1+nyears-1), 2);
        wrt_r_namevector(year1, (year1+nyears-1));
        wrt_r_df_col("year", year1, (year1+nyears-1));
        wrt_r_df_col("S0.vec", S0_vec, year1);
        wrt_r_df_col("R0.vec", R0_vec, year1);
        wrt_r_df_col("steepness.vec", steepness_vec, year1);
        wrt_r_df_col("s.per.r.vec",s_per_r_vec, year1);
    close_r_df();



    // index stuff starts here

    // selectivity by index
    open_r_matrix("index.sel");
        wrt_r_matrix(indexsel, 2, 2);
        wrt_r_namevector(1, nindices);
        wrt_r_namevector(1, nages);
    close_r_matrix();

    wrt_r_complete_vector("index.nobs",index_nobs);

    // index year counter (sequential numbers starting at 1 for first year)
    open_r_list("index.year.counter");
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            wrt_r_complete_vector(indchar,index_time(ind));
        }
    close_r_list();

    // index years
    open_r_list("index.year");
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
```

```
        wrt_r_complete_vector(indchar,index_year(ind));
    }
close_r_list();

// index CV
open_r_list("index.cv");
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        wrt_r_complete_vector(indchar,index_cv(ind));
    }
close_r_list();

// index sigmas (derived from input CV)
open_r_list("index.sigma");
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        wrt_r_complete_vector(indchar,index_sigma(ind));
    }
close_r_list();

// index observations
open_r_list("index.obs");
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        wrt_r_complete_vector(indchar,index_obs(ind));
    }
close_r_list();

// predicted indices
```

```
  open_r_list("index.pred");
      for (ind=1;ind<=nindices;ind++)
      {
          if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
          {
              itoa(ind, onednm, 10);
              twodnm = "0" + onednm;
          }
          else if (ind <=99)
          {
              itoa(ind,twodnm, 10);
          }
          else
          {
              twodnm = "00";
          }
          indchar = "ind" + twodnm;
          wrt_r_complete_vector(indchar,index_pred(ind));
      }
  close_r_list();

  // index standardized residuals
  open_r_list("index.std.resid");
      for (ind=1;ind<=nindices;ind++)
      {
          if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
          {
              itoa(ind, onednm, 10);
              twodnm = "0" + onednm;
          }
          else if (ind <=99)
          {
              itoa(ind,twodnm, 10);
          }
          else
          {
              twodnm = "00";
          }
          indchar = "ind" + twodnm;
          wrt_r_complete_vector(indchar,index_stdresid(ind));
      }
  close_r_list();

  // index proportions at age related output
  if (max(index_estimate_proportions)>0)  // check to see if any West Coast style indices, skip this section if
all are East Coast style
  {
      // Index Age Comp
      open_r_list("index.comp.mats");
          for (ind=1;ind<=nindices;ind++)
          {
              if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
              {
                  itoa(ind, onednm, 10);
                  twodnm = "0" + onednm;
              }
              else if (ind <=99)
              {
                  itoa(ind,twodnm, 10);
              }
              else
              {
                  twodnm = "00";
              }
              indchar = "ind" + twodnm;

              adstring acomp_ob = indchar + adstring(".ob");
              open_r_matrix(acomp_ob);
                  wrt_r_matrix(output_index_prop_obs(ind), 2, 2);
                  wrt_r_namevector(year1, (year1+nyears-1));
                  wrt_r_namevector(1,nages);
```

```
            close_r_matrix();

            adstring acomp_pr = indchar + adstring(".pr");
            open_r_matrix(acomp_pr);
                wrt_r_matrix(output_index_prop_pred(ind), 2, 2);
                wrt_r_namevector(year1, (year1+nyears-1));
                wrt_r_namevector(1, nages);
            close_r_matrix();
        }
    close_r_list();

  // Neff for indices initial guess
  open_r_matrix("index.Neff.init");
      wrt_r_matrix(index_Neff_init, 2, 2);
      wrt_r_namevector(1, nindices);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

  // Neff for indices estimated
  open_r_matrix("index.Neff.est");
      wrt_r_matrix(index_Neff_est, 2, 2);
      wrt_r_namevector(1, nindices);
      wrt_r_namevector(year1, (year1+nyears-1));
  close_r_matrix();

}  // end if-statement to test for any index age comp


// deviations section: only reported if associated with lambda > 0
if (lambda_N_year1_devs > 0)
{
    // note: obs and pred include age 1 while std.resid does not - do not use age 1 when plotting
    open_r_list("deviations.N.year1");
        wrt_r_complete_vector("N.year1.obs",NAA(1));
        wrt_r_complete_vector("N.year1.pred",nyear1temp);
        wrt_r_complete_vector("N.year1.std.resid",N_year1_stdresid);
    close_r_list();
}


// RMSE number of observations section
open_r_info_list("RMSE.n", false);
    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring rmse_n_catch_fleet = adstring("rmse.n.catch.") + ifleetchar;
            wrt_r_item(rmse_n_catch_fleet,nyears);
        }
    }
    wrt_r_item("rmse.n.catch.tot",(nyears*nfleets));

    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring rmse_n_discard_fleet = adstring("rmse.n.discard.") + ifleetchar;
            if (sum(Discard_tot_fleet_obs(ifleet)) > 0)
            {
                wrt_r_item(rmse_n_discard_fleet,nyears);
            }
            else
            {
                wrt_r_item(rmse_n_discard_fleet,0);
            }
```

```
        }
    }
    if (sum(Discard_tot_fleet_obs) > 0)
    {
        wrt_r_item("rmse.n.discard.tot",(nyears*nfleets));
    }
    else
    {
        wrt_r_item("rmse.n.discard.tot",0);
    }

    if (nindices>1)
    {
        for (ind=1;ind<=nindices;ind++)
        {
            if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
            {
                itoa(ind, onednm, 10);
                twodnm = "0" + onednm;
            }
            else if (ind <=99)
            {
                itoa(ind,twodnm, 10);
            }
            else
            {
                twodnm = "00";
            }
            indchar = "ind" + twodnm;
            adstring rmse_n_ind = adstring("rmse.n.") + indchar;
            wrt_r_item(rmse_n_ind,index_nobs(ind));
        }
    }
    wrt_r_item("rmse.n.ind.total",sum(index_nobs));

    wrt_r_item("rmse.n.N.year1",N_year1_rmse_nobs);

    wrt_r_item("rmse.n.Fmult.year1",Fmult_year1_rmse_nobs);

    if (nfleets>1)
    {
        for (ifleet=1;ifleet<=nfleets;ifleet++)
        {
            if (nfleets < 10) itoa(ifleet, onenum, 10);
            else onenum="0";
            ifleetchar = "fleet" + onenum;
            adstring rmse_n_Fmult_devs_fleet = adstring("rmse.n.Fmult.devs.") + ifleetchar;
            wrt_r_item(rmse_n_Fmult_devs_fleet,Fmult_devs_fleet_rmse_nobs(ifleet));
        }
    }
    wrt_r_item("rmse.n.Fmult.devs.total",Fmult_devs_rmse_nobs);

    wrt_r_item("rmse.n.recruit.devs",SR_rmse_nobs);

    wrt_r_item("rmse.n.fleet.sel.params",sel_rmse_nobs);

    wrt_r_item("rmse.n.index.sel.params",indexsel_rmse_nobs);

    wrt_r_item("rmse.n.q.year1",q_year1_rmse_nobs);

    wrt_r_item("rmse.n.q.devs",q_devs_rmse_nobs);

    wrt_r_item("rmse.n.SR.steepness",steepness_rmse_nobs);

    wrt_r_item("rmse.n.SR.scaler",SR_scaler_rmse_nobs);

close_r_info_list();

// RMSE section
open_r_info_list("RMSE", false);
    if (nfleets>1)
```

```
{
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring rmse_catch_fleet = adstring("rmse.catch.") + ifleetchar;
        wrt_r_item(rmse_catch_fleet,sqrt(mean(square(Catch_stdresid(ifleet)))));
    }
}
wrt_r_item("rmse.catch.tot",sqrt(mean(square(Catch_stdresid))));

if (nfleets>1)
{
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
        if (nfleets < 10) itoa(ifleet, onenum, 10);
        else onenum="0";
        ifleetchar = "fleet" + onenum;
        adstring rmse_discard_fleet = adstring("rmse.discard.") + ifleetchar;
        if (sum(Discard_tot_fleet_obs(ifleet)) > 0)
        {
            wrt_r_item(rmse_discard_fleet,sqrt(mean(square(Discard_stdresid(ifleet)))));
        }
        else
        {
            wrt_r_item(rmse_discard_fleet,0);
        }
    }
}
if (sum(Discard_tot_fleet_obs) > 0)
{
    wrt_r_item("rmse.discard.tot",sqrt(mean(square(Discard_stdresid))));
}
else
{
    wrt_r_item("rmse.discard.tot",0);
}

if (nindices>1)
{
    for (ind=1;ind<=nindices;ind++)
    {
        if (ind <= 9)  // note have to deal with one digit and two digit numbers separately
        {
            itoa(ind, onednm, 10);
            twodnm = "0" + onednm;
        }
        else if (ind <=99)
        {
            itoa(ind,twodnm, 10);
        }
        else
        {
            twodnm = "00";
        }
        indchar = "ind" + twodnm;
        adstring rmse_ind = adstring("rmse.") + indchar;
        wrt_r_item(rmse_ind,sqrt(mean(square(index_stdresid(ind)))));
    }
}
wrt_r_item("rmse.ind.total",sqrt(mean(square(index_stdresid))));

wrt_r_item("rmse.N.year1",N_year1_rmse);

wrt_r_item("rmse.Fmult.year1",Fmult_year1_rmse);

if (nfleets>1)
{
    for (ifleet=1;ifleet<=nfleets;ifleet++)
    {
```

```
             if (nfleets < 10) itoa(ifleet, onenum, 10);
             else onenum="0";
             ifleetchar = "fleet" + onenum;
             adstring rmse_Fmult_devs_fleet = adstring("rmse.Fmult.devs.") + ifleetchar;
             wrt_r_item(rmse_Fmult_devs_fleet,Fmult_devs_fleet_rmse(ifleet));
         }
     }
     wrt_r_item("rmse.Fmult.devs.total",Fmult_devs_rmse);

     wrt_r_item("rmse.recruit.devs",SR_rmse);

     wrt_r_item("rmse.fleet.sel.params",sel_rmse);

     wrt_r_item("rmse.index.sel.params",indexsel_rmse);

     wrt_r_item("rmse.q.year1",q_year1_rmse);

     wrt_r_item("rmse.q.devs",q_devs_rmse);

     wrt_r_item("rmse.SR.steepness",steepness_rmse);

     wrt_r_item("rmse.SR.scaler",SR_scaler_rmse);

 close_r_info_list();

 open_r_list("Neff.stage2.mult");
     wrt_r_complete_vector("Neff.stage2.mult.catch", Neff_stage2_mult_catch);
     wrt_r_complete_vector("Neff.stage2.mult.discard", Neff_stage2_mult_discard);
     wrt_r_complete_vector("Neff.stage2.mult.index", Neff_stage2_mult_index);
 close_r_list();

// close file
close_r_file();
```

AGEPRO User Guide

Jon Brodziak
NOAA Fisheries
Pacific Islands Fisheries Science Center
2570 Dole Street
Honolulu, HI 96822
Tel: 808-983-2964
Fax: 808-983-2902
Email: Jon.Brodziak@NOAA.GOV

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Abstract

This User Guide describes the AGEPRO version 3.4 model and software to perform stochastic projections for an exploited age-structured fish stock. This new version allows for multiple recruitment models to account for alternative hypotheses about recruitment dynamics and applies model-averaging to predict the distribution of realized recruitment given estimates of recruitment model probabilities. The AGEPRO model can be used to quantify the probable effects of a harvest scenario on an age-structured population over a given time horizon. Primary outputs include the projected distribution of spawning biomass, fishing mortality, recruitment, and landings by time period. This guide describes the numerical algorithms as well as the theoretical basis of the projection model. Program inputs, outputs, structure and general usage are also described in detail. The AGEPRO model is distributed in the hope that it will be useful, but includes no warranty. If you have problems with the software, please consult the User Guide and if the problem persists, please contact Alan.Seaver@NOAA.GOV or Jon.Brodziak@NOAA.GOV.

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Introduction

The AGEPRO program can be used to perform stochastic projections of the abundance of an exploited age-structured population over a given time horizon. The primary purpose of the AGEPRO model is to produce management strategy projections that characterize the sampling distribution of key fishery system outputs such as landings, spawning stock biomass, population age structure, and fishing mortality accounting for uncertainty in initial population estimates, future recruitment, and natural mortality. The acronym "AGEPRO" derives from **age**-structured **pro**jections, in contrast to size- or biomass-based projection models. The user can evaluate alternative harvest scenarios by setting quotas or fishing mortality rates in each year of the time horizon.

Three elements of uncertainty can be included in an AGEPRO projection: **recruitment**, **initial population size**, and **natural mortality**. Recruitment is the primary stochastic element in the population model, where recruitment is defined as the number of fish entering the modeled population at the beginning of each year in the time horizon. There are a total of fifteen stochastic recruitment models that can be used for population projection. It is also possible to simulate a deterministic recruitment trajectory (see recruitment model 9 below).

Initial population size is the second potential element of uncertainty for population projection. To include this element, a distribution of initial population sizes at age must be calculated a priori. This is typically done using bootstrapping, Markov chain Monte carlo simulation, or other techniques in most age-structured assessments. If recruitment occurs at an age greater than age-1, then additional distributions of population size at age and fishing mortality at age prior to the projection time horizon are needed. Alternatively, projections can be based on the best point estimate of initial population size.

The third potential element of uncertainty is natural mortality. The user can choose to simulate natural mortality as a constant or a stochastic process at age. In the stochastic case, the instantaneous natural mortality rate is simulated as an autocorrelated lognormal process. Annual natural mortality rates at age are random samples from age-specific uniform distributions with means equal to the age-specific vulnerabilities of each age class to the full natural mortality rate and with age-specific coefficients of variation.

The AGEPRO model was initially developed in 1994 to determine optimal strategies to rebuild a depleted fish stock. The model was reviewed at the May 1994 meeting of the Northeast Fisheries Science Center Methods Working Group (Brodziak and Rago, 1994; Brodziak et al. 1998). Subsequently, the model was applied to groundfish stocks at the 18th SARC (NEFSC 1994) to evaluate Amendment 5 harvest scenarios (NEFMC 1994) and was applied again in 1995 to assist with Amendment 7 (NEFMC 1996). The User Guide was prepared in 1997 to provide documentation and has been updated since then to describe modifications to the model and software. The current program is written in Fortran 95 to allow for dynamic array allocation and to achieve rapid processing speeds.

Age-Structured Population Model

A simple age-structured population model is the basis for the AGEPRO model and software. This model represents an iteroparous fish population whose abundance changes due to fluctuations in recruitment, natural mortality, and fishing mortality. Population size at age changes continuously throughout the year due to the concurrent forces of natural and fishing mortality. Recruitment (R) to the population occurs at the beginning of each year (January 1st) and is the first element in the population size at age vector (Table 1).

Population Abundance, Survival, and Spawning Biomass

The AGEPRO model calculates the number of fish alive within each age class of the population through time. Let Y denote the number of years in a projection where t indexes time for t=1,2, ..., Y. The maximum number of years (Y) in the projection is a dynamic variable specified by the user and constrained by the amount of computer memory. The youngest age class comprises the recruits and the age of recruitment (r) is specified by the user. The oldest age class is a plus-group which consists of all fish that are at least as old as a cutoff age (A). The maximum number of age classes is 100. For each age class, the number of fish alive at the beginning of a each calendar year (January 1st) is $N_j(t)$ where “j” indexes age class and “t” indexes year. Note that $N_A(t)$ is the number of fish that are age-A or older at the beginning of year t. Given this, the population abundance at the beginning of year t is the vector $\underline{N}(t)$ with R(t) used as an alternate notation to emphasize that a recruitment submodel is needed to stochastically generate recruitment through time horizon

$$(1) \qquad \underline{N}(t) = \begin{bmatrix} N_r(t) \\ N_{r+1}(t) \\ N_{r+2}(t) \\ \vdots \\ N_A(t) \end{bmatrix} = \begin{bmatrix} R(t) \\ N_{r+1}(t) \\ N_{r+2}(t) \\ \vdots \\ N_A(t) \end{bmatrix}$$

When the age of recruitment is greater than age-1, the modeled age classes are age-r through the plus-group. In this case, the dynamics of age classes younger than age-r are not explicitly modeled.

Population survival at age from year t-1 to year t is calculated using instantaneous fishing and mortality rates at age. To describe annual survival through mortality, let $M_a(t)$ denote the instantaneous natural mortality rate on age group a and let $F_j(t)$ denote the instantaneous fishing mortality rate for age-j fish in year t. Population size at age in year t for the age classes indexed by a= r +1 to A-1 is given by

$$(2) \qquad N_a(t) = N_{a-1}(t-1) \cdot e^{-M_{a-1}(t-1) - F_{a-1}(t-1)}$$

Similarly, population size at age in year t for the plus group of fish age-A and older is given by

(3) $$N_A(t) = N_A(t-1)\cdot e^{-M_A(t-1)-F_A(t-1)} + N_{A-1}(t-1)\cdot e^{-M_{A-1}(t-1)-F_{A-1}(t-1)}$$

where survival for the plus-group involves an age-A and an age-(A-1) component. Incoming recruitment is determined through a stochastic process that is either dependent or independent of spawning biomass in year t-r (see **Stock-Recruitment Relationship** below).

Annual spawning biomass ($B_S(t)$) is calculated from the population size vector $\underline{N}(t)$ and total mortality rates as well as information on sexual maturity and weight at age. To describe natural mortality at age in year t, let M(t) denote the instantaneous natural mortality rate and let $P_{M,a}(t)$ be the fraction of the natural mortality rate experienced by age group a . The age-specific natural mortality rate ($M_a(t)$) is then the product of M and the vulnerability at age-a, i.e., $M_a(t) = M(t)PM_a(t)$. To describe annual survival, let $F_j(t)$ be the instantaneous fishing mortality rate for age-j fish in year t. Further, let $P_{S,j}(t)$ denote the average fraction of age-j fish that are sexually mature in year t and let $W_{S,j}(t)$ denote the average spawning weight of an age-j fish in year t. Last, let $P_Z(t)$ denote the proportion of total mortality that occurs from January 1st to the mid-point of the spawning season. Given this, population size at the midpoint of the spawning season in year t ($\underline{N}_s(t)$) is obtained by applying instantaneous natural and fishing mortality rates that occur prior to the spawning season to the population vector at the beginning of the year, $\underline{N}(t)$.

(4) $$\underline{N}_S(t) = \begin{bmatrix} N_r(t)\cdot e^{-P_Z(t)[M_R(t)+F_R(t)]} \\ N_{r+1}(t)\cdot e^{-P_Z(t)[M_{R+1}(t)+F_{R+1}(t)]} \\ N_{r+2}(t)\cdot e^{-P_Z(t)[M_{R+2}(t)+F_{R+2}(t)]} \\ \vdots \\ N_A(t)\cdot e^{-P_Z(t)[M_A(t)+F_A(t)]} \end{bmatrix}$$

The amount of spawning biomass in year t, $B_S(t)$, is the sum of the weight of mature fish at the midpoint of the spawning season

(5) $$B_S(t) = \sum_{a=r}^{A} W_{S,a}(t)\cdot P_{S,a}(t)\cdot N_a(t)\cdot e^{-P_Z(t)[M_a(t)+F_a(t)]}$$

Catch, Landings, and Discards

The fishery catch depends on the fraction of the population that is vulnerable to harvest or the exploitable stock size. Catch by age class is determined by the Baranov catch equation (see, for example, Quinn and Deriso 1999), and the catch of age-a fish in year t ($C_a(t)$) is

(6) $$C_a(t) = \frac{F_a(t)}{M_a(t) + F_a(t)}\left[1 - e^{-M_a(t) - F_a(t)}\right]\cdot N_a(t)$$

To account for age-specific discarding of fish, let $P_{D,a}(t)$ be the proportion of age-a fish that are discarded and die in year t, and let $W_{L,a}(t)$ and $W_{D,a}(t)$ be the average weight at age-a in year t for landed and discarded fish, respectively. Then, if discarding is included in the projections (discflag=true), the total landed weight in year t, denoted by L(t), is

(7) $$L(t) = \sum_{a=r}^{A} C_a(t)\cdot\left[1 - P_{D,a}(t)\right]\cdot W_{L,a}(t)$$

Similarly, the total weight of discarded fish in year t, denoted by D(t), is

(8) $$D(t) = \sum_{a=r}^{A} C_a(t)\cdot P_{D,a}(t)\cdot W_{D,a}(t)$$

Population Harvest

There are two options for determining the level of population harvest in each year of the time horizon. The first option is a user-input fishing mortality rate (effort-based management, quotaflag=false & mixflag=false). The second option is a user-input landings quota (quota-based management, quotaflag=true & mixflag=false). These two harvest options can be mixed in any order within a given projection run where effort-based management is applied in some years and quota-based management in the other years (mixflag=true). In this case, the user sets a binary index I(t) to determine the harvest option for each year in the projection time horizon. If I(t) =1, a quota-based management is applied in year t; else if I(t)=0, effort-based management is applied in year t. A mixture of quotas and effort-based harvest can be useful when projecting forward from a previous assessment when only catch is available for intervening years.

When effort-based management is applied, catch at age is determined by setting $F_a(t)$ for each age class. In this case, the fishing mortality rate on age-a fish in year t is the product of the fully-selected fishing mortality rate, denoted by F(t), and the age-specific fishery selectivity (or partial recruitment) of age-a fish, denoted by $P_{F,a}(t)$

(9) $$F_a(t) = F(t)\cdot P_{F,a}(t)$$

Landings and discards, if applicable, are then determined from $F_a(t)$. When quota-based management is applied, however, the F(t) that would yield the landings quota must be determined numerically.

Under quota-based management, the landings quota in year t, denoted by Q(t), will translate into a variety of effective fishing mortality rates depending on population size, fishery selectivity, and discarding, if applicable. Ignoring the time dimension for a moment, a landings quota Q can be expressed as a function of F, Q= L(F), where F is the fully-recruited F and L is the landings as a function of F. To see this result, observe that the catch of age-a fish can be expressed as a function of F

(10) $$C_a(F) = \frac{F \cdot P_{F,a}(t)}{M_a(t) + F \cdot P_{F,a}(t)} \left[1 - e^{-M_a(t) - F \cdot P_{F,a}(t)}\right] \cdot N_a(t)$$

As a result, landings can also be expressed as a function of F

(11) $$L(F) = \sum_{a=r}^{A} C_a(F) \cdot \left[1 - P_{D,a}(t)\right] \cdot W_{L,a}(t)$$

The fully-recruited fishing mortality which satisfies the equation Q=L(F) can be found using Newton's method. Details of this numerical approach are provided below (see Appendix). Quotas which exceed the exploitable biomass of the population are infeasible; conditions defining infeasible quotas are also specified below (Appendix).

Stock-Recruitment Relationship

In general, the relationship between spawning stock B_S and recruitment R is highly variable owing to intrinsic variability in factors governing early life history survival and to measurement error in the estimates of recruitment and the spawning biomass that generated it. The stock-recruitment relationship ultimately defines the sustainable yield curve and its expected variability assuming that the stochastic processes of growth, maturation, and natural mortality are density-independent and stationary throughout the time horizon. Quinn and Deriso (1999) provide a useful general discussion of stock-recruitment models, renewal processes, and sustainable yield. Note that the assumed stock-recruitment relationship does not affect the initial population abundance at the beginning of the time horizon (see **Initial Population Abundance**).

A total of nineteen stochastic recruitment models are available for population projection in the AGEPRO software. Twelve of the recruitment models are functionally dependent on B_S while seven do not depend on B_S. Five of the recruitment models have time-dependent parameters, ten are time-invariant, and four may include time as a predictor, or not. The user is responsible for the choice and parameterization of the recruitment models. In what follows, the age of recruitment to the population is denoted as “r”; the recruitment age is either age-1 or age-r for r>1. A description of each of the recruitment models follows. Also note that the absolute units for recruitment are numbers of age-r fish, while for B_S, the absolute units are kilograms of spawning biomass in each of the recruitment models below.

Model 1. Markov Matrix

A Markov matrix approach to modeling recruitment may be useful when there is uncertainty about the functional form of the stock-recruitment relationship. A Markov matrix contains transition probabilities that define the probability of obtaining a given level of recruitment given that B_S was within a defined interval range. In particular, the distribution of recruitment is assumed to follow a multinomial distribution conditioned on the spawning biomass interval (state). The Markov matrix model depends on spawning biomass and is time-invariant.

An empirical approach to estimate a Markov matrix uses stock-recruitment data to determine the parameters of a multinomial distribution for each spawning biomass state. In this case, matrix elements can be empirically determined by counting the number of times that a recruitment observation interval lies within a given spawning biomass state, defined by an interval of spawning biomass, and normalizing over all spawning states. To do this, assume that there are m recruitment states and n spawning biomass states defined by disjoint intervals on the recruitment and spawning biomass axes

$$I_j = \left[B_{S,j}, B_{S,j+1}\right] \text{ and } O_k = \left[R_k, R_{k+1}\right] \tag{12}$$

where $B_{S,j}$ and R_k are endpoints of the disjoint intervals of spawning biomass and recruitment. Note that $B_{S,1}=0$ and that the spawning biomass intervals are defined by the cut points $B_{S,2}$, $B_{S,3}$, ..., $B_{S,J}$.

The conditional probability of realizing the k^{th} recruitment state given that spawning biomass ($P_{j,k}$) is in the j^{th} state is the element in the j^{th} row and k^{th} column of the Markov matrix where

$$P_{j,k} = \Pr\left(N_r \in O_k \,|\, B_S \in I_j\right) \tag{13}$$

This conditional probability can be approximated by the computing the number of points in the stock recruitment data set that fall within the I_j x O_k cell and normalizing within each spawning biomass interval I_j. If x_{jk} represents the number of stock-recruitment observations in cell I_j x O_k and there is at least one observation in spawning state j, then an empirical estimate of $P_{j,k}$ is

$$\Pr\left(R \in O_k \mid B_S \in I_j\right) = \frac{x_{j,k}}{\sum_k x_{j,k}} \tag{14}$$

Note that the $P_{j,k}$ are nonnegative and the sum of $P_{j,k}$ over k is unity.

If there are few stock-recruitment observations, then an empirical approach will produce imprecise estimates of the $P_{j,k}$. In this case, elements of the Markov matrix might be estimated using either a frequentist bootstrapping or a Bayesian parametric approach.

Up to 25 recruitment states and up to 10 B_S states can be used in the Markov matrix model. The simulated recruitments ($N_{r,k}$) are defined to be the midpoints of the recruitment intervals O_k. That is, $R = N_{r,k} = (R_k + R_{k+1})/2$. For each spawning biomass interval, the user also needs to specify the conditional probabilities of realizing the expected recruitment level, e.g., the $P_{j,k}$.

Model 2. Empirical Recruits Per Spawning Biomass Distribution

For some stocks, the distribution of recruits per spawner may be independent of the number of spawners over the range of observed data. The recruitment per spawning biomass (R/B_S) model randomly generates recruitment under the assumption that the distribution of the R/B_S ratio is stationary and independent of stock size. The empirical recruits per spawning biomass distribution model depends on spawning biomass and is time-invariant.

To describe this nonparametric approach, let S_t be the R/B_S ratio for the t^th stock recruitment data point

(15) $$S_t = \frac{N_r(t)}{B_S(t-r)}$$

and let R_S represent the s_{th} element in the ordered set of S_t. The empirical probability density function for R_S, denoted as $g(R_S)$, is 1/T for all values of R/B_S where T = the number of stock-recruitment data points. Let $G(R_S)$ denote the cumulative distribution function (cdf). Let $G(R_{MIN}) = 0$ and $G(R_{MAX}) = 1$ so that the cdf of R_s can be written as

(16) $$G(R_S) = \frac{s-1}{T-1}$$

Random values of $S=R/B_S$ can be generated by applying the probability integral transform to the empirically derived cdf. To do this, let U be a uniformly distributed random variable on the interval [0,1]. The value of R/B_S corresponding to U is determined by applying the inverse function of the cdf $G(R_s)$. In particular, when U is an integer multiple of 1/(T-1) so that U=s/(T-1) then $R/B_S = G^{-1}(U) = R_S$. Otherwise R/B_S can be obtained by linear interpolation when U is not a multiple of 1/(T-1).

In particular, if (s-1)/(T-1) < U < s/(T-1), then

(17) $$U = \left(\frac{\frac{s}{T-1} - \frac{s-1}{T-1}}{R_{S+1} - R_S} \right) \left(\frac{R}{B_S} - R_S \right) + \frac{s-1}{T-1}$$

Solving for R/B_S as a function of U yields

(18) $$\frac{R}{B_S} = (T-1)(R_{S+1} - R_S)\left(U - \frac{s-1}{T-1} \right) + R_S$$

where the interpolation index s is determined as the greatest integer in 1+U(T-1). Given a random value of R/B_S, recruitment is generated as

(19) $$R(t) = N_r(t) = B_S(t-r)\cdot\frac{R}{B_S}$$

The AGEPRO program can generate stochastic recruitments using model 2 with up to 100 stock-recruitment data points.

Model 3. Empirical Recruitment Distribution

Another simple model for generating recruitment is to draw randomly from the observed set of recruitments { $N_r(1), N_r(2), ..., N_r(T)$}. This may be a useful approach when the recruitment has randomly fluctuated about its mean and appears to be independent of spawning biomass for the observed range of data. In this case, the recruitment distribution may be modeled as a multinomial random variable where the probability of randomly choosing a particular recruitment is 1/T given T observed recruitments. The empirical recruitment distribution model does not depend on spawning biomass and is time-invariant.

In this model, realized recruitment N_r is simulated using

(20) $$\Pr\left(R = N_r(t)\right) = \frac{1}{T}\ ,\quad for\ t \in \{1,2,...,T\}$$

The empirical recruitment distribution approach is nonparametric and assumes that future recruitment is totally independent of spawning stock biomass. When current levels of B_S are near the midrange of historical values this assumption is acceptable. However, if contemporary B_S values are near the bottom of the range, then this approach could be overly optimistic, for it assumes that all historically observed recruitment levels are possible, regardless of B_S. The AGEPRO program allows up to 100 observed recruitments for random sampling. Note that the empirical recruitment distribution model can be used to make deterministic projections by specifying a single observed recruitment.

Model 4. Two-Stage Empirical Recruits Per Spawning Biomass Distribution

The two-stage recruits per spawning biomass model is a direct generalization of the R/B_S model where the spawning stock of the population is categorized into “low” and “high” states. The two-stage empirical recruits per spawning biomass distribution model depends on spawning biomass and is time-invariant.

In this model, there is an R/B_S distribution for the low spawning biomass state and an R/B_S distribution for the high spawning biomass state. Let G_{LOW} be the cdf and let T_{LOW} be the number of R/B_S values for the low B_S state. Similarly, let G_{HIGH} be the cdf and let T_{HIGH} be the number of R/B_S values for the high B_S state. Further, let B_S^* denote the cutoff level of B_S such that, if $B_S > B_S^*$, then B_S falls in the high state. Conversely if $B_S < B_S^*$ then B_S falls in the low state. Recruitment is stochastically generated from G_{LOW} or G_{HIGH} using equations (18) and (19) dependent on the B_S state. The AGEPRO program can generate stochastic recruitments using the two-stage model with up to 100 stock-recruitment data points per B_S state.

Model 5. Beverton-Holt Curve with Lognormal Error

The Beverton-Holt curve (Beverton and Holt 1957) with lognormal errors is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. The Beverton-Holt curve with lognormal error model depends on spawning biomass and is time-invariant.

The Beverton-Holt curve with lognormal error generates recruitment as

$$n_r(t) = \frac{\alpha \cdot b_S(t-r)}{\beta + b_S(t-r)} \cdot e^w$$

(21)

$$\textit{where } \ w \sim N\left(0, \sigma_w^2\right),\ R(t) = c_R \cdot n_r(t),\ \textit{and } \ B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters "α", "β", and the error variance"σ_w^2" and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Beverton-Holt curve have been estimated in relative units determined (e.g., $n_r(t)$ and $b_S(t-r)$) which can be converted to absolute values with the conversion coefficients. Note that the absolute value for recruitment is numbers of fish, while for B_S, the absolute value is kilograms of B_S. For example, if the stock-recruitment curve was estimated with stock-recruitment data that were measured in millions of fish and thousands of metric tons of B_S, then $c_R = 10^6$ and $c_B = 10^6$. It may be important to estimate the parameters of the stock-recruitment curve in relative units to reduce the potential effects of roundoff error on parameter estimates. It is important to note that the expected value of the lognormal error term is not unity but is $\exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $\exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Beverton-Holt curve has a log-scale error term w with zero mean.

The Beverton-Holt curve is often reparameterized in a modified form with steepness (h), virgin recruitment (R_0), and virgin spawning biomass ($B_{S,0}$) parameters. The modified Beverton-Holt curve produces $h \cdot R_0$ recruits when $B_S = 0.2 \cdot B_{S,0}$ and has the form

(22)
$$R = \frac{4hR_0B_S}{B_{S,0}(1-h) + B_S(5h-1)}$$

The parameters α and β can be expressed as functions of the parameters of the modified Beverton-Holt curve as

(23) $$\alpha = \frac{4hR_0}{5h-1} = 4B_{S,0}\frac{h}{\left(\frac{B_{S,0}}{R_0}\right)(5h-1)}$$

and

(24) $$\beta = \frac{B_{S,0}(1-h)}{(5h-1)} = \frac{\alpha\left(\frac{B_{S,0}}{R_0}\right)(h^{-1}-1)}{4}$$

Thus, parameter estimates for the modified curve can be used to determine the Beverton-Holt parameters for the AGEPRO program.

Model 6. Ricker Curve with Lognormal Error

The Ricker curve (Ricker 1954) with lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. The Ricker curve with lognormal error model depends on spawning biomass and is time invariant.

The Ricker curve with lognormal error generates recruitment as

(25)
$$n_r(t) = \alpha \cdot b_S(t-r) \cdot e^{-\beta \cdot b_S(t-r)} \cdot e^w$$
$$\text{where } w \sim N(0, \sigma_w^2),\ R(t) = c_R \cdot n_r(t),\ \text{and } B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters "α", "β", and the error variance "σ_w^2" and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Ricker curve have been estimated in relative units determined by the user (e.g., $n_r(t)$ and $b_S(t-r)$) and then converted to absolute values with the conversion coefficients. It is important to note that the expected value of the lognormal error term is not unity but is $\exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $\exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Ricker curve has a log-scale error term w with zero mean.

Model 7. Shepherd Curve with Lognormal Error

The Shepherd curve (Shepherd 1982) with lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to stochastic variation. The Shepherd curve with lognormal error model depends on spawning biomass and is time-invariant.

The Shepherd curve with lognormal error generates recruitment as

$$n_r(t) = \frac{\alpha \cdot b_S(t-r)}{1 + \left(\frac{b_S(t-r)}{k}\right)^{\beta}} \cdot e^w$$

(26)

$$where \;\; w \sim N\left(0, \sigma_w^2\right),\; R(t) = c_R \cdot n_r(t),\; and \;\; B_S(t) = c_B \cdot b_S(t)$$

The stock-recruitment parameters "α", "β", "k" and the error variance "σ_w^2" and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. Here it is assumed that the parameter estimates for the Shepherd curve have been estimated in relative units determined by the user (e.g., $n_r(t)$ and $b_S(t-r)$) and then converted to absolute values with the conversion coefficients. It is important to note that the expected value of the lognormal error term is not unity but is $\exp\left(\frac{1}{2}\sigma_w^2\right)$. To generate a recruitment model that has a lognormal error term that is equal to 1, premultiply the parameter α by $\exp\left(-\frac{1}{2}\sigma_w^2\right)$; this mean correction applies when the lognormal error used to fit the Shepherd curve has a log-scale error term w with zero mean.

<u>Model 8. Lognormal Distribution</u>

The lognormal distribution provides a parametric model for stochastic recruitment generation. <u>The lognormal distribution model does not depend on spawning biomass and is time-invariant.</u>

The lognormal distribution generates recruitment as

$$n_r(t) = e^w$$

(27)

$$where \;\; w \sim N\left(\mu_{\log(r)}, \sigma_{\log(r)}^2\right) \;\; and \;\; R(t) = c_R \cdot n_r(t)$$

The lognormal distribution parameters "$\mu_{\log(r)}$" and the log-scale variance "$\sigma_{\log(r)}^2$" as well as the conversion coefficient for recruitment c_R are specified by the user. It is assumed that the parameters of the lognormal distribution have been estimated in relative units (e.g., $n_r(t)$) and then converted to absolute values with the conversion coefficients.

<u>Model 9. Time-Varying Empirical Recruitment Distribution</u>

The time-varying empirical recruitment distribution model is a time-dependent extension of model 3. The time-varying empirical recruitment distribution model does not depend on spawning biomass and is time-dependent.

In this approach, the empirical model for the estimation of recruitment draws randomly from a set of T recruitments levels for year t of the time horizon { $N_r(t,1)$, $N_r(t,2)$, ..., $N_r(t,T)$ }. Here the recruitment distribution for each year of the time horizon is a time-dependent multinomial random variable where the probability of randomly choosing a particular recruitment level is 1/T given T levels of recruitment. In particular, realized recruitment in year t is simulated using

$$\Pr\left(R(t) = N_r\left(t,k\right)\right) = \frac{1}{T} \ , \quad for\ k \in \{1,2,...,T\} \tag{28}$$

This approach is nonparametric and assumes that future recruitment is totally independent of spawning stock biomass. Further, it is the responsibility of the USER to determine an appropriate set of recruitment levels for each year of the time horizon. The AGEPRO software permits up to 100 observed recruitments for the recruitment distribution in each year of the time horizon. The user must input T potential recruitment levels in each year for a total of TY recruitment inputs. As in recruitment model 3, the time-varying empirical recruitment distribution model can be used to make deterministic projections by specifying a single recruitment level for each year of the time horizon. In this case, recruitment will be constant time series over the time horizon.

Model 10. Beverton-Holt Curve with Autocorrelated Lognormal Error

The Beverton-Holt curve with autocorrelated lognormal errors is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially-correlated stochastic variation. The Beverton-Holt curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.

The Beverton-Holt curve with autocorrelated lognormal error generates recruitment as

$$n_r\left(t\right) = \frac{\alpha \cdot b_S\left(t-r\right)}{\beta + b_S(t-r)} \cdot e^{\varepsilon_t}$$

$$\begin{aligned} &where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t\ \ where\ Var\left(\varepsilon\right) = \sigma^2, \\ &\sigma_w^2 = \left(1-\phi^2\right)\sigma^2,\ \ w_t \sim N\left(0,\sigma_w^2\right), \\ &R\left(t\right) = c_R \cdot n_r\left(t\right),\ and\ \ B_S\left(t\right) = c_B \cdot b_S\left(t\right) \end{aligned} \tag{29}$$

The stock-recruitment parameters "α", "β", "ε_0", "φ" and error variance "σ^2" and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If this value is not known, set ε_0=0.

Model 11. Ricker Curve with Autocorrelated Lognormal Error

The Ricker curve with autocorrelated lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially correlated stochastic variation. The Ricker curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.

The Ricker curve with autocorrelated lognormal error generates recruitment as

$$\begin{gathered} n_r(t) = \alpha \cdot b_S(t-r) \cdot e^{-\beta \cdot b_S(t-r)} \cdot e^{\varepsilon_t} \\ \text{where } \varepsilon_t = \phi \varepsilon_{t-1} + w_t \text{ where } Var(\varepsilon) = \sigma^2, \\ \sigma_w^2 = \left(1-\phi^2\right)\sigma^2,\ w_t \sim N\left(0,\sigma_w^2\right), \\ R(t) = c_R \cdot n_r(t), \text{ and } B_S(t) = c_B \cdot b_S(t) \end{gathered} \tag{30}$$

The stock-recruitment parameters “α”, “β”, “ε_0”, “φ” and error variance “σ^2” and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If the log-scale residual value is not known, set $\varepsilon_0=0$.

Model 12. Shepherd Curve with Autocorrelated Lognormal Error

The Shepherd curve with autocorrelated lognormal error is a parametric model of recruitment generation where survival to recruitment age is density dependent and subject to serially-correlated stochastic variation. The Shepherd curve with autocorrelated lognormal error model depends on spawning biomass and is time-dependent.

The Shepherd curve with autocorrelated lognormal error generates recruitment as

$$\begin{gathered} n_r(t) = \frac{\alpha \cdot b_S(t-r)}{1 + \left(\dfrac{b_S(t-r)}{k}\right)^{\beta}} \cdot e^{\varepsilon_t} \\ \text{where } \varepsilon_t = \phi \varepsilon_{t-1} + w_t \text{ where } Var(\varepsilon) = \sigma^2, \\ \sigma_w^2 = \left(1-\phi^2\right)\sigma^2,\ w_t \sim N\left(0,\sigma_w^2\right), \\ R(t) = c_R \cdot n_r(t), \text{ and } B_S(t) = c_B \cdot b_S(t) \end{gathered} \tag{31}$$

The stock-recruitment parameters ““α”, “β”, “k”, “ε_0”, “φ” and error variance “σ^2” and the conversion coefficients for recruitment c_R and spawning stock biomass c_B are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If this value is not known, set $\varepsilon_0=0$.

Model 13. Autocorrelated Lognormal Distribution
The autocorrelated lognormal distribution provides a parametric model for stochastic recruitment generation with serial correlation. The autocorrelated lognormal distribution model does not depend on spawning biomass and is time-dependent.

The autocorrelated lognormal distribution is

$$n_r\left(t\right) = e^{\mu_{\log(r)}} \cdot e^{\varepsilon_t}$$

$$\begin{aligned}(32)\qquad & where\ \ \varepsilon_t = \phi\varepsilon_{t-1} + w_t\ \ where\ Var\left(\varepsilon\right) = \sigma^2_{\log(r)},\\ & \sigma^2_w = \left(1-\phi^2\right)\sigma^2_{\log(r)},\ \ w_t \sim N\left(0,\sigma^2_w\right),\\ & and\ \ R\left(t\right) = c_R \cdot n_r\left(t\right)\end{aligned}$$

The lognormal distribution parameters "$\mu_{\log(r)}$", "$\sigma^2_{\log(r)}$", "ε_0", "φ" and the conversion coefficient for recruitment c_R are specified by the user. The parameter ε_0 is the log-scale residual for the stock-recruitment fit in the first time period prior to the projection. If this value is not known, set $\varepsilon_0=0$.

Model 14. Empirical Cumulative Distribution Function of Recruitment
The empirical cumulative distribution function of recruitment can be used to randomly generates recruitment under the assumption that the distribution of the R is stationary and independent of stock size. The empirical cumulative distribution function of recruitment model does not depend on spawning biomass and is time-invariant.

To describe this nonparametric approach, let R_S represent the S^{th} element in the ordered set of observed recruitment values. The empirical probability density function for R_S, denoted as $g(R_S)$, is 1/T for all observed values of R where T is the number of stock-recruitment data points. Let $G(R_S)$ denote the cumulative distribution function of observed recruitment.

Random values of R can be generated by applying the probability integral transform to the empirically derived cdf. Let U be a uniformly distributed random variable on the interval [0,1]. The value of R corresponding to U is determined by applying the inverse of the cdf $G(R_S)$. In particular, when U is an integer multiple of 1/(T-1) so that U=s/(T-1) then $R = G^{-1}(U) = R_S$. Otherwise R can be obtained by linear interpolation when U is not a multiple of 1/(t-1). In particular, if $(s-1)/(T-1) < U < s/(T-1)$, then

(33)
$$U = \left(\frac{\frac{s}{T-1} - \frac{s-1}{T-1}}{R_{S+1} - R_S} \right) \left(R - R_S \right) + \frac{s-1}{T-1}$$

Solving for R as a function of U yields

(34)
$$R = \left(T-1 \right) \left(R_{S+1} - R_S \right) \left(U - \frac{s-1}{T-1} \right) + R_S$$

where the interpolation index s is determined as the greatest integer in 1+U(T-1). The AGEPRO program can generate stochastic recruitments using model 14 with up to 100 recruitment data points.

Model 15. Two-Stage Empirical Cumulative Distribution Function of Recruitment

The two-stage empirical cumulative distribution function of recruitment model is an extension of Model 14 where the spawning stock of the population is categorized into "low" and "high" states. The two-stage empirical cumulative distribution function of recruitment model depends on spawning biomass and is time-invariant.

In particular, there is a cdf for R when the population is in the low B_S state and a cdf for R when the population is in the high B_S state. Let G_{LOW} be the cdf and let T_{LOW} be the number of R values for the low B_S state. Similarly, let G_{HIGH} be the cdf and let T_{HIGH} be the number of R values for the high B_S state. Further, let B_S* denote the cutoff level of B_S such that, if $B_S > B_S$*, then B_S falls in the high state, while if $B_S < B_S$* then B_S falls in the low state. Recruitment is stochastically generated from G_{LOW} or G_{HIGH} using equations (33) and (34) dependent on the B_S state. The AGEPRO program can generate stochastic recruitments using model 15 with up to 100 stock-recruitment data points.

Model 16. Linear Recruits Per Spawning Biomass Predictor with Normal Error

The linear recruits per spawning biomass predictor with normal error is a parametric model to simulate random values of recruits per spawning biomass R/B_S and associated random recruitments. The predictors in the linear model ($X_p(t)$) can be any continuous variable and may typically be survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. Similarly, if this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of R/B_S is generated using the linear model

(35) $$\frac{R}{B_S} = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient of the p^{th} predictor and ε is a normal distribution with zero mean and constant variance σ^2. It is possible negative values of R/B_S to be generated using this formulation; such values are excluded from the set of simulated values of R/B_S from equation (35) by testing if R/B_S repeating the random sampling until an acceptable positive value of R/B_S is obtained. This model randomly generates R/B_S values under the assumption that the linear predictor of the R/B_S ratio is stationary and independent of stock size. Random values of R/B_S are multiplied by realized spawning biomass to generate recruitment in each time period. The linear recruits per spawning biomass predictor with normal error depends on spawning biomass and is time-invariant unless time is used as a predictor.

Model 17. Loglinear Recruits Per Spawning Biomass Predictor with Lognormal Error

The loglinear recruits per spawning biomass predictor with lognormal error is a parametric model to simulate random values of recruits per spawning biomass R/B_S and associated random recruitments. Predictors for the loglinear model ($X_p(t)$) can be any continuous variable and could include survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. If this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of the natural logarithm of R/B_S is generated using the loglinear model

(36) $$\log\left(\frac{R}{B_S}\right) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient for the pth predictor and ε is a normal distribution with constant variance σ^2 and mean equal to $-\frac{1}{2}\sigma^2$. In this case, the mean of ε implies that the expected value of the lognormal error term is unity. This model generates positive random values of R/B_S under the assumption that the linear predictor of the R/B_S ratio is stationary and independent of stock size. Random values of R/B_S are multiplied by realized spawning biomass to generate recruitment in each time period. The loglinear recruits per spawning biomass predictor with lognormal error depends on spawning biomass and is time-invariant unless time is used as a predictor.

Model 18. Linear Recruitment Predictor with Normal Error

The linear recruitment predictor with normal error is a parametric model to simulate random values of recruitment R. The predictors in the linear model ($X_p(t)$) can be any continuous variable and could represent survey indices of cohort abundance or environmental covariates correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. Similarly, if this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of R is generated using the linear model

(37)
$$\begin{gathered} n_r(t) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon \\ with\ R(t) = c_R \cdot n_r(t) \end{gathered}$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient for the pth predictor, ε is a normal distribution with zero mean and constant variance σ^2, and the conversion coefficients for recruitment is c_R. It is possible that negative values of R can be generated using this formulation; such values are excluded from the set of simulated values of R from equation (37) by testing if R repeating the random sampling until an acceptable positive value of R is obtained. This model randomly generates R values under the assumption that the linear predictor of R is stationary and independent of stock size. The linear recruitment predictor with normal error does not depend on spawning biomass and is time-invariant unless time is used as a predictor.

Model 19. Loglinear Recruitment Predictor with Lognormal Error

The loglinear recruitment predictor with lognormal error is a parametric model to simulate random values of recruitment R. Predictors for the loglinear model ($X_p(t)$) can be any continuous variable such as survey indices of cohort abundance or environmental covariates that are correlated with recruitment strength. Input values of each predictor are required for each time period. If a value of a predictor is missing or not known for one or more periods, the missing values can be imputed using appropriate measures of central tendency, e.g., mean or median values. If this model has zero probability in a given time period (e.g., is not a member of the set of probable models), then dummy values can be input for each predictor. For each time period and simulation, a random value of the natural logarithm of R is generated using the loglinear model

(38)
$$\begin{gathered} \log(n_r(t)) = \beta_0 + \sum_{p=1}^{N_p} \beta_p \cdot X_p(t) + \varepsilon \\ with\ R(t) = c_R \cdot n_r(t) \end{gathered}$$

where N_p is the number of predictors, β_0 is the intercept, β_p is the linear coefficient for the pth predictor, ε is a normal distribution with constant variance σ^2 and mean equal to $-\frac{1}{2}\sigma^2$, and the conversion coefficients for recruitment is c_R. In this case, the mean of ε implies that the expected value of the lognormal error term is unity. This model generates positive random values of R under the assumption that the linear predictor of the R is stationary and independent of stock size. The loglinear recruitment predictor with lognormal error does not depend on spawning biomass and is time-invariant unless time is used as a predictor.

Constrained Recruits Per Spawning Biomass For Lognormal Error Models

The lognormal error terms for the six parametric recruitment models and the two lognormal distribution models can produce outliers of R/B_S in a projection analysis because lognormal distributions are highly skewed and generally have a wide tail. The impact of recruitment outliers on a projection analysis can be substantial. To address this issue, realized R/B_S values can be constrained for the eight stock-recruitment models that use the lognormal distribution by setting the bounded recruitment flag to be true (bdrecflag=true). Two constraints can be applied based on the level of B_S within the stock. Let $B_{S,CUT}$ denote a cutoff of B_S, where one R/B_S constraint operates below $B_{S,CUT}$ and another constraint operates above $B_{S,CUT}$. Let $[L_{Low} , U_{Low}]$ and $[L_{High} , U_{High}]$ denote the lower and upper R/B_S constraint intervals. If $B_S(t) < B_{S,CUT}$ in year t, then the realized R/B_S value generated from a lognormal recruitment model must lie within the interval $[L_{Low} , U_{Low}]$

(39) $$B_S(t) < B_{S,CUT} \Rightarrow \Pr\left(\frac{N_r(t)}{B_S(t)} \in \left[L_{Low}, U_{Low} \right] \right) = 1$$

If the realized R/B_S falls outside the interval $[L_{Low} , U_{Low}]$, additional recruitments are simulated until one falls within the constraining interval. Similarly, if $B_S(t) > B_{S,CUT}$ in year t then the realized R/B_S value generated from the recruitment model must lie within the interval $[L_{High} , U_{High}]$

(40) $$B_S(t) > B_{S,CUT} \Rightarrow \Pr\left(\frac{N_r(t)}{B_S(t)} \in \left[L_{High}, U_{High} \right] \right) = 1$$

If R/B_S values are expected to be more variable when B_S is above $B_{S,CUT}$ then it is natural to choose to have the interval $[L_{Low} , U_{Low}]$ to be within the interval $[L_{High} , U_{High}]$. In this case, the endpoints of the intervals are ordered as $L_{High} < L_{Low} < U_{Low} < U_{High}$.

The use of R/B_S constraints may be appropriate when the stock is near an historic low value of B_S. In this case, it would be natural to set $B_{S,CUT}$ to be the historic minimum value of B_S. Extrapolating R/B_S values that would result if $B_S(t)$ falls below $B_{S,CUT}$ could have substantial influence on estimating a rebuilding strategy for the stock. For example, one might constrain the realized R/B_S values when $B_S(t)$ falls below $B_{S,CUT}$ to be between the 10th and 90th percentiles of the empirical R/B_S distribution taken from the assessment. When $B_S(t)$ is above $B_{S,CUT}$, one might consider other bounds on the R/B_S values such as 1/100 of the minimum observed R/SB value or 100 times the maximum observed R/B_S value. Similar comments apply for a population that is near its historic maximum value of B_S. While the AGEPRO program requires the user to set two bounding intervals for R/B_S

values when the R/B_S constraint option is selected, one can create a single interval by either (i) setting the intervals to be equal or (ii) setting $B_{S,CUT}$ to be 0.

Recruitment Model Probabilities

Model uncertainty about the appropriate stock-recruitment model can be directly incorporated into AGEPRO projections. Multiple recruitment models may be appropriate when each model provides a similar statistical fit to a set of stock-recruitment data, where similarity can be measured using Akaike's, Bayesian, or deviance information criterion. Given a measure of a model's relative likelihood compared to a set of alternative models, one can use information criteria to calculate an individual model's probability of best representing the true state of nature. Alternatively, one can assign model probabilities based on judgment of other measures of goodness of fit or use this principle of indifference to assign equal probabilities in the absence of compelling information.

Regardless of the approach used to develop model probabilities, such probabilities can be used in AGEPRO to drive the stochastic recruitment dynamics in a straightforward manner. Suppose there are a total of N_M probable recruitment models, as determined by the user. The probability that recruitment model m is realized in year t is denoted by $P_{R,m}(t) \geq 0$. The conservation of probability implies that the sum of model probabilities over the set of probable models in each year is unity

$$\sum_{m=1}^{N_M} P_{R,m}(t) = 1 \tag{41}$$

This gives a conditional probability distribution for randomly sampling recruitment models in each year of the projection time horizon. As in previous versions of AGEPRO, a single recruitment model can be chosen for the entire projection time horizon by setting $N_M=1$. One advantage of including multiple recruitment models with possibly time-varying probabilities is that one can use auxiliary information on recruitment strength, such as survey indices of relative cohort abundance or environmental covariates, to make short-term recruitment predictions (1-2 years) and then change to a different recruitment model or set of models for medium-term recruitment predictions (3-5 years). Another advantage of including multiple recruitment models is to account for model selection uncertainty, which can be a substantial source of uncertainty.

Initial Population Abundance

There are two ways to set the initial population abundance, defined as the vector of the absolute number of fish alive on January 1st of the first year of the projection time horizon ($\underline{N}(1)$). The primary option is to use a set of samples from the distribution of the estimator of $\underline{N}(1)$. This option explicitly incorporates uncertainty in the estimate of initial population abundance into the projections and occurs when the logical variable bootflag=true. In this case, either frequentist methods such as bootstrapping or Bayesian methods such as Markov Chain Monte Carlo simulation could be used to determine the sampling distribution of $\underline{N}(1)$. The secondary option is to ignore uncertainty in the estimator of initial population abundance and use a single best estimate for the value of

$\underline{N}(1)$. In this case, only a point estimate of $\underline{N}(1)$ is required for the projections (bootflag=false).

The primary option uses a set of B initial population vectors, denoted by $\{ \underline{N}_{(1)}(1), \underline{N}_{(2)}(1), ..., \underline{N}_{(B)}(1) \}$, for stochastic projections. In this case, the set of B values are random samples from the distribution of the estimator of $\underline{N}(1)$ generated by the assessment model or other means. Given this, stochastic projection can be used to characterize the sampling distribution of key fishery outputs accounting for the uncertainty in the estimate of the initial population size. The age of recruitment determines the amount of information needed to use the primary option. If the age of recruitment is age-1 (age1recflag=true), then the primary option only requires the set of initial population vectors, $\underline{\mathbf{N}} = \{ \underline{N}_{(1)}(1), \underline{N}_{(2)}(1), ..., \underline{N}_{(B)}(1) \}$ to do the projections. For each initial condition $\underline{N}_{(j)}(1)$, a set of simulations will be performed using the specified harvest strategy. Since dynamic array allocation is used to dimension the set of initial population vectors, the user may choose to input a large number of initial population vectors (B>1000) within the practical constraint of available computer memory.

If the age of recruitment is age-r for r>1 (age1recflag=false), then the primary option requires additional information to do the projections. In particular, a set of B population vectors for each of the previous (R-1) years are needed: $\underline{\mathbf{N}}(0), \underline{\mathbf{N}}(-1), ..., \underline{\mathbf{N}}(2-R)$, where $\underline{\mathbf{N}}(j) = \{ \underline{N}_{(1)}(j), \underline{N}_{(2)}(j), ..., \underline{N}_{(B)}(j) \}$ for year j and the ordering of the population vectors within each $\underline{\mathbf{N}}(j)$ is identical for all prior time periods j. That is, the sequence of vectors $\{ \underline{N}_{(b)}(2-R), ..., \underline{N}_{(b)}(-1), \underline{N}_{(b)}(0), \underline{N}_{(b)}(1) \}$ represents the b^{th} distinct estimate of the trajectory of population numbers at age from time=2-R to time=1 as calculated from the assessment model. Similarly, a set of B fishing mortality at age vectors for each of the previous (R-1) years are needed: $\underline{\mathbf{F}}(0), \underline{\mathbf{F}}(-1), ..., \underline{\mathbf{F}}(2-R)$, where $\underline{\mathbf{F}}(j) = \{ \underline{F}_{(1)}(j), \underline{F}_{(2)}(j), ..., \underline{F}_{(B)}(j) \}$. Here $\underline{F}_{(b)}(j)$ is the vector of fishing mortalities at age in time j for the b^{th} initial population trajectory $\underline{F}_{(b)}(j) = \{ F_{r,(b)}(j) , F_{r+1,(b)}(j), ..., F_{A,(b)}(j)\}$. As with the $\underline{\mathbf{N}}(j)$, the ordering of the fishing mortality at age vectors within each $\underline{\mathbf{F}}(j)$ must be the same for all prior time periods. That is, each initial population and fishing mortality vector represents a single trajectory from the assessment model.

The secondary option is to use a single point estimate of $\underline{N}(1)$ for projection. In this case, one estimate of population abundance is assumed to characterize the initial state of the population. Since there is no uncertainty in the initial state of the population this option allows one to characterize the sampling distribution of key fishery outputs due to uncertainty in recruitment or natural mortality. Note that it is not possible to use an age of recruitment r>1 along with a single initial population vector which is entered directly in the input file (i.e., one cannot set both bootflag=false and age1recflag=false, see Table 1). It is possible, however, to use a single population vector with age of recruitment r>1 input from a file using the bootstrap input file option with the number of bootstraps B=1 (i.e., set bootflag=true and age1recflag=false).

Regardless of which initial population abundance option is used, the user must also specify the units of the initial population size vector taken from the assessment model. In particular, the initial population abundance vector can be input in relative units ($\underline{n}(1)$)

along with a conversion coefficient (k_N) to compute absolute numbers where absolute initial population abundance is the conversion coefficient times the relative abundance estimate, i.e., $\underline{N}(1) = k_{N^*}\underline{n}(1)$.

Retrospective Adjustment

One can adjust the initial population numbers at age vector $\underline{N}(1)$ to reflect a retrospective pattern in calculating these estimates (retroflag=true). In this case, the user must determine an appropriate vector of retrospective bias-correction coefficients, denoted by $\underline{C}$, to apply to the vector $\underline{N}(1)$. These multiplicative bias-correction coefficients may be age-specific or constant across age classes. The bias-corrected initial population vector $\underline{N}^*(1)$ is calculated from the element-wise product of $\underline{N}(1)$ and $\underline{C}$ as

$$(42) \qquad \underline{N}^*\left(1\right) = \left(C_r \cdot N_r(1),...,C_a \cdot N_a(1),...,C_A \cdot N_A(1)\right)^T$$

Note that the bias-correction coefficients are applied to all initial population vectors. If the bias-correction coefficients are determined to be constant across age classes then $\underline{C} = (C, C, ..., C)^T$ and the bias-corrected initial population vector is

$$(43) \qquad \underline{N}^*\left(1\right) = \left(C \cdot N_1(1),...,C \cdot N_a(1),...,C \cdot N_A(1)\right)^T = C \cdot \underline{N}\left(1\right)$$

The bias-correction coefficients are only applied in the first time period of the projection time horizon to reflect uncertainty in the estimated population size at age. Mohn (1999) provides a useful discussion of the retrospective problem in sequential population analysis.

Stochastic Natural Mortality

Natural mortality is often assumed to be constant over recruited age classes and equal to its long-term average for assessment purposes. The effects of constant age-specific natural mortality can be investigated using AGEPRO (set varmflag=false). The potential effects of variation in the age-specific instantaneous natural mortality rates can also be assessed when performing stochastic projections. To do this, the natural mortality rate at age can be modeled as a random variable in the AGEPRO program (set varmflag=true). In this case, the natural mortality rate can be modeled as a autocorrelated, or uncorrelated lognormal process where the natural mortality rate at age a in year t would be simulated as

$$(44) \qquad \begin{aligned} M_a\left(t\right) &= M\left(t\right) \cdot P_{M,a}(t) \ \ where \\ M\left(t\right) &= M \cdot \exp\left(\varepsilon_t - 0.5\sigma_M^2\right) \ \ and \\ \varepsilon_t &= \rho_M \cdot \varepsilon_{t-1} + \sqrt{1-\rho_M^2} \cdot \upsilon_t \ \ and \\ \upsilon_t &\sim N\left(0, \sigma_M^2\right) \end{aligned}$$

Here the simulated natural mortality rate M(t) in year t depends on a the input mean value M which is adjusted annually with an autocorrelated random error ε_t which has a lognormal distribution. Autocorrelation in the random errors ε_t can be turned off by setting ρ_M=0. The multiplicative lognormal error has a mean value of unity due to the application of the bias-adjustment factor ($-0.5\sigma_M^2$). The simulated natural mortality rate at age a in year t is M(t) times the vulnerability of age class a to the full natural mortality rate, denoted by $P_{M,a}(t)$, in year t. The vulnerabilities at age are simulated as uniform distributions with means equal to the input vulnerability values at age $P_{M,a}$ and the input coefficients of variation CV_a. In particular, the probability density function for $P_{M,a}$ is $f(P_{M,a}(t))$ which is given by

(45)
$$f\left(P_{M,a}(t)\right) = \frac{1}{U_a - L_a} \quad where \quad L_a \le P_{M,a}(t) \le U_a$$
$$and \quad L_a = P_{M,a}\left(1-\sqrt{3}\cdot CV_a\right) \quad and \quad U_a = P_{M,a}\left(1+\sqrt{3}\cdot CV_a\right)$$

Note that the input coefficient of variation cannot be greater than $\sqrt{3}$ for any age class otherwise the lower bound of the uniform distribution (L_a) is not feasible.

Total Stock Biomass

Total stock biomass (B_T) is the sum over the recruitment age (r) to the plus-group age (A) of stock biomasses at age on January 1st. The computational formula for B_T in year

(46)
$$B_T(t) = \sum_{a=r}^{A} W_{P,a}(t)\cdot N_a(t)$$

where $W_{P,a}(t)$ is the population mean weight of age-a fish on January 1st in year t.

Mean Biomass

Mean stock biomass (B_M) is the average biomass of the stock over a given year. In particular, mean stock biomass depends on the total mortality rate experienced by the stock in each year. In the AGEPRO model, the user selects the range of ages to be used for calculating mean biomass. One can choose the full range of ages in the model (age-r through age-A) or alternatively choose a smaller range if desired. The upper age (A_U) for mean biomass calculations must be less than or equal to A; similarly the lower age (A_L) must be greater than or equal to r. Let $W_{M,a}(t)$ denote the mean weight of age-a fish at the mid-point of year t. The computational formula for B_M in year t is

(47)
$$B_M(t) = \sum_{j=A_L}^{A_U} W_{M,j}(t)\cdot N_j(t)\cdot\frac{\left(1-\exp\left(-M_j(t)-F_j(t)\right)\right)}{\left(M_j(t)+F_j(t)\right)}$$

Fishing Mortality Weighted by Mean Biomass

Fishing mortality weighted by mean biomass ($F_B(t)$) in year t is the mean-biomass weighted sum of fishing mortality at age over the age range of A_L to A_U (see Mean Biomass above). This quantity may be useful for equilibrium comparisons with fishing mortality reference points developed from surplus production models. The computational formula for fishing mortality weighted by mean biomass is

(48)
$$F_B(t) = \frac{\sum_{j=A_L}^{A_U} B_{M,j}(t) \cdot F_j(t)}{B_M(t)}$$
$$where \;\; B_{M,j}(t) = W_{M,j}(t) N_j(t) \frac{\left(1-\exp\left(-M_j(t)-F_j(t)\right)\right)}{\left(M_j(t)+F_j(t)\right)}$$

Feasible Simulations

A feasible simulation is defined as one where the input landings quota can be harvested in each year of the projection time horizon. An infeasible simulation is one where the exploitable biomass is less than the landings quota in at least one year of the time horizon. All simulations are feasible for projections where population harvest is based solely on fishing mortality values. For projections that specify a landings quota in one or more years, the feasibility of harvesting the landings quota is evaluated using an upper bound on F that defines infeasible quotas relative to the exploitable biomass (Appendix). For purposes of summarizing projection results, the total number of simulations is denoted as K_{TOTAL} and the total number of feasible simulations is denoted as $K_{FEASIBLE}$.

Biomass Thresholds

The user can specify biomass thresholds for spawning biomass ($B_{S,THRESHOLD}$), mean biomass ($B_{M,THRESHOLD}$), and total stock biomass ($B_{T,THRESHOLD}$) for Sustainable Fisheries Act policy evaluation. This is the SFA-threshold option (sfaflag=true). If the SFA-threshold option is chosen, projected biomass values are compared to the input thresholds through time. Probabilities that biomasses meet or exceed threshold values are computed for each year. In addition, the probability that biomass thresholds were exceeded in at least one year within a single simulated population trajectory is computed. If the user specifies fishing mortality-based harvesting with no landings quotas, then the SFA-threshold probabilities are computed over the entire set of simulations. Let K_B(t) be the number of times that projected biomass B(t) meets or exceeds the threshold biomass $B_{THRESHOLD}$ in year t. The counter K_B(t) is evaluated for each year and biomass series (spawning, mean, or total stock). Given that K_{TOTAL} is the total number of feasible simulation runs, the estimate of the annual probability that $B_{THRESHOLD}$ would be met or exceeded in year t is

(49)
$$\Pr\left(B(t) \geq B_{THRESHOLD}\right) = \frac{K_B(t)}{K_{TOTAL}}$$

Note that this also provides an estimate of the probability of the complementary event that biomass does not exceed the threshold via

(50) $$\Pr\left(B(t) < B_{THRESHOLD}\right) = 1 - \Pr\left(B(t) \geq B_{THRESHOLD}\right) = 1 - \frac{K_B(t)}{K_{TOTAL}}$$

Next, if $K_{THRESHOLD}$ denotes the number of simulations where biomass exceeded its threshold at least once, then the probability that $B_{THRESHOLD}$ would be met or exceeded at least

(51) $$\Pr\left(\exists t \in \left[1,2,...,Y\right] \text{ such that } B\left(t\right) \geq B_{THRESHOLD}\right) = \frac{K_{THRESHOLD}}{K_{TOTAL}}$$

If the user specifies landings quota-based harvesting in one or more years, then the SFA-threshold probabilities can be computed over the set of feasible simulations. In this case, the year-specific conditional probability that $B_{THRESHOLD}$ would be met or exceeded for feasible simulations is

(52) $$\Pr\left(B\left(t\right) \geq B_{THRESHOLD}\right) = \frac{K_B\left(t\right)}{K_{FEASIBLE}}$$

Note that the counter KB(t) can only be incremented in a feasible simulation. In contrast, the joint probability that $B_{THRESHOLD}$ would be met or exceeded for the entire set of simulations is given by Equation 42 and the probability that $B_{THRESHOLD}$ would be met or exceeded at least once during the projection time horizon is given by Equation 43.

Fishing Mortality Thresholds

The user can specify fishing mortality rate thresholds for annual fishing mortality ($F_{THRESHOLD}$) and fishing mortality weighted by mean biomass ($F_{B,THRESHOLD}$) under the SFA-threshold option. If the SFA-threshold option is chosen (sfaflag=true), projected F and F_B values are compared to the thresholds through time. Probabilities that fishing mortalities exceed threshold values are computed for each year in the same manner as for biomass thresholds (see Biomass Thresholds above). In particular, if $K_F(t)$ is the number of times that fishing mortality F(t) exceeds the threshold fishing mortality $F_{THRESHOLD}$ in year t, then the annual probability that the fishing mortality threshold is exceeded is

(53) $$\Pr\left(F\left(t\right) > F_{THRESHOLD}\right) = \frac{K_F\left(t\right)}{K_{TOTAL}}$$

and the complementary probability that the fishing mortality threshold is not exceeded is

(54) $$\Pr\left(F(t) \leq F_{THRESHOLD}\right) = 1 - \frac{K_F(t)}{K_{TOTAL}}$$

Target Fishing Mortality

In some projections, it may be necessary to change the fishing mortality rate when a spawning biomass threshold is met or exceeded. This can occur, for example, if the $B_{S,THRESHOLD}$ is the spawning biomass to produce maximum sustainable yield (B_{MSY}). In this case, the fishing mortality rate can be increased from a rebuilding value to F_{MSY}. The AGEPRO software includes an option to specify a target F (F_{TARGET}) that will be applied in the year subsequent to the year in which the $B_{S,THRESHOLD}$ is met or exceeded. This is the F-target option (ftarflag=true). Note that the F-target option requires that the SFA-threshold option is selected (sfaflag=true).

The F-target option depends on the spawning biomass realized in each year of the time horizon. In a given simulated population trajectory, F_{TARGET} is applied in the year following a year in which the $B_{S,THRESHOLD}$ is met or exceeded. In addition to specifying a target F, a calendar year within the projection time horizon when the F-target option may occur must also be specified; denote this initial year as $Y_{FTARGET}$. For example, if the projection time horizon is the interval [2002, 2007] , then $Y_{FTARGET}$ might be chosen to be 2005. Given this, the F in year 2005 would be set to F_{TARGET} if the spawning biomass threshold was achieved in 2004. In general, the F-target option sets $F(t+1) = F_{TARGET}$ in year t+1 provided that

$$(55) \qquad F\left(t+1\right) = F_{TARGET} \quad \Leftrightarrow \quad t \geq Y_{TARGET} \ \ and \ \ B_S\left(t\right) \geq B_{S,THRESHOLD}$$

Fishing Mortality Bounds

In some projections, it may be necessary to specify bounds on fishing mortality under a quota-based harvest strategy. In this case one can input an upper bound on realized fishing mortality (F_{UPPER}). If a harvest quota generates a realized F that exceeds F_{UPPER}, then the realized F is set equal to F_{UPPER} and the catch biomass generated by applying F_{UPPER} is the realized catch, not the user-specified quota. Similarly, one can set a lower bound on fishing mortality (F_{LOWER}). Fishing mortality bounds can be applied by setting the bounded F flag to be true (bdFflag=true)). When the bounded F flag is true and the harvest strategy is composed of a mixture of catch quotas and fishing mortality rates, the upper and lower bounds on F apply to both quotas and fishing mortality rates. In particular, F(t) is bounded above and below for all years t when the bounded F flag is true.

$$(56) \qquad Bounded\ F\ \ flag = true \ \Rightarrow \ F_{LOWER} \ \leq \ F(t) \ \leq \ F_{UPPER} \ \ for\, all\, t$$

Landings by Market Category

It may be necessary to partition projected landings into market categories for economic analyses. In particular, evaluating the expected benefits of a harvest policy can depend on whether fish price differs by fish size or market category. By setting the market category flag to be true (mcflag=1 for standard output or mcflag=2 for full distribution output), one can partition landings at age into up to three market categories. Both the number of landed fish and total weight of landed fish can be partitioned into market categories based on fish age. To apply this option, one must specify the proportion of each age class within each market category. Let $q_{a,j}$ denote the proportion of age-a fish in the j^{th} market category. These proportions must be nonnegative and less than one, $0 < q_{a,j} < 1$. Further the proportions must sum to unity across market categories for each age a.

(57) $$\sum_j q_{a,j} = 1$$

Given the proportions $q_{a,j}$ for each age class, the total number of landed fish ($L_{N,j}(t)$) in the j^{th} market category is

(58) $$L_{N,j}(t) = \sum_{a=r}^{A} q_{a,j} \cdot C_a(t) \cdot (1 - P_{D,a}(t))$$

Similarly, the total weight of fish ($L_{W,j}(t)$) in the j_{th} market category is

(59) $$L_{W,j}(t) = \sum_{a=r}^{A} q_{a,j} \cdot C_a(t) \cdot W_{L,a}(t) \cdot (1 - P_{D,a}(t))$$

Time-Varying Weights and Fraction Mature at Age

It may be necessary to investigate the effects of trends in mean weights and fraction mature at age through time. In particular, if average fish weights have decreased as population size has been increasing, it may be important to characterize what would happen if the trends continue in the future. The time-varying weight and fraction mature option allows one to specify a time series of average fish weights at age and fraction mature at age during the projection time horizon. If the time-varying weight option is true (varwtflag=true), the user must input a time series of Y vectors for average population ($W_a(t)$), landed ($W_{L,a}(t)$), spawning ($W_{S,a}(t)$), and mid-year ($W_{M,a}(t)$) weights at age along with a time series of Y vectors for the fraction mature at age ($P_{S,a}(t)$). In addition, if the discard option is selected, then the user must also input a time series of vectors for average discard weights at age ($W_{D,a}(t)$).

Time-Varying Fishery Selectivity at Age

It may also be necessary to assess the effects of trends in fishery selectivity at age or in the amount of total mortality occurring prior to spawning through time. If the time-varying fishery selectivity flag is set to be true (prflag=true), then the user can input a sequence of Y vectors for fishery selectivity at age ($P_{F,a}(t)$) and a set of Y values for the fraction of total mortality occurring prior to spawning ($P_Z(t)$). Of course, constant values of $P_Z(t) = P_Z$ can be input if only the effect of time-varying selectivity is of interest.

Time-Varying Discard Fraction at Age

It may also be useful to quantify the potential effects of changes in discard fraction at age through time. If the constant fishery discard flag is set to be false (constdiscflag=flag), then the user can input a sequence of Y vectors for fishery discard fraction at age ($P_{D,a}(t)$) to quantify the effects of trends in discarding practices.

Age-Specific Summaries of Spawning Biomass and Population Size

The user may select the age summary option (agesumflag=true) to produce summaries of the distribution of spawning biomass at age and population size at age by year in the standard output file. Otherwise, age-specific summaries will not be output.

Auxiliary Output Files

The user may select the outfile option (outfileflag=true) to create auxiliary output files to record simulated trajectories of spawning biomass, mean biomass, fishing mortality, and landings. This option can be useful if one wants to depict the variability of one or more simulated trajectories in a graph. One file is created for each output ($B_S(t)$, $B_M(t)$, F(t), L(t)). The four output files have the same structure. In each output file, a single row represents a single simulated time trajectory with Y entries ordered from time t=1 to time t=Y. Within the file, trajectories are ordered by initial population vector (bootstrap) and then simulation for that initial vector. For example, if $B_{S,\,(b),k}(t)$ denotes the spawning biomass realized from the b^{th} initial population vector and the k^{th} simulation for that vector, then the output file for spawning biomass with B initial vectors and N simulations would have B·N rows that were ordered as

$$(60) \qquad \begin{bmatrix} B_{S,(1),1}(1) & B_{S,(1),1}(2) & \cdots & B_{S,(1),1}(Y) \\ B_{S,(1),2}(1) & B_{S,(1),2}(2) & \cdots & B_{S,(1),2}(Y) \\ \vdots & \vdots & \vdots & \vdots \\ B_{S,(B),N}(1) & B_{S,(B),N}(2) & \cdots & B_{S,(B),N}(Y) \end{bmatrix}$$

The output units of spawning biomass, mean biomass, and landings are kilograms. The units of F are instantaneous fishing mortality rate per year.

Age-Structured Projection Software

Software to implement the current age-structured projection model has been revised several times since 1996 to reflect requests and technical improvements. As a result, input files for previous versions of the code will need some revision to be compatible with version 3.4. The required modifications, however, are relatively minor. Input files for more recent versions (i.e., versions 3.0x and higher) can be converted to the new format using the PC graphical user interface, with the caveat that the user must still input missing data not present in the older file format.

This part of the User Guide provides operational details for the AGEPRO software and is organized into four sections. First, input data requirements and projection options are covered and the structure of an input file is described. Second, model outputs are described in relation to logical flags in the input file and the structure of an output file is described. Third, a section on program structure describes the flow of data and calculations. Fourth, a set of examples are provided to identify some general features of the software.

Input Data

There are four categories of input data for an AGEPRO projection run: *system*, *simulation*, *biological*, and *fishery* (Figure 1). The *system* data are read from standard input (e.g., from a terminal or via input redirection) while the *simulation*, *biological* and *fishery* data are read from an input file. A description of each data category follows.

System Data

The *system* data are the file names for the input and output files for the projection run. The input and output filenames are stored in the text file that must be named "agepro34.ctl"; this is the control file for the AGEPRO application. To manually change the names of input and output files for a projection at the DOS command line prompt, first delete the existing control file "agepro34.ctl" and then move a new control file to be named "agepro34.ctl". This approach can be used to set up batch runs consisting of many projection runs with different model configurations with input and output file names. *It is recommended that the USER run the AGEPRO GUI to set up an initial set of control and input files before running the program in a batch mode.*

To run the AGEPRO program from the DOS command line, enter "agepro34.exe". You will see the following output in the command line screen:

```
>agepro34.exe
>
>Projection analysis is running ...
>
> Simulation completed for bootstrap: 1
> Simulation completed for bootstrap: 2
...
>Bootstrap loop completed. Summarizing results ...
>
>Projection analysis has been completed.
>
>Results are in the file: my_output_filename
```

The software checks whether the input file exists and prompts the user for another filename if the input file does not exist. Similarly, the software checks whether the output file already exists and prompts the user for another filename if the output file already exists. Running several large projections concurrently in batch mode can cause system crashes.

To run the AGEPRO program from the GUI, use the pull down menus to select the command "run model".

Simulation Data

The *simulation* data are the inputs needed to setup and define the simulation run. These data are required to run the AGEPRO software and are read from the input file (Tables 2 and 3, Figure 1).

Here is a description of the simulation data inputs:

1. Character tag that identified the AGEPRO version.
2. Character string that identifies the projection run (64 characters).
3. First year of the time horizon.
4. Length of time horizon.
5. Number of simulations to perform for each initial population vector.
6. Number of probable recruitment models for the projection
7. Number of replications to initialize the random number generator.
8. Age-1 recruitment flag (age1recflag). If true, recruitment occurs at age-1; else it occurs at an older age r.
9. Harvest mixture flag (mixflag). If true, the harvest scenario is a mixture of quotas and fishing mortality rates; else it is either all quotas or all fishing mortality rates.
10. Discard flag (discflag). If true, discards at age are included in the projection; else no discards are included.
11. Quota flag (quotaflag). If true, the harvest scenario is all quota-based; else it is all F-based.
12. Age summary flag (agesumflag). If true, age-specific summaries of the distribution of spawning biomass and population size at age by year are produced; else not.
13. Target F flag (ftarflag). If true, then a target value of F is applied in the year after any year when the SB threshold is achieved; otherwise no change occurs.
14. Retrospective adjustment flag (retroflag). If true, an age-specific retrospective adjustment coefficient is applied to each initial population vector; else not.
15. SFA biomass and fishing mortality threshold flag (sfaflag). If true, realized spawning biomass, mean stock biomass, total stock biomass, fully-recruited fishing mortality, and biomass-weighted fishing mortality are compared to a threshold level; otherwise no comparisons are made.
16. Market category flag (mcflag). If true, landings are summarized by market category and output to file; otherwise no market category summaries are made.
17. Time-varying weight and fraction mature at age flag (varwtflag). If true, fish weights and fraction mature at age can vary from year to year; otherwise there is no annual variation.
18. Time-varying fishery selectivity flag (prflag). If true, both the partial recruitment at age and the fraction of total mortality that occurs prior to spawning can vary from year to year; otherwise there is no annual variation.
19. Constant discard at age flag (constdiscflag). If true, the fraction discarded at age is constant; otherwise the fraction discarded at age can vary from year to year.
20. Bounded recruitment flag (bdrecflag). If true, then realized recruitments generated with the lognormal, Beverton-Holt, Ricker, and Shepherd stock-recruitment models will be bounded based on realized R/B_S ratios; otherwise no bounds are applied.
21. Bounded fishing mortality flag (bdFflag). If true realized fishing mortality is constrained within user-specified upper and lower bounds.
22. Stochastic natural mortality flag (varmflag). If true, natural mortality at age varies according to a lognormal process that may be serially correlated and the vulnerability at age to natural mortality varies according to a uniform distribution.

23. Bootstrap flag (bootflag). If true, a file of initial population vectors is used in the projection analysis; otherwise a single initial population vector is used.
24. Output file flag (outfileflag). If true, auxiliary output files for spawning biomass, mean biomass, fishing mortality, and landings are created; else not.

Biological Data

The *biological* data are the values of a set of biological inputs needed to describe the dynamics of the age-structured population. Most of these data are required to run the AGEPRO software although some data are optional and dependent upon the simulation settings (Table 3). The biological data are read from the input file. By convention, optional inputs will be enumerated sequentially along with required inputs. Note that, if recruitment age is age-R, there is no accounting of fish younger than age-R in the model.

Here is a description of the biological data inputs

25. This input is the number of age classes in the population model (A), where $A < 100$ along with lower and upper bound on range of ages for computing mean biomass, Lowerage and Upperage, and the age of recruitment (r) if this age is not equal to 1.
26. This input is the instantaneous natural mortality rate (M) and the vulnerability to M at age vector ($P_{M,a}$). If natural mortality at age is stochastic, then the log-variance σ_M^2 , correlation parameter ρ_M, initial error ε_0 (set to 0 if unknown), and coefficient of variation of the uniform distribution for vulnerability to M, CV_a.
27. This input is the vector of mean stock weights at age on January 1 ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
28. This input is the vector of mean landed weights at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
29. This input is the vector of mean spawning weights at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
30. This input is the vector of mean mid-year weights at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
31. If discards at age are included in the projection, this input is the vector of mean weights at age of discarded fish ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight option is selected.
32. This input is the vector of fraction mature at age ordered from youngest (left) to oldest (right) with Y vectors of weights if the time-varying weight and fraction mature option is selected.
33. This input is the fraction of total mortality that occurs prior to spawning (P_Z). If the partial recruitment flag is true, then a set of Y values of P_Z must be input.
34. This input is the recruitment flag which is a number from 1 to 19 that identifies the choice of stochastic stock-recruitment model to be used. These models are

numbered 1 to 19 in exact correspondence with their descriptions (see **Stock-Recruitment Relationship**).

35. This input is the set of parameters needed for the probable stock-recruitment models. The set of parameters depends on the set of probable models; these parameters are specified in Table 3 for each of the nineteen stock-recruitment models.
36. This input is the set of parameters to constrain recruitment for stock-recruitment models with lognormal error terms. These parameters are input only if the bounded recruitment flag is true. If this flag is true, then the endpoints of the constraining intervals are input on one line as L_{HIGH}, L_{LOW}, U_{LOW}, U_{HIGH}, while $B_{S,CUT}$ is input on the next line.
37. This input is the set of parameters to define the initial population sizes for projection. The set of parameters depends on the value of the age-1 recruitment flag and the bootstrap flag (see Table 3).
38. This input is the set of coefficients for the retrospective bias adjustment. These parameters are input only if the retrospective adjustment flag is true.
39. This input is the set of SFA status determination parameters. These thresholds are input only if the SFA threshold flag is true.
40. This input is the set of parameters to apply the F target option. These parameters are input only if the target F flag is true and are listed in Table 3.
41. This input is the set of parameters to apply the bounded F option. These parameters are input only if the bounded F flag is true and are listed in Table 3.

Fishery Data

The *fishery* data are the values of a set of inputs needed to describe fishery impacts on the population and yields.

Here is a description of the fishery data inputs

42. This input is the set of parameters to define fishery selectivity through time. These parameters depend upon the time-varying fishery selectivity flag (Table 3).
43. This input is the set of parameters to define age-specific discarding through time. These parameters depend upon the discard and constant discard flags (Table 3).
44. This input is the set of parameters to define the harvest strategy. These parameters depend upon the harvest mixture, quota-based, and constant harvest strategy flags (Table 3).
45. This input is the set of parameters to define the market category summarization. These parameters depend upon the market category flag (Table 3).
46. This input is the set of auxiliary output file names for spawning biomass, mean biomass, fishing mortality, and landings.

Model Outputs

The AGEPRO program creates a standard output file that summarizes the projection analysis results. The program may also create an output file for market category summaries and auxiliary files storing simulated trajectories of spawning biomass, mean biomass, fishing mortality, and landings, if applicable (Figure 1).

There are twelve general categories of output in the standard output file. The first output describes the AGEPRO projection run and lists the input and output file names and the recruitment models and associated model probabilities. The second output shows the user-input harvest scenario in terms of quotas or fishing mortality rates. The third output characterizes the distribution of projected spawning biomass through time including the probability that spawning biomass exceeds a threshold if applicable. The fourth output characterizes the distribution of the projected trajectory of mean biomass. The fifth output describes the distribution of the fishing mortality weighted by mean biomass trajectory. The sixth output characterizes the distribution of the projected trajectory of total stock biomass. The seventh output characterizes the distribution of projected recruitment through time. The eighth output characterizes the distribution of the projected landings through time. The ninth output characterizes the distribution of the population numbers at age (on January 1st) through time, if applicable. The tenth output characterizes the distribution of projected landings by market category through time, if applicable. The eleventh output characterizes the distribution of projected discards and catch biomass through time, if applicable. The twelfth output characterizes the distribution of the realized fishing mortality rates through time including the probability that fishing mortality exceeds a threshold, if applicable.

There are six categories of output in the market category summary file which will be created if the market category option is selected (mcflag=1 or 2). The first output describes the AGEPRO projection run and lists the input and output file names. The second output characterizes the distribution of the projected trajectory of landed weight by market category. The third output describes the distribution of numbers of landed fish by year and market category. The fourth output shows the average total weight and numbers of fish landed weight by market category. The fifth output gives the median total weight and numbers of fish landed weight by market category. The sixth output lists the entire set of simulated trajectories of landings and weight by market category; this output occurs only if full market category output is selected (mcflag=2). In this case, each row represents market category information from a single trajectory. The output variables in a row (in order): year, total landings (kg), market category 1 landings (kg), market category 2 landings (kg), and market category 3 landings (kg). The rows are ordered by year (time), initial population vector (bootstrap), and simulation (sim). The full output option can create a large market category summary file; a 5-year projection with 1000 initial population vectors and 100 simulations per vector will produce a market category file with over 500,000 lines.

There is one category of output in the auxiliary files for spawning biomass, mean biomass, fishing mortality, and landings. These files are created if the output file option is selected (outfileflag=true). Each row in an auxiliary output file gives the trajectory of the output variable through time, ordered from the 1st to the last year in the projection time horizon.

Examples

The following two examples show some general features of the AGEPRO program. These projections are hypothetical and for the purposes of illustration only.

Example 1: This example is a projection for Acadian redfish from 2004 through 2009 using recruitment model 14. This projection illustrates the mixed harvest, SFA threshold, and stochastic natural mortality options. Fishing mortality in 2004 is assumed to be equal to the 2003 estimate. Catch biomass of redfish in 2005 is estimated from the first half-year landings in 2005. Fishing mortality in 2006-2009 is assumed to be constant with $F_{2006}=0.01$. This harvest scenario represents an increase in F over 2003. Mean vulnerability to natural mortality (M=0.05) is constant across age classes ($P_{M,a}=1$ for each age class a) but the coefficient of variation of vulnerability is $CV_a=0.2$ for ages 1-9 and $CV_a=0.1$ for ages 10 and older. Natural mortality has a log-variance of $\sigma_M^2 = 0.2$ with an autocorrelation parameter of $\rho_M=0.5$ and an initial random shock of $\varepsilon_0=0$. Three hypothetical questions are posed. Does this scenario reduce the spawning potential of the redfish stock ? Is there any chance that the stock would be at B_{MSY} in 2009 under this scenario? What are the potential redfish landings in 2009 under this scenario ?

These hypothetical questions can be readily answered using the output and graphing capabilities of the AGEPRO GUI. First, graphing the spawning biomass variable with 5% to 95% confidence limits shows that spawning biomass is likely to increase under this harvest scenario (Figure 3.1). Based on this graph it appears that there is a chance that the spawning biomass threshold B_{MSY} will be exceeded in 2009 and also a small chance that spawning biomass will not increase beyond 2008. In the Output Report File, one can see that the annual probabilities of exceeding BMSY are:

```
ANNUAL PROBABILITY THAT SSB EXCEEDS THRESHOLD:   236.700 THOUSAND MT
 YEAR    Pr(SSB >= Threshold Value) FOR FEASIBLE SIMULATIONS
 2004          0.000
 2005          0.000
 2006          0.000
 2007          0.019
 2008          0.154
 2009          0.289
```

This output indicates that there is a 29% probability that BMSY would be exceeded in 2009, a moderate chance. This can also be shown by graphing of the probability of achieving this threshold (Figure 3.3). Last, graphing the landings variable with 5% to 95% confidence limits shows that landings would be very likely to increase under this harvest scenario (Figure 3.3). By 2009 the probable range of redfish landings indexed by the 5th and 90th percentiles would be (1.898, 2.496) thousand mt, a substantial increase over the 2005 catch estimate.

Example 2: This example is a projection for Georges Bank haddock from 2005 through 2014 using recruitment model 15. This projection illustrates the discard, age summary and market category options. Fishing mortality in 2005 is based on an expected catch of about 22.5 thousand mt. Fishing mortality in 2006-2014 is assumed to be constant with $F_{2006}=0.26$. Hypothetical discard fractions of age-1 to age-3 fish are 20%, 10%, and 5%

while discard fraction of fish ages 4 and older is 1%. Three hypothetical questions are posed. What is the likely trend in discard biomass through time ? What is the likely contribution of the 2003 year class to spawning biomass in 2009? What are the likely trends of landings by market category under this scenario ?

These hypothetical questions can be generally addressed using graphical output from the projection run while quantitative answers can be gathered from the Output Report File. First, plotting the time trend in discard biomass indicates it would increase to about 1500 mt in 2006 and then decline to about 600 mt in 2014 (Figure 4.1). Second, the contribution of the 2003 year class to spawning biomass in 2009 is substantial but uncertain (Figure 4.2). The median contribution of this exceptional year class would be about 300 kt but with a probable range of roughly 100-600 kt. Third, the projected landings of large haddock would increase sharply to a peak of about 50 kt during 2008-2010 and then gradually decline to about 30 kt in 2014 (Figure 4.3). In comparison, landings of scrod haddock were projected to increase to about 70 kt in 2007-2008 and then decline to about 20 kt in 2014 (Figure 4.4). The growth and eventual decline in landings from both market categories have relatively large probable ranges. This reflects uncertainty in the size of the 2003 year class which dominates the projected landings and spawning biomass in 2007-2012.

Example 3: This example is a model-averaged projection for Georges Bank haddock that compares the results of using recruitment model 15 versus using a model-averaged combination of alternative models 18 and 19 to predict recruitment during 2005-2007. The existing (status quo) recruitment prediction model for haddock was taken from the recommendations of the 2005 Groundfish Assessment Review Meeting (Mayo and Terceiro 2006). This status quo model was a two-stage cumulative distribution function for observed recruitments above and below the productivity threshold of 75,000 mt of spawning biomass (NEFSC 2002).

The first alternative model ($M_{HAD,R1}$) was a linear model with no intercept fit to log-scale R during 1985-2004 from Brodziak et al. (2006) as a function of sea surface temperature on Georges Bank during February-May. The fitted model was

$$\begin{aligned} &\log(R) = 0.3588 \cdot ST2.spr.mm + \varepsilon \\ &where\ \ \varepsilon \sim N(-1.209,\ 2.418) \end{aligned} \tag{61}$$

The fitted model was highly significant (P<0.001) and explained a good amount of variation in the R data relative to the model log(R) = 0 + ε (multiple $R^2 = 0.72$).

The second alternative model to predict haddock recruitment ($M_{HAD,R2}$) also used sea surface temperature during February-May and the haddock age-0 survey index but was fitted to untransformed haddock R. The estimated model was

$$\begin{aligned} &R = 1.1362 \cdot ST2.spr.mm + 1.5567 \cdot age0.had + \varepsilon \\ &where\ \ \varepsilon \sim N(0,386.5) \end{aligned} \tag{62}$$

This model was also highly significant (P<0.001) and explained much of the variation in haddock R relative to the model R = 0 + ε (multiple $R^2 = 0.99$).

The model-averaged combination of the two alternative models to predict haddock recruitment ($M_{HAD,MA}$) was a weighted average of models $M_{HAD,R1}$ and $M_{HAD,R2}$. In the absence of a preference, the two model probabilities were equal to 0.5 and each model was randomly sampled with probability one-half to simulate recruitment in each year of the stochastic projections.

To compare the status quo and alternative model-averaged prediction model, estimates of recruitment for Georges Bank haddock during 2005-2007 were gathered from the recently completed 2008 stock assessment (NEFSC 2008a, NEFSC 2008b). Observed values of sea surface temperatures were not available in 2007 and SST in 2007 was imputed using the average sea surface temperature during 1985-2006. Observed catch biomasses of Georges Bank haddock during 2005 to 2007 were input to the AGEPRO model to compute annual fishing mortality during 2005-2007 for each projection. For haddock, the catch biomasses in 2005-2007 were 21814, 15989, and 16815 mt.

Because the 2008 stock assessment for Georges Bank haddock was a bench mark assessment, and not a simple assessment update, estimates of recruitment, spawning biomass, and other variables were expected to have a somewhat different scale than those from the 2005 assessments. In this case, comparing the projected recruitments during 2005-2007 with the observed values from the assessment could be misleading. To address this concern, the best-fitting linear model to predict observed from the 2008 assessment as a function of the 2005 assessment value during 1985-2004 was used to rescale predicted recruitments during 2005-2007 to be comparable to the values in the 2008 assessments of haddock. Regression analyses and associated Akaike information criteria values indicated that the best fitting linear model relating the new 2008 VPA estimates of Georges Bank haddock recruitment to the old estimates from the 2005 assessment was $R_{NEW} = 6.076 + 0.6247 \cdot R_{OLD}$. This model was used to rescale the predicted recruitment values from the projections using both the status quo models and the model-averaged alternative using the environmental covariates.

Results of the projections indicated that the model-averaged combination of two predictive models, one that used sea surface temperature and the haddock age-0 index and one that used only sea surface temperature, provided more accurate predictions of haddock recruitment during 2005-2007 (Figure 5). This model-averaged combination had a root mean-square prediction error that was roughly 5-fold lower than the status quo model. This example illustrates that the use of multiple predictive models may be able to improve predictive accuracy in some cases.

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Table 1. Notation for variables used in the AGEPRO model.

Variable	Description
A	Age of plus-group (fish age-A and older) and last index value for N.
$B_S(t)$	Spawning biomass in year t.
$B_M(t)$	Mean stock biomass in year t.
$B_T(t)$	Total stock biomass on January 1st of year t.
B	Number of input initial population vectors N(1).
$C_a(t)$	Number of age-a fish that are captured and die in year t.
D(t)	Total weight of discarded fish in year t.
$F_a(t)$	Instantaneous fishing mortality rate for age-a fish in year t.
F(t)	Instantaneous fully-recruited fishing mortality rate in year t.
$F_B(t)$	Instantaneous fishing mortality weighted by mean biomass in year t.
I(t)	Harvest index for year t. If I(t) = 1, then harvest is based on a landings quota Q(t). If I(t) = 0, then harvest is based on a fishing mortality rate F(t).
L(t)	Total weight of landed fish in year t.
M(t)	Instantaneous fully-vulnerable natural mortality rate in year t.
$M_a(t)$	Instantaneous natural mortality rate for age-a fish in year t.
$N_a(t)$	Number of age-a fish alive on January 1st of year t.
N_M	Number of probable recruitment models used in the projection.
$P_{D,a}(t)$	Proportion of age-a fish discarded in year t.
$P_{F,a}(t)$	Selectivity to F(t) for age-a fish (age-specific fishery selectivity).
$P_{M,a}(t)$	Selectivity to M(t) for age-a fish (age-specific natural mortality multiplier).
$P_{R,m}(t)$	Probability that the mth recruitment model is randomly sampled in year t.
$P_{S,a}(t)$	Proportion of age-a fish that are sexually mature in year t.
$P_Z(t)$	Proportion of total mortality occurring prior to spawning in year t.
Q(t)	Landings quota in year t.
r	Age of recruitment and age of first element in population vector N.
R(t)	Recruitment (absolute number of age-r fish on January 1st) in year t.
$W_{P,a}(t)$	Average population weight of an age-a fish on January 1st in year t.
$W_{L,a}(t)$	Average landed weight of an age-a fish in year t.
$W_{S,a}(t)$	Average spawning weight of an age-a fish in year t.
$W_{M,a}(t)$	Average mid-year weight of an age-a fish in year t.
$W_{D,a}(t)$	Average weight of an age-a fish that is discarded in year t.
Y	Number of years (t) in projection time horizon where t = 1, 2, ..., Y.

Table 2. Summary of logical flags used in AGEPRO version 3.4.

Flag	Name	Description
1	Age-1 Recruitment	If true, recruitment age is age-1. Otherwise recruitment age is age-2 or older.
2	Harvest Mixture	If true, a mixture of F-based and quota-based harvest can be specified in the projection. Otherwise, harvest is either F-based or it is quota-based.
3	Discard	If true, discards at age are incorporated in the projection. Otherwise, there are no discards included in the projection.
4	Quota-Based	If true, catches are determined as quotas. Otherwise, catches are determined from fishing mortality rates.
5	Age Summary	If true, age-specific summaries of spawning biomass and population size are output. Otherwise, no summaries are output.
6	Target F	If true, a target value of F is applied if the current year is greater than or equal to the F-target year and the B_S threshold was achieved in the previous year. Otherwise, no target F is applied.
7	Retrospective	If true, retrospective adjustment coefficients are applied to each initial population vector. Otherwise no adjustments are made.
8	SFA Threshold	If true, realized B_S, B_M, B_T, F, and F_B are compared to thresholds. Otherwise, no comparisons are made.
9	Market Category	If true, landings by market category are output. Otherwise, no market category summaries are made.
10	Time-Varying Weights	If true, stock, landed, and discard weights at age and fraction mature at age can vary through time. Otherwise, they do not.
11	Time-Varying Selectivity	If true, fishery selectivity at age vector and the fraction of total mortality that occurs prior to spawning can vary through time. Otherwise, they do not.
12	Constant Discard	If true, discard proportions at age are constant. Otherwise, discard proportion at age can vary through time.
13	Bounded Recruitment	If true, realized recruitments from models with lognormal errors are constrained based on R/B_S ratios. Otherwise, no constraints are applied.
14	Bounded F	If true, realized fishing mortality is bounded below by F_{LOWER} and above by F_{UPPER}. Otherwise, no constraints are applied to F.
15	Stochastic M	If true, natural mortality at age varies stochastically through time. Otherwise, natural mortality at age is constant.
16	Bootstrap	If true, a file of initial population vectors is used for the projection analysis. Otherwise, a single initial population vector in the standard input file is used.
17	Outfile	If true, trajectories of spawning biomasses, mean biomasses, fishing mortalities, and landings are output to auxiliary files. Otherwise, no auxiliary files are created.

Table 3. Structure of an AGEPRO version 3.4 input file. Inputs can be delimited by a comma or a space.

Input #	Is input required?	Input description
1	Yes	AGEPRO version tag
2	Yes	Name of projection run, input: up to 64 character string
3	Yes	First year of projection run, input: 4-digit year (Positive integer)
4	Yes	Length of planning horizon, input: Y (Positive integer)
5	Yes	Number of simulations per initial population vector, input: Positive integer
6	Yes	Number of recruitment models (nmodel), input: Positive integer ≤ 19
7	Yes	Number of "warmups" for random number generator, input: Positive integer
8	Yes	Age-1 recruitment flag, input: Integer (1=true; 0=false)
9	Yes	Harvest mixture flag, input: Integer (1=true; 0=false)
10	Yes	Discard flag, input: Integer (1=true; 0=false)
11	Yes	Quota-based flag, input: Integer (1=true; 0=false)
12	Yes	Age summary flag, input: Integer (1=true; 0=false)
13	Yes	F target flag, input: Integer (1=true; 0=false)
14	Yes	Retrospective adjustment flag, input: Integer (1=true; 0=false)
15	Yes	SFA threshold flag, input: Integer (1=true; 0=false)
16	Yes	Market category flag, input: Integer (1=standard output; 2=standard and full output; 0=false)
17	Yes	Time-varying weights flag, input: Integer (1=true; 0=false)
18	Yes	Time-varying selectivity flag, input: Integer (1=true; 0=false)
19	Yes	Constant discard flag, input: Integer (1=true; 0=false)
20	Yes	Bounded recruitment flag, input: Integer (1=true; 0=false)
21	Yes	Bounded F flag, input: Integer (1=true; 0=false)
22	Yes	Stochastic natural mortality flag, input: Integer (1=true; 0=false)
23	Yes	Bootstrap flag, input: Integer (1=true; 0=false)
24	Yes	Outfile flag, input: Integer (1=true; 0=false)
25	Yes; depends on flag 1	If flag 1= true, then input number of age classes, lower and upper bound on range. If flag 1= false, then input number of age classes, lower & upper bound on range of ages for computing mean biomass, and recruitment age: A, A_L, A_U, r
26	Yes; depends on flag 15	Natural mortality rate. Input: M. Input: $P_{M,r}$, $P_{M,r+1}$, ..., $P_{M,A}$. If flag 15=true, then input: σ_M^2 and input: ρ_M, ε_0 and input: CV_r , CV_{r+1}, ..., CV_A
27	Yes; depends on flag 10	If flag 10=true, input mean population weights at age: $W_r(t)$, $W_{r+1}(t)$,... , $W_A(t)$, for t=1..Y. Else input W_r, W_{r+1} ,... , W_A

Table 3. Continued.

Input #	Is input required?	Input description
28	Yes; depends on flag 10	If flag 10=true, input mean landed weights at age: $W_{L,r}(t)$, $W_{L,r+1}(t)$,... , $W_{L,A}(t)$, for t=1..Y. Else input $W_{L,r}$, $W_{L,r+1}$,... , $W_{L,A}$
29	Yes; depends on flag 10	If flag 10=true, input mean spawning weights at age: $W_{S,r}(t)$, $W_{S,r+1}(t)$,... , $W_{S,A}(t)$, for t=1..Y. Else input $W_{S,r}$, $W_{S,r+1}$,... , $W_{S,A}$
30	Yes; depends on flag 10	If flag 10=true, input mean mid-year weights at age: $W_{M,r}(t)$, $W_{M,r+1}(t)$,... , $W_{M,A}(t)$, for t=1..Y. Else input $W_{M,r}$, $W_{M,r+1}$,... , $W_{M,A}$
31	No; required if flag 3=true	If flags 3 and 10=true, input mean discarded weights at age: $W_{D,r}(t)$, $W_{D,r+1}(t)$,... , $W_{D,A}(t)$, for t=1..Y. Else input $W_{D,r}$, $W_{D,r+1}$,... , $W_{D,A}$
32	Yes; depends on flag 10	If flag 10=true, input fraction mature at age: $P_{S,r}(t)$, $P_{S,r+1}(t)$,... , $P_{S,A}(t)$, for t=1..Y. Else input $P_{S,r}$, $P_{S,r+1}$,... , $P_{S,A}$
33	Yes; depends on flag 11	If flag 11=false, then input: P_Z If flag 11=true, input: $P_Z(1)$, $P_Z(2)$, ..., $P_Z(Y)$
34	Yes	Recruitment model vector, input: integer vector of length nmodel with elements between 1 and 19. Input only one copy of each model.
35	Yes; depends on input #34	If input #34 includes 1, input number of recruitment states: K and on the next line input: $N_{r,1}$, $N_{r,2}$, $N_{r,3}$, ..., $N_{r,K}$ and on the next line input number of spawning biomass states: J and on the next line input J-1 cut points: $B_{S,2}$, $B_{S,3}$, $B_{S,4}$, ..., $B_{S,J}$ and on the next J lines input: $p_{1,1}$, $p_{1,2}$, $p_{1,3}$, ..., $p_{1,K}$ $p_{2,1}$, $p_{2,2}$, $p_{2,3}$, ..., $p_{2,K}$ ... $p_{J,1}$, $p_{J,2}$, $p_{J,3}$, ..., $p_{J,K}$ If input #34 includes 2, input: T and on the next line input: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T)$ and on the next line input: $B_S(1-r)$, $B_S(2-r)$, $B_S(3-r)$, ..., $B_S(T-r)$ If input #34 includes 3, input: T and on the next line input: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T)$ If input #34 includes 4, input: T_{LOW} , T_{HIGH} and on the next line input: B_S* and on the next line the low-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{LOW})$ and on the next line the low-B_S state spawning biomass series: $B_S(1-r)$, B_S (2-r) , B_S (3-r) , ..., B_S (T_{LOW}-r) and on the next line the high-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{HIGH})$ and on the next line the high-B_S state spawning biomass series: $B_S(1-r)$, B_S (2-r) , B_S (3-r) , ..., B_S (T_{HIGH}-r) If input #34 includes 5, input: α, β, σ_W^2 and on the next line input: c_B , c_R

Table 3. Continued.

Input #	Is input required?	Input description
35	Yes; depends on input #34	If input #34 includes 6, input: α, β, σ_W^2 and on the next line input: c_B , c_R If input #34 includes 7, input: α, β, k, σ_W^2 and on the next line input: c_B , c_R If input #34 includes 8, input: $\mu_{\log(r)}$, $\sigma_{\log(r)}^2$ and on the next line input: c_R If input #34 includes 9, input: T and on the next line input: $N_r(1,1)$, $N_r(1,2)$, $N_r(1,3)$, ..., $N_r(1,T)$ and on the next line input: $N_r(2,1)$, $N_r(2,2)$, $N_r(2,3)$, ..., $N_r(2,T)$ ... and on the next line input: $N_r(Y,1)$, $N_r(Y,2)$, $N_r(Y,3)$, ..., $N_r(Y,T)$ If input #34 includes 10, input: α, β, σ^2 and on the next line input: φ , ε_0 and on the next line input: c_B , c_R If input #34 includes 11, input: α, β, σ^2 and on the next line input: φ , ε_0 and on the next line input: c_B , c_R If input #34 includes 12, input: α, β, k, σ^2 and on the next line input: φ , ε_0 and on the next line input: c_B , c_R If input #34 includes 13, input: $\mu_{\log(r)}$, $\sigma_{\log(r)}^2$ and on the next line input: φ , ε_0 and on the next line input: c_R If input #34 includes 14, input: T and on the next line input: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T)$

Table 3. Continued.

Input #	Is input required?	Input description
35	Yes; depends on input #34	If input #34 includes 15, input: T_{LOW} , T_{HIGH} and on the next line input: B_S* and on the next line the low-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{LOW})$ and on the next line the high-B_S state recruitment series: $N_r(1)$, $N_r(2)$, $N_r(3)$, ..., $N_r(T_{HIGH})$ If input #34 includes 16, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1), X_1(2),..., X_1(Y)$ $X1_2(1), X_2(2),..., X_2(Y)$ ... $X_p(1), X_p(2),..., X_p(Y)$ If input #34 includes 17, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1), X_1(2),..., X_1(Y)$ $X1_2(1), X_2(2),..., X_2(Y)$ ... $X_p(1), X_p(2),..., X_p(Y)$ If input #34 includes 18, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1), X_1(2),..., X_1(Y)$ $X1_2(1), X_2(2),..., X_2(Y)$ ... $X_p(1), X_p(2),..., X_p(Y)$ and on the next line input: c_R If input #34 includes 19, input: N_p and on the next line input: β_0 and on the next line input: β_1 , β_2 , ..., β_{Np} and on the next line input: σ^2 and on the next N_p lines input: $X_1(1), X_1(2),..., X_1(Y)$ $X1_2(1), X_2(2),..., X_2(Y)$ ... $X_p(1), X_p(2),..., X_p(Y)$ and on the next line input: c_R

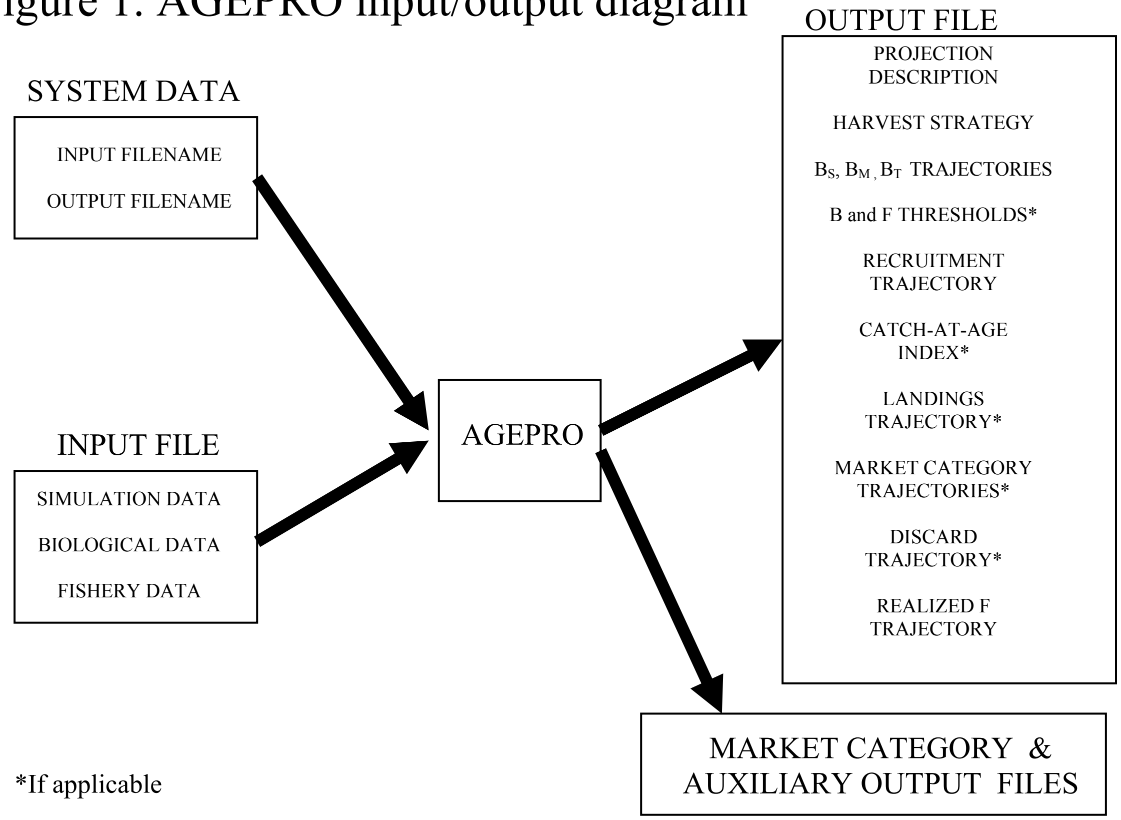
Table 3. Continued.

Input #	Is input required?	Input description
36	Yes	Input recruitment model probabilities for each year t=1,2, ..., Y Input: $P_{R,1}(1)$, $P_{R,2}(1)$, ..., $P_{R,Nm}(1)$ and on the next line input: $P_{R,1}(2)$, $P_{R,2}(2)$, ..., $P_{R,Nm}(2)$ ... and on the next line input: $P_{R,1}(Y)$, $P_{R,2}(Y)$, ..., $P_{R,Nm}(Y)$
37	No; required if flag 13=true	R/B_S constraints, input: L_{High} , L_{Low} , U_{Low} , U_{High} and on the next line input: $B_{S,CUT}$
38	Yes; depends on flags 16 and 1	Initial population abundance parameters. If flag 16=true and flag 1=true, input: B and on the next line input: name of the file (bfile1) containing B initial population vectors $\underline{n}(1)$ in relative units (one vector per row) and on the next line input the conversion coefficient: k_N If flag 16=true and flag 1=false, input: B and on the next line input: name of the file (bfile1) containing B initial population vectors $\underline{n}(1)$ in relative units (one vector per row) and B prior population vectors at time t=0 in relative units, and so on to time t=2-r. Note that in bfile1, the bootstrap data are grouped by time in blocks of B rows and where the first time block corresponds to the first year (t=1) in the time horizon, the second time block corresponds to the year prior to the first year (t=0), the third time block corresponds to the next previous year (t=-1) and so on... and on the next line input the conversion coefficient: k_N and on the next line, input: name of the file (bfile2) containing B fishing mortality at age vectors $\underline{F}(0)$ (one vector per row) and B fishing mortality at age vectors $\underline{F}(-1)$ at time t=-1, and so on to time t=2-r where the bootstrap data are grouped by time in blocks of size nboot with the first time block corresponds to the year prior to the first year (t=0), the second time block corresponds to the next prior year (t=-1) and so on... where the order of the population vectors matches the order of the fishing mortality at age vectors. If flag 16=false, input: c_N and on the next line input: $n_r(1)$, $n_{r+1}(1)$, ..., $n_A(1)$
39	No; required if flag 7=true	Retrospective adjustment coefficients, input: C_r, C_{r+1}, ..., C_A
40	No; required if flag 8=true	SFA thresholds, input: $B_{S,THRESHOLD}$,$B_{T,THRESHOLD}$, $F_{THRESHOLD}$, $B_{M,THRESHOLD}$, $F_{B,THRESHOLD}$
41	No; required if flag 6=true	F target parameters, input: F_{TARGET} and on the next line input: Y_{TARGET}
42	No; required if flag 14=true	Bounded F parameters, input: F_{LOWER} , F_{UPPER}

Table 3. Continued.

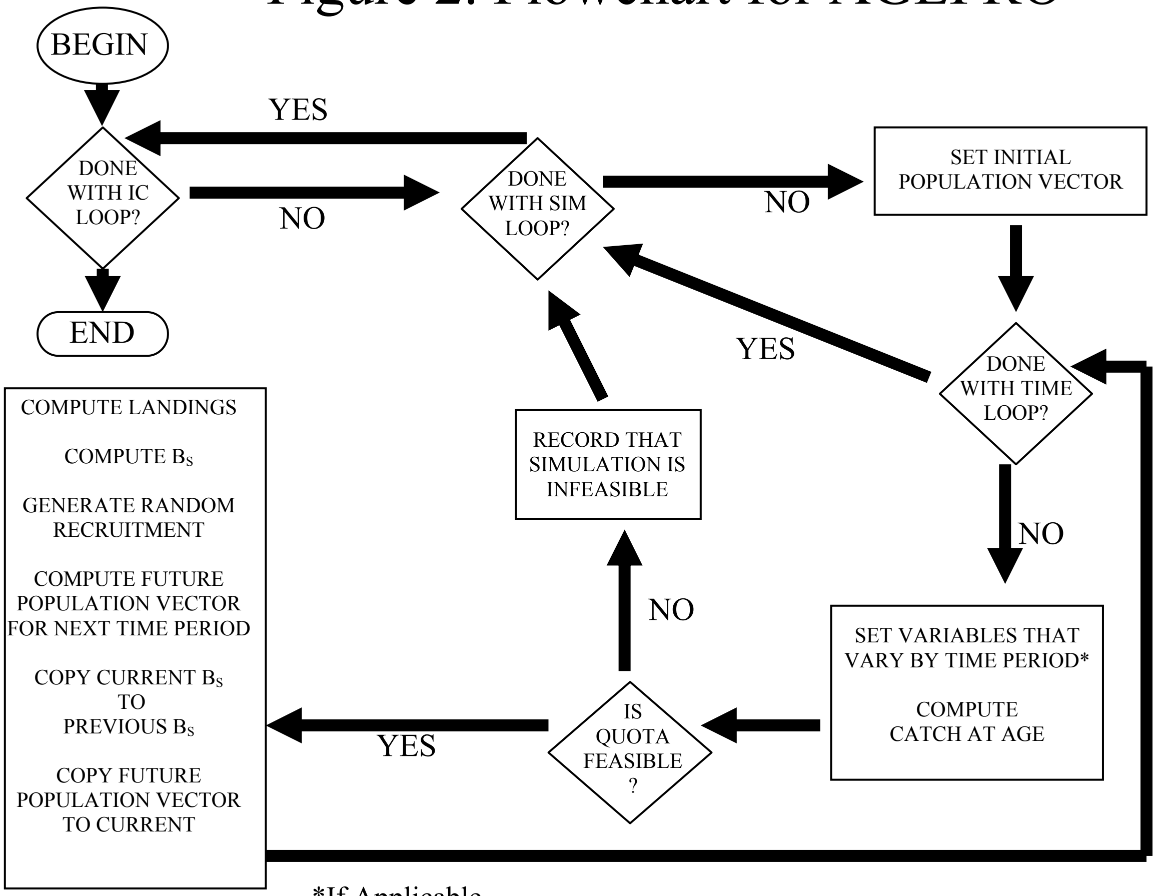
Input #	Is input required?	Input description
43	Yes; depends on flag 11	Fishery selectivity parameters. If flag 11=true, input: $P_{F,r}(1)$, $P_{F,r+1}(1)$, ... , $P_{F,A}(1)$ and on the next Y-1 lines input: $P_{F,r}(2)$, $P_{F,r+1}(2)$, ... , $P_{F,A}(2)$ $P_{F,r}(3)$, $P_{F,r+1}(3)$, ... , $P_{F,A}(3)$ ... $P_{F,r}(Y)$, $P_{F,r+1}(Y)$, ... , $P_{F,A}(Y)$ If flag 11=false, input: $P_{F,r}$, $P_{F,r+1}$, ... , $P_{F,A}$
44	No; required if flag 3=true and depends on flag 12	Discard parameters. If flag 3=true and flag 12=true, input: $P_{D,r}$, $P_{D,r+1}$, ... , $P_{D,A}$ If flag 3=true and flag 12=false, on the next Y lines input: $P_{D,r}$ (1) , $P_{D,r+1}$ (1) , ... , $P_{D,A}$ (1) $P_{D,r}$ (2) , $P_{D,r+1}$ (2) , ... , $P_{D,A}$ (2) ... $P_{D,r}$ (Y) , $P_{D,r+1}$ (Y) , ... , $P_{D,A}$ (Y)
45	Yes; depends on flags 2 and 4	Harvest strategy parameters. If flag 2=false and flag 4=true, input: Q(1) , Q(2) , Q(3) , ... , Q(Y) If flag 2=false and flag 4=false, input: F(1) , F(2) , F(3) , ... , F(Y) If flag 2=true, input: I(1) , I(2) , I(3) , ... , I(Y) where I(year)=1 indicates a quota-based harvest and I(year)=0 indicates an F-based harvest in a given year and on the next line input: Q(1) , Q(2) , Q(3) , ... , Q(Y) with placeholder values (-1) for F-based years and on the next line input: F(1) , F(2) , F(3) , ... , F(Y) with placeholder values (-1) for quota-based years
46	No; required if flag 9=true	Market category parameters, input number of market categories: MC (integer between 1 and 3) and on the next 2*MC lines input: Market category 1 label (character string) $q_{r,1}$, $q_{r+1,1}$, ..., $q_{A,1}$ Market category 2 label (character string) $q_{r,2}$, $q_{r+1,2}$, ..., $q_{A,2}$ Market category 3 label (character string) $q_{r,3}$, $q_{r+1,3}$, ..., $q_{A,3}$ and on the next line input: Market category file name (character string)
47	No; required if flag 17=true	Auxiliary output file names (4), input on four successive lines. Input: Spawning biomass output file name (character string) Input: Mean biomass output file name (character string) Input: Fishing mortality output file name (character string) Input: Landings output file name (character string)

Figure 1. AGEPRO input/output diagram



*If applicable

Figure 2. Flowchart for AGEPRO



*If Applicable

Figure 3.1. Projected median spawning biomass of redfish with 90% confidence intervals.

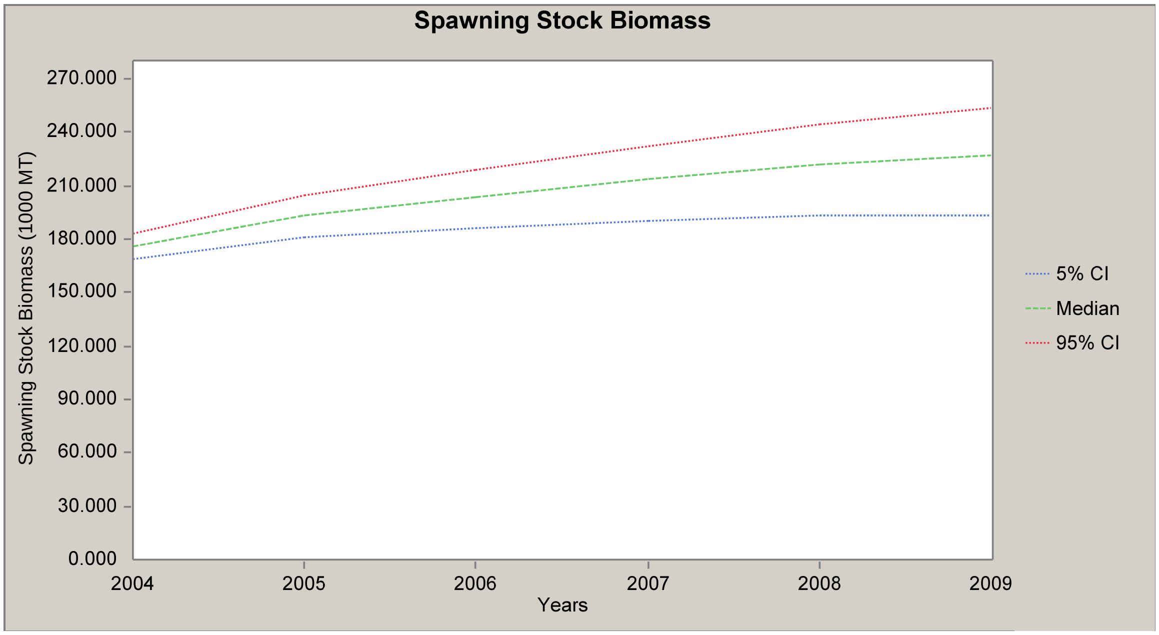


Figure 3.2. Projected annual probability of exceeding redfish spawning biomass threshold B_{MSY}.

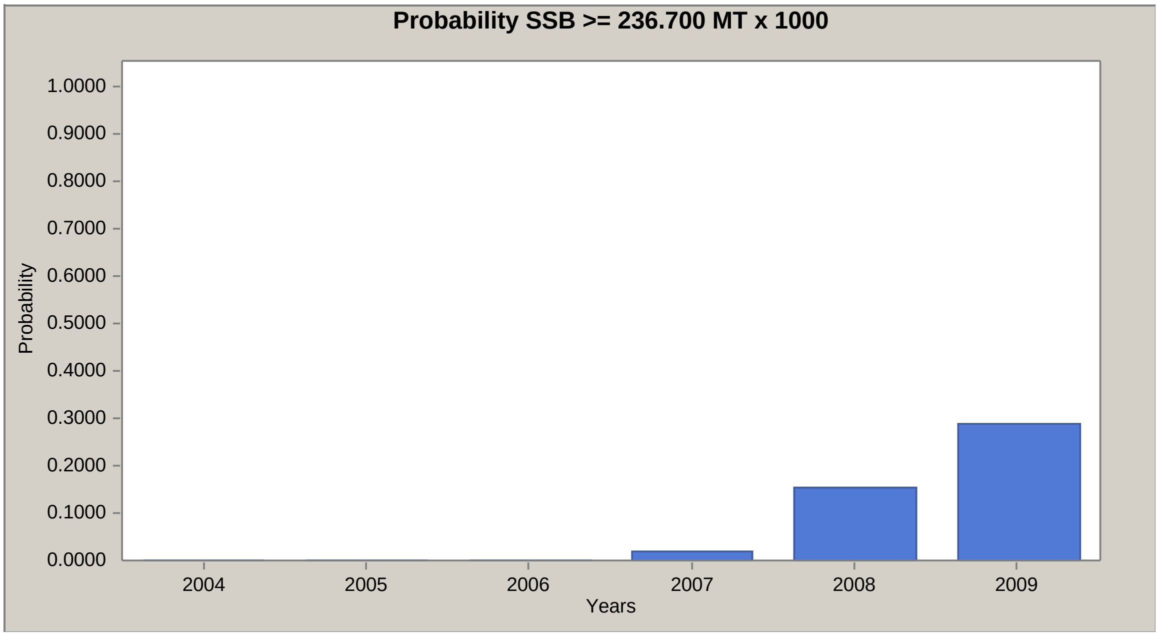


Figure 3.3. Projected median landings of redfish with 90% confidence intervals.

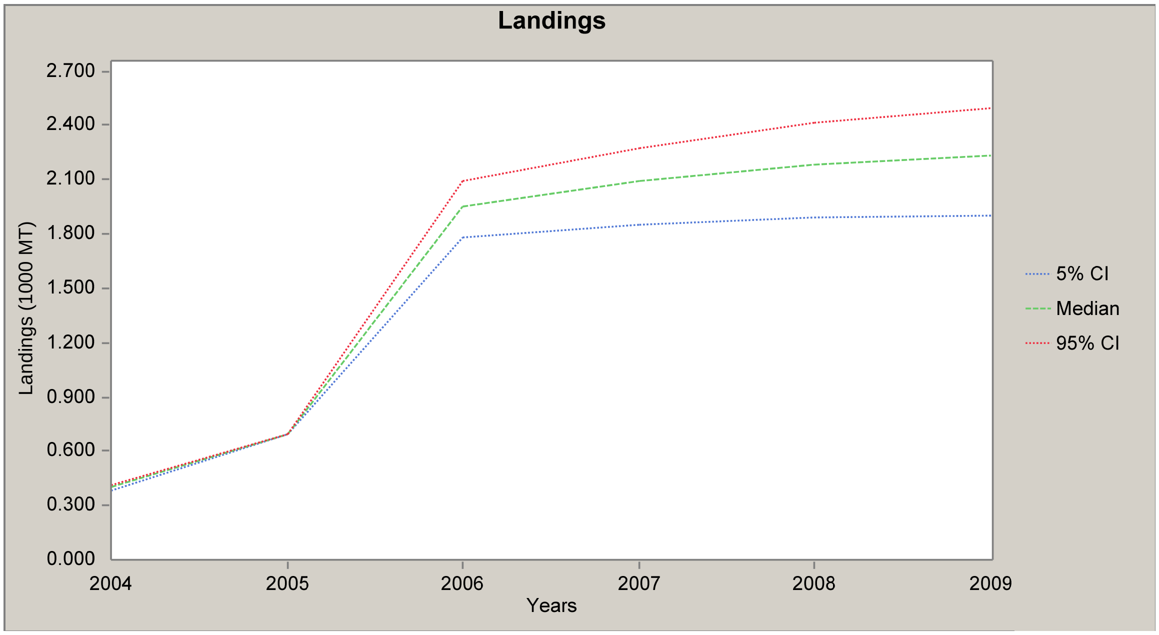


Figure 4.1. Projected median discard biomass of Georges Bank haddock with 90% confidence intervals.

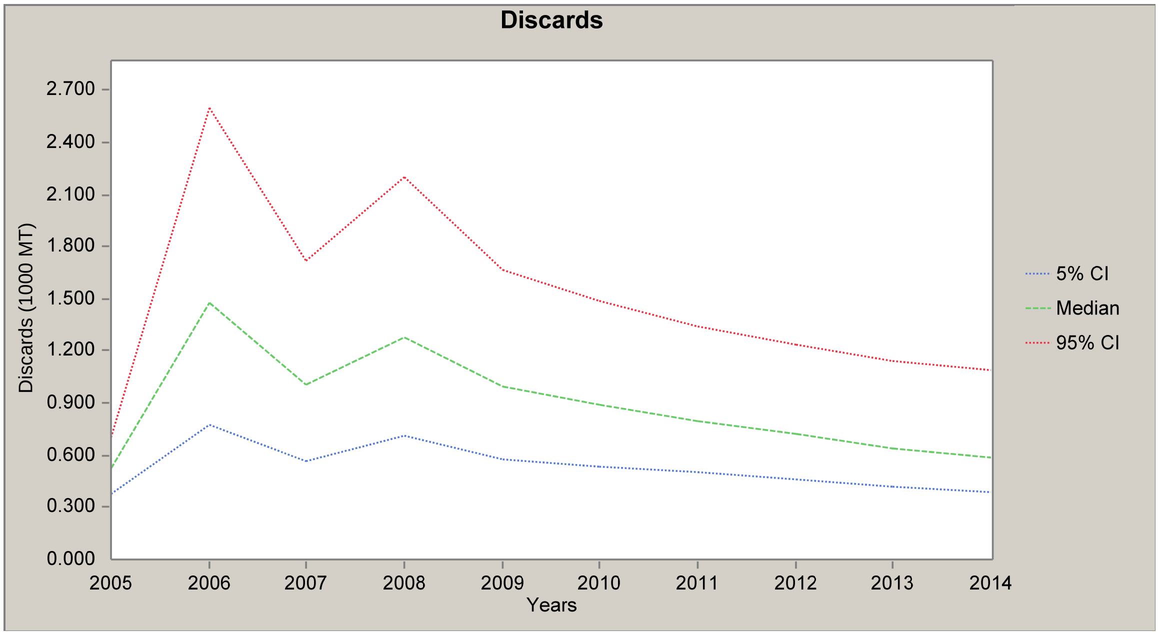


Figure 4.2. Projected median contribution of age-6 Georges Bank haddock to spawning biomass through time with 90% confidence intervals. The 2003 year class would be age 6 in 2009.

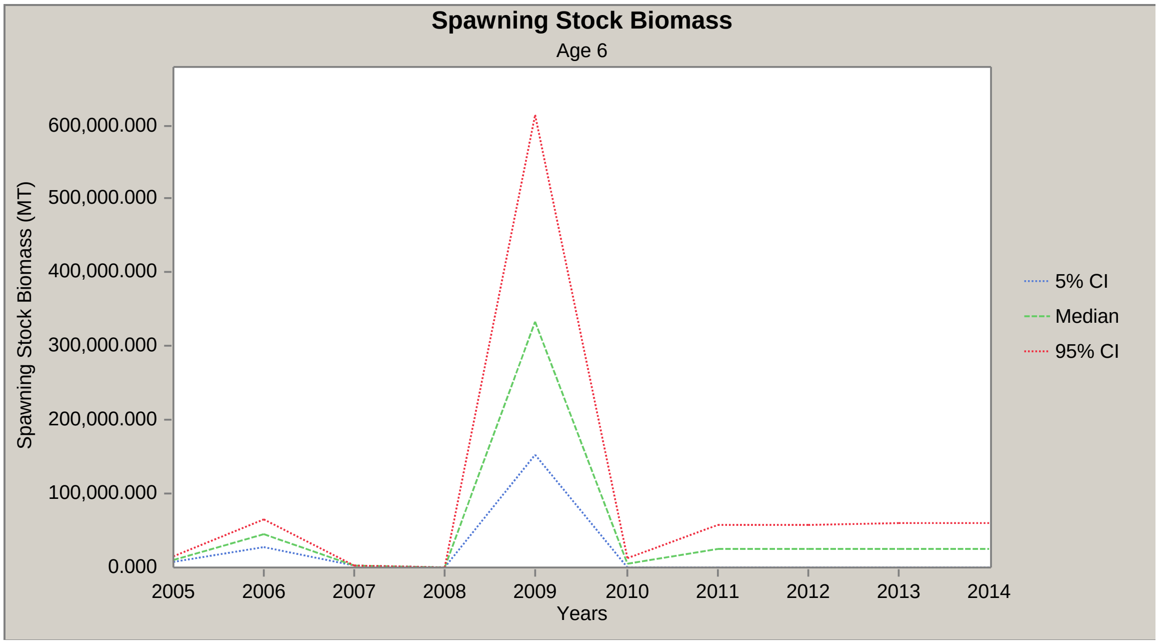


Figure 4.3. Projected median landings of large market category Georges Bank haddock with 90% confidence intervals.

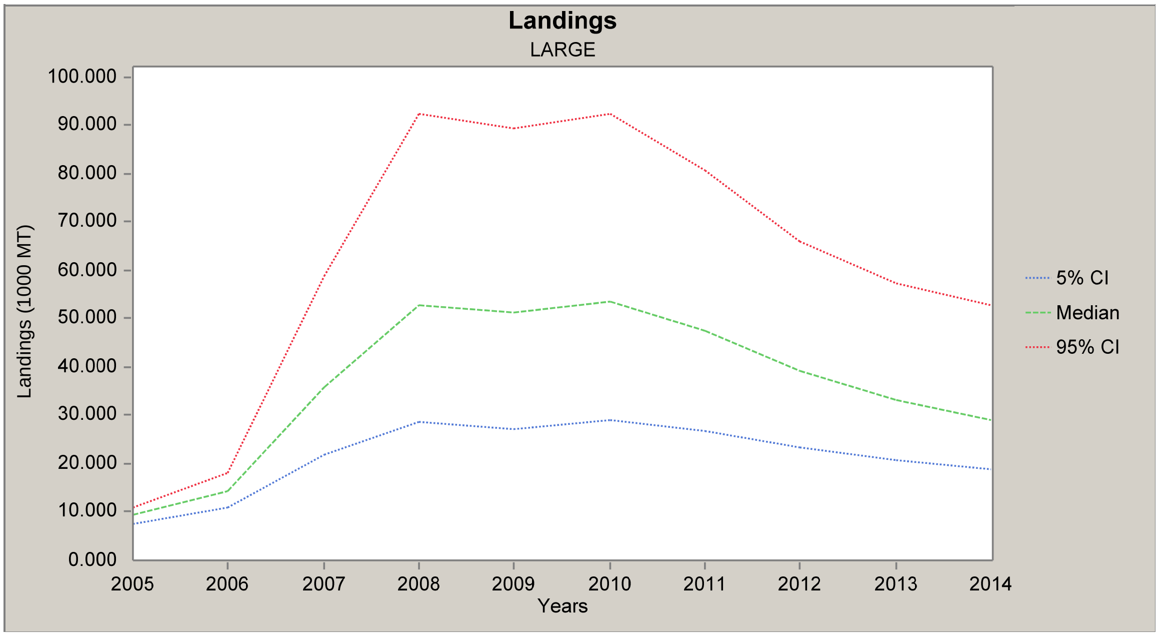


Figure 4.4. Projected median landings of scrod market category Georges Bank haddock with 90% confidence intervals.

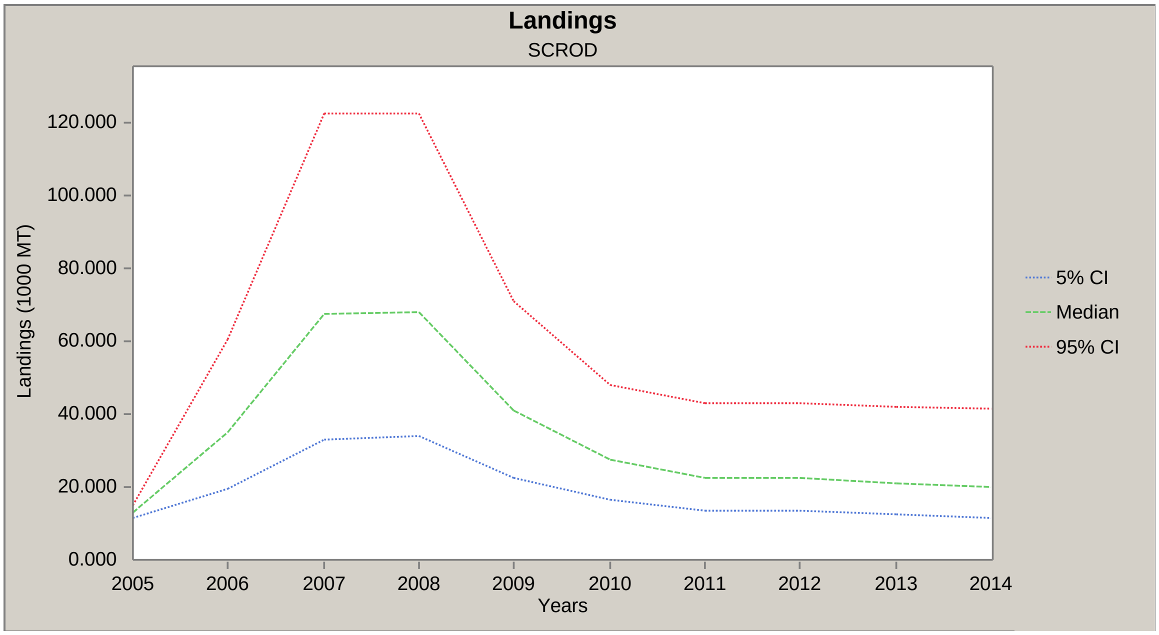
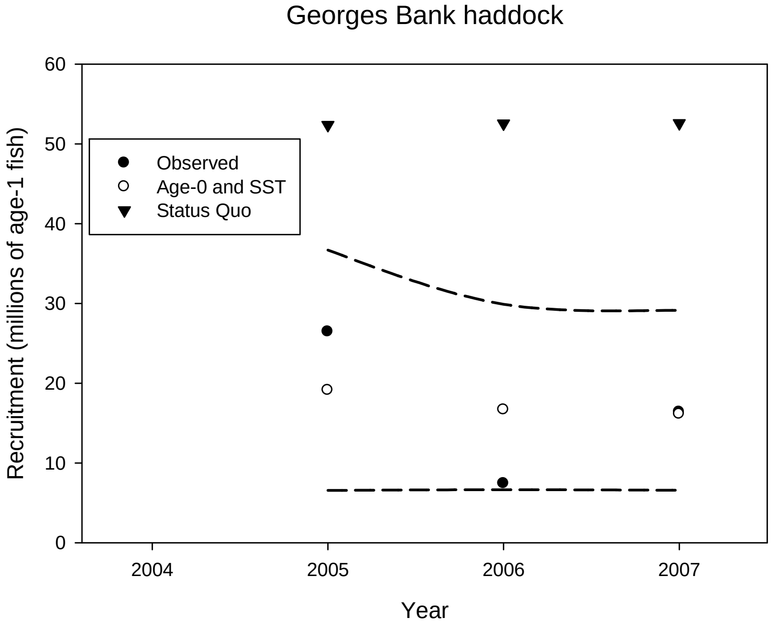


Figure 5. Comparison of Georges Bank haddock observed recruitment (solid circle) during 2005-2007 (NEFSC 2008a) and rescaled recruitment predictions from the best predictive model (open circle), a model-averaged combination of predictors using the haddock age-0 survey index and average sea surface temperature (SST) during February-May, and the status quo model (solid triangle) from Mayo and Terceiro (2006) along with 80% confidence intervals for the Age-0 index and SST-based prediction.



Appendix

Application of Newton's Method

To solve for the fishing mortality F that would yield the landings quota Q, we define a function g() and find its root. Let g(F) = L(F) - Q where L(F) is defined in Equation 11. The first order Taylor series expansion of g(F) about an arbitrary positive real number x is

(63)
$$g(F) = g(x) + g'(x)\cdot(F-x)$$

Solving for the value of F that implies g(F) = 0, one obtains

(64)
$$F = x - \frac{g(x)}{g'(x)}$$

One can numerically solve g(F)=0 by successively substituting iterates of $x=F^{(n)}$

(65)
$$F^{(n+1)} = F^{(n)} - \frac{g\left(F^{(n)}\right)}{g'\left(F^{(n)}\right)}$$

The function g'(F) is the first derivative of L(F) - Q with respect to F. Since Q is a constant, this derivative is g'(F) = L'(F) where

(66)
$$L'(F) = \sum_{a=r}^{A}\left(1-P_{D,a}\right)\cdot W_{L,a}\cdot C_a'(F)$$

The derivative of catch with respect to F can be derived by taking the derivative of F with respect to C. After some algebra the derivative g'(F) reduces to

(67)
$$g'(F) = \sum_{a=r}^{A}\left(1-P_{D,a}\right)\cdot W_{L,a}\cdot\frac{P_{F,a}N_a}{\left(M_a+P_{F,a}F\right)^2}\cdot\left(M_a+\left(M_aP_{F,a}F-M_a+P_{F,a}^2F^2\right)\cdot e^{-M_a-P_{F,a}F}\right)$$

Therefore, the iterative solution for F that results in catch of the quota Q can be found from

(68)
$$F^{(n+1)} = F^{(n)} - \frac{L\left(F^{(n)}\right)-Q}{g'\left(F^{(n)}\right)}$$

The iterates $F^{(n)}$ are constrained to remain within a bounded interval to ensure that the iterates $F^{(n)}$ converge to the solution of g(F)=0. In this case, the bounded interval of feasible iterates $F^{(n)}$ for g(F)=0 is set to be [0, 25] and the iteration has numerically converged when $| F^{(n+1)} - F^{(n)} | < 0.0005$.

Definition of Infeasible Quotas

An infeasible quota occurs when the landings quota cannot be removed from the exploitable biomass for some maximum feasible fishing mortality, denoted by F*. In this case, it is assumed that the maximum feasible F is F*=25.0 . Given this choice of F*and a constant M=0.2, it follows that the survival probability of average recruit would be exp(-Z) = exp(-25.2) ≈ $1.137 \cdot 10^{-11}$, or roughly 1 chance in 100 billion. This survival probability was small enough to characterize the maximum fishing mortality rate on a stock. Given F*, the maximum landings in time period t, denoted by L*, are

(69)

$$L^*\left(F^*\right) = \sum_{a=r}^{A}\left(1-P_{D,a}\left(t\right)\right)\cdot W_{L,a}\left(t\right)\cdot N_a\left(t\right)\cdot\frac{P_{F,a}\left(t\right)F^*}{M_a\left(t\right)+P_{F,a}\left(t\right)F^*}\cdot\left(1-e^{-M_a(t)-P_{F,a}(t)F^*}\right)$$

Appendix 3: ASAP Input Files for the LIS and NJ-NYB Regional Assessments

```
# ASAP VERSION 3.0
# LIS
#
# ASAP GUI 15 AUG 2012
#
# Number of Years
31
# First Year
1984
# Number of Ages
12
# Number of Fleets
1
# Number of Sensitivity Blocks
4
# Number of Available Survey Indices
6
# Natural Mortality
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
0.15       0.15       0.15       0.15       0.15       0.15
```

```
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
0.15        0.15        0.15        0.15        0.15        0.15
# Fecundity Option
0
# Fraction of year that elapses prior to SSB calculation (0=Jan-
1)
.42
# Maturity
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
0           0           0.8         1           1           1
1           1           1           1           1           1
```

```
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
0          0          0.8        1          1          1
1          1          1          1          1          1
# Number of Weights at Age Matrices
2
# Weight Matrix - 1
0.072           0.266           0.32            0.498
0.839           1.032           1.492           1.814
2.011           2.334           2.589           3.07
0.075           0.157           0.32            0.568
0.701           1.203           1.46            1.631
2.241           2.541           2.825           3.531
0.164           0.268           0.486           0.753
0.989           1.287           1.402           1.995
1.976           2.624           2.625           5.042
0.066           0.161           0.405           0.542
0.912           1.303           1.657           1.969
```

2.507	2.661	3.048	4.305
0.213	0.379	0.492	0.587
0.867	1.088	1.514	1.631
1.932	2.111	2.887	3.925
0.118	0.103	0.426	0.604
0.779	1.059	1.273	1.739
2.201	2.818	3.063	3.741
0	0	0.416	0.596
1.024	1.017	1.386	1.687
1.779	2.63	2.998	4.495
0.18	0.278	0.701	0.645
1.058	1.271	1.699	2.041
2.102	2.412	2.589	3.678
0.179	0.242	0.341	0.7
0.745	1.069	1.579	1.664
2.263	2.446	2.503	3.444
0.087	0.263	0.372	0.601
0.711	1.037	1.394	1.878
2.16	2.026	2.809	3.543
0.22	0.239	0.646	0.859
0.911	1.013	1.268	1.804
2.252	1.797	3.717	3.269
0.15	0.212	0.281	0.952
1.101	1.28	1.523	2.012
2.383	2.613	2.383	3.793
0.153	0.209	0.784	0.933
1.193	1.512	1.684	1.959
2.493	2.601	2.85	3.594
0	0.193	0.843	1.166
1.278	1.479	1.993	2.197
2.487	2.646	3.255	4.276
0.095	0.163	0.727	1.015
1.372	1.644	1.814	2.165
2.374	3.314	3.251	4.16
0.11	0.27	0.782	1.134
1.345	1.595	1.951	2.52
2.643	3.115	3.346	4.297
0	0.149	0.368	1.002
1.186	1.415	1.718	2.11
2.481	2.889	2.986	3.987
0.077	0.09	0.825	0.544
1.155	1.49	1.724	2.062
2.371	2.869	2.853	3.978
0.076	0.206	0.391	0.887
1.122	1.338	1.693	1.957
2.281	2.638	2.747	3.804
0.094	0.156	0.608	0.791
1.077	1.385	1.726	1.975
2.512	2.606	2.796	3.869
0.106	0.265	0.427	0.807
1.052	1.312	1.686	2.09
2.403	2.549	2.845	3.836
0.111	0.127	0.28	0.777
1.121	1.438	1.757	2.23

```
2.5             2.65            3.221           3.909
0.142           0.177           0.443           0.836
1.118           1.292           1.571           1.957
2.044           2.347           2.702           3.657
0.125           0.135           0.623           0.656
1.053           1.242           1.541           1.808
2.128           2.332           2.446           3.109
0.103           0.129           0.37            0.689
1.062           1.37            1.431           1.807
2.079           2.365           2.406           3.143
0.153           0.27            0.533           1.05
1.269           1.384           1.566           1.765
1.915           2.332           2.905           3.42
0.122           0.155           0.662           1.02
1.417           1.428           1.66            1.949
2.122           2.672           2.77            3.455
0.105           0.252           0.412           1.067
1.266           1.706           1.821           2.239
2.219           2.621           3.309           3.239
0.066           0.225           0.483           0.889
1.495           1.674           1.963           2.092
2.59            2.704           3.172           3.596
0.102           0.207           0.417           0.792
1.427           1.716           1.817           2.19
2.682           2.612           2.996           4.261
0.131           0.368           0.509           0.985
1.427           1.532           1.794           2.098
2.271           2.569           3.325           3.418
# Weight Matrix - 2
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
```

1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092
1.056389268	1.41316957	1.771964835	2.119423119
2.446614519	2.748223276	3.021683861	3.266405267
0.05815781	0.199068032	0.426010863	0.719833092

```
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
0.05815781      0.199068032     0.426010863     0.719833092
1.056389268     1.41316957      1.771964835     2.119423119
2.446614519     2.748223276     3.021683861     3.266405267
# Weights at Age Pointers
1
1
1
1
2
2
# Selectivity Block Assignment
# Fleet 1 Selectivity Block Assignment
1
1
1
2
2
2
2
2
2
2
2
3
3
3
3
3
3
3
3
3
3
3
3
3
3
3
3
3
4
4
4
```

```
# Selectivity Options for each block 1=by age, 2=logisitic, 3
=double logistic
2  2  2  2
# Selectivity Block #1 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #2 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #3 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

```
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #4 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Fleet Start Age
1
# Fleet End Age
12
# Age Range for Average F
8  12
# Average F report option (1=unweighted, 2=Nweighted, 3
=Bweighted)
2
# Use Likelihood constants? (1=yes)
0
# Release Mortality by Fleet
0.025
# Catch Data
# Fleet-1 Catch Data
523             5819            34444           91952
138068          127003          93294           68923
60309           46932           18556           66249
1051773.405
2371            15209           19294           114471
88858           63136           50319           40337
54819           51866           43769           172595
1338977.954
452             13440           65538           57991
76129           154671          164525          92940
79788           28488           32274           290603
2551980.423
290             2850            11370           30544
81925           142345          148618          126702
```

```
94879           62538           61029           292907
2628821.385
3033            4679            51686           77743
155259          109122          86298           94992
87427           55676           19983           174518
1641520.507
709             3678            31235           94402
90746           102278          104165          78365
44224           46814           39734           191993
1587879.661
0               0               21006           68348
140659          57912           47881           90651
52037           16023           31134           126804
1269734.552
141             1545            27693           120956
146024          132402          66154           61028
45965           33689           21050           69297
1144863.545
131             3428            16016           28715
72531           145906          109266          70415
38082           29169           18414           92357
1047820.354
311             2482            16694           27876
34952           131976          101103          36718
25347           47292           13936           71193
837193.572
19              521             15885           25052
46560           52519           48999           38468
27633           13144           7907            12616
415536.295
53              284             1031            30114
56474           22251           23688           42945
12940           13928           10435           12738
382579.438
25              651             7403            19053
36058           34352           18302           21847
13025           12533           3785            10872
307227.42
0               342             6047            20156
28492           23425           16270           12871
7668            3369            1749            19794
278744.4
102             849             2947            22938
43679           35489           32221           22989
7804            15316           2065            7819
360588.474
182             1001            4718            13625
33314           35961           27261           27875
14382           9751            7663            19950
424778.391
2               30              309             2470
6017            11264           9844            7304
5281            4997            2647            17270
162289.202
```

```
43                111               1325              1632
5537              9871              12921             13898
17170             9513              7051              17382
231295.705
23                460               2813              28734
84802             107853            106867            105493
49339             37431             18638             56342
1130323.03
69                509               848               14593
61399             72797             52663             32479
26622             15772             6662              37581
606141.605
154               1783              3827              9766
29016             67406             52122             45920
49841             33387             26603             52084
793167.251
41                347               1967              2805
22460             40500             43585             31106
17063             7746              10817             13198
381757.689
92                931               2665              16298
52127             72838             60266             72695
43135             32005             21310             49218
805163.778
119               1906              5022              14999
54918             114288            103806            100490
79686             66703             41563             85721
1247958.442
88                571               3272              12084
38803             79468             76646             58378
59494             43041             35665             91742
974503.744
187               1843              4275              26948
56996             51418             58861             45689
31828             18022             18047             51759
679828.282
69                399               10919             30554
37762             43815             50218             41746
21612             19621             15665             32099
571847.2
113               995               3382              25478
23377             36629             30864             23510
11736             4642              4807              14086
329507.388
296               1703              3974              8951
55023             49603             46853             41126
51568             15422             8405              36047
685130.31
1042              1698              2893              5900
18965             47790             46525             36897
33954             8781              16169             34078
588397.283
638               13393             13119             19490
84343             105595            92670             71114
```

```
26007           23455           4700            39168
897285.092
# Discards
# Fleet-1 Discards Data
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
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0               0               0               0
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0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
# Release Proportion
# Fleet-1 Release Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Survey Index Data
# Aggregate Index Units
2  2  2  2  2  2
# Age Proportion Index Units
2  2  2  2  2  2
# Weight at Age Matrix
2  2  2  2  2  2
# Index Month
5  5  6  5  5  5
# Index Selectivity Link to Fleet
-1  -1  -1  -1  -1  -1
# Index Selectivity Options 1=by age, 2=logisitic, 3=double
logistic
2  1  2  1  1  1
# Index Start Age
1  1  1  1  1  1
# Index End Age
12  1  12  1  1  1
# Estimate Proportion (Yes=1)
1  0  1  0  0  0
# Use Index (Yes=1)
1  1  1  1  0  0
# Index-1 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-2 Selectivity Data
1               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
```

```
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-3 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-4 Selectivity Data
1               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-5 Selectivity Data
1               -1              0               0
0               -1              0               0
```

```
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              0              0              0
0              0              0              0
0              0              0              0
0              0              0              0
0              0              0              0
0              0              0              0
# Index-6 Selectivity Data
1              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              -1             0              0
0              0              0              0
0              0              0              0
0              0              0              0
0              0              0              0
0              0              0              0
0              0              0              0
# Index-1 Data
1984  1.697409106    0.485338992    0.004464286    0.03125
0.071428571    0.102678571    0.113839286    0.104910714
0.102678571    0.091517857    0.095982143    0.09375
0.033482143    0.154017857    16
1985  0.955933641    0.45190654     0
0.024221453    0.034602076    0.107266436    0.096885813
0.110726644    0.117647059    0.124567474    0.110726644
0.089965398    0.065743945    0.117647059    20
1986  1.033135691    0.36410516     0.003710575
0.018552876    0.057513915    0.027829314    0.079777365
0.14471243     0.166975881    0.141001855    0.128014842
0.070500928    0.06864564     0.092764378    31
1987  0.829253884    0.362768133    0.014450867
0.063583815    0.046242775    0.046242775    0.075144509
0.132947977    0.132947977    0.12716763     0.080924855
0.054913295    0.052023121    0.173410405    32
1988  0.616695509    0.367808108    0.013761468    0.03440367
0.052752294    0.052752294    0.068807339    0.064220183
```

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0.077981651     0.112385321     0.139908257     0.094036697
0.055045872     0.233944954     32
1989  0.771265927     0.363951391     0.001821494
0.036429872     0.052823315     0.122040073     0.056466302
0.089253188     0.120218579     0.118397086     0.081967213
0.076502732     0.049180328     0.194899818     32
1990  0.786839961     0.363928907     0.005434783
0.061594203     0.14673913      0.081521739     0.108695652
0.032608696     0.043478261     0.110507246     0.088768116
0.032608696     0.088768116     0.199275362     32
1991  1.039156441     0.359774667     0.007075472
0.025943396     0.051886792     0.113207547     0.113207547
0.122641509     0.091981132     0.108490566     0.087264151
0.08490566      0.054245283     0.139150943     32
1992  0.465447409     0.418810184     0.007936508
0.047619048     0.051587302     0.027777778     0.055555556
0.111111111     0.130952381     0.087301587     0.067460317
0.067460317     0.063492063     0.281746032     25
1993  0.257415538     0.391560101     0.013333333     0.04
0.086666667     0.053333333     0.026666667     0.106666667
0.106666667     0.08            0.08            0.08
0.066666667     0.26            32
1994  0.27694918      0.389221171     0.004975124
0.049751244     0.064676617     0.109452736     0.099502488
0.099502488     0.089552239     0.139303483     0.084577114
0.059701493     0.039800995     0.15920398      32
1995  0.142073952     0.419807197     0.016666667
0.033333333     0.033333333     0.15            0.233333333
0.1             0.083333333     0.1             0.066666667
0.083333333     0.016666667     0.083333333     32
1996  0.206126913     0.40050034      0               0.08
0.056           0.072           0.168           0.136
0.088           0.104           0.096           0.08
0.024           0.096           32
1997  0.277797364     0.388918248     0               0.07486631
0.144385027     0.14973262      0.165775401     0.128342246
0.085561497     0.080213904     0.053475936     0.021390374
0.010695187     0.085561497     32
1998  0.364657178     0.380989271     0
0.032085561     0.042780749     0.117647059     0.181818182
0.13368984      0.14973262      0.128342246     0.053475936
0.069518717     0.032085561     0.058823529     32
1999  0.505163296     0.371827855     0.04784689
0.076555024     0.081339713     0.105263158     0.153110048
0.167464115     0.110047847     0.110047847     0.062200957
0.019138756     0.023923445     0.043062201     32
2000  0.453549837     0.374218884     0
0.056737589     0.070921986     0.085106383     0.106382979
0.195035461     0.166666667     0.102836879     0.067375887
0.042553191     0.024822695     0.081560284     32
2001  0.543382818     0.373306452     0.009615385
0.028846154     0.096153846     0.092948718     0.125
0.125           0.141025641     0.121794872     0.08974359
0.054487179     0.048076923     0.067307692     32
```

```
2002  0.955009865     0.360697332     0.001808318
0.019891501     0.045207957     0.092224231     0.150090416
0.157323689     0.157323689     0.160940325     0.072332731
0.05244123      0.028933092     0.061482821     32
2003  0.393174332     0.408823538     0               0.01025641
0.015384615     0.112820513     0.235897436     0.220512821
0.148717949     0.087179487     0.071794872     0.035897436
0.020512821     0.041025641     25
2004  0.348500718     0.383300359     0.00456621      0.02739726
0.054794521     0.059360731     0.114155251     0.251141553
0.159817352     0.095890411     0.091324201     0.059360731
0.03196347      0.050228311     31
2005  0.293824831     0.387286161     0.005813953
0.046511628     0.075581395     0.046511628     0.145348837
0.197674419     0.191860465     0.122093023     0.075581395
0.034883721     0.029069767     0.029069767     32
2006  0.396188311     0.467858285     0               0.02259887
0.033898305     0.101694915     0.146892655     0.141242938
0.124293785     0.15819209      0.096045198     0.073446328
0.04519774      0.056497175     19
2007  0.365848238     0.380773084     0
0.025830258     0.025830258     0.055350554     0.070110701
0.092250923     0.118081181     0.136531365     0.129151292
0.114391144     0.073800738     0.158671587     32
2008  0.378764766     0.410168591     0.005813953
0.034883721     0.046511628     0.075581395     0.11627907
0.13372093      0.122093023     0.087209302     0.093023256
0.058139535     0.063953488     0.162790698     25
2009  0.263561732     0.391055726     0.00625         0.0625
0.01875         0.075           0.1375          0.1125
0.14375         0.13125         0.0875          0.0625
0.05            0.1125          32
2010  0.169582153     0.603536234     0.019607843
0.039215686     0.156862745     0.117647059     0.098039216
0.098039216     0.137254902     0.098039216     0.039215686
0.039215686     0.058823529     0.098039216     12
2011  0.176935069     0.435835962     0.029126214
0.097087379     0.116504854     0.155339806     0.087378641
0.145631068     0.116504854     0.106796117     0.048543689
0.019417476     0.019417476     0.058252427     27
2012  0.285464913     0.3881398       0.06870229
0.145038168     0.160305344     0.129770992     0.175572519
0.091603053     0.061068702     0.06870229      0.061068702
0.007633588     0.007633588     0.022900763     32
2013  0.286080815     0.387949048     0.033333333
0.086666667     0.146666667     0.16            0.186666667
0.173333333     0.1             0.053333333     0.02
0.006666667     0.013333333     0.02            32
2014  0.328312393     0.38486676      0.047904192
0.203592814     0.095808383     0.089820359     0.203592814
0.143712575     0.071856287     0.077844311     0.023952096
0.023952096     0               0.017964072     31
# Index-2 Data
1984  -999            -999            0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
1985  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1986  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1987  0.206567565     0.31143104      0               0
0               0               0               0
0               0               0               0
0               0               0
1988  0.21846089      0.29800028      0               0
0               0               0               0
0               0               0               0
0               0               0
1989  0.90035506      0.282025717     0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.354135897     0.286799504     0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.285969892     0.288825756     0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.131862053     0.302678352     0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.227490495     0.293223995     0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.076321412     0.308452806     0               0
0               0               0               0
0               0               0               0
0               0               0
1995  0.088572524     0.309916534     0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.233486202     0.292887217     0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.176895408     0.301811412     0               0
0               0               0               0
0               0               0               0
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0               0               0
1998  0.24979087      0.295210213     0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.169911618     0.298424866     0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.085285273     0.312015046     0               0
0               0               0               0
0               0               0               0
0               0               0
2001  0.326175564     0.290295487     0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.1365723       0.301228535     0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.208143345     0.299913512     0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.144845973     0.302279102     0               0
0               0               0               0
0               0               0               0
0               0               0
2005  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
2006  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.218854187     0.293218119     0               0
0               0               0               0
0               0               0               0
0               0               0
2008  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.923531717     0.281162225     0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0.423930158     0.319907964     0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.102574155     0.318710294     0               0
```

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0               0               0               0
0               0               0               0
0               0               0
2012  0.161136939     0.298402265     0               0
0               0               0               0
0               0               0               0
0               0               0
2013  1.133440218     0.322799914     0               0
0               0               0               0
0               0               0               0
0               0               0
2014  0.407378242     0.294134051     0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-3 Data
1984  1.6597093       0.403532089     0.001154182
0.012841654     0.076012705     0.202924174     0.30469522
0.280276437     0.205885766     0.15210265      0.133092853
0.103571835     0.040950289     0.146201536     7
1985  1.3833302       0.41508728      0.004574163
0.029341392     0.037222225     0.220838876     0.171425958
0.121802756     0.09707604      0.077818642     0.105757496
0.100060532     0.084439699     0.33297242      6
1986  1.2586193       0.353808632     0.0005383
0.016006074     0.078051048     0.069063114     0.090664168
0.184202046     0.195937452     0.110684861     0.095021774
0.033927161     0.038436015     0.346087289     8
1987  1.4753378       0.337646401     0.00040516
0.003981747     0.015885074     0.042673149     0.114457758
0.198870791     0.207634826     0.177015891     0.132555845
0.0873721       0.08526387      0.409221588     8
1988  3.5301878       0.228222703     0.011632848     0.01794596
0.198237847     0.298177552     0.595484463     0.418529397
0.330989625     0.364334822     0.335319821     0.213541199
0.076643325     0.66935094      16
1989  2.5372833       0.214675083     0.002171726
0.011266019     0.095675395     0.289161154     0.277962523
0.313285995     0.319066033     0.240038493     0.135461779
0.143395164     0.121708537     0.58809048      20
1990  1.4650254       0.191729413     0               0
0.047166967     0.153468907     0.315836353     0.130035866
0.107512213     0.203548164     0.116844115     0.035978116
0.069908424     0.284726274     30
1991  1.7734996       0.178552778     0.000344467
0.003774474     0.067654701     0.295498575     0.356740335
0.323461443     0.161615899     0.149092952     0.112293661
0.082303081     0.051425684     0.169294328     30
1992  2.401782        0.186708725     0.000503873
0.013185319     0.061603287     0.110448201     0.27898027
0.561206868     0.420276271     0.270841375     0.146477046
0.112194448     0.070826856     0.355238186     27
1993  1.8451679       0.215553615     0.001125455
0.008981931     0.060412711     0.100878443     0.126485268
```

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0.477598413     0.365874343     0.132876118     0.091726427
0.171141603     0.050431984     0.257635205     21
1994  1.365141        0.279017048     8.96E-05
0.002458285     0.074951749     0.118205301     0.2196886
0.247805533     0.231196773     0.181507326     0.130383486
0.06201862      0.037308371     0.059527306     13
1995  0.8781094       0.364014907     0.000205129     0.00109918
0.003990333     0.116551789     0.218574276     0.086119209
0.091680905     0.166212279     0.050082359     0.053906267
0.040387126     0.049300548     9
1996  1.0525647       0.34806206      0.00014791
0.003851582     0.043799178     0.112725345     0.213333884
0.20324049      0.108282122     0.129255792     0.07706123
0.074150357     0.022393609     0.064323201     9
1997  0.7165275       0.31781711      0
0.001748089     0.030908468     0.10302482      0.145633219
0.119733896     0.083162027     0.065788473     0.039194003
0.017220213     0.00893979      0.101174503     12
1998  0.6015903       0.329742217     0.000315945
0.002629778     0.009128333     0.07105046      0.135295713
0.109927186     0.099804555     0.071208433     0.024172892
0.047441314     0.006396338     0.024219354     12
1999  0.673189        0.305111361     0.000626117
0.003443642     0.016230872     0.046872749     0.114606881
0.123713095     0.09378334      0.095895624     0.049476982
0.033545407     0.026362266     0.068632025     13
2000  0.233443        0.404802686     6.92E-06
0.000103852     0.00106968      0.008550518     0.02082934
0.038993133     0.034077451     0.02528461      0.018281493
0.017298357     0.009163248     0.059784394     12
2001  0.282495        0.333590104     0.000125939
0.000325097     0.003880667     0.00477981      0.016216796
0.028910239     0.037843095     0.040704538     0.050287589
0.027861726     0.020651007     0.050908496     17
2002  1.0079203       0.296202354     3.87E-05
0.000774294     0.004734976     0.048366439     0.142742771
0.181543313     0.179883631     0.177570848     0.083049758
0.063005644     0.03137237      0.094837541     14
2003  0.8180218       0.245802429     0.000175294
0.001293108     0.002154334     0.037073337     0.155983405
0.184939884     0.133789704     0.0825125       0.067632864
0.040068572     0.016924729     0.095474069     22
2004  0.6700774       0.296257645     0.000277466
0.003212474     0.006895198     0.017595637     0.052278826
0.121447013     0.093909462     0.08273517      0.08979973
0.060154162     0.047931266     0.093840997     14
2005  0.83986         0.311723428     0.000179687
0.001520763     0.008620579     0.0122932       0.098433249
0.177495395     0.191015723     0.136325228     0.074780344
0.033947638     0.04740661      0.057841586     13
2006  1.0811674       0.289805043     0.000234826
0.002376332     0.006802283     0.041599854     0.133051639
0.185915461     0.153826041     0.185550461     0.110099995
0.08169121      0.054392741     0.125626557     13
```

```
2007  0.927224        0.289719184     0.000164878
0.002640815     0.006958118     0.020781525     0.076090391
0.15834915      0.143826052     0.139231644     0.110407133
0.092418831     0.057586673     0.11876879      14
2008  0.9020014       0.282801193     0.00015899
0.001031629     0.005911541     0.021832231     0.070105599
0.143575283     0.13847676      0.105471861     0.107488145
0.077762417     0.064436156     0.165750788     15
2009  0.8171805       0.336489088     0.000417666
0.004116356     0.009548249     0.06018859      0.127301057
0.114842546     0.131466551     0.102046775     0.071088112
0.040252292     0.04030813      0.115604173     11
2010  0.8692267       0.28535244      0.000196981
0.001139065     0.031171563     0.087225564     0.107802964
0.125083069     0.143362355     0.119176488     0.061697941
0.056014034     0.044720445     0.091636231     17
2011  0.7903823       0.369842155     0.000497237
0.004378325     0.014881905     0.112111526     0.10286644
0.16117957      0.135811686     0.103451683     0.051642235
0.020426317     0.021152371     0.061983003     9
2012  0.7083347       0.305316535     0.000657323     0.00378183
0.008825009     0.019877368     0.122188852     0.110152729
0.10404584      0.091327967     0.114516379     0.034247432
0.018664873     0.080049098     15
2013  0.5495226       0.315238783     0.002248216
0.003663599     0.006241927     0.01272982      0.04091882
0.103111543     0.100382183     0.079608843     0.073259036
0.018945856     0.03488618      0.073526578     15
2014  1.106992        0.267775509     0.00143057
0.030030756     0.029416373     0.043701891     0.18911999
0.236772766     0.207791394     0.159456967     0.058314781
0.052592502     0.010538681     0.08782533      20
# Index-4 Data
1984  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1985  0.368517487     0.252905445     0               0
0               0               0               0
0               0               0               0
0               0               0
1986  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1987  0.051630543     0.369688704     0               0
0               0               0               0
0               0               0               0
0               0               0
1988  0.032507047     0.362236071     0               0
0               0               0               0
0               0               0               0
0               0               0
1989  1.24363834      0.226976371     0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
1990  0.026140344     0.455354663     0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.18745065      0.283795878     0               0
0               0               0               0
0               0               0               0
0               0               0
1992  2.932268303     0.22329676      0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.450121953     0.228226799     0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.008599389     0.575180537     0               0
0               0               0               0
0               0               0               0
0               0               0
1995  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.064864457     0.383690813     0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0.043049791     0.366646666     0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.281331736     0.292093823     0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.214573131     0.267230511     0               0
0               0               0               0
0               0               0               0
0               0               0
2000  1.004488972     0.222541041     0               0
0               0               0               0
0               0               0               0
0               0               0
2001  1.772020936     0.201772735     0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.03435668      0.344738479     0               0
0               0               0               0
0               0               0               0
```

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0               0               0
2003  0.547712448     0.205000859     0               0
0               0               0               0
0               0               0               0
0               0               0
2004  0.934900352     0.187235735     0               0
0               0               0               0
0               0               0               0
0               0               0
2005  0.045305162     0.286410527     0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.330962752     0.222932881     0               0
0               0               0               0
0               0               0               0
0               0               0
2007  0.172472326     0.267096546     0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.063856545     0.255929209     0               0
0               0               0               0
0               0               0               0
0               0               0
2009  0.03991959      0.299375629     0               0
0               0               0               0
0               0               0               0
0               0               0
2010  -999            -999            0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.009747232     0.485426587     0               0
0               0               0               0
0               0               0               0
0               0               0
2012  0.008482781     0.494140103     0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0.401775065     0.207927152     0               0
0               0               0               0
0               0               0               0
0               0               0
2014  0.025192277     0.339405772     0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-5 Data
1984  3168.98         0.350686176     0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
1985  1910.17         0.22327986      0               0
0               0               0               0
0               0               0               0
0               0               0
1986  5167.94         0.472643815     0               0
0               0               0               0
0               0               0               0
0               0               0
1987  4476.6          0.435894222     0               0
0               0               0               0
0               0               0               0
0               0               0
1988  3061.85         0.306633037     0               0
0               0               0               0
0               0               0               0
0               0               0
1989  2630.13         0.347440155     0               0
0               0               0               0
0               0               0               0
0               0               0
1990  3128.98         0.388479133     0               0
0               0               0               0
0               0               0               0
0               0               0
1991  2039.45         0.343614488     0               0
0               0               0               0
0               0               0               0
0               0               0
1992  2127.01         0.373292393     0               0
0               0               0               0
0               0               0               0
0               0               0
1993  1188.9          0.283331245     0               0
0               0               0               0
0               0               0               0
0               0               0
1994  1381.8          0.237886953     0               0
0               0               0               0
0               0               0               0
0               0               0
1995  1370.04         0.284606467     0               0
0               0               0               0
0               0               0               0
0               0               0
1996  1847.11         0.251102895     0               0
0               0               0               0
0               0               0               0
0               0               0
1997  2265.05         0.655696203     0               0
0               0               0               0
0               0               0               0
0               0               0
1998  627.48          0.236148014     0               0
0               0               0               0
```

```
0               0               0               0
0               0               0
1999  1015.24         0.417229603     0               0
0               0               0               0
0               0               0               0
0               0               0
2000  1671.99         0.423489786     0               0
0               0               0               0
0               0               0               0
0               0               0
2001  2392.99         0.398796842     0               0
0               0               0               0
0               0               0               0
0               0               0
2002  3028.03         0.438328738     0               0
0               0               0               0
0               0               0               0
0               0               0
2003  2075.16         0.3499906       0               0
0               0               0               0
0               0               0               0
0               0               0
2004  2172.59         0.356366713     0               0
0               0               0               0
0               0               0               0
0               0               0
2005  3824.53         0.362742825     0               0
0               0               0               0
0               0               0               0
0               0               0
2006  2307.28         0.398333124     0               0
0               0               0               0
0               0               0               0
0               0               0
2007  3384.17         0.449110164     0               0
0               0               0               0
0               0               0               0
0               0               0
2008  4360.59         0.60538288      0               0
0               0               0               0
0               0               0               0
0               0               0
2009  4297.66         0.5259713       0               0
0               0               0               0
0               0               0               0
0               0               0
2010  4345.74         0.526666876     0               0
0               0               0               0
0               0               0               0
0               0               0
2011  2508.5          0.522029703     0               0
0               0               0               0
0               0               0               0
0               0               0
```

```
2012  3432.18         0.626018298     0               0
0               0               0               0
0               0               0               0
0               0               0
2013  3412.91         0.487946485     0               0
0               0               0               0
0               0               0               0
0               0               0
2014  4056.67         0.540578393     0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-6 Data
1984  35.03           0.357320895     0               0
0               0               0               0
0               0               0               0
0               0               0
1985  3.08            0.426603941     0               0
0               0               0               0
0               0               0               0
0               0               0
1986  13.69           0.328239123     0               0
0               0               0               0
0               0               0               0
0               0               0
1987  3.3             0.277559858     0               0
0               0               0               0
0               0               0               0
0               0               0
1988  6.78            0.323320882     0               0
0               0               0               0
0               0               0               0
0               0               0
1989  15.99           0.292635335     0               0
0               0               0               0
0               0               0               0
0               0               0
1990  13.09           0.396773741     0               0
0               0               0               0
0               0               0               0
0               0               0
1991  34.21           0.279805141     0               0
0               0               0               0
0               0               0               0
0               0               0
1992  101.49          0.170000067     0               0
0               0               0               0
0               0               0               0
0               0               0
1993  13.2            0.270182496     0               0
0               0               0               0
0               0               0               0
0               0               0
1994  6.65            0.348232841     0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
1995  12.44           0.294452946     0               0
0               0               0               0
0               0               0               0
0               0               0
1996  8.56            0.495566233     0               0
0               0               0               0
0               0               0               0
0               0               0
1997  17.87           0.253182489     0               0
0               0               0               0
0               0               0               0
0               0               0
1998  2.4             0.275421492     0               0
0               0               0               0
0               0               0               0
0               0               0
1999  14.32           0.382232855     0               0
0               0               0               0
0               0               0               0
0               0               0
2000  64.27           0.536515934     0               0
0               0               0               0
0               0               0               0
0               0               0
2001  12.93           0.652949942     0               0
0               0               0               0
0               0               0               0
0               0               0
2002  120.59          0.486264342     0               0
0               0               0               0
0               0               0               0
0               0               0
2003  66.66           0.882824246     0               0
0               0               0               0
0               0               0               0
0               0               0
2004  453.56          0.590830421     0               0
0               0               0               0
0               0               0               0
0               0               0
2005  100.4           0.749710987     0               0
0               0               0               0
0               0               0               0
0               0               0
2006  256.97          0.237144747     0               0
0               0               0               0
0               0               0               0
0               0               0
2007  20.81           0.941629301     0               0
0               0               0               0
0               0               0               0
```

```
0               0               0
2008  623.58          0.325352329     0               0
0               0               0               0
0               0               0               0
0               0               0
2009  13.87           0.549453046     0               0
0               0               0               0
0               0               0               0
0               0               0
2010  204.35          0.390037889     0               0
0               0               0               0
0               0               0               0
0               0               0
2011  55.43           0.532239203     0               0
0               0               0               0
0               0               0               0
0               0               0
2012  41.6            0.390358644     0               0
0               0               0               0
0               0               0               0
0               0               0
2013  133.73          0.262270543     0               0
0               0               0               0
0               0               0               0
0               0               0
2014  21.78           0.645465663     0               0
0               0               0               0
0               0               0               0
0               0               0
# Phase Control
# Phase for F mult in 1st Year
1
# Phase for F mult Deviations
2
# Phase for Recruitment Deviations
2
# Phase for N in 1st Year
2
# Phase for Catchability in 1st Year
3
# Phase for Catchability Deviations
-1
# Phase for Stock Recruitment Relationship
3
# Phase for Steepness
3
# Recruitment CV by Year
0.5
0.5
0.5
0.5
0.5
0.5
0.5
```

```
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
0.5
# Lambdas by Index
1  1  1  1  1  1
# Lambda for Total Catch in Weight by Fleet
1
# Lambda for Total Discards at Age by Fleet
1
# Catch Total CV by Year and Fleet
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.3699
0.472
0.492
0.384
```

```
0.275
0.221
0.267
0.239
0.499
0.305
0.521
0.291
# Discard Total CV by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Catch Effective Sample Size by Year and Fleet
26
26
26
26
26
26
26
26
26
26
26
26
26
```

```
26
26
26
26
26
26
26
26
26
26
26
26
26
26
26
26
26
26
# Discard Effective Sample Size by Year and Fleet
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Lambda for F Mult in First year by Fleet
0
# CV for F Mult in First year by Fleet
0.5
```

```
# Lambda for F Mult Deviations by Fleet
0.5
# CV for F Mult Deviations by Fleet
0.5
# Lambda for N in 1st Year Deviations
0
# CV for N in 1st Year Deviations
0.5
# Lambda for Recruitment Deviations
.5
# Lambda for Catchability in First year by Index
0  0  0  0  0  0
# CV for Catchability in First year by Index
1  1  1  1  1  1
# Lambda for Catchability Deviations by Index
0  0  0  0  0  0
# CV for Catchability Deviations by Index
1  1  1  1  1  1
# Lambda for Deviation from Initial Steepness
0
# CV for Deviation from Initial Steepness
0.5
# Lambda for Deviation from Unexploited Stock Size
0
# CV for Deviation from Unexploited Stock Size
0.5
# NAA Deviations Flag
2
# Initial Numbers at Age in 1st Year
829  701  587  462  356  256  186  142  89  64  42  93
# Initial F Mult in 1st Year by Fleet
1
# Initial Catchabilty by Index
0.001  0.001  0.001  0.001  0.001  0.001
# Stock Recruitment Flag
0
# Initial Unexploited Stock
10000
# Initial Steepness
0.7
# Maximum F
5
# Ignore Guesses (Yes=1)
0
# Projection Control
# Do Projections (Yes=1)
0
# Fleet Directed Flag
1
# Final Year in Projection
2015
# Projection Data by Year
2015     -1        3    -99        1
# Do MCMC (Yes=1)
```

```
1
# MCMC Year Option
0
# MCMC Iterations
1000
# MCMC Thinning Factor
200
# MCMC Random Seed
314156
# Agepro R Option
1
# Agepro R Option Start Year
1984
# Agepro R Option End Year
2014
# Export R Flag
1
# Test Value
-23456
######
###### FINIS ######
# Fleet Names
#$Rec + Com
# Survey Names
#$CT Trawl
#$NY Trawl
#$MRIP CPUE
#$NYSeine
#$MillstoneEggs
#$MillstoneLarve
#
```

```
# ASAP VERSION 3.0
# NJ-NYB
#
# ASAP GUI 15 AUG 2012
#
# Number of Years
26
# First Year
1989
# Number of Ages
12
# Number of Fleets
1
# Number of Sensitivity Blocks
4
# Number of Available Survey Indices
3
# Natural Mortality
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
.15        .15        .15        .15        .15        .15
```

```
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
.15         .15         .15         .15         .15         .15
# Fecundity Option
0
# Fraction of year that elapses prior to SSB calculation (0=Jan-1)
0.42
# Maturity
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
0           0           .8          1           1           1
1           1           1           1           1           1
```

```
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
0          0          .8         1          1          1
1          1          1          1          1          1
# Number of Weights at Age Matrices
2
# Weight Matrix - 1
0.07            0.27            0.6             0.76
0.9             1.09            1.25            1.51
1.61            2.02            2.15            2.67
0.07            0.27            0.6             0.76
0.9             1.09            1.25            1.51
1.61            2.02            2.15            2.67
0.07            0.27            0.6             0.76
0.9             1.09            1.25            1.51
1.61            2.02            2.15            2.67
0.07            0.27            0.6             0.76
0.9             1.09            1.25            1.51
1.61            2.02            2.15            2.67
0.07            0.27            0.6             0.76
0.9             1.09            1.25            1.51
1.61            2.02            2.15            2.67
0.07            0.27            0.6             0.76
0.9             1.09            1.25            1.51
1.61            2.02            2.15            2.67
0.09            0.09            0.66            0.78
0.77            0.91            1.2             1.42
1.67            2.01            2.82            3.58
0               0.57            0.83            0.82
0.88            1.09            1.07            1.54
1.57            2.61            2.73            3.33
0.05            0.27            0.59            0.84
0.92            1.04            1.18            1.49
1.76            1.73            1.48            2.31
0.07            0.17            0.37            0.58
0.89            1.16            1.37            1.58
1.44            2.33            2.31            2.59
0.12            0.25            0.55            0.78
```

```
1.03            1.22            1.43            1.5
1.61            1.39            1.4             1.53
0               0.23            0.99            1.01
1.17            1.3             1.64            1.73
2.05            2.09            2.34            3.45
0.14            0.26            0.91            1.21
1.22            1.27            1.28            1.57
1.8             1.97            2.36            3.18
0               0.18            0.37            1.03
1.22            1.31            1.57            1.8
2.1             2.23            2.21            3.8
0               0.21            1.01            1.03
1.11            1.16            1.52            1.88
2.13            3.23            2.74            4.17
0               0.36            0.62            1.06
1.13            1.21            1.33            1.58
1.76            1.89            2.16            3.49
0.07            0.61            0.86            1.12
1.14            1.22            1.34            1.5
2.37            2.14            2.24            4.58
0               0.47            0.6             0.93
1.05            1.16            1.31            1.53
1.72            2.37            1.97            3.44
0.05            0.7             1.05            1.07
1.22            1.29            1.36            1.6
1.78            1.94            1.97            2.52
1.22            0.26            0.79            0.98
1.14            1.26            1.31            1.44
1.73            1.96            2.27            3.21
0.12            0.32            0.9             1.15
1.18            1.23            1.36            1.79
2.01            2.26            2.69            3.35
0.13            0.6             0.94            1.12
1.26            1.3             1.31            1.6
1.77            2.28            2.46            2.69
0.11            0.26            0.86            1.07
1.15            1.34            1.53            1.73
1.64            2.09            2.3             3.53
0.15            0.29            0.56            0.85
1.25            1.48            1.54            1.64
2.18            1.86            2.63            3.09
0.17            0.46            0.78            1.17
1.28            1.48            1.78            1.76
2.07            2.44            2.94            2.93
0.1             0.52            0.91            1.15
1.28            1.46            1.63            2.02
2.32            2.32            3.81            3.76
# Weight Matrix - 2
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
```

0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298
0.307	0.448	0.61	0.79
0.984	1.187	1.398	1.613
1.83	2.045	2.258	3.298

```
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
0.307           0.448           0.61            0.79
0.984           1.187           1.398           1.613
1.83            2.045           2.258           3.298
# Weights at Age Pointers
1
1
1
1
2
2
# Selectivity Block Assignment
# Fleet 1 Selectivity Block Assignment
1
1
1
1
1
1
1
1
1
2
2
2
2
2
2
3
3
3
3
3
3
3
3
4
4
4
# Selectivity Options for each block 1=by age, 2=logisitic, 3
```

```
=double logistic
2  2  2  2
# Selectivity Block #1 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #2 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #3 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
```

```
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Selectivity Block #4 Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Fleet Start Age
1
# Fleet End Age
12
# Age Range for Average F
8  12
# Average F report option (1=unweighted, 2=Nweighted, 3
=Bweighted)
2
# Use Likelihood constants? (1=yes)
0
# Release Mortality by Fleet
.025
# Catch Data
# Fleet-1 Catch Data
2.29            29.65           191.751         253.225
224.377         137.603         80.707          77.158
44.761          24.04           25.414          53.576
927.2317325
14.287          47.776          247.942         386.507
363.157         196.48          87.41           71.433
51.002          22.275          13.365          34.411
1183.004296
0               23.563          254.144         342.001
364.218         212.236         113.608         109.905
71.531          45.948          36.859          108.895
1696.443787
58.48           124.39          233.369         380.876
232.956         108.704         74.166          48.985
28.483          22.566          14.861          48.16
```

```
1554.140048
11.401          66.003          211.329         350.416
200.769         116.885         76.923          47.282
28.681          16.441          18.721          55.082
1194.982511
0               0               44.988          60.561
157.504         36.883          31.783          26.091
15.163          17.85           2.869           61.699
418.9167592
0.178           0.16            29.141          130.248
267.904         154.113         106.537         67.74
26.108          38.669          4.402           36.665
935.2385055
0               8.678           56.641          121.276
174.235         104.334         57              34.812
12.606          10.938          10.034          11.15
640.8222493
0.02            1.506           15.129          32.857
46.567          75.873          49.048          34.985
16.925          8.525           3.406           6.531
319.0592707
0.044           1.676           3.235           9.667
11.581          10.449          7.474           4.857
1.986           1.248           0.556           1.163
61.70122495
0.179           4.052           7.478           13.997
51.883          61.858          61.315          40.55
18.4            7.568           3.251           2.68
351.4289506
0               1.204           88.873          65.112
84.413          77.897          110.887         57.512
20.013          21.165          13.646          23.654
944.1605267
0.418           1.68            36.913          113.346
72.093          72.963          87.983          68.732
52.519          19.785          10.033          18.824
789.6749847
0               0.43            3.057           63.504
154.4           134.493         92.422          71.675
31.473          22.162          9.943           28.161
947.9140127
0               0.2             6.7             22.145
47.012          62.091          27.707          16.439
10.517          4.513           5.455           10.747
250.3209027
0               2.026           6.624           25.907
42.038          35.679          22.629          10.345
8.932           4.345           2.036           12.536
237.4199129
0.029           0.635           10.266          24.879
18.451          14.686          9.952           6.037
3.555           1.404           1.01            3.834
130.2893848
0               2.987           6.115           31.336
```

```
70.263          110.758         70.822          40.998
25.529          13.027          4.316           9.721
555.5820358
0.018           5.494           54.503          76.236
65.888          60.99           51.2            40.958
29.5            16.535          7.781           13.762
646.3010123
0.246           2.399           22.75           64.409
66.923          48.373          36.679          24.735
16.464          10.552          10.673          23.294
447.0617118
0.076           6.326           17.05           39.964
80.215          69.508          38.44           21.001
12.791          5.977           3.974           11.921
450.2796357
0.149           6.202           86.787          139.419
112.169         69.371          35.1            24.269
5.914           4.491           2.954           2.371
602.3342576
0.37            1.805           25.191          83.762
63.112          40.155          19.285          9.367
3.422           2.308           1.417           6.947
328.9524909
0.177           2.801           7.105           6.28
17.928          25.103          20.439          9.327
9.134           1.675           2.58            4.353
165.307588
0.159           4.966           18.694          33.928
41.612          42.252          23.209          15.41
8.425           4.668           0.921           3.973
308
0.256           11.168          30.544          69.86
107.074         90.427          63.2            21.977
11.96           6.011           1.783           16.847
654
# Discards
# Fleet-1 Discards Data
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
```

0	0	0	0
0	0	0	0
0			
0	0	0	0
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```
0
0               0               0               0
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0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
0               0               0               0
0               0               0               0
0               0               0               0
0
# Release Proportion
# Fleet-1 Release Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
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0	0	0	0
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0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

```
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Survey Index Data
# Aggregate Index Units
2  2  2
# Age Proportion Index Units
2  2  2
# Weight at Age Matrix
2  2  2
# Index Month
5  6  6
# Index Selectivity Link to Fleet
-1  -1  -1
# Index Selectivity Options 1=by age, 2=logisitic, 3=double
logistic
1  2  2
# Index Start Age
1  1  1
# Index End Age
1  12  12
# Estimate Proportion (Yes=1)
0  1  1
# Use Index (Yes=1)
1  1  1
# Index-1 Selectivity Data
1               -1              0               1
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               -1              0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-2 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
```

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0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-3 Selectivity Data
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
5               2               0               0
0.6             2               0               0
0               0               0               0
0               0               0               0
0               0               0               0
0               0               0               0
# Index-1 Data
1989  1.28            1.36            0               0
0               0               0               0
0               0               0               0
0               0               0
1990  0.994           1.46            0               0
0               0               0               0
0               0               0               0
0               0               0
1991  0.407           1.29            0               0
0               0               0               0
0               0               0               0
0               0               0
1992  0.421           1.39            0               0
0               0               0               0
0               0               0               0
0               0               0
1993  0.013           2.98            0               0
0               0               0               0
0               0               0               0
0               0               0
1994  0.121           1.62            0               0
0               0               0               0
0               0               0               0
```

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0               0               0
1995  0.09            2.05            0               0
0               0               0               0
0               0               0               0
0               0               0
1996  0.052           3.34            0               0
0               0               0               0
0               0               0               0
0               0               0
1997  0               2.5             0               0
0               0               0               0
0               0               0               0
0               0               0
1998  0.052           2.33            0               0
0               0               0               0
0               0               0               0
0               0               0
1999  0.853           1.23            0               0
0               0               0               0
0               0               0               0
0               0               0
2000  0.634           1.16            0               0
0               0               0               0
0               0               0               0
0               0               0
2001  1.112           1.32            0               0
0               0               0               0
0               0               0               0
0               0               0
2002  0.135           1.6             0               0
0               0               0               0
0               0               0               0
0               0               0
2003  0.24            1.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2004  1.859           1.24            0               0
0               0               0               0
0               0               0               0
0               0               0
2005  1.477           1.2             0               0
0               0               0               0
0               0               0               0
0               0               0
2006  0.622           1.3             0               0
0               0               0               0
0               0               0               0
0               0               0
2007  1.041           1.24            0               0
0               0               0               0
0               0               0               0
0               0               0
2008  0.423           1.46            0               0
```

```
0               0               0               0
0               0               0               0
0               0               0
2009  0.042           2.78            0               0
0               0               0               0
0               0               0               0
0               0               0
2010  0               2.5             0               0
0               0               0               0
0               0               0               0
0               0               0
2011  0.066           2.29            0               0
0               0               0               0
0               0               0               0
0               0               0
2012  2.745           1.17            0               0
0               0               0               0
0               0               0               0
0               0               0
2013  0.706           1.31            0               0
0               0               0               0
0               0               0               0
0               0               0
2014  0.922           1.17            0               0
0               0               0               0
0               0               0               0
0               0               0
# Index-2 Data
1989  1.27            0.5             0.03            0.06
0.13            0.21            0.13            0.12
0.09            0.07            0.05            0.03
0.02            0.05            16
1990  1.57            0.53            0               0.03
0.17            0.22            0.2             0.12
0.07            0.07            0.04            0.02
0.02            0.05            16
1991  0.99            0.52            0.01            0.03
0.16            0.25            0.24            0.13
0.06            0.05            0.03            0.01
0.01            0.02            16
1992  1.32            0.51            0               0.01
0.15            0.2             0.22            0.13
0.07            0.07            0.04            0.03
0.02            0.06            16
1993  0.69            0.52            0.04            0.09
0.17            0.28            0.17            0.08
0.05            0.04            0.02            0.02
0.01            0.04            16
1994  0.43            0.54            0.01            0.06
0.18            0.29            0.17            0.1
0.06            0.04            0.02            0.01
0.02            0.05            16
1995  0.6             0.52            0               0
0.07            0.14            0.36            0.09
```

```
0.07            0.05            0.03            0.03
0.01            0.13            16
1996  0.2             0.55            0.01            0.13
0.11            0.28            0.18            0.07
0.04            0.03            0.04            0.04
0.02            0.06            16
1997  0.11            0.59            0               0.05
0.09            0.2             0.17            0.15
0.12            0.09            0.05            0.03
0.01            0.04            16
1998  0.3             0.53            0.01            0.02
0.07            0.21            0.17            0.15
0.12            0.08            0.04            0.04
0.03            0.05            16
1999  0.62            0.52            0.06            0.08
0.11            0.12            0.18            0.17
0.12            0.08            0.04            0.01
0.01            0               16
2000  0.33            0.54            0.08            0.13
0.14            0.17            0.15            0.09
0.09            0.07            0.02            0.01
0.02            0.02            16
2001  0.29            0.55            0.06            0.09
0.21            0.17            0.2             0.08
0.05            0.04            0.02            0.02
0.01            0.06            16
2002  1.48            0.5             0.01            0.02
0.1             0.22            0.26            0.14
0.08            0.06            0.03            0.02
0.01            0.06            16
2003  0.6             0.52            0               0
0.02            0.24            0.21            0.24
0.11            0.09            0.04            0.02
0.02            0.02            16
2004  0.35            0.54            0.01            0.14
0.26            0.17            0.18            0.13
0.04            0.02            0.01            0
0               0.04            16
2005  0.66            0.54            0.04            0.11
0.24            0.18            0.17            0.07
0.05            0.04            0.02            0.02
0.02            0.03            16
2006  0.76            0.52            0               0.06
0.03            0.19            0.17            0.15
0.12            0.07            0.07            0.05
0.03            0.06            16
2007  0.36            0.53            0               0.07
0.17            0.35            0.14            0.07
0.06            0.04            0.04            0.02
0.01            0.03            16
2008  0.9             0.51            0.01            0.03
0.1             0.2             0.19            0.12
0.09            0.07            0.05            0.03
0.03            0.07            16
```

```
2009  0.57          0.52            0.03            0.18
0.19          0.17            0.17            0.07
0.07          0.04            0.03            0.01
0.01          0.04            16
2010  0.44          0.53            0.02            0.1
0.35          0.17            0.12            0.08
0.04          0.03            0.01            0.01
0.02          0.05            16
2011  0.14          0.59            0.08            0.16
0.22          0.21            0.19            0.08
0.04          0.02            0               0
0             0               16
2012  0.25          0.55            0.06            0.21
0.4           0.13            0.1             0.05
0.03          0.02            0               0
0             0               16
2013  0.42          0.53            0.02            0.32
0.28          0.14            0.1             0.05
0.03          0.03            0.01            0
0             0.02            16
2014  0.72          0.53            0.02            0.35
0.2           0.12            0.11            0.07
0.05          0.03            0.02            0.01
0             0.02            16
# Index-3 Data
1989  2.54          0.38            0.002           0.0259
0.1675        0.2212          0.196           0.1202
0.0705        0.0674          0.0391          0.021
0.0222        0.0468          0
1990  1.47          0.34            0.0093          0.0311
0.1614        0.2516          0.2364          0.1279
0.0569        0.0465          0.0332          0.0145
0.0087        0.0224          0
1991  1.77          0.31            0               0.014
0.151         0.2032          0.2164          0.1261
0.0675        0.0653          0.0425          0.0273
0.0219        0.0647          0
1992  2.4           0.34            0.0425          0.0904
0.1696        0.2768          0.1693          0.079
0.0539        0.0356          0.0207          0.0164
0.0108        0.035           0
1993  1.85          0.38            0.0095          0.055
0.1761        0.292           0.1673          0.0974
0.0641        0.0394          0.0239          0.0137
0.0156        0.0459          0
1994  1.37          0.48            0               0
0.0988        0.133           0.3459          0.081
0.0698        0.0573          0.0333          0.0392
0.0063        0.1355          0
1995  0.88          0.53            0.0037          0.0037
0.0976        0.1879          0.4035          0.1227
0.0758        0.0485          0.0162          0.0196
0.0022        0.0187          19
1996  1.05          0.5             0               0.0783
```

```
0.1079          0.2877          0.2737          0.1178
0.056           0.0402          0.0107          0.0094
0.0084          0.0099          19
1997  0.72            0.49            0.0011          0.0497
0.1717          0.2235          0.17            0.176
0.0989          0.0494          0.0347          0.0119
0.0049          0.0082          19
1998  0.6             0.62            0.0042          0.1174
0.1936          0.3633          0.1803          0.0757
0.0378          0.0072          0.0176          0.0015
0.0005          0.0011          19
1999  0.67            0.52            0.0064          0.1107
0.1071          0.1391          0.1899          0.1559
0.1374          0.0793          0.0391          0.0133
0.0172          0.0047          19
2000  0.23            0.54            0               0.0301
0.1523          0.3187          0.1606          0.0766
0.1046          0.0556          0.0375          0.0319
0.0089          0.0231          19
2001  0.28            0.41            0.0096          0.0361
0.1774          0.2576          0.2343          0.0976
0.0666          0.05            0.0327          0.0124
0.0059          0.02            19
2002  1.01            0.45            0               0.007
0.0663          0.2894          0.3043          0.1486
0.0639          0.0456          0.0211          0.0147
0.0077          0.0314          19
2003  0.82            0.43            0               0.0236
0.0174          0.1673          0.2246          0.2225
0.0822          0.06            0.0386          0.0288
0.0268          0.1083          19
2004  0.67            0.45            0.0036          0.0923
0.1542          0.1144          0.1901          0.1054
0.0579          0.0268          0.0377          0.0172
0.0111          0.1893          19
2005  0.84            0.52            0               0.0471
0.2071          0.1897          0.2231          0.1082
0.066           0.068           0.0227          0.0135
0.0087          0.0459          19
2006  1.08            0.49            0               0.0082
0.0929          0.3309          0.2554          0.147
0.0717          0.0385          0.0253          0.0156
0.0056          0.0088          19
2007  0.93            0.48            0               0.0274
0.163           0.31            0.1838          0.1042
0.079           0.053           0.0364          0.0203
0.0115          0.0114          19
2008  0.9             0.46            0.0003          0.0347
0.1729          0.3007          0.2364          0.0993
0.059           0.0321          0.0209          0.0116
0.0109          0.0212          19
2009  0.82            0.47            0.003           0.1738
0.1982          0.1949          0.2197          0.079
0.0885          0.0173          0.0104          0.0046
```

```
0.0028          0.008           19
2010  0.87            0.5             0               0.0688
0.4104          0.239           0.1253          0.0926
0.0297          0.0188          0.0043          0.0034
0.003           0.0047          19
2011  0.79            0.54            0.0134          0.0498
0.2464          0.3162          0.2306          0.0922
0.0284          0.0104          0.0044          0.0023
0.0012          0.0047          19
2012  0.71            0.53            0.015           0.1388
0.3632          0.2166          0.1115          0.0696
0.0415          0.022           0.0114          0.0023
0.003           0.0051          19
2013  0.55            0.53            0.0026          0.2396
0.2679          0.1239          0.171           0.0758
0.0415          0.0385          0.0139          0.0087
0.0056          0.0111          19
2014  1.11            0.53            0.0106          0.2975
0.2118          0.1534          0.1452          0.0824
0.0541          0.0171          0.0091          0.0046
0.0014          0.0128          19
# Phase Control
# Phase for F mult in 1st Year
1
# Phase for F mult Deviations
2
# Phase for Recruitment Deviations
2
# Phase for N in 1st Year
2
# Phase for Catchability in 1st Year
3
# Phase for Catchability Deviations
-1
# Phase for Stock Recruitment Relationship
3
# Phase for Steepness
3
# Recruitment CV by Year
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
```

```
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
.5
# Lambdas by Index
1  1  1
# Lambda for Total Catch in Weight by Fleet
1
# Lambda for Total Discards at Age by Fleet
1
# Catch Total CV by Year and Fleet
0.164
0.1387
0.1324
0.1661
0.2179
0.259
0.2607
0.3902
0.2643
0.4499
0.3513
0.328
0.1993
0.2676
0.2667
0.3728
0.3162
0.374
0.2288
0.2268
0.197
0.4314
0.3332
0.2855
0.3261
0.5215
# Discard Total CV by Year and Fleet
0
0
0
0
0
0
0
0
0
```

```
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Catch Effective Sample Size by Year and Fleet
0
0
0
0
0
0
40
41
33
18
38
33
62
67
45
62
33
56
59
84
67
57
51
37
40
40
# Discard Effective Sample Size by Year and Fleet
0
0
0
0
0
0
0
0
0
```

```
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
0
# Lambda for F Mult in First year by Fleet
0
# CV for F Mult in First year by Fleet
0.5
# Lambda for F Mult Deviations by Fleet
0.5
# CV for F Mult Deviations by Fleet
0.5
# Lambda for N in 1st Year Deviations
0
# CV for N in 1st Year Deviations
0.5
# Lambda for Recruitment Deviations
.5
# Lambda for Catchability in First year by Index
0  0  0
# CV for Catchability in First year by Index
1  1  1
# Lambda for Catchability Deviations by Index
0  0  0
# CV for Catchability Deviations by Index
1  1  1
# Lambda for Deviation from Initial Steepness
0
# CV for Deviation from Initial Steepness
0.5
# Lambda for Deviation from Unexploited Stock Size
0
# CV for Deviation from Unexploited Stock Size
0.5
# NAA Deviations Flag
2
# Initial Numbers at Age in 1st Year
2487  2103  1762  1385  1067  767  557  426  268  191  127  279
# Initial F Mult in 1st Year by Fleet
1
# Initial Catchabilty by Index
```

```
.001  .001  .001
# Stock Recruitment Flag
0
# Initial Unexploited Stock
1000
# Initial Steepness
.7
# Maximum F
100
# Ignore Guesses (Yes=1)
0
# Projection Control
# Do Projections (Yes=1)
0
# Fleet Directed Flag
1
# Final Year in Projection
2015
# Projection Data by Year
2015     -1         3     -99        1
# Do MCMC (Yes=1)
1
# MCMC Year Option
0
# MCMC Iterations
1000
# MCMC Thinning Factor
200
# MCMC Random Seed
1126
# Agepro R Option
2
# Agepro R Option Start Year
1989
# Agepro R Option End Year
2014
# Export R Flag
1
# Test Value
-23456
######
###### FINIS ######
# Fleet Names
#$All removals
# Survey Names
#$NY seine
#$NJ trawl
#$MRFSS
#
```

Atlantic States Marine Fisheries Commission

1050 N. Highland Street • Suite 200A-N • Arlington, VA 22201
703.842.0740 • 703.842.0741 (fax) • www.asmfc.org

Tautog Tagging Trial
Preliminary Methods
July 12, 2016

The Tautog Management Board (Board) formed a Law Enforcement Sub-Committee (Subcommittee) in 2015 to investigate the illegal harvest of tautog and provide intervention recommendations. At the suggestion of the Subcommittee, the Board is exploring tagging alternatives as part of a proposed commercial harvest tagging program. The Subcommittee has developed program objectives, procured tags and interviewed industry members to test the feasibility of a commercial harvest tagging program (see May Subcommittee meeting summary). The next step is a tank trial with research partners to test the feasibility of applying tags to live tautog.

The New York Division of Marine Resources and Stony Brook University are leading a tank trial to investigate the impacts of tagging live tautog. The following describes the materials that will be used in the study, the collection methods and the preliminary design of the tank trial. This is a working document; the methods described in this document are subject to change.

The research team is currently experimenting with tag locations on dead tautog. Two out of the three tags are traditionally used for livestock, therefore, the team is actively trying to determine if the tags will fit on a fish. In addition, the research team is taking the necessary steps to adhere to Stony Brook University's Vertebrae Handling Protocol. The trial is expected to begin in August 2016.

Research Team

- New York Division of Marine Resources
- Stony Brook University, School of Marine and Atmospheric Sciences

Materials

- The trial will take place at Flax Pond Marine Laboratory (Stony Brook, New York)
- A total of three tags will be tested: strap tag, button tag and a rototag. The tags and applicators have been transferred to the research team. *(Image A-C)*
- 10 ventless traps will be used to collect tautog in the Long Island Sound *(Image D)*
- A large holding pen was constructed for the dock *(Image E)*

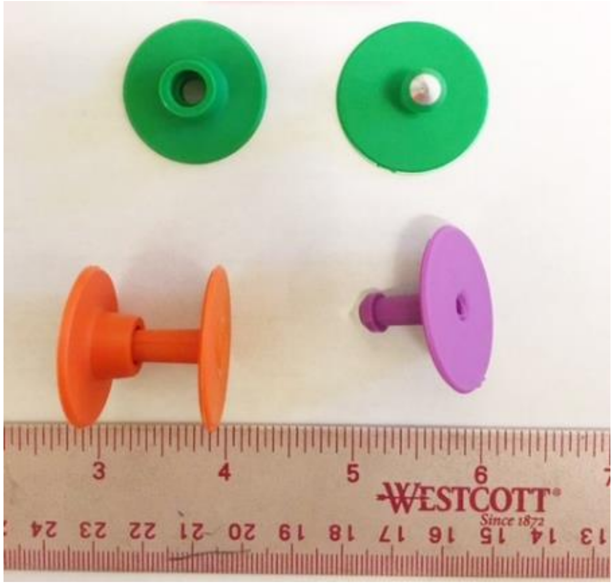
Collection Methods

- Overall, eighty tautog will be collected from the Long Island Sound. There will be two replicates of the treatment (tag application), therefore, 40 fish will be collected for the first replicate and another forty fish will be collected for the second replicate
- Fish will be collected using ventless fish traps
- Fish will be transferred from the traps to a holding pen at the dock, where they will remain for 1-2 days or until forty fish are collected
- Fish will be transferred from the holding pen to the wet lab for the tank trial

Tank Trial Methods

- Length: Each fish will be tagged and monitored for 4 weeks
- Replicate 1
  - 10 fish will be tagged with Tag A
  - 10 fish will be tagged with Tab B
  - 10 fish will be tagged with Tag C
  - 10 fish will serve as the control
- Replicate 2
  - 10 fish will be tagged with Tag A
  - 10 fish will be tagged with Tab B
  - 10 fish will be tagged with Tag C
  - 10 fish will serve as the control
- Stocking density: 10 fish per tank
- Tank: 6’ x 3’ cylindrical tanks *(Image F)*
- Open flow, salt water set at 55-60 degrees
- Food: fiddler crabs or mussels, 2-3x per week

Image A: Button Tag



QC Supply – button tag that is attached with an applicator; tag traditionally used for livestock, *could* be attached to the operculum or base of the caudal fin

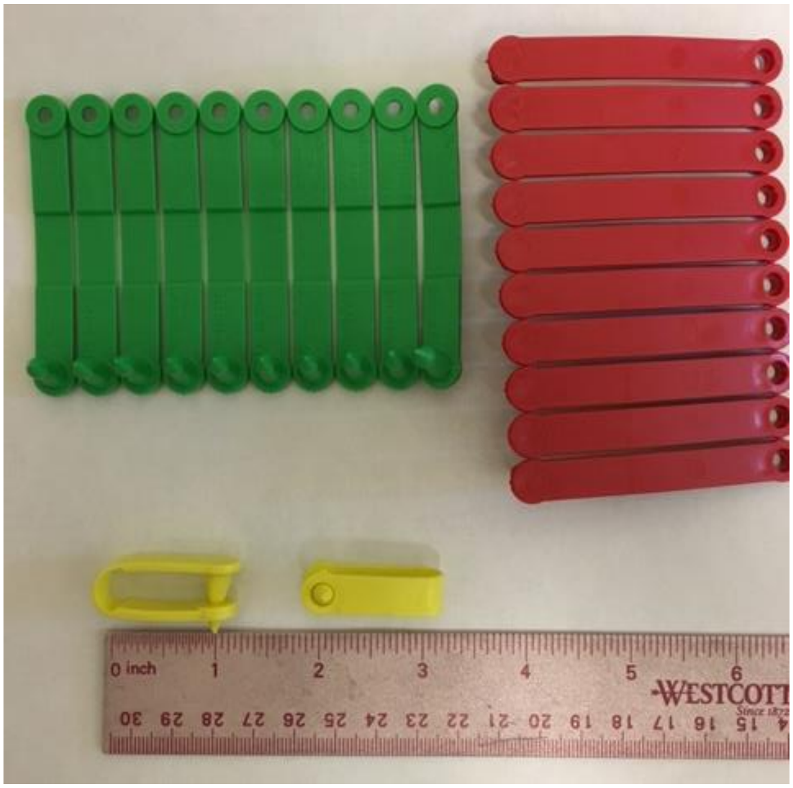
- *Subcommittee feedback:* The tag is heavy duty and cannot be easily manipulated or re-used. It comes in multiple colors and has enough room to apply state, year and unique ID. There was concern that it might be too large for a fish and since it is a generic livestock tag it might be easily obtained online (and duplicated illegally).

Image B: Strap Tag

National Band – strap tag made of monel (nickel-copper); attached to the operculum or lower jaw with an applicator, does not come in other colors

- *Subcommittee feedback:* The best option as far as size. Law enforcement attempted to open the tag using pliers and was not successful, as it was deformed in a manner that would be noticeable. The durability of the tag outweighed the lack of color options (i.e. silver only).
- The following unique IDs can be applied to each tag: (6 refers to the year, 2016)
    - Massachusetts: M#####6 (# range from 1-20,000)
    - Rhode Island: R#####6 (# range from 1-18,000)
    - Connecticut: C####6 (# range from 1-2,000)
    - New York: Y#####6 (# range from 1-40,000)
    - Etc.

Image C: Rototag



OS ID (Norway based) – rototag that is generally attached the operculum or base of the dorsal fin via an applicator

- *Subcommittee feedback:* The variety of colors is favorable, however the tag may be too large. Given these are also used in the livestock industry, staff should look for similar tags by a U.S. based company. However, if the tags are readily available then they might be easy to replicate.

Image D. 10 Ventless Traps

Image E: Holding Pen

Image F: Fish Tanks