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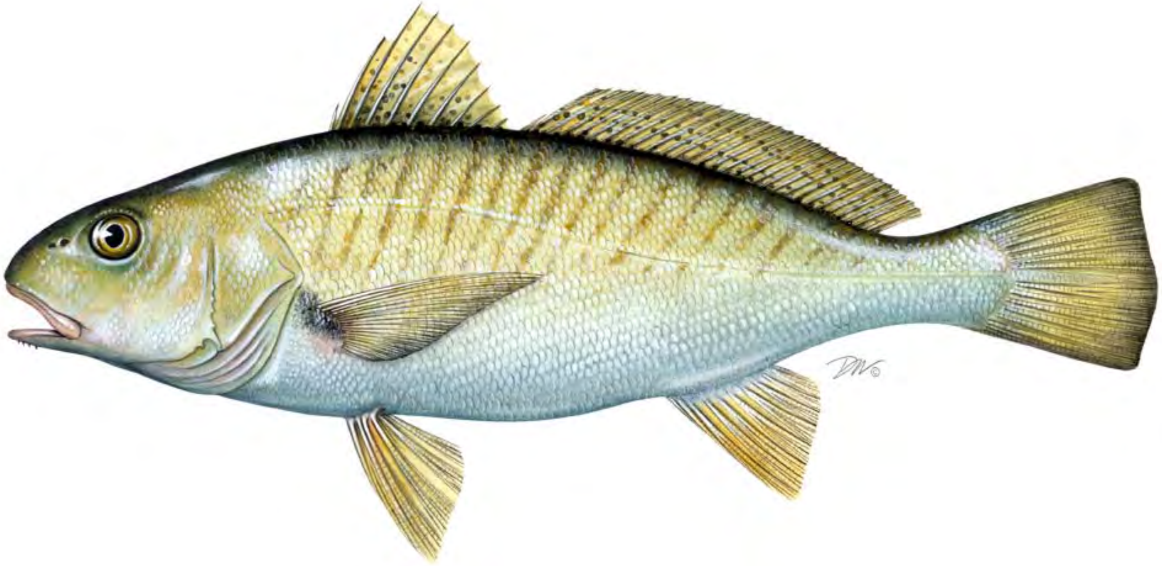
Atlantic States Marine Fisheries Commission

2017 Atlantic Croaker Stock Assessment Peer Review



May 2017

Vision: Sustainably Managing Atlantic Coastal Fisheries

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Atlantic States Marine Fisheries Commission

2017 Atlantic Croaker Stock Assessment Peer Review

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Prepared by the
ASMFC Atlantic Croaker and Spot Stock Assessment Review Panel

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Executive Summary

The Atlantic croaker, *Micropogonias undulatus*, is a demersal sciaenid common in estuarine and nearshore waters from the Gulf of Maine to Argentina. Along the U.S. Atlantic coast, the species is abundant between Indian River Lagoon, Florida, and Chesapeake Bay and supports important commercial and recreational fisheries in both the South Atlantic Bight (NC to FL) and Mid-Atlantic Bight (NY to VA). Atlantic croaker are migratory along the Atlantic coast and genetic studies indicate a single stock for Atlantic coast. The management area for Atlantic croaker is the Atlantic coast from New Jersey to Florida, from inshore estuarine waters seaward to the boundary of the Exclusive Economic Zone.

The majority of annual removals for Atlantic croaker were discards from the shrimp trawl fishery, followed by commercial landings and recreational harvest. From 1989-2014, total annual removals of Atlantic croaker from all fishery sources (landings and discards) ranged from 101,132 to 519,449 metric tons. Removals, while annually variable, have been relatively stable since the series peak in 1991, ranging from approximately 125,000 to 225,000 metric tons. The relative stability of total removals in the mid-1990s coincides with the requirement of bycatch reduction devices (BRDs) across shrimp trawl fisheries. The long term mean annual removals was 193,621 metric tons. Annual discards from the shrimp trawl fishery ranged from 82,040 to 513,801 metric tons with a long term mean of 179,873 metric tons. Shrimp trawl bycatch accounted for 81-99% of annual Atlantic croaker removals and averaged 91.6% of all removals. Indices of relative abundance suggest biomass of adult Atlantic croaker generally increased from the mid-1990s to the late 2000s, but decreased somewhat in the most recent years. Surveys of juveniles suggest substantial annual variability without clear trends.

The current stock status of Atlantic croaker could not be determined because the assessment results were sensitive to certain modeling assumptions, particularly those regarding fishery and survey gear selectivity (i.e., commercial fleet, NMFS/Northeast Fisheries Science Center fall groundfish trawl survey). In the base model configuration, selectivity in all fisheries and surveys was estimated to be strongly dome-shaped. This configuration allowed the model to estimate a substantial increase in ‘cryptic biomass’ of spawners and a corresponding decrease in fishing mortality, which allowed biomass estimates that indicated a healthy stock status (i.e. not overfished; no overfishing). However, the magnitude of this increase in abundance was not corroborated by the available length and age composition data, which indicated a static if not declining population. During the Review Workshop, the Panel requested and evaluated plausible alternative model configurations, including asymptotic selectivity, that indicated current stock status was both overfished and undergoing overfishing.

Although the current stock status could not be inferred with confidence, the Panel noted the base model and all sensitivity runs evaluated suggested the spawning biomass was increasing. Therefore, the Panel agreed that recent removals are likely sustainable (i.e., unlikely to result in further depletion of Atlantic croaker), and no immediate management actions are required.

Until a new assessment is conducted and uncertainties addressed, monitoring of abundance indices, fishery removals, and age/length composition should continue. If new information suggests the stock could be declining, a new assessment should be expedited.

The Panel noted the uncertainty of the stock assessment outcome was due to inherent data uncertainties, and to conflicting information regarding population trends contained in the various data components. The Panel agreed the assessment included the best available information, all significant removals were incorporated, the data analyses conducted were based on current best practices, the structure and application of the assessment model was reasonable, and that important uncertainties were identified and explored. The Panel commended the analytical team for their expertise, professionalism, and comprehensive understanding and communication of the model inputs and results.

Terms of Reference

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

The Review Panelists commended the analytical team for their concise and comprehensive presentation of the data inputs used in the stock assessment. The panelists agreed the written report and summary presentations were unusually complete which greatly facilitated evaluation.

All major sources of removals of Atlantic croaker were described including: commercial and recreational landings and discards, the scrap (bait) fishery (NC and VA), and bycatch from the southern shrimp trawl fishery and the mid-Atlantic gill net and trawl fin fisheries. Five relative indices of abundance from fishery-independent surveys were used in base and sensitivity models including: the NMFS/Northeast Fisheries Science Center fall groundfish trawl survey (NMFS), the Southeast Area Monitoring and Assessment Program (SEAMAP) coastal trawl survey, the Virginia Institute of Marine Science juvenile trawl survey in Chesapeake Bay (VIMS), the North Carolina Pamlico Sound Survey (NC195), and the Chesapeake Bay Monitoring and Assessment Program (ChesMMAP) trawl survey. While biological information (e.g. length composition, age composition) from all of the survey programs were used in the base model, the relative index developed from the ChesMMAP survey was excluded (for reasons described below). The base model was also fit to effort estimates for the southern shrimp trawl fishery. The assessment period was 1989-2014. This timeframe was used because fishery dependent and independent data sets were more widely available. The Panelists noted that important removals began much earlier than 1989. Therefore, it may be useful to attempt to recover or estimate historical removals to improve initial estimates of depletion in the stock assessment.

The justification for inclusion or elimination of available data sources was evaluated, particularly criteria for inclusion of abundance indices. A total of 35 fishery-independent surveys that encountered Atlantic croaker were considered during the assessment. Of all the surveys, only five met most of the criteria for inclusion. The criteria included the length and continuity of the time series, the spatial scale (e.g. population-wide/regional/local) and the constancy of survey methodologies. The Panelists agreed the index selection criteria were adequate and correctly applied. Some potential data sources were not considered during the assessment, including fishery-dependent catch rate indices and annual effort estimates from the commercial and recreational fleets. It was not mandatory to include these inputs in the assessment, and some reviewers would not recommend including fishery-dependent indices in assessment models when high-quality fishery-independent indices are available. However, the availability of fishery catch-per-unit-effort (CPUE) indices may have facilitated interpretation of the commercial and recreational catch series in the context of increasing stock biomass predicted by the assessment model. I.e., catch in many of the fisheries has been decreasing while the indices of abundance have been increasing. Typically, catches increase with increasing population abundance.

All but one of the indices of relative abundance were developed using a statistical standardization (e.g., delta-logormal, negative-binomial). The exception was the NMFS/Northeast Fisheries Science Center fall groundfish trawl survey which was a non-standardized, nominal index developed from stratified design-based estimates. The Panelists noted that many expert reviewers endorse this approach, but also suggested that a standardized index be developed for future assessments, and that the sensitivity of the model results to these alternative approaches be considered.

Data strengths and weaknesses – such as temporal and spatial scale, gear selectivities, ageing accuracy, sample size – were described in the stock assessment report, and input directly in the stock assessment when possible (sample sizes, annual estimates of variance by data source, ageing imprecision and otolith reader error). Known and assumed changes in gear selectivity due to size limits or different proportions of gear types in the commercial fishery were modeled using time-varying parameters. Annual estimates of variance for each data source were available and used in the base model to scale the uncertainty of annual estimates within each data source, and to inform initial weightings of the various data components. Final relative weightings of the model components were computed using an automated reweighting procedure (Francis 2011). Although these are standard and supported practices for stock assessment, the Panelists expressed concerns that the determination of stock status was quite sensitive to the weightings of the various data components (e.g., survey indices, length and age composition) and recommended future assessments consider criteria to better evaluate the reliability of each model component. See TOR 3-c below for more detail.

Atlantic croaker are a major component of Atlantic coast scrap (bait) landings. Quantifying the amount of croaker landed as scrap fish along the Atlantic coast is problematic due to the limited availability of sampling data. The Panel agreed the methods used in the assessment appear reasonable, but noted the resulting estimates from the scrap fishery are quite uncertain due to the number of required assumptions. However, as the magnitude of scrap landings is very small relative to total croaker removals, the Panel agreed the assessment is not likely to be sensitive to these assumptions.

2. Evaluate methods used to develop discard and bycatch estimates.

Estimates of Atlantic croaker discard rates in South Atlantic shrimp trawl fisheries were developed using discard rate data from the Shrimp Trawl Observer Program to estimate the magnitude of discard rates and the SEAMAP Trawl Survey to estimate the trend of discards prior to (1989-2000) and during the observer program (2001-2014). Discard rate estimates were then applied to effort data from state trip ticket programs and the South Atlantic Shrimp System (SASS) to estimate total discards in these fisheries from 1989-2014 following the methods used by Walter and Isley (2014). Discard rates were applied to effort estimates summarized by "strata" (combinations of factors included in the model). Because there were no observer data before Bycatch Reduction Devices (BRDs) were required in the penaeid shrimp fishery, discard estimates prior to 1997 were adjusted for the reduction in catch due to the required use of certified BRDs on observed tows. Adjustments were based on a weighted average of Atlantic croaker catch reductions in the Gulf of Mexico shrimp trawl fishery estimated depending on the distance of fisheye BRDs from tie-off rings (Helies et al. 2009).

Discards from the Mid-Atlantic gill net and trawl fisheries were estimated using observer data from the Northeast Fisheries Science Center's Northeast Fisheries Observer Program (NEFOP) and At-Sea Monitoring Program (ASM). Annual ratios of observed discarded Atlantic croaker to observed landings of all species by gillnets and bottom trawls were calculated, then applied to reported gillnet and bottom trawl landings of all species to estimate total discards of croaker.

The Panelists recognized that discard/bycatch estimates are unusually uncertain due to data insufficiencies, but agreed the method used to develop estimates of croaker bycatch from the southern shrimp trawl fishery was current, supported, and similar (or identical) to methods used in SEDAR assessments of South Atlantic king mackerel, and Gulf of Mexico red snapper, king mackerel, gray triggerfish and domestic sharks. The Panel also agreed the method used to estimate Atlantic croaker discards from the commercial and recreational fisheries were acceptable given the available data, and the relatively small contribution of these discards to the total removals.

3. Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, including but not limited to:

The Atlantic croaker assessment used a state-of-the-art forward-projecting length-based, age-structured model (Stock Synthesis (SS) text version 3.24y). SS has been simulation tested, and is widely used in the United States and internationally. With a few exceptions noted below, the Panelists agreed the base model configuration and parameterization were appropriate to capture the primary biological dynamics and differences in fleet characteristics (e.g., selectivity, catchability).

The base model configuration suggested an extremely depleted stock in 1989 (<3% of unfished biomass) which experienced a rapid increase in spawning biomass through the time series, mostly due to reduced effort/fishing mortality in the shrimp fishery, and recovered to a healthy stock status by 2014 (not overfished, not undergoing overfishing). To evaluate the plausibility of this outcome, the Panelists requested and explored alternative model configurations (see TOR 4-a below). Noting the assessment results were quite sensitive to certain assumptions, the Panel made several recommendations for future assessments:

a. **Evaluate the choice and justification of the preferred model(s). Was the most appropriate model (or model averaging approach) chosen given available data and life history of the species?**

The Panel noted the initial stock depletion is often difficult to estimate, particularly when significant but largely uncertain removals occur before the initial year of the model (1989). The model may be more stable with a recent starting year when more data sources are available. However, to improve the characterization of initial depletion, the Panelists recommended an attempt be made to recover/estimate the magnitude of total removals that occurred before 1989, as far back to the unfished condition as feasible.

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

The Stock Synthesis was the single primary model put forth as part of the Atlantic croaker assessment. No secondary models were included in the assessment report. A non-equilibrium Schaefer form of the surplus production model (ASPIC) for was run during development of the croaker assessment but not put forth as a supporting model. The Panel requested and were provided with the ASPIC croaker model results at the Review Workshop. The model used two fishery-independent surveys, the fall portions of the NMFS and SEAMAP trawl surveys, as well as the complete time series of harvest data. Coast-wide total harvest was calculated in weight (mt) from 1989-2014 from commercial and recreational landings, recreational discards, commercial discards from mid-Atlantic gillnet and trawl fisheries, landings from the scrap/bait fishery, and bycatch from the shrimp trawl fishery.

Both the ASPIC and SS models estimated similar trends; average biomass increased over the time series while total fishing mortality declined. The base ASPIC model indicated that current fishing mortality on Atlantic croaker appears to be sustainable, and it is not likely that overfishing is occurring or that the stock is overfished in recent years. However, the Panel observed these determinations were sensitive to the assumed initial biomass, which could not be reliably estimated.

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

The Panelists noted that some selectivity and retention parameters were poorly estimated (i.e., very large standard variations, and values that do not move away from initial guesses). To improve the estimation of parameters the panel recommended:

- Assume an asymptotic selectivity function (e.g., logistic) for at least one fleet/survey to improve the estimation of selectivity and retention parameters for all fleets.
- When poorly estimated (as determine by large asymptotic standard errors or failure to move from starting values), consider fixing retention parameters at reasonable values (e.g., knife-edged retention at size limit)
- Consider a "super-year" approach to estimate the annual discards of fleets that are characterized by large uncertainty and variability. Fit to the average discards over specified years, but allow annual estimates to be informed by an effort series.
- Consider aggregating fisheries with small removals and similar selectivity patterns to reduce the number of parameters that require estimation without sufficient data to support those estimations.
- The Panelists noted SS model results are often quite sensitive to assumptions regarding the growth function and variability in length-at-age, and recommended further exploration the relationship between the coefficient of variation and age/length and reader error/bias.
- The Panel also made several general recommendations:
  - Poorly estimated parameters – unusually large standard deviations, or final values unchanged from initial guess – should be identified and addressed to the extent possible. In addition to the recommendations above, the Panel also recommended estimating the 'problem parameters' separately in the final phase of estimation.
  - Bounded growth, selectivity, and retention parameters should be addressed since they degrade model performance, and can influence model results.
  - Model reweighting should not be attempted until the model fits have been optimized (see recommendations above). The reweighting coefficients (model component weightings) should be examined to determine their acceptability, and set to sensible values if expert opinion suggests the coefficients derived from the statistical reweighting are implausible. For example, when variability of all model components is greatly inflated, or better known components are downweighted in favor of other less certain components.

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

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

A range of sensitivity analyses were conducted to explore how results from the base Stock Synthesis model responded to alternative assumptions. Overall, the range of sensitivity diagnostics conducted by the assessment team was reasonable. The Review Panel recommended additional sensitivity analyses around the shapes of the selectivity function for some fleets and additional sensitivity runs for the Coefficients of Variation (CVs) and effective sample sizes of the data. The Stock Synthesis model was quite sensitive to the assumed shape of the selectivity pattern for the commercial fleet. The model with dome-shaped selectivity estimated that biomass was substantially above the overfished reference point, while a model with logistic (asymptotic) selectivity estimated biomass to be substantially below the overfished reference point.

The model was also quite sensitive to the amount of observation error (CVs and effective sample sizes) for the indices, size compositions, and size-age compositions. The sensitivities are likely caused by substantial differences in the indices with regard to how much the stock has increased since the beginning of the time series. The NMFS trawl survey indicates about a 15X increase in biomass (1990-1993 average 1.75 kg/tow; 2011-2014 average 25.7 kg/tow), whereas the SEAMAP trawl survey indicates about a 2.5X increase in biomass (1990-1993 average 1.3 kg/tow; 2011-2014 average 3.2 kg/tow). The model has a very difficult time reconciling the two trends. The CVs for both surveys should be increased as the model interprets the CVs as representing the total error between observed CPUE and stock size rather than just the precision of the CPUE estimate. However, increasing CVs for the indices does not completely solve the problem.

The base model results were low to moderately sensitive to assumptions about the value of shrimp trawl bycatch in 1991, the discard mortality for shrimp trawl bycatch, recreational discard mortality, inclusion of indices, and steepness. Although there is a substantial amount of uncertainty around recreational discard mortality, it did not have a substantial effect on the estimates. The discard mortality for shrimp trawl bycatch had a larger effect than the recreational discard mortality because shrimp trawl bycatch is a much larger fraction of removals than recreational discards.

b. Retrospective analysis

Retrospective analyses were conducted by the assessment team for the base Stock Synthesis model. The model had a moderate retrospective pattern for biomass in which the biomass estimates were lower, on average, in the terminal year after new data were added. In contrast, there was relatively little retrospective pattern for fishing mortality.

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

The assessment primarily used asymptotic standard errors to estimate the uncertainty in model estimates. Profiling over the likelihood may have been helpful for better understanding the uncertainty associated with certain key parameters such as the steepness of the stock-recruitment relationship.

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

The Review Panel does not recommend using specific estimates of stock biomass, abundance, and exploitation for management because of the sensitivity of the model to several key assumptions. Changing the shape of the selectivity curve for the commercial fishery led to very large changes in estimated biomass and stock status. The Panel and Stock Assessment Subcommittee were not able to develop a new base model during the Review Workshop that they believed would provide reliable estimates of biomass, abundance, or fishing mortality.

Despite the inability to arrive at a new base model, several patterns seem clear from the data:

1) The indices of abundance for croaker appear to be increasing across most of the stock's range.
2) Catch appears to be stable or declining over time.
3) The combination of these two patterns indicates that it is likely that fishing mortality rates have also declined over time such that the relative status of the stock in the most recent years is likely better than it was in the late 1980s – early 1990s.
4) Shrimp fishery effort and croaker bycatch magnitude appear to be declining. The Stock Assessment Subcommittee should consider adding shrimp bycatch estimates to annual Traffic Light analyses. The new estimates of shrimp bycatch are a notable improvement from previous croaker assessments and should be reviewed annually given their substantial contribution to overall croaker removals and mortality.

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

Because of the uncertainty in the scale of biomass and fishing mortality, the Review Panel does not recommend specific values for reference points. Additionally, given that models with alternative plausible selectivity assumptions resulted in very different estimates of stock status, stock status cannot be determined reliably at this time.

Going forward, the Review Panel recommends using Spawning Potential Ratio (SPR) reference points for management because the stock-recruitment parameters for calculating maximum sustainable yield (MSY) reference points did not appear to be well estimated.

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

The Panel thoroughly reviewed the research recommendations identified by the Technical Committee, in addition to noting addition research and data collection needs. Following discussions with the SASC at the Review Workshop, the Panel worked closely with the SASC chair to refine and prioritize a final set of research recommendations, adapted from the stock assessment report and provided here as High or Medium Priorities, within Short-term vs. Long-term research categories.

<u>Short term:</u>

HIGH PRIORITY

- Increase observer coverage for commercial discards, particularly the shrimp trawl fishery. Develop a standardized, representative sampling protocol for observers to use to increase the collection of individual lengths and ages of discarded finfish.

- Describe the coast-wide distribution, behavior, and movement of croaker by age, length, and season, with emphasis on collecting larger, older fish.

MEDIUM PRIORITY

- Conduct studies of discard mortality for recreational and commercial fisheries by each gear type in regions where removals are highest.

- In the recreational fishery, develop sampling protocol for collecting lengths of discarded finfish and collect otolith age samples from retained fish.

- Encourage fishery-dependent biological sampling, with proportional landings representative of the distribution of the fisheries. Develop and communicate clear protocols on truly representative sampling.

Long term:

HIGH PRIORITY

- Continue state and multi-state fisheries-independent surveys throughout the species range and subsample for individual lengths and ages. Ensure NEFSC trawl survey continues to take lengths and ages. Examine potential factors affecting catchability in long-term fishery independent surveys.

- Quantify effects of BRDs and TEDs implementation in the shrimp trawl fishery by examining their relative catch reduction rates on Atlantic croaker.

- Continue to develop estimates of length-at-maturity and year-round reproductive dynamics throughout the species range. Assess whether temporal and/or density-dependent shifts in reproductive dynamics have occurred.
- Re-examine historical ichthyoplankton studies for an indication of the magnitude of estuarine and coastal spawning, as well as for potential inclusion as indices of spawning stock biomass in future assessments. Pursue specific estuarine data sets from the states (NJ, VA, NC, SC, DE, ME) and coastal data sets (MARMAP, EcoMon).

MEDIUM PRIORITY

- Investigate environmental covariates in stock assessment models, including climate cycles (e.g., Atlantic Multi-decadal Oscillation, AMO, and El Nino Southern Oscillation, El Nino) and recruitment and/or year class strength, spawning stock biomass, stock distribution, maturity schedules, and habitat degradation.

- Utilize NMFS Ecosystem Indicators bi-annual reports to consider folding indicators into the assessment; identify mechanisms for how environmental indicators affect the stock

- Encourage efforts to recover historical landings data, determine whether they are available at a finer scale for the earliest years than are currently reported.

- Collect data to develop gear-specific fishing effort estimates and investigate methods to develop historical estimates of effort.

- Develop gear selectivity studies for commercial fisheries with emphasis on age 1+ fish.

- Conduct studies to measure female reproductive output at size and age (fecundity, egg and larval quality) and impact on assessment models and biomass reference points

- Develop and implement sampling programs for state-specific commercial scrap and bait fisheries in order to monitor the relative importance of Atlantic croaker. Incorporate biological data collection into program.

- Investigate the relationship between estuarine nursery areas and their proportional contribution to adult biomass. I.e., are select nursery areas along Atlantic coast ultimately contributing more to SSB than others, reflecting better quality juvenile habitat?

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

A benchmark stock assessment is recommended in five years. No assessment updates are called for given challenges with the current model, and the existing annual use of Traffic Light analyses. Despite uncertainty in the assessment model results and an inability to confidently determine stock status, trends in landings and indices do not indicate immediate cause for concern, and therefore do not call for a subsequent new stock assessment in the short-term.

I. Literature Cited

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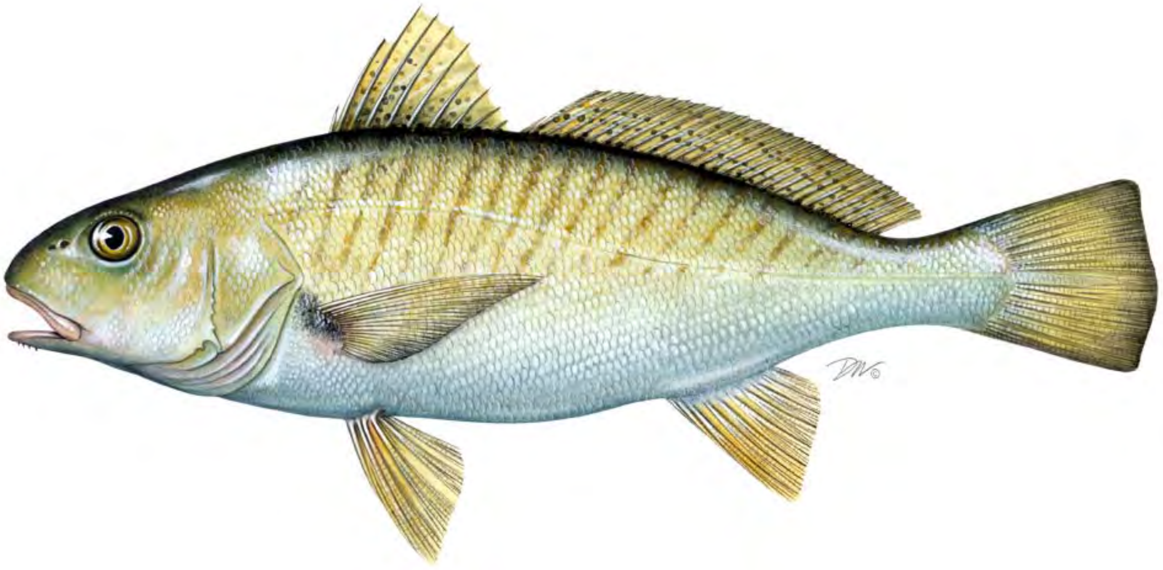
Atlantic States Marine Fisheries Commission

2017 Atlantic Croaker Benchmark Stock Assessment



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Atlantic Croaker Benchmark Stock Assessment

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Prepared by the
ASMFC Atlantic Croaker and Spot Stock Assessment Subcommittee

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Executive Summary

The Atlantic croaker, *Micropogonias undulatus*, is a demersal sciaenid common in estuarine and nearshore waters from the Gulf of Maine to Argentina. Along the U.S. Atlantic coast, the species is abundant between Indian River Lagoon, Florida, and Chesapeake Bay and supports important commercial and recreational fisheries in both the South Atlantic Bight (NC to FL) and Mid-Atlantic Bight (NY to VA). Atlantic croaker are migratory along the Atlantic coast and genetic studies indicate a single stock for Atlantic coast. The management area for Atlantic croaker is the entire Atlantic coast from New Jersey to Florida, from inshore estuarine waters eastward to the boundary of the Exclusive Economic Zone. The current assessment evaluates the status of the resource as one population within the management area due to inadequate evidence to support the existence of two separate regional stocks.

Fishery dependent data sources included commercial and recreational landings and discards, the scrap (bait) fishery (NC and VA), as well as bycatch data from the southern shrimp trawl fishery and the mid-Atlantic gill net and trawl fin fisheries. Thirty five fishery independent surveys that encountered Atlantic croaker were reviewed during the assessment for use. Biological data from all surveys were used to estimate life history parameters (e.g. growth, maturity). Indices of relative abundance from five surveys were used in the preferred Stock Synthesis (ver. 3) model. These surveys included the NMFS/Northeast Fisheries Science Center fall groundfish trawl survey (NMFS), the Southeast Area Monitoring and Assessment Program (SEAMAP), the Virginia Institute of Marine Science juvenile trawl survey in Chesapeake Bay (VIMS), the North Carolina Program 195 Survey in Pamlico Sound (NC195), and the Chesapeake Bay Monitoring and Assessment Program (ChesMMAP) trawl survey. The time frame for the assessment was 1989-2014 as this was where data was available for all fishery dependent and independent data sets (except for ChesMMAP, which was 2002-2014).

Atlantic croaker are caught in commercial and recreational fisheries in coastal and estuarine waters primarily from New Jersey to Florida with the center of distribution occurring off of Virginia and North Carolina. The majority of annual removals for Atlantic croaker were discards from the shrimp trawl fishery, followed by commercial landings and recreational harvest. Data to estimate discards in South Atlantic shrimp trawl fisheries were available starting in 1989 and the terminal year of data for this assessment was 2014. From 1989-2014, total annual removals of Atlantic croaker from all fishery sources (landings and discards) ranged from 101,132 to 519,449 metric tons. Removals, while annually variable, have been relatively stable since the series peak in 1991, ranging from approximately 125,000 to 225,000 metric tons. The relative stability of total removals in the mid-1990s coincides with the requirement of bycatch reduction devices (BRDs) across shrimp trawl fisheries. The long term mean annual removals was 193,621 metric tons. Annual discards from the shrimp trawl fishery ranged from 82,040 to 513,801 metric tons with a long term mean of 179,873 metric tons. Shrimp trawl bycatch accounted for 81-99% of annual Atlantic croaker removals and averaged 91.6% of all removals.

Overall abundance from the indices for adult Atlantic croaker (NMFS and SEAMAP) showed general increasing trends from the mid-1990s to peak levels in the late 2000s, after which they

have declined through 2014. The juvenile surveys (VIMS and NC195) had much more annual variability with no clear trends. Assessment model output showed a steady increase in overall abundance through the entire time frame with the highest level occurring in the terminal year.

Estimated spawning stock biomass (SSB) ranged from 6,204 (1991) to 304,345 (2014) metric tons annually. However, confidence intervals became increasingly wider in later years of the model indicating a higher degree of variability in the estimate. Estimated recruitment was more variable with peak years occurring in 1990 and 2011. Recruitment ranged from 1.1 to 7.4 billion fish annually, with highest recruitment year occurring in 2011 (7.4 billion fish). Fishing mortality has declined steadily throughout the time series, reflecting the increasing trend in SSB. Initial fishing mortality was 0.507 with the highest F occurring in 1991 (0.906) after which it has followed a general declining trend. While F has remained below 0.5 since 1995, there have been a few years where values jumped up to 0.3 range (1999 and 2004). Overall, F has remained below 0.2 since 2008. The results of the retrospective analysis suggested there was no consistent over or underestimation of terminal year values for recruitment, female SSB, or fishing mortality.

SS3 was used to estimate the fishing mortality and SSB targets and thresholds as defined in Addendum I to Amendment I of the ASMFC FMP for Atlantic croaker (ASMFC 2011). The fishing mortality threshold is defined as F_{MSY} and the fishing mortality target is 0.75 * F_{MSY}. The SSB threshold is defined as 0.70 * $\mathrm{SSB}_{\mathrm{MSY}}$ and the SSB target is defined as $\mathrm{SSB}_{\mathrm{MSY}}$. The final (reweighted) base run predicted $F_{\mathrm{Threshold}} = 0.393$ and $F_{\mathrm{Target}} = 0.295$. The value for $\mathrm{SSB}_{\mathrm{Threshold}}$ was predicted at 55,607 mt and $\mathrm{SSB}_{\mathrm{Target}}$ was 79,438 mt. The SSB target and threshold were most sensitive to varying levels of the steepness parameter. The SSB reference points were also sensitive assuming reduced levels of the observed shrimp trawl bycatch. The fishing mortality reference points were most sensitive to assuming reduced levels of the observed shrimp trawl bycatch. Varying the levels of the steepness parameter had the next largest impact on the fishing mortality target and threshold. Changing the assumption about the value of the recreational fishery discard mortality had relatively little impact on the SSB and fishing mortality reference points.

Overfishing Status

The base run predicted that terminal year fishing mortality was 0.167 ($F_{2014} = 0.167$). The fishing mortality threshold estimate from the base run was 0.393 ($F_{\mathrm{MSY}} = F_{\mathrm{Threshold}} = 0.393$). Relative status for fishing mortality is then $F_{2014} / F_{\mathrm{Threshold}} = 0.167 / 0.393 = 0.426$, which is less than one. The results of the base run suggest that overfishing is currently not occurring.

Overfished Status

The base run predicted that terminal year SSB was 304,345 mt (SSB_{2014} = 304,345 mt). The SSB threshold is 0.70 * $\mathrm{SSB}_{\mathrm{MSY}}$, which is 0.70 * 79,438 mt = 55,607 mt ($\mathrm{SSB}_{\mathrm{Threshold}}$ = 55,607 mt). Relative status for SSB is $\mathrm{SSB}_{2014} / \mathrm{SSB}_{\mathrm{Threshold}}$ = 304,345 mt / 55,607 mt = 5.47, which is greater than one. The results of the base run suggest that the stock is currently not overfished.

Uncertainty

All sensitivity runs resulted in a stock that was not overfished and in which overfishing was not occurring in the terminal year. Stock status relative to the overfished condition was most optimistic when steepness was assumed equal to 1.0. Stock status relative to overfishing was most optimistic when the level of shrimp trawl bycatch was assumed equal to 50% of the original values.

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TERMS OF REFERENCE

For the Atlantic Croaker Benchmark Stock Assessment

Board Approved August 2015

Terms of Reference for the Atlantic Croaker Assessment

1. Characterize uncertainty of fishery-dependent and fishery-independent data used in the assessment, including the following but not limited to:
    a. Provide descriptions of each data source (e.g., geographic location, sampling methodology, potential explanation for outlying or anomalous data)
    b. Describe calculation and potential standardization of abundance indices.
    c. Discuss trends and associated estimates of uncertainty (e.g., standard errors)
    d. Justify inclusion or elimination of available data sources.
    e. Discuss the effects of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivities, ageing accuracy, sample size) on model inputs and outputs.
2. Review estimates and PSEs of MRIP recreational fishing estimates. Request participation of MRIP staff in the data workshop process to compare historical and current data collection and estimation procedures and to describe data caveats that may affect the assessment..
3. Develop estimates of Atlantic croaker discards in the South Atlantic shrimp trawl fishery. Develop estimates of bycatch and discards in other fisheries where possible. Characterize uncertainty of all discard and bycatch estimates.
4. Develop models used to estimate population parameters (e.g., *F*, biomass, abundance) and biological reference points, and analyze model performance.
    a. Describe stability of model (e.g., ability to find a stable solution, invert Hessian)
    b. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    c. Perform sensitivity analyses for starting parameter values, priors, etc. and conduct other model diagnostics as necessary.
    d. Clearly and thoroughly explain model strengths and limitations.
    e. Briefly describe history of model usage, its theory and framework, and document associated peer-reviewed literature. If using a new model, test using simulated data.
    f. If multiple models were considered, justify the choice of preferred model and the explanation of any differences in results among models.
5. State assumptions made for all models and explain the likely effects of assumption violations on synthesis of input data and model outputs. Examples of assumptions may include (but are not limited to):
    a. Choice of stock-recruitment function.

   b. Calculation of *M*. Choice to use (or estimate) constant or time-varying *M* and catchability.
   c. Choice of equilibrium reference points or proxies for MSY-based reference points.
   d. Choice of a plus group for age-structured species.
   e. Constant ecosystem (abiotic and trophic) conditions.
6. Characterize uncertainty of model estimates and biological or empirical reference points.
7. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., *F*, SSB), reference points, and/or management measures.
8. Recommend stock status as related to reference points (if available). For example:
   a. Is the stock below the biomass threshold?
   b. Is F above the threshold?
9. Other potential scientific issues:
   a. Compare trends in population parameters and reference points with current and proposed modeling approaches, including recent results of the Traffic Light Approach. If outcomes differ, discuss potential causes of observed discrepancies.
   b. Compare reference points derived in this assessment with what is known about the general life history of the exploited stock. Explain any inconsistencies.
10. If a minority report has been filed, explain majority reasoning against adopting approach suggested in that report. The minority report should explain reasoning against adopting approach suggested by the majority.
11. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.
12. Recommend timing of next benchmark assessment and intermediate updates, if necessary relative to biology and current management of the species.

1 INTRODUCTION

1.1 Management Unit Definition

The existing management unit, area, and regions are defined in the Atlantic States Marine Fisheries Commission (ASMFC) Amendment 1 to the Interstate Fishery Management Plan for Atlantic croaker (ASMFC 2005a).

Management unit refers to the resource under management. The Atlantic croaker management unit is the entire coast-wide distribution of the resource from the estuaries eastward to the inshore boundary of the EEZ. Management area refers to the geographic area under management. The Atlantic croaker management area covers the entire Atlantic coast distribution of the management unit from New Jersey through Florida. In early assessments (ASMFC 2005b, 2005d) Atlantic croaker were examined separately as two Atlantic regions (northern and southern) which is why the FMP has this language. The last assessment (ASMFC 2010) and this one now use a single coast-wide region that is the same as the management unit.

1.2 Regulatory History

1.2.1 Interstate Management

The Atlantic croaker interstate management program functions under the ASMFC's Interstate Fishery Management Program (ISFMP), with immediate oversight by the South Atlantic State-Federal Fisheries Management Board (Management Board).

The Fishery Management Plan (FMP) for Atlantic croaker was adopted in 1987 and included states from Maryland through Florida (ASMFC 1987). The major problem addressed in the plan was the lack of stock assessment data needed for effective management of the resource. Research and data collection programs were recommended, as were two management measures: the use of bycatch reduction devices (BRDs) in shrimp and finfish trawls, and increasing fishery selectivity to Atlantic croaker age one and older.

In 1993, the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA) was established, allowing for enforcement of ASMFC management plans. Subsequently, the Management Board reviewed the FMP and found its recommendations to be vague and invalid, and the ISFMP Policy Board agreed that the FMP contained no requirements. The Management Board recommended that an amendment be prepared to define management measures necessary to achieve the goals of the FMP. A workshop was held the same year to gather and review available data from which specific and rational management measures could be drawn, and later in 1997, an Atlantic croaker Technical Committee (TC) was appointed to continue the data collection and analysis initiated at the 1993 workshop.

In 2002, the Management Board directed the Atlantic croaker TC to conduct the first ASMFC-sponsored coast-wide stock assessment of the species in preparation of developing an amendment. The stock assessment was approved by a Southeast Data, Assessment, and Review (SEDAR) review panel for use in management in June 2004, after which the Management Board initiated the development of an amendment to update the FMP. In November 2005, the

Management Board approved Amendment 1 to the Atlantic croaker FMP, which was fully implemented by January 1, 2006 (ASMFC 2005a).

The goal of Amendment 1 is to use interstate management to perpetuate the self-sustainable Atlantic croaker resource throughout its range and generate the greatest economic and social benefits from its commercial and recreational harvest and utilization over time. Amendment 1 contains four objectives:

1) Manage the fishing mortality rate for Atlantic croaker to provide adequate spawning potential to sustain long-term abundance of the Atlantic croaker population.
2) Manage the Atlantic croaker stock to maintain the spawning stock biomass above the target biomass levels and restrict fishing mortality to rates below the threshold.
3) Develop a management program for restoring and maintaining essential Atlantic croaker habitat.
4) Develop research priorities that will further refine the Atlantic croaker management program to maximize the biological, social, and economic benefits derived from the Atlantic croaker population.

Amendment 1 expanded the management area to include the states from New Jersey through Florida. Consistent with the 2005 ASMFC stock assessment, it defines two Atlantic coast management units: the south Atlantic region, including the states of Florida through South Carolina; and the mid-Atlantic region, including the states of North Carolina through New Jersey.

Amendment 1 does not require any specific measures restricting recreational or commercial harvest of Atlantic croaker. Those states with more conservative measures are encouraged to maintain their regulations. Through adaptive management, the Management Board may revise Amendment 1, and regulatory and/or monitoring requirements (enforceable through the ACFCMA) could be included in the resulting addendum. The only existing requirement is for states to submit an annual compliance report by July 1 of each year that contains commercial and recreational landings as well as results from any monitoring programs that intercept Atlantic croaker.

The Board initiated Addendum I to Amendment I at its August 2010 meeting, following the updated stock assessment, in order to address the proposed reference points and management unit. The stock assessment evaluated the stock based on a coast-wide unit, rather than the two management units established within Amendment I. In approving Addendum I, the Management Board endorsed the consolidation of the stock into one management unit, as proposed by the stock assessment. In addition, Addendum I established a procedure, similar to other species, by which the Board may approve peer-reviewed biological reference points (BRPs) without a full administrative process, such as an amendment or addendum.

In August 2014, the Board approved Addendum II to the Atlantic croaker FMP. The Addendum established the Traffic Light Approach (TLA) as the new precautionary management framework to evaluate fishery trends and develop management actions. The TLA was originally developed as a management tool for data poor fisheries. The name comes from assigning a color (red, yellow, or green) to categorize relative levels of population indicators. When a population characteristic improves, the proportion of green in the given year increases. Harvest and abundances thresholds of red proportions of 30% and 60% were established in Addendum II, representing moderate and significant concern for the fishery. If thresholds for both population characteristics achieve or exceed a threshold for a three-year period, then management action is enacted.

The TLA framework replaces the management triggers stipulated in Addendum I. Under the previous management scheme, action was taken if recreational and commercial landings dropped below 70% of the previous two year average. These triggers, however, were limited in their ability to illustrate long-term declines or increases in stock abundance. In contrast, the TLA approach better illustrates long-term trends in the fishery through changes in the proportion of green, yellow, and red coloring.

1.2.2 State Management

Despite there being no required regulations, several states in the management unit have implemented regulations including creel/trip limits, size limits, and seasonal closures specific to Atlantic croaker (Table 1.1). In addition, gear restrictions such as minimum mesh sizes, BRDs, and area closures implemented for other or multiple species limit the harvest and bycatch of Atlantic croaker (Table 1.2).

1.3 Assessment History

1.3.1 Previous ASMFC Assessment

There have been two previous peer-reviewed coast-wide assessments for Atlantic croaker. The first assessment, completed in 2004, split the stock into two regions: the south Atlantic region, including the states of Florida through South Carolina; and the mid-Atlantic region, including the states of North Carolina through New Jersey. The assessment used an age-structure production model which linked the population is successive years using a Beverton and Holt stock-recruitment relationship re-parameterized in terms of steepness.

The results of the 2003/2004 assessment were used to develop the first recommendations for BRPs for Atlantic croaker. Reference points based on maximum sustainable yield (MSY) were recommended for the mid-Atlantic region. The status of the Atlantic croaker occurring in the south Atlantic region could not be determined during the 2003/2004 stock assessment. As such, reference points were not developed for the south Atlantic region. The assessment concluded that the mid-Atlantic portion of the stock was not overfished and overfishing was not occurring.

A major limitation of the 2003/2004 assessment was that the data available was not sufficient to produce annual estimates of Atlantic croaker bycatch from the shrimp trawl fishery, which is believed to be an important source of mortality. At that time, the bait/scrap fishery landings of Atlantic croaker were not directly observed and reported but it was known that Atlantic croaker bycatch could be significant. For the 2003/2004 assessment, Atlantic croaker scrap landings were estimated for North Carolina and Virginia which were the only states with any data on the scrap fishery. The peer reviewers suggested including at-sea observer data for discards and bycatch.

The next, and most recent, coast-wide stock assessment was completed in 2010. The 2010 Benchmark Stock Assessment of Atlantic croaker occurred through a joint ASMFC and Southeast Data, Assessment, and Review (SEDAR) process. The assessment combined the Atlantic croaker stock into a single unit due to a lack of genetic evidence for separate stock groups.

1.3.2 2010 ASMFC Assessment Data

The following data were used in the 2010 ASMFC stock assessment of Atlantic croaker. Catch data included:

- Commercial landings: 1988–2008 NOAA general canvas reports by state.
- Recreational catch: 1988–2008 National Marine Fisheries Service (NMFS) estimates from the Marine Recreational Fisheries Statistics Survey (MRFSS).
- Scrap landings: 1988-2008 North Carolina Division of Marine Fisheries (NCDMF) scrap estimates.
- Bycatch: 1993-2008 Northeast Fisheries Science Center (NEFSC) observer data; discard to landings ratio for ocean gill nets and trawls.

Both fishery-dependent and fishery-independent indices were used:

- Fishery-dependent: 1981–2008 MRFSS catch per unit effort (CPUE).
- Fishery-independent: 1981–2008 NMFS northeast bottom trawl survey (fall only), 1990–2008 Southeast Area Monitoring and Assessment Program (SEAMAP) survey (fall only), 1987-2008 NCDMF Pamlico Sound Survey (Program 195), and 1988–2008 Virginia Institute of Marine Sciences (VIMS) spring trawl survey.

Biological data were provided by the NCDMF, VMRC, Maryland Department of Natural Resources (MDDNR), and MRFSS:

- Length composition of commercial catch: 1982–2008 NCDMF fish house sampling of lengths and weights; 1986–2008 NCDMF scrap fishery sampling of lengths and weights; 1999–2008 VMRC fish house sampling; 1993–2008 MDDNR pound net sampling of lengths and weight (1999+).
- Age composition of commercial catch: 1982–2008 NCDMF fish house sampling; 1986–2008 NCDMF scrap fishery sampling; 1999–2008 VMRC fish house sampling; 1999–2008 MDDNR pound net sampling.

Length composition of recreational landings: 1981–2008 MRFSS sampling.

1.3.3 Biological Reference Points

The 2010 stock assessment established new BRPs for a single stock. The biomass target of spawning stock biomass at maximum sustainable yield (SSB_{MSY}), was estimated to be 26,268 mt in the base model. The biomass threshold is estimated as $(1 - M)*SSB_{MSY}$. Using the average M

over ages 1–15+ (0.25), the biomass threshold has a value of 19,700 mt. Estimated *SSB* in 2008 was 39,728 mt, above both the threshold and the target, indicating the stock is not overfished.

The fishing mortality threshold for Atlantic croaker is defined as F_{MSY}, which was estimated to equal 0.455 in the current assessment. The fishing mortality target ($0.75F_{MSY}$) was estimated at 0.341. The current population-weighted *F* averaged over ages 1–15+ ($F_{2008} = 0.22$) is below the estimated fishing mortality threshold and the target, indicating overfishing was not occurring.

1.3.4 Summary of Models

1.3.4.1 Model Description

A statistical catch-at-age (SCA) model was used to assess Atlantic croaker. This model combined the catch-at- age data from the commercial and recreational fisheries with information from fishery-independent surveys and biological information such as growth rates and natural mortality rates to estimate the size of each age class and the exploitation rate of the population.

A series of sensitivity runs conducted over a range of plausible values of shrimp-trawl fishing mortality found that the ratio of directed fishing mortality to F_{MSY} was less than one in all cases, indicating overfishing was not occurring. The model trends agreed with the trends in the fishery-independent data and the expanding age structure that has been observed in the catch.

1.3.4.2 Model Assumptions and Limitations

Because of the high degree of uncertainty of the estimates of shrimp trawl bycatch, the model estimates of stock size and fishing mortality were not considered reliable. Therefore, the assessment could only provide trends in spawning stock biomass and estimates of relative fishing mortality and not absolute numbers.

1.3.4.3 Data Time Series and Limitations

A large proportion of Atlantic croaker removals were not adequately documented, which included landings and bycatch from the scrap/bait fishery, at-sea discards from directed fisheries and, most importantly, bycatch in southern shrimp trawl fishery.

There are no continuous monitoring programs to account for discards in the shrimp-trawl fishery. The studies that have looked at bycatch rates in shrimp trawls occur infrequently, cover small geographical ranges, and often use different methods of sampling and reporting data. As a result, many assumptions have to be made to develop a time series of total croaker catch from the shrimp trawl fishery.

The low sample size of observed trips in the NMFS Observer Program made estimates of Atlantic croaker discards uncertain.

1.3.4.4 Review of Other Models Available

In addition to the catch-at-age model, the Stock Assessment Committee (SASC) considered an age-structure production model (ASPM), a non-equilibrium production model (ASPIC), catch curve analysis, and stock synthesis. The ASPM model was used in the 2004/2004 stock assessment and was therefore used to produce continuity runs. The Stock Synthesis model, ASPIC, and catch curve models failed to converge or produced unrealistic parameter estimates and was not used to compare against the SCA model.

1.3.5 Results of the Assessment

The 2010 stock assessment concluded that Atlantic croaker was not experiencing overfishing. The SCA model estimates of SSB were too uncertain to be used to precisely determine overfished stock status; however, given that biomass was increasing and the age-structure of the population had expanded since the late 1980s, the stock assessment concluded that it is unlikely the stock is in trouble.

1.3.6 Peer Review Comments

The Peer Review Panel commented that:

- Overfishing was probably not occurring. From examination of the data compiled for the stock assessment it appears that there has been an upward trend in biomass since the 1980s and a decreasing trend in *F* (since commercial catches have been fairly constant since the mid-1990s).
- It was not possible to be confident with regard to the overfished status until the discards from the shrimp fisheries are properly incorporated into the stock assessment.
- The lack of adequate estimates of Atlantic croaker bycatch in the shrimp trawl fishery was a major concern. The Panel recommended development of a time series of effort for the shrimp fishery for use in estimating bycatch of Atlantic croaker. In addition, the Panel recommended the development and implementation of sampling programs for shrimp fisheries in order to monitor the relative importance of Atlantic croaker in these fisheries.

1.3.7 Strengths and Weaknesses of Previous ASMFC Assessment

- The assessment was able to give an overfishing status determination for the entire stock.
- Data sets from North Carolina allowed the estimates of Atlantic croaker landings from the bait/scrap fisheries.
- The use of a catch-at- age model allowed for the inclusion of data from the commercial and recreational fisheries as well as information from fishery-independent surveys. Model estimates of spawning stock biomass were too uncertain to be used to precisely determine and overfished stock status.
- There was concern that the shrimp trawl bycatch estimates track shrimp catch rather than bycatch. This is an important distinction given that bycatch estimates could be as large as or larger than landings.
- The estimates method for trawl and gill net discards was unreliable. The number of trips that observed landed croaker was very small and a geometric mean was not effective for a low sample size.

- There was little ability to estimates steepness in the model in regards to the stock-recruit relationship.
- The gill net selectivity was static in the model; however, it is likely that selectivity has changed over time due to the growing importance of the gill net fishery.

1.3.8 Past Research Recommendations

Research recommendations were developed by both the SASC and the review panel during the 2010 ASMFC assessment review.

Recommendations from the SASC included:

1. Continue fisheries-independent surveys throughout the species range and subsample for individual weights and ages, particularly in the southern range.
2. Encourage fishery-dependent biological sampling of Atlantic croaker from the southern region. Collect age samples from the recreational fishery when the length distribution of the recreational fishery samples is not adequately represented by the fisheries from which the age-length keys are developed.
3. Increased observer coverage for commercial discards.
4. Collect data on fishing attributes necessary to develop gear-type-specific fishing effort estimates.
5. Develop and implement sampling programs for state-specific commercial scrap fisheries in order to monitor the relative importance of Atlantic croaker in the scrap landings.
6. Develop a coast-wide tagging program for Atlantic croaker to evaluate migration and movement and continue any coast-wide studies (e.g., genetics, otolith microchemistry) designed to improve understanding of stock definition.

Recommendations from the peer review panel included:

1. Develop a time series of effort for the shrimp fishery for use in estimating bycatch of Atlantic croaker.
2. Develop and implement sampling programs for shrimp fisheries in order to monitor the relative importance of Atlantic croaker in these fisheries.
3. Determine the maturity at age schedule using a definition of cohorts based on the spawning season in the mid-Atlantic region.
4. Explore the method of calculating spawning biomass using a length-based maturity ogive along with predicted yearly length composition.
5. Re-examine development of recreational CPUE index using the Stephens and MacCall (2004) method with the coast divided into subareas based on expected species association with Atlantic croaker by area.
6. Examine alternative types of reference points that do not rely on a defined stock–recruitment relationship.

2 LIFE HISTORY

The Atlantic croaker, *Micropogonias undulatus*, is a demersal sciaenid common in estuarine and nearshore waters from the Gulf of Maine to Argentina (Joseph 1972; Chao and Musick 1977; Nelson et al. 1991; Stone et al. 1994). Along the U.S. Atlantic coast, the species is abundant between Indian River Lagoon, Florida, and Chesapeake Bay and supports important commercial and recreational fisheries in both the South Atlantic Bight and Mid-Atlantic Bight (Lankford and Targett 2001; Lee et al. 2001; ASMFC 2007). Jung and Houde (2003) observed that Atlantic croaker were the dominant species (by biomass) in their mid-water trawl in the lower Chesapeake Bay.

The Chesapeake Bay is important as both a spawning and nursery ground (Murdy et al. 1997). For Atlantic croaker, the upper bay region is important as a nursery ground for larval and juveniles, whereas older and mature fish exploit the lower bay as a spawning and feeding area.

Differences in spatial and temporal distribution, as well as differences in feeding behavior, reduce competition between juvenile sciaenids, such as Atlantic croaker and spot (*Leiostomus xanthurus*), and allow them to coexist. Predators of Atlantic croaker are larger piscivorous species such as striped bass (*Morone saxatilis)*, southern flounder (*Paralichthys lethostigma*), bluefish (*Pomatomus saltatrix*), weakfish (*Cynoscion regalis*), and spotted seatrout (*Cynoscion nebulosus*) (ASMFC 1987).

2.1 Age

Initial studies of the age of Atlantic croaker in the Gulf of Mexico were based on the analysis of marks on scales (White and Chittenden 1977). These researchers found few age groups and concluded that this species has a short life span, has an early age at maturity, and could withstand considerable exploitation. Barger (1985) found that transverse sections of sagittal otoliths gave the most repeatable age estimates of Atlantic croaker from the Gulf of Mexico. Marginal increment analysis indicated that a single mark was deposited annually on the sagittae. Also, eight age groups were found suggesting that scales underestimate the true age of the fish in that area.

Ross (1988) also aged Atlantic croaker from North Carolina waters using scale analysis. Subsequently, Barbieri et al. (1994b) used sections of sagittae to age fish from the Chesapeake Bay during 1988–1991. A single annulus formed each year during April and May for all age classes. Their maximum age was 8 years. Since the publication of this study, the population has expanded and maximum observed age has increased. Age-12 fish were landed in Virginia and North Carolina in 2001 (NCDMF 1999; Bobko et al. 2003). More recently, a 17-year-old fish were landed by the Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP). Sections of Atlantic croaker otoliths removed from archeological excavations near St. Augustine, Florida indicated that coastal Indians from the First Spanish Period captured fish with a maximum age of 15 years (Hales and Reitz 1992).

Since Atlantic croaker have an extended spawning season and recruit to the estuarine nursery areas over an extended period, there are some problems associated with the assignment of the first annuli to fish taken along the Atlantic coast of the U.S. Atlantic. Croaker move into the estuaries north of North Carolina as early as July. This results in some Atlantic croaker being approximately seven to ten months of age during their first spring. Along the southeast coast (North Carolina and south), most Atlantic croaker recruit to the estuaries during January through March. These fish would be from two to five months of age during their initial spring. The young-of-year (YOY) north of Cape Hatteras form a rather indistinct mark near the core of the otolith that has been designated as the first annulus by some researchers (e.g., Barbieri et al. 1994b). This mark is not seen in the transverse sections of the sagittae of all fish coast-wide, posing a challenge for developing standardized ageing protocol. In those fish with the ring proximate to the core, the indistinct mark is designated as the first annulus. If the mark is absent and the distance to the first well-defined increment is relatively large, one is added to the number of annuli. South of Chesapeake Bay, some fish do have the hazy area near the core, but many fish lack it. Ages of the fish from North Carolina and south have been determined by designating the first well-defined, distinct ring as the first annulus.

In October 2008, the ASMFC sponsored an Atlantic croaker ageing workshop in order to compare methods in sectioning and reading otoliths and establish coast-wide age interpretation methods (ASMFC 2008, 2010). For the purposes of stock assessments and other coast-wide analyses, the decision was made to count the first distinct ring as the first annulus and not count any ‘check marks’ that occurred in close proximity to the core of the otolith as annuli. Given the potential birth-date for an Atlantic croaker born between October and March, the check mark can be deposited between 3 and 8 months of age. The first true annulus is put down at the end of the second over-wintering period. The primary reason for not counting this check mark is to prevent an inaccurate year-class assignment resulting in a shift of the age distribution. It was noted that historical age data from Virginia (VMRC/ODU and VIMS) should be reviewed and possibly adjusted to account for this difference in ageing methodology.

In March 2016, the ASMFC held a Quality Assurance/Quality Control Fish Ageing Workshop to revisit species that had their own ageing workshop, like Atlantic croaker. During this workshop, Atlantic croaker otoliths had an average percent error of 8% (ASMFC 2016). Differences in age readings were attributed to the persisting disagreement over the presence/absence of the check mark and whether or not to count it when present. Because of a research recommendation that came out of the workshop to revisit this topic, the ASMFC held a conference call in June 2016 for agers along the Atlantic and Gulf coast. It was agreed that more age validation studies are needed and ageing labs should continue to not count the check mark but to provide more information regarding their methods when submitting final ages, including presence/absence of the check mark and annulus counts.

Age data (sectioned otoliths) for the current assessment were available from the following areas and sources (**Table 2.1**):

1) Virginia commercial landings (1998–2014) aged by Old Dominion University;
2) Maryland commercial landings (2002–2014) aged by South Carolina DNR;
3) North Carolina fishery-independent and -dependent survey samples (1979–2014) aged by NCDMF;
4) Virginia and Maryland ChesMMAP (2002–2014) samples aged by VIMS;

5) Massachusetts – North Carolina: NMFS fall groundfish trawl survey (1997-2014) aged by SCDNR.
6) North Carolina-Florida SEAMAP (2001-2014) aged by South Carolina DNR.
7) New Jersey commercial landings (2006–2014) aged by New Jersey Division of Fish and Wildlife.
8) Georgia fishery independent surveys (2010-2012) aged by the Georgia Dept. of Natural Resources.

2.1.1 Commercial Age Data

The states of North Carolina, Maryland, Virginia, and New Jersey collect both age and length samples of Atlantic croaker from their commercial fisheries. Together, North Carolina, Virginia, and Maryland account for the majority of the total commercial landings of Atlantic croaker along the Atlantic coast, ranging from 88.3 to 99.6% annually.

One of the research recommendations from previous ASMFC stock assessments (ASMFC 2005b; ASMFC 2010) was to standardize ageing procedures across states. The ASMFC held a workshop in 2008 to standardize methods for both red drum (*Sciaenops ocellatus*) and Atlantic croaker (ASMFC 2008). At the workshop, it was agreed that readers would not count the smudge or check mark that occurred near the core in many Atlantic croaker and, instead, would count from the first distinct annulus. The birth-date for modeling purposes was considered to be January 1.

Maryland

Otoliths were processed and aged by the South Carolina Department of Natural Resources prior to 2011. Since 2012, otoliths have been processed and aged by MD DNR using the same protocol described for SCDNR (described below).

Virginia

The otoliths collected through the VMRC's Biological Sampling Program are processed and read by the Old Dominion University's Center for Quantitative Fisheries Ecology. Otoliths are processed following the methods described in Barbieri et al. (1994a) with a few modifications. Briefly, the left or right sagittal otolith is randomly selected and attached to a glass slide with Aremco's clear Crystalbond™ 509 adhesive. At least two serial transverse sections are cut through the core of each otolith with a Buehler Isomet low-speed saw equipped with a three-inch, fine-grit Norton diamond-wafering blade. Otolith sections are placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium.

All fish are aged in chronological order based on collection date, without knowledge of the specimen lengths. Two readers must age each otolith independently. When the readers' ages agree, that age is to be assigned to the fish. When the two readers disagree, both readers must re-age the fish together, again without any knowledge of previously estimated ages or specimen lengths and assign a final age to the fish. When the readers are unable to agree on a final age, the fish is excluded from further analysis.

The process for ageing Atlantic croaker otoliths in Virginia involves two steps: (1) read the otolith—count the number of annuli in the otolith transverse cross-section; and (2) determine the age of the fish in terms of sacrifice date and annulus formation period.

Historically, Virginia has counted the wide band/smudge closest to the otolith core as the first annulus, whereas most other states do not; however, since all Atlantic croaker in Virginia form that band and because Virginia uses the January 1 model birth-date, the sampled fish should be scored as the same age-class assignment as those scored in other states.

North Carolina

Atlantic croaker sagittal otolith samples are collected monthly from the winter trawl, long haul-seine, pound-net, sink-net fisheries, and NCDMF fisheries-independent programs. Sagittal otoliths have been collected since 1996. Each month, samples (n=15) are distributed across the length range in 15-mm length classes starting at 100 mm total length (TL). Sagittal otoliths are removed, cleaned, and stored dry. Fish are weighed to the nearest 0.01 kg and measured for TL to the nearest millimeter. Date, gear, and water location are also recorded for each sample.

A transverse section through the focus on a plane perpendicular to the horizontal axis of the left otolith is prepared using a Hillquist thin-sectioning machine as described by Cowan et al. (1995). The system is calibrated with an ocular micrometer before each reading session. Sections are viewed under reflected light at 21X magnification. Ages are assigned based on the number of otolith annuli viewed. The ageing lab biologist reads the otolith section. The samples are then independently read by the species lead biologist. If any differences are not resolved, the data are omitted.

The NCDMF publishes three-year reports that include species-specific age-length keys, which have been applied to expanded length-frequency data to estimate length-at-age for total commercial landings on an annual basis (for example, see NCDMF 2001, 2002). The age-length keys and expansions are applied on a seasonal basis: winter (January–March and October–December); and summer (April–September).

South Carolina

In the laboratory, the left sagittae are viewed under low magnification with a binocular microscope (10X) and marked with a soft lead pencil on the core. These are then embedded in epoxide resin in silicon molds. After the resin has polymerized, the embedded otoliths are glued to a card held in a jig attached to the arm of a low speed saw. The otolith is positioned so that a transverse section ~0.5-mm thick can be taken through the core. The Isomet Saw is equipped with a pair of diamond-wafering blades, separated by a plastic washer so that the section can be taken with a single cut. The resulting section is mounted on a labeled microscope slide with Cytoseal-XLY. After polymerization of the mounting medium, slides are stored in boxes until viewing. These are examined with a Nikon SMZU microscope equipped with a Supercircuits model PC - 23C high resolution camera with transmitted light. The video image is captured by a frame grabber board in a personal computer and is subsequently analyzed with the Image-Pro image analysis software. The following measurements are taken on each otolith section:

1) radius—distance in millimeters from the center of the core to the edge of the section as measured along the sulcus acousticus
2) a_1—distance in millimeters from the center of the core to the distal edge of the first annulus
3) a_2—distance in millimeters from the center of the core to the distal edge of the second annulus
4) a_3 to a_n—distance from the center of the core to the distal edge of the third annulus and from the core to the distal edge of the nth annulus
5) marginal increment—distance from the distal edge of the last annulus to the edge of the otolith section

Some Atlantic croaker otoliths vary with respect to diffuse, undefined marking near the core of the otolith. These diffuse areas are not interpreted as being a ring. The first annulus is considered the first well-defined, opaque band that can be traced around the entire section.

Georgia

Atlantic croaker captured in GA DNR fishery independent surveys from March 2010 to October 2012 were aged as part of a master's thesis. Several gears were used including trawl, hook and line, gill nets, and trammel nets. Otoliths were removed from a maximum of 30 fish per site, per day, from all surveys. If more than 30 fish were collected from an individual site, otoliths were removed from only a random subsample of each size class. The left sagittal otolith was primarily used for ageing. Otoliths were sectioned and aged based on manual counts of growth bands, without knowledge of specimen lengths, in chronological order by collection date. Methods used for ageing Atlantic croaker in this study differed from methods outlined in the ASMFC ageing workshop as the check mark near the core was counted as the first annulus.

2.2 Growth

Atlantic croaker may grow to over 50 centimeters in TL (Ross 1988) and have a maximum reported age of 17 years (ChesMMAP survey data, this report). Atlantic croaker exhibit rapid growth during their first year, but the annual growth rate declines sharply in the second year and decreases progressively as they grow older (Ross 1988; Barbieri et al. 1994a). Barbieri et al. (1994a) looked at Atlantic croaker collected from the Chesapeake Bay and Virginia and North Carolina coastal waters and found that 64% of the cumulative total observed growth in length occurred in the first year and 84% was completed after two years. Jung and Houde (2003) reported similar growth patterns for the Chesapeake Bay.

Previous studies suggest that length at age may vary among geographic regions (**Table 2.2**), but direct comparison of these estimates is complicated by differences in collection gear, age structure, ageing method and criteria, and time period. For this report, average TL by sex at age were calculated using available data from fisheries-independent and fisheries-dependent (**Table 2.3**) surveys. Only otolith-based age data were used. The resulting estimates are within the range of the published estimates, but comparisons may be misleading due to the differences previously listed.

Published estimates of the von Bertalanffy age-length function for Atlantic croaker show large variation (**Table 2.4**). Estimates of L_∞ have ranged from 31.2 to 64.5 cm TL, and estimates of K have ranged from 0.093 to 0.36 year^{-1}. For this report, von Bertalanffy age-length parameters were estimated using current available otolith-based age data for three different growth models by sex and for combined groups (**Table 2.5**). The current estimates of L_∞ were within the mid-range of earlier estimates (Barger 1985; Barbieri et al. 1994a). Current estimates of the growth coefficient, K, were generally lower than earlier estimates (Barger 1985; Barbieri et al. 1994a) that used otoliths for ageing; this was due to the higher estimates of L_∞, because K and L_∞ are inversely related.

For Atlantic croaker, length may be a poor predictor of age. Previous studies have reported that observed length distributions showed large overlap among ages (White and Chittenden 1977; Barger 1985; Ross 1988; Barbieri et al. 1994a; Chittenden et al. 1994). Examination of the age-length data available for the current assessment also found that lengths varied greatly within ages.

Parameters of the length-weight relationship have been estimated for Atlantic croaker in a number of studies (**Table 2.6**). The relationship of TL in centimeters to weight in grams was modeled for this report using available data. The estimated parameters of the allometric length-weight function for each data source are presented in **Table 2.7**.

Sex-specific differences in growth are a characteristic of many fish populations. Previous studies found no difference in growth between sexes for Atlantic croaker—either in the length-weight relationship (Barger 1985; Barbieri et al. 1994a; Chittenden et al. 1994) or in length-at-age (Barger 1985; Barbieri et al. 1994a). For this report, the analysis of the residual sum of squares (ARSS) method was performed to compare growth between males and females within each available dataset (Chen et al. 1992; Haddon 2001). The ARSS method provides a procedure for testing whether two or more nonlinear curves are statistically different. The approach requires that the same model be fit to each dataset being compared. The ARSS analysis was applied to compare estimated von Bertalanffy age-length curves and estimated length-weight curves between sexes within each dataset. Sex-specific parameter estimates of the von Bertalanffy age-length function were previously shown in **Table 2.5**, and sex-specific parameter estimates of the allometric length-weight function are shown in **Table 2.8**. Estimated values of L_∞ and K were generally higher for females than males (**Table 2.5**). Parameter estimates for both males and females collected from New Jersey commercial gill nets were associated with relatively large standard errors and may not be reliable. The value of L_∞ estimated for females collected from North Carolina commercial pound nets was exceptionally high and associated with a large standard error; this estimate is not considered reliable. The ARSS detected significant differences ($P<0.001$; $\alpha=0.01$) between male and female age-length curves in most of the datasets (**Table 2.9**). Comparison of the length-weight curves between sexes yielded similar results; significant differences ($P<0.001$; $\alpha=0.01$) between sexes were found in seven of the thirteen datasets. The results of the current analysis suggest that Atlantic croaker may exhibit differential sex-specific growth.

2.2.1 Length Data Conversions

Measurements of Atlantic croaker length are reported in standard length (SL), fork length (FL), and total length (TL) depending on data set (**Table 2.10**). The definitions of the different length measurements can be found in **Table 2.11**. Length conversion factors for each data set for this assessment from available biological data sources are reported in **Table 2.12**. All length data compiled for this report were converted to TL (if TL was not available) using the conversion factors from this assessment analysis. Length-length conversions were determined using the linear regression model Y = a + (X * b). The model was fit to length measured in cm. Coefficients of determination (r^2) ranged from 0.984 to 0.997.

2.3 Reproduction

2.3.1 Spawning

Atlantic croaker have reproductive seasonality, spawning in warm pelagic waters between early September and late December, depending on latitude (White and Chittenden 1977; Music and Pafford 1984; Able and Fahay 1997). Spawning peaks in the fall north of Cape Hatteras, NC and in the winter and early spring further south (Welsh and Breder 1924; Hildebrand and Schroeder 1928; Wallace 1940; Haven 1957, 1959; Ingle et al. 1962; Beaumariage and Wittich 1966; Morse 1980; Music and Pafford 1984; Norcross and Austin 1988; Norcross 1991; Hare and Able 2007). A laboratory experiment found that optimal spawning for croaker in captivity occurred at 19°C (Sink et al. 2010), although previous work on similar species suggested the optimal spawning temperature to be 23°C.

2.3.2 Maturity

Published estimates of maturity for Atlantic croaker in the Atlantic Ocean are somewhat variable (**Table 2.13**). Welsh and Breder (1924) reported that Atlantic croaker reach maturity at age 3 or 4. Wallace (1940) reported that males first reach maturity at age 2 and females reach maturity at age 3. Wallace (1940) also reported a minimum length at maturity of 24 cm TL for males and 27.5 cm TL for females. More recent studies on Atlantic croaker maturity suggest this species matures at a smaller size and earlier age than reported previously. Morse (1980) and Barbieri et al. (1994b) reported minimum lengths at maturity for males and females that were smaller than those reported by Wallace (1940), but similar to each other. Barbieri et al. (1994b) found that over 85% of Atlantic croaker were mature by age 2 and all were mature by age 3. One reason for the difference in estimates between the earlier and more recent studies may be due to how ages were determined. The earlier estimates were based on ages derived from length frequencies (Welsh and Breder 1924) and scales (Welsh and Breder 1924; Wallace 1940), which are considered less reliable than otolith ages for Atlantic croaker (Barbieri et al. 1994a). Barbieri et al. (1994b) used ages derived from otoliths to determine age at maturity.

Length and age at maturity were determined using a two-parameter logistic model was applied to estimate length and age at 50% maturity. The calculated maturity estimates were similar to the findings of Morse (1980) and Barbieri et al. (1994b), suggesting Atlantic croaker mature at a small size and early age (**Table 2.13; Figure 2.1**). The work of Barbieri et al. (1994b) and the current results suggest almost all Atlantic croaker are mature at age 2. Variability among the estimates may be partly attributable to sampling differences and the time of year when samples are collected, given the protracted, bimodal spawning season. The Stock Synthesis (SS3) model used in this assessment only requires female-only maturity parameters. These parameters were estimated based on suggestions from the peer review panel of the 2010 ASMFC assessment and the estimation is described in section 7.2.1.9 (maturity).

2.3.3 Sex Ratio

Barbieri et al. (1994b) computed monthly sex ratios of Atlantic croaker collected mostly from commercial fisheries operating in the Chesapeake Bay. They found monthly fluctuations in sex ratio and that females dominated during the main spawning period (June/July–September/October) and were highest during August–October in both years of their study. Chittenden et al. (1994) reported similar results for the Chesapeake Bay. Barbieri et al. (1994b) suggested that the higher proportions of females observed during the first months of spawning could indicate that males migrate out of the bay earlier than females or that spawning-phase females are more susceptible to the commercial fishing gears from which samples were collected.

Annual and monthly sex ratios were calculated for the current assessment using available assessment data sets (**Table 2.14**). The monthly sex ratios show higher proportions of females were observed in all months for most of the datasets, except October for the NMFS survey (**Table 2.15**). Sex ratios were similar among the fisheries-independent trawl surveys with overall estimates ranging from 53% to 62%. Overall sex ratios were higher for the commercial fisheries data, ranging from 59% to 72%. Annual estimates derived from commercial fisheries samples (MDDNR, VMRC, and NCDMF) were generally higher than sex ratios derived from fisheries-independent samples (NMFS, ChesMMAP, and SEAMAP) (**Table 2.14**). Sex ratios at length (**Figure 2.2**) indicated female dominance, particularly at lengths > 34 cm. Sex ratio at age was relatively consistent across all ages at 60% females to 40% males (**Figure 2.3**).

2.3.4 Fecundity

The two estimates of fecundity for Atlantic croaker found in the literature suggest fecundity may be high for this species. Hildebrand and Schroeder (1928) reported that a 39.5-cm female contained approximately 180,000 eggs. That estimate was based on a single fish caught in the mouth of the York River in October 1921. Morse (1980) estimated fecundity based on ovaries collected during the fall component of the NMFS Bottom Trawl Survey in 1973 and 1974. He estimated that fecundity ranged from 100,800 to 1,742,000 eggs for females ranging from 19.6 cm to 39.0 cm TL. Morse's (1980) estimates were based on the assumption of determinate fecundity; however, Barbieri et al. (1994b) concluded that Atlantic croaker have indeterminate fecundity and suggested that estimates based on the assumption of determinate fecundity should not be used for management. A study to evaluate croaker for its potential as a broodstock found fecundity to be approximately 81,000 eggs in a passively induced laboratory setting which increased to 267,000 eggs with the application of a hormone implant (Sink et al. 2010).

2.3.5 Stock Definition

The current ASMFC management plan for Atlantic croaker assumes a single stock for the Atlantic coast (ASMFC 2011); however Amendment 1 originally identified two management areas: the mid-Atlantic and south Atlantic. The question of whether one or two stocks of Atlantic croaker occur along the U.S. Atlantic coast has been investigated by a number of studies. White and Chittenden (1977) reported differences between the life histories of Atlantic croaker occurring in the warm-temperate waters of the Carolina Province than those found in the cold-temperate waters north of Cape Hatteras. These differences included spawning season, size- and age-at-maturity, and maximum size. White and Chittenden (1977) did note that growth rates appeared similar between the regions. Results reported by Ross (1988) were consistent with the proposed northern group life history (larger sizes and older ages), though he considered Cape Lookout as the zoogeographic boundary. He suggested that the possible mixing of Atlantic croaker may confound fishery management until adequate separation techniques are produced. Barbieri et al. (1994a) disputed the existence of a group of larger, older Atlantic croaker in the Chesapeake Bay as compared to fish occurring in more southern waters and suggested that the hypothesis of different groups occurring above and below Cape Hatteras should be reevaluated. They recommended that surveys of the age and size composition of Atlantic croaker over time were needed to fully assess this inquiry.

Two analyses of otolith microchemistry offer conflicting information for its use evaluating population structure. One study found no significant differences between juveniles from North Carolina and Virginia, suggesting larvae from north and south of Cape Hatteras may come from a single spawning site (Thorrold et al. 1997). A second study found significant variation in otolith chemistries for croaker collected from Delaware to North Carolina and suggested this could be a tool to distinguish larvae from different spawning grounds for future studies (Schaffler et al. 2009). A study of Atlantic croaker genetic population structure using mitochondrial DNA analysis found no evidence that Cape Hatteras represents a genetic stock boundary (Lankford 1997; Lankford et al. 1999). Lankford and Targett (2001) investigated adaptive variation in growth capacity and cold tolerance of YOY Atlantic croaker and found no geographic variation in these physiological traits, lending further support to hypothesis of a single stock along the Atlantic coast. More recently, a study by Baker et al. (2007) using macroparasites as biological tags provided weak support for the idea of two stocks roughly separated at Cape Hatteras.

An assessment of Atlantic croaker performed by Lee (2005) assumed a single stock occurring along the Atlantic coast due to lack of genetic evidence for separate stock groups. That assessment also reported strong correlations in year-class strength for Virginia and North Carolina, adding support to the coast-wide approach. Previous assessments for Atlantic croaker assessment used both a regional approach (ASMFC 2005b) as well as a single coast wide stock approach (ASMFC 2010). The SASC reported differences in population trends between the northern (North Carolina and north) and southern (South Carolina to Florida) regions. The peer review panel debated whether the available information supported separating the stock into northern and southern components and concluded that further investigation into the question of stock structure was needed (ASMFC 2005c). An update of the ASMFC assessment reviewed and discussed the available research in detail (ASMFC 2005d). The SASC noted that genetic analyses have not supported the existence of separate stocks and suggested that further studies are needed. The most recent stock assessment (ASMFC 2010) concluded that there was no biological justification for the regional split. While there were some differences between the southern and mid-Atlantic regions in population characteristics, it was unclear whether these differences were due to legitimate differences in population dynamics or simply inconsistencies in the data for the southern region (which did not converge in the models).

For this assessment, the SASC decided to continue to treat the Atlantic coast stock as a single coast wide unit since there was no new data or evidence suggesting a regional management approach was warranted.

2.4 Natural Mortality

For the stock assessment, a variety of indirect methods were applied to available data to derive estimates of natural mortality (*M*). Approaches for computing both an age-constant *M* and age-varying *M* values were considered; the methods and resulting estimates are described below.

2.4.1 Age-Constant *M* Approaches

There have been numerous methods developed to estimate age-constant *M* based on the relationship of natural mortality to various life history characteristics. These different methods have used maximum age (T_{max}) of a population (Hoenig, 1983; Alagaraja,1984; Hewitt and Hoenig 2005). Other approaches have been based on von Bertalanffy growth and require estimates of asymptotic length (L_∞), the growth coefficient (*K*), as well as T_{max} to determine *M* (Alverson and Carney 1975; Pauly 1980; Ralston 1987; Jensen 1996). Recent work by Then et al. (2015) re-evaluated different estimators of M for various combinations of T_{max}, growth parameters, and water temperature for > 200 independent direct estimates of M in order to determine how well they worked in terms of prediction error and how they ranked amongst all methods. They determined that a T_{max} based estimator performed best among all of the estimators evaluated such that $M = 4.889 * T_{max}^{-0.916}$. If T_{max} was not available the next best estimator was growth based, using the von Bertalanffy parameters ($M = 4.118 * K^{0.73} * L_\infty^{-0.33}$. Since Then et al. (2015) represents an improvement on the reliable estimate of *M*, estimates were made using both T_{max} and growth parameter methods for comparison purposes.

Mortality estimates were made using all age data combined (including fish of undetermined sex), for all fish where sex was known, and for males and females separately using three different growth models and can be seen in **Table 2.16**. The growth models used were the traditional von Bertalanffy model, the Schnute re-paramaritization of the von Bertalanffy model, and the Richards model. All three models produced the same *M* (0.306 year $^{-1}$) for all data sets, except females (*M* = 0.336 year^{-1}) where T_{max} was different (15 years for females and 17 years for males). The *M* estimates using growth parameter values were lower than the T_{max} estimates ranging from 0.260 – 0.299 year^{-1} depending on the group tested (**Table 2.16**).

2.4.2 Age-Varying *M* Approaches

A number of approaches have been developed to provide indirect estimates of *M* at age (for example, see Peterson and Wroblewski 1984, Boudreau and Dickie 1989, and Lorenzen 1996, 2005). Lorenzen's (2005) method was used to calculate age-specific *M* values for Atlantic croaker using available data. This approach requires estimates of the von Bertalanffy age-length growth function (to translate length to age) and the range of ages over which *M* will be estimated. The cumulative natural mortality estimates across the selected age range were set equal to the target *M* to scale age-specific estimates using Then et al. (2015) T_{max} method. Since there was a significant difference in growth ($p < 0.05$) between males and females, the age varying *M* was calculated by sex as well as for the combined sexes and for all ages (whether there was sex designation or not; **Table 2.17**).

Estimated natural mortality rates decreased with increasing age as would be expected. The different data groups had very similar overall mean *M* values for fully recruited ages (1+) (range of 0.243 – 0.263 year $^{-1}$) with all data group having a higher *M* level (0.263 year $^{-1}$) than the other groups. Females had the lowest mean *M* (0.243 year $^{-1}$) which was due to the lower T_{max} (15 years) and higher growth coefficient for females. Age-specific estimates of *M* based on all available data ranged from 0.203 to 0.451 year^{-1} depending on the group and age with a mean of 0.263 year^{-1} and a median value of 0.337 year $^{-1}$.

2.4.3 Discard Mortality

No direct estimates of discard mortality for Atlantic croaker released alive from the recreational fishery were identified by the TC or SASC. A review of recreational angler discard mortality studies found a median discard mortality of 11% and a mean of 18% across studies (Bartholomew and Bohnsack 2005). The SAS believes a value approximately in the middle of the range between the median and mean (15%) is an appropriate approximation of the discard mortality rate for Atlantic croaker in recreational fisheries.

Another study on Atlantic croaker by Johnson (2003) determined the immediate (15–30 minutes) survival of discards onboard estuarine commercial shrimp trawlers. His results showed that the survival of Atlantic croaker decreased as time on deck increased—from 40% survival for Atlantic croaker that were on deck less than 20 minutes to 8% survival for Atlantic croaker that were on deck longer than 20 minutes. This study did not take into account mortality due to tow time or mortality and increased vulnerability to predation post discarding. Duration of observed tows from the Southeast Shrimp Trawl Observer Program (Section 4.1.2.4) ranged from twelve minutes to just under nine hours with a median of three hours. Because there is no information from the observer program on the time discards spent on deck and unknown additional mortality from other causes (e.g., stress during long tow durations, increased vulnerability to predation), 100% discard mortality is assumed for Atlantic croaker discarded in commercial fisheries. Although, model sensitivity runs were made with discard mortalities less than 100% to gauge effect. This will be discussed in greater detail in sections 4.1.3.4.

2.5 Diet

Atlantic croaker are opportunistic bottom-feeders on benthic epifauna and infauna and consume a variety of invertebrates, including polychaetes, mollusks, ostracods, copepods, amphipods, mysids, decapods, and occasionally fish (see ASMFC 1987 for a review). In Delaware Bay marsh creeks, Nemerson and Able (2004) found that juvenile diet transitioned along a salinity gradient but with high consumption of annelids occurring at all sites. In lower salinity, crustaceans figured prominently in the diet (15–34%), whereas mysids dominated at higher salinity sites (46%). The adult Atlantic croaker is an opportunistic bottom feeder of benthic epifauna and infauna.

Several studies published since 2000 have reported information on adult Atlantic croaker diet. Results from the Chesapeake Bay Fishery-Independent Multi-Species Fisheries Survey (CHESFIMS) stated that most Atlantic croaker stomachs contained polychaetes and mysids (Miller et al. 2003b). Results of work conducted by the Chesapeake Bay Trophic Interactions Laboratory verified these results and documented similarities and differences in diet between seagrass habitat and river habitats as well as a shift in diet across seasons (Parthee et al. 2006). Diet was similar among seagrass and river habitats, with polychaetes and bivalves as primary prey types. Of bivalves, the softshell clam was the most heavily exploited species in seagrass beds but found only rarely in the diet of Atlantic croaker in rivers. In rivers, amphipods, isopods, mysids, and crabs were important. Miscellaneous material in the diet included unidentified vegetation, detritus, sand, mud, and woody debris. Seasonal diet analysis showed that mysids and polychaetes were year-round prey items, supplemented by clams in the summer and crustaceans in the fall. Nye et al. (2011) confirmed that the diet of croaker exhibited seasonal variation in the Chesapeake Bay, but found that a greater portion consists of anchovy in the summer months than previously believed. A study of adult diet conducted in the Neuse River Estuary, North Carolina during the summers of 1997 and 1998 documented a shift in diet due to hypoxic events (Powers et al. 2005). Whereas clams were normally an abundant item in the diet, less nutritional items such as plant and detrital material were seen after hypoxia.

2.6 Migration Patterns

The distribution and migration of larval and juvenile Atlantic croaker have been observed to follow the general trend of ontogenetic migration by estuarine fish described by Dando (1984) in which the post-larvae are normally found in the highly productive zone just down-estuary from the freshwater interface, and juveniles descend to the middle and lower reaches of an estuary as they grow. A three-year (1996–1999) multigear survey conducted by Miller et al. (2003a) in Delaware Bay found a regular pattern of egress out of tidal creeks and estuaries during the late summer and fall. A 1998 tag-recapture study by Miller and Able (2002) on juvenile (age 0) Atlantic croaker in restored and reference marsh creeks of Delaware Bay found that 95% of the recaptures occurred in the subtidal and intertidal portions of the creek from which fish were tagged. A subsequent study of the restored Delaware Bay marshes by

Nemerson and Able (2004) found juvenile Atlantic croaker abundance was one to three orders of magnitude higher in the lower bay, high-salinity marshes than in the upper bay, low-salinity marshes. A study conducted by Jung and Houde (2003) in Chesapeake Bay found most YOY concentrated near the estuarine turbidity maximum (a zone in the upper bay of increased suspended particle concentration) in the upper bay between summer and fall and moved down-estuary afterward. Miller et al. (2003a) found that each year-class migrated out of Delaware Bay and tidal creeks between late summer and October–November. This result was consistent with that of Haven (1957) in Chesapeake Bay.

Studies investigating the vertical distribution of oceanic larval Atlantic croaker have drawn conflicting conclusions. Govoni et al. (1994) found evidence of diel (day-night) vertical migration with Atlantic croaker larvae more common in deeper water during nighttime hours, while Comyns and Lyczkowski-Shultz (2004) found evidence for the reverse situation with Atlantic croaker larvae were more common in deeper water during daylight. Atlantic croaker larvae were reported to migrate inshore from shelf waters in the lower layers of the Atlantic Ocean off of North Carolina in a study by Hare and Govoni (2005), while larval Atlantic croaker in the Gulf of Mexico displayed no consistent vertical distribution pattern in a study by Sogard et al. (1987).

The distribution of adult Atlantic croaker is associated with both seasonal coast-wide migrations and inshore/offshore migrations associated with spawning and maturity. Evidence based on field collections suggests that oceanic settlements of adult Atlantic croaker coincide with spawning in warm pelagic waters with area-specific recruitment peaks—in the fall north of Cape Hatteras, NC, and in the winter and early spring further south (Haven 1957, 1959; Ingle et al. 1962; Beaumariage and Wittich 1966; Music and Pafford 1984; Norcross and Austin 1988; Hare and Able 2007).

In the Mid-Atlantic Bight, including the ocean south of Cape Hatteras, Atlantic croaker move northward and inshore during the warmer months, and southward and into the ocean during late fall or winter (Haven 1959; Norcross and Austin 1988; see also ASMFC 1987 for a review). This information is supported by reports from trawlers targeting Atlantic croaker and tagging programs conducted in Chesapeake Bay and along the North Carolina coast (Haven 1957, 1959; Pacheco 1958, cited by Norcross and Austin 1988).

The Maryland Department of Natural Resources (MDDNR) conducted a tagging study on Atlantic croaker in the Chesapeake Bay during 2005 and 2006 as part of a statewide MDDNR-sponsored fishing tournament. Nine hundred fifty-six Atlantic croaker were tagged in 2005 and 448 were tagged in 2006 (MDDNR Fisheries Service, unpublished data). Twenty-six Atlantic croaker tag returns were made in 2005 and 2006 combined, and all fish were recaptured in the same year they were released. Fifteen fish were recaptured in Maryland, all of which were released in June and recaptured during June through August of the same year. Three fish released in June 2005 were recaptured in Virginia—from Hampton to Virginia Beach—during October and November in 2005. Three Atlantic croaker released from the same net near the mouth of the Potomac River on June 2, 2005, were recaptured in New Jersey during September through October in 2005. Another fish released from the net in the Potomac River in June 2005 was recaptured in North Carolina on December 28, 2005. Two Atlantic croaker released in the mouth of the Choptank River in June 2005 were recaptured in North Carolina in October 2005.

One fish released in Tangier Sound in July 2006 was recaptured in October 2006 in North Carolina. The results of the MDDNR tagging study provide supporting evidence of a fall-winter migration from estuary to ocean for Atlantic croaker.

In the South Atlantic Bight, the migratory patterns of Atlantic croaker have been investigated through tagging programs in Florida and Georgia. Although there were no recaptures from Florida's program (Ingle et al. 1962; Beaumariage and Wittich 1966), enough recoveries were obtained from Georgia's program to determine seasonal movement (Music and Pafford 1984). The period of greatest movement was during spring-fall, and few Atlantic croaker remained in estuaries during winter. Although most recoveries were from the general area of release, there were three recoveries (3.5%) that moved far away—two fish traveled southward (138 km) and were recaptured during May and August in the St. Johns River, Florida, and the third fish moved northward (179 km) and was recaptured in May near Cane Island, South Carolina.

3 HABITAT

3.1 Brief Overview of Habitat Requirements

Atlantic croaker are found in several different habitat types including, but not limited to, submerged aquatic vegetation, non-vegetated bottom, marsh edge, wetlands, sandy bottom and shell bottom (Petrik et al. 1999; Street et al. 2005). Their habitat range is from Massachusetts to Florida but are most commonly found from New Jersey to Florida and in the Gulf of Mexico (Diaz and Onuf 1985; Robbins and Ray 1986; Ross, 1988; Able and Fahey 1997). Habitat preference changes based on stage of development.

Localized processes like currents and tidal regimes influence the dispersal of larvae to nursery areas (Petrik et al. 1999). Field surveys of post-settlement Atlantic croaker in estuarine nursery areas found no significant differences in abundances among submerged aquatic vegetation, marsh edge, and sandy bottom (Petrik et al. 1999). Nursery areas differ considerably among locations, possibly in response to tidal range. Upon initial arrival in the estuary, larval croaker are restricted to the surface water but will eventually settle into bottom waters where they complete their development into juveniles (Miller et al. 2003a).

Juvenile Atlantic croaker are typically found in estuaries along the Atlantic coast (Diaz and Onuf 1985; Robbins and Ray 1986; Ross 1988; Able and Fahey 1997). Substrate plays a larger role in distribution once Atlantic croaker reach the juvenile stage. Juveniles are positively correlated with mud bottoms that have large amounts of detritus and high amounts of benthic prey (Cowan and Birdsong 1985). Juveniles migrate downstream as they develop and by late fall, most juveniles emigrate out of the estuaries for open ocean habitats (Miglarese et al. 1982).

Adult Atlantic croaker, over one year of age, are found over muddy and sandy substrates as well as are typically observed near oyster, coral, and sponge reefs (White and Chittenden 1977; TSNL 1982). Temperature and depth are strong predictors of adult croaker distribution and the interaction between the two variables may also influence distribution (Eby and Crowder 2002).

Atlantic croaker are able to tolerate a wide range of salinity, water temperature, and water depth; however, significant hypoxia-induced habitat shifts have been noted in several studies

(Eby et al. 2005; Craig and Crowder 2005; Tuckey and Fabrizio 2016). Prolonged exposure to hypoxia has detrimental effects on reproduction in Atlantic croaker. Hypoxia has been linked to decreased gonadal growth, gametogenesis, and endocrine function as well as lower hatching success and larval survival (Thomas et al. 2007; Thomas and Rahman 2009). Juveniles are associated with areas of stable salinity, but adults prefer areas of high salinity and become less tolerant of cold temperatures. YOY less than 50 mm TL, inhabit low salinity or upriver areas (Haven 1957; Dahlberg 1972; Chao and Musick 1977; White and Chittenden 1977; Wenner and Sedberry 1989; Miller et al. 2003a). Juvenile Atlantic croaker between 100-150 mm TL are commonly found in the transitional zone within bays or estuaries. Most adults over 150 mm TL are collected from the higher salinity waters, presumably during the seaward migrations during the summer and fall (White and Chittenden 1977; Miller et al. 2003a).

While Atlantic croaker can tolerate a wide range of temperatures, they are vulnerable when exposed to low temperatures. Young-of-year (30-60 mm SL) will experience 100% mortality when exposed to 1° C for a period of 8 days. Prolonged exposure (12-24 d) to water temperatures of 3° C can also lead to high mortality rates (Lankford and Targett 2001). Hare and Able (2007) studied winter temperature variability and its effect on Atlantic croaker population dynamics. They showed a correlation between Atlantic croaker adult abundance and winter temperatures with high abundance corresponding with warm winter water temperatures (Hare and Able 2007). A coupled climate-population model based on temperature-driven, overwinter mortality of juveniles in estuarine habitats was developed (Hare et al. 2010). The model indicated that both exploitation and climate change significantly affected Atlantic croaker abundance and distribution. They recommended that climate effects be incorporated into the stock assessment models and used for scientific advice to achieve sustainable exploitation.

Atlantic croaker spawn in tidal inlets, estuaries, and on the continental shelf, at depths ranging from 7 to 81 m (26 to 266 ft) and in polyhaline and eurohaline zones (Diaz and Onuf 1985). Location of spawning may be more dependent on temperature than substrate type. Spawning along the Mid Atlantic Bight has been correlated with bottom temperatures higher than 16°C (Norcross and Austin 1988). Refer to the Atlantic Sciaenid Habitats: A Review of Utilization, Threats, and Recommendations for Conservation, Managements, and Research Needs (ASMFC 2015) for more detailed information regarding Atlantic croaker habitat.

4 FISHERY DESCRIPTION

4.1 Commercial

Atlantic croaker have been part of a mixed-stock commercial fishery on the Atlantic coast since the 1800s. Atlantic croaker are caught commercially with a wide variety of gear. The dominant gears include gill nets, pound nets, haul seines, and trawls. Atlantic coast commercial landings of Atlantic croaker exhibit a cyclical pattern, with low domains in the early 1950s, the 1960s to early 1970s and the 1980s to early 1990s, and high domains occurred in the late 1950s, the mid-to-late 1970s and the mid-1990s to 2011 (**Figure 4.1**). Commercial landings increased from a low of 647 metric tons in 1968 to 13,913 metric tons in 1977; however, landings have declined consistently since 2003 to 1,408 metric tons in 2014, which is well below the 1950-2014 average of 5,740 metric tons. Within the management unit, the majority of 2014 commercial landings came from Virginia (49%) and North Carolina (37%) (**Table 4.1**). Maryland had the next highest level, with 7% of coast-wide landings, while the remaining states all had landings of 3% or less. South Carolina and Georgia typically have the lowest landings among all Atlantic coast states across the entire time period. In comparison, Atlantic coast recreational harvest (data available only from 1981-2014) ranged from 953 – 7,997 metric tons annually and typically made up 20-40% of the total annual harvest of Atlantic croaker.

4.1.1 Commercial Scrap Landings, Shrimp Trawl Fishery, and Commercial Fin Fishery Bycatch

Estimated bycatch information suggests that the magnitude of Atlantic croaker commercial landings and bycatch from the shrimp trawl fishery annually is high. This is particularly true of the estimated bycatch levels from the shrimp trawl fishery where the estimated annual bycatch is an order of magnitude higher than all other fishery sources combined (**Figure 4.2**). In comparison, total annual removals without the shrimp trawl fishery bycatch levels indicate most removals were due to commercial and recreational landings followed by discards and scrap fishery landings (**Figure 4.3**). However, annual removals were highly variable and driven not only by relative abundance of Atlantic croaker and target species, but also fishery regulations.

4.1.2 Scrap Landings

Atlantic croaker are a major component of Atlantic coast scrap landings (NCDMF 2001). A scrap fishery is one in which fish species that are unmarketable as food, due to size or palatability, are sold unsorted, usually as bait. Because they are unsorted, scrap fishery landings are not included in state and federal Atlantic croaker landings estimates but they represent an additional source of removals.

Quantifying the amount of Atlantic croaker landed as scrap fish along the Atlantic coast is difficult due to the limited availability of sampling. Currently, North Carolina is the only state along the east coast that routinely samples their commercial scrap landings (see section 5.1.4, this report). The total weight of each species in the scrap fish samples is calculated by determining the proportion of that species in the subsample and expanding to the respective species’ proportional weight of the total scrap fish for the trip. The number of individuals per species in the scrap fish component is calculated by expanding the number of individuals in the sample to represent the total weight of the species for the scrap fish in the samples. Estimates of total scrap fish landings for individual species are determined by applying the tri-annual ratio of marketable fish to scrap fish in the fish house samples to the reported tri-annual marketable landings. For the 2017 Atlantic croaker stock assessment, the SASC used estimates of scrap landings from 1994–2014 from North Carolina to establish annual proportions of Atlantic croaker to total unclassified finfish landings. Virginia is the only other state within the Atlantic croaker range in which scrap landings are reported; however, Virginia does not subsample their scrap landings. In order to estimate the amount of Virginia scrap landings attributed to Atlantic croaker, data from North Carolina’s scrap landings subsampling program were applied. Specifically, the proportion of Atlantic croaker occurring in North Carolina’s scrap landings by month and gear were applied to Virginia's total scrap landings by month and gear to estimate Virginia's scrap landings of Atlantic croaker. For a few years, certain gear-specific samples were not available; in these cases, the proportions were averaged over other gears within each specific month and applied to the landings.

Because both Virginia's and North Carolina's trip ticket programs did not begin collecting information on scrap landings until 1994, it was necessary to hindcast estimates of scrap landings back to 1989. Annual ratios of Atlantic croaker scrap landings to total unclassified finfish landings from 1994–2014 were calculated for both North Carolina and Virginia. The average ratio over 1994–1996 was then computed and used to generate hindcast estimates of scrap landings for 1981–1993 by applying this ratio to total unclassified finfish landings during this time period for both states. The estimates for Virginia and North Carolina were added to produce total scrap landings for Atlantic croaker. Long-term trends indicated a steady decline in the scrap fishery for Atlantic croaker (**Figure 4.4**).

4.1.3 Shrimp Trawl Bycatch

Estimates of Atlantic croaker discard rates in South Atlantic shrimp trawl fisheries were developed using discard rate data from the Shrimp Trawl Observer Program to estimate the magnitude of discard rates and the SEAMAP Trawl Survey to estimate the trend of discards prior to (1989-2000) and during the observer program. Discard rate estimates were then applied to effort data from state trip ticket programs and the South Atlantic Shrimp System (SASS) to estimate total discards in these fisheries from 1989-2014 following the methods used by Walter and Isley (2014).

4.1.3.1 Shrimp Trawl Discard Rates

Only discarded Atlantic croaker are recorded by shrimp trawl observers, so no adjustments were needed to account for fish landed. Observer data were subset to exclude operation codes X, M, H, and J (Appendix 1). Observations with all other operation codes were included under the assumption that these observations are representative of effort in the shrimp trawl fisheries. Inclusion of observed nets with BRDs ended in years after the requirement of BRDs became mandatory and were also dropped from the analysis. BRDs were required in federal penaeid shrimp fisheries in 1996 under Amendment 2 to the Shrimp FMP for the South Atlantic Region (1995) and federal rock shrimp fisheries in 2005 under Amendment 6 to the Shrimp FMP (2004). State BRD regulations generally fit these time frames.

Trends in catch rates (number of fish/hour fished) of the SEAMAP Trawl Survey and the Shrimp Trawl Observer Program are in **Figure 4.5** and generally track well during overlapping years. Spatial coverage of both surveys overlap throughout most of the sampled ranges (**Figure 4.6**). Catch rates by tow from the combined data sets are in **Figures 4.7 and 4.8**. Length data from observer tows were only collected in 2003 and ranged from 10 to 29 cm TL for Atlantic croaker (**Figure 4.9**).

Discard rates in weight and numbers of Atlantic croaker were modeled with the delta-lognormal method (Lo et al. 1992). Discard estimates in numbers were preferred for the croaker Stock Synthesis model. The delta lognormal method combines a lognormal GLM used to predict discard rates of positive observations and a binomial GLM to predict the probability of a positive observation, with effort as an offset variable. The final discard rate is the product of the response variables from these two models. The negative binomial GLM predicts the number of fish caught per observation with effort as an offset variable. The negative binomial GLM for Atlantic croaker discard rates in numbers did not converge with full or reduced model structures. Distributions of the response variables for each model are in **Figures 4.10 and 4.11**. Factors considered in the models were year, data set, depth zone, state, and season. Data sets included observer data from the rock shrimp (observer project types W, X, Y) and penaeid shrimp (observer project types A, C) commercial fisheries and fishery-independent data from SEAMAP tows. Depth zones were less than or equal to 10 meters (=<10m), greater than 10 meters to 30 meters (10-30m), and greater than 30 meters (>30m). All SEAMAP tows were conducted in the shallowest depth zone. State borders were defined by the latitudes used by Scott-Denton et al. (2012). Seasons were December through March (offseason) and April through November (peak season). There were decreases in catch rates during June due to a reduced number of SEAMAP tows (**Figure 4.12**), but the seasons were defined to align with shrimp fishing relative to operation in nearshore waters throughout the time series. Shrimp fishing in nearshore waters where catch rates are expected to increase has generally started as early as April and lasted through November. Discard rate data by factor are summarized in **Tables 4.5 and 4.6**.

Model structure was evaluated with stepwise deletion of factors and the model with the lowest AIC was selected as the final model. Final model summaries are in **Tables 4.7 – 4.10**. All factors were retained for all models (**Table 4.11-4.12**).

4.1.3.2 Shrimp Trawl Effort

Effort data was available from trip ticket systems from FL (1986-present), GA (2001-present), SC (2004-present), and NC (1994-present) and the SASS from 1978 to the year trip ticket programs were implemented in each state, with the exception of NC. There was a gap in 1993 in NC when data was not available from either a trip ticket program or the SASS. Trip counts were provided by state, year, month, and gear following the methods described in Gloeckner (2014). The number of monthly trips in NC in 1993 were estimated as the average of the two adjacent years (1992, 1994). Average hours fished per trip and average number of nets fished per tow by state and year were used from NMFS Sustainable Fisheries Branch (2012) and are originally from trip ticket data. Averages were used before trip ticket data were collected and also for 2011-2014. Fishing hours were calculated as the product of total number of trips, average hours fished per trip, and average number of nets fished per tow. Effort is summarized by state and year in **Table 4.13** and by month in **Figure 4.13**. As effort was only available by state, year, and month, some assumptions were made to partition the effort among depth zones and fisheries. The proportions of observations from the observer data by depth zone were applied to overall effort, assuming that the observer data was representative of fishing effort at depth and that fishing effort at depth is static over time. A similar assumption was then made to partition the effort data into different state fisheries since data was collected at the state level. The proportions of observations in each depth zone allocated to penaeid and rock shrimp fisheries were applied to the effort data in the respective depth zone. Proportions used to partition effort are in **Table 4.14**.

4.1.3.3 Shrimp Trawl Discards

Discard rates were applied to effort estimates summarized by “strata” (i.e., combination of factors included in the model). Because there were no observer data before BRDs were required in the penaeid shrimp fishery, discard estimates for penaeid shrimp trawl effort prior to 1997 were adjusted for the reduction in catch due to the required use of certified BRDs on observed tows. Adjustments were based on a weighted average of Atlantic croaker catch reductions in the Gulf of Mexico shrimp trawl fishery estimated depending on the distance of fisheye BRDs from tie-off rings (Helies et al. 2009). 99.6% of observer trips used fisheye BRDs. BRDs in the observed trips ranged from 6 to 21 feet from tie-off rings. Catch reduction estimates were available for BRDs <9 feet (69.7% reduction), 9-10 feet (0% reduction), and 10-11 feet (17.2% reduction) from the tie off rings. There was no estimated reduction for fisheye BRDs greater than 11 feet from the tie-off rings, so the estimate for the 10-11 foot category was used for the proportion of nets greater than 11 feet from the tie-off rings. The proportion of observed trips that fell into the categories of <9 feet, 9-10 feet, 10-11 feet, and >11 feet were 0.22, 0.28, 0.31, and 0.20, respectively. The weighted average adjustment was 0.23 (i.e., adjusted discard = discard*1/(1-adjustment)). We assumed that observed trips were representative of BRDs used in the fisheries.

Final discard estimates with 95% confidence intervals are in **Tables 4.15 – 4.16** and **Figures 4.14** (weight)**, and 4.15** (numbers). Mean weights for Atlantic croaker derived from discard number and weight estimates can be found in **Table 4.17**. Discards were relatively high, but decreasing in the early 1990s before BRDs were required. There were particularly high discards in 1991 due to high effort and CPUE (**Figure 4.16**). Discards then became relatively stable throughout the 2000s. Despite slightly declining or stable trends in effort during the 2010s, there was an increasing trend in discards (**Figure 4.17**). This increase was likely driven by increasing CPUE over these years. Discard estimates generally followed the same trends as landings by shrimp trawlers (**Figure 4.17**). Atlantic croaker discard estimates from this assessment were generally greater than discard estimates developed for the 2010 benchmark assessment (**Table 4.18**), averaging 7.6 times greater than the 2010 estimates in the overlapping years.

4.1.3.4 Shrimp Trawl Discard Mortality Rate

A study by Johnson (2003) determined the immediate (15–30 minutes) survival of discards onboard estuarine commercial shrimp trawlers. His results showed that the survival of Atlantic croaker decreased as time on deck increased—from 40% survival for Atlantic croaker that were on deck less than 20 minutes to 8% survival for Atlantic croaker that were on deck longer than 20 minutes. This study does not take into account mortality due to tow time or mortality and increased vulnerability to predation post discarding. Duration of observed tows from the Shrimp Trawl Observer Program ranged from twelve minutes to just under nine hours with a median of three hours. Because there is no information from the observer program on the time discards spent on deck and unknown additional mortality from other causes (e.g., stress during long tow durations, increased vulnerability to predation), 100% discard mortality is assumed. Effects of this assumed discard mortality are evaluated with sensitivity analysis (80% based roughly on the middle of the range reported by Johnson (2003) 60-92% mortality).

4.1.4 Finfish Fishery Bycatch (Mid-Atlantic Gill Net and Trawl Fishery Discards)

Observer data from the Northeast Fisheries Science Center's Northeast Fisheries Observer Program (NEFOP) and At-Sea Monitoring Program (ASM) were used to develop annual ratios of observed discarded Atlantic croaker to observed landings of all species by gillnets and bottom trawls. Ratios were then applied to reported gillnet and bottom trawl landings of all species to estimate total discards from 1989-2014. The SASC investigated effort data from Vessel Trip Reports (VTRs), but deemed these data unreliable for discard estimates due to data caveats. For example, it was unclear how fishers interpreted certain data fields such as hours fished for trawl nets and whether or not these data fields are interpreted consistently among fishers through time. Orphanides and Palka (2007) also noted issues with inconsistent and incomplete gillnet effort from VTRs. VTRs are only required for federally regulated species and Atlantic croaker is not a federally regulated species. Any non-federally permitted vessels (i.e. state permitted vessels) are not required to submit VTRs, therefore effort data from VTRs is incomplete.

Annual geometric mean ratios were used in the last Atlantic croaker stock assessment. These ratios require excluding any trips where the species of interest were not discarded, landed, or both and was deemed unreliable for Atlantic croaker by the Peer Review Panel (ASMFC 2010). This methodology has the potential to bias ratios high by excluding zero discard trips and bias ratios low by excluding trips where the species was not landed, but was discarded. This also decreases sample size. For this assessment, ratios by gear type (gill nets and bottom trawls, **Table 4.19**) were calculated as the ratio of the mean discards (D) of Atlantic croaker per observation (*i)* (i.e., tow or net set) (L), in pounds, to the mean landings of aggregated species per observation (*i)*, also in pounds (equation 1).

$$Equation\ 1: R = \frac{\overline{D}}{\overline{L}} = \frac{\sum_1^n D_i}{\sum_1^n L_i}$$

This ratio estimator includes all observations with observed landings of any species, including those where no Atlantic croaker were discarded. The variance of the ratio estimator was calculated with equation 2 (Pollock et al. 1994).

$$Equation\ 2: Var(R) = \frac{1}{n(n-1)\overline{L}^2}\left(\sum_1^n D_i^2 + R^2\sum_1^n L_i^2 - 2R\sum_1^n D_i L_i\right)$$

Observer data are summarized by year and gear in **Tables 4.20-4.22**. Small sample sizes of positive observations precluded developing ratios at finer resolution (e.g., by state or season). All observations from trips that landed in ports from North Carolina to New York were used to estimate ratios. We are assuming that discarding rates during these trips are representative of overall discarding rates. There were few observations of Atlantic croaker in state areas off the coast of Rhode Island (537, 539) and they were infrequently caught northeast of Long Island Sound. The number of observations by state area are in **Table 4.23**.

Subsamples of the observed discards are taken from the total discards, weighed (aggregate weights), and each fish is counted and measured to the nearest centimeter. Annual mean weights were calculated as the total number counted divided by the total sample weight and were applied to the discard estimates in weight to derive discard estimates in numbers. Length frequencies by gear are in **Figures 4.18-4.19**. In years with no observer data (see yellow highlights in Table 4.20: 5 out of 26 years), averages of adjacent year observations were pooled to estimate ratios. In years with no preceding observer data, averages of the closest two year period were used.

Landings of all species combined by gillnet and bottom trawl gears (**Table 4.24**) were provided by ACCSP by year and state landed from North Carolina through New York. Some landings are not available at the gear level (“NOT CODED”). These landings were partitioned into trawl and gillnet landings by calculating the annual proportion of landings by these gear categories and then apply these proportions to the “NOT CODED” landings. Total landings by year and gear are in **Tables 4.20-4.22**. It was assumed that finfish gillnet and trawl trips landing north of New York and South of North Carolina (non-Shrimp Fishery related) discarded no Atlantic croaker0.

Ratios estimates and variances are in **Tables 4.25-4.26**. Discard estimates are in **Tables 4.27-4.28** and **Figure 4.20**. A discard mortality rate of 100% is assumed for both gillnet and trawl discards of Atlantic croaker and spot.

4.1.5 Commercial Catch Rates

Available effort data was insufficient (spatially and temporally) to calculate CPUE from the commercial fishery. Although some states ask harvesters to report additional information important for standardization such as the number of nets fished, length of nets, etc., that information has not been consistently provided and was considered unreliable.

5 FISHERY DEPENDENT DATA COLLECTION

5.1 Commercial Fisheries

5.1.1 Data Collection Methods

Commercial landings data are collected by the NMFS and individual state agencies. Federally permitted dealers and fishermen must report to the NMFS using the appropriate reporting process. Individual states may also have reporting requirements for dealers and commercial fishermen harvesting and/or landing in their state. The NMFS has collected commercial fisheries landings statistics since 1880 and has performed in-depth surveys of commercial fisheries landings of all coastal states since 1951. State fishery agencies obtain commercial landings data through voluntary and/or mandatory reporting and surveys. Commercial data are also collected by the Atlantic Coastal Cooperative Statistics Program (ACCSP) through the Standard Atlantic Fisheries Information System (SAFIS). In addition to SAFIS, commercial fisheries data collected through the other state and federal programs are submitted to the ACCSP. The ACCSP requires trip level reporting of specific data elements and provides quality assurance and quality control measures to ensure data are comparable and accurate (ACCSP 2004). For the current assessment, commercial landings data were obtained from the ACCSP Data Warehouse and, in three cases, from individual state reports. The types of information and level of detail collected varies among and within the NMFS and various state programs. Commercial landings by gear are available for all states for 1950 through 2014.

5.1.2 State Methods

New Jersey

New Jersey relies on the NMFS for collecting commercial landings data.

Delaware

Delaware requires commercial fishermen to complete monthly logbook reports that detail daily effort and harvest. Federally-licensed fish dealers in Delaware report their Atlantic croaker purchases, but there is no reporting requirement for state-licensed fish dealers.

Maryland

Maryland DNR has a mandatory reporting system for commercial fishermen that began in 1980. Catch in pounds, days fished, area fished and amount and type of gear used were reported by month prior to 2006. A daily trip log was phased in from 2002 to 2005 with all fishermen using the daily log for the entire year beginning in 2006. Effort data is only available for 1980-1984, 1990 and 1992 – 2014. Maryland relied on the NMFS for collecting commercial landing data prior to 1980.

Potomac River Fisheries Commission

In 1964, the Potomac River Fisheries Commission (PRFC) required commercial fishermen to report daily fishing activity on a monthly basis. Since 1991, the PRFC has mandated that fishermen submit the daily activity reports every week. From 1964 through 1979, the PRFC sent the commercial harvest reports to the NMFS in Easton, Maryland to be summarized. Those reports were published in a NMFS monthly landing bulletin along with Maryland and Virginia data. After the office in Easton closed, the NMFS office in Hampton, Virginia collected the PRFC commercial harvest data. The PRFC now sends their data to the Virginia Marine Resources Commission (VMRC), which then forwards the data to the NMFS.

Virginia

The VMRC's commercial fisheries records include information on both commercial harvest (fish caught and kept from an area) and landings (fish offloaded at a dock) in Virginia. Records of fish harvested from federal waters and landed in Virginia have been provided by the NMFS and its predecessors since 1929 (NMFS, pers. comm.). The VMRC began collecting voluntary reports of commercial landings from seafood buyers in 1973. A mandatory harvester reporting system was initiated in 1993 and collects trip-level data on harvest and landings within Virginia waters. Data collected from the mandatory reporting program are considered reliable starting in 1994, the year after the pilot year of program.

North Carolina

Prior to 1978, the NMFS collected commercial landings data for North Carolina. In 1978, the North Carolina Division of Marine Fisheries (NCDMF) entered into a cooperative program with the NMFS to maintain the monthly surveys of North Carolina's major commercial seafood dealers and to obtain data from more dealers. North Carolina initiated a Trip Ticket Program in January, 1994, in response to a decrease in the NCDMF/NMFS cooperative reporting and due to an increase in demand for complete and accurate trip-level commercial landings statistics by fisheries managers. A trip ticket is a form used by state-licensed fish dealers to document all transfers of fish from the fishermen to the dealer. These forms collect information such as transaction date, area fished, gear used, and the quantity of each species landed. The data obtained through the North Carolina Trip Ticket Program allow for the calculation of fishery-specific effort (i.e., trips, licenses, participants, vessels) and provide a more detailed record of North Carolina's seafood landings. Beginning in 1994, the NCDMF instituted a trip-ticket system to track commercial landings. Total catch by gear, area, and market category are used to expand these data

South Carolina

Landings of Atlantic croaker in South Carolina were collected by the NMFS through the early 1980s. In 2003, South Carolina instituted a wholesale dealer reporting system that provides monthly summaries from wholesale dealers with weight (and value) of fish purchased per species per month. Historically, lengths and otoliths were not collected from commercial fisheries; however, this program is part of the NMFS Trip Interview Program (TIP), and Atlantic croaker was recently added to the NMFS TIP target species list, so SC port samplers started collecting biological samples in 2009, however only limited data was available for this assessment. Atlantic croaker landed as bycatch from the shrimp trawl fishery are also reported through the wholesale dealer reporting system.

Georgia

In 1989, Georgia instituted mandatory trip-level reporting for commercial fisheries dealers and fishermen. Georgia's estimates of Atlantic croaker landings are questionable since they are landed by trawls and sold as unsorted mixed fish along with spot, whiting, and small flounder.

Florida

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

5.1.3 Sampling Intensity and Potential Biases

Daily or trip-level commercial landings data are currently collected in most of the states within the ASMFC management region. Commercial fishermen are required to report daily or trip-level activity in Delaware, Maryland, the PRFC jurisdiction, Virginia, and Georgia. In North Carolina, South Carolina, Georgia, and Florida, dealers must report trip-level data. There are no reporting requirements for commercial fisheries in New Jersey. For a number of states, the method of collecting commercial fisheries data has changed over time (see Section 5.1.2, this report). Within these states, data may not be comparable before and after the methodology changed. Other data limitations vary by state.

5.1.4 Biological Sampling

Several states have sampling programs that collect biological samples from their commercial fisheries. An overview of these sampling programs is provided below.

There are distinct seasonal and gear differences (selectivity) among the Atlantic croaker commercial fisheries. Because of these differences and the rapid growth of Atlantic croaker, commercial samples should be collected from each of the major gears throughout the year.

Market-grade landings of Atlantic croaker comprise only a portion of the total Atlantic croaker catch. The sampling programs described below, generally, do not collect biological samples from commercial catch that is discarded at sea (e.g., bycatch in shrimp trawls). However, there is some limited length data from North Carolina commercial fisheries as well as biological samples from bait/scrap fisheries also available from North Carolina.

New Jersey

New Jersey initiated biological monitoring of commercially landed Atlantic croaker in 2006, partly supported with funding from the ACCSP. Annual sampling of the trawl and gill-net fisheries is conducted primarily from August through October along the New Jersey coast in Belford, Point Pleasant, Barnegat Light, and Cape May. Total length (mm), weight (kg), gear type, and location are recorded. Otoliths are collected for age determination and processed using the protocol from the ASMFC's Atlantic croaker age workshop (ASMFC 2008).

Maryland

Commercial pound nets were sampled in Maryland's portion of Chesapeake Bay, and in the mouths of its major tributaries, from the Patuxent River south to the Potomac River. Sampling locations varied each year depending on where the cooperating fishermen's nets were set. The survey has been conducted every year from 1993 to 2014 from Late May to early September. Each site was generally sampled once every two weeks, weather and fisherman's schedule permitting. The commercial fishermen set all nets sampled as part of their regular fishing routine. Net soak time and manner in which they were fished were consistent with the fishermen's day-to-day operations. All Atlantic croaker, regardless of whether they were of legal size (9 inches), were measured from commercial pound nets, when possible. In instances when it was not practical to measure all fish, a random sample was measured and the remaining individuals enumerated. Total length was measured to the nearest millimeter. Otoliths and sex were taken from a sub sample of Atlantic croaker.

Virginia

In Virginia, staff from the Virginia Marine Resources Commission (VMRC) sample Atlantic croaker commercial landings from 50-pound boxes of the graded catch obtained at seafood dealers and buyers. Atlantic croaker are measured for TL in millimeters and weighed to the nearest 0.1 pound. Market category, harvest area, gear type, and total catch are noted. Beginning in 1998, samples have been purchased to excise otoliths for age determination. All ageing work (processing and reading) is performed at Old Dominion University's (ODU) Center for Quantitative Fisheries Ecology (CQFE).

North Carolina

The North Carolina Division of Marine Fisheries (NCDMF) has sampled major commercial fisheries since 1982. Atlantic croaker are sampled by gear, market category (in culled catches only), and area fished at local fish houses. Fish are measured for TL to the nearest millimeter and sample weights, as well as total weights, are taken to expand the sample data to the entire landings. Subsamples of Atlantic croaker are purchased from the major commercial fisheries to excise otoliths for age determination.

The NCDMF initiated sampling of scrap fish in 1986. The NCDMF defines scrap fish as those fish not marketed for human consumption and instead sold for bait, industrial use, or discarded. Staff samples at least one-half basket (~12 kg) of the scrap fish from each catch. The sample is sorted by species and weighed (kg). All individuals in the sample are measured for FL or TL to the nearest millimeter. If the catch of a particular species is exceptionally large, a random subsample of at least 30 individuals is taken for measurement, and the remaining fish are counted. The total weight of each species in the scrap fish samples is calculated by determining the proportion of that species in the subsample and expanding to the respective species' proportional weight of the total scrap fish for the trip. The number of individuals per species in the scrap fish component is calculated by expanding the number of individuals in the sample to represent the total weight of the species for the scrap fish in the samples. Estimates of total scrap fish landings for individual species are determined by applying the tri-annual ratio of marketable fish to scrap fish in the fish house samples to the reported tri-annual marketable landings. The quantity (weight or numbers) and percentage of scrap fish (total or by species) landed by the fishery was determined by applying the seasonal (6 month periods) weight ratio of marketable fish to scrap fish in the fish house samples to the reported seasonal marketable landings from the NCTTP. The estimated scrap fish quantity is for landed fish and does not account for discards at sea. The reported commercial landings of scrap fish (unclassified for scrap or industrial purposes) from the NCTTP were not used because of inconsistencies in dealer reporting. This ratio method of estimating scrap fish assumes marketable fish are accurately collected by the NCTTP. The percent scrap fish reported was computed on a per sampled trip basis, i.e. the percent scrap fish for each sampled trip was determined and the mean was taken across all trips, thereby accounting for sampled trips with no scrap fish. Each sampled catch was viewed as an independent estimate of scrap fish.

South Carolina

South Carolina port agents collect lengths and otoliths from a number of species as part of their commercial fisheries monitoring program. Otoliths, when they have been collected, were processed and read by SCDNR staff. Atlantic croaker were collected occasionally but were not a species with a very high intercept rate annually so available data was very limited.

Georgia

The Marine Sportfish Carcass Recovery Project, a partnership with recreational anglers along the Georgia coast, was used to collect biological data from finfish such as red drum, spotted seatrout, southern flounder, sheepshead, and southern kingfish. Chest freezers were located at public access points along the Georgia coast. Each freezer was clearly marked and contained a supply of plastic bags, pencils, and data cards. Anglers placed their filleted fish carcasses in plastic bags along with completed data card in the freezer. Personnel at the Coastal Resources Division collected the carcasses and processed them to determine species, length, sex, and maturity stage when possible. Sagittal otoliths were removed and processed to determine the age of the fish. In 2014, a total of 3,659 fish carcasses were donated through this program. Even though not on the list of requested species, there were 4 Atlantic croaker donated in 2014.

Florida

Florida collects sample lengths from the commercial fisheries and, when opportunity allows, collects weights of Atlantic croaker intercepted through a Trip Interview Program (TIP) at fish houses. While Atlantic croaker is included on the list of species to be sampled, they are only sampled "as available" due to its low priority and the small amounts that are generally landed. These data are available from 1991 through 2008.

5.2 Northeast Fisheries Observer Program (NEFOP)

5.2.1 Survey Methods

The Northeast Fisheries Observer Program (NEFOP) is conducted by the NMFS' Northeast Fisheries Science Center (NEFSC) in order to collect data on catch (landed and discarded), gear, effort, and biological data during commercial fishing trips from NC-ME by trained fishery observers. The total catch and a subsample of the total catch from each observation (e.g., towed trawl net) are weighed. The observer program is mandatory for federally permitted vessels which are selected at random for observation during fishing trips. The program began in 1989. Atlantic croaker is a second tier priority species for Mid-Atlantic gillnet sampling and a third tier priority for Mid-Atlantic inshore trawl sampling (NEFSC 2016). See the NEFOP website for additional details (http://nefsc.noaa.gov/fsb/program.html).

5.2.2 Biological Sampling

Each fish from the catch subsample was counted and measured to the nearest centimeter. The biological sampling program has a target of 100 lengths per sampling area for this species in its priority regions. Length sampling of discarded Atlantic croaker is summarized in **Table 5.1**. There was a bimodal distribution of Atlantic croaker discarded from gillnets and a unimodal distribution of Atlantic croaker discarded from trawls (**Figure 4.18** and **Figure 4.19**).

No Atlantic croaker age samples have been collected by NEFOP.

5.3 Georgia Shrimp Trawl Observer Program

5.3.1 Survey Methods

The Large Shrimp Trawl Bycatch Observer Study was conducted over a six year period from 1995 to 1998 and 2001 to 2005. The purpose of the study was to gather bycatch information associated with the shrimp trawl fishery. All NMFS protocols for observer bycatch studies were observed (NMFS 1992). A total of 185 tows were sampled aboard 129 individual trips. Field sampling was conducted on-board commercial shrimp trawling trips in the offshore state waters and in the EEZ off Georgia (beaches extending to 7 miles offshore), targeting selected species to characterize size, age, and genetic structuring, as well as providing estimates of catch rates by season. After gaining permission from the captains of these vessels, two on-board observers accompanied the captain and crew on a trip. The observers recorded information on each vessel including the vessel code, tow number, date, vessel name, length, identification number, year model, construction, weight, horsepower, and crew size. In addition, records of the economic costs of the trip, such as fuel, oil, ice, food and wages were documented. The type of net used in each application was noted and the specifications on each Turtle Excluding Device (TED) and BRDs were recorded. Just prior to deploying the net, the observers recorded the latitude and longitude and the time of day. After completing the tow, the observers again recorded the latitude and longitude as well as the exact time the net was removed from the water. The shrimp, crabs, and fish were then sorted into different groups for examination. The shrimp were weighed and their numbers were estimated when necessary. The fish and crabs were counted and weighed by species. Length measurements were recorded for the fish depending on species.

5.3.2 Biological Sampling

For the core target species, which includes weakfish, Atlantic croaker, and spot lengths were recorded for every specimen, while age and genetic samples were collected from a predetermined number of the samples. The lengths for all secondary target species, which include kingfishes (*Menticirrhus* spp.), paralichthid flounders (*Paralichthys* spp.), mackerels (*Scomberomorous* spp.), menhadens (*Brevoonia* spp.), bluefish, sturgeons (*Acipenser* spp.), and other seatrouts (*Cynoscion* spp.) were also recorded. For all other fish species, the largest and smallest specimen were measured to provide the observers with a range for the sample (Ottley et al. 1998). Otoliths and fin clippings obtained from core target species were sent to the South Carolina Department of Natural Resources for age and genetic analysis.

5.4 Southeast Shrimp Trawl Observer Program

5.4.1 Survey Methods

A voluntary shrimp trawl bycatch observer program was implemented in the South Atlantic (NC-FL) through a cooperative agreement between NOAA Fisheries, the Gulf and South Atlantic Fishery Management Councils, and the Gulf and South Atlantic Fisheries Foundation, Inc. to characterize catch and bycatch, as well as evaluate BRDs. Total catch, total shrimp catch, and a subsample (one basket per net, or approximately 32 kg) for species composition is taken from each observed net. Beginning in 2008, the program became mandatory in the South Atlantic and NMFS-approved observers were placed on randomly selected shrimp vessels. The voluntary component of the observer program also continued. Penaeid shrimp (primarily inshore) and rock shrimp (primarily offshore) fisheries in the South Atlantic are covered by the observer program. Observed coverage is allocated by previous effort, or shrimp landings when effort data are not available. Based on nominal industry sea days, observer coverage of South Atlantic shrimp trawl fisheries ranged from 0.2-1.4% and totaled 0.9% from 2007-2010 (see Scott-Denton (2012) Table 1). Number of observed tows are in **Table 5.2**. See Scott-Denton (2007) for more details on the voluntary component of the Shrimp Trawl Observer Program and Scott-Denton et al. (2012) for more details on the mandatory Shrimp Trawl Observer Program.

5.4.2 Biological Sampling

Biological information, such as length and weight of bycatch species, was collected from the subsample of total catch in observed nets. Very limited biological sampling has been conducted for Atlantic croaker. Only 1,343 Atlantic croaker were measured for length, caught from just thirty sex tows on two trips occurring from October to November in 2003. Lengths ranged from 10 to 29 cm TL (**Figure 4.9**).

No Atlantic croaker age samples have been collected by the Southeast Shrimp Trawl Observer Program.

5.4.3 Trends

Atlantic croaker are typically one of the most prevalent bycatch species, often outweighing and/or outnumbering individual species of shrimp (see Scott-Denton (2007) Figure 9, Figure 11, Table A2 and Scott-Denton (2012) Table 9, Table 11, Table 12, Figure 6). Discard rates have been variable, but have generally decreased over the time series (**Figure 4.17**).

5.5 South Atlantic Shrimp System (SASS)

5.5.1 Survey Methods

Detailed catch and effort statistics from individual commercial shrimp fishing trips were collected and processed by a cooperative effort between the South Atlantic states (NC-FL) and, beginning in 1982, the NMFS' Southeast Fisheries Science Center (SEFSC). Data collection began in 1978 in North Carolina and Georgia, 1979 in South Carolina, and 1981 in Florida. Data are available by year, month, state, and port. Florida and North Carolina quit collecting data for the SASS after 1992. The data are maintained by the NMFS. See Gloeckner (2014) for more details on the SASS.

5.6 Recreational

Recreational anglers target Atlantic croaker by bottom fishing and chumming with shrimp, clams, worms, cut fish, and soft or peeler crabs. Atlantic croaker are also caught and retained by recreational anglers targeting other species.

Statistics for recreational total catch, catch size composition, and effort were provided by the Marine Recreational Fisheries Statistics Survey (MRFSS) from 1981-2006, Marine Recreational Information Program (MRIP) from 2007-2014, and the Southeast Region Headboat Survey (SERHS) from 1981-2014. Additional recreational fishery data have been collected by several state monitoring programs (SCDNR, GADNR, VMRC).

5.6.1 Marine Recreational Fisheries Statistics Survey (MRFSS) and Marine Recreational Information Program (MRIP)

Estimates of Atlantic coastal recreational fishing effort (angler hours, number of trips), harvest in numbers and weight, numbers of fish released alive, and catch size composition from 1981-2003 are from the MRFSS and estimates from 2007-2014 are from the MRIP which replaced the MRFSS in 2007.

5.6.1.1 Data Collection and Treatment

5.6.1.1.1 Survey Methods

Data are collected in independent, complementary surveys. The Access Point Angler Intercept Survey (APAIS) and at-sea sampling are designed to collect catch rate data and biological samples. The Coastal Household Telephone Survey (CHTS) and For-Hire Survey (FHS) are designed to collect effort data. Data from the surveys are combined to generate estimates. Angler participation in the MRIP surveys is voluntary. An overview of these surveys from the MRIP website (http://www.st.nmfs.noaa.gov/recreational-fisheries/index) is provided below. See the website and data user handbook at (http://www.st.nmfs.noaa.gov/recreational-fisheries/MRIP-Handbook/MRIP_handbook.pdf) for additional details.

Catch Rate Surveys
APAIS conducts interviews of intercepted anglers at public fishing access sites (e.g., marinas, piers) that collect information on area(s) fished, catch, and angler participation during recreational fishing trip (example questionnaires are available on the MRIP website). Stratified random sampling is used to select access sites in a site registry. Sampling is stratified by state (FL-ME), fishing mode, and wave (i.e., bimonthly period). The four fishing modes for stratifying sampling are private boats (including rentals), shoreline (e.g., pier, jetty, etc.), charter boats, and headboats (i.e., party boats). The charter boat and headboat modes were combined as one mode from 1981-1985 and 1981-2003 in the South Atlantic (NC-FL) and north of NC, respectively, before being split into separate modes. Headboat anglers from NC-FL have not been sampled through APAIS since 1985; data from these anglers are collected by the SERHS (see section 5.22 SERHS). Headboat anglers north of NC were not sampled by the APAIS after 2004. Since 2005, catch has been sampled during ride-along, at-sea sampling. Sampling is conducted in six waves, each wave being two consecutive calendar months starting with wave 1 (January and February) and ending with wave 6 (November and December). Sample allocation by wave has varied over time but generally covers all six waves in FL, with the exception of wave 1 in 1981, all six waves in NC since 1989, waves 2-6 from GA-MA, and waves 2-5 from NH-ME. Sampling before 2013 was primarily done during peak daylight hours. In 2013, sampling was allocated to cover non-peak hours. Sampling is post-stratified into marine water areas based on the primary area fished during trips, as reported by anglers. Areas include inshore coastal waters (e.g., bays and tidal rivers), state territorial seas (0-3 miles from the coast), and the federal exclusive economic zone (EEZ, >3-200 miles from the coast).

The number of Atlantic croaker caught during a trip is recorded as harvested fish observed by the interviewer in whole form (type A catch), fish reported as harvested by the angler but not observed by the interviewer (i.e., bait, filleted, discarded dead on headboats; type B1 catch), and fish reported as released alive (type B2 catch).

Effort Surveys
The CHTS is a stratified random digit dialing telephone survey that includes only households in coastal counties (generally counties within 25-50 miles of coastline, depending on state). The CHTS is stratified by county and wave. Sampling is conducted over a two-week period at the end of each wave (last week of the wave and first week of the next wave) and is allocated proportional to county population. The number of telephone interviews conducted during each wave varies based on the amount of fishing activity expected for the season (NMFS, pers. comm.). Specifically, the Section B, Page 29 allocation is based on the ratio of the square root of the population within each county to the sum of the square roots of all county populations

within the state. Information is collected on the number of trips in the previous wave and details about those trips (example questionnaires are available on the MRIP website).

Evaluation of the CHTS found that for-hire modes (headboat and charter boat) were being underrepresented due to the nature of these fisheries (e.g., out of state clients). Beginning in 2005, angler effort on charter boats and headboats from ports north of North Carolina has been sampled through the For-Hire Survey (FHS) and several overlapping sampling programs, replacing the CHTS for for-hire modes. The FHS is also a random digit dial telephone survey that uses a vessel directory as a sampling frame. Other overlapping programs include the Vessel Trip Report (VTR) Program for New Jersey through Virginia (census logbook) and various state logbook programs.

5.6.1.1.2 Biological Sampling Methods

Length and weight measurements are obtained from type A catch encountered during APAIS intercepts to develop harvest size composition (numbers-at-length) and harvest estimates in weight. Length measurements are FL to the nearest millimeter and weight measurements are to the nearest tenth of a kilogram. Lengths used for the assessment analysis were converted to TL. Information on sample sizes was retrieved from the MRIP and MRFSS raw intercept files. **Table 5.3** include Atlantic croaker length and weight sample sizes obtained during APAIS sampling by year.

Beginning in 2004, length measurements have been obtained from type B2 catch encountered during at-sea sampling of headboats (type 9 samples). Sample sizes by year and state are in **Table 5.4**.

While no age samples (e.g., otoliths) were collected during APAIS sampling or at-sea sampling of headboats, some of the states (VA and SC) do collect a handful of recreational samples annually.

5.6.1.1.3 Catch Estimation Methods

Effort data from the CHTS and FHS are combined with U.S. Bureau of Census data on population size to estimate the total number of trips in a stratum. The estimated number of trips in a stratum are applied to the Atlantic croaker catch-per-trip for each catch type from APAIS intercepts and at-sea sampling in a stratum to obtain stratum catch estimates. Estimates are summed across strata for total number of Atlantic croaker harvested (A+B1), released alive (B2), or caught (A+B1+B2).

Mean weight of Atlantic croaker weighed during APAIS intercepts for a stratum are applied to the number of harvested Atlantic croaker in the stratum to obtain estimates of harvest in weight. The mean weight of type B1 catch in each stratum is assumed to be the same as type A catch in the stratum. Some strata prior to 2004 have zero harvest estimates in weight and positive harvest estimates in numbers, biasing the weight estimates low. This occurred if all intercepted, harvested fish for the stratum were type B1 catch or if interviewers were unable to obtain weight measurements for type A catch. MRIP methods of imputation using length-weight relationships have been used for addressing missing harvest estimates in weight and there are no strata with missing estimates after 2003. Thirty-three strata had zero weight estimates with positive number estimates. To estimate harvest in weight for these strata, individual weight observations for APAIS intercepts were pooled from surrounding strata until a threshold sample size was obtained (n=20). Samples were pooled over areas, followed by modes, states within sub-region (Mid-Atlantic or South Atlantic), and finally waves until the threshold sample size was reached. The SASC used this pooling hierarchy so that an adequate sample size could be attained starting from localized areas through modes and states and up to the regional level (if necessary). Mean weights were calculated and applied to the stratum harvest number estimate to estimate harvest weight. Numbers of harvest weight estimates by pooling level are in **Table 5.5**. The original estimate of harvest in numbers, the mean weight from pooling, and the new estimate of harvest in weight are in **Table 5.6**.

The proportions of Atlantic croaker measured for length in 1 cm length bins in each stratum are applied to the total number of Atlantic croaker harvested in the stratum to obtain size composition estimates of the harvest in numbers. A custom request was made through MRIP to provide annual size compositions of fish released alive estimated from type 9 length samples collected on headboats. SAS code using the MRIP weighted estimation methodology was provided and annual estimates were generated for years when data were available (2004-2014). These size composition estimates were assumed representative of and used as a proxy for total recreational releases.

Catch estimate provided by MRFSS and MRIP through the MRIP online data query (NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.) were adjusted for survey design changes through time, according to recommendation by Carmichael and Van Voorhees (2014) and the SEDAR Best Practice Workshop (SEDAR 2016). Adjustments were made by (1) calibrating estimates generated from APAIS intercepts during peak daylight hours only and the MRIP estimation methodology (2004-2012) to 2013 estimates generated from APAIS data collected during peak and non-peak hours and the MRIP estimation methodology, (2) calibrating for-hire estimates generated from CHTS effort data to fire-hire estimates generated from FHS effort data (years are state-specific), and, subsequently, (3) calibrating estimates generated from the MRFSS estimation methodology (1981-2003) to estimates generated from the MRIP estimation methodology (2004-2014). MRFSS estimates from 2004-2007 are already re-estimated with the new estimation methodology when estimates are provided. The combination of for-hire modes from 1981-1985 in the South Atlantic requires splitting the MRFSS estimates into headboat estimates and charter boat estimates so headboat estimates are not double counted when using the preferred SERHS estimates in these years. However, due to the negligible catch estimates from the SERHS (**Table 4.2** harvest, **Tables 4.3** releases, section 5.2.2), MRFSS for-hire catch estimates from NC-FL during 1981-1985 were assumed to be from charter boats.

Recommendations of Carmichael and Van Voorhees (2014) were followed to calibrate catch estimates for the change in APAIS intercept timing. A ratio of 2013 catch estimated with intercept data from peak hours sampled for prior years up to 2013 estimated catch with intercept data from all hours sampled in 2013 was applied to catch estimates from 2004-2012. Ratios were developed at the mode and state level. If a threshold number of intercepts (n=30) were not available at this level, pooling was done until the threshold was reached. Pooling was done by collapsing over states within a sub-region, followed by collapsing over species within a state, followed by collapsing over species and states within a sub-region. If the threshold was still not reached, no adjustments were made to original estimates. Headboat estimates provided by MRIP (i.e., north of NC) were not adjusted because catch rates are developed from at-sea sampling and that sampling design did not change (personal communication from the MRIP, March 29 2016). Catch estimates by pooling levels are in **Tables 5.7** and **5.8**. The range of ratios for harvest number estimates was 1-4.85 with a mean of 1.61. The range of ratios for harvest weight estimates was 1-8.65 with a mean of 1.66. The range of ratios for released alive estimates was 1-4.70 with a mean of 1.75. For-hire catch estimates from NC-FL during 1981-1985 were calibrated using conversion factors (i.e., ratios of effort estimates) developed by Matter et al. (2012), estimates from NC-FL during 1986-2002 were calibrated using conversion factors developed by SEDAR (2011), and estimates from NY-VA during 1981-2003 were calibrated using conversion factors developed by SEDAR (2008). Estimates were calibrated for the change in estimation methodology according to recommendations of Salz et al. (2012). A ratio of mean catch estimates generated from the two estimation methodologies (i.e., MRIP:MRFSS) during overlapping years (2004-2014) was applied to the MRFSS estimates from 1981-2003. Estimates using the MRFSS estimation methodology were queried from the ACCSP Data Warehouse. Ratios were developed at the broadest scale appropriate for the stock unit (i.e., coast-wide), to avoid a deterioration in precision (Salz et al. 2012).

There is a pending change in effort surveys, with the CHTS to be replaced by a mail-based effort survey, but data were not available for this assessment to calibrate estimates generated from CHTS effort data to estimates generated from the new mail effort survey. These data are anticipated sometime in 2018 and should be considered for future updates of this assessment.

5.6.1.2 Trends

5.6.1.2.1 Recreational Catch Rates (CPUE)

Catch rates were not developed from MRFSS and MRIP data for modeling due to the availability of several regional fishery-independent surveys and common issues with fishery-dependent CPUE (i.e., identification of unsuccessful effort and hyperstability).

5.6.1.2.2 Recreational Harvest

5.7.1.2.2.1 Total Harvest

Harvest was generally the primary component of MRFSS coast-wide recreational catch through the 1980s, but has been equal to or less than live releases since the mid-1990s (Figure 4.22). Harvest has averaged 50% of annual catch from 1981-2014. Along the Atlantic coast, annual recreational harvest of Atlantic croaker has ranged from a low of 4.292 million fish in 1981 to a high of 20.572 million fish in 2001, during 1981 through 2014 (**Table 5.9, Figure 5.1**). The harvest generally increased through the 1980s and 1990s, before decreasing from the peak harvest in 2001. In terms of weight, recreational harvest has ranged from 952 metric tons in 1981 to 7,981 metric tons in 2001 (**Table 5.10, Figure 5.2**). Recreational harvest in 2014 was 6.271 million fish, or 1,405 metric tons. The final, adjusted estimates (see section 5.7.1.1.3) follow the same trend as the original estimates but are scaled up, on average, by about 4.2 million fish or 1,314 metric tons (**Figures 5.3 and 5.4**).

The majority of the Atlantic croaker recreational harvest was taken in Virginia (**Tables 5.9-5.10; Figure 5.5**), followed by Maryland, North Carolina, New Jersey, and Florida. Other states harvest relatively few Atlantic croaker.

The majority of Atlantic croaker recreational harvest was taken during waves three and four (May-August; **Figures 5.6**) by private or rental boat anglers (**Figure 5.7**). The majority of Atlantic croaker were harvested from inshore waters (**Figure 5.8**).

5.7.1.2.2.2 Harvest Size Composition

The lengths of Atlantic croaker harvested by recreational anglers along the Atlantic coast have varied between 2-54 cm TL (**Figure 5.9**). The average TL of Atlantic croaker harvested recreationally has ranged from a low of 20.3 cm TL in 1983 to a high of 28.5 cm TL in 2006 (**Figure 5.10**). The length-frequency distributions and annual average lengths demonstrated a slightly increasing trend in the length of recreationally harvested Atlantic croaker during the early to mid-2000s.

5.6.1.2.3 Recreational Releases

5.7.1.2.3.1 Total Releases

The estimated number of Atlantic croaker released alive by recreational anglers has followed a trend similar to harvest, ranging from a low of 1.774 million fish in 1982 to a high of 26.398 million fish in 2000 with a long term mean of 13.501 million fish (**Table 5.11, Figure 5.11**). Recreational releases in 2014 were estimated at 9.981 million fish. The final, adjusted estimates follow the same trend as the original estimates but are scaled up, on average, by about 4.8 million fish.

Released alive estimates break down similarly to harvest estimates. The majority of fish released alive were captured in VA (**Figure 5.12**), during waves 3-4 (**Figure 5.13**), by private or rental boat anglers (**Figure 5.14**). The majority of fish released alive throughout the time series were caught in inshore waters (**Figure 5.15**).

Fifteen percent of fish released alive were assumed to die post-release as result of factors such as hooking related injuries and improper handling (life history section 2.4.2; **Table 5.12**).

5.7.1.2.3.2 Release Size Composition

The only sources of biological data characterizing fish released by recreational anglers are the MRIP at-sea headboat survey (2005–present) and Maryland's headboat sampling program (1997–2000). The Maryland survey was an onboard head boat creel survey conducted from 1997-2000 from June through September. The survey focused on Atlantic croaker, spot, and weakfish. Anglers were queried as to whether or not they would like to participate in the survey. Each creel clerk surveyed a maximum of six anglers. Total fishing time was determined from the time fishing began until the lines were removed at the last fishing location. All Atlantic croaker caught by participating anglers were measured to the nearest mm TL and whether it was harvested or released was recorded.

Annual length frequencies of Atlantic croaker released alive by headboat anglers estimated from type 9 biological sampling are in **Figure 5.16.** The MRIP headboat live releases of Atlantic croaker ranged in length from 10 to 32 cm TL during 2005 to 2014. Atlantic croaker sampled from headboat harvest by the MRIP ranged from 9 to 30 cm TL during the same years.

Maryland's headboat survey samples both harvested and released fish. The lengths of Atlantic croaker releases sampled in the Maryland headboat survey ranged from 13.0 to 28.1 cm TL during 1997 to 2000 (**Figure 5.17**). Samples of fish harvested by Maryland headboats ranged from 15.8 to 46.7 cm TL.

The 2010 Atlantic croaker stock assessment (ASMFC 2010) showed comparisons of the length-frequency distributions of harvested and released Atlantic croaker collected from headboats by the MRIP and Maryland surveys during the years where they overlapped demonstrating that the released fish are smaller than harvested fish (ASMFC 2010: Fig. 5.2.2.4, p.116 (MRIP) and Fig. 5.2.3.1, p. 117 (MD)). The Kolmogorov-Smirnov two-sample test was used to test the null hypothesis that fish harvested and released from recreational headboats have identical length-frequency distributions against the one-sided alternative that the length-frequency distribution of fish released from headboats is less than the length-frequency distribution of fish harvested by headboats (Steel et al. 1997). Comparisons were made by year within each dataset (MRIP headboat samples: 2005–2008; Maryland headboat survey: 1997–2000). For each year tested within each dataset, the null hypothesis was rejected ($P<0.001$) in favor of the alternative; that is, Atlantic croaker released from recreational headboats are smaller than Atlantic croaker harvested by recreational headboats. These results suggest that recreational anglers are discarding smaller fish.

5.6.1.3 Potential Biases, Uncertainty, and Measures of Precision

The MRIP estimates are based on a stratified random sampling design and so are designed to be unbiased. The proportional standard error (PSE) is provided with MRFSS and MRIP estimates as a measure of precision (**Tables 5.13-5.15**). The PSE is the percentage of the standard error relative to the catch estimate. PSEs of MRFSS estimates are calibrated similar to catch estimates to address the change in estimation methodology, but the PSE calibration accounts for the additional uncertainty from the estimate of the calibration factor (Salz et al. 2012). A workshop was conducted in 2014 to evaluate acceptable levels of precision for MRFSS and MRIP catch estimates through simulation (ACCSP 2016). PSEs for coast-wide catch estimates all fall in or below the general rule of thumb range (40-60%) proposed at this workshop for acceptable levels of precision, with the exception of some estimates in the 1980s (1981-1983 and 1986 for harvest number estimates, 1981-1984 and 1986 for harvest weight estimates, and 1981-1982 and 1985 for released alive estimates).

5.6.2 Southeast Region Headboat Survey (SERHS)

5.6.2.1 Data Collection and Treatment

5.6.2.1.1 Survey Methods

The SERHS estimates catch (harvest and releases) and effort and provides biological samples of harvested fish from trips on headboats in the South Atlantic (home ports from NC-FL). The SERHS began in the 1970s, but only data from 1981-2014 were provided. This matches the time series of the catch estimates from other modes of fishing provided by the MRFSS and MRIP. Estimates of released fish from the SERHS are only available since 2004.

There are two complementary components of the design for this survey. The first was designed as a census logbook program for captain self-reporting of total harvest in numbers and weight, total releases in numbers by disposition (alive, dead, or unknown), and effort on all headboat trips. The logbook program was originally voluntary, but became mandatory. Despite the mandatory nature of the program, there has been known non-reporting that has varied through time. The second component of the survey is intercepts of headboat anglers upon arrival at port following the trip to obtain biological samples from harvested fish. See Brennan (2010) for more details on the SERHS.

5.6.2.1.2 Biological Sampling Methods

Biological sampling is described as a systematic opportunistic sampling of harvest by vessels assigned to port agents. Port agents are instructed to focus on uncommon catches in attempts to collect sufficient sample sizes from all catch. Port agents attempt to sample all vessels they are assigned to proportionally and in a systematic rotation. Fish are measured and weighed and otoliths are collected for ageing.

Sample sizes of lengths and weights from Atlantic croaker from 1981-2014 are in **Table 5.16**. No age structures have been collected from Atlantic croaker.

5.6.2.1.3 Catch Estimation Methods

Catch was summed across headboat logbooks to provide total catch estimates. If necessary, port agents develop correction factors based on records of vessel activity and effort to adjust for non-reporting by applying correction factors to reported catch.

5.6.2.2 Trends

5.6.2.2.1 Recreational Catch Rates (CPUE)

Catch rates were not developed from SERHS data for modeling due to the availability of several regional fishery-independent surveys and common issues with fishery-dependent CPUE (i.e., identification of unsuccessful effort and hyperstability).

5.6.2.2.2 Recreational Total Harvest

Atlantic croaker are infrequently harvested on South Atlantic headboats and harvest estimates from this survey make a negligible contribution to total fishery removals. Only 5,505 Atlantic croaker were harvested from 1981-2014.

5.7.2.2.2.1 Harvest Size Composition

Due to limited biological sampling, total harvest size compositions were not developed.

5.6.2.2.3 Recreational Total Releases

Atlantic croaker are infrequently caught on south Atlantic headboats and dead release estimates from this survey make a negligible contribution to total fishery removals. Only 2,910 Atlantic croaker were caught and released from 2004-2014. All fish with unknown disposition and 15% of fish released alive were assumed to die post-release. Due to these negligible numbers during the available time series, releases from 1981-2014 were assumed to be zero (**Table 5.18**).

5.7.2.2.3.1 Release Size Composition

Due to limited biological sampling, total release size compositions were not developed.

5.6.2.3 Potential Biases, Uncertainty, and Measures of Precision

No measures of precision were provided with catch estimates.

5.6.3 Recreational Age Data

Annual sex-specific age compositions were available from the recreational fishery harvest for limited numbers and a limited number of years (1993, 1995, 1997, 2001–2004, 2006, 2008, 2011, 2013–2014) from only a few of the age data sets (VMRC, GADNR, SCDNR).

6 FISHERY INDEPENDENT DATA COLLECTION

The SASC reviewed and evaluated 43 fishery independent and dependent surveys for the development of abundance indices for Atlantic croaker (**Table 6.1**). For a more thorough description of the surveys or discussion about its inclusion or exclusion, please see Appendix 3 in the previous stock assessment (ASMFC 2010). Criteria were developed by the SASC for evaluating each survey to determine which should be included in this assessment either for its biological data or as an abundance index. The following criteria was used by the SASC to evaluate the surveys:

1. Time series is at least 17 years long, the age of the oldest Atlantic croaker in the data for this assessment.
2. Time series is continuous and there have been no changes in methodology or gear.
3. Survey operates within the Atlantic croaker geographic range at a time when the fish are typically occurring.
4. There are a high proportion of positive tows.

These criteria were used as a guide and when surveys were used to develop indices, the SASC then considered if the index is correlated with other indices, whether it provided a conflicting signal to other indices or the catch history, or the index was not representative of the stock unit. The six selected surveys and indices evaluated and used in this assessment are described in this section.

6.1 NMFS Northeast Fisheries Science Center Bottom Trawl Survey

6.1.1 Survey Design & Methods

In 1963, the National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) implemented a multispecies bottom trawl program, which surveys over a large portion of the Atlantic shelf (Avarovitz 1981; Grosslein 1969). The objective of the program is to monitor trends in abundance and distribution, characterize age/length structure, and better understand the biology and ecology of a wide array of finfish and invertebrate species. The survey uses a stratified random design, with strata based on depth (0.0–9.0 m; 9.0–18 m; 18–27 m; 27–55 m; 55–110 m; 110–188 m; 188–366 m). Both inshore and offshore strata are sampled. The autumn survey is an inshore survey that samples sites from Cape Hatteras to Cape Cod. The area within each stratum is subdivided into one-nautical mile blocks that are selected randomly prior to the sampling trip. The sampling gear is a #36 Yankee otter trawl rigged with rollers, 5-fathom legs, and 1,000- pound polyvalent door. A small-mesh cod-end liner (0.5-inch mesh) is used to retain YOY fish. Tow duration is 30 minutes.

6.1.2 Sampling Intensity

The fall component of the survey was initiated in 1963 but has been conducted consistently since 1972. There is also a spring survey (begun in 1968), however only the fall survey data was used for the assessment because Atlantic croaker are not caught regularly in the spring survey. Summer and winter surveys have been performed intermittently.

6.1.3 Biological and Environmental Sampling

The catch of each tow is identified, counted, weighed, and measured. When the catch of a particular species is large, a subsample of individuals is measured. Data on lengths, weight, sex, and maturity, were recorded. Otoliths were removed from a subsample of Atlantic croaker caught and later aged at the laboratory. Latitude, longitude, gear information, salinity, temperature, weather, and hydrographic parameters are recorded.

6.1.4 Ageing Methods

Otoliths collected from the NMFS survey were processed and aged by SCDNR using the same protocol from section 2.2.1.

6.1.5 Evaluation of Survey Data

Data collected from the fall component of the survey from 1972 onward were evaluated. An evaluation of the proportion of zero catches indicated that the occurrence of Atlantic croaker has been consistent throughout the duration of the survey. For the model time series in this assessment (1989-2014), this survey had 70% positive tows for Atlantic croaker. The survey encountered the population of Atlantic croaker most reliably during the fall months. The length-frequency distributions of Atlantic croaker suggest the survey has primarily encountered age-1 fish (**Figure 6.1**). Ages have been collected in the fall since 1997 and range from 0-13 years old (**Figure 6.2**), although most Atlantic croaker are ages 0-4. Early (≤ 8 cm TL) and late (mode at about 12–16 cm TL) age-0 Atlantic croaker were observed in some years (e.g., 1972, 1975, 1998, 1999, and 2001). These results are consistent with those documented by Lee (2005). The SASC supported developing an index from this data set because of the survey's design, ability to catch Atlantic croaker, long time series, and its geographic coverage.

6.1.6 Development of Estimates

Data from the fall months (September–November) were used to develop an index relative biomass (kilograms per tow) (**Table 6.2, Fig. 6.3**). Sampling frequency varied among years and NMFS strata, making it necessary to pool data across strata in order to generate comparable, non-biased metrics of abundance across years. In 2009 there was a change in the sampling protocol for both gear and vessel for the fall survey with the decommissioning of the RV Albatross and the transition to the the RV Bigelow for all future surveys. The RV Bigelow is not able to sample the nearshore strata due to the increased draft of this vessel and the midshore strata was not sampled as frequently. For continuity of sampling in the nearshore and midshore strata, these areas were taken over in 2008 by the Northeast Area Monitoring & Assessment Program (NEAMAP) trawl survey based out of the Virginia Institute of Marine Science (VIMS), Gloucester Point, VA. Annual estimates of the survey index for Atlantic croaker was re-formatted using only the outer offshore strata in order to maintain continuity and effective use of the entire time series (1972-2015). Additionally, stratified mean catch per unit effort (kg per tow) for the RV Bigelow for 2009 – 2015 were converted to RV Albatross equivalent units using reported species specific conversion factors from calibration experiments performed between the two vessels doing side by side tows in 2008 (Miller et al. 2010).

Pooling of the offshore strata resulted in 5 pooled strata arranged into five separated latitudinal regions (Region 1 = most northerly, Region 5 = most southerly).

6.1.7 Trends

The length frequency distribution has varied from 1989-2014 but the majority of Atlantic croaker caught in the fall component of the survey is between 18-24 cm TL (**Figure 6.1**) and most are ages 0-4 (**Figure 6.2**). The index of relative biomass developed from the fall months of the NMFS NEFSC survey shows low biomass from the 1970s through the mid-1990s (**Figure 6.3**). Biomass was then variable with some notable peaks in 1999-2000 and throughout the 2000s.

6.2 Virginia Institute of Marine Science Juvenile Trawl Survey

6.2.1 Survey Design and Methods

The Virginia Institute of Marine Science (VIMS) Juvenile Trawl Survey was implemented in 1955 to monitor the seasonal distribution and abundance of important finfish and invertebrate species occurring in the Chesapeake Bay and its tributaries. The main objective of this survey is to develop indices of relative abundance to track year-class strength of target species.

The survey sites and sampling frequency has not been consistent throughout the history of the survey (Tuckey and Fabrizio 2013). The survey currently employs a mixed design, incorporating both stratified random sites and fixed (historical mid-channel) sites. The stratification system is based on depth and latitudinal regions in the bay (random stations), or depth and longitudinal regions in the tributaries (random and fixed stations). Each bay region spans 15 latitudinal minutes and consists of six strata: western and eastern shore shallow (4–12 ft), western and eastern shoal (12–30 ft), central plain (30–42 ft), and deep channel (>42 ft). Each tributary is partitioned into four regions of approximately ten longitudinal minutes, with four depth strata in each (4–12 ft, 12–30 ft, 30–42 ft, and >42 ft). Strata are collapsed in areas where certain depths are limited. In each tributary, fixed stations are spaced at approximately 5-mile intervals from the river mouths up to the freshwater interface. Fixed sites are assigned to strata based on location and depth. The stratified random sites are selected randomly from the National Ocean Service's Chesapeake Bay bathymetric grid, a database of depth records measured or calculated at 15-cartographic-second intervals.

The trawl gear configuration has been modified a number of times, but was standardized in 1979. The various gear configurations have been compared through extensive sampling in order to standardize the catch rates associated with each gear combination. Currently, a 30-ft semi-balloon otter trawl is towed by the R/V *Fish Hawk* using a 60-ft bridle. The trawl is composed of 1.5-in stretch mesh body, a 0.25-in mesh cod end liner, two 28 in × 19 in steel china-v doors, and an attached tickler chain. Tows are made along the bottom during daylight hours for five minutes. The trawl doors were changed in 1991, but the change did not significantly alter the catch.

6.2.2 Sampling Intensity

Two to four sites are randomly selected for each bay stratum each month, and the number of sites varies seasonally. In shallow water strata, only one station is sampled per month. One to two stations are randomly selected for most river strata each month. Fixed stations are sampled monthly.

6.2.3 Biological and Environmental Sampling

The catch from each tow is sorted by species, and fish are enumerated and measured for length and all are released. Lengths are measured to the nearest millimeter using the length type appropriate for the morphology of each species. Random subsamples are taken when catches of a particular species are too large to process efficiently in the field.

Hydrographic and station data such as latitude and longitude, depth, tidal current stage, secchi depth, water temperature, salinity, and dissolved oxygen are also collected. Data characterizing the habitat or substrate type sampled by the trawl have been recorded since May 1998.

6.2.4 Ageing Methods

Ageing of Atlantic croaker by VIMS followed the protocol described in section 2.2.1.

6.2.5 Evaluation of Survey Design

Data collected from the spring months (April-June) from 1988-2014 was evaluated in order to develop an index of relative abundance for YOY Atlantic croaker. VIMS uses a length cutoff by month to determine YOY from age-1+ Atlantic croaker. The length cutoff for YOY is 11 cm in April, 13.5 cm in May, and 16 cm in June. All Chesapeake Bay and river stations were considered. Percent of tows with zero Atlantic croaker varied but on average for 1988-2014 the amount of positive tows was 29% for the spring months. Because this survey reliably catches YOY Atlantic croaker during spring months, has a relatively long time series, and uses a random sampling design, the SASC supported its use for developing an index of relative abundance.

6.2.6 Development of Estimates

Data from the spring months (April–June) were used to develop an index of relative abundance for Atlantic croaker (number per tow). The modified spring index (recommended by Woodward 2009) is calculated using a delta-lognormal model from catches of juvenile croaker less than 11 cm, 13.5 cm, and 16 cm TL in April, May, and June.
(**Table 6.2, Fig. 6.4**).

6.2.7 Trends

The index of relative YOY abundance developed from the VIMS survey shows low abundance in the mid-1990s and mid-2000s with some large peaks in 1997, 2009, and 2013 (**Figure 6.4**). The abundance has been more variable in the last few years of the survey, with large abundances followed by small values.

6.3 SEAMAP

6.3.1 Survey Design & Methods

The Southeast Area Monitoring and Assessment Program - South Atlantic (SEAMAP-SA) Coastal Survey (previously known as the Shallow Water Trawl Survey) began in 1986 and is conducted by the South Carolina Department of Natural Resources (SCDNR) Marine Resources Division (MRD). This survey has provided long-term, fisheries-independent data characterizing the seasonal abundance and biomass of all finfish, elasmobranchs, decapod and stomatopod crustaceans, sea turtles, horseshoe crabs, and cephalopods that are accessible by high-rise trawls. The sampling area extends from the coastal zone of the South Atlantic Bight (SAB) between Cape Hatteras, North Carolina, and Cape Canaveral, Florida (SEAMAP-South Atlantic Committee 2005). The survey uses a stratified random design, where strata are delineated by the 4-m depth contour inshore and the 10-m depth contour off shore. A total of 102 stations are sampled each season within 24 shallow water strata. The R/V Lady Lisa, a 23-m wooden-hulled, double-rigged, St. Augustine shrimp trawler owned and operated by the SCDNR, is used to tow paired 22.9-m mongoose-type Falcon trawl nets, without turtle excluder devices (TEDs). The body of the trawl is constructed of #15 twine with 47.6-mm stretch mesh. The cod end of the net is constructed of #30 twine with 41.3-mm stretch mesh and is protected by chafing gear of #84 twine with 10-cm stretch “scallop” mesh. A 91.4-m three-lead bridle is attached to each of a pair of wooden chain doors, which measure 3.0 m × 1.0 m and to a tongue centered on the headrope. The 26.3-m headrope, excluding the tongue, has one large (60 cm) Norwegian “polyball” float attached top center of the net between the end of the tongue and the tongue bridle cable and two 22.3-cm PVC foam floats located one-quarter of the distance from each end of the net webbing. A 1-ft chain drop-back is used to attach the 89-ft footrope to the trawl door. A 0.6-cm tickler chain, which is 0.9 m shorter than the combined length of the footrope and drop-back, is connected to the door alongside the footrope. Trawls are towed for twenty minutes, excluding wire-out and haul-back time, exclusively during daylight hours (1 hour after sunrise to 1 hour before sunset). Each net is processed separately and assigned a unique collection number.

6.3.2 Sampling Intensity

Multi-legged cruises are conducted in the spring (April–May), summer (July), and fall (October).

6.3.3 Biological and Environmental Sampling

After each tow, the contents of each net are sorted to species or genus, and the total biomass and number of individuals are recorded for all species of finfish, elasmobranchs, decapod and stomatopod crustaceans, cephalopods, sea turtles, xiphosurans, and cannonball jellies. Where a large number of individuals of a species occur in a tow, the entire catch is sorted and all individuals of that species are weighed; a random subsample is processed and the total number is estimated. For large trawl catches, the contents of each net are weighed prior to sorting and a randomly chosen subsample of the total catch is then sorted and processed. In every collection, each of the majority of priority species is weighed collectively and individuals were measured to the nearest centimeter. When a large number of individuals of any of the priority species are collected in a tow, a random subsample consisting of 30 to 50 individuals is weighed and measured

6.3.4 Ageing Methods

Gonad and otolith specimens were collected from Atlantic croaker during 2001 through 2014. Biological sampling was discontinued in 2007 due to insufficiency of allocated funds, but began again in 2008. Aging methods were the same as described in section 2.2.1.

6.3.5 Evaluation of Survey Data

The autumn component of the SEAMAP-SA Coastal Survey has been conducted consistently since 1990, so data collected from 1990 onward were evaluated. An evaluation of the proportion of zero tows indicates that the SEAMAP-SA Coastal Survey has regularly encountered Atlantic croaker in the spring, summer, and fall components of the survey. Zero tows have been most prevalent during the spring component of the survey. For all months sampled, zero tows accounted for 47% of all the tows although that number dropped to 39% of the tows when using only the fall months Throughout the year and also in the fall months, most Atlantic croaker caught in the survey were ages 0-1 (**Figure 6.5 and Figure 6.6**). The length frequency from the fall months (**Figure 6.7**) also indicated that the survey primarily caught ages 0 and 1. The SASC supported its development for an index since SEAMAP catches Atlantic croaker, is statistically designed, and covers an important geographic range. The SASC decided to use the fall component since that is when Atlantic croaker were most reliably caught.

6.3.6 Development of Estimates

An index of relative biomass (kilograms per tow) was calculated using data from the fall component (September- November) of the SEAMAP-SA Coastal Survey (**Table 6.2, Fig. 6.8**).

6.3.7 Trends

The index of relative biomass developed from the fall component of the SEAMAP survey shows a lot of annual variation, with the highest biomass occurring in 1991, 2005, and 2012, and lowest biomass occurring in 1997 and 2001 (**Figure 6.8**)

6.4 North Carolina Pamlico Sound Survey (Program 195)

6.4.1 Survey Design and Methods

The Pamlico Sound Survey, also known as Program 195 (P195), was initiated by the NCDMF in 1987 to provide a long-term, fisheries-independent database for the waters of the Pamlico Sound, eastern Albemarle Sound, and the lower Neuse and Pamlico rivers. The survey samples fifty-two randomly selected stations based on a grid system (one-minute by one-minute grid system equivalent to one square nautical mile). Sampling is stratified by depth and geographic area. Shallow water is considered water between 6 to 12 feet in depth and deep water is considered water greater than 12 feet in depth. The seven designated strata are: Neuse River; Pamlico River; Pungo River; Pamlico Sound east of Bluff Shoal, shallow and deep; and Pamlico Sound west of Bluff Shoal, shallow and deep. As of March 1989, the randomly selected stations have been optimally allocated among the strata based upon all the previous sampling in order to provide the most accurate abundance estimates (PSE < 20) for selected species. A minimum of three stations (replicates) are maintained in each stratum. A minimum of 104 stations are sampled each year to ensure maximum areal coverage. Tow duration is 20 minutes at 2.5 knots using the R/V Carolina Coast, which is equipped with double-rigged demersal mongoose trawls. The R/V Carolina Coast is a 44-ft fiberglass hulled double-rigged trawler owned and operated by the NCDMF. The body of the trawl is constructed of #9 twine with 47.6-mm stretch mesh. The cod end of the net is constructed of #30 twine with 38.1-mm stretch mesh. The tailbag is 80 meshes around and 80 meshes long (approximately 3.1 m). A 36.6-m three-lead bridle is attached to each of a pair of wooden chain doors that measure 1.22 m × 0.0610 m and to a tongue centered on the headrope. A 60-cm “polyball” is attached between the end of the tongue and the tongue bridle cable. A 4.76-mm tickler chain that is 0.90 Section B, Page 38 m shorter than the 10.4-m footrope is connected to the door next to the footrope. Trawl door coverage area is 9.51 sq m. The sampling coverage area is 8,152 sq m and the sampling coverage volume is 13,042 cu m. Environmental data are recorded, including temperature, salinity, and dissolved oxygen.

6.4.2 Sampling Intensity

The sampling season has undergone some changes since the survey’s inception. Beginning in 1991, sampling has been performed over a two-week period, usually the second and third weeks of both June and September. Sampling since 1991 has occurred only in the Pamlico Sound and associated rivers and bays.

6.4.3 Biological and Environmental Sampling

All species are sorted, and a total number and aggregate weight is recorded for each species. For target species, thirty to sixty individuals are measured, and total aggregate weights are taken. The catches from each of the two towed nets are combined to form a single sample.

6.4.4 Ageing Methods

Ageing methods for North Carolina were described in section 2.2.1.

6.4.5 Evaluation of Survey Data

An evaluation of the proportion of zero catches indicated that Atlantic croaker have been regularly encountered during both the June and September components of the survey. The length-frequency distributions indicate that age-0 and age-1 Atlantic croaker were captured during the June component of the Pamlico Sound Survey and that only age-0 Atlantic croaker were encountered during the September component of the survey. Because this survey reliably catches YOY Atlantic croaker, is statistically designed, and represents a portion of the Atlantic croaker geographic range, the SASC supported its use as an abundance index when sub-setted to the month of June.

6.4.6 Development of Estimates

An index of relative YOY abundance (number per tow) was developed using the June observations of Atlantic croaker less than 14 cm TL (**Table 6.2, Fig. 6.9**) (Lee 2005; Woodward 2009).

6.4.7 Trends

The index of relative abundance for YOY Atlantic croaker developed from the NC195 program indicated relatively low biomass in the late 1980s followed by some variability and then high abundance in the late 1990s (**Figure 6.9**). The 2000s were relatively low, with the exception of 2004. The last 5 years of the time series alternate between some of the highest and lowest values, ending with a mid-range abundance for the terminal year of 2014.

6.5 ChesMMAP

6.5.1 Survey Design and Methods

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) Trawl Survey has been sampling the mainstem of the Chesapeake Bay, from Poole’s Island, MD to the Virginian Capes at the mouth of the bay since 2002. This survey is designed to sample the late juvenile and adult stages of the living marine resources in Chesapeake Bay, and as such the timing of sampling is meant to coincide with the seasonal residency of these life stages in the estuary.

The ChesMMAP survey area is stratified into five latitudinal regions, and each region is comprised of three depth strata. Depth strata bounds are consistent across regions, and correspond to shallow (3.0m to 9.1m), middle (9.1m to 15.2m), and deep (>15.2m) waters in the bay. Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A four-seam, two-bridle, semi-balloon bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.5kts. The trawl has a 13.7m headline length, and is made of

15.2cm stretch mesh webbing in the body of the net and 7.6cm stretch mesh in the codend. The codend is not outfitted with a liner which enables the net to be towed effectively at relatively high speeds, facilitating the capture of the target late juvenile and adult stages. Trawl wingspread and headline height are measured during each tow.

6.5.2 Sampling Intensity

ChesMMAP conducts 5 cruises annually, during the months of March, May, July, September, and November. A total of 80 sites are sampled per cruise.

6.5.3 Biological and Environmental Sampling

A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation [PAR]), atmospheric data, and station identification information are recorded at each sampling site.

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

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

6.5.4 Ageing Methods

The Multispecies Research Group (MRG) at the Virginia Institute of Marine Science (VIMS) has been ageing Atlantic croaker collected by the group’s ChesMMAP Trawl Survey since 2002 and 2007, respectively. Whole otoliths are taken from a subsample of each size class of each species from each tow; these ageing structures are labeled and stored dry at sea.

Upon completion of all field sampling in a given year, each set of whole otoliths of a given species collected by a given survey is assigned a random number, such that location and time of collection are not known during the subsequent processing and assignment of age. Processing protocols follow the methods developed during the ASMFC Atlantic Croaker and Red Drum Ageing Workshop (ASMFC 2008) for croaker.

Since mark formation typically occurs during the late spring/early summer period, the age of specimens collected prior to June is given by the number of annuli present plus one, while those collected in June or later are assigned an age equal to the number of annuli present.

After ages are assigned, a final age is determined for each fish by taking the mode of the three independent assigned ages for that specimen. If no mode exists (i.e., all three reads generated different ages), the otolith section for that specimen is re-read by each of the three original readers. If this procedure fails again to produce a mode, the sample is discarded. Upon completion of final age assignments, age data are then incorporated into the appropriate survey database.

6.5.5 Evaluation of Survey Data

The ChesMMAP survey uses a random design and encounters the population of Atlantic croaker, so the SASC supported developing this survey into an abundance index. In May, July, and September months, the annual length frequency is variable (**Figure 6.10**) and ages range from 0-13, although ages 0-5 are the most frequently caught (**Figure 6.11**). Outside of those months, Atlantic croaker are not as reliably caught with nearly 70% of tows having zero Atlantic croaker. The ChesMMAP program develops an index of relative abundance using data collected during May, July, and September tows in Regions 4 and 5 from only the mid-depth and deep strata because that reliably catches Atlantic croaker, so the SASC followed that advice when developing an index for this survey. Additionally, the data supported that the survey was capturing croaker more reliably during those months with 55% of the tows catching zero croaker.

6.5.6 Development of Estimates

An index of relative biomass (kilograms per tow) was calculated using data from the May-September component of the ChesMMAP survey using only Regions 4 and 5 (**Table 6.2, Fig. 6.12**).

6.5.7 Trends

The ChesMMAP index of relative biomass for Atlantic croaker indicated that biomass was high in the early and mid-2000s and has been on a steady decline since 2007 (**Table 6.2, Figure 6.12**). Relative biomass in the terminal year of 2014 is at the lowest point in the time series.

6.6 NEAMAP

6.6.1 Survey Design and Methods

The Northeast Area Monitoring and Assessment Program, Mid-Atlantic/Southern New England Nearshore Trawl Survey (hereafter, NEAMAP) has been sampling the coastal ocean from Martha's Vineyard, MA to Cape Hatteras, NC since the fall of 2007.

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

A four-seam, three-bridle, 400x12cm bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.0kts. The gear is of the same size as and nearly identical in design to that used by the NMFS survey, only sweep configuration and trawl door type differ between the two programs. Tow times and tow speeds are consistent between the two programs. The net is outfitted with a 2.54cm knotless nylon liner to retain the early life stages of the various fishes and invertebrates sampled by the trawl. Trawl wingspread, doorspread, headline height, and bottom contact are measured during each tow, and those in which net performance falls outside of defined acceptable ranges are either re-towed or excluded from analyses in an effort to maintain sampling consistency.

6.6.2 Sampling Intensity

NEAMAP conducts two cruises per year, one in the spring and one in the fall, mirroring the efforts of the NMFS-NEFSC Bottom Trawl Surveys offshore. Spring cruises begin during the third week in April and conclude around the end of May, while the fall surveys span from the third week in September until the beginning of November. Sampling progresses from south to north in the spring and in the opposite direction in the fall, so as to follow the general migratory pattern of the living marine resources of these regions.

Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A total of 150 sites are sampled per cruise, except 160 sites were sampled in the spring and fall of 2009 as part of an investigation into the adequacy of the program's stratification approach.

6.6.3 Biological and Environmental Sampling

A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation [PAR]), atmospheric data, and station identification information are recorded at each sampling site.

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

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

6.6.4 Ageing Methods

The Multispecies Research Group (MRG) at the Virginia Institute of Marine Science (VIMS) has been ageing Atlantic croaker collected by the group's NEAMAP Trawl Survey since 2007. Whole otoliths are taken from a subsample of each size class of each species from each tow; these ageing structures are labeled and stored dry at sea.

Upon completion of all field sampling in a given year, each set of whole otoliths of a given species collected by a given survey is assigned a random number, such that location and time of collection are not known during the subsequent processing and assignment of age. Processing protocols follow the methods developed during the ASMFC Atlantic Croaker and Red Drum Ageing Workshop (ASMFC 2008) for croaker. Since mark formation typically occurs during the late spring/early summer period, the age of specimens collected prior to June is given by the number of annuli present plus one, while those collected in June or later are assigned an age equal to the number of annuli present.

After ages are assigned to each read, a final age is determined for each fish by taking the mode of the three independent assigned ages for that specimen. If no mode exists (i.e., all three reads generated different ages), the otolith section for that specimen is re-read by each of the three original readers. If this procedure fails again to produce a mode, the sample is discarded. Upon completion of final age assignments, age data are then incorporated into the appropriate survey database.

6.6.5 Evaluation of Survey Data

The SASC did not use this survey for modeling purposes because the time series is too short (2007-2014) relative to the lifespan of Atlantic croaker. The SASC did suggest considering this survey for future assessments since it covers a representative geographic range, has a random stratified sampling design, and it reliability catches Atlantic croaker.

6.6.6 Development of Estimates

An index of relative biomass (kilograms per tow) was calculated using data from the fall component (September- November) of the NEAMAP (**Table 2, Fig. 6.13**).

6.6.7 Trends

The index of relative biomass developed from the NEAMAP survey indicates that the biomass was high in 2007 and 2012-2013 but otherwise remains low throughout the time series (**Figure 6.13**).

6.7 Summary of Indices

All of the surveys considered for developing indices had random designs, represented a geographic area within the range of Atlantic croaker, and reliably caught Atlantic croaker during a portion of the year. The limited use of a couple surveys for inclusion in the base run of the model were due to a short time series or conflicting signal of the index. Four indices of relative biomass and two indices of relative YOY abundance were evaluated for inclusion in the model (**Figure 6.14**, **Figure 6.15**). The indices of relative biomass developed from the NMFS and SEAMAP surveys were used in the base run of the stock synthesis model (Section 7). While the time series for ChesMMAP is shorter than the other surveys considered, the main concern of the SASC about using this survey was that it was negatively correlated with the other abundance indices (**Figure 6.16**). It provided a conflicting signal in the model although it was included in sensitivity runs and all the biological data was included in the base run (see section 7.2.1.13 for more discussion). The index developed from NEAMAP was not included due to the short time series, although it should be considered in future assessments. The indices of YOY relative abundance developed from the VIMS and NC 195 surveys were used in the modeling. The surveys that were included in modeling were abbreviated to 1989-2014 when necessary. All the surveys that were considered were positively correlated with each other except for ChesMMAP which was negatively correlated with all the other surveys.

7 METHOD—STOCK SYNTHESIS

7.1 Background

7.1.1 Assessment Model Description

This assessment is based on a forward-projecting length-based, age-structured model. A two-sex model is assumed. The stock was modeled using Stock Synthesis text version 3.24y (SS3) software (Methot 2000, 2015; Methot and Wetzel 2013).

7.1.2 Reference Point Model Description

Stock Synthesis was also used to estimate reference points and relative stock status.

7.2 Configuration

7.2.1 Assessment Model

7.2.1.1 Spatial and Temporal Coverage

The assessment model was applied to data collected from the Atlantic Coast (New Jersey through the east coast of Florida) from 1989 through 2014. The year 1989 was selected as the start year because that was the earliest year available for several of the fisheries-independent surveys and commercial discard data. The terminal year, 2014, was selected because that was the most recent year with complete data for all data sets.

7.2.1.2 Catch

Annual landings were entered for each of four fleets. The fleets were the commercial fishery, the recreational fishery, the commercial scrap fishery, and the shrimp trawl fishery, which was modeled as a bycatch-only fleet. Shrimp trawl bycatch was assumed to be a function of the shrimp trawl fishing fleet effort, thereby scaling the fishing mortality for this fleet to the associated effort.

Additionally, dead discards were included for the commercial, recreational, and shrimp trawl fisheries. In the base run of the model, all commercial fishery and shrimp trawl discards were assumed dead, while total recreational fishery discards were multiplied by 15% (i.e., assumed a discard mortality of 15%) to obtain dead recreational discards (see section 5.2.1.2.3).

7.2.1.3 Selection and Treatment of Indices

Four fisheries-independent surveys were selected to generate relative indices for input into the model. Two represented general indices of relative biomass (weight per effort). These were the NMFS and SEAMAP surveys, which were assumed to be proportional to stock size. The remaining two surveys—VIMS and NC195—were entered as relative indices of age-0 abundance (numbers per effort). An index of relative effort was entered for the shrimp trawl fishery as a survey to index F (see also section 7.2.1.2). Catchability was assumed time-invariant for all indices since survey methods were consistent across time.

Initial runs of the model considered inclusion of the ChesMMAP index; however, including this index resulted in poor fits to the observed data (**Figure 7.1**), suggesting the index may not be providing much information to the model. An alternate explanation could be that the population sampled by ChesMMAP differed from the offshore population sampled by NMFS and SEAMAP (which suggests spatial variation). The working group decided to remove the ChesMMAP index from the base run (assigned a lambda of 0.0) but kept the associated biological data.

7.2.1.4 Selectivity

In SS3, selectivity can be a function of length and/or age. As the length data were more complete for all fleets and surveys, selectivity was assumed to be a function of length. A double-normal curve was used for modeling the selectivity of all fleets and surveys as this is the recommended option and offers flexibility in that it can range from a dome shape to an asymptotic shape depending on the values estimated for the required parameters. The recreational fleet was assumed to be associated with an asymptotic pattern, which required fixing of the double-normal distribution.

Initial runs of the model led to an estimated selectivity pattern for the NEFSC survey index that the working group felt was unrealistic (**Figure 7.2**). For the base run, the selectivity parameters associated with the NEFSC survey index were fixed to produce a more realistic dome-shaped pattern.

Time-varying selectivity was used to model catches from the commercial fishery. An evaluation of the major fishery gears over time revealed that the major gear type switched from haul seines to gill nets in 1993 (**Figure 7.3**). Examination of the length distributions collected from the commercial fishery shows that there was a difference before and after 1993 (**Figure 7.4**). For these reasons, the selectivity of the commercial fleet was initially split into two time blocks: (1) 1989 to 1992 and (2) 1993 to 2014. In the initial runs of the model, SS3 estimated an asymptotic-shaped selectivity pattern for the second time block (**Figure 7.5**). This seemed unreasonable given that the major gear during this time block was the gill net, which is typically associated with a dome-shaped pattern. For this reason, the selectivity parameters of the commercial fleet were fixed to values that would result in a reasonable dome-shaped pattern.

Selectivity was modeled in two time blocks for the shrimp trawl fleet as well (1989 to 1995 and 1996 to 2014). The time blocks coincide with the institution of the BRD requirement in state waters. Preliminary runs resulted in an unusually wide dome-shaped selectivity pattern estimated for the initial time block (1989 to 1995; **Figure 7.6**). The SASC felt this was unrealistic and so fixed the necessary selectivity patterns to produce a more realistic dome shape for the shrimp trawl fishery in the first time block for the base run.

7.2.1.5 Length Composition

Annual length frequencies (sexes combined) were input for the commercial fishery landings (1989–2014) and associated discards (1993–2011, 2013–2014); recreational fishery harvest (1989–2014) and associated discards (2004–2014); commercial scrap landings (1990–2014); shrimp trawl bycatch (1995–1997, 2001–2005, 2007–2009, 2012–2014); NEFSC survey (1989–2014); ChesMMAP survey (2002–2014); and the SEAMAP survey (1989–2014). Length frequencies for the surveys were calculated using the same reference data used to develop the indices. For example, the length frequencies for the fall component (offshore strata only) of the NEFSC survey were generated from observations collected during the fall (offshore strata only).

7.2.1.6 Age Data

Annual sex-specific age compositions were input for the commercial fishery landings (1996–2014); recreational fishery harvest (1993, 1995, 1997, 2001–2004, 2006, 2008, 2011, 2013–2014); NEFSC survey (1997–2012, 2014); ChesMMAP survey (2002–2014); and the SEAMAP survey (2001–2006, 2008–2014). The age data were input as raw age-at-length data, rather than age compositions generated from applying age-length keys to the catch-at-length compositions. The input compositions are therefore the distribution of ages obtained from samples in each length bin (conditional age-at-length).

As with the length frequencies, the survey age compositions were calculated using the same reference data used to develop the indices for the surveys. Age 8 was treated as a plus group that included ages 8 through 17. The SASC decided to use the 8+ truncated age group as these fish represented only 3.43% of the available ages. Ages were assumed to be associated with no bias and negligible imprecision.

7.2.1.7 Sex Ratio at Length

Information on sex ratio at length by year was provided to the model for the commercial fishery landings (1996–2014); recreational fishery harvest (1993, 1995, 1997, 2001–2004, 2006, 2008, 2011, 2013–2014); NEFSC survey (1997–2012, 2014); ChesMMAP survey (2002–2014); and the SEAMAP survey (2001-2006, 2008–2014). As with the length frequencies and age data, the sex ratio-at-length data were calculated using the same reference data used to develop the indices for the surveys.

7.2.1.8 Average Length at Age

Annual sex-specific estimates of average length at age were input for the commercial fishery landings (1996–2014); recreational fishery harvest (1993, 1995, 1997, 2001–2004, 2006, 2008, 2011, 2013–2014); NEFSC survey (1997–2012, 2014), ChesMMAP survey (2002–2014), and the SEAMAP survey (2001–2006, 2008–2014). As with the other biological data, the average length-at-age data were calculated using the same reference data used to develop the indices for the surveys.

7.2.1.9 Biological Parameters

Natural Mortality

The Lorenzen option was selected for modeling age-varying natural mortality. Natural mortality at age 2 was fixed for both females (0.314) and males (0.323) as this was the age at which full recruitment to the fishery occurred. Refer to section 2.4.2 for more details on the estimation of natural mortality at age using the Lorenzen model.

Growth

The von Bertalanffy age-length growth model was selected for modeling the growth of Atlantic croaker. The growth model parameterization selected was the one that uses length at a given reference age, L_∞, and *K*. The selected reference age was age 1. The von Bertalanffy parameters were assumed to be sex-specific. All von Bertalanffy parameters for both sexes were estimated, including the CVs at age 1 and age 17. Initial values for the growth curves were those estimated as described in section 2.2. Allowing SS3 to estimate the growth curve ensures that the assumptions about selectivity are consistent with other parts of the model and that uncertainty in the growth estimates is reflected in the estimates of spawning stock biomass, fishing mortality, and reference points (Hall 2013).

Parameters of the allometric length-weight relationship were fixed for both males and females. The assumed values were those estimated in this report as described in section 2.2.

Maturity

Female maturity was defined using the length logistic maturity option in SS3. Following the recommendation of the review panel for the 2010 ASMFC assessment, the maturity curve was estimated using data based on the spawning season in the mid-Atlantic region (Chesapeake Bay). Specifically, data collected by the ChesMMAP survey (see section 6.5.3) during August through November were used to estimate maturity parameters. Maturity at length (M_l) was modeled as:

$$M_l = \frac{1}{1 + e^{\alpha(l-\beta)}}$$

where l is length, α is the slope, and β is the inflection point.

The parameters α and β were estimated via logistic regression. The estimated value for α was -0.320 and the estimated value for β was 19.3 cm (**Figure 7.7**). The maturity parameters were fixed in the model at these values.

Fecundity

The selected fecundity option in SS3 was that which causes eggs to be equivalent to spawning biomass.

7.2.1.10 Stock-Recruitment

A Beverton-Holt stock-recruitment relationship was assumed as was done in the previous assessment (ASMFC 2010). Recruitment varied log-normally about the curve. The steepness parameter (h) and virgin recruitment (R0) were estimated within the model. A full beta distribution was assumed for the prior value of 0.76 on steepness—the value used in the previous ASMFC assessment (ASMFC 2010) and the value estimated by J. Munyandorero (Appendix: A1). The value for σR was fixed at an assumed value of 0.60.

7.2.1.11 Initial Conditions

Non-equilibrium conditions were assumed for the initial age structure. Initial equilibrium catch values were set equal to half the minimum observed landings over the 1989 through 2014 time period for each fleet, with the exception of the shrimp trawl fleet; for this fleet, initial equilibrium landings were set at a reasonably low value (see also next section).

7.2.1.12 Weighting of Likelihoods

SS3 assumes an error distribution for each data component and assigns a variance to each observation. The commercial landings, recreational harvest, and commercial scrap landings were fit in the model assuming a lognormal error structure. Commercial landings were assumed well known and assigned a minimal observation error (SE = 0.05). The observation error for the recreational harvest and scrap landings was assumed equal to twice the value assumed for the commercial landings (SE = 0.10). Composition information was fit assuming a multinomial error structure with variance described by the effective sample size. For each fleet and survey, the effective sample size was the number of sampled trips assuming a maximum of 200. Survey indices were fit assuming a lognormal error distribution with variance estimated from sampling statistics. A normal error structure was assumed for the effort deviations of the shrimp trawl fishery.

The objective function for the base model included likelihood contributions from the landings, discards, survey indices, length compositions, age data, length at age data, initial equilibrium catch, and recruitment deviations. The total likelihood is the weighted sum of the individual components. Most likelihood components were assigned a lambda weight of 1.0 in the base model with two exceptions. Nil emphasis (lambda = 0.0) was assigned to the likelihood components for the average length-at-age data. This is the recommended approach when age data are entered as conditional age-at-length and growth parameters are being estimated (Methot 2015). Nil emphasis (lambda = 0.0) was also placed on the likelihood components for the initial equilibrium catch of each fleet because of the high uncertainty in the values assumed for the initial equilibrium catches.

With the exception of the steepness parameter (see section 7.2.1.10), no prior assumptions were made regarding any of the other estimated parameters (i.e., no priors were used); however, bounds were established on all parameters to prevent estimation of unrealistic parameter values and convergence problems.

After the (unweighted) base model was run, it was reweighted in two stages, following the recommendations of Francis (2011): (1) an initial reweighting to adjust the sample sizes for the length and age compositions to the effective sample sizes needed to make the different components (age and length) equivalently weighted and (2) making the suggested variance adjustments to the lognormal likelihoods for the indices to make the variances more consistent with the model fits. It is debatable whether this second step should be done more than once, i.e., iterative re- weighting. Here, it was done only once where applied.

7.2.1.13 Sensitivity Analyses

A number of sensitivity analyses were performed. These included varying the assumption about the recreational fishery discard mortality, removing the data associated with each survey individually, varying assumptions about steepness, and varying assumptions about the level of shrimp trawl bycatch. For each of these sensitivity runs, the effect on predicted recruitment, spawning stock biomass, fishing mortality, and relative stock status was evaluated. A jitter analysis to examine model stability was also performed. Additional details on each of the sensitivity analyses are given below.

Recreational Discard Mortality

In the base model, a discard mortality of 15% was assumed for the recreational fishery and applied to the estimated live discards. Other plausible estimates were considered in a series of sensitivity analyses: 8%, 11%, and 18%. All three of these values came from a meta-analysis conducted by Bartholomew and Bohnsack (2005). Eleven percent was the mean discard mortality of all species and 18% was the median discard mortality value of all species. For each of these runs, the two-stage Francis (2011) reweighting was applied before obtaining final results.

Remove One Survey at a Time

The contribution of a data source can be manipulated by changing the value of lambda. Here, the uncertainty of the base model results was explored by assessing the contribution of different surveys using this approach. In a series of runs, the contribution of each survey was examined by effectively removing (assigned a lambda weight of 0.0) all inputs (index, length compositions, age data) derived from the particular survey. As the ChesMMAP index was not included in the base run, the sensitivity analysis associated with this survey (“No ChesMMAP”) explored removing of the biological data collected from this survey. For all of these runs, the two-stage Francis (2011) reweighting was applied before obtaining final results.

Steepness

The sensitivity of model results to steepness was evaluated by assuming a range of fixed values for the parameter. Values of 0.60 to 1.0 at increments of 0.10 were explored. For each of these runs, the two-stage Francis (2011) reweighting was applied before obtaining final results.

Shrimp Trawl Bycatch

A number of sensitivity runs explored the shrimp trawl bycatch values. As the 1991 observation for shrimp trawl bycatch was high relative to the rest of the time series (Figure 4.17), one sensitivity run was configured to omit the 1991 observation from the likelihood calculation. In another sensitivity run, the 1991 value was set equal to the median of values from pre-BRD years (1989 to 1995).). A series of runs examined lowering the original shrimp trawl bycatch by 10%, 20%, 30%, 40%, and 50% to address uncertainty in the estimates. For each of these runs, the two-stage Francis (2011) reweighting was applied before obtaining final results.

Jitter Analysis

The SS3 software includes several processes to evaluate model stability. The “jitter” analysis varies the initial parameter values by a user-specified fraction and so allows the evaluation of varying input parameter values on model results to ensure the model is not converging on a local minimum. A model that is well behaved should converge on a global solution across a reasonable range of initial parameter estimates (Cass-Calay et al. 2014). Initial parameters were randomly jittered by 5% for a series of 50 random trials. Model runs that resulted in a Hessian matrix that was not positive definite or could not find a solution were discarded. The total likelihood value, terminal F, terminal SSB, and relative stock status from the successful jitter runs were compared to the unweighted base run results. Temporal trends in predicted SSB and fishing mortality were also evaluated.

7.2.1.14 Retrospective Analyses

A retrospective analysis was run to examine the consistency of estimates over time. This type of analysis gives an indication of how much recent data have changed our perspective of the past (Harley and Maunder 2003). The analysis is run by removing one year of data at a time from the end of the time series, evaluating results, removing the new end year of data from the time series, evaluating results, and so on. The Francis (2011) reweighting procedure was applied to each run of the retrospective analysis before obtaining final results.

8 RESULTS

8.1 Assessment Model

A summary of the majority of the data used as input in the base run can be found in **Figure 8.1**. The final base run resulted in a final gradient (0.00377) larger than the convergence criteria (0.0001) but was considered sufficiently converged as it was less than one. Five parameters were estimated near their bounds out of the 208 estimated parameters (**Table 8.1**). Two of those five parameters were initial equilibrium *F* parameters (commercial and scrap fisheries). The other three parameters estimated near their bounds were related to SEAMAP survey selectivity and commercial fishery retention. Note also that the model resulted in a *not positive definite* Hessian matrix after the first stage reweighting of the base run.

8.1.1 Goodness of Fit

There was good agreement between observed and predicted landings for the commercial fishery (**Figure 8.2**), recreational fishery (**Figure 8.3**), and scrap fishery (**Figure 8.4**). The base run of the model underestimated commercial fishery dead discards in almost all years (**Figure 8.5**). This same pattern was evident in almost all alternative run scenarios. Predicted dead discards for the recreational (**Figure 8.6**) and shrimp trawl (**Figure 8.7**) fisheries matched the observed values well.

The base run of the model underestimated the observed values for the shrimp trawl relative effort from 1992 to 1999 and overestimated values from 2006 through 2011 (**Figure 8.8**). Fits to the survey indices were relatively good. The base run captured the overall observed trends in the NMFS (**Figure 8.9**), SEAMAP (**Figure 8.10**), VIMS (**Figure 8.11**), and NC195 (**Figure 8.12**) survey indices, though did not capture all the observed inter-annual variability. The model did not capture the relatively high peaks observed in recent years in the two recruitment surveys (**Figures 8.11 and 8.12**). The runs test was applied to the standardized residuals from the fit to the survey indices and none of the resulting P values were significant, suggesting there were no patterns in the residuals over time. The Shapiro-Wilk test is a test of normality and was also applied to the standardized residuals of the survey fits. The results of this test suggested the residuals from all the fits to the surveys followed normal distributions.

Fits to the observed length distributions varied among fleets, surveys, and catch types (landings or discards). The predicted length distributions matched well with the observed length distributions for the landings (retained catch; **Figure 8.13**) and discards (**Figure 8.14**) for all fleets and surveys. The fits to the length distributions for the commercial landings were especially good from 1989 through 1995 (**Figure 8.15**); there was some prediction of smaller lengths than observed from 1996 on (**Figures 8.15 and 8.16**). For the commercial discard length distributions, fits ranged from good to poor among years (**Figures 8.17 and 8.18**). Note that the adjusted effective sample sizes are fairly low and good fits would not generally be expected. Fits to the length distributions for the recreational landings were reasonable (**Figures 8.19 and 8.20**). The predicted length distributions for the recreational discards exhibited some deviations for larger sizes in later years (**Figure 8.21**). Fits to the length distributions for the scrap landings (**Figures 8.22 and 8.23**) and shrimp trawl bycatch (**Figure 8.24**) were good. The fits to the NEFSC survey length distributions tended to predict smaller lengths than observed in many years (**Figures 8.25 and 8.26**). The predicted length distributions for the ChesMMAP survey showed predictions of smaller lengths than observed in some years and larger lengths than observed in others (**Figure 8.27**). Fits to the SEAMAP length distributions were especially good (**Figures 8.28 and 8.29**).

8.1.2 Parameter Estimates

8.1.2.1 Selectivity and Catchability

Selectivity was modeled as a function of length for all fleets and surveys. Terminal year (2014) selectivity for all fleets and surveys is summarized in **Figure 8.30**. Commercial fishery selectivity was modeled in two time blocks (see section 7.2.1.4). The model estimated a dome-shaped curve for the first time block (1989–1992) associated with the commercial fishery (**Figure 8.31**). The commercial fishery selectivity for the second time block (1993–2014) was fixed to a dome shape. The base run of the model predicted that a higher proportion of smaller fish would be retained in the second time block as compared to the first time block (**Figure 8.32**). All the commercial discards input into the model were assumed dead (**Figure 8.33**). The selectivity pattern for the recreational fishery was assumed to have an asymptotic shape and all discards input into the model were assumed dead (15% of total released alive; **Figure 8.34**). A dome-shaped curve was predicted for the scrap fishery (**Figure 8.35**). While selectivity for the shrimp trawl fishery was split into two time blocks (see section 7.2.1.4), selectivity among the time blocks was fairly similar (**Figure 8.36**). Selectivity for the first time block (1989–1995) was fixed to a dome shape and the model predicted a dome shape for the second time block (1996–2014). All shrimp trawl bycatch entered into the model was assumed dead (**Figure 8.37**). The selectivity for the NEFSC survey was fixed to a dome shape in the model (**Figure 8.38**). The model predicted dome-shaped selection curves for the ChesMMAP (**Figure 8.39**) and SEAMAP (**Figure 8.40**) surveys. The ChesMMAP survey (**Figure 8.39**) was predicted to select for a broader range of lengths than the NMFS (**Figure 8.38**) or SEAMAP (**Figure 8.40**) surveys.

8.1.2.2 Exploitation Rates

SS3 allows several options for reporting *F*. The *F* values reported here represent a numbers-weighted *F* for ages 0–8+. Predicted fishing mortality exhibited a peak in 1991 at 0.906 and showed an overall general decrease throughout the rest of the time series (**Table 8.2; Figure 8.41C**). The smallest fishing mortality was observed in 2005 at a value of 0.113.

8.1.2.3 Abundance & Biomass Estimates

Predicted recruitment was variable over the time series and demonstrated a decrease in the last few years (**Table 8.2; Figure 8.41A**). Variance about the recruitment estimates increased with time. Female SSB showed an increasing trend over time and, similar to the recruitment variance, the variance in female SSB was greatest at the end of the time series (**Table 8.2; Figure 8.41B**). A plot of the predicted stock-recruitment relationship suggests the relation is not particularly strong (**Figure 8.42**). This is further evidenced by the estimated value of 0.985 for the steepness parameter (**Table 8.1**). The trend in annual recruitment deviations generally showed the expected pattern, though the 1989 deviate was somewhat low (**Figure 8.43**).

Predicted population numbers at age for females and males suggest a rebuilding of the age structure over the time series (**Tables 8.3–8.6**). Evidence for rebuilding is also present in the predicted catch at age for the commercial (**Table 8.7**) and recreational (**Table 8.8**) fisheries.

Predicted catch at age for the scrap and shrimp trawl fisheries can be found in **Tables 8.9** and **8.10**.

8.1.3 Sensitivity Analyses

Most of the sensitivity runs resulted in a final gradient slightly larger than the convergence criteria (0.0001) but always less than one and so were considered successfully converged except where noted below.

8.1.3.1 Recreational Discard Mortality

When recreational discard mortality was assumed equal to 8% and before the Francis (2011) reweighting and after the first stage reweighting, the model did not converge successfully. It did converge after the second stage reweighting. The model also did not converge before any reweighting when the recreational discard mortality was assumed equal to 11% and 18%. These models did converge after reweighting.

Varying the assumption about the level of of recreational discard mortality had little impact on estimates of recruitment, female SSB, and fishing mortality (**Figure 8.44**). The relative low impact of recreational discard mortality on the model was likely due to low discard mortality estimates and the low numbers of fish discarded, particularly compared with the shrimp trawl bycatch.

8.1.3.2 Remove One Survey at a Time

Francis (2011) reweighting was required when comparing sensitivity runs dropping surveys because of convergence problems. The model resulted in a bad Hessian matrix when the NMFS or ChesMMAP survey data were removed and before any reweighting. The model also resulted in a bad Hessian matrix after the first reweighting when either the SEAMAP or VIMS survey data were removed.

Recruitment and SSB in recent years appeared most sensitive to which survey data were removed (**Figure 8.45**). Removal of the NMFS and SEAMAP survey data had the biggest impact on recent recruitment (**Figure 8.45A**). Removing the NMFS or SEAMAP survey resulted in higher predicted female SSB than the base run or runs in which any of the other survey data were removed (**Figure 8.45B**). Removing the ChesMMAP or VIMS survey data resulted in lower estimates of SSB than the base run, especially in the more recent years of the time series. Fishing mortality was minimally affected by the removal of survey data (**Figure 8.45C**).

8.1.3.3 Steepness

When steepness was assumed equal either 0.70 or 0.90 and before the Francis (2011) reweighting, the model resulted in a bad Hessian matrix. Also, when steepness was assumed equal to 0.80 or 1.0 and both prior to reweighting and after the first stage weighting, the result was a bad Hessian matrix.

As expected, the assumption about steepness had a discernable impact on predicted recruitment (**Figure 8.46A**) and female SSB (**Figure 8.46B**). Assuming smaller levels of steepness resulted in higher estimates of recruitment, especially in recent years (**Figure 8.46A**). Similarly, assuming smaller levels of steepness resulted in higher predicted estimates of female SSB, especially in the final years of the model (**Figure 8.46B**). Predicted fishing mortality tended to be smaller at smaller assumed values of steepness (**Figure 8.46C**).

8.1.3.4 Shrimp Trawl Bycatch

The model could not find a solution when the shrimp trawl bycatch values were assumed equal to 30% of the original values, suggesting that bycatch removals are probably not underestimated. Varying the assumption about the 1991 shrimp trawl bycatch value impacted recruitment and fishing mortality in the early part of the time series (**Figure 8.47**); there was negligible impact to predicted SSB. Lowering the entire time series of shrimp trawl bycatch by certain percentages resulted in smaller estimates of recruitment, female SSB, and fishing mortality (**Figure 8.48**).

8.1.3.5 Jitter Analysis

A total of 59 jitter trials were run, eight of which resulted in Hessian matrices that were not positive definite and one that could not find a solution. None of the jitter trial runs resulted in a total likelihood value that was lower than that in the unweighted base run (**Table 8.11**). The majority of the jitter trials resulted in a total likelihood value identical to that of the unweighted base run, suggesting a global minimum was found. Evaluation of the trends in SSB (**Figure 8.49**) and fishing mortality (**Figure 8.50**) found no substantial differences in the magnitude or trends of these quantities in the majority of runs, providing further evidence that the base run found a global solution.

8.1.4 Retrospective Analyses

The results of the retrospective analysis suggested there was no consistent over or underestimation of terminal year values for recruitment, female SSB, or fishing mortality (**Figure 8.51**).

8.2 Reference Point Model

8.2.1 Parameter Estimates

SS3 was used to estimate the fishing mortality and SSB targets and thresholds as defined in Addendum I to Amendment I of the ASMFC FMP for Atlantic croaker (ASMFC 2011). The fishing mortality threshold is defined as F_{MSY} and the fishing mortality target is 0.75 * F_{MSY}. The SSB threshold is defined as 0.70 * $\mathrm{SSB}_{\mathrm{MSY}}$ and the SSB target is defined as $\mathrm{SSB}_{\mathrm{MSY}}$. The final (reweighted) base run predicted $F_{\mathrm{Threshold}} = 0.393$ and $F_{\mathrm{Target}} = 0.295$. The value for $\mathrm{SSB}_{\mathrm{Threshold}}$ was predicted at 55,607 mt and $\mathrm{SSB}_{\mathrm{Target}}$ was 79,438 mt.

8.2.2 Sensitivity Analyses

The SSB target and threshold were most sensitive to varying levels of the steepness parameter (**Table 8.12**). The SSB reference points were also sensitive assuming reduced levels of the observed shrimp trawl bycatch. The fishing mortality reference points were most sensitive to assuming reduced levels of the observed shrimp trawl bycatch. Varying the levels of the steepness parameter had the next largest impact on the fishing mortality target and threshold. Changing the assumption about the value of the recreational fishery discard mortality had relatively little impact on the SSB and fishing mortality reference points.

9 STOCK STATUS

9.1 Current Overfishing, Overfished/Depleted Definitions

The current definition of stock status is defined in Addendum I to Amendment I of the ASMFC FMP for Atlantic croaker (ASMFC 2011). Determination of stock status is based on the ratio of current (terminal year) fishing mortality and SSB to their respective thresholds, which are then compared to one. The fishing mortality threshold is defined as F_{MSY} and the SSB threshold is defined as 0.70 * SSB_{MSY}. If F_{Current} / $F_{\text{Threshold}}$ is greater than one, then overfishing is occurring. If $\text{SSB}_{\text{Current}}$ / $\text{SSB}_{\text{Threshold}}$ is less than one, then the stock is overfished.

9.2 Stock Status Determination

9.2.1 Overfishing Status

The (reweighted) base run predicted that terminal year fishing mortality was 0.167 (F_{2014} = 0.167; **Table 8.2**). The fishing mortality threshold estimate from the base run was 0.393 (F_{MSY} = $F_{\text{Threshold}}$ = 0.393). Relative status for fishing mortality is then F_{2014} / $F_{\text{Threshold}}$ = 0.167 / 0.393 = 0.426, which is less than one. The results of the base run suggest that overfishing is currently not occurring (**Figure 9.1**).

9.2.2 Overfished Status

The (reweighted) base run predicted that terminal year SSB was 304,345 mt (SSB_{2014} = 304,345 mt; **Table 8.2**). The SSB threshold is 0.70 * SSB_{MSY}, which is 0.70 * 79,438 mt = 55,607 mt ($\text{SSB}_{\text{Threshold}}$ = 55,607 mt). Relative status for SSB is SSB_{2014} / $\text{SSB}_{\text{Threshold}}$ = 304,345 mt / 55,607 mt = 5.47, which is greater than one. The results of the base run suggest that the stock is currently not overfished (**Figure 9.1**).

9.2.3 Uncertainty

All sensitivity runs resulted in a stock that was not overfished and in which overfishing was not occurring in the terminal year (**Table 8.12**). Stock status relative to the overfished condition was most optimistic when steepness was assumed equal to 1.0. Stock status relative to overfishing was most optimistic when the level of shrimp trawl bycatch was assumed equal to 50% of the original values.

10 RESEARCH RECOMMENDATIONS

<u>Short term:</u>

HIGH PRIORITY

- Increased observer coverage for commercial discards, particularly the shrimp trawl fishery. Develop a standardized, representative sampling protocol for collection of individual lengths and ages of discarded finfish.

- Describe the coast-wide distribution, behavior, and movement of croaker by age, length, and season, with emphasis on collecting larger, older fish.

MEDIUM PRIORITY

- Conduct studies of discard mortality for recreational and commercial fisheries by each gear type in regions where removals are highest.

- In the recreational fishery, develop sampling protocol for collecting lengths of discarded finfish and collect otolith age samples from retained fish.

- Encourage fishery-dependent biological sampling, with proportional landings representative of the distribution of the fisheries. Develop and communicate clear protocols on truly representative sampling.

<u>Long term:</u>

HIGH PRIORITY

- Continue state and multi-state fisheries-independent surveys throughout the species range and subsample for individual lengths and ages. Ensure NEFSC trawl survey continues to take lengths and ages. Examine potential factors affecting catchability in long-term fishery independent surveys.

- Quantify effects of BRDs and TEDs implementation in the shrimp trawl fishery by examining their relative catch reduction rates on Atlantic croaker.

- Continue to develop estimates of length-at-maturity and year-round reproductive dynamics throughout the species range. Assess whether temporal and/or density-dependent shifts in reproductive dynamics have occurred.
- Re-examine historical ichthyoplankton studies for an indication of the magnitude of estuarine and coastal spawning. Pursue specific estuarine data sets from the states (NJ, VA, NC, SC, DE, ME) and coastal data sets (MARMAP, EcoMon).

MEDIUM PRIORITY

- Investigate environmental covariates in stock assessment models, including climate cycles (e.g., Atlantic Multi-decadal Oscillation, AMO, and El Nino Southern Oscillation, El Nino) and recruitment and/or year class strength, spawning stock biomass, stock distribution, maturity schedules, and habitat degradation.

- Utilize NMFS Ecosystem Indicators bi-annual reports to consider folding indicators into the assessment; identify mechanisms for how environmental indicators affect the stock

- Encourage efforts to recover historical landings data, determine whether they are available at a finer scale for the earliest years than are currently reported.

- Collect data to develop gear-specific fishing effort estimates and investigate methods to develop historical estimates of effort.

- Develop gear selectivity studies for commercial fisheries with emphasis on age 1+ fish.

- Conduct studies to measure female reproductive output at size and age (fecundity, egg and larval quality) and impact on assessment models and biomass reference points

- Develop and implement sampling programs for state-specific commercial scrap and bait fisheries in order to monitor the relative importance of Atlantic croaker. Incorporate biological data collection into program.

- Investigate the relationship between estuarine nursery areas and their proportional contribution to adult biomass. I.e., are select nursery areas along Atlantic coast ultimately contributing more to SSB than others, reflecting better quality juvenile habitat?

The SAS and TC recommend that the next assessment be completed five years from the completion of this assessment (i.e., 2022). Though the completion of the spot and Atlantic croaker assessments together was useful for the first assessment of spot, the SAS and TC recommend a staggered schedule for future spot and Atlantic croaker assessments due to the overlap in personnel.

11 MINORITY OPINION

There was no minority opinion submitted by any member(s) of the SAS or TC.

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13 TABLES

Table 1.1 History of state regulations specific to Atlantic croaker.

State	Regulation	Date
NJ	Minimum 3.75” stretched diamond mesh or 3.375” stretched square mesh in beam or otter trawl cod end for directed harvest (>100 pounds)	2001
DE	8” total length minimum size limit	1984
MD	10” total length minimum size limit	1960s
	9” total length minimum size limit; 20 fish recreational creel limit	1993
	9” total length minimum size limit; 20 fish recreational creel limit; commercial closure January 1–March 15	1995
	9” total length minimum size limit; 25 fish recreational creel limit; commercial closure January 1–March 15	1997
PRFC	10” total length commercial minimum size limit	1963
	10” total length commercial and recreational minimum size limit	1982
	10” total length minimum size limit; 20 fish recreational creel limit	1996
	25 fish recreational creel limit; no size limits	1999
SC	Small Sciaenidae species (Atlantic croaker, spot, kingfish sp.) aggregate bag limit of 50 fish per person per day.	2014
GA	8” total length minimum size limit; 25 fish/day recreational and commercial, except shrimp trawlers (no limit)	1989

Table 1.2 Additional regulations affecting the harvest and bycatch of Atlantic croaker.

State	Regulation	Date
NJ	Weakfish gill-net and pound-net seasonal closures established and trawl minimum mesh reduced (3” diamond)	1992
	Weakfish trawl seasonal closure established, gill-net seasonal closure lengthened, and trawl minimum mesh increased (3.25”)	1995
DE	Weakfish gill-net minimum mesh size (3.125”) and seasonal closures affect the harvest of Atlantic croaker	1995
MD	Weakfish trawl minimum mesh increased to 3.375” square or 3.75” diamond and gill-net and trawl seasonal closure lengthened	1995
	Trawling prohibited in Chesapeake Bay and coastal bays, and within 1 mile of coastal shore	1933
VA	Trawling prohibited in all state waters	1989
	Weakfish commercial gear minimum mesh sizes increased and seasonal closures established or increased	1995

Table 1.2 *Continued*.

State	Regulation	Date
NC	Minimum mesh size restrictions in shrimp trawl (1.5” tailbag) and crab trawls (3.0”) established	Pre-1975
	Finfish trawling prohibited in internal waters; shrimp and crab trawls limited to 1,000 lb of incidental finfish bycatch per trip	1983
	Shrimp and crab trawls in inside waters limited to 500 lb of incidental finfish from December 1–February 28 and 1,000 lb from March 1–November 30	1991
	Catch of unclassified bait limited to 5,000 lb/vessel/day	1991
	Minimum mesh size restriction in shrimp trawls (1.5” tailbag) and crab trawls (3.0”); shrimp trawls prohibited areas established and headrope length limited to 90 ft	1991
	Fly net minimum stretched mesh size of 3.0” square or 3.5” diamond; fly nets defined as nets having the first body (belly) section consisting of 35 or more continuous meshes of 8.0” or greater (stretched mesh) webbing behind the bottom and top line, with tailbags less than 15 feet in length; tailbags constructed of square mesh may have the terminal 3 feet of mesh hung on a diamond with a minimum stretched mesh length of 2.0”	1992
	Bycatch reduction devices required in all shrimp trawls.	1994
	Fly nets prohibited in ocean waters from Cape Hatteras to NC/SC state line	1994
	Fly net vessels limited to 150 lb weakfish unless all fly nets onboard meet definition; gill nets limited to 150 lb weakfish unless mesh length > 2.875” stretched	1996
	Shrimp and crab trawls in Atlantic Ocean prohibited from possessing incidental finfish December 1–March 31 unless weight of the combined shrimp and crab catch exceeds weight of finfish	1997
	Small mesh (<5.0”) estuarine gill-net attendance requirement, May 1–November 30 in select areas in inside waters	1998
	Mandatory use of long haul cull panels and swipe nets south/west of a line from Bluff Point in Pamlico Sound to Ocracoke Island	1999
	Authorized gear allowed and restrictions applied to the Recreational Commercial Gear License; modified in 2008 to allow mechanical retrieval of shrimp trawl	1999
	Crab trawl minimum mesh size increased to 4” in western Pamlico Sound	2005
	Headrope length internally limited to 90 feet and shrimp trawl prohibited areas established	2006

Table 1.2 *Continued*.

State	Regulation	Date
SC	Net ban	1987
	Turtle excluder devices required in shrimp trawls in summer	1988
	Turtle excluder devices required in shrimp trawls year-round	1991
	Bycatch reduction devices required in shrimp trawls	1996
GA	Gill nets prohibited (except for shad and diamondback terrapin)	1957
	All sounds closed to large trawl shrimp fishery; TEDs mandated	1990
	Bycatch reduction devices mandatory in large trawl shrimp fishery.	1996
FL	Entangling nets (e.g., trammel and gill nets) prohibited in all state waters	1995
	Directed finfish trawl prohibited; bycatch reduction devices mandatory	1996

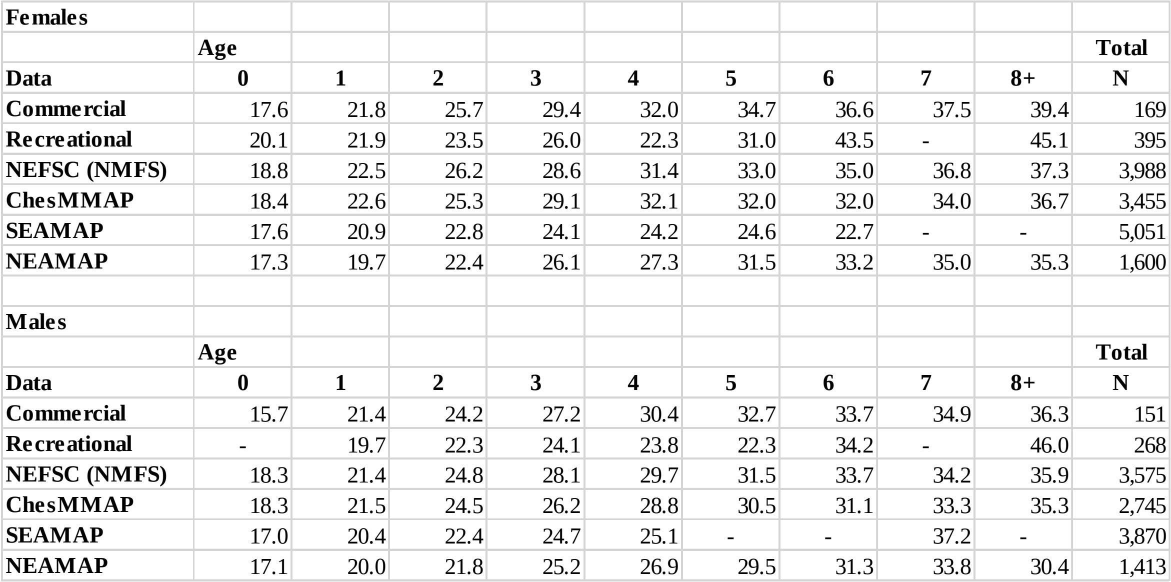
Table 2.1. Available Age Data Table by data source.

Data Source	Data Type	Age Range	Number
VMRC (VA)	C	0-15	18,462
MDDNR	C	0-13	3,342
ChesMMAP	FI	0-17	4,789
NEAMAP	FI	0-11	3,287
SEAMAP	FI	0-7	9,148
NEFSC (NMFS)	FI	0-13	6,776
NCDMF	FI	0-15	21,271
GADNR	FI	0-6	2,395

Table 2.2. Published values of observed average total length (centimeters) at age for Atlantic croaker.

			Age									
Location	Age Structure	Collection Period	0	1	2	3	4	5	6	7	8	Reference
Georgia	scale		14.8	24.8	26.8	29.7		38.9				Music and Pafford 1984
Northern Gulf of Mexico	otolith	1980–1981		21.9	26.9	30.4	34.4	35.8	38.5	41.6	37.4	Barger 1985
North Carolina	scale	1979–1981	14.4	19.2	27.1	32.0	37.1	43.0	47.3	51.4		Ross 1988
Chesapeake Bay	otolith	1988–1991		20.1	26.3	27.4	28.5	29.0	30.7	30.9	31.3	Barbieri et al. 1994a

Table 2.3. Mean TL (cm) at age by sex and data set



Females										
	Age									**Total**
Data	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**N**
Commercial	17.6	21.8	25.7	29.4	32.0	34.7	36.6	37.5	39.4	169
Recreational	20.1	21.9	23.5	26.0	22.3	31.0	43.5	-	45.1	395
NEFSC (NMFS)	18.8	22.5	26.2	28.6	31.4	33.0	35.0	36.8	37.3	3,988
ChesMMAP	18.4	22.6	25.3	29.1	32.1	32.0	32.0	34.0	36.7	3,455
SEAMAP	17.6	20.9	22.8	24.1	24.2	24.6	22.7	-	-	5,051
NEAMAP	17.3	19.7	22.4	26.1	27.3	31.5	33.2	35.0	35.3	1,600
Males										
	Age									**Total**
Data	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**N**
Commercial	15.7	21.4	24.2	27.2	30.4	32.7	33.7	34.9	36.3	151
Recreational	-	19.7	22.3	24.1	23.8	22.3	34.2	-	46.0	268
NEFSC (NMFS)	18.3	21.4	24.8	28.1	29.7	31.5	33.7	34.2	35.9	3,575
ChesMMAP	18.3	21.5	24.5	26.2	28.8	30.5	31.1	33.3	35.3	2,745
SEAMAP	17.0	20.4	22.4	24.7	25.1	-	-	37.2	-	3,870
NEAMAP	17.1	20.0	21.8	25.2	26.9	29.5	31.3	33.8	30.4	1,413

Table 2.4. Parameter estimates of the von Bertalanffy age-length growth functions for Atlantic croaker from previous studies. Values of L_∞ represent total length in cm. [1] Adjusted for month age, weight sample size (1/count age group), [2] Adjusted for month age, not sample size weighted, [3] Based on biological age in months

Location	Age Structure	Collection Period	L_∞	K	t_o	Reference
North Carolina	Scale		59.0	0.310	-0.016	Chittenden 1977
Northern Gulf of Mexico	Otolith	1980-1981	41.9	0.270	-1.410	Barger 1985
North Carolina	Scale	1979-1981	64.5	0.200	-0.600	Ross 1988
Chesapeake Bay	Otolith	1988-1991	31.2	0.360	-3.260	Barbieri et al. 1994a
Florida	Otolith	~1450-1765	42.2	0.180	-2.360	Hales and Rietz 1992
North Carolina	Otolith	1996-2002	43.4	0.240	-1.960	ASMFC 2005a
Virginia	Otolith	1998-2002	55.8	0.093	-4.140	ASMFC 2005a[1]
Virginia	Otolith	1998-2002	50.5	0.140	-2.710	ASMFC 2005a[2]
Virginia	Otolith	1998-2002	47.9	0.160	-3.260	ASMFC 2005a[3]
U.S. Atlantic Coast	Otolith	1998-2002	44.8	0.250		Lee 2005
U.S. Atlantic Coast	Otolith	1996-2002	43.4	0.242	-1.957	ASMFC 2010

Table 2.5. Parameter estimates for von Bertalanffy growth equation by model, sex and combined groups for Atlantic croaker from available assessment age data on the Atlantic coast of the U.S. *Area Residual Sum of Squares (ARSS) for Schnute integer growth by sex: $F_{(3,40444)} = 590.72$, $p < 0.001$

Model	Data Set	Number	L∞ ± SE	K ± SE	t_o	Age: min	Age: max
Traditional VOB	All Data	48,653	45.6 ± 0.224	0.175 ± 0.002	-2.536	0	17
	M & F	40,444	45.9 ± 0.301	0.161 ± 0.003	-2.834	0	17
	Females	24,506	47.7 ± 0.421	0.159 ± 0.003	-2.798	0	15
	Males	15,938	44.2 ± 0.431	0.156 ± 0.004	-3.011	0	17
Schnute	All Data	48,653	44.1 ± 0.158	0.175 ± 0.002	-2.536	0	17
Reparameterization	*M & F	40,444	44.1 ± 0.200	0.161 ± 0.003	-2.834	0	17
Of VOB	Females	24,506	44.9 ± 0.242	0.159 ± 0.003	-2.798	0	15
	Males	15,938	42.2 ± 0.278	0.156 ± 0.004	-3.011	0	17
Richards Model	All Data	48,653	51.6 ± 0.116	0.175 ± 0.0001		0	17
	M & F	40,444	48.4 ± 0.402	0.195 ± 0.005		0	17
	Females	24,506	48.1 ± 0.460	0.196 ± 0.007		0	15
	Males	15,938	45.1 ± 0.432	0.195 ± 0.004		0	17

Table 2.6. Parameter estimates for von Bertalanffy growth equation by sex and combined sexes for each age data set used in the stock assessment for Atlantic croaker with Area Residual Sum of Squares (ARSS) F-statistic and associated p-value.

Data Set	Sex	L_{inf}	L_{inf} 95% CI	K	K 95% CI	t_o	N	SSR	ARSS	P-value
Commercial	M & F	47.5	0.164	0.1428	0.002	-3.8264	9,710	172327	0.065	0.973
	F	47.9	2.907	0.1555	0.025	-2.8528	169	2353		
	M	34.3	0.677	0.3483	0.041	-1.5241	151	1615		
ChesMMAP	M & F	42.2	0.173	0.1621	0.002	-3.2888	6,216	75168	49.3	<0.001
	F	42.8	0.222	0.1657	0.002	-3.1553	3,466	46015		
	M	41.1	0.266	0.1608	0.003	-3.4176	2,750	27839		
NEAMAP	M & F	46.2	1.033	0.1028	0.005	-4.2944	3,036	29604	70.9	<0.001
	F	43.3	1.024	0.1193	0.006	-3.9754	1,600	16458		
	M	53.3	2.804	0.0772	0.007	-4.8725	1,413	11789		
NMFS	M & F	43.1	0.174	0.1783	0.002	-2.9856	7,624	82958	154.4	<0.001
	F	44.3	0.244	0.1789	0.003	-2.9223	3,988	48196		
	M	42.7	0.281	0.1646	0.003	-3.2578	3,575	31283		
SEAMAP	M & F	41.4	1.672	0.1025	0.007	-4.6589	9,148	55009	1085.2	<0.001
	F	33.9	0.997	0.1535	0.010	-4.1613	5,051	31157		
	M	33.6	1.097	0.1806	0.012	-3.2199	3,870	16300		
Fishery	M & F	44.6	0.181	0.1480	0.001	-3.1093	28,491	792141	2660.7	<0.001
Independent	F	42.6	0.204	0.1689	0.002	-3.0753	14,815	385118		
Combined	M	39.7	0.179	0.1896	0.002	-2.9116	11,910	245180		

Table 2.7. Parameter estimates of the allometric length-weight function for Atlantic croaker from previous studies, where length is measured as total length in centimeters and weight is measured in grams.

Location	Collection Period	*a*	*b*	Reference
NW Gulf of Mexico		0.00741	3.15	Dawson 1965
Galveston Bay, TX	1963–1964	0.00773	3.10	Parker 1971
Albemarle Sound, NC	1972–1973	0.00721	3.15	Hester and Copeland 1975
Neuse River Estuary, NC	1972–1973	0.00444	3.34	Hester and Copeland 1975
NW Gulf of Mexico	1974	0.00776	3.15	White and Chittenden 1976, 1977
Georgia		0.0120	2.99	Shipman 1983
Georgia		0.00676	3.20	Music and Pafford 1984
Northern Gulf of Mexico	1980–1981	0.00722	3.13	Barger 1985
North Carolina	1979–1981	0.00545	3.23	Ross 1988
Chesapeake Bay	1988–1991	0.00481	3.30	Barbieri et al. 1994a
Northeast Atlantic	1992–1999	0.00918	3.09	Wigley et al. 2003
Atlantic Coast of U.S.	1997-2008	0.00549	3.13	ASMFC 2010

Table 2.8. Estimated length versus weight regression parameters from available assessment data sets.

Type	Area	Gear	Source	Sex	n	a	a (SE)	b	b (SE)
Survey	NE Atlantic	Trawl	NMFS	M	3,575	8.34894E-06	0.0212	3.119	0.0067
				F	3,988	8.63466E-06	0.0200	3.109	0.0062
Survey	NE Atlantic	Trawl	NEAMAP	M	1,623	1.11954E-05	0.0597	3.032	0.0197
				F	1,872	1.12196E-05	0.0531	3.032	0.0174
Survey	Ches. Bay	Trawl	ChesMMAP	M	2,864	1.11056E-05	0.0278	3.028	0.0087
				F	3,625	9.76669E-06	0.0255	3.073	0.0079
Survey	SE Atlantic	Trawl	SEAMAP	M	3,884	5.70511E-06	0.0293	3.190	0.0103
				F	5,074	5.32425E-06	0.0296	3.215	0.0102
Survey	NC	All	NCDMF	M	1,724	1.05529E-05	0.0584	3.042	0.0180
				F	6,172	9.44124E-06	0.0306	3.089	0.0094
Survey	SC	All	SC DNR	M	78	3.39838E-06	0.1373	3.404	0.0469
				F	465	4.51808E-06	0.1006	3.316	0.0326
Survey	GA	All	GA DNR	M	307	4.53999E-06	0.0648	3.310	0.0227
				F	721	4.17347E-06	0.0527	3.343	0.0185
Commercial	MD	Pound Net	MDDNR	M	967	9.16579E-06	0.0775	3.090	0.0229
				F	1,945	8.22487E-06	0.0490	3.126	0.0142
Commercial	MD	Gill Net	MDDNR	M	113	8.95381E-06	0.3619	3.107	0.1089
				F	210	1.088411E-05	0.2723	3.062	0.0813
Commercial	NC	All	NCDMF	M	2,508	8.89385E-06	0.0333	3.071	0.0101
				F	5,027	1.01867E-05	0.0225	3.036	0.0067

Table 2.9. Fixed allometric length vs. weight regression parameters used in the SS3 assessment model for Atlantic croaker.

Sex	n	a [SE]	b [SE]
Male	17,650	6.1406×10^{-6} (0.012259)	3.200647 (0.003917)
Female	29,322	6.4951×10^{-6} (0.009882)	3.186664 (0.003087)

Table 2.10. Sources of Atlantic croaker data and associated length measurements.

Source	Total Length (max)	Fork Length (midline)	Standard Length
NMFS	X	X	
NJBMF	X		
MDDNR	X	X	X
NEAMAP	X		
ChesMMAP	X		
VMRC	X	X	X
NCDMF	X		X
SEAMAP	X	X	X
SCDNR	X	X	X
GADNR	X	X	X
FLFWC	X	X	X
MRIP		X	

Table 2.11. Description of length measurements used for Atlantic croaker.

Measurement	Description
Total Length (max)	Measured from the most anterior point of the fish to the farthest tip of the tail with the tail compressed or squeezed together.
Total Length (relaxed)	Measured from the most anterior point of the head to the tip of the tail when the tail is left in the “natural position” (not squeezed).
Fork Length (midline)	Measured from the most anterior point of the fish to the rear center edge of the tail.
Standard Length	Measured from the most anterior point of the fish to the end of the vertebral column (caudal peduncle).

Table 2.12. Parameter estimates (standard error in parentheses) for isometric length conversion factors calculated for the current assessment for all data sets pooled across sexes and years for length in cm.

Type	Area	Gear	Source	Length (X)	Length (Y)	n	Length Range (cm)	a	b	r^2
Survey	SE Atlantic	Trawl	SEAMAP	SL	TL	9,175	7.5 - 37.5	1.177 (0.01319)	1.053 (0.01933)	0.989
Commercial	New Jersey	ALL	NJDFW	FL	TL	2,197	19.7 - 49.7	1.025 (0.00139)	-0.168 (0.42913)	0.996
Commercial	Virginia	ALL	VMRC	SL	TL	86,894	12.5 - 64.8	1.161 (0.00046)	1.282 (0.01111)	0.987
Commercial	Virginia	ALL	VMRC	FL	TL	7,635	12.5 - 64.8	1.013 (0.00147)	0.060 (0.04847)	0.984
Survey	Georgia	ALL	GADNR	SL	FL	409	2.3 - 31.8	1.176 (0.00373)	1.185 (0.05341)	0.996
Survey	South Carolina	ALL	SCDNR	SL	TL	24,325	1 - 42.5	1.206 (0.00043)	0.547 (0.00621)	0.997

Table 2.13. Maturity schedule for Atlantic croaker from previous studies and estimated here based on available datasets, pooled over years. Length is represented as total length in centimeters.

						Min. Length at Maturity		Length at 50% Maturity[1]		Min. Length at 100% Mature		% Mature at Age 2		
Type	**Area**	**Gear**	**Source**	**Collection Period**	**n**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Reference**
Survey	Ches. Bay		Literature			24.0	27.5					45.0	0	Wallace 1940
Survey	NE Atlantic	Trawl	Literature	1973–1976	1,708	17.0	18.0	18.7–22.4	18.5–23.3	23.0	25.0			Morse 1980
Commercial	Ches. Bay, VA, & NC	Various	Literature	1990–1991	3,091	17.0	15.0	18.2	17.3	25.0	26.0	>85.0		Barbieri et al. 1994b
Survey	NE Atlantic	Trawl	NMFS	1997–2014	4,856	14.0	13.0	16.9	18.4	27.0	30.0	98.1	97.5	ASMFC 2010
Survey	Ches. Bay	Trawl	ChesMMAP	2002–2014	4,454	14.1	13.6	22.3	20.7	34.0	32.0	63.9	83.9	ASMFC 2010
Survey	SE Atlantic	Trawl	SEAMAP	2001–2014	3,771	13.0	13.0	18.4	19.0	25.0	25.0	69.0	72.9	ASMFC 2010
Commercial	North Carolina	All	NCDMF[2]	1996–2014	4,352	18.0	11.0	22.4	19.3	25.0	29.0	66.7	90.4	ASMFC 2010
Survey	South Carolina	Trammel	SCDNR[3]	2014	340	19.0	19.0	18.5	13.9	21.0	26.0	100	97.1	SCDNR[3] 2015
All Data	Atlantic Coast	All	This Study	1996-2014	19,081	12.0	11.0	16.5	17.5	27.0	29.0	96.8	97.0	This Study

[1] Length at 50% maturity values were model-estimated based on observed data

[2] Maturity data were collected from the NCDMF's Program 930 are not considered overly reliable and should be interpreted with caution; estimates for males are based on very low sample sizes (n=92 for entire time period)

[3] SCDNR Unpublished Data

Table 2.14. Sex ratio by data set for Atlantic croaker on the Atlantic coast of the U.S.

Sampling Program	**Data Type**	**Males**	**Females**	**Total**	**Proportion Males**	**Proportion Females**	**Sex Ratio F:M**	**X^2**	**p-value**
NCDMF Fishery Dependent Sampling	FD	4,161	10,768	14,929	0.279	0.721	2.588	2929.2	<0.001
ChesMMAP	FI	2,788	3,522	6,310	0.442	0.558	1.263	12.3	<0.001
EMS (GADNR)	FD	178	389	567	0.314	0.686	2.185	287.3	<0.001
Fish House Sampling (MD)	FD	227	333	560	0.405	0.595	1.467	5.14	0.023
Gill Net (GADNR)	FD	30	162	192	0.156	0.844	5.400	11.13	0.001
NMFS Groundfish Survey	FI	3,575	3,988	7,563	0.473	0.527	1.116	22.5	<0.001
Hook and Line (GADNR)	FD	54	83	137	0.394	0.606	1.537	6.14	0.013
NEAMAP	FI	1,615	1,851	3,466	0.466	0.534	1.146	16.1	<0.001
SEAMAP	FI	3,884	5,074	8,958	0.434	0.566	1.306	664.9	<0.001
Summer Pound Net Survey (MDDNR)	FD	885	1,807	2,692	0.329	0.671	2.042	315.7	<0.001
GA Trammel Net	FI	58	395	453	0.128	0.872	6.810	250.7	<0.001
UGA Bulldog Trawl	FI	29	48	77	0.377	0.623	1.655	4.69	0.031
Fishery Dependent (Combined)	FD	5,481	13,542	19,023	0.288	0.712	2.471	342.1	<0.001
Fishery Independent (Combined	FI	11,949	14,878	26,827	0.445	0.555	1.245	407.6	<0.001
Total	-	17,430	28,420	46,858	0.372	0.607	1.631	2842.1	<0.001

Table 2.15. Monthly sex ratio by data set for Atlantic croaker on the Atlantic coast of the U.S.

Area	Gear	Data Type	Source	Collection Period	n	% Female											
						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
NE Atlantic	Trawl	FI	NMFS	1997-2014	7,560									53.2	46.5		
NE Atlantic	Trawl	FI	NEAMAP	2007-2014	3,303				50.5					54.8			
Ches. Bay	Trawl	FI	ChesMMAP	2002-2014	6,380			60.7		52.1		55.8		59	56.7	54.9	
SE Atlantic	Trawl	FI	SEAMAP	2001-2014	8,956				55.6	57.8		54.6	50.6	57.4	60.2	55.6	
Maryland	Pound Net	FD	MDDNR	2001-2014	3,313					62.7	64.6	62.6	71.2	90.8	40.3	66.7	
Georgia	All	FI	GADNR	2010-2012	1,026	50.0	87.5	91.7	77.6	75.0	71.2	67.0	67.2	68.3	70.7	66.7	100.0
North Carolina	All	FD	NCDMF	1996-2014	7,053	72.0	62.9	65.6	66.1	58.9	74.6	67.1	64.7	84.9	79.2	61.7	65.8
North Carolina	All	FI	NCDMF	1996-2014	7,515	73.6	64.8	68.5	71.4	71.4	72.7	82.3	82.8	86.2	89.6	78.5	71.0

Table 2.16. Estimates of age constant natural mortality (M) for Atlantic croaker by growth model using methods from Then et al. (2015) for both maximum age (T_{max}): where $M = 4.899 * T_{max}^{-0.916}$ and the von Bertalanffy (VOB) growth parameters: where $M = 4.118 * K^{0.73} * L_{\infty}^{-0.33}$.

Model	Sample Group	n	L_{∞} (cm)	K	T_{max}	Then et al. 2015 T_{max}	Then et al. 2015 VOB
VOB	All Age Samples	48,653	45.6	0.175	17	0.306	0.279
	Males & Females	40,444	45.9	0.161	17	0.306	0.267
	Females	24,506	47.7	0.159	15	0.336	0.260
	Males	15,938	44.2	0.156	17	0.306	0.262
Schnute	All Age Samples	48,653	44.1	0.175	17	0.306	0.282
	Males & Females	40,444	44.1	0.161	17	0.306	0.267
	Females	24,506	44.9	0.159	15	0.336	0.256
	Males	15,938	42.2	0.156	17	0.306	0.262
Richards	All Age Samples	48,653	51.6	0.175	17	0.306	0.269
	Males & Females	40,444	48.4	0.195	17	0.306	0.293
	Females	24,506	48.1	0.196	15	0.336	0.295
	Males	15,938	45.1	0.195	17	0.306	0.299

Table 2.17. Estimates of age-specific natural mortality (M) by sex and combined for Atlantic croaker based on Lorenzen (2005) using von Bertalanffy growth parameters (L_∞, k, t_o) and scaled using Then et al. 2015.

Age	All Data (n=48,653)	Males and Females (n = 40,444)	Females: n = 24,506	Males: n=15,938
0	0.451	0.423	0.410	0.415
1	0.385	0.365	0.352	0.360
2	0.343	0.326	0.314	0.323
3	0.314	0.299	0.287	0.297
4	0.293	0.280	0.268	0.278
5	0.278	0.265	0.253	0.263
6	0.266	0.254	0.242	0.252
7	0.257	0.245	0.233	0.243
8	0.249	0.237	0.226	0.236
9	0.244	0.232	0.221	0.230
10	0.239	0.227	0.216	0.226
11	0.235	0.223	0.212	0.222
12	0.232	0.220	0.209	0.218
13	0.230	0.217	0.207	0.216
14	0.228	0.215	0.204	0.214
15	0.226	0.213	0.203	0.212
16	0.225	0.212	-	0.210
17	0.223	0.210	-	0.209
Mean after age 1 (age at full recruitment)	0.263	0.249	0.243	0.248

Table 4.1. Commercial harvest (pounds) of Atlantic croaker by state, 1981-2014. Asterik indicates values occurred in that year but are confidential.

Year	NJ	DE	MD	PRFC	VA	NC	SC	GA	FL	Total
1981	23,500	0	2,104	648	429,800	11,205,342	2,441	1,038	72,112	11,736,985
1982	100	0	7,091	188	119,300	10,824,953	386	2,177	95,357	11,049,552
1983	200	0	417	1,549	150,400	7,249,680	3,200	1,097	81,737	7,488,280
1984	57,700	0	27,072	73,701	817,700	9,170,775	3,793	434	131,375	10,282,550
1985	48,800	100	9,510	19,854	2,171,821	8,714,432	1,256		153,803	11,119,576
1986	106,000	500	135,922	99,373	2,367,000	9,424,828	924		173,531	12,308,078
1987	357,600	800	119,409	102,691	2,719,500	7,289,191	698	553	217,932	10,808,374
1988	30,100	200	98,855	12,796	1,749,200	8,434,415	2,614	304	140,033	10,468,517
1989	137,100	0	89,173	5,579	949,649	6,824,088	1,950		95,021	8,102,560
1990	644	42	2,473	5,115	201,353	5,769,512	1,190		104,402	6,084,731
1991	31,292	700	6,183	996	164,126	3,436,960	*		56,739	3,696,996
1992	51,600	800	17,050	17,692	1,339,353	2,796,612			79,040	4,302,147
1993	183,414	2,500	114,159	262,482	5,326,293	3,267,652	*		52,031	9,208,531
1994	117,256	3,000	158,918	240,271	5,759,975	4,615,754	*		96,018	10,991,192
1995	334,654	13,000	489,506	606,184	6,949,639	6,021,284	*		22,879	14,437,146
1996	621,889	9,681	792,326	1,427,285	9,409,904	9,961,834			26,045	22,248,964
1997	1,994,446	10,509	1,088,969	1,518,196	12,832,221	10,711,667	*		36,577	28,192,585
1998	1,029,332	10,368	1,006,529	610,885	11,898,586	10,865,897			26,418	25,448,015
1999	2,071,046	14,729	948,191	1,190,138	12,481,326	10,185,507			26,824	26,917,761
2000	2,130,465	11,121	902,379	1,812,130	12,822,400	10,122,627			37,953	27,839,075
2001	1,389,837	22,736	1,488,815	1,963,294	13,214,731	12,017,424		*	14,831	30,111,668
2002	1,828,484	10,732	894,879	1,421,094	12,133,834	10,189,153	*	*	17,191	26,495,367
2003	1,575,738	16,561	713,205	1,128,003	10,937,167	14,429,197	140	*	16,348	28,816,359
2004	2,067,992	30,369	1,354,982	1,631,596	8,550,574	11,993,003	*	*	11,413	25,639,929
2005	1,847,753	36,624	972,800	481,912	8,211,802	11,903,292	41	*	16,520	23,470,744
2006	1,617,144	19,307	466,833	670,276	9,252,110	10,396,554	160	*	30,272	22,452,656
2007	1,358,000	13,522	474,388	188,567	10,557,370	7,301,295	*		27,028	19,920,170
2008	946,062	10,465	592,211	337,062	11,796,771	5,791,874	116	*	31,560	19,506,121
2009	585,552	16,341	433,238	234,101	8,808,677	6,135,427	215	0	32,313	16,245,864
2010	342,116	6,182	490,067	162,571	7,879,847	7,312,159	3	0	36,960	16,229,905
2011	465,117	12,252	736,259	243,196	5,611,855	5,054,186	44	*	44,932	12,167,841
2012	363,381	2,811	901,455	273,849	6,963,815	3,106,616	62	*	74,023	11,686,012
2013	337,313	6,700	884,363	130,285	6,621,836	1,928,637	2	0	71,573	9,980,709
2014	271,706	9,647	478,674	177,777	3,406,958	2,629,793	247	0	45,314	7,020,116

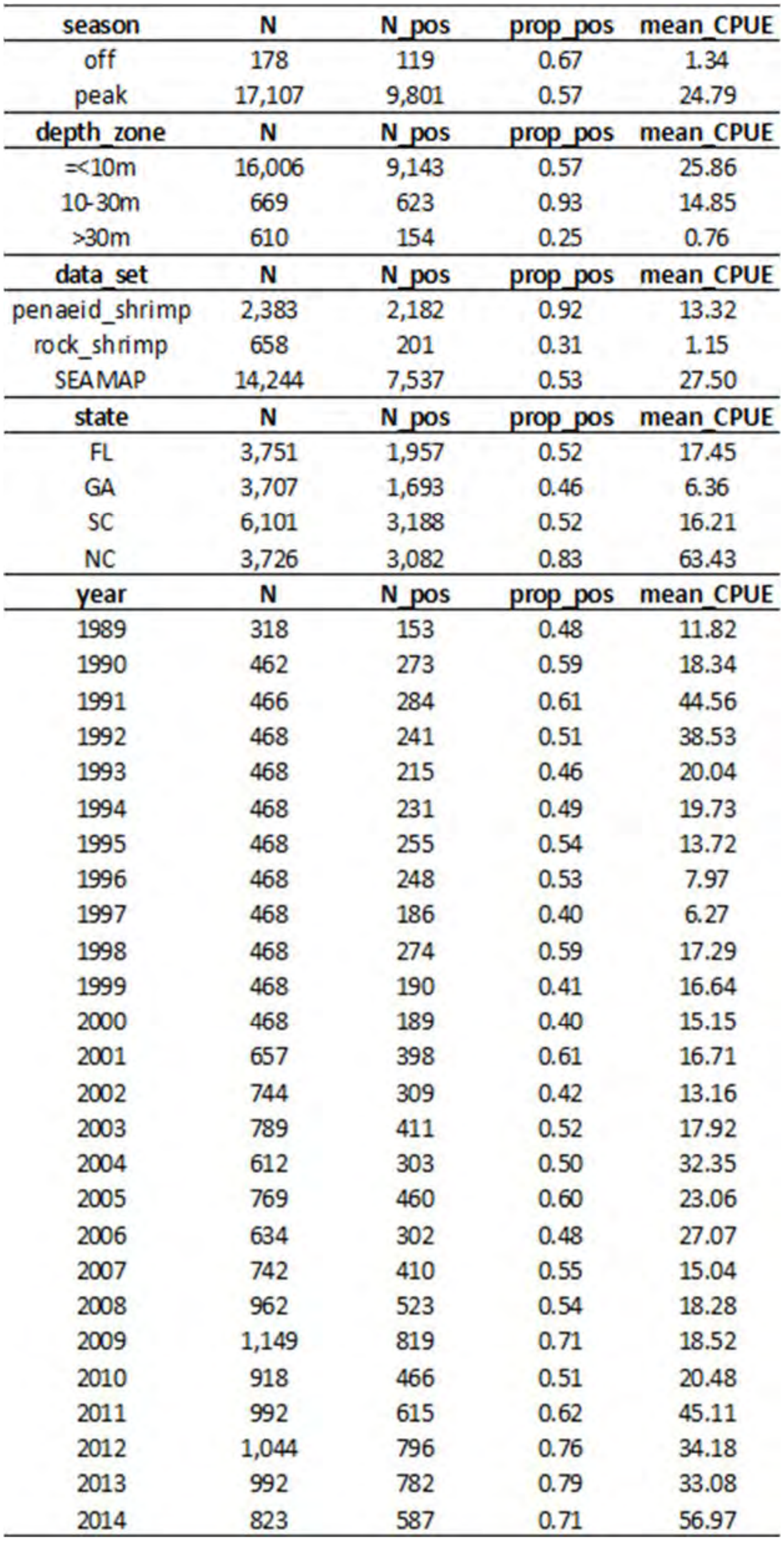
Table 4.2. Recreational harvest (numbers) of Atlantic croaker by state, 1981-2014.

Year	NJ	DE	MD	VA	NC	SC	GA	FL	Total
1981	1,054	3,003	0	964,013	1,043,240	165,742	35,591	598,896	2,811,539
1982			10,452	273,039	596,493	193,554	169,749	1,682,619	2,925,906
1983			108,355	2,154,133	1,620,909	60,811	75,173	1,148,227	5,167,608
1984			211,035	2,047,720	2,147,871	588,114	202,364	2,781,742	7,978,846
1985			21,276	2,284,334	723,933	260,265	144,341	1,306,955	4,741,104
1986		4,694	123,578	6,384,966	356,742	599,442	69,887	5,118,552	12,657,861
1987	0	0	208,488	3,234,224	904,030	166,978	44,783	2,580,727	7,139,230
1988		1,186	1,005,452	4,048,690	2,256,128	144,057	64,093	685,778	8,205,384
1989		478	22,871	2,203,504	2,131,763	217,023	72,598	359,417	5,007,654
1990		281	100,673	2,374,679	1,063,452	346,631	585,380	304,064	4,775,160
1991	16,235	37,500	288,471	4,298,542	434,067	100,816	184,435	1,030,115	6,390,181
1992	0	9,854	117,427	4,524,040	723,823	74,051	440,185	754,595	6,643,975
1993	2,552	19,352	805,560	4,990,098	755,998	32,700	89,734	304,067	7,000,061
1994	1,567	5,718	1,633,581	6,494,691	1,179,735	188,520	102,974	599,032	10,205,818
1995	15,184	136,865	827,183	5,029,708	850,606	75,422	100,826	438,076	7,473,870
1996	35,037	235,389	775,115	4,997,021	662,240	37,464	61,957	116,575	6,920,798
1997	342,089	385,586	1,053,232	8,066,926	661,116	118,428	64,050	235,430	10,926,857
1998	143,404	391,231	1,126,058	6,730,181	387,427	170,528	64,953	234,360	9,248,142
1999	357,261	662,724	1,209,572	5,881,671	442,185	54,761	104,438	403,982	9,116,594
2000	1,023,442	517,886	2,674,880	5,486,159	391,056	32,332	128,922	455,870	10,710,547
2001	1,177,813	312,005	1,319,928	9,335,313	635,552	19,802	21,503	426,264	13,248,180
2002	253,472	261,634	1,223,385	9,129,060	408,944	66,409	36,497	177,751	11,557,152
2003	692,391	341,174	1,619,766	6,695,192	490,399	198,339	248,853	165,459	10,451,573
2004	855,927	389,218	896,855	8,259,608	511,418	171,544	38,599	415,570	11,538,739
2005	1,227,349	825,267	784,246	7,657,147	326,777	143,387	39,561	302,784	11,306,518
2006	511,220	763,216	754,969	7,221,148	556,024	58,500	34,081	172,586	10,071,744
2007	406,238	359,064	872,838	6,944,886	461,162	38,147	45,068	310,130	9,437,533
2008	600,975	368,911	619,942	8,388,497	317,940	65,853	38,246	449,054	10,849,418
2009	193,464	451,849	1,335,439	5,327,388	368,990	238,900	82,269	438,209	8,436,508
2010	63,027	75,404	1,136,589	4,743,697	478,156	46,464	35,635	132,664	6,711,636
2011	40,855	92,289	554,206	3,305,707	246,676	349,464	44,044	476,292	5,109,533
2012	237,994	84,403	701,482	3,445,232	288,812	27,541	38,402	589,643	5,413,509
2013	875,200	222,401	1,155,538	4,273,744	411,882	99,356	54,915	586,411	7,679,447
2014	266,664	359,010	1,085,339	3,429,768	541,474	146,430	64,138	298,332	6,191,145

Table 4.3. Recreational releases (number) of Atlantic croaker by state, 1981-2014.

Year	NJ	DE	MD	VA	NC	SC	GA	FL	Total
1981			16,233	324,238	704,259	128,192	13,481	85,740	1,272,143
1982				77,756	641,327	107,340	111,630	188,277	1,126,330
1983			1,507,184	1,410,151	424,562	119,036	70,499	379,021	3,910,453
1984			70,192	673,080	1,701,418	746,905	37,573	236,432	3,465,600
1985			13,132	1,616,052	1,596,901	238,678	66,649	1,146,582	4,677,994
1986		1,757	43,399	2,578,268	137,841	84,335	40,623	318,511	3,204,734
1987	1,374	861	32,074	2,056,580	560,853	108,366	76,908	1,770,697	4,607,713
1988		582	273,231	832,284	984,219	112,271	20,021	200,630	2,423,238
1989		1,307	41,822	1,342,169	891,926	58,642	17,632	72,822	2,426,320
1990		1,268	88,688	3,922,564	1,351,152	111,085	317,497	168,144	5,960,398
1991	91,633	75,319	3,352,190	7,418,045	669,385	25,168	140,402	647,824	12,419,966
1992	4,103	43,583	856,292	4,167,137	954,494	26,729	178,267	251,343	6,481,948
1993	5,799	13,194	2,504,362	5,795,479	1,499,217	16,949	83,203	138,875	10,057,078
1994	17,253	14,069	1,628,824	7,676,780	3,110,528	141,513	99,026	331,736	13,019,729
1995	31,019	41,574	496,046	5,494,289	1,172,716	108,345	89,609	141,732	7,575,330
1996	17,585	76,851	403,776	5,151,206	1,218,799	64,494	60,282	126,300	7,119,293
1997	111,468	384,233	1,497,670	7,275,160	1,443,568	138,107	25,630	116,276	10,992,112
1998	221,324	839,932	3,021,780	4,990,541	1,060,928	266,068	159,928	152,744	10,713,245
1999	860,325	1,017,499	2,483,800	5,668,925	1,368,478	116,826	57,567	967,894	12,541,314
2000	688,746	694,813	4,967,856	7,811,048	1,569,385	96,402	169,903	428,131	16,426,284
2001	853,621	285,123	1,585,806	7,086,706	1,256,807	115,284	192,362	282,461	11,658,170
2002	369,003	361,355	2,523,276	7,107,656	925,806	92,498	194,474	217,054	11,791,122
2003	833,508	654,697	1,393,224	6,543,524	1,552,315	440,446	965,496	192,356	12,575,566
2004	1,237,164	599,207	854,132	6,276,767	1,656,049	320,788	154,259	253,951	11,352,317
2005	1,692,401	674,684	1,136,876	8,738,109	1,401,413	321,861	280,889	293,692	14,539,925
2006	503,490	937,193	1,783,557	4,193,675	2,578,819	595,075	283,851	187,562	11,063,222
2007	590,078	672,771	1,258,131	8,504,212	1,608,120	224,454	228,564	321,559	13,407,889
2008	2,373,945	601,994	2,127,219	7,806,627	1,419,019	205,373	293,926	596,450	15,424,553
2009	108,370	537,587	1,137,578	7,621,484	1,912,670	514,839	434,608	406,822	12,673,958
2010	167,191	228,936	1,011,236	4,824,151	1,598,139	187,138	263,987	188,637	8,469,415
2011	62,391	88,524	365,716	4,872,928	1,798,230	240,605	262,493	452,669	8,143,556
2012	1,134,778	444,935	1,578,524	5,091,063	1,255,215	216,420	167,488	641,569	10,529,992
2013	765,652	764,045	2,905,537	5,968,340	1,984,701	793,500	298,409	550,130	14,030,314
2014	206,098	630,964	1,148867	3,606,078	2,714,578	763,159	470,751	393,360	9,933,855

Table 4.5. Number of observations, number of positive observations, proportion positive observations, and mean CPUE (weight in kg) of Atlantic croaker by factor level considered in the model.



season	N	N_pos	prop_pos	mean_CPUE
off	178	119	0.67	1.34
peak	17,107	9,801	0.57	24.79

depth_zone	N	N_pos	prop_pos	mean_CPUE
=<10m	16,006	9,143	0.57	25.86
10-30m	669	623	0.93	14.85
>30m	610	154	0.25	0.76

data_set	N	N_pos	prop_pos	mean_CPUE
penaeid_shrimp	2,383	2,182	0.92	13.32
rock_shrimp	658	201	0.31	1.15
SEAMAP	14,244	7,537	0.53	27.50

state	N	N_pos	prop_pos	mean_CPUE
FL	3,751	1,957	0.52	17.45
GA	3,707	1,693	0.46	6.36
SC	6,101	3,188	0.52	16.21
NC	3,726	3,082	0.83	63.43

year	N	N_pos	prop_pos	mean_CPUE
1989	318	153	0.48	11.82
1990	462	273	0.59	18.34
1991	466	284	0.61	44.56
1992	468	241	0.51	38.53
1993	468	215	0.46	20.04
1994	468	231	0.49	19.73
1995	468	255	0.54	13.72
1996	468	248	0.53	7.97
1997	468	186	0.40	6.27
1998	468	274	0.59	17.29
1999	468	190	0.41	16.64
2000	468	189	0.40	15.15
2001	657	398	0.61	16.71
2002	744	309	0.42	13.16
2003	789	411	0.52	17.92
2004	612	303	0.50	32.35
2005	769	460	0.60	23.06
2006	634	302	0.48	27.07
2007	742	410	0.55	15.04
2008	962	523	0.54	18.28
2009	1,149	819	0.71	18.52
2010	918	466	0.51	20.48
2011	992	615	0.62	45.11
2012	1,044	796	0.76	34.18
2013	992	782	0.79	33.08
2014	823	587	0.71	56.97

Table 4.6. Number of observations, number of positive observations, proportion positive observations, and mean CPUE (number) of Atlantic croaker by factor level considered in the model.

season	N	N_pos	prop_pos	mean_CPUE
off	178	119	0.67	21.07
peak	17,096	9,788	0.57	490.31

depth_zone	N	N_pos	prop_pos	mean_CPUE
=<10m	15,997	9,132	0.57	510.25
10-30m	667	621	0.93	330.13
>30m	610	154	0.25	5.76

data_set	N	N_pos	prop_pos	mean_CPUE
penaeid_shrimp	2,370	2,169	0.92	428.78
rock_shrimp	658	201	0.31	13.30
SEAMAP	14,246	7,537	0.53	516.72

state	N	N_pos	prop_pos	mean_CPUE
FL	3,750	1,954	0.52	329.26
GA	3,704	1,699	0.46	135.31
SC	6,099	3,192	0.52	339.17
NC	3,721	3,062	0.82	1231.28

year	N	N_pos	prop_pos	mean_CPUE
1989	318	153	0.48	215.41
1990	462	273	0.59	366.70
1991	466	284	0.61	678.18
1992	468	241	0.51	636.02
1993	468	215	0.46	313.72
1994	468	231	0.49	356.59
1995	468	255	0.54	225.78
1996	468	248	0.53	176.08
1997	468	185	0.40	110.79
1998	468	275	0.59	358.53
1999	468	189	0.40	331.53
2000	468	190	0.41	257.04
2001	657	397	0.60	347.31
2002	744	310	0.42	206.97
2003	789	411	0.52	265.12
2004	612	302	0.49	530.75
2005	769	460	0.60	459.91
2006	634	302	0.48	547.79
2007	743	411	0.55	232.52
2008	962	523	0.54	414.46
2009	1,149	819	0.71	387.27
2010	917	464	0.51	483.27
2011	992	615	0.62	937.14
2012	1,044	796	0.76	648.20
2013	982	772	0.79	849.34
2014	822	586	0.71	1241.48

Table 4.7. Lognormal model summary for Atlantic croaker discard rate in weight.

```
Call:
glm(formula = lnCPUE ~ YEAR + data_set + depth_zone + state + 
    season, family = gaussian, data = trips_pr_pos, na.action = na.exclude)

Deviance Residuals: 
    Min       1Q   Median       3Q      Max  
-7.6045  -1.3629   0.1546   1.4066   6.2395  

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)    
(Intercept)         -2.85505    0.26001 -10.981  < 2e-16 ***
YEAR1990             1.17156    0.19716   5.942 2.91e-09 ***
YEAR1991             1.90070    0.19588   9.703  < 2e-16 ***
YEAR1992             1.56210    0.20181   7.740 1.09e-14 ***
YEAR1993             0.81657    0.20654   3.954 7.75e-05 ***
YEAR1994             1.06951    0.20356   5.254 1.52e-07 ***
YEAR1995             0.96549    0.19960   4.837 1.34e-06 ***
YEAR1996             0.56078    0.20065   2.795 0.005204 ** 
YEAR1997             0.21108    0.21309   0.991 0.321936    
YEAR1998             0.85043    0.19701   4.317 1.60e-05 ***
YEAR1999             0.97552    0.21202   4.601 4.26e-06 ***
YEAR2000             0.65038    0.21226   3.064 0.002189 ** 
YEAR2001             1.00309    0.18617   5.388 7.29e-08 ***
YEAR2002             0.75396    0.19529   3.861 0.000114 ***
YEAR2003             1.00687    0.18812   5.352 8.87e-08 ***
YEAR2004             1.46040    0.19384   7.534 5.34e-14 ***
YEAR2005             1.19672    0.18293   6.542 6.37e-11 ***
YEAR2006             1.93074    0.19393   9.956  < 2e-16 ***
YEAR2007             1.00821    0.18573   5.428 5.82e-08 ***
YEAR2008             1.75814    0.18143   9.691  < 2e-16 ***
YEAR2009             1.52103    0.17483   8.700  < 2e-16 ***
YEAR2010             1.63185    0.18323   8.906  < 2e-16 ***
YEAR2011             2.21120    0.17785  12.433  < 2e-16 ***
YEAR2012             1.98725    0.17442  11.393  < 2e-16 ***
YEAR2013             1.91042    0.17423  10.965  < 2e-16 ***
YEAR2014             2.37701    0.17827  13.333  < 2e-16 ***
data_setrock_shrimp -0.34494    0.27901  -1.236 0.216370    
data_setSEAMAP       1.09095    0.06021  18.120  < 2e-16 ***
depth_zone>30m       0.17719    0.31509   0.562 0.573899    
depth_zone10-30m     1.06246    0.10532  10.088  < 2e-16 ***
stateGA             -0.67295    0.06917  -9.729  < 2e-16 ***
stateNC              1.33076    0.06334  21.011  < 2e-16 ***
stateSC             -0.07407    0.06294  -1.177 0.239323    
seasonpeak           2.13060    0.19528  10.910  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 3.809441)

    Null deviance: 47723  on 9919  degrees of freedom
Residual deviance: 37660  on 9886  degrees of freedom
AIC: 41456

Number of Fisher Scoring iterations: 2
```

Table 4.8. Binomial model summary for Atlantic croaker discard rate in weight.

```
Call:
glm(formula = success ~ YEAR + data_set + depth_zone + state +
    season, family = binomial(link = "logit"), data = trips_pr,
    na.action = na.exclude, offset = effort)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-3.3728  -1.0353   0.3251   1.0834   3.0136

Coefficients:
                    Estimate Std. Error z value Pr(>|z|)
(Intercept)         -2.69404    0.26710 -10.086  < 2e-16 ***
YEAR1990             0.47068    0.15235   3.089 0.002006 **
YEAR1991             0.55413    0.15247   3.634 0.000279 ***
YEAR1992             0.13690    0.15134   0.905 0.365679
YEAR1993            -0.10491    0.15176  -0.691 0.489356
YEAR1994             0.04405    0.15141   0.291 0.771089
YEAR1995             0.26594    0.15141   1.756 0.079028 .
YEAR1996             0.20111    0.15135   1.329 0.183917
YEAR1997            -0.38175    0.15314  -2.493 0.012673 *
YEAR1998             0.45606    0.15174   3.006 0.002651 **
YEAR1999            -0.33813    0.15282  -2.213 0.026926 *
YEAR2000            -0.35580    0.15294  -2.326 0.019999 *
YEAR2001             0.42309    0.14511   2.916 0.003549 **
YEAR2002            -0.40111    0.14305  -2.804 0.005048 **
YEAR2003             0.28950    0.14239   2.033 0.042043 *
YEAR2004            -0.05615    0.14507  -0.387 0.698743
YEAR2005             0.04695    0.14305   0.328 0.742750
YEAR2006            -0.08194    0.14443  -0.567 0.570464
YEAR2007            -0.06157    0.14295  -0.431 0.666711
YEAR2008            -0.09848    0.14119  -0.698 0.485490
YEAR2009             0.35112    0.13965   2.514 0.011925 *
YEAR2010            -0.28155    0.14104  -1.996 0.045903 *
YEAR2011             0.10346    0.13936   0.742 0.457844
YEAR2012             0.74368    0.14230   5.226 1.73e-07 ***
YEAR2013             1.20224    0.14638   8.213  < 2e-16 ***
YEAR2014             0.75999    0.14476   5.250 1.52e-07 ***
data_setrock_shrimp -1.51067    0.49170  -3.072 0.002124 **
data_setSEAMAP       0.01436    0.10054   0.143 0.886428
depth_zone>30m      -2.72439    0.49921  -5.457 4.83e-08 ***
depth_zone10-30m     0.92592    0.20408   4.537 5.70e-06 ***
stateGA             -0.25713    0.05371  -4.787 1.69e-06 ***
stateNC              1.53275    0.06045  25.355  < 2e-16 ***
stateSC              0.04216    0.04938   0.854 0.393196
seasonpeak           2.05873    0.23615   8.718  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 24180  on 17284  degrees of freedom
Residual deviance: 20199  on 17251  degrees of freedom
AIC: 20267

Number of Fisher Scoring iterations: 5
```

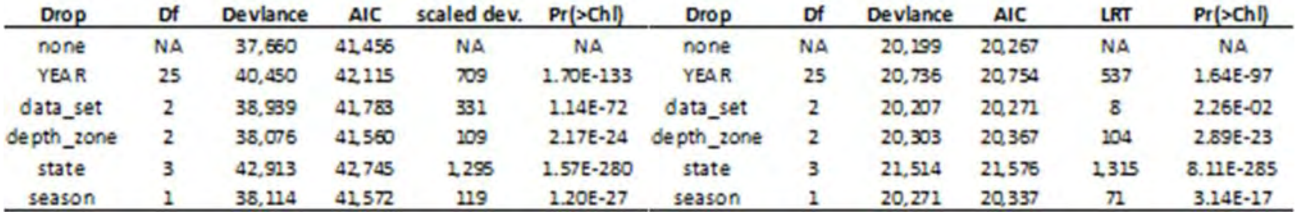
Table 4.9. Lognormal model summary for Atlantic croaker discard rate in numbers.

```
Call:
glm(formula = lnCPUE ~ YEAR + data_set + depth_zone + state + 
    season, family = gaussian, data = trips_pr_pos, na.action = na.exclude)

Deviance Residuals: 
    Min       1Q   Median       3Q      Max  
-5.8513  -1.4029   0.1647   1.3888   5.5853  

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)    
(Intercept)          0.51729    0.26204   1.974 0.048405 *  
YEAR1990             1.16439    0.19865   5.862 4.73e-09 ***
YEAR1991             1.78677    0.19735   9.054  < 2e-16 ***
YEAR1992             1.31359    0.20333   6.460 1.09e-10 ***
YEAR1993             0.78797    0.20809   3.787 0.000154 ***
YEAR1994             0.97146    0.20509   4.737 2.20e-06 ***
YEAR1995             0.92757    0.20111   4.612 4.03e-06 ***
YEAR1996             0.63392    0.20216   3.136 0.001720 ** 
YEAR1997             0.18231    0.21495   0.848 0.396374    
YEAR1998             1.00285    0.19838   5.055 4.37e-07 ***
YEAR1999             1.15445    0.21387   5.398 6.90e-08 ***
YEAR2000             0.66504    0.21361   3.113 0.001855 ** 
YEAR2001             1.11302    0.18764   5.932 3.10e-09 ***
YEAR2002             0.75062    0.19666   3.817 0.000136 ***
YEAR2003             0.91211    0.18952   4.813 1.51e-06 ***
YEAR2004             1.49380    0.19540   7.645 2.29e-14 ***
YEAR2005             1.28536    0.18431   6.974 3.28e-12 ***
YEAR2006             1.99701    0.19540  10.220  < 2e-16 ***
YEAR2007             1.11264    0.18707   5.948 2.81e-09 ***
YEAR2008             1.76145    0.18281   9.636  < 2e-16 ***
YEAR2009             1.40212    0.17616   7.959 1.92e-15 ***
YEAR2010             1.76902    0.18472   9.577  < 2e-16 ***
YEAR2011             2.15329    0.17920  12.016  < 2e-16 ***
YEAR2012             1.84774    0.17575  10.514  < 2e-16 ***
YEAR2013             2.06256    0.17567  11.741  < 2e-16 ***
YEAR2014             2.38504    0.17965  13.276  < 2e-16 ***
data_setrock_shrimp -0.53611    0.28115  -1.907 0.056565 .  
data_setSEAMAP       0.47859    0.06081   7.871 3.90e-15 ***
depth_zone>30m      -1.13347    0.31760  -3.569 0.000360 ***
depth_zone10-30m     0.58611    0.10639   5.509 3.70e-08 ***
stateGA             -0.66073    0.06971  -9.478  < 2e-16 ***
stateNC              1.26699    0.06395  19.813  < 2e-16 ***
stateSC             -0.06262    0.06346  -0.987 0.323787    
seasonpeak           2.30204    0.19679  11.698  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 3.867061)

    Null deviance: 47967  on 9906  degrees of freedom
Residual deviance: 38179  on 9873  degrees of freedom
AIC: 41550

Number of Fisher Scoring iterations: 2
```

Table 4.10. Binomial model summary for Atlantic croaker discard rate in numbers.

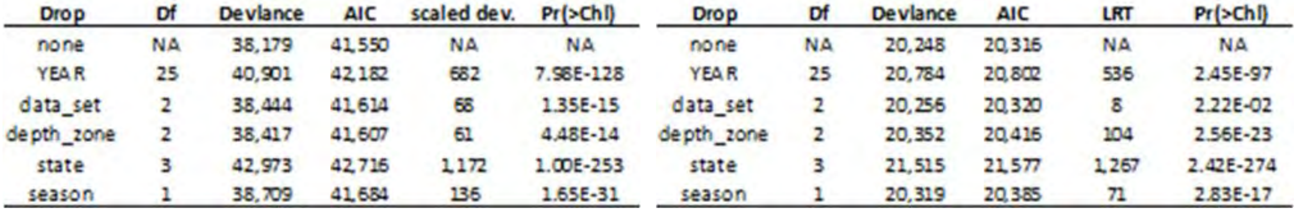
```
Call:
glm(formula = success ~ YEAR + data_set + depth_zone + state + 
    season, family = binomial(link = "logit"), data = trips_pr, 
    na.action = na.exclude, offset = effort)
Deviance Residuals: 
    Min       1Q   Median       3Q      Max  
-3.3766  -1.0345   0.3273   1.0822   3.0119  

Coefficients:
                    Estimate Std. Error z value Pr(>|z|)    
(Intercept)         -2.70734    0.26696 -10.141  < 2e-16 ***
YEAR1990             0.46986    0.15215   3.088  0.00201 ** 
YEAR1991             0.55318    0.15227   3.633  0.00028 ***
YEAR1992             0.13702    0.15111   0.907  0.36454    
YEAR1993            -0.10406    0.15152  -0.687  0.49220    
YEAR1994             0.04444    0.15118   0.294  0.76879    
YEAR1995             0.26572    0.15120   1.757  0.07885 .  
YEAR1996             0.20106    0.15113   1.330  0.18340    
YEAR1997            -0.38969    0.15295  -2.548  0.01084 *  
YEAR1998             0.46468    0.15158   3.066  0.00217 ** 
YEAR1999            -0.34615    0.15263  -2.268  0.02334 *  
YEAR2000            -0.34422    0.15263  -2.255  0.02412 *  
YEAR2001             0.41708    0.14486   2.879  0.00399 ** 
YEAR2002            -0.39082    0.14278  -2.737  0.00619 ** 
YEAR2003             0.29080    0.14218   2.045  0.04082 *  
YEAR2004            -0.06019    0.14483  -0.416  0.67769    
YEAR2005             0.04980    0.14281   0.349  0.72731    
YEAR2006            -0.07896    0.14418  -0.548  0.58390    
YEAR2007            -0.05513    0.14268  -0.386  0.69922    
YEAR2008            -0.09580    0.14096  -0.680  0.49674    
YEAR2009             0.35286    0.13944   2.531  0.01139 *  
YEAR2010            -0.28364    0.14081  -2.014  0.04397 *  
YEAR2011             0.10596    0.13914   0.762  0.44632    
YEAR2012             0.74534    0.14210   5.245 1.56e-07 ***
YEAR2013             1.19945    0.14623   8.202 2.36e-16 ***
YEAR2014             0.76101    0.14456   5.264 1.41e-07 ***
data_setrock_shrimp -1.50952    0.49178  -3.069  0.00214 ** 
data_setSEAMAP       0.02117    0.10052   0.211  0.83315    
depth_zone>30m      -2.71726    0.49929  -5.442 5.26e-08 ***
depth_zone10-30m     0.93278    0.20412   4.570 4.88e-06 ***
stateGA             -0.24214    0.05369  -4.510 6.49e-06 ***
stateNC              1.50644    0.06017  25.037  < 2e-16 ***
stateSC              0.04989    0.04937   1.010  0.31227    
seasonpeak           2.06115    0.23608   8.731  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 24180  on 17273  degrees of freedom
Residual deviance: 20248  on 17240  degrees of freedom
AIC: 20316

Number of Fisher Scoring iterations: 5
```

Table 4.11. Model selection summary for Atlantic croaker lognormal (left) and binomial (right) models of discard rate in weight.



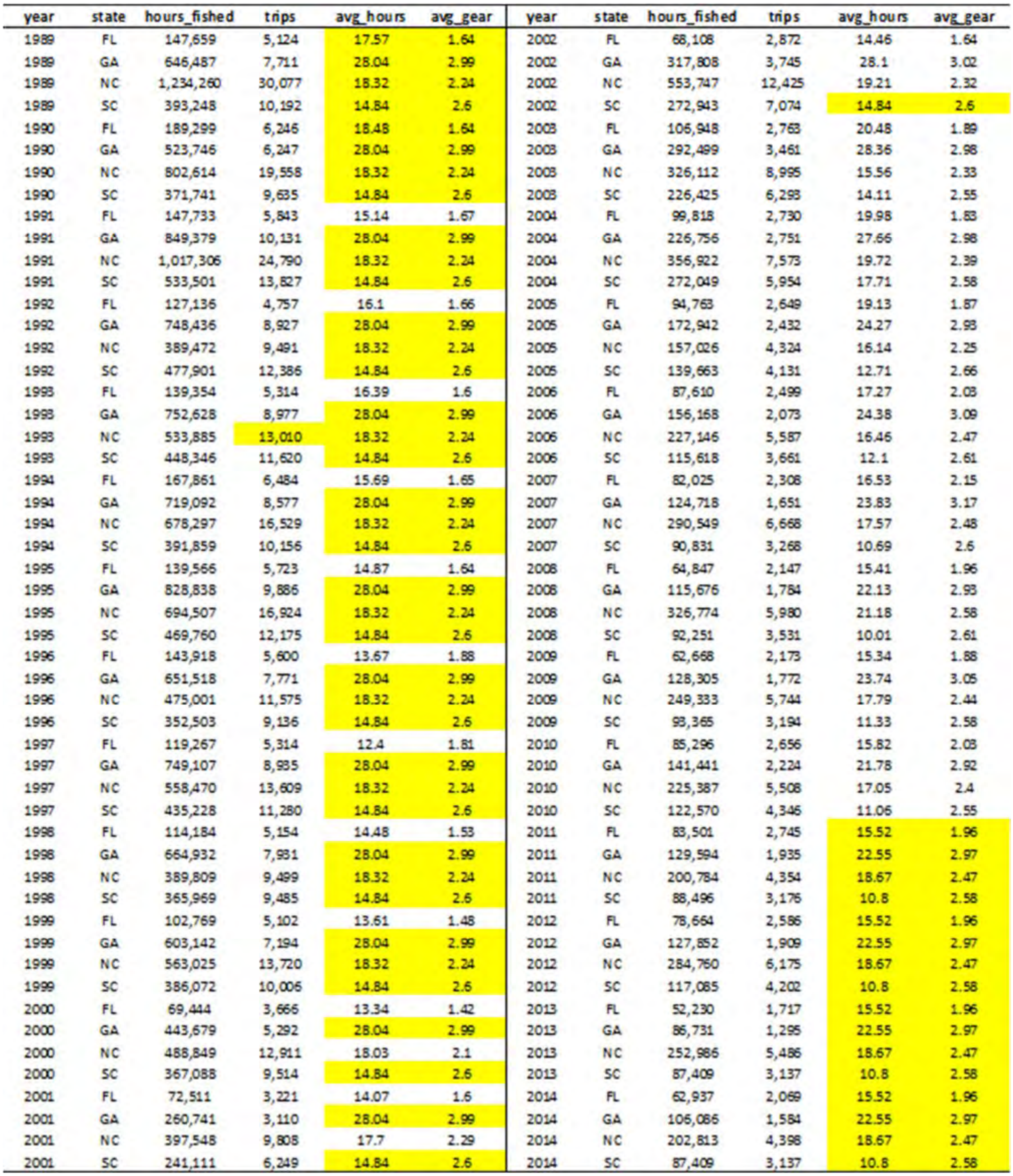
Drop	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	Drop	Df	Deviance	AIC	LRT	Pr(>Chi)
none	NA	37,660	41,456	NA	NA	none	NA	20,199	20,267	NA	NA
YEAR	25	40,450	42,115	709	1.70E-133	YEAR	25	20,736	20,754	537	1.64E-97
data_set	2	38,939	41,783	331	1.14E-72	data_set	2	20,207	20,271	8	2.26E-02
depth_zone	2	38,076	41,560	109	2.17E-24	depth_zone	2	20,303	20,367	104	2.89E-23
state	3	42,913	42,745	1,295	1.57E-280	state	3	21,514	21,576	1,315	8.11E-285
season	1	38,114	41,572	119	1.20E-27	season	1	20,271	20,337	71	3.14E-17

Table 4.12. Model selection summary for Atlantic croaker lognormal (left) and binomial (right) models of discard rate in numbers.



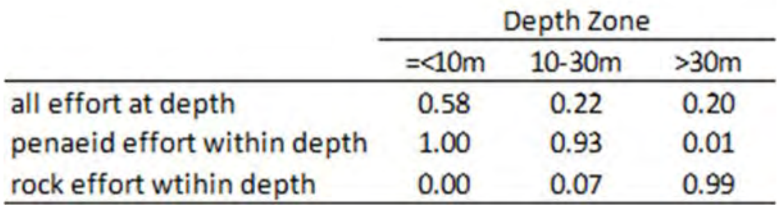
Drop	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	Drop	Df	Deviance	AIC	LRT	Pr(>Chi)
none	NA	38,179	41,550	NA	NA	none	NA	20,248	20,316	NA	NA
YEAR	25	40,901	42,182	682	7.98E-128	YEAR	25	20,784	20,802	536	2.45E-97
data_set	2	38,444	41,614	68	1.35E-15	data_set	2	20,256	20,320	8	2.22E-02
depth_zone	2	38,417	41,607	61	4.48E-14	depth_zone	2	20,352	20,416	104	2.56E-23
state	3	42,973	42,716	1,172	1.00E-253	state	3	21,515	21,577	1,267	2.42E-274
season	1	38,709	41,684	136	1.65E-31	season	1	20,319	20,385	71	2.83E-17

Table 4.13. Summary of effort data by year and state. Averages are highlighted in yellow.



year	state	hours_fished	trips	avg_hours	avg_gear
1989	FL	147,659	5,124	17.57	1.64
1989	GA	646,487	7,711	28.04	2.99
1989	NC	1,234,260	30,077	18.32	2.24
1989	SC	393,248	10,192	14.84	2.6
1990	FL	189,299	6,246	18.48	1.64
1990	GA	523,746	6,247	28.04	2.99
1990	NC	802,614	19,558	18.32	2.24
1990	SC	371,741	9,635	14.84	2.6
1991	FL	147,733	5,843	15.14	1.67
1991	GA	849,379	10,131	28.04	2.99
1991	NC	1,017,306	24,790	18.32	2.24
1991	SC	533,501	13,827	14.84	2.6
1992	FL	127,136	4,757	16.1	1.66
1992	GA	748,436	8,927	28.04	2.99
1992	NC	389,472	9,491	18.32	2.24
1992	SC	477,901	12,386	14.84	2.6
1993	FL	139,354	5,314	16.39	1.6
1993	GA	752,628	8,977	28.04	2.99
1993	NC	533,885	13,010	18.32	2.24
1993	SC	448,346	11,620	14.84	2.6
1994	FL	167,861	6,484	15.69	1.65
1994	GA	719,092	8,577	28.04	2.99
1994	NC	678,297	16,529	18.32	2.24
1994	SC	391,859	10,156	14.84	2.6
1995	FL	139,566	5,723	14.87	1.64
1995	GA	828,838	9,886	28.04	2.99
1995	NC	694,507	16,924	18.32	2.24
1995	SC	469,760	12,175	14.84	2.6
1996	FL	143,918	5,600	13.67	1.88
1996	GA	651,518	7,771	28.04	2.99
1996	NC	475,001	11,575	18.32	2.24
1996	SC	352,503	9,136	14.84	2.6
1997	FL	119,267	5,314	12.4	1.81
1997	GA	749,107	8,935	28.04	2.99
1997	NC	558,470	13,609	18.32	2.24
1997	SC	435,228	11,280	14.84	2.6
1998	FL	114,184	5,154	14.48	1.53
1998	GA	664,932	7,931	28.04	2.99
1998	NC	389,809	9,499	18.32	2.24
1998	SC	365,969	9,485	14.84	2.6
1999	FL	102,769	5,102	13.61	1.48
1999	GA	603,142	7,194	28.04	2.99
1999	NC	563,025	13,720	18.32	2.24
1999	SC	386,072	10,006	14.84	2.6
2000	FL	69,444	3,666	13.34	1.42
2000	GA	443,679	5,292	28.04	2.99
2000	NC	488,849	12,911	18.03	2.1
2000	SC	367,088	9,514	14.84	2.6
2001	FL	72,511	3,221	14.07	1.6
2001	GA	260,741	3,110	28.04	2.99
2001	NC	397,548	9,808	17.7	2.29
2001	SC	241,111	6,249	14.84	2.6
2002	FL	68,108	2,872	14.46	1.64
2002	GA	317,808	3,745	28.1	3.02
2002	NC	553,747	12,425	19.21	2.32
2002	SC	272,943	7,074	14.84	2.6
2003	FL	106,948	2,763	20.48	1.89
2003	GA	292,499	3,461	28.36	2.98
2003	NC	326,112	8,995	15.56	2.33
2003	SC	226,425	6,293	14.11	2.55
2004	FL	99,818	2,730	19.98	1.83
2004	GA	226,756	2,751	27.66	2.98
2004	NC	356,922	7,573	19.72	2.39
2004	SC	272,049	5,954	17.71	2.58
2005	FL	94,763	2,649	19.13	1.87
2005	GA	172,942	2,432	24.27	2.93
2005	NC	157,026	4,324	16.14	2.25
2005	SC	139,663	4,131	12.71	2.66
2006	FL	87,610	2,499	17.27	2.03
2006	GA	156,168	2,073	24.38	3.09
2006	NC	227,146	5,587	16.46	2.47
2006	SC	115,618	3,661	12.1	2.61
2007	FL	82,025	2,308	16.53	2.15
2007	GA	124,718	1,651	23.83	3.17
2007	NC	290,549	6,668	17.57	2.48
2007	SC	90,831	3,268	10.69	2.6
2008	FL	64,847	2,147	15.41	1.96
2008	GA	115,676	1,784	22.13	2.93
2008	NC	326,774	5,980	21.18	2.58
2008	SC	92,251	3,531	10.01	2.61
2009	FL	62,668	2,173	15.34	1.88
2009	GA	128,305	1,772	23.74	3.05
2009	NC	249,333	5,744	17.79	2.44
2009	SC	93,365	3,194	11.33	2.58
2010	FL	85,296	2,656	15.82	2.03
2010	GA	141,441	2,224	21.78	2.92
2010	NC	225,387	5,508	17.05	2.4
2010	SC	122,570	4,346	11.06	2.55
2011	FL	83,501	2,745	15.52	1.96
2011	GA	129,594	1,935	22.55	2.97
2011	NC	200,784	4,354	18.67	2.47
2011	SC	88,496	3,176	10.8	2.58
2012	FL	78,664	2,586	15.52	1.96
2012	GA	127,852	1,909	22.55	2.97
2012	NC	284,760	6,175	18.67	2.47
2012	SC	117,085	4,202	10.8	2.58
2013	FL	52,230	1,717	15.52	1.96
2013	GA	86,731	1,295	22.55	2.97
2013	NC	252,986	5,486	18.67	2.47
2013	SC	87,409	3,137	10.8	2.58
2014	FL	62,937	2,069	15.52	1.96
2014	GA	106,086	1,584	22.55	2.97
2014	NC	202,813	4,398	18.67	2.47
2014	SC	87,409	3,137	10.8	2.58

Table 4.14. Proportions used to partition effort data. Effort data are partitioned across depth zones first and then within each depth zone across fisheries.



	Depth Zone		
	=<10m	10-30m	>30m
all effort at depth	0.58	0.22	0.20
penaeid effort within depth	1.00	0.93	0.01
rock effort wtihin depth	0.00	0.07	0.99

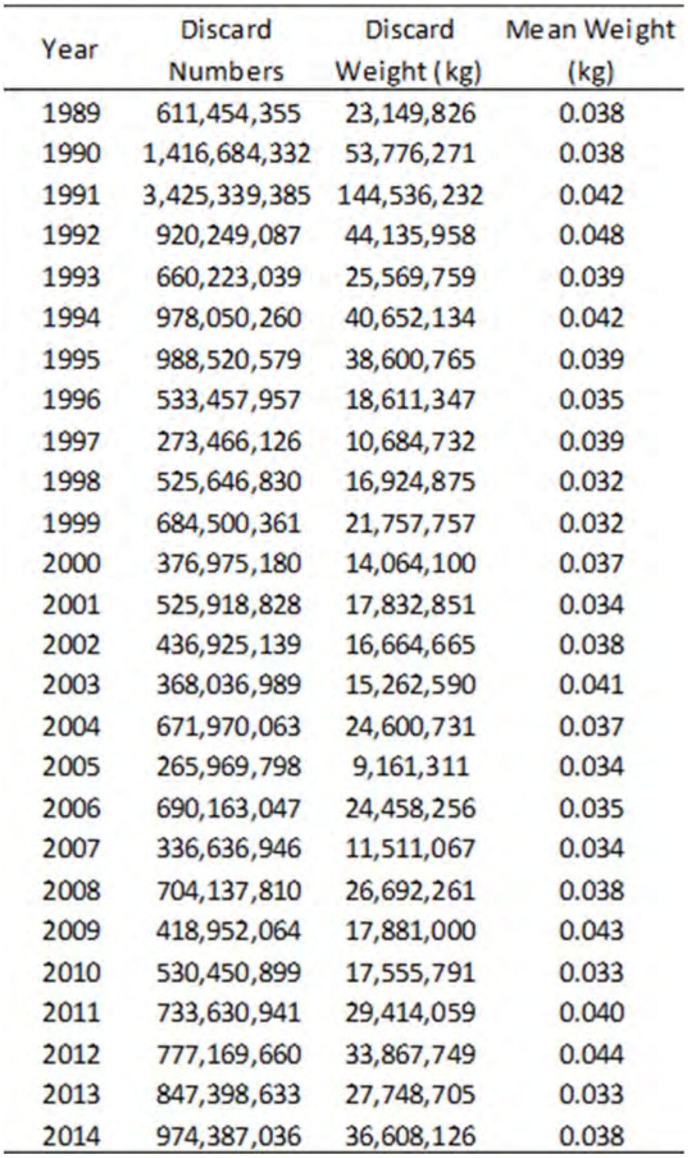
Table 4.15. Atlantic croaker discard estimates in weight (metric tons) with values corresponding to 95% confidence intervals. Unadjusted estimates are estimates before making adjustments due to catch reductions by BRDs.

Year	LCI	Discards	UCI	Unadjusted Discards
1989	15,974	23,150	33,629	17,964
1990	39,494	53,776	73,447	41,786
1991	106,524	144,536	196,726	112,339
1992	31,945	44,136	61,173	34,239
1993	18,307	25,570	35,820	19,828
1994	29,362	40,652	56,450	31,541
1995	28,155	38,601	53,086	29,967
1996	13,533	18,611	25,673	14,444
1997	7,510	10,685	15,254	0
1998	12,393	16,925	23,202	0
1999	15,335	21,758	30,979	0
2000	9,907	14,064	20,033	0
2001	13,546	17,833	23,572	0
2002	12,291	16,665	22,678	0
2003	11,491	15,263	20,339	0
2004	18,215	24,601	33,355	0
2005	7,046	9,161	11,970	0
2006	18,111	24,458	33,158	0
2007	8,766	11,511	15,186	0
2008	20,870	26,692	34,315	0
2009	14,335	17,881	22,426	0
2010	13,549	17,556	22,858	0
2011	23,126	29,414	37,600	0
2012	27,003	33,868	42,719	0
2013	22,083	27,749	35,062	0
2014	28,635	36,608	47,039	0

Table 4.16. Atlantic croaker discard estimates in numbers (1,000s of fish) with values corresponding to 95% confidence intervals. Unadjusted estimates are estimates before making adjustments due to catch reductions by BRDs.

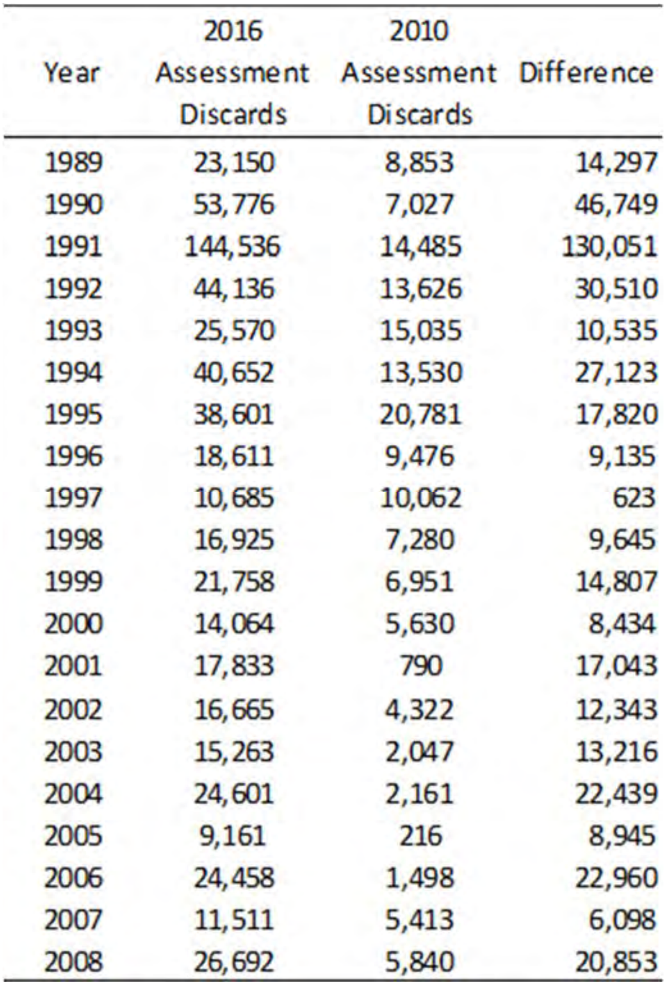
Year	LCI	Discards	UCI	Unadjusted Discards
1989	423,482	611,454	884,284	472,679
1990	1,046,497	1,416,684	1,921,735	1,095,660
1991	2,540,189	3,425,339	4,628,587	2,649,374
1992	669,275	920,249	1,268,160	711,287
1993	474,699	660,223	920,170	510,234
1994	709,660	978,050	1,350,689	756,018
1995	724,758	988,521	1,351,147	764,269
1996	389,766	533,458	731,630	412,395
1997	192,853	273,466	388,711	0
1998	387,377	525,647	715,104	0
1999	484,143	684,500	970,175	0
2000	266,870	376,975	533,770	0
2001	402,219	525,919	689,519	0
2002	324,140	436,925	590,504	0
2003	278,850	368,037	486,862	0
2004	500,360	671,970	904,889	0
2005	206,103	265,970	344,398	0
2006	514,099	690,163	929,025	0
2007	258,526	336,637	439,808	0
2008	555,608	704,138	895,710	0
2009	339,099	418,952	519,534	0
2010	412,407	530,451	684,683	0
2011	581,806	733,631	928,320	0
2012	626,842	777,170	967,316	0
2013	681,864	847,399	1,057,031	0
2014	770,062	974,387	1,237,186	0

Table 4.17. Mean weight of Atlantic croaker discarded in the shrimp trawl fisheries based on the discard estimates in weight and numbers.



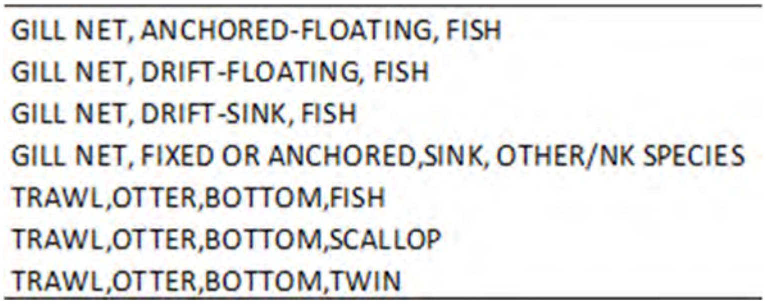
Year	Discard Numbers	Discard Weight (kg)	Mean Weight (kg)
1989	611,454,355	23,149,826	0.038
1990	1,416,684,332	53,776,271	0.038
1991	3,425,339,385	144,536,232	0.042
1992	920,249,087	44,135,958	0.048
1993	660,223,039	25,569,759	0.039
1994	978,050,260	40,652,134	0.042
1995	988,520,579	38,600,765	0.039
1996	533,457,957	18,611,347	0.035
1997	273,466,126	10,684,732	0.039
1998	525,646,830	16,924,875	0.032
1999	684,500,361	21,757,757	0.032
2000	376,975,180	14,064,100	0.037
2001	525,918,828	17,832,851	0.034
2002	436,925,139	16,664,665	0.038
2003	368,036,989	15,262,590	0.041
2004	671,970,063	24,600,731	0.037
2005	265,969,798	9,161,311	0.034
2006	690,163,047	24,458,256	0.035
2007	336,636,946	11,511,067	0.034
2008	704,137,810	26,692,261	0.038
2009	418,952,064	17,881,000	0.043
2010	530,450,899	17,555,791	0.033
2011	733,630,941	29,414,059	0.040
2012	777,169,660	33,867,749	0.044
2013	847,398,633	27,748,705	0.033
2014	974,387,036	36,608,126	0.038

Table 4.18. Comparison of shrimp trawl discard estimates (metric tons) from the 2010 Atlantic croaker assessment and the estimates developed for this assessment.



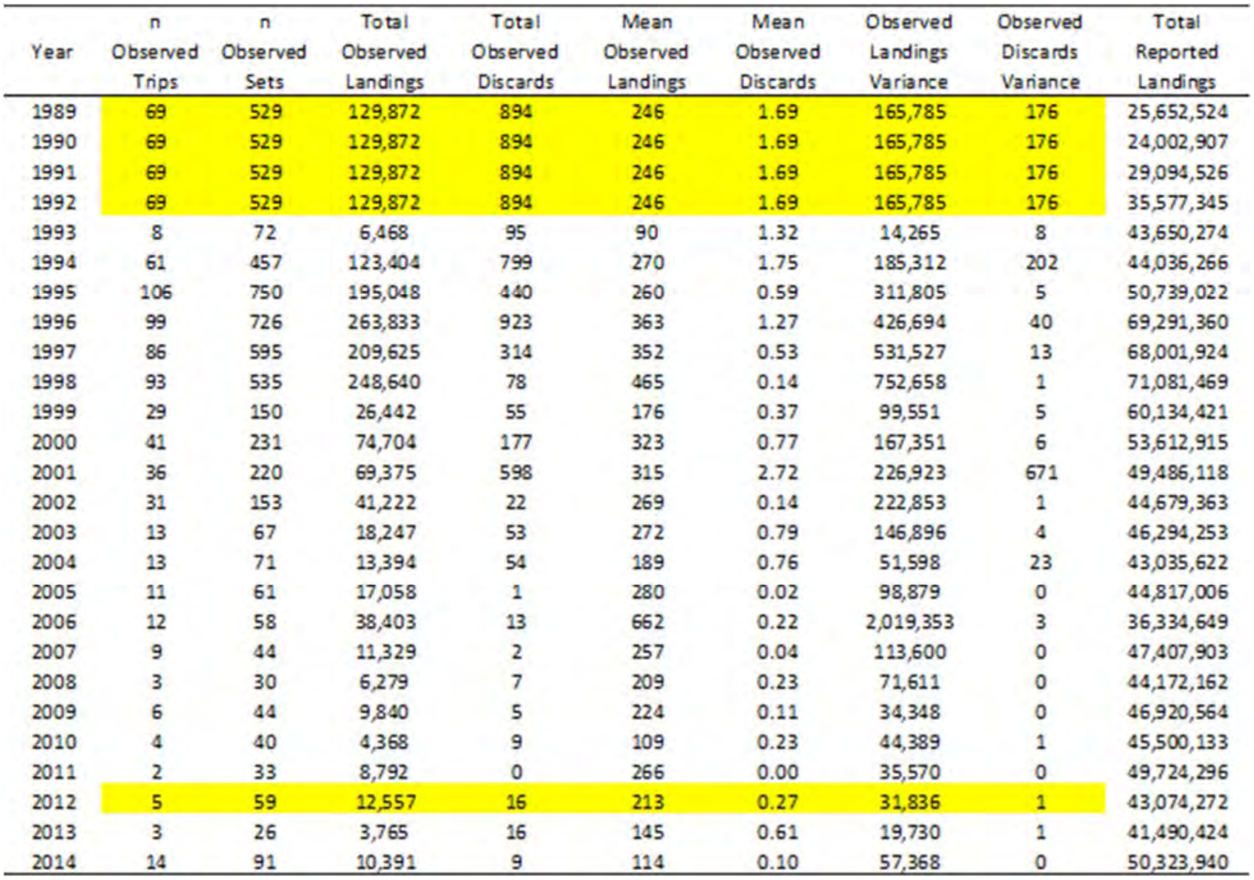
Year	2016 Assessment Discards	2010 Assessment Discards	Difference
1989	23,150	8,853	14,297
1990	53,776	7,027	46,749
1991	144,536	14,485	130,051
1992	44,136	13,626	30,510
1993	25,570	15,035	10,535
1994	40,652	13,530	27,123
1995	38,601	20,781	17,820
1996	18,611	9,476	9,135
1997	10,685	10,062	623
1998	16,925	7,280	9,645
1999	21,758	6,951	14,807
2000	14,064	5,630	8,434
2001	17,833	790	17,043
2002	16,665	4,322	12,343
2003	15,263	2,047	13,216
2004	24,601	2,161	22,439
2005	9,161	216	8,945
2006	24,458	1,498	22,960
2007	11,511	5,413	6,098
2008	26,692	5,840	20,853

Table 4.19. Gears observed on trips that encountered Atlantic croaker.



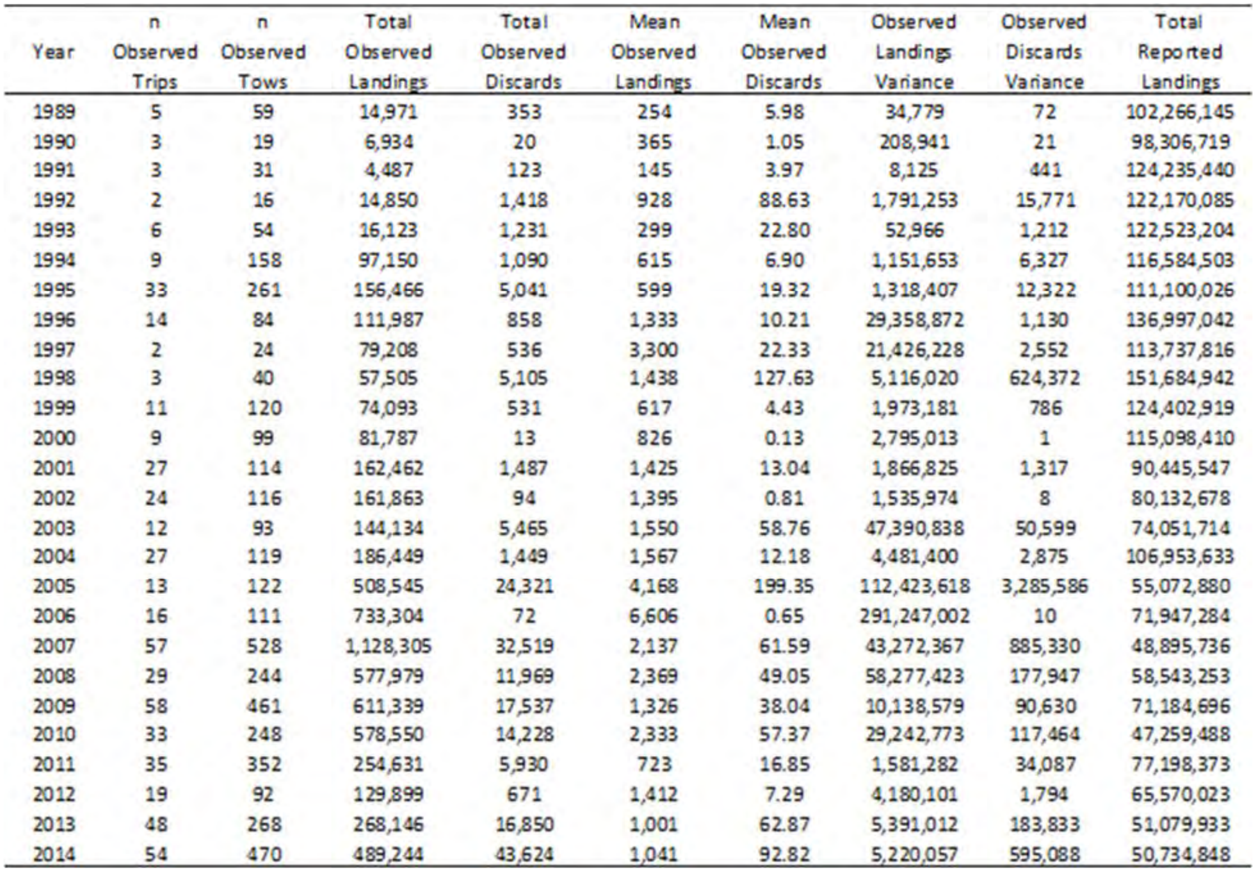
GILL NET, ANCHORED-FLOATING, FISH
GILL NET, DRIFT-FLOATING, FISH
GILL NET, DRIFT-SINK, FISH
GILL NET, FIXED OR ANCHORED,SINK, OTHER/NK SPECIES
TRAWL,OTTER,BOTTOM,FISH
TRAWL,OTTER,BOTTOM,SCALLOP
TRAWL,OTTER,BOTTOM,TWIN

Table 4.20. Gillnet observer data from trips encountering Atlantic croaker and total aggregate landings of all species summarized by year. All landings and discard values are in pounds. Values highlighted in yellow are averages of adjacent years or the closest two year period with data.



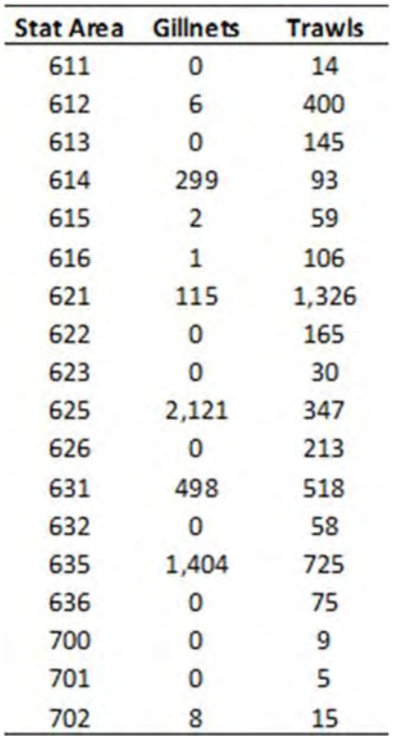
Year	n Observed Trips	n Observed Sets	Total Observed Landings	Total Observed Discards	Mean Observed Landings	Mean Observed Discards	Observed Landings Variance	Observed Discards Variance	Total Reported Landings
1989	69	529	129,872	894	246	1.69	165,785	176	25,652,524
1990	69	529	129,872	894	246	1.69	165,785	176	24,002,907
1991	69	529	129,872	894	246	1.69	165,785	176	29,094,526
1992	69	529	129,872	894	246	1.69	165,785	176	35,577,345
1993	8	72	6,468	95	90	1.32	14,265	8	43,650,274
1994	61	457	123,404	799	270	1.75	185,312	202	44,036,266
1995	106	750	195,048	440	260	0.59	311,805	5	50,739,022
1996	99	726	263,833	923	363	1.27	426,694	40	69,291,360
1997	86	595	209,625	314	352	0.53	531,527	13	68,001,924
1998	93	535	248,640	78	465	0.14	752,658	1	71,081,469
1999	29	150	26,442	55	176	0.37	99,551	5	60,134,421
2000	41	231	74,704	177	323	0.77	167,351	6	53,612,915
2001	36	220	69,375	598	315	2.72	226,923	671	49,486,118
2002	31	153	41,222	22	269	0.14	222,853	1	44,679,363
2003	13	67	18,247	53	272	0.79	146,896	4	46,294,253
2004	13	71	13,394	54	189	0.76	51,598	23	43,035,622
2005	11	61	17,058	1	280	0.02	98,879	0	44,817,006
2006	12	58	38,403	13	662	0.22	2,019,353	3	36,334,649
2007	9	44	11,329	2	257	0.04	113,600	0	47,407,903
2008	3	30	6,279	7	209	0.23	71,611	0	44,172,162
2009	6	44	9,840	5	224	0.11	34,348	0	46,920,564
2010	4	40	4,368	9	109	0.23	44,389	1	45,500,133
2011	2	33	8,792	0	266	0.00	35,570	0	49,724,296
2012	5	59	12,557	16	213	0.27	31,836	1	43,074,272
2013	3	26	3,765	16	145	0.61	19,730	1	41,490,424
2014	14	91	10,391	9	114	0.10	57,368	0	50,323,940

Table 4.21. Trawl observer data from trips encountering Atlantic croaker and total aggregate landings of all species summarized by year. All landings and discard values are in pounds.



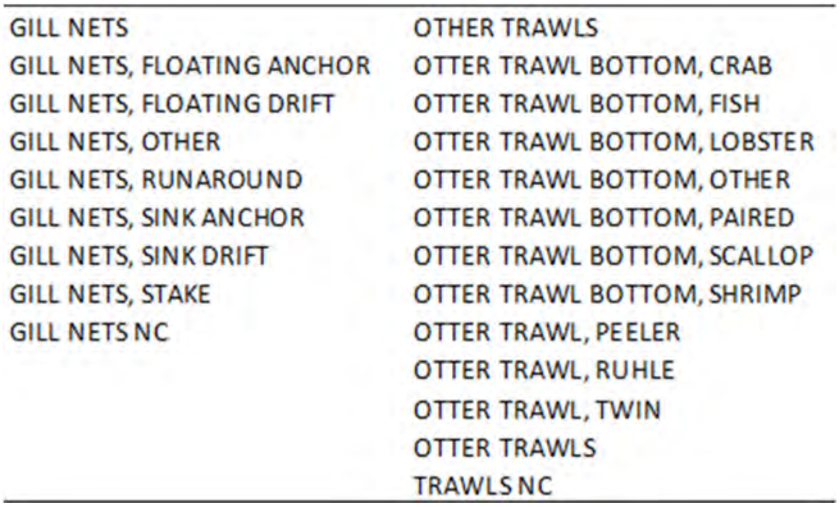
Year	n Observed Trips	n Observed Tows	Total Observed Landings	Total Observed Discards	Mean Observed Landings	Mean Observed Discards	Observed Landings Variance	Observed Discards Variance	Total Reported Landings
1989	5	59	14,971	353	254	5.98	34,779	72	102,266,145
1990	3	19	6,934	20	365	1.05	208,941	21	98,306,719
1991	3	31	4,487	123	145	3.97	8,125	441	124,235,440
1992	2	16	14,850	1,418	928	88.63	1,791,253	15,771	122,170,085
1993	6	54	16,123	1,231	299	22.80	52,966	1,212	122,523,204
1994	9	158	97,150	1,090	615	6.90	1,151,653	6,327	116,584,503
1995	33	261	156,466	5,041	599	19.32	1,318,407	12,322	111,100,026
1996	14	84	111,987	858	1,333	10.21	29,358,872	1,130	136,997,042
1997	2	24	79,208	536	3,300	22.33	21,426,228	2,552	113,737,816
1998	3	40	57,505	5,105	1,438	127.63	5,116,020	624,372	151,684,942
1999	11	120	74,093	531	617	4.43	1,973,181	786	124,402,919
2000	9	99	81,787	13	826	0.13	2,795,013	1	115,098,410
2001	27	114	162,462	1,487	1,425	13.04	1,866,825	1,317	90,445,547
2002	24	116	161,863	94	1,395	0.81	1,535,974	8	80,132,678
2003	12	93	144,134	5,465	1,550	58.76	47,390,838	50,599	74,051,714
2004	27	119	186,449	1,449	1,567	12.18	4,481,400	2,875	106,953,633
2005	13	122	508,545	24,321	4,168	199.35	112,423,618	3,285,586	55,072,880
2006	16	111	733,304	72	6,606	0.65	291,247,002	10	71,947,284
2007	57	528	1,128,305	32,519	2,137	61.59	43,272,367	885,330	48,895,736
2008	29	244	577,979	11,969	2,369	49.05	58,277,423	177,947	58,543,253
2009	58	461	611,339	17,537	1,326	38.04	10,138,579	90,630	71,184,696
2010	33	248	578,550	14,228	2,333	57.37	29,242,773	117,464	47,259,488
2011	35	352	254,631	5,930	723	16.85	1,581,282	34,087	77,198,373
2012	19	92	129,899	671	1,412	7.29	4,180,101	1,794	65,570,023
2013	48	268	268,146	16,850	1,001	62.87	5,391,012	183,833	51,079,933
2014	54	470	489,244	43,624	1,041	92.82	5,220,057	595,088	50,734,848

Table 4.22. Number of observations from observer data for Atlantic croaker by NMFS Statistical Area (Stat Area) and gear. NMFS statistical area used for commercial fisheries data collection area designation.



Stat Area	Gillnets	Trawls
611	0	14
612	6	400
613	0	145
614	299	93
615	2	59
616	1	106
621	115	1,326
622	0	165
623	0	30
625	2,121	347
626	0	213
631	498	518
632	0	58
635	1,404	725
636	0	75
700	0	9
701	0	5
702	8	15

Table 4.23. Gears contributing to aggregate landings used to expand ratios to discard estimates. Additional landings recorded as "NOT CODED" were included in the total landings (GILL NETS NC, TRAWLS NC).



GILL NETS
GILL NETS, FLOATING ANCHOR
GILL NETS, FLOATING DRIFT
GILL NETS, OTHER
GILL NETS, RUNAROUND
GILL NETS, SINK ANCHOR
GILL NETS, SINK DRIFT
GILL NETS, STAKE
GILL NETS NC

OTHER TRAWLS
OTTER TRAWL BOTTOM, CRAB
OTTER TRAWL BOTTOM, FISH
OTTER TRAWL BOTTOM, LOBSTER
OTTER TRAWL BOTTOM, OTHER
OTTER TRAWL BOTTOM, PAIRED
OTTER TRAWL BOTTOM, SCALLOP
OTTER TRAWL BOTTOM, SHRIMP
OTTER TRAWL, PEELER
OTTER TRAWL, RUHLE
OTTER TRAWL, TWIN
OTTER TRAWLS
TRAWLS NC

Table 4.24. Estimated ratios, variances, and CVs of discarded Atlantic croaker to total aggregate landings of all species from observed gillnets. Values highlighted in yellow are averages of adjacent years or the closest two year period with data.

Year	Ratio	Ratio Variance	Ratio CV
1989	0.000945	7.9E-08	0.2973
1990	0.000945	7.9E-08	0.2973
1991	0.000945	7.9E-08	0.2973
1992	0.000000	0	NA
1993	0.001720	2.54E-07	0.2929
1994	0.001199	2.09E-07	0.3808
1995	0.000414	3.59E-09	0.1448
1996	0.000851	2.71E-08	0.1936
1997	0.000330	9.01E-09	0.2876
1998	0.000111	1.09E-09	0.2976
1999	0.009350	4.39E-05	0.7089
2000	0.001332	7.19E-08	0.2012
2001	0.005318	1.17E-05	0.6421
2002	0.000057	3.23E-09	0.9979
2003	0.000027	1.72E-10	0.4808
2004	0.000021	3.36E-10	0.8706
2005	0.000001	7.29E-13	1.0662
2006	0.000007	5.25E-11	1.0426
2007	0.000003	6.60E-12	0.9486
2008	0.000070	1.46E-09	0.5456
2009	0.000008	4.10E-11	0.7870
2010	0.000011	8.92E-11	0.8573
2011	0.000000	0	NA
2012	0.000000	0	NA
2013	0.000044	6.04E-10	0.5537
2014	0.000013	6.93E-11	0.6462

Table 4.25. Estimated ratios, variances, and CVs of discarded Atlantic croaker to total aggregate landings of all species from observed trawls.

Year	Ratio	Ratio Variance	Ratio CV
1989	0.001571	1.77E-07	0.2678
1990	0.000084	7.06E-09	1.0002
1991	0.000177	2.91E-08	0.9624
1992	0.002784	1.53E-06	0.4448
1993	0.004601	1.59E-06	0.2741
1994	0.003709	1E-05	0.8538
1995	0.007734	7.81E-06	0.3613
1996	0.000527	4.13E-08	0.3858
1997	0.000489	5.98E-08	0.4997
1998	0.007621	5.66E-05	0.9876
1999	0.000673	1.87E-07	0.6425
2000	0.000005	9.94E-12	0.6081
2001	0.000433	1.79E-08	0.3093
2002	0.000102	2.17E-09	0.4585
2003	0.009695	1.75E-05	0.4318
2004	0.000340	2.02E-08	0.4171
2005	0.012987	0.000106	0.7915
2006	0.000020	1.00E-10	0.4960
2007	0.010158	4.64E-05	0.6703
2008	0.005046	8.02E-06	0.5614
2009	0.004314	2.67E-06	0.3791
2010	0.003376	1.73E-06	0.3898
2011	0.001299	5.84E-07	0.5883
2012	0.000362	4.92E-08	0.6122
2013	0.005324	5.16E-06	0.4266
2014	0.009560	1.36E-05	0.3863

Table 4.26. Estimated Atlantic croaker gillnet discards in weight (lbs) and numbers. Lower confidence intervals are truncated at zero due to large variances. Values highlighted in yellow are averages of adjacent years or the closest two year period with data.

Year	Discards (lbs)	Discards LCI (lbs)	Discards UCI (lbs)	n Fish Counted	Total Subsample Weight (lbs)	n Subsamples	Mean Weight (lbs)	Discards (numbers)
1989	24,248	9,828	38,668	78	77	8	0.981	24,723
1990	22,688	9,196	36,181	78	77	8	0.981	23,133
1991	27,501	11,147	43,856	78	77	8	0.981	28,040
1992	0	0	0	78	77	8	0.981	0
1993	75,083	31,094	119,073	78	77	8	0.981	76,556
1994	52,714	12,565	92,863	78	77	8	0.981	53,748
1995	20,942	14,879	27,006	8	11	3	1.313	15,956
1996	58,503	35,854	81,153	78	77	8	0.981	59,651
1997	22,383	9,508	35,259	70	66	5	0.943	23,740
1998	7,799	3,158	12,440	71	67	6	0.944	8,265
1999	554,925	0	1,341,747	1	1	1	1.000	554,925
2000	70,546	42,157	98,934	128	83	11	0.651	108,402
2001	259,028	0	591,650	88	60	11	0.685	378,017
2002	2,516	0	7,537	5	6	4	1.100	2,287
2003	1,246	48	2,445	23	14	9	0.617	2,019
2004	893	0	2,449	11	11	4	1.018	878
2005	36	0	111	23	24	5	1.048	34
2006	250	0	772	12	13	1	1.075	233
2007	128	0	371	1	1	1	0.900	142
2008	3,085	0	6,452	3	3	3	1.000	3,085
2009	381	0	980	2	2	2	1.050	363
2010	500	0	1,357	17	10	8	0.565	885
2011	0	0	0	17	10	8	0.565	0
2012	0	0	0	17	10	8	0.565	0
2013	1,825	0	3,846	15	8	6	0.500	3,650
2014	646	0	1,480	2	1	2	0.500	1,291

Table 4.27. Estimated Atlantic croaker trawl discards in weight (lbs) and numbers. Lower confidence intervals are truncated at zero due to large variances. Values highlighted in yellow are averages of adjacent years or the closest two year period with data.

Year	Discards (lbs)	Discards LCI (lbs)	Discards UCI (lbs)	n Fish Counted	Total Subsample Weight (lbs)	n Subsamples	Mean Weight (lbs)	Discards (numbers)
1989	150,051	69,691	230,411	284	143	10	0.504	297,587
1990	7,703	0	23,113	284	143	10	0.504	15,278
1991	20,368	0	59,572	284	143	10	0.504	40,395
1992	315,945	34,903	596,988	284	143	10	0.504	626,595
1993	505,019	228,188	781,849	77	14	1	0.182	2,777,603
1994	362,860	0	982,507	284	143	10	0.504	719,638
1995	715,805	198,553	1,233,058	207	129	9	0.624	1,146,840
1996	56,080	12,807	99,353	98	40	1	0.403	139,135
1997	45,274	31	90,518	52	16	1	0.298	151,888
1998	992,782	0	2,953,650	110	37	1	0.336	2,951,513
1999	61,410	0	140,326	49	18	1	0.367	167,172
2000	426	0	944	1,567	947	45	0.604	705
2001	33,384	12,733	54,036	1,518	929	44	0.612	54,550
2002	6,962	578	13,346	147	44	23	0.299	23,260
2003	755,896	103,153	1,408,639	287	258	7	0.899	840,862
2004	21,837	3,622	40,052	167	175	12	1.045	20,898
2005	669,016	0	1,728,122	10	4	1	0.400	1,672,539
2006	1,324	10	2,638	96	30	2	0.313	4,237
2007	462,036	0	1,081,411	86	26	1	0.302	1,528,272
2008	334,515	0	710,108	89	42	6	0.466	717,393
2009	361,475	87,430	635,520	137	61	7	0.446	810,508
2010	192,439	42,407	342,471	390	110	7	0.282	682,284
2011	82,139	0	178,777	3	1	2	0.467	176,012
2012	19,699	0	43,819	146	56	7	0.384	51,358
2013	226,659	33,287	420,031	143	55	5	0.382	593,632
2014	417,482	94,915	740,050	70	18	4	0.254	1,641,783

Table 5.1. Number of discarded Atlantic croaker measured for length (total) by the Northeast Fisheries Observer Program (NEFOP).

Year	Trawls	Gill Nets
1989	0	0
1990	0	0
1991	0	0
1992	0	0
1993	77	0
1994	38	287
1995	207	9
1996	98	0
1997	52	70
1998	110	0
1999	49	1
2000	0	138
2001	1518	88
2002	147	5
2003	287	23
2004	167	11
2005	10	0
2006	0	12
2007	86	1
2008	147	0
2009	137	2
2010	390	0
2011	4	0
2012	0	0
2013	143	15
2014	71	2

Table 5.2. Number of tows observed by the Southeast Shrimp Trawl Observer Program by South Atlantic fishery and year.

Year	Fishery	
	Penaeid Shrimp	Rock Shrimp
2001	30	16
2002	14	119
2003	0	177
2004	0	0
2005	158	0
2006	0	22
2007	135	0
2008	239	111
2009	458	19
2010	187	60
2011	320	0
2012	377	0
2013	308	96
2014	174	39

Table 5.3. Atlantic croaker length and weight sample sizes by year obtained during APAIS sampling.

Year	Length	Weight	Year	Length	Weight
1981	610	554	1998	3,351	3,324
1982	932	922	1999	3,070	3,158
1983	1,181	1,092	2000	3,191	3,314
1984	1,367	1,335	2001	5,227	5,251
1985	2,992	2,898	2002	6,374	6,494
1986	4,728	4,619	2003	5,561	5,649
1987	2,836	2,819	2004	5,703	5,524
1988	2,532	2,466	2005	7,707	7,751
1989	2,793	3,027	2006	4,125	4,289
1990	1,720	1,686	2007	5,041	5,195
1991	1,614	1,850	2008	5,718	5,813
1992	2,259	2,338	2009	4,902	4,894
1993	2,029	2,041	2010	5,278	5,568
1994	5,360	5,369	2011	4,270	4,349
1995	2,659	2,648	2012	3,469	2,628
1996	2,671	2,637	2013	5,696	2,287
1997	3,050	3,132	2014	4,606	1,548

Table 5.4. Atlantic croaker length sample size from at-sea sampling of headboats by year and state.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	Total
2004	0	26	0	505	332	31	14	50	0	958
2005	0	3	6	456	625	84	137	13	0	1,324
2006	0	0	0	227	273	50	193	81	0	824
2007	0	39	0	359	1,681	98	235	35	0	2,447
2008	0	0	26	414	550	71	376	34	0	1,471
2009	0	0	5	184	622	154	370	37	0	1,372
2010	0	0	2	234	1,128	65	120	9	0	1,558
2011	0	0	5	184	1,400	18	69	42	0	1,718
2012	0	0	79	69	629	136	105	15	7	1,040
2013	0	0	19	95	1,178	129	309	29	0	1,759
2014	0	0	7	417	574	194	328	3	0	1,523

Table 5.5. Number of harvest weight estimates by pooling level for MRFSS strata with zero harvest weight estimates and positive harvest number estimates.

Factor Collapsed for Pooling			
Area	Mode	State	Wave
1	2	18	12

Table 5.6. Total harvest number estimates without weight, imputed harvest weight estimates, and mean weights for MRFSS strata with zero harvest weight estimates and positive number estimates.

Year	Numbers	Weight (lbs.)	Mean Weight
1981	0	NA	NA
1982	54,082	148,579	2.75
1983	0	NA	NA
1984	0	NA	NA
1985	27,920	9,853	0.35
1986	9,898	4,734	0.48
1987	0	NA	NA
1988	29,385	12,258	0.42
1989	0	NA	NA
1990	27,350	8,320	0.30
1991	126,150	46,818	0.37
1992	1,458	500	0.34
1993	0	NA	NA
1994	0	NA	NA
1995	1,452	553	0.38
1996	24,948	18,953	0.76
1997	0	NA	NA
1998	0	NA	NA
1999	45,518	22,073	0.48
2000	0	NA	NA
2001	0	NA	NA
2002	0	NA	NA
2003	6,071	5,094	0.84

Table 5.7. MRIP harvest estimates (numbers or weight) by pooling level for APAIS design change calibration. Headboat estimates were not adjusted (No Ratio) because the design for this mode (at-sea sampling) did not change in 2013.

Ratio Pooling Level				
No Pooling	Collapse State	Collapse Species	Collapse State and Species	No Ratio
81	99	36	0	37

Table 5.8. MRIP released alive (number) estimates by pooling level for APAIS design change calibration. Headboat estimates were not adjusted (No Ratio) because the design for this mode (at-sea sampling) did not change in 2013.

Ratio Pooling Level				
No Pooling	Collapse State	Collapse Species	Collapse State and Species	No Ratio
152	63	1	0	37

Table 5.9. MRFSS and MRIP recreational harvest (millions of fish) by state and coast-wide, 1981-2014.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	RI	MA	Coastwide
1981	0.917	0.055	0.254	1.598	1.463	0.000	0.005	0.002	0.000	0.000	0.000	0.000	4.292
1982	2.577	0.260	0.296	0.935	0.418	0.016	0.000	0.000	0.000	0.000	0.000	0.000	4.502
1983	1.758	0.115	0.093	2.486	3.281	0.165	0.000	0.000	0.000	0.000	0.000	0.000	7.898
1984	4.260	0.310	0.901	3.467	2.973	0.295	0.000	0.000	0.000	0.000	0.000	0.000	12.206
1985	2.002	0.220	0.399	1.336	3.425	0.035	0.000	0.000	0.000	0.000	0.000	0.000	7.416
1986	7.839	0.107	0.918	0.626	9.556	0.187	0.007	0.000	0.000	0.000	0.000	0.000	19.240
1987	3.952	0.069	0.256	1.385	4.935	0.319	0.000	0.000	0.000	0.000	0.000	0.000	10.915
1988	1.050	0.098	0.221	3.456	6.015	1.549	0.002	0.000	0.000	0.000	0.000	0.000	12.391
1989	0.550	0.112	0.332	3.267	3.347	0.035	0.001	0.000	0.000	0.000	0.000	0.000	7.644
1990	0.466	0.898	0.531	1.629	3.608	0.156	0.000	0.000	0.000	0.000	0.000	0.000	7.288
1991	1.578	0.285	0.154	0.665	6.576	0.446	0.062	0.024	0.000	0.000	0.000	0.000	9.790
1992	1.156	0.675	0.113	1.108	6.819	0.182	0.015	0.000	0.000	0.000	0.000	0.000	10.067
1993	0.466	0.137	0.054	1.158	7.461	1.445	0.029	0.004	0.000	0.000	0.000	0.000	10.755
1994	0.917	0.158	0.289	1.810	9.700	2.668	0.009	0.002	0.000	0.000	0.000	0.000	15.554
1995	0.671	0.154	0.116	1.308	7.421	1.326	0.227	0.023	0.000	0.000	0.000	0.000	11.246
1996	0.179	0.095	0.057	1.032	7.534	1.243	0.374	0.054	0.000	0.000	0.000	0.000	10.568
1997	0.361	0.098	0.181	1.012	11.912	1.627	0.590	0.806	0.000	0.000	0.000	0.000	16.588
1998	0.359	0.099	0.261	0.606	10.125	1.808	0.626	0.266	0.000	0.000	0.000	0.002	14.153
1999	0.633	0.161	0.084	0.744	8.929	2.161	1.266	0.649	0.000	0.000	0.000	0.000	14.628
2000	0.698	0.197	0.050	0.602	8.201	4.475	0.845	1.612	0.000	0.000	0.000	0.000	16.680
2001	0.653	0.033	0.030	0.974	14.178	2.108	0.547	2.049	0.000	0.000	0.000	0.000	20.572
2002	0.273	0.056	0.102	0.627	13.809	2.197	0.414	0.387	0.000	0.000	0.000	0.000	17.865
2003	0.253	0.381	0.312	0.762	10.094	2.563	0.555	1.072	0.000	0.000	0.000	0.000	15.994
2004	0.538	0.061	0.209	0.902	12.873	1.214	0.620	0.855	0.000	0.000	0.000	0.000	17.269
2005	0.461	0.060	0.186	0.381	12.061	1.044	1.031	1.177	0.000	0.000	0.000	0.000	16.402
2006	0.200	0.048	0.035	0.775	9.872	1.264	0.995	0.473	0.000	0.000	0.000	0.000	13.663
2007	0.468	0.061	0.048	0.727	9.472	1.223	0.446	0.453	0.000	0.000	0.000	0.000	12.898
2008	1.049	0.034	0.138	0.515	11.816	0.926	0.549	0.684	0.000	0.000	0.000	0.000	15.712
2009	1.033	0.173	0.518	0.529	8.045	2.058	0.617	0.280	0.000	0.000	0.000	0.000	13.252
2010	0.352	0.073	0.094	0.693	7.264	1.604	0.097	0.071	0.000	0.000	0.000	0.000	10.246
2011	1.068	0.092	0.661	0.419	5.702	0.824	0.118	0.048	0.000	0.000	0.000	0.000	8.933
2012	1.467	0.071	0.052	0.474	5.091	1.301	0.131	0.366	0.000	0.000	0.000	0.000	8.953
2013	0.412	0.055	0.099	0.412	4.318	1.140	0.232	0.890	0.002	0.000	0.000	0.006	7.565
2014	0.298	0.064	0.149	0.542	3.461	1.080	0.413	0.264	0.000	0.000	0.000	0.000	6.271

Table 5.10. MRFSS and MRIP recreational harvest (metric tons) by state and coast-wide, 1981-2014.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	RI	MA	Coastwide
1981	217	7	48	302	376	0	2	0	0	0	0	0	952
1982	535	32	48	192	428	50	0	0	0	0	0	0	1,284
1983	362	18	10	281	343	23	0	0	0	0	0	0	1,036
1984	1,316	57	115	433	430	55	0	0	0	0	0	0	2,407
1985	488	29	56	228	588	13	0	0	0	0	0	0	1,401
1986	1,975	15	125	102	1,409	82	2	0	0	0	0	0	3,709
1987	713	11	46	250	925	136	0	0	0	0	0	0	2,079
1988	233	14	39	664	1,659	659	1	0	0	0	0	0	3,269
1989	190	15	57	468	935	14	0	0	0	0	0	0	1,679
1990	96	146	88	246	615	28	0	0	0	0	0	0	1,218
1991	344	40	26	112	1,224	84	9	3	0	0	0	0	1,841
1992	289	94	20	166	1,235	38	2	0	0	0	0	0	1,845
1993	128	39	14	201	1,389	395	7	1	0	0	0	0	2,174
1994	239	24	91	249	2,100	758	2	1	0	0	0	0	3,465
1995	214	15	18	232	1,847	421	63	7	0	0	0	0	2,817
1996	49	15	10	249	1,896	517	149	28	0	0	0	0	2,913
1997	80	19	38	219	3,775	805	241	296	0	0	0	0	5,474
1998	101	22	54	117	4,125	845	214	108	0	0	0	1	5,587
1999	169	39	19	167	3,502	859	462	251	0	0	0	0	5,467
2000	172	44	10	144	3,412	2,062	363	816	0	0	0	0	7,023
2001	227	6	8	252	5,407	947	244	890	0	0	0	0	7,981
2002	84	8	21	172	4,968	949	184	190	0	0	0	0	6,575
2003	56	51	43	232	3,991	1,483	195	488	0	0	0	0	6,539
2004	85	10	35	240	5,059	633	226	394	0	0	0	0	6,683
2005	80	10	19	91	5,105	596	427	520	0	0	0	0	6,849
2006	61	5	5	127	4,623	647	435	253	0	0	0	0	6,156
2007	100	9	6	92	3,384	508	187	227	0	0	0	0	4,512
2008	190	5	15	95	3,119	305	227	270	0	0	0	0	4,227
2009	215	31	69	86	2,741	1,074	152	87	0	0	0	0	4,455
2010	58	9	11	157	2,478	640	24	18	0	0	0	0	3,395
2011	185	21	199	73	1,425	291	31	12	0	0	0	0	2,236
2012	289	11	10	75	1,314	327	44	65	0	0	0	0	2,136
2013	93	8	13	64	1,011	334	47	245	1	0	0	2	1,818
2014	75	15	16	103	733	275	94	93	0	0	0	0	1,405

Table 5.11. MRFSS and MRIP recreational live releases (millions of fish) by state and coast-wide, 1981-2014.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	RI	MA	Coastwide
1981	0.134	0.021	0.200	1.099	0.506	0.025	0.000	0.000	0.007	0.000	0.000	0.000	1.993
1982	0.294	0.174	0.168	1.017	0.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.774
1983	0.592	0.110	0.186	0.674	2.201	2.361	0.000	0.000	0.000	0.000	0.000	0.000	6.123
1984	0.369	0.059	1.166	2.698	1.039	0.104	0.000	0.000	0.000	0.000	0.000	0.000	5.434
1985	1.790	0.104	0.373	2.628	2.508	0.022	0.000	0.000	0.000	0.000	0.000	0.000	7.424
1986	0.497	0.064	0.132	0.256	3.986	0.064	0.003	0.000	0.000	0.000	0.000	0.000	5.000
1987	2.764	0.120	0.169	0.876	3.187	0.050	0.003	0.004	0.000	0.000	0.000	0.000	7.172
1988	0.313	0.032	0.175	1.541	1.298	0.432	0.001	0.000	0.000	0.000	0.000	0.000	3.793
1989	0.114	0.028	0.092	1.393	2.084	0.065	0.002	0.000	0.000	0.000	0.000	0.000	3.777
1990	0.262	0.500	0.173	2.109	6.102	0.176	0.002	0.000	0.000	0.000	0.000	0.000	9.325
1991	1.011	0.225	0.039	1.045	11.458	5.548	0.125	0.142	0.000	0.000	0.000	0.000	19.594
1992	0.392	0.281	0.042	1.490	6.448	1.357	0.068	0.006	0.000	0.000	0.000	0.000	10.083
1993	0.217	0.130	0.026	2.341	8.953	4.168	0.020	0.009	0.000	0.000	0.000	0.000	15.864
1994	0.518	0.155	0.221	4.865	11.787	2.606	0.022	0.027	0.000	0.000	0.000	0.000	20.201
1995	0.221	0.141	0.169	1.833	8.403	0.801	0.066	0.048	0.000	0.000	0.000	0.000	11.682
1996	0.197	0.095	0.101	1.912	7.963	0.636	0.119	0.027	0.000	0.000	0.000	0.000	11.049
1997	0.182	0.040	0.216	2.254	11.173	2.292	0.611	0.218	0.000	0.000	0.000	0.000	16.986
1998	0.239	0.251	0.415	1.704	7.702	4.765	1.326	0.355	0.000	0.000	0.000	0.016	16.775
1999	1.519	0.090	0.182	2.149	8.789	4.167	1.864	1.395	0.000	0.000	0.000	0.000	20.155
2000	0.670	0.266	0.151	2.454	12.052	8.610	1.114	1.081	0.000	0.000	0.000	0.000	26.398
2001	0.441	0.300	0.180	1.963	10.966	2.480	0.471	1.413	0.000	0.000	0.000	0.000	18.213
2002	0.339	0.304	0.146	1.450	10.927	4.399	0.567	0.569	0.000	0.000	0.000	0.000	18.700
2003	0.300	1.511	0.688	2.434	10.169	2.216	1.042	1.291	0.000	0.000	0.000	0.000	19.651
2004	0.294	0.487	0.467	2.059	9.277	1.248	0.939	2.403	0.000	0.000	0.000	0.000	17.175
2005	0.374	0.770	0.517	1.829	12.834	1.172	0.922	3.435	0.000	0.000	0.000	0.000	21.853
2006	0.250	0.563	0.675	3.589	6.106	2.518	1.261	0.799	0.000	0.000	0.000	0.000	15.761
2007	0.427	0.534	0.346	2.295	10.662	1.564	0.809	1.169	0.000	0.000	0.000	0.000	17.805
2008	0.791	0.997	0.387	2.100	10.369	3.062	0.940	5.678	0.000	0.000	0.000	0.345	24.669
2009	0.496	1.232	0.891	2.880	10.681	1.617	0.747	0.191	0.000	0.000	0.000	0.000	18.736
2010	0.176	0.769	0.308	2.419	6.800	1.540	0.359	0.379	0.000	0.000	0.000	0.000	12.750
2011	0.468	0.696	0.327	2.887	7.055	0.519	0.101	0.153	0.000	0.000	0.000	0.000	12.207
2012	0.744	0.475	0.237	2.073	6.849	3.383	0.738	2.501	0.000	0.000	0.000	0.000	17.000
2013	0.318	0.298	0.794	1.985	6.015	2.937	0.770	0.774	0.024	0.005	0.000	0.000	13.920
2014	0.393	0.471	0.780	2.714	3.607	1.146	0.665	0.206	0.000	0.000	0.000	0.000	9.981

Table 5.12. Total numbers (millions) of MRFSS and MRIP fish caught and released by recreational anglers assumed to die post-release (15%).

Year	Millions
1981	0.299
1982	0.266
1983	0.918
1984	0.815
1985	1.114
1986	0.750
1987	1.076
1988	0.569
1989	0.567
1990	1.399
1991	2.939
1992	1.513
1993	2.380
1994	3.030
1995	1.752
1996	1.657
1997	2.548
1998	2.516
1999	3.023
2000	3.960
2001	2.732
2002	2.805
2003	2.948
2004	2.576
2005	3.278
2006	2.364
2007	2.671
2008	3.700
2009	2.810
2010	1.912
2011	1.831
2012	2.550
2013	2.088
2014	1.497

Table 5.13. MRFSS and MRIP coast-wide recreational harvest (millions of fish) and PSEs, 1981-2014.

Year	Mean	PSE
1981	4.292	69.4
1982	4.502	105.7
1983	7.898	93.8
1984	12.206	55.7
1985	7.416	50.3
1986	19.240	77.3
1987	10.915	59.8
1988	12.391	47.4
1989	7.644	30.6
1990	7.288	41.3
1991	9.790	43.9
1992	10.067	43.6
1993	10.755	41.5
1994	15.554	28.2
1995	11.246	39.7
1996	10.568	47.0
1997	16.588	52.4
1998	14.153	40.4
1999	14.628	38.0
2000	16.680	34.2
2001	20.572	27.6
2002	17.865	26.1
2003	15.994	25.2
2004	17.269	26.0
2005	16.402	22.3
2006	13.663	29.2
2007	12.898	21.5
2008	15.712	29.1
2009	13.252	19.2
2010	10.246	23.2
2011	8.933	17.8
2012	8.953	18.7
2013	7.565	12.0
2014	6.271	8.2

Table 5.14. MRFSS and MRIP coast-wide recreational harvest (metric tons) and PSEs, 1981-2014.

Year	Mean	PSE
1981	952	69.2
1982	1,284	106.5
1983	1,036	85.2
1984	2,407	81.7
1985	1,401	51.9
1986	3,709	94.0
1987	2,079	53.1
1988	3,269	54.8
1989	1,679	33.0
1990	1,218	43.1
1991	1,841	44.5
1992	1,845	40.5
1993	2,174	39.5
1994	3,465	29.3
1995	2,817	42.5
1996	2,913	47.1
1997	5,474	51.9
1998	5,587	43.0
1999	5,467	40.6
2000	7,023	36.3
2001	7,981	28.8
2002	6,575	26.1
2003	6,539	27.6
2004	6,683	25.7
2005	6,849	24.1
2006	6,156	31.3
2007	4,512	21.5
2008	4,227	27.0
2009	4,455	20.5
2010	3,395	24.7
2011	2,236	18.9
2012	2,136	20.7
2013	1,818	12.5
2014	1,405	8.2

Table 5.15. MRFSS and MRIP coast-wide recreational harvest (millions of fish) and PSEs, 1981-2014.

Year	Mean	PSE
1981	1.993	70.2
1982	1.774	88.9
1983	6.123	33.7
1984	5.434	45.5
1985	7.424	86.8
1986	5.000	35.4
1987	7.172	44.8
1988	3.793	34.8
1989	3.777	21.1
1990	9.325	29.1
1991	19.594	24.2
1992	10.083	25.2
1993	15.864	22.7
1994	20.201	16.1
1995	11.682	22.4
1996	11.049	22.3
1997	16.986	22.3
1998	16.775	17.3
1999	20.155	15.7
2000	26.398	15.4
2001	18.213	13.9
2002	18.700	14.1
2003	19.651	14.1
2004	17.175	12.7
2005	21.853	12.3
2006	15.761	10.3
2007	17.805	8.4
2008	24.669	13.0
2009	18.736	9.8
2010	12.750	9.5
2011	12.207	8.6
2012	17.000	11.5
2013	13.920	6.2
2014	9.981	7.0

Table 5.16. Annual sample sizes of lengths and individual weights collected by the SERHS.

Year	Length	Weight	Year	Length	Weight
1981	0	0	1998	1	1
1982	0	0	1999	4	4
1983	0	0	2000	5	5
1984	0	0	2001	3	3
1985	0	0	2002	11	12
1986	0	0	2003	0	0
1987	0	0	2004	2	1
1988	0	0	2005	16	10
1989	3	3	2006	10	7
1990	2	2	2007	12	6
1991	0	0	2008	15	8
1992	17	10	2009	14	9
1993	8	7	2010	30	19
1994	5	5	2011	34	29
1995	0	0	2012	37	37
1996	2	2	2013	54	54
1997	0	0	2014	55	55

Table 5.17. Atlantic croaker harvest estimates (number of fish) from the Southeast Region Headboat Survey.

Year	Harvest	Year	Harvest
1981	0	1998	15
1982	0	1999	84
1983	0	2000	3
1984	0	2001	8
1985	0	2002	10
1986	0	2003	0
1987	41	2004	671
1988	23	2005	152
1989	12	2006	29
1990	45	2007	19
1991	0	2008	184
1992	778	2009	42
1993	39	2010	66
1994	33	2011	189
1995	3	2012	528
1996	53	2013	1244
1997	1	2014	1233

Table 5.18. Atlantic croaker release estimates (number of fish) by disposition from the Southeast Region Headboat Survey.

Year	Dead	Live	Disposition Unknown
2004	40	260	0
2005	0	0	0
2006	0	182	0
2007	0	0	0
2008	0	664	0
2009	0	0	0
2010	0	150	0
2011	0	20	0
2012	0	104	0
2013	0	0	342
2014	0	0	1,148

Table 6.1. Surveys considered for developing abundance indices by the Atlantic croaker SASC for this assessment.

Survey Considered	Time Series Available	Used	Reason Not Used
NJ Seine Survey	1980-2014	N	Localized survey, too many zeros
NJ Bay Trawl Survey	1991-2014	N	Localized survey, fixed design
NJ Ocean Trawl Survey	1989-2014	N	Not representative of whole range
DE 30ft Trawl Survey	1966-1971, 1979-1984, 1990-2014	N	Fixed design, localized survey
DE 17ft Trawl Survey	1978-2014	N	Fixed design, localized survey
MD Commercial Sampling	1993-2014	N	Fishery dependent
Chesapeake Blue Crab Trawl Survey	1980, consistent from 1989-2014	N	Fixed design
MD Striped Bass Seine Survey	1966-2014	N	Too many zeros
MD Coastal Bays Trawl Survey	1972-2014, standardized 1989	N	YOY survey, others used instead
MD Coastal Bay Seine Survey	1972-2014	N	Too many zeros
MD Choptank Rive Gill Net Survey	2013-2014	N	Short time series
MD Tagging Data	2005-2006	N	Short time series
VA Commercial Sampling	1989-2014, aging began in 1998	N	Fishery dependent
VIMS Juvenile Trawl Survey	1988-2014	Y	
NC P120 (estuarine trawl survey)	1970-2014	N	YOY survey, others used instead
NC P195	1987-2014	Y	
NC P915	1987-2014	N	No representative of stock
NC P135	1990-2014	N	Other survey used instead
NC P123	1991-2014	N	Other survey used instead
NC P100		N	Fixed design
NC P430 (pound net survey)	1986-2014	N	Other survey used instead
NC P433	1979-2014	N	Other survey used instead
NC P434 (gill net survey)	1982-2014	N	Other survey used instead
NC P435 (beach seine)		N	Other survey used instead
NC P537	1978-2014	N	Other survey used instead
NC P441	1978-2014	N	Other survey used instead
NC P447 (long-haul seine)		N	Other survey used instead
NC P461 (estuarine gill nets)	1992-2014	N	Other survey used instead
NC P466 (gill net observer)	2001-2014	N	Other survey used instead
NC P570 (shrimp at-sea observer)		N	Other survey used instead
SC Bears Bluff Shrimp Trawl	1952-1969	N	Localized survey, not representative

Table 6.1 Continued

Survey Considered	Time Series Available	Used	Reason Not Used
SC Trammel Net Survey	1990-2014	N	Localized survey, not representative
SC Electroshock Survey	2001-2014	N	Too many zeros, not representative of stock
SEAMAP	1990-2014	Y	
GA Ecological Monitoring Trawl Survey	1976-2014	N	YOY survey, others more representative
GA Gill Net Survey	2003-2014	N	Localized survey, not representative
FL Commercial Sampling	1992-2014	N	Fishery dependent
FL Fishery Independent Monitoring Program	1990-2014	N	Localized survey, not representative
NEFSC Groundfish Survey	1972-2014	Y	
MRFS/MRIP	1981-2014	N	Fishery dependent
NEAMAP	2007-2014	Y	
ChesMMAP	2002-2014	Y	
ACCSP Commercial Landings		N	Fishery dependent

Table 6.2. Indices developed from fishery independent surveys for the Atlantic croaker assessment

	NMFS (kg/tow)		SEMAP Fall (kg/tow)		ChesMMAP (kg/tow)		NEAMAP (kg/tow)		VIMS (num/tow)		NC195 (num/tow)	
Year	Index	SE [Index]	Index	SE [Index]	Index	SE [Index]	Index	SE [Index]	Index	SE [Index]	Index	SE [Index]
1989	26.321	1.950							6.858	2.160	119.340	22.654
1990	4.796	0.719	3.859	0.837					3.000	1.078	355.530	69.365
1991	0.213	0.051	12.263	2.741					23.231	5.780	266.025	24.152
1992	1.228	0.261	2.162	0.512					14.988	5.097	65.896	8.214
1993	0.782	0.086	9.342	3.700					24.011	5.300	437.616	70.074
1994	45.618	8.615	7.320	1.985					3.103	1.707	164.594	17.610
1995	14.024	0.669	2.538	0.664					10.836	3.784	157.346	24.273
1996	36.858	3.585	2.571	0.465					0.099	0.037	65.366	9.183
1997	12.709	1.632	1.149	0.364					34.815	8.829	386.785	52.191
1998	16.536	2.469	2.327	0.556					21.684	3.685	701.647	162.104
1999	107.829	10.197	8.740	2.209					12.978	4.867	777.893	84.137
2000	84.401	7.308	2.093	0.593					1.793	0.388	162.334	19.552
2001	35.460	1.864	1.331	0.324					2.014	0.854	112.275	23.822
2002	32.516	2.296	4.621	1.603	10.625	2.993			13.496	2.999	77.386	14.376
2003	54.822	4.322	7.062	1.811	15.765	3.953			0.349	0.204	163.886	25.440
2004	149.236	11.531	7.731	1.574	36.722	6.835			9.702	2.001	445.921	109.843
2005	86.339	4.126	11.915	2.482	22.373	5.903			6.880	1.857	220.378	46.409
2006	85.274	2.555	6.039	0.941	16.733	2.814			20.875	4.046	129.254	21.357
2007	223.440	14.071	4.585	1.119	16.980	3.358	50.776	20.502	16.825	3.753	111.707	23.213
2008	20.359	1.864	5.817	1.157	2.967	0.792	17.161	7.156	56.514	7.915	308.807	71.006
2009	139.904	25.187	4.346	0.728	3.523	0.732	20.905	5.101	40.006	9.541	79.523	14.356
2010	32.444	2.143	10.193	1.995	2.313	0.717	24.571	9.694	14.177	2.701	1185.427	202.120
2011	48.958	4.570	3.098	0.652	2.338	0.570	21.658	6.240	2.229	0.615	89.866	17.128
2012	32.649	1.259	18.365	3.073	0.884	0.220	72.520	16.833	76.761	13.480	1141.973	160.618
2013	48.136	3.435	12.102	2.473	4.657	1.074	45.082	13.853	26.859	7.729	577.262	83.281
2014	50.070	3.108	8.586	1.792	0.765	0.533	16.237	3.164	4.890	1.317	319.252	52.096

Table 8.1. Parameter values, standard deviations, and status from the base run of the Atlantic croaker stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD	Status
1	NatM_p_1_Fem_GP_1	0.314		fixed
2	L_at_Amin_Fem_GP_1	11.1	0.410	estimated
3	L_at_Amax_Fem_GP_1	40.0	0.864	estimated
4	VonBert_K_Fem_GP_1	0.278	0.0177	estimated
5	CV_young_Fem_GP_1	0.242	0.0132	estimated
6	CV_old_Fem_GP_1	0.0930	0.00646	estimated
7	NatM_p_1_Mal_GP_1	0.323		fixed
8	L_at_Amin_Mal_GP_1	11.0	0.311	estimated
9	L_at_Amax_Mal_GP_1	38.8	0.754	estimated
10	VonBert_K_Mal_GP_1	0.250	0.0154	estimated
11	CV_young_Mal_GP_1	0.236	0.0105	estimated
12	CV_old_Mal_GP_1	0.0766	0.00591	estimated
13	Wtlen_1_Fem	6.50E-06		fixed
14	Wtlen_2_Fem	3.19		fixed
15	Mat50%_Fem	19.3		fixed
16	Mat_slope_Fem	-0.320		fixed
17	Eggs/kg_inter_Fem	1		fixed
18	Eggs/kg_slope_wt_Fem	0		fixed
19	Wtlen_1_Mal	6.14E-06		fixed
20	Wtlen_2_Mal	3.20		fixed
21	RecrDist_GP_1	0		fixed
22	RecrDist_Area_1	0		fixed
23	RecrDist_Seas_1	0		fixed
24	CohortGrowDev	0		fixed
25	SR_LN(R0)	14.9	0.126	estimated
26	SR_BH_steep	0.985	0.0104	estimated
27	SR_sigmaR	0.600		fixed
28	SR_envlink	0.100		fixed
29	SR_R1_offset	0		fixed
30	SR_autocorr	0		fixed
31	Main_InitAge_17	-0.0182	0.592	estimated
32	Main_InitAge_16	-0.0169	0.593	estimated
33	Main_InitAge_15	-0.0173	0.593	estimated
34	Main_InitAge_14	-0.0181	0.592	estimated
35	Main_InitAge_13	-0.0193	0.592	estimated
36	Main_InitAge_12	-0.0210	0.592	estimated
37	Main_InitAge_11	-0.0236	0.591	estimated
38	Main_InitAge_10	-0.0275	0.590	estimated
39	Main_InitAge_9	-0.0312	0.589	estimated
40	Main_InitAge_8	-0.0336	0.588	estimated

Table 8.1 (*continued*). Parameter values, standard deviations, and status from the base run of the Atlantic croaker stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD	Status
41	Main_InitAge_7	-0.0302	0.589	estimated
42	Main_InitAge_6	-0.0118	0.592	estimated
43	Main_InitAge_5	0.0424	0.603	estimated
44	Main_InitAge_4	0.160	0.627	estimated
45	Main_InitAge_3	0.294	0.623	estimated
46	Main_InitAge_2	-0.294	0.532	estimated
47	Main_InitAge_1	-1.68	0.338	estimated
48	Main_RecrDev_1989	0.0369	0.218	estimated
49	Main_RecrDev_1990	1.27	0.254	estimated
50	Main_RecrDev_1991	0.730	0.195	estimated
51	Main_RecrDev_1992	0.0987	0.171	estimated
52	Main_RecrDev_1993	0.240	0.140	estimated
53	Main_RecrDev_1994	0.170	0.140	estimated
54	Main_RecrDev_1995	-0.386	0.142	estimated
55	Main_RecrDev_1996	-0.473	0.113	estimated
56	Main_RecrDev_1997	0.223	0.106	estimated
57	Main_RecrDev_1998	0.0296	0.122	estimated
58	Main_RecrDev_1999	-0.763	0.134	estimated
59	Main_RecrDev_2000	-0.449	0.125	estimated
60	Main_RecrDev_2001	0.054	0.106	estimated
61	Main_RecrDev_2002	-0.796	0.122	estimated
62	Main_RecrDev_2003	-0.0361	0.117	estimated
63	Main_RecrDev_2004	-0.542	0.117	estimated
64	Main_RecrDev_2005	0.156	0.115	estimated
65	Main_RecrDev_2006	-0.656	0.130	estimated
66	Main_RecrDev_2007	0.353	0.118	estimated
67	Main_RecrDev_2008	-0.169	0.135	estimated
68	Main_RecrDev_2009	0.164	0.134	estimated
69	Main_RecrDev_2010	-0.0750	0.141	estimated
70	Main_RecrDev_2011	1.08	0.166	estimated
71	Main_RecrDev_2012	0.790	0.179	estimated
72	Main_RecrDev_2013	0.680	0.213	estimated
73	Main_RecrDev_2014	0.0167	0.413	estimated
74	InitF_1Comm	7.24E-07	0.00145	estimated—LO
75	InitF_2Rec	0.154	0.148	estimated
76	InitF_3Scrap	2.05E-07	0.000410	estimated—LO
77	InitF_4ShrimpTrawl	3.38	0.495	estimated
78	F_fleet_1_YR_1989_s_1	1.01	0.257	estimated
79	F_fleet_1_YR_1990_s_1	1.23	0.371	estimated
80	F_fleet_1_YR_1991_s_1	0.304	0.0693	estimated

Table 8.1 (*continued*). Parameter values, standard deviations, and status from the base run of the Atlantic croaker stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD	Status
81	F_fleet_1_YR_1992_s_1	0.174	0.0326	estimated
82	F_fleet_1_YR_1993_s_1	0.136	0.0209	estimated
83	F_fleet_1_YR_1994_s_1	0.0998	0.0146	estimated
84	F_fleet_1_YR_1995_s_1	0.0966	0.0139	estimated
85	F_fleet_1_YR_1996_s_1	0.130	0.0193	estimated
86	F_fleet_1_YR_1997_s_1	0.177	0.0289	estimated
87	F_fleet_1_YR_1998_s_1	0.156	0.0273	estimated
88	F_fleet_1_YR_1999_s_1	0.131	0.0229	estimated
89	F_fleet_1_YR_2000_s_1	0.111	0.0201	estimated
90	F_fleet_1_YR_2001_s_1	0.121	0.0236	estimated
91	F_fleet_1_YR_2002_s_1	0.117	0.0252	estimated
92	F_fleet_1_YR_2003_s_1	0.125	0.0288	estimated
93	F_fleet_1_YR_2004_s_1	0.105	0.0261	estimated
94	F_fleet_1_YR_2005_s_1	0.0984	0.0262	estimated
95	F_fleet_1_YR_2006_s_1	0.0869	0.0244	estimated
96	F_fleet_1_YR_2007_s_1	0.0716	0.0211	estimated
97	F_fleet_1_YR_2008_s_1	0.0649	0.0200	estimated
98	F_fleet_1_YR_2009_s_1	0.0476	0.0151	estimated
99	F_fleet_1_YR_2010_s_1	0.0412	0.0134	estimated
100	F_fleet_1_YR_2011_s_1	0.0269	0.00884	estimated
101	F_fleet_1_YR_2012_s_1	0.0237	0.00797	estimated
102	F_fleet_1_YR_2013_s_1	0.0152	0.00506	estimated
103	F_fleet_1_YR_2014_s_1	0.00947	0.00313	estimated
104	F_fleet_2_YR_1989_s_1	0.207	0.0384	estimated
105	F_fleet_2_YR_1990_s_1	0.227	0.0493	estimated
106	F_fleet_2_YR_1991_s_1	0.125	0.0232	estimated
107	F_fleet_2_YR_1992_s_1	0.0841	0.0144	estimated
108	F_fleet_2_YR_1993_s_1	0.0563	0.00883	estimated
109	F_fleet_2_YR_1994_s_1	0.0561	0.00827	estimated
110	F_fleet_2_YR_1995_s_1	0.0342	0.00490	estimated
111	F_fleet_2_YR_1996_s_1	0.0333	0.00490	estimated
112	F_fleet_2_YR_1997_s_1	0.0569	0.00933	estimated
113	F_fleet_2_YR_1998_s_1	0.0406	0.00713	estimated
114	F_fleet_2_YR_1999_s_1	0.0317	0.00547	estimated
115	F_fleet_2_YR_2000_s_1	0.0352	0.00626	estimated
116	F_fleet_2_YR_2001_s_1	0.0466	0.00902	estimated
117	F_fleet_2_YR_2002_s_1	0.0435	0.00938	estimated
118	F_fleet_2_YR_2003_s_1	0.0355	0.00803	estimated
119	F_fleet_2_YR_2004_s_1	0.0376	0.00916	estimated
120	F_fleet_2_YR_2005_s_1	0.0367	0.00968	estimated

Table 8.1 (*continued*). Parameter values, standard deviations, and status from the base run of the Atlantic croaker stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD	Status
121	F_fleet_2_YR_2006_s_1	0.0274	0.00754	estimated
122	F_fleet_2_YR_2007_s_1	0.0248	0.00719	estimated
123	F_fleet_2_YR_2008_s_1	0.0274	0.00832	estimated
124	F_fleet_2_YR_2009_s_1	0.0215	0.00684	estimated
125	F_fleet_2_YR_2010_s_1	0.0140	0.00454	estimated
126	F_fleet_2_YR_2011_s_1	0.0121	0.00398	estimated
127	F_fleet_2_YR_2012_s_1	0.0108	0.00371	estimated
128	F_fleet_2_YR_2013_s_1	0.00672	0.00223	estimated
129	F_fleet_2_YR_2014_s_1	0.00420	0.00139	estimated
130	F_fleet_3_YR_1989_s_1	0.209	0.0416	estimated
131	F_fleet_3_YR_1990_s_1	0.0919	0.0171	estimated
132	F_fleet_3_YR_1991_s_1	0.0182	0.00278	estimated
133	F_fleet_3_YR_1992_s_1	0.0142	0.00199	estimated
134	F_fleet_3_YR_1993_s_1	0.0152	0.00198	estimated
135	F_fleet_3_YR_1994_s_1	0.0129	0.00160	estimated
136	F_fleet_3_YR_1995_s_1	0.0271	0.00332	estimated
137	F_fleet_3_YR_1996_s_1	0.0296	0.00389	estimated
138	F_fleet_3_YR_1997_s_1	0.0178	0.00266	estimated
139	F_fleet_3_YR_1998_s_1	0.00462	0.000705	estimated
140	F_fleet_3_YR_1999_s_1	0.00965	0.00141	estimated
141	F_fleet_3_YR_2000_s_1	0.00787	0.00121	estimated
142	F_fleet_3_YR_2001_s_1	0.0136	0.00236	estimated
143	F_fleet_3_YR_2002_s_1	0.00654	0.00127	estimated
144	F_fleet_3_YR_2003_s_1	0.00980	0.00194	estimated
145	F_fleet_3_YR_2004_s_1	0.00534	0.00115	estimated
146	F_fleet_3_YR_2005_s_1	0.00264	0.000625	estimated
147	F_fleet_3_YR_2006_s_1	0.00467	0.00114	estimated
148	F_fleet_3_YR_2007_s_1	0.00423	0.00111	estimated
149	F_fleet_3_YR_2008_s_1	0.00324	0.000887	estimated
150	F_fleet_3_YR_2009_s_1	0.00315	0.000950	estimated
151	F_fleet_3_YR_2010_s_1	0.00437	0.00134	estimated
152	F_fleet_3_YR_2011_s_1	0.00139	0.000437	estimated
153	F_fleet_3_YR_2012_s_1	0.000803	0.000263	estimated
154	F_fleet_3_YR_2013_s_1	8.86E-05	2.88E-05	estimated
155	F_fleet_3_YR_2014_s_1	0.000336	0.000110	estimated
156	F_fleet_4_YR_1989_s_1	2.60	0.376	estimated
157	F_fleet_4_YR_1990_s_1	1.70	0.229	estimated
158	F_fleet_4_YR_1991_s_1	2.94	0.265	estimated
159	F_fleet_4_YR_1992_s_1	1.26	0.145	estimated
160	F_fleet_4_YR_1993_s_1	0.889	0.118	estimated

Table 8.1 (*continued*). Parameter values, standard deviations, and status from the base run of the Atlantic croaker stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD	Status
161	F_fleet_4_YR_1994_s_1	1.23	0.140	estimated
162	F_fleet_4_YR_1995_s_1	1.60	0.164	estimated
163	F_fleet_4_YR_1996_s_1	1.71	0.233	estimated
164	F_fleet_4_YR_1997_s_1	0.704	0.116	estimated
165	F_fleet_4_YR_1998_s_1	0.669	0.104	estimated
166	F_fleet_4_YR_1999_s_1	1.17	0.172	estimated
167	F_fleet_4_YR_2000_s_1	1.41	0.204	estimated
168	F_fleet_4_YR_2001_s_1	1.56	0.209	estimated
169	F_fleet_4_YR_2002_s_1	0.721	0.114	estimated
170	F_fleet_4_YR_2003_s_1	1.04	0.167	estimated
171	F_fleet_4_YR_2004_s_1	1.27	0.194	estimated
172	F_fleet_4_YR_2005_s_1	0.642	0.119	estimated
173	F_fleet_4_YR_2006_s_1	0.987	0.171	estimated
174	F_fleet_4_YR_2007_s_1	0.808	0.162	estimated
175	F_fleet_4_YR_2008_s_1	0.833	0.157	estimated
176	F_fleet_4_YR_2009_s_1	0.668	0.141	estimated
177	F_fleet_4_YR_2010_s_1	0.677	0.142	estimated
178	F_fleet_4_YR_2011_s_1	1.07	0.236	estimated
179	F_fleet_4_YR_2012_s_1	0.411	0.100	estimated
180	F_fleet_4_YR_2013_s_1	0.493	0.123	estimated
181	F_fleet_4_YR_2014_s_1	0.672	0.186	estimated
182	LnQ_base_4_ShrimpTrawl	-0.191	0.109	estimated
183	LnQ_base_5_NEFSC	-7.36	0.288	estimated
184	LnQ_base_6_ChesMMAP	-10.2	104,009	estimated
185	LnQ_base_7_SEAMAP	-8.34	0.253	estimated
186	LnQ_base_8_VIMS	-12.5	0.310	estimated
187	LnQ_base_9_NC195	-9.30	0.157	estimated
188	SizeSel_1P_1_Comm	29.0	537	estimated
189	SizeSel_1P_2_Comm	-0.00122	224	estimated
190	SizeSel_1P_3_Comm	3.50	123	estimated
191	SizeSel_1P_4_Comm	3.50	123	estimated
192	SizeSel_1P_5_Comm	-999		fixed
193	SizeSel_1P_6_Comm	-999		fixed
194	Retain_1P_1_Comm	28.0	581	estimated
195	Retain_1P_2_Comm	5.05	111	estimated
196	Retain_1P_3_Comm	1.00		fixed
197	Retain_1P_4_Comm	0		fixed
198	SizeSel_2P_1_Rec	23.9	0.482	estimated
199	SizeSel_2P_2_Rec	-0.0289	231	estimated
200	SizeSel_2P_3_Rec	2.92	0.142	estimated

Table 8.1 (*continued*). Parameter values, standard deviations, and status from the base run of the Atlantic croaker stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD	Status
201	SizeSel_2P_4_Rec	5.00		fixed
202	SizeSel_2P_5_Rec	-999		fixed
203	SizeSel_2P_6_Rec	15.0		fixed
204	Retain_2P_1_Rec	15.9	1.07	estimated
205	Retain_2P_2_Rec	5.32	0.768	estimated
206	Retain_2P_3_Rec	1.00		fixed
207	Retain_2P_4_Rec	0		fixed
208	SizeSel_3P_1_Scrap	21.5	0.476	estimated
209	SizeSel_3P_2_Scrap	-9.68	8.80	estimated
210	SizeSel_3P_3_Scrap	3.39	0.124	estimated
211	SizeSel_3P_4_Scrap	2.56	0.265	estimated
212	SizeSel_3P_5_Scrap	-999		fixed
213	SizeSel_3P_6_Scrap	-999		fixed
214	SizeSel_4P_1_ShrimpTrawl	29.0	537	estimated
215	SizeSel_4P_2_ShrimpTrawl	0.00252	224	estimated
216	SizeSel_4P_3_ShrimpTrawl	3.50	123	estimated
217	SizeSel_4P_4_ShrimpTrawl	3.50	123	estimated
218	SizeSel_4P_5_ShrimpTrawl	-999		fixed
219	SizeSel_4P_6_ShrimpTrawl	-999		fixed
220	SizeSel_5P_1_NEFSC	19		fixed
221	SizeSel_5P_2_NEFSC	-3.00		fixed
222	SizeSel_5P_3_NEFSC	2.00		fixed
223	SizeSel_5P_4_NEFSC	3.80		fixed
224	SizeSel_5P_5_NEFSC	-999		fixed
225	SizeSel_5P_6_NEFSC	-999		fixed
226	SizeSel_6P_1_ChesMMAP	22.5	1.14	estimated
227	SizeSel_6P_2_ChesMMAP	-9.07	21.4	estimated
228	SizeSel_6P_3_ChesMMAP	4.10	0.199	estimated
229	SizeSel_6P_4_ChesMMAP	4.33	0.378	estimated
230	SizeSel_6P_5_ChesMMAP	-999		fixed
231	SizeSel_6P_6_ChesMMAP	-999		fixed
232	SizeSel_7P_1_SEAMAP	17.2	0.286	estimated
233	SizeSel_7P_2_SEAMAP	-9.81	5.61	estimated—LO
234	SizeSel_7P_3_SEAMAP	1.41	0.231	estimated
235	SizeSel_7P_4_SEAMAP	2.06	0.197	estimated
236	SizeSel_7P_5_SEAMAP	-999		fixed
237	SizeSel_7P_6_SEAMAP	-999		fixed
238	SizeSel_1P_1_Comm_BLK1repl_1989	25.8	0.654	estimated
239	SizeSel_1P_1_Comm_BLK1repl_1993	26.1		fixed
240	SizeSel_1P_2_Comm_BLK1repl_1989	-9.45	14.0	estimated

Table 8.1 (*continued*). Parameter values, standard deviations, and status from the base run of the Atlantic croaker stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD	Status
241	SizeSel_1P_2_Comm_BLK1repl_1993	-9.00		fixed
242	SizeSel_1P_3_Comm_BLK1repl_1989	2.49	0.227	estimated
243	SizeSel_1P_3_Comm_BLK1repl_1993	2.80		fixed
244	SizeSel_1P_4_Comm_BLK1repl_1989	2.32	0.549	estimated
245	SizeSel_1P_4_Comm_BLK1repl_1993	4.60		fixed
246	Retain_1P_1_Comm_BLK1repl_1989	2.03	0.808	estimated—LO
247	Retain_1P_1_Comm_BLK1repl_1993	2.00	0.0347	estimated—LO
248	Retain_1P_2_Comm_BLK1repl_1989	4.94	0.393	estimated
249	Retain_1P_2_Comm_BLK1repl_1993	2.91	0.108	estimated
250	SizeSel_4P_1_ShrimpTrawl_BLK2repl_1989	11.0		fixed
251	SizeSel_4P_1_ShrimpTrawl_BLK2repl_1996	12.2	0.545	estimated
252	SizeSel_4P_2_ShrimpTrawl_BLK2repl_1989	-5.00		fixed
253	SizeSel_4P_2_ShrimpTrawl_BLK2repl_1996	-5.50	8.17	estimated
254	SizeSel_4P_3_ShrimpTrawl_BLK2repl_1989	2.00		fixed
255	SizeSel_4P_3_ShrimpTrawl_BLK2repl_1996	1.40	0.356	estimated
256	SizeSel_4P_4_ShrimpTrawl_BLK2repl_1989	3.00		fixed
257	SizeSel_4P_4_ShrimpTrawl_BLK2repl_1996	2.51	0.466	estimated

Table 8.2. Predicted recruitment, female SSB, fishing mortality, and associated standard deviations from the base run of the assessment model, 1989–2014.

Year	Recruits (000s fish)		Female SSB (mt)		Fishing Mortality (ages 0-8)	
	Value	SD	Value	SD	Value	SD
1989	1,930,310	285,597	8,849	1,892	0.507	0.0752
1990	5,911,000	860,638	6,204	1,507	0.359	0.0554
1991	3,809,330	422,133	8,445	1,616	0.906	0.0983
1992	2,160,410	228,636	10,758	1,813	0.438	0.0539
1993	2,793,440	280,815	19,614	2,776	0.266	0.0357
1994	2,768,450	285,774	32,446	4,245	0.378	0.0455
1995	1,631,080	189,166	45,339	5,831	0.513	0.0572
1996	1,512,630	145,815	54,460	7,186	0.306	0.0408
1997	3,043,970	263,849	57,774	8,396	0.126	0.0168
1998	2,516,970	243,559	60,888	9,824	0.189	0.0254
1999	1,150,160	122,627	73,483	12,070	0.358	0.0463
2000	1,583,330	154,997	85,642	14,544	0.246	0.0325
2001	2,625,930	274,309	91,304	16,639	0.229	0.0318
2002	1,122,260	129,658	90,216	18,294	0.248	0.0383
2003	2,402,460	276,308	94,240	20,445	0.173	0.0263
2004	1,449,550	201,084	96,964	22,748	0.324	0.0561
2005	2,914,610	382,710	98,961	25,104	0.113	0.0199
2006	1,296,960	197,704	104,142	28,037	0.305	0.0589
2007	3,564,620	524,045	111,792	31,664	0.114	0.0224
2008	2,119,360	361,787	121,077	35,854	0.235	0.0488
2009	2,966,690	499,239	133,893	41,211	0.133	0.0289
2010	2,341,800	377,965	151,536	47,827	0.165	0.0359
2011	7,438,650	1,583,890	172,163	55,014	0.118	0.0281
2012	5,590,220	1,221,970	191,641	62,790	0.114	0.0281
2013	5,021,130	1,201,970	237,229	77,028	0.121	0.0305
2014	2,595,530	1,122,560	304,345	97,889	0.167	0.0452

Table 8.3. Predicted population numbers (000s) at age of females at the beginning of the year from the base run of the assessment model, 1989–2014.

Year	Age																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1989	965,156	67,389	17,373	10,456	5,292	3,101	2,006	1,365	951	671	475	338	240	171	122	87	62	154
1990	2,955,500	307,583	6,752	4,065	2,899	1,802	1,329	1,022	775	575	421	305	220	158	113	81	58	144
1991	1,904,660	1,092,560	58,895	1,904	1,081	899	711	636	553	451	350	263	193	141	102	73	52	132
1992	1,080,210	573,739	94,076	19,529	951	619	561	471	437	389	322	251	190	140	102	74	53	135
1993	1,396,720	429,533	157,544	47,202	11,762	618	425	400	344	324	291	242	190	144	107	78	56	144
1994	1,384,220	590,933	152,887	87,443	29,799	7,749	419	296	285	248	237	215	180	142	108	80	59	151
1995	815,539	553,785	167,044	80,330	55,906	20,177	5,410	300	215	210	185	177	162	136	108	82	61	160
1996	756,314	306,790	120,952	81,594	51,243	38,489	14,395	3,953	223	162	159	142	137	125	105	84	64	172
1997	1,521,990	356,450	65,406	56,695	50,720	34,371	26,791	10,293	2,885	165	122	121	108	105	96	81	64	182
1998	1,258,490	733,982	146,832	36,985	35,011	32,347	22,610	18,143	7,140	2,039	118	88	88	79	77	71	60	184
1999	575,079	607,416	311,438	85,885	23,726	23,172	22,018	15,799	12,957	5,187	1,500	88	66	66	60	58	54	186
2000	791,666	274,394	185,413	165,767	55,220	16,082	16,198	15,779	11,550	9,618	3,894	1,136	67	50	51	46	45	185
2001	1,312,960	375,681	71,675	94,487	106,815	37,860	11,372	11,724	11,630	8,631	7,262	2,963	869	51	39	39	36	179
2002	561,128	620,930	88,700	34,910	59,320	71,676	26,255	8,083	8,494	8,550	6,415	5,441	2,233	658	39	30	30	164
2003	1,201,230	270,507	254,614	51,886	22,896	40,379	50,114	18,782	5,890	6,277	6,386	4,829	4,121	1,699	502	30	23	149
2004	724,773	574,857	89,863	139,194	33,557	15,547	28,246	35,916	13,724	4,368	4,708	4,829	3,674	3,149	1,303	386	23	133
2005	1,457,310	345,072	165,134	47,316	90,557	23,111	11,026	20,485	26,507	10,264	3,300	3,583	3,695	2,823	2,427	1,006	299	121
2006	648,480	703,816	149,409	99,527	31,801	63,093	16,509	8,043	15,193	19,913	7,785	2,520	2,751	2,849	2,183	1,881	781	326
2007	1,782,310	310,720	243,035	84,455	66,969	22,500	45,860	12,247	6,061	11,589	15,325	6,031	1,962	2,150	2,232	1,714	1,479	872
2008	1,059,680	857,494	120,736	143,645	58,017	48,162	16,594	34,466	9,338	4,672	9,005	11,979	4,735	1,546	1,698	1,766	1,358	1,865
2009	1,483,340	509,540	327,918	71,111	98,886	41,854	35,619	12,497	26,317	7,204	3,632	7,041	9,406	3,730	1,220	1,343	1,398	2,557
2010	1,170,900	715,951	217,325	201,843	50,158	72,854	31,560	27,303	9,698	20,608	5,680	2,878	5,599	7,500	2,980	977	1,076	3,174
2011	3,719,330	565,029	303,681	134,279	143,807	37,400	55,604	24,476	21,424	7,676	16,415	4,545	2,311	4,508	6,050	2,408	790	3,442
2012	2,795,110	1,778,740	185,508	174,317	95,431	108,482	28,913	43,631	19,407	17,117	6,166	13,242	3,678	1,874	3,662	4,921	1,960	3,450
2013	2,510,560	1,357,070	900,538	122,493	127,747	72,620	84,255	22,770	34,708	15,551	13,790	4,987	10,741	2,990	1,526	2,985	4,015	4,420
2014	1,297,770	1,216,620	651,387	587,924	90,363	98,231	56,997	67,008	18,278	28,048	12,629	11,238	4,075	8,794	2,451	1,253	2,452	6,936

Table 8.4. Predicted population numbers (000s) at age of males at the beginning of the year from the base run of the assessment model, 1989–2014.

Year	Age																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1989	965,156	69,120	14,946	7,062	3,281	1,877	1,204	815	566	398	281	200	142	101	72	51	37	91
1990	2,955,500	313,139	6,181	3,271	1,873	961	668	525	415	320	239	176	128	92	66	48	34	85
1991	1,904,660	1,102,680	55,825	1,784	874	500	307	267	250	223	185	145	110	81	59	43	31	78
1992	1,080,210	586,025	81,662	15,455	834	474	295	194	177	172	157	132	104	79	59	43	31	80
1993	1,396,720	431,667	150,517	38,036	9,037	525	314	204	139	130	128	118	99	79	60	45	33	85
1994	1,384,220	591,719	146,395	79,237	23,637	5,876	350	214	142	98	93	93	86	73	58	45	33	88
1995	815,539	556,337	156,535	70,853	49,264	15,767	4,038	246	153	103	72	69	69	64	55	44	34	92
1996	756,314	309,316	111,565	68,325	43,367	33,255	11,056	2,900	180	113	77	55	52	53	49	42	34	97
1997	1,521,990	355,847	61,662	46,199	40,768	28,532	22,697	7,739	2,073	131	84	57	41	40	40	38	32	101
1998	1,258,490	730,345	142,452	33,589	28,329	25,694	18,373	14,976	5,227	1,428	91	59	41	30	29	29	28	98
1999	575,079	604,334	301,129	80,133	21,383	18,561	17,169	12,547	10,445	3,712	1,029	67	44	30	22	21	22	95
2000	791,666	273,450	175,833	147,635	50,276	14,296	12,749	12,057	8,985	7,603	2,737	767	50	33	23	17	16	89
2001	1,312,960	374,679	67,456	80,855	92,119	33,971	9,950	9,063	8,727	6,601	5,652	2,054	579	38	25	18	13	82
2002	561,128	619,576	83,136	29,374	49,014	60,836	23,154	6,936	6,440	6,299	4,824	4,171	1,527	433	29	19	13	72
2003	1,201,230	269,181	246,326	46,390	19,017	33,011	41,873	16,260	4,960	4,676	4,629	3,580	3,118	1,148	327	22	14	65
2004	724,773	572,636	85,658	125,280	29,366	12,747	22,704	29,426	11,647	3,610	3,447	3,447	2,686	2,353	871	249	17	61
2005	1,457,310	343,990	156,176	41,140	79,209	19,955	8,904	16,186	21,346	8,570	2,687	2,588	2,606	2,042	1,796	667	191	60
2006	648,480	700,183	144,751	90,084	27,300	54,649	14,058	6,391	11,811	15,791	6,410	2,027	1,966	1,989	1,565	1,381	514	194
2007	1,782,310	309,465	231,856	76,033	59,190	19,083	39,190	10,275	4,746	8,884	12,001	4,910	1,562	1,522	1,546	1,220	1,079	554
2008	1,059,680	853,533	116,065	128,877	51,156	42,095	13,905	29,070	7,734	3,614	6,830	9,292	3,823	1,222	1,194	1,216	961	1,289
2009	1,483,340	507,228	314,734	64,133	86,805	36,498	30,776	10,344	21,932	5,901	2,782	5,293	7,240	2,991	959	939	958	1,778
2010	1,170,900	712,318	209,833	183,630	44,355	63,296	27,246	23,350	7,949	17,022	4,615	2,189	4,184	5,743	2,379	764	750	2,190
2011	3,719,330	562,179	292,887	122,612	128,084	32,721	47,843	20,929	18,159	6,241	13,464	3,671	1,749	3,354	4,615	1,915	616	2,377
2012	2,795,110	1,772,040	176,210	153,878	84,343	95,429	25,078	37,249	16,478	14,418	4,987	10,812	2,959	1,414	2,717	3,745	1,556	2,437
2013	2,510,560	1,349,050	878,077	112,095	111,000	63,614	73,540	19,605	29,434	13,128	11,558	4,017	8,740	2,399	1,148	2,211	3,051	3,259
2014	1,297,770	1,209,760	631,635	547,924	81,138	84,562	49,572	58,117	15,650	23,674	10,618	9,389	3,274	7,141	1,963	941	1,814	5,187

Table 8.5. Predicted population numbers (000s) at age of females at mid-year from the base run of the assessment model, 1989–2014.

Year	Age																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1989	544,853	21,331	8,404	5,506	3,088	2,030	1,432	1,029	740	531	381	272	195	139	99	71	51	126
1990	1,796,960	134,592	3,586	2,096	1,614	1,132	919	752	591	449	332	243	176	127	91	65	47	117
1991	1,045,360	320,598	33,914	1,345	818	710	578	527	464	381	297	223	165	120	87	62	45	113
1992	681,164	300,648	66,638	15,156	766	513	474	402	376	337	279	219	165	122	89	65	47	118
1993	908,499	256,261	117,372	37,505	9,547	509	355	337	292	277	250	209	164	125	92	68	49	125
1994	875,535	314,184	110,822	69,918	24,521	6,475	354	252	244	214	205	186	156	124	94	70	51	132
1995	500,199	258,808	116,747	64,159	46,387	17,043	4,625	258	187	183	162	156	142	120	95	72	54	141
1996	519,219	141,655	82,809	64,331	41,967	32,112	12,172	3,377	192	140	139	123	120	109	92	73	56	151
1997	1,056,930	228,776	49,184	44,553	40,505	27,877	22,047	8,573	2,426	140	103	103	92	90	82	70	56	157
1998	874,314	478,111	112,297	29,623	28,483	26,687	18,900	15,333	6,086	1,749	102	76	76	69	67	62	52	160
1999	397,238	335,593	227,214	68,866	19,533	19,374	18,639	13,508	11,164	4,494	1,306	77	58	58	52	51	47	163
2000	545,357	140,240	132,360	133,065	45,723	13,524	13,780	13,547	9,984	8,358	3,397	994	59	44	45	40	40	163
2001	902,917	182,545	50,022	74,867	87,499	31,528	9,588	9,979	9,971	7,441	6,286	2,573	757	45	34	34	31	157
2002	389,601	397,615	67,840	28,272	48,942	59,933	22,206	6,900	7,302	7,389	5,566	4,735	1,948	575	34	26	26	144
2003	830,985	155,912	188,257	41,727	18,867	33,772	42,425	16,055	5,072	5,436	5,553	4,212	3,602	1,488	440	26	20	131
2004	500,099	308,105	65,207	112,272	27,848	13,093	24,054	30,855	11,869	3,796	4,107	4,224	3,221	2,765	1,145	340	20	117
2005	1,012,760	227,061	128,200	38,791	75,588	19,533	9,417	17,642	22,974	8,939	2,884	3,140	3,245	2,482	2,137	887	263	107
2006	448,883	413,584	112,331	81,641	26,749	53,790	14,219	6,982	13,269	17,469	6,852	2,224	2,432	2,522	1,934	1,668	693	290
2007	1,236,250	193,688	186,844	69,999	56,792	19,323	39,757	10,694	5,322	10,215	13,549	5,344	1,742	1,910	1,985	1,525	1,317	777
2008	734,813	530,271	92,659	119,182	49,277	41,418	14,401	30,117	8,202	4,120	7,963	10,615	4,203	1,374	1,510	1,571	1,209	1,662
2009	1,030,530	332,770	257,270	59,723	84,878	36,344	31,185	11,009	23,288	6,397	3,233	6,279	8,399	3,334	1,092	1,202	1,252	2,291
2010	813,384	466,284	170,828	170,371	43,312	63,647	27,793	24,186	8,628	18,393	5,081	2,579	5,024	6,736	2,679	878	968	2,857
2011	2,572,110	323,755	230,080	113,201	124,902	32,884	49,255	21,794	19,150	6,880	14,743	4,089	2,081	4,063	5,456	2,172	713	3,108
2012	1,947,610	1,265,630	150,743	149,226	83,247	95,604	25,659	38,914	17,372	15,363	5,546	11,926	3,316	1,691	3,306	4,445	1,771	3,119
2013	1,747,690	940,202	727,632	105,208	112,021	64,336	75,138	20,401	31,200	14,014	12,449	4,508	9,719	2,707	1,383	2,705	3,640	4,009
2014	901,573	795,022	517,453	504,686	79,470	87,317	50,992	60,213	16,476	25,340	11,429	10,183	3,696	7,981	2,226	1,138	2,228	6,305

Table 8.6. Predicted population numbers (000s) at age of males at mid-year from the base run of the assessment model, 1989–2014.

	Age																	
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1989	549,753	20,670	6,992	3,637	1,775	1,119	795	582	425	309	223	160	114	82	58	42	30	75
1990	1,805,260	132,215	3,321	1,690	967	544	422	363	305	243	186	139	102	74	53	38	27	69
1991	1,056,490	300,078	29,373	1,220	643	384	244	218	208	187	156	123	93	69	50	37	26	67
1992	682,854	296,996	55,733	11,818	662	385	245	164	152	148	136	114	91	69	51	38	27	70
1993	909,102	251,384	109,209	29,984	7,287	429	259	170	117	110	109	101	85	68	52	39	28	73
1994	877,551	304,344	101,845	62,478	19,305	4,871	293	181	121	84	80	80	74	63	51	39	29	77
1995	502,254	249,134	103,418	55,432	40,476	13,203	3,422	210	132	89	63	60	60	56	48	39	30	81
1996	518,779	138,105	71,793	52,778	35,176	27,473	9,250	2,452	153	97	67	47	46	46	43	37	30	85
1997	1,054,310	225,147	45,510	36,177	32,365	22,896	18,437	6,361	1,721	109	70	49	35	34	34	32	28	86
1998	872,093	468,965	106,842	26,800	22,931	21,003	15,183	12,507	4,405	1,212	78	51	35	25	25	25	24	85
1999	396,554	325,978	210,848	63,473	17,484	15,383	14,387	10,618	8,911	3,188	888	58	38	27	19	19	19	83
2000	544,629	135,816	119,235	116,619	41,327	11,927	10,750	10,257	7,701	6,555	2,371	667	44	29	20	15	14	79
2001	901,932	176,492	44,514	62,952	74,861	28,045	8,307	7,640	7,414	5,643	4,855	1,771	501	33	22	15	11	71
2002	388,645	390,663	62,102	23,635	40,224	50,472	19,403	5,866	5,488	5,400	4,156	3,606	1,324	377	25	17	12	63
2003	829,379	151,847	175,669	36,909	15,569	27,376	35,102	13,762	4,232	4,015	3,994	3,101	2,709	1,000	285	19	13	57
2004	499,314	299,052	59,363	99,616	24,207	10,654	19,170	25,062	9,991	3,114	2,987	2,997	2,342	2,056	762	218	14	53
2005	1,010,140	223,144	118,613	33,513	65,793	16,749	7,544	13,826	18,359	7,412	2,334	2,256	2,277	1,787	1,575	585	168	52
2006	447,975	402,916	104,909	73,021	22,824	46,279	12,018	5,507	10,244	13,766	5,610	1,779	1,730	1,754	1,381	1,220	454	172
2007	1,233,390	189,520	172,861	62,366	49,916	16,289	33,753	8,914	4,142	7,789	10,560	4,333	1,382	1,348	1,371	1,083	958	493
2008	733,144	518,301	86,276	105,769	43,210	35,993	11,993	25,250	6,755	3,171	6,013	8,202	3,382	1,082	1,059	1,080	854	1,147
2009	1,027,920	326,241	240,405	53,335	74,124	31,534	26,807	9,067	19,322	5,219	2,468	4,706	6,448	2,668	856	839	857	1,591
2010	811,330	456,759	160,399	153,363	38,096	55,029	23,879	20,592	7,043	15,139	4,116	1,957	3,746	5,148	2,135	686	674	1,970
2011	2,567,250	314,740	212,294	101,693	110,557	28,645	42,215	18,570	16,181	5,579	12,065	3,296	1,572	3,019	4,157	1,727	556	2,145
2012	1,941,840	1,247,390	140,543	130,692	73,249	83,773	22,173	33,112	14,708	12,909	4,476	9,720	2,664	1,274	2,451	3,380	1,405	2,202
2013	1,742,750	923,098	693,628	95,368	96,884	56,156	65,375	17,517	26,398	11,807	10,417	3,626	7,900	2,170	1,040	2,003	2,765	2,956
2014	899,287	778,082	486,893	464,644	70,988	74,908	44,223	52,098	14,080	21,355	9,597	8,499	2,967	6,477	1,782	855	1,648	4,715

Table 8.7. Predicted catch (000s) at age for the commercial fishery from the base run of the assessment model, 1989–2014.

Year	Age																
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1989	0	752	4,795	5,769	3,029	1,442	665	302	138	65	32	17	9	5	3	2	1	2
1990	0	5,202	2,517	2,891	1,969	925	478	249	127	64	33	18	10	6	3	2	1	3
1991	0	3,446	5,690	459	265	146	70	40	23	13	7	4	2	1	1	1	0	1
1992	0	1,578	6,104	2,746	148	70	36	17	10	6	4	2	1	1	0	0	0	0
1993	0	1,422	9,501	6,182	1,875	103	61	44	31	26	22	18	13	10	7	5	4	9
1994	0	1,304	6,586	8,875	3,584	912	47	28	20	15	13	11	9	7	5	4	3	7
1995	0	1,069	6,651	7,767	6,869	2,352	567	29	18	13	10	9	8	6	5	4	3	7
1996	0	794	6,327	10,283	8,231	6,265	2,038	490	26	16	12	9	8	8	6	5	4	10
1997	0	1,635	5,170	9,637	10,587	7,263	5,265	1,712	420	23	14	11	9	8	7	6	5	14
1998	0	3,001	10,497	5,901	6,571	5,997	3,895	2,822	936	236	13	8	7	5	5	5	4	13
1999	0	1,817	17,793	11,638	3,977	3,674	3,167	2,052	1,515	516	134	8	5	4	3	3	3	11
2000	0	655	8,730	18,687	7,942	2,290	1,999	1,716	1,131	856	299	79	5	3	3	2	2	9
2001	0	935	3,573	11,218	16,079	5,820	1,589	1,379	1,204	813	630	226	61	4	2	2	2	9
2002	0	1,877	4,683	4,079	8,535	10,415	3,573	971	857	767	531	421	154	42	3	2	2	8
2003	0	802	14,113	6,625	3,540	6,188	7,134	2,437	673	609	559	396	321	119	33	2	1	8
2004	0	1,346	4,069	14,961	4,484	2,014	3,328	3,819	1,326	375	348	327	236	195	73	21	1	6
2005	0	899	7,476	4,776	11,392	2,883	1,222	2,008	2,340	832	241	229	219	161	135	51	15	5
2006	0	1,469	5,828	9,014	3,527	7,020	1,673	704	1,173	1,399	509	151	146	142	106	89	34	13
2007	0	562	7,940	6,353	6,253	2,057	3,861	913	389	663	809	301	91	89	88	66	57	30
2008	0	1,395	3,576	9,781	4,909	4,053	1,255	2,335	559	243	424	528	200	61	61	61	46	61
2009	0	637	7,273	3,599	6,182	2,603	2,022	620	1,167	285	127	225	286	110	34	34	35	62
2010	0	772	4,186	8,913	2,738	3,936	1,559	1,198	371	712	178	81	146	188	73	23	23	66
2011	0	357	3,668	3,861	5,165	1,331	1,800	704	547	172	338	86	40	73	95	37	12	47
2012	0	1,195	2,113	4,435	3,026	3,423	830	1,108	438	346	111	222	57	27	50	66	26	42
2013	0	572	6,623	2,041	2,598	1,479	1,569	375	505	203	164	54	109	29	14	26	34	35
2014	0	303	2,916	6,127	1,163	1,236	660	691	167	228	93	77	26	53	14	7	13	35

Table 8.8. Predicted catch (000s) at age for the recreational fishery from the base run of the assessment model, 1989–2014.

Year	Age																	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1989	1	847	1,826	1,727	1,023	670	471	339	244	176	126	90	65	46	33	24	17	42
1990	3	5,306	870	783	601	393	312	258	206	159	119	87	64	46	33	24	17	43
1991	1	7,825	4,380	277	178	137	104	94	85	71	57	44	32	24	17	12	9	23
1992	0	4,211	5,500	1,945	116	75	61	48	45	41	35	28	22	16	12	9	6	16
1993	0	2,335	6,737	3,249	918	53	35	29	23	22	20	17	14	11	8	6	4	11
1994	0	2,905	6,330	6,336	2,380	635	36	24	21	17	16	15	13	11	8	6	5	12
1995	0	1,500	4,022	3,492	2,872	1,031	276	16	11	9	8	7	7	6	5	4	3	8
1996	0	804	2,759	3,333	2,483	1,976	715	195	12	8	7	6	6	5	5	4	3	8
1997	0	2,084	2,843	3,929	4,020	2,886	2,315	855	237	14	10	9	7	7	7	6	5	14
1998	0	3,099	4,683	1,954	2,023	1,933	1,390	1,137	428	121	7	5	5	4	4	4	3	10
1999	0	1,737	7,345	3,569	1,133	1,097	1,049	767	638	244	70	4	3	3	2	2	2	8
2000	0	820	4,714	7,497	2,962	893	866	841	625	527	204	59	4	3	2	2	2	9
2001	0	1,429	2,353	5,489	7,320	2,768	837	825	814	612	521	203	59	4	3	2	2	11
2002	0	2,766	2,977	1,924	3,748	4,783	1,814	557	558	558	424	364	143	42	3	2	2	9
2003	0	898	6,825	2,378	1,181	2,162	2,759	1,062	331	336	340	260	225	89	26	2	1	7
2004	0	1,905	2,485	6,790	1,891	889	1,629	2,110	825	261	268	272	210	182	72	21	1	6
2005	0	1,329	4,766	2,260	5,014	1,327	624	1,159	1,523	602	192	199	203	157	137	54	16	6
2006	0	1,832	3,139	3,604	1,311	2,728	720	343	646	858	342	110	114	117	91	79	31	13
2007	0	771	4,700	2,793	2,555	879	1,827	488	235	448	600	241	78	81	83	65	57	32
2008	0	2,330	2,578	5,235	2,442	2,108	723	1,519	410	200	383	516	208	67	70	73	57	77
2009	0	1,139	5,612	2,062	3,292	1,449	1,246	432	917	250	123	236	319	129	42	44	45	84
2010	0	1,043	2,441	3,859	1,101	1,656	726	630	220	472	129	64	123	167	68	22	23	68
2011	0	637	2,828	2,211	2,749	741	1,109	490	429	151	325	90	44	86	117	47	15	64
2012	0	2,156	1,645	2,563	1,626	1,922	516	778	347	305	108	234	65	32	62	85	34	57
2013	0	1,001	5,003	1,144	1,354	805	945	255	388	174	154	55	119	33	16	32	43	47
2014	0	532	2,212	3,451	608	676	400	472	128	196	88	79	28	61	17	8	16	46

Table 8.9. Predicted catch (000s) at age for the scrap fishery from the base run of the assessment model, 1989–2014.

	Age																	
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1989	402	3,304	2,519	1,243	373	116	37	12	4	2	1	0	0	0	0	0	0	0
1990	573	8,289	483	229	88	27	10	4	1	1	0	0	0	0	0	0	0	0
1991	67	4,384	872	29	10	3	1	0	0	0	0	0	0	0	0	0	0	0
1992	33	2,749	1,270	237	7	2	1	0	0	0	0	0	0	0	0	0	0	0
1993	47	2,432	2,496	633	92	3	1	0	0	0	0	0	0	0	0	0	0	0
1994	39	2,573	1,995	1,059	203	26	1	0	0	0	0	0	0	0	0	0	0	0
1995	47	4,589	4,373	2,012	857	146	18	0	0	0	0	0	0	0	0	0	0	0
1996	52	2,763	3,363	2,147	828	318	52	7	0	0	0	0	0	0	0	0	0	0
1997	64	2,515	1,221	888	469	162	60	10	1	0	0	0	0	0	0	0	0	0
1998	14	1,361	733	162	86	39	13	5	1	0	0	0	0	0	0	0	0	0
1999	13	2,042	3,074	794	130	60	26	9	4	1	0	0	0	0	0	0	0	0
2000	15	706	1,444	1,218	250	36	16	7	3	1	0	0	0	0	0	0	0	0
2001	42	1,610	943	1,163	803	147	20	9	4	2	1	0	0	0	0	0	0	0
2002	9	1,606	615	210	211	130	23	3	2	1	0	0	0	0	0	0	0	0
2003	28	956	2,589	478	122	107	63	11	2	1	1	0	0	0	0	0	0	0
2004	9	1,044	484	702	101	23	19	11	2	0	0	0	0	0	0	0	0	0
2005	9	369	471	118	136	17	4	3	2	0	0	0	0	0	0	0	0	0
2006	7	1,205	735	447	84	84	10	2	2	1	0	0	0	0	0	0	0	0
2007	18	507	1,100	347	164	27	26	3	1	1	1	0	0	0	0	0	0	0
2008	8	1,066	420	452	109	45	7	7	1	0	0	0	0	0	0	0	0	0
2009	11	645	1,132	221	182	38	15	2	3	0	0	0	0	0	0	0	0	0
2010	12	1,254	1,045	876	129	93	19	8	1	1	0	0	0	0	0	0	0	0
2011	12	283	447	186	119	15	11	2	1	0	0	0	0	0	0	0	0	0
2012	5	620	168	139	46	26	3	2	0	0	0	0	0	0	0	0	0	0
2013	1	51	91	11	7	2	1	0	0	0	0	0	0	0	0	0	0	0
2014	1	164	243	202	18	10	3	1	0	0	0	0	0	0	0	0	0	0

Table 8.10. Predicted catch (000s) at age for the shrimp trawl fishery from the base run of the assessment model, 1989–2014.

	Age																	
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1989	481,821	97,042	10,485	1,355	140	17	3	0	0	0	0	0	0	0	0	0	0	0
1990	1,026,324	363,560	3,028	377	49	6	1	0	0	0	0	0	0	0	0	0	0	0
1991	1,052,534	1,674,023	47,443	426	48	7	1	0	0	0	0	0	0	0	0	0	0	0
1992	286,652	578,096	37,842	1,869	20	2	0	0	0	0	0	0	0	0	0	0	0	0
1993	267,457	336,383	49,374	3,291	164	2	0	0	0	0	0	0	0	0	0	0	0	0
1994	357,530	578,843	64,164	9,028	591	30	0	0	0	0	0	0	0	0	0	0	0	0
1995	267,670	638,861	86,796	10,590	1,548	105	6	0	0	0	0	0	0	0	0	0	0	0
1996	38,562	356,877	66,599	10,615	1,257	165	10	1	0	0	0	0	0	0	0	0	0	0
1997	32,308	223,086	16,679	3,013	487	58	8	1	0	0	0	0	0	0	0	0	0	0
1998	25,379	441,052	36,680	2,023	326	51	6	1	0	0	0	0	0	0	0	0	0	0
1999	20,202	554,980	128,865	8,327	417	65	11	2	0	0	0	0	0	0	0	0	0	0
2000	33,406	283,504	89,176	18,799	1,182	58	10	2	0	0	0	0	0	0	0	0	0	0
2001	61,184	412,631	37,136	11,430	2,422	151	8	1	0	0	0	0	0	0	0	0	0	0
2002	12,194	396,813	23,382	1,986	612	128	8	1	0	0	0	0	0	0	0	0	0	0
2003	37,580	227,749	95,096	4,378	341	102	23	2	0	0	0	0	0	0	0	0	0	0
2004	27,501	554,118	39,592	14,341	631	48	15	4	0	0	0	0	0	0	0	0	0	0
2005	28,206	200,891	39,503	2,470	869	38	3	1	0	0	0	0	0	0	0	0	0	0
2006	19,249	570,980	53,745	8,165	467	160	7	1	0	0	0	0	0	0	0	0	0	0
2007	43,399	217,253	72,641	5,716	827	46	17	1	0	0	0	0	0	0	0	0	0	0
2008	26,587	613,451	37,269	10,006	738	104	6	3	0	0	0	0	0	0	0	0	0	0
2009	29,901	306,679	82,991	4,034	1,017	73	11	1	0	0	0	0	0	0	0	0	0	0
2010	23,922	435,574	56,002	11,717	528	130	10	2	0	0	0	0	0	0	0	0	0	0
2011	119,594	486,361	118,493	12,286	2,415	106	27	2	0	0	0	0	0	0	0	0	0	0
2012	34,704	710,537	29,747	6,115	615	119	6	2	0	0	0	0	0	0	0	0	0	0
2013	37,405	634,717	174,716	5,284	984	96	19	1	0	0	0	0	0	0	0	0	0	0
2014	26,297	735,861	168,306	34,857	970	176	18	4	0	0	0	0	0	0	0	0	0	0

Table 8.11. Results of the jitter analysis.

Run	Total LL	SSB_{2014}	$\text{SSB}_{\text{Threshold}}$	$\text{SSB}_{2014}/\text{SSB}_{\text{Threshold}}$	F_{2014}	$F_{\text{Threshold}}$	$F_{2014}/F_{\text{Threshold}}$
base	12,639	406,304	77,464	5.25	0.179	0.381	0.470
1	12,639	406,304	77,464	5.25	0.179	0.381	0.470
2	12,639	406,304	77,464	5.25	0.179	0.381	0.470
3	12,639	406,304	77,464	5.25	0.179	0.381	0.470
4	bad Hessian matrix						
5	12,639	406,304	77,464	5.25	0.179	0.381	0.470
6	12,639	406,304	77,464	5.25	0.179	0.381	0.470
7	12,639	406,304	77,464	5.25	0.179	0.381	0.470
8	12,649	393,582	76,626	5.14	0.185	0.382	0.485
9	12,840	286,005	79,238	3.61	0.243	0.398	0.610
10	12,639	406,304	77,464	5.25	0.179	0.381	0.470
11	12,639	406,304	77,464	5.25	0.179	0.381	0.470
12	12,639	406,304	77,464	5.25	0.179	0.381	0.470
13	12,639	406,304	77,464	5.25	0.179	0.381	0.470
14	12,639	406,304	77,464	5.25	0.179	0.381	0.470
15	12,639	406,303	77,464	5.25	0.179	0.381	0.470
16	bad Hessian matrix						
17	could not find a solution						
18	12,639	406,304	77,464	5.25	0.179	0.381	0.470
19	12,649	393,580	76,618	5.14	0.185	0.382	0.485
20	13,002	754,297	123,597	6.10	0.110	0.392	0.281
21	12,911	399,932	76,247	5.25	0.181	0.381	0.476
22	12,639	406,304	77,464	5.25	0.179	0.381	0.470
23	12,639	406,304	77,464	5.25	0.179	0.381	0.470
24	12,840	286,005	79,238	3.61	0.243	0.398	0.610
25	12,639	406,304	77,464	5.25	0.179	0.381	0.470
26	12,649	393,580	76,618	5.14	0.185	0.382	0.485
27	12,639	406,304	77,464	5.25	0.179	0.381	0.470
28	12,639	406,304	77,465	5.25	0.179	0.381	0.470
29	12,639	406,304	77,465	5.25	0.179	0.381	0.470

Table 8.11 (*continued*). Results of the jitter analysis.

Run	Total LL	SSB_{2014}	$\text{SSB}_{\text{Threshold}}$	$\text{SSB}_{2014}/\text{SSB}_{\text{Threshold}}$	F_{2014}	$F_{\text{Threshold}}$	$F_{2014}/F_{\text{Threshold}}$
30	12,639	406,302	77,463	5.25	0.179	0.381	0.470
31	bad Hessian matrix						
32	12,639	406,304	77,464	5.25	0.179	0.381	0.470
33	12,948	256,644	76,018	3.38	0.259	0.397	0.653
34	12,639	406,305	77,465	5.25	0.179	0.381	0.470
35	12,639	406,304	77,464	5.25	0.179	0.381	0.470
36	12,911	399,932	76,247	5.25	0.181	0.381	0.476
37	12,639	406,304	77,464	5.25	0.179	0.381	0.470
38	bad Hessian matrix						
39	12,639	406,304	77,464	5.25	0.179	0.381	0.470
40	12,911	399,932	76,247	5.25	0.181	0.381	0.476
41	12,911	399,932	76,247	5.25	0.181	0.381	0.476
42	12,649	393,580	76,618	5.14	0.185	0.382	0.485
43	bad Hessian matrix						
44	bad Hessian matrix						
45	12,639	406,304	77,463	5.25	0.179	0.381	0.470
46	bad Hessian matrix						
47	12,639	406,304	77,464	5.25	0.179	0.381	0.470
48	12,646	406,384	77,458	5.25	0.179	0.381	0.469
49	12,646	406,384	77,458	5.25	0.179	0.381	0.469
50	12,639	406,304	77,464	5.25	0.179	0.381	0.470
51	12,639	406,304	77,464	5.25	0.179	0.381	0.470
52	12,639	406,304	77,464	5.25	0.179	0.381	0.470
53	12,639	406,304	77,464	5.25	0.179	0.381	0.470
54	12,639	406,304	77,463	5.25	0.179	0.381	0.470
55	12,646	406,384	77,458	5.25	0.179	0.381	0.469
56	12,967	400,101	76,685	5.22	0.181	0.381	0.476
57	12,737	371,983	73,873	5.04	0.191	0.383	0.500
58	bad Hessian matrix						
59	12,639	406,304	77,464	5.25	0.1790	0.381	0.470

Table 8.12. Estimated (A) reference points and relative stock status and (B) percent difference from base over a series of sensitivity analyses.

			Recreational Discard Mortality			Survey Sensitivity				
	Quantity	**Base**	**8%**	**11%**	**18%**	**No NEFSC**	**No ChesMMAP**	**No SEAMAP**	**No VIMS**	**No NC195**
(A)	SSB_{2014}	304,345	237,155	284,200	290,052	475,507	230,617	427,138	209,509	350,810
	SSB_{Target}	79,438	70,178	77,442	78,244	94,986	79,496	71,705	72,058	82,441
	$SSB_{Threshold}$	55,607	49,125	54,209	54,771	66,490	55,647	50,193	50,441	57,709
	$SSB_{2014}/SSB_{Threshold}$	5.47	4.83	5.24	5.30	7.15	4.14	8.51	4.15	6.08
	F_{2014}	0.167	0.204	0.174	0.173	0.1149	0.191	0.157	0.214	0.164
	F_{Target}	0.295	0.297	0.294	0.294	0.294	0.286	0.301	0.291	0.298
	$F_{Threshold}$	0.393	0.395	0.392	0.392	0.392	0.382	0.401	0.388	0.397
	$F_{2014}/F_{Threshold}$	0.426	0.515	0.444	0.441	0.293	0.500	0.391	0.550	0.412

(B)	SSB_{2014}		24.8	6.85	4.81	-43.9	27.6	-33.6	36.9	-14.2
	SSB_{Target}		12.4	2.54	1.51	-17.8	-0.0727	10.2	9.74	-3.71
	$SSB_{Threshold}$		12.4	2.54	1.51	-17.8	-0.0727	10.2	9.74	-3.71
	$SSB_{2014}/SSB_{Threshold}$		12.5	4.30	3.30	-26.6	27.6	-43.4	27.4	-10.5
	F_{2014}		-19.6	-3.86	-3.42	37.1	-13.3	6.57	-24.3	2.16
	F_{Target}		-0.621	0.273	0.143	0.258	2.85	-1.99	1.31	-1.07
	$F_{Threshold}$		-0.621	0.273	0.143	0.258	2.85	-1.99	1.31	-1.07
	$F_{2014}/F_{Threshold}$		-18.9	-4.13	-3.56	36.9	-16.1	8.56	-25.6	3.23

Table 8.12 (*continued*). Estimated (A) reference points and relative stock status and (B) percent difference from base over a series of sensitivity analyses.

(A)

		Steepness					**Shrimp Trawl Discards**					
Quantity	**Base**	**h 0.60**	**h 0.70**	**h 0.80**	**h 0.90**	**h 1.0**	**No 1991**	**Dampen 1991**	**10%**	**20%**	**40%**	**50%**
SSB_{2014}	304,345	1,398,740	801,047	555,857	397,775	196,712	335,476	267,001	162,039	153,210	149,716	152,797
SSB_{Target}	79,438	1,585,940	871,293	470,597	233,649	10,803	87,713	82,675	67,458	56,975	43,164	41,725
$SSB_{\text{Threshold}}$	55,607	1,110,158	609,905	329,418	163,554	7,562	61,399	57,872	47,220	39,883	30,215	29,208
$SSB_{2014}/SSB_{\text{Threshold}}$	5.47	1.26	1.31	1.69	2.43	26.0	5.46	4.61	3.43	3.84	4.96	5.23
F_{2014}	0.167	0.0557	0.0829	0.109	0.137	0.225	0.160	0.184	0.0476	0.0191	0.0121	0.0113
F_{Target}	0.295	0.127	0.153	0.182	0.220	0.389	0.292	0.287	0.158	0.111	0.0958	0.0948
$F_{\text{Threshold}}$	0.393	0.170	0.204	0.243	0.294	0.519	0.389	0.382	0.211	0.148	0.128	0.126
$F_{2014}/F_{\text{Threshold}}$	0.426	0.329	0.406	0.451	0.467	0.433	0.411	0.481	0.226	0.129	0.0943	0.0896

(B)

SSB_{2014}		-129	-89.9	-58.5	-26.6	43.0	-9.73	13.1	61.0	66.1	68.1	66.3
SSB_{Target}		-181	-167	-142	-98.5	152	-9.90	-3.99	16.3	32.9	59.2	62.3
$SSB_{\text{Threshold}}$		-181	-167	-142	-98.5	152	-9.90	-3.99	16.3	32.9	59.2	62.3
$SSB_{2014}/SSB_{\text{Threshold}}$		125	123	106	76.9	-130	0.170	17.0	45.9	35.0	9.94	4.52
F_{2014}		100	67.5	41.9	19.7	-29.4	4.57	-9.42	111	159	173	175
F_{Target}		79.5	63.4	47.3	28.8	-27.6	0.984	2.72	60.4	90.8	102	103
$F_{\text{Threshold}}$		79.5	63.4	47.3	28.8	-27.6	0.984	2.72	60.4	90.8	102	103
$F_{2014}/F_{\text{Threshold}}$		25.7	4.61	-5.73	-9.31	-1.80	3.59	-12.1	61.3	107	127	130

14 FIGURES

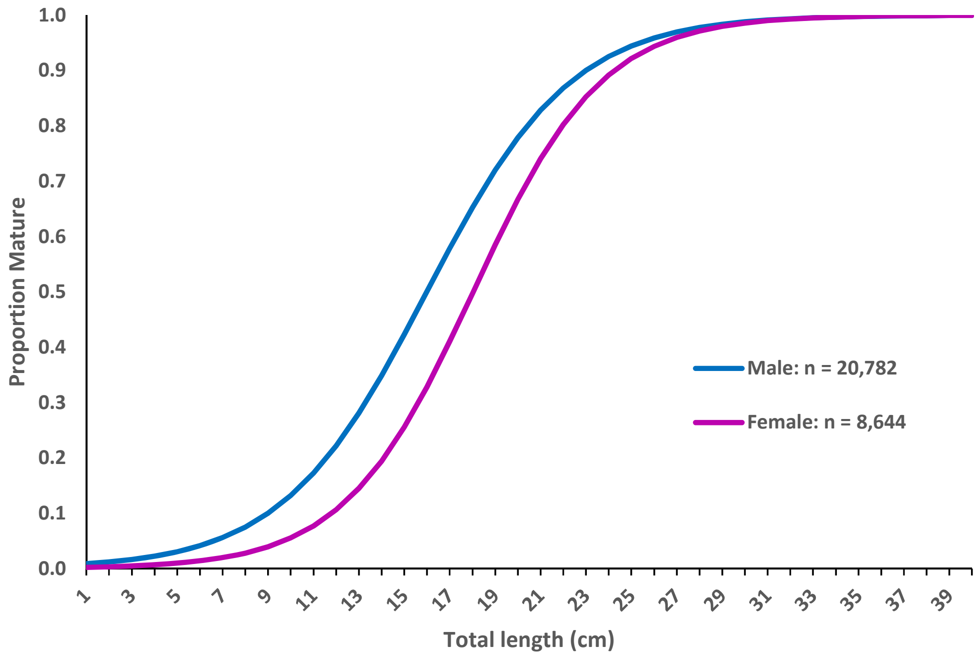


Figure 2.1 Proportion mature at length (cm) by sex for Atlantic croaker from available assessment data.

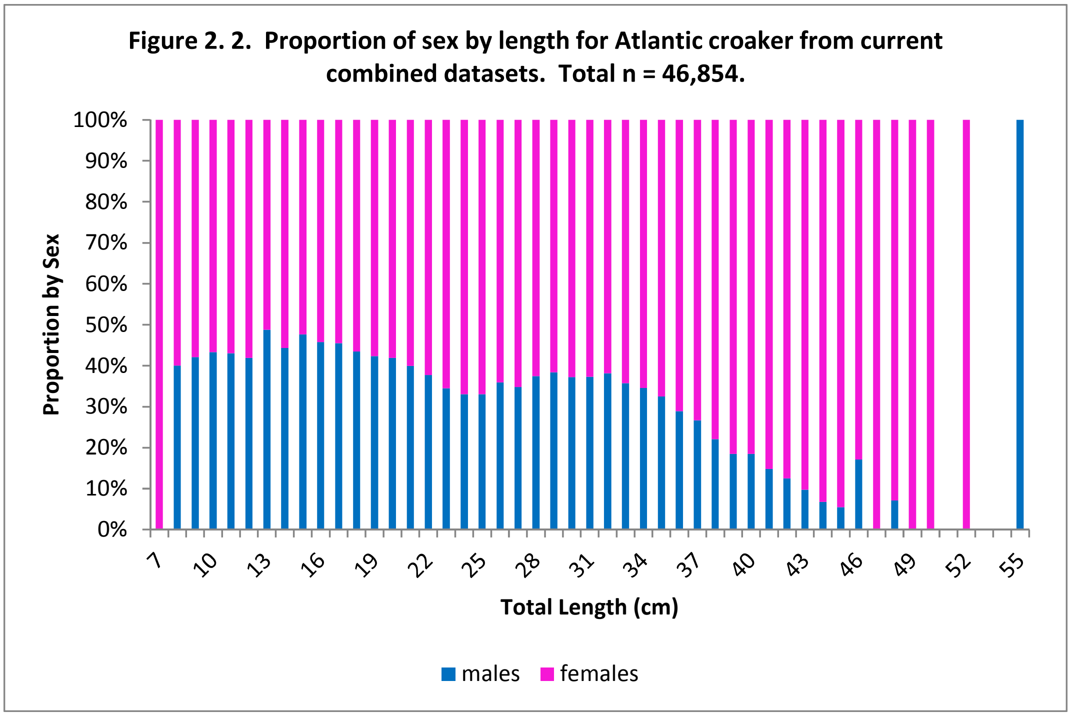


Figure 2.2 Proportion of sex by length for Atlantic croaker from combined datasets. N = 46,854

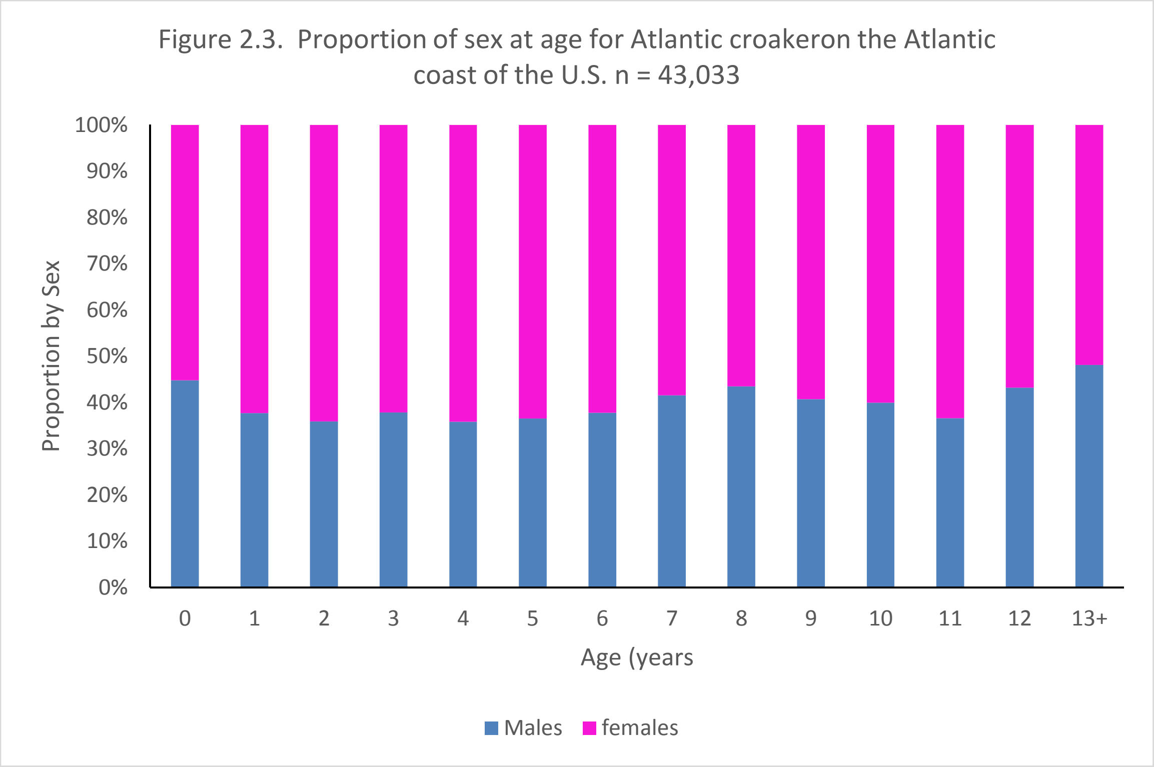


Figure 2.3 Proportion of sex at age for Atlantic croaker from combined dataset.

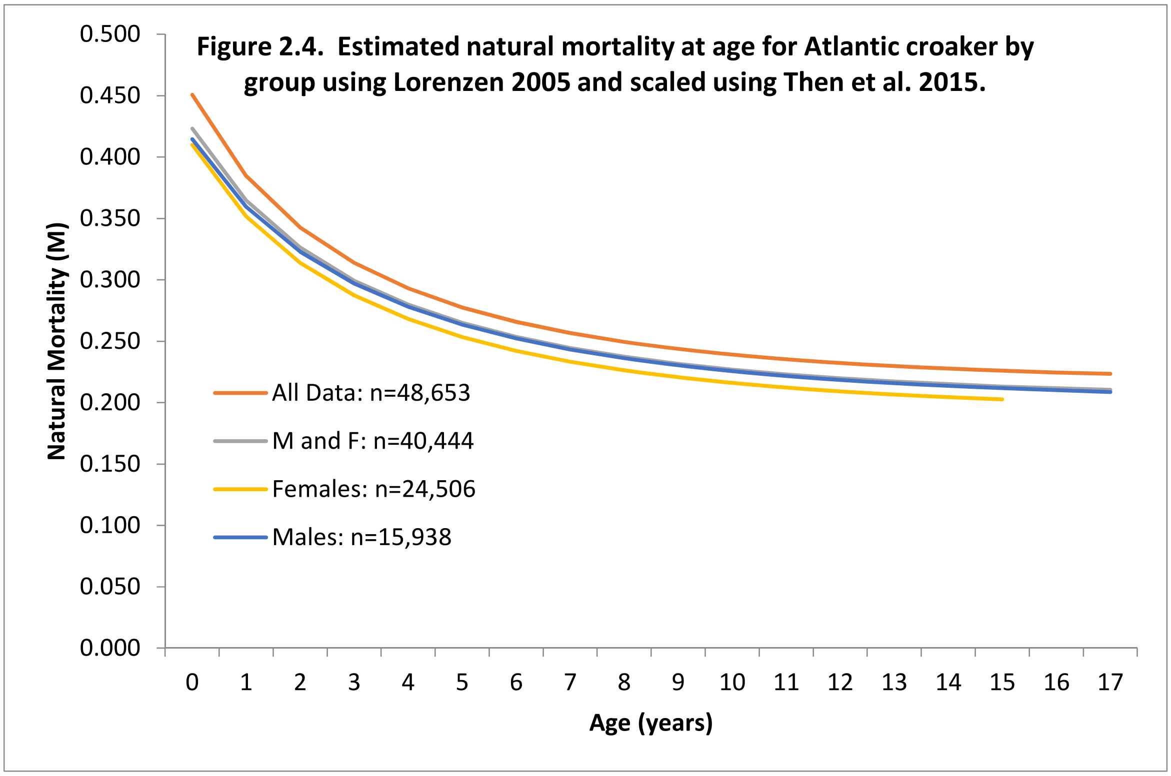


Figure 2.4 Estimated natural mortality at age for Atlantic croaker by group using Lorenzen et al. (2005 and scaled by Then et al. (2015).

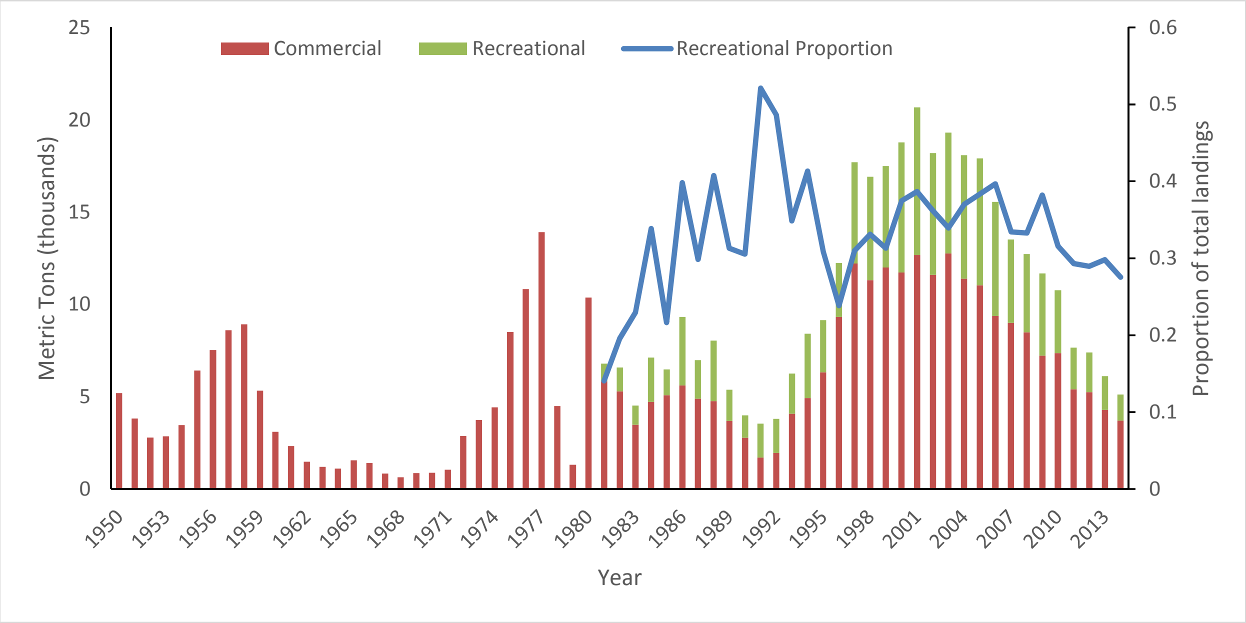


Figure 4.1 Atlantic croaker commercial and recreational landings with recreational proportion of total landings (metric tons). Reliable recreational landings estimates are not available before 1981.

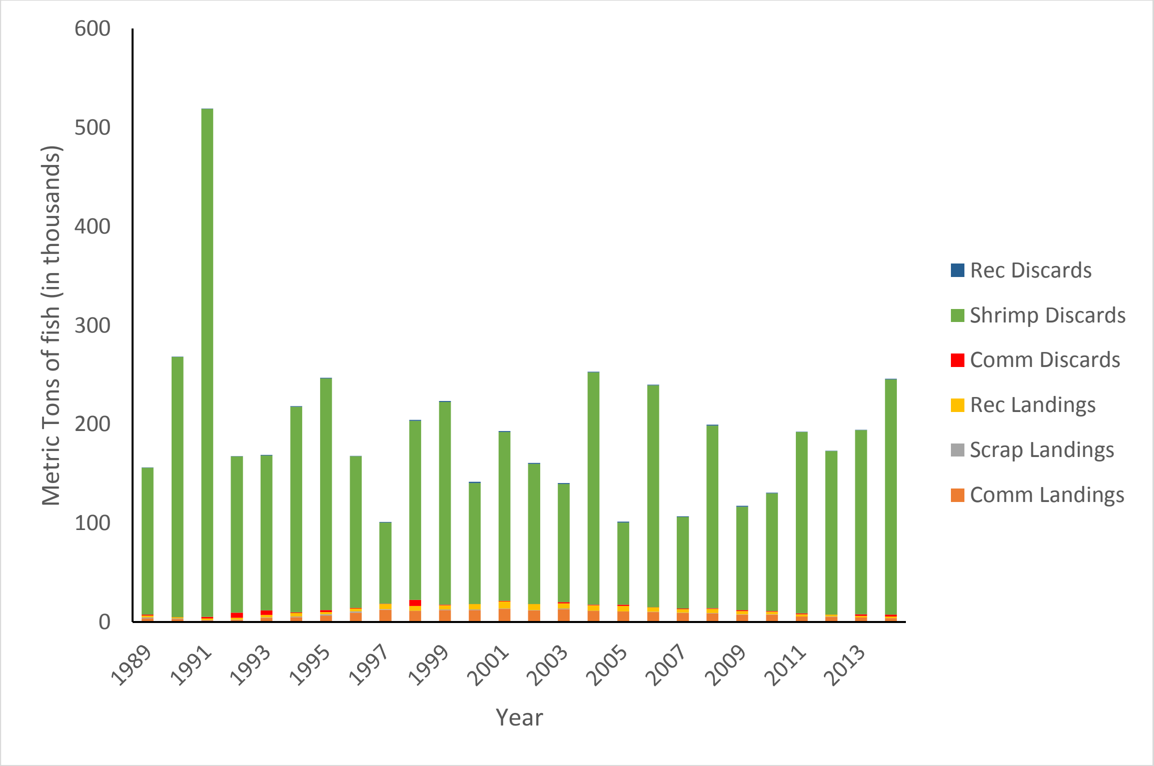


Figure 4.2 Total annual removals of Atlantic croaker by fishery on the Atlantic coast of the United States.

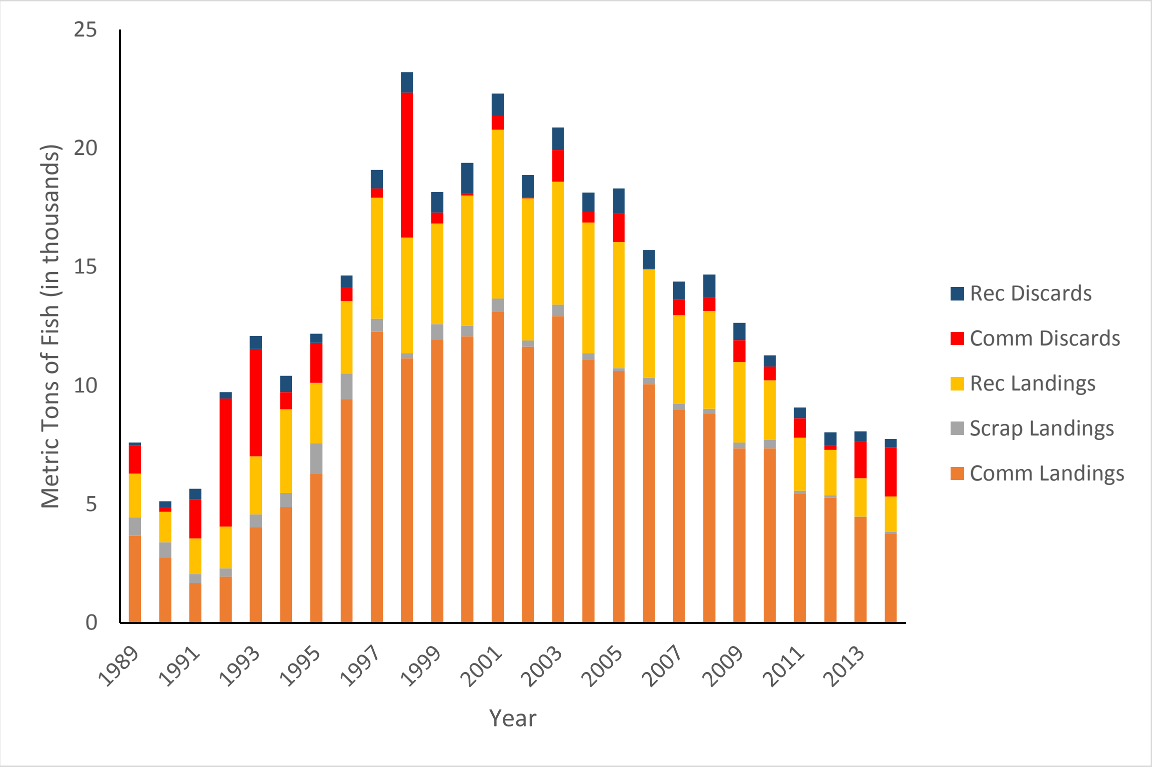


Figure 4.3 Total annual removals of Atlantic croaker by fishery, without the shrimp trawl fishery annual bycatch, on the Atlantic coast of the United States.

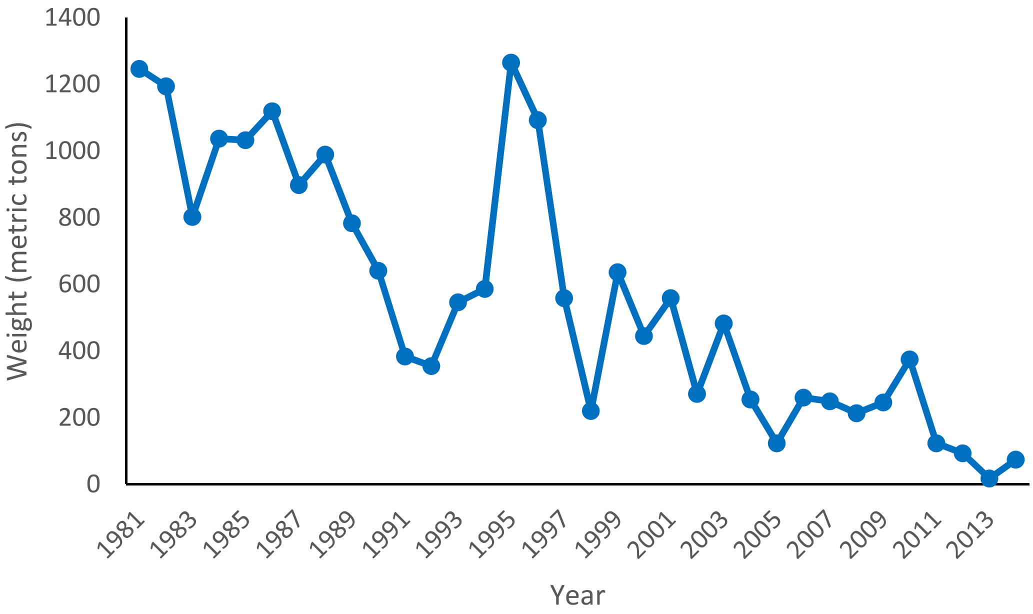


Figure 4.4 Total annual estimates of scrap landings for Atlantic croaker from the NC and VA scrap fisheries.

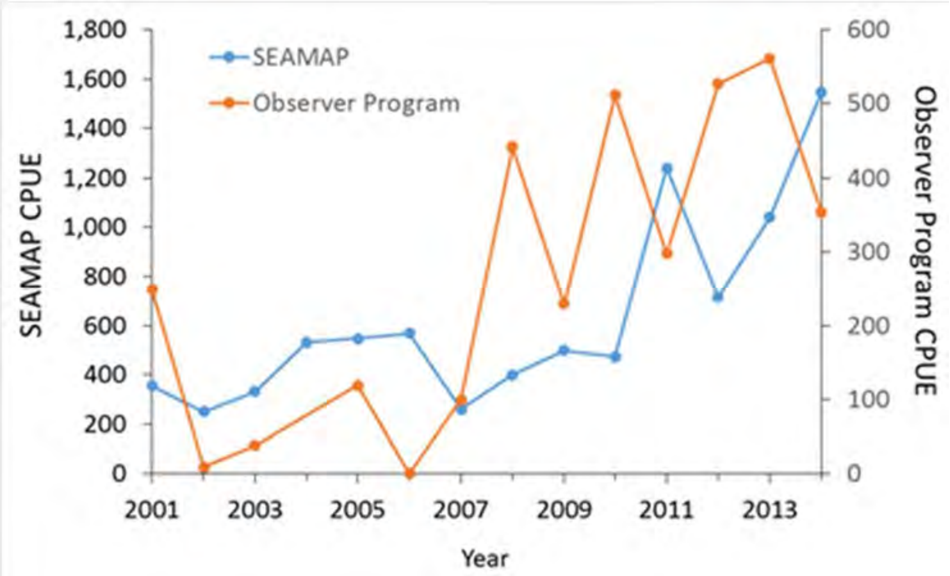


Figure 4.5. Annual mean CPUE of Atlantic croaker (number of fish/hour fished) during SEAMAP tows and observer program tows.

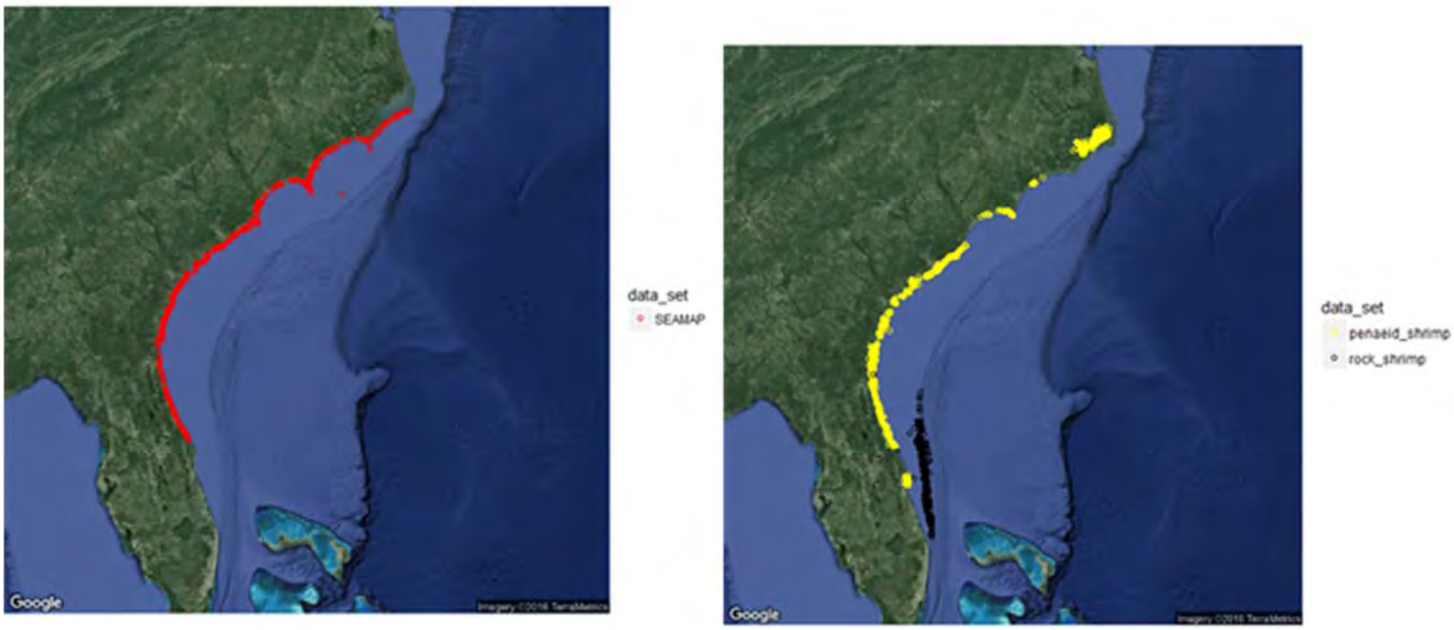


Figure 4.6. Map of SEAMAP tows (left) and observer tows (right). Depth ranges for SEAMAP and Penaid fishery were very similar with ranges from 3 to 5m.

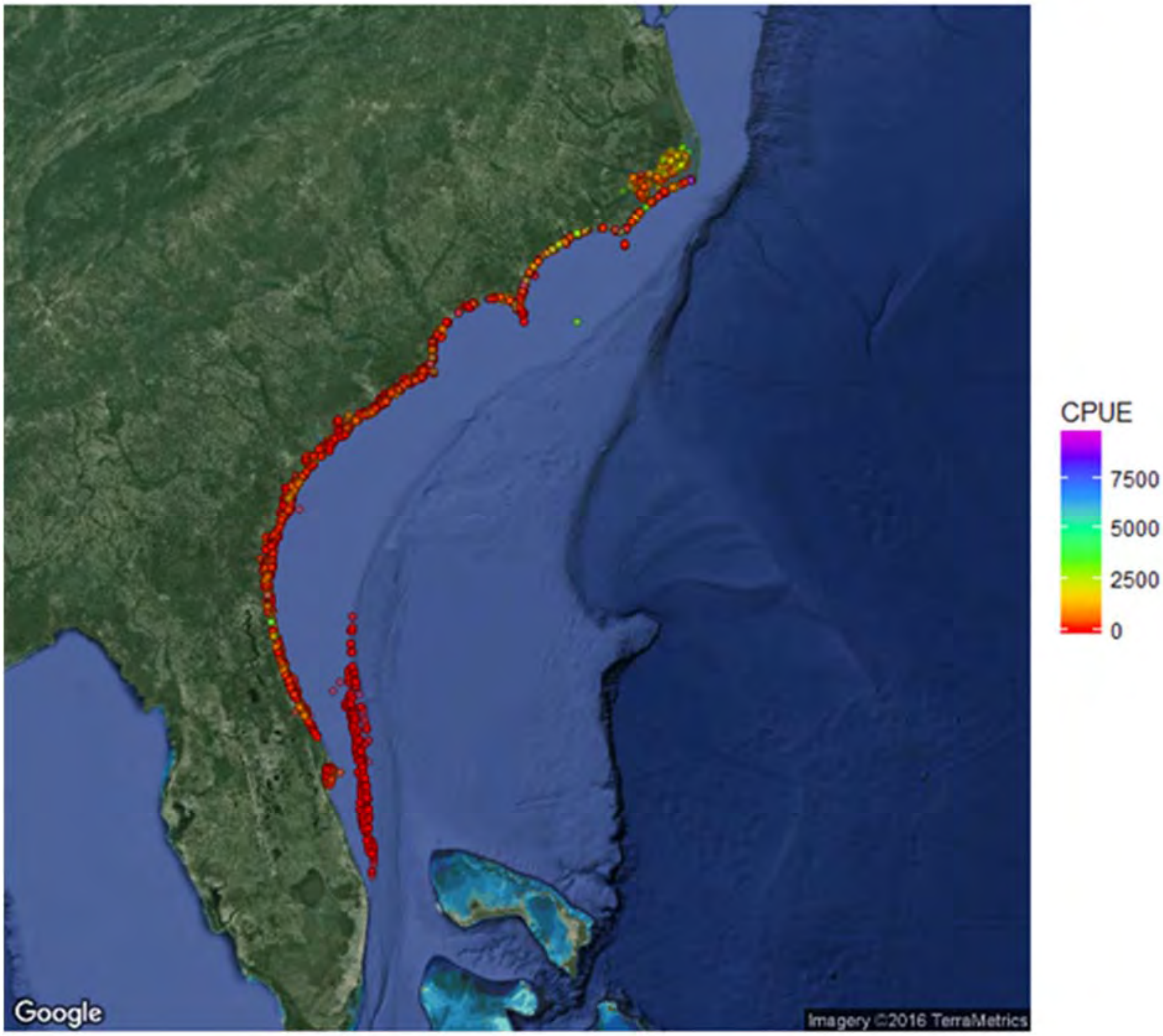


Figure 4.7. Tows from catch rate data set that encountered less than 10,000 Atlantic croaker per hour fished.

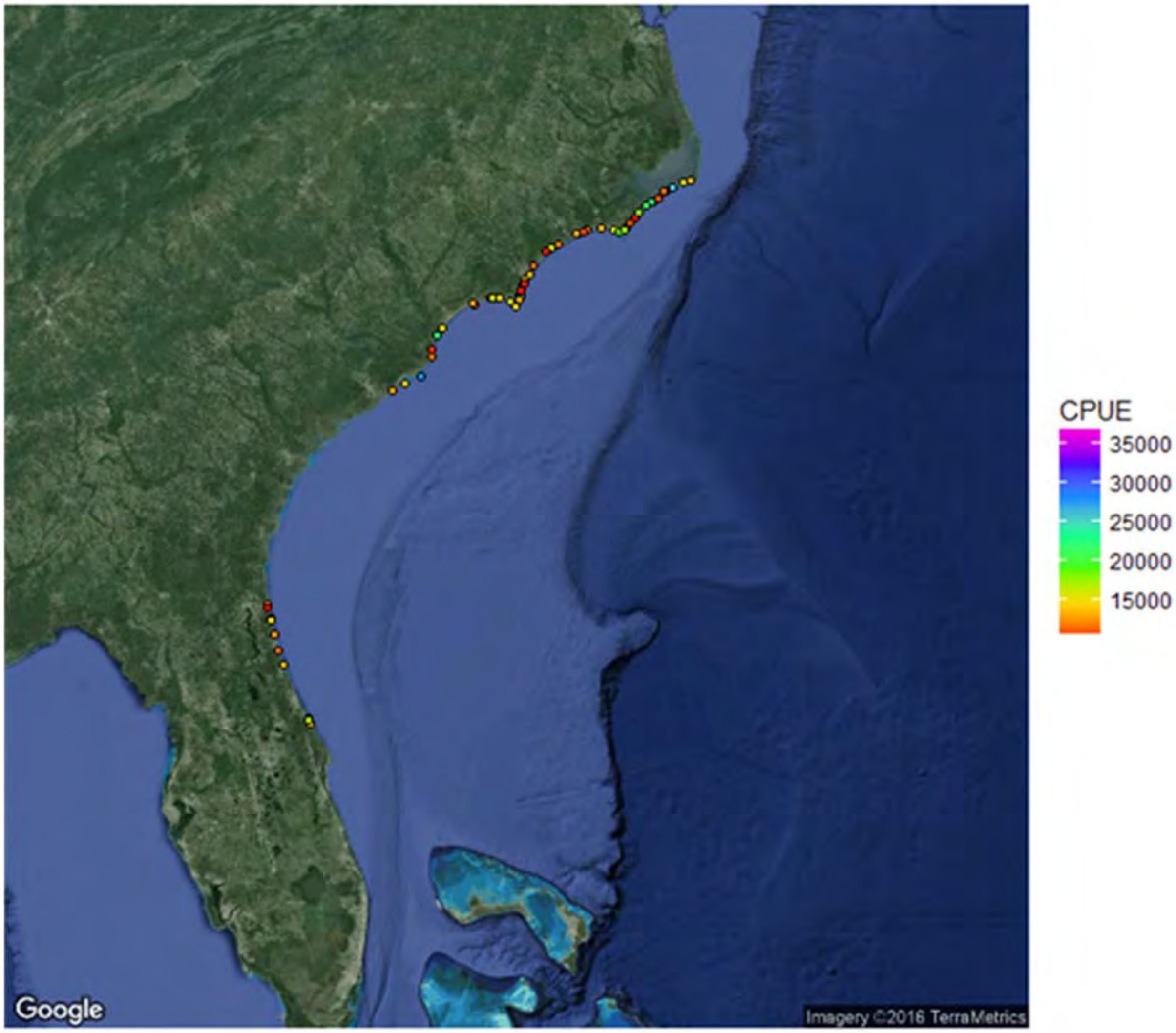


Figure 4.8 Tows from catch rate data set that encountered at least 10,000 Atlantic croaker per hour fished.

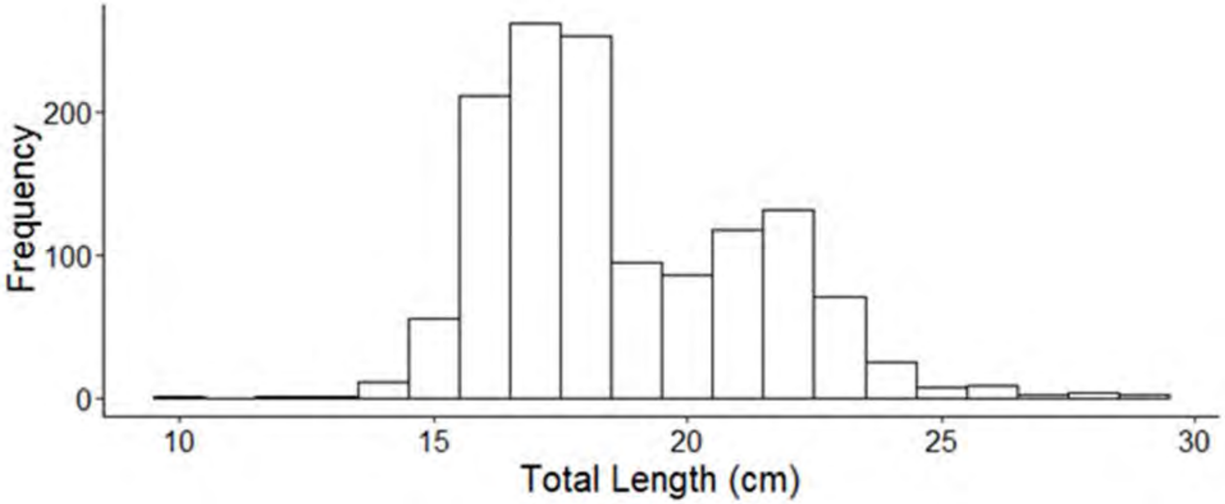


Figure 4.9. Length distribution of Atlantic croaker measured by shrimp trawl observers. All length samples were collected in 2003.

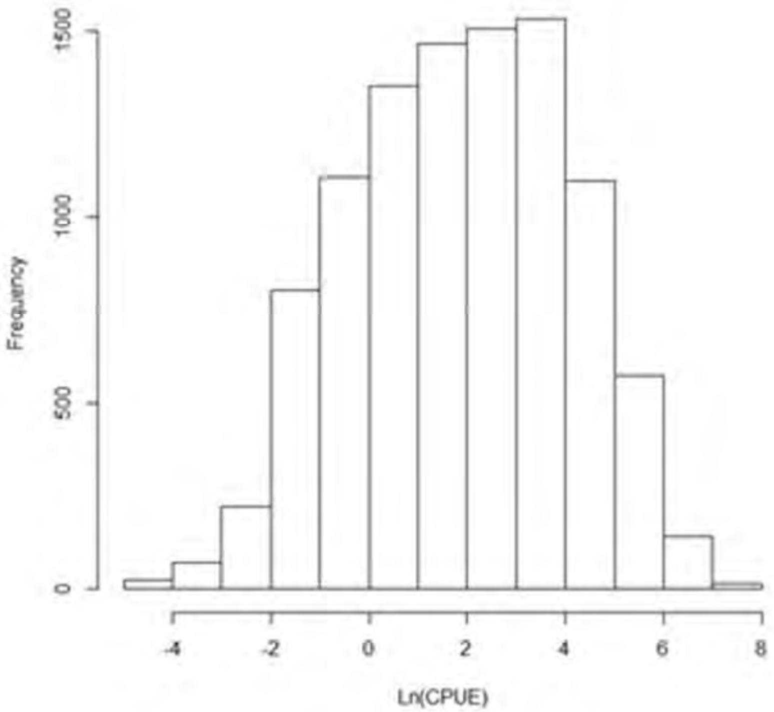


Figure 4.10. Distribution of positive Atlantic croaker CPUE observations (weight in kg) on the log scale.

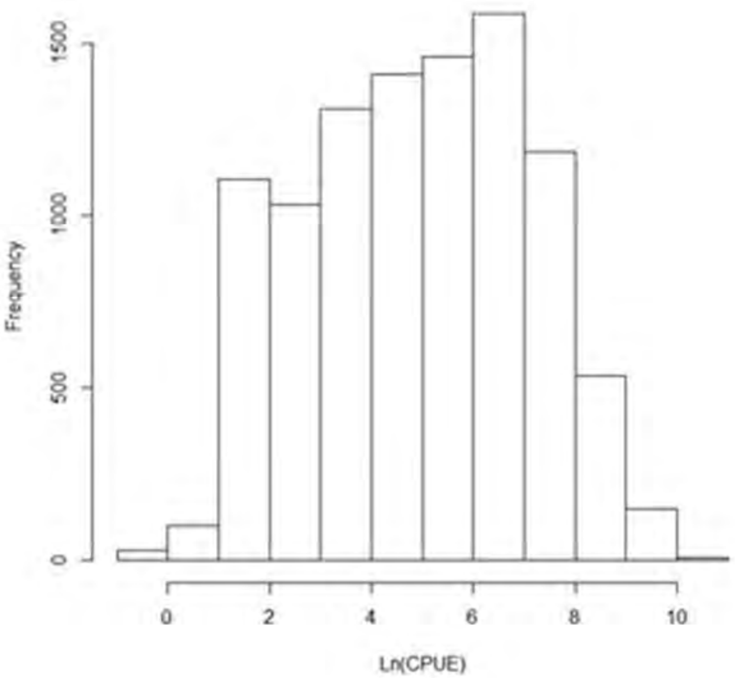


Figure 4.11 Distribution of positive Atlantic croaker CPUE observations (number) on the log scale.

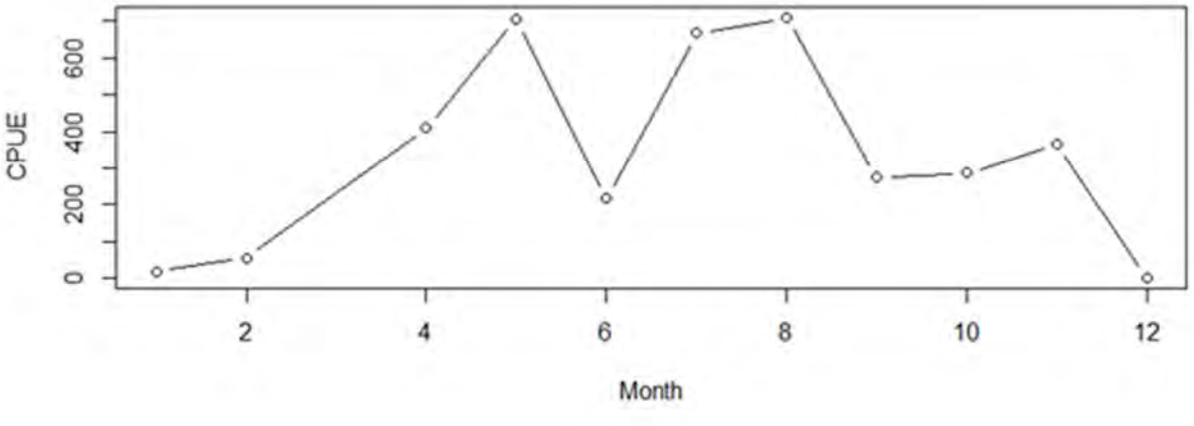


Figure 4.12. Atlantic croaker CPUE (numbers) by month from all catch rate data.

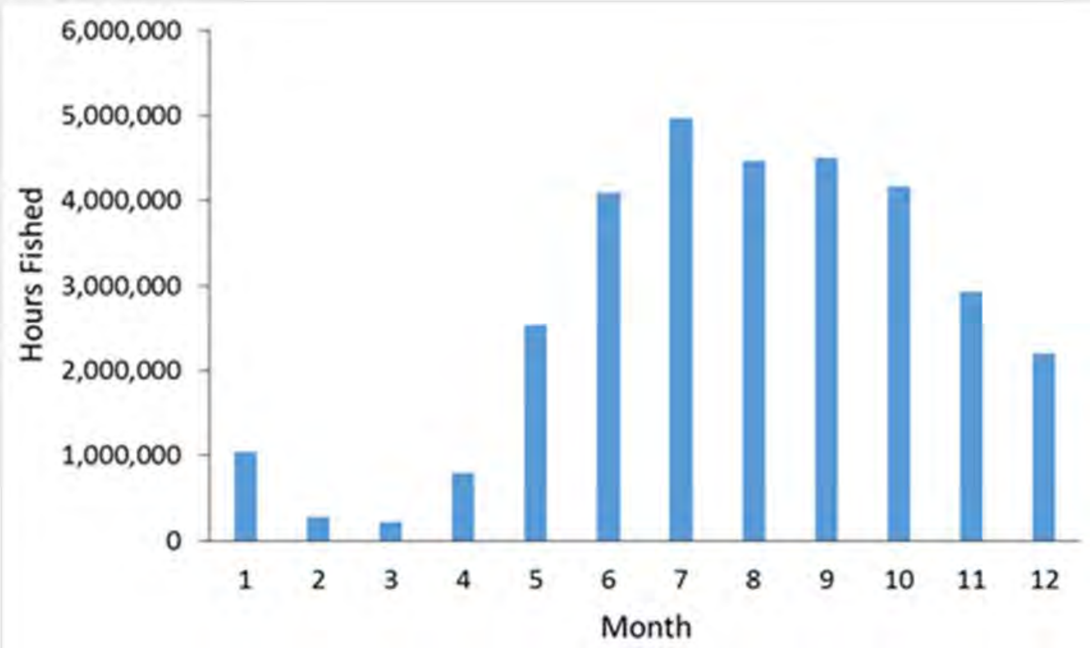


Figure 4.13. Shrimp trawl fishery effort (hours fished) by month.

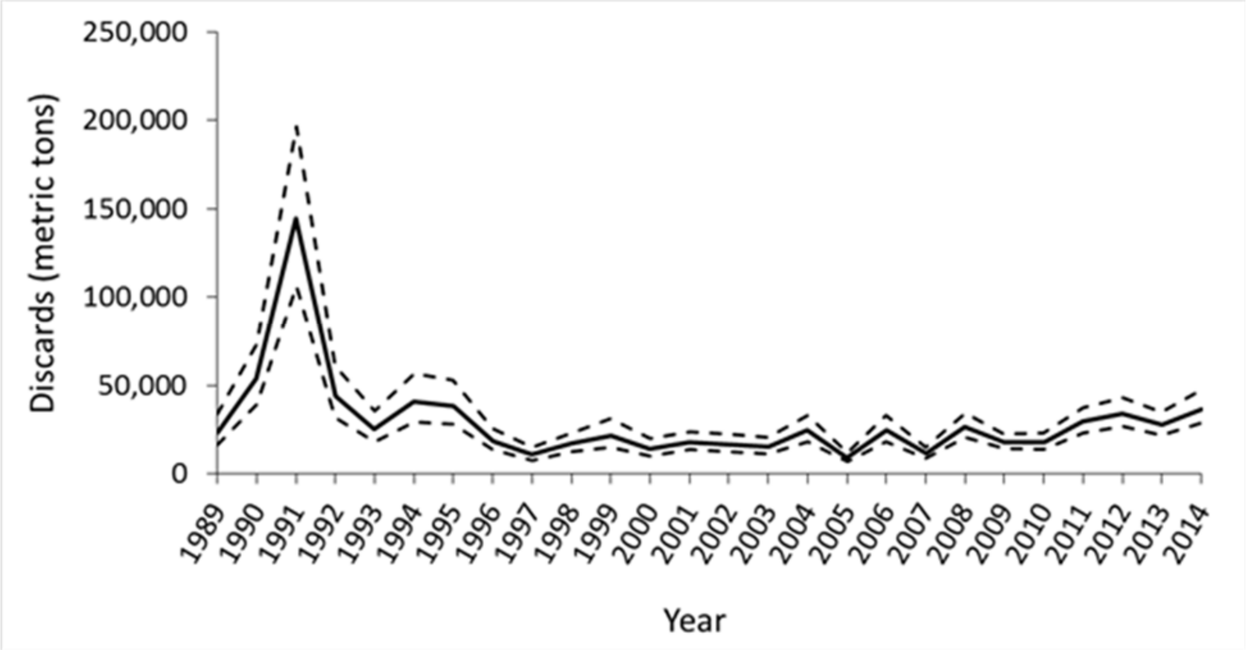


Figure 4.14. Atlantic croaker discard estimates in weight (metric tons) with 95% confidence intervals.

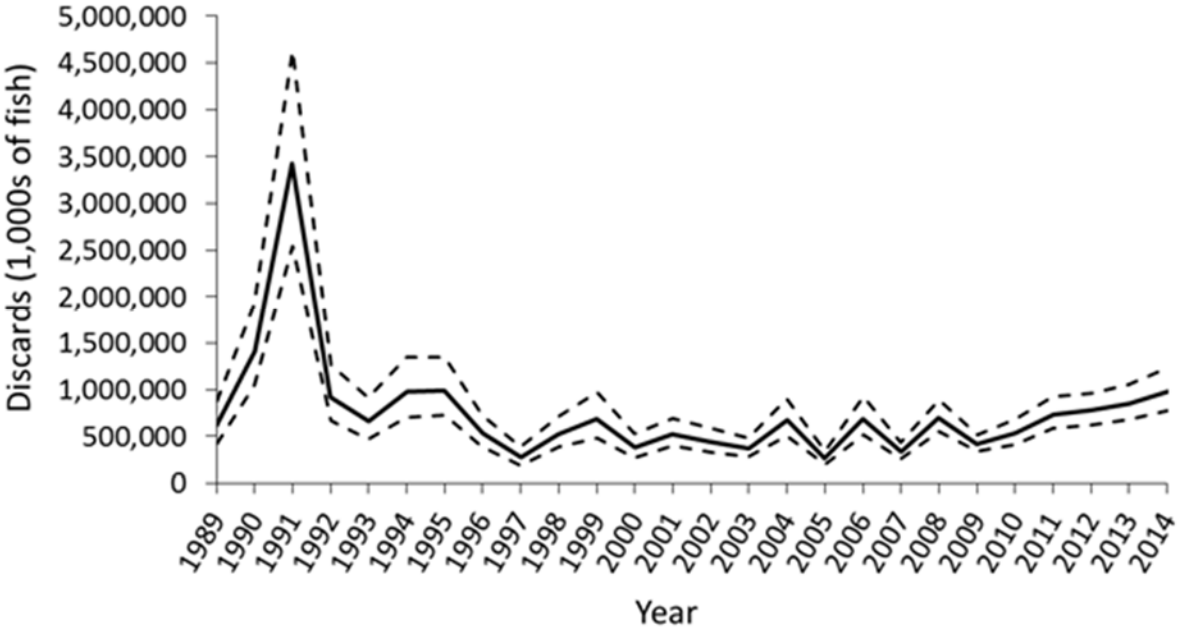


Figure 4.15. **Atlantic croaker discard estimates in numbers (1,000s of fish) with 95% confidence intervals.**

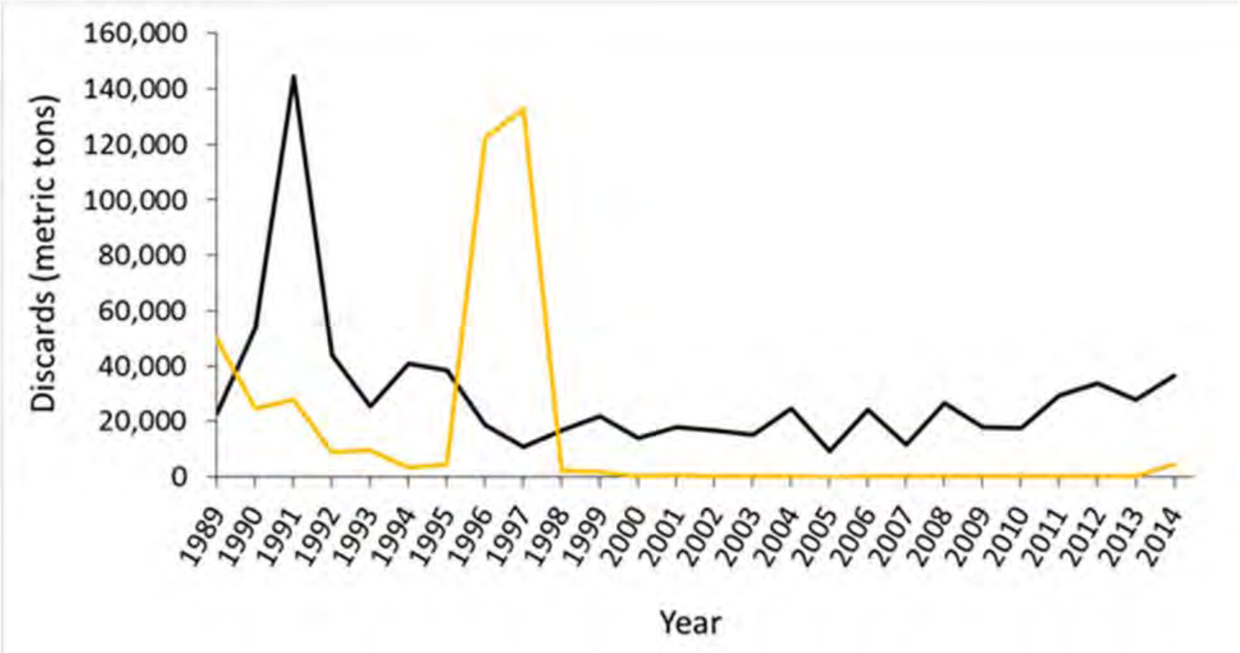


Figure 4.16. **Comparison of Atlantic croaker discard estimates (black line) and Atlantic croaker landings by South Atlantic shrimp trawls (gold line). Landings scale is on secondary axis and values are not included (possibly) due to confidentiality.**

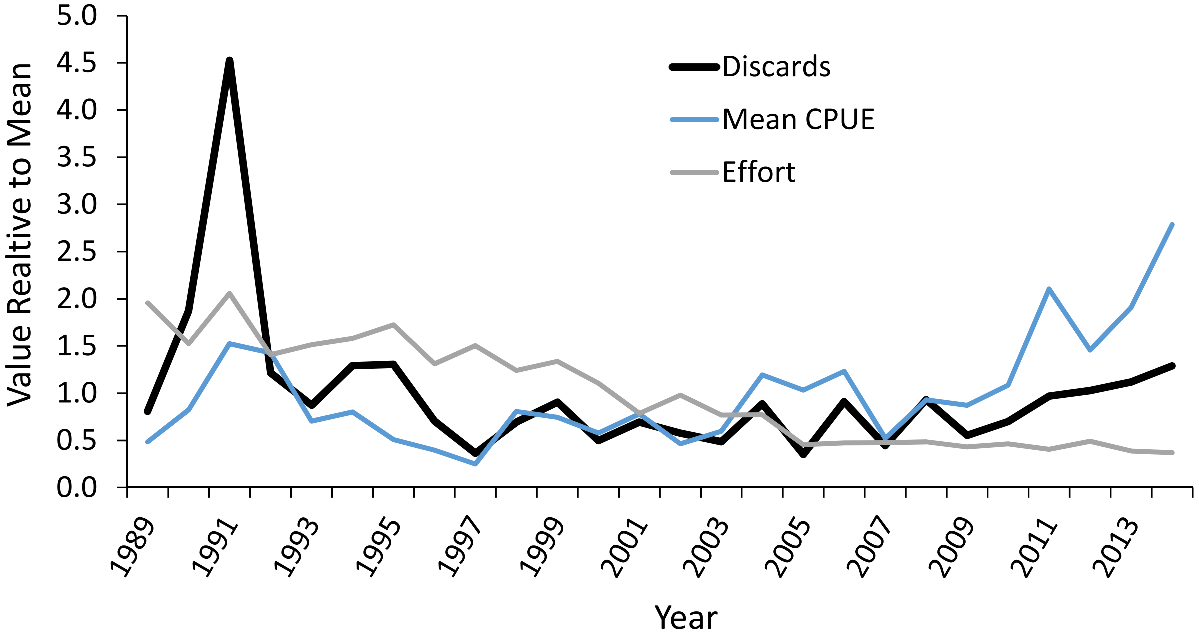


Figure 4.17. Shrimp trawl effort, Atlantic croaker discard estimates (numbers), and mean Atlantic croaker CPUE (number of fish/hour fished) scaled to time series means.

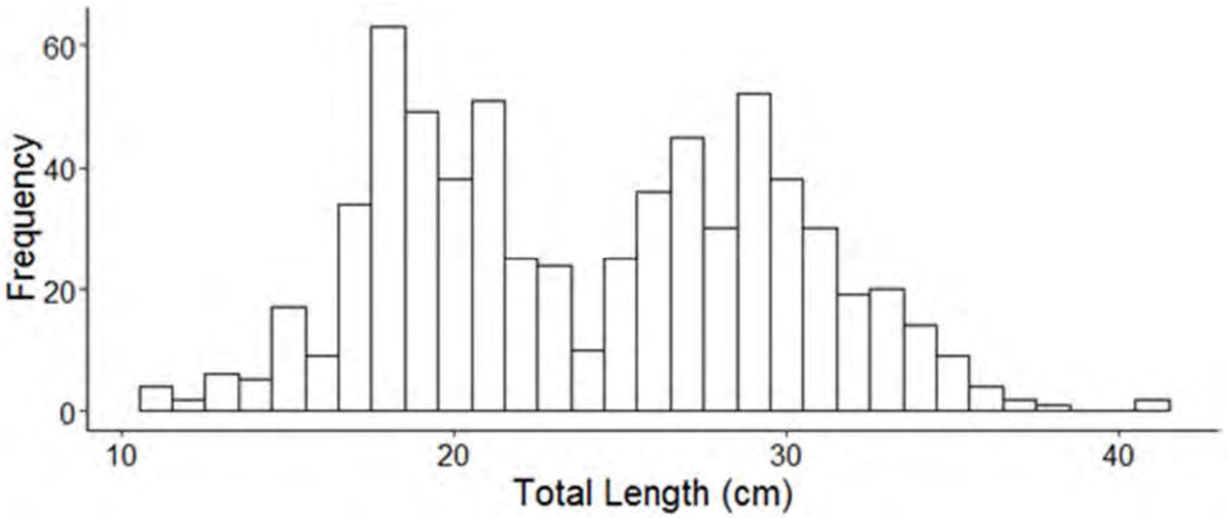


Figure 4.18. Length distribution of discarded Atlantic croaker observed in gillnets.

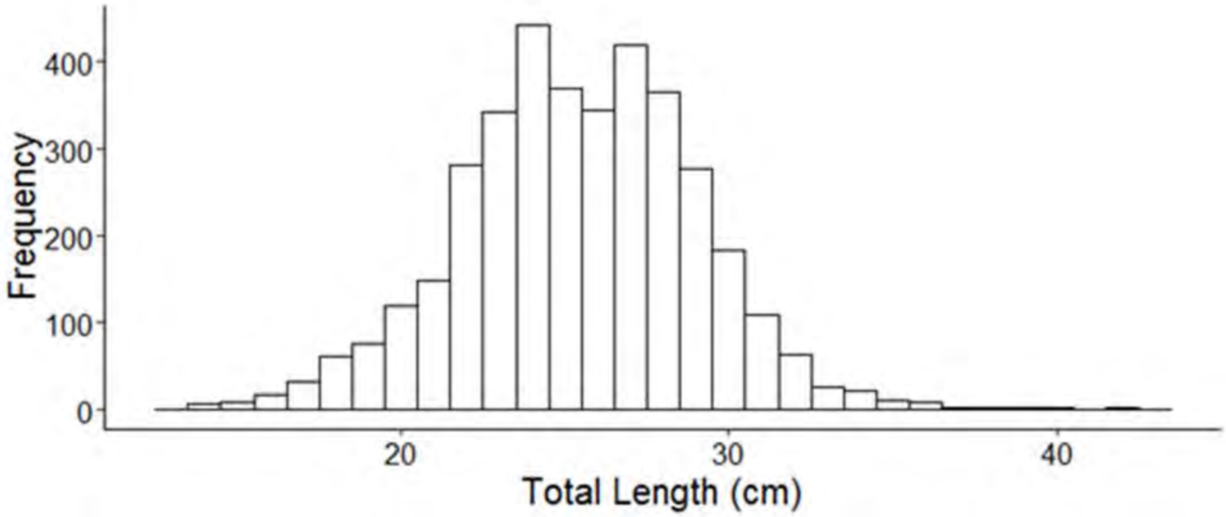


Figure 4.19. Length distribution of discarded Atlantic croaker observed in trawls.

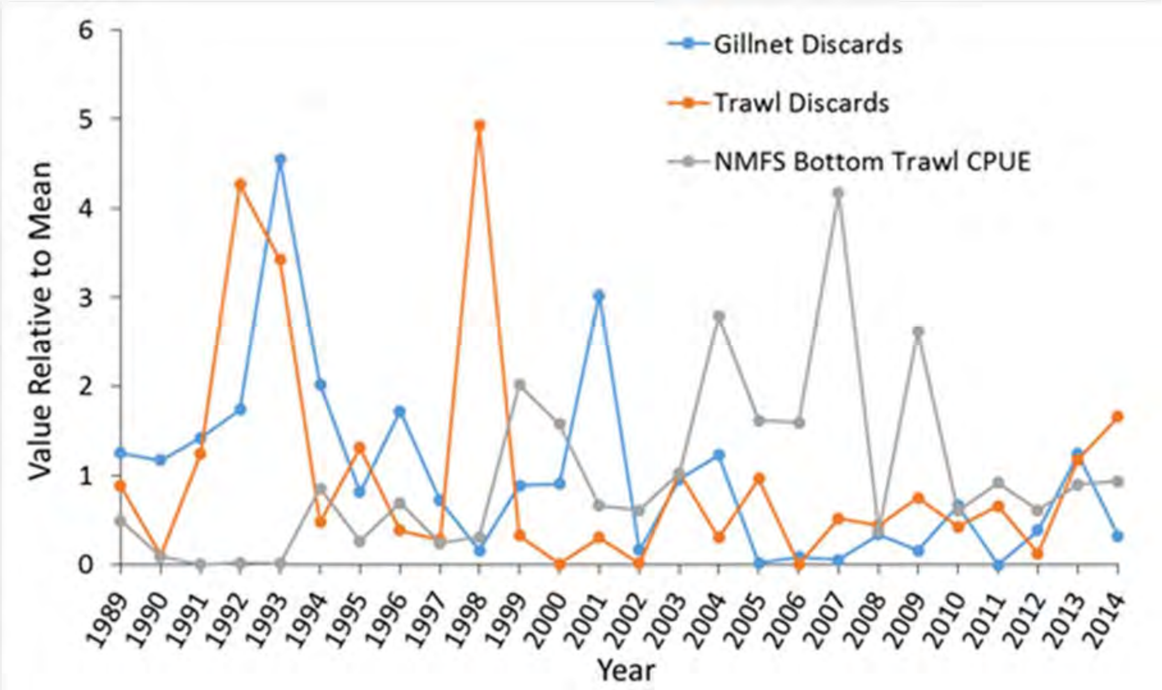


Figure 4.20. Atlantic croaker gillnet discards, trawl discards, and CPUE from the NMFS Bottom Trawl Survey scaled to time series means.

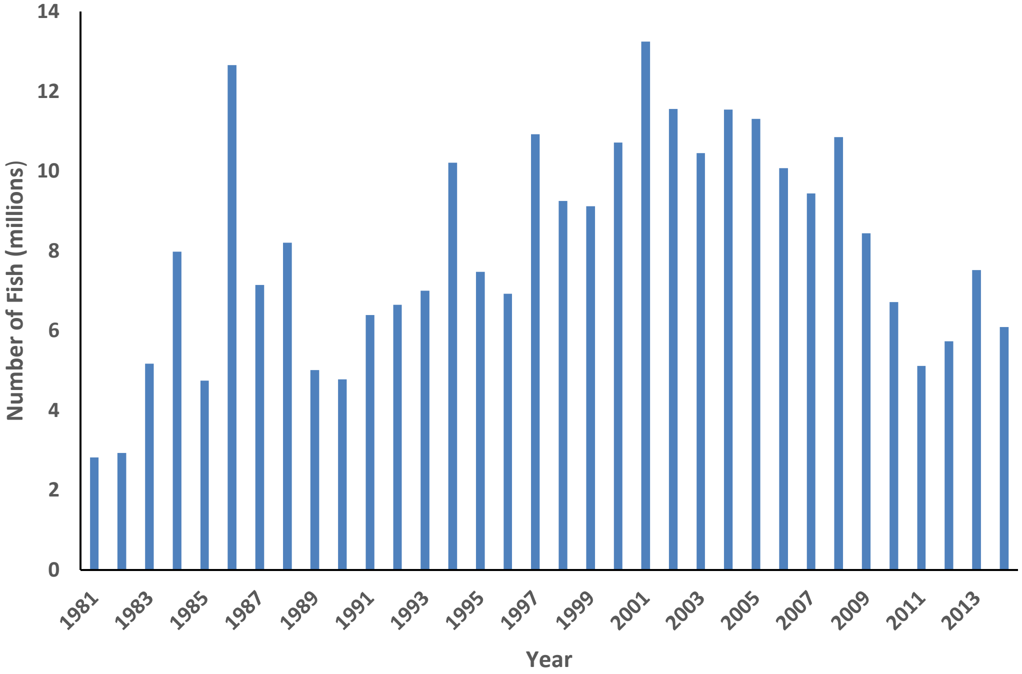


Figure 5.1. MRFSS and MRIP coast-wide recreational harvest in numbers (millions of fish), 1981-2014.

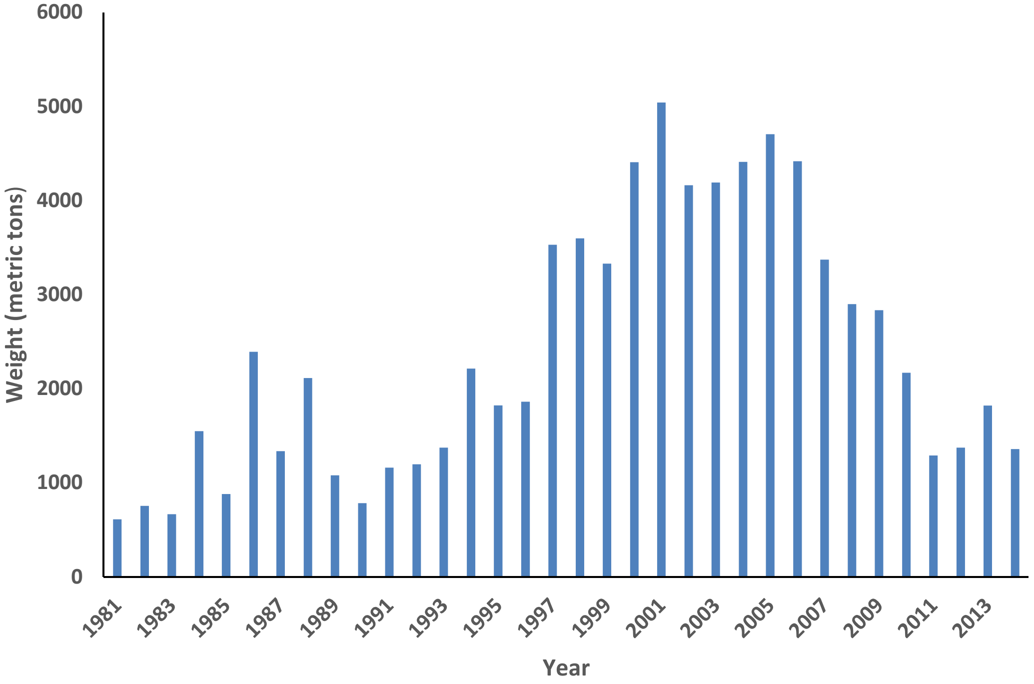


Figure 5.2. MRFSS and MRIP coast-wide recreational harvest (metric tons), 1981-2014

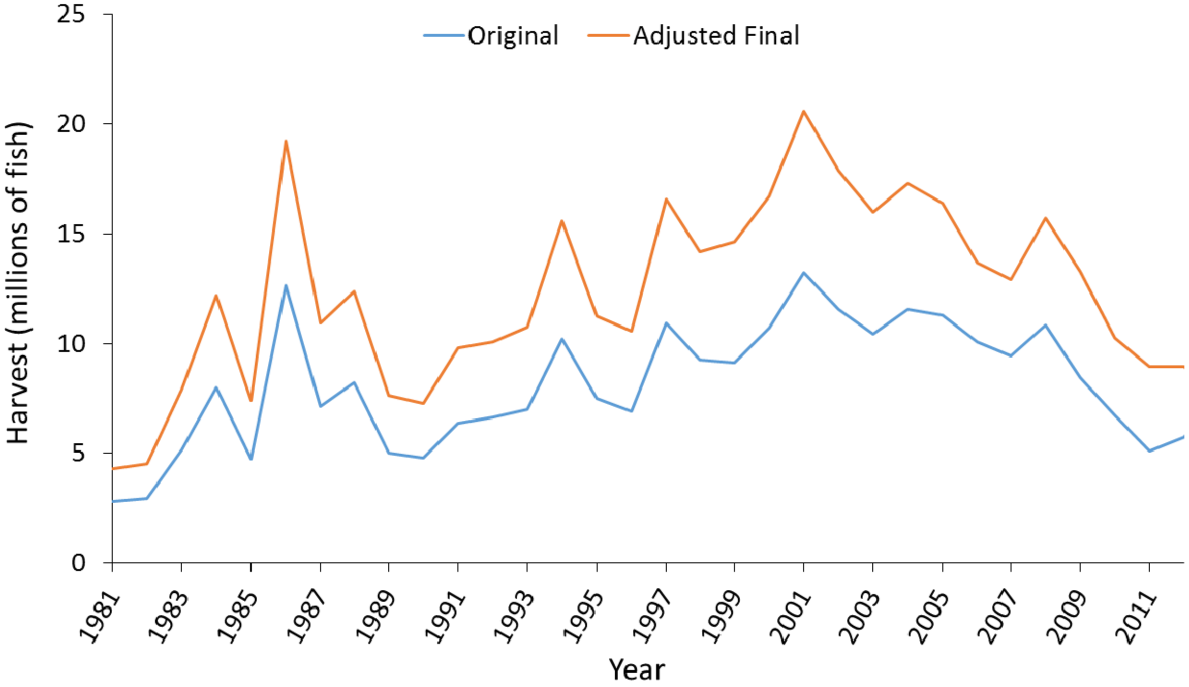


Figure 5.3. Comparison of MRFSS and MRIP recreational harvest estimates (millions of fish) before (blue line) and after (orange line) adjustments.

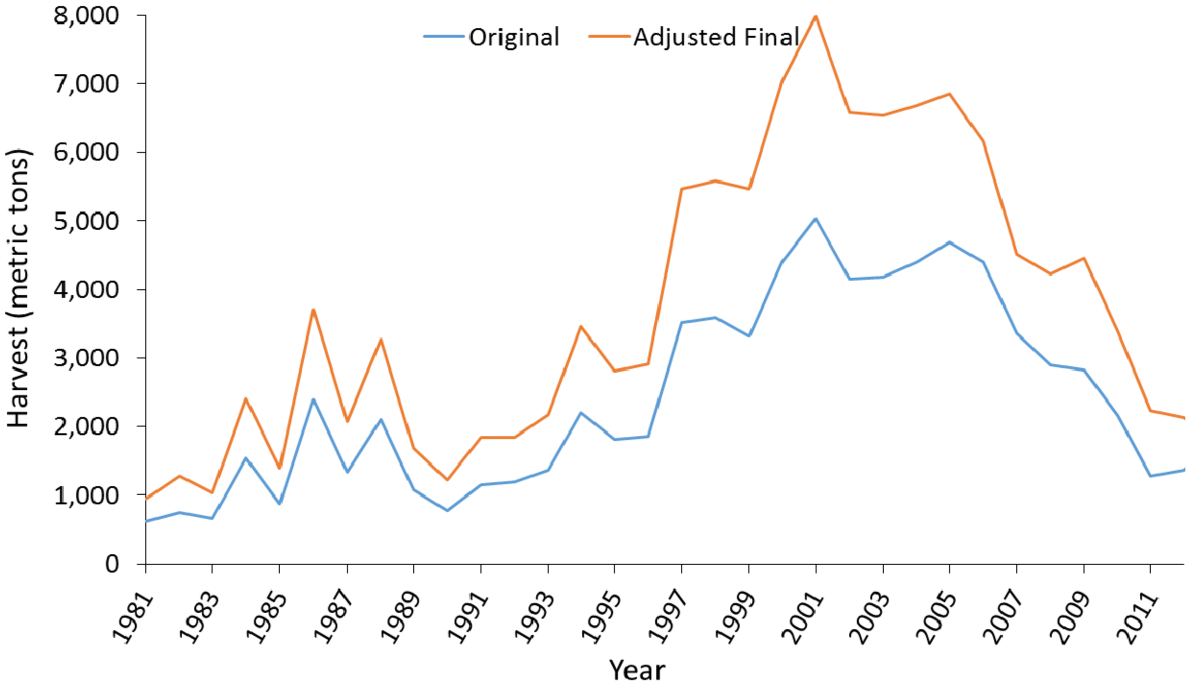


Figure 5.4. Comparison of MRFSS and MRIP recreational harvest estimates (metric tons) before (blue line) and after (orange line) adjustments.

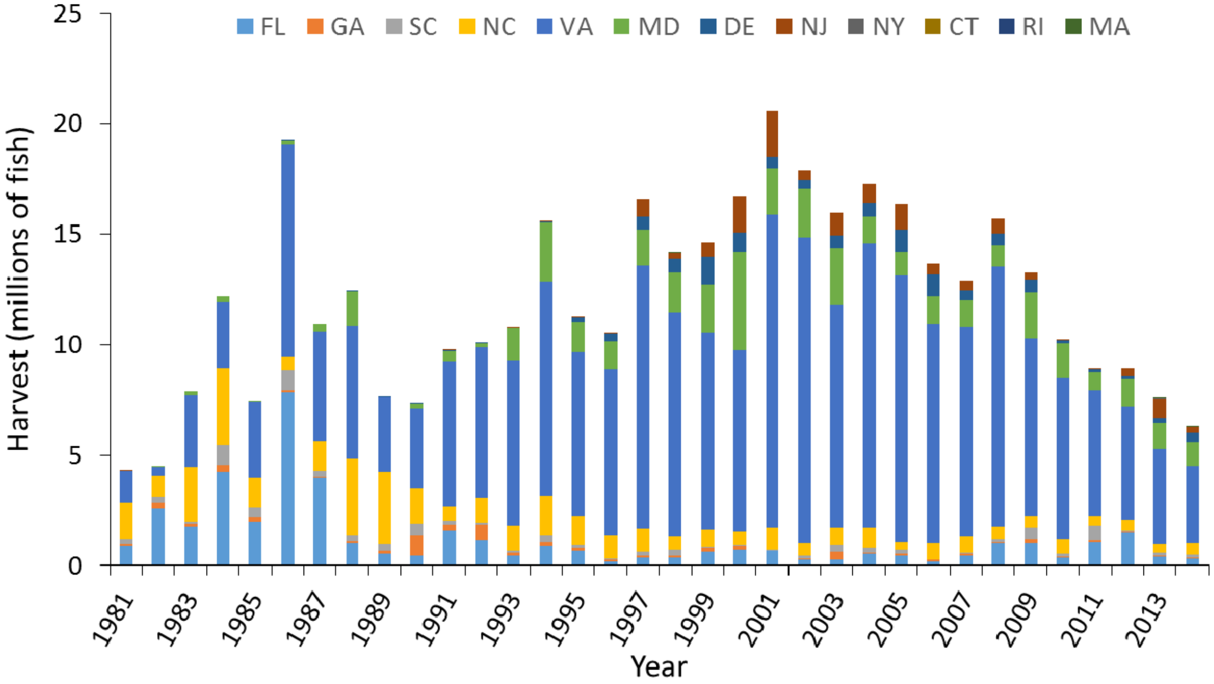


Figure 5.5. MRFSS and MRIP recreational harvest estimates (millions of fish) by state and year, 1981-2014.

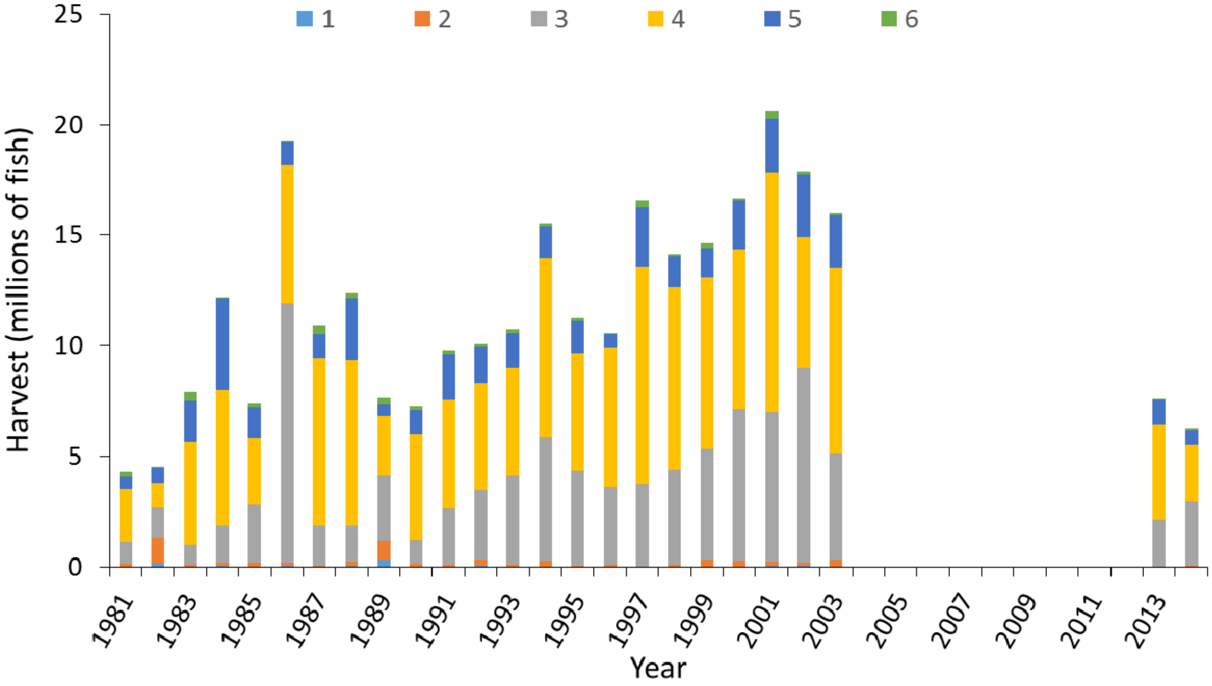


Figure 5.6. MRFSS and MRIP recreational harvest estimates (millions of fish) by wave and year, 1981-2014. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by wave from the provided SAS code.

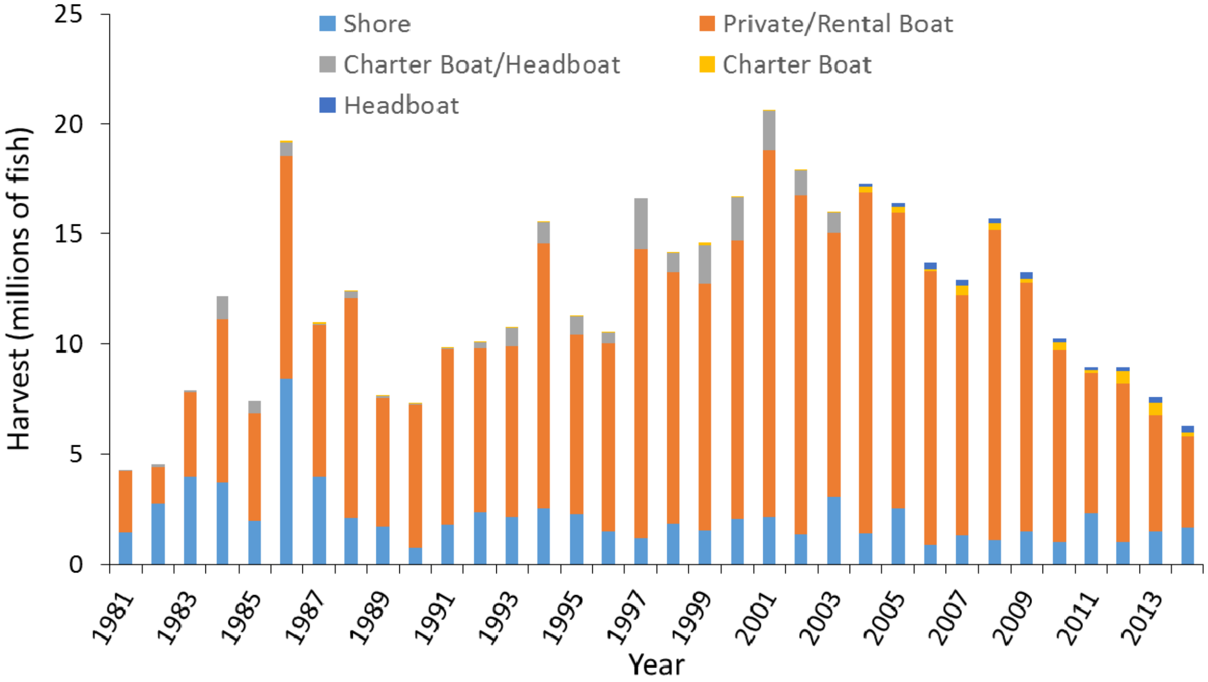


Figure 5.7. MRFSS and MRIP recreational harvest estimates (millions of fish) by mode and year, 1981-2014.

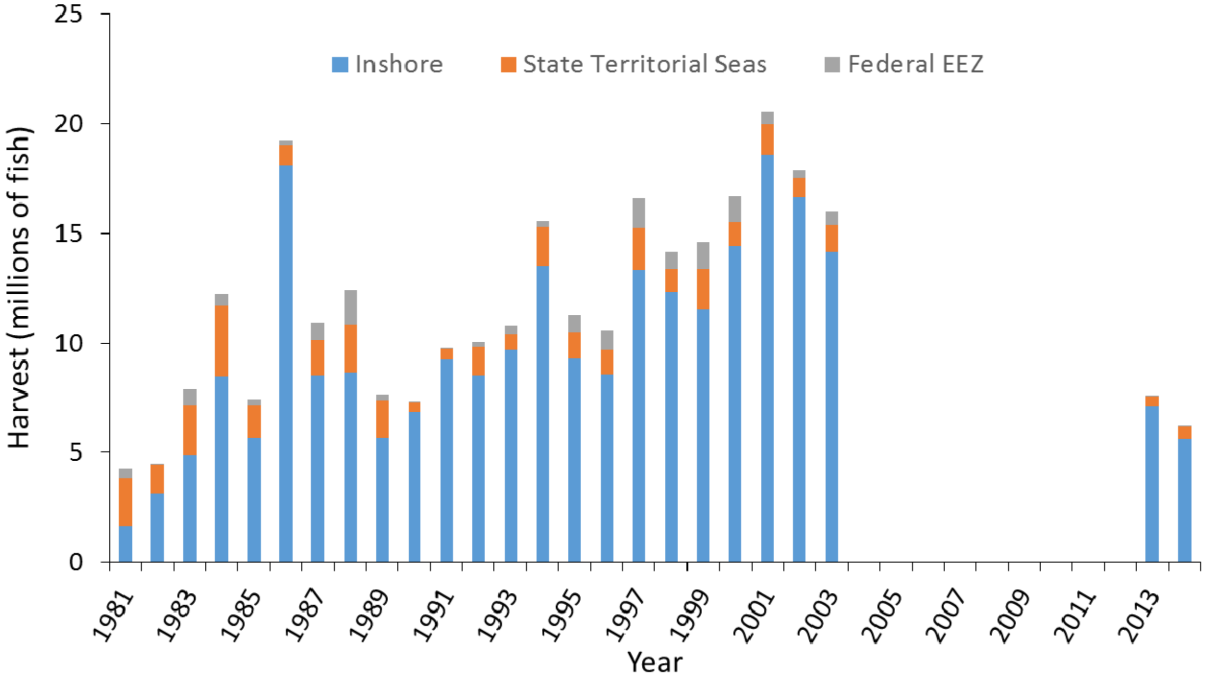


Figure 5.8. MRFSS and MRIP recreational harvest estimates (millions of fish) by area and year, 1981-2014. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by area from the provided SAS code.

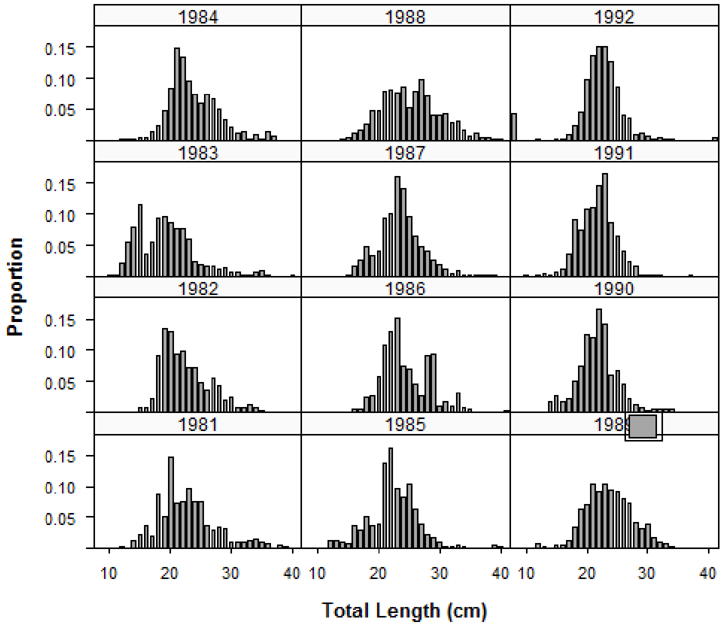


Figure 5.9 MRFSS and MRIP recreational harvest length frequency estimates, 1981-1992. The x-axes have been subset to exclude lengths that did not account for more than 1% of the annual harvest in any year (<8cm and >41cm).

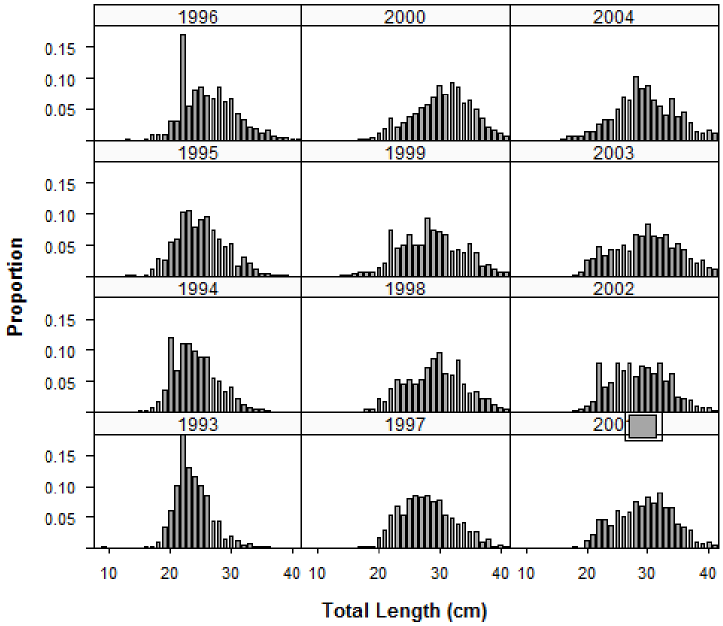


Figure 5.9 ***Continued.*** **MRFSS and MRIP recreational harvest length frequency estimates, 1993-2004. The x-axes have been subset to exclude lengths that did not account for more than 1% of the annual harvest in any year (<8cm and >41cm).**

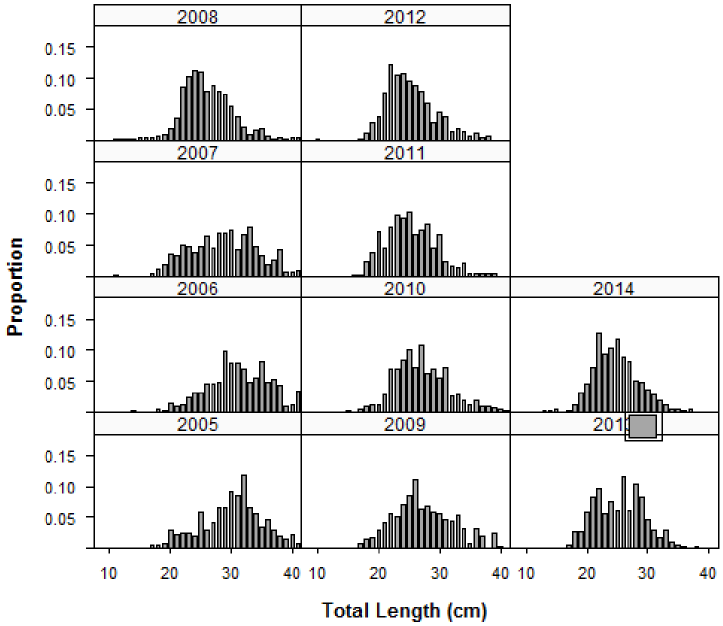


Figure 5.9. ***Continued.*** **MRFSS and MRIP recreational harvest length frequency estimates, 2005-2014. The x-axes have been subset to exclude lengths that did not account for more than 1% of the annual harvest in any year (<8cm and >41cm).**

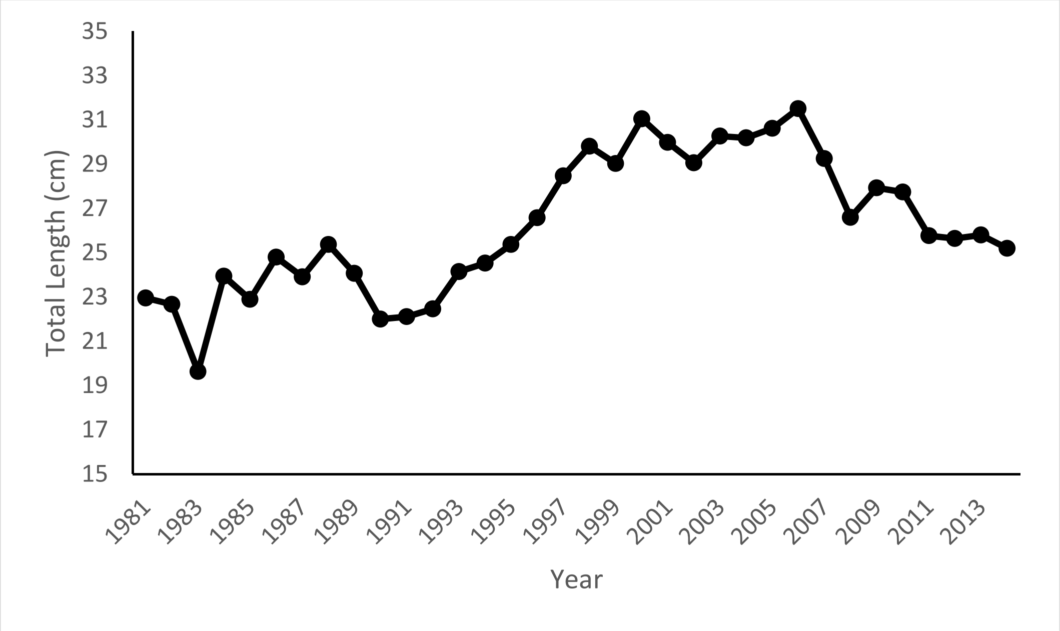


Figure 5.10. Mean annual total length of recreationally harvested Atlantic croaker on the Atlantic coast of the U.S. Data: MRIP/NMFS.

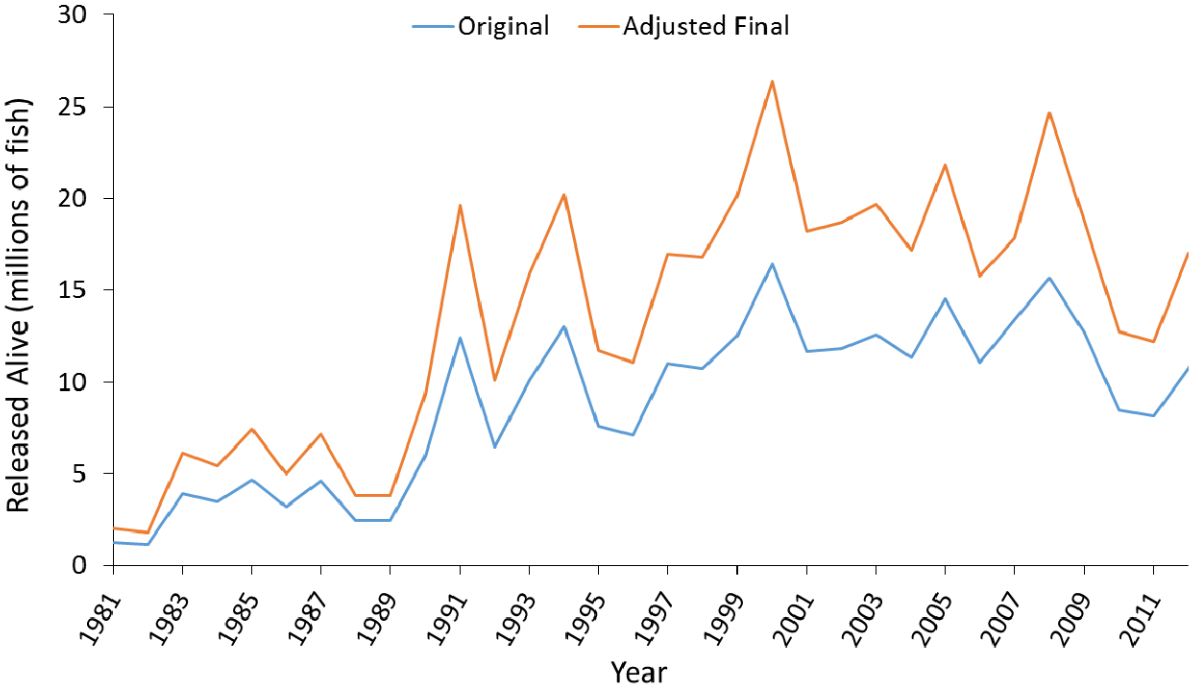


Figure 5.11. Comparison of MRFSS and MRIP recreational released alive estimates (millions of fish) before (blue line) and after (orange line) adjustments.

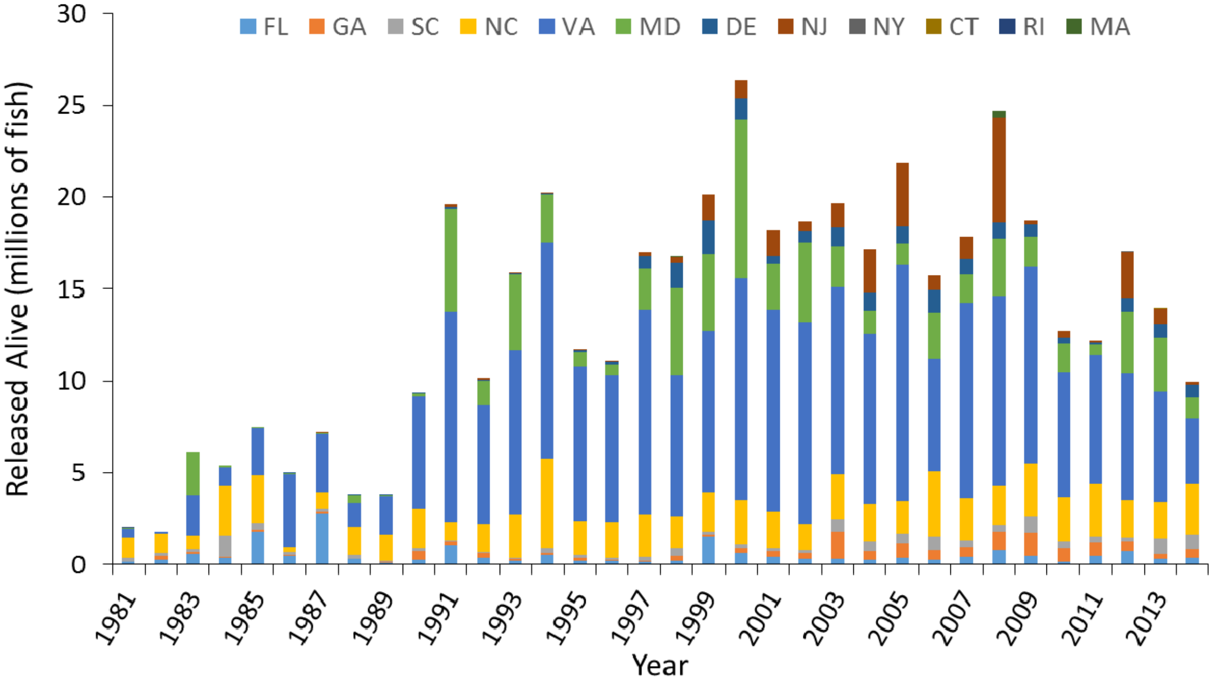


Figure 5.12. MRFSS and MRIP recreational released alive estimates (millions of fish) by state and year, 1981-2014.

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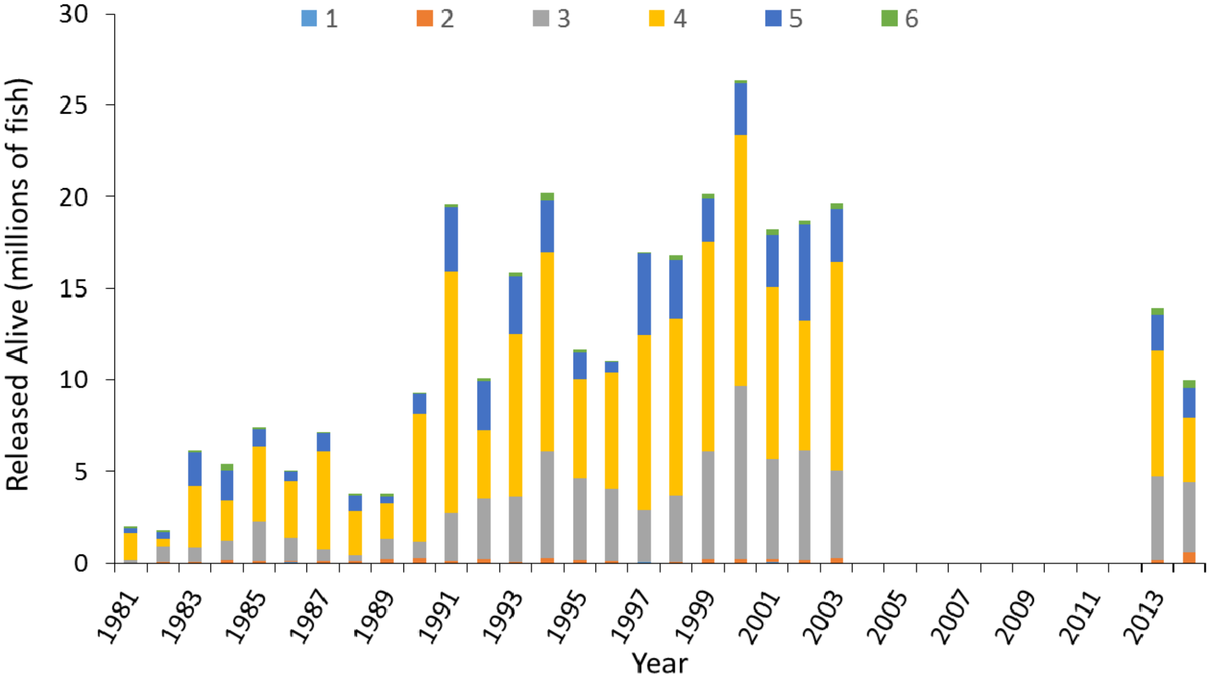

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Figure 5.13. MRFSS and MRIP recreational released alive estimates (millions of fish) by wave and year, 1981-2014. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by wave from the provided SAS code.

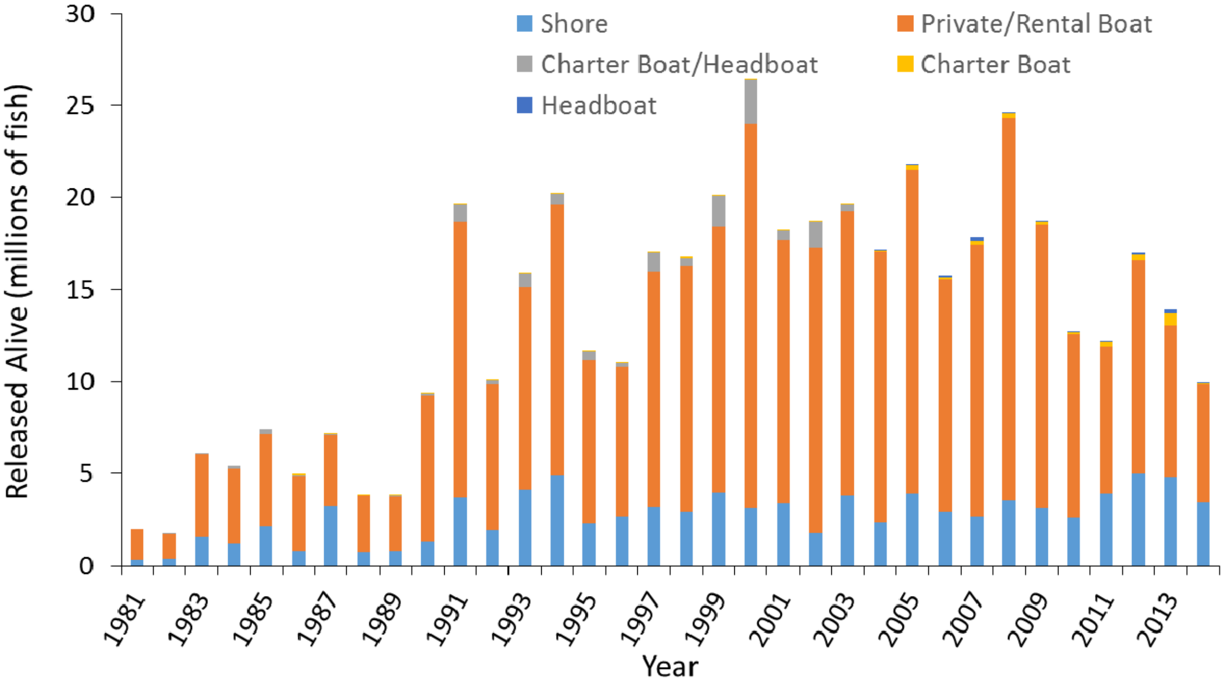

Figure 5.14. MRFSS and MRIP recreational released alive estimates (millions of fish) by mode and year, 1981-2014.

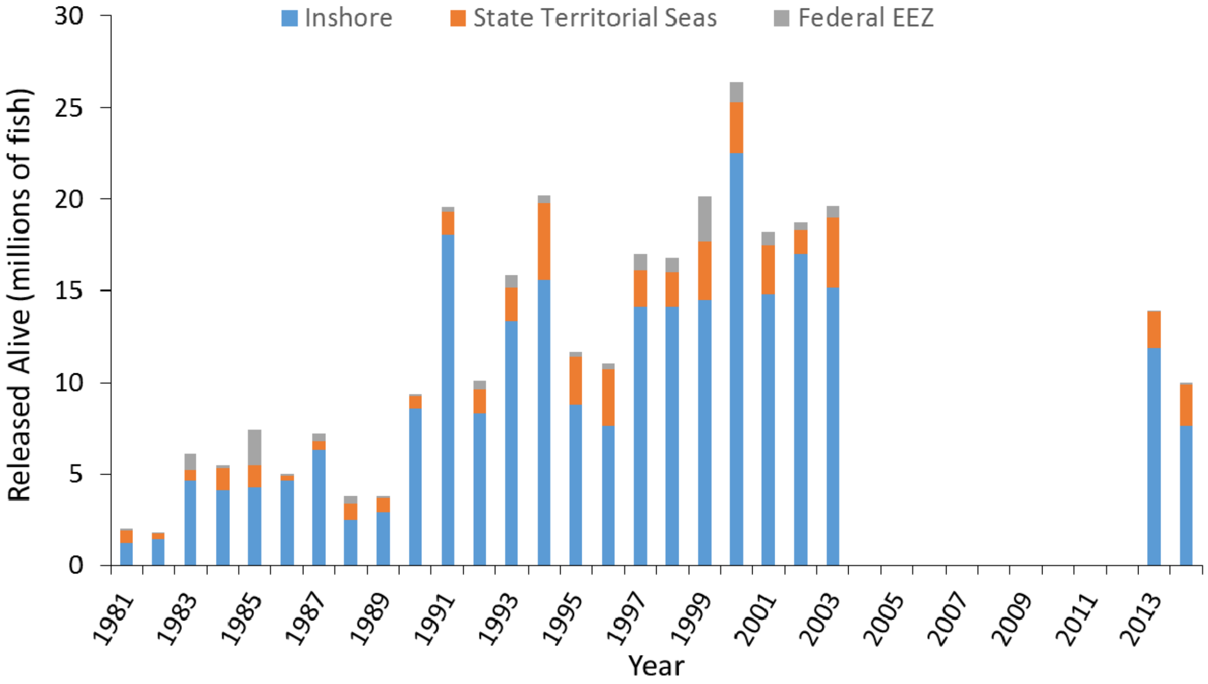

Figure 5.15. **MRFSS and MRIP recreational released alive estimates (millions of fish) by area and year, 1981-2014. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by area from the provided SAS code.**

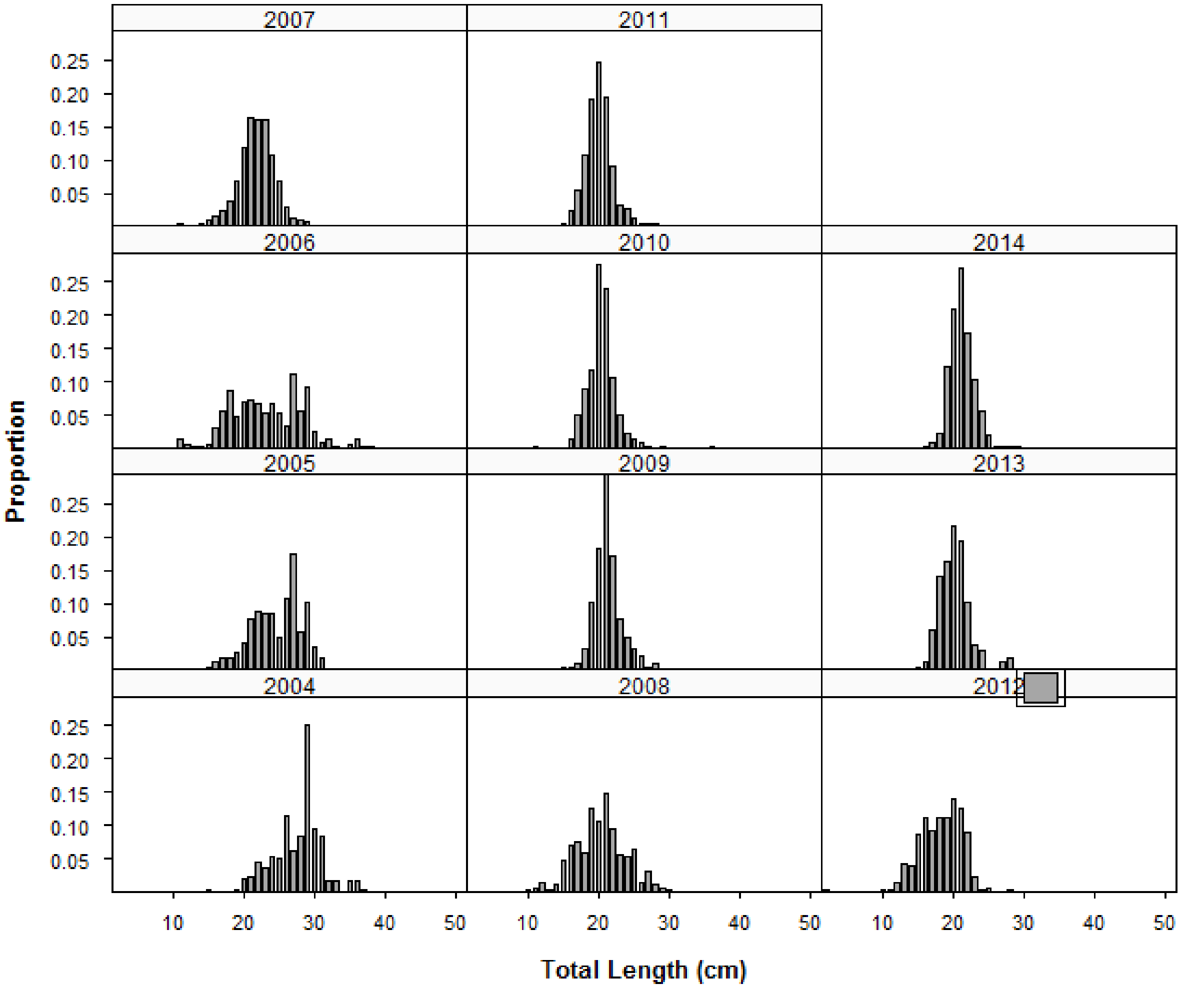

Figure 5.16. Annual size compositions of Atlantic croaker caught and released on headboats estimated from MRIP type 9 sampling data.

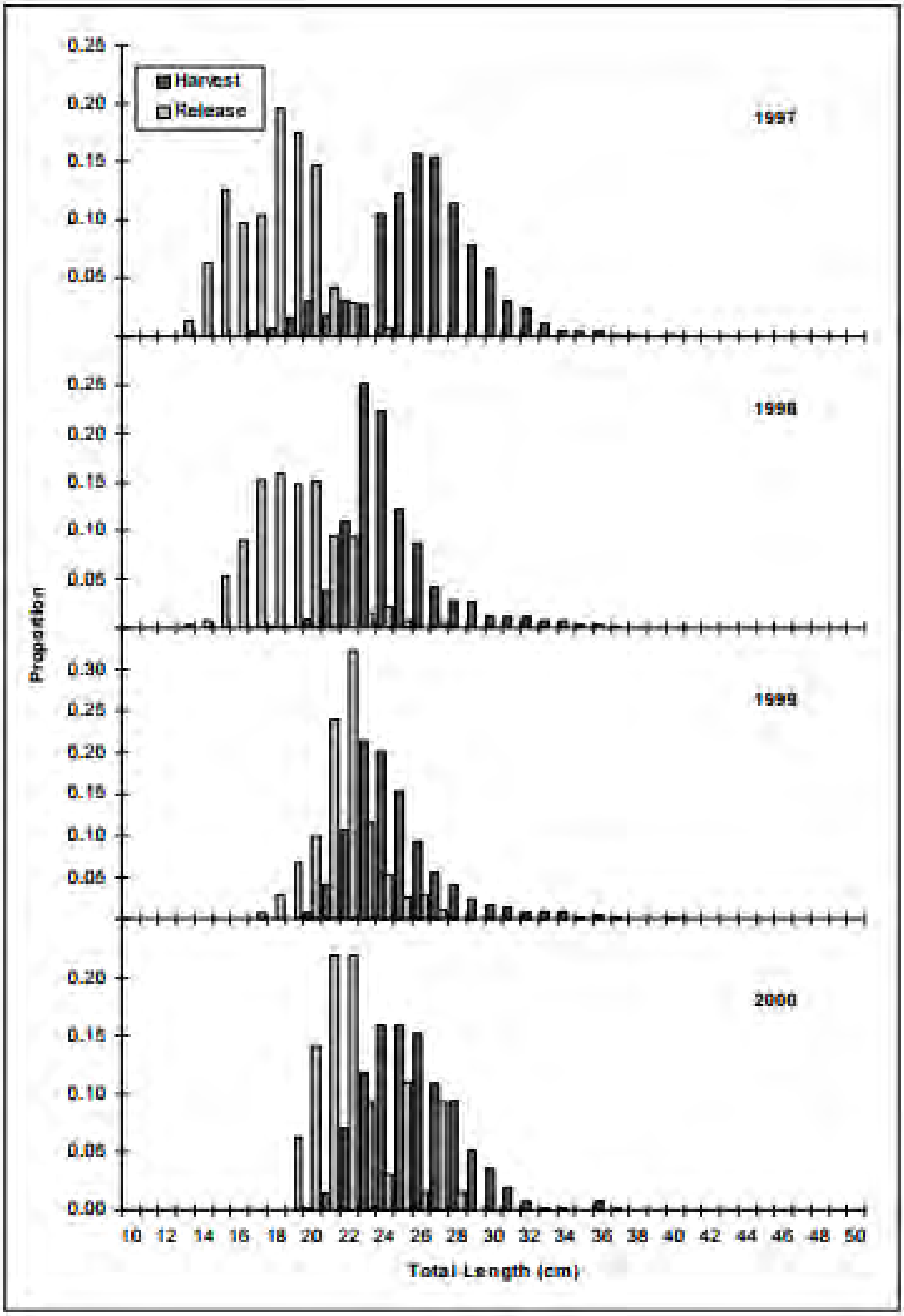

Figure 5.17. Length-frequency distribution of Atlantic croaker sampled during Maryland's headboat survey of recreational headboat harvest and releases in Maryland, 1997-2000.

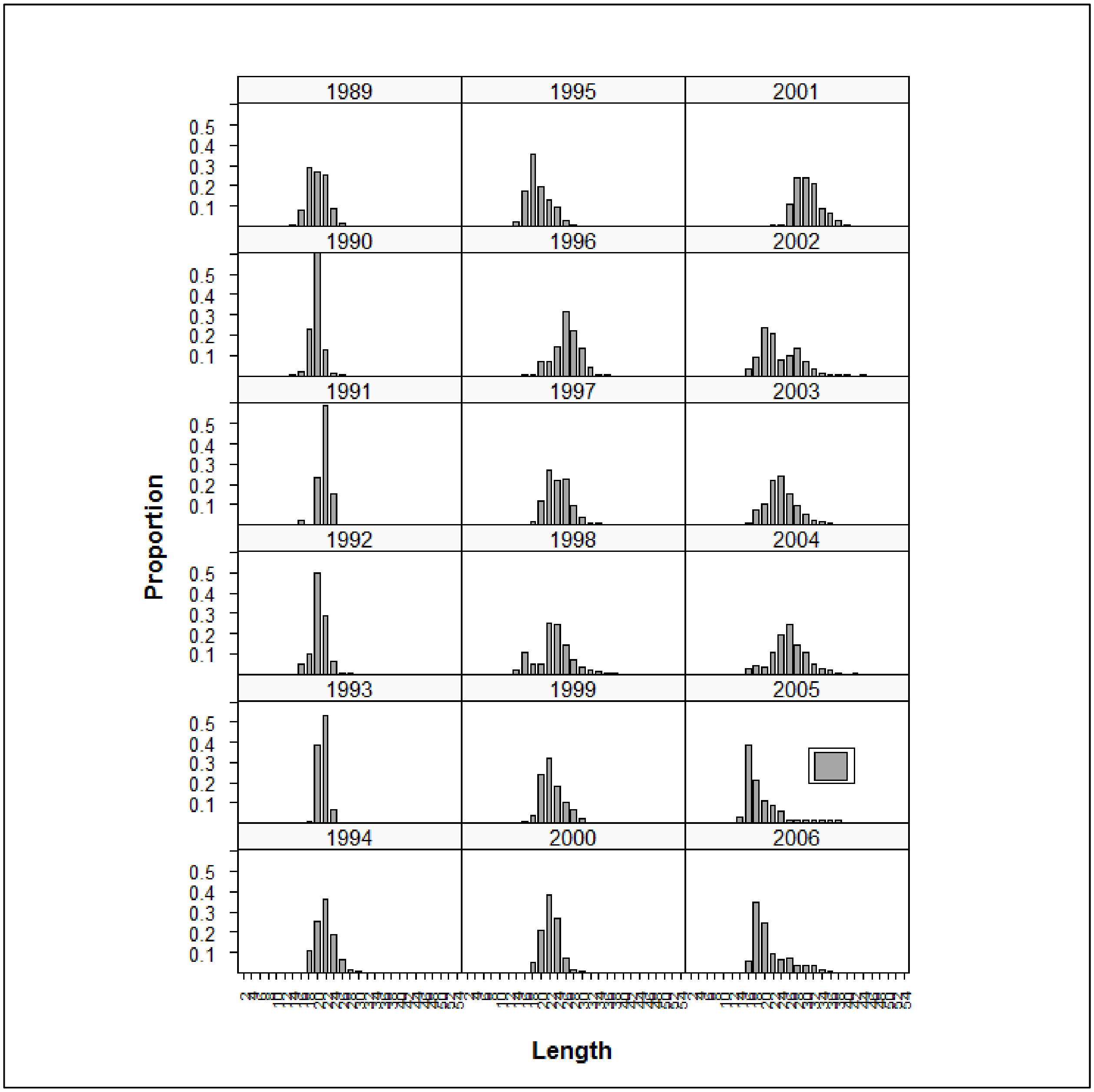

Figure 6.1 Annual length frequencies of Atlantic croaker sampled from the fall component of the NMFS survey, 1989-2014.

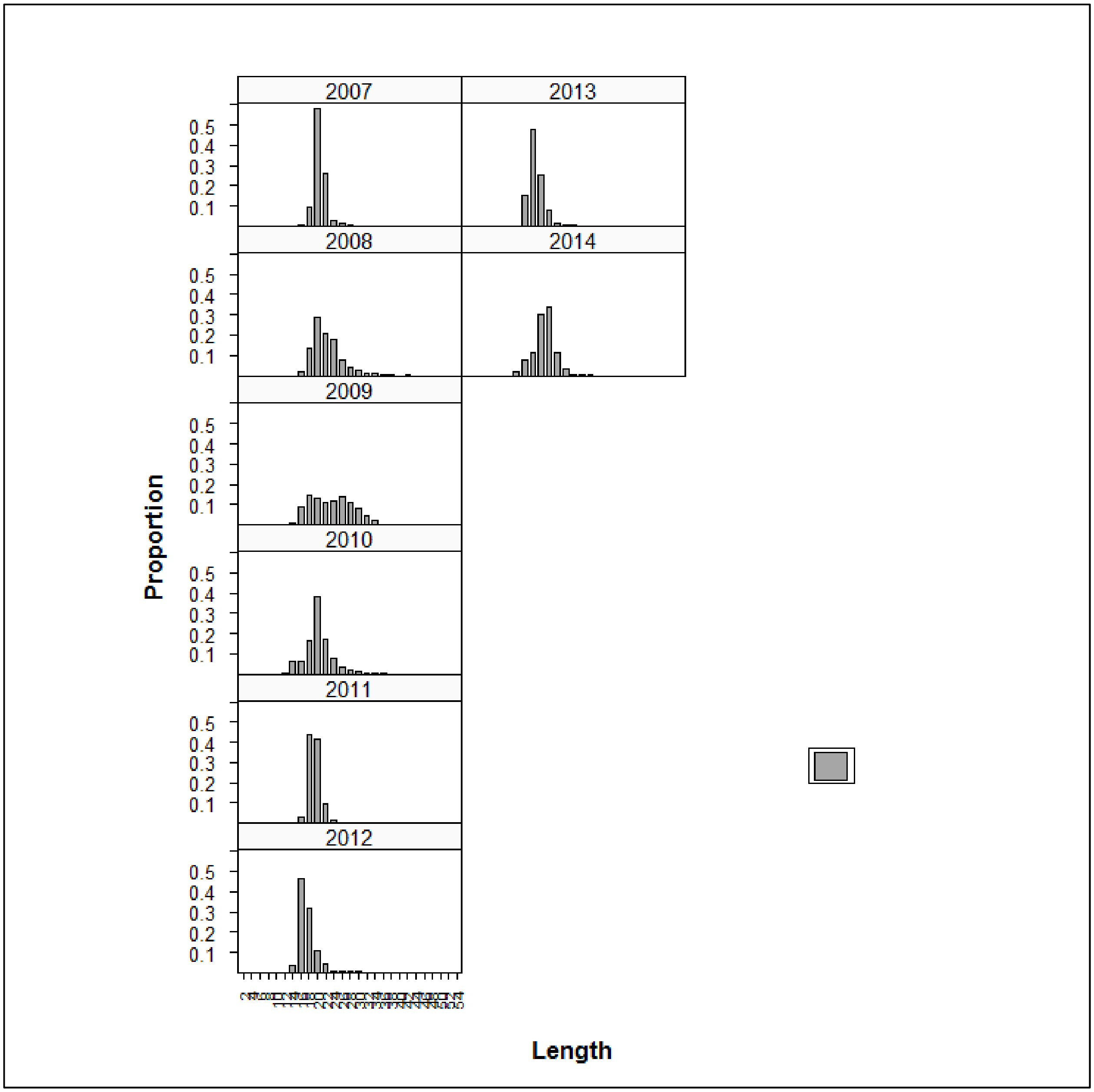

Figure 6.1 Continued, Annual length frequencies of Atlantic croaker sampled from the fall component of the NMFS survey, 1989-2014.

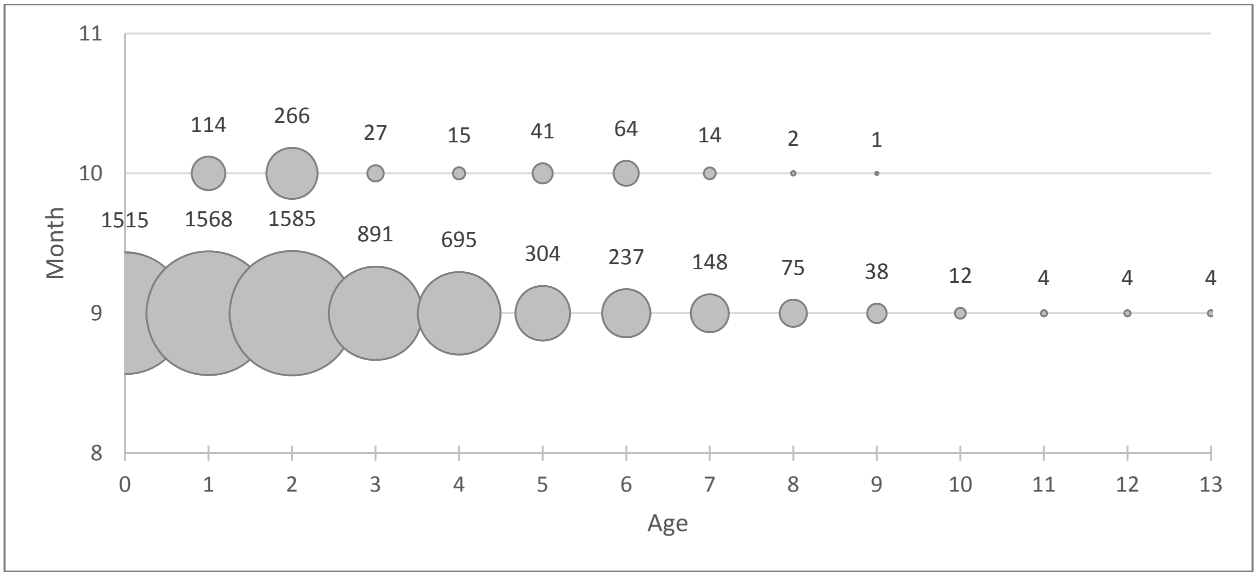

Figure 6.2 Number of Atlantic croaker at age collected during September-October in the NMFS survey from 1997-2014 with sample sizes.

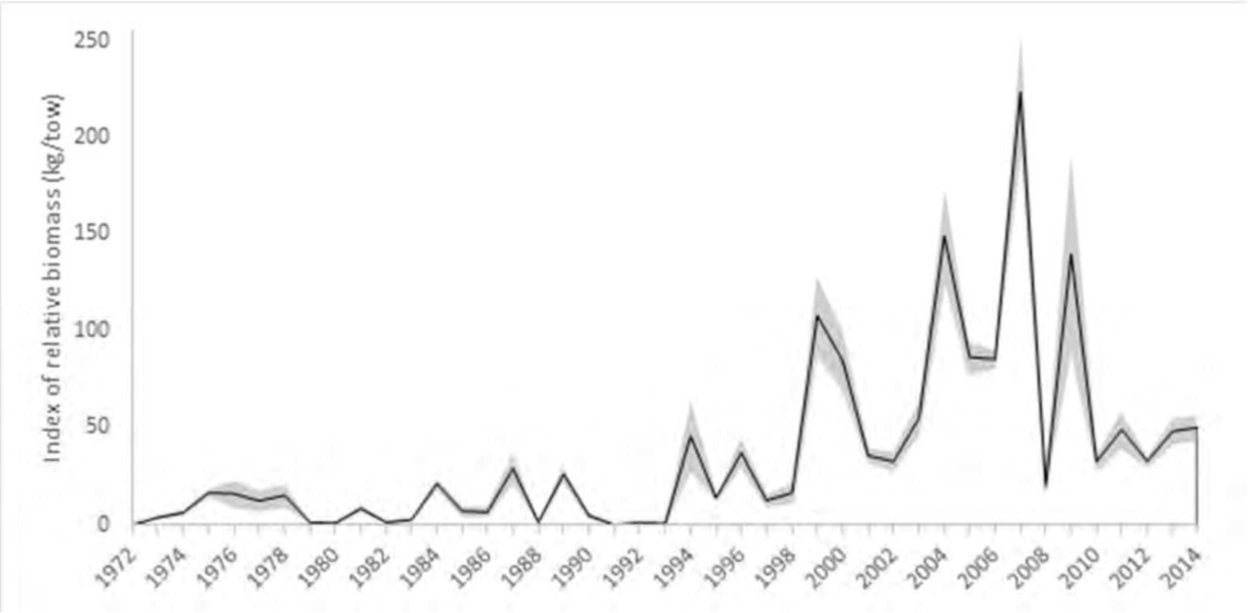

Figure 6.3. Index of relative biomass developed from the fall months (September – November) of the NMFS NEFSC survey for 1972-2014 with 95% confidence intervals.

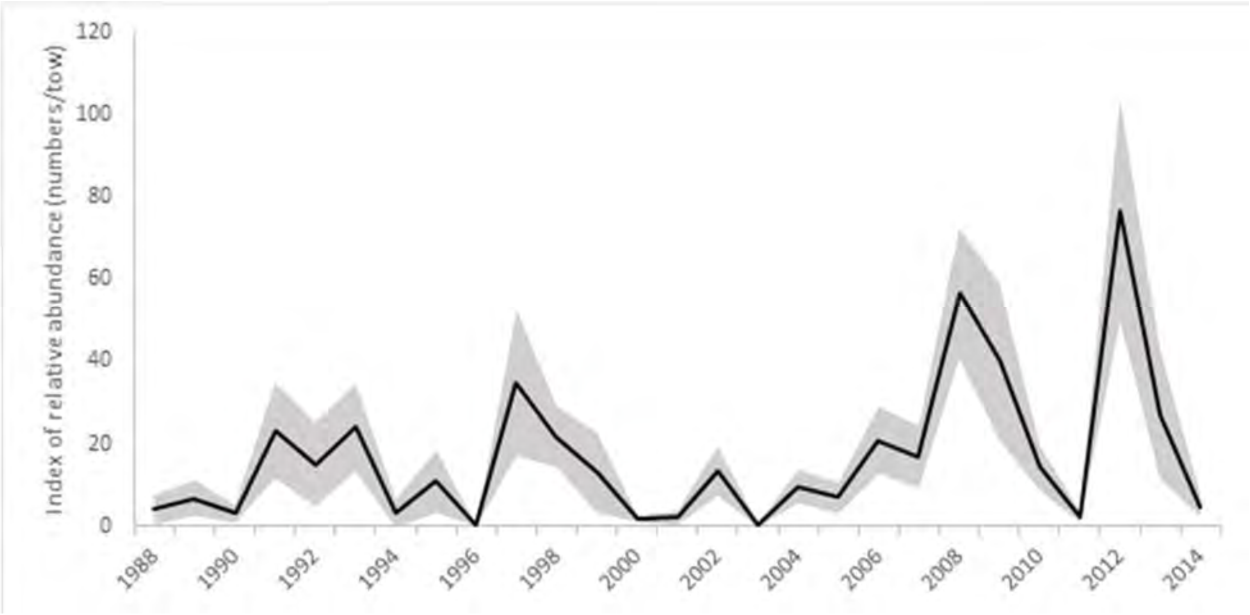

Figure 6.4. Index of relative YOY abundance developed from the May-June portion of the VIMS survey for 1988-2014 with 95% confidence intervals.

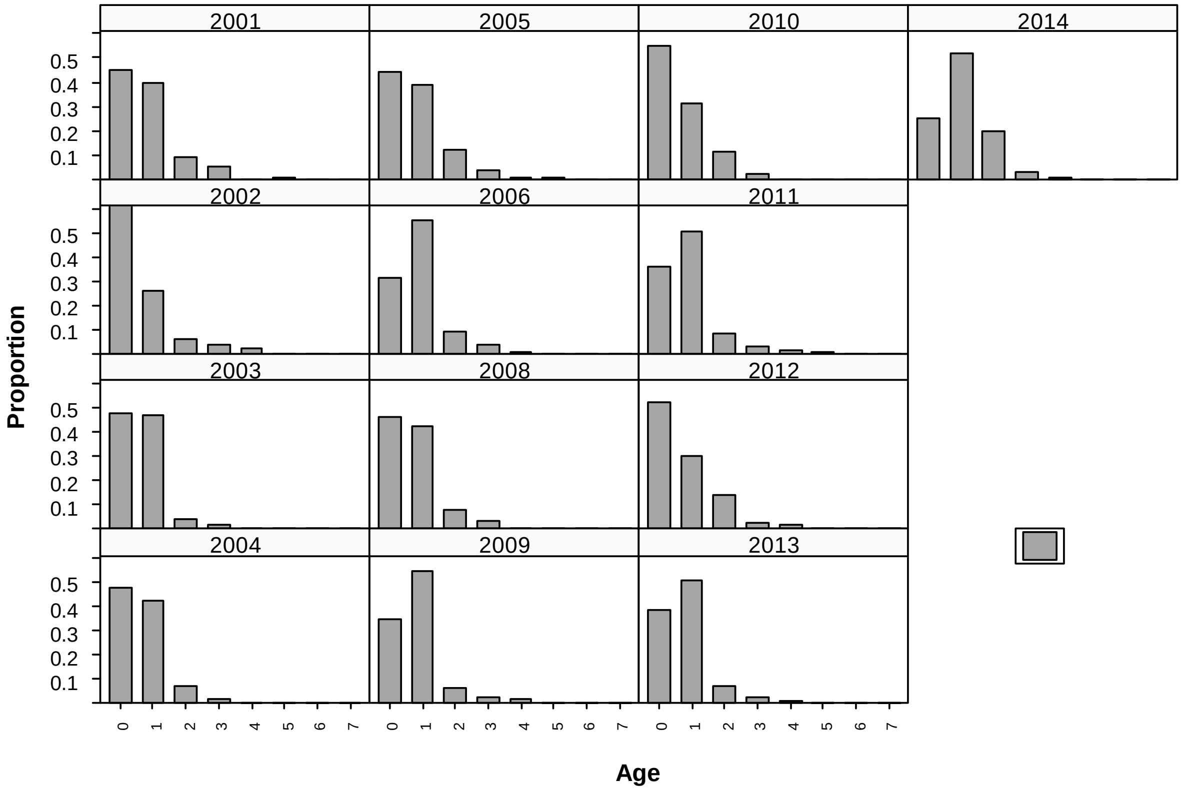

Figure 6.5 Annual age frequency of Atlantic croaker caught in the SEAMAP survey.

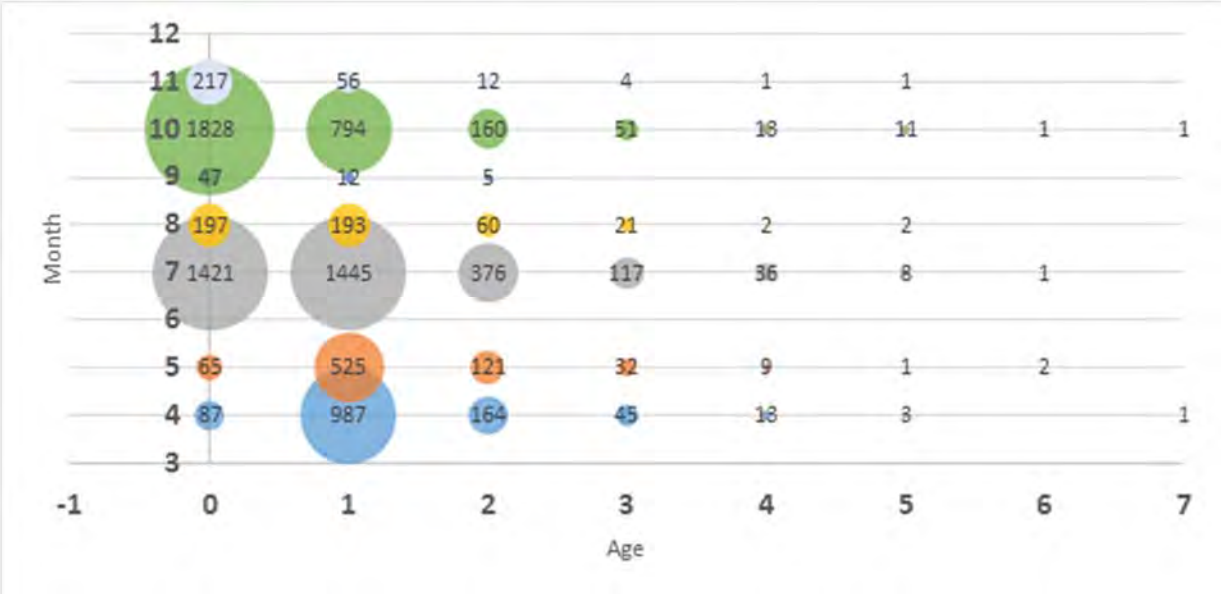

Figure 6.6 Bubble plot of numbers at age for each month of the SEAMAP survey with sample size labeled.

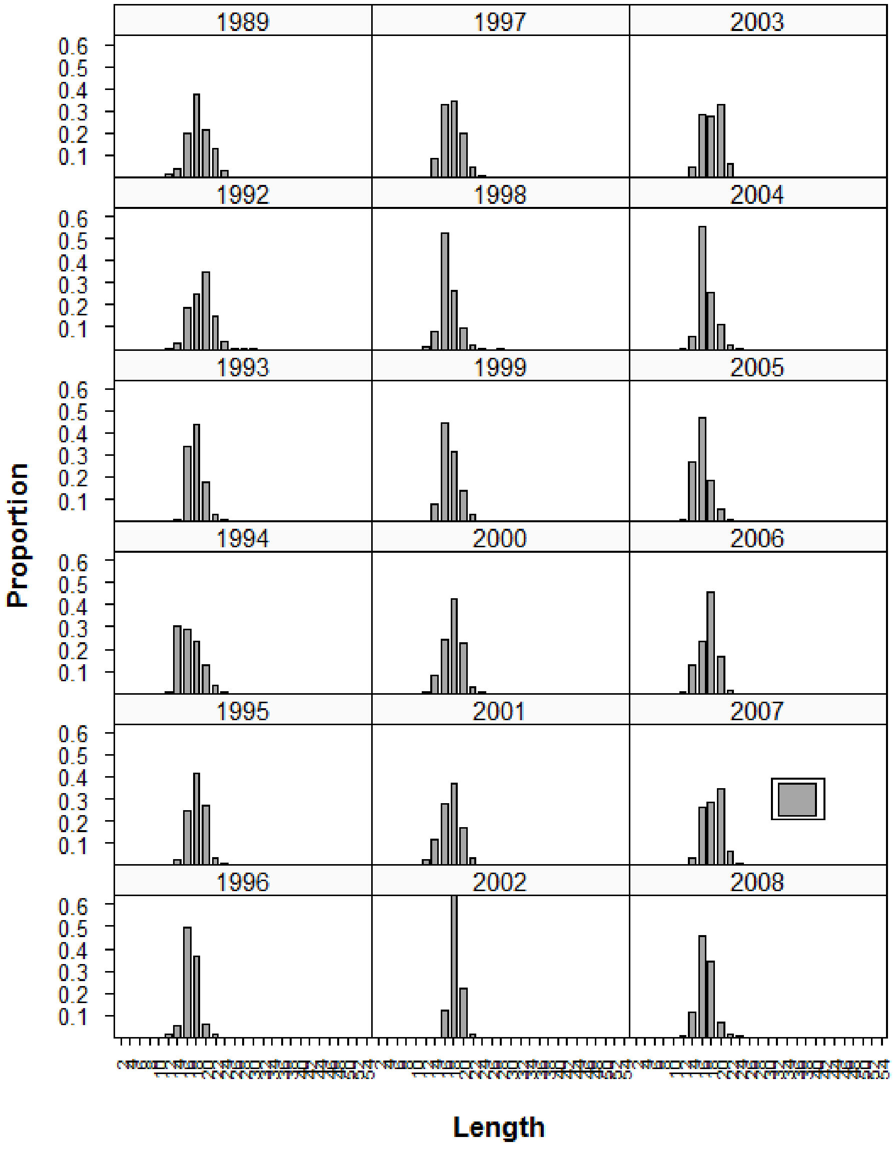

Figure 6.7 Annual length frequencies of Atlantic croaker sampled from the fall component of the SEAMAP survey, 1989-2014.

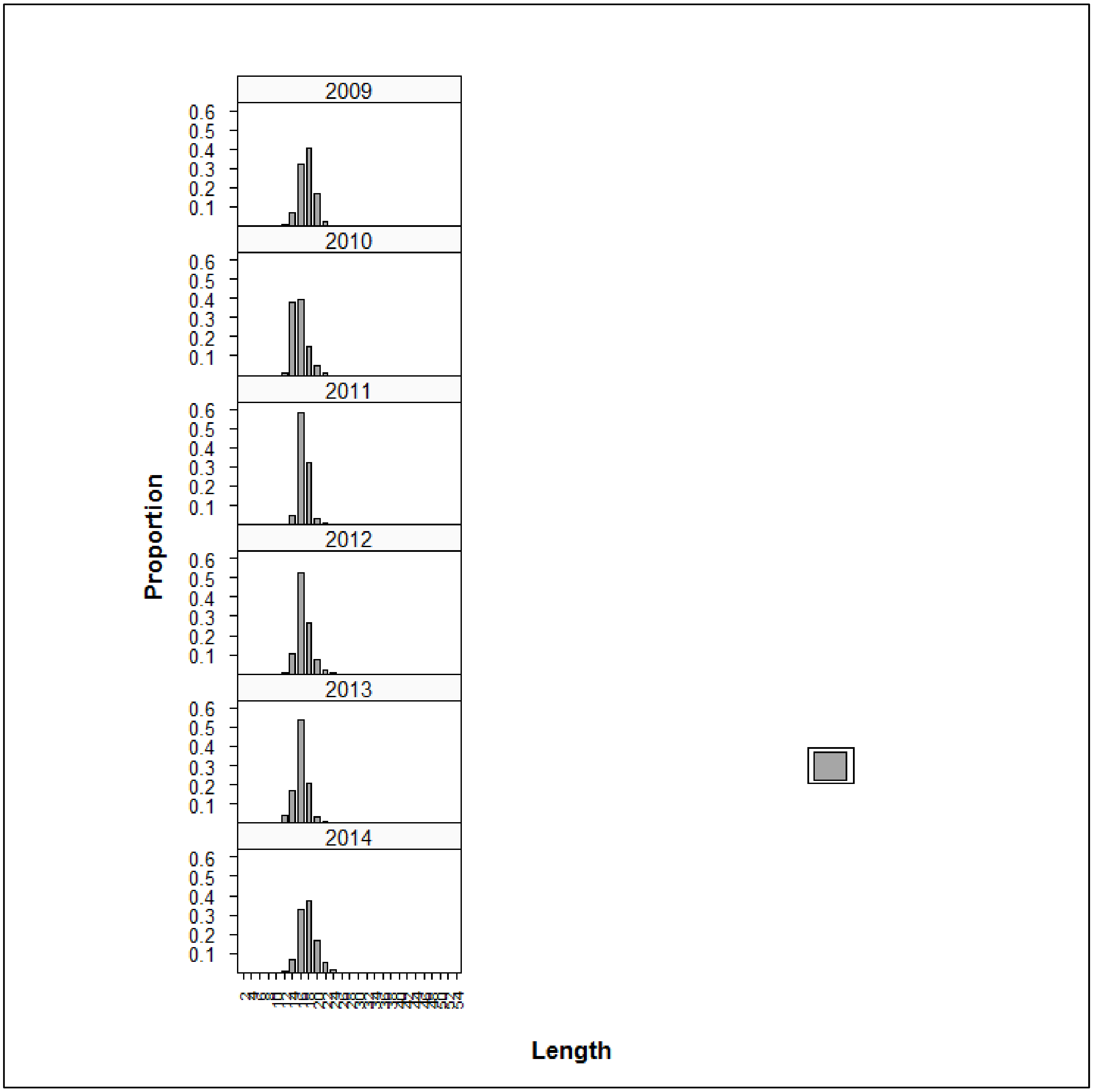

Figure 6.7 Continued. Annual length frequencies of Atlantic croaker sampled from the fall component of the SEAMAP survey, 1989-2014.

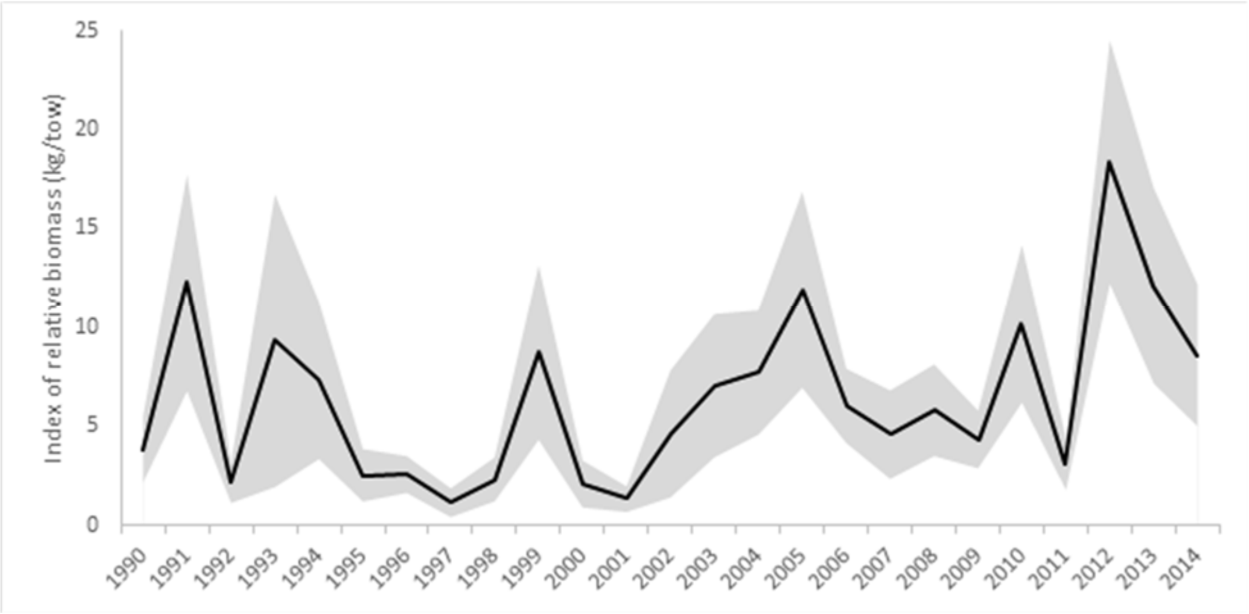

Figure 6.8. Index of relative biomass developed from the fall months of the SEAMAP survey for 1990-2014 with 95% confidence intervals.

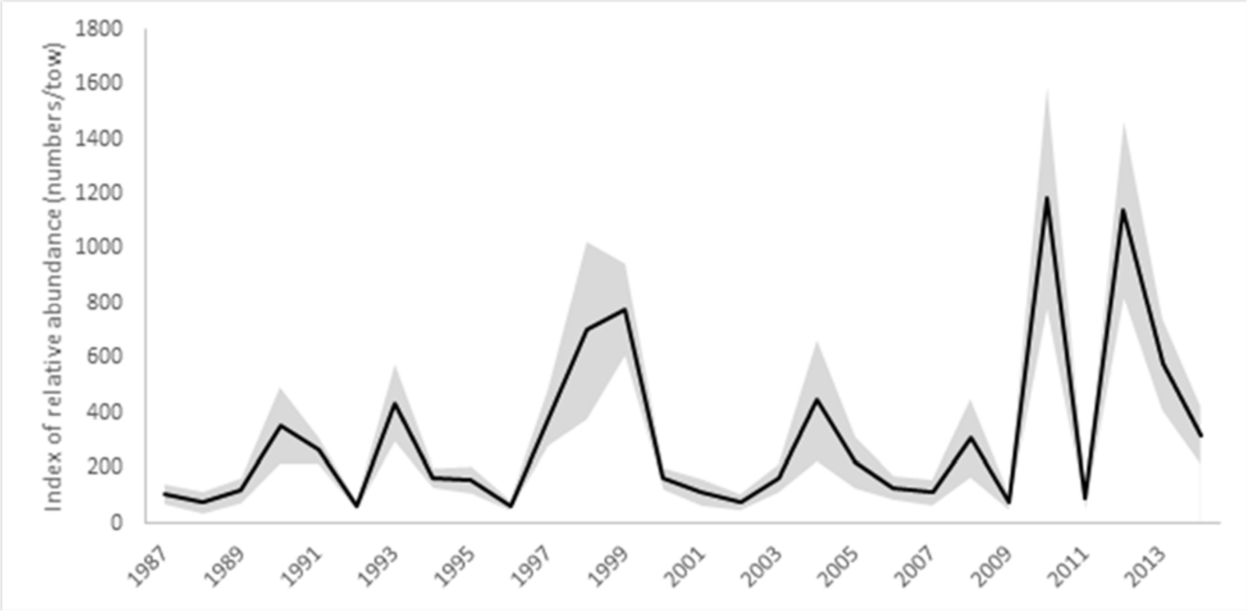

Figure 6.9. Index of relative YOY abundance developed from the June portion of the NC195 program survey for 1987-2014 with 95% confidence intervals.

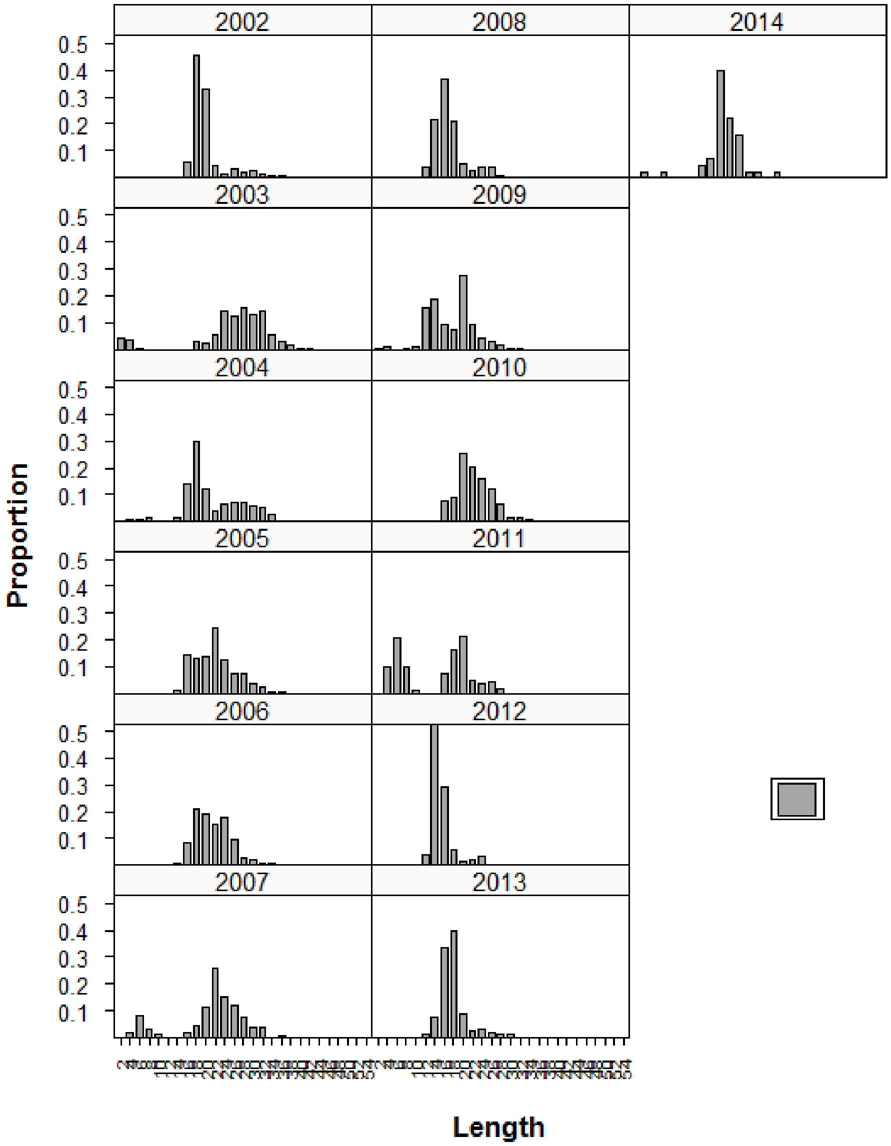

Figure 6.10 Annual length frequencies of Atlantic croaker sampled from the May/July/September component of the ChesMMAP survey, 2002-2014.

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Figure 6.11 Bubble plot of ages collected by month in the ChesMMAP survey with sample sizes.

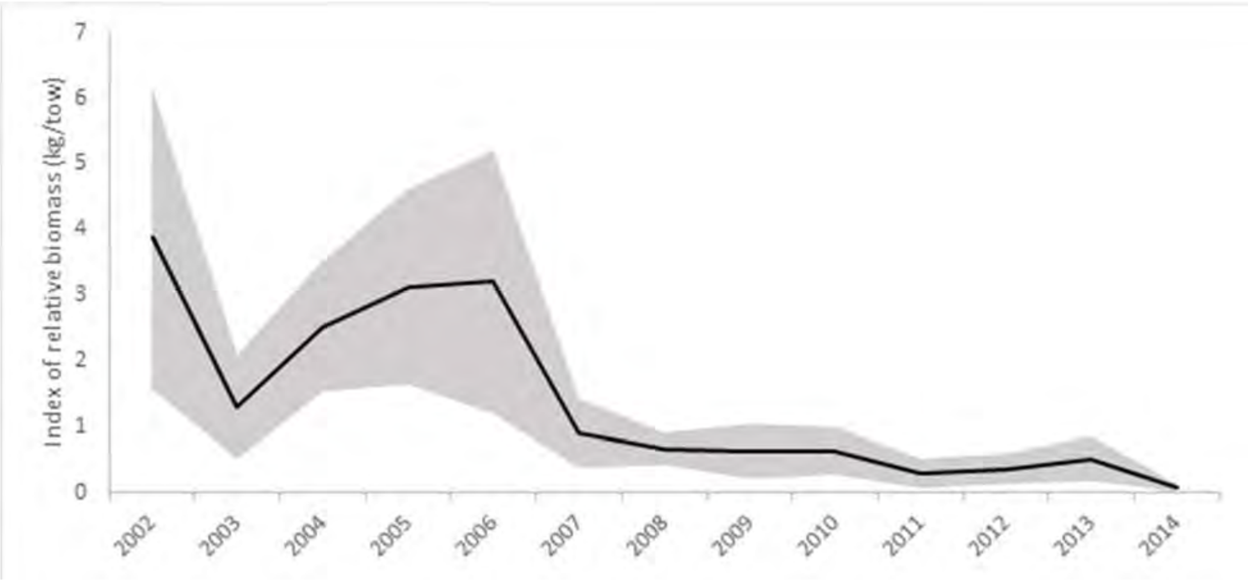

Figure 6.12. Index of relative biomass developed from May-September months of the ChesMMAP survey for 2002-2014 with 95% confidence intervals.

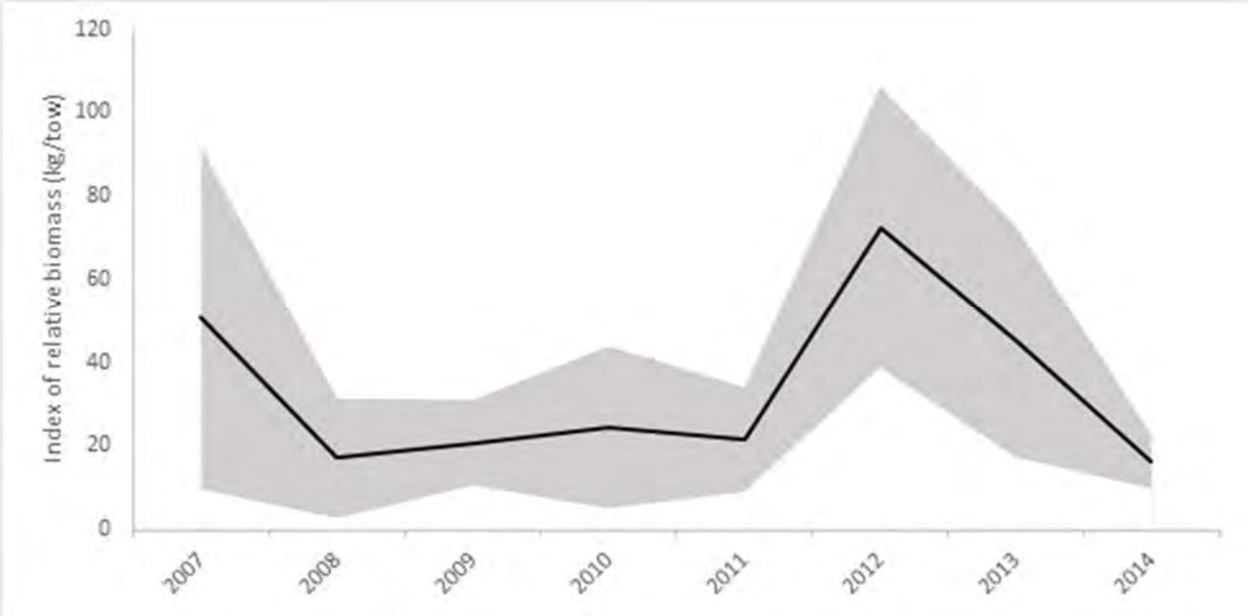

Figure 6.13. Index of relative biomass developed from the fall months of the NEAMAP survey for 2007-2014 with 95% confidence intervals.

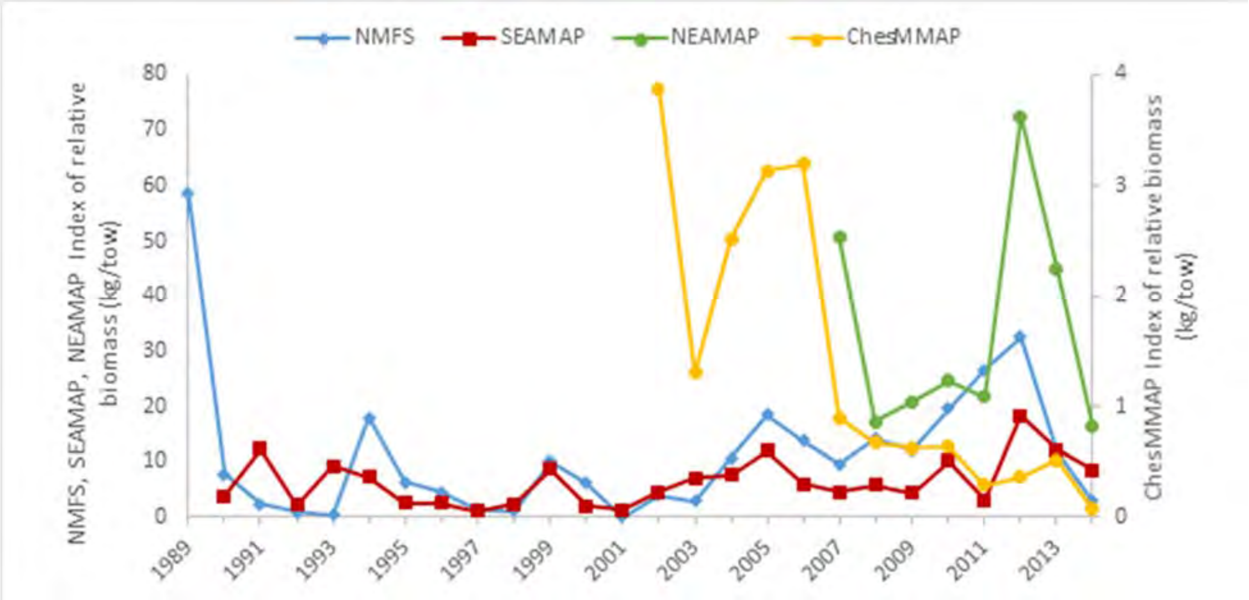

Figure 6.14. Indices of relative biomass of Atlantic croaker in kilograms per tow for surveys considered for the base run of the model.

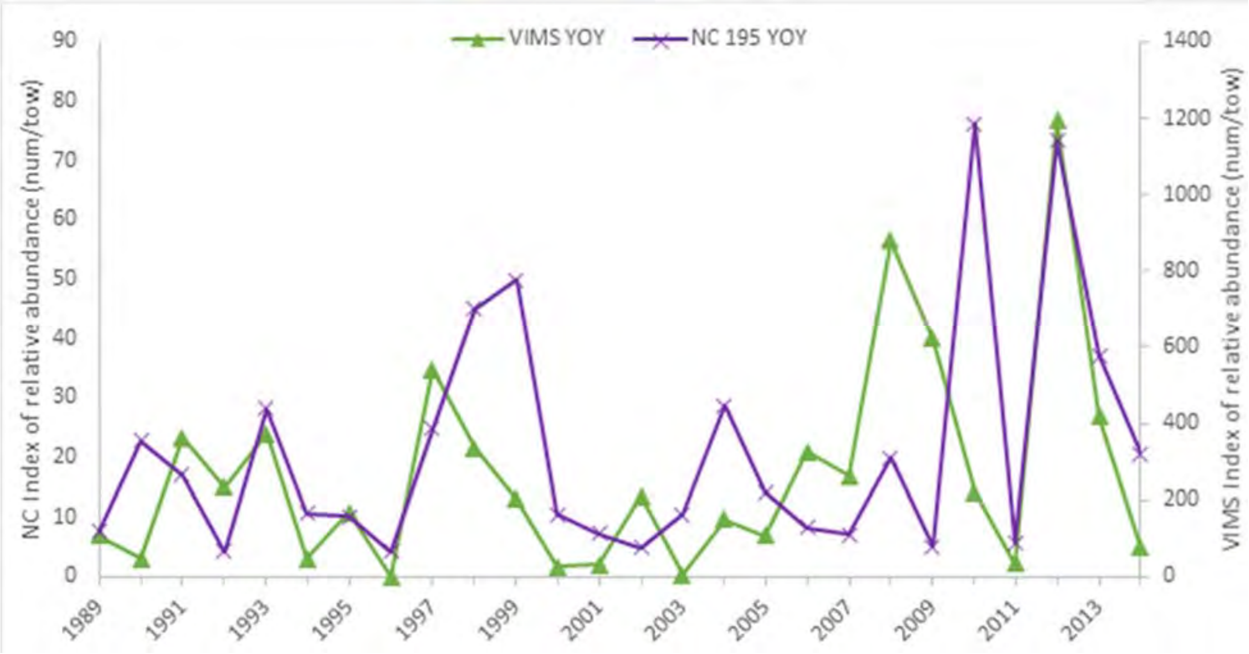

Figure 6.15. Indices of relative abundance of young-of-the-year Atlantic croaker in numbers per tow for surveys considered for the base run of the model.

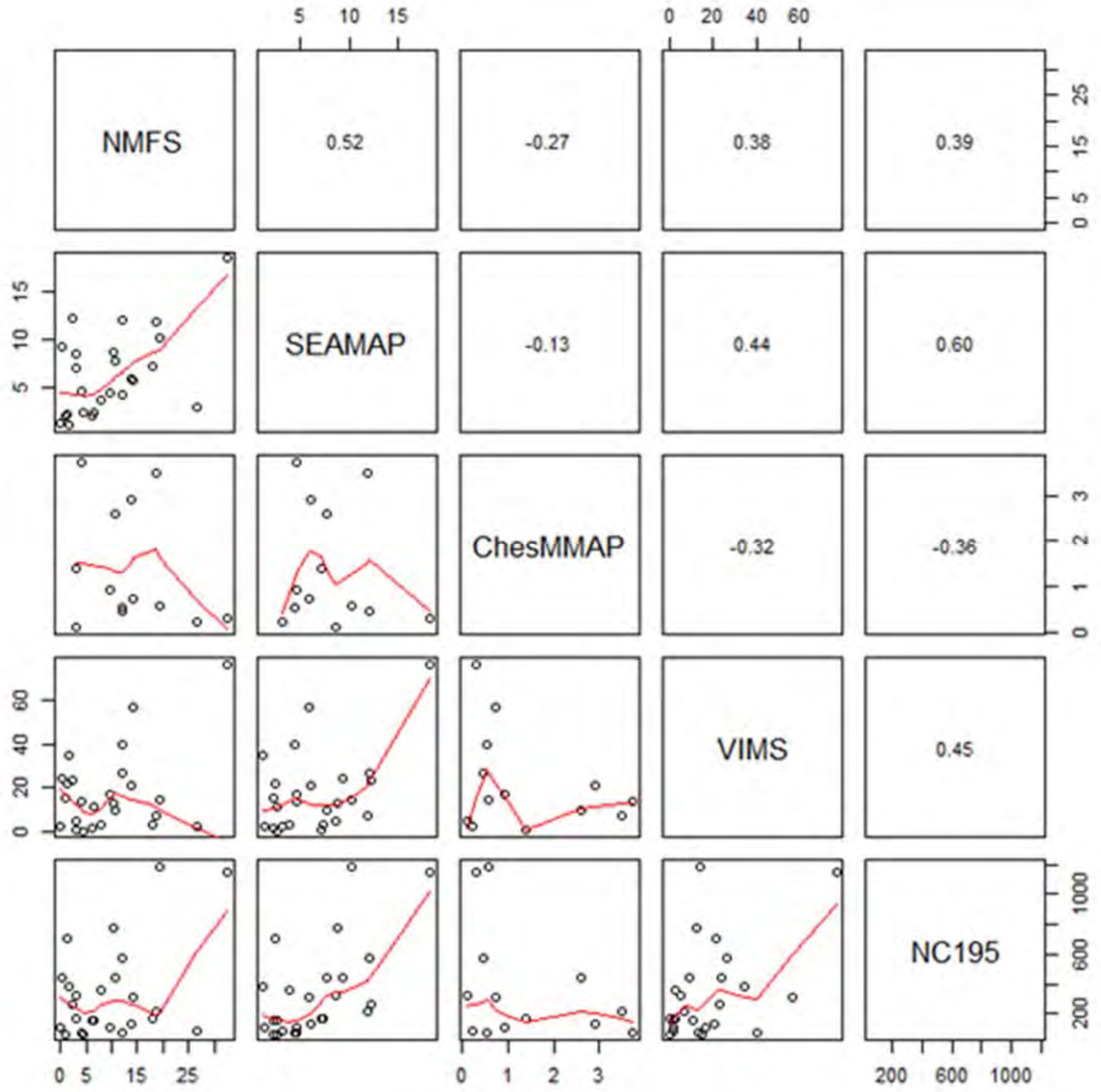

Figure 6.16. Correlation coefficients and scatter plots for the indices considered for Atlantic croaker. NEAMAP was not included because of its limited time series.

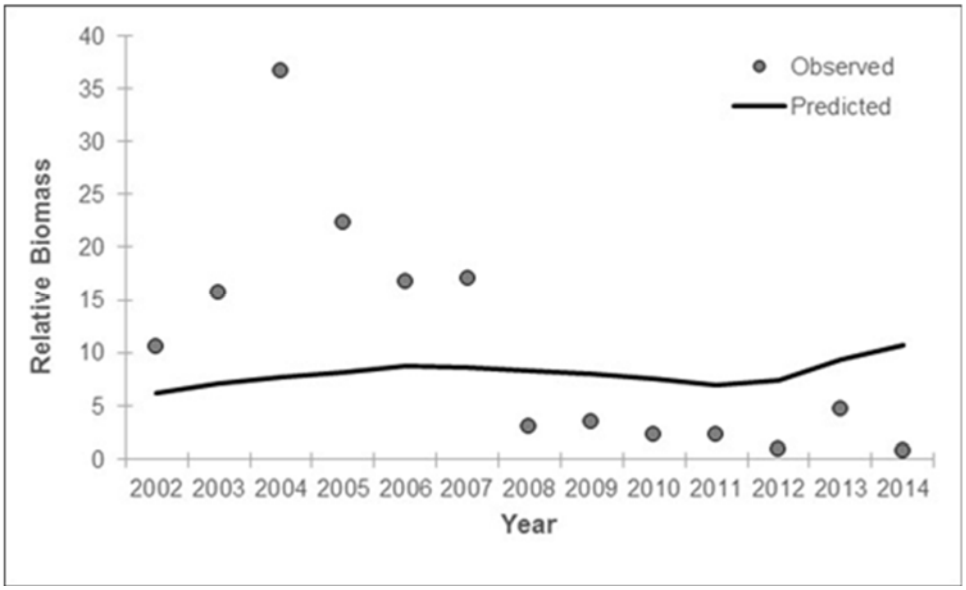

Figure 7.1. Observed and predicted index of relative biomass for the ChesMMAP survey from preliminary runs.

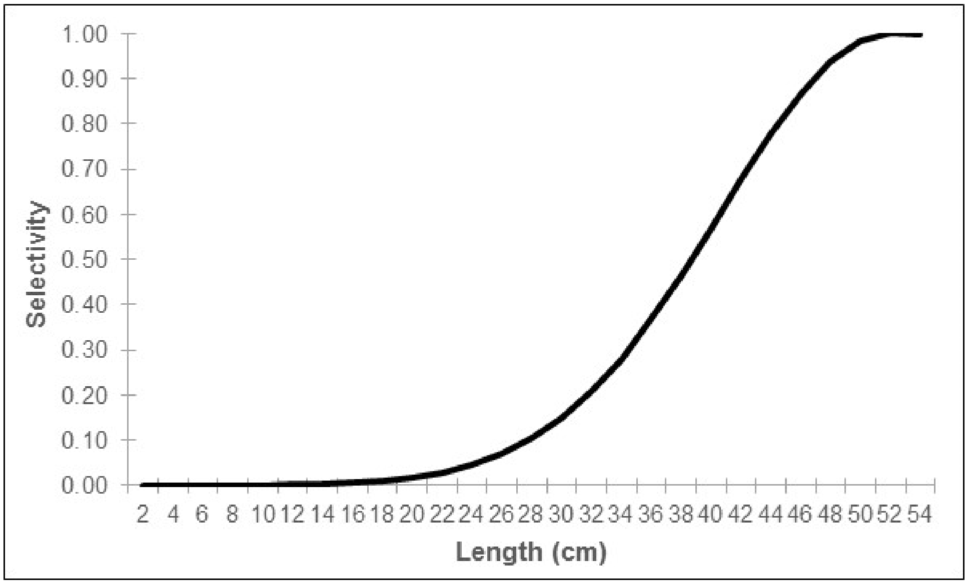

Figure 7.2. Predicted selectivity pattern for the NMFS survey from preliminary runs.

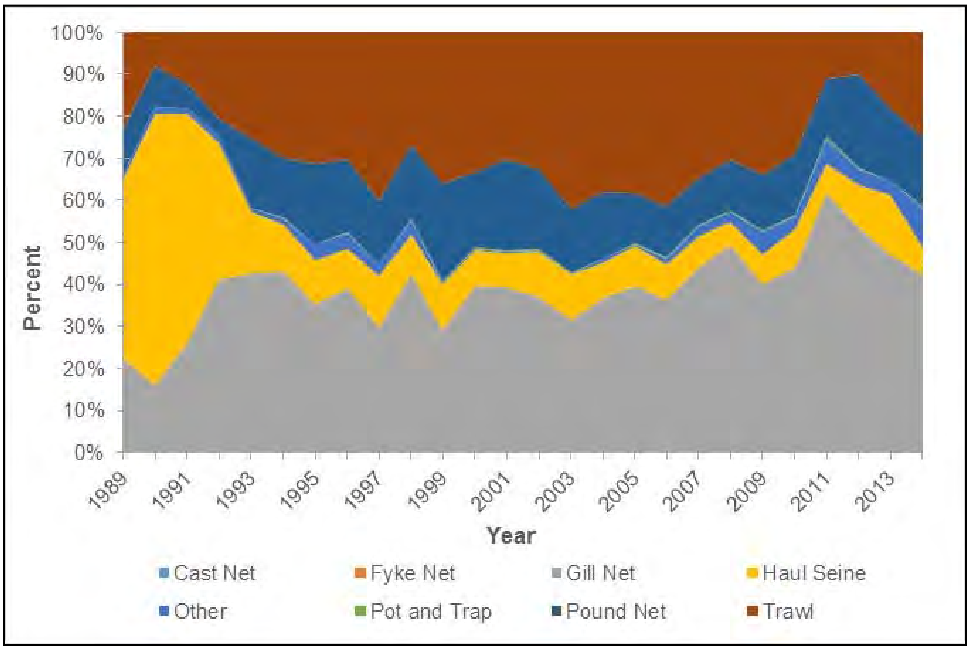

Figure 7.3. Major gear types for the commercial fishery for Atlantic croaker, 1989–2014.

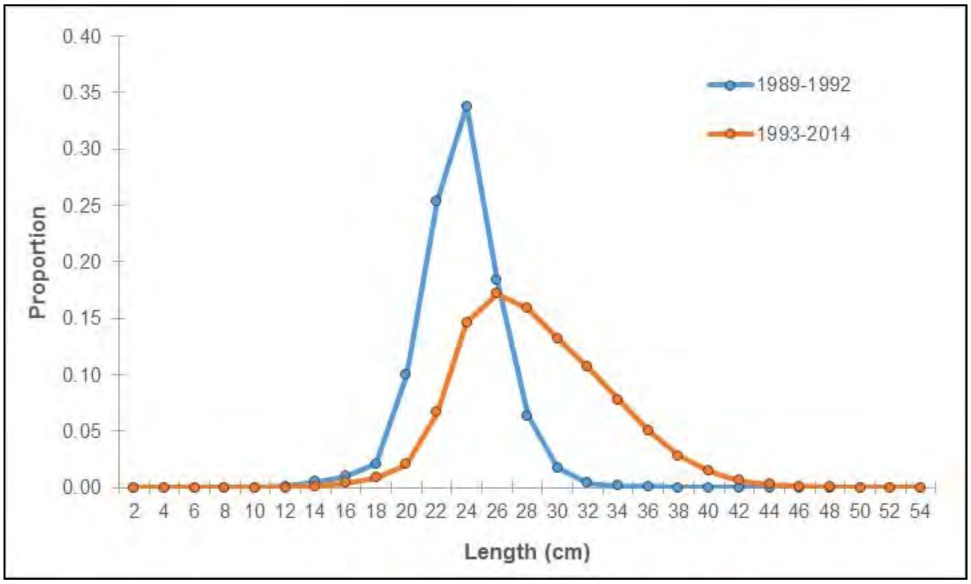

Figure 7.4. Observed proportions at length for the commercial fishery for two time blocks.

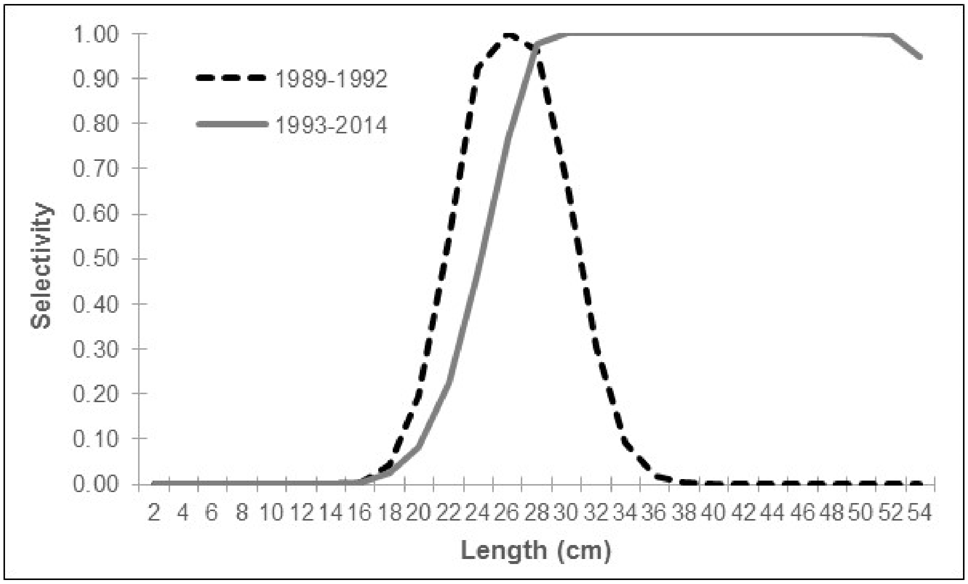

Figure 7.5. Predicted time-varying selectivity for the commercial fishery from preliminary runs.

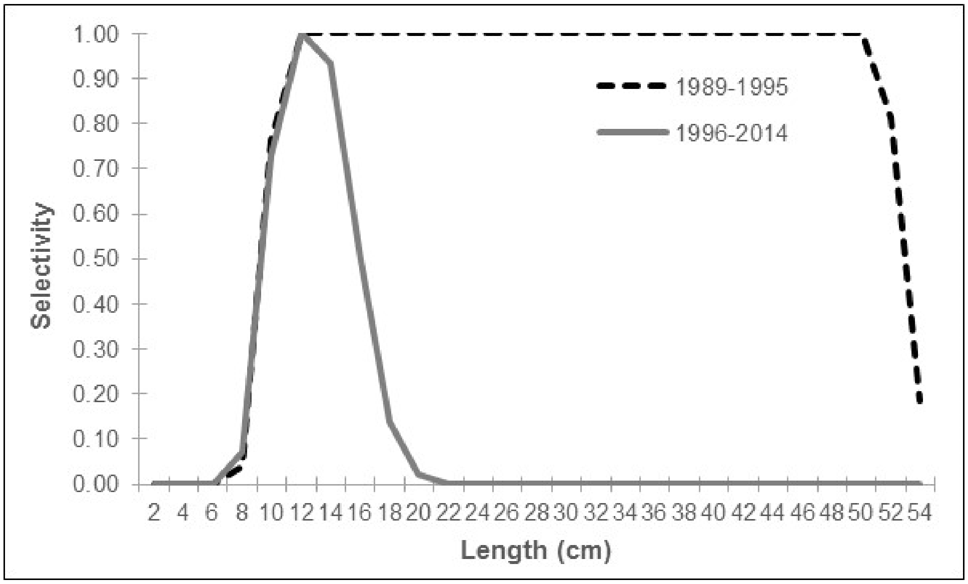

Figure 7.6. Predicted time-varying selectivity for the shrimp trawl fishery from preliminary runs.

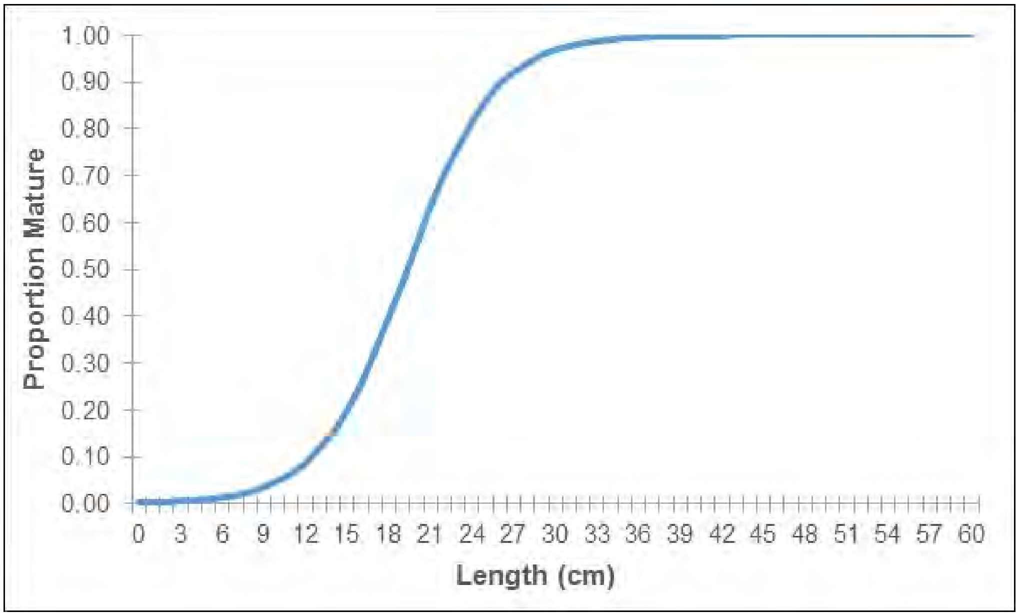

Figure 7.7. Predicted female maturity at length based on data collected by the ChesMMAP survey during August through November.

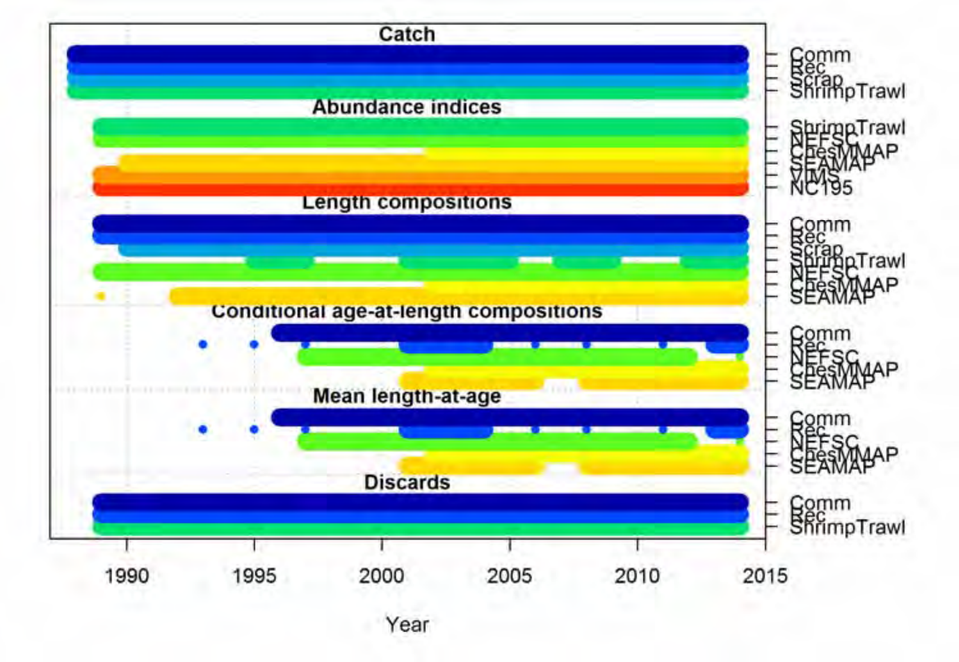

Figure 8.1. Summary of the data types available for the Atlantic croaker stock assessment model.

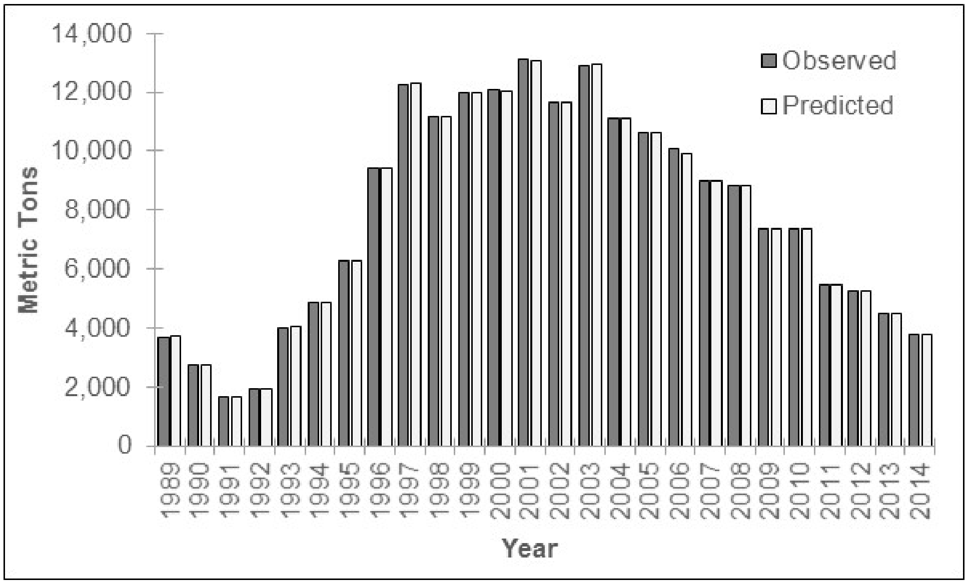

Figure 8.2. Observed and predicted commercial landings from the base run of the assessment model, 1989–2014.

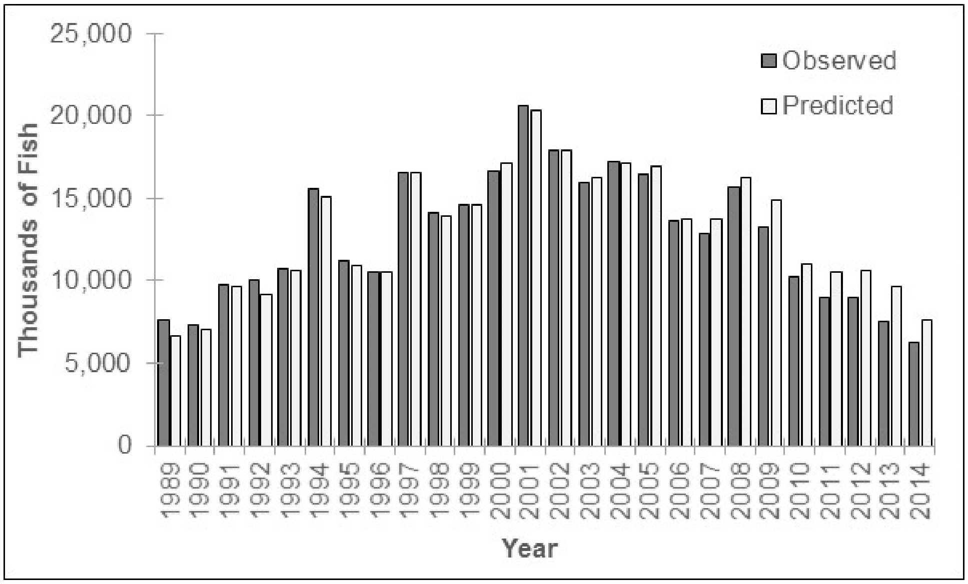

Figure 8.3. Observed and predicted recreational landings from the base run of the assessment model, 1989–2014.

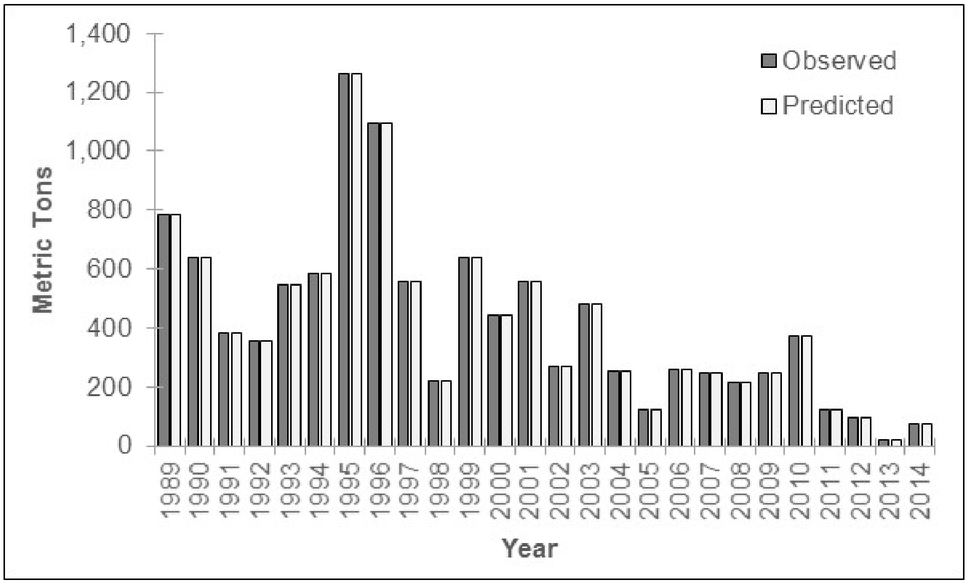

Figure 8.4. Observed and predicted scrap landings from the base run of the assessment model, 1989–2014.

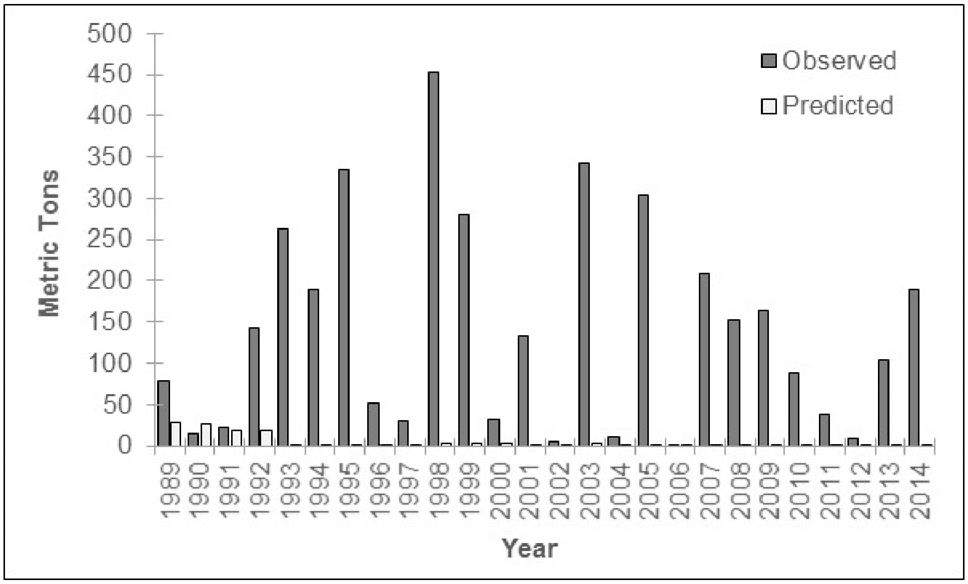

Figure 8.5. Observed and predicted commercial dead discards from the base run of the assessment model, 1989–2014.

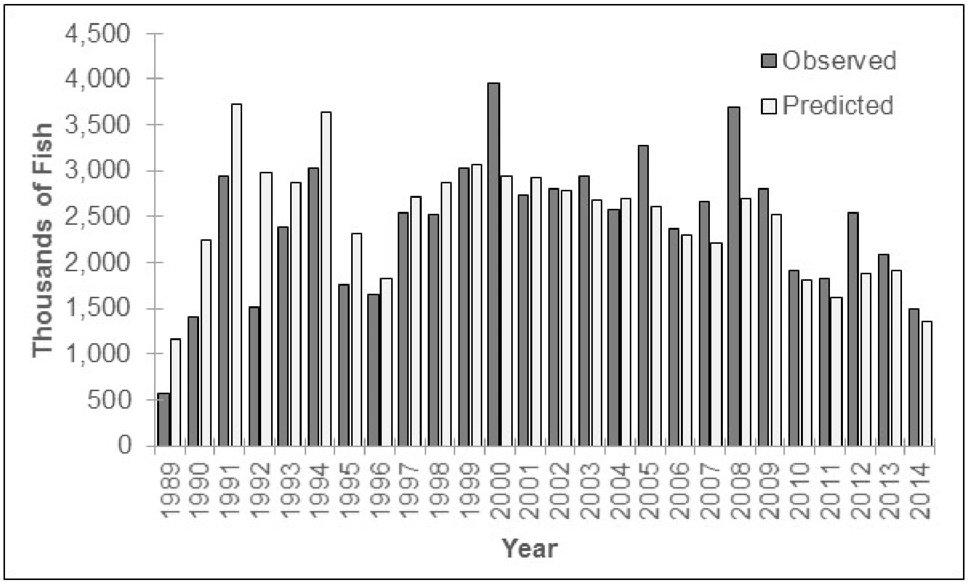

Figure 8.6. Observed and predicted recreational dead discards from the base run of the assessment model, 1989–2014.

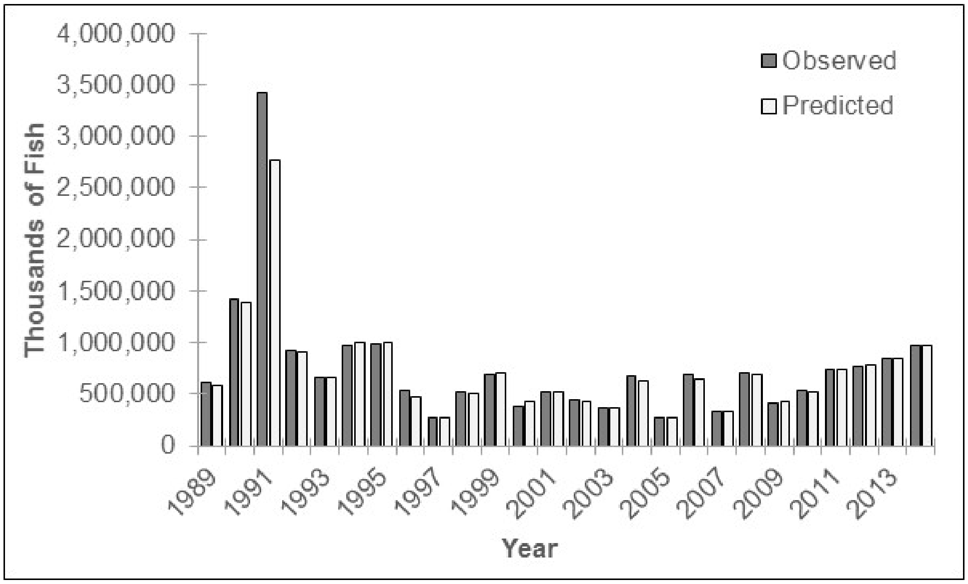

Figure 8.7. Observed and predicted shrimp trawl dead bycatch from the base run of the assessment model, 1989–2014.

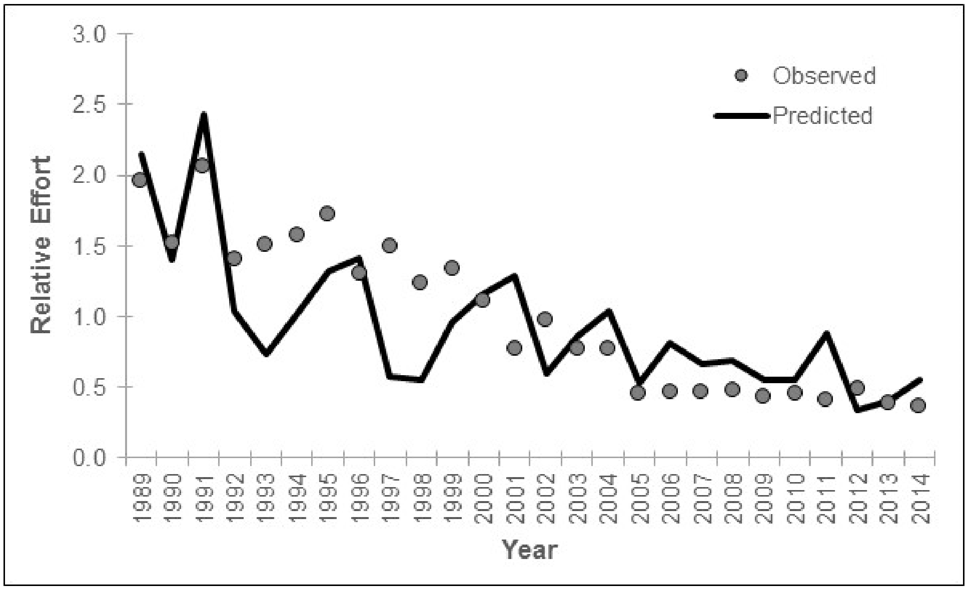

Figure 8.8. Observed and predicted shrimp trawl relative effort from the base run of the assessment model, 1989–2014.

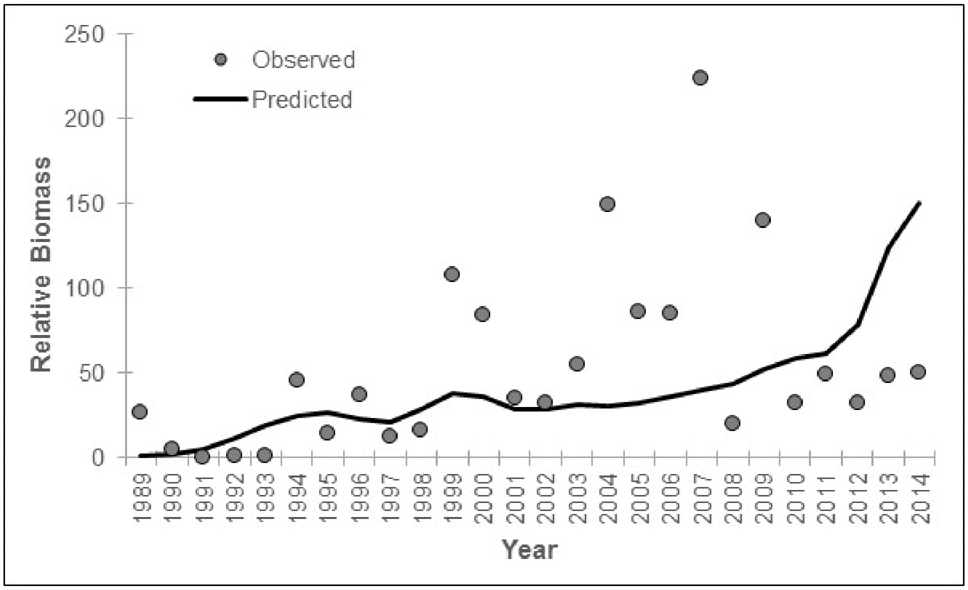

Figure 8.9. Observed and predicted NMFS survey relative biomass from the base run of the assessment model, 1989–2014.

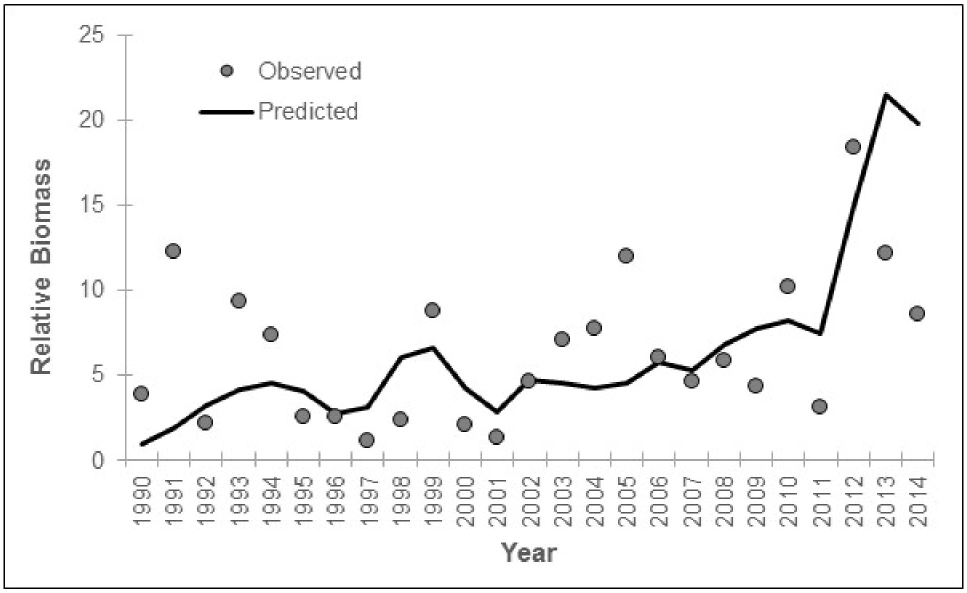

Figure 8.10. Observed and predicted SEAMAP survey relative biomass from the base run of the assessment model, 1989–2014.

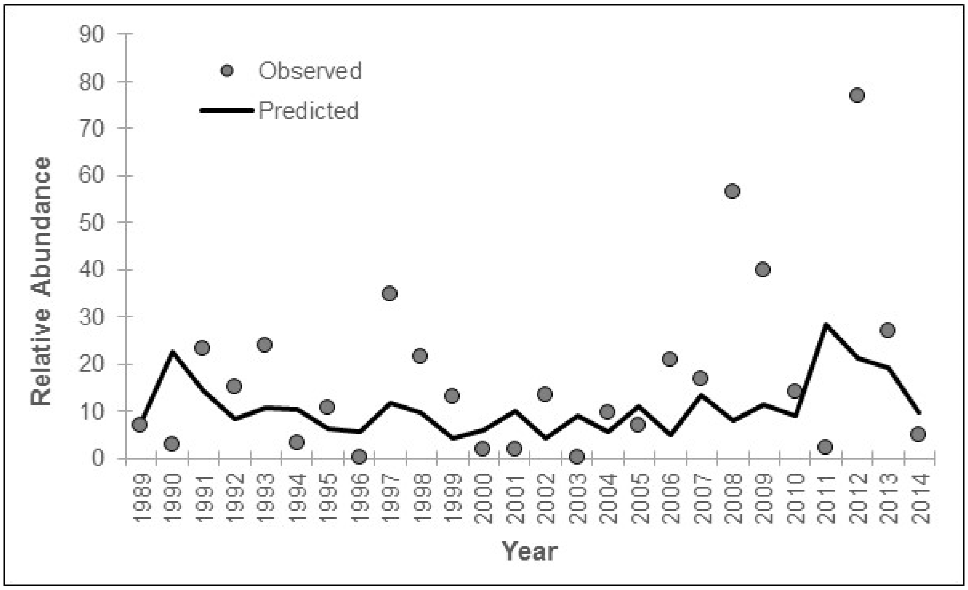

Figure 8.11. Observed and predicted VIMS survey relative abundance of age-0 recruits from the base run of the assessment model, 1989–2014.

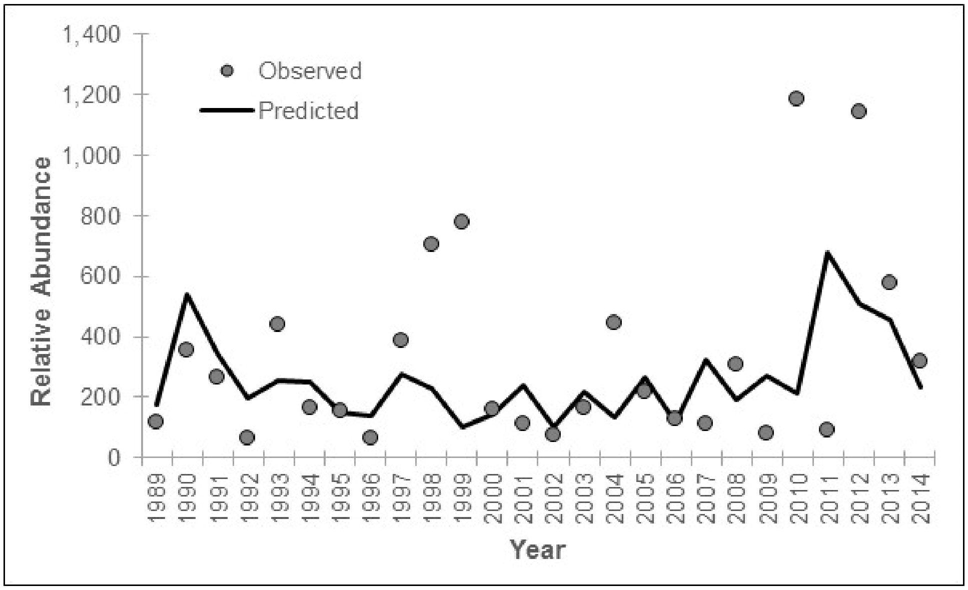

Figure 8.12. Observed and predicted NC195 survey relative abundance of age-0 recruits from the base run of the assessment model, 1989–2014.

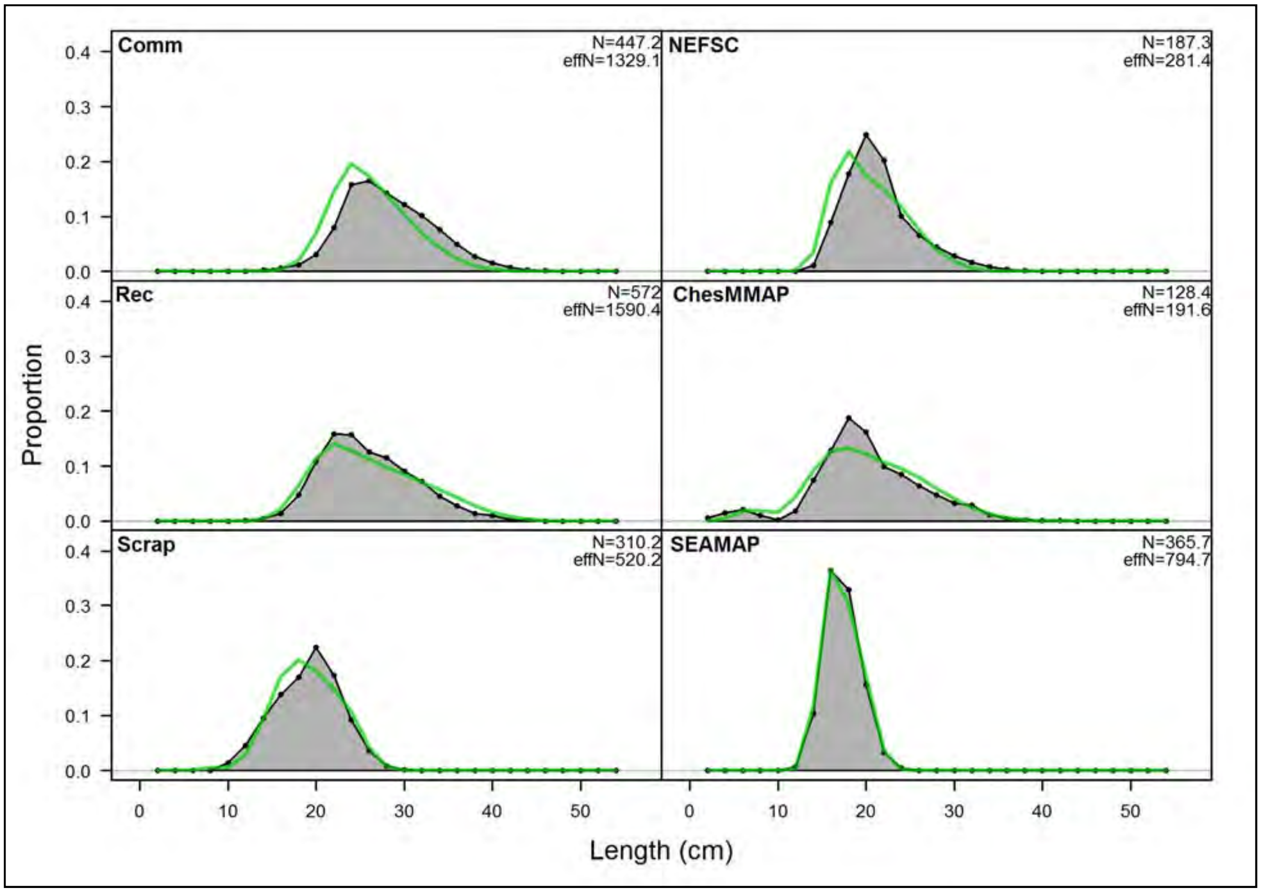

Figure 8.13. Observed and predicted length distributions for landings and survey catches from the base run of the assessment model aggregated across time by fleet and survey.

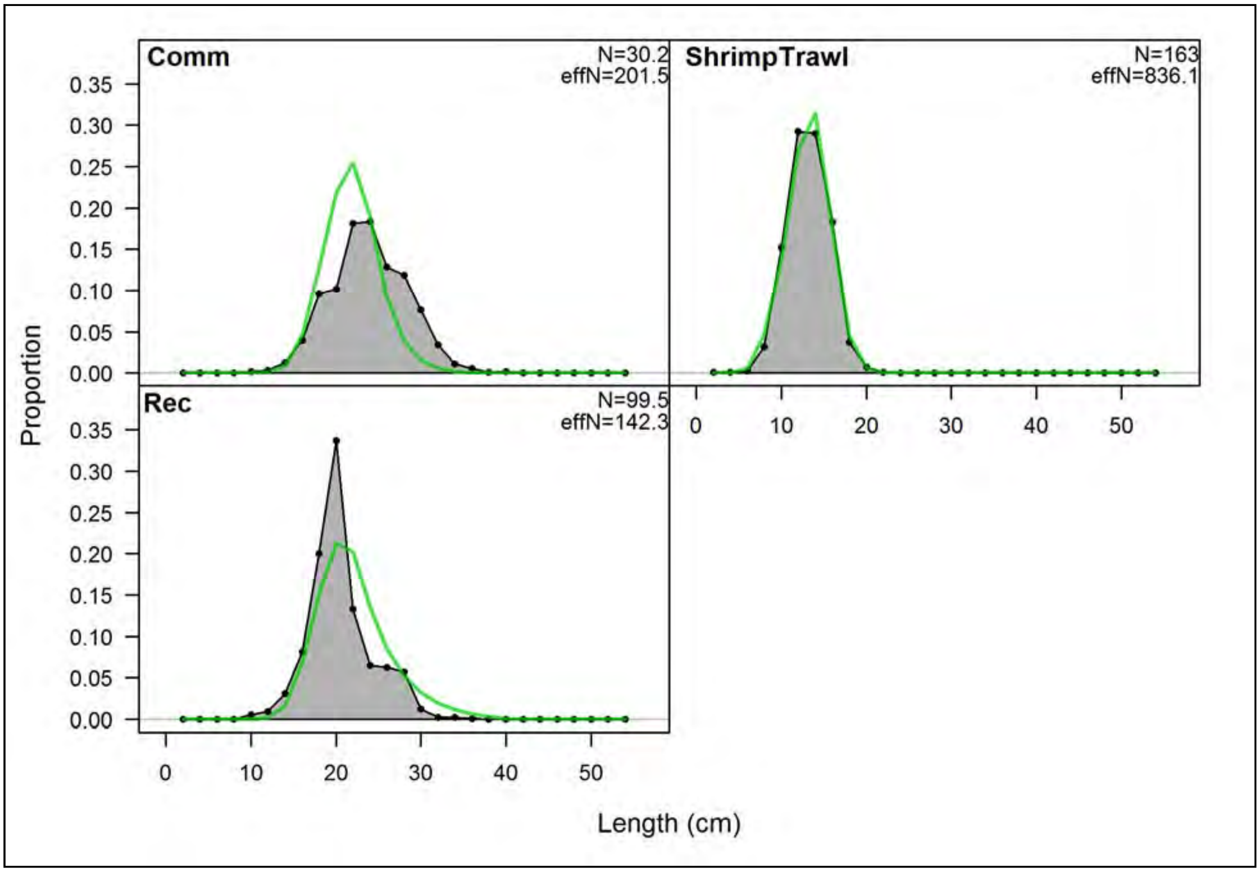

Figure 8.14. Observed and predicted length distributions for discards from the base run of the assessment model aggregated across time by fleet.

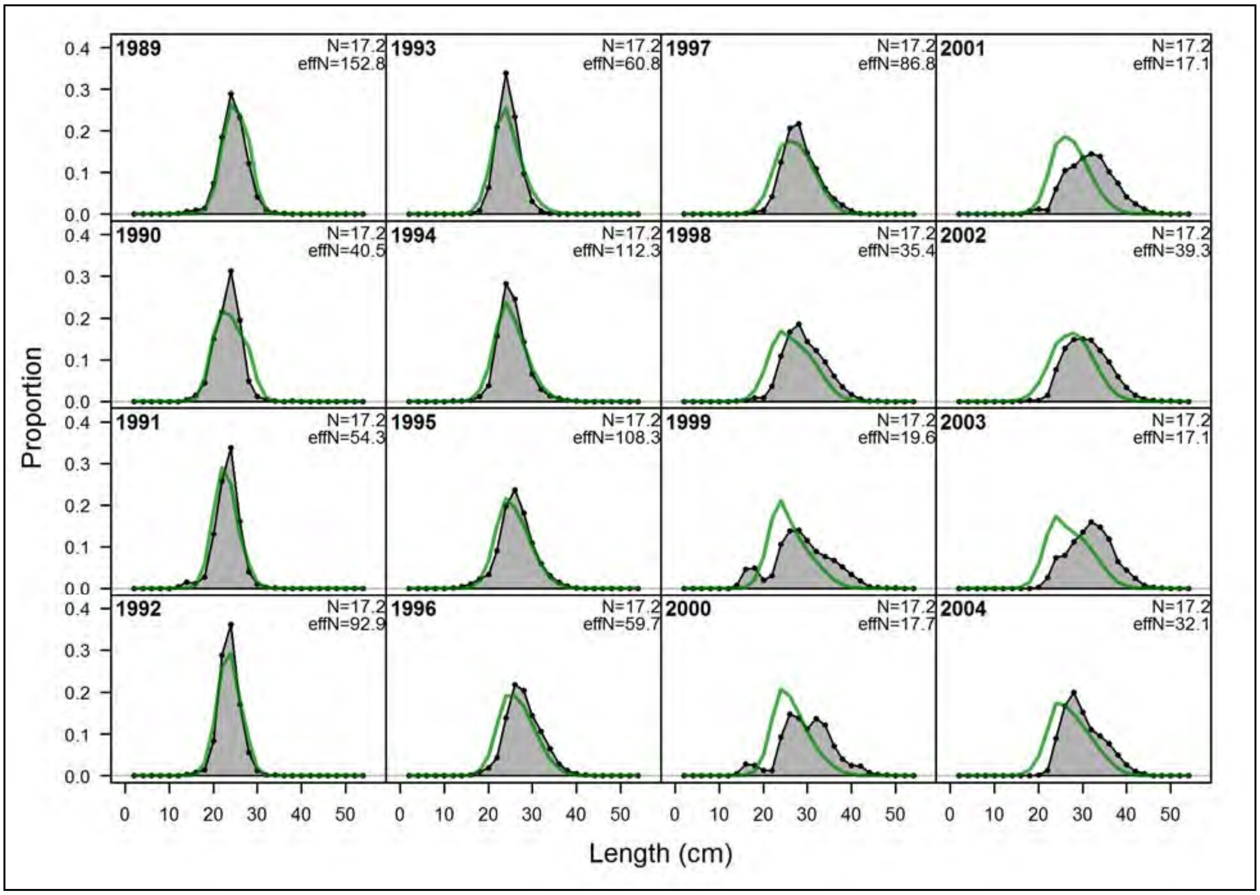

Figure 8.15. Observed and predicted length distributions for the commercial landings from the base run of the assessment model, 1989–2004.

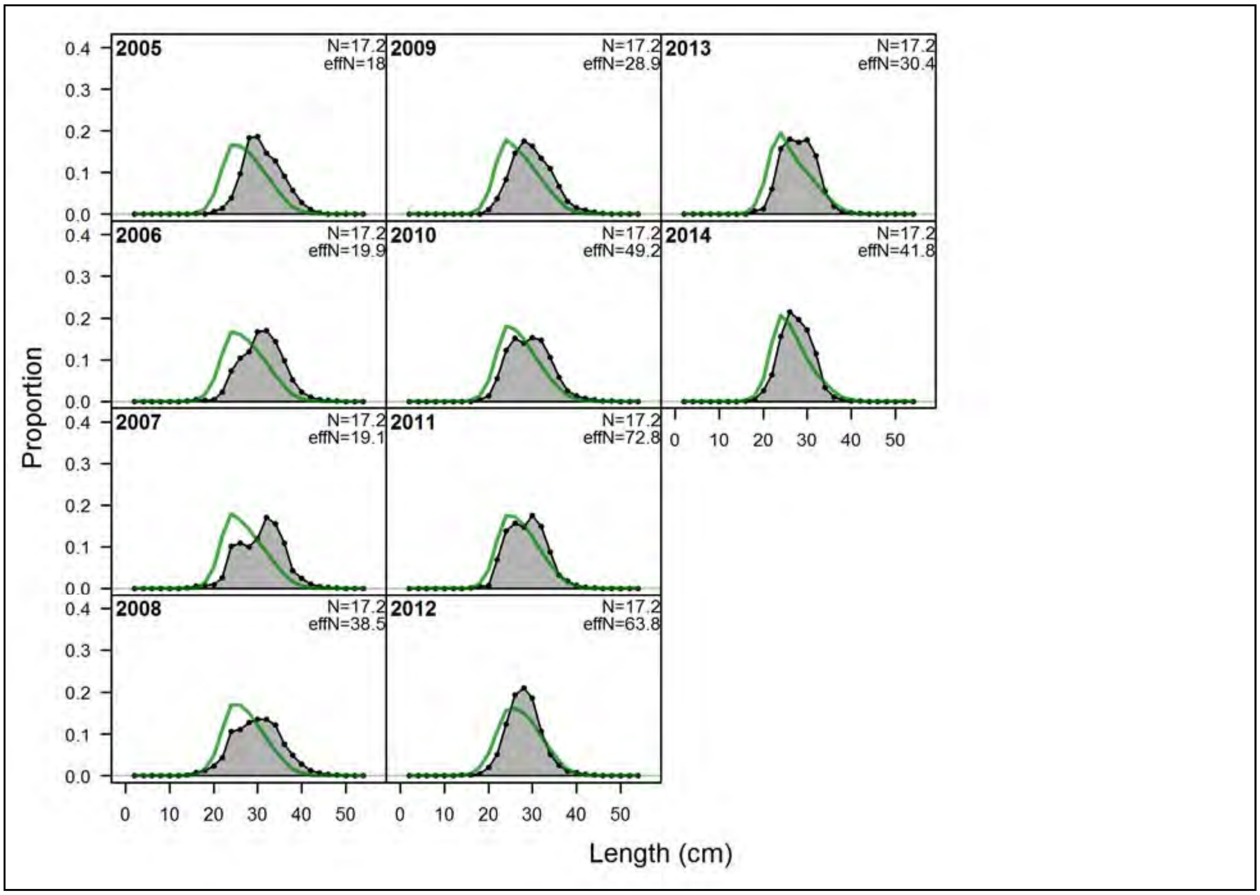

Figure 8.16. Observed and predicted length distributions for the commercial landings from the base run of the assessment model, 2005–2014.

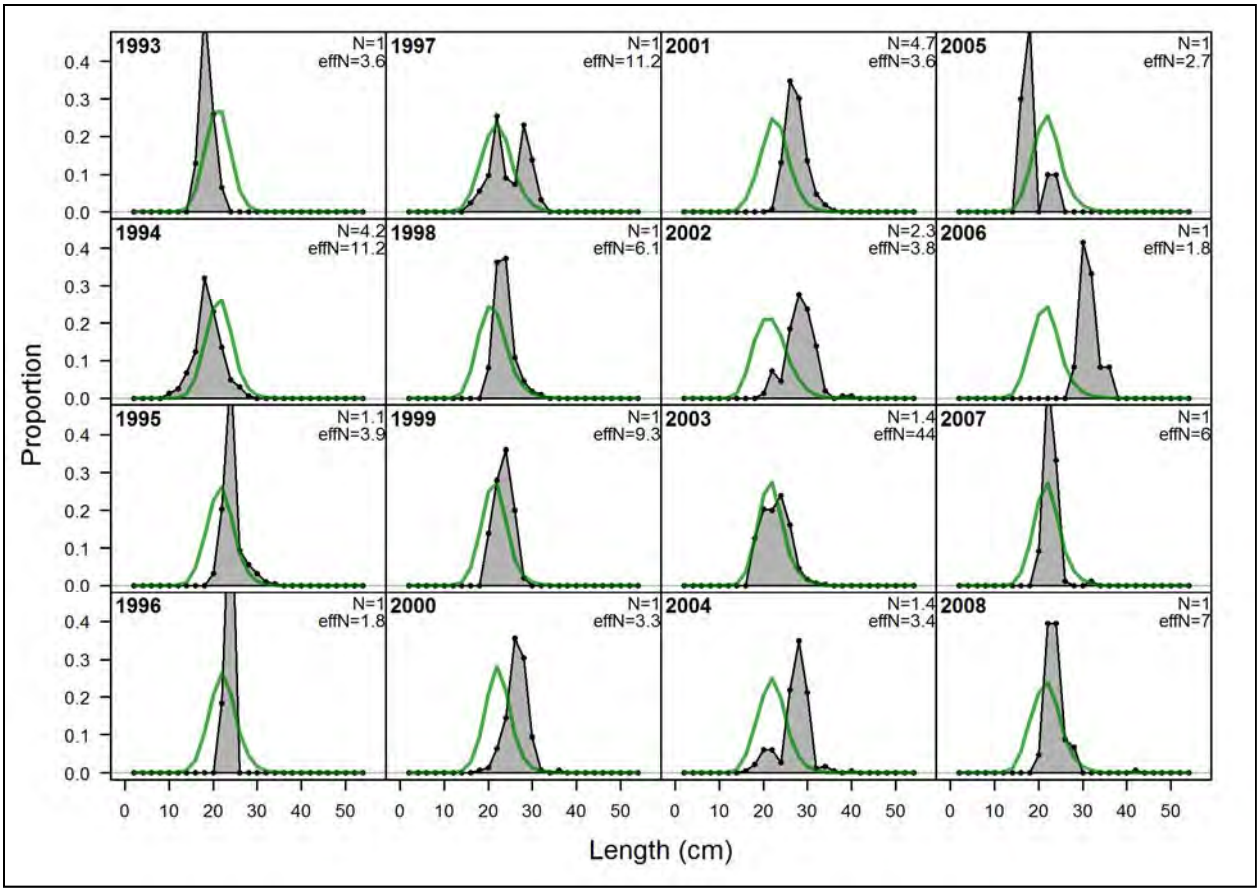

Figure 8.17. Observed and predicted length distributions for the commercial discards from the base run of the assessment model, 1993–2008.

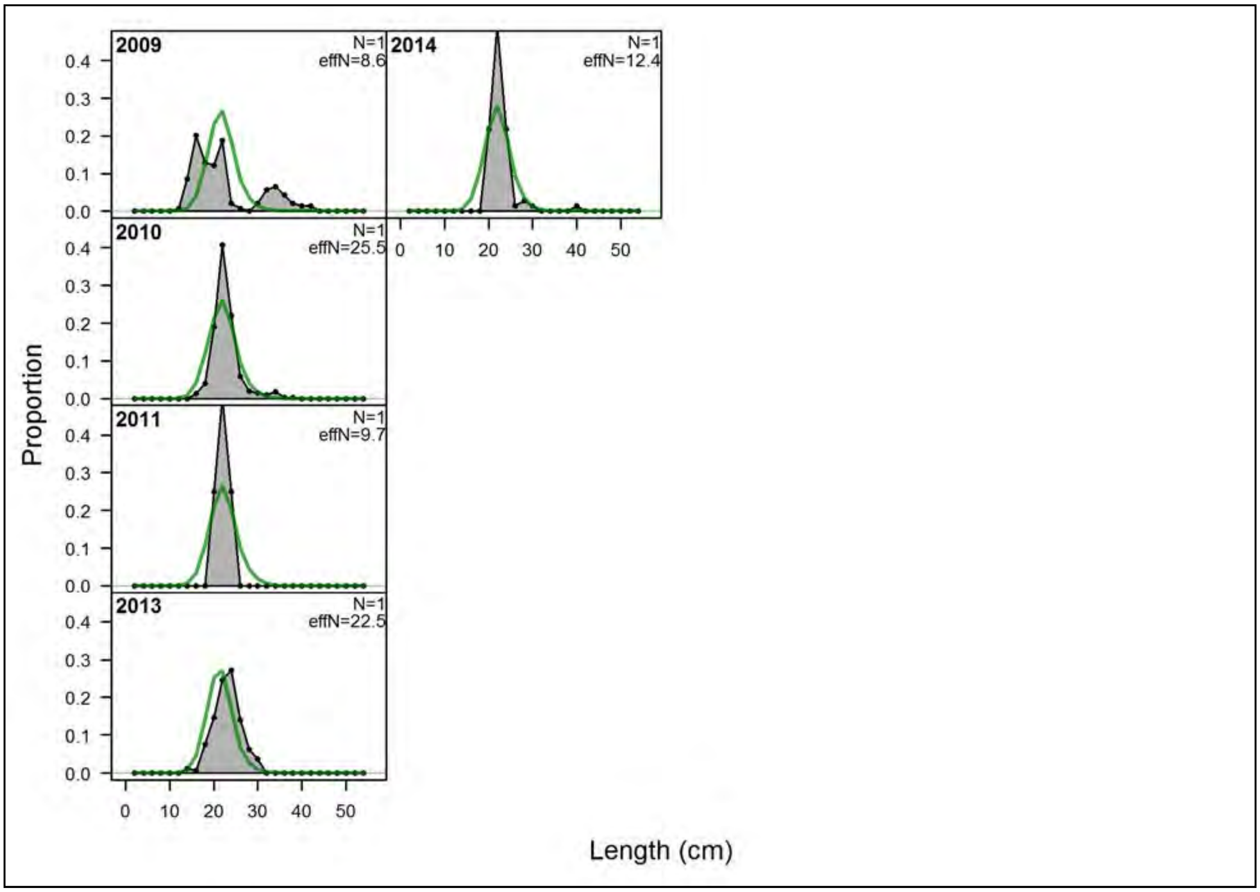

Figure 8.18. Observed and predicted length distributions for the commercial discards from the base run of the assessment model, 2009–2014.

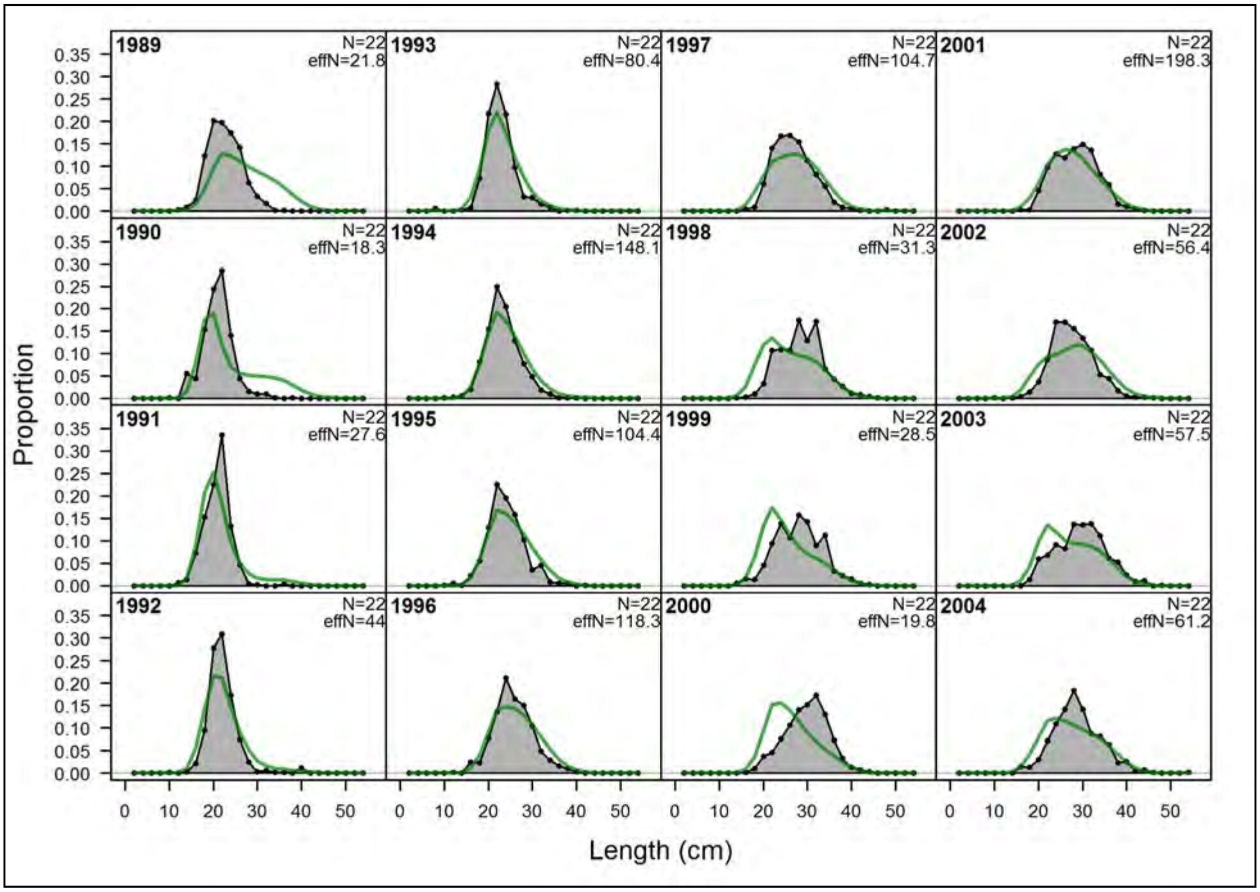

Figure 8.19. Observed and predicted length distributions for the recreational landings from the base run of the assessment model, 1989–2004.

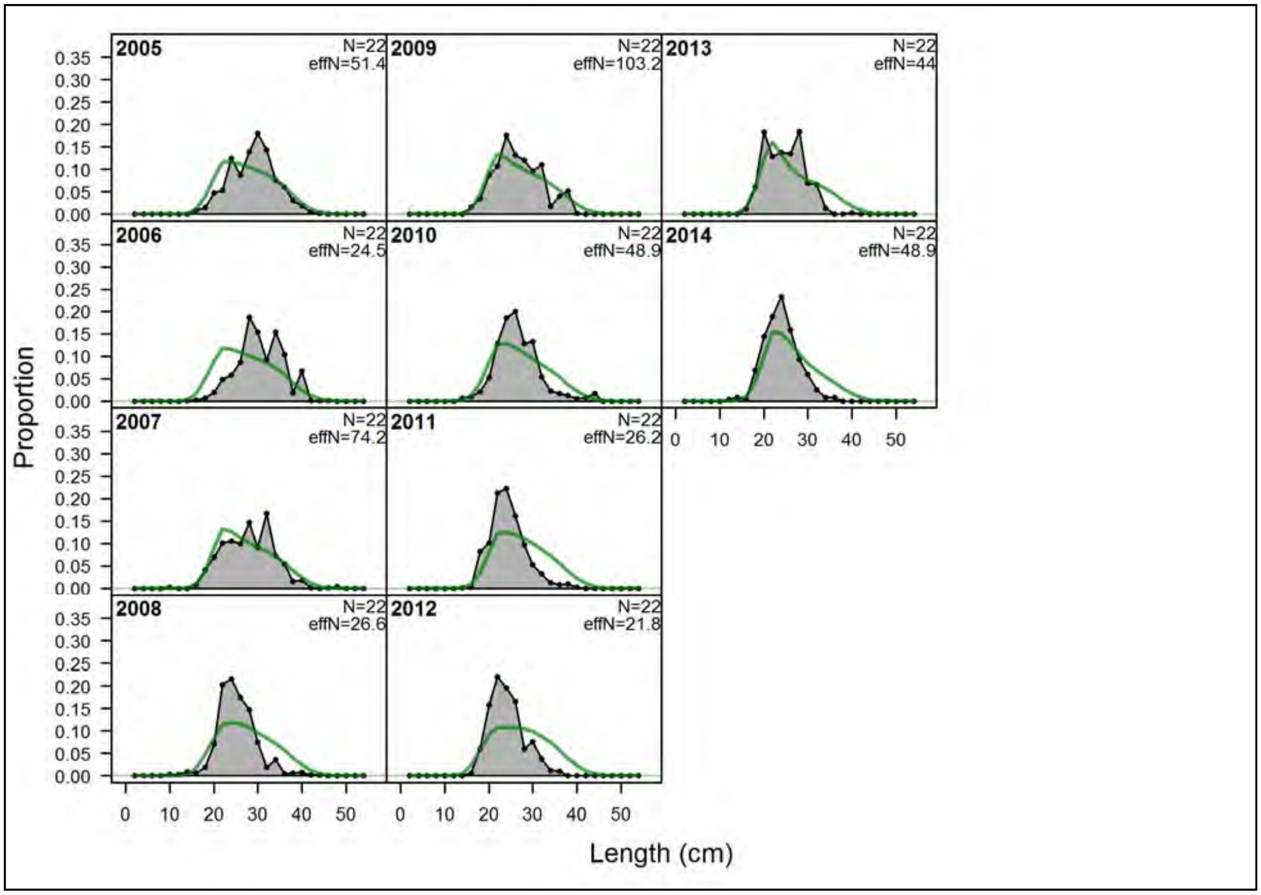

Figure 8.20. Observed and predicted length distributions for the recreational landings from the base run of the assessment model, 2005–2014.

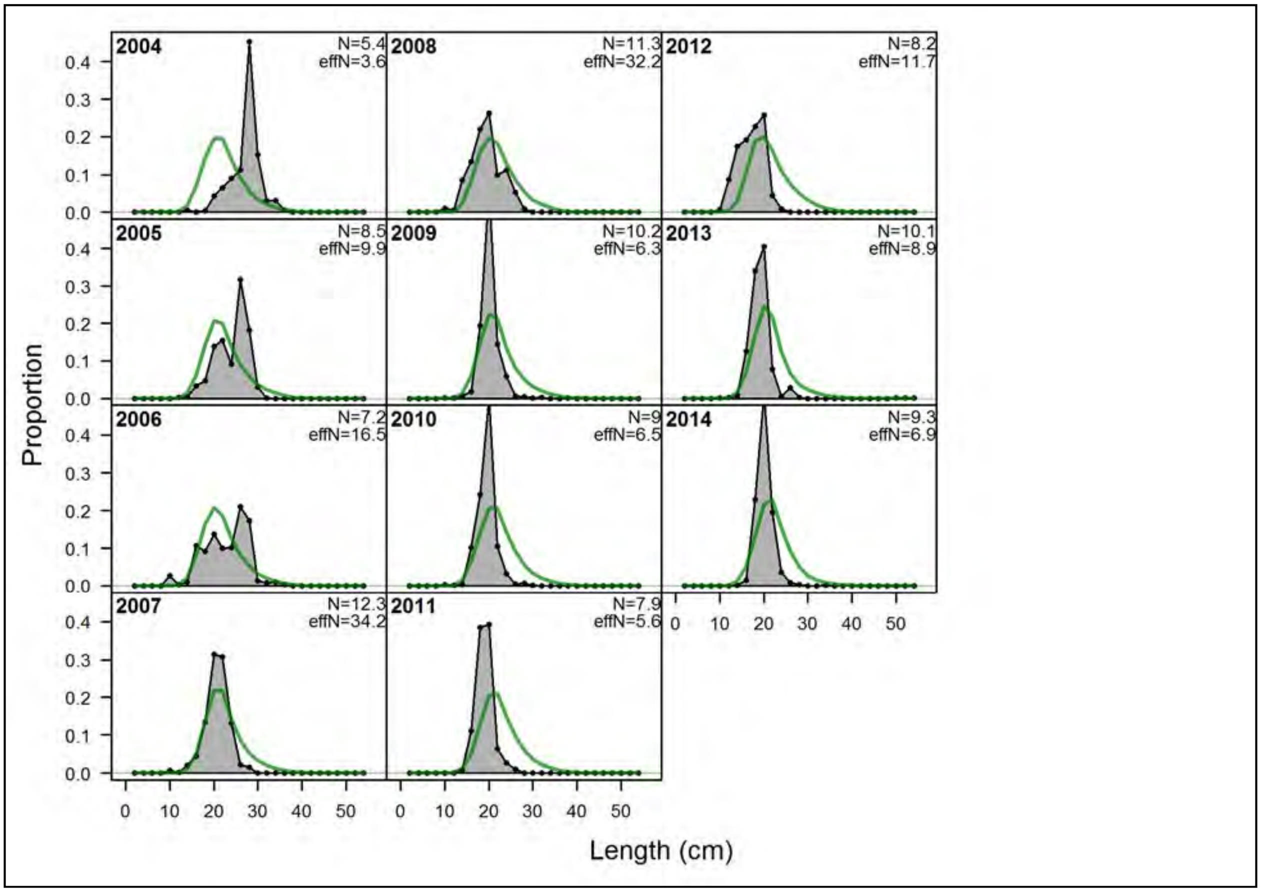

Figure 8.21. Observed and predicted length distributions for the recreational discards from the base run of the assessment model, 2004–2014.

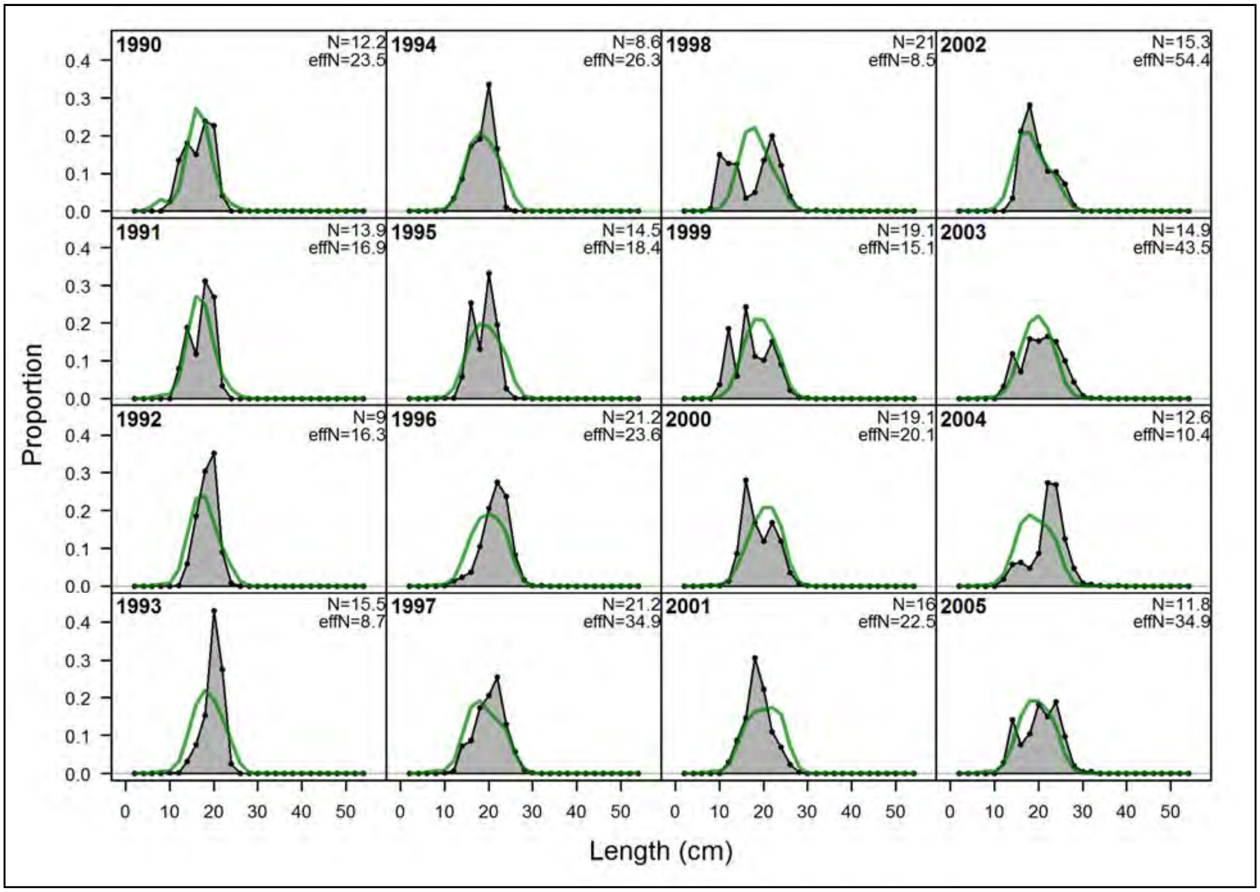

Figure 8.22. Observed and predicted length distributions for the scrap landings from the base run of the assessment model, 1990–2005.

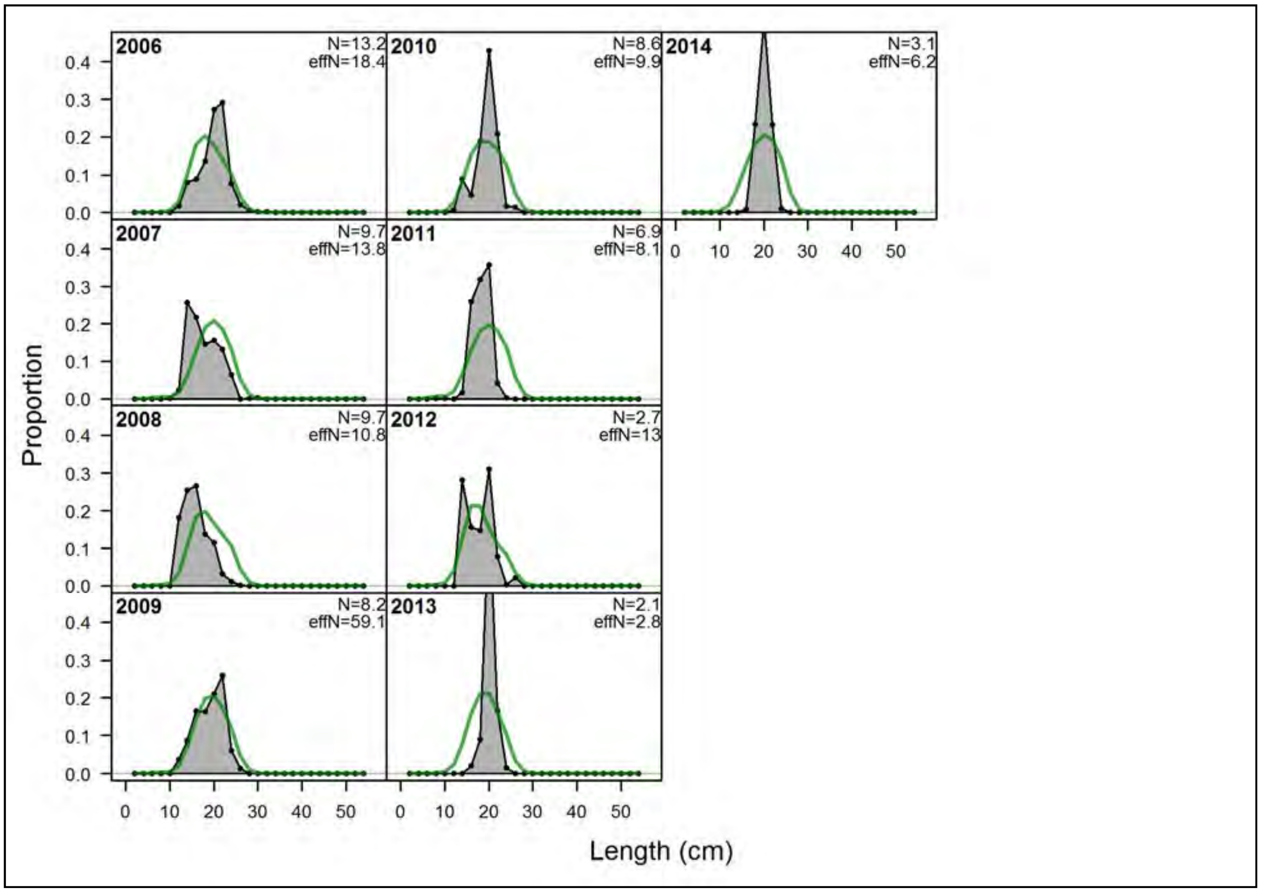

Figure 8.23. Observed and predicted length distributions for the scrap landings from the base run of the assessment model, 2006–2014.

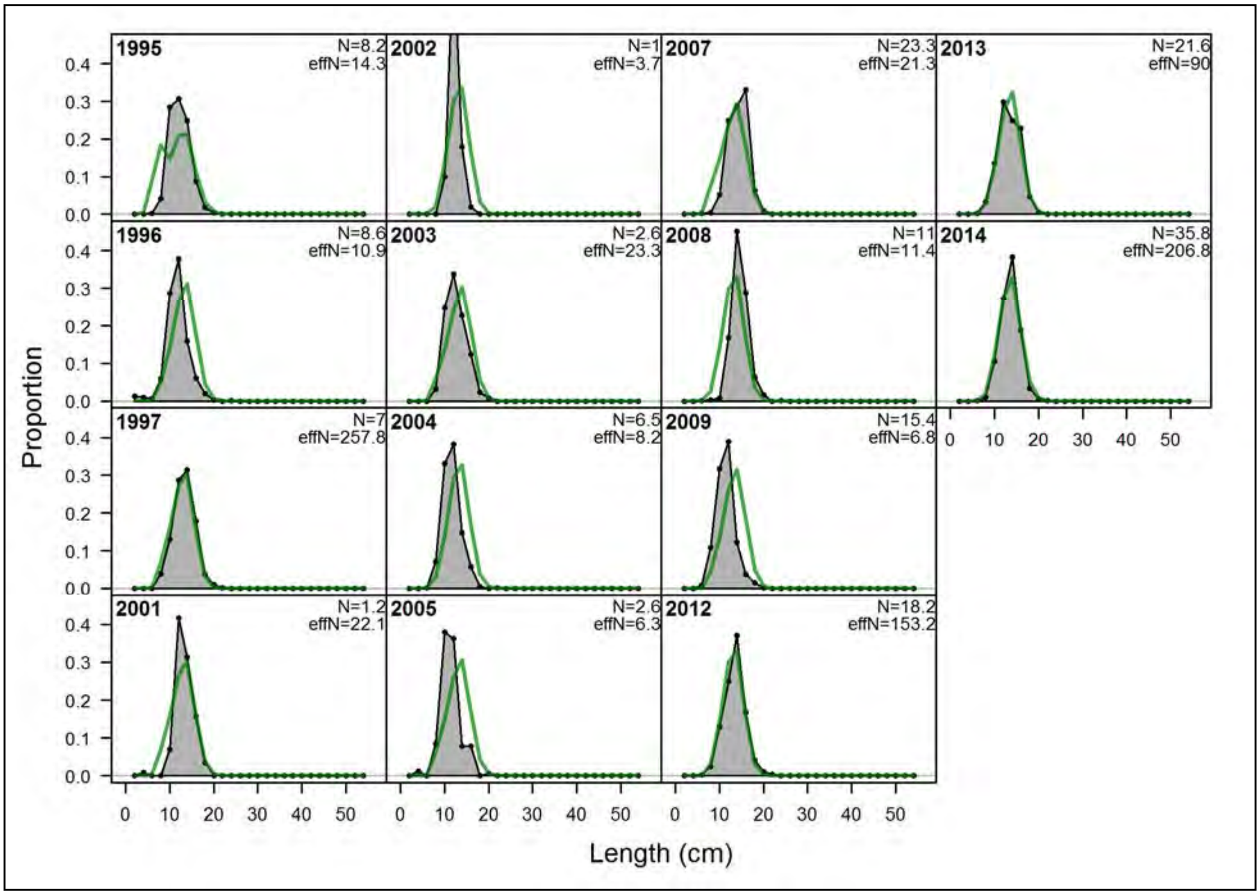

Figure 8.24. Observed and predicted length distributions for the shrimp trawl bycatch from the base run of the assessment model, 1995–2014.

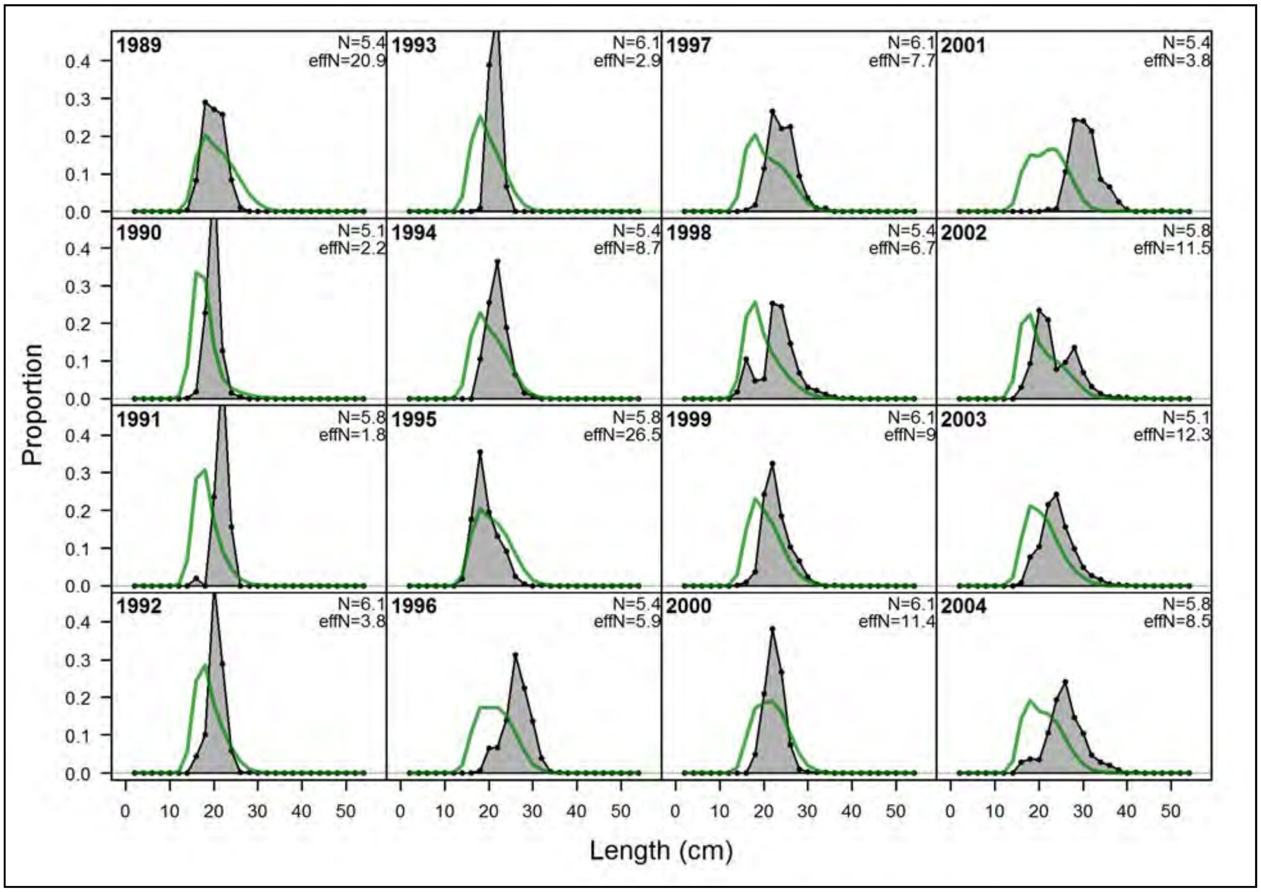

Figure 8.25. Observed and predicted length distributions for the NEFSC survey from the base run of the assessment model, 1989–2004.

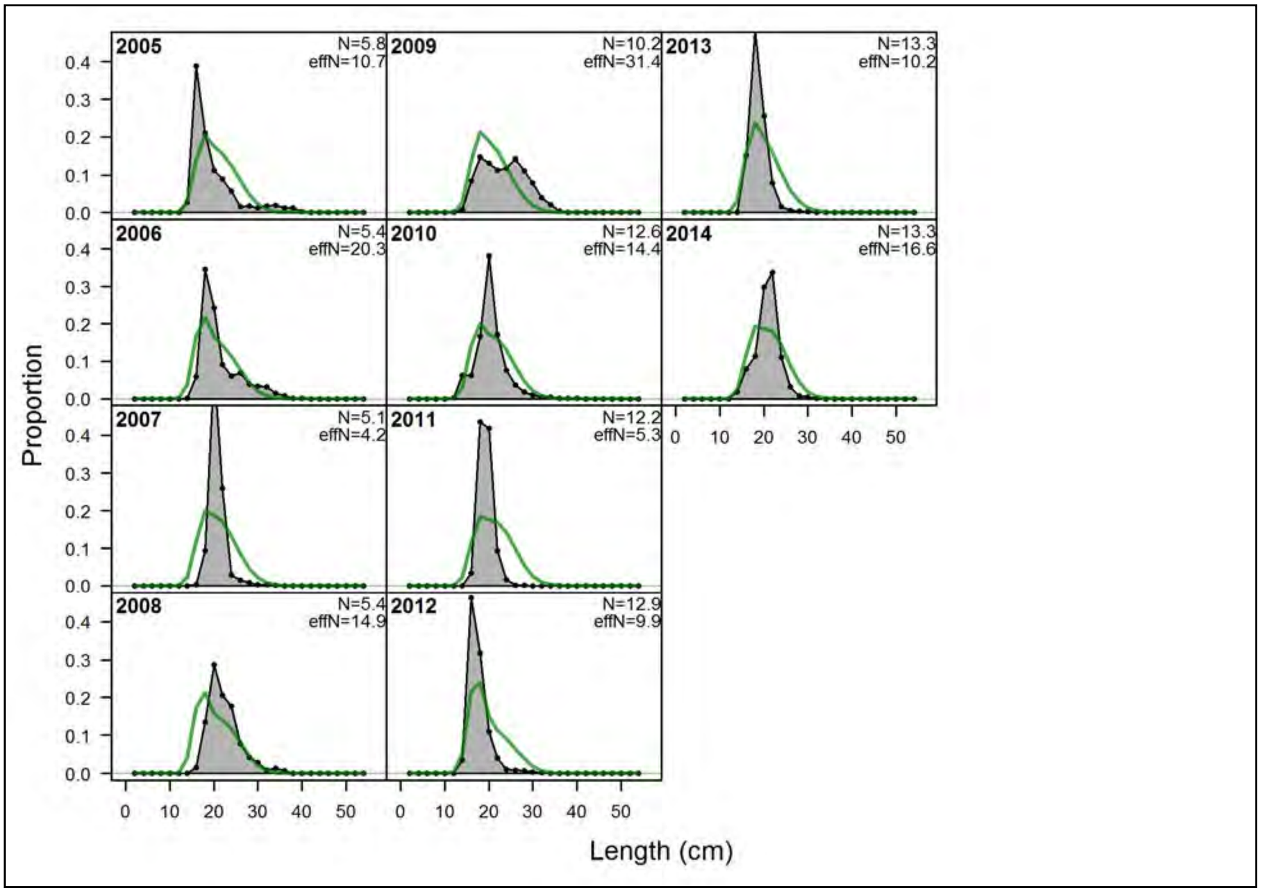

Figure 8.26. Observed and predicted length distributions for the NEFSC survey from the base run of the assessment model, 2005–2014.

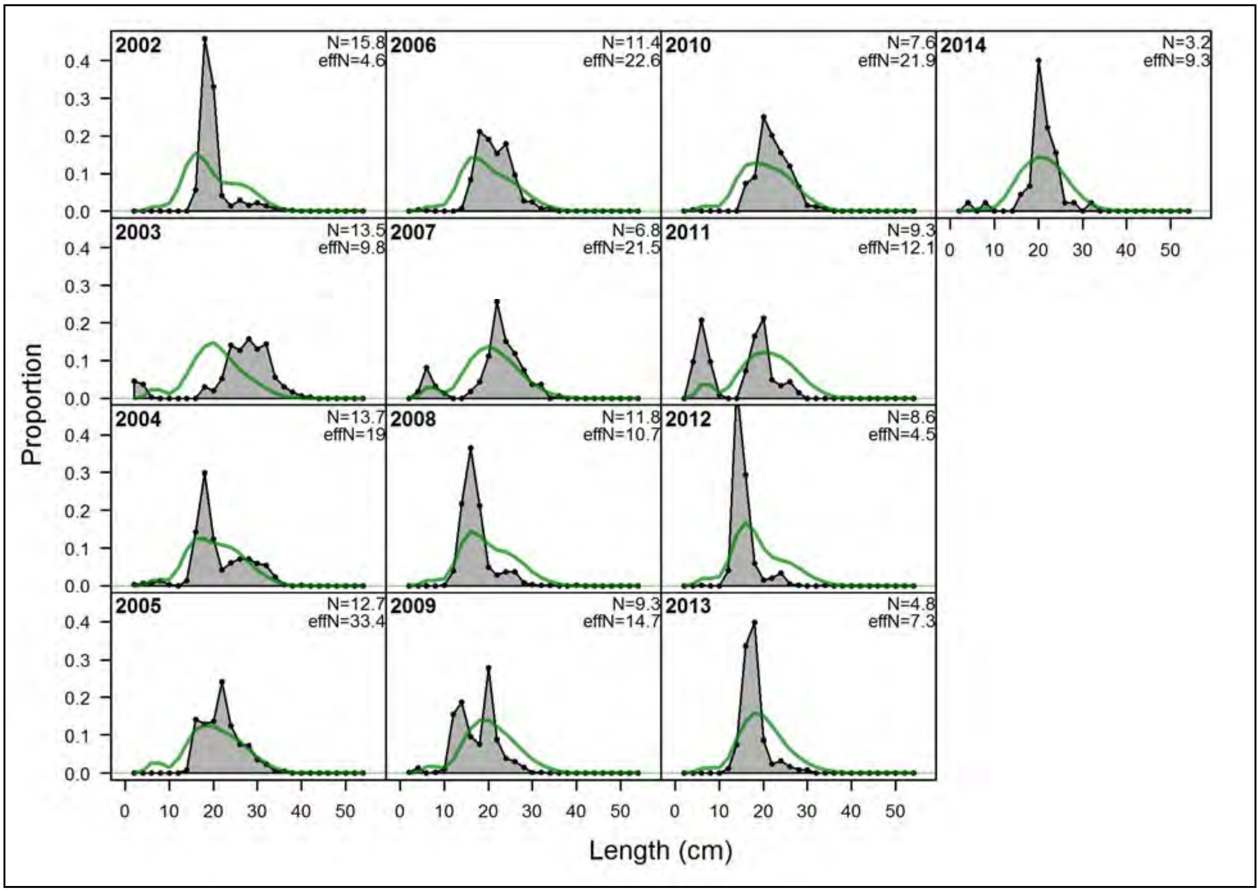

Figure 8.27. Observed and predicted length distributions for the ChesMMAP survey from the base run of the assessment model, 2002–2014.

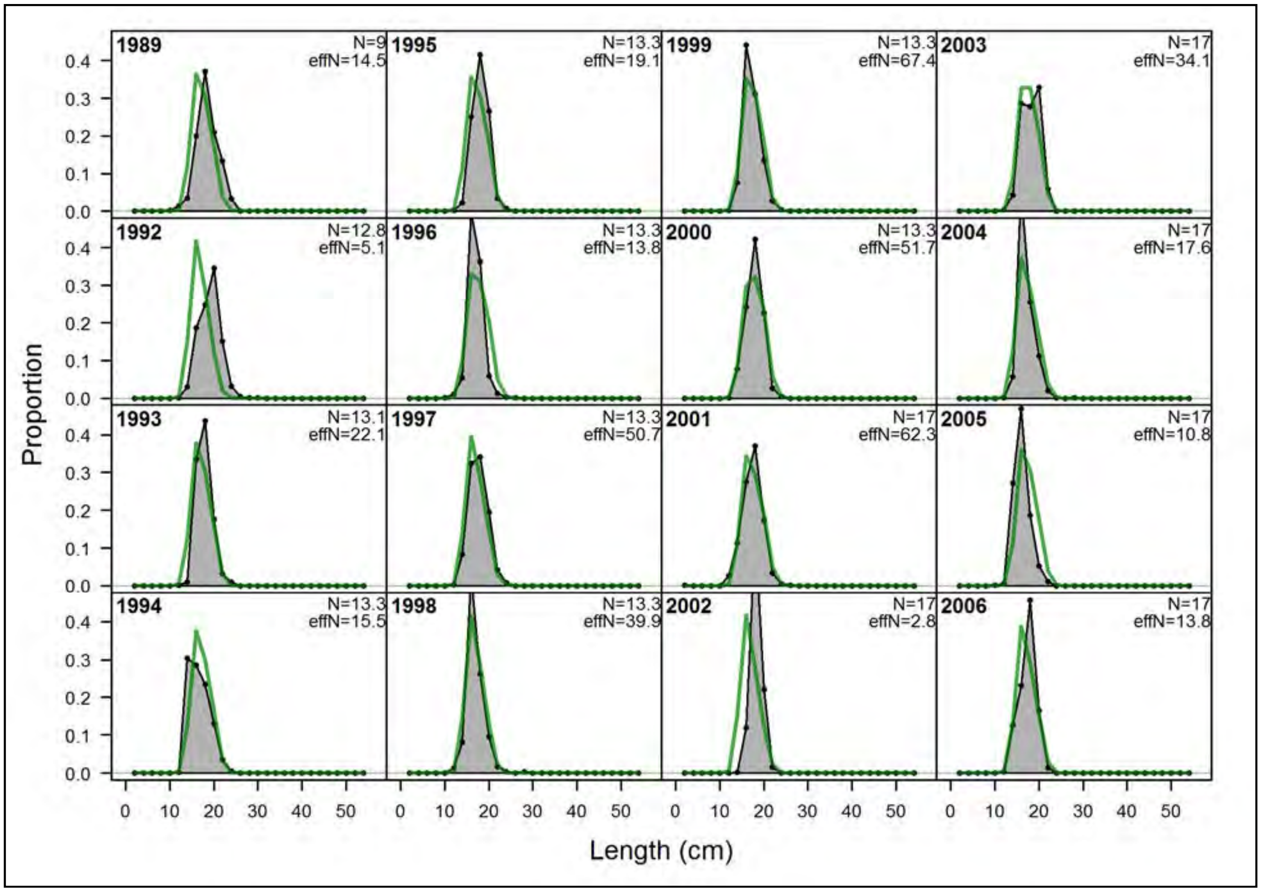

Figure 8.28. Observed and predicted length distributions for the SEAMAP survey from the base run of the assessment model, 1989–2006.

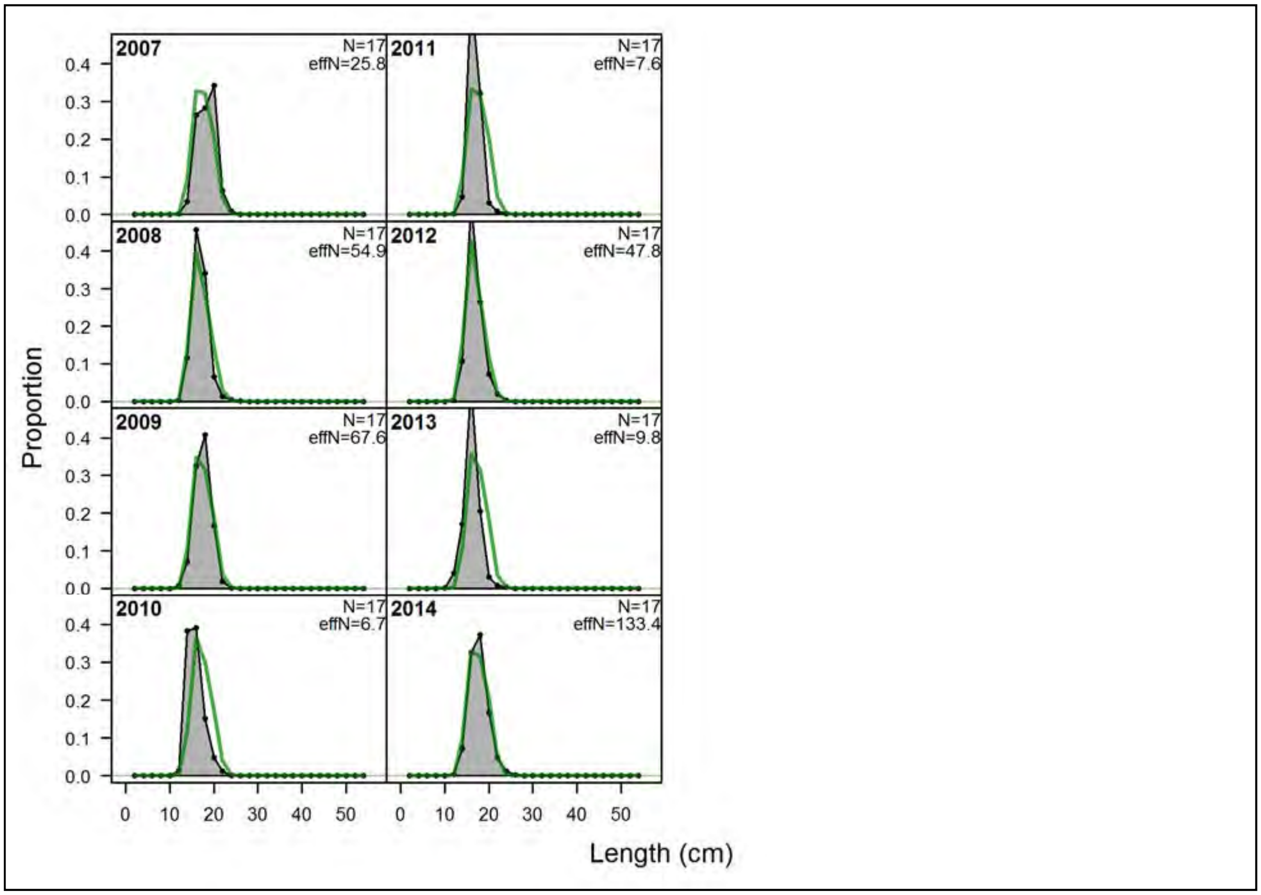

Figure 8.29. Observed and predicted length distributions for the SEAMAP survey from the base run of the assessment model, 2007–2014.

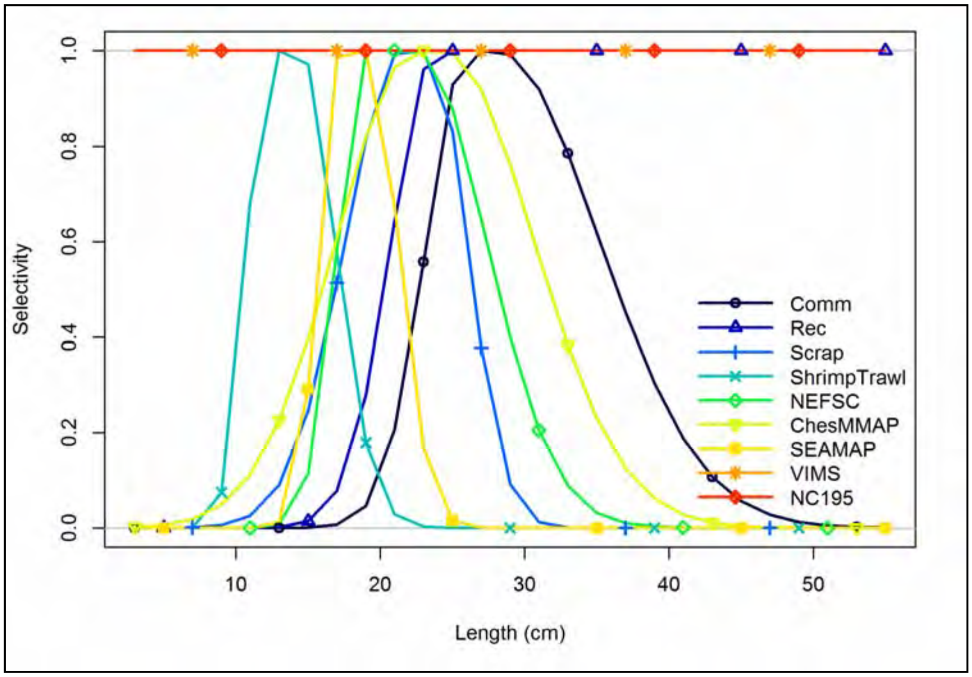

Figure 8.30. Predicted length-based selectivity by fleet in 2014.

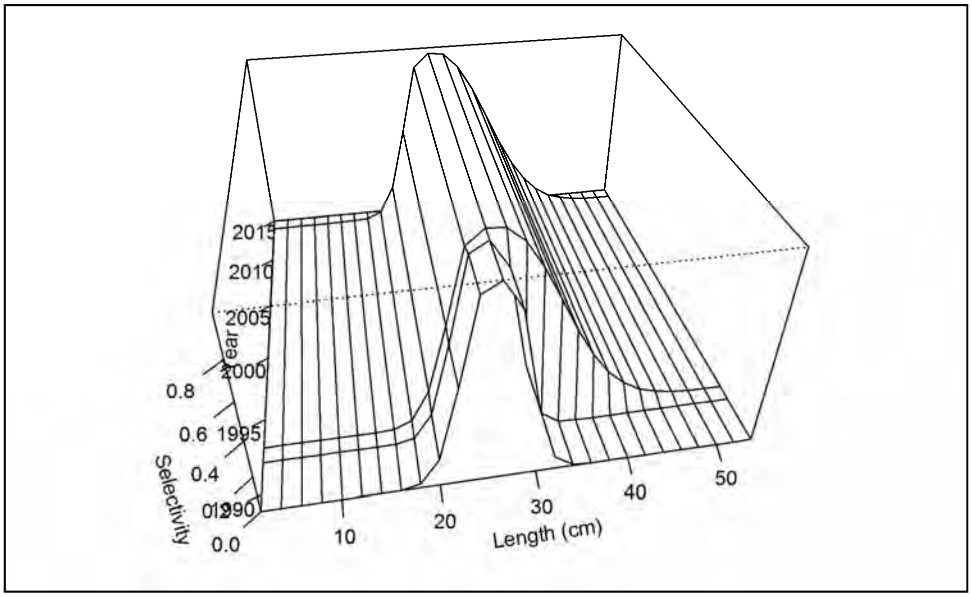

Figure 8.31. Predicted time-varying selectivity for the commercial fishery. The selectivity curve for the second time block (1993–2014) was fixed to a dome shape.

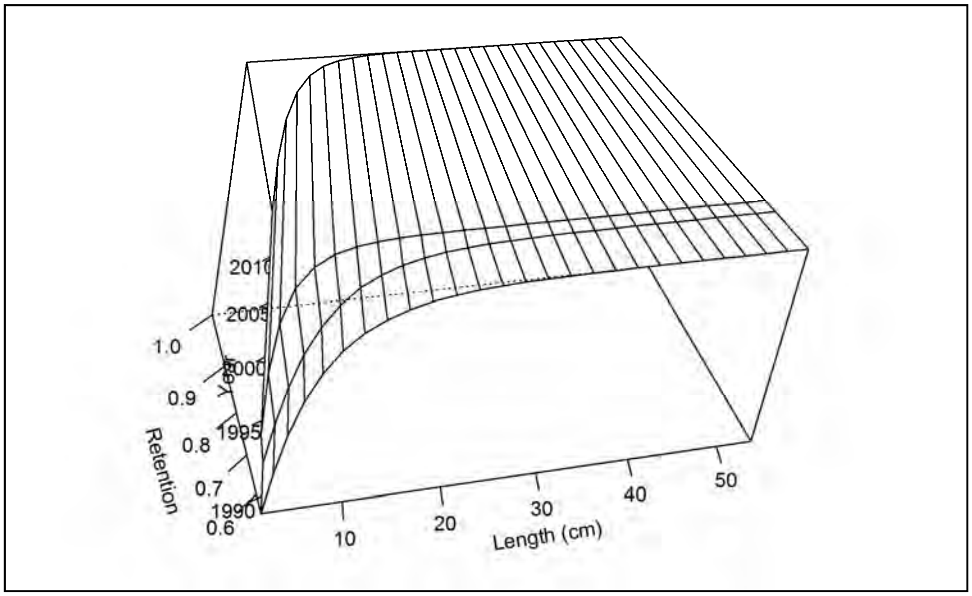

Figure 8.32. Predicted time-varying retention for the commercial fishery.

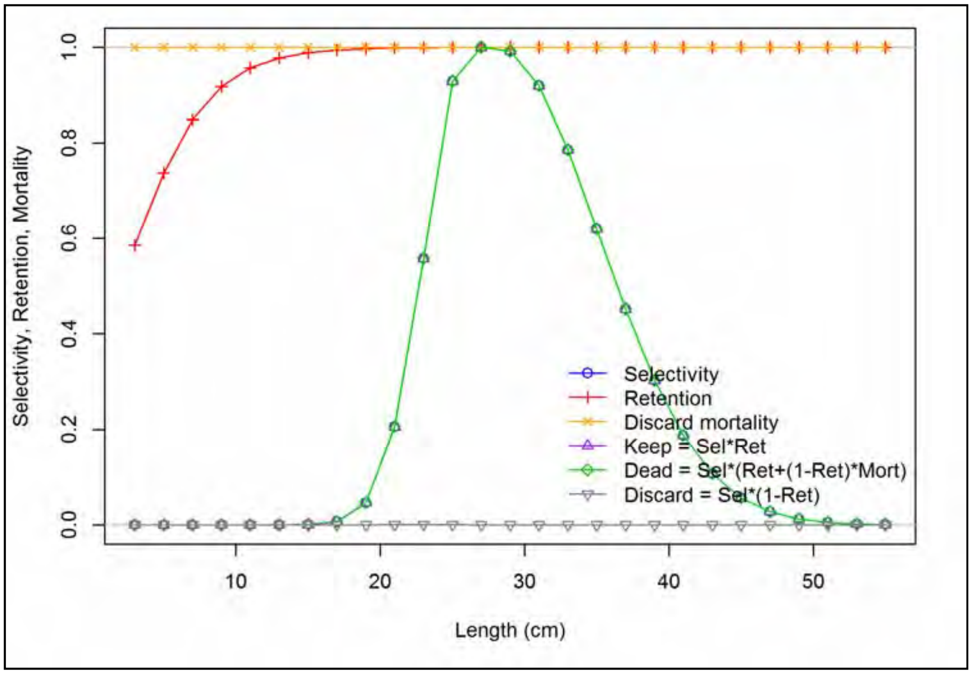

Figure 8.33. Predicted terminal year (2014) selectivity, retention, and discard mortality for the commercial fishery.

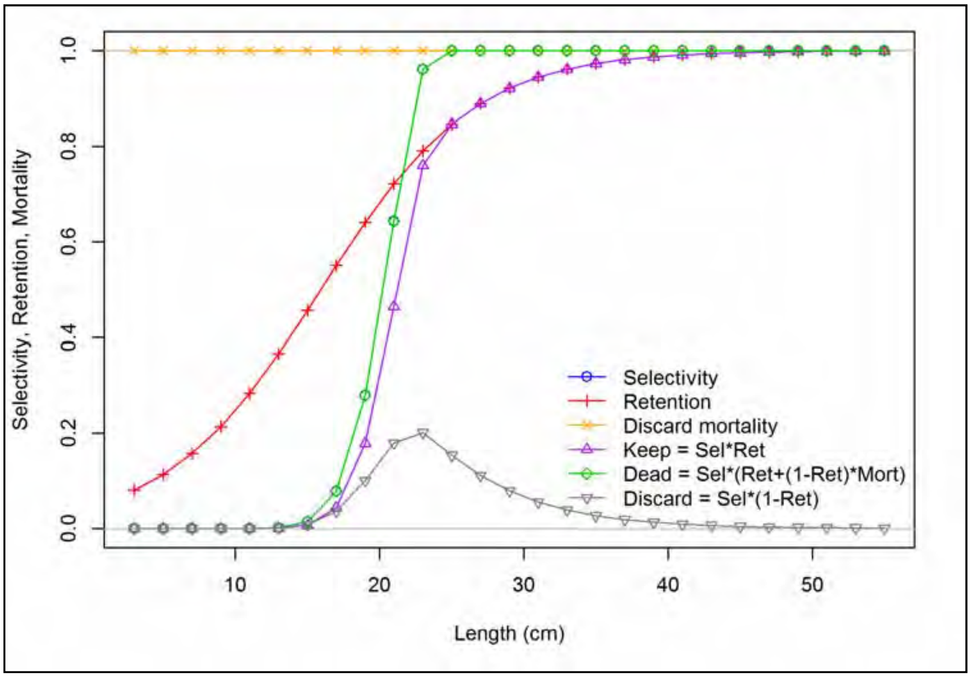

Figure 8.34. Predicted terminal year (2014) selectivity, retention, and discard mortality for the recreational fishery. The selectivity curve was assumed to be asymptotic.

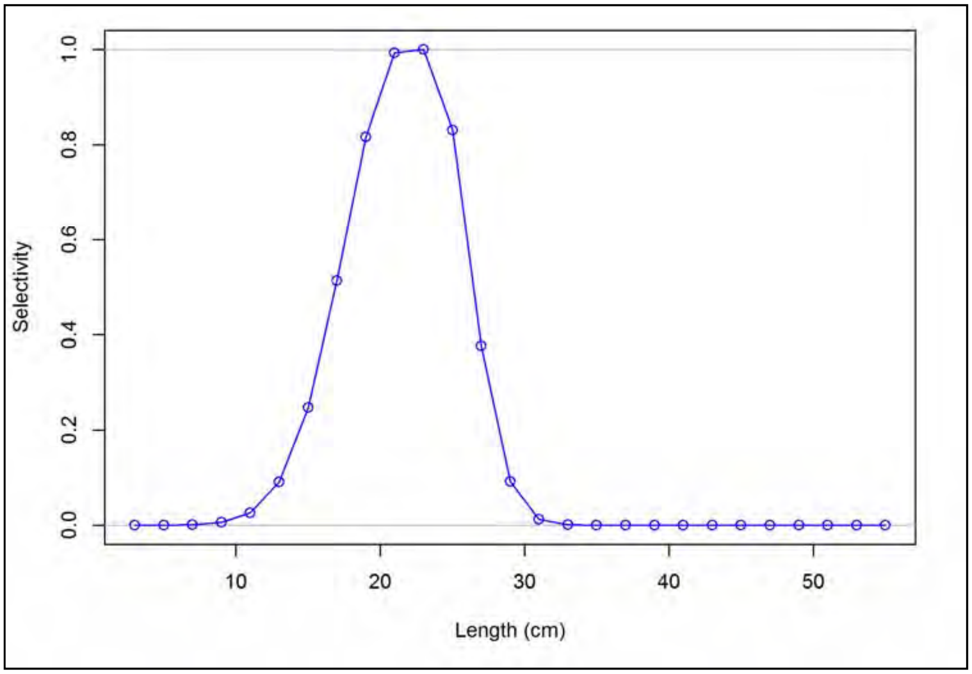

Figure 8.35. Predicted terminal year (2014) selectivity for the scrap fishery.

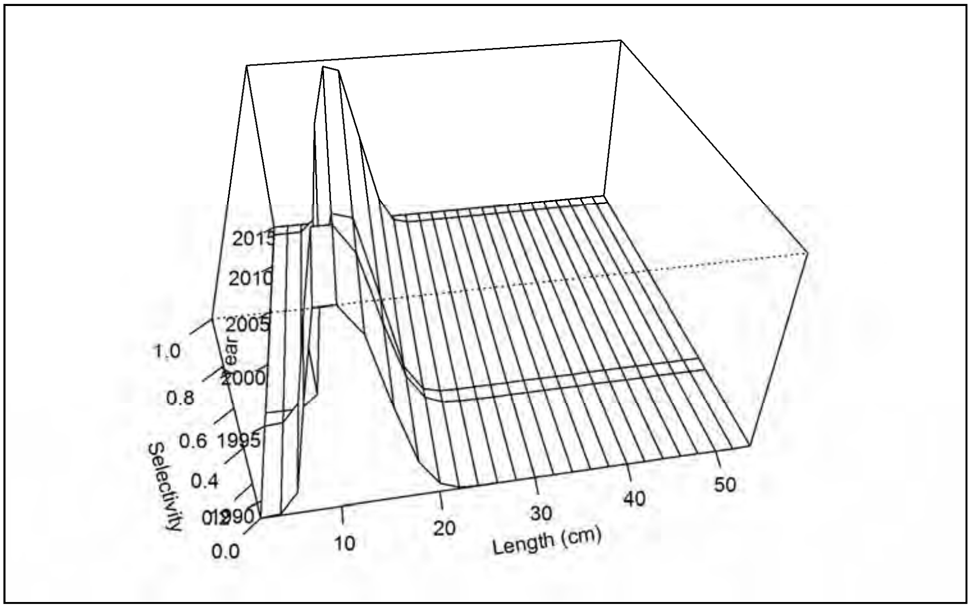

Figure 8.36. Predicted time-varying selectivity for the shrimp trawl fishery. The selectivity curve for the first time block (1989–1995) was fixed to a dome shape.

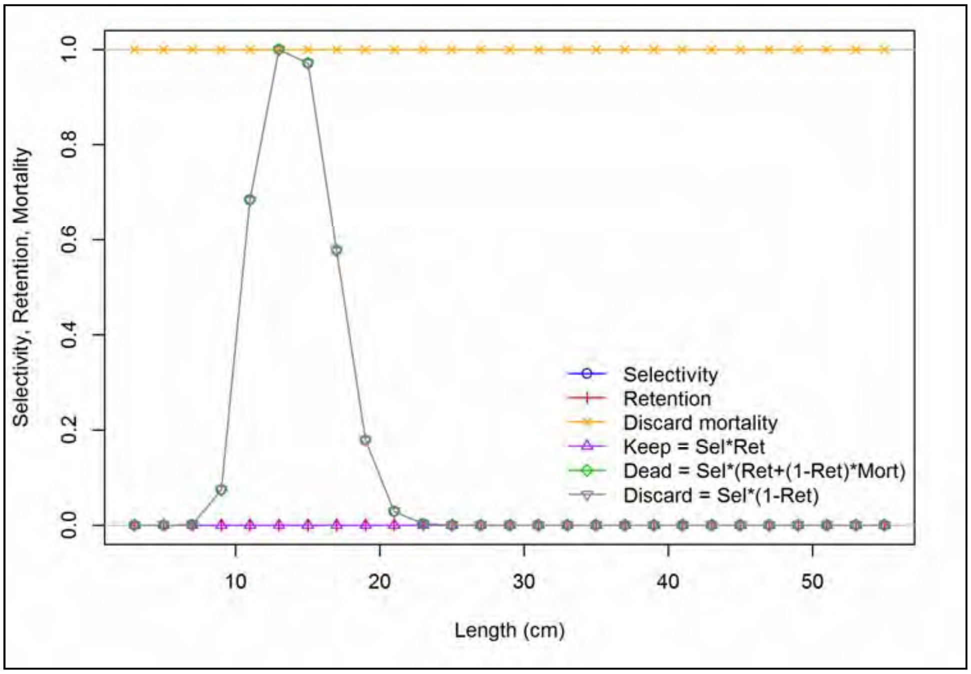

Figure 8.37. Predicted terminal year (2014) selectivity, retention, and discard mortality for the shrimp trawl fishery.

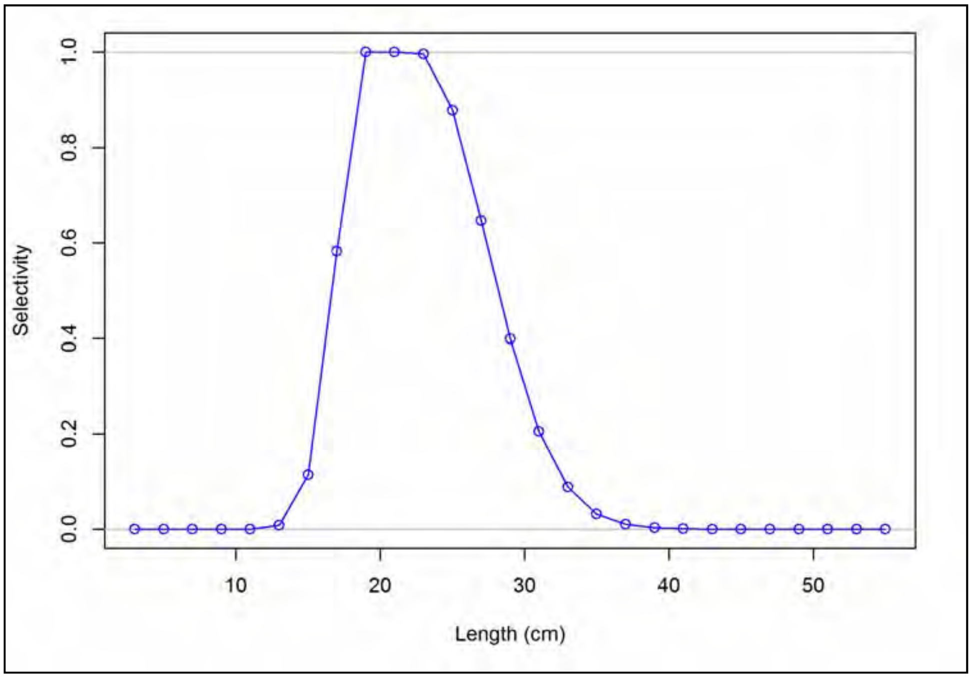

Figure 8.38. Predicted terminal year (2014) selectivity for the NEFSC survey. The selectivity curve was fixed to a dome shape.

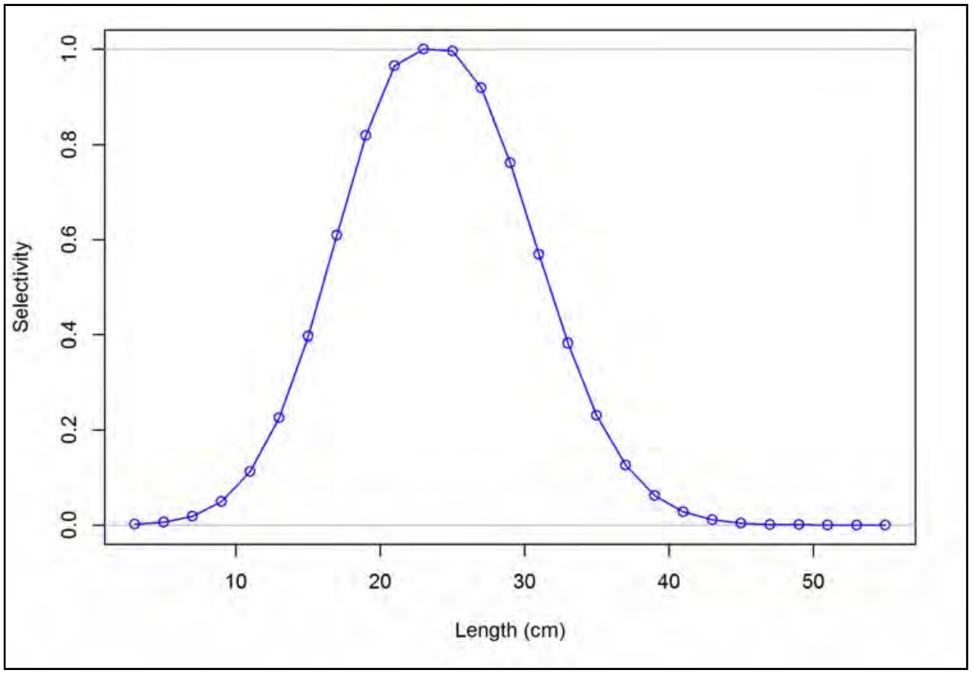

Figure 8.39. Predicted terminal year (2014) selectivity for the ChesMMAP survey.

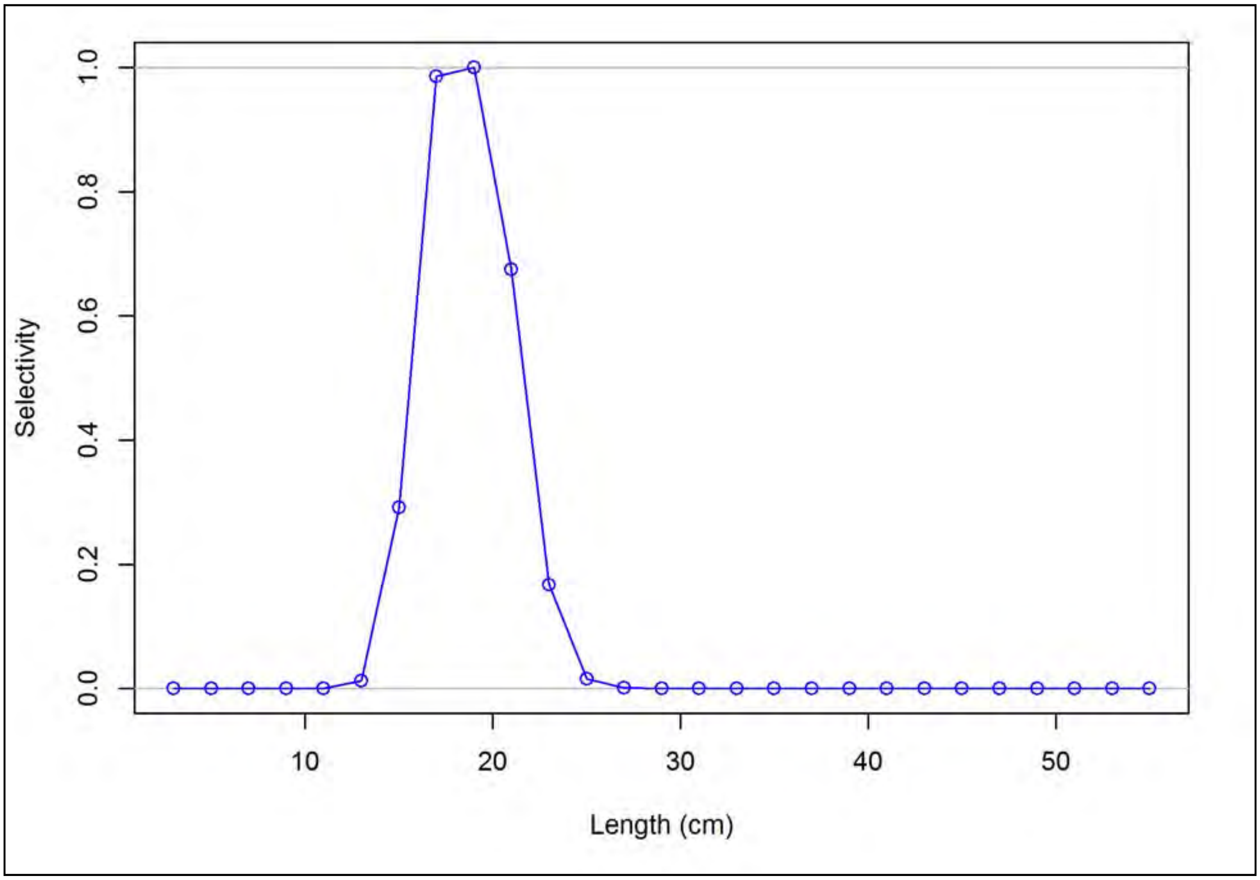

Figure 8.40. Predicted terminal year (2014) selectivity for the SEAMAP survey.

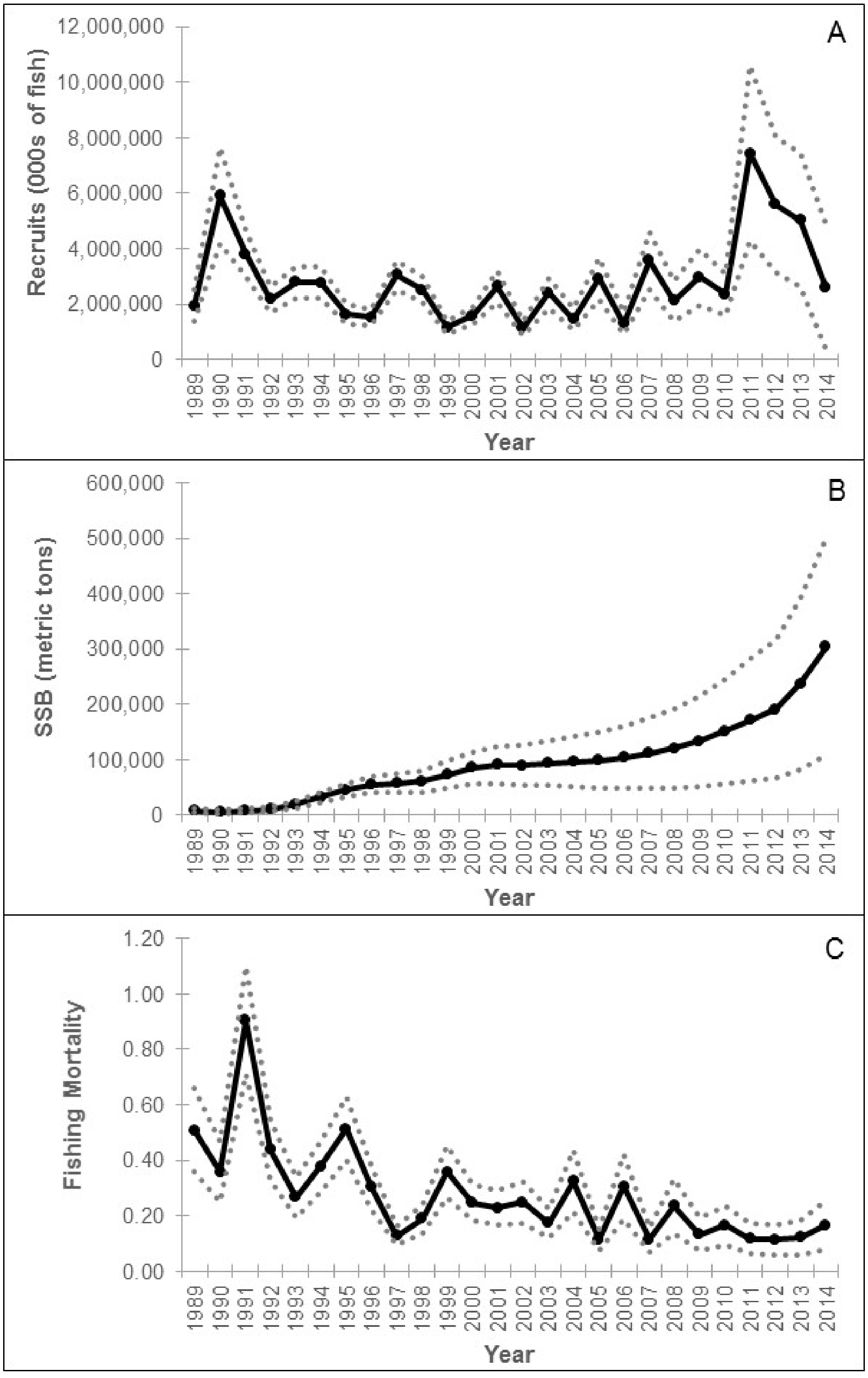

Figure 8.41. Predicted (A) recruitment, (B) female SSB, and (C) fishing mortality from the base run of the assessment model, 1989–2014. Dotted lines represent ± 2 standard deviations of the estimated values.

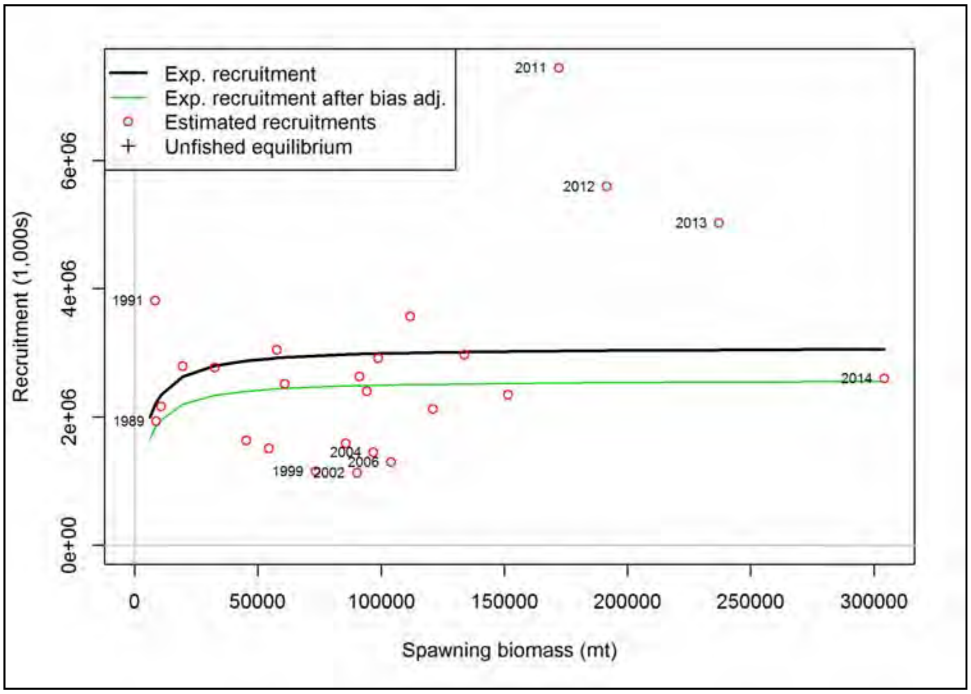

Figure 8.42. Spawner-recruit curve with labels on first, last, and years with (log) deviations > 0.5

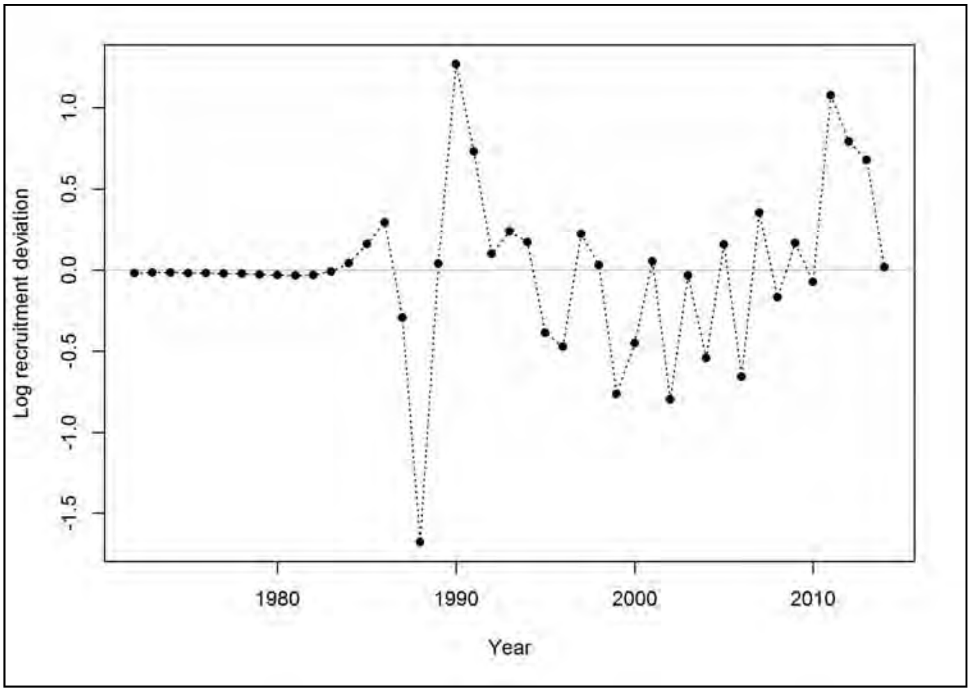

Figure 8.43. Predicted annual recruitment deviations from the base run of the assessment model, 1989–2014. Years prior to 1989 represent the "burn-in" period.

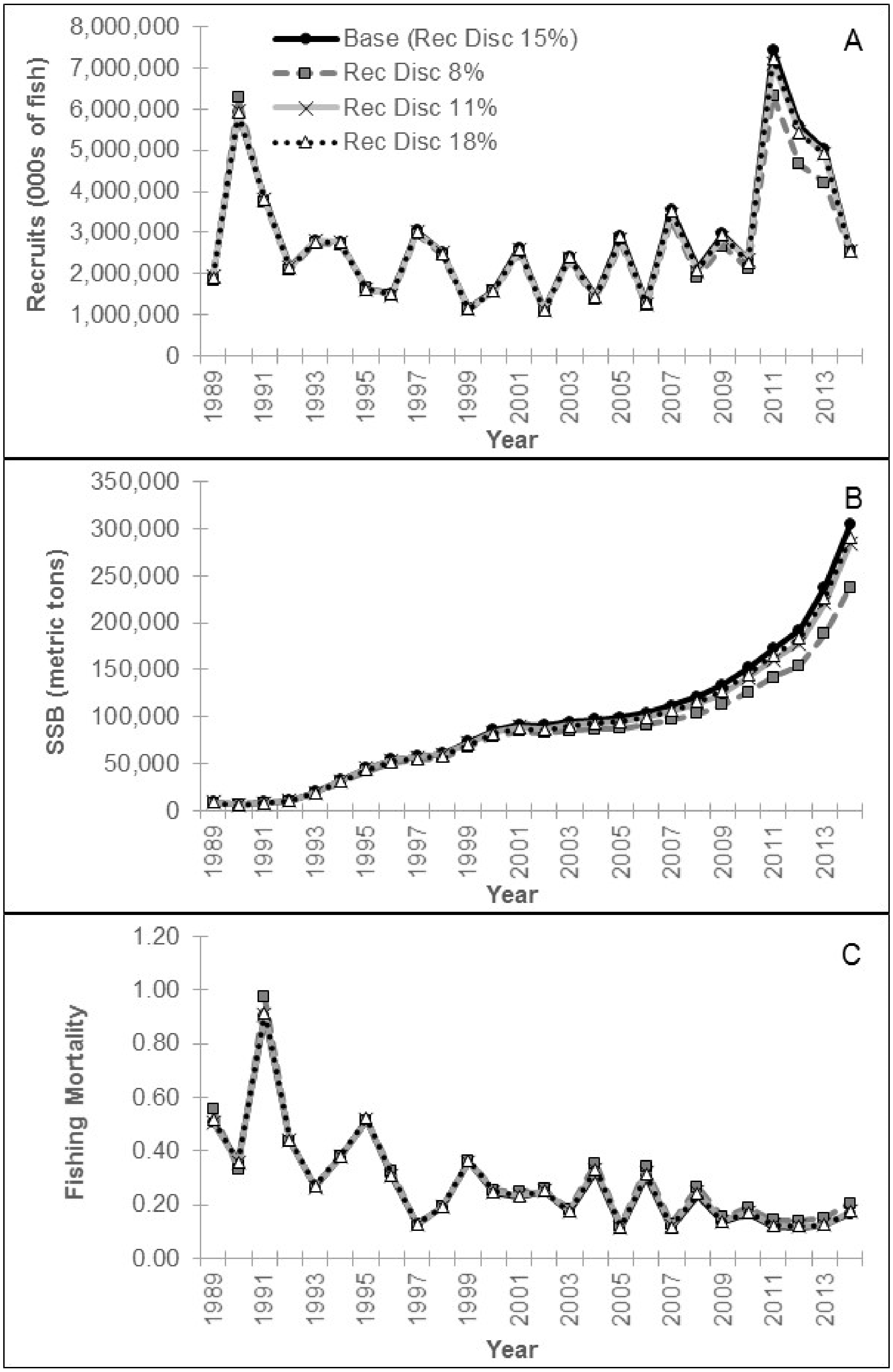

Figure 8.44. Sensitivity of model-predicted (A) recruitment, (B) female SSB, and (C) fishing mortality to varying assumptions about recreational discard mortality.

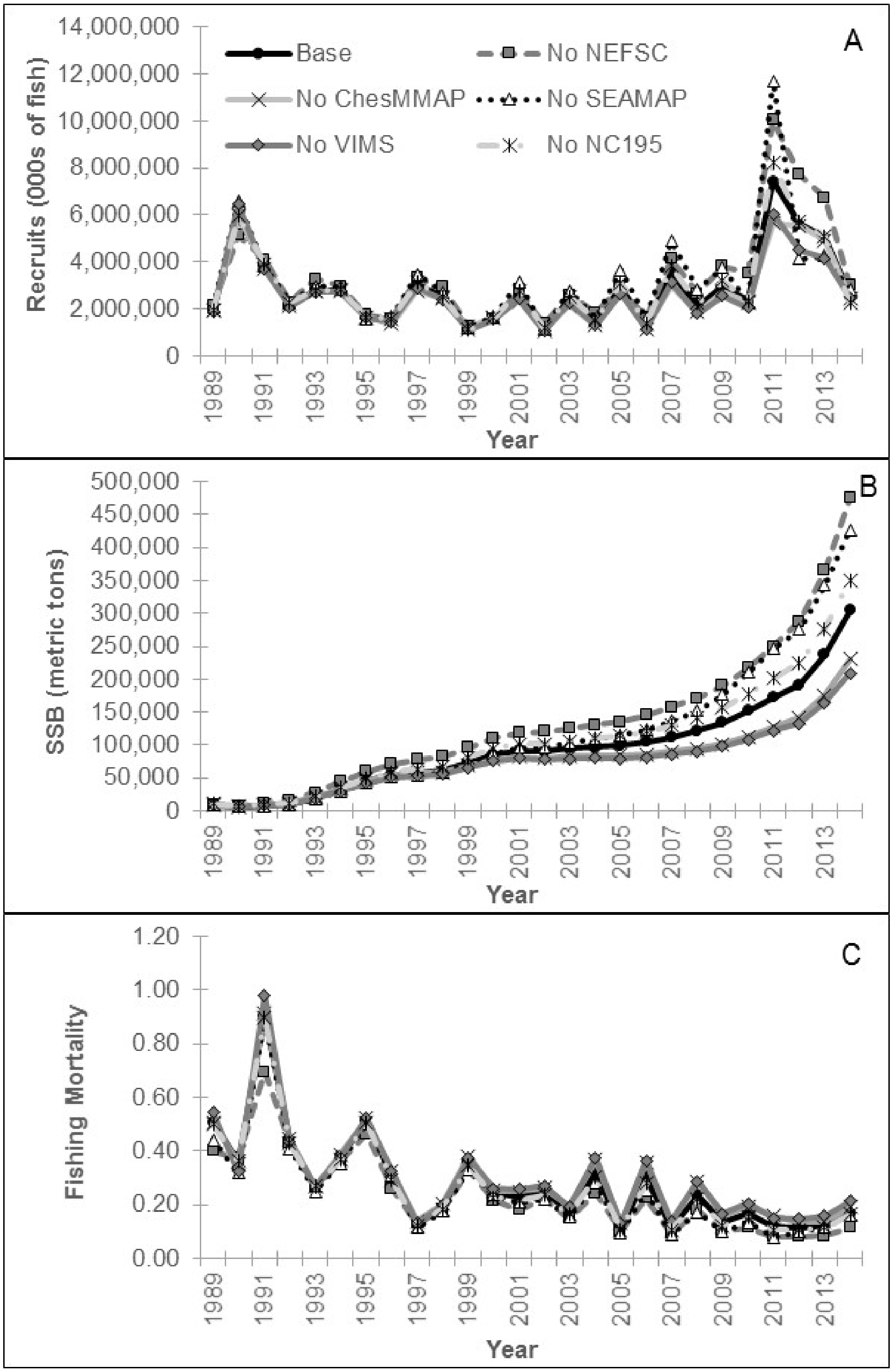

Figure 8.45. Sensitivity of model-predicted (A) recruitment, (B) female SSB, and (C) fishing mortality to removal of survey data.

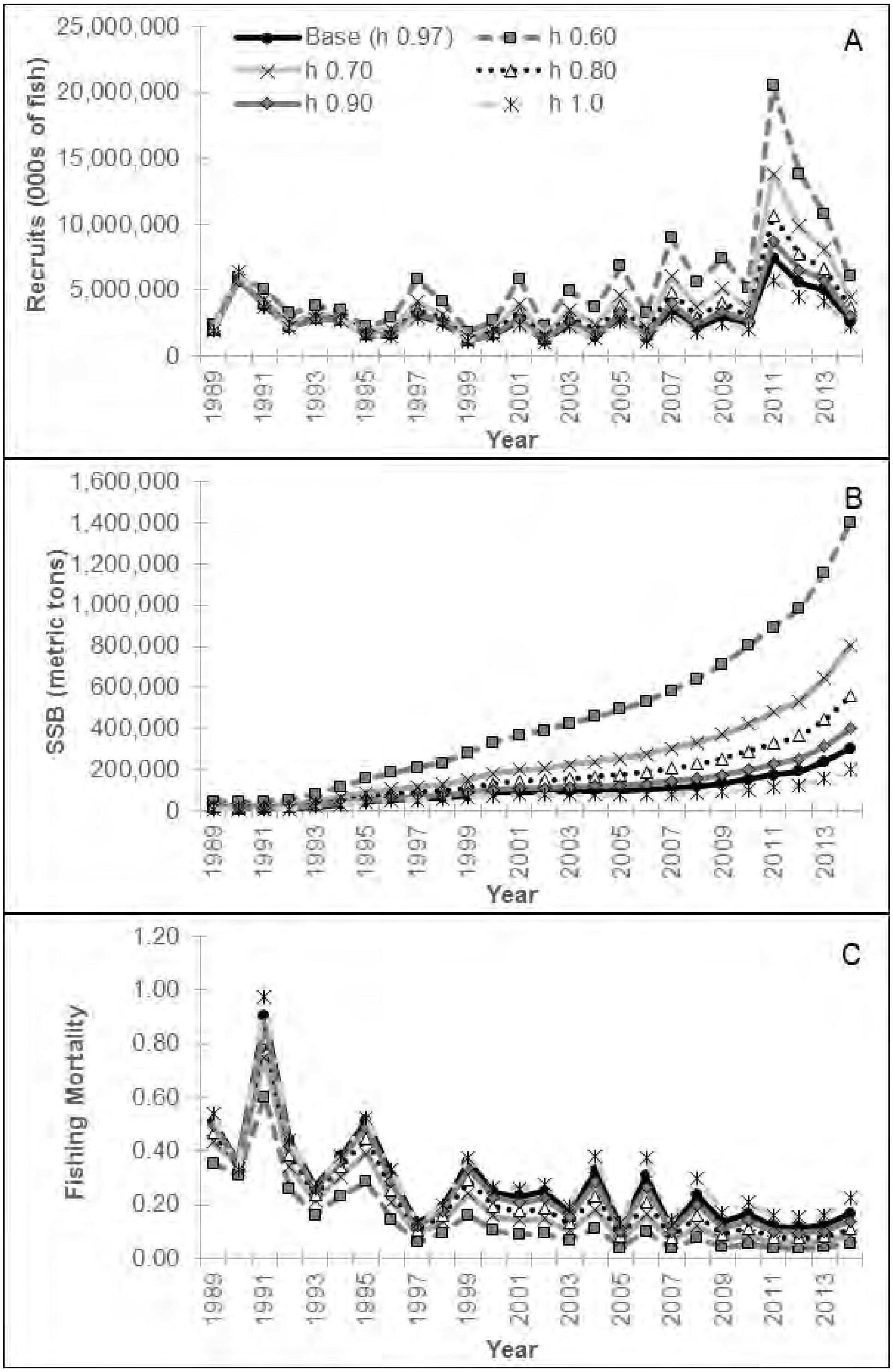

Figure 8.46. Sensitivity of model-predicted (A) recruitment, (B) female SSB, and (C) fishing mortality to varying assumptions about steepness.

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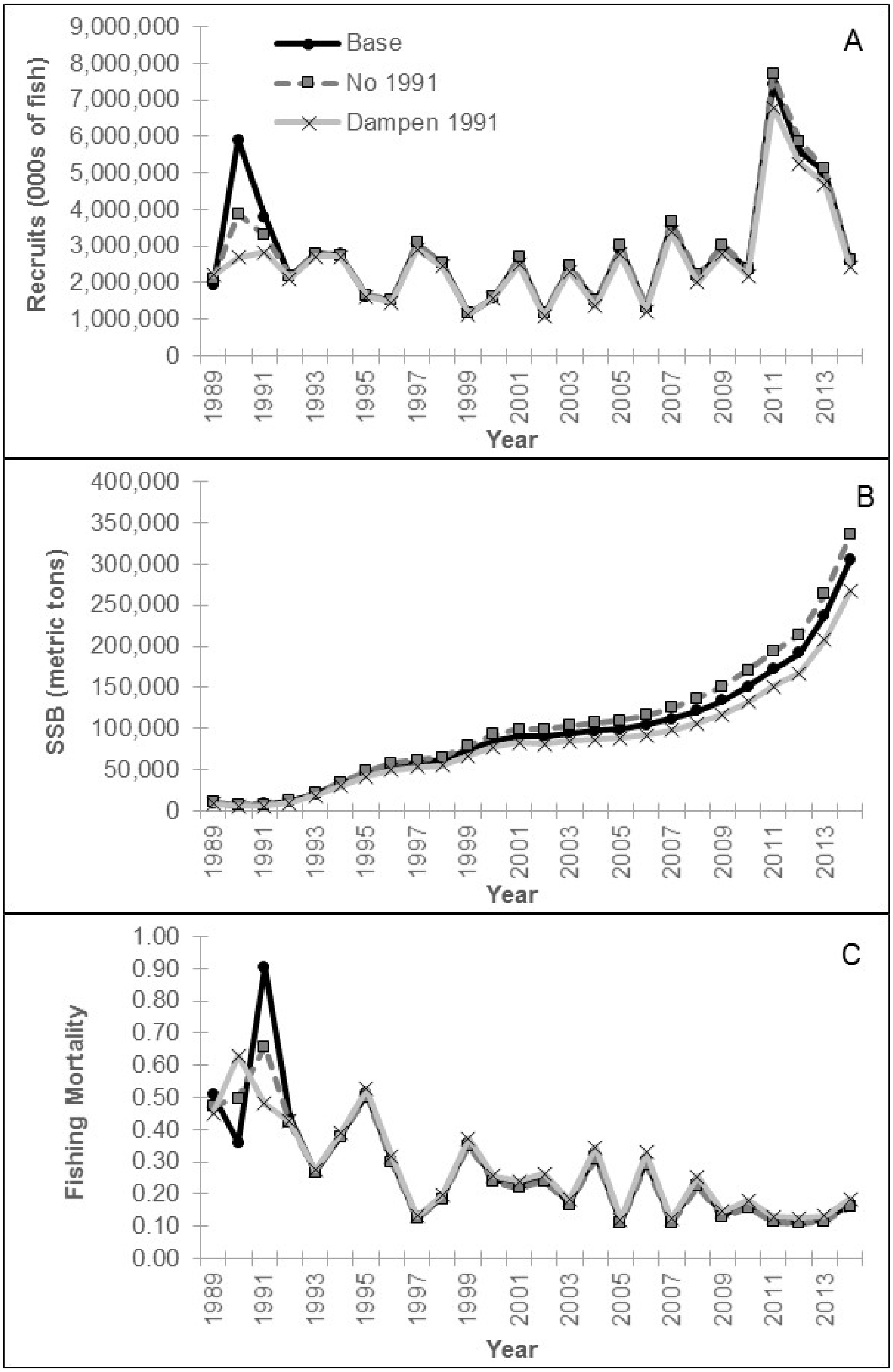

Figure 8.47. Sensitivity of model-predicted (A) recruitment, (B) female SSB, and (C) fishing mortality to the 1991 value of the shrimp trawl bycatch. The "No 1991" run is the run in which the 1991 value was excluded from the likelihood calculation. The "Dampen 1991" run is the run in which the 1991 value was set equal to the median of the pre-BRD time series.

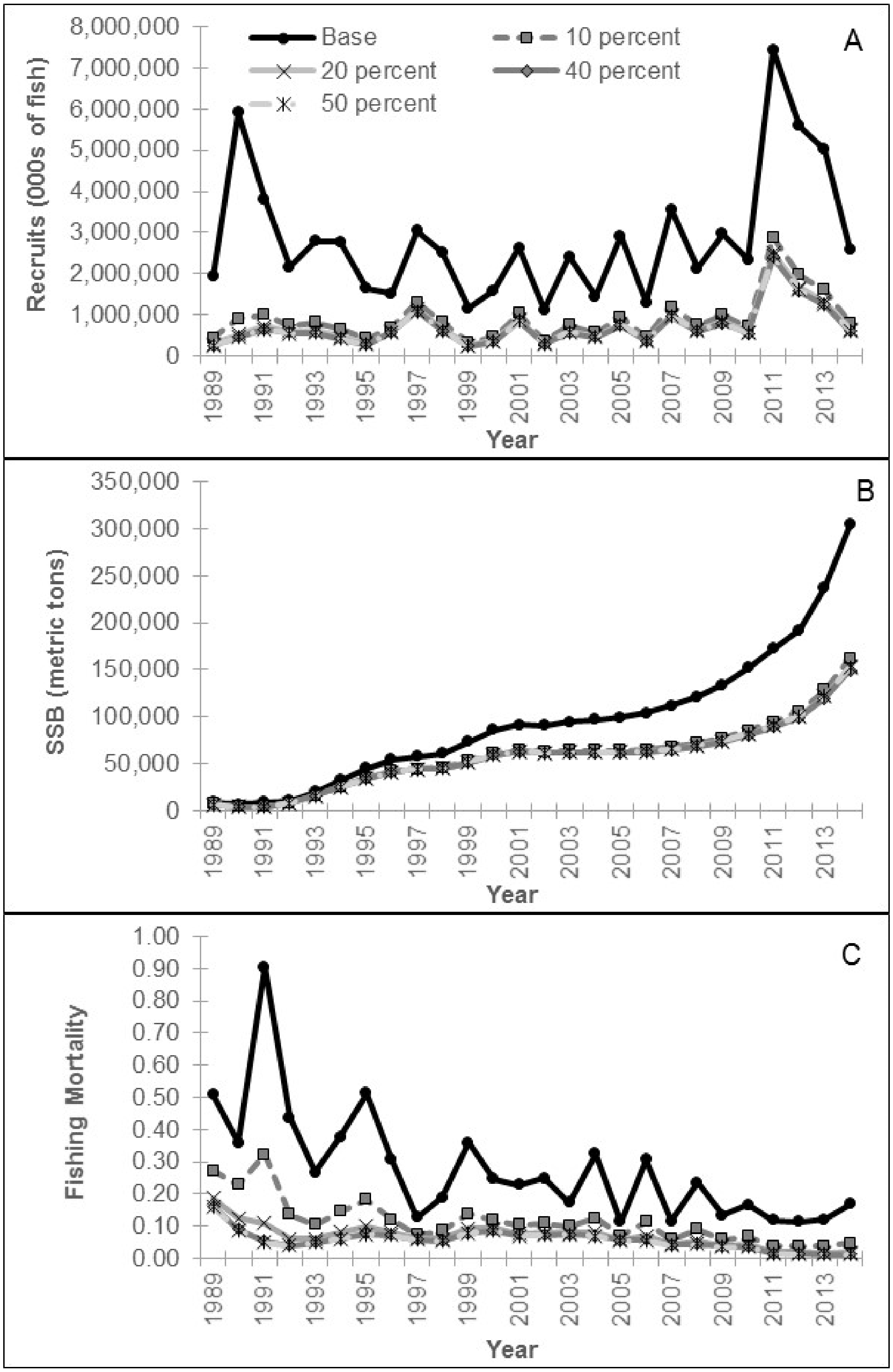

Figure 8.48. Sensitivity of model-predicted (A) recruitment, (B) female SSB, and (C) fishing mortality to the assumed level of the shrimp trawl bycatch.

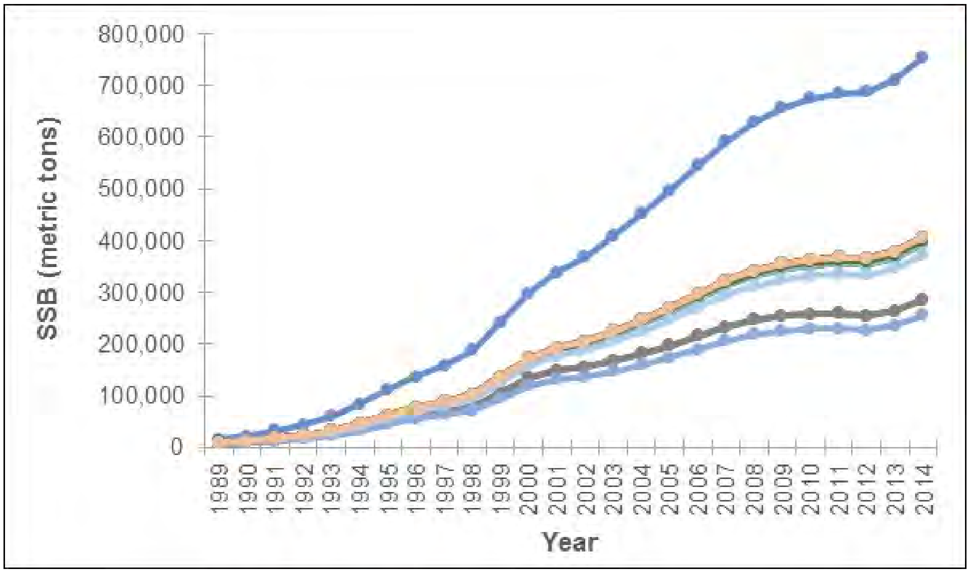

Figure 8.49. Predicted female SSB from 50 successful jitter trials.

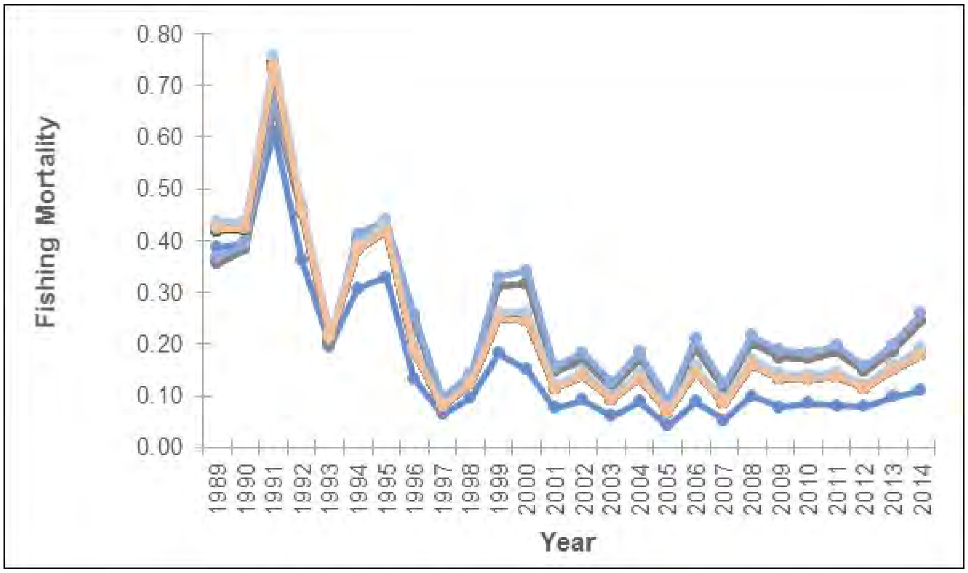

Figure 8.50. Predicted fishing mortality from 50 successful jitter trials.

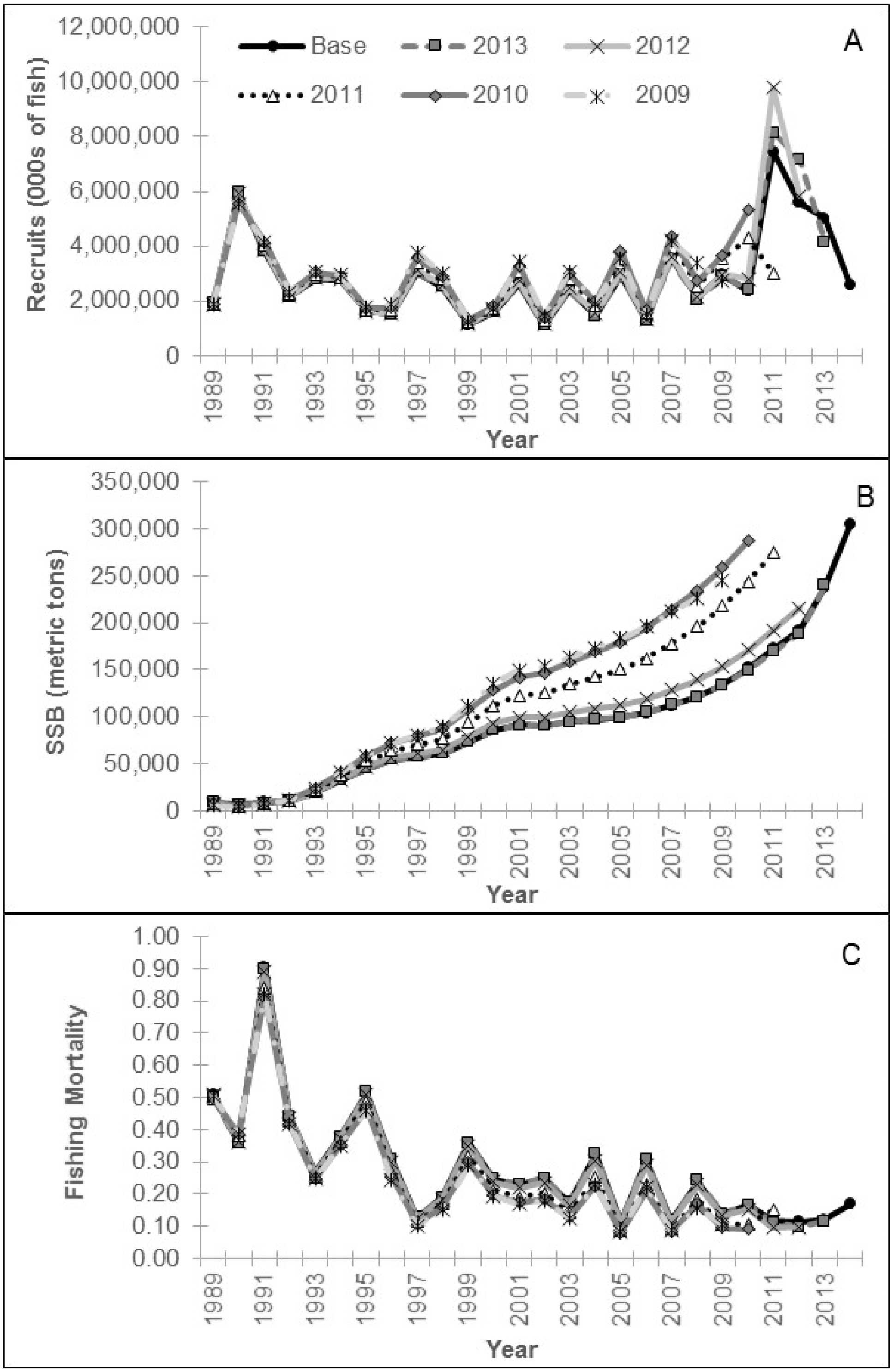

Figure 8.51. Predicted (A) recruitment, (B) female SSB, and (C) fishing mortality from the runs of the retrospective analysis.

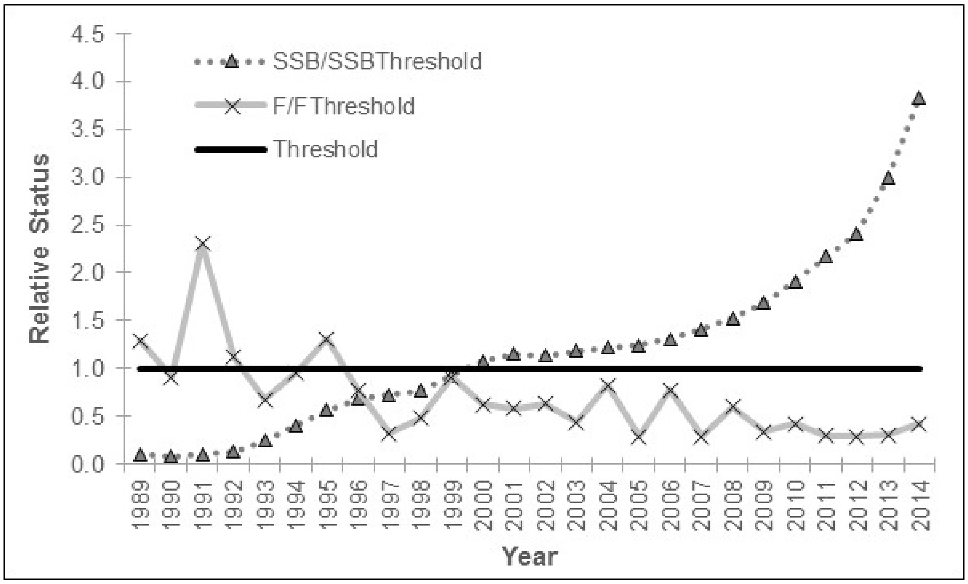

Figure 9.1. Relative stock status predicted from the base run of the assessment model.

15 APPENDICES

Appendix A1. Shrimp trawl observer database net performance operation codes.

A - Nets not spread; typically doors are flipped or doors hung together so net could not spread.
B - Gear bogged; the net has picked up a large quantity of sand, clay, mud, or debris in the tail bag possibly affecting trawl performance.
C - Bag obstructed; the catch in the net is prevented from getting into the bag by something (i.e. grass, sticks, turtle, tires, metal/plastic containers etc.) or constriction of net (i.e. twisting of the lazy-line around net).
D - Gear not digging; the net is fishing off the bottom due to insufficient weight or not enough cable let out (etc.).
E - Twisted warp or line; the cables composing the bridle get twisted (from passing over blocks which occasionally must be removed before continuing to fish). Use this code if catch was affected.
F - Gear fouled; the gear has become entangled in itself or with another net. Typically this involves the webbing and some object like a float or chains or lazy line (etc.).
G -Bag untied; bag of net not tied when dragging net.
H - Rough weather. Bags mixed due to rough seas (too dangerous to separate); if the weather is so bad fishing is stopped, then the previous tow should receive this code if the rough conditions affected the catch.
I - Torn, damaged, or lost net; usually results from hanging the net and tearing it loose. The net comes back with large tears etc. if at all. Do not use this code if there are only a few broken meshes. Continue using this code until net is repaired or replaced
J - Dumped catch; tow was made but catch was discarded, perhaps because of too mud. Give reason in comments. SEDAR38RW01 18
K - Catch not emptied on deck; nets brought to surface, boat changes location, nets redeployed. (explain in comments)
L - Hung up; untimely termination of a tow by a hang. Specify trawl(s) which were hung and caused lost time in Comments.
M - Bags dumped together, catches could not be kept separate.
N - Net did not fish; no apparent cause. Describe reasoning in comments.
O - Gear fouled on submerged object but tow was not terminated. Performance of tow could be affected. Give specifics in Comments.
P - No measurement taken of shrimp and/or total catch.
Q - Main cable breaks and entire rigging lost. Describe in Comments.
R - Net caught in wheel.
S - Tickler chain heavily fouled, tangled, or broken.
T - Other problems. Describe in comments.
U - Turtle excluder gear intentionally disabled.
V – Unknown operation code.
W - Damaged (i.e., bent or broken) excluder gear.
X - BRD intentionally disabled or non-functional. (Damaged) Describe in comments.
Y - Net trailing behind try net.
Z - Successful tow.

Appendix A2. Prior distributions of stock–recruit steepness for the Atlantic croaker (*Micropogonias undulatus*) and Spot (*Leiostomus xanthurus*) populations in the U.S. Atlantic Ocean

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Abstract: The stock–recruit steepness is difficult to estimate. Estimation difficulties are often reduced upon fixing steepness at a "reasonable" value or assigning it a prior distribution. This contribution is devoted to the development of steepness prior distributions for Atlantic croaker and spot inhabiting the U.S. Atlantic coast. To this end, a relationship between slopes at the origin of stock–recruit curves (α) and asymptotic sizes is constructed to infer the plausible values of α, which in turn are combined with species-specific unfished spawning biomass per-recruit (Φ_0). Monte Carlo (MC) simulations are used to propagate uncertainty in growth parameters into natural mortality, Φ_0 and steepness. Under assumptions of Beverton–Holt stock–recruit dynamics, median steepness is 0.78 (80% probable range: 0.68–0.84, mean = 0.76 and mode = 0.79) for Atlantic croaker and 0.66 (80% probable range: 0.33–0.89, mean = 0.64 and mode = 0.79) for spot. If Ricker stock–recruit relationships were assumed, mean and median steepness are 1.68 (80% probable range: 1.1–2.25, mode = 1.78) for Atlantic croaker; for spot, median steepness is 1.58 (80% probable range: 0.35–3.28, mean = 1.03 and mode = 0.52). Two-parameter beta functions are fitted to empirical distributions of the Beverton–Holt stock–recruit steepness for both species. A normal function and a gamma function appear appropriate for fitting the Ricker stock–recruit steepness of Atlantic croaker and spot, respectively. The previous tendency statistics or probable ranges of steepness can guide its estimation. Alternatively, the fitted parameters can be used to select parametric prior for stock–recruit steepness of Atlantic croaker and spot.

Introduction

Contemporary assessments and management of data-rich stocks largely infer from stock–recruit relationships (SRRs). Inferences are made at two levels. First, assessment models include stock-recruit functions designed to govern the recruitment production. Second, nominally sustainable levels (i.e., maximum sustainable yield (MSY)-based benchmarks) and the determination of stock status in principle follow from the combination of (reliable) SRR and per-recruit models (Shepherd, 1982).

Since about the mid-1980s, data-rich stock assessments focused on recasting the stock–recruitment parameters (i.e., maximum recruits per spawner as spawner abundance approaches zero and the degree of compensation) in terms of "steepness" (*h*; i.e., the fraction of the unexploited recruitment produced by 20% of the unexploited parental stock). This move was adopted because the definition of *h* was considered biologically meaningful (Hilborn and Mangel, 1997; Haddon, 2001). The previous definition of steepness and related biological and management interpretations are, however, intelligible for and suited to the Bevertion–Holt SRR (BH–SRR). They are difficult to comprehend for other SRRs.

Steepness measures the degree of dependence of average recruitment on the parental stock. For the BH–SRR, it reflects the stock's productivity, whereby its higher values are thought to be associated with highly productive populations, especially at lower density (Beddington and Kirkwood, 2005; Lee et al., 2012; Maunder, 2012; Shertzer and Conn, 2012). In those cases, the stocks are considered to be resilient to harvest. In theory, therefore, intense exploitation and growth-overfishing associated with higher steepness would not affect recruitment or lead to recruitment-overfishing!

Unfortunately, steepness is difficult to estimate. Estimation difficulties arise from reasons such as changes of steepness over time, uninformative fishery data, large fluctuations in recruitment at low stock size, and lack of contrast (i.e., how well the possible range is covered) for the stock–recruit data (Walters and Martell, 2004; Conn et al., 2010; Shertzer and Conn, 2012). For example, in most assessments involving the BH–SRR where steepness is bounded between 0.2 and 1.0, the steepness estimates tend to hit the upper bound irrespective of whether the stock is or is not productive (e.g., Conn et al., 2010; Lee et al., 2012).

Strategies commonly adopted to reduce the estimation difficulties of steepness include: (i) fixing h to an assumed "reasonable" value in a base-model run and conduct sensitivity runs involving alternative values of h; (ii) constraining h between selected lower and upper bounds (e.g., Conn et al., 2010; Anonymous, 2011; Rademeyer et al., 2012); or (iii) developing a prior distribution (penalty function in a maximum likelihood context) for h. The first strategy, along with a fixed natural mortality rate (M), fixes biological reference points, BRPs (Mangel et al., 2013). The second strategy basically is a uniform distribution for h, a "reasonable" estimate of which depends on information contained in fishery data and on possible contrasts that the spawning stock may have exhibited. The third strategy relies on met-population analyses (Myers et al., 1999, 2002; Rose et al., 2001; Shertzer and Conn, 2012; Punt and Dorn, 2014), persistence principles (He et al., 2006), or uncertainty in reproductive and life history parameters (Mangel et al., 2010; Simon et al., 2012; Brodziak et al., 2015). This strategy is somewhat similar to the first strategy when M is fixed, but differ from it in that: (i) given a long and comprehensive time series of fishery data and variable spawning stock, the prior distribution of h can be updated, usually through Bayes' rule, into a posterior distribution; and (ii) the resulting BRPs have distributions.

For the current benchmark assessments of the Atlantic croaker (*Micropogonias undulatus*) and spot (*Leiostomus xanthurus*) stocks in the U.S. Atlantic coast, this note aims to construct plausible prior distributions for stock–recruit steepness of the stocks in question. Analyses combine: (i) the relationship between published stock productivity levels at low stock size and asymptotic lengths; (ii) species-specific parameters on growth and maturity/fecundity (the estimation of M follows from a nonlinear empirical equation in Then et al., 2015); and (iii) the unfished spawning biomass (or number of eggs) per-recruit (Φ_0).

Materials and methods

Basic parameters, relationships and assumptions

The construction of prior distributions of the stock–recruit steepness (h) for Atlantic croaker and spot relies on two main characteristics. First, the slopes at the origin of spawner-recruit curves (α, the maximum recruits per-spawner at lower spawner abundance) is negatively and significantly related to the parameters L_∞ and W_∞ of the von Bertlanffy growth (VBG) equation (Denney et al., 2002; Goodwin et al., 2006; Hall et al, 2006). Therefore, given species-specific values of L_∞ and longevity or W_∞ falling in the range of meta-analytic relationships $\alpha \sim L_\infty$ or $\alpha \sim W_\infty$, plausible species-specific values of α can be estimated. Second, the definition of h reduces to a nonlinear function h of α and the unfished spawning biomass (or number of eggs) per-recruit (Φ_0): $h = f(\alpha, \Phi_0)$ (Mangel et al., 2010, 2013 and references therein).

The previous aspects are accounted for by compiling estimates of α, L_∞, and Φ_0 that have preferably been estimated and published simultaneously. Otherwise, when only α is available, L_∞ values are compiled from various sources including FishBase (http://fishbase.org). Most α values were estimated employing the Ricker SRR (R–SRR)—Myers et al. (1999, 2002) argue that at the limit of small population size, the BH–SRR and R–SRR coincide, having the same α, although they produce different estimates of α once fitted to the same data (Michielsens and McAllister, 2004; Forrest et al., 2010; Galindo-Cortes et al., 2010). In this note, all compiled α values are used irrespective of the standard BH–SRR or standard R–SRR they were derived with, provided the BH–SRR was of the form similar to the equation used below for defining steepness. Furthermore, α estimates for the BH–SRR are preferred over those for R–SRR if they are available for the same stock. The relationship between α and L_∞ is (Fig. A1:1a, b; $r^2 = 0.67$, $P < 0.001$):

$$\alpha = 856213.7L_\infty^{-2.9393} \qquad (1)$$

The VBG parameters (L_∞, K year^{-1}, and age_0 (years)) and the length–growth scales (a) and exponents (b) for females of Atlantic croaker[1] include those in ASMFC (2010a) and those that have been updated during this assessment benchmark. The growth parameters for females of spot are available during this assessment benchmark only, so they also include those values that have been estimated for both sexes in ASMFC (2010b). Estimated growth parameters are treated as "observed data." Then, the variability in these parameters is considered reflective of scientific uncertainty, but note that the majority of them are linearly and significantly related (Fig. A1:1c–h). No unique combination made up of each point estimate from their respective sets is preferred *a priori* over other combinations in calculating composite life history metrics, such as M and Φ_0.

Characterizing uncertainty through random samples of growth parameters

Because at least two sets of the observed growth parameters are linearly and significantly related (Fig. A1:1c–h), the VBG parameters on the one hand, and the length-weight scales and exponents on the other, are jointly simulated as multivariate normal distributions given their empirical mean vectors and covariance matrices. Sampling is performed (number of iterations n = 10000) with the R package MASS (Venables and Ripley, 2002). (A different sampling scheme such as Monte Carlo (MC) simulations assuming uniform distributions would be appropriate if the previous pairs of growth parameters were not linearly related). Except for Atlantic croaker's parameter age_0 versus L_∞, stochastic realizations of various growth parameters are expectedly related linearly (Fig. A1:2a–h). In particular, isopleths have the highest probability density at about (L_∞, K) = (42 cm, 0.2 year^{-1}) and (a, b) = (0.015, 3.0) for Atlantic croaker and at bout (L_∞, K) = (370 mm, 0.35 year^{-1}) and (a, b) = (3.5×10^{-5}, 3.0) for spot.

During the sampling, some iterations can yield negative values for the parameter a and positive values for the parameter age_0. Such random draws are conducive, respectively, to negative mean weights and negative mean lengths at age-0, which are unfeasible. It is therefore necessary to subset the initial iterations, only keeping draws of L_∞, K, and b associated with positive values of a and negative values of age_0. The number of kept draws is denoted $n+$ and, for each of them, the following quantities are derived or calculated through MC simulations.

Natural mortality

Constant M (Figs. A1:3a, b) is estimated using the Pauly's nonlinear empirical equation (Then et al., 2015):

$$M = 4.118K^{0.73}L_\infty^{-0.33} \qquad (2a)$$

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[1] The triplets (L_∞, K, age_0) equal to (85.4, 0.0638, −0.0016) and (64.5, 0.2, −3.06) are excluded because they appear to be outliers.

(Hoenig's updated nonlinear empirical equation can also be used, on the basis of maximum ages that individual studies have recorded). Natural mortality at age (M_{age}) follows from Lorenzen's (2000, 2005) natural survival equation at age (S_{age}) for the VBG function (L_∞ is treated as reference length and M relates to L_∞):

$$S_{age} = \left[\frac{L_{age}}{L_{age}+L_\infty(e^K-1)}\right]^{\frac{M}{K}} \tag{2b}$$

where L_{age} is mean length at age estimated with the VBG equation. It follows that $M_{age} = -\log(s_{age})$:

$$M_{age} = \frac{M}{K}\log\left[1+\frac{L_\infty}{L_{age}}(e^K-1)\right] \tag{2c}$$

Figures A3c, d show levels (medians and empirical 95% confidence intervals) and trajectories of natural mortality at age.

Mean weights

The asymptotic weight (W_∞) is given by:

$$W_\infty = aL_\infty^{b} \tag{3a}$$

Mean weight at age (W_{age}) is calculated as:

$$W_{age} = W_\infty\{1 - \exp[-K(age - age_0)]\}^{b} \tag{3b}$$

The unfished spawning stock biomass per-recruit (SSBR)

The unfished SSBR at age (starting from age-0) for females ($\psi_{age.F=0}$) is calculated as:

$$\Psi_{ageF=0} = l_{age} sr_{age} W_{age} \mu_{age} \frac{\sum_{m=1}^{12}\pi_m exp(-\varphi_m M_{age})}{\sum_{m=1}^{12}\pi_m} \tag{4}$$

where sr_{age} is the sex-ratio at age; μ_{age} is the probability mature at age; π_m is the monthly proportion of spawning-capable females; φ_m is the fraction of the year elapsed at the beginning of the spawning month m (calculated assuming that natural mortality by age is uniformly distributed over the year; by convention, φ_1 for the month of January is zero, $\varphi_2 = 1/12$ for the month of February consistent with the elapsed month of January, and so on); and l_{age} is the unfished survivorship to a given age (note: at age-0, $l_{age} = 1$): $l_{age} = l_{age-1}\, exp(-M_{age-1}) = exp(-\sum_0 M_{age-1})$. Figures A3e, f describe the estimated l_a levels and trajectories.

The sex-ratios and probability mature ate age (s_{age}, μ_{age}) as well as the vector φ_m used in Eq. (4) were developed during this assessment benchmarks. Together with the vector π_m, they are treated as deterministic.

The total unfished SBPR (Φ_0) is given by:

$$\Phi_0 = \sum_{age=0}^{T_{max}} \Psi_{ageF=0} \tag{5}$$

where T_{max} is maximum observed age (17 years for Atlantic croaker, 6 years for spot).

Calculating the steepness parameter

The BH–SRR and R–SRR are commonly used in stock assessment models of population dynamics. Here, the steepness (h) is calculated on the ground that its definition relies on a BH–SRR of the form R = αS/(1 + βS), where R is recruitment, S is spawning stock biomass producing R, and α and β are parameters[2]:

$$h = a\Phi_0/(4 + a\Phi_0) \tag{6a}$$

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[2] If the steepness were defined based on BH–SRRs of the forms R = αS/(β + S) and R = S/(α + βS), h would be expressed as $h = \alpha\Phi_0/(4\beta + \alpha\Phi_0)$ and $h = \Phi_0/(4\alpha + \Phi_0)$, respectively.

If there is evidence for mechanisms supporting the R–SRR, R = αS exp(−βS), then

$$h = 0.2(a\Phi_0)^{0.8} \tag{6b}$$

The quantity $\alpha\Phi_0$ is the maximum lifetime reproductive rate at low density (Myers et al., 1999, 2002), i.e., the number of recruits produced by a recruit over its lifespan in the absence of fishing (Brooks et al., 2010). It corresponds to the Goodyear (1977, 1980) compensation ratio and is related to steepness (Walters and Martell, 2004; Martell et al. 2008; Brooks et al., 2010; Fig. A1:4).

Some properties and estimation considerations of the steepness

The range of *h* is [0.2, 1) for the BH–SRR and [0.2, ∞) for the R–SRR; its domain (i.e., values of $\alpha\Phi_0$) is [1, ∞). The variation of *h* against $\alpha\Phi_0$ (Fig. A1:4) indicates that, for the BH–SRR for example, (i) $h = 0.5$ when $\alpha\Phi_0 = 4$; (ii) for $\alpha\Phi_0 > 4$, $h > 0.5$ (e.g., $h = 0.75$ if $\alpha\Phi_0 = 12$ and $h = 0.95$ if $\alpha\Phi_0 = 76$), but $h < 1$ because $\alpha\Phi_0 < 4 + \alpha\Phi_0$ (i.e., 1 should never upper-bound *h*); and (iii) for $\alpha\Phi_0 < 4$, $h < 0.5$ and $h = 0.2$ when $\alpha\Phi_0 = 1$.

Although the steepness is dimensionless and is considered a tool for comparison across species (e.g., Beddington and Kirkwood, 2005; Kell et al. 2013, Rossberg et al., 2013), the units chosen to calculate Φ_0 influence its magnitude. For example, given α in number of recruits per spawning biomass, values of *h* based on Φ_0 in g would be higher than those that would be based on Φ_0 in kg. For the BH–SRR in particular, it may be useful to develop Φ_0 with a unit in such a way that the order of magnitude for the $\alpha\Phi_0$ value is comparable with 4 on the denominator (typical values of $\alpha\Phi_0$ are single-digit and double-digit numbers; Figs. A1:4). For Φ_0 calculated as SSBR, as is here, use of kg is deemed appropriate and is recommended to facilitate comparisons among life histories. The previous remarks suggest that comparison of species of different life histories on the basis of the stock–recruit steepness make sense when their Φ_0 is in the same unit.

Estimating parameters of prior distributions for steepness

The R ExtDist package is used to estimate the parameters that provide the maximum likelihood fit to the empirical steepness distributions as obtained from MC simulations. Specifically, the fitted probability density functions (pdfs) are: (i) the two-parameter beta pdf for the BH–SRR steepness, and (ii) the normal or gamma pdf for the R–SRR steepness.

The forms of the fitted normal, gamma, and two-parameter beta pdfs are, respectively:

$$f(h) = \frac{e^{-\frac{(h-\mu_h)}{\sigma^2}}}{2\sqrt{2\pi}} \tag{7a}$$

$$f(h) = \frac{h^{p-1}e^{-\frac{h}{\theta}}}{\Gamma(p)\theta^p} \tag{7b}$$

$$f(h) = \frac{\Gamma(p+q)}{\Gamma p \Gamma q} h^{p-1}(1-h)^{q-1} \tag{7c}$$

The parameters are the mean μ_h and the standard deviation σ (> 0) for the normal pdf, the shape *p* (> 0) and the scale *θ* (> 0) for the gamma pdf, and the shape parameters *p* and *q* (> 0) for the two-parameter beta pdf. The mean and variance are given by $p\theta$ and $p\theta^2$ for the gamma pdf and, for the two-parameter beta pdf, by $p/(p + q)$ and $pq/[(p + q)^2(p + q + 1)]$, respectively.

Results

The distributions of the BH–SRR steepness are left skewed for both the Atlantic croaker and Spot (Fig. A2:5a, b) with MC sample medians of 0.78 (80% probable range: 0.68–0.84) and 0.66 (80% probable range: 0.33–0.89), respectively. The MC sample mean of the BH–SRR steepness is 0.76 (CV = 0.11) for Atlantic croaker and 0.64 (CV = 0.32) for spot.

The parameters of the fitted beta density (Fig. A2:5a, b) are p = 22.07 (standard error, SE = 0.324) and q = 6.93 (SE = 0.099) for Atlantic croak and p = 3.05 (SE = 0.05) and q = 1.73 (SE = 0.027) for spot.

The R–SRR steepness for Atlantic croaker is normally distributed (Fig. A2:5c) with an MC sample mean of 1.68 (CV = 0.28; 80% probable range: 1.1–2.25). For spot, the R–SRR steepness is right skewed (Fig. A2:5d), with an MC sample median of 1.03 and an MC sample mean of 1.58 (80% probable range: 0.35–3.28). The fitting of a gamma pdf to the MC sampled data for this distribution produces p = 1.42 and θ = 0.91 (mean = 0.61; standard deviation = 0.27).

Shertzer and Conn (2012) argue that, if data are informative, “a prior distribution (for steepness) informs the estimation process in that the best estimate occurs at the mode.” If so, the modes of the BH–SRR steepness are 0.79 for both Atlantic croaker and spot. The modes of the R–SRR steepness for these species, respectively, are 1.78 and 0.52.

Discussion

This note builds upon a relationship that exits between the slopes at the origin of stock–recruit curves (α) and asymptotic lengths (L_∞). Empirical inferences of α for Atlantic croaker and spot are then made on the ground that their L_∞ values are in the range of the aforementioned relationship. Finally, the calculated α values are combined with the species-specific unexploited spawning biomass per-recruit (Φ_0) to develop the corresponding stock–recruit steepness. The construction of empirical distributions of steepness is made possible through: (i) Monte Carlo simulations of growth parameters, (ii) calculations of constant M using the realized L_∞ and K, and (iii) the propagation of uncertainty in L_∞, K, constant M and length-weight parameters into M-at-length and Φ_0. Therefore, contrary to fully meta-analytic approaches (Myers et al., 1999, 2002; Rose et al., 2001; Shertzer and Conn, 2012; Punt and Dorn, 2014) and methods exclusively based on reproductive and life history parameters (Mangel et al., 2010; Simon et al., 2012; Brodziak et al., 2015), the methodology used here combines results on α and L_∞ gained from other stocks and life history parameters of the species of interest. As such, the proposed approach is hybrid.

Apart from the relationship $\alpha \sim L_\infty$ (which may change depending on the selected pairs), a key step to estimating the steepness is the calculation of Φ_0 (Eq. (5)). Here, a calculation methodology is proposed to account for the protracted nature of the spawning activity for Atlantic croaker and spot. However, because the incorporation of the reproductive dynamics into equilibrium per-recruit models is challenging, Eq. (4) attempts to address the protracted spawning season through a weighted average of monthly survival rates (i.e., $\frac{\sum_{m=1}^{12}\pi_m exp(-\varphi_m M_{age})}{\sum_{m=1}^{12}\pi_m}$) themselves based on φ_m values; the weights are monthly proportions of spawning-capable females. Such a procedure implies simplifying assumptions that all age-specific schedules are conserved each month and that females in a cohort can survive at the beginning of any month of a year but spawn only during a single month.

The previous weighting of monthly survival rates is flexible in that it can accommodate various configurations depending on species-specific reproductive dynamics in a year. For example, the proportion π_m should simply be set to zero in months during which a species is reproductively inactive. In that case, the resting months would weigh nothing. At another extreme,

π_m would equal one if females reproducing in each month all were spawning-capable (the denominator = 12). It is of note that Gabriel et al.'s (1989) equation, applicable for a single month of peak spawning assuming (π_m = 1), is a special case of Eq. (4).

Parametric density functions (normal, gamma, and beta) for steepness are fitted to the empirical steepness distributions to the estimate their parameters. It is anticipated that the fitted parameters can be used to select parametric prior for stock–recruit steepness of Atlantic croaker and spot assuming either the BH–SRR or the R–SRR.

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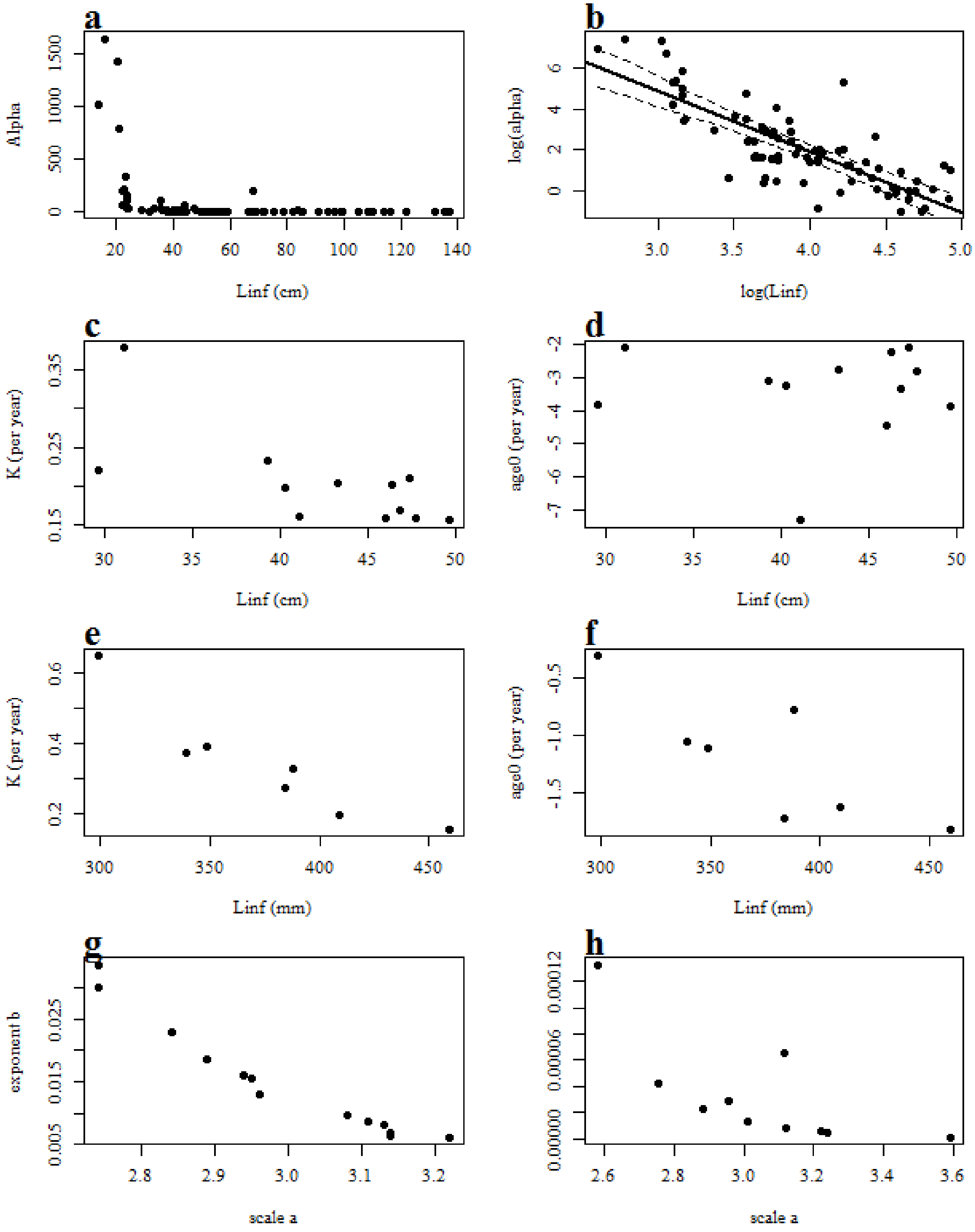


Fig. A2:1 Relationships between (a, b) “observed” values of alpha and L_∞, on arithmetic and log scale, respectively; (c, d) the VBG parameters *K* and age$_0$ for Atlantic croaker, (e, f) for spot; and (g, h) the exponent and the scale of length-weight for Atlantic croaker and spot, respectively.

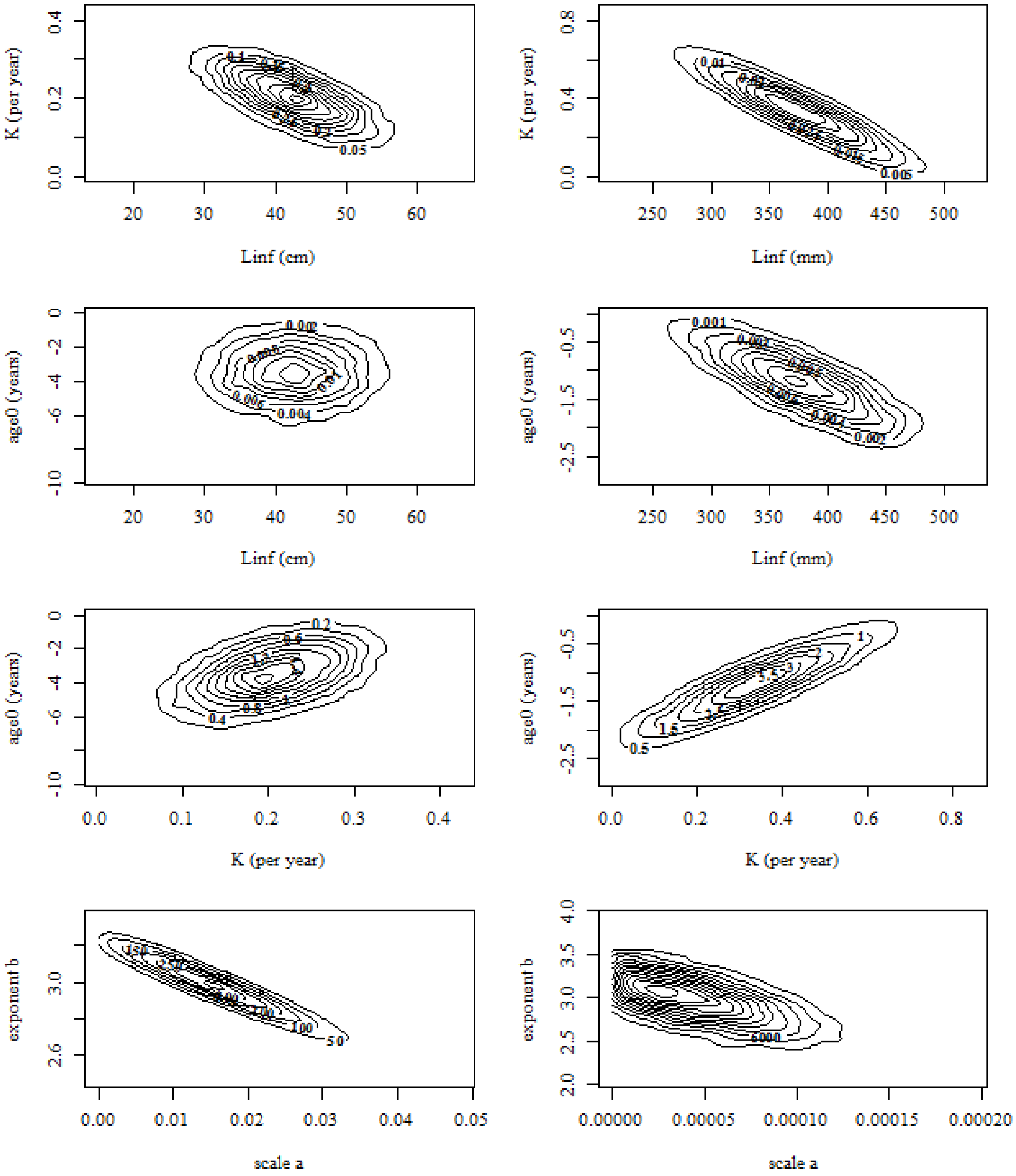


Fig. A2:2 Isopleth contours showing relationships between the growth parameters for Atlantic croaker (left panel; the number of draws producing the scale *a* > 0 and age-0 < 0, n+, is = 9394) and spot (right panel; n+ = 7632).

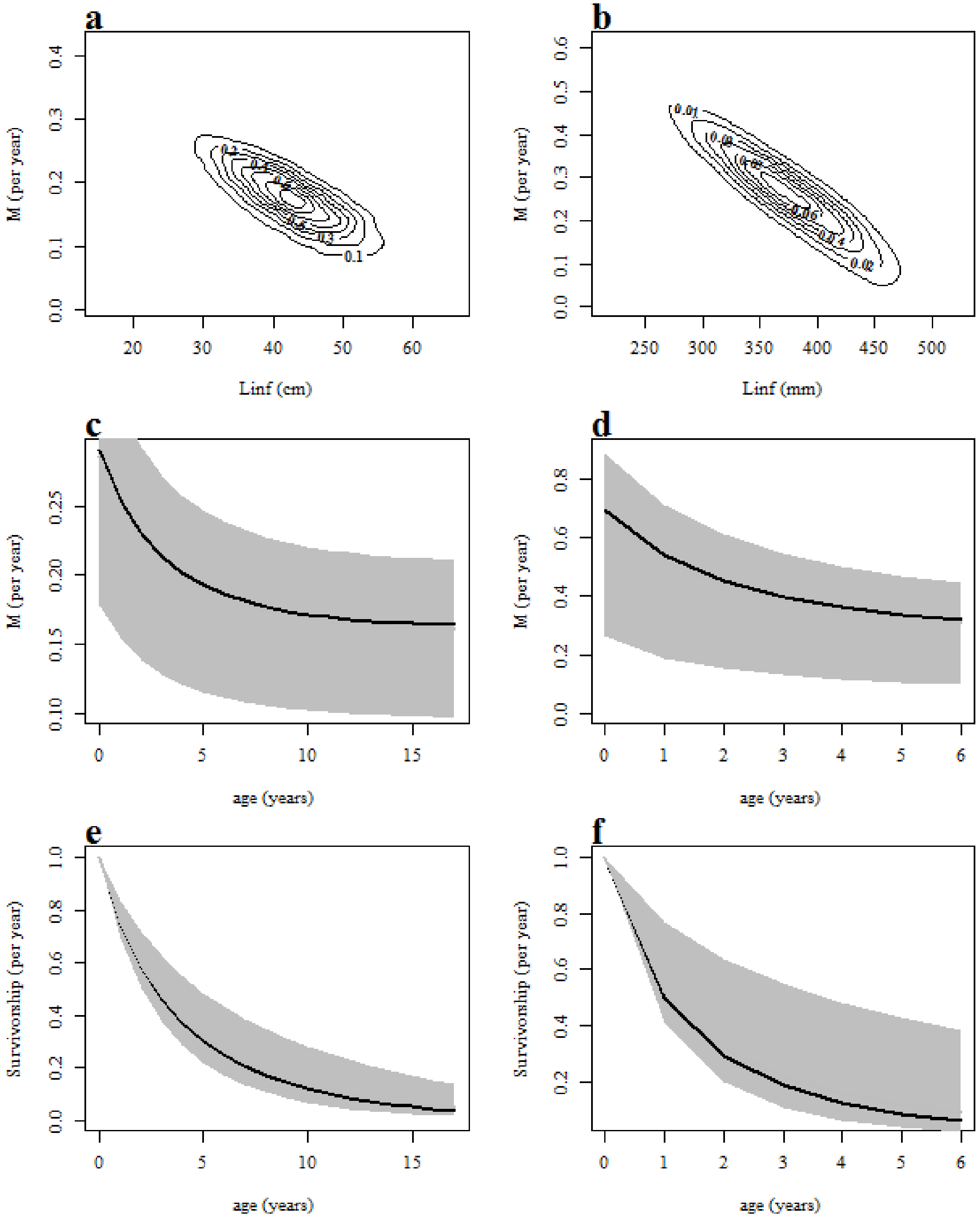


Fig. A2:3 Relationships between (a, b) the realized natural mortality (*M*) and L_∞; trajectories of median (black line) and 95% confidence intervals (gray color area) of (c, d) age-specific natural mortality and (e, f) survivorship for Atlantic croaker (left panel) and spot (right panel).

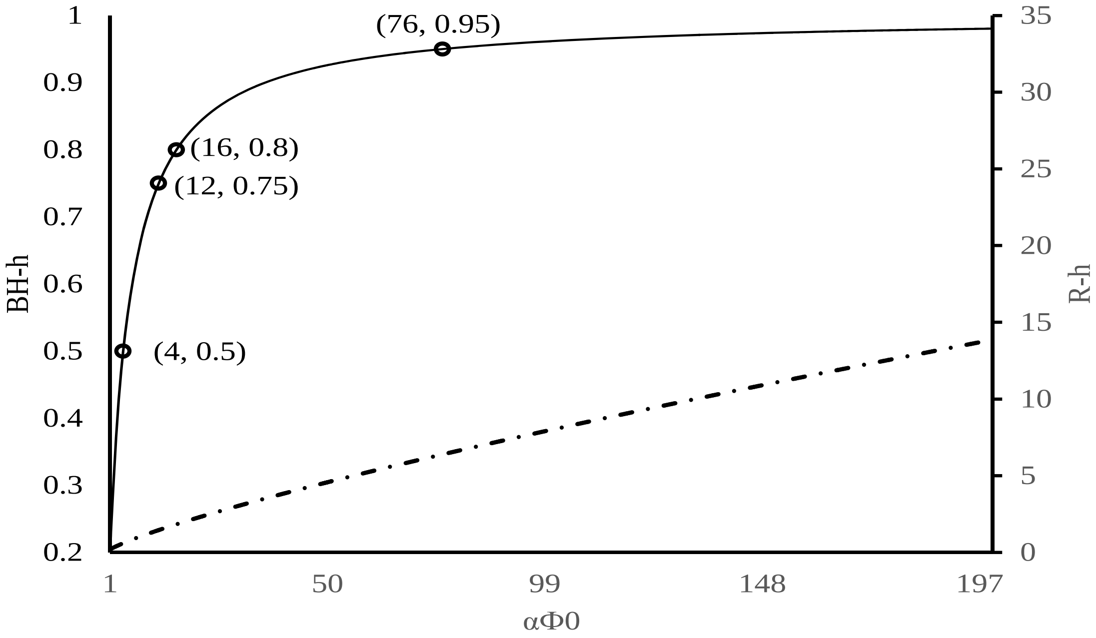


Fig A2:4 Curves for the BH–SRR steepness (BH–h) and R–SRR steepness (R–h) in relation with the maximum lifetime reproductive rate (a.k.a. Goodyear recruitment compensation ratio), $\alpha\Phi_0$. The selected coordinates for the BH–SRR relate to some commonly-assumed values of steepness.

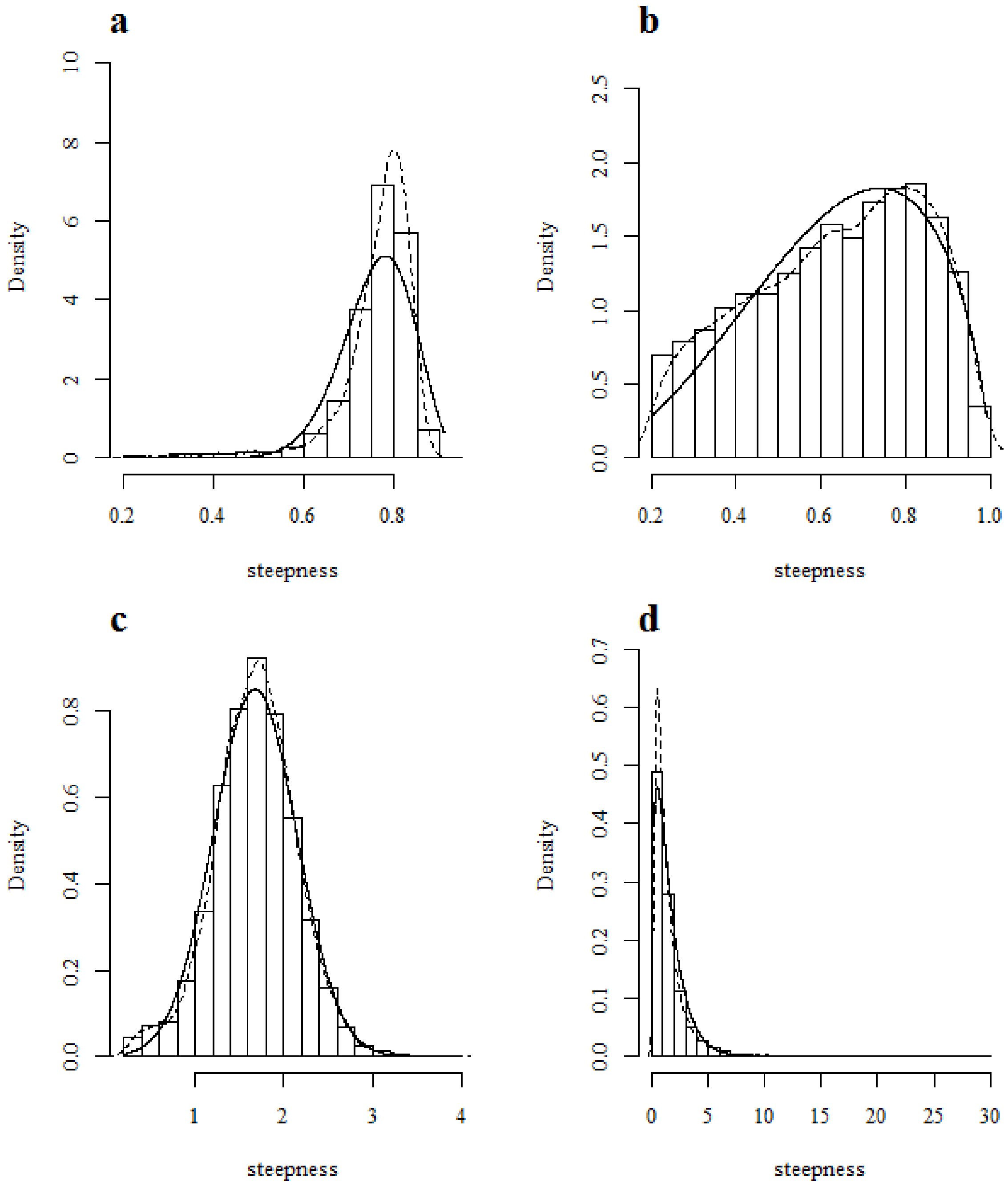


Fig A2:5 – Frequency histograms of steepness along with empirical (dashed lines) and parametric (solid lines) density functions fitted to those data for (a, b) the BH–SRR and (c, d) the R–SRR for Atlantic croaker (left panel) and spot (right panel) off the U.S. Atlantic coast.

Appendix 3. Traffic Light Analysis

Traffic Light Analysis of Atlantic Croaker: Alternate Model for 2017 ASMFC Stock Assessment
C. McDonough (SCDNR) and H. Rickabaugh (MD DNR)

INTRODUCTION

The Traffic Light method (TLA) was originally developed (Caddy and Mahon, 1995; Caddy, 1998, 1999) as a precautionary management framework for data poor fisheries whereby reference points could be developed that would allow for a reasonable level of resource management. The name comes from assigning a color (red, yellow, or green) to categorize relative levels of different indicators of the state of either a fish population or a fishery. These indicators can be combined to form composite characteristics within similar categories and can include biological indicators such as growth and reproduction, population level indicators such as abundance and stock biomass estimates, or fishery indicators such as harvest/landings and fishing mortality. However, each indicator must be evaluated separately in order to determine its appropriateness for use in a management scheme.

The purpose of developing the TLA for Atlantic croaker within the assessment was to provide a second alternative model from which comparisons could be made to the preferred model (SS3). It is important to note that while the TLA does provide a management guidance framework based on different index metrics, it does not provide population level parameters such as biomass (B_{msy}) spawning potential ratios (SPR) or fishing mortality (F_{msy}), so its utility for providing stock specific fishery parameters is limited. However, the ability to illustrate trends in different fishery or population parameters (abundance, landings, etc) is useful to compare to more rigorous population models such as the model produced in SS3.

METHODS

The specific TLA model used is the fuzzy traffic light model. In the fuzzy traffic light model, we use boundary reference points to determine the relative proportion of each color that includes the buffer (yellow) zone based on the upper and lower 95% confidence intervals from the index values for either the entire data series or a pre-determined reference period (Halliday et al., 2001). In the case of this assessment we are using the 1996-2008 reference time period established in Addendum II of the Atlantic croaker FMP (ASMFC 2014). This is done by setting the mean index value at 1.0 for yellow and 0.0 for both red and green as this is the exact center of the buffer zone. The 0.5 proportion value for all three colors is set at the mean index value minus the lower 95% confidence interval (CI) (red and left yellow leg) and the mean index value plus the upper CI (green and the right yellow leg). Finally, the value of 1.0 is set for red at the mean index value minus 2X the lower CI or zero, if the index mean minus 2X the lower CI is a negative number. For green the 1.0 value is set at 2X the upper 95% confidence limit. Once the known index values at the proportion values for each color are determined, the relative color proportions for each year can be estimated via linear regression using the annual values of the index. Any negative values are reset to zero and the proportion of yellow are set at 1 minus the color proportion for either red or green in that year. This allows a better illustration of the annual trends within a given color and whether or not values are approaching levels of concern about the reference boundaries.

Composite figures of combined indices can then be created using the color proportion tables from each individual index. These indexes are additive and the total index is re-scaled to 0-1. It is possible to add weighting factors to each index via the color proportion tables if necessary, although in practice indexes are commonly weighted prior to being run through the TLA. This type of composite index is what Halliday et al. (2001) referred to as a Characteristic, while the individual indices that make it up are the Indicators.

Fishery Dependent Data

For the fishery dependent data there were two separate sets of indicator data. The first was harvest or landings data by weight (in metric tons) and the second was discard data, also by weight in metric tons.

The landings data indicators included commercial landings, recreational harvest and scrap fishery landings (NC and VA only). Under the current TLA management trigger scheme, only commercial and recreational landings are used.

The discard indicator data sets included estimated annual discards from the south Atlantic shrimp trawl fishery, mid-Atlantic gill net fishery, mid-Atlantic trawl fishery, and recreational discards. None of the discard indicators are currently used for the annual management trigger exercise. In fact, this assessment is the first one to do a comprehensive analysis of discard data from all available sources. The inclusion of the discard data in future management trigger considerations will have to be examined once the assessment is completed. The purpose of this Appendix report was to address the comparison of the SS3 model output with the current TLA management trigger scheme (TOR number 9). However, additional material that includes the discard and bycatch removals is included for informational purposes as well as “total removals” composite TLA index which included removals from all fishery dependent sources.

Mortality for the shrimp trawl, gill net and mid-Atlantic trawl fisheries was set at 100% as bycatch discard were typically released dead in these fisheries and there was no other available estimate of discard mortality. The recreational discard mortality was set at 15% as determined by the Stock Assessment Subcommittee at the Assessment workshop. The recreational discard index used was the estimated annual discards lost through mortality. All of the discard indices were treated as part of the total removals from the stock, along with the harvest landings.

Fishery Independent Data

The fishery independent indicator data included survey data from the NCDMF, NMFS, VIMS and SEAMAP. The reference time period (1996-2008) was the same as that used for the fishery dependent data sets. The NMFS and SEAMAP data sets were used for all age class (primarily adults), and the NCDMF and VIMS data sets were for YOY only.

Additional fishery independent data sets used in the assessment included the ChesMMAP and NEAMAP surveys. However, these data are not used in the current TLA management trigger scheme because of their shorter time periods. They will likely be considered for future use in the TLA trigger scheme once the assessment is completed. The data presented on these data sets using the TLA was for informational purposes in order to compare how the TLA compared with the SS3 model results.

RESULTS

Fishery Dependent

The harvest landings data characteristic indicated high proportions of red through the 1980s and early 1990s, with the proportion of red decreased through the late 1990s (**Fig. 1**). Color proportions were predominantly yellow with some green through the mid-2000s, before reverting to steadily increasing proportions of red through 2014. Under the current management trigger guidelines for Atlantic croaker (ASMFC 2014) the landings characteristic would have triggered from 2012-2014 with the three consecutive years average at or exceeding the 30% threshold indicating moderate management concern. The trigger guidelines require both the harvest and fishery independent composite characteristics to trip in the same time frame to initiate a management response. The female SSB estimates from the SS3 model indicate an increasing trend the past several years. This contradicts the assumption of a decreased availability of harvestable stock suggested by the TLA harvest characteristic over the same time period.

Adding the scrap fishery landings to the harvest landings composite demonstrated the effect of adding additional indexes to the composite characteristic. The scrap fishery landings for Atlantic croaker have been steadily declining since the mid 1990s, and as a result of the low scrap landings in recent years, the red proportions declined for the last several years putting the index below the 30% threshold (Fig. 2). This is solid evidence that the indexes used in the TLA must be carefully vetted for scale and contribution to the overall harvest. In the case of the scrap landings, the scale of the scrap landings compared to the recreational and commercial harvest would make the argument for a weighting or standardization scheme among the indexes a good idea. Adding the scrap landings into the harvest composite does move the TLA model back towards the increasing trend seen in the SSB estimates from the SS3 model, however there was still red present in recent years where the relative levels of SSB might indicate more green likely.

The fishery discard characteristic is not included in the TLA management guidelines, since the first consistent time series of estimates was developed for this assessment. The color proportion were assigned so higher levels of discards were red, and lower levels green. This is the opposite of the way the TLA colors are usually assigned. This was done because while increased harvest levels were generally an indication of increased available abundance (assuming constant effort), when discards are small, the resulting biomass lost prior to recruiting to the directed fisheries is less, which is really a positive indication and thus assigned green in the TLA. High levels of bycatch would indicate the opposite (thus assigned red in the

TLA) with higher bycatch levels indicating higher removals from the fishery. The annual proportion of red in the discards characteristic was highest in the beginning of the time series, which coincides with the time period prior to BRDs being implemented (Fig. 3). Color proportions were more variable from the mid-1990s to the mid-2000s, with higher proportions of yellow and green. Recent years have included higher red proportions, with 2012 and 2014 exceeding the 30% threshold. One important factor in the discard composite to note is that the three discard indices (shrimp fishery, commercial fishery, and recreational fishery) were not weighted in any way for the composite characteristic. Since the shrimp fishery made up approximately 98% of total discards annually over the entire time frame (1989-2014), the composite discard characteristic does not necessarily show how the index was driven specifically by the shrimp fishery discards. This, again, illustrates the need for a weighting scheme for combining all of the discards. However, this issue is beyond the current scope of this assessment and needs further study.

Figure 1. Annual fishery dependent TLA landings characteristic (commercial and recreational) for Atlantic croaker on the Atlantic coast of the USA for 1981-2014 (1996-2008 reference period).

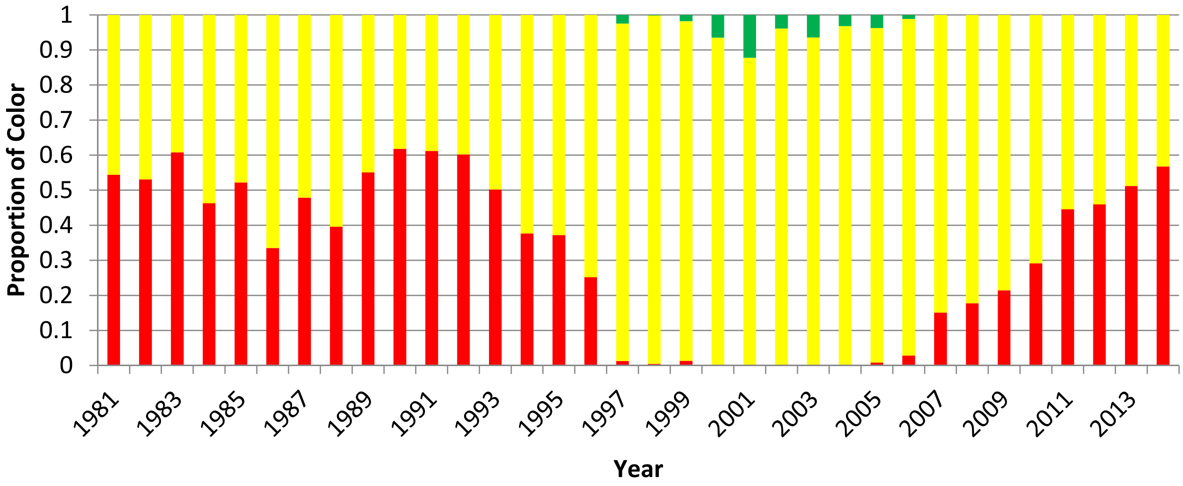


Figure 2. Annual color proportions for harvest composite TLA of Atlantic croaker recreational, commercial and scrap fishery landings

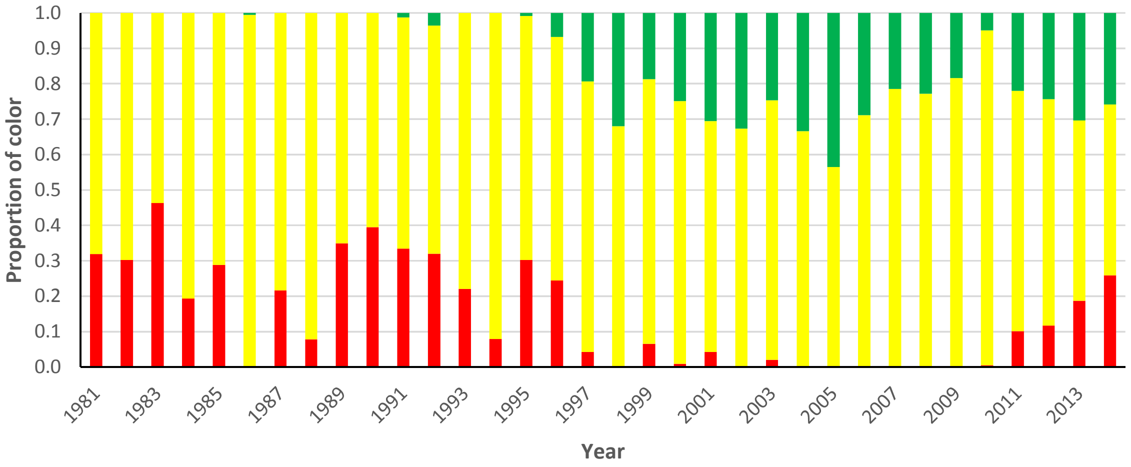
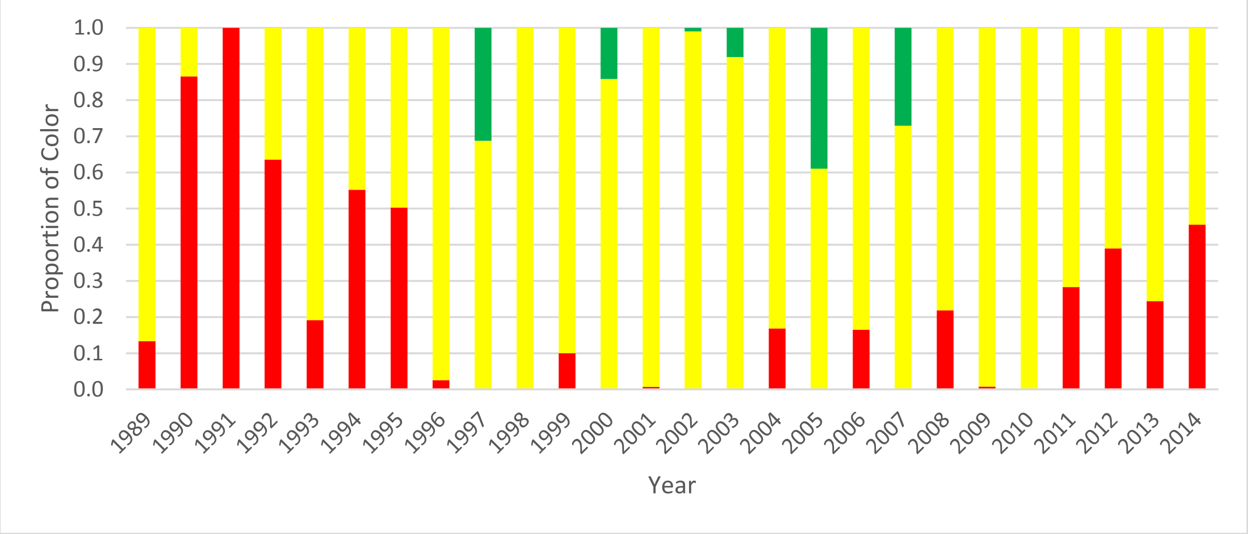
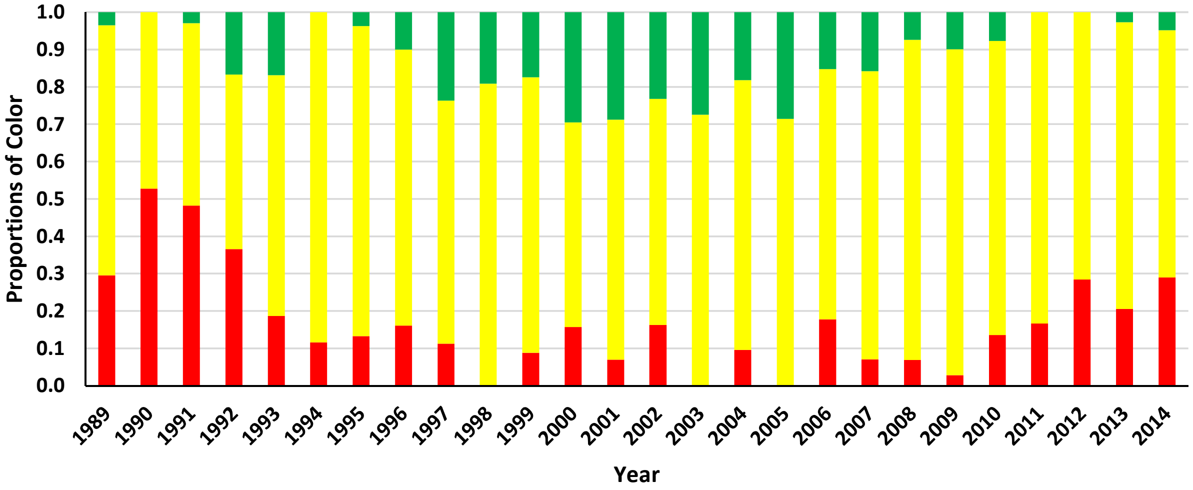


Figure 3. Annual fishery dependent TLA fishery discards characteristic (shrimp trawl fishery, mid-Atlantic gill net, mid-Atlantic trawl and recreational dead discards) for Atlantic croaker on the Atlantic coast of the USA for 1989-2014 (1996-2008 reference period).



When the landings characteristic was combined with the discards characteristic to form a "total removals" characteristic, the resulting TLA (Fig. 4) indicated elevated red proportions approaching but not exceeding the 30% threshold since 2012. While this in and of itself was not direct indication of whether Atlantic croaker were being overfished or overfishing was occurring, it does show an increased impact of total removals along the Atlantic coast by the upward trend in the proportion of red. The decreased red proportions in the total removal characteristic below the 30% threshold does bring the TLA more in line with the SS3 results showing that Atlantic croaker were not overfished and that overfishing was not occurring (if that standard was applied to the TLA).

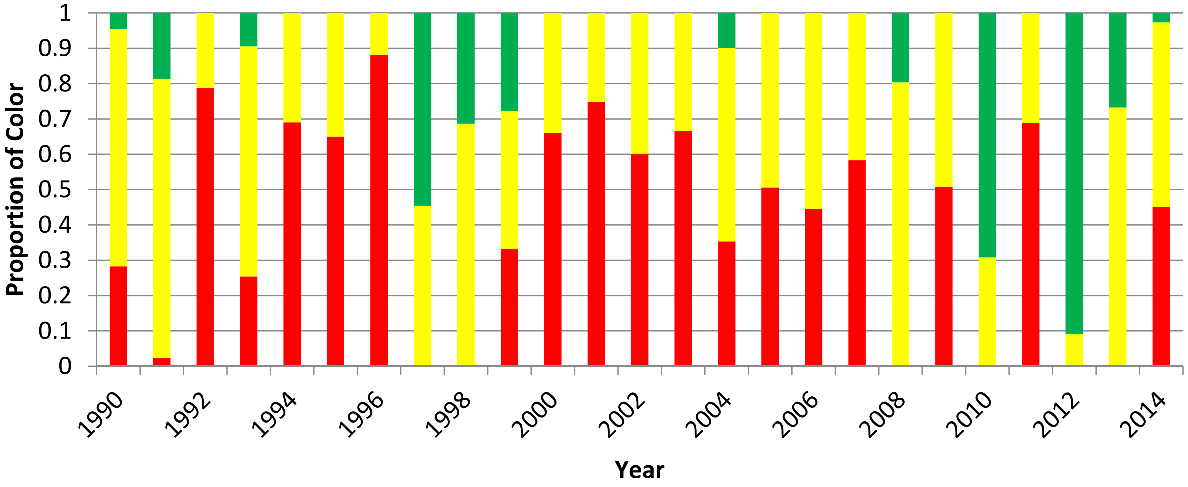
Figure 4. Combined composite TLA characteristic of total annual removals, harvest and fishery discards for Atlantic croaker on the Atlantic coast of the USA for 1989-2014 (1996-2008 reference period).



Fishery Independent

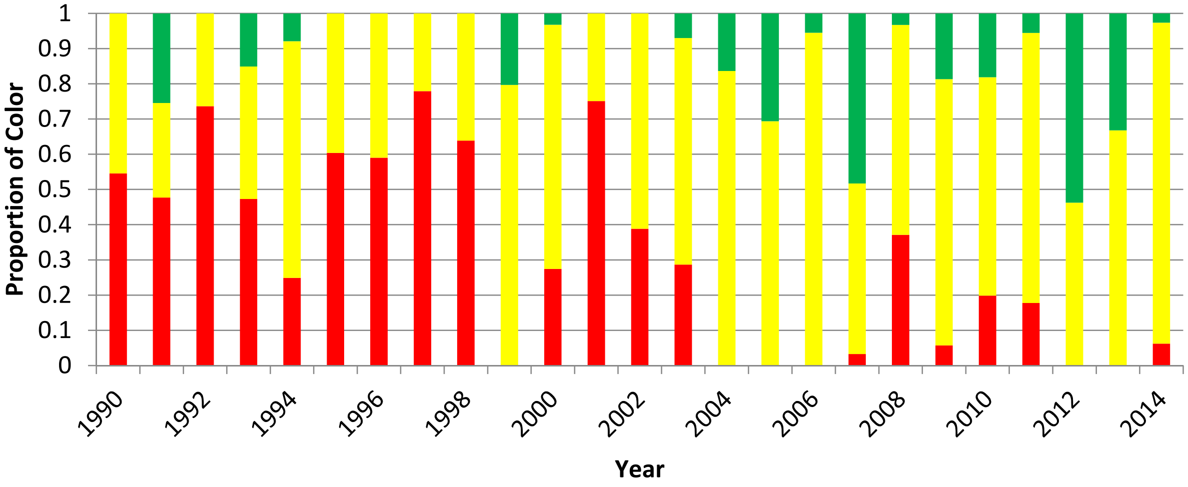
The fishery independent survey characteristic for age 0 Atlantic croaker indicated high inter-annual variability in the red proportions (Fig. 5), which was likely due to annual recruitment variability and year-class strength. Proportions of red were above 30% from 1999 to 2007, indicating a period of sustained below average recruitment. Recent years have been more variable with 2010 and 2012 having the highest proportions of green in the time series. The SS3 model did not match these trends exactly but did indicate sustained low to moderate recruitment in the middle of the time series, and higher recruitment levels from 2011 to 2013.

Figure 5. Annual fishery independent TLA for age 0 Atlantic croaker on the Atlantic coast of the USA using survey data from NCDMF and VIMS (1996-2008 reference period).



The survey index characteristic for adult Atlantic croaker (Fig.6) indicated high annual proportions of red early in the time series, and higher proportion of green in the later part of the time series. In general annual proportions of red exceeded the 30% threshold for adult Atlantic croaker for most of the 1990s, six years exceeding 50%. The elevated levels of green for adults from 2004 through 2007, conflict with the age 0 indices indicating poor recruitment prior to and during that time period. The SS3 model's increasing estimates of female SSB are similar to the trend of the fishery independent characteristic.

Figure 6. Annual fishery independent TLA for adult Atlantic croaker on the Atlantic coast of the USA using survey data from NEFSC (NMFS) and SEAMAP (1996-2008 reference period).

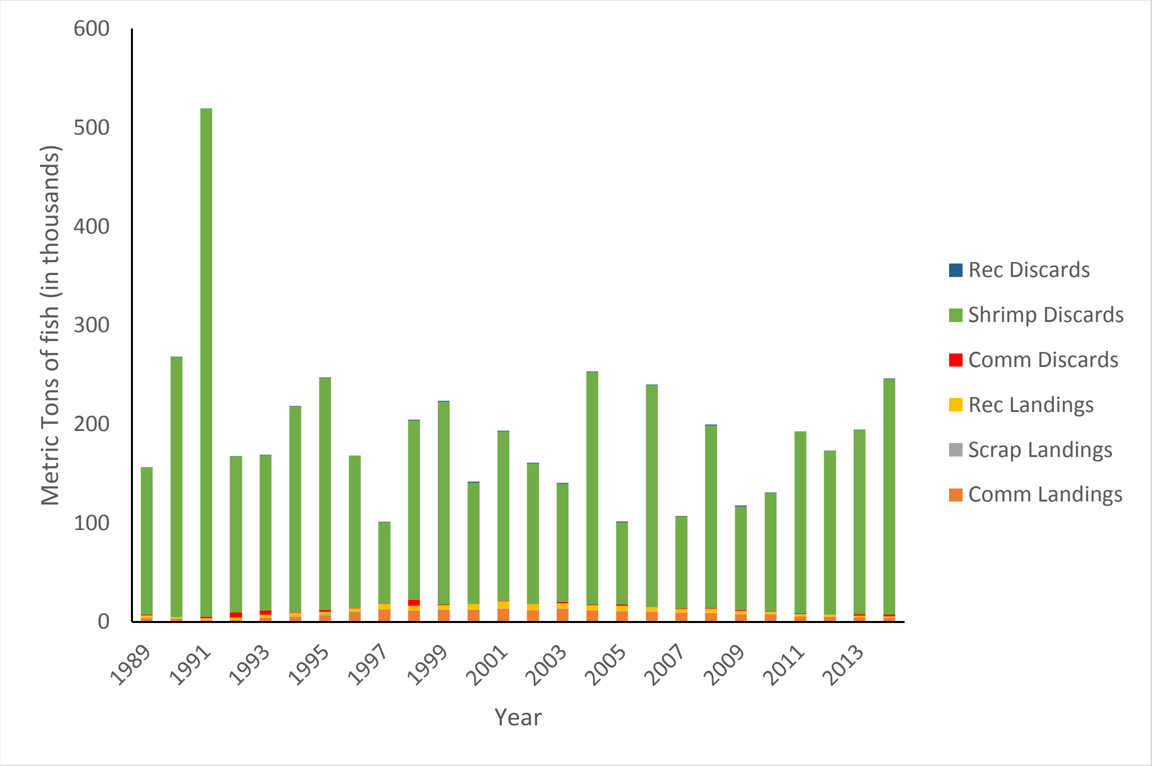


Summary

The Atlantic croaker TC has noted the conflicting signal given by the TLA harvest and adult abundance characteristics the past few years. When examining age structure of the harvest vs fishery independent data, the harvested fish (excluding discards and bycatch) tend to be older than those captured in the independent surveys. This could help explain the differences in the trends, since they are not tracking the exact same population segments. While an in depth examination of effort has not been conducted, primarily due to insufficient / inconsistent data, the TC has assumed there has not been a significant decline in overall effort. The only known decrease in commercial effort is in the NC fly net fishery, due to logistical constraints. Dock side value has not decreased, and there is no evidence that either commercial or recreational interest in harvesting Atlantic croaker has declined.

The SS3 model accounts for all removals and uses the same two fishery independent indices to track trends in adult abundance as the TLA. Since shrimp trawl discards far exceed direct removals, and have increased in recent years (Fig. 7), the SS3 model does not pick up on the declining trend in directed harvest indicated in the TLA's harvest characteristic. It instead couples the increasing landings and index values to estimate higher overall abundance. If these estimates are correct they are not resulting in higher availability of biomass to the directed commercial and recreational fisheries. Since the independent trawl surveys are indexing younger fish than those being harvested, and the majority of removals are pre recruits from the shrimp trawl fishery, it is possible that a reduced proportion of fish are reaching older ages, and becoming vulnerable to harvest. There also could be shifts in migration patterns leading to a higher proportion of the stock reaming outside the estuaries for a greater part of the year. Thereby decreasing vulnerability, since the majority of harvest is form inshore waters.

Figure 7. Total annual removals of Atlantic croaker by fishery on the Atlantic coast of the United States.



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Appendix 4: Atlantic croaker surplus production model description

A surplus production model was developed for Atlantic croaker as an exercise but was not considered by the Atlantic croaker stock assessment subcommittee to be a candidate model for the assessment report. Upon request by the review committee, the following results of the surplus production model were supplied.

The non-equilibrium Schaefer, or logistic, form of the surplus production model (ASPIC; Prager 1994) was used as a secondary, supporting model for Atlantic croaker. Briefly, this analysis used two fishery-independent surveys, the fall portions of the NMFS trawl and SEAMAP, as well as the complete harvest data. Both survey indices were calculated in weight (kg) per unit effort and were weighted equally in the model. The indices were tested for correlation and were found to be positively correlated (r=0.15) but not significantly (p=0.48).

Coast-wide total harvest was calculated in weight (mt) from 1989-2014 from commercial and recreational landings, recreational discards, commercial discards from mid-Atlantic gillnet and trawl fisheries, landings from the scrap/bait fishery, and bycatch from the shrimp trawl fishery (Figure 1).

Parameter and projection estimates:
The surplus production model fit the general trend of the NMFS and SEAMAP abundance indices (Figures 2 and 3). The model estimated that average biomass has been increasing steadily over the time series and has remained stable since 2008. The largest average biomass was in the terminal year of the model, 2014. Production model estimates of total fishing mortality were at their highest in 1991 (F=0.41) and have been on a steady decline since then, with the lowest value of the time series in 2005 (F=0.01).

Population status:
Based on the production model, current fishing mortality on Atlantic croaker appears to be sustainable and it is unlikely that overfishing is occurring. The ratio of F/F_{MSY} has been under 1 since 1992 and is currently low at $F_{2014}/F_{MSY} = 0.1492$. Biomass estimates also indicate that the population of Atlantic croaker is likely not overfished in recent years. B/B_{MSY} has been greater than 1 since 2000, but has been on the increase since then with the highest value in 2014 (B_{2014}/B_{MSY}=1.8830).

The parameter of B1/K was inputted in the model with a starting guess of 0.5, the suggested ratio. The model estimated B1/K to be 0.1053.

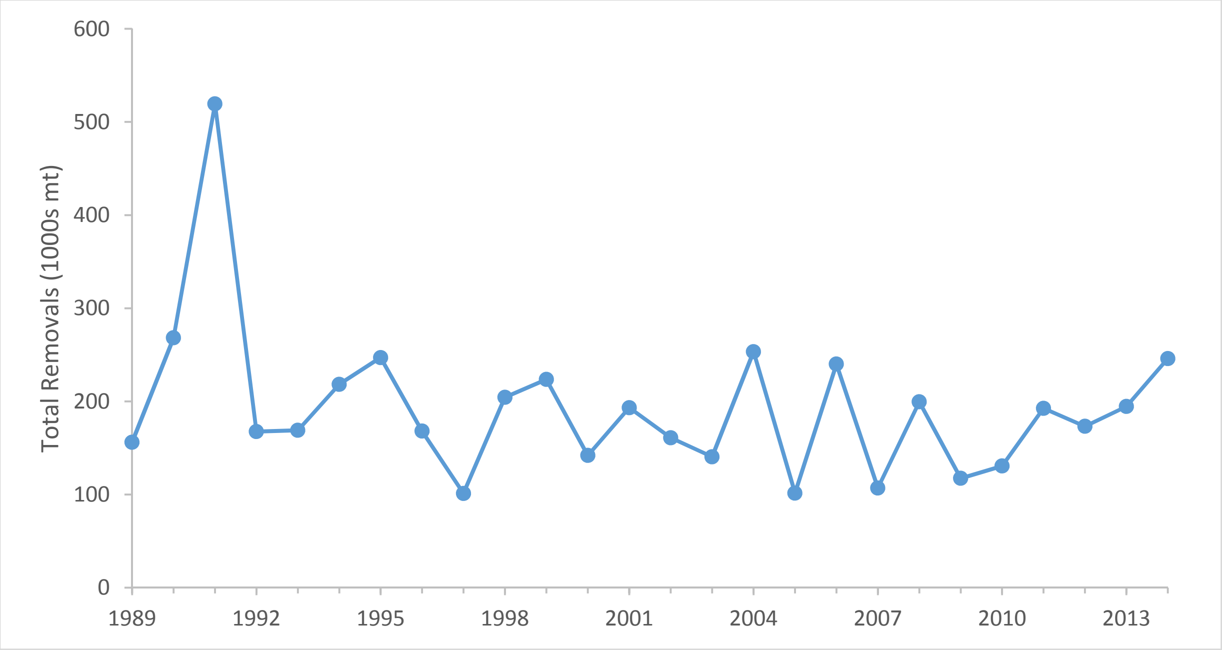

Figure 1. Total removals of Atlantic croaker.

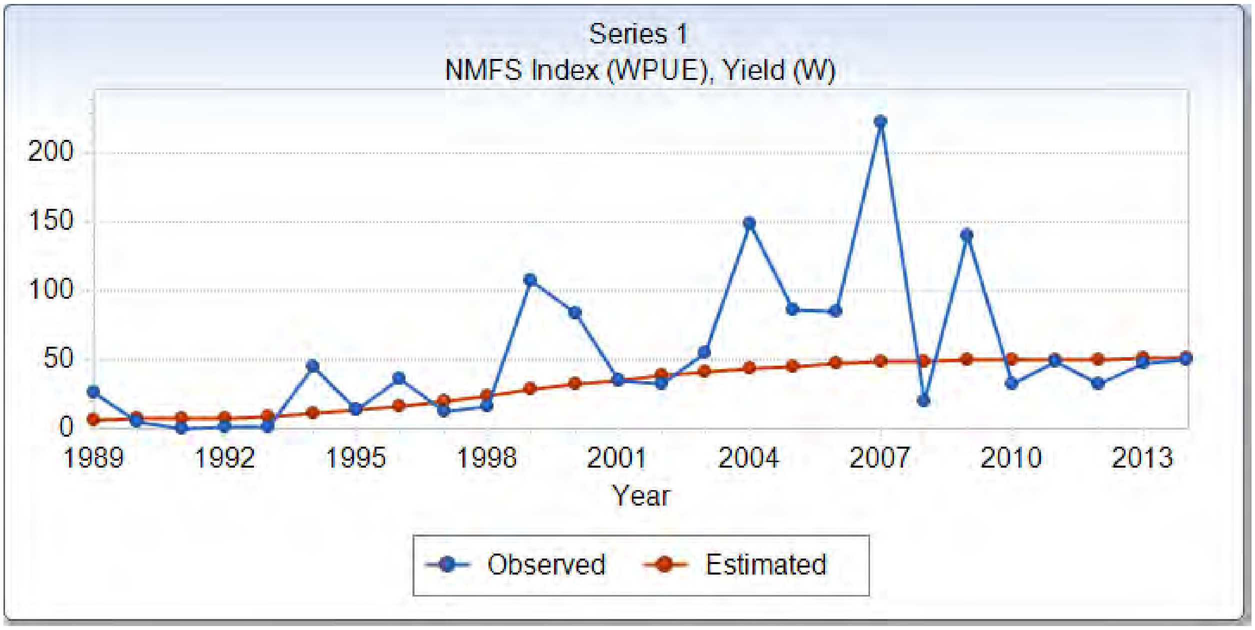

Figure 2. The surplus production model fit to the NMFS index.

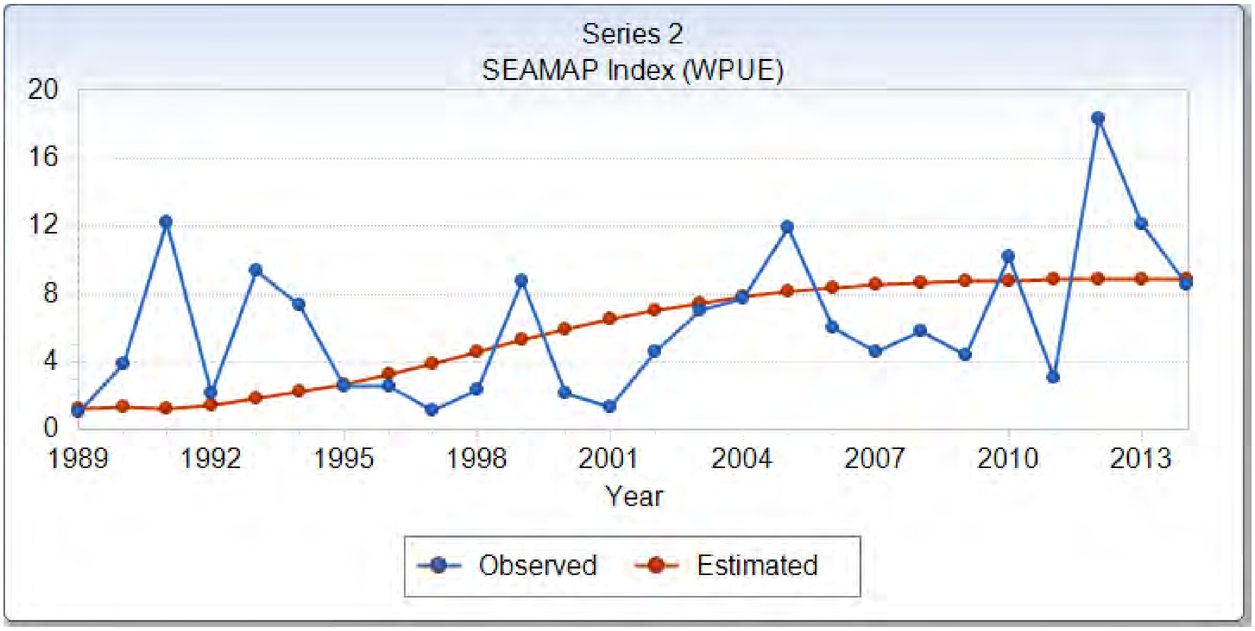

Figure 3. The surplus production model fit to the SEAMAP index.

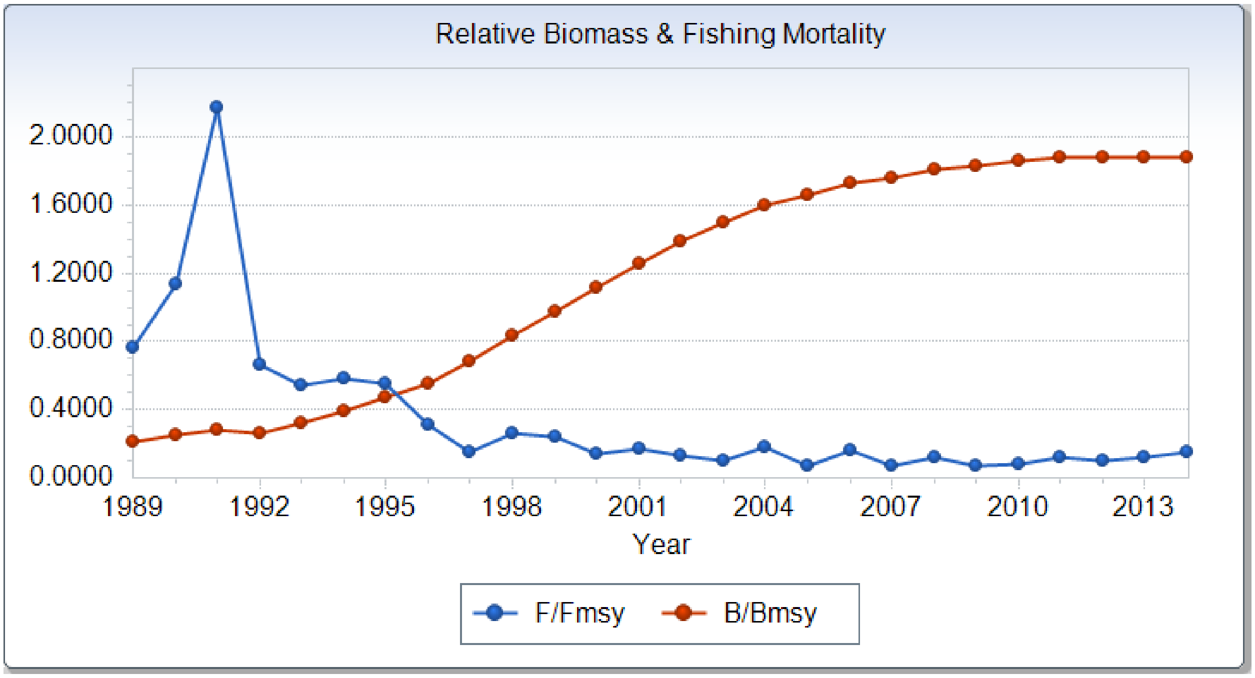

Figure 4. Estimated relative biomass and fishing mortality of spot from the Atlantic croaker surplus production model.

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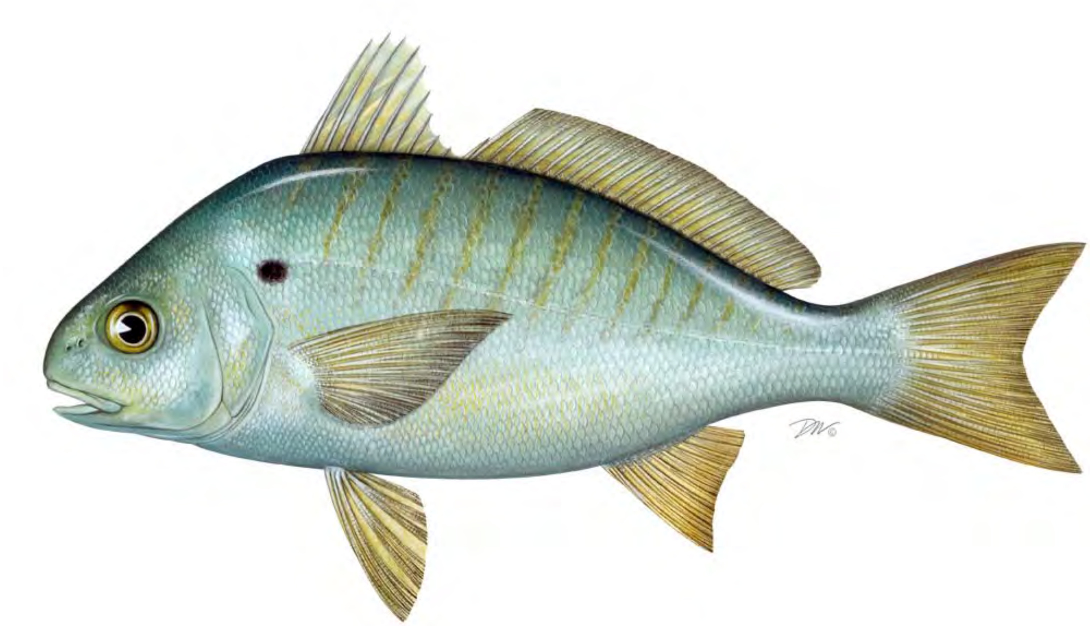
Atlantic States Marine Fisheries Commission

2017 Spot Stock Assessment Peer Review



May 2017

Vision: Sustainably Managing Atlantic Coastal Fisheries

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Atlantic States Marine Fisheries Commission

2017 Spot Stock Assessment Peer Review

Conducted on
April 18-21, 2017
Raleigh, North Carolina

Prepared by the
ASMFC Atlantic Croaker and Spot Stock Assessment Review Panel

Dr. Ken Able, Rutgers University, Institute for Marine and Coastal Science
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Executive Summary

Spot are caught in commercial and recreational fisheries, primarily in the Chesapeake Bay and Mid-Atlantic (New York-Virginia) and South Atlantic (North Carolina-Florida) coastal waters. The majority of annual fishery removals of spot were discards in South Atlantic shrimp trawl fisheries, followed by commercial landings and recreational harvest. Data to estimate discards in South Atlantic shrimp trawl fisheries were available starting in 1989 and the terminal year of data for this assessment was 2014. From 1989-2014, total annual removals of spot from all fishery sources (landings and discards) have ranged from between 4,637 and 57,287 metric tons, or 41 and 1,324 million fish. Removals were relatively large, but variable in the 1990s. Removals since 1997 have been relatively stable, coinciding with the requirement of bycatch reduction devices (BRDs) across shrimp trawl fisheries. The long term mean removals were 12,785 metric tons, or 254 million fish. However, total removals after the peak year that occurred in 1991 averaged 9,399 metric tons, or 158 million fish.

Indices of relative abundance from the NMFS Trawl Survey and the NCDMF Pamlico Sound Trawl Survey were used in the preferred stock assessment model (modified-CSA model). The indices generally suggested a period of low abundance through the 1990s and early 2000s, followed by increasing abundance in the late 2000s and 2010s. There was a decline across indices in the assessment terminal year (2014).

Although the current stock status could not be inferred with confidence, the Panel noted that the models generally suggested spawning biomass was increasing. Therefore, the Panel agreed no immediate management actions are required. However, monitoring of abundance indices, removals, and age/length composition should continue (Traffic Light Analysis). If new information suggests the stock could be declining, a new assessment should be expedited.

The Panel noted the uncertainty of the stock assessment outcome was due to inherent data uncertainties, and to conflicting information regarding population trends contained in the various data components. The Panel agreed the assessment used the best available information, all significant removals were incorporated, the data analyses conducted were based on current best practices, the structure and application of the assessment model appeared reasonable, and that important uncertainties were identified and explored.

Terms of Reference

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

The Review Panel commended the analytical team for their concise and comprehensive presentation of data inputs used in the stock assessment. The Panelists agreed the written report and summary presentations were unusually complete which greatly facilitated evaluation.

All major sources of removals of Spot were thoroughly described including: discards in the shrimp trawl fisheries, commercial landings, and recreational harvest. Discards from the shrimp trawl fisheries accounted for 31-70% of annual removals, commercial landings for 10-40% most years, while recreational harvest typically accounted for approximately 10% each year. The remaining sources of fishery removals were typically 5% or less of total annual removals over the last 20+ years (e.g., scrap fishery). The assessment period was 1989-2014. This timeframe was used because fishery dependent and independent data sets were more widely available. The Panelists noted that important removals began much earlier than 1989. Therefore, it may be useful to attempt to recover or estimate historical removals to improve initial estimates of depletion in the stock assessment.

Data strengths and weaknesses – temporal and spatial scale, sample sizes, coefficients of variation (CV) – were described in the stock assessment report, and input directly in assessment models when possible with an adjustment applied for the CVs of the indices. The justification for inclusion or elimination of available data sources was evaluated, particularly criteria for inclusion of abundance indices. A total of 35 fishery-independent surveys that encountered Spot were reviewed during the assessment. Of these, five met most of the criteria for inclusion. The criteria included the length and continuity of the time series, the spatial scale (population-wide/regional/local) and the constancy of survey methodologies. The Panelists agreed index selection criteria were adequate and suitably applied. The base model application (Catch-Survey Analysis or CSA Model) used indices of abundance for Age 0 and Age 1+ Spot from two sources, the NMFS NEFSC Groundfish Trawl Survey and the NCDMF Pamlico Sound Trawl Survey. The effect of index selection was explored through sensitivity runs.

Some potential data sources were not considered during the assessment, including fishery-dependent catch rate indices and annual effort estimates from the commercial and recreational fleets. It was not mandatory to include these inputs in the assessment, and some reviewers would not recommend including fishery-dependent indices in assessment models if high quality fishery independent indices are available. However, the availability of fishery-dependent catch-per-unit-effort (CPUE) inputs may have facilitated better interpretation of the commercial and recreational catch series in the context of increasing stock biomass predicted by the assessment model. I.e. catch in some fisheries has declined while the indices of abundance have increased. Typically, catches are expected to increase with increasing population abundance.

All but one of the indices of relative abundance were developed using a statistical standardization (e.g., delta-logormal, negative-binomial). The exception was the NMFS/Northeast Fisheries Science Center fall groundfish trawl survey which was a non-standardized, nominal index developed from design-based estimates. The Panelists noted many expert reviewers recommend a non-standardized approach, but also suggested that a standardized index be developed for future assessments, and that the sensitivity of the model results to these alternative approaches be considered.

Spot are an important component of Atlantic coast scrap (bait) landings. Quantifying the amount of spot landed as scrap fish along the coast is problematic due to the limited availability of sampling data. The Panel agreed the methods used during the assessment appear reasonable, but noted the resulting estimates from the scrap fishery are quite uncertain due to the number of required assumptions. However, as the magnitude of scrap landings is very small relative to total removals, the Panel agreed the assessment is not likely to be sensitive to these assumptions.

2. Evaluate methods used to develop discard and bycatch estimates.

Estimates of spot discard rates in South Atlantic shrimp trawl fisheries were developed using discard rate data from the Shrimp Trawl Observer Program to estimate the magnitude of discard rates and the SEAMAP Trawl Survey to estimate the trend of discards prior to (1989-2000) and during the observer program (2001-2014). Discard rate estimates were then applied to effort data from state trip ticket programs and the South Atlantic Shrimp System (SASS) to estimate total discards in these fisheries from 1989-2014 (Walter and Isley, 2014). Discard rates were applied to effort estimates summarized by “strata” (combinations of factors included in the model). Because there were no observer data before Bycatch Reduction Devices (BRDs) were required in the penaeid shrimp fishery, discard estimates prior to 1997 were adjusted for the reduction in catch due to the required use of certified BRDs on observed tows. Adjustments were based on a weighted average of Atlantic croaker catch reductions in the Gulf of Mexico shrimp trawl fishery estimated depending on the distance of fisheye BRDs from tie-off rings (Helies et al. 2009).

Discards from the Mid-Atlantic gill net and trawl fisheries were estimated using observer data from the Northeast Fisheries Science Center’s Northeast Fisheries Observer Program (NEFOP) and At-Sea Monitoring Program (ASM). Annual ratios of observed discarded spot to observed landings of all species by gillnets and bottom trawls were calculated, then applied to reported gillnet and bottom trawl landings of all species to estimate total discards of spot.

The Panelists recognized discard/bycatch estimates are unusually uncertain due to data insufficiencies, but agreed the method used to develop estimates of spot bycatch from the southern shrimp trawl fishery was current, supported, and similar (or identical) to methods used in SEDAR assessments of South Atlantic king mackerel, and Gulf of Mexico red snapper, king mackerel, gray triggerfish and domestic sharks. The Panel also agreed the method used to estimate spot discards from the commercial and recreational fisheries were acceptable given the available data, and noted the relatively small contribution of these discards to total removals.

3. Evaluate the methods and models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, including but not limited to:

a. Evaluate the choice and justification of the preferred model(s). Was the most appropriate model (or model averaging approach) chosen given available data and life history of the species?

The Assessment Team chose a catch-survey analysis (CSA) model as their preferred base model. The Review Panel agreed with the choice of the CSA model over the surplus production model because the CSA model uses more of the available information. However, the Review Panel also noted that the CSA (and production model) results did not follow the same pattern as catch-curve estimates of the total mortality rates; catch curves indicated relatively stable total mortality, while the CSA model indicated declining total mortality. Additionally, the CSA model had some difficulties reconciling differences in trends between the two primary indices, which was why the models that allowed catchability to change over time improved the model fits. The NMFS trawl survey index of Age 1+ biomass indicated about a 6.4X increase between 1990-1993 and 2011-2014, while the SEAMAP index of Age 1+ biomass indicated about a 10% increase. Given the inherent conflicts in the data (among the indices) and the conflicts between the catch curve and CSA estimates of Z, a more complicated model that can make fuller use of the available data may allow future progress in spot stock assessments. In future efforts the Assessment Team may want to consider simple age-length structured models (e.g., SCALE) that can use all of the available data or a simple Stock Synthesis model.

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

The Assessment Team applied CSA and surplus production models. The base CSA model and the base surplus production model generally agreed on the trend and stock status determinations. The approach of fitting multiple models is considered best practices.

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

In general, the Review Panel agreed the approaches used by the Assessment Team for specifying the assessment models were appropriate and followed best practices. The Assessment Team used the approach of adding a constant to the CV of the index for each year to represent the process error in the indices of abundance. CSA models separate the population into pre-recruits (Age 0) and fully recruited (Age 1+) age classes, which seems reasonable for a short-lived species like spot. The Assessment Team used a maximum age approach combined with a Lorenzen size-based adjustment to calculate natural mortality, M. The CSA model included a Beverton-Holt stock-recruitment relationship. The base CSA model did not include time-varying parameters, but allowing catchability to change was explored in sensitivity analyses. These choices by the Assessment Team appear to be well founded and follow standard practices used in the region. One of the assumptions that caused fairly large changes in the results was whether catchability changes were allowed in the indices. See TOR 8 below for research recommendations from the Review Panel that would support research to better understand the need for time-varying catchability.

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

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

Sensitivity analyses were conducted for both assessment models including evaluations of sensitivity described in the Stock Assessment Report Table 95 for the CSA and sensitivity analyses around the assumed initial level of biomass relative to carrying capacity (i.e., initial depletion) for the surplus production model. During the Review Workshop, the Panel requested additional sensitivity runs for the penalty on total instantaneous mortality (Z) that was calculated outside the CSA, and alternative initial depletion levels. The CSA was sensitive to the time trend in Z because the catch curves indicated a relatively stable Z, but the model without the time series of Z values estimated declining Z. The model that used the time series of Z values resulted in the stock being overfished in the last year, while the CSA that only used mean Z during the period resulted in no concerns about stock status. The surplus production model was sensitive to the assumed initial depletion level and values of initial depletion below about 0.16 of carrying capacity resulted in the stock being overfished in the most recent year. However, the overfishing determination was less sensitive to these alternative assumptions.

b. Retrospective analysis

The Assessment Team conducted retrospective analyses for the base CSA model. The results of the retrospective analyses indicated no concerning patterns in estimates of static Spawning Potential Ratio (sSPR), fishing mortality, recruitment, or spawning stock biomass. The calculated Mohn's Rho statistics and visual inspection of plotted patterns are standard best practices used by the Assessment Team.

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

The Assessment Team used asymptotic standard errors and Markov Chain Monte Carlo (MCMC) to estimate uncertainty for the CSA. The Review Panel thought the asymptotic standard errors were a reasonable approach for quantifying uncertainty for this model. Although MCMC is a justifiable approach, there were some issues with its diagnostics for select parameters (particularly the parameters of the stock-recruitment relationship). Specifically, the chains for these parameters showed very high autocorrelation that indicates the distribution derived from the MCMC chain likely does not fully describe the distributions for those parameters.

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

The Review Panel recommends against using specific estimates of stock biomass, abundance, and exploitation for management purposes because of the sensitivity of the models to several key assumptions. Specifically, the differences in estimates were quite large between CSA models that used the time series for Z from models that only used the average Z value and indicated the estimates of abundance and fishing mortality rates were very sensitive to a range of reasonable assumptions. The surplus production model showed similar issues, but the key assumption appeared to be the initial level of depletion in 1989.

Despite the inability to arrive at a new base model, several patterns seem clear from the data:

1) The indices of abundance for spot appear to be stable or increasing across most of the stock's range.
2) Catch appears to be stable or declining over time.
3) The combination of these two patterns indicates it is likely that fishing mortality rates have also declined over time such that the relative status of the stock in the most recent years is likely better than it was in the late 1980s – early 1990s.
4) Shrimp fishery effort and spot bycatch magnitude appear to be declining. The Stock Assessment Subcommittee should consider adding shrimp bycatch estimates to annual Traffic Light analyses. The new estimates of shrimp bycatch are a notable improvement from previous spot assessments and should be reviewed annually given their substantial contribution to overall spot removals and mortality.

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

The Spawning Potential Ratio (SPR) reference points appeared to be appropriate for the species (30% threshold, 40% target) and are consistent with reference points used for similar species in the region. However, given uncertainties in fishing mortality and biomass estimates exhibited by the sensitivity analyses, stock status cannot be reliably determined. In particular, models with different sets of plausible assumptions resulted in estimates of biomass above and below the limit reference point. The result of whether the stock was overfished in the most recent year depended on how low stock size was at the beginning of the time series. In contrast, all of the models indicated that overfishing is unlikely in the most recent years and that stock size appears to be increasing over the time series.

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

The Panel thoroughly reviewed the research recommendations identified by the Technical Committee, and noted additional research and data collection priorities. Following discussions with the SASC at the Review Workshop, the Panel worked closely with the SASC chair to refine and prioritize a final set of research recommendations, adapted from the stock assessment report and provided here as High or Medium Priorities, within Short-term vs. Long-term research categories.

Short-term

HIGH PRIORITY

- Expand collection of life history data for examination of lengths and age, especially fishery-dependent data sources.
- Organize an otolith exchange and develop an ageing protocol between ageing labs.
- Increase observer coverage for commercial discards, particularly the shrimp trawl fishery. Develop a standardized, representative sampling protocol and pursue collection of individual lengths and ages of discarded finfish.

MEDIUM PRIORITY

- Develop and implement sampling programs for state-specific commercial scrap and bait fisheries in order to monitor the relative importance of Spot. Incorporate biological data collection into program.

- Conduct studies of discard mortality for commercial fisheries. Ask commercial fishermen about catch processing behavior for Sp/Cr when trawl/gillnets brought over the rail to determine if the discard mortality rate used in the assessment is reasonable.
- Conduct studies of discard mortality for recreational fisheries.
- Collect data to develop gear-specific fishing effort estimates and investigate methods to develop historical estimates of effort.

Long-term

HIGH PRIORITY

- Continue state and multi-state fisheries-independent surveys throughout the species range and subsample for individual lengths and ages. Ensure NEFSC trawl survey continues to take lengths and ages. Examine potential factors affecting catchability in long-term fishery independent surveys.
- Continue to develop estimates of length-at-maturity and year-round reproductive dynamics throughout the species range. Assess whether temporal and/or density-dependent shifts in reproductive dynamics have occurred.
- Re-examine historical ichthyoplankton studies for an indication of the magnitude of estuarine and coastal spawning, as well as for potential inclusion as indices of spawning stock biomass in future assessments. Pursue specific estuarine data sets from the states (NJ, VA, NC, SC, DE, ME) and coastal data sets (MARMAP, EcoMon).

MEDIUM PRIORITY

- Identify stocks and determine coastal movements and the extent of stock mixing, via genetic and tagging studies.
- Investigate environmental and recruitment/ natural mortality covariates and develop a time series of potential covariates to be used in stock assessment models.
- Investigate environmental covariates in stock assessment models, including climate cycles (e.g., Atlantic Multi-decadal Oscillation, AMO, and El Nino Southern Oscillation, El Nino) and recruitment and/or year class strength, spawning stock biomass, stock distribution, maturity schedules, and habitat degradation.
- Investigate the effects of environmental changes (especially climate change) on maturity schedules for spot, particularly because this is an early-maturing species, and because the sSPR estimates are sensitive to changes in the proportion mature.
- Investigate environmental and oceanic processes in order to develop better understanding of larval migration patterns into nursery grounds.
- Investigate the relationship between estuarine nursery areas and their proportional contribution to adult biomass. I.e., are select nursery areas along Atlantic coast contributing more to SSB than others, reflecting better juvenile habitat quality?
- Develop estimates of gear-specific selectivity.

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

A benchmark stock assessment is recommended in five years. No assessment updates are called for given challenges with the current model, and the existing annual use of Traffic Light analyses. Despite uncertainty in the assessment model results and an inability to confidently determine stock status, trends in landings and indices do not indicate immediate cause for concern, and therefore do not call for a subsequent new stock assessment in the short-term.

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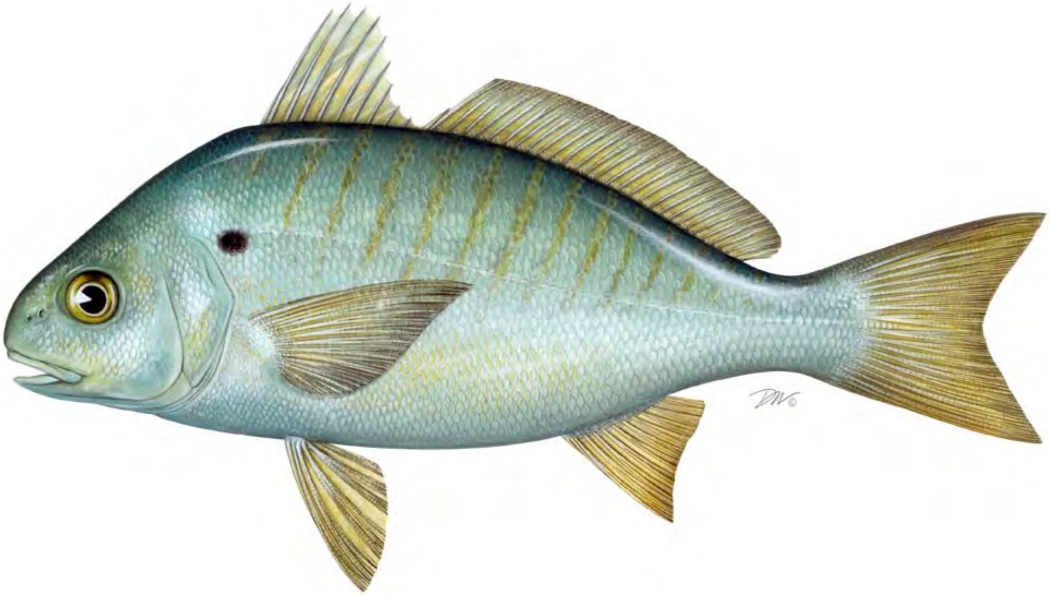
Atlantic States Marine Fisheries Commission

2017 Spot Benchmark Stock Assessment



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Atlantic States Marine Fisheries Commission

2017 Spot Benchmark Stock Assessment

May 2017

Prepared by the
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EXECUTIVE SUMMARY

This is the first stock assessment of spot on the Atlantic coast. The management area of spot is the distribution of the resource from New Jersey through Florida (Monroe County). Spot are considered one coastwide stock.

Spot are caught in commercial and recreational fisheries, primarily in the Chesapeake Bay and Mid-Atlantic (New York - Virginia) and South Atlantic (North Carolina - Florida) coastal waters. The majority of annual fishery removals of spot were discards in South Atlantic shrimp trawl fisheries, followed by commercial landings and recreational harvest. Data to estimate discards in South Atlantic shrimp trawl fisheries were available starting in 1989 and the terminal year of data for this assessment was 2014. From 1989-2014, total annual removals of spot from all fishery sources (landings and discards) have ranged from between 4,637 and 57,287 metric tons, or 41 and 1,324 million fish. Removals were relatively large, but variable in the 1990s. Removals since 1997 have been relatively stable, coinciding with the requirement of bycatch reduction devices (BRDs) across shrimp trawl fisheries. The long term mean removals was 12,785 metric tons, or 254 million fish. However, total removals after the peak year that occurred in 1991 averaged 9,399 metric tons, or 158 million fish.

Thirty five fishery-independent surveys that encountered spot were reviewed during the assessment. Biological data from all surveys were used to estimate life history parameters (e.g., growth, maturity). Indices of relative abundance from the NMFS Trawl Survey and the NCDMF Trawl Survey were used in the preferred modified-CSA model. These indices generally show a period of low abundance through the 1990s and early 2000s, followed by increasing abundance in the late 2000s and 2010s. There was a decline across indices in the assessment terminal year (2014).

Both age-0 abundance (914 million fish) and age-1+ abundance (654 million fish) were estimated to be relatively high in 1989. Age-0 abundance remained high through 1991 as age-1+ abundance steadily declined. Total abundance was highly variable through the mid-1990s as age-0 abundance fluctuated drastically. Age-0 abundance (99 million fish) and total abundance (166 million fish) hit a time series lows in 1997. Abundance then fluctuated around an increasing trend through 2013, with the exception of several subsequent poor recruitments from 2006-2009. The 2014 recruitment was relatively poor (205 million fish) resulting in a decline in total abundance, despite increasing age-1+ abundance. Age-1+ abundance in the end of the time series increased close to levels at the beginning of the time series, while age-0 abundance in recent years (excluding the terminal year) increased to about half the magnitude of peak age-0 abundance at the beginning of the time series. Spawning stock biomass followed a similar trajectory as total abundance, generally increasing since 1996 with the exception of the lowest spawning stock biomass of the time series in 2001 (208 metric tons). There was a slight down turn of spawning stock biomass in 2014 (19,032 metric tons), but the estimate was still the second highest of the time series.

Initial fishing mortality was estimated at 1.06 and increased steeply in the next two years. Full fishing mortality then generally fluctuated around a declining trend throughout the time series. Full fishing mortality has remained below 0.50 since 2005. Very low static spawning potential ratios (< 0.2) occurred in the beginning of the time series, when shrimp trawl discards were highest, and during years with large peaks in fishing mortality. Static spawning potential ratios fluctuated around a mean over the last five model years (0.48, 2010-2014) about seven times greater than the mean static spawning potential ratios during years when BRDs were not required (0.07; 1989-1995).

The assessment recommends an overfishing threshold associated with a 30% static spawning potential ratio (F 30%) and a fishing target associated with a 40% static spawning potential ratio (F 40%). The assessment also recommends the equilibrium spawning stock biomass resulting from fishing at F 30% and the recruitment levels estimated from 1996-2014 as a spawning stock biomass threshold and the equilibrium spawning stock biomass resulting from fishing at F 40% and the recruitment levels estimated from 2003-2014 as a spawning stock biomass target. Based on the recommended reference points, overfishing of the Atlantic coast spot stock did not occur in 2014 and the stock was not overfished. The 2014 full fishing mortality was estimated at 0.249, below the threshold (0.5) and target (0.36). The 2014 beginning year spawning stock biomass (2013 end year spawning stock biomass) was estimated at 19,032 metric tons, above the recommended threshold (4,730 metric tons) and target (7,854 metric tons). This stock status determination is reasonable, given the significant decline of discards in South Atlantic shrimp trawl fisheries and the recent increases in relative abundance observed across indices of abundance.

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For the Spot Benchmark Stock Assessment

Board Approved August 2015

1. Characterize uncertainty of fishery-dependent and fishery-independent data used in the assessment, including the following but not limited to:
    a. Provide descriptions of each data source (e.g., geographic location, sampling methodology, potential explanation for outlying or anomalous data)
    b. Describe calculation and potential standardization of abundance indices.
    c. Discuss trends and associated estimates of uncertainty (e.g., standard errors)
    d. Justify inclusion or elimination of available data sources.
    e. Discuss the effects of data strengths and weaknesses (e.g., temporal and spatial scale, gear selectivity, ageing accuracy, sample size) on model inputs and outputs.
2. Review estimates and PSEs of MRIP recreational fishing estimates. Request participation of MRIP staff in the data workshop process to compare historical and current data collection and estimation procedures and to describe data caveats that may affect the assessment.
3. Develop estimates of spot discards in the South Atlantic shrimp trawl fishery. Develop estimates of bycatch and discards in other fisheries where possible. Characterize uncertainty of all discard and bycatch estimates.
4. Develop models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points, and analyze model performance.
    a. Describe stability of model (e.g., ability to find a stable solution, invert Hessian)
    b. Justify choice of CVs, effective sample sizes, or likelihood weighting schemes.
    c. Perform sensitivity analyses for starting parameter values, priors, etc. and conduct other model diagnostics as necessary.
    d. Clearly and thoroughly explain model strengths and limitations.
    e. Briefly describe history of model usage, its theory and framework, and document associated peer-reviewed literature. If using a new model, test using simulated data.
    f. If multiple models were considered, justify the choice of preferred model and the explanation of any differences in results among models.
5. State assumptions made for all models and explain the likely effects of assumption violations on synthesis of input data and model outputs. Examples of assumptions may include (but are not limited to):
    a. Choice of stock-recruitment function.
    b. Calculation of M. Choice to use (or estimate) constant or time-varying M and catchability.
    c. Choice of equilibrium reference points or proxies for MSY-based reference points.

   - d. Choice of a plus group for age-structured species.
   - e. Constant ecosystem (abiotic and trophic) conditions.
6. Characterize uncertainty of model estimates and biological or empirical reference points.
7. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., F, SSB), reference points, and/or management measures.
8. Recommend stock status as related to reference points (if available). For example:
   - a. Is the stock below the biomass threshold?
   - b. Is F above the threshold?
9. Other potential scientific issues:
   - a. Compare trends in population parameters and reference points with recent results of the Traffic Light Approach. If outcomes differ, discuss potential causes of observed discrepancies.
   - b. Compare reference points derived in this assessment with what is known about the general life history of the exploited stock. Explain any inconsistencies.
10. If a minority report has been filed, explain majority reasoning against adopting approach suggested in that report. The minority report should explain reasoning against adopting approach suggested by the majority.
11. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.
12. Recommend timing of next benchmark assessment and intermediate updates, if necessary relative to biology and current management of the species.

1. Introduction

1.1 Brief Overview and History of Fisheries

Spot (*Leiostomus xanthurus*) are caught in commercial and recreational fisheries, primarily in the Chesapeake Bay and Mid-Atlantic (New York - Virginia) and South Atlantic (North Carolina - Florida) coastal waters. Spot along the Mid-Atlantic coast are generally available to commercial and recreational fisheries from April through October, the bulk being taken from August through October when spot are moving out of estuaries (Pacheco 1962a). In the South Atlantic, spot are caught year round but are most abundant during the fall months (Johnson 2013). Commercially, spot are caught in mixed species or opportunistic fisheries and as bycatch. Historically, haul seines have been used to land the majority of spot, but gillnets have become the dominant gear for spot landings in recent years. During winter, spot are taken in the winter trawl fishery operating off Cape Hatteras, North Carolina (Pearson 1932). Spot bycatch is often discarded at sea or landed as scrap. The North Carolina Division of Marine Fisheries (NCDMF) defines scrap fish as those fish not marketed for human consumption and instead sold for bait, industrial use, or discarded. Spot are a major component of Atlantic coast scrap landings Spot are also one of the most frequent species caught in shrimp trawl fisheries in the South Atlantic (Scott-Denton 2007 and Scott-Denton 2012). Most of these fish are discarded at sea. Generally, a majority of annual recreational catches of spot from hook and line fisheries are harvested. Spot are often kept by recreational anglers to be used as bait, as it is a popular bait species for striped bass recreational fisheries.

1.2 Management Unit Definition

The management area of spot is the Atlantic coast distribution of the resource from New Jersey through Florida (Monroe County).

1.3 Stock Definitions

Spot on the Atlantic coast are considered one coastwide stock due to their migratory behavior (Section 2.1) and the lack of any solid evidence to manage the species on a regional basis (McBride 2014).

1.4 Regulatory History

Historically, any management regulations for spot were left up to the individual states. There have been few regulatory measures enacted by the states for spot (Table 1). States have issued regulations for other species or fisheries that have likely affected spot harvest (Table 2). For example, in North Carolina waters, the elimination of fly-net fishing south of Cape Hatteras (1994), the introduction of bycatch reduction devices (BRDs) in shrimp trawls (1994, by proclamation authority), limits on the incidental catch of finfish by shrimp and crab trawls in inside waters (since 1970s), and culling panels in long haul seines (1999) all likely affected the catch of spot.

The Atlantic States Marine Fisheries Commission's (ASMFC) Fishery Management Plan (FMP) for Spot was adopted in 1987 and includes the states from Delaware through Florida (ASMFC 1987). In reviewing the early plans created under the Interstate Fisheries Management Plan process, the ASMFC found the FMP for Spot to be in need of evaluation and possible revision. Specifically, the ASMFC South Atlantic State/Federal Management Board (Board) found recommendations in the plan to be vague and perhaps no longer valid, and recommended that an amendment be prepared to the FMP for Spot to define the management measures necessary to achieve the goals of the FMP. In August 2009, the Board expanded the initiated amendment to the FMP for Spanish Mackerel to include spot and spotted seatrout, creating the Omnibus Amendment for Spot, Spotted Seatrout and Spanish Mackerel. The goal of the Omnibus Amendment was to update all three plans with requirements specified under the Atlantic Coastal Fisheries Cooperative Management Act (1993) and the Interstate Fishery Management Program Charter (1995). In August 2011, the Board approved the Omnibus Amendment for Spot, Spotted Seatrout, and Spanish Mackerel.

The Omnibus Amendment objectives are to: (1.) Increase the level of research and monitoring on spot bycatch in other fisheries, in order to complete a coastwide stock assessment (2.) Manage the spot population to maintain the spawning stock biomass above the target biomass level. (3.) Develop research priorities that will further refine the spot management program to maximize the biological, social, and economic benefits derived from the spot population. The Omnibus Amendment does not require specific fishery management measures in either the recreational or commercial fisheries for states within the management unit range. However, for years between benchmark stock assessments, the Omnibus Amendment does task the Spot Plan Review Team (PRT) with conducting annual monitoring analysis. This annual analysis has been known as the trigger exercises, where annual statistics were compared to the 10th percentile of the data sets' time series.

In August of 2014, the Board approved Addendum I to the Omnibus Amendment for Spot, Spotted Seatrout, and Spanish Mackerel which altered the method by which the trigger exercises were carried out by the Spot PRT. This Addendum establishes the use of the Traffic Light Approach (Caddy and Mahon 1995, Caddy 1998, Caddy 1999; TLA) within a precautionary management framework for the management of spot. The management framework using the TLA replaces the management triggers as stipulated in the Omnibus Amendment. The Board initiated this addendum at its February 2014 meeting following the development of the TLA report and management memo by the Atlantic Croaker Technical Committee (TC) and Spot PRT. The Spot PRT recommended spot for a benchmark stock assessment with the proposed TLA providing guidance in the interim period. The TLA methodology was extended to develop some additional metrics for comparison to the results of this assessment (Appendix 1, Section 8.3).

The TLA was originally developed as a precautionary management framework for data poor fisheries whereby reference points could be developed that would allow for a reasonable level of resource management. The name comes from assigning a color (red, yellow, or green) to categorize relative levels of different indicators for either a fish population or a fishery. These indicators can be combined to form composite characteristics within similar categories and can include biological indicators, such as growth and reproduction; population level indicators, such as abundance and stock biomass estimates; or fishery indicators, such as harvest/landings and fishing mortality. However, each indicator must be evaluated separately to determine its appropriateness for use in management. In general practice when applying the TLA, the green/yellow boundary is typically set at the long-term mean of the data series reference period (Halliday et al. 2001) of the indicator and the yellow/red boundary is set at 60% of the long-term mean, which would indicate a 40% decline from the series mean. Index values in the intermediate zone can be represented by a mixture of either yellow/green or yellow/red depending on where they fall in the transition zone. Since increasing proportions of red reflect decreasing trends away from the time series mean, the relative proportion of red of the indicator may offer one way of determining if any management response is necessary.

1.5 Assessment History

A formal coastwide stock assessment of spot has not been conducted prior to this assessment. The 1987 FMP recognized the lack of biological and fisheries data necessary for stock assessment and effective management of the resource. A review of available biological data and survey data was conducted through a life history workshop in 2010 to evaluate availability of data for a stock assessment (ASMFC 2010b). It was determined during this workshop that the available data do not support a complex stock assessment model, such as a statistical catch-at-age model, but may support a simpler assessment approach. Commercial and recreational catch and effort data have only been analyzed since 2010 to determine the relationship between landings and abundance via the annual trigger exercises using the TLA.

2. Life History

A review of literature and analyses of available data were conducted to characterize spot life history. For life history analyses, biological samples include paired length-length, length-weight, length-age, and age-maturity data, and sex data. Four commercial, three recreational, and six fishery-independent sources provided these data (Table 3). Descriptions of these sources' sampling and processing methods are provided in the Sections 4 and 5.

2.1 Migration Patterns

Spot larvae have been collected from within estuaries to the edge of the continental shelf (Hildebrand and Cable 1930, Berrien et al. 1978, Lewis and Judy 1983, Warlen and Chester 1985, Hare et al. 1999) from October through May. Larvae were smaller and more numerous offshore (34–128 meters) than inshore (17–26 meters; Berrien et al. 1978, Lewis and Judy 1983, Warlen and Chester 1985). Warlen and Chester (1985) reported that spot larvae may be present at any depth but occurred more frequently near the bottom. However, Lewis and Wilkens (1971) found this to be true only at night. Hare et al. (1999) found spot eggs and yolk sac stage spot at mean depths of 17 meters while older larvae (first and second stage) were typically found at greater mean depths of 20-28 meters.

Direct across-shelf transport has been suggested as the major transport mechanism for larvae of sciaenids and other species along the Mid-Atlantic coast (Nelson et al. 1976, Norcross and Austin 1981, Miller et al. 1984). Spot larvae exhibit this type of cross-shelf transport from the offshore spawning area to nursery habitat in winter and early spring (Govoni and Spach, 1999, Hare et al. 1999). Larval transport from the continental shelf is driven primarily by strong wind events as well as location where larvae were spawned (Hare et al. 1999). However, vertical distribution within the water column has also played a role in the success of larval recruitment, with spot occurring north of Cape Hatteras being transported farther along the Gulf Stream compared to spot transported cross shelf south of Cape Hatteras (Hare et al., 1999). Actual recruitment into estuarine nursery areas from offshore was subject to both vertical movement within tidal cycles as well as fine scale depth patterns within the given estuary (Forward et al. 1999). Spot larvae entered a North Carolina estuary at an average age of 59 days (range 40–74 days) and an average size of 13.6 millimeters (mm; range 11.4 to 15.6 mm; Warlen and Chester 1985). Larvae entered the estuary segregated by age. Recruitment of the new year-class into the Chesapeake Bay occurs in March through May (Norcross 1989). Postlarval spot have been collected in estuarine nursery areas chiefly in April in Delaware Bay (DeSylva et al. 1962), in January and February in the Chesapeake Bay (Welsh and Breder 1923) and North Carolina (Hildebrand and Cable 1930, Tagatz and Dudley 1961, Williams and Deubler 1968, Turner and Johnson 1973, Weinstein 1979, Weinstein and Walters 1981, Lewis and Judy 1983, Warlen and Chester 1985), and from February through May in South Carolina (Shenker and Dean 1979, Bozeman and Dean 1980, Beckman and Dean 1984), Georgia (Music 1974, Music and Pafford 1984), and Florida (Welsh and Breder 1923).

Young-of-year (YOY) spot are largely resident in nursery habitat for the duration of warm weather, but as temperature drops in the fall, they emigrate to deeper estuarine waters and offshore waters (Weinstein and O'Neil 1986). Hildebrand and Schroeder (1928) reported that some YOY overwinter in the deeper waters of the Chesapeake Bay although studies only collected spot from April or May through December in the York River and Chesapeake Bay, respectively (Pacheco 1962b; Markle 1976). YOY spot are found year round in South Carolina in low salinity and brackish waters, but were most abundant during the spring (South Carolina Department of Natural Resources (SCDNR), Unpublished Data).

Adult spot migrate seasonally between estuarine and coastal waters. They enter bays and sounds during spring, but seldom occur as far up-estuary as do the young. They remain in these areas until late summer or fall before moving offshore to spawn or escape low water temperatures (Hildebrand and Schroeder 1928, Roelofs 1951, Dawson 1958, Hoese 1973). A tagging study in Georgia estuaries indicated offshore movement of spot; the longest distance traveled was 118 km (Music and Pafford 1984).

2.2 Diet

The following is a brief summary from the 1987 FMP for Spot (ASMFC 1987), and is included to provide a general description of spot diet. For a more extensive description and references, please refer to the FMP.

Spot are opportunistic bottom feeders that mainly eat polychaetes, small crustaceans and mollusks, and detritus. Spot larvae primarily feed upon copepodid and adult copepods, pteropods, and pelecypods. Juvenile spot, 40–99 mm, fed on micro-bottom surface animals such as ostracods, harpacticoid copepods, ispods, amphipods, minute gastropods, and foraminifera. Isopods, amphipods, and mollusks predominate in the diet of larger spot (>100 mm). Small spot tend to be selective; larger spot are more opportunistic.

2.3 Age

2.3.1 Ageing Methods

Spot have been aged using scales, otoliths, and length frequency analysis. Barger and Johnson (1980) evaluated marks on scales, otoliths, and vertebrae and found that the otoliths possessed the highest potential as age determination structures. Marginal increment analysis indicated that spot annuli on scales were formed in October and November in the Chesapeake Bay (Pacheco 1957), from March through May in North Carolina (DeVries 1982), from April through June in South Carolina (Dawson 1958), and from late February through early April in Georgia (Music and Pafford 1984).

To date, there has not been a formal hard part exchange to evaluate precision or bias of age determinations among agencies ageing spot. There has also not been a formal workshop or efforts to establish a standardized ageing protocol among agencies. Ageing workshops have been held for other species of sciaenids (Atlantic croaker and red drum) and those species have been found to be relatively straightforward to age (ASMFC 2008). Similar protocols have been found to work well with spot.

2.3.1.1 Maryland Department of Natural Resources

The left otolith (the right one is substituted when necessary) is mounted to a glass slide using Crystalbond™ 509, and sectioned using a Buehler IsoMet® Low Speed Saw using two blades separated by a 0.4 mm spacer. The Buehler 15 HC diamond wafering blades are 101.6 mm in diameter and 0.3048 mm thick. The 0.4 mm sections were then mounted on microscope slides and viewed under a microscope to determine the number of annuli. All age structures were read by two readers. If readers did not agree, both readers reviewed the structures together, and if agreement still could not be reached the sample was not assigned an age.

2.3.1.2 Old Dominion University

The otoliths collected through the Virginia Marine Resources Commission's (VMRC) Biological Sampling Program (BSP) are processed and read by the Old Dominion University's (ODU) Center for Quantitative Fisheries Ecology (CQFE). Otoliths are processed following the methods described in Barbieri et al. (1994) with a few modifications. Briefly, the left or right sagittal otolith is randomly selected and attached to a glass slide with Aremco's clear Crystalbond™ 509 adhesive. At least two serial transverse sections are cut through the core of each otolith with a Buehler Isomet low-speed saw equipped with a three-inch, fine-grit Norton diamond-wafering blade. Otolith sections are placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium.

All fish are aged in chronological order based on collection date, without knowledge of the specimen lengths. Two readers must age each otolith independently. When the readers' ages agree, that age is to be assigned to the fish. When the two readers disagree, both readers must reage the fish together, again without any knowledge of previously estimated ages or specimen lengths and assign a final age to the fish. When the readers are unable to agree on a final age, the fish is excluded from further analysis.

The process for ageing spot otoliths at ODU involves two steps: (1) read the otolith—count the number of annuli in the otolith transverse cross-section; and (2) determine the age of the fish in terms of sacrifice date and annulus formation period.

2.3.1.3 Virginia Institute of Marine Science

The Multispecies Research Group (MRG) at the Virginia Institute of Marine Science (VIMS) has been ageing spot collected by the group's Chesapeake Bay Multispecies Monitoring and Assessment (ChesMMAP) Trawl Survey and Northeast Area Monitoring and Assessment Program (NEAMAP) Trawl Survey since 2002 and 2007, respectively. Whole otoliths are taken from a subsample of each size class of each species from each tow; these ageing structures are labeled and stored dry at sea.

Upon completion of all field sampling in a given year, each set of whole otoliths of a given species collected by a given survey is assigned a random number, such that location and time of collection are not known during the subsequent processing and assignment of age. Processing protocols for spot follow the methods developed during the ASMFC Atlantic Croaker and Red Drum Ageing Workshop (ASMFC 2008), as they are also similar members of the drum family, Sciaenidae. Specifically, the right whole otolith is selected for each specimen, and a thin (0.3-0.4mm) transverse section is taken through the nucleus of the structure and perpendicular to the sulcal groove. The section is mounted on a glass slide using Crystal-bond™ adhesive.

Each transverse section is viewed under a dissecting microscope (12x magnification), and the number of annuli on the structure is recorded. Each is read independently by three different readers, where one individual is assigned as the "senior" reader. This individual is typically the most experienced in the ageing of the species under consideration. Following the reading of the structures, ages are assigned to each fish (for each of the three reads) based on the number of annuli on the structure and the time of capture. Since mark formation (annuli deposition) typically occurs during the early to mid-summer period, the age of specimens collected prior to June is given by the number of annuli present plus one, while those collected in June or later are assigned an age equal to the number of annuli present.

After ages are assigned to each read, a final age is determined for each fish by taking the mode of the three independent assigned ages for that specimen. If no mode exists (i.e., all three reads generated different ages), the otolith section for that specimen is re-read by each of the three original readers. If this procedure fails again to produce a mode, the sample is discarded. Upon completion of final age assignments, age data are then incorporated into the appropriate survey database.

2.3.1.4 North Carolina Division of Marine Fisheries

Sagittal otoliths are removed, cleaned, and stored dry in plastic vials. Whole otoliths are read from an image on a high resolution monitor coupled with a video camera mounted in a stereo microscope. Ages are assigned based on the number of otolith annuli viewed. The ageing lab biologist conducts a first read of the whole otolith. The samples are then independently read by the species lead biologist. If any differences are not resolved, the data are omitted.

2.3.1.5 South Carolina Department of Natural Resources

In the laboratory, the left sagittae are viewed under low magnification with a binocular microscope (10X) and marked with a soft lead pencil on the core. These are then embedded in epoxide resin in silicon molds. After the resin has polymerized, the embedded otoliths are glued to a card held in a jig attached to the arm of a low speed saw. The otolith is positioned so that a transverse section ~0.5-mm thick can be taken through the core. The Isomet Saw is equipped with a pair of diamond-wafering blades, separated by a plastic washer so that the section can be taken with a single cut. The resulting section is mounted on a labeled microscope slide with Cytoseal-XLY. After polymerization of the mounting medium, slides are stored in boxes until viewing. These are examined with a Nikon SMZU microscope equipped with a Supercircuits model PC - 23C high resolution camera with transmitted light. The video image is captured by a frame grabber board in a personal computer and is subsequently analyzed with the Image-Pro image analysis software. The following measurements are taken on each otolith section:

1) radius—distance in mm from the center of the core to the edge of the section as measured along the sulcus acousticus
2) a_1—distance in mm from the center of the core to the distal edge of the first annulus
3) a_2—distance in mm from the center of the core to the distal edge of the second annulus
4) a_3 to a_n—distance from the center of the core to the distal edge of the third annulus and from the core to the distal edge of the nth annulus
5) marginal increment—distance from the distal edge of the last annulus to the edge of the otolith section

Some spot otoliths vary with respect to diffuse, undefined marking near the core of the otolith. These diffuse areas are not interpreted as being a ring. The first annulus is considered the first well-defined, opaque band that can be traced around the entire section.

2.3.2 Age Characteristics

Spot is a short-lived species, rarely attaining a maximum age of six years (NCDMF 2005). The maximum lifespan of spot appears to be greater along the Mid-Atlantic coast. Maximum ages reported in the literature include: age 4.5 (290 mm TL) in New Jersey (Welsh and Breder 1923), age 5 (237.5 mm FL) in the Chesapeake Bay (Pacheco 1962b), age 6 (355–369 mm FL) in North Carolina, although fish greater than age 3 were rare (DeVries 1981b), age 3 (210–283 mm TL) in Georgia (Music and Pafford 1984), and age 3 in South Carolina (Johnson 2013). Age 0–2 spot were predominate in populations throughout the range (Pacheco 1962b, Joseph 1972, DeVries 1981a, DeVries 1982, Music and Pafford 1984, NCDMF 2005). A summary of available age data by data source is in Table 3**.**

2.4 Growth

Growth of spot is very rapid. Daily growth rates for juvenile spot range from 0.02–0.04 g/day (Peters et al. 1978, Warlen at al. 1979, Weinstein 1983, Currin et al. 1984). An average of 84% of the cumulative growth of spot occurs within the first year, and 99% occurs by the end of the second year (Piner and Jones 2004). The reported range of lengths were similar throughout the Atlantic coast for most previous studies, though spot reach a greater maximum size in the northern part of the range (i.e., north of South Carolina; 0). Maximum sizes reported in the literature were 33 centimeter (cm) in New Jersey (Welsh and Breder 1923), 34.5 cm in Chesapeake Bay (Hildebrand and Schroeder 1928), and 34.6 cm in Core Sound, NC (DeVries 1982). Estimated relative growth is lower in the south and increases with latitude, with the higher growth rates found in the northern latitudes of the Northeast Atlantic (Johnson 1999).

Identifying an appropriate model describing change in length with age is useful given that many stock assessment models rely on an age-length relationship. Estimates of natural mortality for this assessment were also derived from growth model parameters (see Section 2.7). Several growth models were evaluated during the ASMFC Spot Life History Workshop, but no one model consistently outperformed the other. The broad overlap in length ranges observed from adjacent age classes indicate that there is not a well-defined relationship between these characteristics (ASMFC 2010b). A similar analysis was completed during this assessment with additional data collected during recent years. There were ten data sets with paired length and age data (Table 5). Ages ranged from 0-6 with sizes ranging from 4-36 cm total length (TL). All age data derived from scales or lengths were dropped from the analysis. Models compared were the von Bertalanffy, Richard’s, Gompertz, and logistic models using the FSA package in R (Ogle 2016, Table 6). The models were fit to all age-length data combined (regardless of presence or absence of sex data), all age-length data with sex data (males and females combined), and all age-length data with sex data by sex. According to Akaike information criterion (AIC), the von Bertalanffy model fit the data best for the entire and reduced data sets (Table 7-Table 10). Analysis of residual sum of squares (ARSS) was used to compare growth between males and females (Chen et al. 1992). The ARSS method provides a procedure for testing whether two or more nonlinear curves are statistically different. There was a significant difference in growth between males and females ($F_{(3,\ 20105)} = 113.3$, $p < 0.0001$). Model predictions, by sex, are in Figure 1 and Figure 2. Residual plots for the von Bertalanffy fit to the data, by sex, are in Figure 3 and Figure 4. Asymptotic average length (L_{inf}) ranged from 34.4-38.5 cm TL depending on the data set (Table 7). Males had the highest L_{inf} value, while the other groups had a narrower range (34.4-35.4 cm). Growth coefficients (k) ranged from 0.220-0.324. These values are a narrower range than estimates for the von Bertalanffy growth parameters from the Spot Life History Workshop which listed L_{inf} values of 30-46 cm and k values of 0.156-0.648 year $^{-1}$ (ASMFC 2010b).

2.5 Meristics and Conversion Factors

2.5.1 Length-Length Relationship

Measurements of spot length are reported in standard length (SL), fork length (FL), and TL, the definitions of which can be found in Table 11**.** Length conversion factors from the literature and those developed for this assessment from available data sources are reported in Table 12**.** All length data compiled for this report were converted to TL (if TL was not available) using the conversion developed from coastwide aggregated data in this assessment prior to use in any life history analyses.

2.5.2 Length-Weight Relationship

Previously estimated length-weight relationships for spot were available for North Carolina (Hester and Copeland 1975), South Carolina (Dawson 1958), and Georgia (Music and Pafford 1984) (Table 13). For this assessment, parameters of the length-weight relationship were modeled using a non-linear power regression with length in mm and weight in grams (g). There were eleven data sets with available length-weight data (Table 3). A subset of the data sets demonstrated typical allometric growth patterns with a highly significant relationship between length and weight (Table 14). There was no significant difference between male and female spot length-weight relationships estimated from these data sets as tested with ARSS (Table 15). All length-weight data were combined for a coastwide conversion (Table 13) to be applied for conversions in this assessment.

2.6 Reproduction

2.6.1 Spawning Seasonality

Spot is a late fall to early spring spawner. Time of spawning for spot has been estimated from gonadal development and the appearance of larval and post-larval fish. Spawning off the Chesapeake Bay, North Carolina, and South Carolina occurs from October to March (Welsh and Breder 1923, Hildebrand and Schroeder 1928, Lippson and Moran 1974, Colton et al. 1979, Hildebrand and Cable 1930, Dawson 1958, Berrien et al. 1978, Lewis and Judy 1983, Warlen and Chester 1985, Flores-Coto and Warlen 1993, Johnson 2013). DeVries (1982) reported that back-calculated lengths at the first annulus for North Carolina spot with one annulus were bimodally distributed with modes at 94-134 mm TL and 172–206 mm TL. This bimodality may represent two peaks in spawning as length frequencies of trawled age-0 spot from North Carolina estuaries showed a bimodal distribution from June to September (Ross 1980, Ross and Carpenter 1983, Ross and Epperly 1985). Peak spawning in North Carolina and South Carolina occurs in December and January (Warlen and Chester 1985) with the bulk of larval and juvenile fish moving into estuarine nursery habitat from January to April (Johnson 2013). In Georgia, spot spawn from October to April (Dahlberg 1972, Mahood et al. 1974, Music 1974; Setzler 1977). There are no references that estimate individual spawning frequency.

2.6.2 Sexual Maturity

Early studies using gross visual assessment of gonads estimated that spot mature at the end of their second year or early in their third year of life (Hildebrand and Cable 1930, Dawson 1958). Other studies have supported spot maturity occurring at an age of two years for most fish

(Hales and Van Den Avyle 1989, Phillips et al. 1989). Recent histological data indicate that spot can begin to mature before reaching one year in age, with 50% maturity for both males and females occurring between age one and two (Johnson 2013). Both males and females reached 100% maturity by age-2 (Johnson 2013). Reported sizes at maturity have ranged from 14.6-21.4 cm TL on the Atlantic coast (Hildebrand and Cable 1930, Dawson 1958, Hales and Van Den Avyle 1989, Phillips et al. 1989, Waggy et al. 2006, Johnson, 2013).

Of the different data sets available for the assessment, seven of the data sets had information on maturity (Table 3). Only SCDNR and VMRC provided paired age-maturity data for maturity estimates. VMRC uses a maturity schedule (Feigenbaum et al. 1985) that does not differentiate between mature and immature fish and, therefore, only SCDNR data were used for maturity-at-age estimates with a logistic regression model. SCDNR uses the Brown-Peterson et al. (2011) maturity schedule. These data were subset to female samples collected from August-December and assessed with histological methods as opposed to macroscopic methods.

Observed and predicted maturity ogives are in Table 16 and Figure 5. Female spot maturity-at-age-1 (January 1 after their first full year) is estimated to be 0.215. Some spot younger than age-1 are estimated to be mature and 50% maturity was estimated to occur at approximately the beginning of September (age-1.75), consistent with the estimates by Johnson (2013). The estimate of 100% maturity occurs when spot are age-4 and is different from the previous studies, including Johnson (2013), that indicate 100% maturity around age-2. This estimate may be a result of low sample size for fish age-2 and older. The average sample size for fish younger than two years is 36.8 and decreases to 5.9 for fish two years and older.

2.6.3 Sex Ratio

Only one study reporting sex ratio for spot was identified. Hata (1985) reported a 1:1 ratio of females to males for spot occurring in the northwestern Gulf of Mexico.

Combined (Table 17) and age-specific (Table 18) sex ratios of spot were calculated by data set. The chi-square (X^2) goodness-of-fit test with Yate's correction for continuity was applied to test whether the observed sex ratios departed from a 1:1 ratio (Zar 1999). The heterogeneity chi-square analysis was also applied to determine if performing a goodness-of-fit test on pooled data (i.e., all commercial and all fisheries-independent data) would be justified. The null hypothesis of the heterogeneity chi-square analysis is that the individual datasets have the same sex ratios.

The sex ratio (female:male) for spot ranged from 1.014 (50.4% female) to 2.729 (73.2% female) among the individual data sets (Table 17). The highest percentages of females were observed in North Carolina's fishery-independent surveys (73.2%) and Virginia's commercial fisheries data (70.5%). The chi-square goodness-of-fit indicated that the sex ratios derived from all datasets significantly deviated from a 1:1 ratio, except for the Southeast Area Monitoring and Assessment Program (SEAMAP) Coastal Trawl Survey data (X^2 = 0.063, p=0.801). The results of the heterogeneity chi-square analysis suggest that there are significant differences in the sex ratios among the individual commercial fisheries datasets (X^2 = 81.2; df = 2; $P < 0.001$) and that these data sets should not be pooled. The sex ratios of the fisheries-independent datasets were also found to be heterogeneous ($X^2 = 672.6$; df = 5; $P < 0.001$). These results suggest pooling of all data would not be justified.

The sex ratios-at-age indicated a predominance of females at most ages from commercial fisheries data (Table 18). The age-specific sex ratios tended to be higher for the commercial data than the fisheries-independent data. The majority of the age-specific sex ratios and corresponding X^2 values were found to be significantly different from a 1:1 ratio ($P < 0.01$; Table 18).

It should be noted that the months sampled and the available years of data varies among the individual datasets, so the proportion of females by month was also examined across data sets to determine if sex ratios were relatively consistent across months where data was available (Table 19). The proportion female by month was often around 50% across fishery-independent data sets. The proportion of females was greater than 50% in the majority of months across commercial fishery data sets.

2.6.4 Fecundity

Spot, like all of the sciaenids, are batch spawners and there is very limited information on fecundity of this species. Dawson (1958) calculated fecundity gravimetrically for two spot (15.8 and 18.7 cm SL) caught off South Carolina. The estimated the number of eggs >200 micrometers (µm) in diameter to be 77,730 and 83,900, respectively, but it was not known whether these were representative of fully ripe fish. The average size of oocytes undergoing full oocyte maturation (FOM) stage in other sciaenid species typically range from 700–900 µm (Roumillat and Brouwer 2004, Overstreet 1983), so the Dawson fecundity levels may be an overestimation due to the inclusion of oocytes that would not have developed enough to be spawned during that spawning event. Sheridan et al. (1984) listed batch fecundity in spot from the Gulf of Mexico as ranging from 20,900–514,400 oocytes per ovary, with relative fecundity relating poorly to both length and weight.

2.7 Natural Mortality

A variety of indirect methods were applied to available data to derive estimates of natural mortality (M). Approaches for estimating both an age-constant M and age-specific M were considered.

2.7.1 Age-Constant M Approaches

There have been numerous methods developed to estimate age-constant M based on the relationship of M to various life history characteristics. Some commonly used methods are based on maximum age (T_{max}) of a population (Hoenig 1983, Alagaraja 1984, Hewitt and Hoenig, 2005). Other approaches use von Bertalanffy growth model parameter estimates (L_{inf} and K), as well as $T_{\max}$ to determine M (Alverson and Carney 1975, Pauly 1980, Ralston 1987, Jensen 1996). Recent work by Then et al. (2015) evaluated different estimators of M using various combinations of $T_{\max}$, growth model parameters, and water temperature for greater than 200 independent, direct estimates of M in order to determine how well the estimators worked in terms of prediction error. They determined that a T_{max} based estimator performed best among all of the estimators evaluated such that $M = 4.889 * T_{max}^{-0.916}$. If T_{max} was not available, the next best estimator was growth based ($M = 4.118 * K^{0.73} * L_{inf}^{-0.33}$). *M* estimates were made using both T_{max} and growth parameter methods for comparison purposes. Since there was a significant difference in growth between males and females, *M* estimates were made using T_{max} and parameter estimates from the von Bertalanffy growth model for all age data combined, all age data with sex data, and age data by sex (Table 20). The Then et al. (2015) T_{max} method produced the same *M* (0.613 year $^{-1}$) for each data set since T_{max} (six) was the same across all data sets. The *M* estimates using growth parameter estimates were markedly lower than the T_{max} estimates, ranging from 0.336– 0.427 year^{-1} depending on the data set (Table 20).

2.7.2 Age-Specific M Approaches

Lorenzen's (2005) method was used to estimate age-specific *M* of spot. This approach requires estimates of the von Bertalanffy growth model parameters (to translate length to age) and the range of ages over which *M* will be estimated. The age-specific estimates of *M* are scaled such that the cumulative *M* across the selected age range is equal to a "target" *M*. This "target" *M* for spot was set equal to the age-constant *M* estimate from the T_{max} method recommended by Then et al. (2015). Since there was a significant difference in growth between males and females, *M* estimates were made using the parameter estimates from the von Bertalanffy growth model for all age data combined, all age data with sex data, and age data by sex (Table 21).

Estimated *M* rates decrease with increasing age as would be expected. The different data sets had very similar mean *M* for ages 1+ (range of 0.306 – 0.396 year $^{-1}$), with the combined data set having the highest *M* (0.396 year $^{-1}$) and males having the lowest *M* (0.306 year $^{-1}$) which was likely due to the lower von Bertalanffy K parameter estimate for males. Age-specific estimates of *M* based on all available data ranged from 0.356 to 0.542 year^{-1} with a mean of 0.396 year^{-1} and a median value of 0.489 year $^{-1}$.

2.8 Discard Mortality

No studies on spot discard mortality rate were identified. A review of recreational angler discard mortality studies found a median discard mortality of 0.11 and a mean of 0.18 across studies (Bartholomew and Bohnsack 2005). The SAS believes a value approximately in the middle of the range between the median and mean (0.15) is an appropriate approximation of the discard mortality rate for spot in recreational fisheries.

A study on Atlantic croaker, a species similar to spot, by Johnson (2003) determined the immediate (15–30 minutes) survival of discards onboard estuarine commercial shrimp trawlers. His results showed that the survival of Atlantic croaker decreased as time on deck increased—from 40% survival for Atlantic croaker that were on deck less than 20 minutes to 8% survival for Atlantic croaker that were on deck longer than 20 minutes. This study does not take into account mortality due to tow time or increased vulnerability to predation and mortality post discarding. Duration of observed tows from the Southeast Shrimp Trawl Observer Program

(Section 4.1.2.4) ranged from twelve minutes to just under nine hours with a median of three hours. Because there is no information from the observer program on the time discards spent on deck and unknown additional mortality from other causes (e.g., stress during long tow durations, increased vulnerability to predation), 100% discard mortality is assumed for spot discarded in commercial fisheries.

3. Habitat Description

3.1 Overview

Spot are found in estuaries and coastal areas from the Gulf of Maine to the Bay of Campeche, Mexico to depths of at least 205 meters, but are most commonly found from the Chesapeake Bay to South Carolina (Smith and Goffin 1973, Bigelow and Schroeder 1953, Dawson 1958, Springer and Bullis 1958, Phillips et al. 1989, Chesapeake Bay Program 1991, Murdy et al. 1997, Mercer 1987). Larval spot are spawned on the continental shelf off the Atlantic coast and use this habitat as they are transported toward the coast and juvenile nursery habitat. Juveniles use estuarine habitat. As they mature, spot are found on the continental shelf during spawning and inshore, estuarine habitat during warm summer and fall months.

3.1.1 Spawning, egg, and larval habitat

Fall migrations of mature spot to offshore waters were reported from Chesapeake Bay (Hildebrand and Schroeder 1928), North Carolina (Roelofs 1951), and South Carolina estuaries (Dawson 1958). During the migration to offshore habitats, some adults may spawn in estuaries and nearshore on the inner continental shelf during the late fall, if water temperatures remain warm enough (Dawson 1958; Lewis and Judy 1983). Smith (1907) stated that, in North Carolina, spot spawn in the sounds and inlets and Hidebrand and Cable (1930) suggested that spawning occurred in close proximity to inlet passes off North Carolina. However, larval distributions of spot indicate that spawning occurs more heavily in offshore waters of the outer continental shelf (26-128 meters) where temperatures are suitable for spawning and egg development (17.5 to 25ºC; Hettler and Powell 1981) than inshore (14.6-20.1 m; Berrien et al. 1978, Lewis and Judy 1983, Warlen and Chester 1985). Govoni and Spach (1999) found that larval spot occurred on both sides of the frontal zone along the Gulf Stream edge indicating spawning on the outer continental shelf in or along the Gulf Stream frontal boundary, with cross-shelf transport of larvae occurring towards the coast and inshore nursery waters. Ripe spot were collected in depths up to 82 meters off South Carolina (Dawson 1958) and 8-10 miles off the Georgia coast (Hoese 1973). Data indicate that spot spawn further offshore and in deeper waters than other sciaenids (Barbieri et al. 1994).

Newly hatched larvae are likely still close to offshore spawning locations, which have been suggested to be up to or beyond 90 kilometers offshore (Flores-Coto and Warlen 1993). Larvae depend on wind and currents (e.g., warm water eddies) for transportation and do much of their developing in the continental shelf waters during the winter (Able and Fahay 2010). In the winter and through early spring, larval spot ingress into estuarine habitats, often into upper regions of an estuary.

3.1.2 Juvenile and adult habitats

Tidal salt marshes and larger estuaries are recognized primary nurseries for spot (Weinstein 1979, Currin et al. 1984), although juvenile spot have been frequently collected on the inner continental shelf (Woodland et al. 2012). Juvenile spot prefer shallow water areas, less than 8 meters, over fine sediment and in tidal marshes (Phillips et al. 1989, Stickney and Cuenco 1982, Chesapeake Bay Program 1991). Juvenile spot are found from polyhaline to tidal fresh water in nursery areas. Although densities of spot were twice as high in polyhaline marshes versus oligohaline marshes in the York River (O'Neil and Weinstein 1987), patterns in other systems suggest that the production of spot may be highest in lower salinity, upper estuarine habitats (Brackin 2002, Ross 2003). The preferred temperature range of juvenile spot is 6–20°C, with a tolerable temperature range extending from 1.2–35.5°C (Parker 1971; Stickney and Cuenco 1982; Phillips et al. 1989, ASMFC 1987). Juvenile spot can tolerate dissolved oxygen (DO) levels as low as 1.3 milligrams/liter (mg/L), but prefer concentration of 5.0 mg/L or higher (ASMFC 1987; Phillips et al. 1989).

Adult spot are bottom-oriented, and require substrates to forage on epifauna and benthic infauna (Chao and Musick 1977). Adults likely prefer muddy substrates to sand or vegetated substrate, which has been reported for juveniles, although offshore adults will likely utilize sand substrates, which are more common outside of estuaries. Adults are likely tolerant of a wide range of DO, but prefer normoxic conditions (> 4.0 mg/L; Chao and Musick 1977). Adult spot are tolerant of salinities up to 60 parts per thousand (ppt, ASMFC 1987; Phillips et al. 1989) and are more abundant in coastal waters and lower estuaries and less abundant in lower salinity areas, compared to juveniles. Survival in adults dropped to 5% when DO was lowered to 0.6 mg/L, which suggests a strong (lethal) effect of DO below 0.8 mg/L (Burton et al., 1980). Recent work has begun to show that spot actively avoid hypoxic areas and even inhabit the margins of these areas (Campbell and Rice 2014). Hypoxic conditions (< 2.0mg/L) are less common offshore, and thus DO is probably less of a concern for adults than for juveniles.

4. Fishery-Dependent Data Sources

4.1 Commercial Data

4.1.1 Commercial Landings

4.1.1.1 Data Collection and Treatment

Commercial landings data are collected by the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS; aka NOAA Fisheries) and individual state agencies, depending on year and granter of permit(s) (i.e., state and/or federal). Federally permitted dealers and fishermen must report landings to the NMFS using the appropriate reporting process. Individual states may also have reporting requirements for dealers and fishermen landing in-state and some state agencies conduct biological sampling. The types of information and level of detail collected varies among and within the NMFS and various state agencies. Frequency of reporting also has varied over time. The Atlantic Coastal

Cooperative Statistics Program (ACCSP) provides a summary of reporting frequency by state and year on their website (http://www.accsp.org/data-warehouse).

Commercial landings are also maintained at the ACCSP Data Warehouse. The ACCSP provides quality assurance and quality control measures to ensure data are comparable and accurate. For this assessment, commercial landings data were obtained from the ACCSP Data Warehouse and vetted with state agencies (J. Myers, personal communication, January 7, 2016). Commercial landings by gear are available for all states from 1950-present. Though there have been some landings in states north of New Jersey (New York-Massachusetts), they make up such a small proportion of total commercial landings that details of data collection programs in these states are not provided.

4.1.1.1.1 Survey Methods

4.1.1.1.1.1 New Jersey

Commercial landings for spot are obtained from the NMFS reporting. There is no mandatory state reporting of spot in New Jersey.

4.1.1.1.1.2 Delaware

Delaware Division of Fish and Wildlife monitors the commercial fishery through mandatory monthly logbook reporting. Trip-based data collected from these reports include pounds landed by species, area fished, and gear type.

4.1.1.1.1.3 Maryland

The Maryland Department of Natural Resources (MD DNR) has a mandatory reporting system for commercial fishermen that began in 1980. Catch in pounds, days fished, area fished and amount and type of gear used were reported by month prior to 2006. A daily trip log was phased in from 2002 to 2005 with all fishermen using the daily log for the entire year beginning in 2006. Effort data is only available for 1980-1984, 1990 and 1992 – 2014. Maryland relied on the NMFS for collecting commercial landing data prior to 1980.

4.1.1.1.1.4 Virginia Marine Resources Commission

The VMRC's commercial fisheries records include information on both commercial harvest (fish caught and kept from an area) and landings (fish offloaded at a dock) in Virginia. Records of fish harvested from federal waters and landed in Virginia have been provided by the NMFS. The VMRC began collecting voluntary reports of commercial landings from seafood buyers in 1973. A mandatory harvester reporting system was initiated in 1993 and collects trip-level data on harvest and landings within Virginia waters. Data collected from the mandatory reporting program are considered reliable starting in 1994, the year after the pilot year of the program. The Potomac River Fisheries Commission (PRFC) has provided information on fish caught in their jurisdiction and landed in Virginia since 1973.

4.1.1.1.1.5 North Carolina

Prior to 1978, the NMFS collected commercial landings data for North Carolina. In 1978, the NCDMF entered into a cooperative program with the NMFS to maintain the monthly surveys of

North Carolina's major commercial seafood dealers and to obtain data from more dealers. North Carolina initiated a Trip Ticket Program (NCTTP) in January 1994 in response to a decrease in the NCDMF/NMFS cooperative reporting and due to an increase in demand for complete and accurate trip-level commercial landings statistics by fisheries managers. A trip ticket is a form used by state-licensed fish dealers to document all transfers of fish from the fishermen to the dealer. These forms collect information such as transaction date, area fished, gear used, and the quantity of each species landed from non-scrap landings. Scrap landings are recorded as bait landings on trip tickets but species is not identified. The data obtained through the NCTTP allow for the calculation of fishery-specific effort (i.e., trips, licenses, participants, vessels) and provide a more detailed record of North Carolina's seafood landings.

4.1.1.1.1.6 South Carolina

Landings of spot in South Carolina were collected by the NMFS through the early 1980s. In 2003, SCDNR instituted a wholesale dealer reporting system that provides monthly summaries from wholesale dealers with weight (and value) of fish purchased per species per month. Spot landed as bycatch and sold from the shrimp trawl fishery are also reported through the wholesale dealer reporting system.

4.1.1.1.1.7 Georgia

Commercial landings of all finfish, including spot, from 1950 through 1988 were collected by the NMFS. In 1989, the Georgia Department of Natural Resources (GADNR) instituted mandatory trip-level reporting for commercial fisheries dealers and fishermen.

4.1.1.1.1.8 Florida

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

4.1.1.1.2 Biological Sampling Methods

4.1.1.1.2.1 New Jersey

No biological sampling of spot from commercial landings has been conducted.

4.1.1.1.2.2 Delaware

No biological sampling of spot from commercial landings has been conducted.

4.1.1.1.2.3 Maryland

Commercial pound nets were sampled by the MD DNR in Maryland's portion of the Chesapeake Bay, and in the mouths of its major tributaries, from the Patuxent River south to the Potomac River. Sampling locations varied each year depending on where the cooperating fishermen's nets were set. The survey has been conducted every year from 1993 to 2014 from late May to early September. Each site was generally sampled once every two weeks, weather, and fisherman's schedule permitting. The commercial fishermen set all nets sampled as part of their regular fishing routine. Net soak time and manner in which they were fished were consistent with the fishermen's day-to-day operations. All spot were measured from each net when possible. In instances when it was not practical to measure all fish, a random sample was measured and the remaining individuals enumerated if possible. From 2008 through 2010 additional samples were obtained at fish dealers. All spot sampled at fish houses were from the pound net fishery, and were measured for length and weighed to the nearest g. All measurements were to the nearest mm TL. The aggregate length frequency is in Figure 6 and annual length sample sizes are in 0. Otoliths, weight to the nearest g, TL in mm and sex were taken during onboard pound net sampling from a subsample of spot beginning in 2007, and during all three years of the fish house survey. The otoliths were processed and aged by MD DNR from 2011 to 2014. The archived 2007 through 2010 otoliths were aged in 2011. Spot sample for age ranged from age-0 to age-2, with the majority being age-1 (Table 23).

4.1.1.1.2.4 Virginia

The VMRC's BSP has been collecting finfish biological data (length, weight, sex, and age) since 1988. The early sampling techniques included manual weighing and measuring of commercially harvested fish and removal of scales.

Several changes in the program have occurred since its inception. These include a switch from mechanical to electronic weighing scales and from manual to electronic fish measuring boards. The switch from mechanical to electronic equipment has increased precision of measurements and allowed a greater rate of sampling. In 1998 the BSP's sampling protocol initiated the removal of otoliths from thirteen important finfish species, including spot. ODU's CQFE Laboratory processes and reads otoliths and provides the VMRC age data for these finfish species.

Biological data sample sizes are in Table 24. Annual and aggregate length frequencies of spot sampled by the BSP are in Figure 7 and Figure 8, respectively. Spot have ranged from 11 to 39 cm TL. Spot sampled for age have ranged from age-0 to age-6, with the majority being age-1 to age-2 (Figure 9).

4.1.1.1.2.5 North Carolina

The NCDMF has sampled marketable landings from major commercial fisheries since 1982. Spot are sampled by gear, market category (in culled catches only), and area fished at local fish houses. Information on area fished and gear type is provided by the vessels captain or crew. As many random samples (usually 50 pound (lb) cartons) as possible were obtained from each market category with more samples being collected from cartons of larger grades since they contained fewer fish. Each sample was weighed to the nearest 0.1 kilogram (kg), individual fish were measured to the nearest mm FL and the total number of individuals was recorded. Annual length frequencies of spot sampled from all non-scrap landings (gears combined) are in Table 25. If the number of individuals in a carton were too numerous to measure, at least 30 were measured and the remainder counted. Subsamples of spot are purchased from the major commercial fisheries to excise otoliths for age determination. Sagittal otoliths have been collected since 1997. Each month, samples (n=10) are distributed across the length range in 20-mm length classes starting at 100 mm FL.

The NCDMF initiated sampling of scrap fish in 1986. Staff samples at least one-half basket (≈12 kg) of the scrap fish from each catch. The sample is sorted by species and weighed (kg). All individuals in the sample are measured for FL or TL to the nearest mm. Annual length frequencies of spot sampled from scrap landings (gears combined) are in Table 26. If the catch of a particular species is exceptionally large, a random subsample of at least 30 individuals is taken for measurement, and the remaining fish are counted.

4.1.1.1.2.6 South Carolina

No biological sampling of spot from commercial landings has been conducted.

4.1.1.1.2.7 Georgia

No biological sampling of spot from commercial landings has been conducted.

4.1.1.1.2.8 Florida

In Florida, biological samples from the commercial fisheries were limited to sample lengths (and, occasionally, to sample weights) of individual spot intercepted through a Trip Interview Program (TIP) at fish houses. While spot is included on the list of species to be sampled, they are only sampled “as available” due to its low priority and the small amounts that are generally landed. Commercial length data of spot were collected since 1992. Annual length sample sizes range from 2 (2005, 2010) to 3,620 (1993; 0). The length frequency from combined gears and years is in Figure 10.

4.1.1.1.3 Catch Estimation Methodology

Reporting of commercial landings in weight is treated as a census, so final reported values are assumed to equal total commercial landings in weight. State-specific commercial landings in weight were converted to numbers with biological sampling data from commercial landings or, if there was no biological sampling of commercial landings, biological sampling of recreational harvest from the Marine Recreational Fisheries Statistics Survey (MRFSS) and/or Marine Recreational Information Program (MRIP; Section 4.2.1). Individual weights or length frequencies and length-weight relationships were used for conversions, depending on the biological data available. Conversion were done at the level of detail permitted by the data to account for differences in size composition and/or mean weight (e.g., by year and gear). Conversions were done for landings from 1981-2014, as there was no fishery-dependent biological sampling prior to these years (recreational sampling began in 1981, see Section 4.2.1).

4.1.1.1.3.1 New Jersey

4.1.1.1.3.1.1 Commercial Landing Numbers

Landings in weight were converted to numbers by applying the wave specific annual average weights estimated for New Jersey from the MRIP and MRFSS, where possible. Average weights by wave from the Mid-Atlantic were used for waves and years when there was no average weight estimated by the MRFSS and MRIP for New Jersey alone. For waves when there is minimal recreational or commercial catches (wave 2 and wave 6, March-April and November-December, respectively) the Mid-Atlantic average weight over all years was used. For waves with no recreational sampling (wave 1; January-February), the Mid-Atlantic average weight over all years from waves 2 and 6 combined was used.

4.1.1.1.3.2 Delaware

4.1.1.1.3.2.1 Commercial Landing Numbers

Landings in weight were converted to numbers using the MRFSS and MRIP mean weight estimates by wave, where possible. If mean weight estimates were not available by wave, the annual estimate was used.

4.1.1.1.3.3 Maryland

4.1.1.1.3.3.1 Commercial Landing Numbers

Maryland spot landings in pounds were converted to numbers using three gear categories, fixed gear, haul seines, and mobile gear (excluding haul seine). Maryland pound net survey data lengths are randomly selected, but weights are not (only take from aged specimens). Spot pound net data was available for 1993-2014, and was used for conversion of weight to numbers for fixed gear for 1993-2008 and 2010- 2014. Maryland fish house sampling data is randomly selected, since fish are weighed and measured on site. Spot were only sampled in 2009 from the fish house survey (all fish were from pound nets), and these data were used to convert the 2009 fixed gear landings.

Virginia length and weight data were available for 1989 through 2014 for several gears and were used to convert Maryland fixed gear landings from 1989-1992 and all Maryland mobile and haul seine landings from 1989 to 2014. All 1981-1989 landing were converted using MRFSS annual mean weights. The ACCSP landings for those years did not include month, so conversions by wave was not possible. Virginia sampling and Maryland landings did not always match up by month. Since Virginia data was used for most conversions, annual landings were used to reduce the complication of matching sampling and landings data by month. ACCSP had several years with landings with gear reported as “NOT CODED”, the Maryland landings (that did not exactly match in total landings) had all gear coded. Some of the NOT CODED category accounted for the majority of landings, therefore, the Maryland proportion of landings by gear was used to place the NOT CODED landings into gear categories prior to conversion to numbers.

4.1.1.1.3.4 Virginia

4.1.1.1.3.4.1 Commercial Landings Numbers

Since 1989, Virginia has had sufficient biological data for spot to predict number of fish landed by size, separated by year, month, and gear. This was done by taking the number of measured and weighed spot in each length bin and using these relative proportions to divide up the total landings in pounds. If there were small sample sizes for any length bins during this time period, the samples were aggregated across all gears. From 1981-1988, when sufficient data were not available, MRFSS values were used to establish the catch frequencies.

4.1.1.1.3.4.2 Total Scrap Landings

Virginia does not subsample their scrap landings. In order to estimate the amount of scrap landings attributed to spot after 1993, data from North Carolina's scrap landings subsampling program were applied. Specifically, the proportion of spot occurring in North Carolina's scrap landings by month and gear were applied to Virginia's total scrap landings by month and gear to estimate scrap landings of spot. For a few years, certain gear-specific samples were not available. In these cases, the proportions were averaged over other gears within each specific month and applied to the landings.

Because VMRC did not begin collecting any information on scrap landings until 1994, it was necessary to hindcast estimates of scrap landings back to 1981. Annual ratios of spot scrap landings to total unclassified finfish landings from 1994–2014 were calculated for Virginia. The median ratio over 1994–2014 was then computed and used to generate hindcast estimates of scrap landings for 1981–1993 by applying this ratio to total unclassified finfish landings during this time period.

4.1.1.1.3.5 North Carolina

4.1.1.1.3.5.1 Commercial Landings Numbers

Numbers of spot landed were determined by calculating the mean number of individuals per sample by market grade and then expanding that number (by market grade and then summed for all market grades) to the total annual landings recorded for all trip tickets.

4.1.1.1.3.5.2 Scrap Landings

Scrap landings have been subsampled since 1994 to determine the species composition of the scrap landings. The total weight of each species in the scrap fish sampled from a trip is calculated by determining the proportion of that species in the subsample and expanding to the respective species' proportional weight of the total scrap fish for the trip. The number of individuals per species in the scrap fish component is calculated by expanding the number of individuals in the sample to represent the total weight of the species for the scrap fish in the samples. Estimates of total scrap fish landings for individual species are determined by applying the tri-annual ratio of marketable fish to scrap fish in the fish house samples to the reported tri-annual marketable landings. The quantity (weight or numbers) and percentage of scrap fish (total or by species) landed by the fishery was determined by applying the seasonal (six-month periods) weight ratio of marketable fish to scrap fish in the fish house samples to the reported seasonal marketable landings from the NCTTP. The estimated scrap fish quantity is for landed fish and does not account for discards at sea. The reported commercial landings of scrap fish (unclassified for scrap or industrial purposes) from the NCTTP were not used because of inconsistencies in dealer reporting. This ratio method of estimating scrap fish assumes marketable fish are accurately reported to the NCTTP. The percent scrap fish reported was computed on a per sampled trip basis, i.e., the percent scrap fish for each sampled trip was determined and the mean was taken across all trips, thereby accounting for sampled trips with no scrap fish. Each sampled catch was viewed as an independent estimate of scrap fish.

Because NCDMF did not begin collecting any information on scrap landings until 1994, it was necessary to hindcast estimates of scrap landings back to 1981. Annual ratios of spot scrap landings to total unclassified finfish landings from 1994–2014 were calculated for North Carolina. The average ratio over 1994–2014 was then computed and used to generate hindcast estimates of scrap landings for 1981–1993 by applying this ratio to total unclassified finfish landings during this time period.

4.1.1.1.3.6 South Carolina

4.1.1.1.3.6.1 Commercial Landing Numbers

There were no surveys that specifically sampled biological data for spot landed by the commercial fishery. While spot were reported commercially, they were generally only reported as total weight of landings by dealer through the Wholesale Dealer reports. There was some fishery dependent biological data available through the MRFSS and MRIP surveys as well as limited data from the South Carolina State Finfish Survey (SC-SFS). The SC-SFS was discontinued in 2012, as the state took over the MRIP survey and the two surveys overlapped.

In order to estimate the number of fish in the commercial landings, annual number of spot were estimated using the length frequency distribution from the recreational harvest, estimated weight at size from the TL to weight relationship from this assessment, and the total annual weight of landings reported in the commercial landings. The protocol required the length frequency be converted to proportion at length into one cm length bins and then the average weight was estimated at each length bin using the length-weight relationship. The total annual landings in weight was then proportioned across the range of TL frequencies and the estimated weight in that bin was then multiplied by the mean weight of that length bin to get the estimated number of spot in that particular length bin. This was done using the annual length frequencies for each year (1981-2014) and matched with the total commercial landings in weight for that year. One major assumption of this method was that the size frequency distribution in the recreational and commercial harvest were similar.

4.1.1.1.3.7 Georgia

4.1.1.1.3.7.1 Commercial Landing Numbers

There are no surveys that collect size, weight or number of spot landed by the commercial fishery. The available data for spot harvested through the commercial fishery include monthly total number of trips, gear used, and total weight landed. This information was not sufficient to estimate numbers of spot landed each year. The only fishery-dependent surveys that collected weights and numbers of spot harvested in Georgia are the MRFSS and MRIP. Therefore, the mean weight of spot harvested recreationally in Georgia was used to determine the total number of spot harvested by the commercial fishery. This was accomplished by dividing the monthly landings in pounds by the mean weight of spot harvested through MRFSS and MRIP in that same month. There were a number of concerns about using recreational information to determine number of harvested spot through the commercial fishery. First concern was that the gears used for each fishery were either different or gear type was not specified for the commercial landings. Another concern was that there were temporal gaps in the MRFSS and MRIP data, not every wave had recorded weights. To compensate for this concern, if there were no observed weights for spot in a month, the number of fish for the commercial landings was not calculated. Most importantly, since there is not a single data point collected on number, size, or weight of spot harvested through Georgia commercial fisheries, there is no way to determine if these estimates generated using this method have any accuracy. The uncertainty surrounding these estimates are very high. For this reason, it was requested that the SAS consider not using these estimates. Since the amount of landings was so low for the state in years for which landings were being converted (1981-2014; Table 29), removing them altogether should have negligible effects on the stock assessment.

4.1.1.1.3.8 Florida

4.1.1.1.3.8.1 Commercial Landings Numbers

The number of spot landed on the east coast of Florida were converted from landings in weight using annual length frequencies obtained from MRFSS recreational samples (1982–1991) and TIP commercial samples from landings made by gillnets (1992–1995) and various gears during 1996–2001 and 2002–2014, as well as a coastwide length-weight relationship. For each length bin during the sampled periods, the conversion was performed as follows:
(1) Estimation of mean weight by applying a weight-length relationship.
(2) Estimation of (i) the sampled weight by multiplying the number of fish sampled with mean weight and (ii) the proportion of sampled weight frequencies.
(3) Estimation of annual landings in weight by multiplying the proportion of sampled weight with total landings weight.
(4) Estimation of annual landings in number by dividing annual landings weight by mean weight.

4.1.1.2 Trends

4.1.1.2.1 Commercial Landings

4.1.1.2.1.1 Catch Rates

Catch rates were not developed from commercial data for modelling due to the availability of several regional fishery-independent surveys.

4.1.1.2.1.2 Total Commercial Landings

Because spot are short-lived and the majority of annual landings often consists of 1-2 year classes, commercial landings from 1950 to present have fluctuated from 638 to 6,586 metric tons (Table 28, Figure 11**)**. Number of spot landed between 1981 and 2014 has ranged between 3.6 and 26.7 million fish (Table 31, Figure 12). Most spot landings occurring in the Chesapeake Bay and South Atlantic states (Table 29). In 2014, 74% of spot were landed in Virginia, 15% in North Carolina, 8% in Maryland, 1% in Delaware, and less than 1% in New Jersey, South Carolina, and Florida. Landings have been negligible from states north of New Jersey. However, landings in these states have increased in recent years. Spot are harvested by a variety of gears including haul seines, pound nets, gillnets, and trawls (Table 30, Figure 11). From the 1950s to the early 1980s, commercial landings were predominately caught in haul seines. In the 1980s, gillnets became the dominant gear contributing to spot landings and has remained so since. In 2014, 77% of commercial landings were caught by gillnets, 8% by haul seines, 8% by fixed nets, 6% by other gears, and less than 1% by trawls.

4.1.1.2.2 Scrap Landings

4.1.1.2.2.1 Catch Rates

Catch rates were not developed from commercial data for modelling due to the availability of several regional fishery-independent surveys.

4.1.1.2.2.2 Total Scrap Landings

Total scrap landings of spot were stable through the 1980s and early 1990s, increased to the highest values of the time series in the late 1990s, and fluctuated around a declining trend through the 2000s and 2010s (Figure 13). Scrap landings were at the lowest levels of the time series in the final two years. North Carolina made the majority of scrap landings through the 1980s and mid-1990s, both states had similar landings through the late 1990s and 2000s, and Virginia made the majority of scrap landings in the most recent years (Table 32).

4.1.1.3 Potential Biases, Uncertainty, and Measures of Precision

4.1.1.3.1 Commercial Landings

Commercial landing reporting is designed to be a census, so there are no measures of precision for these data.

In Georgia, spot landed by trawls may be sold as unsorted mixed fish along with Atlantic croaker, whiting, and small flounder. In these cases, landings are not identified to species level and Georgia’s estimates of spot landings may be underestimated.

Prior to 1986 in Florida, the NMFS collections of landings were most effective for fisheries where the majority of landings were made at the large-volume wholesale dealer outlets. Spot were a low-value species that were landed in small amounts at smaller fish houses so there may have been negative bias (underreporting) in the early commercial landings of spot.

4.1.1.3.2 Scrap Landings

The scrap landings combined from North Carolina and Virginia are likely the minimal estimate from the coastwide scrap fishery. There is currently no scrap landing sampling by other states, but it is believed that North Carolina and Virginia account for the vast majority of Atlantic coast spot scrap landings.

4.1.2 Discards

4.1.2.1 Northeast Fisheries Observer Program

4.1.2.1.1 Survey Methods

The Northeast Fisheries Observer Program (NEFOP) is conducted by the NMFS' Northeast Fisheries Science Center (NEFSC) in order to collect data on catch (harvested and discarded), gear, effort, and biological data during commercial fishing trips from North Carolina to Maine by trained fishery observers. The total catch and a subsample of the total catch from each observation (e.g., towed trawl net) are weighed. The observer program is mandatory for federally-permitted vessels which are selected at random for observation during fishing trips. The program began in 1989. Spot is a third tier priority species for both major gears that encounter spot, Mid-Atlantic gillnets and Mid-Atlantic inshore trawls (NEFSC 2016). See the NEFOP website for additional details (http://nefsc.noaa.gov/fsb/program.html).

4.1.2.1.2 Biological Sampling

Each fish from the catch subsample is counted and measured to the nearest cm. Length sampling of discarded spot has been relatively limited, with no spot measured from trawls and gill nets 14 and 18 years out of 26 years of sampling, respectively (Table 33). Spot discarded from gillnets were slightly larger than spot discarded from trawls (Figure 14 and Figure 15). No spot age samples have been collected.

4.1.2.2 North Carolina Shrimp Trawl Observer Study

4.1.2.2.1 Survey Methods

This study is statewide in all state waters (inshore estuarine and nearshore ocean 0-3 miles) and the primary gear is shrimp otter trawls. The sampling concept is a random design and trip ticket data from previous years is used to estimate coverage by area. Data are available from 2007-2014.

Observers contact and obtain weekly observer trips aboard commercial vessels operating in the commercial shrimp trawl fishery. Participating commercial fishermen are selected randomly from a list of active fishermen derived from license and NCDMF Trip Ticket data. Data collected include overall vessel length, net dimensions and mesh sizes, turtle excluder device (TED) type, tow time, latitude, longitude, depth, and sea surface temperature.

When possible the total catch weight is obtained for all tows, otherwise the total catch weight is estimated. All weights are recorded to the nearest kg or g, depending on the size of the sample categories being weighed. Shrimp are separated from each net and a total weight is obtained. Every tow is sampled. This sampling goal is adjusted according to the practicality of obtaining quality subsamples. Latitude and longitude are taken on each tow when the net is hauled back.

4.1.2.2.2 Biological Sampling

For large catches, a one-basket subsample (approximately 32 kg) is taken from each net. Finfish in each subsample is examined as follows: weigh total sample, separate to species, enumerate and weigh total of individual species, for commercially important species measure TL or FL of 30-60 individuals of each species and weigh this smaller subsample. The aggregate length frequency of spot observed is in Figure 16. Beginning in August 2012, the at-net mortality of select species (spot, croaker, and weakfish) was obtained. Observers randomly select 30 individuals from each of the species and record the status (dead or alive) and lengths. This is the first data obtained from the sample to offer a baseline for the at-net mortality of these species.

4.1.2.3 Georgia Large Shrimp Trawl Bycatch Observer Study

4.1.2.3.1 Survey Methods

The Georgia Large Shrimp Trawl Bycatch Observer Study was conducted over an eight year period from 1995 to 1998 and 2001 to 2005. The purpose of the study was to gather bycatch information associated with the shrimp trawl fishery. All NMFS protocols for observer bycatch studies were observed (NMFS 1992). A total of 185 tows were sampled aboard 129 individual trips. Field sampling was conducted on-board commercial shrimp trawling trips in the offshore state waters and in the Exclusive Economic Zone (EEZ) off Georgia (beaches extending to 7 miles offshore), targeting selected species to characterize size, age, and genetic structuring, as well as providing estimates of catch rates by season. After gaining permission from the captains of these vessels, two on-board observers accompanied the captain and crew on a trip. The observers recorded information on each vessel including the vessel code, tow number, date, vessel name, length, identification number, year model, construction, weight, horsepower, and crew size. In addition, records of the economic costs of the trip, such as fuel, oil, ice, food and wages were documented. The type of net used in each application was noted and the specifications on each TED and BRD were recorded. Just prior to deploying the net, the observers recorded the latitude and longitude and the time of day. After completing the tow, the observers again recorded the latitude and longitude as well as the exact time the net was removed from the water. The shrimp, crabs, and fish were then sorted into different groups for examination. The shrimp were weighed and their numbers were estimated when necessary. The fish and crabs were counted and weighed by species.

4.1.2.3.2 Biological Sampling

For the core target species, which includes weakfish, Atlantic croaker, and spot, lengths were recorded for every specimen, while age and genetic samples were collected from a predetermined number of the samples. Sizes of spot ranged from 5.3 to 24.3 cm TL with an average size of 12.8 cm TL. The aggregate length frequency of spot sampled from 1995-2005 is in Figure 17. Otoliths and fin clippings obtained from core target species were sent to the South Carolina Department of Natural Resources for analysis (Ottley et al., 1998).

4.1.2.4 Southeast Shrimp Trawl Observer Program

4.1.2.4.1 Survey Methods

The South Atlantic component of the Southeast Shrimp Trawl Observer Program (SESTOP) began as a voluntary shrimp trawl bycatch observer program implemented from North Carolina to Florida through a cooperative agreement between NMFS, the Gulf and South Atlantic Fishery Management Councils, and the Gulf and South Atlantic Fisheries Foundation, Inc. to characterize catch, as well as evaluate BRDs. Total discards, total shrimp catch, and a subsample (one basket per net, or approximately 32 kg) for species composition and biological sampling is taken from each observed net. Beginning in 2008, the program became mandatory in the South Atlantic and NMFS-approved observers were placed on randomly selected shrimp vessels. The voluntary component of the observer program also continued. Penaeid shrimp (primarily inshore) and rock shrimp (primarily offshore) fisheries in the South Atlantic are covered by the observer program. Observed coverage is allocated by previous effort, or shrimp landings when effort data are not available. Based on nominal industry sea days, observer coverage of South Atlantic shrimp trawl fisheries ranged from 0.2-1.4% and totaled 0.9% from 2007-2010 (see Scott-Denton (2012) Table 1). Number of observed tows are in Table 34. See Scott-Denton (2007) for more details on the voluntary component of the SESTOP and Scott-Denton et al. (2012) for more details on the mandatory SESTOP.

4.1.2.4.2 Biological Sampling

Biological information, such as length and weight of bycatch species, is collected from the subsample of total catch in observed nets. Very limited biological sampling has been conducted for spot. Only 698 spot have been measured for length, caught from just twenty three tows on three trips occurring from October to November in 2003. Lengths ranged from 13 to 23 cm FL (Figure 18). No spot age samples have been collected.

4.1.2.4.3 Trends

Spot is typically one of the most prevalent bycatch species, often outweighing and/or outnumbering individual species of shrimp (see Scott-Denton (2007) Figure 9, Figure 11, Table A2 and Scott-Denton (2012) Table 9, Table 11, Table 12, Figure 6). Discard rates have been variable, but have generally increased over the time series (Figure 22).

4.1.2.5 South Atlantic Shrimp System

4.1.2.5.1 Survey Methods

Detailed catch and effort statistics from commercial shrimp fishing trips were collected and processed by a cooperative effort between the South Atlantic states and, beginning in 1982, the NMFS' Southeast Fisheries Science Center (SEFSC). Data collection began in 1978 in North Carolina and Georgia, 1979 in South Carolina, and 1981 in Florida. Data are available by year, month, state, and port. Florida and North Carolina quit collecting data for the South Atlantic

Shrimp System (SASS) after 1992. The data are maintained by the NMFS. See Gloeckner (2014) for more details on the SASS.

4.1.2.6 Discard Estimation Methods

4.1.2.6.1 Mid Atlantic Trawl and Gillnet Discards

Observer data from the NEFOP were used to develop annual ratios of observed discarded spot to observed landings of all species by gillnets and bottom trawls. Ratios were then applied to reported gillnet and bottom trawl landings of all species to estimate total discards of spot from 1989-2014. The SAS investigated effort data from Vessel Trip Reports (VTRs), but deemed these data unreliable for discard estimates due to data caveats. For example, it was unclear how fishers interpreted certain data fields such as hours fished for trawl nets and whether or not these data fields are interpreted consistently among fishers through time. Orphanides and Palka (2007) also note issues with inconsistent and incomplete gillnet effort from VTRs. VTRs are only required for federally-regulated species.

Commercial landings are reported to the state where they are landed and initial review of the NEFOP data indicated that observed spot discards did not occur on trips landing in ports north of New York. Therefore, all NEFOP observations from trips that landed in ports from North Carolina to New York were used to estimate ratios and ratios were applied to all landings reported from North Carolina to New York. NEFOP data used in this analysis are summarized by year and gear in Table 35 and Table 36. The number of observations by NMFS statistical area (Figure 19) are in Table 37. Spatial distribution of observations are in Figure 20 and Figure 21.

Annual geometric mean ratios of discarded Atlantic croaker to landed Atlantic croaker were used in the 2010 Atlantic Croaker Stock Assessment. These ratios require excluding any trips where the species of interest was not discarded and landed and were deemed unreliable for Atlantic croaker by the Peer Review Panel (ASMFC 2010a). This methodology has the potential to bias ratios high by excluding zero discard trips and bias ratios low by excluding trips where the species was not landed, but was discarded. This method also decreases sample size. For this assessment, annual ratios by major gear type (gillnets and bottom trawls; Table 38) were calculated as the ratio of the mean discards of spot per observation (i.e., tow or net set), in pounds, to the mean landings of aggregated species per observation, also in pounds (Equation 1).

$$Equation\ 1: R = \frac{\overline{D}}{\overline{L}} = \frac{\sum_1^n D_i}{\sum_1^n L_i}$$

This ratio estimator includes all observations with observed landings of any species, including those where no spot were discarded. The variance of the ratio estimator was calculated with Equation 2 (Pollock et al. 1994).

$$Equation\ 2: Var(R) = \frac{1}{n(n-1)\bar{L}^2}\left(\sum_{1}^{n} D_i^2 + R^2\sum_{1}^{n} L_i^2 - 2R\sum_{1}^{n} D_i L_i\right)$$

It is assumed that discarding rates during observed trips are representative of overall discarding rates in these fisheries. Small sample sizes of positive observations precluded developing ratios at finer resolution (e.g., by state or season).

Annual mean weights were calculated as the total number counted from subsamples divided by the total subsample weight and were applied to the discard estimates in weight to derive discard estimates in numbers. In years with no observer data, averages of adjacent year observations were pooled to estimate ratios. In years with no preceding observer data, averages of the closest two year period were used. Spot discard subsamples from gillnets were particularly sparse, so data were pooled over all years to estimate discards in numbers.

Landings of all species combined by gillnet and bottom trawl gears (Table 39) were provided by ACCSP by year and state landed from North Carolina through New York. Some landings are not available at the gear level (“NOT CODED”). These landings were partitioned into trawl and gillnet landings by calculating the annual proportion of landings by these gear categories and then apply these proportions to the “NOT CODED” landings. Total landings by year and gear are in Table 35 and Table 36.We are assuming that vessels landing north of New York and South of North Carolina discard no spot.

Ratios estimates and variances are in Table 40 and Table 41. A discard mortality rate of 100% is assumed for both gillnet and trawl discards of spot (Section 2.8).

4.1.2.6.2 Shrimp Trawl Discards

Estimates of spot discard rates in South Atlantic shrimp trawl fisheries were developed using discard rate data from the SESTOP to estimate the magnitude of discard rates and the SEAMAP Trawl Survey (Section 5.2) to estimate the trend of discards prior to (1989-2000) and during the observer program. Discard rate estimates were then applied to effort data from state trip ticket programs and the SASS to estimate total discards in these fisheries from 1989-2014 following the methods used by Walter and Isley (2014). The SAS also evaluated the NCDMF observer study data, but the addition of these data resulted in negligible changes to shrimp trawl discard estimates. Only weight data from NCDMF were considered reliable and the SAS was cautioned against using the count data. Due to the negligible impact and lack of count data, the SAS agreed that NCDMF observed data should not be used for South Atlantic shrimp trawl discard estimates.

Only discarded spot are recorded by shrimp trawl observers, so no adjustments are needed to account for fish landed. Observer data were subset to exclude operation codes X, M, H, and J (Appendix 2) because these observations were not considered reliable (e.g., net was dumped overboard without recording catch data). Observations with all other operation codes were included under the assumption that these observations are representative of effort in the shrimp trawl fisheries. Observed nets with disabled BRDs after the requirement of BRDs were also dropped from the analysis. BRDs were required in federal penaeid shrimp fisheries in 1997 under Amendment 2 to the Shrimp Fishery Management Plan for the South Atlantic Region (SAFMC 1996) and federal rock shrimp fisheries in 2005 under Amendment 6 to the Shrimp FMP (SAFMC 2004). State BRD regulations generally fit these time frames.

Trends in catch rates (number of fish/hour fished) of the SEAMAP Trawl Survey and the SESTOP are in Figure 22 and generally track well during overlapping years. Spatial coverage of both surveys overlap throughout most of the sampled ranges (Figure 23). Catch rates by tow from the combined data sets are in Figure 24 and Figure 25.

Discard rates in weight were modelled with the delta-lognormal method (Lo et al. 1992) and discards in numbers were modelled with a negative binomial generalized linear model (GLM). The delta lognormal method combines a lognormal GLM used to predict discard rates of positive observations and a binomial GLM to predict the probability of a positive observation, with effort as an offset variable. The final discard rate is the product of the response variables from these two models. The negative binomial GLM predicts the number of fish caught per observation with effort as an offset variable. Distributions of the response variables for each model are in Figure 26 and Figure 27. Factors considered in the models were year, data set, depth zone, state, and season. Data sets included observer data from the rock shrimp (observer project types W, X, Y) and penaeid shrimp (observer project types A, C) commercial fisheries and fishery-independent data from SEAMAP Trawl Survey tows. Depth zones were less than or equal to 10 meters (=<10m), greater than 10 meters to 30 meters (10-30m), and greater than 30 meters (>30m). All SEAMAP tows were conducted in the shallowest depth zone, while the majority of observer tows were in the shallowest depth zone. State borders were defined by the latitudes used by Scott-Denton et al. (2012). Seasons were December through March (offseason) and April through November (peak season). There are decreases in catch rates during June due to a reduced number of SEAMAP tows (Figure 28), but the seasons were defined to align with shrimp fishing relative to operation in nearshore waters throughout the time series. Shrimp fishing in nearshore waters where catch rates are expected to increase has generally started as early as April and lasted through November. Discard rate data by factor are summarized in Table 42 and Table 43.

Model structure was evaluated with stepwise deletion of factors and the model with the lowest AIC was selected as the final model. Final model summaries are in Table 44-Table 46. All factors were retained for both models (Table 47 and Table 48).

Effort data are available from trip ticket systems from Florida (1986-present), Georgia (2001-present), South Carolina (2004-present), and North Carolina (1994-present) and the SASS from 1978 to the year trip ticket programs were implemented in each state, with the exception of North Carolina. There was a gap from 1992-1993 in North Carolina when data were not available from either a trip ticket program or the SASS. Trip counts were provided by state, year, month, and gear following the methods described in Gloeckner (2014) with a slight modification to eliminate some duplicate reporting issues in Florida (D. Gloeckner, personal communication, April 18, 2016). Code for this “standardized” data query is in Appendix 3. The monthly number of trips in North Carolina in 1993 are estimated as the average of the two adjacent years (1992, 1994). Average hours fished per trip and average number of nets fished per tow by state and year were used from NMFS Sustainable Fisheries Branch (2012) and are originally from trip ticket data. Averages were used before trip ticket data were collected and also for 2011-2014. Fishing hours were calculated as the product of total number of trips, average hours fished per trip, and average number of nets fished per tow. Effort is summarized by state and year in Table 49 and by month in Figure 29. As effort was only available by state, year, and month, some assumptions were made to partition the effort among depth zones and fisheries. The proportions of observations from the observer data by depth zone were applied to overall effort, assuming that the observer data is representative of fishing effort at depth and that fishing effort at depth is static over time. A similar assumption was then made to partition the effort data into fisheries. The proportions of observations in each depth zone allocated to each fishery were applied to the effort data in the respective depth zone. Proportions used to partition effort are in Table 50.

Discard rates were applied to effort estimates summarized by “strata” (i.e., combination of factors included in the model). Standard errors (SEs) of discard estimates made with negative binomial GLMs were estimated with the predict.glm function in the R package stats (R Core Team 2015).

Because there were no observer data before BRDs were required in the penaeid shrimp fishery, discard estimates for penaeid shrimp trawl effort prior to 1997 were adjusted for the reduction in catch due to the required use of certified BRDs on observed tows. Adjustments were based on a weighted average of Atlantic croaker catch reductions in the Gulf of Mexico shrimp trawl fishery estimated depending on the distance of fisheye BRDs from tie-off rings (Helies et al. 2009). The adjustments of spot discard estimates were based on the Atlantic croaker adjustment, as the SAS was unaware of any BRD estimates for spot. 99.6% of observer trips used fisheye BRDs. BRDs in the observed trips ranged from 6 to 21 feet from tie-off rings. Catch reduction estimates were available for BRDs <9 feet (69.7% reduction), 9-10 feet (0% reduction), and 10-11 feet (17.2% reduction) from the tie off rings. There was no estimated reduction for fisheye BRDs greater than 11 feet from the tie-off rings, so the estimate for the 10-11 foot category was used for the proportion of nets greater than 11 feet from the tie-off rings. The proportion of observed trips that fell into the categories of <9 feet, 9-10 feet, 10-11 feet, and >11 feet were 0.22, 0.28, 0.31, and 0.20, respectively. The weighted average adjustment was 0.23 (i.e., discards = unadjusted discards*1/(1-adjustment)). We assumed that observed trips were representative of BRDs used in the fisheries.

All discarded spot were assumed to be dead or to have died post-release (Section 2.8).

4.1.2.7 Discard Trends

4.1.2.7.1 Mid Atlantic Trawl and Gillnet Discards

4.1.2.7.1.1 Total Mid-Atlantic Trawl and Gillnet Discards

Discard estimates are in Table 51 and Table 52 and Figure 30 and Figure 31. Discards from trawls generally make up a larger proportion of the discards than gillnets in Mid-Atlantic fisheries. Discards in numbers of fish for gillnets range between 0 and 59,271 with a median of 2,769, while discards for trawls range between 0 and 25,326,383 with a median of 58,682. Discards in numbers for gillnets range between 0 and 50,021 pounds with a median of 2,336 pounds, while discards for trawls range between 0 and 5,740,647 pounds, with a median of 10,831 pounds. Estimates for both gears are highly variable, with an increasing trend for gillnets and no discernable trend for trawls. The trawl estimates in the first two years are significantly higher than any other year in the time series. There were several very large discard:landings ratios in tows observed these years (one in 1989, five in 1990), inflating the estimates (Table 53). The relative magnitude of the trawl discard estimate for 1989 is similar to the relative magnitude of the NMFS Trawl Survey (Section 5.1) catch rate in 1989 indicating very high relative abundance that was available to these fisheries, though these two sources do not agree on the relative magnitude in the 1990 estimates. The observer data were checked for errors and none could be confirmed, so the SAS agreed that these estimates should not be adjusted.

4.1.2.7.2 Shrimp Trawl Discards

4.1.2.7.2.1 Total Shrimp Trawl Discards

Final discard estimates are in Table 54 and Table 55 and Figure 32 and Figure 33. Mean weights of spot derived from discard number and weight estimates are in Table 56. Discards were relatively high, but decreasing in the early 1990s before BRDs were required. There were particularly high discards of spot in 1991 due to high effort and CPUE (Figure 34). Discards then became relatively stable throughout the 2000s. Despite slightly declining or stable trends in effort during the 2010s, there was an increasing trend in discards. This increase is driven by increasing CPUE over these years. Discard estimates generally follow the same trends as landings by shrimp trawlers (Figure 35).

4.1.2.8 Potential Biases, Uncertainty, and Measures of Precision

4.1.2.8.1 Mid-Atlantic Trawl and Gillnet Discards

Variances of annual ratio estimators were relatively large, resulting in CVs that averaged 0.63 and 0.47 for gillnets and trawls, respectively (Table 40 and Table 41). The relatively large variances were not unexpected given the low sample size of observations and high variances of landings and discards in many years (Table 35 and Table 36). Although variances of these estimates were often large, the estimates make up a small proportion (<3%) of total annual fishery removals (Section 4.3, Figure 59).

4.1.2.8.2 Shrimp Trawl Discards

Shrimp trawl discard estimate 95% confidence intervals are in Table 54 (millions of fish) and Table 55 (metric tons).

4.2 Recreational

Statistics for recreational total catch, catch size composition, and effort were provided by the MRFSS from 1981-2006, MRIP from 2007-2014, and the Southeast Region Headboat Survey (SERHS) from 1981-2014. Additional, though limited, recreational fishery biological sampling has been conducted by several state monitoring programs.

4.2.1 Marine Recreational Fisheries Statistics Survey and Marine Recreational Information Program

Estimates of Atlantic coastal recreational fishing effort (angler hours, number of trips), harvest in numbers and weight, numbers of fish released alive, and catch size composition from 1981-2003 are from the MRFSS and estimates from 2007-2014 are from the MRIP which replaced the MRFSS in 2007.

4.2.1.1 Data Collection and Treatment

4.2.1.1.1 Survey Methods

Data are collected in independent, complementary surveys. The Access Point Angler Intercept Survey (APAIS) and at-sea sampling are designed to collect catch rate data and biological samples. The Coastal Household Telephone Survey (CHTS) and For-Hire Survey (FHS) are designed to collect effort data. Data from the surveys are combined to generate estimates. Angler participation in the MRIP surveys is voluntary. An overview of these surveys from the MRIP website (http://www.st.nmfs.noaa.gov/recreational-fisheries/index) is provided below. See the website and data user handbook at (http://www.st.nmfs.noaa.gov/recreational-fisheries/MRIP-Handbook/MRIP_handbook.pdf) for additional details.

Catch Rate Surveys

APAIS conducts interviews of intercepted anglers at public fishing access sites (e.g., marinas, piers) that collect information on area(s) fished, catch, and angler participation during recreational fishing trips (example questionnaires are available on the MRIP website). Stratified random sampling is used to select access sites in a site registry. Sampling is stratified by state (Florida-Maine), fishing mode, and wave (i.e., bimonthly period). The four fishing modes for stratifying sampling are private boats (including rentals), shoreline (e.g., pier, jetty, etc.), charter boats, and headboats (i.e., party boats). The charter boat and headboat modes were combined as one mode from 1981-1985 and 1981-2003 in the South Atlantic and north of North Carolina, respectively, before being split into separate modes. Headboat anglers in the South Atlantic have not been sampled through APAIS since 1985; data from these anglers are collected by the SERHS (Section 4.2.2). Headboat anglers north of North Carolina have not been sampled by the APAIS since 2004. Catch has been sampled from this mode since 2005 during ride-along, at-sea sampling. Sampling is conducted in six waves, each wave being two consecutive calendar months starting with wave 1 (January and February) and ending with wave 6 (November and December). Sample allocation by wave has varied over time but generally covers all six waves in Florida, with the exception of wave 1 in 1981, all six waves in North Carolina since 1989, waves 2-6 from Georgia-Massachusetts, and waves 2-5 from New Hampshire-Maine. Sampling before 2013 was primarily done during peak daylight hours. In

2013, sampling was allocated to cover non-peak hours. Sampling is post-stratified into marine water areas based on the primary area fished during trips, as reported by anglers. Areas include inshore coastal waters (e.g., bays and tidal rivers), state territorial seas (0-3 miles from the coast), and the EEZ (>3-200 miles from the coast).

The number of spot caught during a trip is recorded as harvested fish observed by the interviewer in whole form (type A catch), fish reported as harvested by the angler but not observed by the interviewer (i.e., bait, filleted, discarded dead on headboats; type B1 catch), and fish reported as released alive (type B2 catch).

Effort Surveys

The CHTS is a stratified random digit dialing telephone survey that includes only households in coastal counties (generally counties within 25-50 miles of coastline, depending on state). The CHTS is stratified by county and wave. Sampling is conducted over a two week period at the end of each wave (last week of the wave and first week of the next wave) and is allocated proportional to county population. The number of telephone interviews conducted during each wave varies based on the amount of fishing activity expected for the season (NMFS, pers. comm.). Information is collected on the number of trips in the previous wave and details about those trips (example questionnaires are available on the MRIP website).

Evaluation of the CHTS found that for-hire modes (headboat and charter boat) were being underrepresented due to the nature of these fisheries (e.g., out of state clients). Beginning in 2005, angler effort on charter boats and headboats from ports north of North Carolina has been sampled through the FHS and several overlapping sampling programs, replacing the CHTS for for-hire modes. The FHS is also a random digit dial telephone survey that uses a vessel directory as a sampling frame. Other overlapping programs include VTRs for New Jersey through Virginia (census logbook) and various state logbook programs.

4.2.1.1.2 Biological Sampling Methods

Length and weight measurements are obtained from type A catch encountered during APAIS intercepts to develop harvest size composition (numbers-at-length) and harvest estimates in weight. Length measurements are FL to the nearest mm and weight measurements are to the nearest tenth of a kg. Information on sample sizes was retrieved from the MRIP and MRFSS raw intercept files. Table 57 include spot length and weight sample sizes obtained during sampling by year.

Beginning in 2004, length measurements have been obtained from type B2 catch encountered during at-sea sampling of headboats (type 9 samples). Sample sizes by year and state are in Table 58.

No age samples (e.g., otoliths) are collected during APAIS sampling or at-sea sampling of headboats.

4.2.1.1.3 Catch Estimation Methods

Effort data from the CHTS and FHS are combined with U.S. Bureau of Census data on population size to estimate the total number of trips in a stratum. The estimated number of trips in a stratum are applied to the spot catch-per-trip for each catch type from APAIS intercepts and at-sea sampling in a stratum to obtain stratum catch estimates. Estimates are summed across strata for total number of spot harvested (A+B1), released alive (B2), or caught (A+B1+B2).

Mean weight of spot weighed during APAIS intercepts for a stratum are applied to the number of harvested spot in the stratum to obtain estimates of harvest in weight. The mean weight of type B1 catch in each stratum is assumed to be the same as type A catch in the stratum. Some strata prior to 2004 have zero harvest estimates in weight and positive harvest estimates in numbers, biasing the weight estimates low. This occurred if all intercepted, harvested fish for the stratum were type B1 catch or if interviewers were unable to obtain weight measurements for type A catch. MRIP methods of imputation using length-weight relationships have been used for addressing missing harvest estimates in weight and there are no strata with missing estimates after 2003. Thirty two strata had zero weight estimates with positive number estimates. To estimate harvest in weight for these strata, individual weight observations for APAIS intercepts were pooled from surrounding strata until a threshold sample size was obtained (n=20). Pooling collapsed over areas, followed by modes, states within sub-region (Mid-Atlantic or South Atlantic), and finally waves until the threshold sample size was reached. Mean weights were calculated and applied to the stratum harvest number estimate to estimate harvest weight. Numbers of harvest weight estimates by pooling level are in Table 59. The original estimate of harvest in numbers, the mean weight from pooling, and the new estimate of harvest in weight are in Table 60.

The proportions of spot measured for length in 1 cm length bins in each stratum are applied to the total number of spot harvested in the stratum to obtain size composition estimates of the harvest in numbers. A custom request was made through MRIP to provide annual size compositions of fish released alive estimated from type 9 length samples collected on headboats. SAS code using the MRIP weighted estimation methodology was provided and annual estimates were generated for years when data were available (2004-2014).

Catch estimate provided by MRFSS and MRIP through the MRIP online data query (NMFS, Fisheries Statistics Division, Silver Spring, MD, pers. comm.) were adjusted for survey design changes through time, according to recommendation by Carmichael and Van Voorhees (2014) and the SEDAR Best Practice Workshop (SEDAR 2016). Adjustments were made by (1) calibrating estimates generated from APAIS intercepts during peak daylight hours only and the MRIP estimation methodology (2004-2012) to 2013 estimates generated from APAIS data collected during peak and non-peak hours and the MRIP estimation methodology, (2) calibrating for-hire estimates generated from CHTS effort data to fire-hire estimates generated from FHS effort data (years are state-specific), and, subsequently, (3) calibrating estimates generated from the MRFSS estimation methodology (1981-2003) to estimates generated from the MRIP estimation methodology (2004-2014). MRFSS estimates from 2004-2007 are already re-estimated with the new estimation methodology when estimates are provided. The combination of for-hire modes from 1981-1985 in the South Atlantic requires splitting the MRFSS estimates into headboat estimates and charter boat estimates so headboat estimates are not double counted when using the preferred SERHS estimates in these years. However, due to the negligible catch estimates from the SERHS (Section 4.2.2), MRFSS for-hire catch estimates in the South Atlantic during 1981-1985 are assumed to be all from charter boats.

Recommendations of Carmichael and Van Voorhees (2014) were followed to calibrate catch estimates for the change in APAIS intercept timing. A ratio of 2013 catch estimated with intercept data from peak hours sampled prior to 2013 to 2013 catch estimated with intercept data from all hours sampled in 2013 was applied to catch estimates from 2004-2012. Ratios were developed at the mode and state level. If a threshold number of intercepts (n=30) were not available at this level, pooling was done until the threshold was reached. Pooling was done by collapsing over states within a sub-region, followed by collapsing over species within a state, followed by collapsing over species and states within a sub-region. If the threshold was still not reached, no adjustments were made to original estimates. Headboat estimates provided by MRIP (i.e., north of NC) were not adjusted because catch rates are developed from at-sea sampling and that sampling design did not change in 2013 (J. Foster, personal communication, March 29, 2016). Catch estimates by pooling levels are in Table 61 and Table 62. The range of ratios for harvest number estimates was 1-4.85 with a mean of 1.53. The range of ratios for harvest weight estimates was 1-8.65 with a mean of 1.60. The range of ratios for released alive estimates was 1-2.60 with a mean of 1.48. For-hire catch estimates from the South Atlantic during 1981-1985 were calibrated using conversion factors (i.e., ratios of effort estimates) developed by Matter et al. (2012), estimates from the South Atlantic during 1986-2002 were calibrated using conversion factors developed by SEDAR (2011), and estimates from the Mid-Atlantic during 1981-2003 were calibrated using conversion factors developed by SEDAR (2008). Estimates were calibrated for the change in estimation methodology according to recommendations of Salz et al. (2012). A ratio of mean catch estimates generated from the two estimation methodologies (i.e., MRIP:MRFSS) during overlapping years (2004-2014) was applied to the MRFSS estimates from 1981-2003. Estimates using the MRFSS estimation methodology were queried from the ACCSP Data Warehouse. Ratios were developed at the broadest scale appropriate for the stock unit (i.e., coastwide), to avoid a deterioration in precision (Salz et al. 2012).

There is a pending change in effort surveys, with the CHTS to be replaced by a mail-based effort survey, but data were not available for this assessment to calibrate estimates generated from CHTS effort data to estimates generated from the new mail effort survey. These data are anticipated sometime in 2018 and should be considered for future updates of this assessment.

To convert recreational releases from numbers to weight, conversion factors were developed from headboat biological sampling (type 9 sampling) from 2004-2014 and annual length-weight relationships developed from the fishery independent biological sampling programs. Numbers of spot released were converted first into lengths using length distributions from the headboat sampling and then converted to weight using year-specific length-weight conversions. For years prior to headboat sampling, a ratio of the average weight of released fish (as calculated from the length frequencies observed on headboats from 2004-2014) to the average weight of harvested fish over that same period was used to estimate the average weight of released fish in years prior to 2004. A ratio of 0.40 was applied to the average weight of harvested fish to calculate the average weight of released fish for the years 1981-2003. The average weight was then applied to coastwide released alive estimates in numbers. This method was also used in the Atlantic Croaker Benchmark Stock Assessment (ASMFC 2010a).

4.2.1.2 Trends

4.2.1.2.1 Recreational Catch Rates (CPUE)

Catch rates were not developed from MRFSS and MRIP data for modelling due to the availability of several regional fishery-independent surveys.

4.2.1.2.2 Recreational Harvest

4.2.1.2.2.1 Total Harvest

Harvest is generally the primary component of MRFSS and MRIP coastwide recreational catch (Figure 36), averaging 65% of annual catch from 1981-2014. Along the Atlantic coast from 1981-2014, annual recreational harvest (type A+B1) of spot has ranged from a low of 4.489 million fish in 1999 to a high of 24.695 million fish in 1983 (Table 63, Figure 36). The harvest has generally declined over the time series. In terms of weight, recreational harvest has ranged between 905 metric tons in 2012 and 3,857 metric tons in 1981 (Table 64, Figure 37). Recreational harvest in 2014 was 8.723 million fish, or 1,328 metric tons. The final, adjusted estimates follow the same trend as the original estimates but are scaled up, on average, by about 2.4 million fish or 405 metric tons (Figure 38 and Figure 39).

The majority of the spot recreational harvest was taken in Virginia and North Carolina (Table 63, Figure 40 and Figure 41), followed by Maryland, South Carolina, Georgia, and Florida. States north of Maryland harvest relatively few spot.

The majority of spot recreational harvest is taken during waves four and five (July-October; Figure 42 and Figure 43) by shore-based anglers and anglers fishing from private or rental boats (Figure 44 and Figure 45). Early in the time series, the majority of spot were harvest from coastal waters, but the majority of harvest since 1986 has generally been from inshore waters (Figure 46 and Figure 47).

4.2.1.2.2.2 Harvest Size Composition

Annual size frequency estimates of coastwide spot harvest are in Figure 48. The figures are subset to a size range between 10 and 31 cm FL, as lengths within this range accounted for at least 1% of the annual harvest for at least one year. The average length of harvested fish generally increased through the 1980s and 1990s (Figure 49). Mean length hit a time series high of 23.2 cm FL in 2004, but has declined since. The mean length of harvested fish in 2014 was 20.4 cm.

4.2.1.2.3 Recreational Releases

4.2.1.2.3.1 Total Releases

Live releases are generally less than recreational harvest in numbers (Figure 36). The estimated number of spot released alive by recreational anglers along the Atlantic coast has been variable, ranging from a low of 2.593 million fish in 2002 to a high of 15.603 million fish in 1981 with a mean of 6.264 million fish (Table 65, Figure 36). Recreational releases in 2014 were estimated at 3.754 million fish. The final, adjusted estimates follow the same trend as the original estimates but are scaled up, on average, by about 1.8 million fish (Figure 50). In terms of weight, recreational releases have ranged from 26 metric tons in 2010 to 156 metric tons in 1981 (Table 66, Figure 51).

Released alive estimates break down similarly to harvest estimates. The majority of fish released alive were captured from North Carolina-Maryland (Figure 52), during waves 3-5 (Figure 53), by shore-based or private or rental boat anglers (Figure 54). The majority of fish released alive throughout the time series were caught in inshore waters (Figure 55).

Fifteen percent of fish released alive were assumed to die post-release as result of factors such as hooking mortality and improper handling (Section 2.8; Table 67).

4.2.1.2.3.2 Release Size Composition

Annual length frequencies of spot released alive by headboat anglers estimated from type 9 biological sampling are in Figure 56. The distributions vary across years with the peak usually occurring between 10 and 20 cm FL.

4.2.1.3 Potential Biases, Uncertainty, and Measures of Precision

The MRIP estimates are based on a stratified random sampling design and so are designed to be unbiased. The proportional standard error (PSE) is provided with MRFSS and MRIP estimates as a measure of precision (Table 68-Table 70). The PSE is the percentage of the SE relative to the catch estimate. PSEs of MRFSS estimates are calibrated similar to catch estimates to address the change in estimation methodology, but the PSE calibration accounts for the additional uncertainty from the estimate of the calibration factor (Salz et al. 2012). A workshop was conducted in 2014 to evaluate acceptable levels of precision for MRFSS and MRIP catch estimates through simulation (ACCSP 2016). PSEs for coastwide catch estimates all fall in or below the general rule of thumb range (40-60%) proposed at this workshop for acceptable levels of precision, with the exception of the released alive estimate in 1981 (72.5%).

4.2.2 Southeast Region Headboat Survey

4.2.2.1 Data Collection and Treatment

4.2.2.1.1 Survey Methods

The SERHS estimates catch (harvest and releases) and effort and provides biological samples of harvested fish from trips on headboats in the South Atlantic (home ports from North Carolina-Florida). The SERHS began in the 1970s, but only data from 1981-2014 were provided. This matches the time series of the catch estimates from other modes of fishing provided by the MRFSS and MRIP. Estimates of released fish from the SERHS are only available since 2004.

There are two, complementary components of the design for this survey. The first was designed as a census logbook program for captain self-reporting of total harvest in numbers and weight, total releases in numbers by disposition (alive, dead, or unknown), and effort on all headboat trips. The logbook program was originally voluntary, but became mandatory. Despite the mandatory nature of the program, there has been known non-reporting that has varied through time. The second component of the survey is intercepts of headboat anglers upon arrival at port following the trip to obtain biological samples from harvested fish. See Brennan (2010) for more details on the SERHS.

4.2.2.1.2 Biological Sampling Methods

Biological sampling is described as a systematic opportunistic sampling of harvest by vessels assigned to port agents. Port agents are instructed to focus on uncommon catches in attempts to collect sufficient sample sizes from all catch. Port agents attempt to sample all vessels they are assigned to proportionally and in a systematic rotation. Fish are measured, weighed and otoliths are collected for ageing.

Only five spot have been sampled for biological data from 1981-2014 and no age structures have been collected from spot.

4.2.2.1.3 Catch Estimation Methods

Catch is summed across headboat logbooks to provide total catch estimates. If necessary, port agents develop correction factors based on records of vessel activity and effort to adjust for non-reporting by applying correction factors to reported catch.

4.2.2.2 Trends

4.2.2.2.1 Recreational Catch Rates (CPUE)

Catch rates were not developed from SERHS data for modelling due to the availability of several regional fishery-independent surveys.

4.2.2.2.2 Recreational Harvest

4.2.2.2.2.1 Total Harvest

Spot are infrequently harvested on South Atlantic headboats and harvest estimates from this survey make a negligible contribution to total fishery removals (Table 71). Only 829 spot were harvested from 1981-2014.

4.2.2.2.3 Recreational Releases

4.2.2.2.3.1 Total Releases

Spot are infrequently caught on South Atlantic headboats and dead release estimates from this survey make a negligible contribution to total fishery removals (Table 72). Only fifteen spot were caught and released from 2004-2014, all with unknown disposition. All of these fish were assumed to die post-release. Due to these negligible numbers during the available time series, releases from 1981-2014 were assumed to be zero.

4.2.2.3 Potential Biases, Uncertainty, and Measures of Precision

No measures of precision were provided with catch estimates.

4.2.3 Maryland Headboat Creel Survey

4.2.3.1 Survey Methods

An onboard headboat creel survey was conducted from 1997-2000 from June through September. The survey focused on Atlantic croaker, spot and weakfish. Anglers were queried as to whether or not they would like to participate in the survey. Each creel clerk surveyed a maximum of six anglers. Total fishing time was determined from the time fishing began until the lines were removed at the last fishing location.

4.2.3.2 Biological Sampling

All spot caught by participating anglers were measured to the nearest mm TL and whether it was harvested or released was recorded.

The time series mean TL of harvested spot was 23.1 cm (n=7,606; Figure 57). Annual mean lengths of harvested spot ranged from 22.0 to 24.3 cm, with sample sizes ranging from 510 to 2,966 fish per year.

The time series mean TL of spot released alive was 15.8 cm (n=480; Figure 57). Annual mean lengths of released spot ranged from 15.3 to 17.2 cm, with sample sizes ranging from 20 to 328 fish per year.

4.2.4 Virginia Marine Resources Commission Marine Sportfish Collection Project

The VMRC's Marine Sportfish Collection Project began in 2007. Chest freezers, bags, and information cards were placed at high activity fishing facilities so that fishermen could donate freshly filleted carcasses with head and tail intact. Bags are collected by the VMRC staff and processed for biological information. Participating anglers receive a shirt, hat, or tape measure as incentive to donate carcasses. When the project began in 2007, freezers where placed at three bait and tackle shops and by 2010 freezers were at seven locations across Capeville, Hampton, Poquoson, Norfolk, and Virginia Beach. Only four spot have been collected through this sampling program (Table 5).

4.2.5 South Carolina Freezer Program

The SCDNR Inshore Fisheries group has run a fish wrack collection program where carcasses of spot were obtained from voluntary contributions of fish "wracks" (the remains of fish after filleting). The samples were collected using freezers for anglers to place the fish wracks in with corresponding catch information at their convenience. A minimum of four freezers were maintained at locations convenient for anglers throughout the Charleston area where fish wracks could be dropped off. Anglers recorded the date and location of where the fish were caught and included this information with the fish wracks. Only length measurements (TL and

SL) were taken for freezer fish since total weight could not be obtained. Sex and maturity were determined through gross morphological examination and otoliths were removed for ageing. Histological samples were not taken since the specimens had been frozen and cellular integrity of the gonad tissue was compromised. Specimens were collected from 2010-2011 (Table 3).

4.3 Total Removals

Total annual removals of spot from all fishery sources (landings and discards) have ranged from between 4,637 and 57,287 metric tons, or 41 and 1,324 million fish (Table 73 and Figure 58). Removals were relatively large, but variable in the 1990s. Removals since 1997 have been relatively stable, coinciding with the requirement of BRDs across shrimp trawl fisheries. The long term mean removals was 12,785 metric tons, or 254 million fish. However, total removals after the peak year that occurred in 1991 averaged 9,399 metric tons, or 158 million fish.

The majority of annual removals were discards in the shrimp trawl fisheries, followed by commercial landings and recreational harvest (Figure 59). Discards from the shrimp trawl fisheries accounted for 31-70% of annual removals depending on year. Commercial landings accounted for 10-40% most years, while recreational harvest typically accounted for approximately 10% each year. The remaining sources of fishery removals were typically 5% or less of total annual removals over the last 20+ years.

5. Fishery-Independent Data

The SAS reviewed 35 fishery-independent surveys that encountered spot (Table 74). Surveys collect biological data used in spot life history analyses (Table 3), as well as catch rate data used to develop indices of relative abundance/biomass. There are several surveys that cover broad geographical areas relative to the stock range and these are believed to be more representative of coastwide relative abundance/biomass than the localized surveys reviewed. These are generally the same surveys that have previously been determined as having utility for assessment of the coastwide Atlantic croaker stock (ASMFC 2010a), as the two species have similar life histories and are often encountered together. These surveys were further narrowed to five surveys that encounter the full age structure of spot which made them candidate surveys for indices of abundance/biomass for the assessment modelling approaches discussed as the SAS reviewed data limitations for spot during the data workshop (e.g., limited size composition information for fishery removals). In anticipation of the potential modelling approaches discussed and review of the first year of complete removal data (i.e., 1989), the SAS requested indices from 1989-2014 in numbers and biomass, as well as surveys split into age-specific (age-0 and age-1+) indices in numbers, when possible. The five selected surveys and indices evaluated and used in this assessment are described in this section.

Additionally, criteria were developed by the SAS for evaluating each survey to determine which should be included in this assessment. The following criteria was used by the SAS to evaluate the surveys:

1. Time series is at least six years long, the age of the oldest spot in the data for this assessment.

2. Time series is continuous and there have been no changes in methodology or gear.
3. Survey operates within the spot geographic range at a time when the fish are typically available.
4. There are a high proportion of positive tows.

These criteria were used as a guide and, when surveys were used to develop indices, the SAS also considered if the index was correlated with other indices, it provided a conflicting signal to other indices or the catch history, or the index was not representative of the stock unit.

5.1 NMFS Trawl Survey

5.1.1 Survey Design & Methods

In 1963, the NMFS NEFSC implemented a multispecies bottom trawl program, which surveys over a large portion of the Atlantic shelf (hereafter referred to as the NMFS Trawl Survey; Avarovitz 1981, Grosslein 1969). The objective of the program is to monitor trends in abundance and distribution, characterize age/length structure, and better understand the biology and ecology of a wide array of finfish and invertebrate species. The survey uses a stratified random design, with strata based on depth (0.0–9.0 m; 9.0–18 m; 18– 27 m; 27–55 m; 55–110 m; 110–188 m; 188–366 m). Both inshore and offshore strata are sampled. The fall survey is an inshore survey that samples sites from Cape Hatteras to Cape Cod. The area within each stratum is subdivided into one-nautical mile blocks that are selected randomly prior to the sampling trip. The sampling gear is a #36 Yankee otter trawl rigged with rollers, 5-fathom legs, and 1,000- pound polyvalent door. A small-mesh cod-end liner (0.5-inch mesh) is used to retain YOY fish.

5.1.2 Sampling Intensity

The fall component has been conducted consistently since 1972. The number of tows per strata and year are in 0. Tow duration is 30 minutes.

5.1.3 Biological and Environmental Sampling

The catch of each tow is identified, counted, weighed, and measured. When the catch of a particular species is large, a subsample of individuals is measured. Data on sex, maturity, stomach contents, and disease are recorded. Latitude, longitude, gear information, salinity, temperature, weather, and hydrographic parameters are recorded.

5.1.4 Evaluation of Survey Data

Data collected from 1972 onward were evaluated. Prior to 1972, the survey protocol changed several times and not all strata were sampled in all years. The survey protocol was standardized beginning in 1972, and with the exception of some vessel changes, has adhered to that protocol since. An evaluation of the proportion of zero catches indicated that the occurrence of spot has been consistent throughout the duration of the survey (Table 76). Zero tows accounted for 50% of the total tows across these years. When the survey was limited to the fall months, when it predominantly encounters spot, and limited to the years 1989-2014, zero tows accounted for 29% of the total tows. Because this survey encounters spot often in a representative geographic range and has a random statistical design, the SAS supported the use of this survey for developing indices of abundance/biomass.

5.1.5 Development of Estimates

Data from the fall months (September–November) and offshore strata were used to develop an index of relative abundance (number per tow) which was split into age-0 (Table 77) and age-1+ (Table 78) indices (Figure 60). The index was split using the age-length key (ALK; 0) from the NEAMAP Trawl Survey to estimate the relative proportions of the two age groups (0 and 1+) annually from the length frequency distributions. The final annual index value for each age group was estimated as the proportion of the total index attributed to that age group. Since there was no age data collected for spot in the NMFS Trawl Survey, the NEAMAP Trawl Survey ALK was used because both were offshore surveys and the geographic range (New York to Cape Hatteras, NC) matched that of the NMFS Trawl Survey. An aggregate index of relative biomass (kg per tow) for all ages was also developed (Figure 61; Table 80). Sampling frequency varied among years and NMFS strata, making it necessary to pool data across strata in order to generate comparable, non-biased metrics of abundance across years. In 2009 there was a change in the sampling protocol for both gear and vessel for the fall survey with the decommissioning of the RV Albatross and the transition to the RV Bigelow for all future surveys. The RV Bigelow is not able to sample the nearshore strata due to the increased draft of this vessel and the mid-shore strata were not sampled as frequently. For continuity of sampling in the nearshore and mid-shore strata, these areas were taken over in 2008 by the NEAMAP Trawl Survey based out of VIMS. Annual estimates of the survey index for spot were reformatted using only the outer offshore strata in order to maintain continuity and effective use of the time series from 1989-2014. Additionally, stratified mean CPUE for the RV Bigelow for 2009-2014 were converted to RV Albatross equivalent units using reported conversion factors from conversion experiments performed between the two vessels doing side by side tows in 2008 (Miller et al. 2010). Pooling of the offshore strata resulted in five pooled strata arranged into five latitudinally separated regions (Region 1 = most northerly, Region 5 = most southerly).

5.1.6 Trends

5.1.6.1 Size Composition

Annual size compositions before splitting the index varied throughout the time series (Figure 62), although on average from 1972-2014 catch was dominated by 16-17 cm TL spot. The length-frequency distributions suggest the survey has primarily encountered spot ages 0+. Young-of-the-year spot (≤ 9 cm TL) and late (mode at 12–13 cm TL) age-0 spot accounted for 0.24-43.4 % of spot annually depending on the year. Prior to 1991, the proportion of YOY fish was higher (9.9%) versus later years (1991-2014, 5.97%). In 2014, the highest proportion of fish was above average at 19 cm TL.

5.1.6.2 Stage-Specific Indices

Abundance was high in the beginning of the time series and remained relatively low in comparison throughout the 1990s and early 2000s for both stages (Figure 60). Abundance for age-0 and age-1+ increased since the mid-2000s to the highest points in the time series in 2012, only to be followed by a decrease in abundance in 2013-2014.

5.1.6.3 Biomass Index

Relative biomass was at its highest in 1989, followed by a low relative biomass through the early 1990s (Figure 61). Biomass was variable through the 2000s, reaching its highest point in 20 years in 2012 followed by another decline and low point in 2014.

5.1.7 Potential biases, Uncertainty, and Measures of Precision

Measures of precision for the index of abundance (CVs) and biomass (SEs) are in Table 77 and Table 80, respectively. An index of total abundance was calculated and then split into age-0 and age-1+ indices, so the CVs reported for these indices are the CVs for the index of total abundance. The CVs for the index of abundance are relatively small, ranging from 0.026 to 0.311 and averaging 0.089.

5.2 SEAMAP Trawl Survey

5.2.1 Survey Design & Methods

The SEAMAP - South Atlantic (SEAMAP-SA) Coastal Survey (previously known as the Shallow Water Trawl Survey; hereafter referred to as the SEAMAP Trawl Survey) began in 1986 and is conducted by the SCDNR Marine Resources Division (MRD). This survey has provided long-term, fisheries-independent data characterizing the seasonal abundance and biomass of all finfish, elasmobranchs, decapod and stomatopod crustaceans, sea turtles, horseshoe crabs, and cephalopods that are accessible by high-rise trawls. The sampling area extends from the coastal zone of the South Atlantic Bight (SAB) between Cape Hatteras, North Carolina, and Cape Canaveral, Florida. The survey uses a stratified random design, where strata are delineated by the 4-m depth contour inshore and the 10-m depth contour offshore. A total of 102 stations are sampled each season within 24 shallow water strata. In previous years (1989–2000), stations in deeper strata—at depths ranging from 10 to 19 m—were also sampled in order to gather data on the reproductive condition of commercially important penaeid shrimp. Those strata were abandoned in 2001 in order to intensify sampling in the shallower depth zone. The R/V Lady Lisa, a 23-m wooden-hulled, double-rigged, St. Augustine shrimp trawler owned and operated by the SCDNR, is used to tow paired 22.9-m mongoose-type Falcon trawl nets, without TEDs. The body of the trawl is constructed of #15 twine with 47.6-mm stretch mesh. The cod end of the net is constructed of #30 twine with 41.3-mm stretch mesh and is protected by chafing gear of #84 twine with 10-cm stretch “scallop” mesh. A 91.4-m three-lead bridle is attached to each of a pair of wooden chain doors, which measure 3.0 m × 1.0 m and to a tongue centered on the headrope. The 26.3-m headrope, excluding the tongue, has one large (60 cm) Norwegian “polyball” float attached top center of the net between the end of the tongue and the tongue bridle cable and two 22.3-cm PVC foam floats located one-quarter of the distance from each end of the net webbing. A 1-ft chain drop-back is used to attach the 89-ft footrope to the trawl door. A 0.6-cm tickler chain, which is 0.9 m shorter than the combined length of the footrope and drop-back, is connected to the door alongside the footrope. Each net is processed separately and assigned a unique collection number.

5.2.2 *Sampling Intensity*

Multi-legged cruises are conducted in the spring (April–May), summer (July), and fall (October). Trawls are towed for twenty minutes, excluding wire-out and haul-back time, exclusively during daylight hours (1 hour after sunrise to 1 hour before sunset).

5.2.3 *Biological and Environmental Sampling*

After each tow, the contents of each net are sorted to species or genus, and the total biomass and number of individuals are recorded for all species of finfish, elasmobranchs, decapod and stomatopod crustaceans, cephalopods, sea turtles, xiphosurans, and cannonball jellies. Only total biomass is recorded for all other miscellaneous invertebrates and algae, which are treated as two separate taxonomic groups. Where a large number of individuals of a species occur in a tow, the entire catch is sorted and all individuals of that species are weighed; a random subsample is processed and the total number is estimated. For large trawl catches, the contents of each net are weighed prior to sorting and a randomly chosen subsample of the total catch is then sorted and processed. In every collection, each of the majority of priority species is weighed collectively and individuals are measured to the nearest cm. When a large number of individuals of any of the priority species are collected in a tow, a random subsample consisting of 30 to 50 individuals is weighed and measured.

Spot otoliths were only collected in 2001 from 745 specimens.

5.2.4 *Evaluation of Survey Data*

The fall component of the SEAMAP Trawl Survey has been conducted consistently since 1989. An evaluation of the proportion of zero tows (37% of all tows) indicates that the SEAMAP Trawl Survey has regularly encountered spot in the spring, summer, and fall components of the survey. Zero tows were more prevalent during the spring component of the survey (41% of all tows). The length-frequency distributions suggest that the majority of spot captured in the spring, summer, and fall components of the survey are age 0+(Figure 65). YOY fish (< 10 cm) were encountered during the fall survey in most years, but not in very high numbers.

5.2.5 *Development of Estimates*

An index of relative abundance (numbers per tow) was developed and split into age-0 and age-1+ components (Table 77 and Table 78; Figure 63). The index was split using the ALK (0) from age samples taken in 2003. The ALK was then used to estimate the relative proportions of the two age groups (0 and 1+) annually from the length frequency distributions. The final annual index value for each age group was estimated as the proportion of the total index attributed to that age group. An index of relative biomass (kg per tow) was calculated using data from the fall component (September-November) of the SEAMAP Trawl Survey (Figure 64).

5.2.6 *Trends*

5.2.6.1 *Size Composition*

Annual size compositions of spot before splitting the index varied throughout the time series (Figure 65), although on average from 1989-2014 ranged from 12-16 cm TL. The length frequency plots indicate that mostly age 0+ spot are caught in this survey, with some YOY (<10 cm) caught during some portions of the year.

5.2.6.2 Stage-Specific Indices

Abundance was low in the beginning of the time series, with a notable peak in the age-1+ index in 1991. Both stage-specific indices remained relatively low throughout the 1990s and early 2000s for both stages (Figure 63). Abundance for age-0 and age-1+ was high in 2005, only to be followed by a decrease in abundance in 2006-2009. The age-0 index had another large peak in 2010 but decreased the following year and remained low until 2014.

5.2.6.3 Biomass Index

The index of relative biomass for spot indicates that abundance was low in 1989 but increased in the early 1990s (Figure 64). From the mid-1990s to the early 2000s abundance remained low. There was a large increase in 2005 followed by almost a decade of ups and downs in abundance.

5.2.7 Potential biases, Uncertainty, and Measures of Precision

Measures of precision for the index of abundance (CVs) and biomass (SEs) are in Table 77 and Table 80, respectively. An index of total abundance was calculated and then split into age-0 and age-1+ indices, so the CVs reported for these indices are the CVs for the index of total abundance. The CVs for the index of abundance range from 0.126 to 0.538 and averaging 0.289.

5.3 NCDMF Trawl Survey

5.3.1 Survey Design and Methods

The Pamlico Sound Survey (hereafter referred to as the NCDMF Trawl Survey), also known as Program 195 (P195), was initiated by the NCDMF in 1987 to provide a long-term, fisheries-independent database for the waters of the Pamlico Sound, eastern Albemarle Sound, and the lower Neuse and Pamlico rivers. The survey samples fifty-two randomly selected stations based on a grid system (one-minute by one-minute grid system equivalent to one square nautical mile). Sampling is stratified by depth and geographic area. Shallow water is considered water between 6 to 12 feet in depth and deep water is considered water greater than 12 feet in depth. The seven designated strata are: Neuse River; Pamlico River; Pungo River; Pamlico Sound east of Bluff Shoal, shallow and deep; and Pamlico Sound west of Bluff Shoal, shallow and deep. As of March 1989, the randomly selected stations have been optimally allocated among the strata based upon all the previous sampling in order to provide the most accurate abundance estimates (PSE < 20) for selected species. A minimum of three stations (replicates) are maintained in each strata. A minimum of 104 stations are sampled each year to ensure maximum areal coverage. Tow duration is 20 minutes at 2.5 knots using the R/V Carolina Coast, which is equipped with double-rigged demersal mongoose trawls. The R/V Carolina Coast is a 44-ft fiberglass hulled double-rigged trawler owned and operated by the NCDMF. The body of the trawl is constructed of #9 twine with 47.6-mm stretch mesh. The cod end of the net is constructed of #30 twine with 38.1-mm stretch mesh. The tailbag is 80 meshes around and 80 meshes long (approximately 3.1 m). A 36.6-m three-lead bridle is attached to each of a pair of wooden chain doors that measure 1.22 m × 0.0610 m and to a tongue centered on the headrope. A 60-cm "polyball" is attached between the end of the tongue and the tongue bridle cable. A 4.76-mm tickler chain that is 0.90 Section B, Page 38 m shorter than the 10.4-m footrope is connected to the door next to the footrope. Trawl door coverage area is 9.51 sq m. The sampling coverage area is 8,152 sq m and the sampling coverage volume is 13,042 cu m. Environmental data are recorded, including temperature, salinity, dissolved oxygen, wind speed, and direction.

5.3.2 Sampling Intensity

The sampling season has undergone some changes since the survey's inception. Beginning in 1991, sampling has been performed over a two-week period, usually the second and third weeks of both June and September. Sampling now occurs only in the Pamlico Sound and associated rivers and bays.

5.3.3 Biological and Environmental Sampling

All species are sorted, and a total number and aggregate weight is recorded for each species. For target species, thirty to sixty individuals are measured, and total aggregate weights are taken. The catches from each of the two towed nets are combined to form a single sample in an effort to reduce variability.

5.3.4 Evaluation of Survey Data

An evaluation of the proportion of zero catches (10% of all tows) indicated that spot have been regularly encountered during the June component of the survey. Because this survey often catches spot, is statistically designed, and represents a portion of the spot geographic range, the SAS supported its use to develop indices of abundance/biomass.

5.3.5 Development of Estimates

An index of relative abundance (numbers per tow) was developed from the June portion of the NCDMF Trawl Survey and split into age-0 and age-1+ components (Figure 66). Due to fast growth of age-0 spot, length separation of these two age groups was most distinct during June. Spot less than 12 cm were considered age-0 fish and those greater than or equal to 12 cm were considered age-1+.

5.3.6 Trends

5.3.6.1 Stage-Specific Indices

Both age-0 and age-1+ abundance indices for spot from the NCDMF Trawl Survey varied throughout the time series. Both were somewhat lower in the 1990s with larger peaks in the mid-2000s. The highest age-0 abundance was in 2008 and the highest age-1+ abundance was in 2006.

5.3.7 Potential biases, Uncertainty, and Measures of Precision

CVs for the age-specific indices of abundance are in Table 77 and Table 78. The CVs for the indices of abundance are similar, averaging 0.177 and 0.183 for the age-0 and age-1+ indices, respectively.

5.4 ChesMMAP Trawl Survey

5.4.1 Survey Design and Methods

The ChesMMAP Trawl Survey has been sampling the mainstem of the Chesapeake Bay, from Poole's Island, Maryland to the Virginian Capes at the mouth of the bay since 2002. This survey is designed to sample the late juvenile and adult stages of the living marine resources in Chesapeake Bay, and as such the timing of sampling is meant to coincide with the seasonal residency of these life stages in the estuary.

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

5.4.2 Sampling Intensity

ChesMMAP conducts 5 cruises annually, during the months of March, May, July, September, and November. A total of 80 sites are sampled per cruise.

5.4.3 Biological and Environmental Sampling

A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation [PAR]), atmospheric data, and station identification information are recorded at each sampling site.

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

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

5.4.4 Evaluation of Survey Data

The ChesMMAP survey encounters spot throughout the year except for March, although the amount of tows with zero spot is higher than some of the other surveys considered at 62%. When limited to May-September cruises, the amount of zero tows decreased to 51% and when limited to only stratum occurring in Regions 4 and 5, the amount of zero tows decreased to 37%. The SAS supported the development of indices using ChesMMAP data in May-September and only in regions 4 and 5 for consideration in the modeling approaches.

5.4.5 Development of Estimates

An index of relative abundance (numbers per tow) and an index of biomass (kg per tow) were developed from the May-September portion of the survey from Regions 4 and 5 (Table 80, Figure 68). The index of relative abundance for a given year was split into age-0 and age-1+ components using ALKs generated by the survey's age data on spot for that year. Specifically, the proportion of age-0 and age-1+ spot in the catch was determined using the associated ALK data for that year (Table 82), and these proportions were applied to the overall index to generate indices for age-0 and age-1+ fish, respectively (Table 77 and Table 78, Figure 69).

5.4.6 Trends

5.4.6.1 Size Composition

Most spot captured in the ChesMMAP survey throughout the year range from 14-20 cm TL (Figure 70) and ages 0 and 1 (Figure 71).

5.4.6.2 *Stage-Specific Indices*

From 2002-2014, age-0 and age-1+ indices indicate that the highest abundance of both age-classes was in 2006 and has been decreasing since then (Figure 69). The terminal year of 2014 experienced very low abundance of both age-0 and age-1+ indices.

5.4.6.3 *Biomass Index*

The index of relative biomass for spot developed from the May-September component of the ChesMMAP Trawl Survey in regions 4-5 only indicated that the highest biomass occurred in 2005 and has been on a decline since then (Figure 68). Biomass has been consistently low since 2010 and was at its lowest in the whole time series in the terminal year of 2014.

5.4.7 Potential biases, Uncertainty, and Measures of Precision

Measures of precision for the index of abundance (CVs) and biomass (SEs) are in Table 77 and Table 80, respectively. An index of total abundance was calculated and then split into age-0 and age-1+ indices, so the CVs reported for these indices are the CVs for the index of total abundance. The CVs for the index of abundance range from 0.208 to 0.348 and averaging 0.280.

5.5 NEAMAP Trawl Survey

5.5.1 Survey Design and Methods

The NEAMAP Mid-Atlantic/Southern New England Nearshore Trawl Survey (hereafter referred to as the NEAMAP Trawl Survey) has been sampling the coastal ocean from Martha’s Vineyard, MA to Cape Hatteras, NC since the fall of 2007.

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

A four-seam, three-bridle, 400x12cm bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.0kts. The gear is of the same size as and nearly identical in design to that used by the NMFS Trawl Survey, only sweep configuration and trawl door type differ between the two programs. Tow times and tow speeds are consistent between the two programs. The net is outfitted with a 2.54cm knotless nylon liner to retain the early life stages of the various fishes and invertebrates sampled by the trawl. Trawl wingspread, doorspread, headline height, and bottom contact are measured during each tow, and those in which net performance falls outside of defined acceptable ranges are either re-towed or excluded from analyses in an effort to maintain sampling consistency.

5.5.2 Sampling Intensity

NEAMAP conducts two cruises per year, one in the spring and one in the fall, mirroring the efforts of the NMFS Trawl Surveys offshore. Spring cruises begin during the third week in April and conclude around the end of May, while the fall surveys span from the third week in September until the beginning of November. Sampling progresses from south to north in the spring and in the opposite direction in the fall, so as to follow the general migratory pattern of the living marine resources of these regions.

Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A total of 150 sites are sampled per cruise, except 160 sites were sampled in the spring and fall of 2009 as part of an investigation into the adequacy of the program's stratification approach.

5.5.3 Biological and Environmental Sampling

A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation [PAR]), atmospheric data, and station identification information are recorded at each sampling site.

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

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

5.5.4 Evaluation of Survey Data

NEAMAP has a statistical, randomly stratified design and does encounter spot throughout the year (65% of all tows were zero), specifically during the fall months (55% zeros). While the SAS was concerned about the length of the time series, indices of abundance and biomass were developed for consideration in modeling approaches.

5.5.5 Development of Estimates

An annual index of relative abundance was developed using data from the NEAMAP Trawl Survey by calculating the geometric mean number of spot caught per standard area swept (i.e., 25,000 m^2) for each year. Calculations were restricted to using catch data from the fall cruises and from tows conducted in Regions 06 to 15 (New York Harbor to Cape Hatteras), which represent the season and locations of consistent spot collections. The index of relative abundance for a given year was split into age-0 and age-1+ components using ALKs generated by the survey's age data on spot for that year. Specifically, the proportion of age-0 and age-1+ spot in the catch was determined using the associated ALK data for that year (Table 83), and these proportions were applied to the overall index to generate indices for age-0 and age-1+ fish, respectively (Table 77 and Table 78, Figure 72). Additionally, an index of relative biomass (kg per tow) was developed from the fall months of the survey (September-November) (Table 80, Figure 73).

5.5.6 Trends

5.5.6.1 Size Composition

Most spot captured in the NEAMAP survey throughout the year range from 14-20 cm TL (Figure 74). Data from the fall portion indicates that most spot caught in this survey are ages 0 and 1 (Figure 75).

5.5.6.2 Stage-Specific Indices

Both the age-0 and age-1+ indices for spot caught in the NEAMAP Trawl Survey show little variability throughout the time series with the exception of 2012 (Figure 72). In 2012, the age-1+ index declines to almost zero and the age-0 index shows high abundance in that year.

5.5.6.3 Biomass Index

The index of relative abundance for spot from the NEAMAP Trawl Survey shows some variability with the highest biomass in 2012 and the lowest in the terminal year of 2014 (Figure 73).

5.5.7 Potential biases, Uncertainty, and Measures of Precision

Measures of precision for the index of abundance (CVs) and biomass (SEs) are in Table 77 and Table 80, respectively. An index of total abundance was calculated and then split into age-0 and age-1+ indices, so the CVs reported for these indices are the CVs for the index of total abundance. The CVs for the index of abundance range from 0.113 to 0.278 and averaging 0.214.

5.6 Index Selection

Association of candidate indices was evaluated with Spearman's rank correlation coefficient, or Spearman's rho (ρ). This is a nonparametric test to evaluate association of two ranked variables over time (i.e., indices of abundance). Associations were evaluated between indices within stages as well as within indices between stages, with the age-0 indices being forward lagged by one year to match the year when these year classes would be indexed by the age-1+ index. It was assumed that age 1 fish are the primary age class in the age-1+ indices when evaluating these associations. There are positive associations within the NCDMF Trawl Survey, NMFS Trawl Survey, NEAMAP Trawl Survey, and ChesMMAP Trawl Survey split indices (Table 84). The SEAMAP Trawl Survey split indices were not associated with each other, but the lagged SEAMAP Trawl Survey age-0 index was positively associated with the NMFS and NCDMF Trawl Survey age-1+ indices. Further visual examination of the split SEAMAP Trawl survey indices suggested that this index was not tracking cohorts when split. For example, there are very large peaks of both age-0 and age-1+ fish in 2005. There does not appear to be any support for such a large increase in relative abundance of age-1+ fish from the preceding year age-0 relative abundance. It is suspected that the splitting method does not reliably partition the catch rates of these two age groups. Visual examination of the trend in the ChesMMAP Trawl Survey indices generally suggested a different trend than the other indices being considered and the SAS suspects that this survey is more reflective of localized relative abundance within the Chesapeake Bay. The

SAS also decided not to include the NEAMAP Trawl Survey in base models because of its short time series relative to the NMFS Trawl Survey that operates parallel to this survey and the potential to confound the modelling approaches and overweight the signal of abundance from the Mid-Atlantic region. Instead, the SAS recommended using the NEAMAP Trawl Survey indices in model sensitivity analysis. The NMFS Trawl and NCDMF Trawl Survey indices were selected as split indices for assessment modelling. These surveys are not positively associated with each other, but the SAS believes the signals are collectively representative of coastwide relative abundance.

The NMFS Trawl and SEAMAP Trawl biomass indices were selected as aggregate indices for assessment modelling because they have previously been used in the TLA and are believed to be representative of the coastwide relative biomass.

6. Methods

Available data guided the choice of modelling approaches for this assessment. Biological sampling from the fishery removals, particularly the dead discards, is a major limitation for spot precluding the development of a reliable time series of catch-at-age data. However, there are estimates of fishery removals in biomass and numbers and several regional surveys indexing the abundance of the entire population age structure that can be partitioned into two distinct groups, or stages, with similar life history characteristics. Single-species models in this assessment include a surplus production model performed in ASPIC (Prager 1994) and Excel and a two-stage, forward projecting model (hereafter referred to as the modified-CSA) with similarities to catch survey analysis (CSA; Collie and Sissenwine 1983) and fully age-structured statistical catch-at-age models.

Neither model is spatially explicit and estimate parameters describing the dynamics and condition of the coastwide stock from aggregated coastwide data. The population dynamics were modelled from 1989-2014. The start year was a pragmatic choice, given data used to generate commercial fishery discard estimates, the vast majority of spot fishery removals early in the time series, are available starting in 1989.

6.1 Surplus Production Model

6.1.1 Model Description

The surplus production model was developed as a secondary, supporting model for spot because of its relatively simple modeling approach. Surplus production models combine the effects of recruitment, growth, and mortality into a single function and assume no size or age structure in the population. It requires a time-series of fishery removals and one or more time-series of catch-per-unit effort from a survey. The non-equilibrium Graham-Schaefer, or logistic, form was used to assess spot (ASPIC; Prager 1994). The model assumes that the population is closed, the environment is constant, abundance indices are proportional to the true population abundance, total catch is known without error, the stock responds instantaneously to changes, and that the intrinsic rate of increase (r) and carrying capacity (K) remain constant.

6.1.2 Reference Point Model Description

The surplus production model estimates maximum sustainable yield (MSY) and the associated MSY-based references points of B_{MSY}, the stock biomass associated with MSY, and F_{MSY}, the fishing mortality that maximizes the yield from the population. These absolute values are usually imprecise (Prager 1994) since they require good estimates of catchability (q). Relative biomass (B_{2014}/B_{MSY}) and relative fishing mortality (F_{2014}/F_{MSY}) can be used to determine overfishing and overfished status.

6.1.3 Configuration

A complete description of inputs for the surplus production model can be found in Table 87, but briefly, this analysis used two fishery-independent surveys, the fall portions of the NMFS Trawl and the SEAMAP Trawl Surveys, as well as the complete fishery removals data.

Coastwide fishery removals from 1989-2014 (Table 73, Figure 58, Figure 59) were calculated in weight (metric tons) and were comprised of commercial and recreational landings, recreational dead discards, commercial dead discards from mid-Atlantic gillnet and trawl fisheries, landings from the scrap fishery, and dead discards from the shrimp trawl fishery (see Section 4).

6.1.3.1 Selection and Treatment of Indices

The surplus production model used the fall portions of the relative biomass indices (kg/tow) developed from NMFS Trawl and SEAMAP Trawl Surveys (Table 80, Figure 61, Figure 64). Indices were weighted equally in the model and were found to be positively correlated (r=0.38) but not significantly (P=0.09).

6.1.3.2 Sensitivity Analyses

The SAS conducted sensitivity runs by including the NEAMAP Trawl Survey as an additional relative biomass index, beginning the model in 1992 after the large peaks in the removal time-series, using alternative formulations of the Pella-Tomlinson model, and including the relative biomass index from the NMFS Trawl Survey only. The base run analysis was also performed in Excel to examine differences from and sensitivities to ASPIC.

6.1.3.3 Projections

The population was projected forward 10 years at a harvest level equal to the 2014 harvest.

6.2 Modified-CSA Model

6.2.1 Assessment Model Description

The modified-CSA was originally developed and subsequently modified for several blue crab stock assessments (Miller et al. 2011, VanderKooy 2013). The version used by VanderKooy (2013) was further modified for this assessment. The two stages for spot are recruits (age-0) and post-recruits (age-1+), according to calendar year ages (January 1-December 31). Unlike the original CSA, the modified-CSA model generates estimates that are not conditioned on catch (i.e., catch is not assumed known without error), can fit to multiple indices of abundance for each stage, does not relate the catchability coefficients of the two stages within a survey, allows for fishing to occur on recruits before the survey, and the population dynamics explicitly involves a stock–recruit relationship. The two-stage population structure and an assumed selectivity-at-stage preclude the need for catch-at-age data. Spot are short-lived and the age data that are available indicate that life history characteristics (i.e., growth, maturity) do not vary much between the majority of fish grouped into post-recruits (ages-1 and 2). The model is implemented in AD Model Builder (ADMB) version 11.2 (Fournier et al. 2012). Model code and data input files are in Appendix 4 and Appendix 5, respectively.

General model definitions and model inputs, population and observation model equations, and likelihood components of the model objective function (negative log-likelihood) are in Table 88, Table 89, and Table 90, respectively. Abundance of both stages is predicted in the initial year (1989) and projected forwarded as a function of total mortality (fishing mortality and natural mortality) and annual recruitment. Prior information on the average total mortality of post-recruits over a range of years can be included in the model to provide guidance on the scale of fishing mortality, and, therefore, the scale of abundance. Recruitment each subsequent year is predicted as a function of the previous year, end-year (December 31) spawning stock biomass through a stock-recruit relationship, parameterized in terms of steepness, and lognormally distributed deviations from the expected relationship. Lognormal recruitment deviations on the log scale have a mean of zero and standard deviation that can be estimated or fixed. Lognormally distributed recruitment deviations are bias corrected for transformation from the log space. Beverton-Holt (1957) and Ricker (1954) forms are options for the stock-recruit relationship. A beta prior distribution on steepness of the stock-recruit relationship and spawning stock biomass estimates are new options included for this assessment. Female spawning stock biomass, as opposed to female spawning stock abundance in the blue crab assessments, is assumed to be a proxy for spot reproductive capacity. Recruits that survive their first year (y) join the post-recruits the following year (y+1) and survive as part of subsequent post-recruit abundances (y+1+n) according to the annual total mortality. Initial full, or apical, fishing mortality is an estimated parameter and fishing mortality each subsequent year is estimated as a freely varying deviation from the initial fishing mortality (i.e., deviation vector not restricted to a mean of zero) to allow for freely trending fishing mortality over time (VanderKooy 2013), particularly due to the declining trend in shrimp trawl discards through the first part of the time series. There are no index of abundance data after the terminal year to tune the terminal year fishing mortality estimate, so the terminal year fishing mortality is equal to the geometric mean of the previous two years fishing mortality estimates.

Predicted indices of abundance are calculated as a function of model estimated abundances during the annual timing of the surveys and derived catchability coefficients and compared to observed indices of abundance as a lognormal likelihood component of the objective function. Predicted catch-at-stage is calculated with the Baranov catch equation (i.e., continuous catch throughout the year; Baranov 1918) as a function of the model estimated fishing mortality, then summed across stages, and compared to the observed total fishery removals as a lognormal likelihood component of the objective function. Other components of the objective function include recruitment deviations from the expected stock-recruit relationship, and prior distributions for steepness and average total mortality. Likelihoods components can be either directly weighted by adjusting the weighting “lambdas” or by adjusting input error for data observations (i.e., CVs).

6.2.2 Reference Point Model Description

Static spawning potential ratios (sSPR), fishing mortality rates and spawning stock biomasses at reference sSPRs (e.g., F40% and SSB40%), and MSY-based reference points are calculated from population model estimates (Table 91). sSPR is calculated as the ratio of spawning stock biomass per recruit experiencing annual fishing mortality to the unfished spawning stock biomass per recruit. Fishing mortality rates at sSPRs ranging from 20-40% were calculated, as these are common sSPR reference levels to approximate MSY (Appendix 6). Being a function of annual fishing mortality, the terminal year sSPR is calculated from the geometric mean fishing mortality from the two years prior to the terminal year. Spawning stock biomass reference points associated with reference sSPRs are calculated by projecting the population dynamics to equilibrium under the reference fishing mortality rate and annual recruitment randomly sampled from the model estimated recruitments. These biomass reference points are calculated under the assumption that recruitment estimates being sampled are representative of equilibrium recruitment levels of a stock fished at the reference fishing mortality rate over time. If recruitment estimates are biased low, biomass reference points would be biased low and vice versa. MSY-based reference points include MSY, F_{MSY}, the exploitation rate at MSY (U_{MSY}), and female spawning stock biomass at MSY (SSB_{MSY}). MSY-based reference points are estimated by calculating reference points at a range of F values (0.00-6.00 at increments of 0.01) and finding the fishing mortality rate that maximizes catch in equilibrium conditions, given the model estimated stock-recruitment relationship and yield per recruit calculations.

6.2.3 Configuration and Data

Fishery removals in numbers were aggregated across recreational fisheries (harvest and dead releases from Florida-Connecticut) and commercial fisheries (marketable landings from Florida and South Carolina-New Jersey, scrap landings from North Carolina and Virginia, shrimp trawl dead discards from Florida-North Carolina, and Mid-Atlantic gillnet and trawl dead discards from North Carolina-New York) into one ‘fleet’. Total removals are in Table 73 and Figure 58. Removal percentages by fishery are in Figure 59. CVs for removal data were assumed to be 0.05.

Indices of abundance from two surveys, the NCDMF Trawl and NMFS Trawl Surveys, were developed for both stages, resulting in four indices of abundance. Indices were developed from catch in numbers and standardized to means. Indices from the NCDMF Trawl Survey were developed using a length cutoff and indices from the NMFS Trawl Survey were developed by applying an ALK borrowed from the NEAMAP Trawl Survey. These surveys parallel each other along the Atlantic coast, sampling fish as they move from inshore areas (NEAMAP) to offshore areas (NMFS). The NCDMF Trawl Survey indices were developed from June observations only and were compared to model estimated abundance at the middle of June (46% of the year past). The NMFS Trawl Survey indices were developed from fall observations (Sep-Oct) and were compared to model estimated abundance at the end of September (75% of the year past). Both surveys occurred throughout the model time series. Index CVs were derived from design-based estimation of catch rate means and variances. Indices of abundance and CVs are in Table 77, Table 78, Figure 60 and Figure 66. See Section 5 for more details on surveys and development and selection of indices.

Natural mortality-at-stage was fixed at estimates generated from weight-based methods of Lorenzen (2005) and was assumed time-invariant. The natural mortality of post-recruits is an average from ages 2-6 (Section 2.7.2). Post-recruits are assumed fully selected. Partial selectivity of recruits (relative to post-recruits) was fixed at 0.43 and assumed time-invariant. This value was developed by comparing length frequencies of fishery-independent surveys and fishery-dependent sampling from the various fisheries. The effects of each fishery on the overall selectivity (i.e., weighting) were determined by the relative magnitude of the respective fishery's removals to total removals (Appendix 7). Prior information on the average total mortality of post-recruits from 1996-2013 estimated from catch curve analysis (Appendix 8) was updated through the likelihood framework according to data informing fishing mortality estimates in the model. The CV on this prior information was assumed to be 0.05 to anchor the model estimates near the observed total mortality while allowing some flexibility (VanderKooy 2013). Maturity of recruits was estimated from a logistic regression and maturity of post-recruits was assumed to be one (Section 2.6.2). There is variability in information on the maturity of age-1 fish, but most supports age-1 spot maturing by the end of the year (time of spawning in the model). There is also variability in information on sex ratios. The only literature estimate of population sex ratio (female:male) is from the Gulf of Mexico and is 1. Estimates from fishery-independent data from the Atlantic coast range between 1 and 2.79 (Section 2.6.3). Ratios also vary by age and month. Fishery-dependent data are more indicative of a skewed sex ratio in the commercial landings, though there are no sex data from the shrimp trawl observer data. Given the variability of the estimates and the lack of sex data from the shrimp trawl fishery, sex ratios of the population and removals are assumed to be 1. Peak spawning is assumed to occur at the end of the calendar year and recruitment is assumed related to spawning stock biomass from the subsequent year through a Beverton-Holt stock-recruit relationship. The CV of the lognormal error around the expected recruitment was fixed at 0.66 (sd on log scale=0.6) based on a meta-analysis by Beddington and Cooke (1983). Prior information on the steepness of the stock-recruit relationship for spot from a meta-analysis (Appendix 9) was updated through the likelihood framework according to data informing estimation of this parameter in the model. The steepness prior was a beta distribution with parameters p=3.05 and q =1.73 (mean=0.64, CV=0.32). Mean weight-at-stage for spawning stock biomass calculations was developed from the NEAMAP Trawl Survey (Table 92), the only broad regional survey with multiple years of age data, and is assumed time-invariant. No significant differences ($p<0.05$) among annual mean weight within each stage were detected with analysis of variance (ANOVA) for these data (Table 93). Assumed inputs are summarized in Table 88.

There are five leading parameters and forty nine deviations estimated (denoted by ^ in Table 89) from 130 data points, not including CVs, and two priors. All parameters and deviations are estimated in the log space.

6.2.4 Weighting of likelihoods

The methods of Francis (2011) were originally implemented until it was discovered that data conflicts required extreme down weighting of index data, to the point of being uninformative, to achieve standard deviations of standardized residuals (SDSRs) near one. To acknowledge process error, the methods of Francis (2003) were ultimately adopted by adding 0.2 to index CVs representing measurement error (Table 94). This weighting was chosen as the preferred weighting, as the model fit to data with this weighting was deemed a better fit than the model fit to data with weighting that did not acknowledge process error (see next section).

6.2.5 Evaluation of Model Fit

The objective function is minimized to find best fit parameter estimates. Goodness of fit was evaluated by inspecting residuals from model predictions of observed data. Evaluation included visual inspection of residual plots, comparing means of standardized residuals to zero with a t-test, comparing sum of squared residuals (SSR), testing for normality of standardized residuals with a Shapiro-Wilk test, and testing for trends in residual signs (positive or negative) with respect to time with a runs test. Ideal results of evaluation were minimized SSR and normally distributed standardized residuals with no trends or means significantly different than zero. Focus was on fits to index of abundance data as Francis (2011) recommends that these data should have primacy in model fitting.

6.2.6 Characterizing Uncertainty

6.2.6.1 Asymptotic standard errors

The delta method within ADMB was used to generate asymptotic standard errors and CVs of key model parameters and derived values.

6.2.6.2 Sensitivity analysis

Sensitivity of the base model to key assumptions and data choices was evaluated by comparing results of alternative model configurations to the base model. Changes for sensitivity configurations relative to the base model are described below and summarized in Table 95. Each sensitivity configuration will be referred to by the name of the configuration in bold below. Four sensitivities focused on shrimp trawl discard estimates because these made up such a large component of the total removals; the model time series was changed to start in 1992 to exclude the relatively large discard estimates in 1990 and 1991 (**1992 start year**), the relatively large discard estimates were changed to equal the median shrimp trawl discard estimate during years when BRDs were not uniformly required (*259 million fish*; **adjust shrimp discards**), and all shrimp trawl discard estimates were scaled down to 10% (**10% shrimp discards**) and 50% (**50% shrimp discards**) of the base model estimates. The adjusted time series of removals for the sensitivity configurations, where applicable, and the base model time series of removals are in Figure 77. Two sensitivity configurations focused on the assumption about the recruit selectivity relative to post-recruit selectivity; the selectivity was estimated in the model which resulted in an estimate lower than the value assumed for the base model (*0.306*; **low selectivity**) and the selectivity was fixed at the value assuming recruits are vulnerable to fishing mortality for three quarters of the year which was higher than the value assumed for the base model (*0.645*; **high selectivity**). The analysis in Appendix 7 indicates that recruits are not even partially vulnerable to fishing mortality for at least the first few months of the calendar year, so this high value is regarded as the extreme upper bound on selectivity. Though the model estimated a reasonable selectivity for recruits, it was not estimated in the base model because the estimate fluctuated drastically across sensitivity runs and retrospective runs, often being estimated at a bound. Four sensitivity configurations focused on assumptions about mortality; natural mortality was developed using the upper and lower 95% confidence intervals on growth model parameters resulting in a lower natural mortality (*0.537 for recruits and 0.389 for post-recruits*; **low M**) and higher natural mortality (*0.550 for recruits and 0.405 for post-recruits*; **high M**), a prior on total mortality using fishery-dependent data only in catch curve analysis was used for a lower prior scenario (*1.157*; **FD Z prior**), and a prior on total mortality using a weighted catch curve with combined fishery-independent and fishery-dependent data was used for a higher prior scenario (*1.613*; **wt comb Z prior**). Six sensitivity configurations focused on choices and treatment of index data; no adjustments were made to original index CVs to incorporate process error (**no reweight**), the NMFS Trawl Survey indices for both stages were excluded from the model (**no NMFS trawl**), the NCDMF Trawl Survey indices for both stages were excluded from the model (**no NC DMF trawl**), the NEAMAP Trawl Survey indices for both stages were included in the model (**add NEAMAP trawl**), and catchability coefficient of the recruit NMFS Trawl Survey index was allowed to vary after 2004 (**change in NMFS recruit q in 2005**) and after 2008 (**change in NMFS recruit q in 2009**). Catchability was allowed to vary in 2005 based on visual inspection of the trend in residuals for the fit to this index in the base model and in 2009 due to the change of vessel conducting the survey. The final four sensitivity configurations focused on assumptions or treatment of aspects relating to the stock-recruit relationship; the steepness was fixed at 0.99 to specify an uninformative stock-recruit relationship (**h = 0.99**), the steepness was fixed at the mode value estimated in the steepness prior analysis (**h = 0.79**), the mean weight-at-stage used to calculate spawning stock biomass was developed from biological sampling of North Carolina commercial landings (**NCDMF comm mean wts**), and the population sex ratio was changed to 1.62, the value from combined fishery-independent data (**sex ratio**). The sex ratio only affects the stock-recruit parameters and spawning stock biomass estimates, so results from the configuration are only included for the spawning stock biomass estimate comparison. The reweighting methods of Francis (2003) were used for all sensitivity configurations to adjust the input CVs for indices of abundance, with the exception of the **no reweight** sensitivity configuration.

6.2.6.3 Retrospective analysis

A retrospective analysis was completed by comparing base model estimates to model estimates with up to five years of data removed from the end of the time series. A modified (i.e., averaged differences as opposed to summed differences among estimates) Mohn's Rho (Mohn 1999) was calculated for sSPR, fishing mortality, recruitment, and spawning stock biomass estimates. Retrospective plots were visually inspected and modified Mohn's Rhos were compared to general rule of thumb values for modelling short-lived species proposed by Hurtado-Ferro et al. (2015) to identify a retrospective bias.

6.2.6.4 Markov Chain Monte Carlo Simulation

Markov chain Monte Carlo (MCMC) sampling algorithms implemented in ADMB were used to sample from the posterior distribution of bounded model parameters.

6.2.6.5 Likelihood profiles

Likelihood profiling capabilities within ADMB were used to develop likelihood profiles for key unbounded derived values.

7. Results

7.1 Assessment Models

7.1.1 Surplus Production Model

7.1.1.1 Goodness of Fit

The surplus production model fit the NMFS Trawl and SEAMAP Trawl relative biomass indices reasonably well (Figure 78 and Figure 79), although there were concerns about how the model was not capturing the dynamics of the terminal year when abundance indices declined but the estimates in the model did not.

7.1.1.2 Parameter Estimates (include precision of estimates)

The surplus production model estimated that relative biomass (B/B_{MSY}) has been increasing steadily since 1999, the lowest point in the time series. B/B_{MSY} has been above 1.0 since 2006 and the largest relative biomass was in 2011 (Table 96, Figure 80). Relative fishing mortality (F/F_{MSY}) fluctuated in the early part of the time series but has been on decline since the late 1990s. F/F_{MSY} has been below 1.0 since 2002 and the lowest relative fishing mortality was in 2010.

7.1.1.2.1 Exploitation Rates

The surplus production model estimated total fishing mortality throughout the time series (Table 96, Figure 80). Fishing mortality was high and variable from the late 1980s through early 1990s, with the highest fishing mortality occurring in 1991. Since the late 1990s, fishing mortality has steadily declined.

7.1.1.2.2 Abundance or Biomass Estimates

The surplus production model estimated the average biomass (Figure 81). The results showed that the biomass decreased in the middle of the time series but began increasing in the late 1990s to high levels from 2009-2014.

7.1.1.3 Sensitivity Analyses

For sensitivity analyses, adding the NEAMAP Trawl Survey as an additional relative biomass index, abbreviating the time series to 1992-2014, omitting the SEAMAP Trawl Survey index, and performing the analysis in Excel resulted in reference point estimates that were on the same scale as the base run (Table 97**)**. Additionally, ASPIC includes a feature where the exponent can be estimated by the model directly to explore the utility of the Fox or Pella-Tomlinson formulations. The model estimated the parameter to be n=2.35 which was not significantly different from the logistic model (*P*=0.42). Overall, the SAS found the surplus production model to be stable based on these sensitivity runs. Additionally, no sensitivity run found B2014/B_{MSY} to be less than one or F2014/F_{MSY} to be greater than one.

7.1.1.4 Projection Estimates

The population was projected forward for 10 years (2015-2025) at a harvest level equal to 2014 landings of 9,492 metric tons. In the projections, relative biomass and fishing mortality remained stable under current conditions (Figure 82 and Figure 83).

7.1.1.5 Reference Point Model(s)

The estimates of the reference points for the base run of the surplus production model can be found in Table 97 along with the results from the sensitivity runs. In 2014, fishing mortality was 0.0884 and average biomass was 107,300 metric tons. Relative fishing mortality (F2014/F_{MSY}) was 0.1824 and has been less than one since 2002. Relative biomass (B2014/B_{MSY}) was 1.8610 and has been greater than 1 since 2006.

7.1.2 Modified-CSA Model

7.1.2.1 Goodness of Fit

The model converged on a solution (i.e., positive definite Hessian matrix) with a maximum final gradient of 1.6059e-004. Measures of model fit are in Table 98. The removals are fit well (Figure 84). Residuals for indices generally exhibited the desired properties, though there were some trends in residuals with respect to time for fits to the post-recruit NCDMF Trawl Survey and recruit NMFS Trawl Survey indices, as well as non-normality of the standardized residuals for the fit to the post-recruit NMFS Trawl Survey index (Table 98, Figure 85-Figure 88). Trends in residuals for the fit to the post-recruit NCDMF Trawl Survey index appear to be driven by conflicting signals and the model’s tendency to fit closer to the post-recruit NMFS Trawl Survey index due to smaller CVs for the latter. This was thought to be the cause of the trend in residuals in the recruit NMFS Trawl Survey index, as the SDSRs of other indices tended to decrease as the recruit NMFS Trawl Survey index was downweighted. However, late in the assessment process, it was determined that the trend is removed by allowing time-varying catchability for this survey.

7.1.2.2 Parameter estimates

7.1.2.2.1 Leading Parameters and Deviations

Model parameter estimates are in Table 99.

Steepness of the stock-recruit relationship was estimated close to the upper bound (0.98), despite the prior information on this parameter. Unfished spawning stock biomass was estimated at 36,086 metric tons. Given the model’s tendency to estimate steepness of the stock-recruit relationship close to the upper bound, the SAS recommends using SPR-based reference points and MSY-based reference points are not reported here. The SAS does believe there is an underlying relationship between recruitment and spawning stock biomass. However, the data do not support reliable estimation of this relationship.

7.1.2.2.2 Abundance and Spawning Stock Biomass

Both recruitment (914 million fish) and post-recruit abundance (654 million fish) are relatively high in 1989 (Table 100, Figure 89-Figure 91). Recruitment remains high through 1991 as post-recruit abundance steadily declines. Total abundance is highly variable through the mid-1990s as recruitment fluctuates drastically. Recruitment and total abundance hit a time series low in 1997. Recruitment and post-recruit abundance then fluctuate around an increasing trend through 2013, with the exception of several subsequent poor recruitments from 2006-2009. The 2014 recruitment was relatively poor resulting in a decline in total abundance, despite increasing post-recruit abundance. Post-recruit abundance in the end of the time series has increased close to levels at the beginning of the time series, while recruitment in recent years (excluding the terminal year) has increased to about half the magnitude of peak recruitments at the beginning of the time series.

Spawning stock biomass follows a similar trajectory as total abundance, generally increasing since 1996 with the exception of the lowest spawning stock biomass of the time series in 2001 (Table 100, Figure 92). There was a slight down turn of spawning stock biomass in 2014, but the estimate was still the second highest of the time series. Post-recruit abundance is a larger component of the total abundance in recent years, resulting in higher spawning stock biomass than during periods of high abundance early in the time series.

7.1.2.2.3 Fishing Mortality and Static Spawning Potential Ratio

Initial fishing mortality was estimated at 1.06 and increased steeply in the next two years (Table 101 and Figure 93). Full fishing mortality then generally fluctuates around a declining trend throughout the time series. There are some exceptionally large peaks in fishing mortality due to upticks in removals, notably in 1991, 1995, and 2001. Full fishing mortality has remained below 0.50 since 2005. The average total mortality from 1996-2013 (1.198) was estimated lower than the prior information (1.356). As an inverse function of fishing mortality, sSPR has fluctuated around an increasing trend throughout the time series (Table 101,Figure 94). Very low sSPR occurred in the beginning of the time series, when shrimp trawl discards were highest, and during years with large peaks in fishing mortality. sSPR has fluctuated around a mean over the last five years (0.48) about seven times greater than the mean sSPR during years when BRDs were not required (0.07; 1989-1995).

7.1.2.2.4 Reference Points

Fishing mortality rates associated with sSPR reference levels (20-40%) are in Table 102. Fishing mortality reference points range from 0.74 (F20%) to 0.36 (F40%).

7.1.2.3 Uncertainty

7.1.2.3.1 Asymptotic Standard Errors

Asymptotic standard errors of model parameters are in Table 99. CVs derived from asymptotic standard errors of model derived population estimates are in Table 100 and Table 101.

Confidence intervals of model derived population estimates are in Figure 90-Figure 94. Estimates of full fishing mortality, sSPR, recruitment, and post-recruit abundance are relatively precise, with mean CVs of 0.11, 0.12, 0.12, and 0.13, respectively. Precision of sSPR estimates tend to increase through time, while precision of recruitment and fishing mortality estimates tends to decrease (Figure 95, Figure 98, and Figure 99). Precision of post-recruit abundance remains relatively stable (Figure 96). CVs are slightly larger for spawning stock biomass estimates, averaging 0.16, though still indicative of relatively precise estimates. Precision of spawning stock biomass estimates is relatively stable with time (Figure 97).

7.1.2.3.2 Sensitivity Analysis

Estimates from sensitivity configurations generally follow the same trend (Figure 100-Figure 119). The **no reweight** configuration estimates a much lower sSPR in 2013 than other configurations due to the model fitting more closely to the NMFS Trawl Survey indices that indicate a sharp decline in abundance over the final two years. As expected, the sensitivities scaling down the shrimp trawl discards estimates (**10% shrimp discards** and **50% shrimp discards**) scaled down abundance. The trend in abundance and the trend and magnitude in fishing mortality and sSPR estimates are relatively insensitive to these changes. The **adjust shrimp discards** configuration results in much smaller recruitment estimates in the years of adjusted removals (1990 and 1991), as lower abundance is expected by the model to account for the reduced removals. Similarly, scaling the selectivity of recruits up (**high selectivity**), scales recruitment and spawning stock biomass down, scales the fishing mortality up, and scales the sSPR estimates down. The most variability in model estimates occurs due to treatment of the indices. This was not to be unexpected, given the somewhat contradictory trends between indices. Most estimates follow the same trend as the base run with some exceptions (i.e., 2013 estimates from the **no reweight** configuration and 1989 estimates from **no NMFS trawl** configuration). Model estimates are relatively insensitive to other configuration changes.

Being per-recruit reference points, the FSPR% reference points are only affected when an input of the per-recruit calculations is changed (e.g., natural mortality; see Table 91). Though a few sensitivity configurations estimate a terminal sSPR below the 95% confidence interval of the base model and the recommended target, all but one (**high selectivity** configuration) estimate the terminal sSPR to be above the threshold (see Section 8.1 for discussion on reference points and Table 103 for F30% threshold estimates). The **high selectivity** configuration is considered an unlikely scenario and represents the extreme upper bound on recruit selectivity.

7.1.2.3.3 Retrospective Analysis

Retrospective plots (Figure 120-Figure 123) show some patterning in estimates, though a consistent retrospective bias is disrupted by estimates from the configuration with 2011 as the terminal year (i.e., three year peel). These estimates reverse trend from the other peels (i.e., underestimates abundance, overestimates fishing mortality). The modified Mohn's Rhos are in Table 104. Modified Mohn's Rho for spawning stock biomass and fishing mortality fall near the bounds proposed by Hurtado-Ferro et al. (2015; -0.22-0.30) as a rule of thumb for values to be concerned about for short-lived species. The value for recruitment estimates exceeds the upper bound, but is driven by the large overestimate in the three year peel model. Dropping this run results in a modified Mohn's Rho (0.27) below the proposed upper bound. Steepness was consistently estimated near the base model estimate from each peel (Table 105).

7.1.2.3.4 MCMC

Two million MCMC samples were drawn from posterior distributions with a burn-in of one thousand samples and a thinning rate of one thousand samples. Samples showed low autocorrelation for the initial condition parameters, but high autocorrelation for parameters of the stock-recruit relationship (steepness, unfished spawning stock biomass; Figure 124-Figure 138). Trace plots indicate stable posterior distributions being sampled for the initial condition parameters, but the presence of a secondary stable region being sampled for the parameters of the stock-recruit relationship. These secondary regions are small relative to the primary stable region being sampled and do not result in bimodality of the density distributions, just more skewed distributions. A similar situation was observed in VanderKooy (2013) for the Western Gulf of Mexico stock.

Autocorrelation is not reduced by increasing the length of the chain (i.e., five million samples with a burn-in of one thousand samples and a thinning rate of one thousand samples; Figure 139 and Figure 140). Autocorrelation is reduced by increasing the thinning rate to ten thousand (Figure 141 and Figure 142), though it is debatable if this is an appropriate solution to approximate precision of the posterior distribution (Link and Eaton 2012). Autocorrelation in the unfished spawning stock biomass estimate is reduced to similar levels as those seen for the initial condition parameters (Figure 143) by fixing steepness and further supports the SAS's recommendation to use SPR-based reference points.

7.1.2.3.5 Likelihood Profile

Likelihood profiling of the terminal year sSPR shows a near identical distribution to the distribution from the asymptotic standard errors (Figure 144).

7.1.2.4 Discussion

The population dynamics predicted with the modified-CSA are heavily influenced by the relatively large magnitude of dead discard estimates from the South Atlantic shrimp trawl fisheries. The decline and stabilization of these discards paired with increasing trends in relative abundance in recent years suggest that the stock is responding favorably to increased regulations in the shrimp trawl fisheries (i.e., requirement of BRDs), which is supported by the model estimates. Though the modified-CSA does generally fit the data well, there are some areas that should serve as focal points for future assessments to improve fits and inconsistencies in the model estimates.

There was borderline indication of retrospective bias, according to general rules of thumb proposed by Hurtado-Ferro et al. (2015). These rules of thumb for short lived species were developed from Pacific sardine with a maximum age of fifteen and the authors note that as species longevity decreases and variability in species dynamics increase, Mohn's rho values and thresholds for concern are expected to increase. Spot have a maximum observed age of six, suggesting that appropriate threshold values for Mohn's rho may be larger than those for a species with a life history similar to Pacific sardine. Hurtado-Ferro et al. (2015) also point out that when biomass is high, the case here for spot, a retrospective pattern may be less problematic and the model results may be less risky for advising management than if biomass were low (i.e., near or below a management threshold). Nonetheless, the direction of the pattern in this assessment (i.e., systematic overestimation of biomass and underestimation of fishing mortality) is of higher concern, from a conservation perspective, and this retrospective pattern should be carefully evaluated in future assessments (Hurtado-Ferro et al. 2015).

Causes of this pattern, though often difficult to pinpoint, should be further explored. Much of this pattern could be due to conflicts in the index of abundance data and the potential change in catchability evaluated with sensitivity analysis. The SAS believes that the indices of abundance from multiple surveys used in the base model represent the coastwide signal of relative abundance better than indices from either survey individually. There were some preliminary attempts to combine the indices into a single index using the methods of Conn (2010), but little effect was observed and the method was not pursued further. The SAS also investigated changing catchability due to improvements in model fit, but believe it is most appropriate to retain time-invariant catchability, given the principal investigators of the survey have calibrated the indices based on side-by-side tow comparisons (Miller et al. 2010). If other causes of a changing catchability can be corroborated (i.e., climate change), modelling these changes would be more defensible.

There is also suspected influence form environmental conditions, particularly temperature, on spot mortality. No appropriate data were identified for this assessment, but identification and incorporation of environmental data time series in future assessment could improve the model's ability to differentiate environmental and density-dependent effects on year class strength. The model results are dependent and sensitive to the assumed selectivity of recruits, as seen with sensitivity analysis. The SAS used the best available estimates, but if additional information becomes available to update this estimate, it would serve future assessments well.

7.1.3 Comparison of Results and Model Selection

The general trends in population estimates from the base surplus production and base modified-CSA models are similar and verify the general dynamics of the stock over the modelled time series, given the input data. It is important to note that there are some major differences between the model estimates and comparison of the magnitude of estimates is not particularly informative. Rather, the objective of the comparison is to check trends in similar estimates provided by two models characterized by very different structures and assumptions. The fishing mortality estimates are in terms of different units (biomass for the surplus production model and numbers for the modified-CSA), but suggest very similar exploitation patterns (Figure 145). The biomass estimates are also in terms of different units (total exploitable biomass for the surplus production model and mature female biomass for the modified-CSA model), but also suggest similar patterns in the response of the reproductive capacity of the stock to exploitation over time (Figure 146). The surplus production model estimates a slower decline in fishing mortality through the 1990s and a slightly more pronounced decline in fishing mortality and increase in biomass in the late 2000s and 2010s.

The modified-CSA is able to incorporate some population structure, allowing more fine-scale changes to be estimated relative to the surplus production model (i.e., high interannual variability in the abundance estimates). The modified-CSA model appears to better capture the interannual variability in abundance and fishing mortality observed from the stock, as indicated by the input data. These different patterns may be due to the surplus production model being more rigid and restrictive, as a function of the constant intrinsic growth rate parameter, in allowing large swings in abundance that occur for stocks like spot that only consist of a few year classes. The terminal year spawning stock biomass estimate from the modified-CSA is more reflective of the decline in relative abundance observed in the indices. Given these points, the SAS recommends the modified-CSA as the preferred modelling approach to inform stock status.

8. Stock Status

8.1 Current Overfishing, Overfished/Depleted Definitions

There are currently no stock status definitions for the Atlantic coast spot stock. The SAS compiled a review of SPR-based reference points (Appendix 6) and recommends an overfishing threshold associated with a 30% sSPR (F 30%) and a fishing target associated with a 40% sSPR (F 40%). These reference point values tend toward precautionary values, acknowledging the potential for high interannual variability in recruitment with an unknown effect from environmental factors and the short life history of spot. Given that sSPR is a per-recruit reference point, a decline in recruitment and/or spawning stock biomass over even a short period could result in adverse impacts to stock condition even if the stock is maintained at relatively high sSPR levels (i.e., greater than the target). Therefore, the SAS also recommends the equilibrium spawning stock biomass resulting from fishing at F 30% and the recruitment levels estimated from 1996-2014 (Table 100) as a spawning stock biomass threshold and the equilibrium spawning stock biomass resulting from fishing at F 40% and the recruitment levels estimated from 2003-2014 (Table 100) as a spawning stock biomass target. The years 1996-2014 and 2003-2014 were chosen as they correspond with the stock fished, on average, at 30% sSPR and 40% sSPR, respectively (Table 101). These years also correspond with the period when BRD requirements were generally implemented and the shrimp trawl discards were at relatively stable levels. Randomly sampled recruitments for the spawning stock biomass threshold and target projections are in Table 106 and Table 107, respectively. Projected spawning stock biomasses and the median over the time series (reference point estimate) are in Figure 147 and Figure 148.

8.2 Stock Status Determination

Based on the recommended reference points, overfishing of the Atlantic coast spot stock did not occur in 2014 and the stock was not overfished. The 2014 full fishing mortality is estimated at 0.249, below the threshold (0.5) and target (0.36). The 2014 sSPR is estimated at 0.507, above the recommended threshold (0.30) and target (0.40). The 2014 beginning year spawning stock biomass (2013 end year SSB) is estimated at 19,032 metric tons, above the recommended threshold (4,730 metric tons) and target (7,854 metric tons). Based on MSY reference points and generic thresholds, the surplus production model status determination (B_{2014}>B_{MSY} and

$F_{2014}<F_{MSY}$) was the same as the modified-CSA determination. This stock status determination is reasonable, given the significant decline of discards in the shrimp trawl fishery and the recent increases in relative abundance observed across indices of abundance.

8.3 Comparison of Assessment Results to the Traffic Light Analysis

The TLA was compared to the assessment results to determine the utility and reliability of using the TLA to inform stock status. The TLA is currently used to inform stock status and the modified-CSA within this assessment is proposed to inform stock status moving forward on an intermittent basis according to future stock assessment schedules. However, the TLA has the potential to inform stock status in the future between stock assessments, so it is important to understand how the approaches compare and contrast. Some additional metrics were developed with the TLA framework (i.e., total fishery removals) to permit comparisons to the modified-CSA results (Appendix 1).

The pattern in the estimates of spawning stock biomass from the modified-CSA model are in agreement with the established abundance metric of the TLA (i.e., adult abundance from the regional SEAMAP Trawl and NMFS Trawl Surveys). Treating spawning stock biomass above the target (not overfished) the same as a TLA proportion red less than 30% (no concern), spawning stock biomass between the target and threshold (not overfished, but below the target) the same as a TLA proportion red between 30% and 60% (moderate concern), and spawning stock biomass below the threshold (overfished) the same as a TLA proportion red greater than 60% (significant concern), the two approaches agree 65% of the time (Table 108, Figure 149). The status from the two approaches is not the opposite (i.e., overfished vs. no concern or vice versa) for any years. The TLA is more conservative in the final two years, suggesting moderate concern, whereas the modified-CSA suggests no concern. There is no recruitment reference point estimated by the modified-CSA, but a qualitative comparison suggests the annual recruitment estimates match the TLA YOY abundance metric proportions well in many years (Figure 150). Specifically, the two approaches agree on relatively weak year classes in 1992, 1995-1996, 1998, 2001, 2003, 2006-2007, and the terminal year (2014). The approaches agree on relatively strong year classes in 1994 and 2010. Notable disagreements occurred for 1989-1991, 1997, 2005, 2011 and 2013. Some of these differences are not surprising given different indices are used in the two approaches and high interannual variability common in juvenile abundance indices.

The harvest metrics from the TLA are not in as close agreement with the modified-CSA sSPR estimates. The established harvest metric from the TLA, as the name suggests, does not include discard information, as there was not a time series of discard estimates established for the TLA. The modified-CSA estimates total fishing mortality across fisheries. Treating sSPR above the target (not overfishing) the same as a TLA proportion red less than 30% (no concern), sSPR between the target and threshold (not overfishing, but above the target) the same as a TLA proportion red between 30% and 60% (moderate concern), and sSPR below the threshold (overfishing) the same as a TLA proportion red greater than 60% (significant concern), the two approaches only agree 15% of the time (Table 109, Figure 151). This is not surprising considering the high proportion of fishery removals used in the modified-CSA attributed to shrimp trawl discards. This is improved slightly when all removals are added to the TLA metric, with agreement 26% of the time (Table 109).

This assessment supports the utility of these analyses as approaches for informing the condition of stock abundance, but highlights the need to further evaluate the incorporation of discards into a fishery removal metric to be used as a comprehensive indicator of fishing pressure between stock assessments with TLA. Given that abundance and fishing mortality are correlated, the abundance measures from both approaches generally agree, and that the abundance and fishing mortality are not independently estimated in the modified-CSA, the harvest metric from the TLA appears to be in disagreement with the other components of the comparison. A potential area of focus could be the appropriate weighting of discards relative to other fishery removals.

9. Research Recommendations and Future Assessments

9.1 Research Recommendations

Short-term

HIGH PRIORITY

- Expand collection of life history data for examination of lengths and age, especially fishery-dependent data sources.
- Organize an otolith exchange and develop an ageing protocol between ageing labs.
- Increased observer coverage for commercial discards, particularly the shrimp trawl fishery. Develop a standardized, representative sampling protocol and pursue collection of individual lengths and ages of discarded finfish.

MEDIUM PRIORITY

- Develop and implement sampling programs for state-specific commercial scrap and bait fisheries in order to monitor the relative importance of Spot. Incorporate biological data collection into program.
- Conduct studies of discard mortality for commercial fisheries. Ask commercial fishermen about catch processing behavior for Sp/Cr when trawl/gillnets brought over the rail.
- Conduct studies of discard mortality for recreational fisheries.
- Collect data to develop gear-specific fishing effort estimates and investigate methods to develop historical estimates of effort.

Long-term

HIGH PRIORITY

- Continue state and multi-state fisheries-independent surveys throughout the species range and subsample for individual lengths and ages. Ensure NEFSC trawl survey continues to take lengths and ages. Examine potential factors affecting catchability in long-term fishery independent surveys.

- Continue to develop estimates of length-at-maturity and year-round reproductive dynamics throughout the species range. Assess whether temporal and/or density-dependent shifts in reproductive dynamics have occurred.
- Re-examine historical ichthyoplankton studies for an indication of the magnitude of estuarine and coastal spawning. Pursue specific estuarine data sets from the states (NJ, VA, NC, SC, DE, ME) and coastal data sets (MARMAP, EcoMon).

MEDIUM PRIORITY

- Identify stocks and determine coastal movements and the extent of stock mixing, via genetic and tagging studies.
- Investigate environmental and recruitment/ natural mortality covariates and develop a time series of potential covariates to be used in stock assessment models.
- Investigate environmental covariates in stock assessment models, including climate cycles (e.g., Atlantic Multi-decadal Oscillation, AMO, and El Nino Southern Oscillation, El Nino) and recruitment and/or year class strength, spawning stock biomass, stock distribution, maturity schedules, and habitat degradation.
- Investigate the effects of environmental changes (especially climate change) on maturity schedules for spot, particularly because this is an early-maturing species, and because the sSPR estimates are sensitive to changes in the proportion mature.
- Investigate environmental and oceanic processes in order to develop better understanding of larval migration patterns into nursery grounds.
- Investigate the relationship between estuarine nursery areas and their proportional contribution to adult biomass. I.e., are select nursery areas along Atlantic coast ultimately contributing more to SSB than others, reflecting better quality juvenile habitat?
- Develop estimates of gear-specific selectivity.

9.2 Recommendation for Timing of Future Stock Assessments

The SAS and PRT recommend that the next assessment be completed five years from the completion of this assessment (i.e., 2022). Though the completion of the spot and Atlantic croaker assessments together was useful for this first assessment of spot, the SAS and PRT recommend a staggered schedule for future spot and Atlantic croaker assessments due to the overlap in personnel.

10. Minority Opinion

There was no minority opinion submitted by any member(s) of the SAS or PRT.

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12. Tables

Table 1. History of Atlantic state regulations specific to spot.

SC	Aggregate bag limit of 50 fish per person per day for small Sciaenidae species for com and rec hook and line gear	2014
FL	Default bag limit for unregulated species is 2 fish or 250 pounds per person per day-whichever is more.	1987
FL	Default bag limit for unregulated species is 2 fish or 100 pounds per person per day-whichever is more.	1989

Table 2. Additional Atlantic state regulations affecting the harvest and bycatch of spot.

State	Regulation	Date
NJ	Weakfish gill-net and pound-net seasonal closures established and trawl minimum mesh reduced (3” diamond)	1992
	Weakfish trawl seasonal closure established, gill-net seasonal closure lengthened, and trawl minimum mesh increased (3.25”)	1995
DE	Weakfish gill-net minimum mesh size (3.125”) and seasonal closures affect the harvest of Atlantic croaker	1995
MD	Weakfish trawl minimum mesh increased to 3.375” square or 3.75” diamond and gill-net and trawl seasonal closure lengthened	1995
	Trawling prohibited in Chesapeake Bay and coastal bays, and within 1 mile of coastal shore	1933
VA	Trawling prohibited in all state waters	1989
	Weakfish commercial gear minimum mesh sizes increased and seasonal closures established or increased	1995

Table 2 *Continued*. **Additional Atlantic state regulations affecting the harvest and bycatch of spot.**

State	Regulation	Date
NC	Minimum mesh size restrictions in shrimp trawl (1.5” tailbag) and crab trawls (3.0”) established	Pre-1975
	Finfish trawling prohibited in internal waters; shrimp and crab trawls limited to 1,000 lb of incidental finfish bycatch per trip	1983
	Shrimp and crab trawls in inside waters limited to 500 lb of incidental finfish from December 1–February 28 and 1,000 lb from March 1–November 30	1991
	Catch of unclassified bait limited to 5,000 lb/vessel/day	1991
	Minimum mesh size restriction in shrimp trawls (1.5” tailbag) and crab trawls (3.0”); shrimp trawls prohibited areas established and headrope length limited to 90 ft	1991
	Fly net minimum stretched mesh size of 3.0” square or 3.5” diamond; fly nets defined as nets having the first body (belly) section consisting of 35 or more continuous meshes of 8.0” or greater (stretched mesh) webbing behind the bottom and top line, with tailbags less than 15 feet in length; tailbags constructed of square mesh may have the terminal 3 feet of mesh hung on a diamond with a minimum stretched mesh length of 2.0”	1992
	Bycatch reduction devices required in all shrimp trawls.	1994
	Fly nets prohibited in ocean waters from Cape Hatteras to NC/SC state line	1994
	Fly net vessels limited to 150 lb weakfish unless all fly nets onboard meet definition; gill nets limited to 150 lb weakfish unless mesh length > 2.875” stretched	1996
	Shrimp and crab trawls in Atlantic Ocean prohibited from possessing incidental finfish December 1–March 31 unless weight of the combined shrimp and crab catch exceeds weight of finfish	1997
	Small mesh (<5.0”) estuarine gill-net attendance requirement, May 1–November 30 in select areas in inside waters	1998
	Mandatory use of long haul cull panels and swipe nets south/west of a line from Bluff Point in Pamlico Sound to Ocracoke Island	1999
	Authorized gear allowed and restrictions applied to the Recreational Commercial Gear License; modified in 2008 to allow mechanical retrieval of shrimp trawl	1999
	Crab trawl minimum mesh size increased to 4” in western Pamlico Sound	2005
	Headrope length internally limited to 90 feet and shrimp trawl prohibited areas established	2006

Table 2 ***Continued*****. Additional Atlantic state regulations affecting the harvest and bycatch of spot.**

State	Regulation	Date
SC	Net ban	1987
	Turtle excluder devices required in shrimp trawls in summer	1988
	Turtle excluder devices required in shrimp trawls year-round	1991
	Bycatch reduction devices required in shrimp trawls	1996
GA	Gill nets prohibited (except for shad and diamondback terrapin)	1957
	All sounds closed to large trawl shrimp fishery; TEDs mandated	1990
	Bycatch reduction devices mandatory in large trawl shrimp fishery.	1996
FL	Entangling nets (e.g., trammel and gill nets) prohibited in all state waters	1995
	Directed finfish trawl prohibited; bycatch reduction devices mandatory	1996

Table 3. Biological data available for life history analyses in the spot stock assessment.

Type	Area	Source	Gear	Length-Weight Data	Age - Length Data	Sex Data	Maturity Data	Length Measured
Commercial	Maryland Chesapeake Bay	MD DNR	Pound Net	2008-2014 (n=3,448)	2007-2014 (n=1,354, ages 0-2)	2007-2014 (n=831 F, n=532 M)		TL
Commercial	Virginia	VMRC	Multiple	1991-2014 (n=148,818)	1998-2014 (n=4,967 ,otolith ages 1-6)	1989-2014 (n=9,944 F, n=4,245 M)	1989-2014 (n=9,917 Maturity Stage 1-5)	TL, SL
Commercial	North Carolina	NCDMF	Multiple	1979-2014 (n=7,124)	1979-1997 (n=5,097, scale ages 0-5); 1997-2013 (n=1,631, otolith ages 0-4)	1996-2015 (n=1,086 F, n=646 M)		TL
Commercial	Florida	FWC	Multiple	2000-2014 (n=330)				FL
Recreational	Florida	NMFS (MRFSS)	Hook & Line	1982-2006 (n=1,653)				FL
Recreational	North Carolina	NCDMF	Hook & Line		1992-1996 (n=316 scale age 1-3); 1998-2013 (n=19, otolith ages 1-3)	2000-2013 (n=11 F, n=4 M)		TL
Recreational	South Carolina	SC	Hook & Line		2010-2011 (n=277, ages 0-3)	2010-2011 (n=102 F, n=46 M)	2010-2011 (n=150, Maturity Status I/M)	TL, SL
Fishery Independent	North Carolina	NCDMF	Multiple	1972-2014 (n=10,720)	1979-1997 (n=1,066, scale ages 0-4); 1997-2013 (n=5,610, otolith ages 0-6)	1995-2015 (n=5,155 F, n=1,887 M)		TL
Fishery Independent	Hudson River, NY to Cape Hatteras, NC	NMFS	Trawl	1992-2014 (n=1,008)		1992-2010 (n=455 F, n=257 M)	1992-2014 (n=782, Maturity Status I/M; n=798 Maturity Stage D/I/R/R/S)	FL
Fishery Independent	Hudson River, NY to Cape Hatteras, NC	NEAMAP	Trawl	2007-2014 (n=2,241)		2007-2015 (n=1,185 F, n=957 M)	2007-2015 (n=2,209 Maturity Stage A-D)	FL
Fishery Independent	Maryland and Virginia Chesapeake Bay	ChesMMAP	Trawl	2002-2014 (n=7,337)	2002-2014 (n=7,104, otolith ages 0-4)	2002-2015 (n=3,532 F, n=3,034 M)	2002-2015 (n=6,851 Maturity Stage, various codes)	FL
Fishery Independent	Cape Hatteras, NC to Cape Canaveral, FL	SEAMAP	Trawl	1998-99,2000-01,2009-10 (n=1,455)	2001 (n=731, otolith ages 0-3)	1998-2010 (n=643 F, n=633 M)	1998-2010 (n=873 Maturity Status I/M; n=585 Maturity Stage, various codes)	TL, FL, SL
Fishery Independent	South Carolia	SC	Multiple	Various from 1984-2014 (n=5,440)	1997, 2010-2011 (n=1,050, otolith ages 0-4)	1984-2014 (n=1,265 F, n=749 M)	1984-2014 (n=2,148, Maturity Status I/M)	TL, SL

Table 4. **Reported size ranges of spot from previous studies along the Atlantic coast of the United States.**

Reference	Region	Length Range (cm)
Welsh and Breder (1923)	NJ - FL	8-33 cm
Hildebrand and Schroeder (1928)	Chesapeake	10-34.5 cm
Hildebrand and Cable (1930)	NC	9-29 cm
Pacheco (1957)	Chesapeake	16-27 cm
Dawson (1958)	SC	8-22.5 cm
DeVries (1982)	NC	6-34.6 cm
Music and Pafford (1984)	GA	11-25 cm
Johnson (2013)	SC	4.5-27 cm

Table 5. Summary of spot paired age-length data by data source based on otolith ages and total length (cm), made available for the stock assessment.

Source		Total length in cm at age						
		0	1	2	3	4	5	6
MD DNR Summer Pound Net Survey (Commercial)	Size Range (cm)	14-25	14-16	18-26				
	Mean (cm)	16	20	23				
	n	217	856	25				
	Percent by age	19.76%	77.96%	2.28%				
MD DNR Fish House Survey (Commercial)	Size Range (cm)	16-23	13-27	21-25				
	Mean (cm)	18	21	23				
	n	14	236	6				
	Percent by age	5.79%	97.52%	2.48%				
NCDMF (Commercial)	Size Range (cm)	9-22	11-27	16-30	22-31	25-31		
	Mean (cm)	15	18	23	27	28		
	n	549	855	170	44	13		
	Percent by age	33.66%	52.42%	10.42%	2.70%	0.80%		
VMRC (Commercial)	Size Range (cm)		13-31	18-34	20-36	26-36	31-36	32-35
	Mean (cm)		23	25	29	30	33	33
	n		2,961	1,552	339	96	15	3
	Percent by age		59.63%	31.25%	6.83%	1.93%	0.30%	0.06%
ChesMMAP Survey (FI)	Size Range (cm)	4-24	7-28	14-30	24-33	23-33		
	Mean (cm)	16	19	23	28	29		
	n	3,837	3,088	155	20	4		
	Percent by age	54.01%	43.47%	2.18%	0.28%	0.06%		
NCDMF (FI)	Size Range (cm)	7-29	11-33	15-31	21-32	24-32	28-32	32-33
	Mean (cm)	16	21	24	27	28	30	32
	n	485	3,036	1,704	308	66	9	2
	Percent by age	8.65%	54.12%	30.37%	5.49%	1.18%	0.16%	0.04%
SEAMAP Survey (FI)	Size Range (cm)	11-22	12-27	16-25	21			
	Mean (cm)	16	18	22	21			
	n	294	415	21	1			
	Percent by age	40.22%	56.77%	2.87%	0.14%			
SCDNR (FI)	Size Range (cm)	4-22	12-27	16-26	23-25	23		
	Mean (cm)	12	21	22	24	23		
	n	693	284	69	3	1		
	Percent by age	66.00%	27.05%	6.57%	0.29%	0.10%		
SCDNR Freezer Survey (R)	Size Range (cm)	16-24	16-29	20-25	33			
	Mean (cm)	19	22	23	33			
	n	68	193	15	1			
	Percent by age	24.55%	69.68%	5.42%	0.36%			
VMRC (R)	Size Range (cm)		22-26	33				
	Mean (cm)		24	33				
	n		3	1				
	Percent by age		75.00%	25.00%				
All Data Combined	Size Range (cm)	3-24	6-31	13-24	19-35	21-36	28-35	32-34
	Mean (cm)	15	20	23	26	29	32	33
	n	6,637	15,041	6,026	997	195	26	5
	Percent by age	25.50%	50.81%	19.69%	3.25%	0.63%	0.08%	0.02%

Table 6. **Description of growth models used to estimate the age-length relationship of spot in the stock assessment. Parameters of the same name do not necessarily have the same interpretation across different models.**

Growth Model	Equation	Parameters
von Bertalanffy	$L_t = L_\infty \left[1 - e^{-K(t-t_0)} \right]$	*Lt* is length at age *t*, *L*∞ (or L_{inf}) is the theoretical asymptotic average length (if *K* > 0), *K* is growth rate at which the asymptote is approached, and *t*0 is the hypothetical age at which length is zero.
Gompertz	$L_t = L_\infty e^{-e^{-K(t-t_0)}}$	*L*∞ (or L_{inf}) is the theoretical asymptotic average length (if *K* > 0) and *t*0 represents an inflection point on the curve.
Richard's	$L_t = L_\infty \left[1 + \frac{1}{p} e^{-K(t-t_0)} \right]^{-p}$	*L*∞ (or L_{inf}) is the theoretical asymptotic average length (if *K* > 0) and *t*0 represents an inflection point on the curve.
Logistic	$L_t = L_\infty \left[1 + e^{-K(t-t_0)} \right]^{-1}$	*L*∞ (or L_{inf}) is the theoretical asymptotic average length (if *K* > 0) and *t*0 represents an inflection point on the curve.

Table 7. **Sample size (n) and parameter estimates and AIC for the von Bertalanffy model fits to spot data sets. There was a significant difference in growth between males and females (ARSS: $F_{3,20105} = 113.31$, $p < 0.0001$).**

Data Set	n	Linf (cm)		K		t0		AIC
		Estimate	SE	Estimate	SE	Estimate	SE	
All available ages	22,734	34.4	0.483	0.324	0.012	-1.84	0.036	116,146
Combined male and female ages	20,111	35.4	0.563	0.288	0.012	-2.12	0.045	99,637
Female ages	12,922	34.4	0.584	0.317	0.015	-2.04	0.054	63,766
Male ages	7,189	38.5	1.552	0.220	0.019	-2.42	0.093	35,541

Table 8. **Sample size (n) and parameter estimates and AIC for the Richard's growth model fits to spot data sets.**

Data Set	n	Lmin (cm)		Lmax (cm)		K		p		Amin	Amax	AIC
		Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE			
All available ages	22,734	15.7	0.084	36.9	0.270	0.369	0.003	1	0.010	0	6	116,352
Combined male and female ages	20,111	16.6	0.120	39.7	0.164	0.306	0.003	1	0.020	0	6	99,857
Female ages	12,922	16.4	0.181	37.8	0.844	0.317	0.010	1	0.035	0	6	64,343
Male ages	7,189	16.2	0.123	47.8	1.150	0.218	0.007	1	0.024	0	6	35,658

Table 9. Sample size (n) and parameter estimates and AIC for the Gompertz growth model fits to spot data sets.

Data Set	n	Linf (cm)		K		t0		AIC
		Estimate	SE	Estimate	SE	Estimate	SE	
All available ages	22,734	31.7	0.295	0.516	0.012	-0.65	0.013	116,177
Combined male and female ages	20,111	32.5	0.339	0.461	0.012	-0.79	0.016	99,664
Female ages	12,922	32.1	0.372	0.487	0.015	-0.83	0.017	63,794
Male ages	7,189	33.9	0.799	0.393	0.019	-0.72	0.045	35,542

Table 10. Sample size (n) and parameter estimates and AIC for the logistic growth model fits for to spot data sets.

Data Set	n	Linf (cm)		K		t0		AIC
		Estimate	SE	Estimate	SE	Estimate	SE	
All available ages	22,734	30.3	0.216	0.713	0.012	-0.07	0.019	116,221
Combined male and female ages	20,111	31.0	0.247	0.638	0.012	-0.15	0.022	99,700
Female ages	12,922	30.7	0.279	0.660	0.016	-0.22	0.024	63,829
Male ages	7,189	31.7	0.543	0.568	0.020	-0.02	0.057	35,545

Table 11. Description of length measurements used for spot.

Measurement	Description
Total Length (max)	Measured from the most anterior point of the fish to the farthest tip of the tail with the tail compressed or squeezed together.
Fork Length (midline)	Measured from the most anterior point of the fish to the rear center edge of the tail.
Standard Length	Measured from the most anterior point of the fish to the end of the vertebral column (caudal peduncle).

Table 12. Length relationships for spot, as reported in the literature and estimated during this assessment.

Reference	Location	Range (mm TL)	N	Relationship	R^2
Dawson (1958)	South Carolina		5,162	SL = 2.000 + 1.2333 TL	0.996
			446	FL = 8.90 + 1.09 SL	0.991
			546	FL = 6.170 + 0.893 TL	0.997
Jorgenson and Miller (1968)	Georgia	14-11	71	TL = -0.606 + 1.2888 SL	0.91
			87	SL = 0.760 + 0.771 TL	0.893
Life History Workshop (2010)	Virginia-Florida	106-370	65,534 (VA)	TL = -0.554 + 1.268 SL	0.949
			65,534	SL = 9.780 + 0.7749 TL	0.949
			745 (SEAMAP)	TL = 6.411 + 0.904 FL	0.984
			745	FL = -4.370 + 1.089 TL	0.984
			745	SL = -7.254 + 0.868 FL	0.97
			745	FL = 12.967 + 1.117 SL	0.97
Stock Assessment (2017)	Coastwide	21-370	43,053	TL = 1.079 FL - 0.843	0.981
			66,494	TL = 1.255 SL + 1.840	0.967

Table 13. **The length-weight relationships for Atlantic coast spot (L= total length in mm; W= total weight in grams), as reported in the literature and estimated during this assessment.**

Author	Area	N	Size Range	Equation
Hester and Copeland (1975)	North Carolina	356	25-195 (mm TL)	log W = -5.230 + 3.221 log L
Dawson (1985)	South Carolina	4,297	45-205 (mm SL)	log W = -4.54396 + 2.95831 log L
Music and Pafford (1984)	Georgia	325	120-283 (mm TL)	log W = -5.096 + 3.121 log L
Stock Assessment (2017)	Coastwide	22,835	Females: 72-375 (mm TL)	log W = -5.401 + 3.248 log L
		12,320	Males: 67-355 (mm TL)	log W = -5.440 + 3.260 log L
		35,155	Combined sexes: 67-375 (mm TL)	log W = -5.433 + 3.260 log L
		189,460	All available L-W data (mm TL)	log W = -4.636 + 2.916 log L

Table 14. **Length-weight relationships for Atlantic coast spot from different data sets using a non-linear power regression in the form: $W=a(L_T)^b$ where L_T = total length (mm); W = weight (g); a = y-intercept; b = slope (regression coefficient).**

Data Source	N	Size Range (TL mm)	a	b	r^2
NMFS (FI)	1,008	96-290	4.601×10^{-6}	3.204	0.935
NEAMAP (FI)	2,241	102-290	1.871×10^{-6}	3.377	0.849
ChesMMAP (FI)	7,337	42-335	4.710×10^{-6}	3.200	0.952
SEAMAP (FI)	1,454	87-271	8.533×10^{-6}	3.073	0.956
MD/VA/NC commercial (FD)	159,697	13-390	2.821 x 10-5	2.879	0.830

Table 15. **Tests of significance using ARSS between male and female spot length-weight relationship by data set.**

Type	Area	Gear	Source	degrees of freedom		*F*-statistic	*P*-value
				numerator	denominator		
Fishery-Independent	NE Atlantic	Trawl	NMFS	2	709	1.022	0.312
Fishery-Independent	NE Atlantic	Trawl	NEAMAP	2	2,139	0.384	0.535
Fishery-Independent	Ches. Bay	Trawl	ChesMMAP	2	6,558	0.019	0.889
Fishery-Independent	SE Atlantic	Trawl	SEAMAP	2	1,272	0.172	0.678
Commercial	Maryland	Pound Net	MDDNR	2	1,360	3.622	0.057
Commercial	Virginia	All	VMRC	2	12,377	1.817	0.178
Commercial	North Carolina	All	NCDMF	2	1,712	1.746	0.187
Commercial	All combined	All	All	2	15,455	2.542	0.111

Table 16. **SCDNR histological maturity-at-age data from August-December and predictions and residuals from a logistic regression model (slope = -1.761, inflection = 1.7).**

Age	All Observed	Observed Mature	Proportion Mature		Residual
			Observed	Predicted	
0.67	18	1	0.056	0.132	-4.4
0.75	33	0	0.000	0.150	-5.4
0.83	37	5	0.135	0.170	-14.8
0.92	46	14	0.304	0.191	-29.9
1.00	42	3	0.071	0.215	-14.1
1.67	19	5	0.263	0.470	-12.7
1.75	37	15	0.405	0.507	-25.7
1.83	74	61	0.824	0.543	-47.4
1.92	25	20	0.800	0.580	-15.2
2.00	6	2	0.333	0.615	-4.8
2.67	5	2	0.400	0.838	-5.8
2.75	12	7	0.583	0.857	-10.8
2.83	14	10	0.714	0.874	-9.6
2.92	2	2	1.000	0.889	-0.2
3.83	1	1	1.000	0.976	0.0
4.75	1	0	0.000	0.995	-5.3

Table 17. **Calculated sex ratios (female:male), sample sizes (n), chi-squared (χ_2) values, and probabilities (*P*) that the spot sex ratio is 1:1 (female:male) by dataset, pooled over ages and available years. Sex ratios were also analyzed using a binomial test with similar results.**

Type	Area	Gear	Source	Males n	Female n	Total n	Sex Ratio (F:M)	Chi-squared		Binomial	
								χ^2	*P*	Probability	*P*
Commercial	MD	Pound Net	MDDNR	532	831	1,363	1.56	65.6	<0.01	0.39	<0.01
Commercial	VA	All	VMRC	3,655	8,725	12,380	2.39	2,076.30	<0.01	0.295	<0.01
Commercial	NC	All	NCDMR	633	1,082	1,715	1.71	117.5	<0.01	0.369	<0.01
Fishery-Independent	North Atlantic	Trawl	NMFS	257	455	712	1.77	55.1	<0.01	0.361	<0.01
Fishery-Independent	North Atlantic	Trawl	NEAMAP	957	1,185	2,142	1.24	24.3	<0.01	0.447	<0.01
Fishery-Independent	Chesapeake Bay	Trawl	ChesMMAP	3,029	3,532	6,561	1.17	38.6	<0.01	0.462	<0.01
Fishery-Independent	NC	Trawl	NCDMF	1,879	5,128	77,007	2.79	1506.5	<0.01	0.291	<0.01
Fishery-Independent	South Atlantic	Trawl	SEAMAP	633	642	1,275	1.01	0.1	0.8	0.496	0.82
Fishery-Independent	Coastwide	All		7,500	12,195	19,695	1.62	1119.2	<0.01	0.385	<0.01
Commercial	MD, VA, NC	All		4,820	10,638	15,458	2.21	2,189.70	<0.01	0.312	<0.01
All	Coastwide	All		12,320	22,833	35,153	1.83	3,144.20	<0.01	0.381	<0.01

Table 18. **Sex ratio (female:male)-at-age by data set for spot on the Atlantic coast. Computed chi-squared (χ_2) values for age-specific sex ratios were pooled over years and were calculated using Yate's correction for continuity. An asterisk (*) indicates a sex ratio significantly (p-value < 0.05) different than 1.**

	Age 0		Age 1		Age 2		Age 3		Age 4		Age 5	
Data Set	Ratio	X^2	Ratio	X^2	Ratio	X^2	Ratio	X^2	Ratio	X^2	Ratio	X^2
MD Commercial	1.037	0.072	1.698	71.6*	1.500	1.2	-	-	-	-	-	-
VA Commercial	-	-	2.620	526.2*	3.098	382.4*	3.671	106.9*	1.879	8.85*	4.000	5.40*
ChesMMAP (FI)	1.108	8.021*	1.207	23.7*	0.943	0.117	0.667	0.60	2.000	-	-	-
SEAMAP (FI)	0.965	0.088	1.109	1.036	2.000	2.333	-	-	-	-	-	-
SCDNR (FI surveys)	1.280	6.627*	2.170	38.02*	2.722	14.3*	2.000	-	1.000	-	-	-
FD Combined	1.139	1.107	2.291	584.5*	3.057	384.8*	3.671	106.9*	1.879	8.85*	4.000	5.40*
FI Combined	1.115	11.18*	1.252	42.1*	1.358	5.16*	0.900	0.052	1.500	-	-	-
Total	1.117	20.3*	1.705	455.9*	2.709	335.2*	3.325	92.7*	1.857	9.33*	4.000	5.40

Table 19. **Percent female spot for available datasets, by month, pooled over years.**

				Collection		% Female											
Type	**Area**	**Gear**	**Source**	**Period**	**n**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
FI Survey	NE Atlantic	Trawl	NMFS	1992-2010	455				100.0	50.0	50.0	50.0		63.3	70.4		
FI Survey	NE Atlantic	Trawl	NEAMAP	2007-2015	1,185				49.3					58.1			
FI Survey	Ches. Bay	Trawl	ChesMMAP	2002-2015	3,532			72.4		56.6		52.1		53.2	85.9	53.2	
FI Survey	SE Atlantic	Trawl	SEAMAP	1998-2010	642				55.3	50.3		47.2	36.4		48.7	52.3	
Commercial	Maryland	Pound Net	MDDNR	2007-2014	689					69.1	62.2	63.1	63.0	53.1			
Commercial	Maryland	Fish House Survey	MDDNR	2009-2010	142						67.2	43.8	51.3				
Commercial	Virginia	All	VMRC	1989-2014	8,725			83.3	69.7	70.6	73.1	69.9	74.2	69.7	65.0	73.1	
Commercial	North Carolina	All	NCDMF	1996-2015	1,082	40.9	62.5	54.2	53.9	59.4	68.8	62.5	62.2	68.0	69.3	66.7	91.7

Table 20. Estimates of age-constant natural mortality (*M*) of spot using methods from Then et al. (2015) based on maximum age (T_{max}, where $M = 4.899 * T_{max}^{-0.916}$) and the von Bertalanffy growth parameters (VOB, where $M = 4.118 * K^{0.73} * L_{inf}^{-0.33}$). Growth model parameters are described in Table 6.

Data Set	n	L_{inf} (cm TL)	K	T_{max}	Then et al. 2015 T_{max}	Then et al. 2015 VOB
All Age Samples	22,734	34.4	0.324	6	0.613	0.427
Males & Females	20,111	35.4	0.288	6	0.613	0.400
Females	12,922	34.4	0.317	6	0.613	0.422
Males	7,189	38.5	0.220	6	0.613	0.336

Table 21. Estimates of spot age-specific natural mortality (*M*) based on the Lorenzen (2005) method using von Bertalanffy growth parameters (L_{inf}, K, t_o) and scaled to the Then et al. (2015) age-constant estimates.

Age	All Data (n=22,734)	Males and Females (n = 20,111)	Females: n = 12,922	Males: n=7,189
0	0.542	0.503	0..528	0.431
1	0.464	0.434	0.458	0.369
2	0.420	0.393	0.417	0.331
3	0.394	0.367	0.392	0.306
4	0.376	0.352	0.375	0.288
5	0.364	0.338	0.364	0.275
6	0.356	0.330	0.356	0.266
Age 1+ Mean	0.396	0.369	0.394	0.306

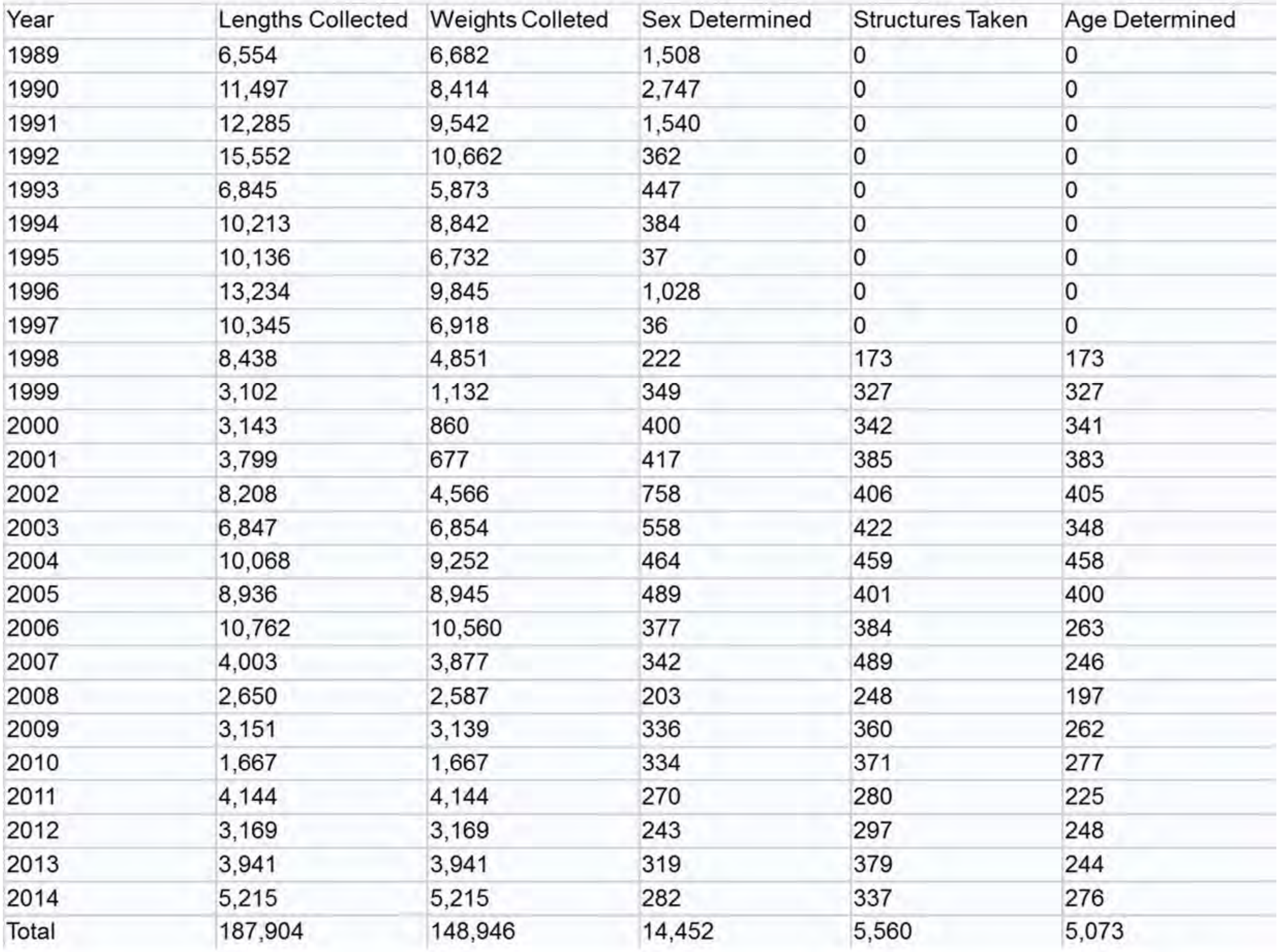
Table 22. **Annual sample size of spot lengths collected during MD DNR commercial pound net sampling.**

Year	n
1993	309
1994	451
1995	158
1996	276
1997	924
1998	60
1999	572
2000	510
2001	126
2002	681
2003	1,354
2004	883
2005	2,818
2006	2,195
2007	519
2008	1,204
2009	614
2010	300
2011	582
2012	1,508
2013	1,302
2014	420

Table 23. **Annual sample size of spot age data collected during MD DNR commercial pound net sampling.**

Year	Age		
	0	1	2
2007	27	68	3
2008	75	129	2
2009	24	205	3
2010	10	74	7
2011	2	171	0
2012	71	151	4
2013	12	155	0
2014	10	139	12

Table 24. **Sample sizes of lengths, individual weights, sex, and age data collected by VMRC's BSP.**



Year	Lengths Collected	Weights Colleted	Sex Determined	Structures Taken	Age Determined
1989	6,554	6,682	1,508	0	0
1990	11,497	8,414	2,747	0	0
1991	12,285	9,542	1,540	0	0
1992	15,552	10,662	362	0	0
1993	6,845	5,873	447	0	0
1994	10,213	8,842	384	0	0
1995	10,136	6,732	37	0	0
1996	13,234	9,845	1,028	0	0
1997	10,345	6,918	36	0	0
1998	8,438	4,851	222	173	173
1999	3,102	1,132	349	327	327
2000	3,143	860	400	342	341
2001	3,799	677	417	385	383
2002	8,208	4,566	758	406	405
2003	6,847	6,854	558	422	348
2004	10,068	9,252	464	459	458
2005	8,936	8,945	489	401	400
2006	10,762	10,560	377	384	263
2007	4,003	3,877	342	489	246
2008	2,650	2,587	203	248	197
2009	3,151	3,139	336	360	262
2010	1,667	1,667	334	371	277
2011	4,144	4,144	270	280	225
2012	3,169	3,169	243	297	248
2013	3,941	3,941	319	379	244
2014	5,215	5,215	282	337	276
Total	187,904	148,946	14,452	5,560	5,073

Table 25. Annual length frequency of spot sampled from commercial fishery landings (combined gears, non-scrap) by the NCDMF.

Fork Length (cm)	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
4	0	0	0	0	2	0	0	0	0	0	0	0	0
5	0	0	1	0	0	0	0	0	0	0	0	0	0
6	0	0	2	0	0	0	0	0	0	0	0	0	0
7	1	0	1	0	0	0	0	0	0	0	0	0	0
8	10	1	2	0	3	0	0	0	3	0	0	0	0
9	33	14	31	1	49	1	0	45	12	0	0	3	0
10	118	115	85	35	218	57	7	403	94	0	0	249	1
11	316	235	230	199	352	108	59	662	228	0	0	386	0
12	341	288	343	289	402	68	151	308	290	0	4	102	0
13	457	392	525	351	270	45	112	173	175	0	0	44	2
14	643	585	914	442	235	80	215	136	95	0	0	41	1
15	730	574	1293	669	382	153	478	71	55	1	3	44	2
16	922	709	1444	766	662	393	505	65	181	17	14	128	10
17	1348	1802	2338	1092	995	620	552	109	690	211	250	519	120
18	2182	3652	3839	2285	1975	760	695	398	1241	1069	778	893	589
19	2966	3839	3303	3078	2606	857	1007	1323	2252	2299	1141	1502	1688
20	2347	2086	2153	2902	2380	849	988	2521	2587	2341	1327	2237	2017
21	1211	794	1030	1482	1466	586	589	2516	1898	1396	999	2021	1893
22	502	197	306	545	543	186	290	1441	938	666	955	1855	2075
23	147	18	38	132	115	35	134	608	481	401	936	1590	2061
24	17	4	13	20	23	10	65	205	203	205	587	800	1465
25	3	1	7	1	1	2	16	55	90	40	186	327	799
26	2	1	0	1	1	1	4	1	27	3	46	105	366
27	0	0	1	1	0	0	1	1	6	1	7	67	301
28	2	1	1	0	0	0	2	2	3	1	6	24	163
29	2	0	1	1	0	0	4	4	0	0	2	8	33
30	0	0	0	0	0	1	8	0	0	0	0	4	10
31	0	0	1	0	0	0	9	0	0	0	0	0	4
32	0	0	0	0	3	0	8	0	0	0	0	0	0
33	0	0	0	0	0	0	11	0	3	0	0	0	0
34	0	0	0	0	0	0	7	0	0	0	0	0	0
35	0	0	0	0	0	0	5	0	0	0	0	0	0
36	0	0	0	0	0	0	1	0	0	0	0	0	0
37	0	0	0	0	0	0	1	0	0	0	0	0	0
38	0	0	0	0	0	0	1	0	0	0	0	0	0
39	0	0	0	0	0	0	2	0	0	0	0	0	0

Table 25 *Continued*. **Annual length frequency of spot sampled from commercial fishery landings (combined gears, non-scrap) by the NCDMF.**

Fork Length (cm)	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	3	0	0	0	0	0	0
11	0	0	0	0	0	0	1	2	0	2	0	1	0
12	0	0	0	0	0	0	1	0	0	0	0	0	0
13	1	0	0	0	1	0	3	1	1	0	0	0	0
14	0	0	2	0	3	0	4	0	6	2	0	0	0
15	2	0	6	1	11	15	21	1	6	7	0	0	0
16	14	4	58	30	37	132	56	17	28	68	5	5	3
17	113	70	142	175	317	602	188	168	141	311	51	33	36
18	608	591	370	648	805	1278	660	736	510	652	352	206	378
19	1403	1549	576	1155	1272	2012	1700	1545	1078	986	972	666	1437
20	2048	1646	817	1286	1889	2653	2258	2123	1788	1409	1156	1113	1949
21	2236	1586	1370	1599	2190	2688	2032	1881	1770	2010	1039	1046	1353
22	1710	1512	2069	1881	2195	2084	1552	1233	1110	1938	571	865	750
23	1264	1662	2418	1860	1555	769	680	629	444	899	114	500	353
24	998	1289	1937	1726	730	141	174	168	131	187	17	163	130
25	487	724	850	1484	369	38	40	40	39	27	5	25	35
26	232	351	315	984	255	15	8	8	8	1	0	4	3
27	124	188	166	634	142	10	1	0	3	2	0	0	2
28	76	136	70	286	64	11	0	1	1	0	0	1	0
29	42	71	29	99	31	7	2	1	1	1	1	1	2
30	24	36	20	34	8	1	2	0	0	0	1	0	0
31	6	12	14	8	0	0	2	0	0	2	0	0	0
32	2	1	19	2	0	0	0	0	0	0	0	0	0
33	0	0	37	1	2	0	1	0	0	1	0	1	1
34	0	0	33	0	0	0	0	0	0	0	0	0	0
35	1	1	13	0	0	0	0	0	0	0	0	0	0
36	1	0	4	0	0	0	0	0	0	0	0	0	0
37	0	0	2	0	0	0	0	0	0	0	0	0	0
38	0	0	1	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0

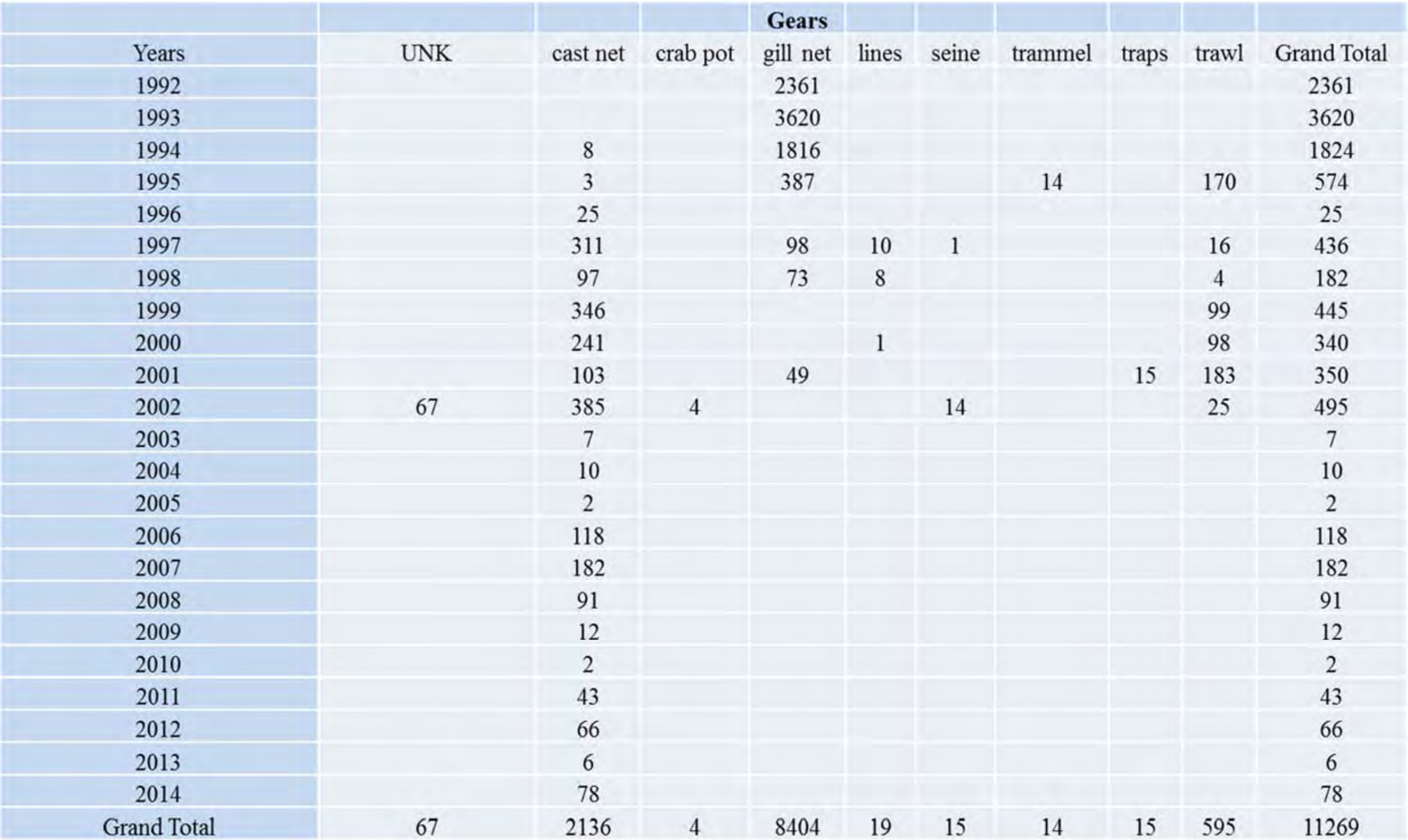
Table 26. **Annual length frequency of spot sampled from scrap landings (combined gears) by the NCDMF.**

Fork Length (cm)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
5	0	1	0	0	0	0	0	0	0	0	0	0	0
6	2	4	0	0	0	0	0	0	0	0	0	0	1
7	5	2	0	0	0	0	0	0	0	0	0	0	0
8	66	15	3	20	2	0	1	8	5	14	6	4	0
9	117	24	6	44	6	0	25	24	26	66	28	15	5
10	147	48	10	65	2	36	103	144	108	120	79	67	21
11	167	173	20	52	4	109	190	275	132	181	130	110	49
12	210	406	31	82	25	140	195	277	155	278	174	148	133
13	348	501	52	96	73	107	123	179	160	188	211	142	138
14	429	675	173	246	176	143	115	206	213	215	222	123	107
15	493	768	431	520	237	185	139	231	368	191	261	126	94
16	504	840	526	662	239	202	216	305	480	188	296	159	121
17	410	620	565	607	152	241	197	485	558	210	345	213	209
18	226	305	490	211	92	226	156	672	573	156	307	278	252
19	62	89	206	87	62	153	112	392	276	146	284	196	229
20	5	32	36	67	22	96	51	103	42	43	183	160	176
21	1	6	6	8	7	74	16	18	6	10	86	131	70
22	0	0	1	0	0	15	1	5	1	4	58	85	20
23	0	0	1	0	0	1	2	0	1	3	15	21	8
24	0	0	0	0	0	0	0	0	0	0	3	15	4
25	0	0	0	0	0	0	0	0	0	2	5	5	2
26	0	0	0	0	0	0	0	0	0	0	2	4	1
27	0	2	0	0	0	0	0	0	1	0	1	0	0
28	0	0	0	0	0	0	0	0	0	0	0	1	1
29	0	0	0	0	0	1	0	0	0	0	0	0	1
30	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	1	0	0	0	0

Table 26. *Continued*. **Annual length frequency of spot sampled from scrap landings (combined gears) by the NCDMF.**

Fork Length (cm)	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
5	0	0	0	0	0	0	0	0	0	0	0	0
6	1	0	0	0	0	0	0	0	0	0	0	0
7	0	0	1	0	0	0	0	0	0	0	0	0
8	2	1	0	0	0	1	0	0	0	0	0	0
9	10	19	2	0	0	23	0	3	0	0	0	0
10	42	112	25	9	30	72	11	26	0	7	1	2
11	96	83	89	38	131	57	12	33	18	29	2	5
12	100	68	99	74	135	67	23	40	21	29	7	10
13	85	66	94	167	146	107	21	34	58	12	8	8
14	90	69	126	202	149	95	39	43	47	20	11	11
15	143	156	235	272	207	161	58	48	61	16	3	16
16	172	171	327	253	208	174	99	62	86	15	9	9
17	227	73	249	273	175	213	143	73	63	12	12	25
18	271	54	210	210	113	213	95	45	29	12	11	38
19	163	51	119	95	69	107	24	12	16	13	2	63
20	64	80	49	25	30	37	5	5	2	5	3	22
21	18	29	6	6	8	17	1	2	0	2	0	2
22	7	9	3	1	1	10	1	2	0	0	0	1
23	0	3	4	2	0	1	0	0	0	0	0	0
24	0	3	1	0	0	0	0	0	0	0	0	0
25	0	1	1	0	0	0	0	0	0	1	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	1	0	0	0	0	1	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	1	0	1	1	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0

Table 27. **Spot length sample sizes by gear and year collected from commercial fisheries by the TIP in Florida. (Entangling gear) Net Ban began in 1995 and cast nets became the main commercial gear. For unknown reasons the TIP stopped recording the gears sampled beginning from 2004. So, since 2004, samples are assumed to come from cast nets landings. UNK stands for unknown gear.**



				Gears						
Years	UNK	cast net	crab pot	gill net	lines	seine	trammel	traps	trawl	Grand Total
1992				2361						2361
1993				3620						3620
1994		8		1816						1824
1995		3		387			14		170	574
1996		25								25
1997		311		98	10	1			16	436
1998		97		73	8				4	182
1999		346							99	445
2000		241			1				98	340
2001		103		49				15	183	350
2002	67	385	4			14			25	495
2003		7								7
2004		10								10
2005		2								2
2006		118								118
2007		182								182
2008		91								91
2009		12								12
2010		2								2
2011		43								43
2012		66								66
2013		6								6
2014		78								78
Grand Total	67	2136	4	8404	19	15	14	15	595	11269

Table 28. **Coastwide spot commercial landings (metric tons).**

Year	Metric Tons	Year	Metric Tons	Year	Metric Tons
1950	4,611	1972	5,066	1994	3,990
1951	5,831	1973	4,726	1995	3,548
1952	6,586	1974	4,548	1996	2,600
1953	3,600	1975	5,778	1997	3,007
1954	3,784	1976	2,477	1998	3,368
1955	3,686	1977	3,201	1999	2,541
1956	5,007	1978	4,328	2000	3,142
1957	4,097	1979	5,065	2001	3,175
1958	4,383	1980	4,634	2002	2,480
1959	4,086	1981	3,403	2003	2,644
1960	4,893	1982	4,736	2004	2,642
1961	3,468	1983	3,246	2005	2,039
1962	3,374	1984	2,676	2006	1,555
1963	2,838	1985	3,255	2007	2,612
1964	3,902	1986	3,157	2008	1,381
1965	2,171	1987	3,675	2009	2,586
1966	2,533	1988	3,123	2010	1,068
1967	4,843	1989	3,213	2011	2,506
1968	2,674	1990	3,010	2012	638
1969	1,766	1991	3,255	2013	1,604
1970	4,422	1992	3,076	2014	2,402
1971	2,676	1993	3,272		

Table 29. **Spot commercial landings (metric tons) by state. Red asterisks indicate confidential values.**

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	MA	RI
1950	41.59		132.18	2,346.11	2,040.44	44.59	4.94	0.64	0.45			
1951	127.23	0.54	1,200.20	2,093.10	2,281.79	58.33	8.03	57.56				4.54
1952	169.05	5.81	825.99	2,516.53	2,683.36	190.46	54.66	140.61				
1953	156.31	3.99	199.58	1,276.73	1,774.59	128.55	20.28	39.01	0.95			
1954	212.60	6.08	226.16	1,084.04	2,010.50	117.12	46.90	79.92	1.00			
1955	163.93	46.72	512.70	860.92	1,791.14	184.88	103.46	22.32				
1956	221.04	18.78	1,897.06	1,167.91	1,454.99	136.30	89.49	20.91				0.05
1957	154.45	29.21	951.59	978.62	1,574.51	267.21	60.01	78.20	2.90			
1958	268.89	17.60	381.88	1,052.74	2,384.26	268.98	7.71	0.54				
1959	468.24	0.14	834.93	1,027.34	1,703.01	38.56	8.94	5.13				
1960	468.47	0.18	1,234.04	1,184.10	1,771.91	226.07	8.26	0.14				
1961	421.21	0.05	1,573.28	932.45	537.01	4.35						
1962	319.65	1.68	1,422.01	552.61	1,065.81	12.20		0.09				
1963	511.15	1.86	1,233.41	415.26	668.96	6.89	0.23					
1964	431.73	1.13	1,436.07	567.53	1,450.50	15.38		0.05				
1965	425.51	4.99	532.52	413.95	794.01	0.27						
1966	546.44	2.40	964.11	495.00	522.90	1.86						
1967	407.51	4.76	1,006.57	1,382.50	1,929.26	112.63		0.05				
1968	501.04	0.91	931.00	714.45	506.21	20.68						
1969	396.71	1.09	205.70	674.85	475.59	9.39		2.90				
1970	634.08	4.22	166.70	693.50	2,663.86	259.73		0.09				
1971	1,311.38	2.63	583.09	539.82	228.43	9.21		1.41				
1972	879.92	14.79	1,029.18	1,769.98	1,338.32	33.43		0.54				
1973	417.58	15.38	659.79	2,448.20	1,168.50	12.29		4.31				
1974	792.79	7.44	162.37	2,543.27	1,021.05	16.78		4.76				
1975	381.33	4.04	676.23	3,764.75	870.41	46.67	7.71	26.54				
1976	242.17	7.94	459.75	1,212.98	540.79	7.44	3.63	1.09	1.41			
1977	466.52	3.22	133.57	1,725.97	846.85	7.44	5.17	9.25	2.54			
1978	450.81	0.14	181.86	2,212.82	1,454.00	14.20	8.85	4.94	0.54			
1979	395.25	0.11	189.82	3,312.77	1,152.69	4.81	8.21	0.82	0.14			
1980	405.11	0.72	186.44	3,220.53	814.11	2.86	2.40	1.09	0.50			
1981	1,269.55	3.50	57.78	1,592.82	465.47	6.44	5.03	2.72				
1982	2,009.97	0.13	28.38	2,231.11	461.49	2.81	1.13	0.82				

Table 29. *Continued*. Spot commercial landings (metric tons) by state. Red asterisks indicate confidential values.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	MA	RI
1983	1,027.97	*	108.91	1,339.14	711.27	58.69		0.36				
1984	684.27	*	59.09	1,579.37	333.42	19.60		0.05				
1985	634.95	*	64.75	1,834.25	708.46	3.49	7.80	1.09				
1986	416.79	0.06	297.27	1,521.43	831.84	47.36	39.19	2.99				
1987	428.17	0.69	100.04	1,272.80	1,687.88	114.21	63.55	7.21				
1988	609.75	0.29	170.65	1,397.18	900.53	26.31	17.55	0.73				
1989	519.25	0.16	14.28	1,476.20	1,133.32	52.53	13.15	3.72				
1990	578.66	0.02	17.17	1,567.37	773.33	58.01	11.29	4.10				
1991	476.93	*	14.42	1,382.23	1,151.82	97.99	107.14	24.69				
1992	342.79	0.12	78.00	1,281.91	1,132.90	150.52	43.09	46.36				
1993	374.61	0.58	113.95	1,212.07	1,472.85	82.64	9.98	4.94	0.03		0.01	
1994	454.69	*	130.74	1,332.34	1,936.57	75.41	45.54	14.25				
1995	253.80	0.11	94.86	1,363.88	1,643.21	150.31	28.12	13.68	0.01			
1996	25.59		27.48	1,038.73	1,354.01	116.44	36.71	0.52	0.14			
1997	103.01	*	39.54	1,192.01	1,598.26	54.58	16.19	2.80	0.09			
1998	73.07	*	28.99	1,087.25	1,999.42	102.48	63.67	12.51	*		*	
1999	33.12	*	4.26	1,026.10	1,349.32	101.36	23.38	3.55				
2000	26.30		3.86	1,283.59	1,726.36	80.26	14.65	6.28	0.43			
2001	14.99	*	5.87	1,403.36	1,577.46	128.59	35.50	9.09	0.07		*	
2002	9.35	*	10.26	990.66	1,397.31	62.89	6.25	0.60	2.60			
2003	4.23		7.74	926.86	1,584.14	83.66	34.94	2.72	0.02			
2004	5.87	*	1.20	1,051.05	1,536.25	19.84	26.54	0.75	0.04			
2005	9.59		4.75	777.68	1,122.60	52.16	71.47	0.35	0.20			
2006	10.21	*	2.58	619.04	876.09	15.91	28.55	1.65	1.34			
2007	6.50		2.88	398.74	1,966.46	176.68	58.15	2.03	0.49		*	
2008	4.16	*	0.68	334.06	969.59	56.11	14.81	0.88	0.49			
2009	10.00		10.23	456.54	1,820.98	239.78	32.41	15.45	0.14			
2010	6.10	*	1.79	259.60	501.07	268.53	27.40	2.74	0.62			
2011	15.37		5.52	425.00	1,706.89	283.32	41.79	24.90	3.70	*		
2012	16.67		0.25	222.11	279.35	46.40	8.21	4.51	57.87	0.53		2.59
2013	14.24		1.11	348.63	952.84	144.89	35.90	21.92	73.59	10.32		0.22
2014	7.58	*	2.68	346.86	1,814.05	161.55	54.26	13.50	1.02			*

Table 30. **Spot commercial landings (metric tons) by gear.**

Year	Haul Seines	Gill Nets	Trawls	Fixed Nets	Other Gears
1950	3,597	296	25	689	3
1951	4,933	354	22	496	26
1952	5,524	482	108	417	54
1953	2,931	272	41	313	43
1954	2,792	385	161	446	1
1955	2,740	412	141	388	4
1956	3,925	442	207	418	15
1957	2,886	506	192	466	47
1958	2,956	739	140	524	23
1959	2,663	642	141	601	40
1960	3,327	711	205	613	38
1961	2,489	515	193	260	11
1962	2,231	572	122	442	8
1963	1,921	638	95	178	6
1964	2,654	771	67	403	7
1965	1,223	590	58	292	8
1966	1,576	692	89	160	16
1967	2,640	924	391	877	12
1968	1,662	629	150	223	10
1969	871	540	179	141	36
1970	1,545	1,571	80	1,154	72
1971	1,134	1,295	126	101	20
1972	2,594	1,423	349	679	22
1973	2,616	910	592	591	17
1974	2,269	1,214	410	619	36
1975	3,918	886	584	374	16
1976	1,516	539	196	213	14
1977	1,539	909	370	357	25
1978	1,663	741	705	764	455
1979	2,610	978	634	444	399
1980	2,468	976	575	210	405
1981	1,323	399	175	236	1,270
1982	1,779	288	235	422	2,012

Table 30. ***Continued.*** **Spot commercial landings (metric tons) by gear.**

Year	Haul Seines	Gill Nets	Trawls	Fixed Nets	Other Gears
1983	1,192	482	159	385	1,028
1984	1,061	478	165	287	686
1985	1,341	852	259	165	638
1986	1,263	1,064	181	227	422
1987	947	1,837	134	303	455
1988	1,252	938	139	168	626
1989	1,040	1,262	161	213	536
1990	1,376	725	121	195	592
1991	1,153	1,505	98	167	332
1992	950	1,776	128	170	51
1993	998	2,060	52	132	29
1994	855	2,753	57	293	31
1995	755	2,304	55	272	161
1996	662	1,606	54	145	134
1997	919	1,797	59	165	68
1998	785	2,239	43	187	113
1999	553	1,792	45	125	26
2000	732	2,207	47	134	22
2001	673	2,163	91	219	29
2002	457	1,753	55	184	31
2003	512	1,806	42	265	19
2004	525	1,918	16	162	21
2005	438	1,433	6	142	21
2006	471	1,014	9	49	12
2007	561	1,819	22	147	64
2008	346	887	11	93	44
2009	293	2,048	30	127	87
2010	197	724	5	77	66
2011	197	1,937	6	140	227
2012	157	345	65	25	47
2013	189	1,099	90	62	164
2014	191	1,847	20	189	154

Table 31. Spot commercial landings (millions of fish). Conversions were not done for Georgia, North Carolina before 1989, or any states north of New Jersey.

Year	FL	SC	NC	VA	MD	DE	NJ	Total
1981	8.087	0.388		2.703	0.024	0.022	0.023	11.247
1982	12.803	0.190		3.263	0.031	0.013	0.008	16.308
1983	6.548	0.731		8.256	0.647	0.000	0.003	16.185
1984	4.359	0.018		2.739	0.108	0.000	0.000	7.224
1985	4.044	0.434		4.519	0.039	0.000	0.007	9.043
1986	2.655	1.995		6.540	0.348	0.288	0.027	11.853
1987	2.727	0.671		11.012	0.504	0.000	0.034	14.948
1988	3.884	1.145		5.269	0.193	0.035	0.005	10.531
1989	3.307	0.096	15.683	6.942	0.287	0.153	0.021	26.490
1990	3.686	0.115	16.821	4.261	0.352	0.086	0.041	25.362
1991	3.038	0.097	15.387	6.666	0.545	0.727	0.254	26.715
1992	2.184	0.523	12.685	6.758	0.872	0.272	0.261	23.555
1993	2.386	0.765	11.517	8.240	0.492	0.072	0.040	23.513
1994	2.896	0.877	5.448	10.060	0.407	0.244	0.223	20.156
1995	1.617	0.636	7.516	7.873	0.685	0.128	0.072	18.527
1996	0.143	0.184	5.451	6.440	0.530	0.101	0.002	12.852
1997	0.575	0.265	5.690	8.627	0.342	0.081	0.013	15.595
1998	0.408	0.195	5.392	10.002	0.492	0.338	0.070	16.897
1999	0.185	0.029	4.416	7.275	0.563	0.094	0.015	12.576
2000	0.147	0.026	6.513	8.202	0.395	0.076	0.099	15.457
2001	0.084	0.039	6.272	5.521	0.493	0.179	0.052	12.640
2002	0.052	0.069	4.367	6.087	0.385	0.038	0.003	11.002
2003	0.023	0.052	4.305	6.869	0.399	0.154	0.013	11.815
2004	0.032	0.008	4.664	6.248	0.111	0.141	0.004	11.208
2005	0.052	0.032	3.328	5.072	0.341	0.300	0.001	9.127
2006	0.055	0.017	3.097	4.586	0.095	0.209	0.010	8.070
2007	0.035	0.019	2.428	11.702	0.955	0.322	0.011	15.473
2008	0.023	0.005	1.929	5.454	0.212	0.109	0.011	7.743
2009	0.054	0.069	2.701	9.161	1.181	0.179	0.103	13.447
2010	0.033	0.012	1.496	2.671	1.422	0.197	0.017	5.847
2011	0.083	0.037	2.332	8.461	1.816	0.308	0.158	13.195
2012	0.090	0.002	1.430	1.610	0.329	0.049	0.057	3.568
2013	0.077	0.007	1.909	5.438	0.978	0.185	0.134	8.727
2014	0.041	0.018	1.999	9.520	1.051	0.201	0.056	12.886

Table 32. **Scrap landings of spot by state.**

Year	NC		VA	
	Millions	Metric Tons	Millions	Metric Tons
1981	3.894	197	0.479	24
1982	5.454	276	0.475	24
1983	3.274	166	0.733	37
1984	3.861	196	0.344	17
1985	4.484	227	0.730	37
1986	3.719	189	0.860	44
1987	3.111	158	1.739	88
1988	3.415	173	0.928	47
1989	3.608	183	1.153	58
1990	3.831	194	0.762	39
1991	3.379	171	1.187	60
1992	3.134	159	1.167	59
1993	2.963	150	1.565	79
1994	5.706	372	1.889	96
1995	1.644	169	3.572	181
1996	6.009	209	2.300	117
1997	5.839	321	1.105	56
1998	3.587	225	3.918	199
1999	2.194	139	2.917	148
2000	1.876	109	1.859	94
2001	1.576	133	1.519	77
2002	0.963	84	0.634	32
2003	1.784	131	1.622	82
2004	1.722	124	1.521	77
2005	0.635	48	0.860	44
2006	0.760	62	2.272	115
2007	2.442	129	2.661	135
2008	2.456	207	1.372	70
2009	1.005	37	0.262	13
2010	0.406	25	0.399	20
2011	1.121	83	0.714	36
2012	0.513	39	1.567	79
2013	0.153	6	0.335	17
2014	0.126	9	0.506	26

Table 33. **Number of discarded spot measured for length (fork) by the NEFOP.**

Year	Trawls	Gill Nets
1989	140	0
1990	300	0
1991	94	0
1992	0	0
1993	0	0
1994	0	0
1995	0	12
1996	0	1
1997	0	0
1998	0	0
1999	0	0
2000	0	32
2001	110	3
2002	240	0
2003	0	19
2004	0	1
2005	0	0
2006	0	2
2007	1	0
2008	9	0
2009	50	0
2010	78	0
2011	0	0
2012	1	0
2013	1	6
2014	5	0

Table 34. Number of tows observed by the SESTOP by South Atlantic fishery and year.

Year	Fishery	
	Penaeid Shrimp	Rock Shrimp
2001	30	16
2002	14	119
2003	0	177
2004	0	0
2005	158	0
2006	0	22
2007	135	0
2008	239	111
2009	458	19
2010	187	60
2011	320	0
2012	377	0
2013	308	96
2014	174	39

Table 35. **NEFOP gillnet observer data from trips encountering spot and total aggregate landings of all species summarized by year. All landings and discard values are in pounds. Values highlighted in yellow are averages of adjacent years or the closest two year period with data.**

Year	n Observed Trips	n Observed Sets	Total Observed Landings	Total Observed Discards	Mean Observed Landings	Mean Observed Discards	Observed Landings Variance	Observed Discards Variance	Total Reported Landings
1989	46	376	79,479	302	211	0.80	103,924	5	25,652,524
1990	46	376	79,479	302	211	0.80	103,924	5	24,002,907
1991	46	376	79,479	302	211	0.80	103,924	5	29,094,526
1992	46	376	79,479	302	211	0.80	103,924	5	35,577,345
1993	6	67	5,433	12	81	0.18	15,615	0	43,650,274
1994	40	309	74,046	290	240	0.94	118,692	6	44,036,266
1995	64	489	94,656	445	194	0.91	47,191	11	50,739,022
1996	32	282	64,431	15	228	0.05	72,069	0	69,291,360
1997	39	299	61,243	11	205	0.04	91,721	0	68,001,924
1998	10	43	6,047	25	141	0.58	14,222	3	71,081,469
1999	12	65	7,519	41	116	0.63	100,860	4	60,134,421
2000	12	73	17,000	46	233	0.63	76,590	7	53,612,915
2001	12	81	18,118	6	224	0.07	40,584	0	49,486,118
2002	13	62	13,125	190	212	3.06	84,019	69	44,679,363
2003	5	38	4,561	45	120	1.17	14,626	4	46,294,253
2004	3	19	1,303	35	69	1.82	2,439	61	43,035,622
2005	1	4	788	0	197	0.05	22,147	0	44,817,006
2006	1	7	1,603	1	229	0.20	7,730	0	36,334,649
2007	1	2	333	5	167	2.50	13,945	13	47,407,903
2008	3	30	6,279	5	209	0.16	71,611	0	44,172,162
2009	6	59	9,421	7	160	0.12	67,321	0	46,920,564
2010	3	29	3,142	2	108	0.07	59,914	0	45,500,133
2011	7	46	6,848	92	149	2.00	49,194	71	49,724,296
2012	7	46	6,848	92	149	2.00	49,194	71	43,074,272
2013	4	17	3,706	90	218	5.31	25,452	182	41,490,424
2014	10	83	6,420	85	77	1.02	17,228	25	50,323,940

Table 36. **NEFOP trawl observer data from trips encountering spot and total aggregate landings of all species summarized by year. All landings and discard values are in pounds. Values highlighted in yellow are averages of adjacent years.**

Year	n Observed Trips	n Observed Tows	Total Observed Landings	Total Observed Discards	Mean Observed Landings	Mean Observed Discards	Observed Landings Variance	Observed Discards Variance	Total Reported Landings
1989	7	67	15,859	3,163	237	47.21	33,506	8,762	102,266,145
1990	10	66	14,111	14,904	214	225.82	95,936	340,475	98,306,719
1991	10	96	75,505	896	787	9.33	2,841,320	561	124,235,440
1992	2	16	14,850	78	928	4.88	1,791,253	162	122,170,085
1993	5	36	11,221	228	312	6.33	64,487	141	122,523,204
1994	3	17	9,397	5	553	0.29	70,928	1	116,584,503
1995	22	179	122,610	416	685	2.32	1,521,473	38	111,100,026
1996	9	55	44,013	72	800	1.31	407,760	13	136,997,042
1997	2	24	79,208	445	3,300	18.54	21,426,228	927	113,737,816
1998	1	18	37,735	45	2,096	2.50	8,432,371	89	151,684,942
1999	3	52	39,878	93	767	1.79	3,055,011	49	124,402,919
2000	2	3	16,048	570	5,349	190.00	27,460,736	73,300	115,098,410
2001	14	67	84,106	46	1,255	0.69	911,833	1	90,445,547
2002	18	91	136,090	45	1,495	0.49	1,116,657	0	80,132,678
2003	22	106	145,557	102	1,373	0.96	1,073,754	4	74,051,714
2004	4	15	9,467	57	631	3.80	187,440	17	106,953,633
2005	5	46	167,852	384	3,649	8.35	37,363,223	1,222	55,072,880
2006	1	6	19,781	0	3,297	0.00	5,791,317	0	71,947,284
2007	16	131	220,367	565	1,682	4.31	12,106,105	519	48,895,736
2008	15	114	161,334	263	1,415	2.31	32,874,979	121	58,543,253
2009	25	164	218,409	350	1,332	2.13	8,222,888	79	71,184,696
2010	9	80	154,000	3,814	1,925	47.68	13,924,724	29,548	47,259,488
2011	12	92	110,180	437	1,198	4.75	2,647,643	690	77,198,373
2012	50	179	143,365	844	801	4.72	776,668	289	65,570,023
2013	75	306	254,069	9,412	830	30.76	3,711,261	44,531	51,079,933
2014	14	70	205,270	2,462	2,932	35.17	33,332,156	17,848	50,734,848

Table 37. **Number of observations from NEFOP observer data for spot by NMFS statistical area and gear. A map of statistical areas is in Figure 19.**

Stat Area	Gillnets	Trawls
611	0	52
612	2	140
613	0	107
614	92	46
615	0	10
616	0	19
621	92	916
622	0	27
623	0	2
625	1,437	142
626	0	37
631	125	168
632	0	14
635	251	283
636	0	27

Table 38. **Gears observed by NEFOP on trips that were used to estimate spot discards.**

GILL NET, ANCHORED-FLOATING, FISH
GILL NET, DRIFT-FLOATING, FISH
GILL NET, DRIFT-SINK, FISH
GILL NET, FIXED OR ANCHORED,SINK, OTHER/NK SPECIES
TRAWL,OTTER,BOTTOM,FISH
TRAWL,OTTER,BOTTOM,RUHLE
TRAWL,OTTER,BOTTOM,SCALLOP
TRAWL,OTTER,BOTTOM,TWIN

Table 39. **Gears contributing to aggregate landings used to expand ratios to discard estimates. Additional landings recorded as “NOT CODED” were included in the total landings (GILL NETS NC, TRAWLS NC).**

GILL NETS	OTHER TRAWLS
GILL NETS, FLOATING ANCHOR	OTTER TRAWL BOTTOM, CRAB
GILL NETS, FLOATING DRIFT	OTTER TRAWL BOTTOM, FISH
GILL NETS, OTHER	OTTER TRAWL BOTTOM, LOBSTER
GILL NETS, RUNAROUND	OTTER TRAWL BOTTOM, OTHER
GILL NETS, SINK ANCHOR	OTTER TRAWL BOTTOM, PAIRED
GILL NETS, SINK DRIFT	OTTER TRAWL BOTTOM, SCALLOP
GILL NETS, STAKE	OTTER TRAWL BOTTOM, SHRIMP
GILL NETS NC	OTTER TRAWL, PEELER
	OTTER TRAWL, RUHLE
	OTTER TRAWL, TWIN
	OTTER TRAWLS
	TRAWLS NC

Table 40. **Estimated ratios, variances, and CVs of discarded spot to total aggregate landings of all species from observed gillnets. Values highlighted in yellow are averages of adjacent years or the closest two year period with data.**

Year	Ratio	Ratio Variance	Ratio CV
1989	0.000119	2.64E-09	0.4304
1990	0.000119	2.64E-09	0.4304
1991	0.000119	2.64E-09	0.4304
1992	0.000000	0	NA
1993	0.000217	8.77E-09	0.4309
1994	0.000428	5.30E-09	0.1703
1995	0.000412	5.27E-09	0.1760
1996	0.000014	1.76E-11	0.3097
1997	0.000011	4.00E-11	0.5566
1998	0.000035	1.87E-10	0.3923
1999	0.000389	2.40E-08	0.3982
2000	0.000353	2.57E-08	0.4538
2001	0.001027	8.80E-07	0.9135
2002	0.000502	2.06E-07	0.9031
2003	0.000022	1.14E-10	0.4801
2004	0.000013	2.13E-10	1.0812
2005	0.000000	2.92E-14	1.0660
2006	0.000001	6.19E-13	1.0431
2007	0.000007	7.12E-11	1.1835
2008	0.000050	5.60E-10	0.4694
2009	0.000000	0	NA
2010	0.000002	6.63E-12	1.0513
2011	0.000000	0	NA
2012	0.000000	0	NA
2013	0.000252	3.58E-08	0.7515
2014	0.000117	7.62E-09	0.7491

Table 41. **Estimated ratios, variances, and CVs of discarded spot to total aggregate landings of all species from observed trawls. Values highlighted in yellow are averages of adjacent years.**

Year	Ratio	Ratio Variance	Ratio CV
1989	0.014079	1.83E-05	0.3040
1990	0.062590	4.83E-04	0.3512
1991	0.001233	1.51E-07	0.3155
1992	0.000153	1.12E-08	0.6916
1993	0.000852	1E-07	0.3713
1994	0.000016	1.3E-10	0.7223
1995	0.000638	1.85E-08	0.2131
1996	0.000044	3.25E-10	0.4077
1997	0.000406	2.60E-08	0.3968
1998	0.000067	3.69E-09	0.9046
1999	0.000122	5.41E-09	0.6048
2000	0.000227	4.15E-08	0.8968
2001	0.000013	1.16E-11	0.2547
2002	0.000049	3.10E-10	0.3621
2003	0.000000	0	NA
2004	0.000014	2.67E-11	0.3620
2005	0.000205	1.66E-08	0.6288
2006	0.000000	0.00E+00	NA
2007	0.000177	6.91E-09	0.4709
2008	0.000111	2.65E-09	0.4643
2009	0.000086	8.65E-10	0.3425
2010	0.000905	1.45E-07	0.4213
2011	0.000096	3.14E-09	0.5854
2012	0.000456	1.64E-08	0.2809
2013	0.002940	1.43E-06	0.4072
2014	0.000558	6.33E-08	0.4514

Table 42. **Number of observations, number of positive observations, proportion positive observations, and mean CPUE (kg per hour fished) of spot by factor level considered in the GLMs for shrimp trawl discard estimates using SEAMAP Trawl Survey and SESTOP data.**

season	N	N_pos	prop_pos	mean_CPUE
off	181	163	0.90	6.94
peak	17,107	11,583	0.68	19.93

depth_zone	N	N_pos	prop_pos	mean_CPUE
=<10m	16,007	10,927	0.68	21.08
10-30m	671	613	0.91	5.68
>30m	610	206	0.34	1.76

data_set	N	N_pos	prop_pos	mean_CPUE
penaeid_shrimp	2,386	2,139	0.90	4.79
rock_shrimp	658	249	0.38	1.69
SEAMAP	14,244	9,358	0.66	23.15

state	N	N_pos	prop_pos	mean_CPUE
FL	3,752	2,640	0.70	20.67
GA	3,708	1,996	0.54	7.54
SC	6,102	3,876	0.64	14.03
NC	3,726	3,234	0.87	40.57

year	N	N_pos	prop_pos	mean_CPUE
1989	318	201	0.63	28.75
1990	462	310	0.67	48.17
1991	466	343	0.74	60.43
1992	468	290	0.62	23.90
1993	468	300	0.64	15.80
1994	468	269	0.57	19.92
1995	468	309	0.66	29.87
1996	468	281	0.60	9.88
1997	468	227	0.49	20.53
1998	468	329	0.70	7.58
1999	468	259	0.55	5.61
2000	468	235	0.50	11.97
2001	657	476	0.72	11.75
2002	744	392	0.53	5.80
2003	789	532	0.67	18.58
2004	612	380	0.62	17.98
2005	770	556	0.72	31.84
2006	634	402	0.63	21.57
2007	742	472	0.64	5.61
2008	962	610	0.63	13.80
2009	1,148	896	0.78	11.63
2010	919	596	0.65	20.78
2011	992	828	0.83	25.82
2012	1,047	890	0.85	17.88
2013	990	733	0.74	19.31
2014	824	630	0.76	31.07

Table 43. **Number of observations, number of positive observations, proportion positive observations, and mean CPUE (numbers per hour fished) of spot by factor level considered in the GLM for shrimp trawl discard estimates using SEAMAP Trawl Survey and SESTOP data.**

season	N	N_pos	prop_pos	mean_CPUE
off	181	163	0.90	100.53
peak	16,815	11,291	0.67	350.86
depth_zone	**N**	**N_pos**	**prop_pos**	**mean_CPUE**
=<10m	15,715	10,635	0.68	371.34
10-30m	671	613	0.91	107.22
>30m	610	206	0.34	16.89
data_set	**N**	**N_pos**	**prop_pos**	**mean_CPUE**
penaeid_shrimp	2,379	2,132	0.90	150.07
rock_shrimp	658	249	0.38	16.77
SEAMAP	13,959	9,073	0.65	397.58
state	**N**	**N_pos**	**prop_pos**	**mean_CPUE**
FL	3,719	2,607	0.70	270.89
GA	3,662	1,950	0.53	129.73
SC	5,961	3,735	0.63	263.17
NC	3,654	3,162	0.87	784.52
year	**N**	**N_pos**	**prop_pos**	**mean_CPUE**
1989	318	201	0.63	487.60
1990	462	310	0.67	808.57
1991	466	343	0.74	899.24
1992	468	290	0.62	365.12
1993	468	300	0.64	194.54
1994	468	269	0.57	327.66
1995	468	309	0.66	547.13
1996	468	281	0.60	212.44
1997	253	12	0.05	10.90
1998	398	259	0.65	91.01
1999	468	259	0.55	119.66
2000	468	235	0.50	186.79
2001	657	476	0.72	252.98
2002	744	392	0.53	99.82
2003	789	532	0.67	405.51
2004	612	380	0.62	339.29
2005	770	556	0.72	557.24
2006	634	402	0.63	401.43
2007	742	472	0.64	100.43
2008	961	609	0.63	221.31
2009	1,147	895	0.78	242.47
2010	919	596	0.65	382.52
2011	992	828	0.83	539.31
2012	1,047	890	0.85	313.92
2013	986	729	0.74	320.47
2014	823	629	0.76	569.78

Table 44. Lognormal GLM summary of spot discard rate in weight (kg) from shrimp trawl fisheries.

```
Call:
glm(formula = lnCPUE ~ YEAR + data_set + depth_zone + state +
   season, family = gaussian, data = trips_pr_pos, na.action = na.exclude)
Deviance Residuals:
   Min      1Q  Median      3Q     Max
-5.6426 -1.1672  0.0818  1.1758  6.2999
Coefficients:
                 Estimate Std. Error t value Pr(>|t|)
(Intercept)        0.616356   0.199370   3.092 0.001996 **
YEAR1990          -0.160520   0.155563  -1.032 0.302157
YEAR1991           0.607467   0.152647   3.980 6.95e-05 ***
YEAR1992          -0.040623   0.157693  -0.258 0.796715
YEAR1993          -0.839396   0.156619  -5.359 8.51e-08 ***
YEAR1994          -0.311419   0.160204  -1.944 0.051933 .
YEAR1995          -0.286344   0.155675  -1.839 0.065887 .
YEAR1996          -1.113360   0.158708  -7.015 2.42e-12 ***
YEAR1997          -0.616578   0.166371  -3.706 0.000212 ***
YEAR1998          -1.041126   0.153780  -6.770 1.35e-11 ***
YEAR1999          -1.565368   0.161498  -9.693  < 2e-16 ***
YEAR2000          -1.149601   0.165046  -6.965 3.45e-12 ***
YEAR2001          -0.763366   0.144870  -5.269 1.39e-07 ***
YEAR2002          -1.104388   0.150616  -7.332 2.41e-13 ***
YEAR2003          -0.480957   0.144169  -3.336 0.000852 ***
YEAR2004          -0.684820   0.150092  -4.563 5.10e-06 ***
YEAR2005          -0.707700   0.141981  -4.984 6.30e-07 ***
YEAR2006           0.005537   0.148637   0.037 0.970284
YEAR2007          -1.069100   0.145217  -7.362 1.93e-13 ***
YEAR2008          -0.733061   0.141184  -5.192 2.11e-07 ***
YEAR2009          -0.442210   0.136145  -3.248 0.001165 **
YEAR2010          -0.561131   0.141127  -3.976 7.05e-05 ***
YEAR2011           0.087099   0.136534   0.638 0.523532
YEAR2012           0.036136   0.135996   0.266 0.790466
YEAR2013          -0.303937   0.138043  -2.202 0.027702 *
YEAR2014           0.285651   0.140181   2.038 0.041599 *
data_setrock_shrimp -0.892799   0.250420  -3.565 0.000365 ***
data_setSEAMAP      1.499818   0.051907  28.895  < 2e-16 ***
depth_zone>30m      1.147655   0.273763   4.192 2.78e-05 ***
depth_zone10-30m    0.430202   0.091865   4.683 2.86e-06 ***
stateGA           -0.876792   0.053438 -16.408  < 2e-16 ***
stateNC            0.631736   0.048937  12.909  < 2e-16 ***
stateSC           -0.322651   0.047437  -6.802 1.08e-11 ***
seasonpeak         0.289818   0.148724   1.949 0.051355 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for gaussian family taken to be 2.950506)

    Null deviance: 43223  on 11745  degrees of freedom
Residual deviance: 34556  on 11712  degrees of freedom
AIC: 46079

Number of Fisher Scoring iterations: 2
```

Table 45. **Binomial GLM summary for spot discard rate in weight (kg) from shrimp trawl fisheries.**

```
Call:
glm(formula = success ~ YEAR + data_set + depth_zone + state +
    season, family = binomial(link = "logit"), data = trips_pr,
    na.action = na.exclude, offset = effort)
Deviance Residuals:
   Min     1Q  Median     3Q    Max
-3.738  -1.101   0.569   0.883  2.418
Coefficients:
                      Estimate Std. Error z value Pr(>|z|)
(Intercept)          -0.025634   0.339908  -0.075  0.93988
YEAR1990              0.156883   0.157416   0.997  0.31895
YEAR1991              0.483034   0.161206   2.996  0.00273 **
YEAR1992             -0.089449   0.155144  -0.577  0.56424
YEAR1993              0.007879   0.155814   0.051  0.95967
YEAR1994             -0.289501   0.154189  -1.878  0.06044 .
YEAR1995              0.097886   0.156548   0.625  0.53179
YEAR1996             -0.176228   0.154667  -1.139  0.25454
YEAR1997             -0.678486   0.153792  -4.412 1.03e-05 ***
YEAR1998              0.305887   0.158633   1.928  0.05382 .
YEAR1999             -0.386874   0.153880  -2.514  0.01193 *
YEAR2000             -0.618228   0.153714  -4.022 5.77e-05 ***
YEAR2001              0.342591   0.151703   2.258  0.02393 *
YEAR2002             -0.601331   0.144336  -4.166 3.10e-05 ***
YEAR2003              0.405722   0.148282   2.736  0.00622 **
YEAR2004             -0.188339   0.148523  -1.268  0.20477
YEAR2005              0.130572   0.147451   0.886  0.37587
YEAR2006             -0.069565   0.148226  -0.469  0.63884
YEAR2007             -0.257696   0.145175  -1.775  0.07589 .
YEAR2008             -0.143364   0.143052  -1.002  0.31626
YEAR2009              0.310370   0.143902   2.157  0.03102 *
YEAR2010             -0.123193   0.143296  -0.860  0.38995
YEAR2011              0.794631   0.150625   5.276 1.32e-07 ***
YEAR2012              0.737029   0.151319   4.871 1.11e-06 ***
YEAR2013              0.307538   0.145325   2.116  0.03433 *
YEAR2014              0.383633   0.149715   2.562  0.01039 *
data_setrock_shrimp -1.230365   0.445437  -2.762  0.00574 **
data_setSEAMAP        1.124871   0.088660  12.687  < 2e-16 ***
depth_zone>30m       -2.430597   0.454551  -5.347 8.93e-08 ***
depth_zone10-30m      0.172479   0.173383   0.995  0.31984
stateGA              -1.006508   0.056627 -17.774  < 2e-16 ***
stateNC               0.762613   0.066937  11.393  < 2e-16 ***
stateSC              -0.509512   0.053344  -9.551  < 2e-16 ***
seasonpeak           -0.488308   0.311995  -1.565  0.11756
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 23041  on 17287  degrees of freedom
Residual deviance: 19372  on 17254  degrees of freedom
AIC: 19440

Number of Fisher Scoring iterations: 5
```

Table 46. Negative binomial GLM summary for spot discard rate in numbers from shrimp trawl fisheries.

```
Call:
glm.nb(formula = catch ~ year + season + data_set + state + depth_zone +
   offset(log_eff), data = CPUE_data, init.theta = 0.1946308757,
   link = log)
Deviance Residuals:
   Min      1Q  Median      3Q     Max
-1.8621  -1.4007  -0.7148  -0.1309   5.2769
Coefficients:
                Estimate Std. Error t value Pr(>|t|)
(Intercept)        5.659865   0.325906  17.367  < 2e-16 ***
year1990           0.799449   0.230525   3.468 0.000526 ***
year1991           0.880239   0.230123   3.825 0.000131 ***
year1992          -0.288392   0.230018  -1.254 0.209938
year1993          -0.622286   0.230071  -2.705 0.006842 **
year1994          -0.199967   0.230006  -0.869 0.384640
year1995           0.281341   0.229958   1.223 0.221179
year1996          -0.887417   0.230129  -3.856 0.000116 ***
year1997          -3.324336   0.271444 -12.247  < 2e-16 ***
year1998          -1.256965   0.238318  -5.274 1.35e-07 ***
year1999          -1.312748   0.230263  -5.701 1.21e-08 ***
year2000          -1.056787   0.230182  -4.591 4.44e-06 ***
year2001          -0.061423   0.216617  -0.284 0.776756
year2002          -1.019844   0.213662  -4.773 1.83e-06 ***
year2003           0.328165   0.213281   1.539 0.123909
year2004          -0.687410   0.219107  -3.137 0.001708 **
year2005           0.065884   0.211645   0.311 0.755581
year2006           0.099218   0.217791   0.456 0.648708
year2007          -1.209071   0.212861  -5.680 1.37e-08 ***
year2008          -0.735592   0.206845  -3.556 0.000377 ***
year2009          -0.243182   0.203655  -1.194 0.232462
year2010          -0.318099   0.207185  -1.535 0.124718
year2011           0.853106   0.205926   4.143 3.45e-05 ***
year2012          -0.187737   0.205454  -0.914 0.360851
year2013          -0.010730   0.206417  -0.052 0.958545
year2014           0.452699   0.210126   2.154 0.031222 *
seasonpeak        -0.904388   0.258977  -3.492 0.000480 ***
data_setrock_shrimp -1.183710   0.437108  -2.708 0.006775 **
data_setSEAMAP     1.141451   0.087538  13.039  < 2e-16 ***
stateGA           -1.083271   0.079646 -13.601  < 2e-16 ***
stateNC            1.124155   0.080906  13.895  < 2e-16 ***
stateSC           -0.170220   0.074022  -2.300 0.021484 *
depth_zone>30m    -0.663407   0.454311  -1.460 0.144240
depth_zone10-30m  -0.009523   0.159439  -0.060 0.952375
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for Negative Binomial(0.1946) family taken to be 1.944617)

    Null deviance: 22410  on 16995  degrees of freedom
Residual deviance: 18875  on 16962  degrees of freedom
AIC: 155001
Number of Fisher Scoring iterations: 1
```

Table 47. Model selection summary for spot lognormal (left) and binomial (right) GLMS of discard rate in weight from shrimp trawl fisheries.

Drop	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	Drop	Df	Deviance	AIC	LRT	Pr(>Chi)
none	NA	34,556	46,079	NA	NA	none	NA	19,372	19,440	NA	NA
YEAR	25	37,123	46,870	842	1.92E-161	YEAR	25	19,839	19,857	468	3.97E-83
data_set	2	37,117	46,914	840	4.44E-183	data_set	2	19,517	19,581	146	2.42E-32
depth_zone	2	34,646	46,105	30	2.51E-07	depth_zone	2	19,416	19,480	44	2.18E-10
state	3	37,634	47,075	1,002	5.92E-217	state	3	20,460	20,522	1,089	1.11E-235
season	1	34,568	46,080	4	5.10E-02	season	1	19,374	19,440	3	1.06E-01

Table 48. Model selection summary for spot negative binomial GLM of discard rate in numbers from shrimp trawl fisheries.

drop	Df	Deviance	AIC	Pr(>Chisq)
none	NA	18,875.3	155,001	NA
year	25	18,934.1	156,266	7.27E-262
season	1	18,876.4	155,024	5.94E-07
data_set	2	18,886.0	155,280	4.88E-62
state	3	18,939.9	156,485	1.03753785626662e-322
depth_zone	2	18,875.6	155,004	3.24E-02

Table 49. Summary of shrimp trawl effort data by year and state. Averages are highlighted in yellow.

year	state	hours_fished	trips	avg_hours	avg_gear
1989	FL	147,659	5,124	17.57	1.64
1989	GA	646,487	7,711	28.04	2.99
1989	NC	1,234,260	30,077	18.32	2.24
1989	SC	393,248	10,192	14.84	2.6
1990	FL	189,299	6,246	18.48	1.64
1990	GA	523,746	6,247	28.04	2.99
1990	NC	802,614	19,558	18.32	2.24
1990	SC	371,741	9,635	14.84	2.6
1991	FL	147,733	5,843	15.14	1.67
1991	GA	849,379	10,131	28.04	2.99
1991	NC	1,017,306	24,790	18.32	2.24
1991	SC	533,501	13,827	14.84	2.6
1992	FL	127,136	4,757	16.1	1.66
1992	GA	748,436	8,927	28.04	2.99
1992	NC	389,472	9,491	18.32	2.24
1992	SC	477,901	12,386	14.84	2.6
1993	FL	139,354	5,314	16.39	1.6
1993	GA	752,628	8,977	28.04	2.99
1993	NC	533,885	13,010	18.32	2.24
1993	SC	448,346	11,620	14.84	2.6
1994	FL	167,861	6,484	15.69	1.65
1994	GA	719,092	8,577	28.04	2.99
1994	NC	678,297	16,529	18.32	2.24
1994	SC	391,859	10,156	14.84	2.6
1995	FL	139,566	5,723	14.87	1.64
1995	GA	828,838	9,886	28.04	2.99
1995	NC	694,507	16,924	18.32	2.24
1995	SC	469,760	12,175	14.84	2.6
1996	FL	143,918	5,600	13.67	1.88
1996	GA	651,518	7,771	28.04	2.99
1996	NC	475,001	11,575	18.32	2.24
1996	SC	352,503	9,136	14.84	2.6
1997	FL	119,267	5,314	12.4	1.81
1997	GA	749,107	8,935	28.04	2.99
1997	NC	558,470	13,609	18.32	2.24
1997	SC	435,228	11,280	14.84	2.6
1998	FL	114,184	5,154	14.48	1.53
1998	GA	664,932	7,931	28.04	2.99
1998	NC	389,809	9,499	18.32	2.24
1998	SC	365,969	9,485	14.84	2.6
1999	FL	102,769	5,102	13.61	1.48
1999	GA	603,142	7,194	28.04	2.99
1999	NC	563,025	13,720	18.32	2.24
1999	SC	386,072	10,006	14.84	2.6
2000	FL	69,444	3,666	13.34	1.42
2000	GA	443,679	5,292	28.04	2.99
2000	NC	488,849	12,911	18.03	2.1
2000	SC	367,088	9,514	14.84	2.6
2001	FL	72,511	3,221	14.07	1.6
2001	GA	260,741	3,110	28.04	2.99
2001	NC	397,548	9,808	17.7	2.29
2001	SC	241,111	6,249	14.84	2.6
2002	FL	68,108	2,872	14.46	1.64
2002	GA	317,808	3,745	28.1	3.02
2002	NC	553,747	12,425	19.21	2.32
2002	SC	272,943	7,074	14.84	2.6
2003	FL	106,948	2,763	20.48	1.89
2003	GA	292,499	3,461	28.36	2.98
2003	NC	326,112	8,995	15.56	2.33
2003	SC	226,425	6,293	14.11	2.55
2004	FL	99,818	2,730	19.98	1.83
2004	GA	226,756	2,751	27.66	2.98
2004	NC	356,922	7,573	19.72	2.39
2004	SC	272,049	5,954	17.71	2.58
2005	FL	94,763	2,649	19.13	1.87
2005	GA	172,942	2,432	24.27	2.93
2005	NC	157,026	4,324	16.14	2.25
2005	SC	139,663	4,131	12.71	2.66
2006	FL	87,610	2,499	17.27	2.03
2006	GA	156,168	2,073	24.38	3.09
2006	NC	227,146	5,587	16.46	2.47
2006	SC	115,618	3,661	12.1	2.61
2007	FL	82,025	2,308	16.53	2.15
2007	GA	124,718	1,651	23.83	3.17
2007	NC	290,549	6,668	17.57	2.48
2007	SC	90,831	3,268	10.69	2.6
2008	FL	64,847	2,147	15.41	1.96
2008	GA	115,676	1,784	22.13	2.93
2008	NC	326,774	5,980	21.18	2.58
2008	SC	92,251	3,531	10.01	2.61
2009	FL	62,668	2,173	15.34	1.88
2009	GA	128,305	1,772	23.74	3.05
2009	NC	249,333	5,744	17.79	2.44
2009	SC	93,365	3,194	11.33	2.58
2010	FL	85,296	2,656	15.82	2.03
2010	GA	141,441	2,224	21.78	2.92
2010	NC	225,387	5,508	17.05	2.4
2010	SC	122,570	4,346	11.06	2.55
2011	FL	83,501	2,745	15.52	1.96
2011	GA	129,594	1,935	22.55	2.97
2011	NC	200,784	4,354	18.67	2.47
2011	SC	88,496	3,176	10.8	2.58
2012	FL	78,664	2,586	15.52	1.96
2012	GA	127,852	1,909	22.55	2.97
2012	NC	284,760	6,175	18.67	2.47
2012	SC	117,085	4,202	10.8	2.58
2013	FL	52,230	1,717	15.52	1.96
2013	GA	86,731	1,295	22.55	2.97
2013	NC	252,986	5,486	18.67	2.47
2013	SC	87,409	3,137	10.8	2.58
2014	FL	62,937	2,069	15.52	1.96
2014	GA	106,086	1,584	22.55	2.97
2014	NC	202,813	4,398	18.67	2.47
2014	SC	87,409	3,137	10.8	2.58

Table 50. **Proportions used to partition South Atlantic shrimp trawl effort data. Effort data are partitioned across depth zones first and then within each depth zone across fisheries.**

	Depth Zone		
	=<10m	10-30m	>30m
all effort at depth	0.58	0.22	0.20
penaeid effort within depth	1.00	0.93	0.01
rock effort wtihin depth	0.00	0.07	0.99

Table 51. **Estimated spot gillnet discards in weight (lbs) and numbers. Lower confidence intervals are truncated at zero due to large variances. Data used to estimate mean weight and discards in numbers were pooled over all years due to small sample size.**

Year	Discards (lbs)	Discards LCI (lbs)	Discards UCI (lbs)	n Fish Counted	Total Subsample Weight (lbs)	n Subsamples	Mean Weight (lbs)	Discards (numbers)
1989	3,063	426	5,699	NA	NA	NA	NA	3,629
1990	2,866	399	5,333	NA	NA	NA	NA	3,396
1991	3,474	483	6,464	NA	NA	NA	NA	4,116
1992	0	0	0	NA	NA	NA	NA	0
1993	9,484	1,310	17,659	NA	NA	NA	NA	11,238
1994	18,796	12,395	25,197	NA	NA	NA	NA	22,272
1995	20,858	13,515	28,201	2	8	1	4.000	24,715
1996	931	355	1,508	1	1	1	1.000	1,104
1997	770	0	1,627	NA	NA	NA	NA	913
1998	2,450	528	4,372	NA	NA	NA	NA	2,903
1999	23,110	4,705	41,515	NA	NA	NA	NA	27,384
2000	18,715	1,730	35,701	32	33	4	1.031	22,176
2001	50,021	0	141,409	3	2	2	0.500	59,271
2002	22,175	0	62,226	NA	NA	NA	NA	26,276
2003	1,020	41	1,999	19	8	3	0.421	1,208
2004	573	0	1,812	1	1	1	0.500	679
2005	7	0	22	NA	NA	NA	NA	8
2006	27	0	84	2	1	1	0.700	32
2007	337	0	1,136	NA	NA	NA	NA	400
2008	2,223	136	4,310	NA	NA	NA	NA	2,634
2009	0	0	0	NA	NA	NA	NA	0
2010	111	0	345	NA	NA	NA	NA	132
2011	0	0	0	NA	NA	NA	NA	0
2012	0	0	0	NA	NA	NA	NA	0
2013	10,353	0	25,914	6	2	1	0.383	12,268
2014	5,838	0	14,584	NA	NA	NA	NA	6,917

Table 52. **Estimated spot trawl discards in weight (lbs) and numbers. Lower confidence intervals are truncated at zero due to large variances. Values highlighted in yellow are averages of adjacent years or the closest two year period with data.**

Year	Discards (lbs)	Discards LCI (lbs)	Discards UCI (lbs)	n Fish Counted	Total Subsample Weight (lbs)	n Subsamples	Mean Weight (lbs)	Discards (numbers)
1989	1,344,507	526,949	2,162,065	140	14	2	0.100	13,445,069
1990	5,740,647	1,708,309	9,772,985	300	68	2	0.227	25,326,383
1991	141,751	52,305	231,197	94	21	2	0.223	634,504
1992	17,379	0	41,417	204	62	30	0.304	57,183
1993	93,537	24,069	163,006	204	62	30	0.304	307,768
1994	1,542	0	3,770	204	62	30	0.304	5,074
1995	59,024	33,867	84,182	204	62	30	0.304	194,210
1996	4,706	869	8,544	204	62	30	0.304	15,484
1997	37,588	7,759	67,417	204	62	30	0.304	123,676
1998	8,751	0	24,583	204	62	30	0.304	28,794
1999	11,098	0	24,523	204	62	30	0.304	36,517
2000	18,678	0	52,179	204	62	30	0.304	61,457
2001	1,033	507	1,559	110	41	28	0.373	2,771
2002	3,333	919	5,747	240	42	37	0.175	19,045
2003	0	0	0	241	42	38	0.176	0
2004	916	253	1,579	241	42	38	0.176	5,220
2005	10,563	0	23,846	241	42	38	0.176	60,181
2006	0	0	0	241	42	38	0.176	0
2007	8,029	468	15,590	1	0	1	0.300	26,763
2008	7,353	525	14,181	9	2	2	0.178	41,361
2009	7,196	2,266	12,125	50	5	2	0.104	69,189
2010	51,590	8,115	95,065	78	13	2	0.160	321,923
2011	6,056	0	13,146	79	13	3	0.163	37,088
2012	24,801	10,868	38,735	1	0	1	0.400	62,003
2013	125,149	23,228	227,069	6	2	2	0.317	395,206
2014	24,348	2,366	46,329	5	2	1	0.300	81,159

Table 53. **Comparison of spot discard estimates from trawls in Mid-Atlantic fisheries with and without large discard tows observed in 1989 (1 tow) and 1990 (5 tows). Ratios are the weight of discarded spot to the weight of all species landed.**

Estimates with all data

Year	Ratio	Ratio Variance	Ratio CV	Discards (lbs)	Discards (numbers)
1989	0.0141	1.83E-05	0.30	1,344,507	13,445,069
1990	0.0626	4.83E-04	0.35	5,740,647	25,326,383

Estimates excluding anomalous tows in 1989 and 1990

Year	Ratio	Ratio Variance	Ratio CV	Discards (lbs)	Discards (numbers)
1989	0.0045	1.41E-06	0.26	432,981	4,329,810
1990	0.0040	2.20E-06	0.37	365,926	1,614,379

Table 54. **Spot discard estimates (millions of fish) from South Atlantic shrimp trawl fisheries with values corresponding to 95% confidence intervals. Unadjusted estimates are estimates before making adjustments due to catch reductions by BRDs.**

Year	LCI	Discards	UCI	Unadjusted Discards
1989	423	583	807	454
1990	694	930	1,250	723
1991	953	1,272	1,705	990
1992	154	208	284	162
1993	132	177	240	138
1994	232	311	419	242
1995	399	538	731	419
1996	87	116	157	91
1997	6	9	13	NA
1998	41	56	77	NA
1999	51	69	95	NA
2000	54	73	98	NA
2001	117	152	198	NA
2002	60	78	101	NA
2003	154	199	258	NA
2004	59	77	102	NA
2005	66	85	111	NA
2006	82	107	140	NA
2007	26	34	45	NA
2008	47	59	76	NA
2009	62	77	96	NA
2010	55	69	88	NA
2011	157	197	249	NA
2012	75	94	118	NA
2013	76	96	121	NA
2014	100	127	163	NA

Table 55. Spot discard estimates (metric tons) from South Atlantic shrimp trawl fisheries with values corresponding to 95% confidence intervals. Unadjusted estimates are estimates before making adjustments due to catch reductions by BRDs.

Year	LCI	Discards	UCI	Unadjusted Discards
1989	20,280	27,545	37,543	21,372
1990	13,157	17,239	22,682	13,382
1991	39,320	50,976	66,366	39,634
1992	8,392	11,219	15,083	8,694
1993	4,823	6,387	8,501	4,953
1994	8,682	11,603	15,581	8,990
1995	10,549	13,911	18,435	10,793
1996	3,043	4,051	5,420	3,139
1997	3,556	4,876	6,719	0
1998	2,577	3,386	4,473	0
1999	1,514	2,044	2,776	0
2000	1,793	2,439	3,334	0
2001	3,044	3,861	4,922	0
2002	2,086	2,720	3,564	0
2003	3,660	4,641	5,911	0
2004	2,630	3,413	4,452	0
2005	1,486	1,874	2,378	0
2006	3,453	4,458	5,784	0
2007	1,316	1,677	2,149	0
2008	2,113	2,628	3,289	0
2009	2,623	3,191	3,906	0
2010	1,977	2,473	3,111	0
2011	4,287	5,243	6,450	0
2012	5,330	6,489	7,948	0
2013	2,904	3,569	4,410	0
2014	4,553	5,650	7,050	0

Table 56. Mean weight of spot discarded in South Atlantic shrimp trawl fisheries based on the discard estimates in weight and numbers.

Year	Discard Numbers	Discard Weight (kg)	Annual Mean Weight
1989	583,370,348	27,545,377	0.047
1990	929,664,646	17,238,964	0.019
1991	1,272,210,025	50,975,781	0.040
1992	208,192,851	11,219,290	0.054
1993	177,436,234	6,387,178	0.036
1994	310,993,951	11,603,132	0.037
1995	538,455,701	13,911,437	0.026
1996	116,476,304	4,051,409	0.035
1997	9,229,182	4,875,524	0.528
1998	55,725,316	3,386,127	0.061
1999	69,292,192	2,044,180	0.030
2000	72,777,842	2,439,134	0.034
2001	152,054,525	3,861,087	0.025
2002	77,579,021	2,720,041	0.035
2003	198,910,447	4,640,864	0.023
2004	77,409,152	3,413,310	0.044
2005	85,110,306	1,873,689	0.022
2006	106,681,825	4,457,674	0.042
2007	34,223,459	1,676,660	0.049
2008	59,337,373	2,627,907	0.044
2009	76,673,915	3,190,751	0.042
2010	69,181,376	2,473,140	0.036
2011	196,989,629	5,243,226	0.027
2012	93,779,860	6,488,747	0.069
2013	95,573,541	3,568,750	0.037
2014	127,347,986	5,650,194	0.044

Table 57. Spot length and weight sample sizes by year obtained during MRFSS and MRIP sampling.

Year	Length	Weight	Year	Length	Weight
1981	1,514	1,719	1998	2,957	2,930
1982	1,905	1,794	1999	1,964	2,011
1983	3,349	3,090	2000	1,850	1,863
1984	1,281	1,146	2001	2,764	2,800
1985	5,104	4,816	2002	1,656	1,689
1986	5,607	5,249	2003	2,921	2,859
1987	3,955	3,741	2004	4,447	4,475
1988	1,834	1,761	2005	3,422	3,260
1989	3,986	3,835	2006	3,947	3,982
1990	2,742	2,716	2007	3,990	3,973
1991	4,764	5,044	2008	3,611	3,632
1992	3,216	3,349	2009	4,856	4,864
1993	2,470	2,403	2010	2,033	1,990
1994	4,581	4,572	2011	3,312	3,344
1995	2,753	2,550	2012	1,172	932
1996	3,150	2,819	2013	1,731	1,151
1997	3,016	2,942	2014	1,289	857

Table 58. Spot length sample size from MRIP at-sea sampling of headboats by year and state.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	Total
2004	0	0	0	9	25	86	0	0	120
2005	0	0	0	6	231	464	0	4	705
2006	0	0	0	31	14	183	0	0	228
2007	0	0	0	3	35	167	3	0	208
2008	0	0	0	57	24	53	16	0	150
2009	0	0	1	13	11	58	1	0	84
2010	0	0	0	2	109	102	3	1	217
2011	0	0	0	7	64	49	5	0	125
2012	0	0	1	3	9	228	6	1	248
2013	0	0	0	7	18	357	0	4	386
2014	0	0	2	40	5	18	1	0	66

Table 59. Number of recreational harvest weight estimates by pooling level for MRFSS strata with zero harvest weight estimates and positive harvest number estimates.

Factor Collapsed for Pooling			
Area	Mode	State	Wave
0	1	16	15

Table 60. **Total harvest number estimates without weight, imputed harvest weight estimates, and mean weights for MRFSS strata with zero harvest weight estimates and positive number estimates.**

Year	Numbers	Weight (lbs.)	Mean Weight
1981	0	NA	NA
1982	0	NA	NA
1983	8,975	2,754	0.31
1984	21,046	5,084	0.24
1985	1,807	551	0.30
1986	0	NA	NA
1987	3,343	843	0.25
1988	10,657	3,885	0.36
1989	1,076	310	0.29
1990	2,881	915	0.32
1991	4,769	1,340	0.28
1992	0	NA	NA
1993	50,385	19,864	0.39
1994	35,127	13,869	0.39
1995	1,962	816	0.42
1996	0	NA	NA
1997	0	NA	NA
1998	8,797	4,058	0.46
1999	0	NA	NA
2000	2,597	943	0.36
2001	0	NA	NA
2002	3,953	1,594	0.40
2003	25,408	11,451	0.45

Table 61. **MRIP harvest estimates (numbers and weight) by pooling level for APAIS design change calibration. Headboat estimates were not adjusted (No Ratio) because the design for this mode (at-sea sampling) did not change in 2013.**

Ratio Pooling Level				
No Pooling	Collapse State	Collapse Species	Collapse State and Species	No Ratio
81	43	64	0	28

Table 62. **MRIP released alive (number) estimates by pooling level for APAIS design change calibration. Headboat estimates were not adjusted (No Ratio) because the design for this mode (at-sea sampling) did not change in 2013.**

Ratio Pooling Level				
No Pooling	Collapse State	Collapse Species	Collapse State and Species	No Ratio
81	94	13	0	28

Table 63. **MRFSS and MRIP recreational harvest of spot (millions of fish) by state and coastwide.**

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	Coastwide
1981	0.983	0.153	0.692	4.948	14.095	1.167	0.022	0.034	0.054	0.000	22.147
1982	0.904	0.103	1.513	5.072	5.444	3.523	0.101	0.477	0.000	0.000	17.136
1983	0.600	0.138	1.194	6.021	14.748	1.976	0.018	0.000	0.000	0.000	24.695
1984	0.487	0.447	0.891	3.392	1.729	1.079	0.019	0.010	0.000	0.000	8.056
1985	1.060	0.077	2.896	10.828	6.259	1.254	0.000	0.015	0.019	0.000	22.408
1986	0.119	0.170	2.468	3.254	5.019	5.223	0.015	0.012	0.005	0.000	16.285
1987	0.091	0.098	0.738	2.618	4.496	4.196	0.000	0.000	0.000	0.000	12.236
1988	0.816	0.071	2.399	3.146	2.451	0.342	0.003	0.429	0.000	0.000	9.656
1989	0.083	0.043	1.326	3.596	4.522	1.805	0.056	0.001	0.001	0.000	11.433
1990	0.009	0.022	0.175	2.443	6.497	3.352	0.055	0.032	0.000	0.000	12.585
1991	0.332	0.013	0.736	2.849	10.803	2.762	0.186	0.109	0.000	0.000	17.788
1992	0.440	0.032	1.464	1.564	7.680	2.428	0.110	0.025	0.000	0.000	13.743
1993	1.164	0.282	1.775	2.530	3.472	2.829	0.004	0.010	0.001	0.000	12.067
1994	0.169	0.012	1.635	7.292	4.027	2.473	0.114	0.178	0.024	0.000	15.922
1995	0.172	0.035	1.076	4.110	3.280	1.822	0.064	0.004	0.000	0.000	10.563
1996	0.079	0.017	1.750	2.470	1.345	0.748	0.001	0.029	0.000	0.000	6.440
1997	0.039	0.007	0.837	1.772	4.060	1.016	0.155	0.025	0.000	0.000	7.910
1998	0.148	0.008	0.601	3.528	2.437	1.648	0.119	0.000	0.000	0.000	8.489
1999	0.325	0.007	0.986	1.609	0.696	0.842	0.024	0.000	0.000	0.000	4.489
2000	0.050	0.004	0.303	2.367	0.638	1.898	0.082	0.346	0.613	0.000	6.302
2001	0.803	0.005	0.905	4.490	1.253	1.483	0.063	0.000	0.000	0.000	9.001
2002	0.032	0.009	0.484	3.182	1.966	0.851	0.027	0.000	0.000	0.000	6.550
2003	0.104	0.014	0.645	4.669	1.769	4.595	0.037	0.000	0.000	0.000	11.833
2004	0.010	0.002	0.948	5.362	1.560	0.996	0.023	0.000	0.000	0.000	8.902
2005	0.037	0.005	0.486	4.200	4.280	2.093	0.181	0.082	0.000	0.000	11.363
2006	0.013	0.002	1.310	4.551	2.895	3.716	0.279	0.016	0.000	0.000	12.782
2007	0.051	0.004	0.663	4.832	7.357	4.291	0.290	0.000	0.002	0.000	17.491
2008	0.094	0.011	3.197	2.557	6.169	2.293	0.224	0.172	0.000	0.000	14.717
2009	0.048	0.033	0.730	1.728	2.765	2.521	0.347	0.014	0.000	0.000	8.184
2010	0.188	0.002	0.252	1.312	2.042	1.366	0.164	1.134	0.000	0.000	6.460
2011	0.306	0.001	0.764	1.609	3.661	0.907	0.374	0.001	0.000	0.000	7.624
2012	0.125	0.000	1.115	1.255	2.336	0.876	0.147	0.878	0.059	0.000	6.791
2013	0.132	0.007	0.732	1.465	4.288	0.936	0.248	0.329	0.013	0.000	8.150
2014	0.609	0.016	0.466	2.112	3.909	1.254	0.345	0.013	0.000	0.000	8.723

Table 64. MRFSS and MRIP recreational harvest of spot (metric tons) by state and coastwide.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	Coastwide
1981	176	29	82	673	2,566	313	5	3	11	0	3,857
1982	133	11	177	616	853	370	11	48	0	0	2,219
1983	96	16	165	921	1,413	201	2	0	0	0	2,814
1984	69	48	95	367	214	194	3	2	0	0	993
1985	120	7	249	1,762	1,014	109	0	2	2	0	3,266
1986	14	13	257	302	657	710	2	1	1	0	1,958
1987	19	8	128	389	716	932	0	0	0	0	2,193
1988	104	8	344	452	400	45	1	48	0	0	1,403
1989	13	4	163	524	781	438	6	0	0	0	1,930
1990	1	4	28	346	1,167	616	7	3	0	0	2,173
1991	61	2	139	410	1,534	442	30	11	0	0	2,629
1992	95	4	224	228	1,271	481	21	5	0	0	2,329
1993	234	62	261	458	534	456	0	1	0	0	2,008
1994	34	2	265	1,039	657	433	20	18	4	0	2,470
1995	25	4	137	707	589	376	13	1	0	0	1,852
1996	15	3	279	401	274	171	0	6	0	0	1,150
1997	8	1	144	408	706	259	29	5	0	0	1,559
1998	27	1	129	705	480	359	21	0	0	0	1,722
1999	48	1	221	365	137	159	6	0	0	0	937
2000	8	1	73	504	141	379	19	26	74	0	1,224
2001	161	1	196	1,000	285	387	11	0	0	0	2,041
2002	5	2	79	556	467	190	6	0	0	0	1,305
2003	20	3	128	967	493	1,042	8	0	0	0	2,661
2004	1	0	154	1,102	449	252	4	0	0	0	1,962
2005	6	1	79	709	943	404	40	19	0	0	2,201
2006	2	0	231	763	647	584	41	2	0	0	2,271
2007	11	1	86	704	1,305	730	59	0	0	0	2,895
2008	14	2	421	428	1,183	350	29	10	0	0	2,437
2009	8	5	126	264	493	471	59	2	0	0	1,428
2010	34	0	34	188	301	245	25	174	0	0	1,000
2011	50	0	125	248	556	153	59	0	0	0	1,192
2012	17	0	137	160	321	153	22	67	28	0	905
2013	19	1	137	209	602	126	49	54	3	0	1,199
2014	75	2	71	320	579	183	95	3	0	0	1,328

Table 65. MRFSS and MRIP recreational live releases of spot (millions of fish) by state and coastwide.

Year	FL	GA	SC	NC	VA	MD	DE	NJ	NY	CT	Coastwide
1981	0.090	0.008	0.115	1.028	12.428	1.896	0.002	0.036	0.000	0.000	15.603
1982	0.287	0.062	0.512	1.128	2.256	2.344	0.007	1.362	0.000	0.000	7.959
1983	0.261	0.056	0.269	0.911	3.790	1.564	0.000	0.080	0.000	0.000	6.931
1984	0.182	0.025	0.484	1.332	3.629	1.603	0.019	0.000	0.000	0.000	7.273
1985	0.238	0.024	0.720	0.642	2.750	1.026	0.000	0.004	0.031	0.000	5.435
1986	0.014	0.029	0.463	1.141	3.102	4.121	0.000	0.111	0.000	0.000	8.982
1987	0.080	0.040	0.425	0.830	2.399	0.375	0.002	0.000	0.000	0.000	4.150
1988	0.154	0.024	0.154	1.392	1.065	1.001	0.008	0.155	0.000	0.000	3.952
1989	0.031	0.002	0.194	0.734	3.494	1.056	0.056	0.006	0.000	0.000	5.574
1990	0.043	0.006	0.019	1.288	6.131	2.827	0.014	0.020	0.000	0.000	10.349
1991	0.235	0.021	0.141	1.323	9.818	3.060	0.095	0.129	0.000	0.000	14.821
1992	0.090	0.024	0.390	1.178	2.887	0.730	0.017	0.002	0.000	0.000	5.318
1993	0.259	0.067	0.193	0.739	1.914	2.386	0.051	0.000	0.000	0.000	5.609
1994	0.469	0.031	0.449	1.906	2.860	1.523	0.074	0.224	0.011	0.000	7.548
1995	0.376	0.014	0.464	1.447	1.602	0.365	0.020	0.031	0.000	0.000	4.318
1996	0.091	0.007	0.295	1.297	0.800	0.297	0.002	0.055	0.010	0.000	2.855
1997	0.025	0.002	0.343	0.630	1.885	1.920	0.124	0.030	0.000	0.000	4.960
1998	0.082	0.017	0.430	0.909	1.216	0.905	0.106	0.018	0.000	0.000	3.683
1999	0.742	0.015	0.121	0.885	0.472	0.867	0.022	0.000	0.000	0.000	3.124
2000	0.076	0.024	0.162	0.675	0.692	1.515	0.043	0.023	0.221	0.000	3.431
2001	0.104	0.016	0.215	1.598	1.329	0.835	0.018	0.003	0.000	0.000	4.119
2002	0.062	0.028	0.145	0.940	0.673	0.700	0.038	0.004	0.003	0.000	2.593
2003	0.149	0.043	0.324	1.583	1.304	0.957	0.019	0.055	0.000	0.000	4.434
2004	0.012	0.013	0.266	2.103	0.790	0.600	0.054	0.000	0.000	0.000	3.840
2005	0.052	0.031	0.222	2.350	2.231	3.200	0.189	0.010	0.000	0.000	8.284
2006	0.029	0.002	0.530	4.262	1.508	2.257	0.091	0.088	0.000	0.000	8.766
2007	0.034	0.011	0.122	2.199	1.893	2.730	0.036	0.200	0.001	0.000	7.226
2008	0.142	0.039	0.191	2.345	1.595	2.885	0.135	1.088	0.000	0.000	8.419
2009	0.043	0.011	0.414	2.090	1.418	1.076	0.188	0.012	0.000	0.000	5.253
2010	0.026	0.001	0.076	1.549	1.234	1.651	0.082	0.315	0.000	0.000	4.933
2011	0.169	0.015	0.267	1.792	2.574	0.508	0.087	0.001	0.000	0.000	5.413
2012	0.406	0.006	0.146	1.437	1.369	1.651	0.064	0.751	0.050	0.000	5.879
2013	0.111	0.009	0.958	1.314	2.218	2.622	0.214	0.748	0.000	0.001	8.194
2014	0.575	0.027	0.427	0.891	1.174	0.566	0.079	0.015	0.000	0.000	3.754

Table 66. MRFSS and MRIP recreational live releases of spot (metric tons) coastwide.

Year	Coastwide
1981	157
1982	60
1983	44
1984	56
1985	45
1986	73
1987	39
1988	35
1989	58
1990	104
1991	129
1992	50
1993	58
1994	67
1995	42
1996	28
1997	63
1998	42
1999	35
2000	40
2001	56
2002	31
2003	60
2004	29
2005	55
2006	98
2007	69
2008	70
2009	69
2010	27
2011	70
2012	50
2013	95
2014	64

Table 67. **Total numbers (millions of fish) and weight (metric tons) of spot caught and released by recreational anglers assumed to die post-release (15%).**

Year	Millions	Metric Tons
1981	2.340	157
1982	1.194	60
1983	1.040	44
1984	1.091	56
1985	0.815	45
1986	1.347	73
1987	0.623	39
1988	0.593	35
1989	0.836	58
1990	1.552	104
1991	2.223	129
1992	0.798	50
1993	0.841	58
1994	1.132	67
1995	0.648	42
1996	0.428	28
1997	0.744	63
1998	0.552	42
1999	0.469	35
2000	0.515	40
2001	0.618	56
2002	0.389	31
2003	0.665	60
2004	0.576	29
2005	1.243	55
2006	1.315	98
2007	1.084	69
2008	1.263	70
2009	0.788	69
2010	0.740	27
2011	0.812	70
2012	0.882	50
2013	1.229	95
2014	0.563	64

Table 68. **MRFSS and MRIP coastwide recreational harvest of spot (millions of fish) and PSEs.**

Year	Mean	PSE
1981	22.147	36.3
1982	17.136	25.4
1983	24.695	41.4
1984	8.056	27.5
1985	22.408	24.2
1986	16.285	25.5
1987	12.236	19.2
1988	9.656	24.8
1989	11.433	15.6
1990	12.585	20.1
1991	17.788	18.7
1992	13.743	23.6
1993	12.067	19.7
1994	15.922	15.3
1995	10.563	22.7
1996	6.440	29.3
1997	7.910	28.1
1998	8.489	21.0
1999	4.489	20.2
2000	6.302	22.2
2001	9.001	20.2
2002	6.550	20.4
2003	11.833	17.6
2004	8.902	12.6
2005	11.363	15.8
2006	12.782	18.3
2007	17.491	15.5
2008	14.717	24.3
2009	8.184	14.3
2010	6.460	18.1
2011	7.624	15.2
2012	6.791	19.5
2013	8.150	7.8
2014	8.723	17.3

Table 69. **MRFSS and MRIP coastwide recreational harvest of spot (metric tons) and PSEs.**

Year	Mean	PSE
1981	3,857	33.9
1982	2,219	30.2
1983	2,814	41.1
1984	993	29.6
1985	3,266	26.7
1986	1,958	25.9
1987	2,193	22.2
1988	1,403	28.5
1989	1,930	16.9
1990	2,173	22.2
1991	2,629	19.0
1992	2,329	25.4
1993	2,008	19.4
1994	2,470	15.2
1995	1,852	24.9
1996	1,150	30.0
1997	1,559	25.5
1998	1,722	22.8
1999	937	22.6
2000	1,224	25.3
2001	2,041	20.5
2002	1,305	22.2
2003	2,661	18.6
2004	1,962	12.7
2005	2,201	16.9
2006	2,271	19.2
2007	2,895	16.1
2008	2,437	28.2
2009	1,428	15.3
2010	1,000	18.4
2011	1,192	14.4
2012	905	19.6
2013	1,199	7.9
2014	1,328	14.9

Table 70. MRFSS and MRIP coastwide recreational live releases of spot (millions of fish) and PSEs.

Year	Mean	PSE
1981	15.603	72.5
1982	7.959	35.0
1983	6.931	57.8
1984	7.273	32.3
1985	5.435	22.1
1986	8.982	27.1
1987	4.150	20.3
1988	3.952	40.7
1989	5.574	16.4
1990	10.349	19.3
1991	14.821	18.1
1992	5.318	20.0
1993	5.609	20.9
1994	7.548	12.9
1995	4.318	17.5
1996	2.855	19.1
1997	4.960	20.4
1998	3.683	16.3
1999	3.124	20.5
2000	3.431	19.5
2001	4.119	13.9
2002	2.593	16.8
2003	4.434	20.0
2004	3.840	11.8
2005	8.284	14.0
2006	8.766	15.8
2007	7.226	13.9
2008	8.419	14.6
2009	5.253	12.7
2010	4.933	13.4
2011	5.413	12.8
2012	5.879	13.0
2013	8.194	8.1
2014	3.754	9.2

Table 71. **Spot harvest estimates (number of fish) from the SERHS.**

Year	Harvest	Year	Harvest
1981	363	1998	0
1982	0	1999	1
1983	0	2000	0
1984	0	2001	0
1985	7	2002	0
1986	0	2003	0
1987	35	2004	0
1988	0	2005	35
1989	0	2006	0
1990	57	2007	0
1991	58	2008	0
1992	227	2009	0
1993	28	2010	0
1994	0	2011	0
1995	0	2012	0
1996	0	2013	17
1997	0	2014	1

Table 72. **Spot release estimates (number of fish) by disposition from the SERHS.**

Year	Dead	Live	Disposition Unknown
2004	0	0	0
2005	0	0	0
2006	0	0	0
2007	0	0	0
2008	0	0	0
2009	0	0	0
2010	0	0	0
2011	0	0	0
2012	0	0	0
2013	0	0	3
2014	0	0	12

Table 73. **Coastwide removals of spot combined across fisheries in metric tons and millions of fish. 1989 is the first year removal data from all fisheries are available.**

Year	Metric Tons	Millions of Fish
1989	33,598	640
1990	25,364	999
1991	57,287	1,324
1992	16,900	251
1993	12,002	219
1994	18,607	356
1995	19,739	574
1996	8,157	145
1997	9,899	41
1998	8,947	89
1999	5,860	92
2000	7,066	99
2001	9,366	177
2002	6,663	97
2003	10,221	227
2004	8,248	101
2005	6,266	108
2006	8,559	132
2007	7,521	73
2008	6,797	87
2009	7,328	100
2010	4,637	83
2011	9,134	220
2012	8,212	107
2013	6,551	115
2014	9,492	150

Table 74. Surveys considered for developing abundance and biomass indices by the spot SAS for this assessment.

Survey Considered	Time Series Available	Used	Reason Not Used (if applicable)
NJ DFW Delaware River Seine Survey	1980-2014	N	Localized survey, too many zeros
NJ DFW Delaware Bay Trawl Survey	1991-2014	N	Localized survey, fixed design
NJ DFW Ocean Trawl Survey	1989-2014	N	Not representative of whole range
DE DFW 30ft Trawl Survey	1966-1971, 1979-1984, 1990-2014	N	Fixed design, localized survey
DE DFW 17ft Trawl Survey	1978-2014	N	Fixed design, localized survey
MD DNR Chesapeake Blue Crab Trawl Survey	1980, consistent from 1989-2014	N	Fixed design
MD DNR Striped Bass Seine Survey	1966-2014	N	Too many zeros
MD DNR Coastal Bays Trawl Survey	1972-2014, standardized 1989	N	YOY survey, others used instead
MD DNR Coastal Bay Seine Survey	1972-2014	N	Too many zeros
MD DNR Choptank River Gill Net Survey	2013-2014	N	Short time series
VIMS Juvenile Trawl Survey	1988-2014	N	YOY survey
NC P120 (estuarine trawl survey)	1970-2014	N	YOY survey, others used instead
NC P195 (NCDMF Trawl Survey)	1987-2014	Y	NA
NC P915	1987-2014	N	Not representative of stock
NC P135	1990-2014	N	Other survey in this region used
NC P123	1991-2014	N	Other survey in this region used
NC P100		N	Fixed design
NC P430 (pound net survey)	1986-2014	N	Other survey in this region used
NC P433	1979-2014	N	Other survey in this region used
NC P434 (gill net survey)	1982-2014	N	Other survey in this region used
NC P435 (beach seine)		N	Other survey in this region used
NC P537	1978-2014	N	Other survey in this region used
NC P441	1978-2014	N	Other survey in this region used
SC DNR Bears Bluff Shrimp Trawl	1952-1969	N	Localized survey, not representative
SC DNR Trammel Net Survey	1990-2014	N	Localized survey, not representative
SC DNR Electroshock Survey	2001-2014	N	Too many zeros, not representative of stock
SEAMAP Trawl Survey	1990-2014	Y	NA
GA DNR Ecological Monitoring Trawl Survey	1976-2014	N	YOY survey, others more representative

Table 74. ***Continued*. Surveys considered for developing abundance and biomass indices by the spot SAS for this assessment.**

Survey Considered	**Time Series Available**	**Used**	**Reason Not Used (if applicable)**
GA DNR Gill Net Survey	2003-2014	N	Localized survey, not representative
FL FWC Fishery Independent Monitoring Bag Seine Survey	1996-2014	N	Localized survey, not representative
FL FWC Fishery Independent Monitoring Haul Seine Survey	1996-2014	N	Localized survey
FL FWC Fishery Independent Monitoring Trawl Survey	1996-2014	N	Localized survey
NMFS Trawl Survey	1972-2014	Y	NA
NEAMAP Trawl Survey	2007-2014	Y	NA
ChesMMAP Trawl Survey	2002-2014	Y	NA

Table 75. Annual number of trawl tows by strata for the NMFS Trawl Survey.

Year	1OFF	2OFF	3OFF	4OFF	5OFF	Total
1972	9	6	6	4	9	34
1973	17	6	4	4	11	42
1974	7	6	5	4	12	34
1975	6	4	4	4	7	25
1976	4	4	4	4	6	22
1977	4	4	4	4	6	22
1978	4	4	4	4	6	22
1979	4	4	4	4	6	22
1980	3	4	4	4	6	21
1981	4	4	4	4	6	22
1982	4	4	4	4	6	22
1983	4	5	4	4	6	23
1984	4	4	4	4	6	22
1985	4	4	4	4	6	22
1986	4	4	4	4	6	22
1987	4	4	4	4	6	22
1988	4	4	4	4	6	22
1989	4	4	4	4	6	22
1990	6	4	4	5	6	25
1991	4	4	4	4	6	22
1992	4	4	4	4	7	23
1993	4	4	4	4	6	22
1994	4	4	4	4	6	22
1995	4	4	4	4	6	22
1996	4	4	4	4	6	22
1997	4	4	4	4	6	22
1998	4	4	4	4	6	22
1999	4	4	4	4	6	22
2000	4	5	4	4	6	23
2001	4	4	4	4	6	22
2002	5	4	4	4	6	23
2003	4	4	4	4	6	22
2004	4	4	4	4	6	22
2005	4	4	4	4	6	22
2006	4	4	4	4	6	22
2007	4	4	4	4	6	22
2008	4	4	4	4	6	22
2009	5	8	6	4	12	35
2010	6	7	6	6	12	37
2011	13	6	6	11	12	48
2012	6	7	6	6	13	38
2013	9	7	6	6	13	41
2014	8	8	6	6	12	40
Total	220	199	187	188	312	1106

Table 76. **Annual proportion of positive tows by strata for spot from the NMFS Trawl Survey using pooled strata scheme.**

Year	1OFF	2OFF	3OFF	4OFF	5OFF
1972	0.00	0.00	0.17	0.75	0.33
1973	0.00	0.00	0.25	0.25	0.91
1974	0.00	0.00	0.20	1.00	0.92
1975	0.00	0.00	0.50	0.75	0.86
1976	0.00	0.25	0.25	0.75	0.83
1977	0.50	0.25	1.00	1.00	0.83
1978	0.00	0.00	0.75	0.75	1.00
1979	0.00	0.00	0.50	1.00	1.00
1980	0.00	0.00	0.25	0.50	0.83
1981	0.00	0.75	1.00	0.75	1.00
1982	0.25	0.25	1.00	1.00	0.67
1983	0.25	0.20	0.50	1.00	0.33
1984	0.00	0.25	1.00	1.00	0.83
1985	0.00	0.50	1.00	1.00	1.00
1986	0.00	0.25	1.00	1.00	1.00
1987	0.00	0.00	0.25	0.50	0.83
1988	0.00	0.25	0.25	0.75	0.67
1989	0.00	0.25	1.00	1.00	1.00
1990	0.00	0.25	0.75	0.80	1.00
1991	0.00	0.00	0.75	0.50	0.67
1992	0.00	0.00	0.50	0.25	0.14
1993	0.00	0.00	0.25	0.50	0.17
1994	0.00	0.00	0.50	1.00	0.33
1995	0.25	0.00	1.00	1.00	1.00
1996	0.00	0.00	0.25	1.00	0.67
1997	0.00	0.00	0.75	0.50	0.67
1998	0.00	0.00	0.75	0.75	0.50
1999	0.00	0.00	0.75	0.50	1.00
2000	0.00	0.00	0.00	0.75	0.67
2001	0.00	0.00	0.00	0.25	0.00
2002	0.00	0.25	1.00	0.50	0.50
2003	0.00	0.00	0.75	0.75	1.00
2004	0.00	0.00	0.50	0.50	0.83
2005	0.00	0.25	0.75	0.25	1.00
2006	0.00	0.50	0.75	1.00	1.00
2007	0.00	0.25	1.00	1.00	0.83
2008	0.25	0.50	1.00	1.00	1.00
2009	0.00	0.00	0.67	1.00	1.00
2010	0.50	0.71	1.00	0.83	0.50
2011	0.31	1.00	1.00	0.91	0.92
2012	0.00	0.71	0.67	1.00	1.00
2013	0.33	0.57	0.83	0.00	0.69
2014	0.13	0.13	0.83	0.83	0.58

Table 77. Age-0 indices of abundance and CVs developed for the spot assessment. All indices were in numbers per tow and have been standardized to their mean.

	NCDMF June Trawl		SEAMAP Fall Trawl		NMFS Fall Trawl		ChesMMAP Summer- Fall Trawl		NEAMAP Fall Trawl	
Year	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV
1989	0.5050	0.1455	0.1918	0.3342	3.8526	0.0664				
1990	2.0224	0.1159	0.2627	0.1849	0.6861	0.0553				
1991	0.6570	0.1561	0.3704	0.1959	0.1380	0.2101				
1992	0.1765	0.2103	0.1281	0.2480	0.0444	0.1228				
1993	1.1139	0.1474	0.1500	0.4129	0.0256	0.1661				
1994	0.1948	0.1689	1.2351	0.2547	1.1866	0.1197				
1995	0.0960	0.2106	0.0719	0.1644	0.3425	0.0592				
1996	0.8724	0.1216	0.5658	0.1751	0.2936	0.1165				
1997	0.3996	0.1613	0.1010	0.2576	0.1236	0.1019				
1998	0.3140	0.2354	0.1505	0.2084	0.0718	0.1065				
1999	1.3754	0.2152	0.7167	0.3830	0.6050	0.0363				
2000	0.2787	0.1960	0.0847	0.4089	0.2985	0.0730				
2001	0.5169	0.2223	0.1527	0.2244	0.0005	0.3110				
2002	0.8841	0.1318	0.3398	0.2269	0.2194	0.1152	0.6630	0.3025		
2003	1.8855	0.1601	0.7943	0.4688	0.1398	0.0666	0.7769	0.2909		
2004	1.2624	0.2440	0.2174	0.2759	0.6557	0.0620	1.2951	0.2853		
2005	0.4614	0.1601	9.2655	0.3407	1.6146	0.0538	1.7277	0.2615		
2006	0.1921	0.1928	0.3094	0.1264	0.9300	0.0421	5.2776	0.2577		
2007	0.3853	0.2424	0.1511	0.2627	0.6343	0.1104	0.7931	0.2915	0.5228	0.2586
2008	3.1594	0.2301	0.5208	0.5379	1.1296	0.0487	1.0832	0.3175	1.3452	0.2783
2009	0.4469	0.1822	0.7962	0.2732	1.3712	0.0333	0.2582	0.2671	0.1634	0.1507
2010	1.6853	0.1895	6.8526	0.3420	2.9291	0.0368	0.6741	0.3483	0.5291	0.2697
2011	0.9423	0.1477	0.6487	0.2156	2.5109	0.0374	0.0215	0.2605	0.0938	0.1477
2012	2.4666	0.1047	0.7748	0.1819	4.4639	0.0263	0.2060	0.2800	5.0683	0.2556
2013	2.7690	0.1697	0.6494	0.4163	1.6031	0.0452	0.1876	0.2689	0.2195	0.2384
2014	0.9370	0.1437	0.4987	0.3872	0.1298	0.0697	0.0362	0.2081	0.0580	0.1125

Table 78. Age-1+ indices of abundance and CVs developed for the spot assessment. All indices were in numbers per tow and have been standardized to their mean.

	NCDMF June Trawl		SEAMAP Fall Trawl		NMFS Fall Trawl		ChesMMAP Summer-Fall Trawl		NEAMAP Fall Trawl	
Year	Index	CV	Index	CV	Index	CV	Index	CV	Index	CV
1989	0.8602	0.1757	0.2930	0.3342	3.5809	0.0664				
1990	0.4149	0.2220	0.4260	0.1849	0.6787	0.0553				
1991	0.8793	0.1032	2.9393	0.1959	0.1338	0.2101				
1992	0.4639	0.1408	0.6342	0.2480	0.1151	0.1228				
1993	0.8786	0.0978	1.1321	0.4129	0.0137	0.1661				
1994	0.9277	0.1227	0.8969	0.2547	1.2423	0.1197				
1995	1.5358	0.1334	0.2904	0.1644	0.6403	0.0592				
1996	0.3939	0.1673	0.6332	0.1751	0.2364	0.1165				
1997	0.6283	0.1433	0.0892	0.2576	0.0811	0.1019				
1998	0.4781	0.2664	0.1318	0.2084	0.0986	0.1065				
1999	0.7560	0.1639	0.3033	0.3830	0.7738	0.0363				
2000	1.7494	0.2053	0.5276	0.4089	0.4935	0.0730				
2001	0.6035	0.1573	0.1289	0.2244	0.0004	0.3110				
2002	0.5230	0.1953	0.3614	0.2269	0.2599	0.1152	0.5862	0.3025		
2003	1.2830	0.1671	0.5989	0.4688	0.4962	0.0666	0.6730	0.2909		
2004	0.9074	0.2671	0.5996	0.2759	0.6906	0.0620	0.8006	0.2853		
2005	1.3612	0.2895	4.2248	0.3407	1.1661	0.0538	1.8229	0.2615		
2006	4.2081	0.1248	0.5699	0.1264	1.6101	0.0421	3.9015	0.2577		
2007	0.9282	0.1939	0.3726	0.2627	0.5816	0.1104	1.3534	0.2915	1.0820	0.2586
2008	0.5587	0.3190	1.9167	0.5379	1.0389	0.0487	0.6614	0.3175	0.6773	0.2783
2009	0.6613	0.2073	1.1684	0.2732	1.6489	0.0333	1.4423	0.2671	1.0868	0.1507
2010	0.6246	0.1417	1.5220	0.3420	1.3827	0.0368	0.0976	0.3483	0.9530	0.2697
2011	1.0763	0.1432	0.6718	0.2156	2.7452	0.0374	1.1048	0.2605	1.9066	0.1477
2012	0.7906	0.2175	1.7912	0.1819	4.3593	0.0263	0.0105	0.2800	0.0121	0.2556
2013	1.3604	0.2086	2.6558	0.4163	1.4933	0.0452	0.4441	0.2689	2.2049	0.2384
2014	1.1479	0.1873	1.1214	0.3872	0.4386	0.0697	0.1017	0.2081	0.0772	0.1125

Table 79. **Age length key proportions from the NEAMAP Trawl Survey used to estimate age group specific index of relative abundance for the NMFS Trawl Survey.**

	Age	
TL_cm	0	1+
3	1	0
4	1	0
5	1	0
6	1	0
7	1	0
8	1	0
9	1	0
10	1	0
11	1	0
12	1	0
13	1	0
14	0.955	0.045
15	0.962	0.038
16	0.939	0.061
17	0.873	0.127
18	0.783	0.217
19	0.754	0.246
20	0.58	0.42
21	0.291	0.709
22	0.115	0.885
23	0.154	0.846
24	0	1
25	0	1
26	0	1
27	0	1
28	0	1
29	0	1

Table 80. **Annual indices of biomass and standard errors for each of the surveys developed for the spot assessment.**

	NMFS Fall (kg/tow)		SEAMAP Fall (kg/tow)		ChesMMAP Summer-Fall (kg/tow)		NEAMAP Fall (kg/tow)	
Year	Index	SE	Index	SE	Index	SE	Index	SE
1989	58.54	7.65	1.63	0.28				
1990	7.81	2.80	1.62	0.26				
1991	2.46	1.57	17.16	3.84				
1992	0.88	0.94	3.66	0.79				
1993	0.34	0.59	7.91	3.48				
1994	17.89	4.23	5.37	1.50				
1995	6.36	2.52	1.56	0.23				
1996	4.58	2.14	2.72	0.65				
1997	1.53	1.24	0.66	0.17				
1998	1.14	1.07	0.64	0.11				
1999	10.22	3.20	1.11	0.27				
2000	6.25	2.50	3.05	1.48				
2001	0.01	0.08	0.79	0.20				
2002	3.95	1.99	2.00	0.45	2.53	0.55		
2003	3.01	1.74	3.11	0.96	2.98	0.83		
2004	10.80	3.29	3.19	0.92	1.86	0.25		
2005	18.57	4.31	31.99	11.54	4.22	0.56		
2006	13.85	3.72	2.80	0.34	3.16	0.54		
2007	9.72	3.12	1.88	0.44	2.29	0.45	26.64	8.27
2008	14.21	3.77	11.55	7.03	1.22	0.17	25.99	5.38
2009	12.17	3.49	5.77	1.52	2.91	1.46	3.85	1.83
2010	19.53	4.42	17.98	5.97	1.08	0.15	33.96	11.45
2011	26.53	5.15	3.69	0.84	1.00	0.19	3.43	1.20
2012	32.65	5.71	9.29	1.74	0.56	0.19	100.65	19.11
2013	11.95	3.46	14.95	6.78	0.38	0.07	12.58	4.22
2014	2.93	6.06	6.06	2.58	0.34	0.13	0.82	0.32

Table 81. **Age length key proportions from the SEAMAP Trawl Survey used to estimate age group specific index of relative abundance.**

	Age	
TL_cm	0	1+
9	1	0
10	1	0
11	1	0
12	0.3706	0.6294
13	0.4503	0.5497
14	0.0899	0.9101
15	0.0185	0.9815
16	0	1
17	0	1
18	0	1
19	0	1
20	0	1
21	0	1
22	0	1
23	0	1
24	0	1
25	0	1
26	0	1
27	0	1

Table 82. **Age length key proportions from the ChesMMAP Trawl Survey used to estimate age group specific index of relative abundance.**

	2002		2003		2004		2005		2006		2007		2008	
LengthCM	Age0	Age1+	Age-0	Age-1+	Age-0	Age-1+	Age-0	Age1+	Age-0	Age-1+	Age-0	Age-1+	Age-0	Age-1+
0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0
3	1	0	1	0	1	0	1	0	1	0	1	0	1	0
4	1	0	1	0	1	0	1	0	1	0	1	0	1	0
5	1	0	1	0	1	0	1	0	1	0	1	0	1	0
6	1	0	1	0	1	0	1	0	1	0	1	0	1	0
7	1	0	1	0	1	0	1	0	1	0	1	0	1	0
8	1	0	1	0	1	0	1	0	1	0	1	0	1	0
9	1	0	1	0	1	0	1	0	1	0	1	0	1	0
10	1	0	1	0	1	0	1	0	1	0	1	0	1	0
11	1	0	1	0	1	0	1	0	1	0	1	0	1	0
12	1	0	1	0	1	0	1	0	1	0	1	0	1	0
13	1	0	1	0	1	0	0.983	0.017	1	0	1	0	0.925	0.075
14	1	0	1	0	0.949	0.051	1	0	0.971	0.029	1	0	0.871	0.129
15	1	0	1	0	0.977	0.023	0.957	0.043	0.905	0.095	1	0	1	0
16	0.923	0.077	0.909	0.091	0.967	0.033	0.927	0.073	0.792	0.208	0	1	0.722	0.278
17	0.833	0.167	0.85	0.15	0.88	0.12	0.893	0.107	0.561	0.439	0.071	0.929	0.359	0.641
18	0.684	0.316	0.755	0.245	0.462	0.538	0.5	0.5	0.431	0.569	0	1	0.341	0.659
19	0.661	0.339	0.725	0.275	0.607	0.393	0.111	0.889	0.244	0.756	0.065	0.935	0.343	0.657
20	0.635	0.365	0.556	0.444	0.103	0.897	0	1	0.037	0.963	0	1	0.04	0.96
21	0.171	0.829	0.2	0.8	0.05	0.95	0	1	0	1	0	1	0.133	0.867
22	0.2	0.8	0	1	0.059	0.941	0	1	0	1	0	1	0	1
23	0	1	0	1	0	1	0	1	0	1	0	1	0	1
24	0	1	0	1	0	1	0	1	0	1	0	1	0	1
25	0	1	0	1	0	1	0	1	0	1	0	1	0	1
26	0	1	0	1	0	1	0	1	0	1	0	1	0	1
27	0	1	0	1	0	1	0	1	0	1	0	1	0	1
28	0	1	0	1	0	1	0	1	0	1	0	1	0	1
29	0	1	0	1	0	1	0	1	0	1	0	1	0	1
30	0	1	0	1	0	1	0	1	0	1	0	1	0	1
31	0	1	0	1	0	1	0	1	0	1	0	1	0	1
32	0	1	0	1	0	1	0	1	0	1	0	1	0	1
33	0	1	0	1	0	1	0	1	0	1	0	1	0	1
34	0	1	0	1	0	1	0	1	0	1	0	1	0	1
35	0	1	0	1	0	1	0	1	0	1	0	1	0	1
36	0	1	0	1	0	1	0	1	0	1	0	1	0	1
37	0	1	0	1	0	1	0	1	0	1	0	1	0	1
38	0	1	0	1	0	1	0	1	0	1	0	1	0	1
39	0	1	0	1	0	1	0	1	0	1	0	1	0	1
40	0	1	0	1	0	1	0	1	0	1	0	1	0	1

Table 82. *Continued.* **Age length key proportions from the ChesMMAP Trawl Survey used to estimate age group specific index of relative abundance.**

	2009		2010		2011		2012		2013		2014	
LengthCM	Age-0	Age-1+	Age-0	Age-1+	Age-0	Age1+	Age-0	Age-1+	Age-0	Age-1+	Age-0	Age-1+
0	1	0	1	0	1	0	1	0	1	0	1	0
1	1	0	1	0	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0	1	0	1	0
3	1	0	1	0	1	0	1	0	1	0	1	0
4	1	0	1	0	1	0	1	0	1	0	1	0
5	1	0	1	0	1	0	1	0	1	0	1	0
6	1	0	1	0	1	0	1	0	1	0	1	0
7	1	0	1	0	1	0	1	0	1	0	1	0
8	1	0	1	0	1	0	1	0	1	0	1	0
9	1	0	1	0	1	0	1	0	1	0	1	0
10	1	0	1	0	1	0	1	0	1	0	1	0
11	1	0	1	0	1	0	1	0	1	0	1	0
12	1	0	1	0	1	0	0.917	0.083	0.9	0.1	1	0
13	0.952	0.048	1	0	1	0	1	0	1	0	1	0
14	0.929	0.071	0.875	0.125	0.5	0.5	0.962	0.038	0.6	0.4	1	0
15	0.615	0.385	0.862	0.138	0	1	1	0	0.5	0.5	1	0
16	0.219	0.781	0.9	0.1	0	1	0.958	0.042	0.205	0.795	0.5	0.5
17	0.057	0.943	0.273	0.727	0	1	0.824	0.176	0.195	0.805	0.529	0.471
18	0.024	0.976	0.048	0.952	0	1	0.75	0.25	0.022	0.978	0.2	0.8
19	0	1	0.043	0.957	0	1	0.25	0.75	0.08	0.92	0.048	0.952
20	0	1	0.143	0.857	0	1	0	1	0	1	0	1
21	0	1	0.5	0.5	0	1	0	1	0.111	0.889	0	1
22	0.045	0.955	0.167	0.833	0	1	0	1	0	1	0	1
23	0	1	0	1	0	1	0	1	0	1	0	1
24	0	1	0	1	0	1	0	1	0	1	0	1
25	0	1	0	1	0	1	0	1	0	1	0	1
26	0	1	0	1	0	1	0	1	0	1	0	1
27	0	1	0	1	0	1	0	1	0	1	0	1
28	0	1	0	1	0	1	0	1	0	1	0	1
29	0	1	0	1	0	1	0	1	0	1	0	1
30	0	1	0	1	0	1	0	1	0	1	0	1
31	0	1	0	1	0	1	0	1	0	1	0	1
32	0	1	0	1	0	1	0	1	0	1	0	1
33	0	1	0	1	0	1	0	1	0	1	0	1
34	0	1	0	1	0	1	0	1	0	1	0	1
35	0	1	0	1	0	1	0	1	0	1	0	1
36	0	1	0	1	0	1	0	1	0	1	0	1
37	0	1	0	1	0	1	0	1	0	1	0	1
38	0	1	0	1	0	1	0	1	0	1	0	1
39	0	1	0	1	0	1	0	1	0	1	0	1
40	0	1	0	1	0	1	0	1	0	1	0	1

Table 83. Age length key proportions from the NEAMAP Trawl Survey used to estimate age group specific index of relative abundance.

	2007		2008		2009		2010		2011	
LengthCM	FallAge-0	FallAge-1+	FallAge-0	FallAge-1+	FallAge-0	FallAge-1+	FallAge-0	FallAge-1+	FallAge-0	FallAge-1+
0	1	0	1	0	1	0	1	0	1	0
1	1	0	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0	1	0
3	1	0	1	0	1	0	1	0	1	0
4	1	0	1	0	1	0	1	0	1	0
5	1	0	1	0	1	0	1	0	1	0
6	1	0	1	0	1	0	1	0	1	0
7	1	0	1	0	1	0	1	0	1	0
8	1	0	1	0	1	0	1	0	1	0
9	1	0	1	0	1	0	1	0	1	0
10	1	0	1	0	1	0	1	0	1	0
11	1	0	1	0	1	0	1	0	1	0
12	1	0	1	0	1	0	1	0	1	0
13	1	0	1	0	1	0	1	0	1	0
14	1	0	0.95	0.05	1	0	0.933	0.067	0.75	0.25
15	1	0	1	0	1	0	0.86	0.14	0.818	0.182
16	0.952	0.048	0.981	0.019	0.917	0.083	0.907	0.093	0.7	0.3
17	0.947	0.053	1	0	0.5	0.5	0.742	0.258	0.2	0.8
18	0.879	0.121	0.96	0.04	0.308	0.692	0.941	0.059	0.347	0.653
19	0.88	0.12	1	0	0.125	0.875	1	0	0.417	0.583
20	0.5	0.5	0.667	0.333	0	1	0	1	0.267	0.733
21	1	0	0	1	0	1	1	0	0.125	0.875
22	0.5	0.5	0	1	0	1	0	1	0	1
23	0	1	0	1	0	1	0	1	0	1
24	0	1	0	1	0	1	0	1	0	1
25	0	1	0	1	0	1	0	1	0	1
26	0	1	0	1	0	1	0	1	0	1
27	0	1	0	1	0	1	0	1	0	1
28	0	1	0	1	0	1	0	1	0	1
29	0	1	0	1	0	1	0	1	0	1
30	0	1	0	1	0	1	0	1	0	1

Table 83. *Continued.* **Age length key proportions from the NEAMAP Trawl Survey used to estimate age group specific index of relative abundance.**

	2012		2013		2014		2015	
LengthCM	FallAge-0	FallAge-1+	FallAge-0	FallAge-1+	FallAge-0	FallAge-1+	FallAge-0	FallAge-1+
0	1	0	1	0	1	0	1	0
1	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0
3	1	0	1	0	1	0	1	0
4	1	0	1	0	1	0	1	0
5	1	0	1	0	1	0	1	0
6	1	0	1	0	1	0	1	0
7	1	0	1	0	1	0	1	0
8	1	0	1	0	1	0	1	0
9	1	0	1	0	1	0	1	0
10	1	0	1	0	1	0	1	0
11	1	0	1	0	1	0	1	0
12	1	0	1	0	1	0	1	0
13	1	0	1	0	1	0	1	0
14	1	0	1	0	1	0	1	0
15	1	0	1	0	1	0	1	0
16	1	0	0.865	0.135	1	0	0.955	0.045
17	1	0	0.792	0.208	0.88	0.12	1	0
18	1	0	0.636	0.364	0.909	0.091	1	0
19	1	0	0.583	0.417	1	0	1	0
20	1	0	0.143	0.857	0.8	0.2	1	0
21	1	0	0.071	0.929	0.375	0.625	1	0
22	1	0	0.071	0.929	0	1	0	1
23	1	0	0.125	0.875	0	1	0	1
24	0	1	0	1	0	1	0	1
25	0	1	0	1	0	1	0	1
26	0	1	0	1	0	1	0	1
27	0	1	0	1	0	1	0	1
28	0	1	0	1	0	1	0	1
29	0	1	0	1	0	1	0	1
30	0	1	0	1	0	1	0	1

Table 84. **Associations evaluated with Spearman's rho (ρ) between age-0 and age-1+ indices where the age-0 indices have been adjusted forward by one year. Significant p-values (<0.05) are bolded and highlighted in yellow.**

Age 0 Indices Forward Lagged 1 Year	Age 1+ Indices														
	NCDMF June Trawl			SEAMAP Fall Trawl			NMFS Fall Trawl			ChesMMAP Trawl			NEAMAP Trawl		
	ρ	p-value	n	ρ	p-value	n	ρ	p-value	n	ρ	p-value	n	ρ	p-value	n
NCDMF June Trawl	0.367	**0.04**	26	0.462	**0.01**	26	0.374	**0.03**	26	-0.016	0.53	13	0.238	0.29	8
SEAMAP Fall Trawl	0.595	**0.00**	26	0.141	0.25	26	0.521	**0.00**	26	0.011	0.49	13	0.357	0.19	8
NMFS Fall Trawl	0.314	0.06	26	0.342	0.05	26	0.564	**0.00**	26	-0.165	0.71	13	0.333	0.21	8
ChesMMAP Trawl	0.154	0.32	13	-0.357	0.88	13	-0.084	0.61	13	0.888	**0.00**	13	0.429	0.15	8
NEAMAP Trawl	0.357	0.22	8	0.107	0.42	8	0.000	0.52	8	0.786	**0.02**	8	0.857	**0.01**	8

Table 85. **Associations evaluated with Spearman's rho (ρ) between age-0 abundance indices for spot. Significant p-values (<0.05) are bolded and highlighted in yellow.**

Age 0 Indices	NCDMF June Trawl			SEAMAP Fall Trawl			NMFS Fall Trawl			ChesMMAP Trawl		
	ρ	p-value	n	ρ	p-value	n	ρ	p-value	n	ρ	p-value	n
SEAMAP Fall Trawl	0.466	**0.01**	26									
NMFS Fall Trawl	0.28	0.08	26	0.5904	**0.00**	26						
ChesMMAP Trawl	-0.291	0.84	13	-0.17	0.72	13	-0.154	0.70	13			
NEAMAP Trawl	0.5238	0.10	8	0.2619	0.27	8	0.4762	0.12	8	0.6667	**0.04**	8

Table 86. **Associations evaluated with Spearman's rho (ρ) between age-1+ abundance indices for spot. Significant p-values (<0.05) are bolded and highlighted in yellow.**

Age 1+ Indices	NCDMF June Trawl			SEAMAP Fall Trawl			NMFS Fall Trawl			ChesMMAP Trawl		
	ρ	p-value	n	ρ	p-value	n	ρ	p-value	n	ρ	p-value	n
SEAMAP Fall Trawl	0.1815	0.19	26									
NMFS Fall Trawl	0.3285	0.05	26	0.3716	0.03	26						
ChesMMAP Trawl	0.4341	0.07	13	-0.242	0.79	13	0.1044	0.37	13			
NEAMAP Trawl	0.381	0.18	8	-0.048	0.56	8	0.1905	0.33	8	0.5952	0.07	8

Table 87. Inputs for the spot base surplus production model calculated in ASPIC.

Parameter or Data Input	Value for Spot Base Model	Justification
Run mode	FIT & BOT	ASPIC fits the model and computes estimates of parameters, then runs bootstrapping program
Error type	LOGISTIC YLD SSE	Logistic (Schaefer) model, condition fitting on yield (recommended), sum of squared errors (recommended)
Verbosity	112	Recommended value
Number of bootstrap trials	700	Recommended value between 500-1000
Monte Carlo search enable	0 10000	Disabled as recommended by author
Convergence crit. for simplex	1.0d-8	Recommended value
Convergence crit. for restarts, N restarts	3.0d-8 6	Recommended value
Convergence crit. for estimating effort	1.0d-4	Recommended value
Maximum F allowed in estimating effort	8d0	Default value
Weighting for B1 > K as residual	0d0	0d0 for no penalty
Number of data series	2	NMFS (1), SEAMAP (1)
Statistical weights for data series	1d0 1d0	Equal weighting
B1/K (starting guess)	0.5	Reasonable default value
MSY (starting guess)	28644	1/2 the maximum catch of 57,287 metric tons
K (starting guess)	572870	10x the maximum catch of 57,287 metric tons
q (starting guess)	1.0d-4 5.4d-5	One for each index as the mean CPUE/(2*Max catch)
Estimate flags	1 1 1 1 1	One for each B/K, MSY, K, q1, q2
Bounds (min and max) on MSY	3.6d3 2.3d5	1/8x and 8x the starting guess of MSY (2.9d4)
Bounds (min and max) on K	7.2d4 4.6d6	1/8x and 8x the starting guess of K (5.7d5)
Random number seed	1952385	
Number of years of data	26	1989-2014; Availability of shrimp discards using SEAMAP (first year = 1989) and Mid-Atlantic discards using observer data (first year = 1989). Only one regional survey being considered that starts earlier than 1989 (NMFS).

Table 88. General definitions and inputs (assumed fixed values and data) of the modified-CSA model for spot.

General Definitions	**Symbol**	**Description/Definition**
Year index	y	1989-2014
Stage index	a	Stage 1 (recruits) = Age-0; Stage 2 (post-recruits) = Age-1+
Total years in model	k_m	26
Total years for each survey	$k_{I,a}$	NC DMF Trawl = 26, NMFS Trawl = 26
Total years of removal data	k_R	26
Inputs	**Symbol**	**Description/Definition**
Observed index of abundance	$I_{a,y}$	Based on catch rates of age-0 and age-1+ fish from the NC DMF Trawl and NMFS Trawl surveys
Observed fishery removals	R_y	Removals in numbers for each year
Observed average total mortality of post-recruits	Z_{prior}	Average catch curve estimates from 1996-2013 (1.356)
Stage-specific natural mortality	M_a	Fixed based on estimates from a Lorenzen curve ($M_{recruits}$=0.542, $M_{post-recruits}$=0.396)
Fishery selectivity	s_a	Fixed based on external analysis of length frequency data ($s_{recruits}$=0.43, $s_{post\text{-}recruits}$=1)
Probability of spawning	ρ_a	Fixed based on logistic regression for recruits and literature estimates for post-recruits ($\rho_{recruits}$=0.215, ρ_{adults}=1)
Stage-specific average weight (kg)	$\overline{wt}_a$	Fixed based on fall weight-at-age from the NEAMAP Trawl survey ($\overline{wt}_{recruits}$=0.0801, $\overline{wt}_{post-recruits}$=0.1324)
Spawn time	κ	Fixed at 1.0 to coincide with spawning at the end of the year (i.e., December 31)
Survey time	τ_a	Proportion of year passed when survey occurs, fixed based on middle of sampling period (NC DMF Trawl=0.46, NMFS Trawl=0.75)
Population proportion female	ω	Fixed at 0.5 (i.e., female:male sex ratio = 1)
Steepness prior	h_{prior}	Mean estimate from meta-analysis (0.64)
Standard deviation for h	σ_h	Estimate from meta-analysis (0.20)
Coefficient of variation for $I_{a,y}$	$cv_{I,a,y}$	Based on annual estimates from observations on the NC DMF Trawl and NMFS Trawl surveys plus any adjustments for process error
Coefficient of variation for R_y	$cv_{R,y}$	Fixed at 0.05
Coefficient of variation for r_y	cv_r	Fixed at 0.66
Coefficient of variation for Z	cv_Z	Fixed at 0.05

Table 89. Population model equations of the modified-CSA model for spot. Estimated parameters are denoted using hat (^) notation, and predicted values are denoted using breve (˘) notation.

Population Model	Symbol	Description/Definition
Fishing mortality	$F_{a,y}$	$\hat{F}_{1989}$ is estimated for the intial year $F_{a,1989} = s_a\hat{F}_{1989}$; $F_{a,y} = s_a\hat{F}_{1989}e^{\hat{\delta}_{F,y}}$; $\hat{\delta}_{F,y}$ are year specific deviations for all years after the initial year $F_{a,2014} = e^{\left(\left(log\left(F_{a,2012}\right) + log\left(F_{a,2013}\right)\right)/2\right)}$ $F_{a,2014}$ equal to geometric mean of previous two years, as there are no index data from 2015 to tune the $F_{a,2014}$ estimates
Total mortality	$Z_{a,y}$	$Z_{a,y} = M_a + F_{a,y}$
Stage 1 abundance	$N_{0,y}$	$N_{0,1989} = \hat{N}_{0,1989}$ is estimated for the initial year Beverton-Holt SR relationship assumed for subsequent years; $N_{0,y+1} = \frac{SSB_y}{SSB_y\beta+\alpha}e^{\hat{\delta}_{r,y+1}-0.5\sigma_r^2}$; $\hat{\delta}_{r,y+1} \sim N(0,\sigma_r^2)$; $\alpha = \frac{\widehat{SSB}_0(1-\hat{h})}{4\hat{h}r_0}$; $\beta = \frac{5\hat{h}-1}{4\hat{h}r_0}$; $r_0 = \frac{\widehat{SSB}_0}{SSBr_0}$; $SSBr_0 = \omega\rho_0\overline{wt}_{0,0}e^{-\kappa M_0} + \omega\rho_1\frac{e^{-(M_0+\kappa M_1)}}{1-e^{-M_1}}$; $\sigma_r = \sqrt{\log(1 + cv_r^2)}$; $\widehat{SSB}_0$ is the unfished SSB, r_0 is the unfished recruitment, σ_r is the standard deviation of lognormal recruitment deviations
Stage 2 abundance	$N_{1,y}$	$N_{1,1989} = \hat{N}_{1,1989}$ is estimated for the initial year $N_{1,y+1} = \sum_{a=0}^{1} N_{a,y}e^{-(M_a+F_{a,y})}$
Female spawning stock biomass	SSB_y	$SSB_y = \sum_{a=0}^{1} \omega\rho_a\overline{wt}_a N_{a,y}e^{-\kappa(M_a+F_{a,y})}$
Predicted catch-at-stage	$\breve{C}_{a,y}$	$\breve{C}_{a,y} = \frac{F_{a,y}}{Z_{a,y}}N_{a,y}[1 - e^{-Z_{a,y}}]$
Predicted removals	$\breve{R}_y$	$\breve{R}_y = \sum_{a=0}^{1} \breve{C}_{a,y}$
Predicted stage 1 index of abundance	$\breve{I}_{0,y}$	$\breve{I}_{0,y} = q_0(N_{0,y}e^{-\tau_0(M_0+F_{0,y})})$; $\log(q_0) = \frac{\sum_y \log(\breve{I}_{0,y}) - \log(N_{0,y})}{k_{I,0}}$; q_0 is the catchability coefficient for stage 1 fish

Predicted stage 2 index of abundance	$\breve{\mathrm{I}}_{1,y}$	$\breve{\mathrm{I}}_{1,y} = \mathrm{q}_1(N_{1,y}e^{-\tau_1(M_1+F_{1,y})})$; $\log(\mathrm{q}_1) = \frac{\sum_{\mathrm{y}} \log(\breve{\mathrm{I}}_{1,y}) - \log(N_{1,y})}{\mathrm{k}_{\mathrm{I},1}}$; q_1 is the catchability coefficient for stage 2 fish

Table 90. Likelihood components of the modified-CSA model for spot. Predicted values are denoted using breve (˘) notation.

Negative Log-Likelihood	Symbol	Description/Definition
Lognormal indices	$\Lambda_{I,a}$	$\Lambda_{I,a} = \lambda_{I,a} \sum_{y} [0.5 \log(2pi) + 0.5 \log(\sigma_{I,a,y}^2) + \log(\mathrm{I}_{a,y}) + \frac{[\log(\mathrm{I}_{a,y} + \chi) - \log(\breve{\mathrm{I}}_{a,y} + \chi)]^2}{2\sigma_{I,a,y}^2}]$; $\sigma_{I,a,y} = \sqrt{\log(1 + cv_{I,a,y}^2)}$; $\lambda_{I,a}$ is a preset weight factor set to 1.0 χ is fixed at a small value (0.000001) for numerical stability
Lognormal removals	Λ_R	$\Lambda_R = \lambda_R \sum_{y} [0.5 \log(2pi) + 0.5 \log(\sigma_{R,y}^2) + \log(\mathrm{R}_y) + \frac{[\log(\mathrm{R}_y + \chi) - \log(\breve{\mathrm{R}}_y + \chi)]^2}{2\sigma_{R,y}^2}]$; $\sigma_{R,y} = \sqrt{\log(1 + cv_{R,y}^2)}$; λ_L is a preset weight factor set to 1.0 χ is fixed at a small value (0.000001) for numerical stability
Lognormal recruitment deviations	Λ_r	$\Lambda_r = \lambda_r \sum_{y} [0.5 \log(2pi) + 0.5 \log(\sigma_r^2) + \log(\hat{\delta}_{r,y}) + \frac{\log(\hat{\delta}_{r,y})^2}{2\sigma_r^2}]$; $\sigma_r = \sqrt{\log(1 + cv_r^2)}$; λ_r is a preset weight factor set to 1.0

Prior distribution for h	Λ_h	$\Lambda_h = \lambda_h\big[(1-Bprior) * \log\big(\chi + h_{prior} - h\_lb\big) + (1-Aprior) * \log\big(\chi + h\_ub - h_{prior}\big) - (1-Bprior) * \log\big(\chi + \hat{h} - h\_lb\big) - (1-Aprior) * \log\big(\chi + h\_ub - \hat{h}\big)\big];$ $Bprior = \tau * \mu;$ $Aprior = \tau * (1.0-\mu);$ h_lb is the lower bound on the steepness parameter estimate (0.00001) h_ub is the upper bound on the steepness parameter estimate (0.99999) χ is fixed at a small value (0.0001) for numerical stability $\mu = \dfrac{\hat{h} - h\_lb}{h\_ub - h\_lb};$ $\tau = \dfrac{\big(\hat{h} - h\_lb\big) * \big(h\_ub - \hat{h}\big)}{{\sigma_h}^2} - 1;$ λ_h is a preset weight factor set to 1.0

Table 90 ***Continued.*** **Likelihood components of the modified-CSA model for spot. Predicted values are denoted using breve (˘) notation.**

Prior distribution for Z	Λ_Z	$\Lambda_Z = \lambda_Z \left[0.5\log(2pi) + 0.5\log(\sigma_Z^2) + \log\left(Z_{prior}\right) + \frac{\left[\log\left(Z_{prior}\right) - \log\left(\overline{Z_{1,1996-2013}}\right)\right]^2}{2\sigma_Z^2} \right];$ $\sigma_Z = \sqrt{\log(1 + cv_Z^2)};$ $\overline{Z_{1,1996-2013}}$ is the mean post-recruit Z from 1996-2013 λ_Z is a preset weight factor set to 1.0

Table 91. Reference point calculations for the modified-CSA model for spot.

Reference Point Components	Symbol	Description/Definition
Fishing rate value: F={0, ….6}	F	F is incremented from 0.0 to 6.0 by 0.01, and the reference point calculations are performed at each F value. All final MSY-based reference points are set at the F that maximizes equilibrium removals (Req), while the spawning potential ratio F targets (F_{SPR}) are each set at the F that produces the SPR closest to an input set of targets (SPR={0.2,0.3,0.4})
Projection year for SSB_{SPR} calculations	py	1-100
Unfished female spawning stock biomass per recruit	$SSBr_0$	$SSBr_0 = \omega\rho_0\overline{wt}_0 e^{-\kappa M_0} + \omega\rho_1\overline{wt}_1 \frac{e^{-(M_0+\kappa M_1)}}{1-e^{-M_1}}$
Fished female spawning stock biomass per recruit	$SSBr$	$SSBr = \omega\rho_0\overline{wt}_0 e^{-\kappa(M_0+s_0\mathrm{F})} + \omega\rho_1\overline{wt}_1 \frac{e^{-(M_0+s_0\mathrm{F}+\kappa M_1+\kappa s_1\mathrm{F})}}{1-e^{-\kappa(M_1+s_1\mathrm{F})}}$
Number per recruit	Nr	$Nr = \frac{e^{-(M_0+s_0\mathrm{F})}}{1-e^{-\kappa(M_1+s_1\mathrm{F})}}$
Yield per recruit	Yr	$Yr = \frac{s_0\mathrm{F}}{M_0+s_0\mathrm{F}}\left[1-e^{-(M_0+s_0\mathrm{F})}\right]\overline{wt}_0 + \frac{s_1\mathrm{F}}{M_1+s_1\mathrm{F}}\left[1-e^{-(M_1+s_1\mathrm{F})}\right]\overline{wt}_1$
Equilibrium recruitment	req	$req = \frac{SSBr-\alpha}{\beta SSBr}$ Beverton-Holt SR relationship
Equilibrium number	Neq	$Neq = Nr * req$
Equilibrium female spawning stock biomass	SSB_{eq}	$SSB_{eq} = SSBr * req$
Equilibrium removals	Req	$Req = Yr * req$
Equilibrium exploitation rate	Ueq	$Ueq = \frac{Req}{Neq\overline{wt}_1 + req\overline{wt}_0 \frac{1-e^{-s_0\mathrm{F}}}{1-e^{-s_1\mathrm{F}}}}$
Maximum sustainable yield	MSY	$MSY = \max(Req)$ across all F values
Number at MSY	N_{MSY}	Neq at MSY
Female spawning stock biomass at MSY	SSB_{MSY}	$SSBeq$ at MSY
Fishing rate at MSY	F_{MSY}	F at MSY
Exploitation rate at MSY	u_{MSY}	Ueq at MSY
Static spawning potential ratio	$sSPR$	$sSPR = \frac{SSBr}{SSBr_0}$
Equilibrium female spawning stock biomass at reference SPR	SSB_{SPR}	$SSB_{py} = \omega\rho_0\overline{wt}_0 N_{0,py} e^{-\kappa(M_0+s_0F_{SPR})} + \omega\rho_1\overline{wt}_1 N_{1,py} e^{-\kappa(M_1+s_1F_{SPR})}$; $N_{0,py}$ is randomly selected from model $N_{0,y}$ estimates during a specified reference period $N_{1,py} = N_{0,py-1} e^{-(M_0+s_0F_{SPR})}$; $SSB_{SPR} = median(SSB_{py2}, \ldots\ldots SSB_{py100})$;

Table 92. Spot stage-specific mean weights by data source.

Data Source	Age Range	Age-0 n	Age-0 Ave wt (kg)	Age-0 sd	Age 1+ n	Ages 1+ Ave wt (kg)	Age 1+ sd
NEAMAP	0-3	1,122	0.0801	0.0298	264	0.1324	0.0524
ChesMMAP	0-4	3,129	0.0628	0.0331	1,025	0.1553	0.0701
SEAMAP	0-2	165	0.0580	0.0240	74	0.1191	0.0467
MD DNR Commercial	0-2	14	0.0598	0.0130	50	0.1804	0.0321
VMRC Commercial	1-4	0			1,344	0.2889	0.1062
NCDMF Commercial	0-4	292	0.0733	0.0311	1,011	0.1829	0.0948

Table 93. Test for significant differences (p<0.05) with analysis of variance (ANOVA) among annual spot mean weights within stage by data source.

Data Source	Age Group	Significant Difference between Years?
SEAMAP	0	Only one year of data
SEAMAP	1+	Only one year of data
ChesMMAP	0	Yes, p=0.016
ChesMMAP	1+	Yes, p=0.002
NEAMAP	0	No, p=0.994
NEAMAP	1+	No, p=0.374
NC DMF Commercial	0	No, p=0.862
NC DMF Commercial	1+	No, p=0.970
MD DNR Commercial	0	Yes, p=0.028
MD DNR Commercial	1+	No, p=0.119
VMRC Commercial	1+	No, p=0.544

Table 94. **CVs for spot indices of abundance used in the modified-CSA model calculated from variance in catch rates (original; observation error) and adjusted according to the methods of Francis (2003) to acknowledge process error (adjusted).**

Year	NC DMF Trawl Recruits		NMFS Trawl Recruits		NC DMF Trawl Post-Recruits		NMFS Trawl Post-Recruits	
	Original	Adjusted	Original	Adjusted	Original	Adjusted	Original	Adjusted
1989	0.1455	0.2473	0.0664	0.2107	0.1757	0.2662	0.0664	0.2107
1990	0.1159	0.2312	0.0553	0.2075	0.222	0.2988	0.0553	0.2075
1991	0.1561	0.2537	0.2101	0.2901	0.1032	0.2251	0.2101	0.2901
1992	0.2103	0.2902	0.1228	0.2347	0.1408	0.2446	0.1228	0.2347
1993	0.1474	0.2484	0.1661	0.26	0.0978	0.2226	0.1661	0.26
1994	0.1689	0.2618	0.1197	0.2331	0.1227	0.2346	0.1197	0.2331
1995	0.2106	0.2904	0.0592	0.2086	0.1334	0.2404	0.0592	0.2086
1996	0.1216	0.2341	0.1165	0.2315	0.1673	0.2607	0.1165	0.2315
1997	0.1613	0.2569	0.1019	0.2245	0.1433	0.246	0.1019	0.2245
1998	0.2354	0.3089	0.1065	0.2266	0.2664	0.3331	0.1065	0.2266
1999	0.2152	0.2938	0.0363	0.2033	0.1639	0.2586	0.0363	0.2033
2000	0.196	0.28	0.073	0.2129	0.2053	0.2866	0.073	0.2129
2001	0.2223	0.299	0.311	0.3698	0.1573	0.2544	0.311	0.3698
2002	0.1318	0.2395	0.1152	0.2308	0.1953	0.2795	0.1152	0.2308
2003	0.1601	0.2562	0.0666	0.2108	0.1671	0.2606	0.0666	0.2108
2004	0.244	0.3155	0.062	0.2094	0.2671	0.3337	0.062	0.2094
2005	0.1601	0.2562	0.0538	0.2071	0.2895	0.3519	0.0538	0.2071
2006	0.1928	0.2778	0.0421	0.2044	0.1248	0.2357	0.0421	0.2044
2007	0.2424	0.3143	0.1104	0.2284	0.1939	0.2786	0.1104	0.2284
2008	0.2301	0.3049	0.0487	0.2058	0.319	0.3765	0.0487	0.2058
2009	0.1822	0.2705	0.0333	0.2028	0.2073	0.2881	0.0333	0.2028
2010	0.1895	0.2755	0.0368	0.2034	0.1417	0.2451	0.0368	0.2034
2011	0.1477	0.2486	0.0374	0.2035	0.1432	0.246	0.0374	0.2035
2012	0.1047	0.2257	0.0263	0.2017	0.2175	0.2955	0.0263	0.2017
2013	0.1697	0.2623	0.0452	0.205	0.2086	0.289	0.0452	0.205
2014	0.1437	0.2463	0.0697	0.2118	0.1873	0.274	0.0697	0.2118

Table 95. Description of sensitivity configurations for the sensitivity analysis of the spot modified-CSA model.

Name	Description
1992 start year	Started the model time series in 1992 to remove relatively large shrimp trawl discard estimates prior to this year.
adjust shrimp discards	Changed the relatively large shrimp trawl discard estimates in 1990 and 1991 to the median value of surrounding, pre-BRD estimates (1989, 1992-1996; 259 million fish).
10% shrimp discards	Scaled the shrimp trawl discard estimates for the entire time series down to 10% of the base model estimates. This configuration can represent two scenarios; the base estimates are overestimated by an order of magnitude and the discard mortlaity rate is unchanged from the base model (100%) or the base model estimates are accurate and the discard mortality rate is 10%.
50% shrimp discards	Scaled the shrimp trawl discard estimates for the entire time series down to 50% of the base model estimates. This configuration can represent two scenarios; the base estimates are twice the true values and the discard mortlaity rate is unchanged from the base model (100%) or the base model estimates are accurate and the discard mortality rate is 50%.
low selectivity	The base model estimates recruit selectivity at 0.306. This is lower than the assumed value in the base model (0.43).
high selectivity	The high selectivity value (0.645) is between the value in the base model (0.43) and the value if we did not assume recruits are not vulnerable to capture for the first half of the year (0.86). The SAS does not consider selectivity values greater than 0.645 as plausible values.
low M	M-at-stage vector calculated from weight-at-age using the upper 95% confidence interval values of the growth parameters Linf, K, and t0. This results in M-at-stage (recruits=0.537, post-recruits=0.389) less than the base model M-at-stage (recruits=0.542, post-recruits=0.396).
high M	M-at-stage vector calculated from weight-at-age using the upper 95% confidence interval values of the growth parameters Linf, K, and t0. This results in M-at-stage (recruits=0.550, post-recruits=0.405) greater than the base model M-at-stage (recruits=0.542, post-recruits=0.396).
FD Z prior	Total mortality prior calculated from only FD data as opposed to FD and FI data (Appendix 8). This value (1.157) is lower than the base model prior value (1.356).
wt comb Z prior	Total mortality prior calculated from FD and FI data using a weighted catch curve (Appendix 8). This value (1.613) is greater than the base model prior value (1.356).
no reweight	Use the original CVs provided with indices. Do not allow for process error due to interannual variability in catchability.
no NMFS trawl	Exclude the NNMFS Trawl Survey indices for recruits and post-recruits.
no NCDMF trawl	Exclude the NCDMF Trawl Survey indices for recruits and post-recruits.
add NEAMAP trawl	Include the NEAMAP Trawl Survey indices for recruits and post-recruits. The reason for excluding these indices from the base model was the short time series realtive to the NMFS Trawl Survey indices.
change in NMFS recruit q 2005	Allowed for time-varying catchability (1989-2004=q1, 2005-2014=q2) in the NMFS Trawl Survey recruit index to address the residual trend after 2005. 2005 was selected based on visual evaluation of the resdiual trend.
change in NMFS recruit q in 2009	Allowed for time-varying catchability (1989-2008=q1, 2009-2014=q2) in the NMFS Trawl Survey recruit index to address the residual trend after 2005. 2009 was selected based on the change of vessel conducting the survey.
h = 0.99	Steepness fixed at 0.99 to specify an uninformative stock-recruit relationship (i.e., recruitment deviates around a time series mean).
h = 0.79	Steepness fixed at 0.79, the mode steepness value from the steepness prior analysis (Appendix 9).
NCDMF comm mean wts	Mean weight-at-stage developed from the fall NC DMF commercial catch sampling (recruits=0.0733 kg, post-recruits=0.1829 kg). There are no significant differences among annual mean weight-at-stage from these data and the SEAMAP Trawl Survey only collected one year of age data.
sex ratio	Proportion females = 0.62 (value from combined FI data). Sex ratio only affects stock-recruit parameters and spanwing stock biomass estimates, so results from this configuration are only included on the spawning stock biomass figure.

Table 96. Population parameter estimates from the base spot surplus production model.

Year	Estimated Total F	Estimated Starting Biomass	Estimated Average Biomass	Observed Total Yield	Model Total Yield	Estimated Surplus Production	Estimated F to F_{MSY}	Estimated B to B_{MSY}
1989	0.6180	57400	54370	33600	33600	28050	1.2740	0.9876
1990	0.4760	51850	53250	25360	25360	27980	0.9822	0.8921
1991	1.7290	54470	33130	57290	57290	22160	3.5650	0.9372
1992	0.9220	19340	18340	16900	16900	14980	1.9000	0.3328
1993	0.6260	17420	19170	12000	12000	15520	1.2910	0.2997
1994	0.9600	20940	19390	18610	18610	15670	1.9790	0.3602
1995	1.4830	18000	13310	19740	19740	11390	3.0570	0.3096
1996	0.8160	9644	9998	8157	8157	8863	1.6820	0.1659
1997	1.0220	10350	9682	9899	9899	8608	2.1080	0.1781
1998	1.0800	9059	8286	8947	8947	7463	2.2260	0.1559
1999	0.6970	7575	8408	5860	5860	7564	1.4370	0.1303
2000	0.6880	9279	10270	7066	7066	9075	1.4190	0.1596
2001	0.7990	11290	11720	9366	9366	10220	1.6480	0.1942
2002	0.4440	12140	14990	6663	6663	12640	0.9163	0.2089
2003	0.4780	18120	21380	10220	10220	16890	0.9856	0.3118
2004	0.2620	24800	31540	8248	8248	22160	0.5392	0.4266
2005	0.1280	38700	49130	6266	6266	27210	0.2629	0.6659
2006	0.1240	59640	69290	8559	8559	26910	0.2547	1.0260
2007	0.0880	78000	85720	7521	7521	21690	0.1809	1.3420
2008	0.0700	92160	97030	6797	6797	15500	0.1444	1.5860
2009	0.0710	100900	103100	7328	7328	11280	0.1465	1.7360
2010	0.0430	104800	106900	4637	4637	8308	0.0894	1.8040
2011	0.0850	108500	107700	9134	9134	7699	0.1749	1.8670
2012	0.0770	107100	107100	8212	8212	8205	0.1582	1.8420
2013	0.0610	107100	107700	6551	6551	7676	0.1254	1.8420
2014	0.0880	108200	107300	9492	9492	7991	0.1824	1.8610

Table 97. **Parameter estimates from the base and sensitivity runs for the spot surplus production model. The base model included relative biomass indices from the SEAMAP Trawl and NMFS Trawl Surveys and the complete harvest data.**

	Base Model 1989-2014	Abbreviated Model 1992-2014	Adding NEAMAP	Fox (n=1)	Pella-Tomlinson (n=2.35)	NMFS only	Excel
MSY	28,190	19,930	30,360	17,240	29,360	33,390	21,070
B_{MSY}	58,120	30,430	59,070	40,210	57,400	67,470	86,171
F_{MSY}	0.485	0.655	0.514	0.429	0.5115	0.495	0.445

Table 98. **Measures of model fit from the base modified-CSA model for spot.**

Likelihood Component	Negative Log-likelihood	Standardized Residual Mean	Standardized Residual sd	Sum of Squared Standardized Residuals	t-test p-value	Shapiro-Wilk p-value	Runs p-value
NC DMF Post-Recruits	161.83	0.165	3.75	352.78	0.412	0.075	0.005
NMFS Post Recruits	177.34	0.332	4.14	430.85	0.343	0.038	0.423
NC DMF Recruits	128.35	-0.003	3.45	298.01	0.498	0.107	1.000
NMFS Recruits	351.98	0.624	5.57	786.65	0.287	0.081	0.016
Removals	106.25	0.000	1.48	54.61	0.500	0.002	0.005
Total Mortality Prior	1.29	NA	NA	NA	NA	NA	NA
Steepness Prior	2.35	NA	NA	NA	NA	NA	NA
Recruitment Deviations	27.06	-0.301	1.18	35.86	0.108	0.331	0.545
Total	**956.46**	**NA**	**NA**	**1,958.77**	**NA**	**NA**	**NA**

Table 99. Parameter estimates from the base modified-CSA model for spot.

Parameter	Estimate	SE	Parameter	Estimate	SE
log(initial post-recruit N)	6.483	0.14	log(1990 R deviation)	1.313	0.11
log(initial recruit N)	6.818	0.12	log(1991 R deviation)	1.356	0.09
log(initial F)	0.064	0.11	log(1992 R deviation)	-0.583	0.15
log(1990 F deviation)	0.656	0.11	log(1993 R deviation)	0.394	0.15
log(1991 F deviation)	1.268	0.10	log(1994 R deviation)	1.274	0.09
log(1992 F deviation)	0.962	0.10	log(1995 R deviation)	-0.229	0.17
log(1993 F deviation)	0.521	0.12	log(1996 R deviation)	-0.537	0.09
log(1994 F deviation)	-0.210	0.11	log(1997 R deviation)	-1.164	0.14
log(1995 F deviation)	0.772	0.10	log(1998 R deviation)	-0.689	0.11
log(1996 F deviation)	0.454	0.11	log(1999 R deviation)	-0.010	0.09
log(1997 F deviation)	-0.615	0.13	log(2000 R deviation)	-1.071	0.12
log(1998 F deviation)	0.029	0.12	log(2001 R deviation)	-0.811	0.11
log(1999 F deviation)	-0.518	0.11	log(2002 R deviation)	0.793	0.39
log(2000 F deviation)	-0.321	0.12	log(2003 R deviation)	-0.109	0.11
log(2001 F deviation)	1.344	0.11	log(2004 R deviation)	0.103	0.11
log(2002 F deviation)	-0.467	0.12	log(2005 R deviation)	0.209	0.11
log(2003 F deviation)	0.212	0.11	log(2006 R deviation)	-0.598	0.13
log(2004 F deviation)	-0.756	0.12	log(2007 R deviation)	-0.616	0.14
log(2005 F deviation)	-1.058	0.11	log(2008 R deviation)	0.107	0.12
log(2006 F deviation)	-0.761	0.12	log(2009 R deviation)	-0.218	0.13
log(2007 F deviation)	-1.117	0.13	log(2010 R deviation)	0.538	0.11
log(2008 F deviation)	-1.159	0.12	log(2011 R deviation)	0.294	0.12
log(2009 F deviation)	-1.118	0.13	log(2012 R deviation)	0.412	0.12
log(2010 F deviation)	-1.627	0.12	log(2013 R deviation)	0.394	0.14
log(2011 F deviation)	-0.762	0.12	log(2014 R deviation)	-0.553	0.18
log(2012 F deviation)	-1.542	0.13	log(unfished SSB)	10.494	0.08
log(2013 F deviation)	-1.371	0.13	log(steepness)	-0.018	0.02

Table 100. **Abundance and end-year spawning stock biomass estimates from the base modified-CSA model for spot. CVs are derived from asymptotic standard errors.**

Year	Recruitment (millions of fish)		Post Recruitment (millions of fish)		Spawning Stock Biomass (metric tons)	
	Estimate	CV	Estimate	CV	Estimate	CV
1989	914	0.12	654	0.14	12,929	0.18
1990	1,317	0.09	488	0.13	5,510	0.18
1991	1,352	0.07	359	0.14	1,689	0.14
1992	182	0.14	160	0.12	712	0.20
1993	431	0.08	39	0.15	1,282	0.16
1994	1,135	0.07	120	0.15	6,175	0.10
1995	278	0.15	489	0.09	2,689	0.19
1996	197	0.09	93	0.12	1,253	0.18
1997	99	0.14	67	0.13	2,076	0.18
1998	167	0.11	70	0.15	1,568	0.18
1999	321	0.08	76	0.14	3,025	0.12
2000	117	0.12	169	0.09	3,898	0.15
2001	153	0.09	101	0.11	208	0.21
2002	439	0.09	17	0.16	2,026	0.11
2003	297	0.11	197	0.11	3,197	0.18
2004	378	0.12	134	0.14	5,137	0.15
2005	429	0.11	232	0.13	8,969	0.14
2006	194	0.14	321	0.11	9,463	0.16
2007	191	0.15	222	0.14	7,804	0.17
2008	391	0.12	201	0.14	8,102	0.16
2009	283	0.13	294	0.13	10,459	0.16
2010	605	0.12	281	0.14	12,932	0.14
2011	476	0.12	475	0.12	14,792	0.17
2012	536	0.13	418	0.14	17,251	0.16
2013	528	0.14	507	0.14	19,567	0.17
2014	205	0.17	533	0.15	19,032	0.18

Table 101. **Full fishing mortality and static spawning potential ratio estimates from the base modified-CSA model for spot. Terminal year (2014) fishing mortality is the geometric mean of the previous two years (2012-2013) and terminal year static spawning potential ratio is calculated from the terminal year fishing mortality estimate. CVs are derived from asymptotic standard errors.**

Year	**Full Fishing Mortality**		**Static Spawning Potential Ratio**	
	Estimate	CV	Estimate	CV
1989	1.07	0.11	0.12	0.16
1990	2.06	0.09	0.04	0.17
1991	3.79	0.06	0.01	0.12
1992	2.79	0.08	0.02	0.16
1993	1.80	0.11	0.05	0.19
1994	0.86	0.08	0.17	0.10
1995	2.31	0.08	0.03	0.15
1996	1.68	0.10	0.06	0.16
1997	0.58	0.13	0.26	0.14
1998	1.10	0.11	0.12	0.16
1999	0.64	0.09	0.24	0.10
2000	0.77	0.10	0.19	0.12
2001	4.09	0.08	0.01	0.16
2002	0.67	0.10	0.23	0.11
2003	1.32	0.10	0.09	0.16
2004	0.50	0.12	0.30	0.11
2005	0.37	0.11	0.39	0.09
2006	0.50	0.13	0.30	0.12
2007	0.35	0.14	0.41	0.10
2008	0.33	0.13	0.42	0.10
2009	0.35	0.14	0.41	0.10
2010	0.21	0.13	0.56	0.06
2011	0.50	0.13	0.30	0.12
2012	0.23	0.14	0.53	0.08
2013	0.27	0.15	0.48	0.09
2014	0.25	0.15	0.51	0.08

Table 102. **Full fishing mortality reference point estimates for static spawning potential ratio reference levels (i.e., 20-40% SPR) from the base modified-CSA model for spot.**

Fishing Mortality Reference Point	Estimate
F20%	0.74
F30%	0.5
F40%	0.36

Table 103. Full fishing mortality reference point estimates for static spawning potential ratio reference levels (i.e., 20-40%) from the base modified-CSA model for spot and all sensitivity configurations.

Model Configuration	F20%	F30%	F40%
base	0.74	0.5	0.36
1992 start year	0.74	0.5	0.36
adjust shrimp discards	0.74	0.5	0.36
10% shrimp discards	0.74	0.5	0.36
50% shrimp discards	0.74	0.5	0.36
low selectivity	0.81	0.54	0.38
high selectivity	0.65	0.45	0.32
low M	0.73	0.5	0.35
high M	0.75	0.51	0.36
FD Z prior	0.74	0.5	0.36
wt comb Z prior	0.74	0.5	0.36
no reweight	0.74	0.5	0.36
no NMFS trawl	0.74	0.5	0.36
no NCDMF trawl	0.74	0.5	0.36
add NEAMAP trawl	0.74	0.5	0.36
change in NMFS recruit q 2005	0.74	0.5	0.36
change in NMFS recruit q in 2009	0.74	0.5	0.36
h = 0.99	0.74	0.5	0.36
h = 0.79	0.74	0.5	0.36
NCDMF comm mean wts	0.71	0.49	0.35
sex ratio	0.74	0.5	0.36

Table 104. Modified Mohn's Rhos (Hurtado-Ferro et al. 2015) for retrospective analysis (5 year peel) of the modified-CSA model for spot. Full fishing mortality and static spawning potential ratio are estimated from the geometric mean full fishing mortality over the two years prior to the terminal year, so calculation are presented for final year estimate (2013) and terminal year derived estimate (2014) for these quantities.

Calculation Year	Recruitment	Spawning Stock Biomass	Full Fishing Mortality	Static Spawning Potential Ratio
Final Year Estimate	0.6029	0.2980	-0.2241	0.2489
Terminal Year Estimate	0.6029	0.2980	-0.0907	0.0964

Table 105. Steepness estimates from retrospective analysis of the base modified-CSA model for spot.

Model Terminal Year	2014	2013	2012	2011	2010	2009
Steepness	0.982	0.977	0.981	0.983	0.982	0.984

Table 106. Randomly sampled recruitment for threshold spawning stock biomass estimate. Recruitment was sampled from model estimated recruitments from 1996-2014.

Projection Year	Recruitment (millions of fish)	Projection Year	Recruitment (millions of fish)	Projection Year	Recruitment (millions of fish)	Projection Year	Recruitment (millions of fish)
1	153	26	378	51	476	76	205
2	99	27	99	52	528	77	297
3	378	28	528	53	476	78	528
4	283	29	536	54	429	79	194
5	191	30	429	55	117	80	191
6	528	31	605	56	321	81	99
7	321	32	429	57	528	82	605
8	321	33	153	58	99	83	429
9	536	34	197	59	476	84	283
10	153	35	297	60	321	85	153
11	476	36	117	61	167	86	194
12	117	37	99	62	99	87	283
13	194	38	439	63	99	88	378
14	191	39	297	64	167	89	297
15	117	40	297	65	476	90	191
16	391	41	283	66	205	91	605
17	429	42	283	67	205	92	153
18	117	43	476	68	476	93	205
19	99	44	283	69	605	94	197
20	197	45	99	70	391	95	194
21	205	46	197	71	283	96	528
22	391	47	153	72	429	97	117
23	191	48	167	73	439	98	536
24	283	49	536	74	391	99	605
25	117	50	117	75	391	100	194

Table 107. **Randomly sampled recruitment for target spawning stock biomass estimate. Recruitment was sampled from model estimated recruitments from 2003-2014.**

Projection Year	Recruitment (millions of fish)	Projection Year	Recruitment (millions of fish)	Projection Year	Recruitment (millions of fish)	Projection Year	Recruitment (millions of fish)
1	194	26	391	51	536	76	205
2	297	27	297	52	205	77	191
3	391	28	205	53	536	78	205
4	476	29	528	54	391	79	283
5	605	30	283	55	429	80	605
6	205	31	536	56	429	81	297
7	429	32	391	57	205	82	536
8	429	33	194	58	297	83	391
9	528	34	297	59	536	84	476
10	194	35	191	60	429	85	194
11	528	36	429	61	378	86	283
12	429	37	297	62	297	87	476
13	283	38	191	63	297	88	391
14	605	39	191	64	378	89	191
15	429	40	191	65	536	90	605
16	605	41	476	66	205	91	476
17	283	42	476	67	205	92	194
18	429	43	536	68	536	93	205
19	378	44	476	69	536	94	297
20	297	45	378	70	605	95	283
21	205	46	297	71	476	96	205
22	476	47	194	72	391	97	429
23	605	48	378	73	191	98	528
24	476	49	528	74	476	99	536
25	429	50	429	75	476	100	283

Table 108. **Comparison of spot stock condition according to the modified-CSA end-year spawning stock biomass and reference point estimates and the TLA proportion of red from the adult abundance metric. Values highlighted in red indicate overfished (modified-CSA) or significant concern (TLA), values highlighted in yellow indicate not overfished, but below the target (modified-CSA) or moderate concern (TLA), and values highlighted in green indicate not overfished (modified-CSA) or no concern (TLA). Bolded values show agreement of condition between the analyses.**

Year	Spawning Stock Biomass (metric tons)	Adult Abundance Metric Proportion Red
1989	**12,929**	**0.27**
1990	**5,510**	**0.48**
1991	1,689	0.37
1992	712	0.57
1993	**1,282**	**0.81**
1994	6,175	0.14
1995	2,689	0.55
1996	1,253	0.48
1997	**2,076**	**0.77**
1998	**1,568**	**0.78**
1999	3,025	0.54
2000	**3,898**	**0.70**
2001	**208**	**0.76**
2002	**2,026**	**0.69**
2003	3,197	0.38
2004	**5,137**	**0.52**
2005	**8,969**	**0.00**
2006	**9,463**	**0.27**
2007	**7,804**	**0.34**
2008	**8,102**	**0.00**
2009	**10,459**	**0.12**
2010	**12,932**	**0.29**
2011	**14,792**	**0.00**
2012	**17,251**	**0.00**
2013	19,567	0.31
2014	19,032	0.56

Table 109. Comparison of spot stock condition according to the modified-CSA static spawning potential ratio estimates and the TLA proportion of red from the harvest and total removal metrics. Values highlighted in red indicate overfishing (modified-CSA) or significant concern (TLA), values highlighted in yellow indicate not overfishing, but above the target (modified-CSA) or moderate concern (TLA), and values highlighted in green indicate not overfishing (modified-CSA) or no concern (TLA). Bolded values show agreement of condition between the analyses.

Year	Static Spawning Potential Ratio	Harvest Metric Proportion Red	Total Removals Metric Proportion Red
1989	0.12	0.00	0.26
1990	0.04	0.00	0.30
1991	0.01	0.00	0.25
1992	0.02	0.00	0.03
1993	0.05	0.00	0.00
1994	0.17	0.00	0.04
1995	0.03	0.00	0.05
1996	0.06	0.16	0.05
1997	0.26	0.07	0.03
1998	0.12	0.03	0.01
1999	0.24	0.20	0.07
2000	0.19	0.14	0.06
2001	0.01	0.00	0.01
2002	0.23	0.13	0.11
2003	0.09	0.00	0.01
2004	0.30	0.00	0.01
2005	0.39	0.03	0.09
2006	0.30	0.18	0.13
2007	**0.41**	**0.00**	**0.01**
2008	**0.42**	**0.20**	**0.08**
2009	**0.41**	**0.10**	**0.16**
2010	**0.56**	0.43	**0.26**
2011	0.30	0.17	0.13
2012	**0.53**	0.52	**0.24**
2013	**0.48**	0.30	**0.27**
2014	**0.51**	**0.15**	**0.18**

13. Figures

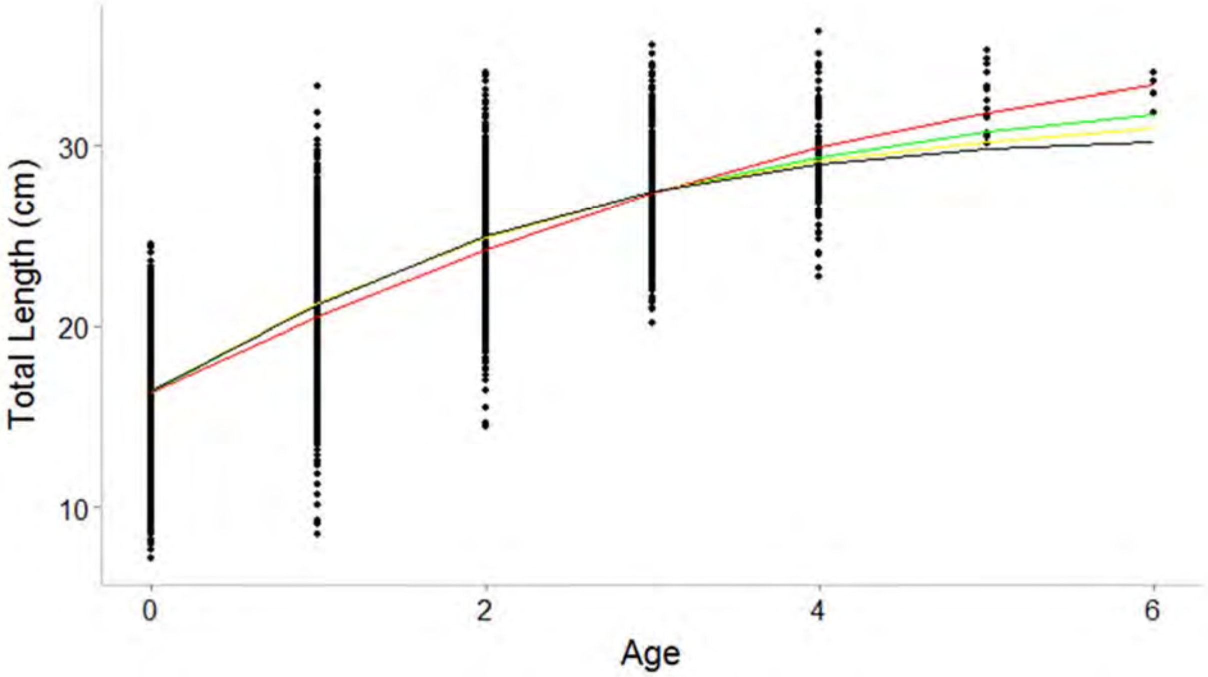


Figure 1. Observed female spot age-at-total length (black circles) and predictions from the von Bertalanffy (green line), Richard's (red line), Gompertz (yellow line), and logistic (black line) growth models.

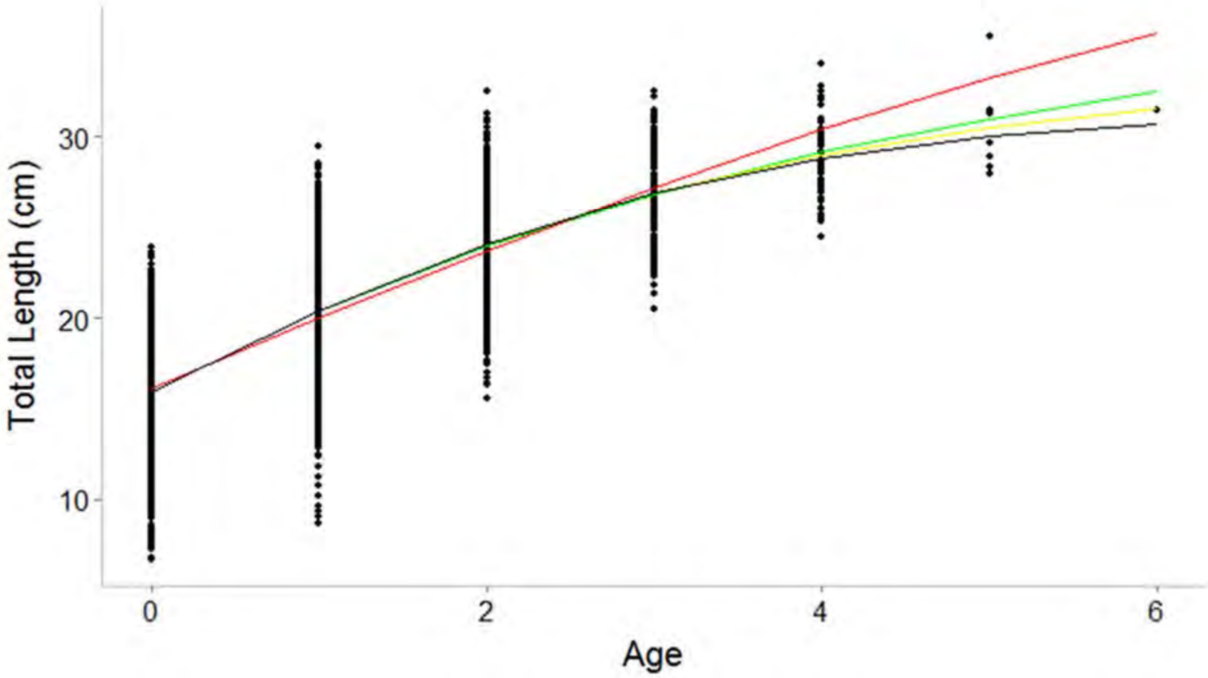


Figure 2. Observed male spot age-at-length (black circles) and predictions from the von Bertalanffy (green line), Richard's (red line), Gompertz (yellow line), and logistic (black line) growth models.

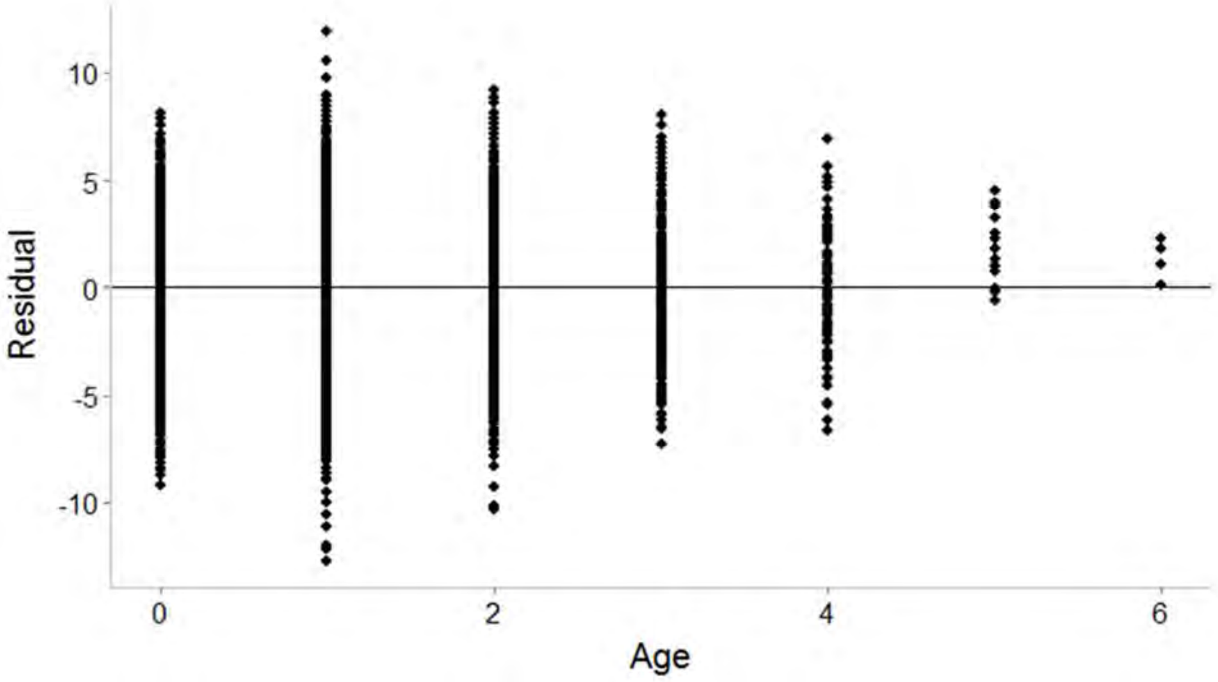


Figure 3. **Residuals of von Bertalanffy growth model fit to observed female spot age-at-total length data.**

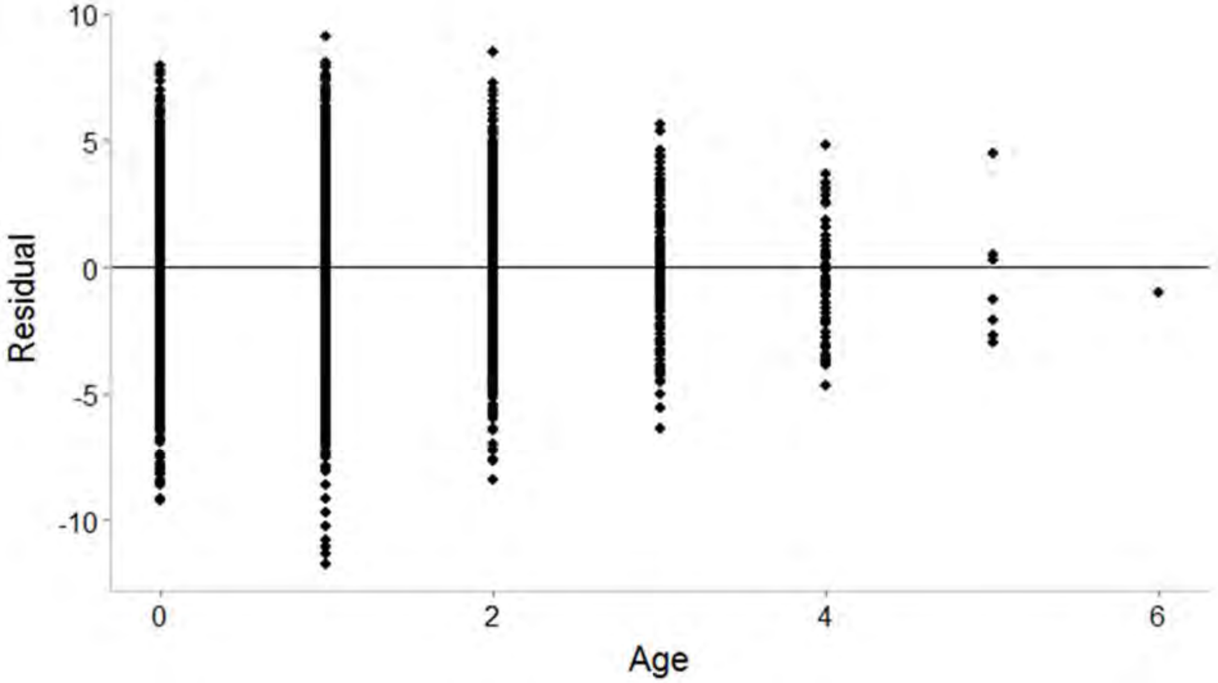


Figure 4. **Residuals of von Bertalanffy growth model fit to observed male spot age-at-length data.**

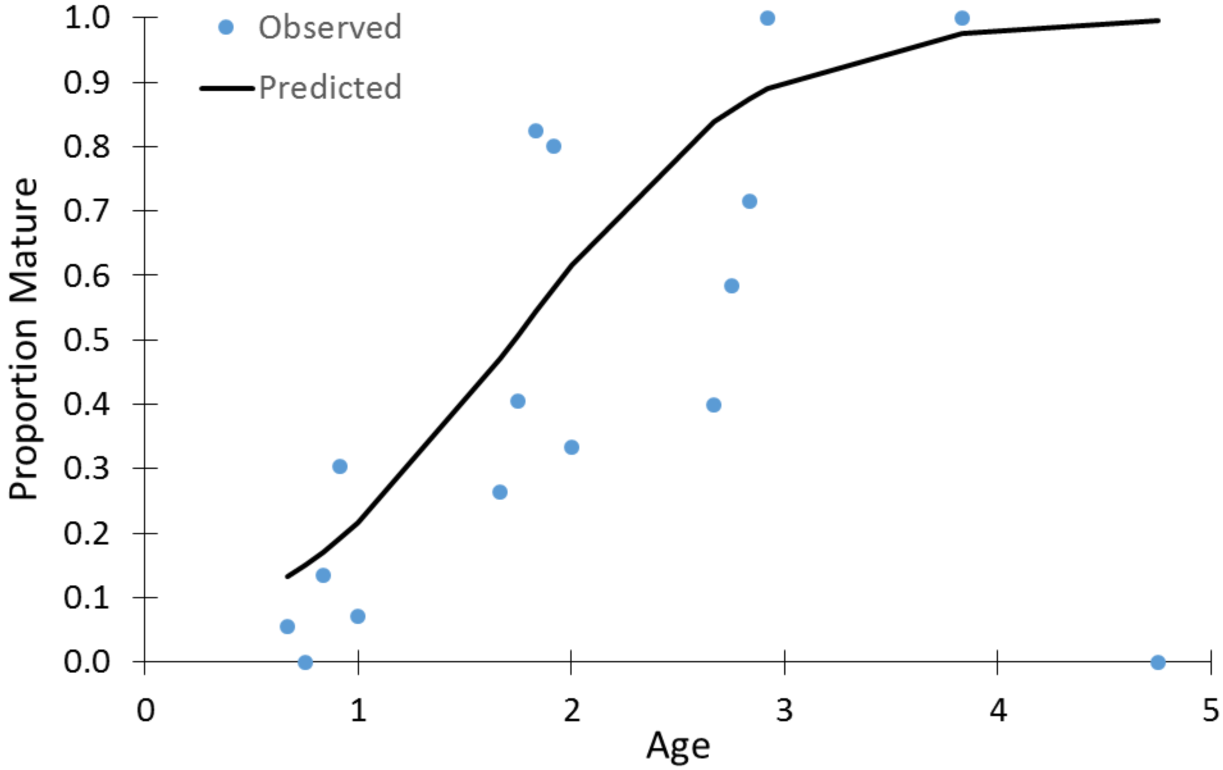


Figure 5. Observed (blue circles) and predicted (black line) proportion female spot mature-at-age using SCDNR maturity data from August-December. Predicted values are from a logistic regression model (slope = -1.761, inflection = 1.7).

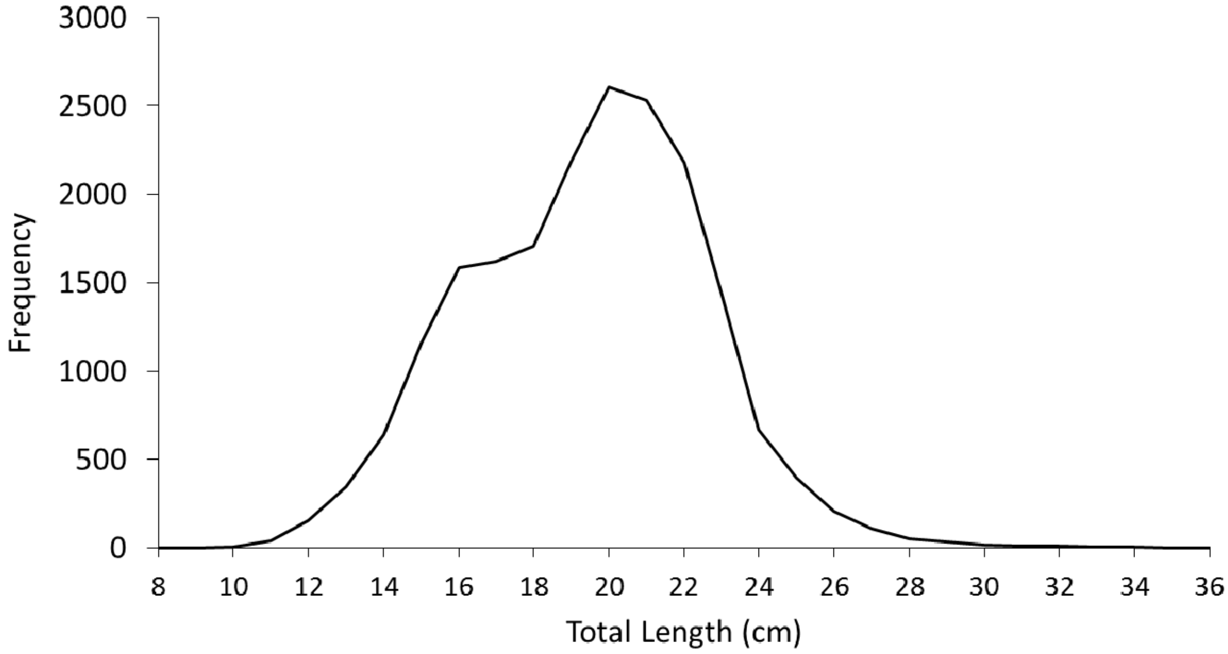


Figure 6. Aggregate length frequency of spot (mm TL) sampled by the MD DNR from commercial pound nets from 1993-2014.

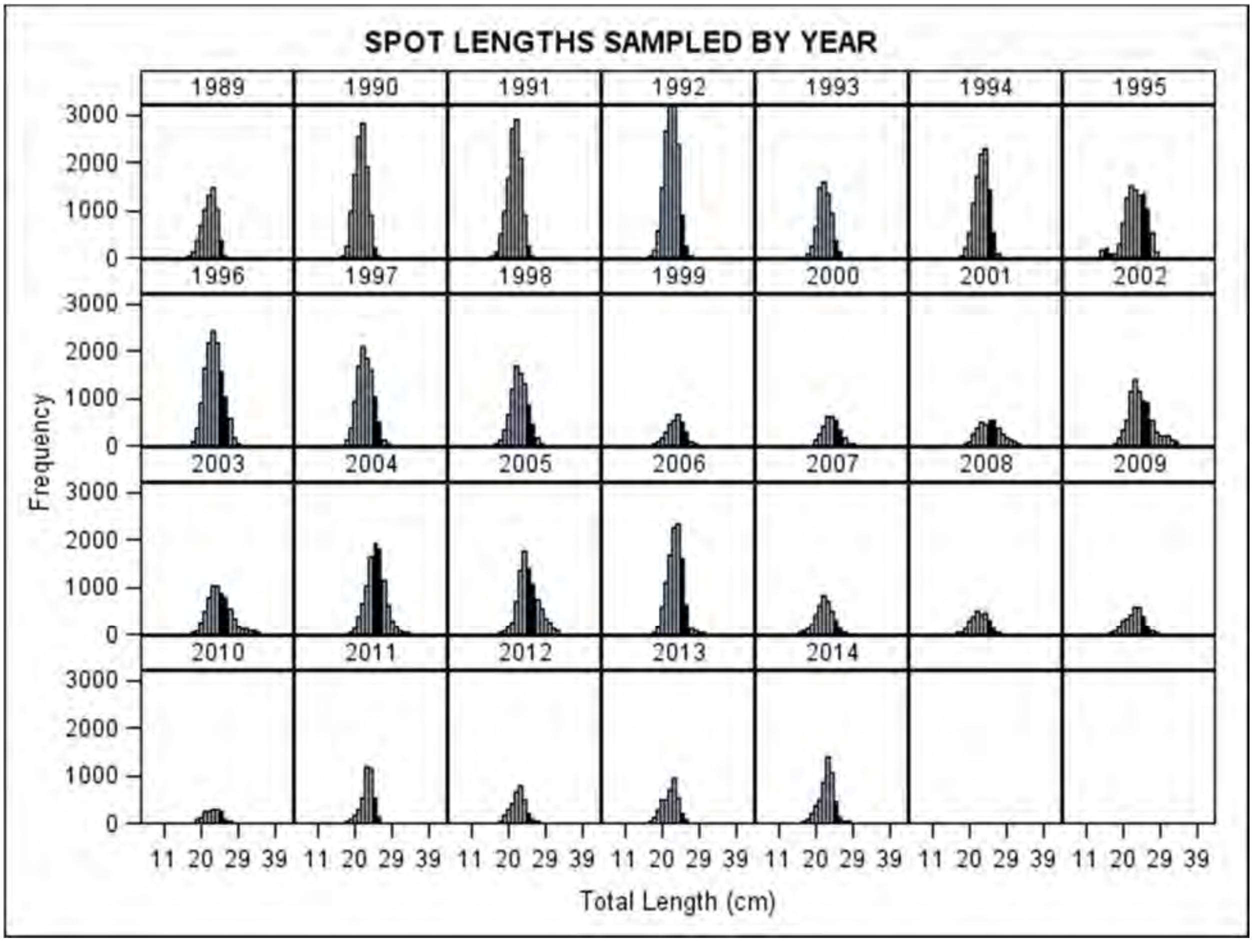


Figure 7. **Annual length frequency of spot sampled by the VMRC's BSP from commercial fisheries.**

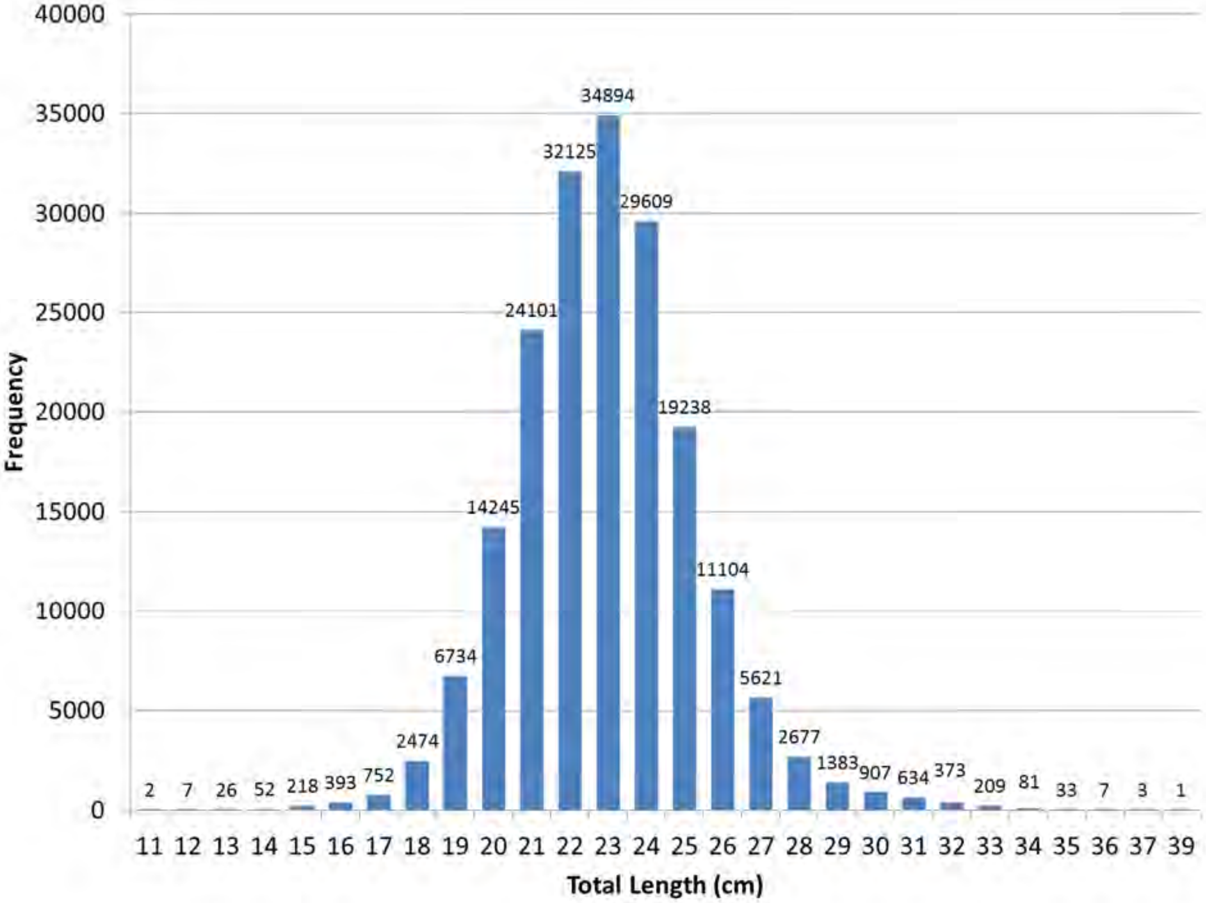


Figure 8. **Aggregate length frequency of spot sampled by the VMRC's BSP from commercial fisheries from 1989-2014.**

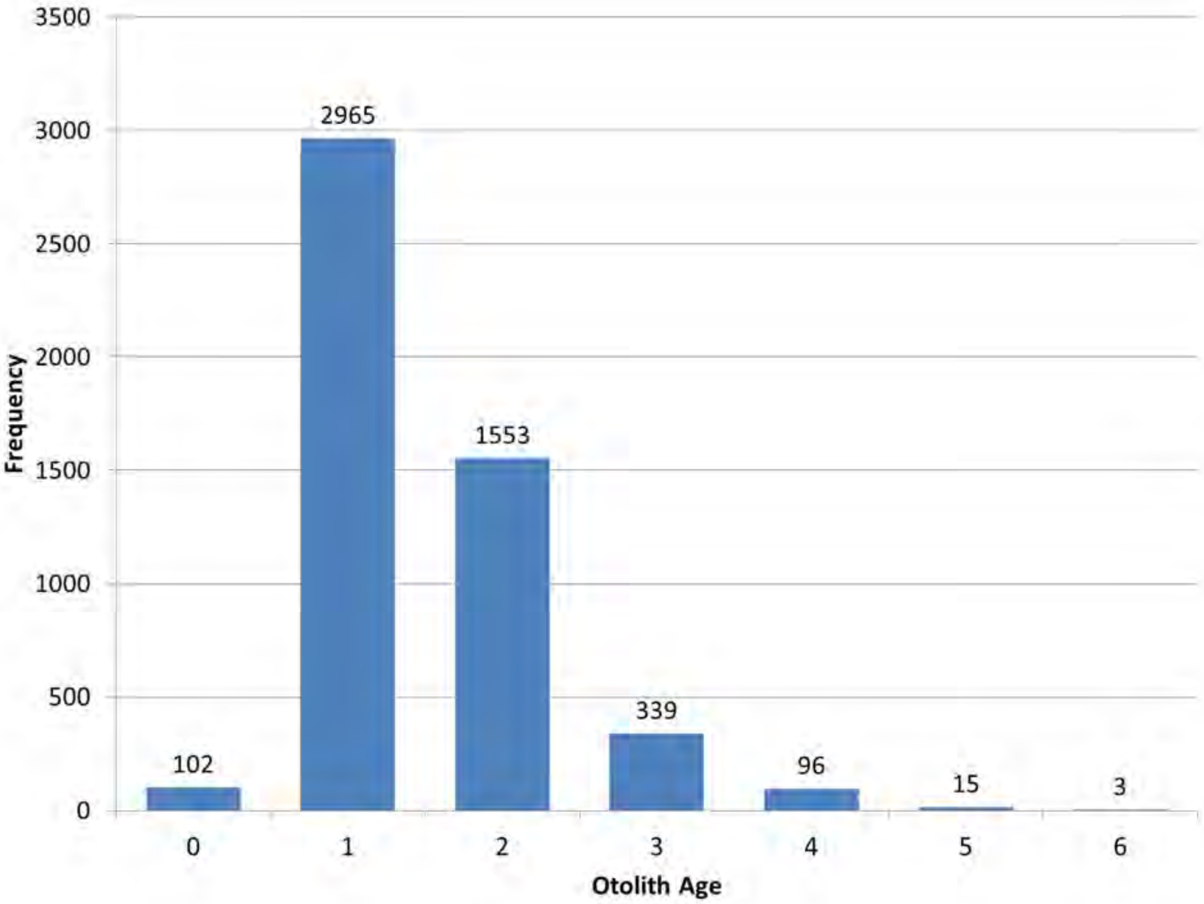


Figure 9. **Aggregate age frequency of spot sampled by the VMRC's BSP from commercial fisheries from 1998-2014.**

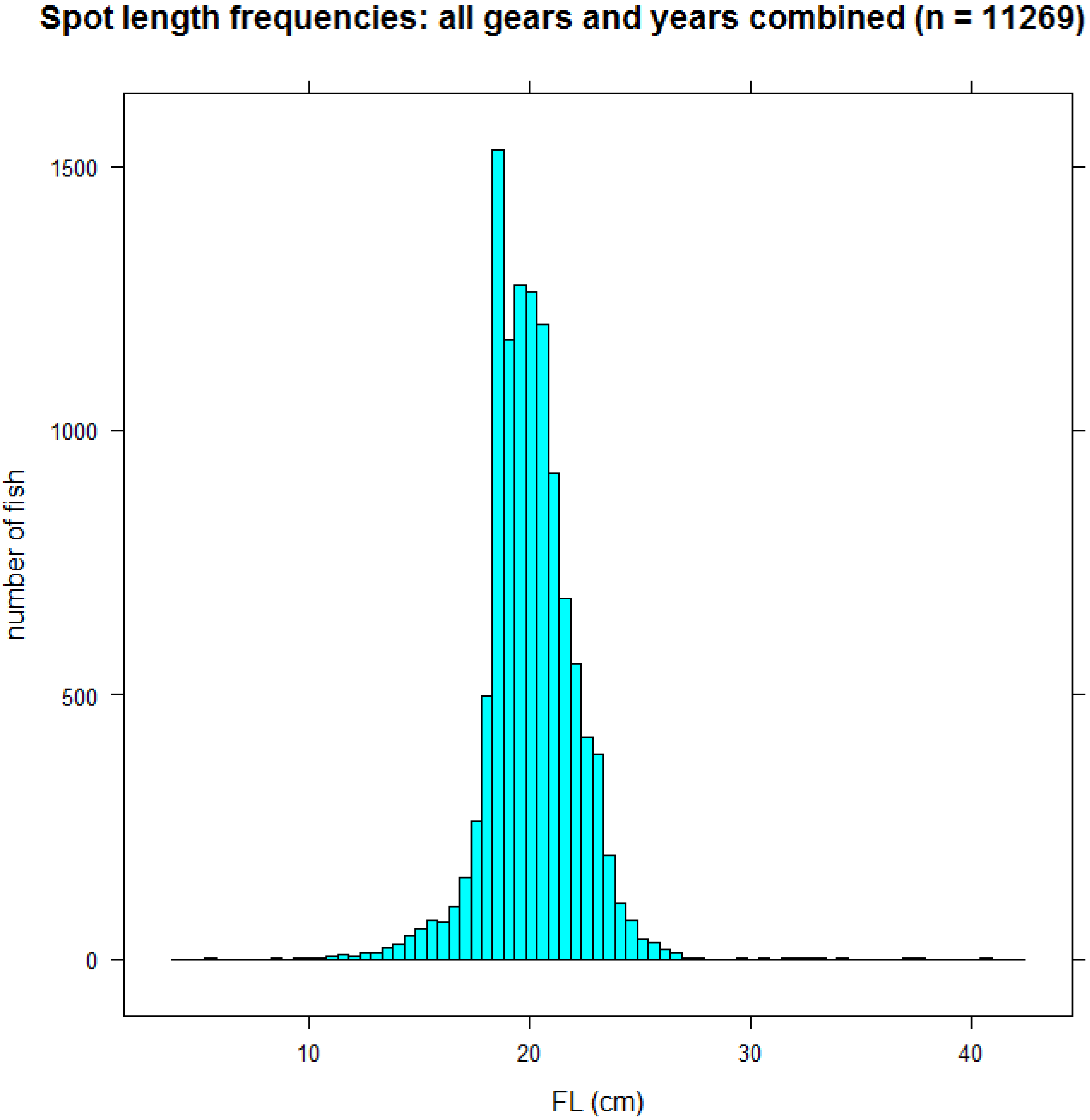


Figure 10. **Length frequency of spot collected by the TIP from commercial fisheries (all gears combined) in Florida from 1992-2014.**

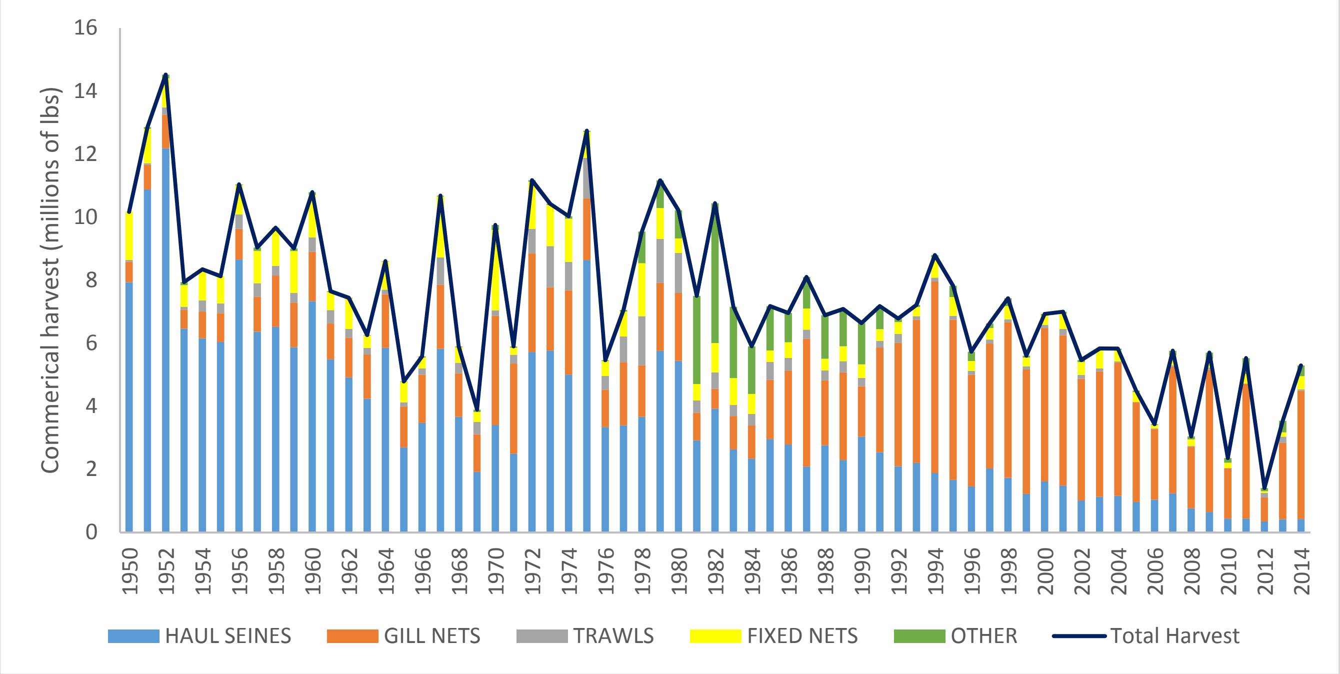


Figure 11. Coastwide spot commercial landings (millions of pounds) by gear.

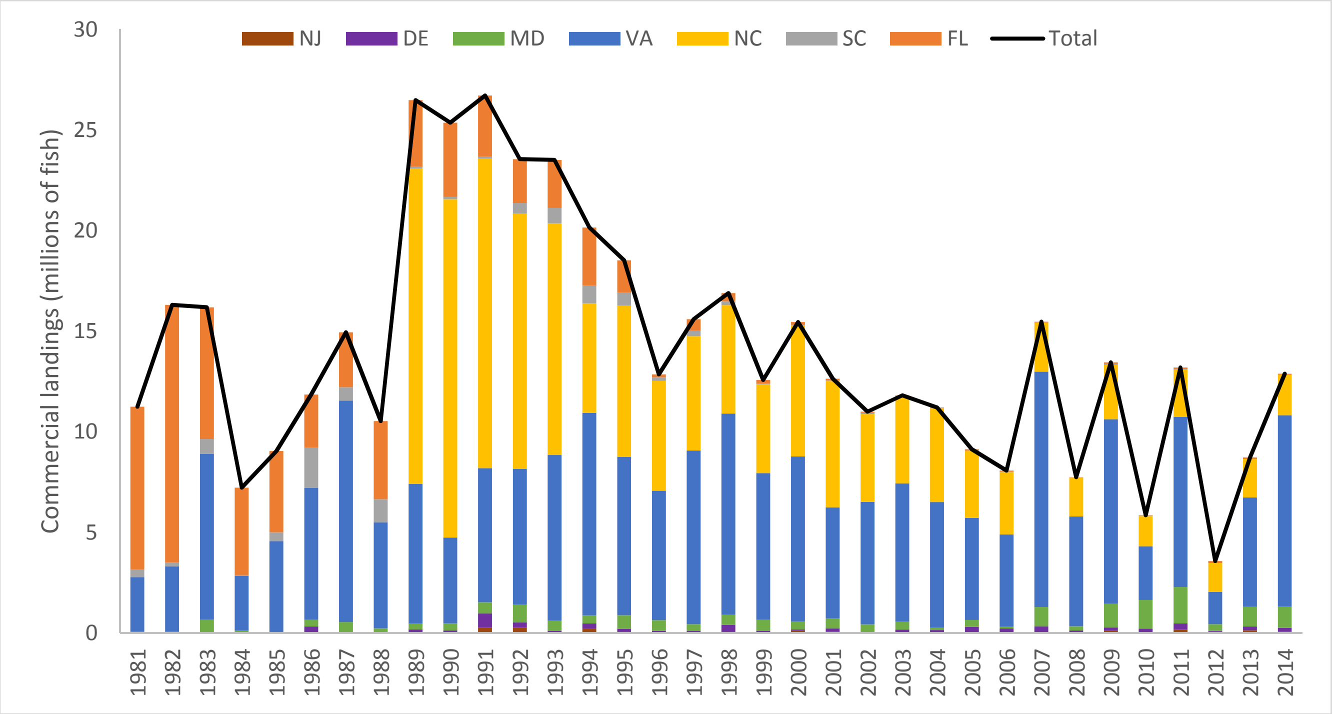


Figure 12. Spot commercial landings (millions of fish) by state.

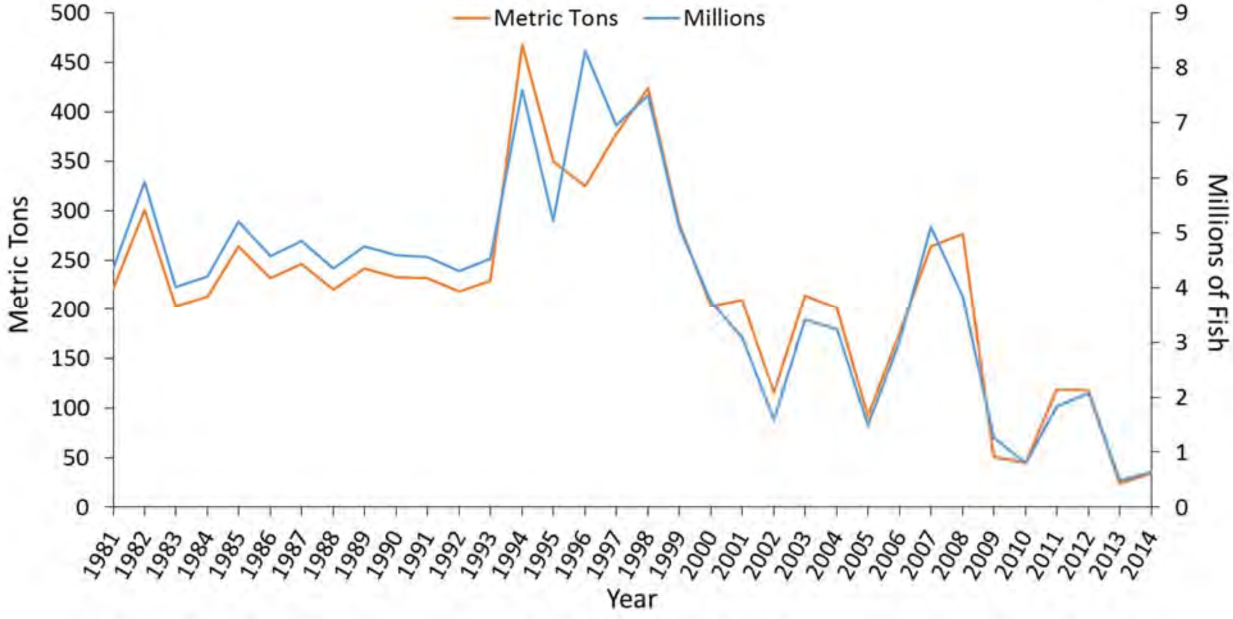


Figure 13. **Annual spot scrap landing estimates in metric tons and millions of fish.**

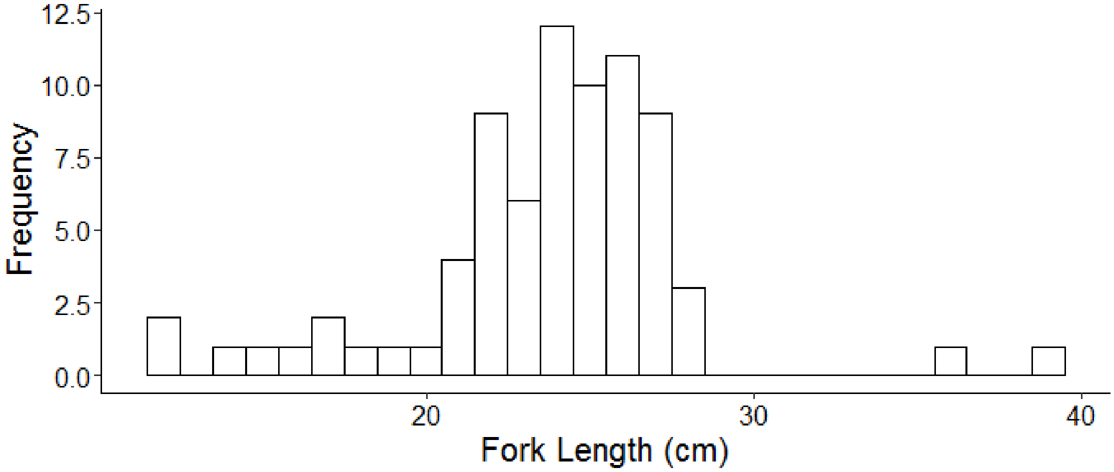


Figure 14. **Length distribution of discarded spot observed in gillnets by the NEFOP.**

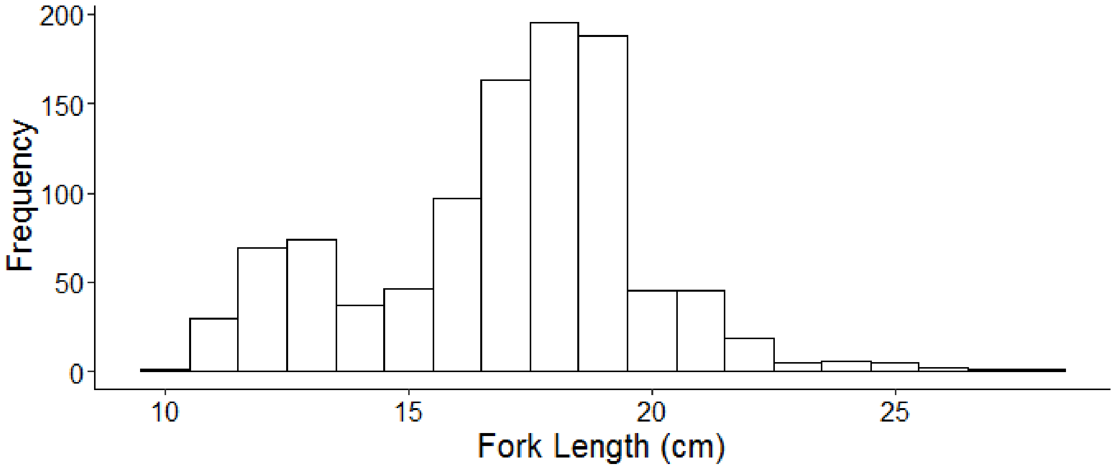


Figure 15. **Length distribution of discarded spot observed in trawls by the NEFOP.**

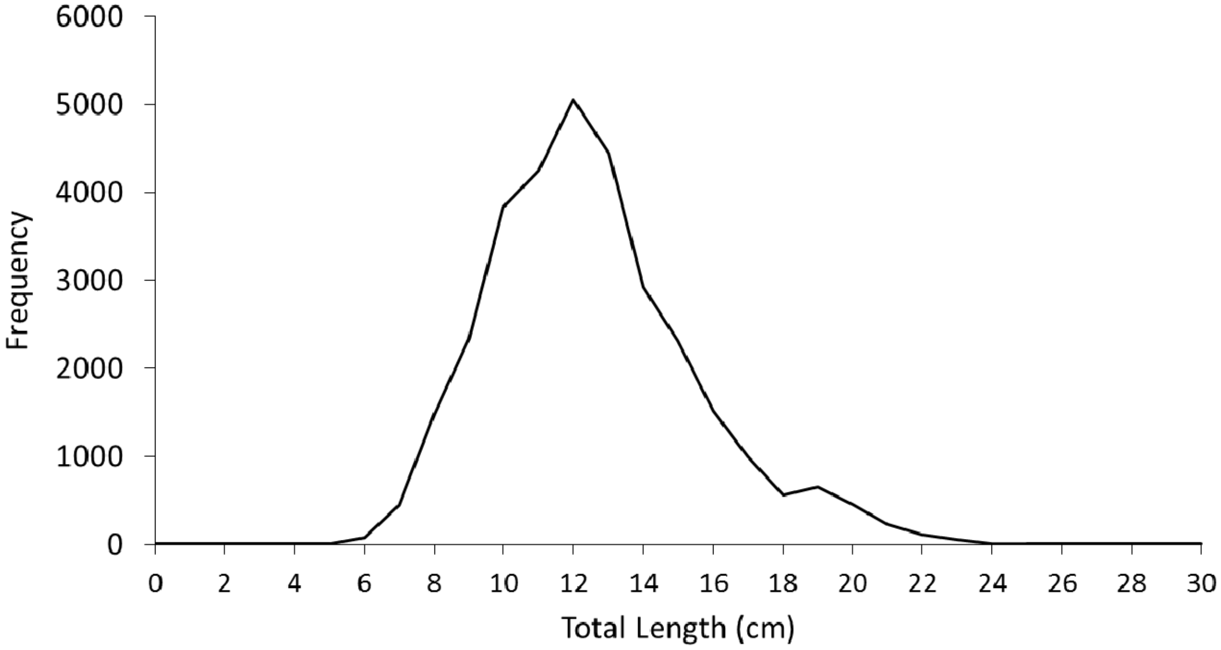


Figure 16. **Length frequency of spot observed during the North Carolina Shrimp Trawl Observer Study (2007-2014).**

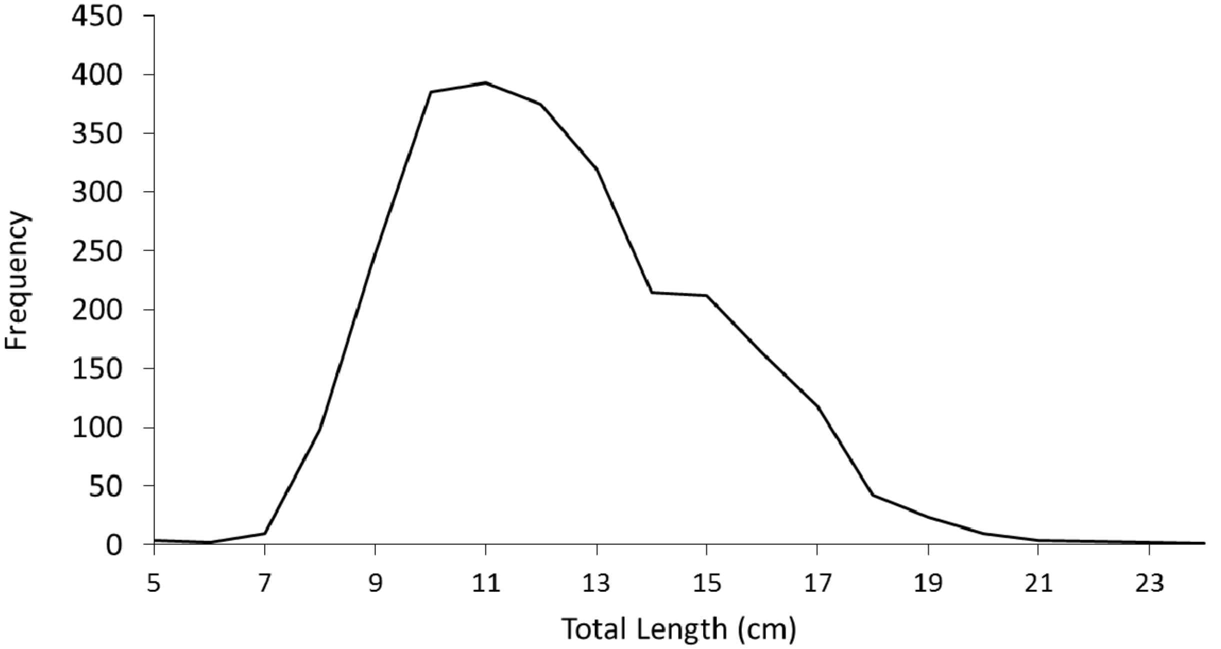


Figure 17. **Length frequency of spot observed during the Georgia Large Shrimp Trawl Bycatch Observer Study (1995-2005).**

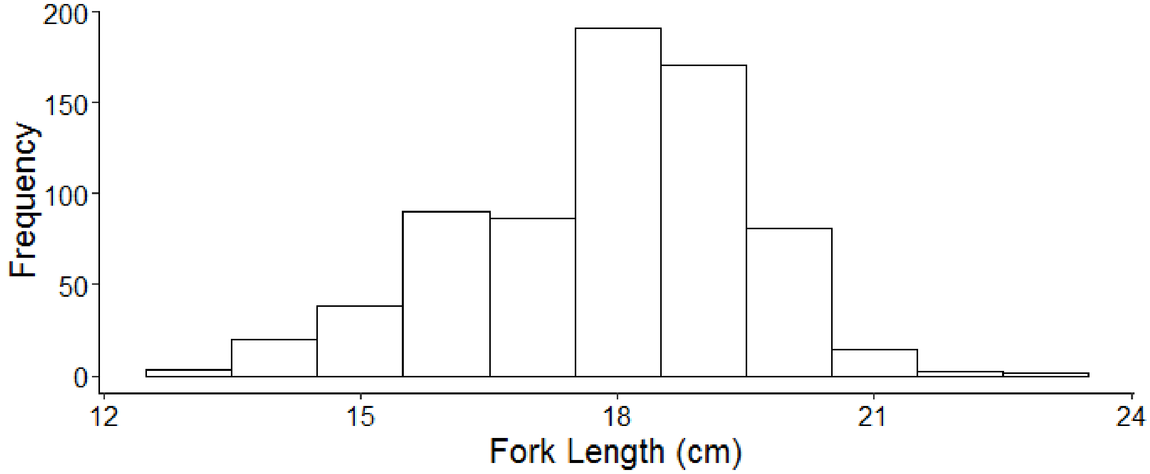


Figure 18. Length distribution of spot measured by the SESTOP. All length samples were collected in 2003.

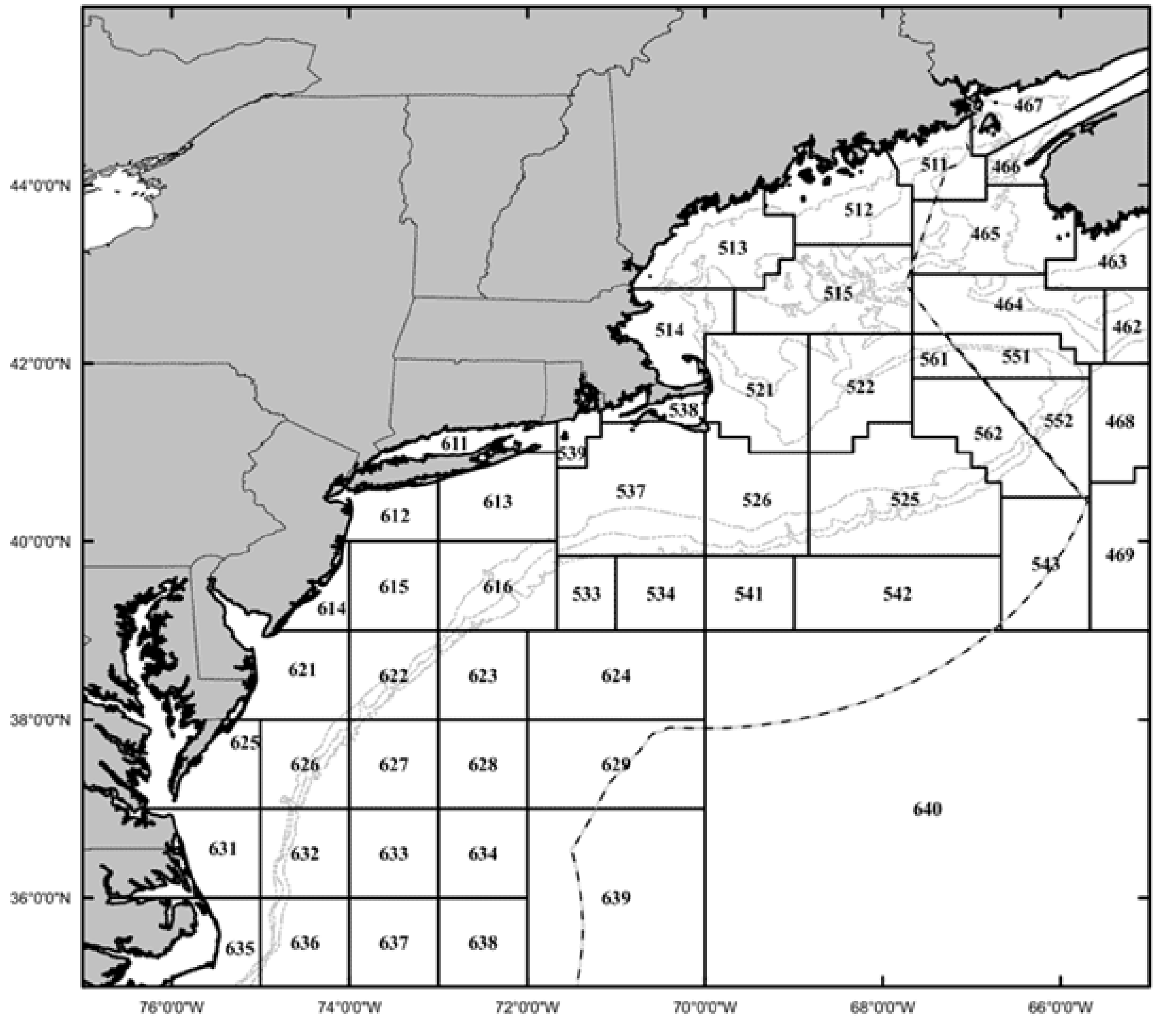


Figure 19. Statistical area used for commercial fisheries data collection by the NMFS in the Northeast Region. The 50, 100 and 500 fa bathymetric lines are shown in

light gray and the U.S. EEZ is indicated by the dashed black line (courtesy of NMFS NEFSC).

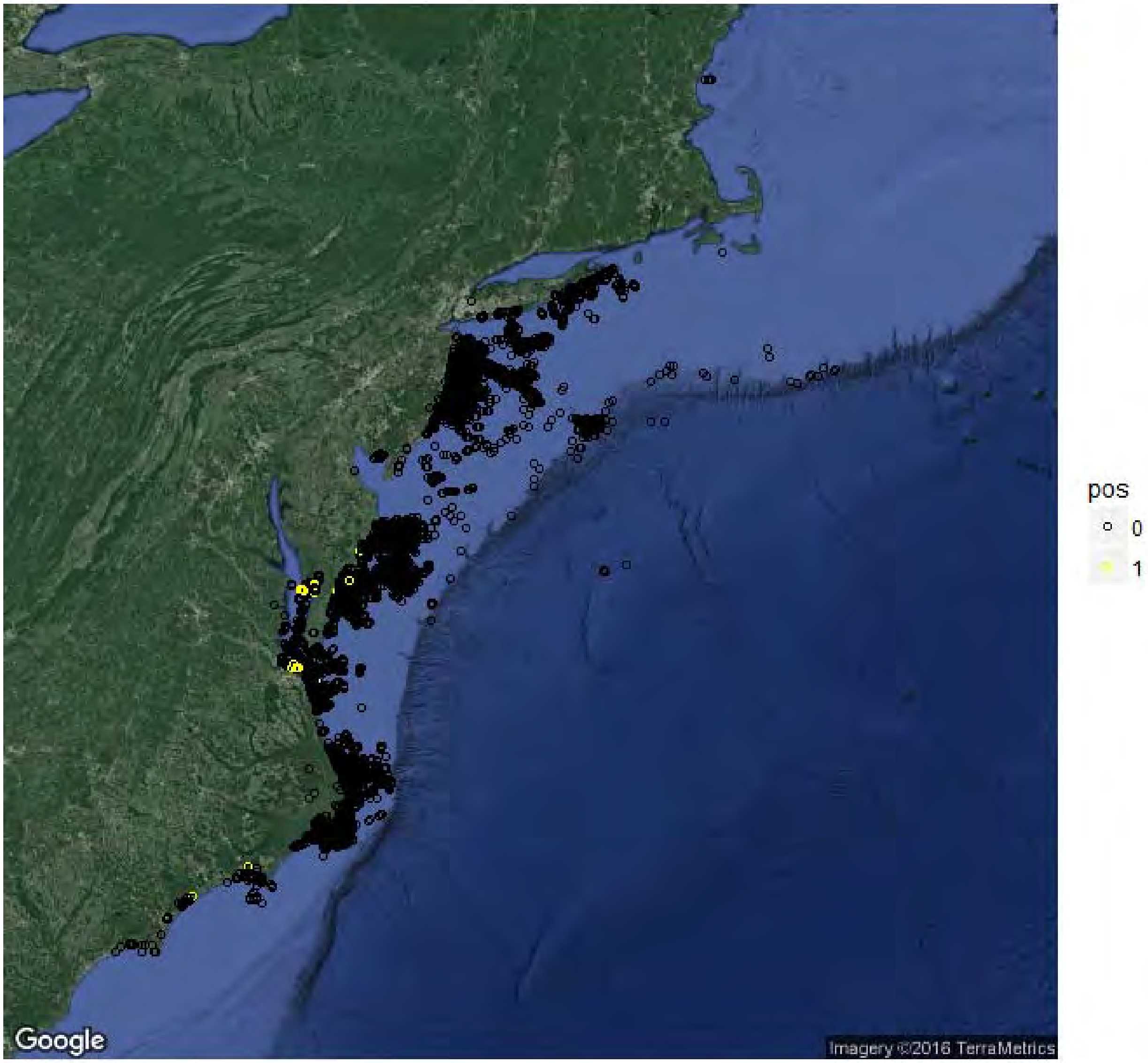


Figure 20. **Gillnet sets observed by the NEFOP. Yellow circles indicate sets where spot were discarded and black circles indicate sets where spot were not discarded.**

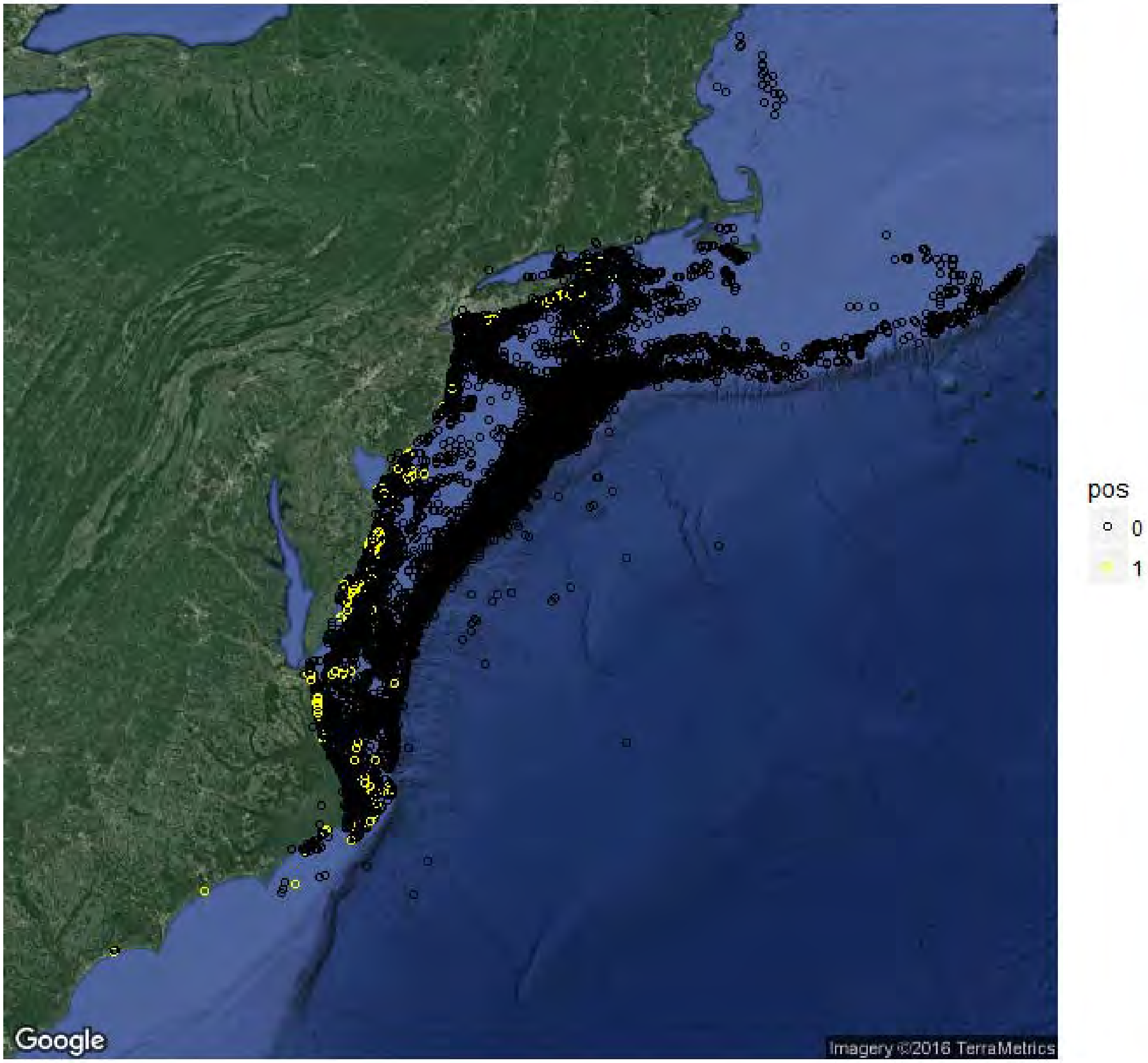


Figure 21. Trawl tows observed by the NEFOP. Yellow circles indicate tows where spot were discarded and black circles indicate tows where spot were not discarded.

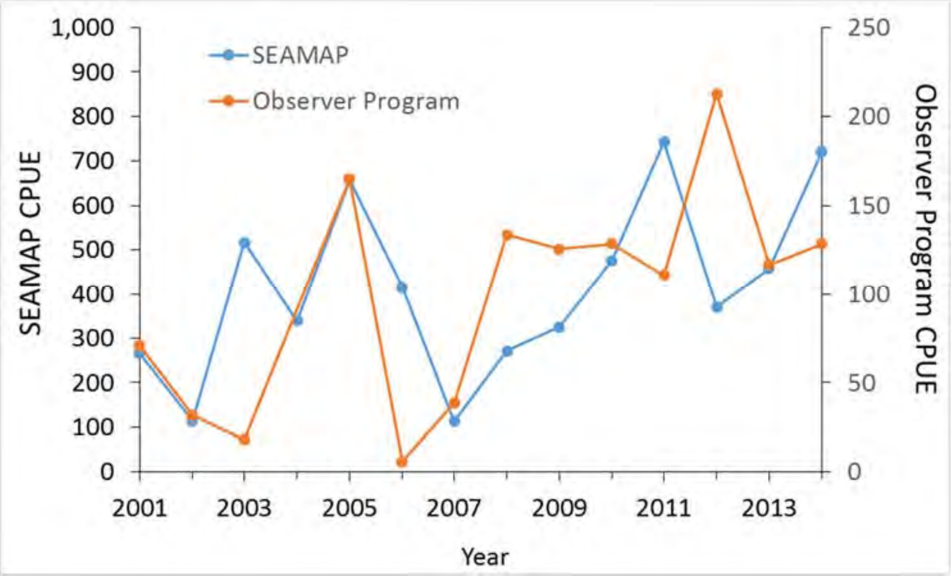


Figure 22. Annual mean CPUE of spot (number of fish/hour fished) during SEAMAP Trawl Survey tows and observer program tows.


data_set
SEAMAP
Google
Imagery ©2016 TerraMetrics

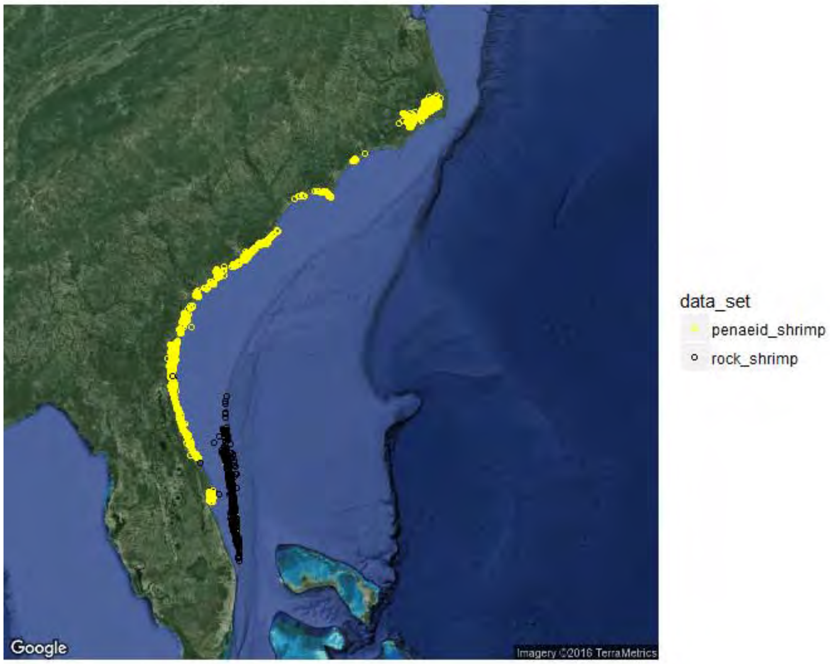

data_set
penaeid_shrimp
rock_shrimp
Google
Imagery ©2016 TerraMetrics

Figure 23. Map of SEAMAP Trawl Survey tows (red circles) and SESTOP observer tows by fishery (yellow circles for the penaeid shrimp fishery and black circles for the rock shrimp fishery).

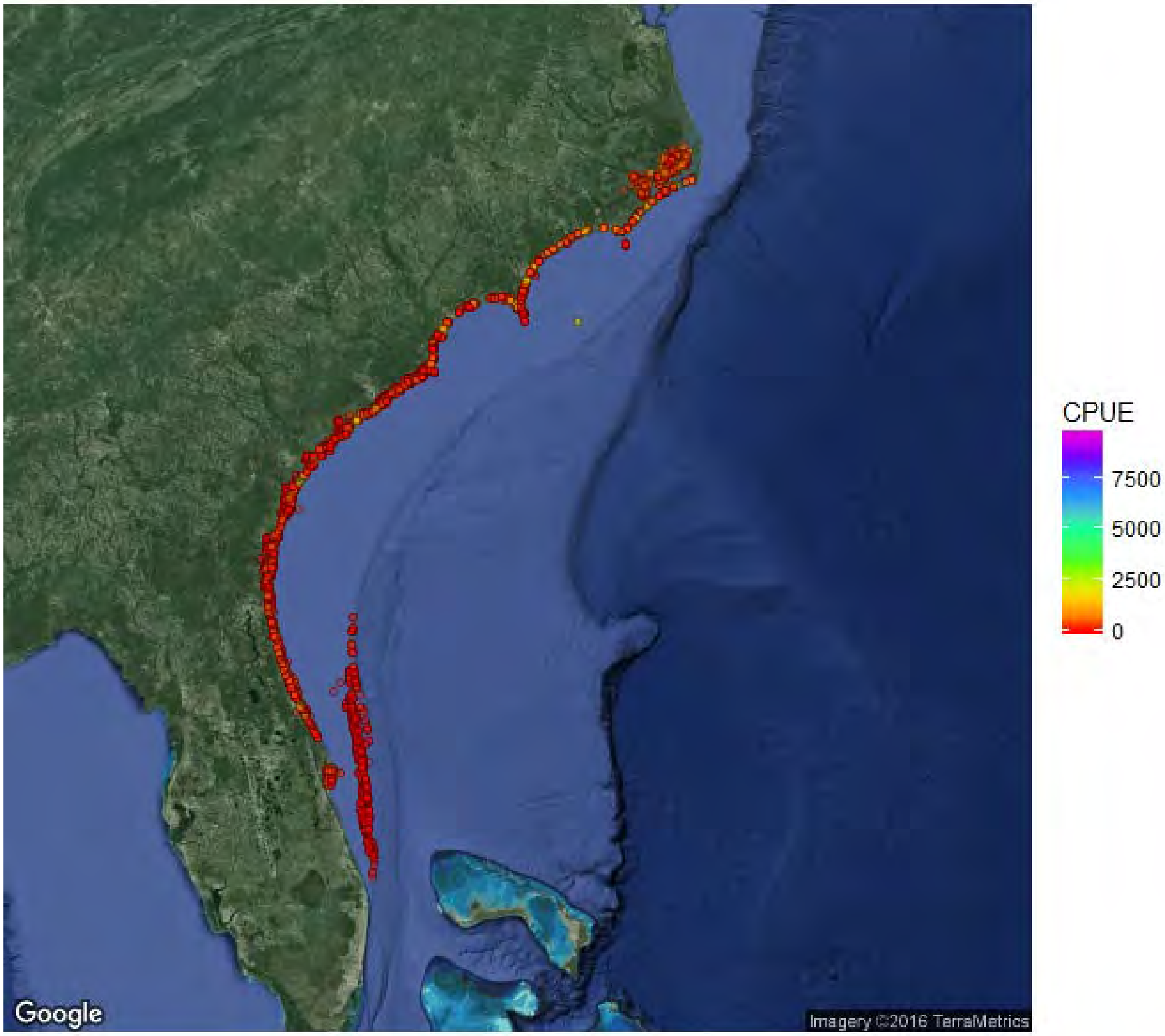


Figure 24. Tows from SEAMAP Trawl Survey and SESTOP catch rate data set that encountered less than 10,000 spot per hour fished (CPUE).

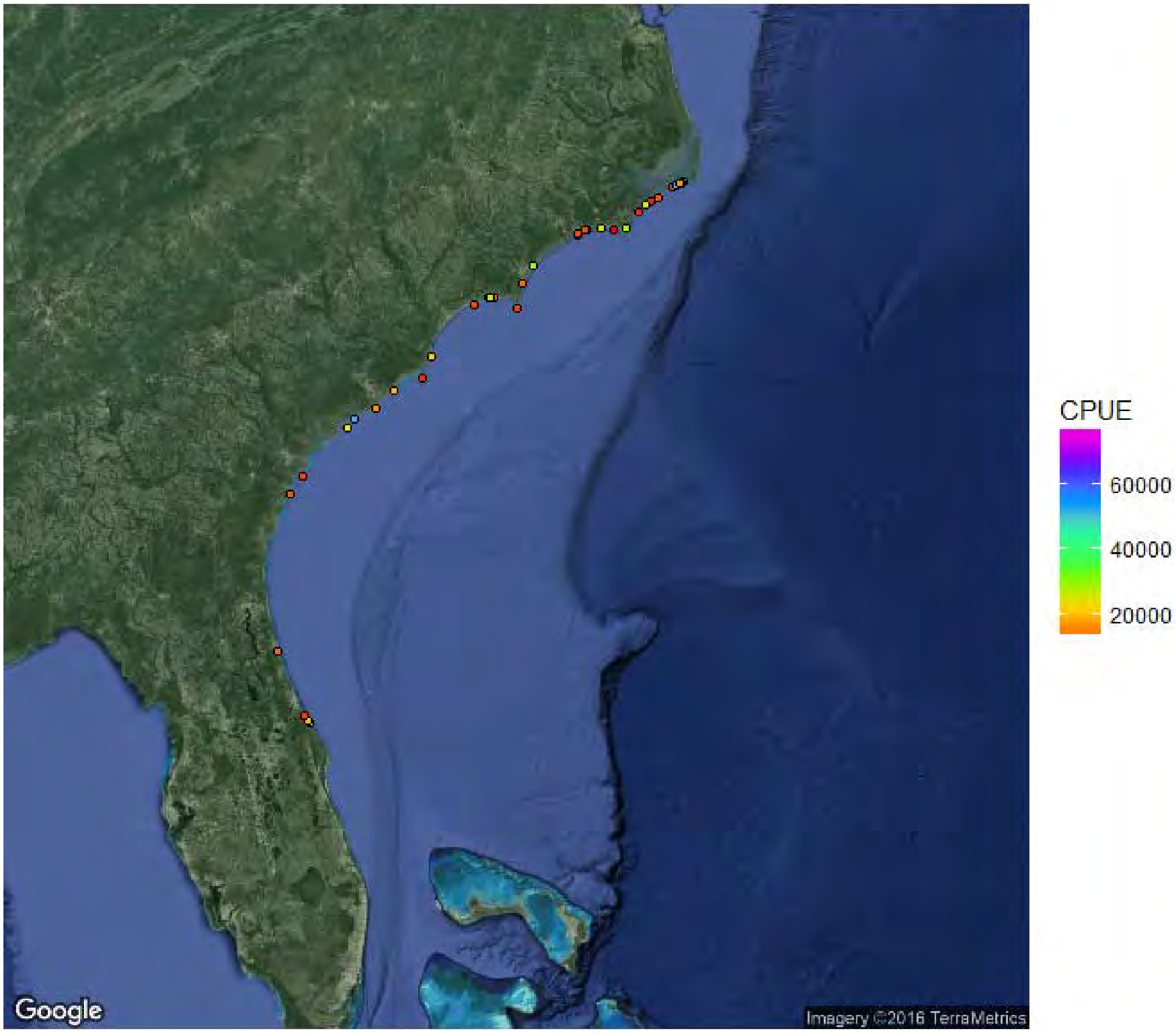


Figure 25. Tows from SEAMAP Trawl Survey and SESTOP catch rate data set that encountered at least 10,000 spot per hour fished (CPUE).

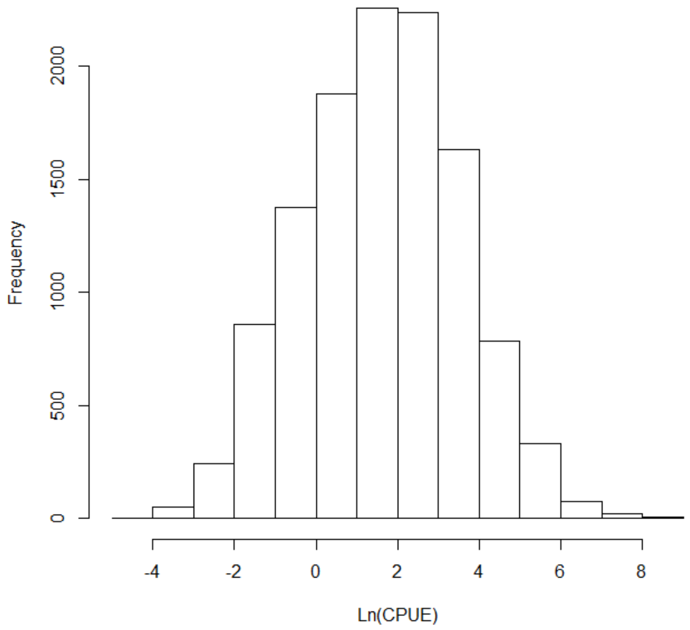


Figure 26. Distribution of positive spot CPUE observations (weight in kg) from the SEAMAP Trawl Survey and SESTOP on the log scale.

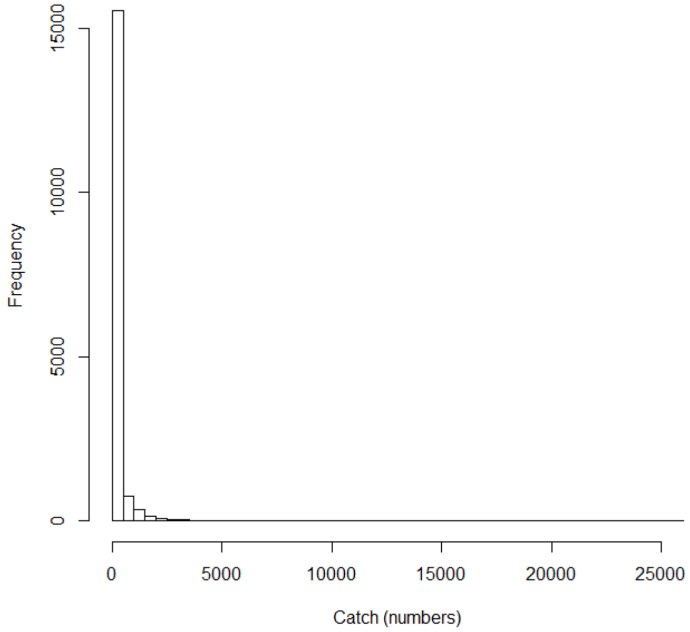


Figure 27. Distribution of spot discards (numbers) during each observation from the SEAMAP Trawl Survey and SESTOP.

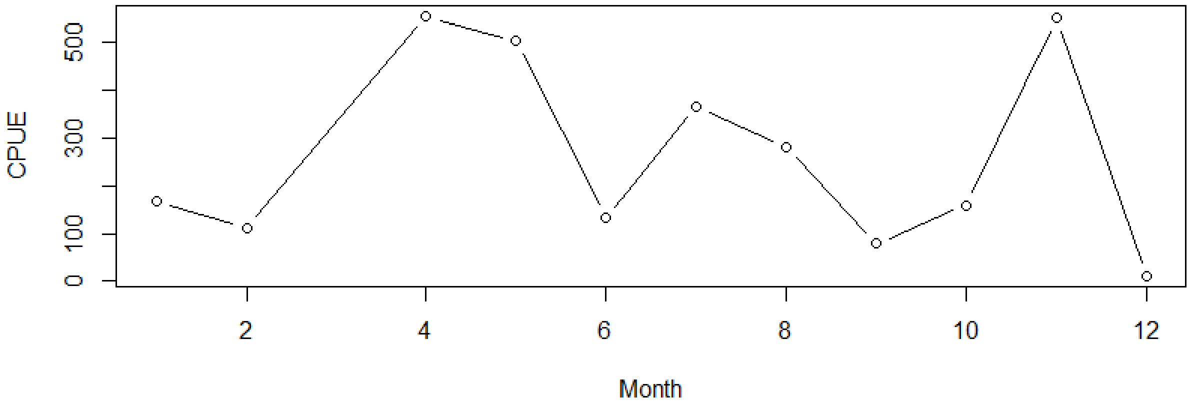


Figure 28. **Spot CPUE (numbers) by month from all SEAMAP Trawl Survey and SESTOP catch rate data.**

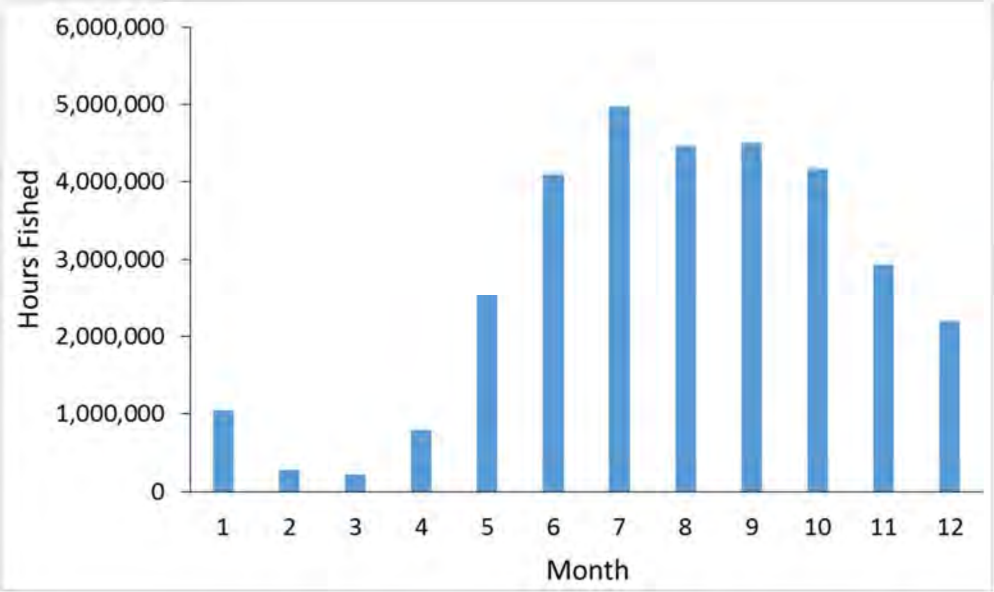


Figure 29. **South Atlantic shrimp trawl effort by month.**

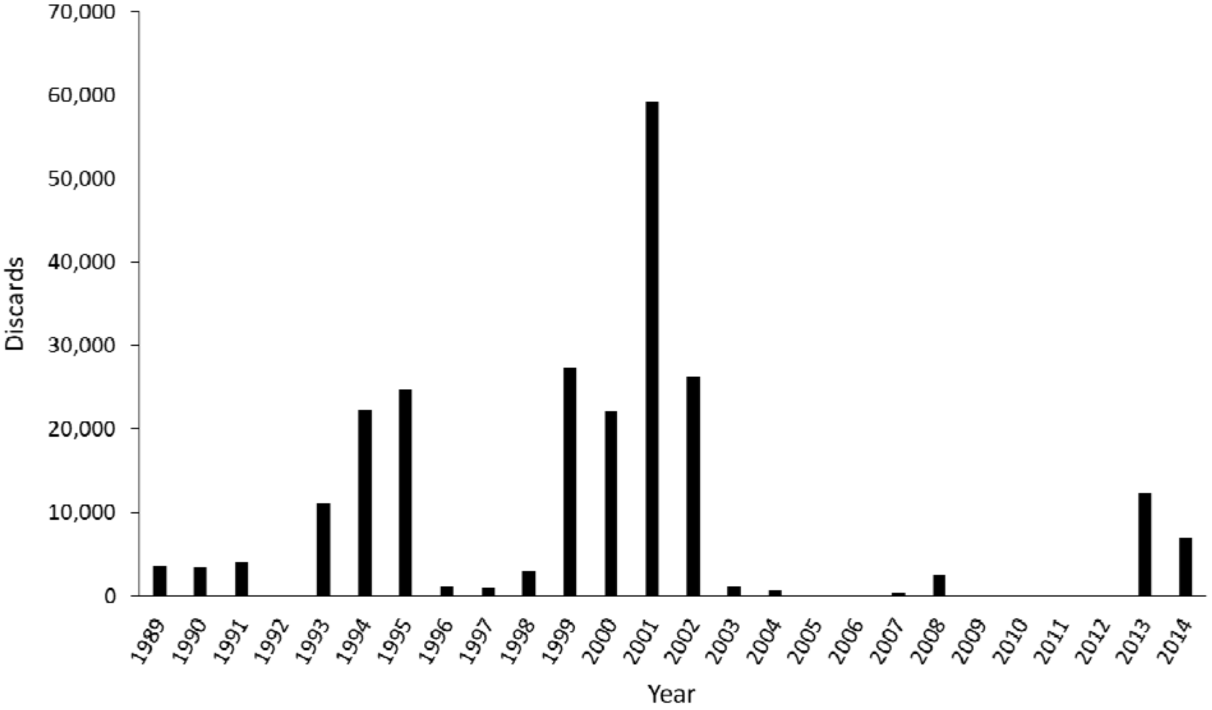


Figure 30. Spot gillnet discards (number of fish) in Mid-Atlantic fisheries.

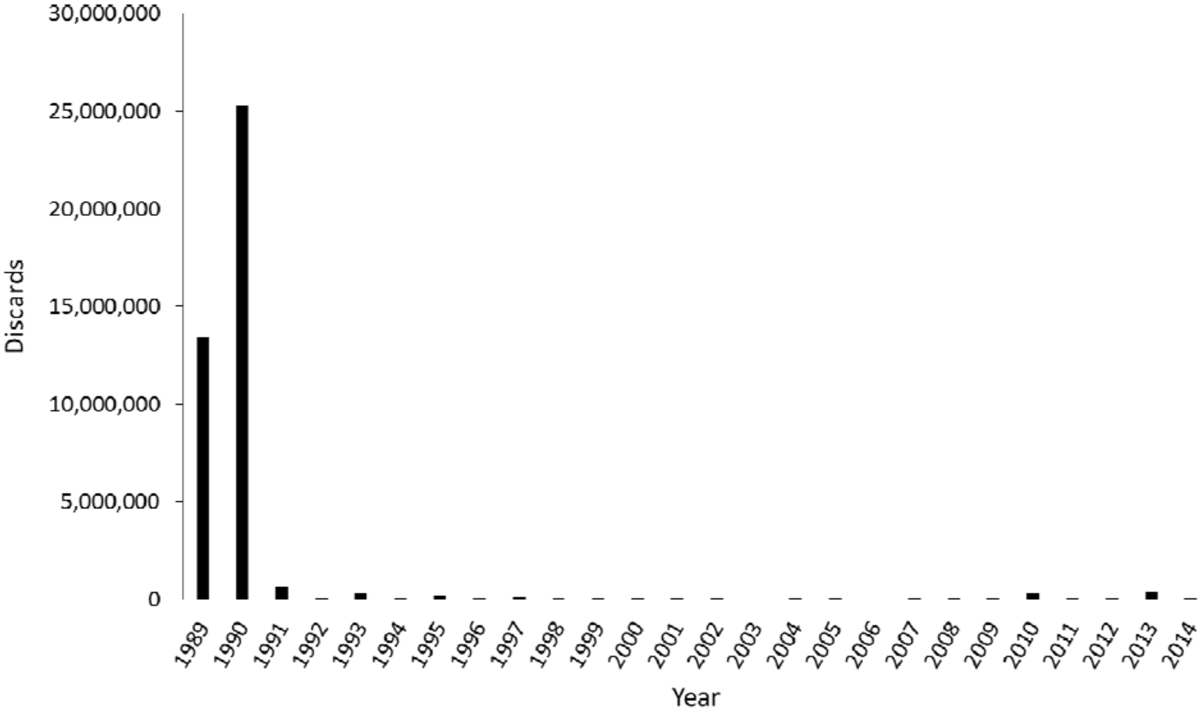


Figure 31. Spot trawl discards (number of fish) in Mid-Atlantic fisheries.

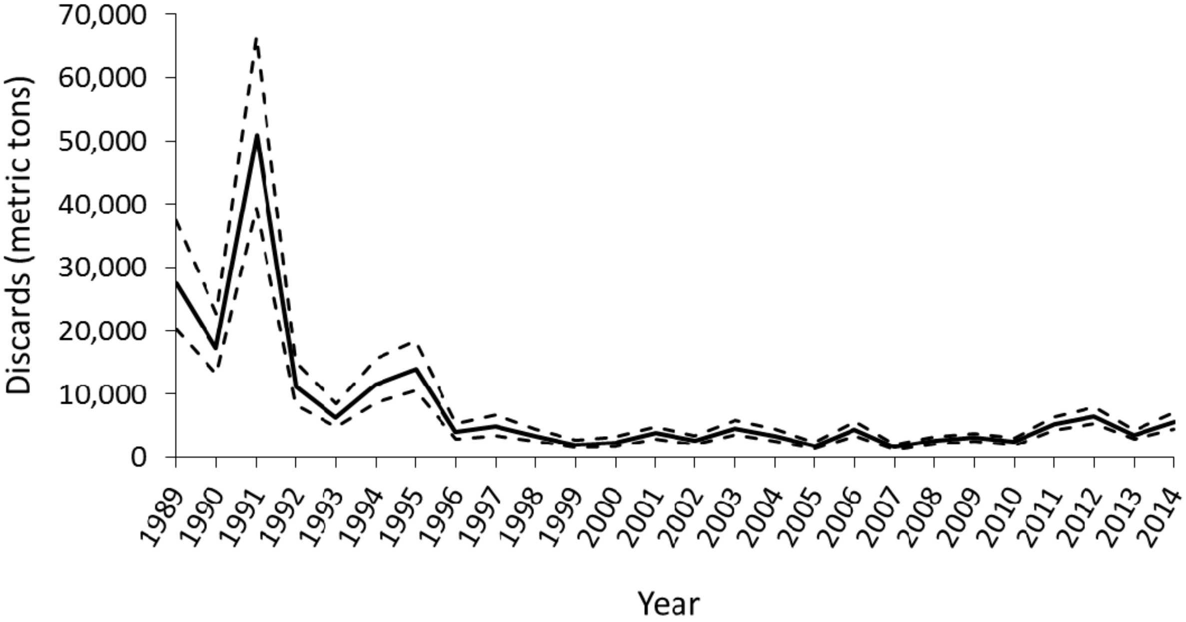


Figure 32. Spot discard estimates (metric tons, solid line) from South Atlantic shrimp trawl fisheries with 95% confidence intervals (dashed lines).

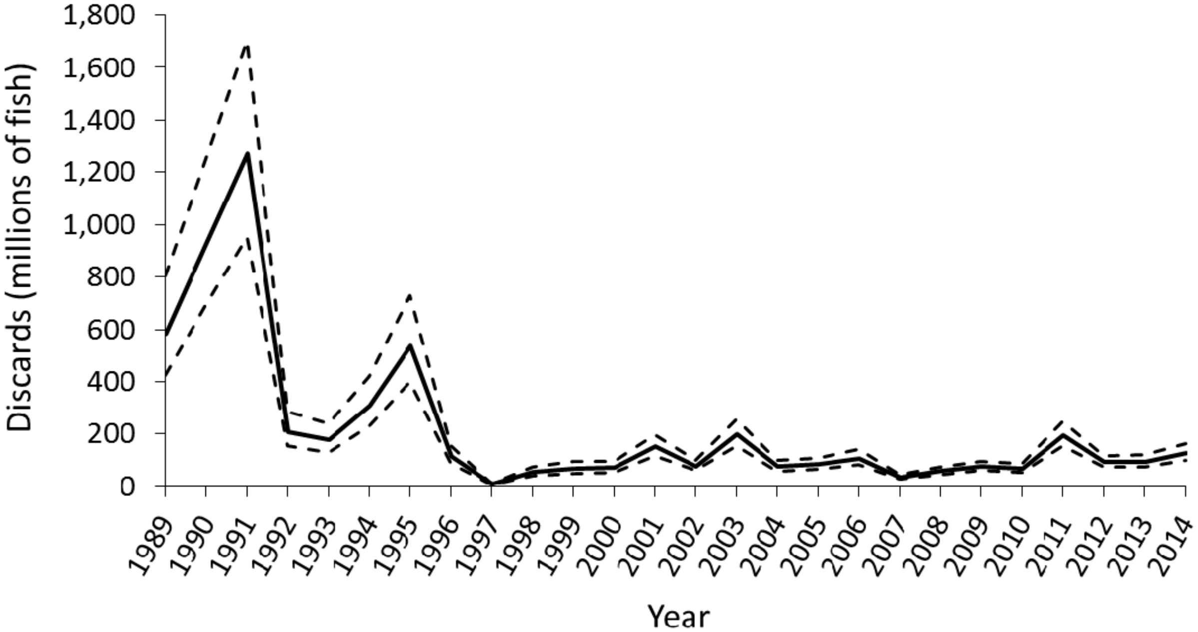


Figure 33. Spot discard estimates (millions of fish, solid line) from South Atlantic shrimp trawl fisheries with 95% confidence intervals (dashed lines).

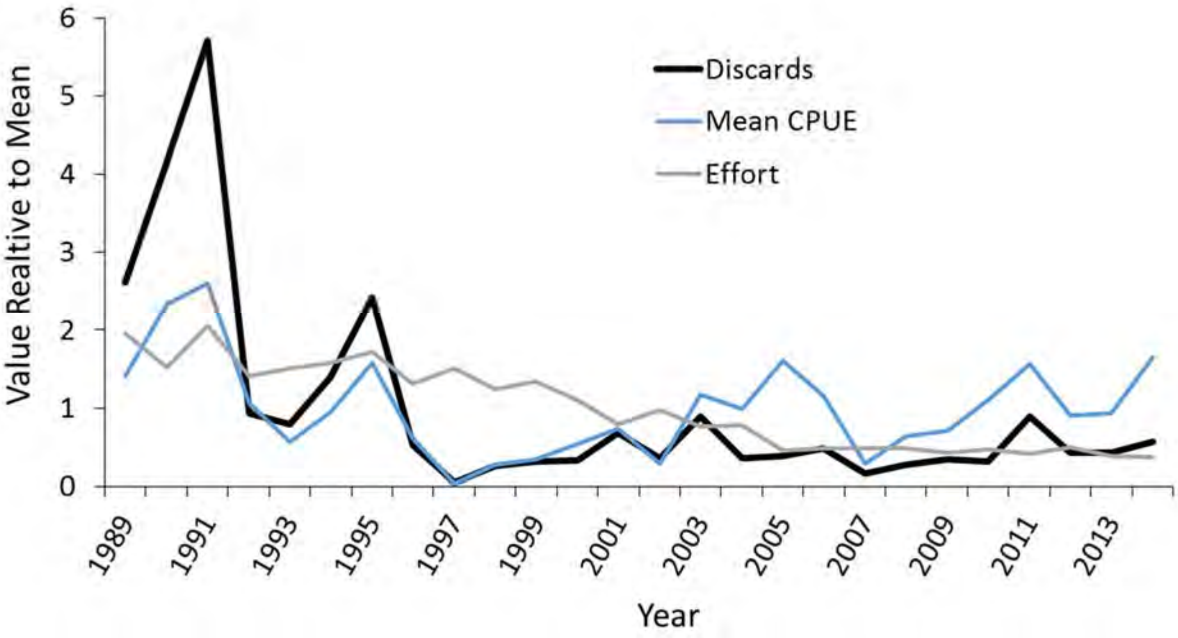


Figure 34. South Atlantic shrimp trawl effort, spot discard estimates (numbers), and mean spot CPUE (number of fish/hour fished) scaled to time series means.

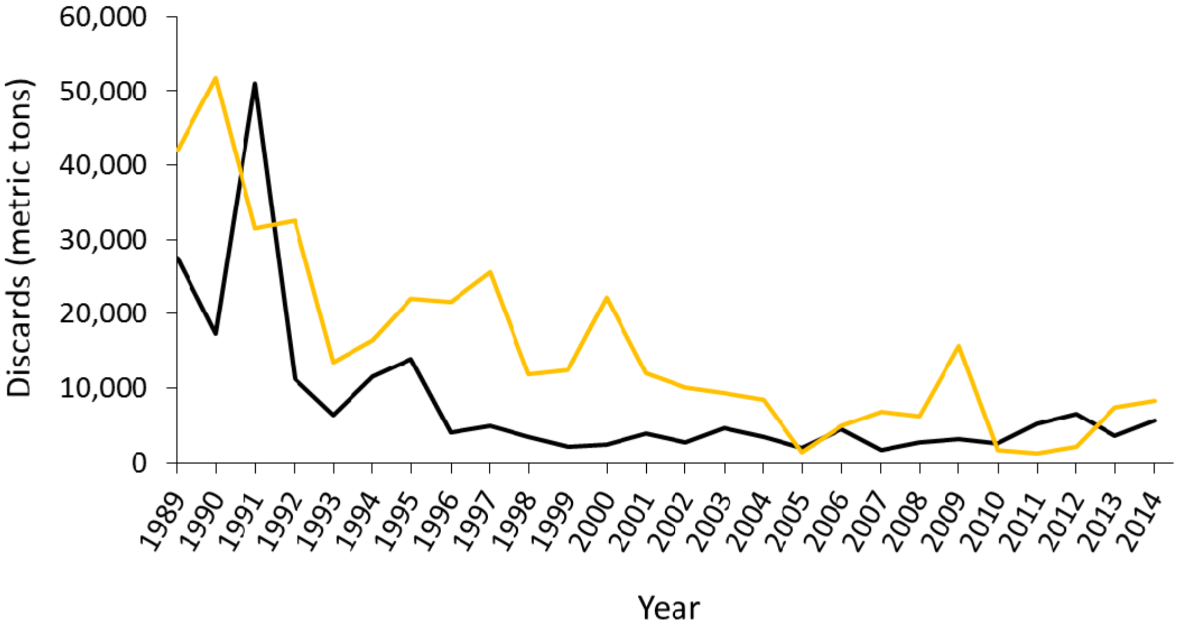


Figure 35. Comparison of spot discard estimates (black line) and spot landings by South Atlantic shrimp trawls (gold line). Landings scale is on secondary axis and values are not included due to confidentiality.

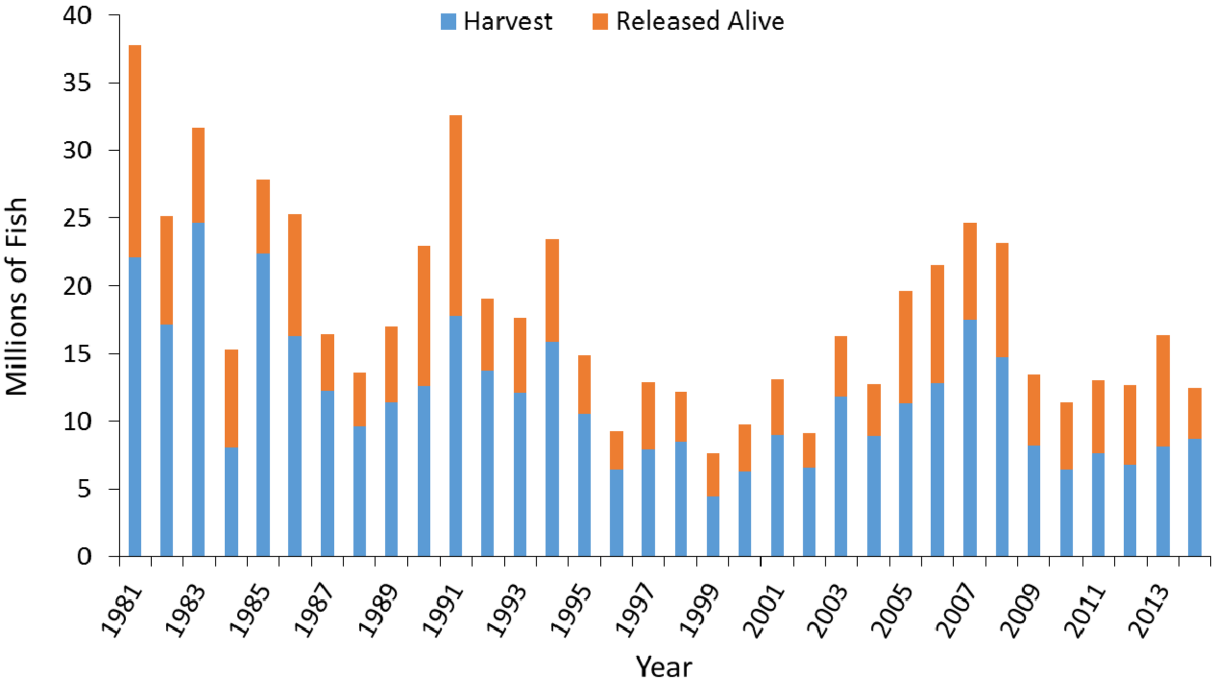


Figure 36. MRFSS and MRIP coastwide recreational harvest and released alive estimates of spot in millions of fish.

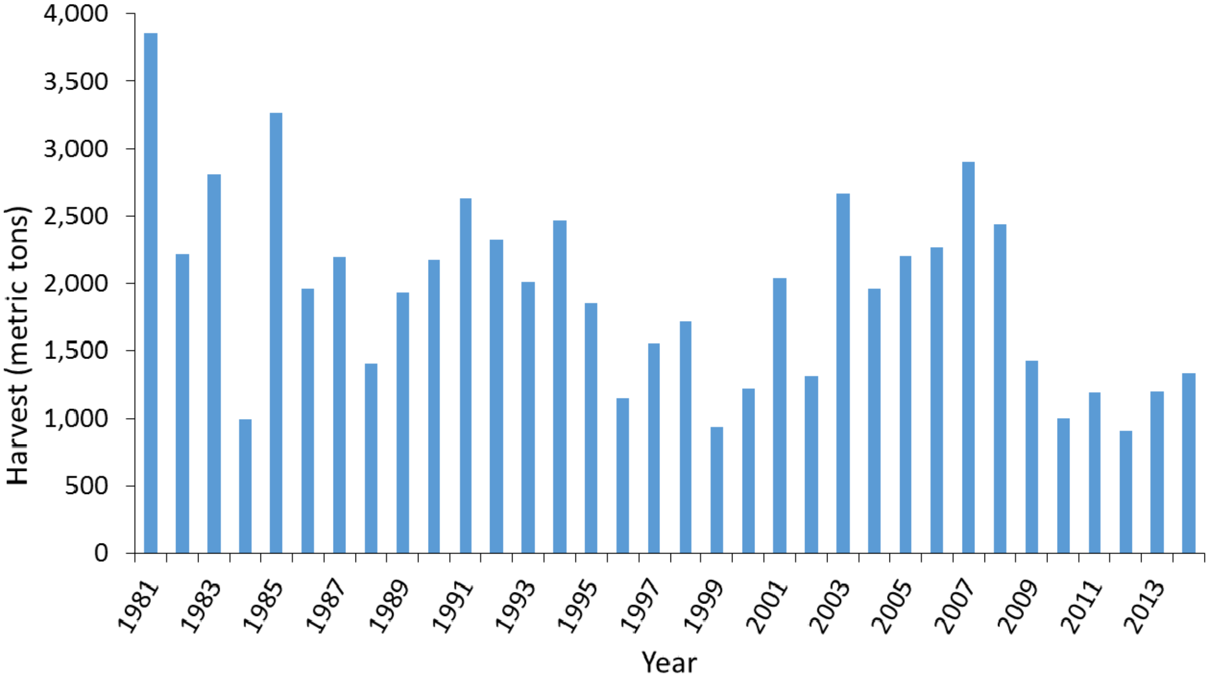


Figure 37. MRFSS and MRIP coastiwde recreational harvest of spot (metric tons).

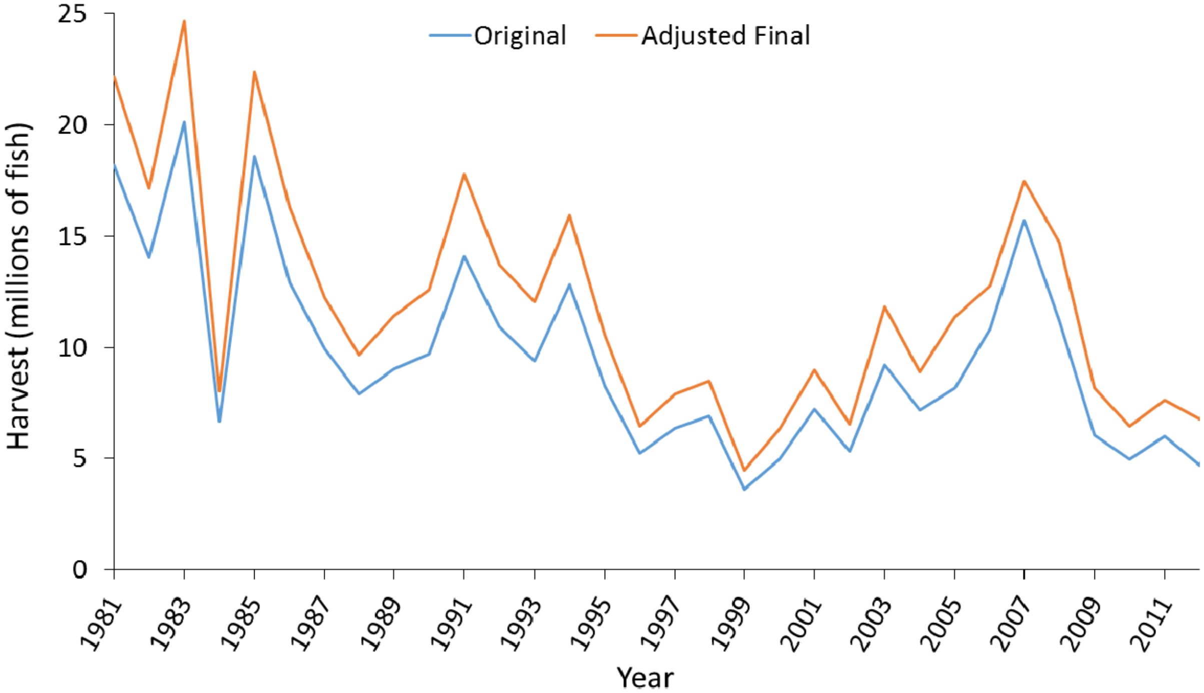


Figure 38. Comparison of MRFSS and MRIP recreational harvest estimates of spot (millions of fish) before (blue line) and after (orange line) adjustments.

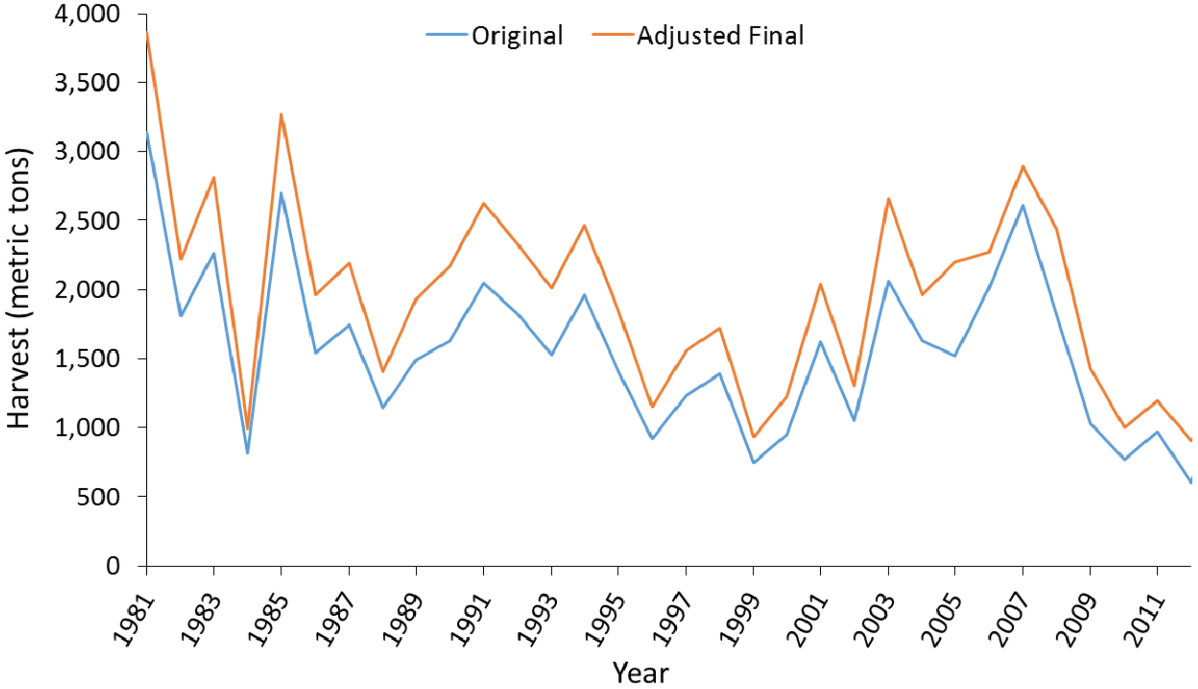


Figure 39. Comparison of MRFSS and MRIP recreational harvest estimates of spot (metric tons) before (blue line) and after (orange line) adjustments.

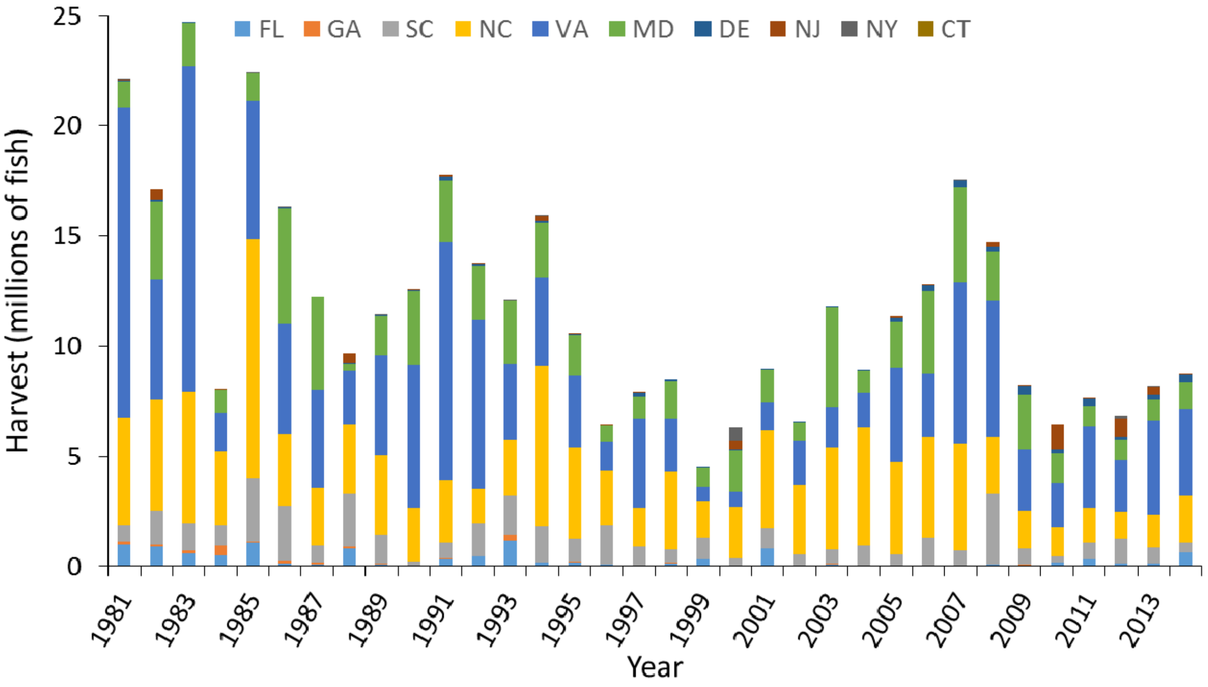


Figure 40. **MRFSS and MRIP recreational harvest estimates of spot (millions of fish) by state and year.**

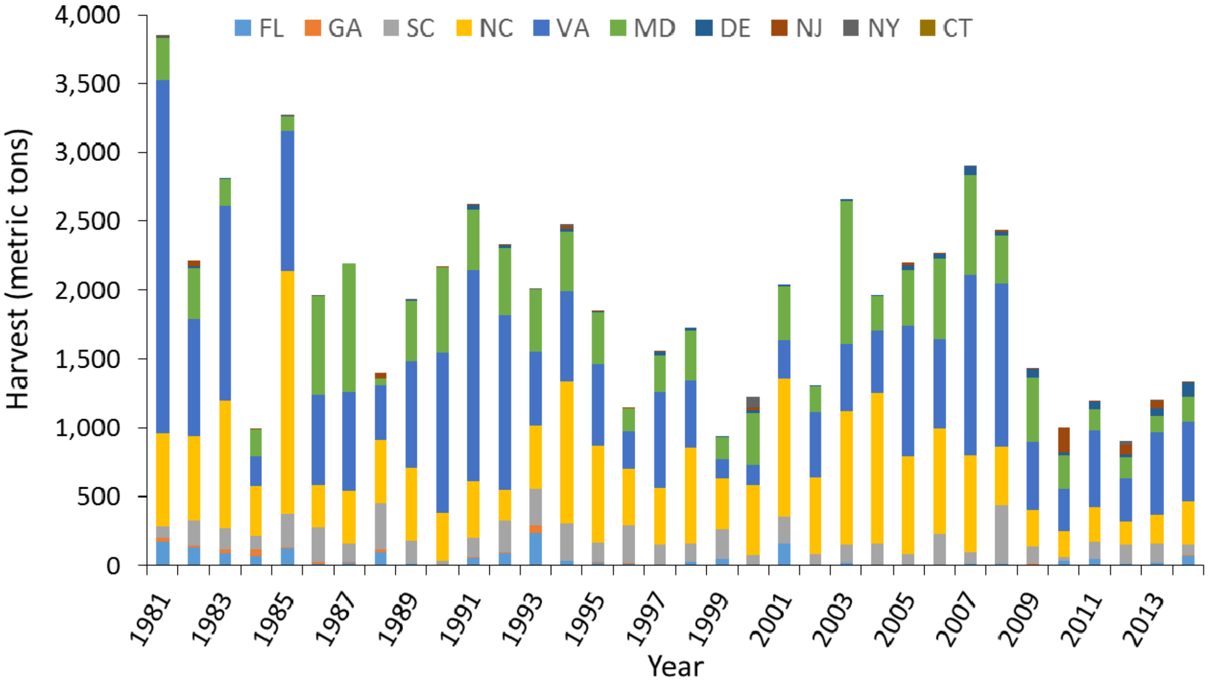


Figure 41. **MRFSS and MRIP recreational harvest estimates of spot (metric tons) by state and year.**

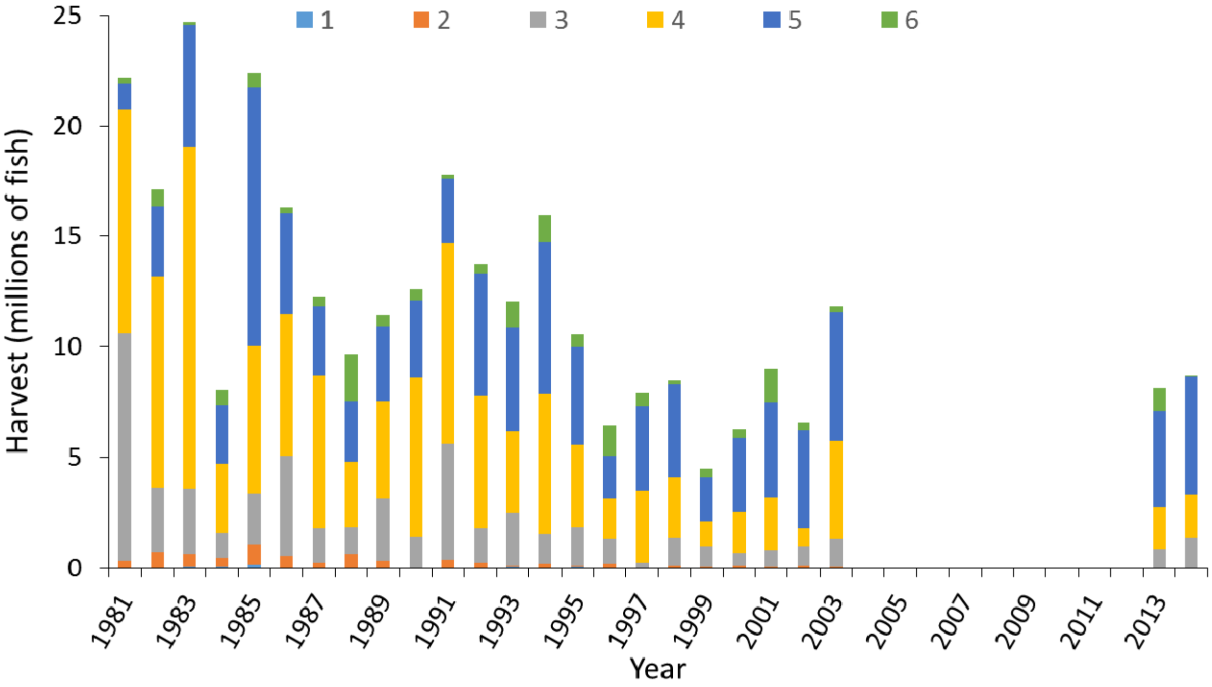


Figure 42. MRFSS and MRIP recreational harvest estimates of spot (millions of fish) by wave and year. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by wave from the provided SAS code.

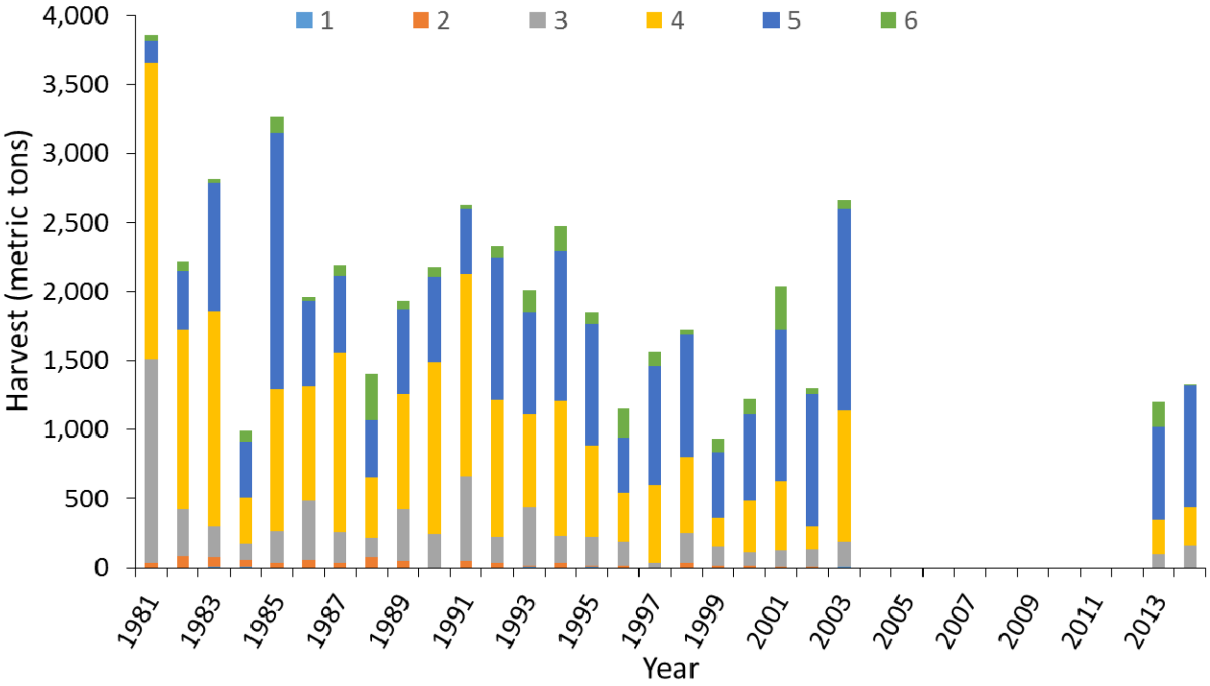


Figure 43. MRFSS and MRIP recreational harvest estimates of spot (metric tons) by wave and year. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by wave from the provided SAS code.

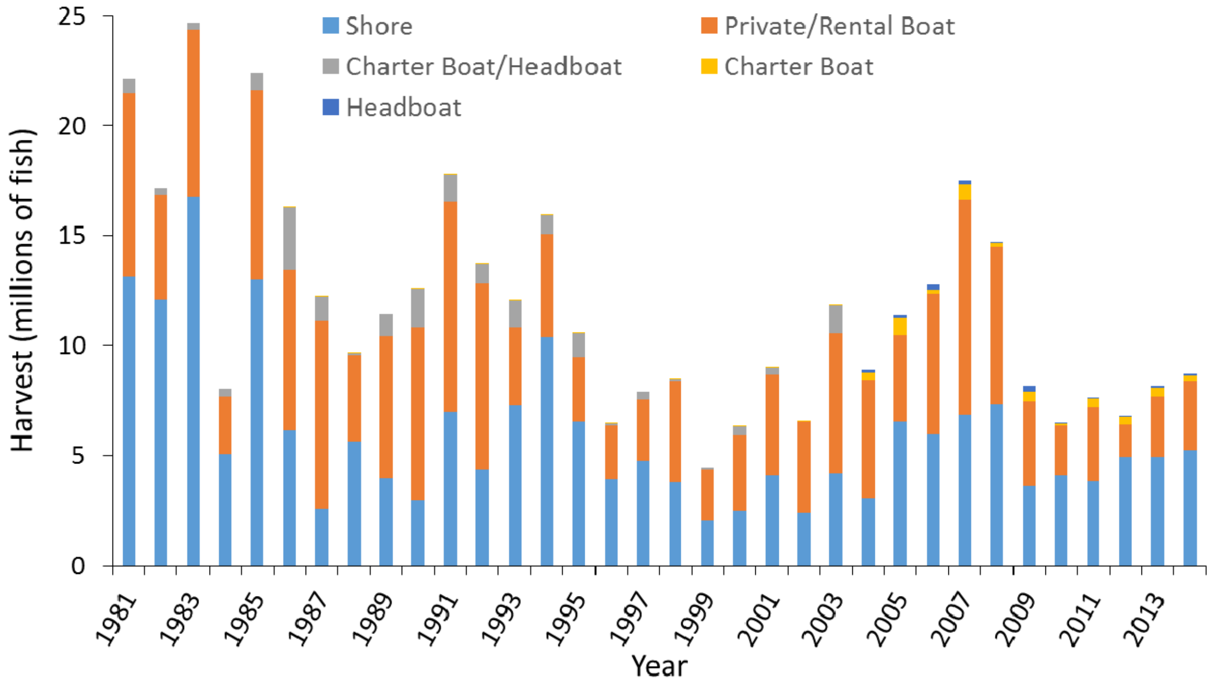


Figure 44. **MRFSS and MRIP recreational harvest estimates of spot (millions of fish) by mode and year.**

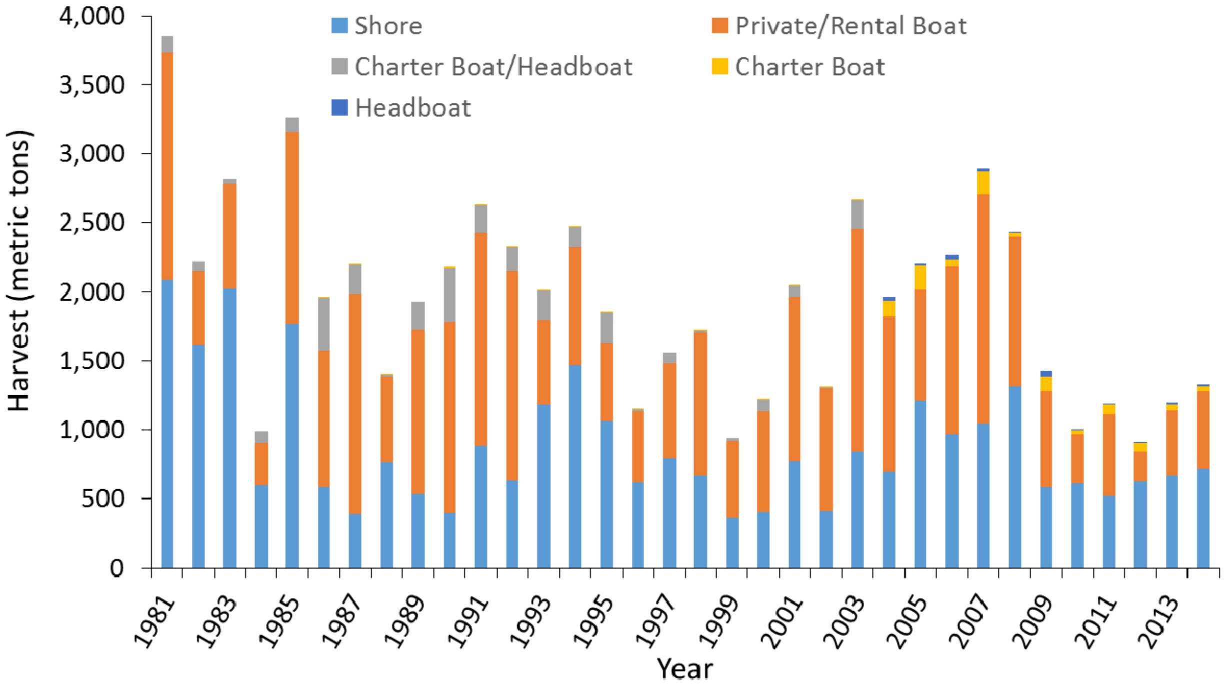


Figure 45. **MRFSS and MRIP recreational harvest estimates of spot (metric tons) by mode and year.**

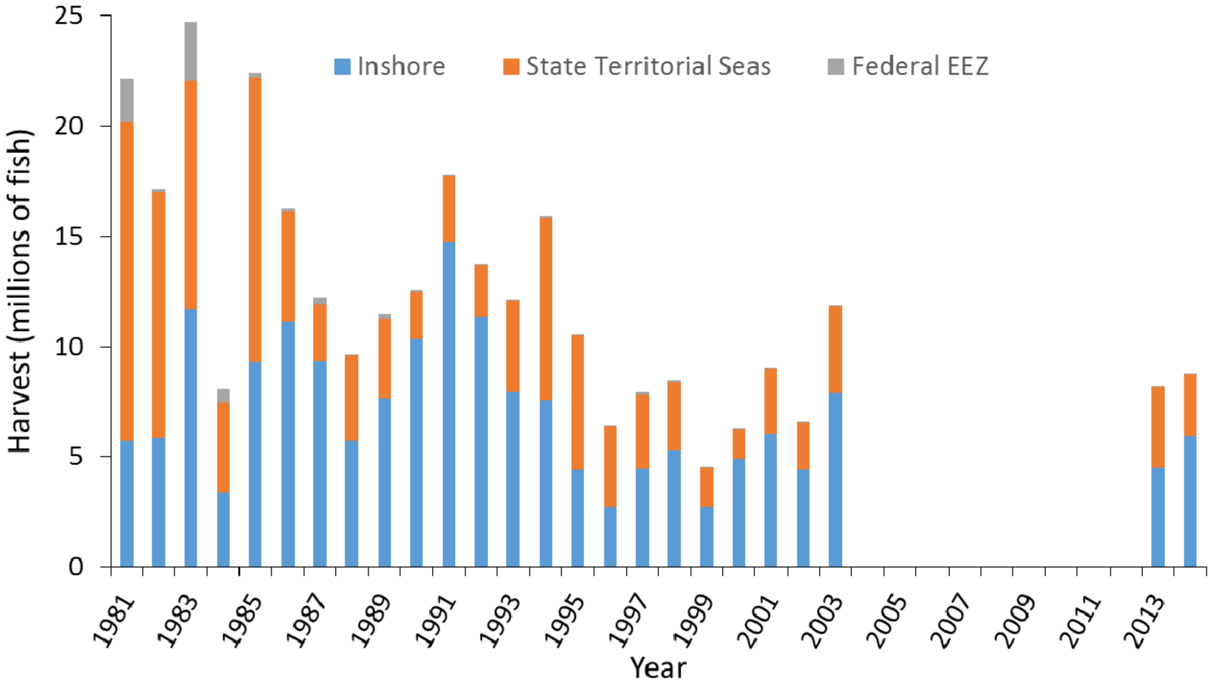


Figure 46. MRFSS and MRIP recreational harvest estimates of spot (millions of fish) by area and year. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by area from the provided SAS code.

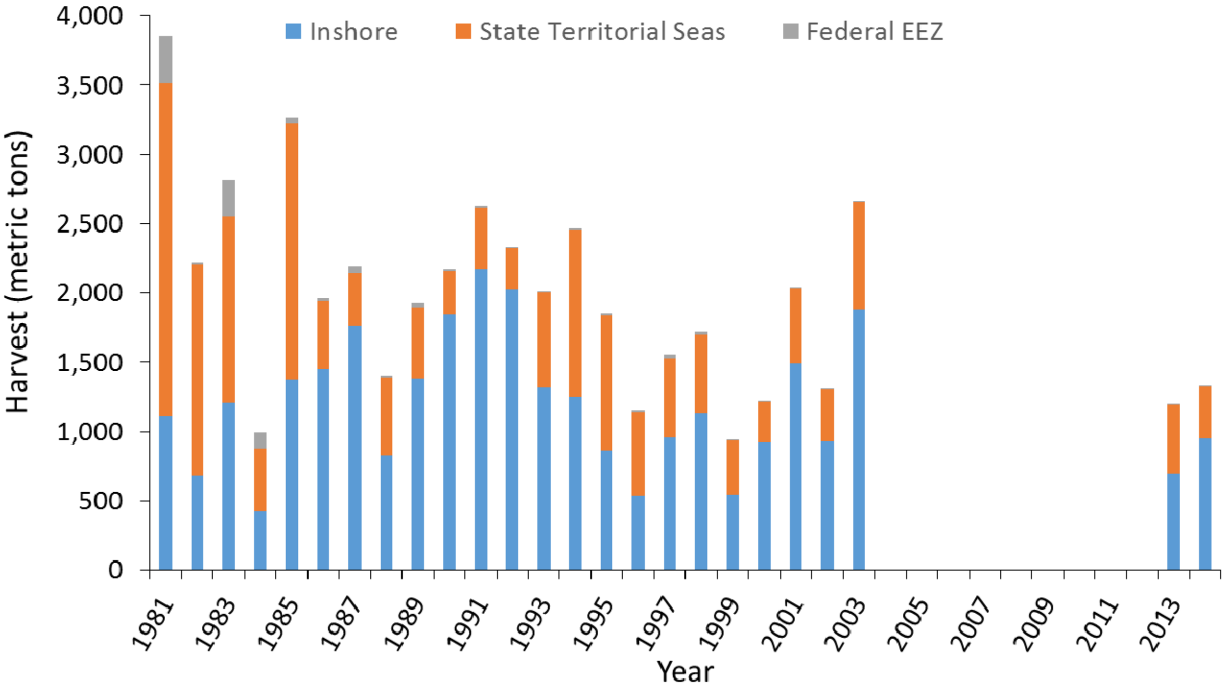


Figure 47. MRFSS and MRIP recreational harvest estimates of spot (metric tons) by area and year. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by area from the provided SAS code.

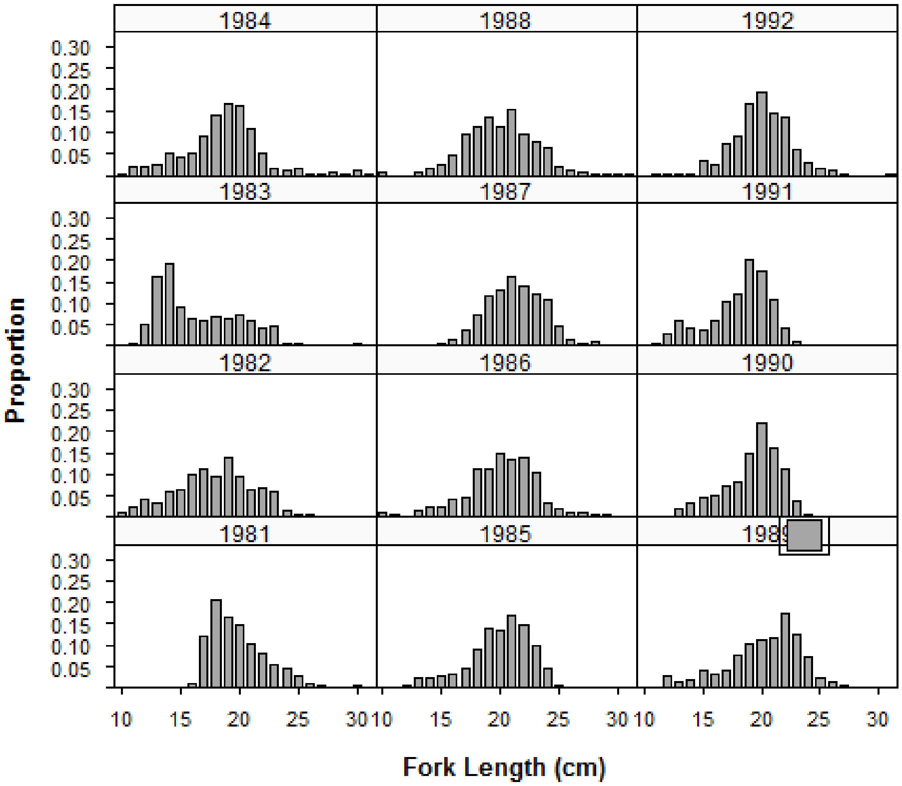


Figure 48. MRFSS and MRIP recreational harvest length frequency estimates for spot. The x-axes have been subset to exclude lengths that did not account for more than 1% of the annual harvest in any year (<10cm and >31cm).

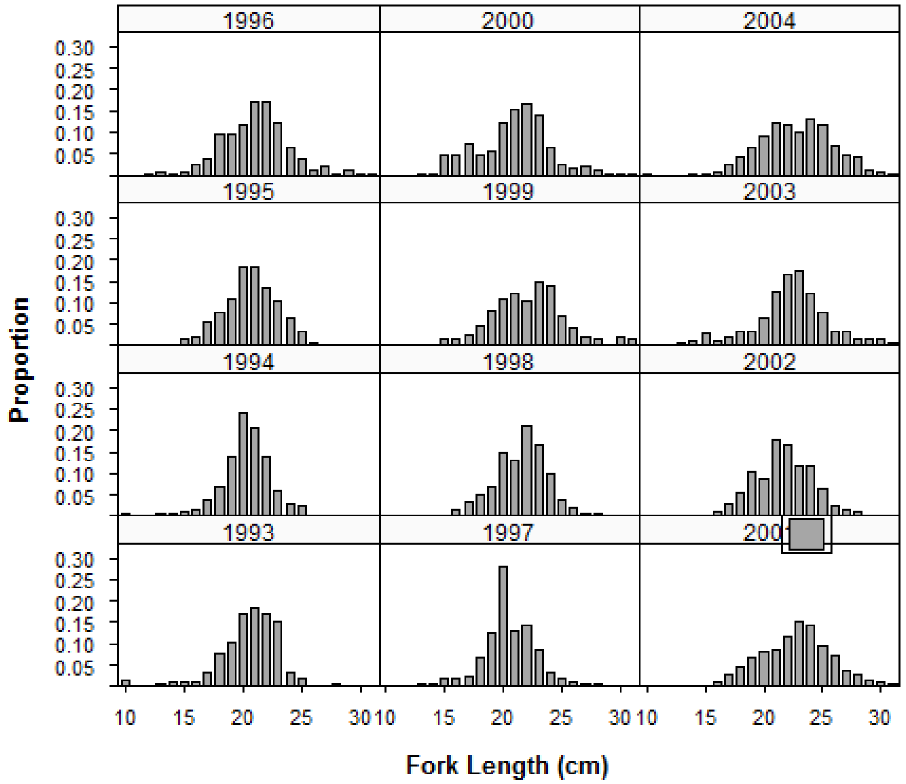


Figure 48. ***Continued.*** **MRFSS and MRIP recreational harvest length frequency estimates. The x-axes have been subset to exclude lengths that did not account for more than 1% of the annual harvest in any year (<10cm and >31cm).**

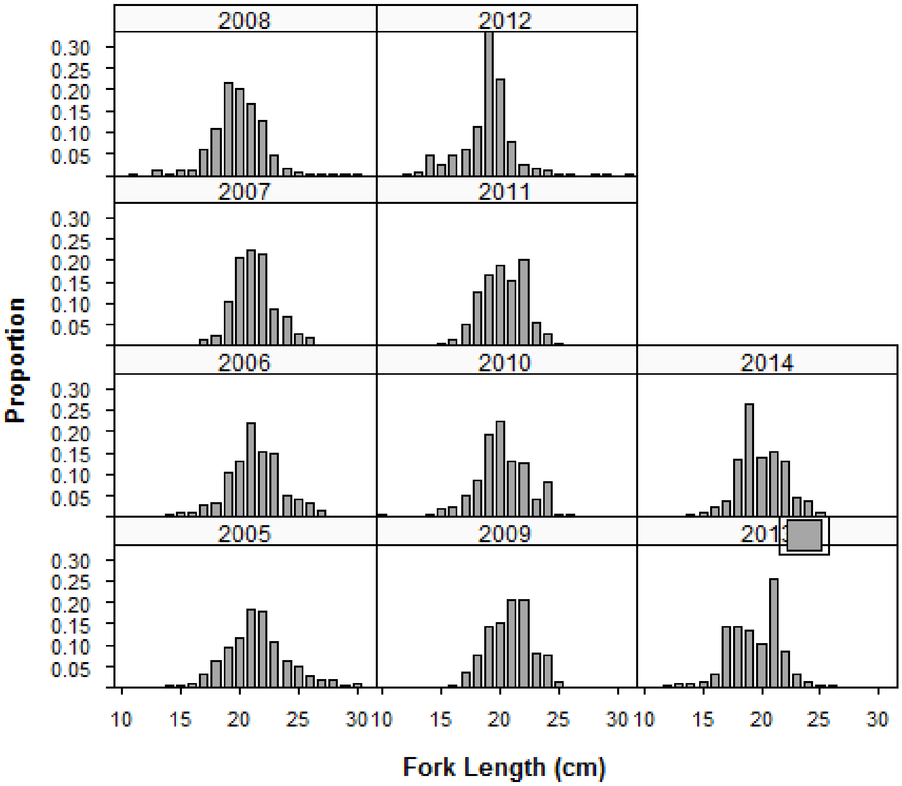


Figure 48. *Continued.* **MRFSS and MRIP recreational harvest length frequency estimates. The x-axes have been subset to exclude lengths that did not account for more than 1% of the annual harvest in any year (<10cm and >31cm).**

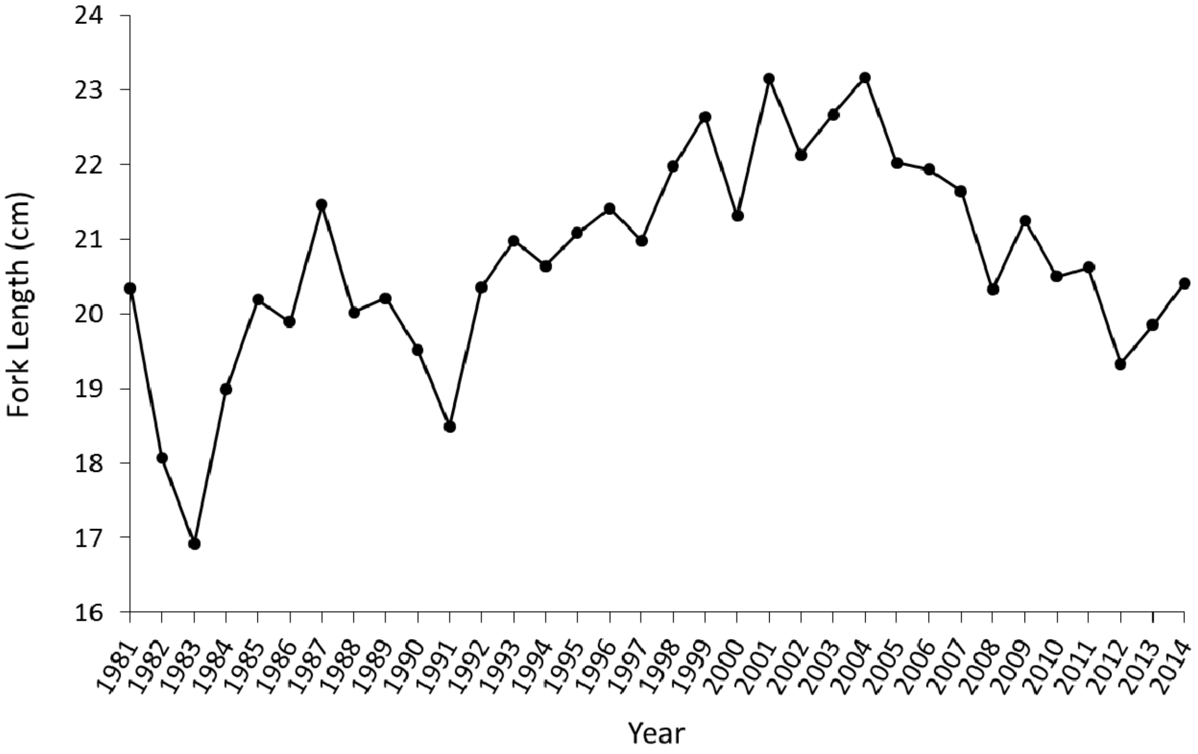


Figure 49. Annual mean fork length (cm) of spot harvested by recreational anglers on the Atlantic coast.

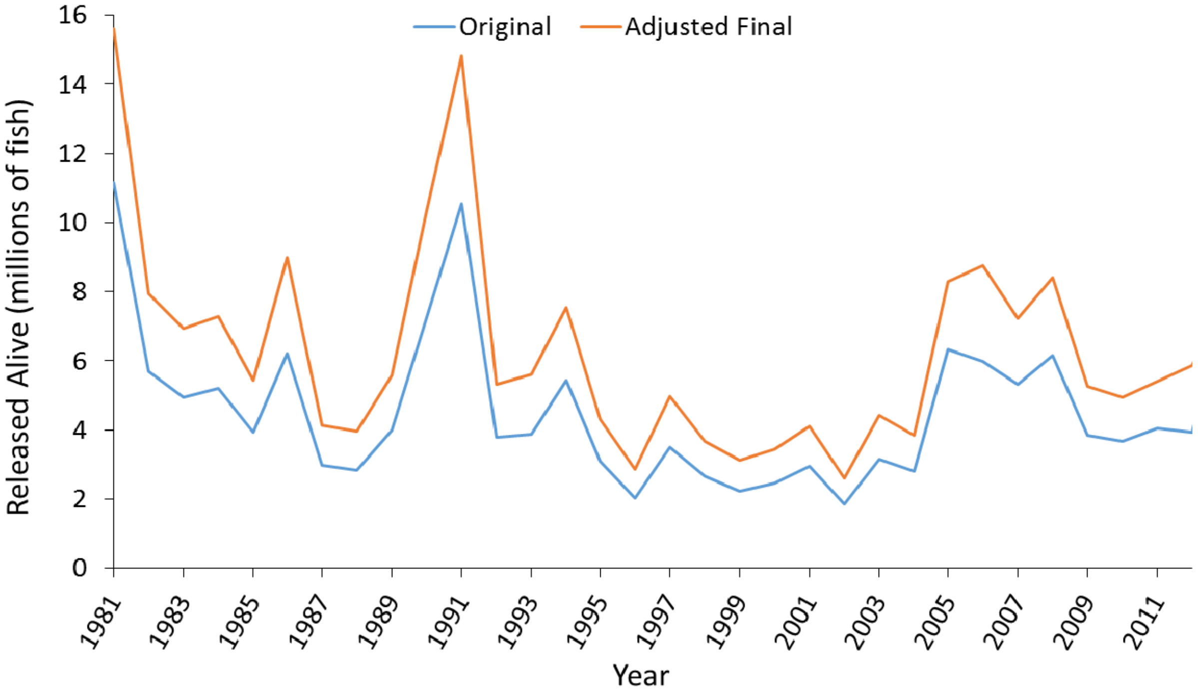


Figure 50. Comparison of MRFSS and MRIP recreational released alive estimates of spot (millions of fish) before (blue line) and after (orange line) adjustments.

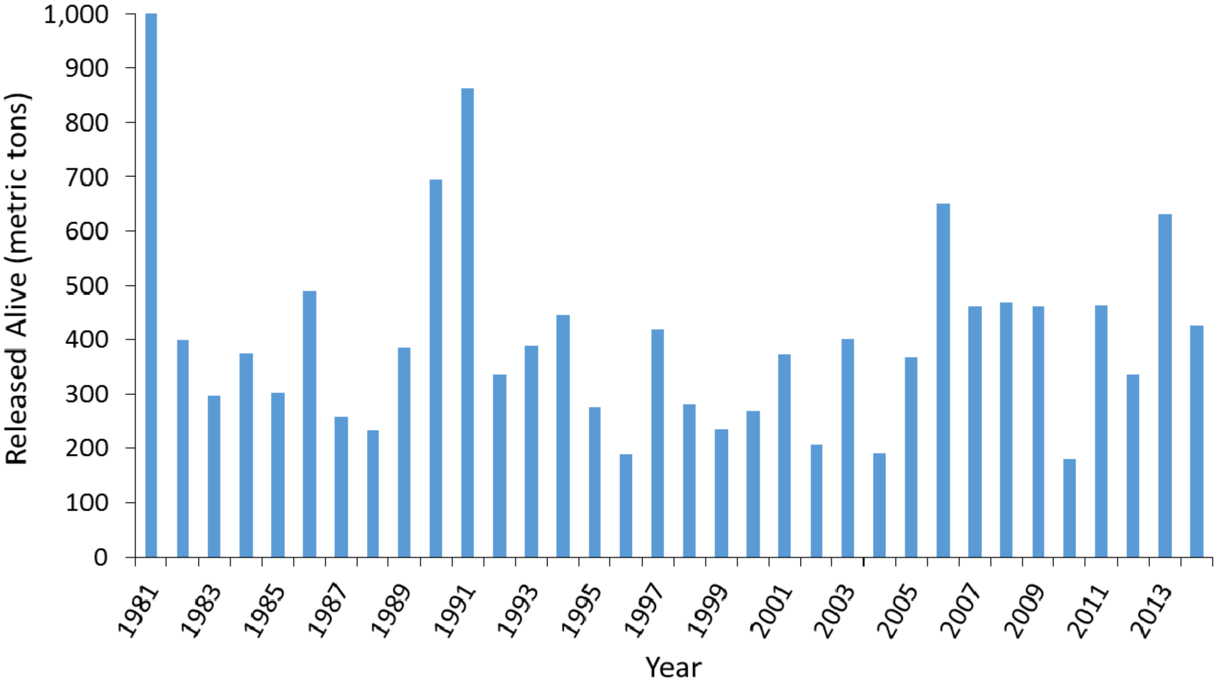


Figure 51. MRFSS and MRIP coastwide recreational live releases of spot (metric tons).

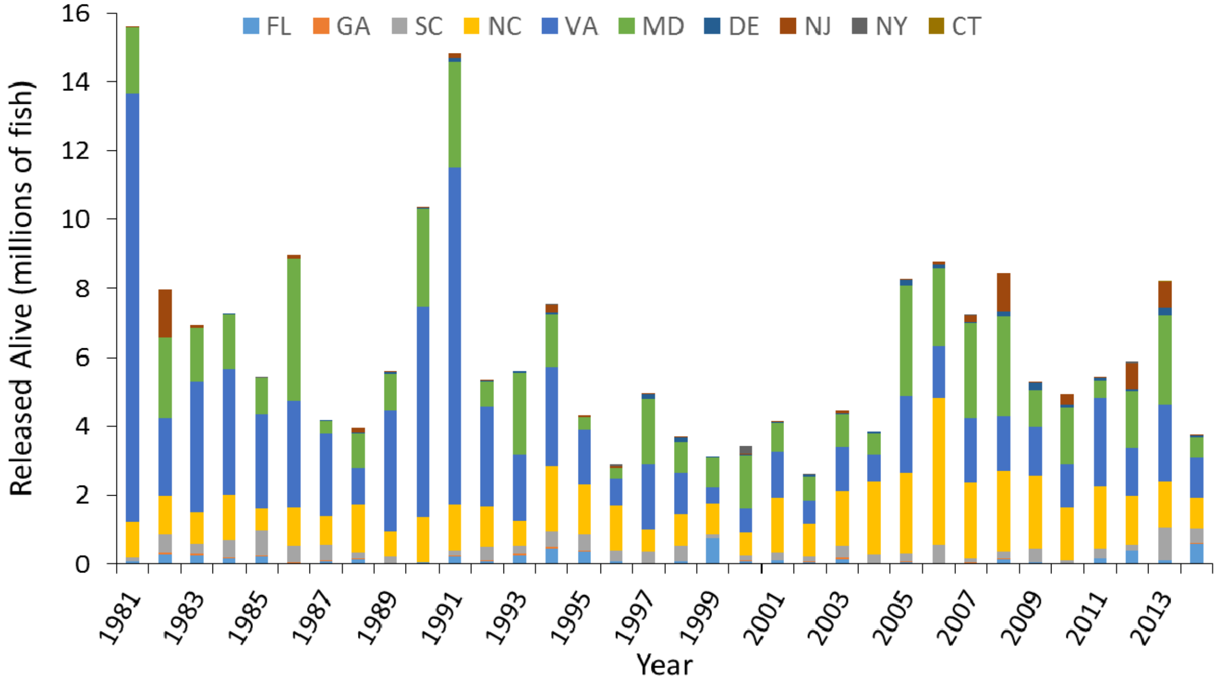


Figure 52. MRFSS and MRIP recreational released alive estimates of spot (millions of fish) by state and year.

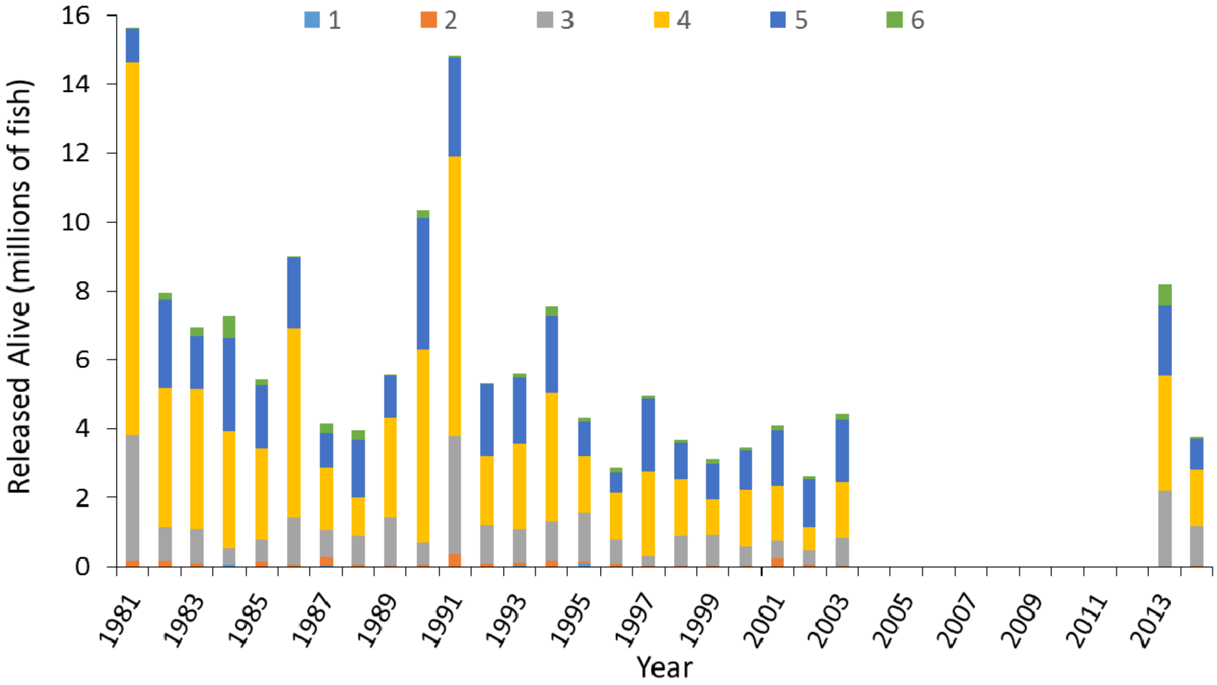


Figure 53. MRFSS and MRIP recreational released alive estimates of spot (millions of fish) by wave and year. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by wave from the provided SAS code.

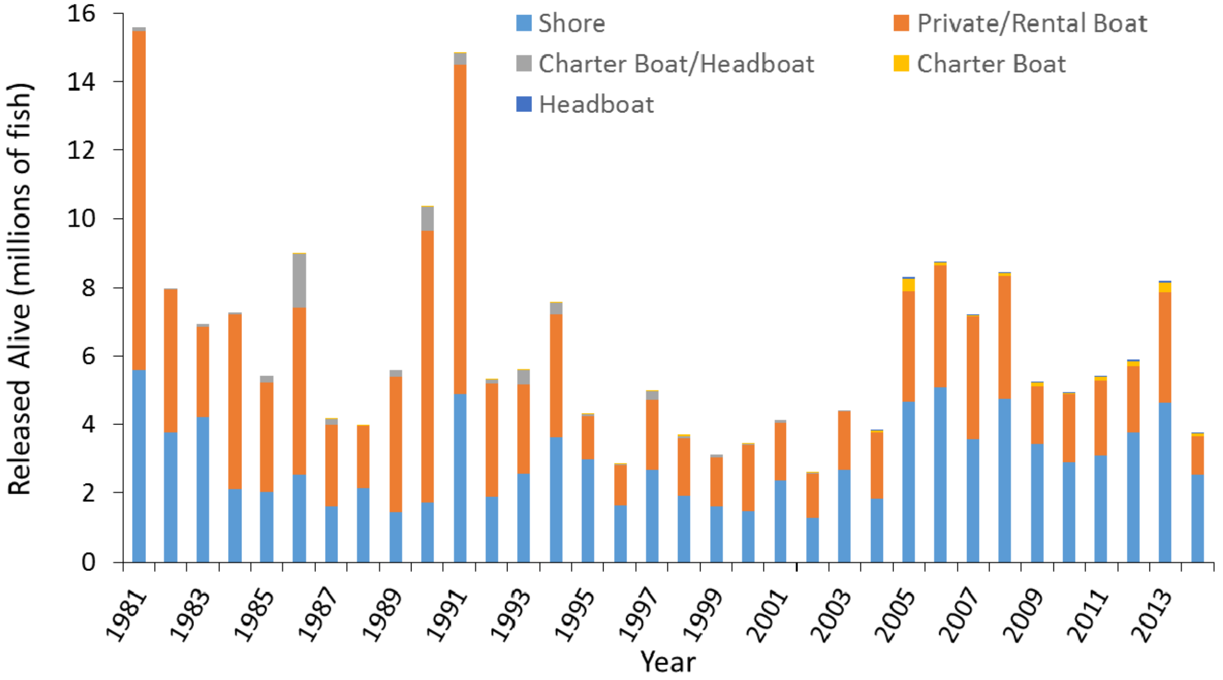


Figure 54. MRFSS and MRIP recreational released alive estimates of spot (millions of fish) by mode and year.

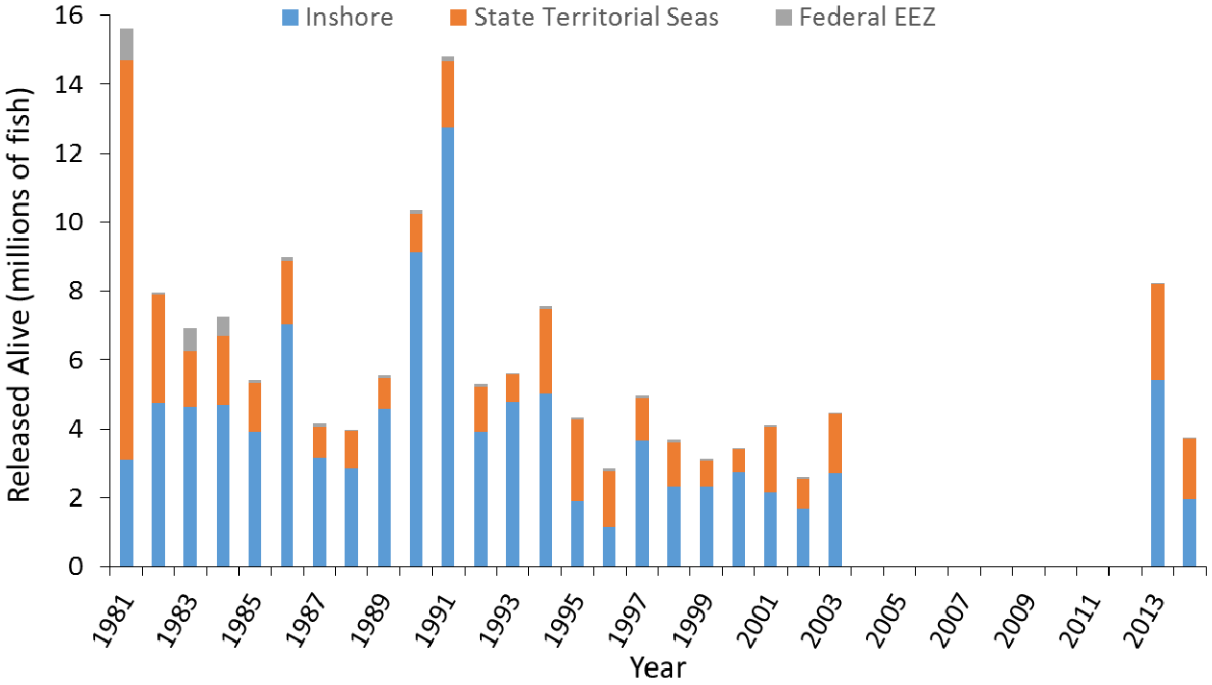


Figure 55. MRFSS and MRIP recreational released alive estimates of spot (millions of fish) by area and year. Estimates adjusted for the change in the APAIS design (2004-2012) are not provided by area from the provided SAS code.

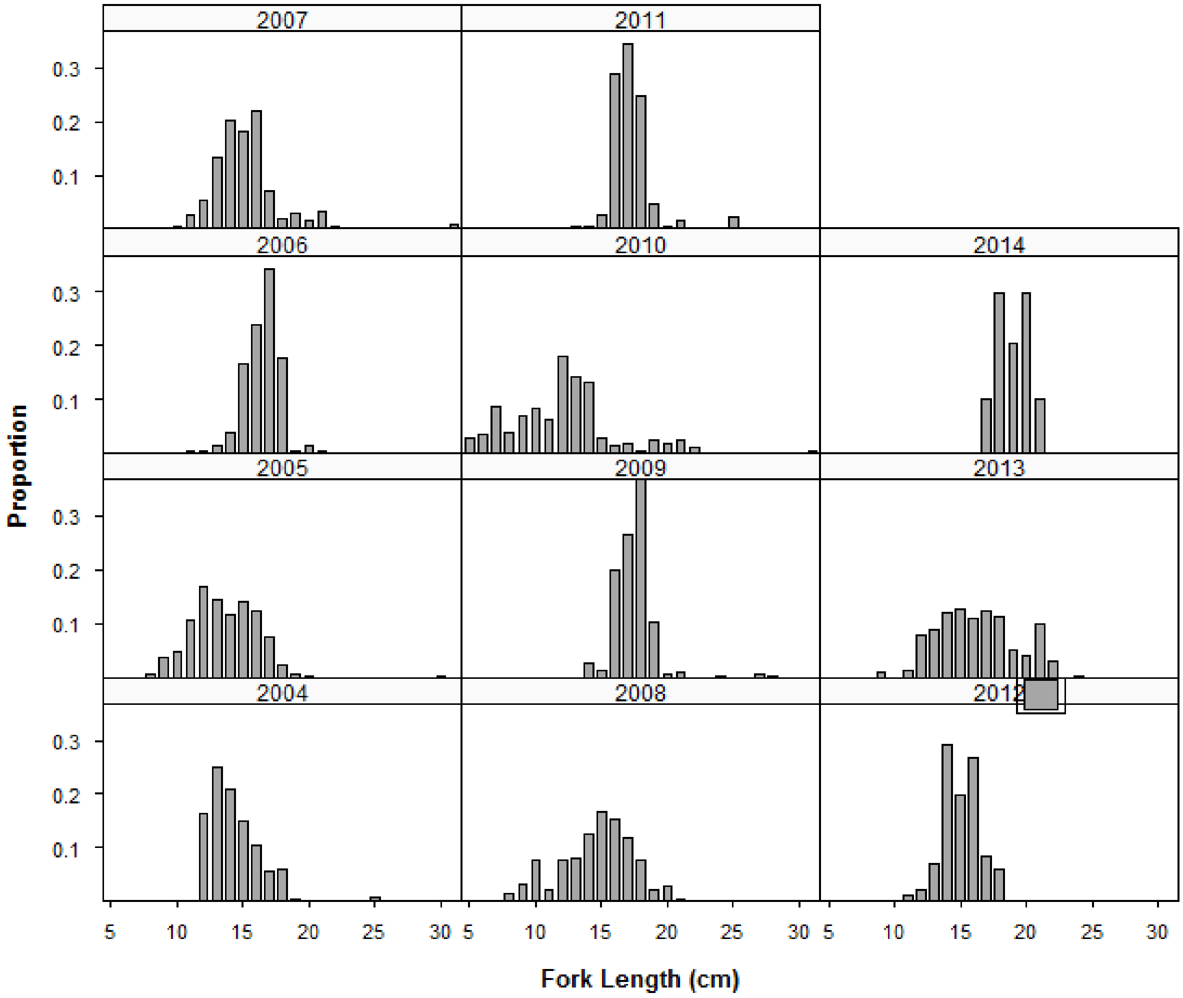


Figure 56. Annual size compositions of spot caught and released on headboats estimated from MRIP type 9 sampling data.

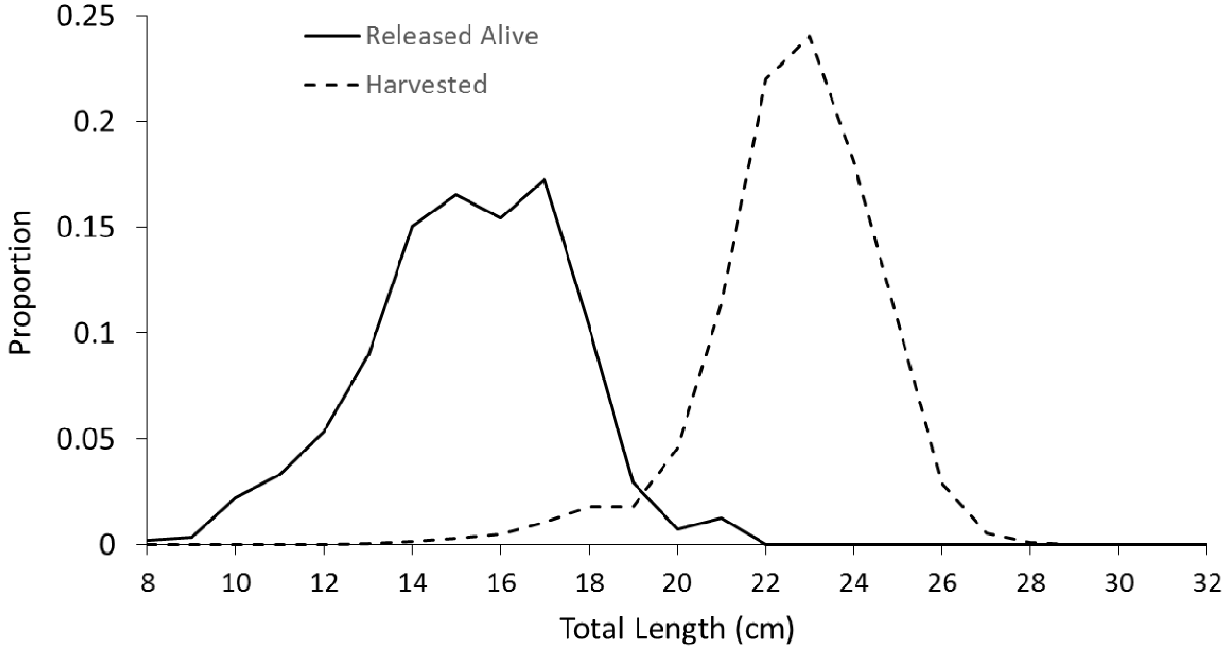


Figure 57. **Aggregate length frequency of spot sampled by the MD DNR Headboat Creel Survey during 1997-2000.**

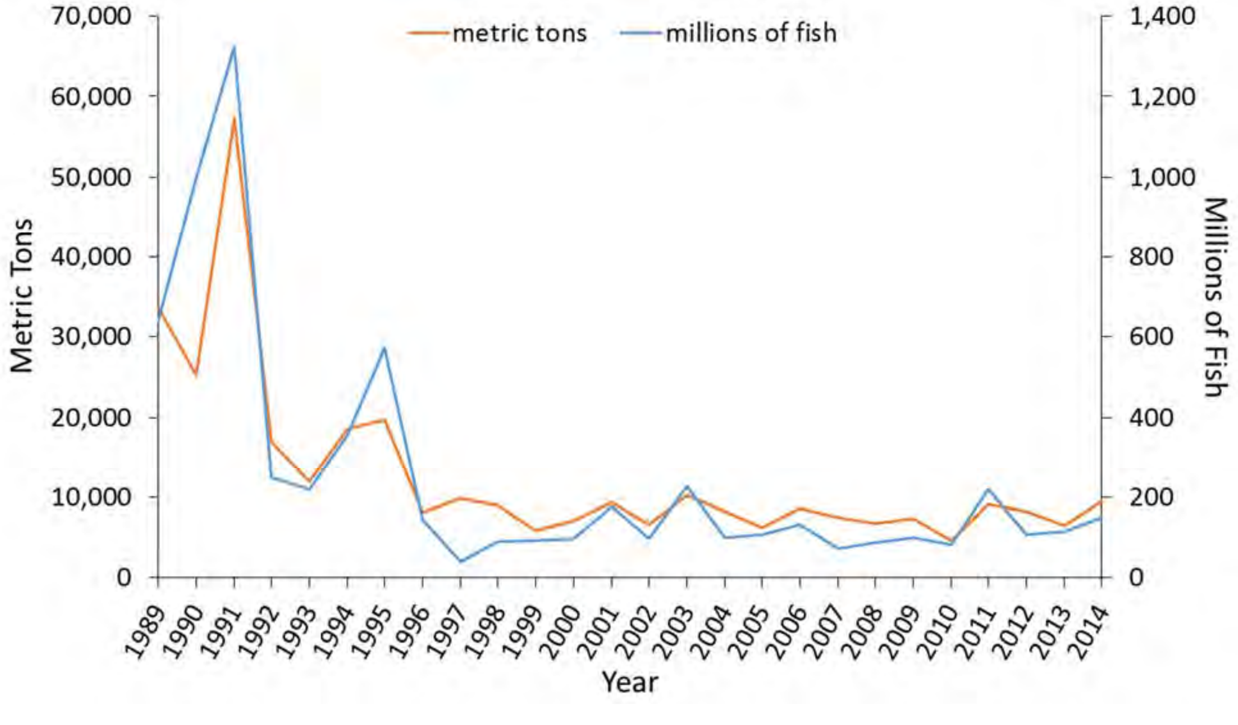


Figure 58. **Coastwide removals of spot combined across fisheries in metric tons (orange line) and millions of fish (blue line). 1989 is the first year removal data from all fisheries are available.**

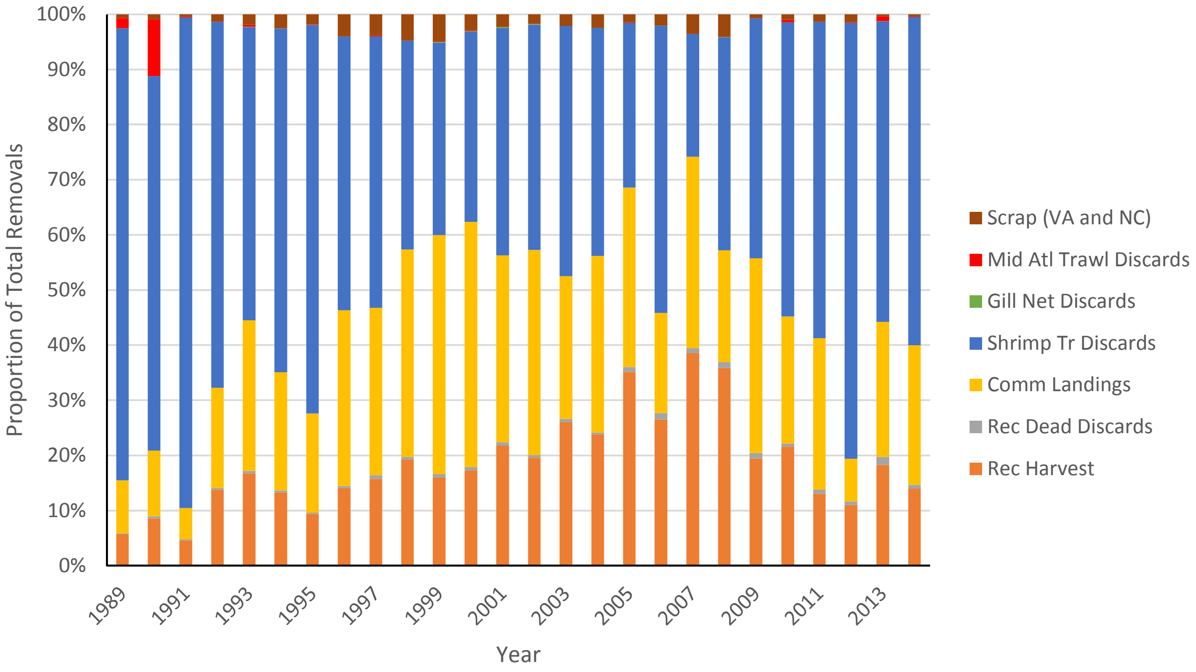


Figure 59. Annual percentage of total spot removals by fishery source on the Atlantic coast.

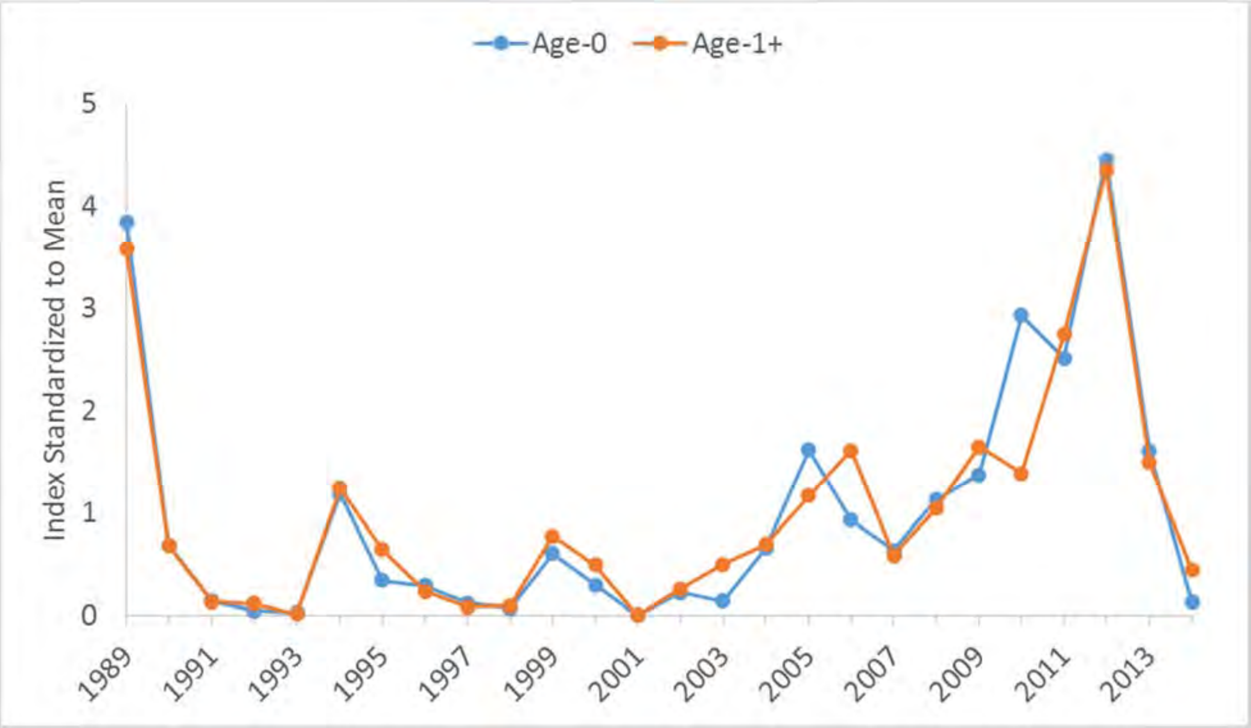


Figure 60. Age-0 and Age-1+ relative abundance indices developed from the fall months and offshore strata of the NMFS Trawl Survey. Indices were developed in numbers per tow and then standardized to their mean.

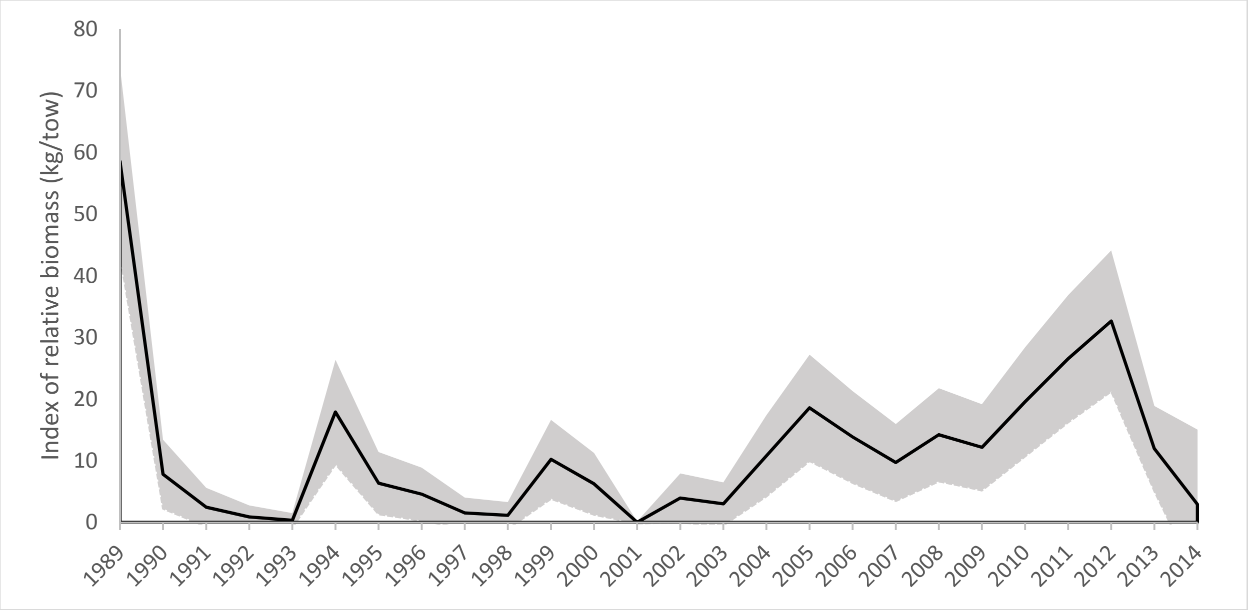


Figure 61. **Index of relative biomass developed from the fall months (September – November) and offshore strata of the NMFS Trawl Survey for 1989-2014 with 95% confidence intervals.**

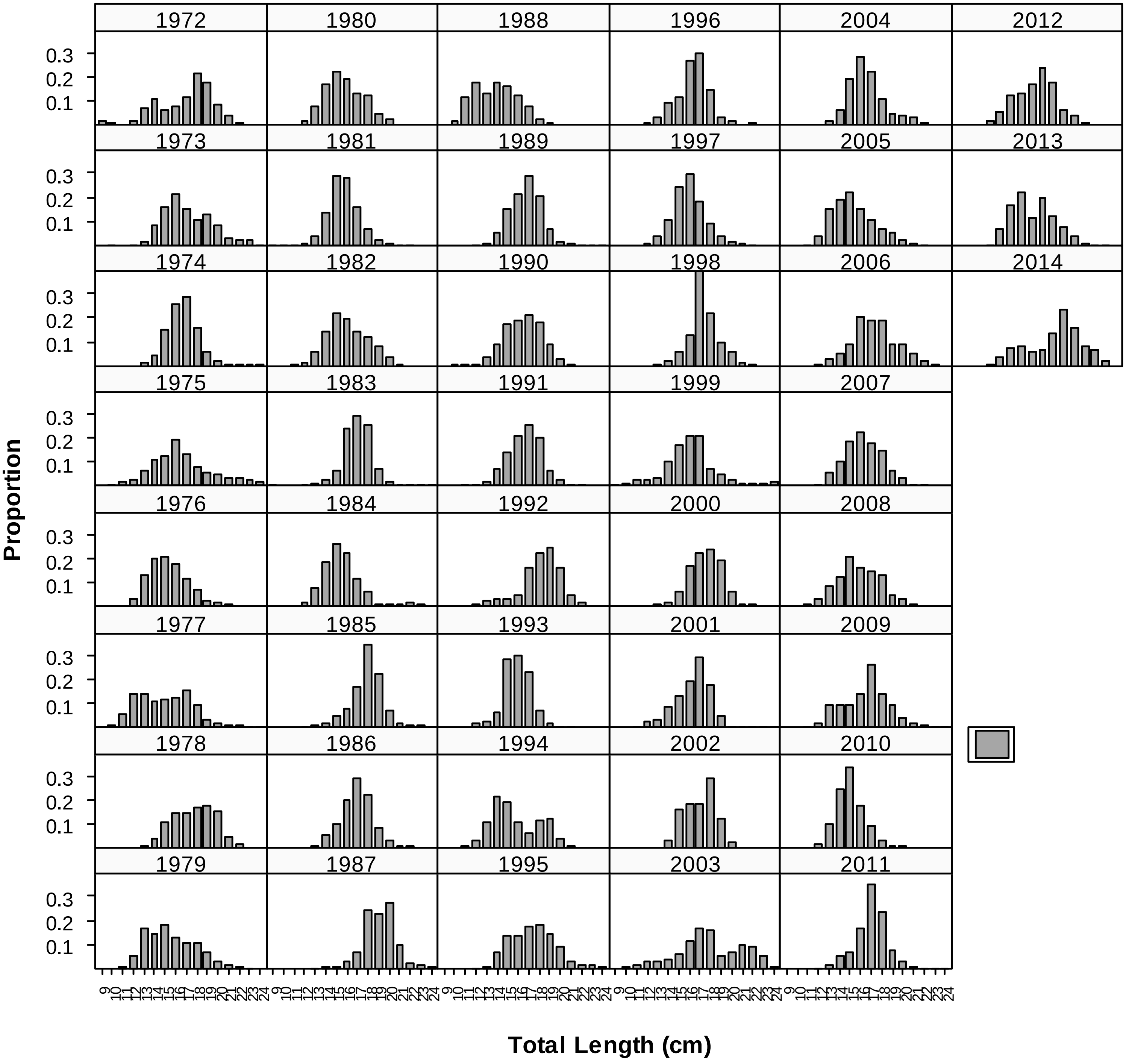


Figure 62. **Annual length frequency of spot caught in the NMFS Trawl Survey from 1972-2014.**

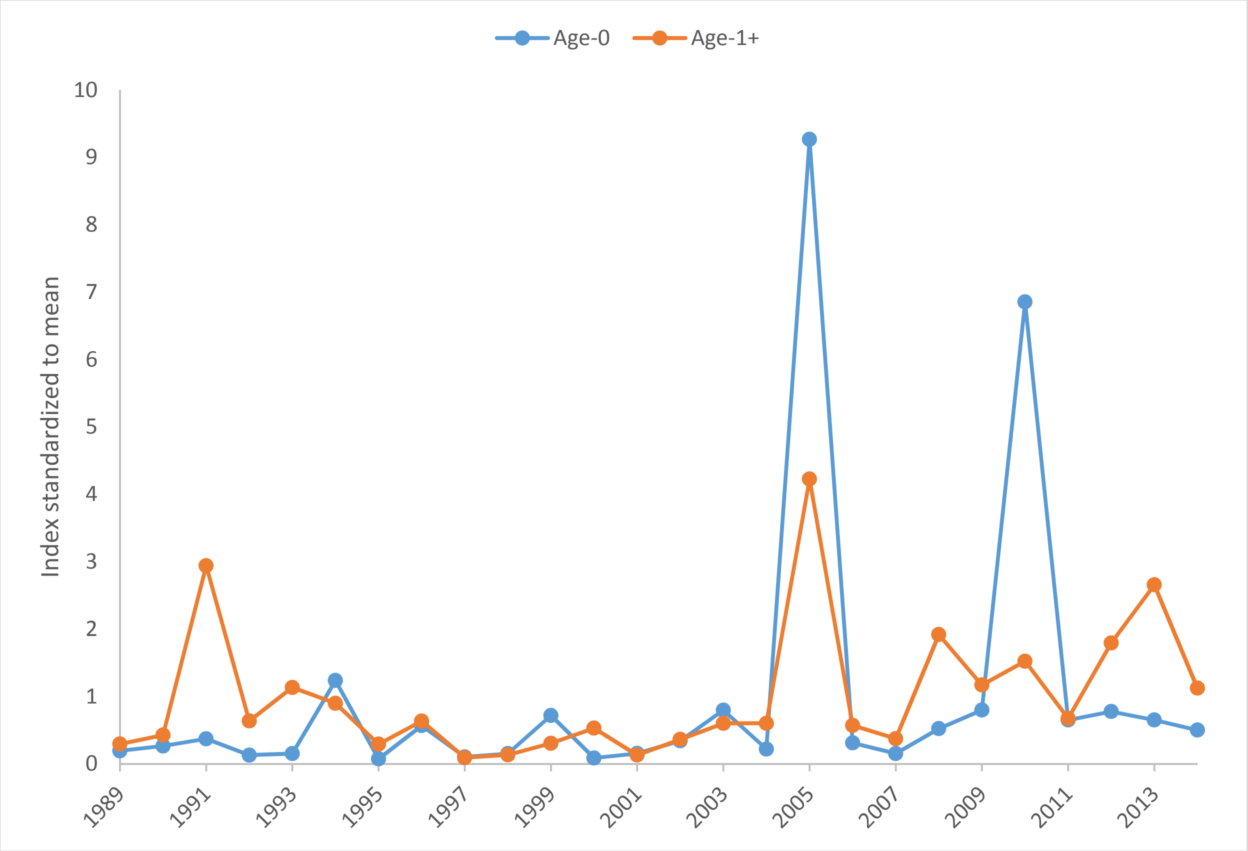


Figure 63. Age-0 and Age-1+ relative abundance indices developed from the fall months of the SEAMAP Trawl Survey. Indices were developed in numbers per tow and then standardized to their mean.

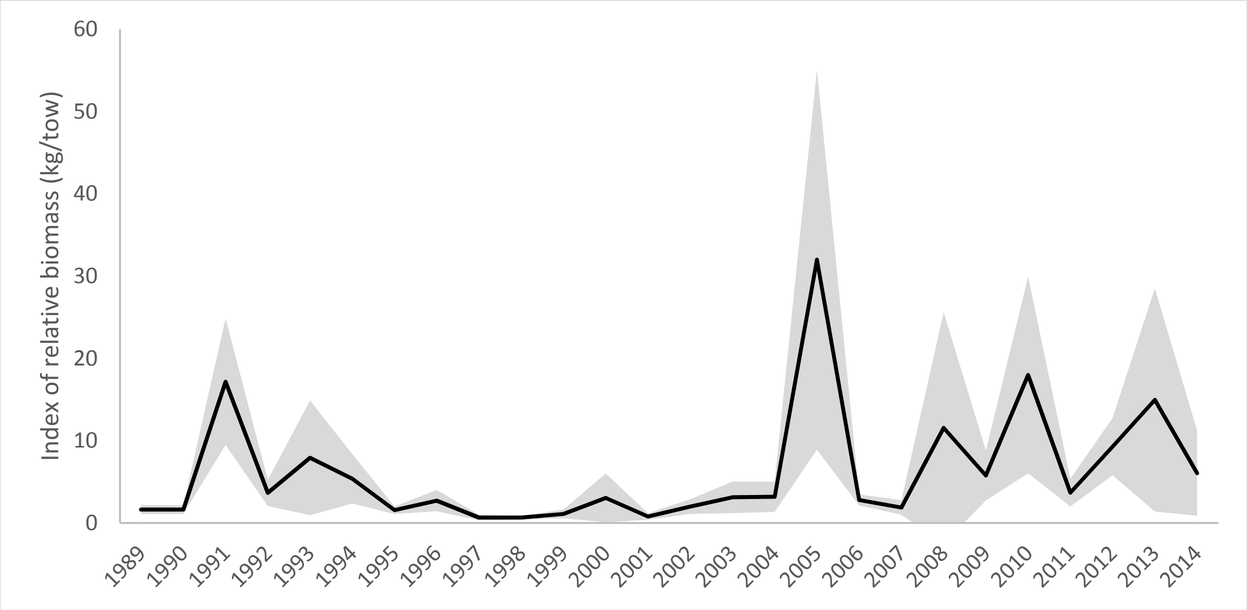


Figure 64. Index of relative biomass of spot developed from the fall (September-November) months of the SEAMAP Trawl Survey (1989-2014).

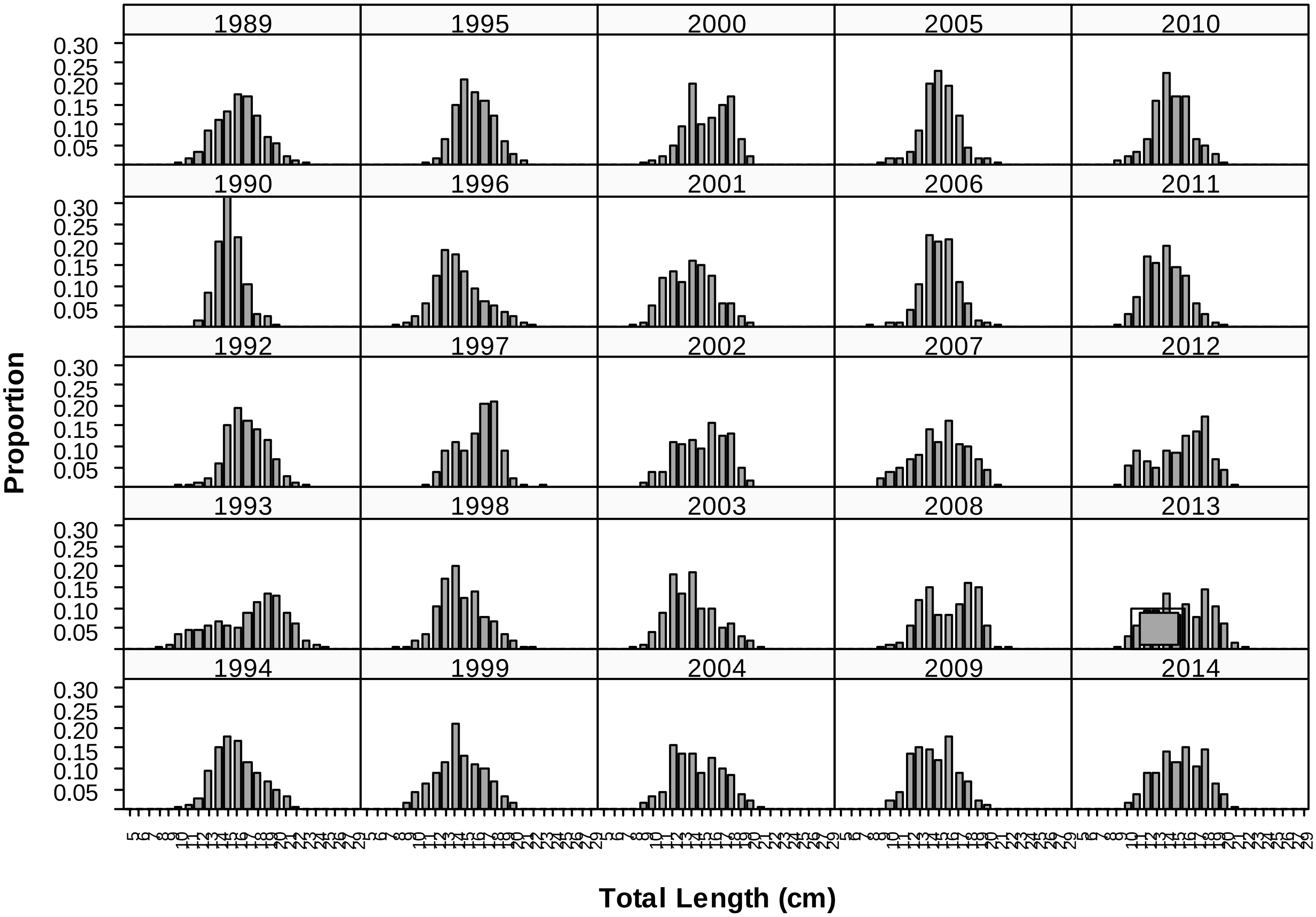


Figure 65. Annual length frequency of spot caught in the SEAMAP Trawl Survey from 1989-2014. Data from 1991 were not available.

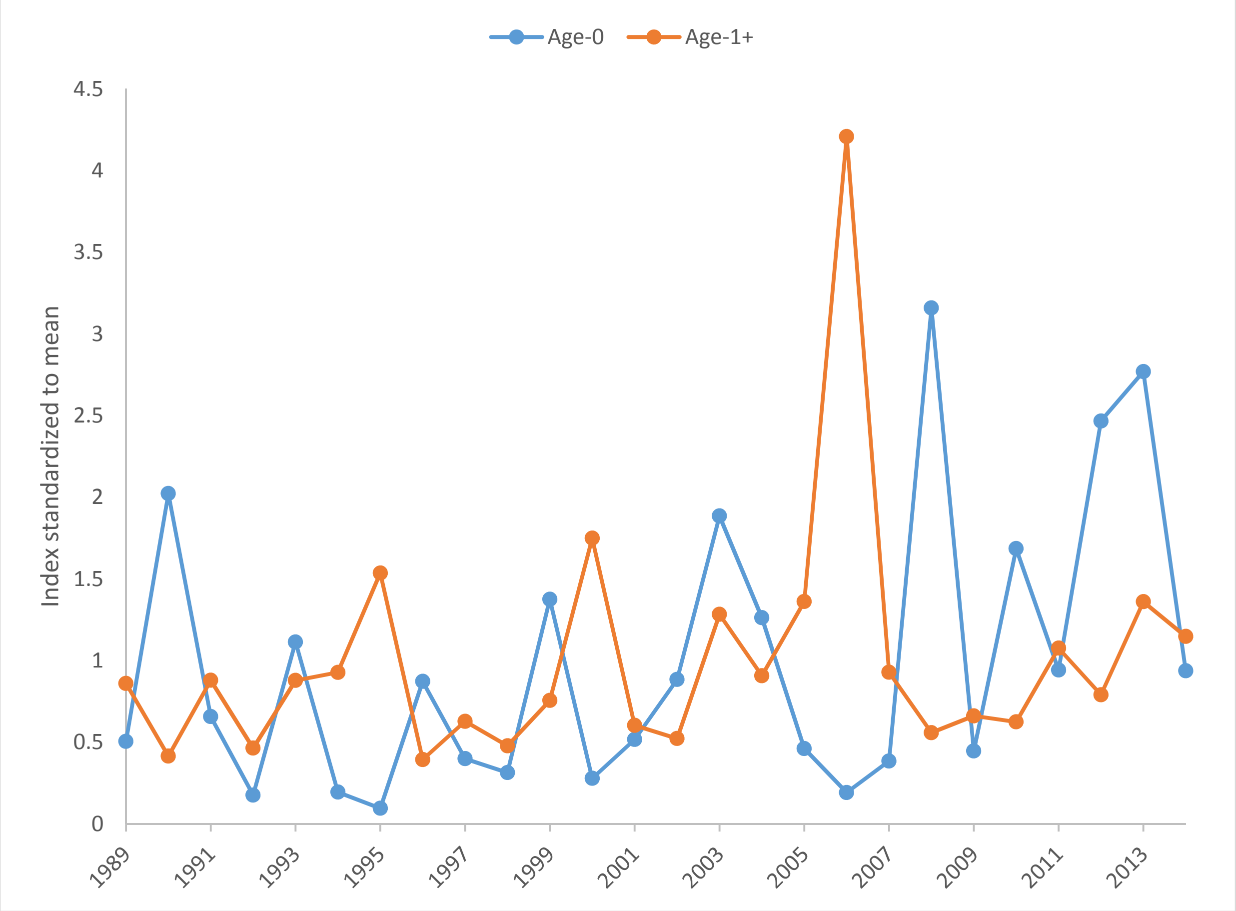


Figure 66. **Age-0 and Age-1+ relative abundance indices developed from the June component of the NCDMF Trawl Survey. Indices were developed in numbers per tow and then standardized to their mean.**

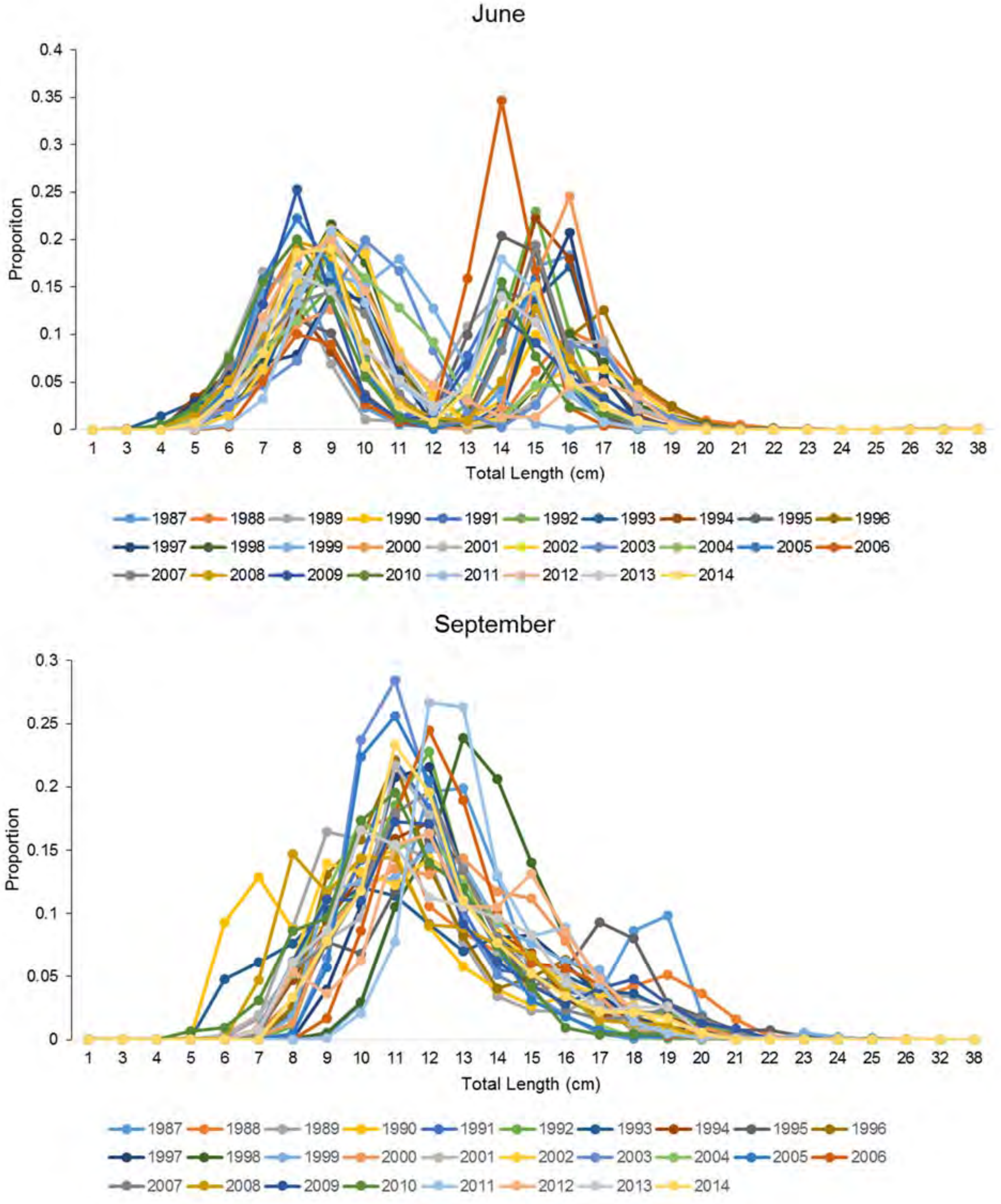


Figure 67. **Annual length frequencies of spot caught in the NC DMF Trawl Survey during June (top figure) and September (bottom figure).**

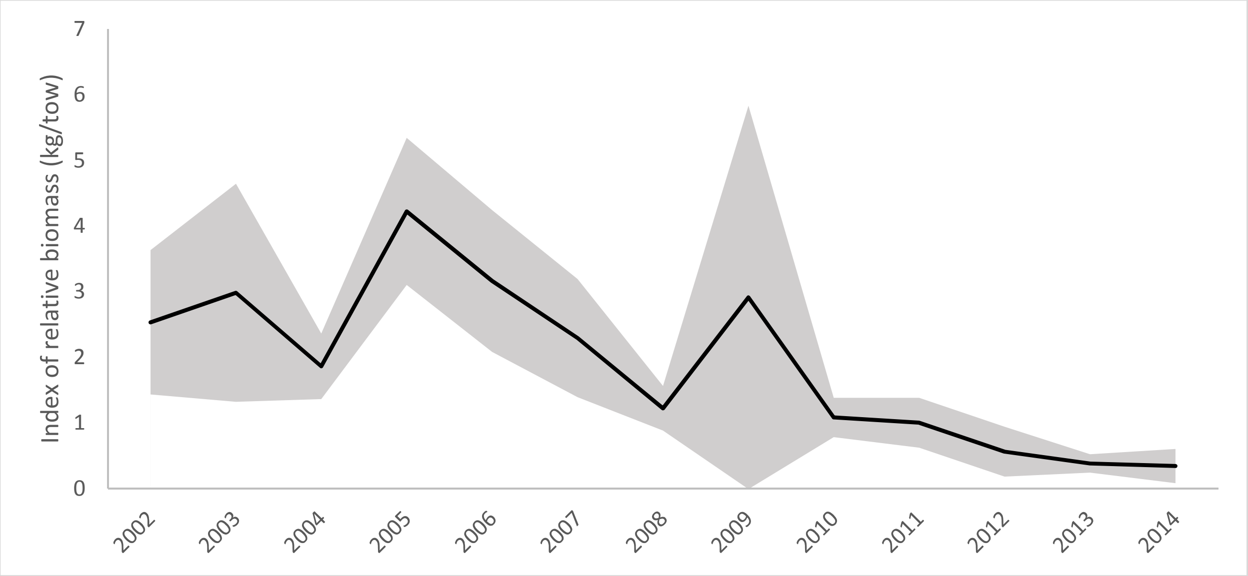


Figure 68. Index of relative biomass for spot developed from the May-September component of the ChesMMAP Trawl Survey in Regions 4-5 only.

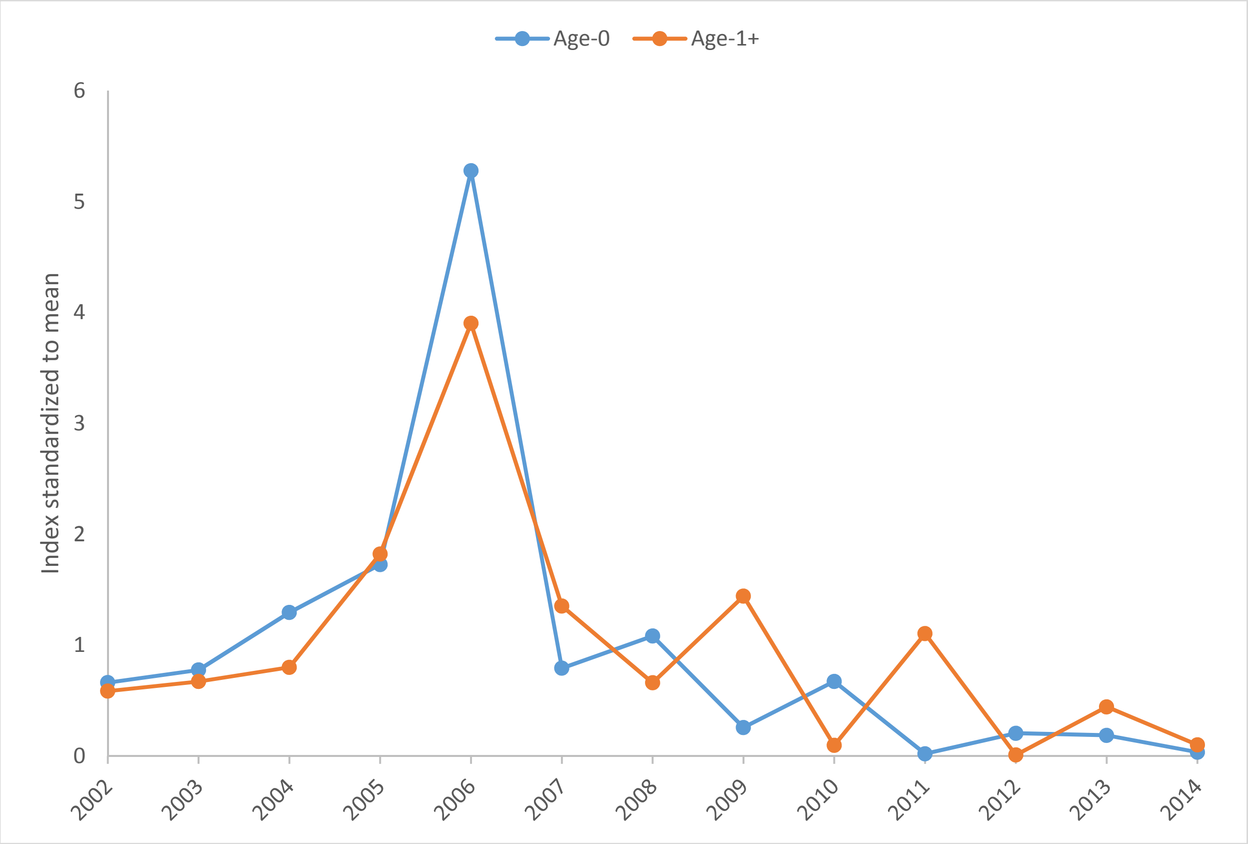


Figure 69. Index of relative abundance for age-0 and age-1+ spot developed from the ChesMMAP Trawl Survey.

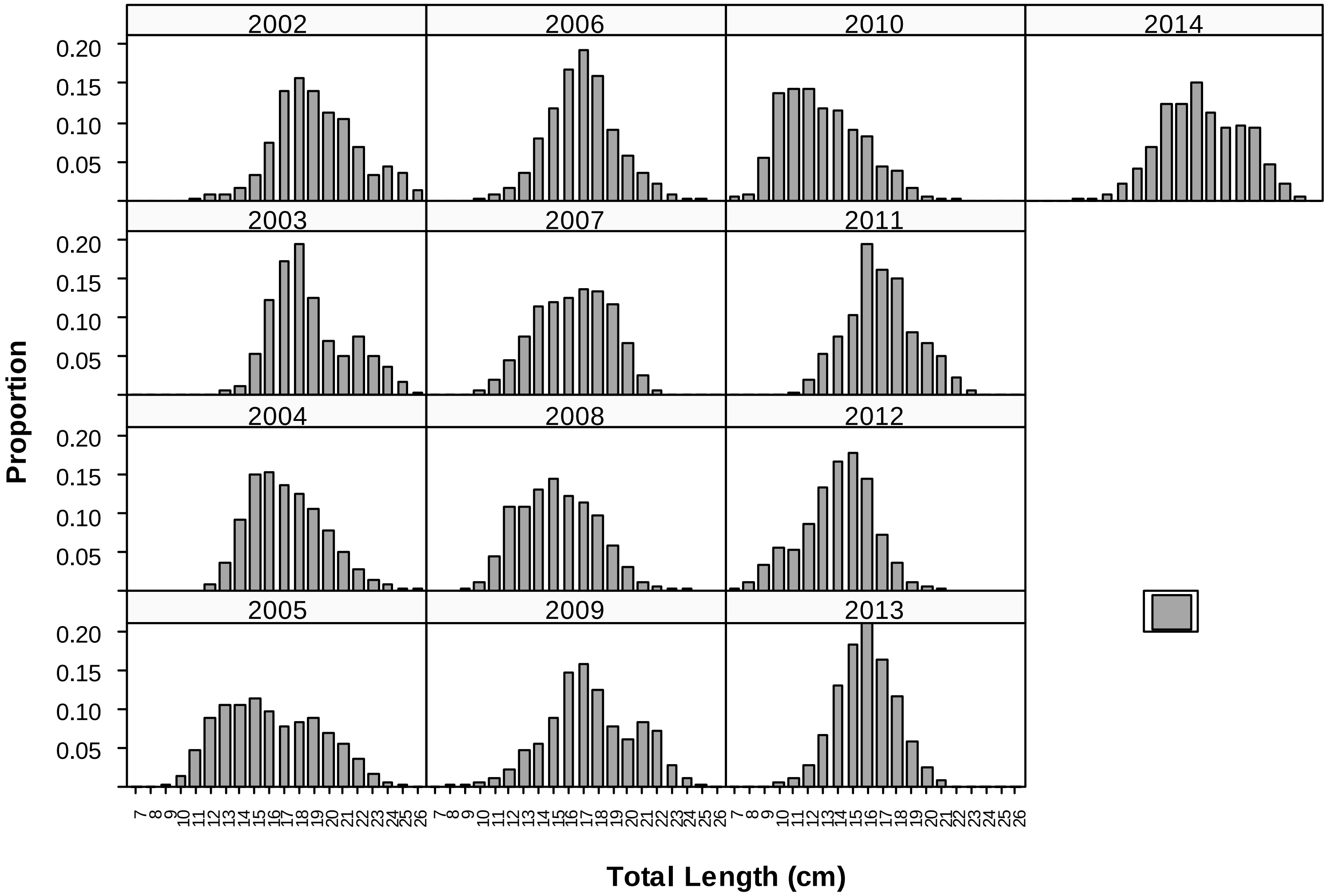


Figure 70. Length frequency of spot captured in the ChesMMAP Trawl Survey.

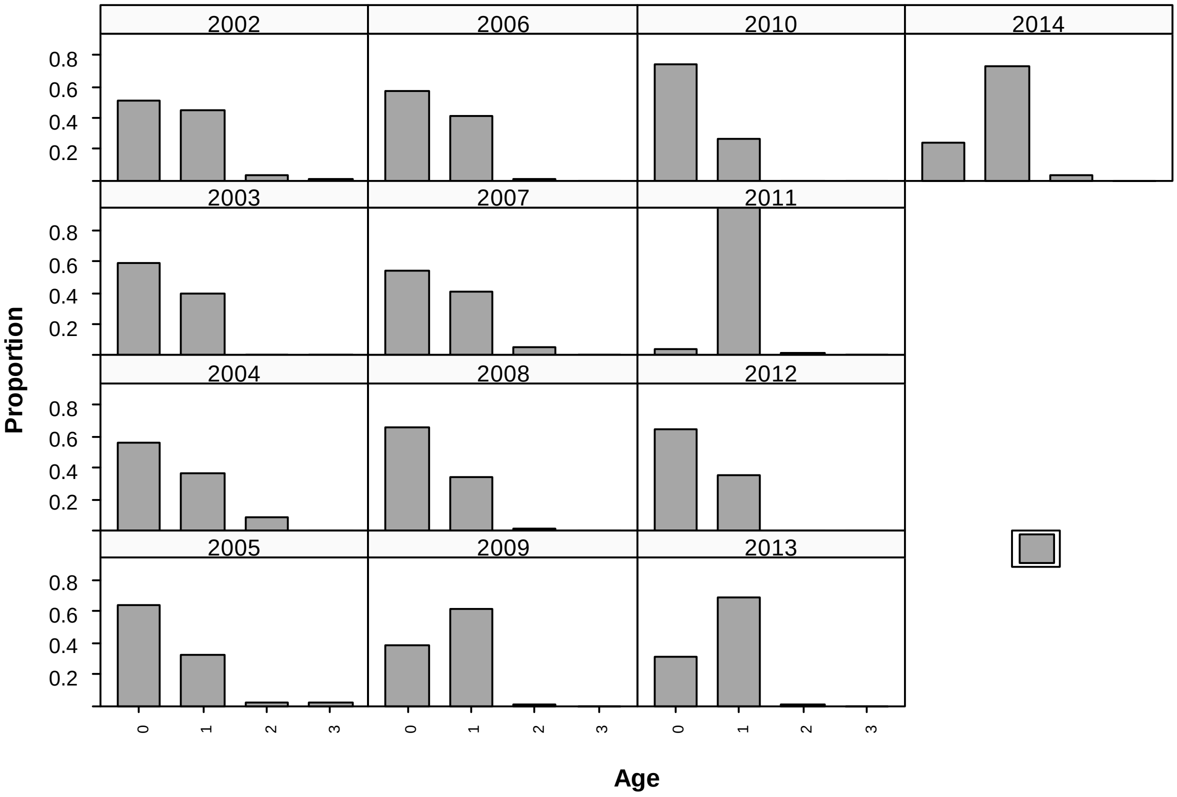


Figure 71. Age frequency of spot captured in the ChesMMAP Trawl Survey for all months.

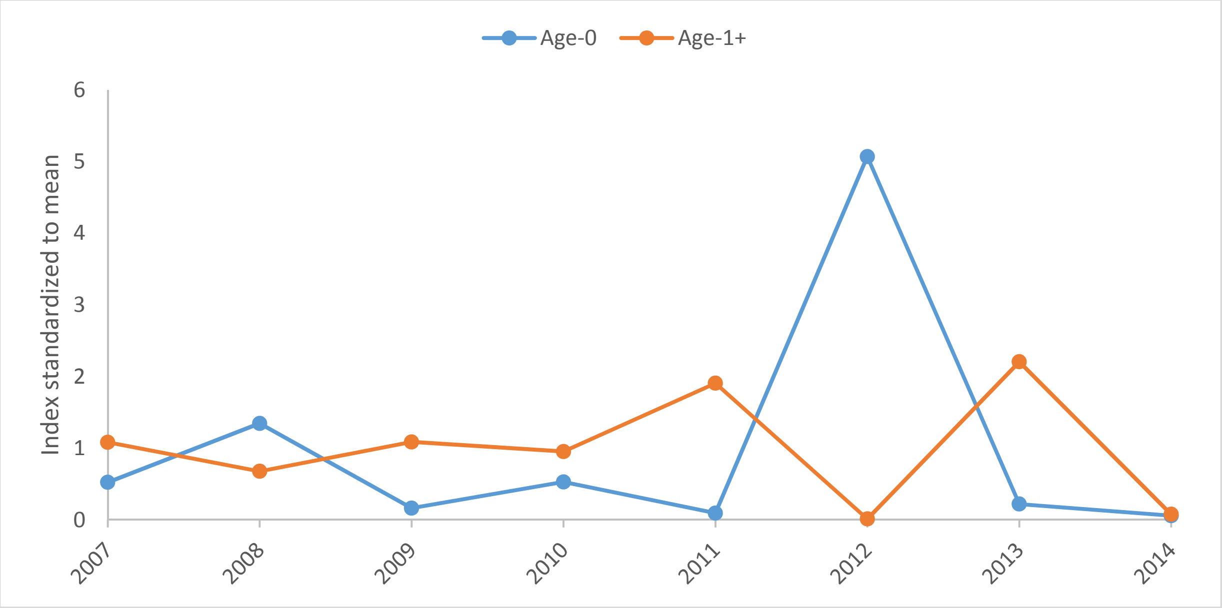


Figure 72. Index of relative abundance for age-0 and age-1+ spot developed from the NEAMAP Trawl Survey.

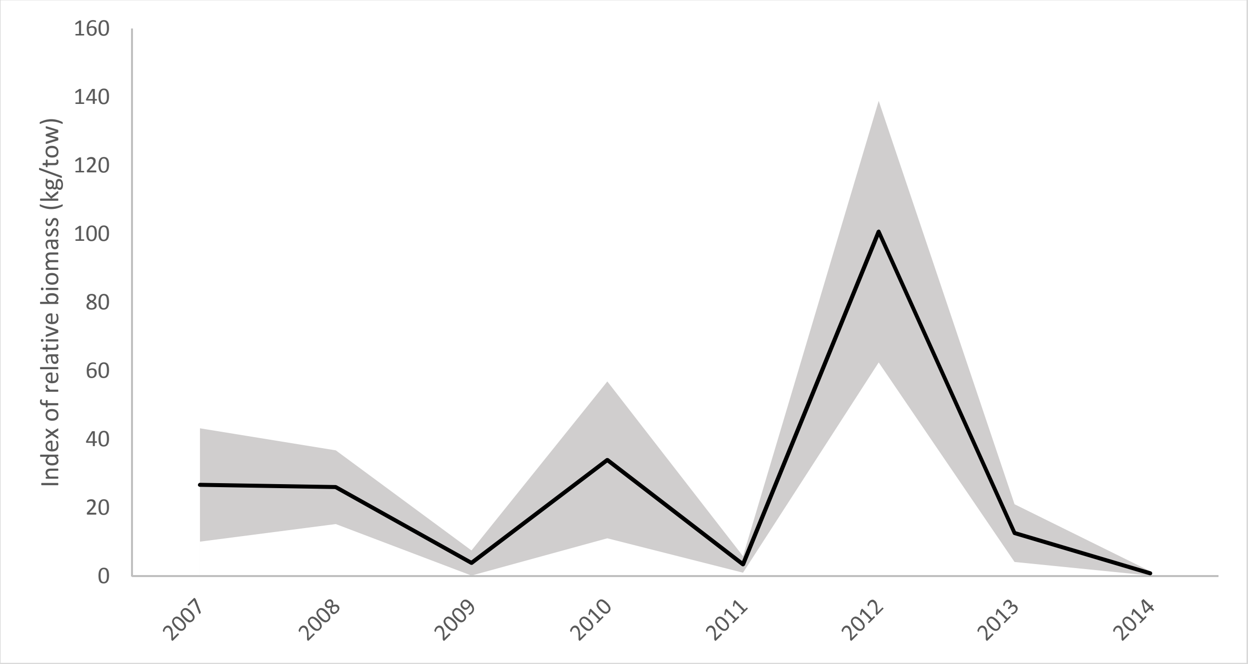


Figure 73. Index of relative biomass developed from the fall component (September-November) of the NEAMAP Trawl Survey for spot.

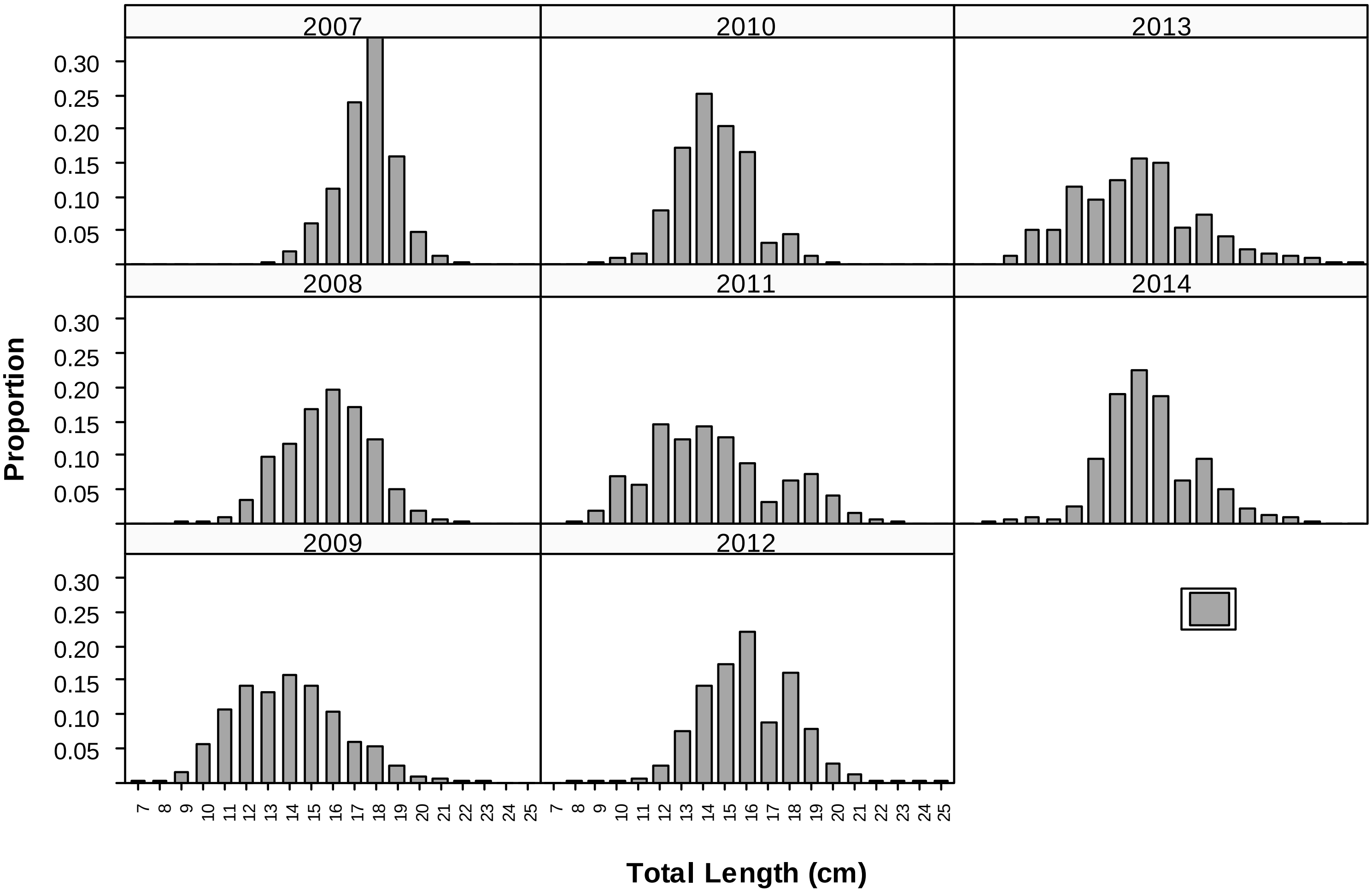


Figure 74. **Length frequency of spot caught in the NEAMAP Trawl Survey.**

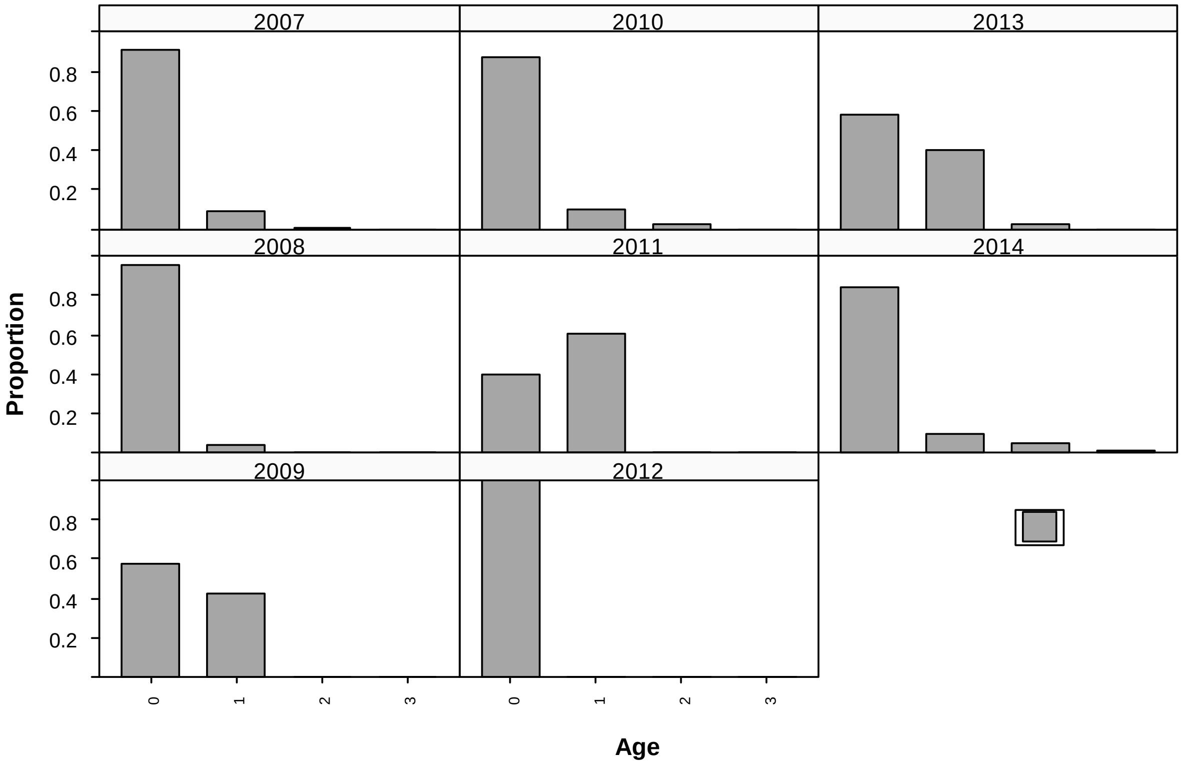


Figure 75. Age frequency of spot caught in the NEAMAP Trawl Survey during the fall component.

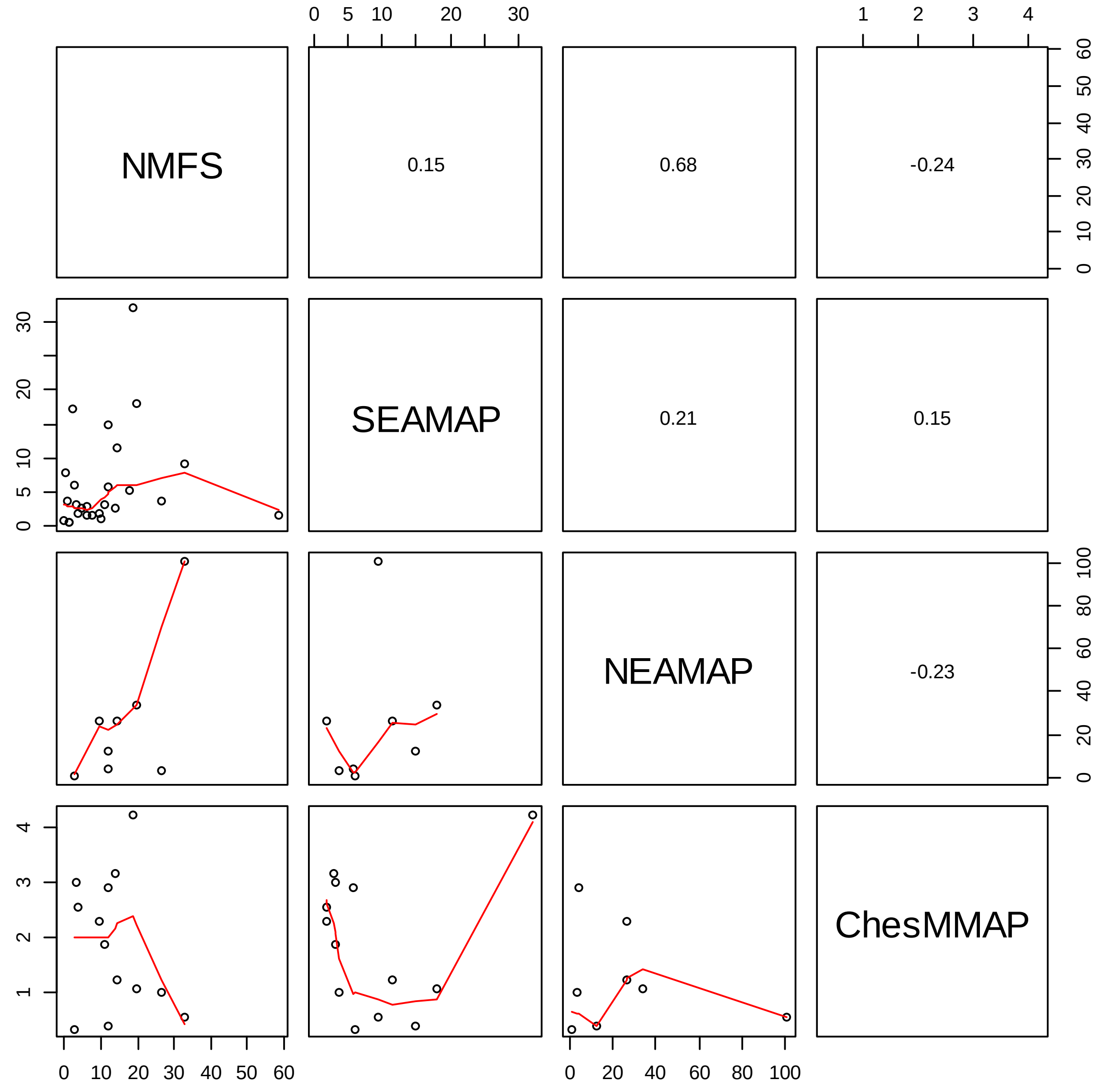


Figure 76. **Correlation coefficients and scatter plots for the aggregate indices considered for spot.**

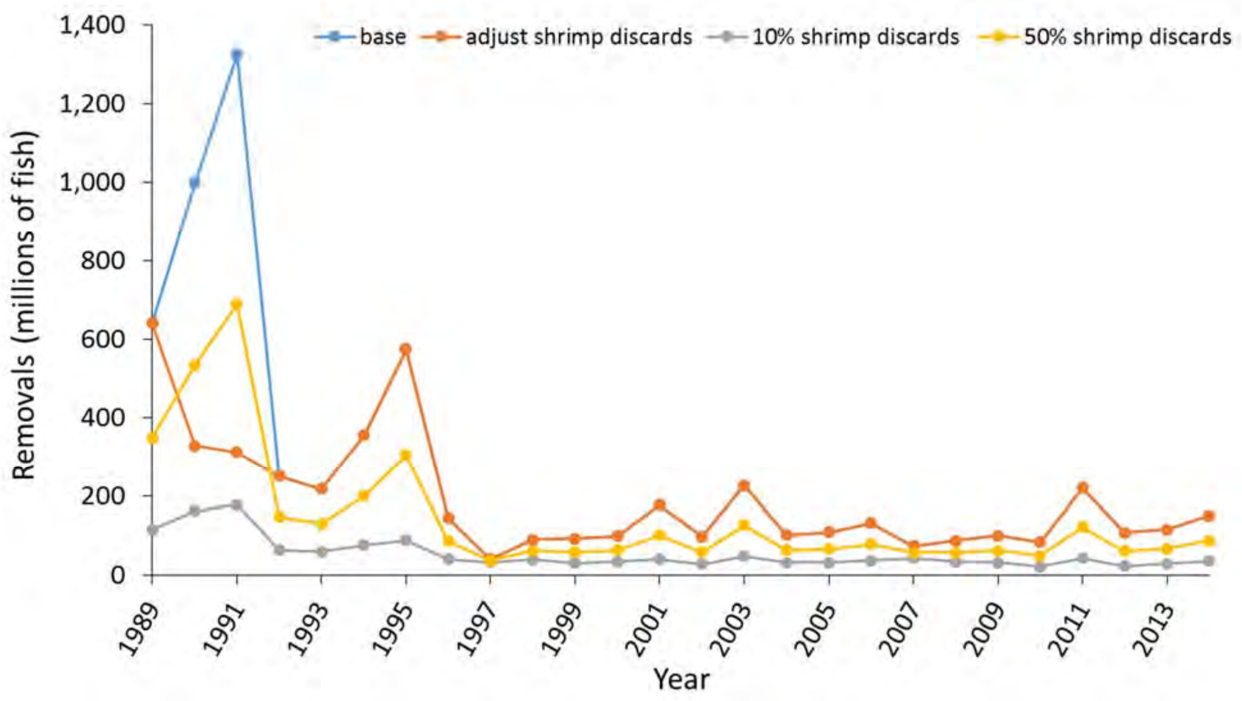


Figure 77. Comparison of removal data time series in the modified-CSA base model and sensitivity configurations for spot with adjusted shrimp trawl discard estimates (see Table 95 for description of sensitivity configurations).

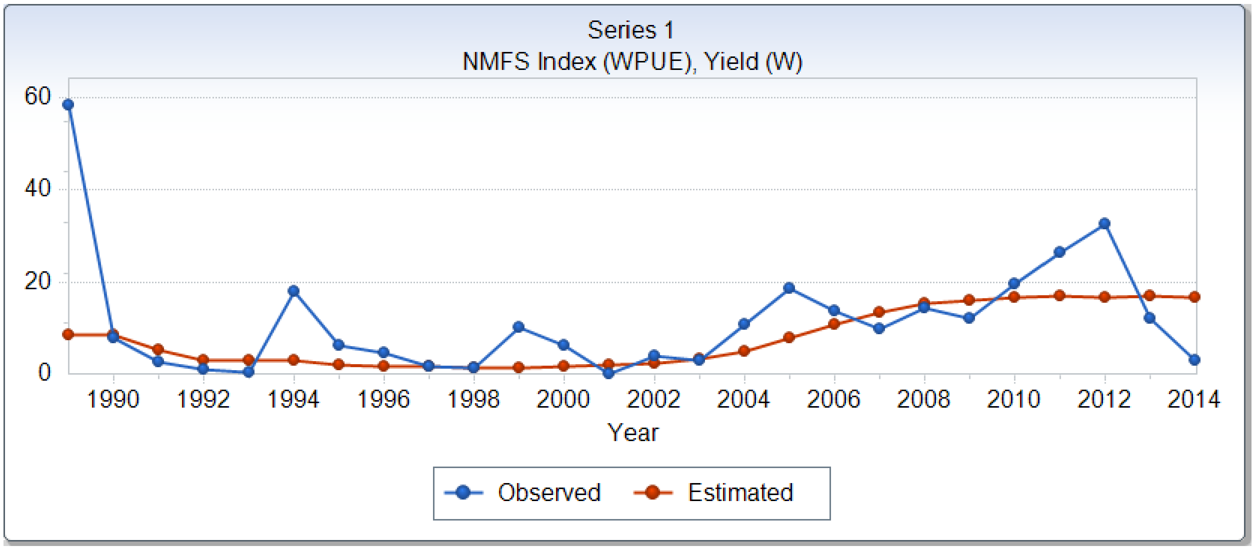


Figure 78. The spot surplus production model fit of the relative biomass index from the NMFS Trawl Survey.

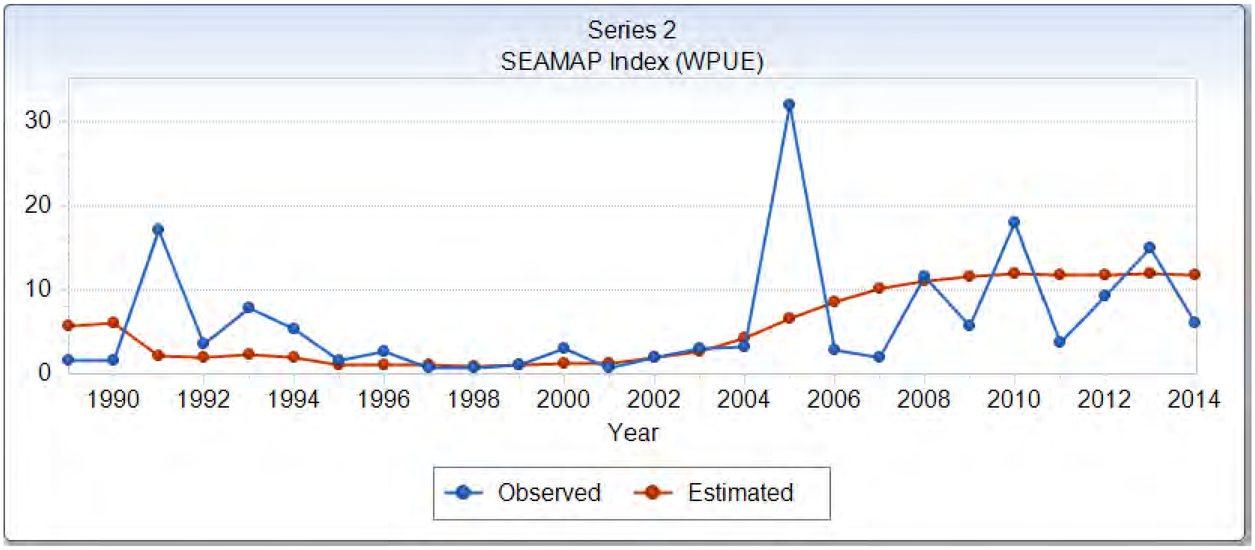


Figure 79. The spot surplus production model fit of the relative biomass index from the SEAMAP Trawl Survey.

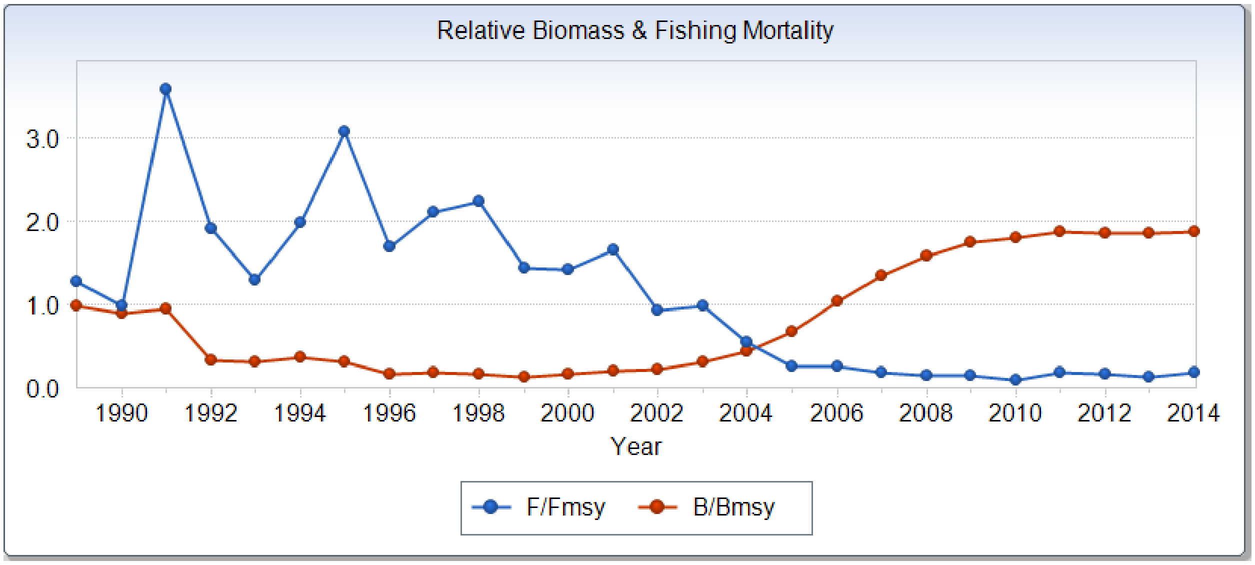


Figure 80. Estimated relative biomass and fishing mortality of spot from the surplus production model.

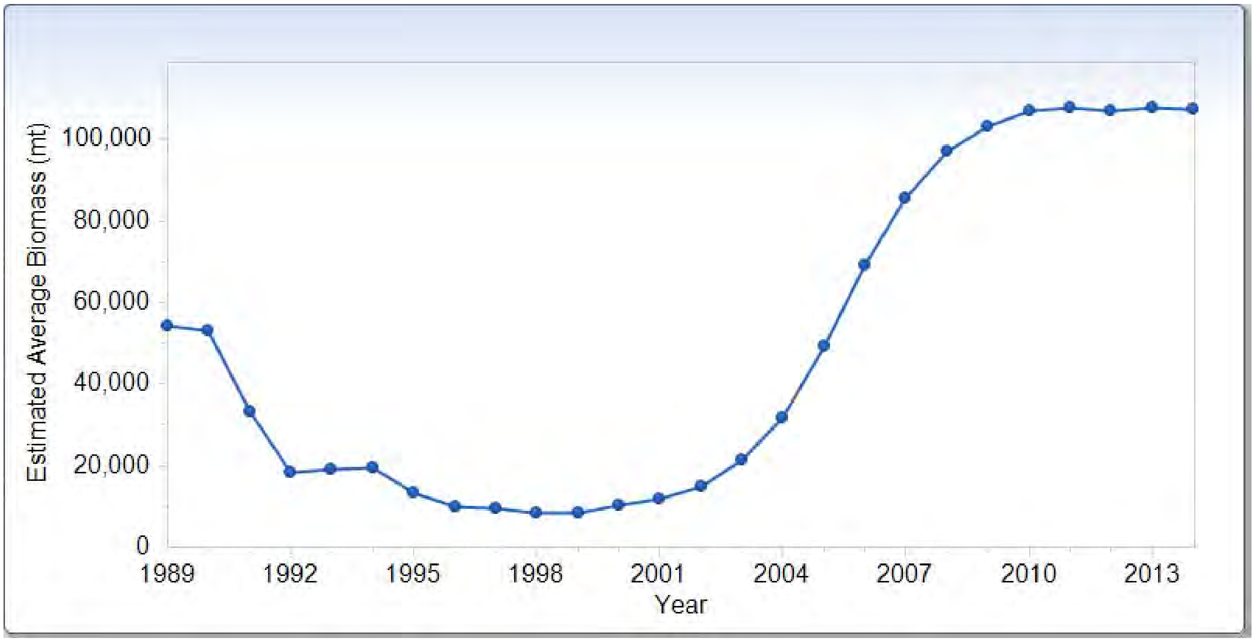


Figure 81. Estimated average biomass (metric tons) of spot from the surplus production model.

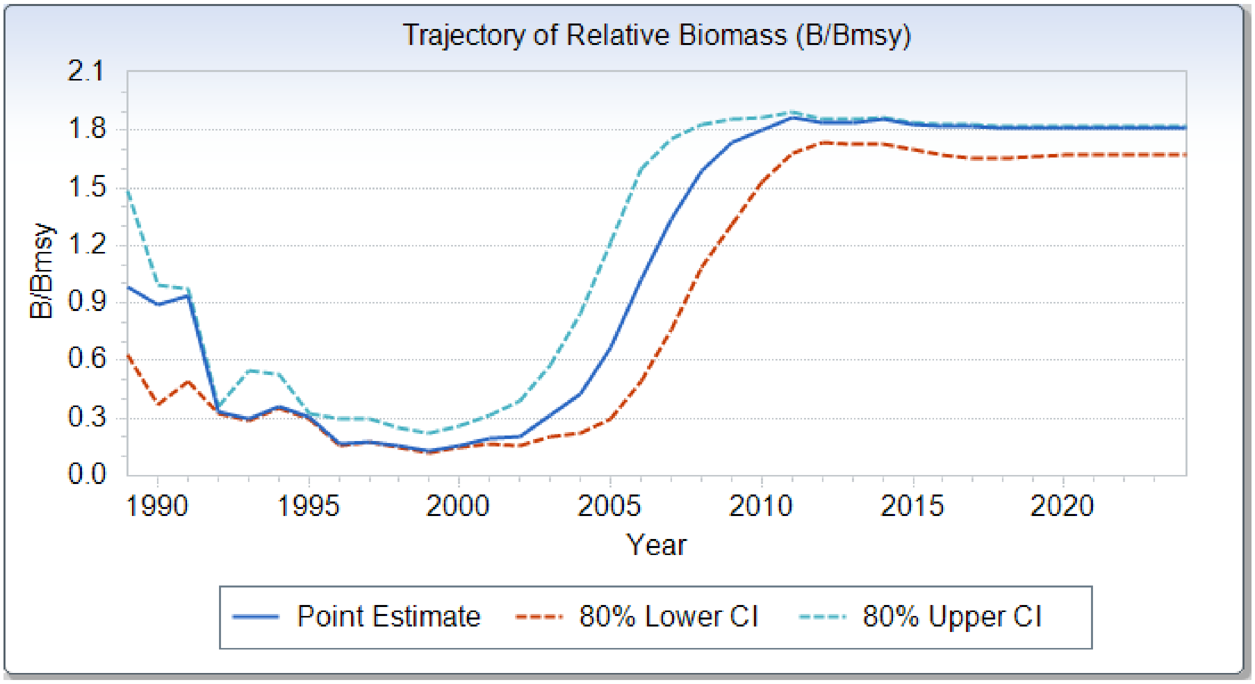


Figure 82. Estimated relative biomass of spot from the surplus production model 10-year projections based on 2014 removal levels.

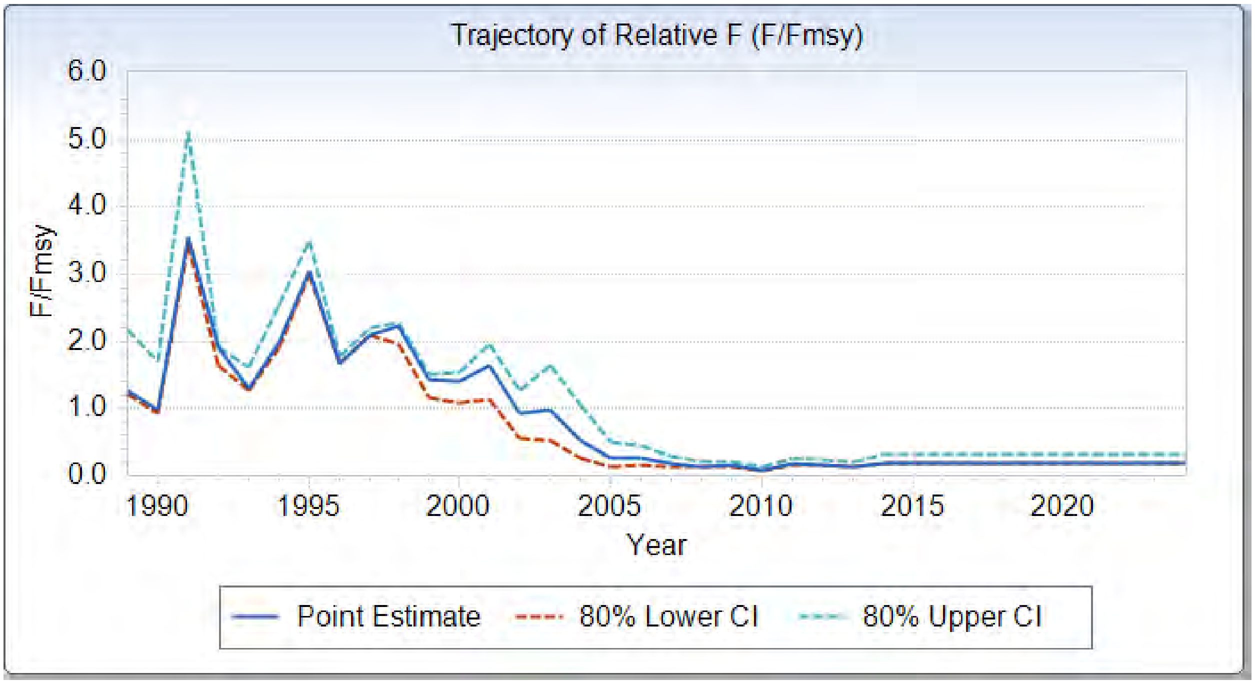


Figure 83. **Estimated relative fishing mortality of spot from the surplus production model 10-year projections based on 2014 removal levels.**

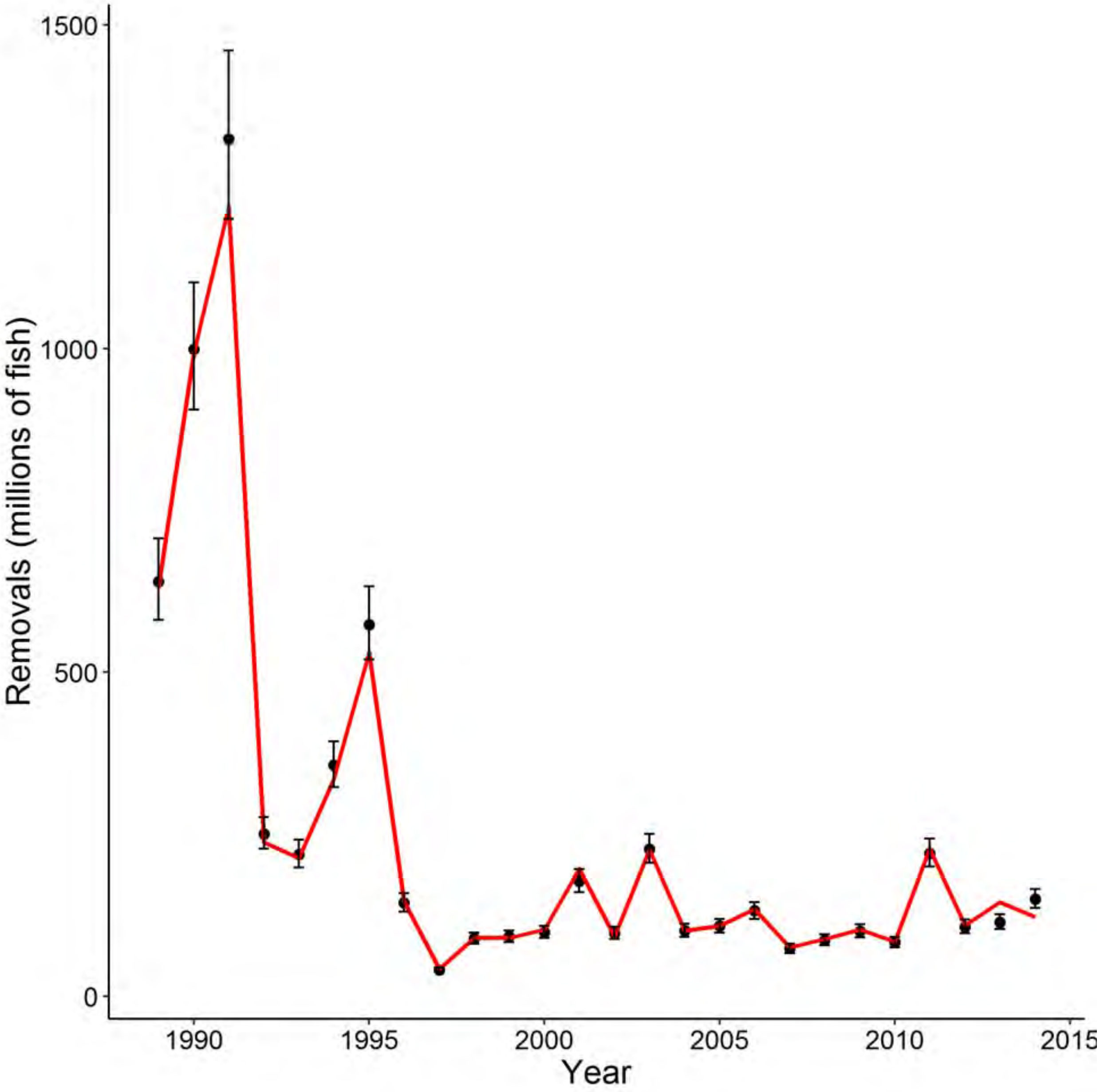


Figure 84. Base modified-CSA model fit to total fishery removal data. The red line is model predicted removals, the black circles are observed removals, and error bars indicate 95% confidence intervals of observed removals based on assumed input CVs of 0.05.

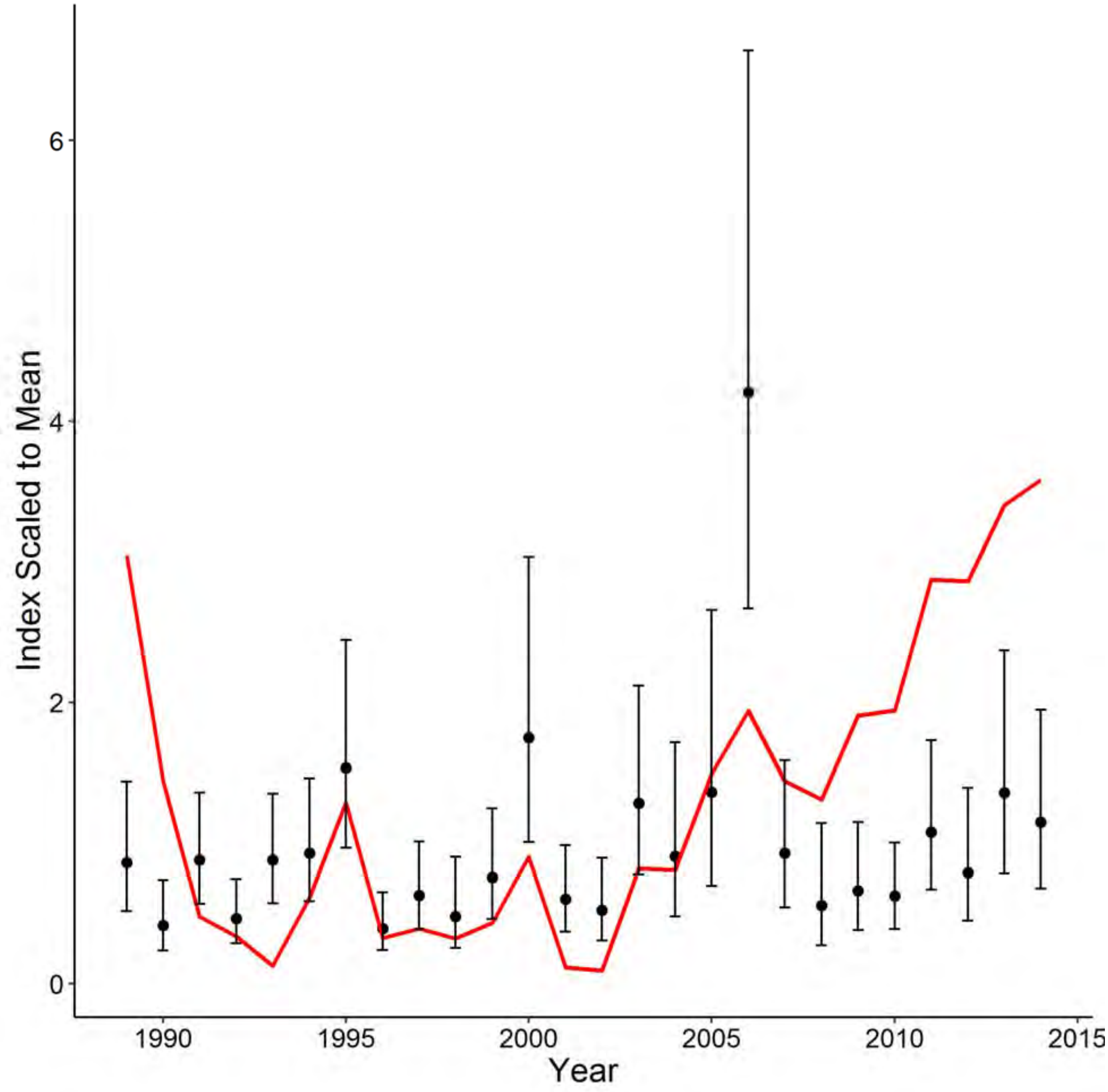


Figure 85. Base modified-CSA model fit to NCDMF Trawl Survey post-recruit index. The red line is the model predicted index, the black circles are observed index values, and error bars indicate 95% confidence intervals of the observed index values based on the input CVs.

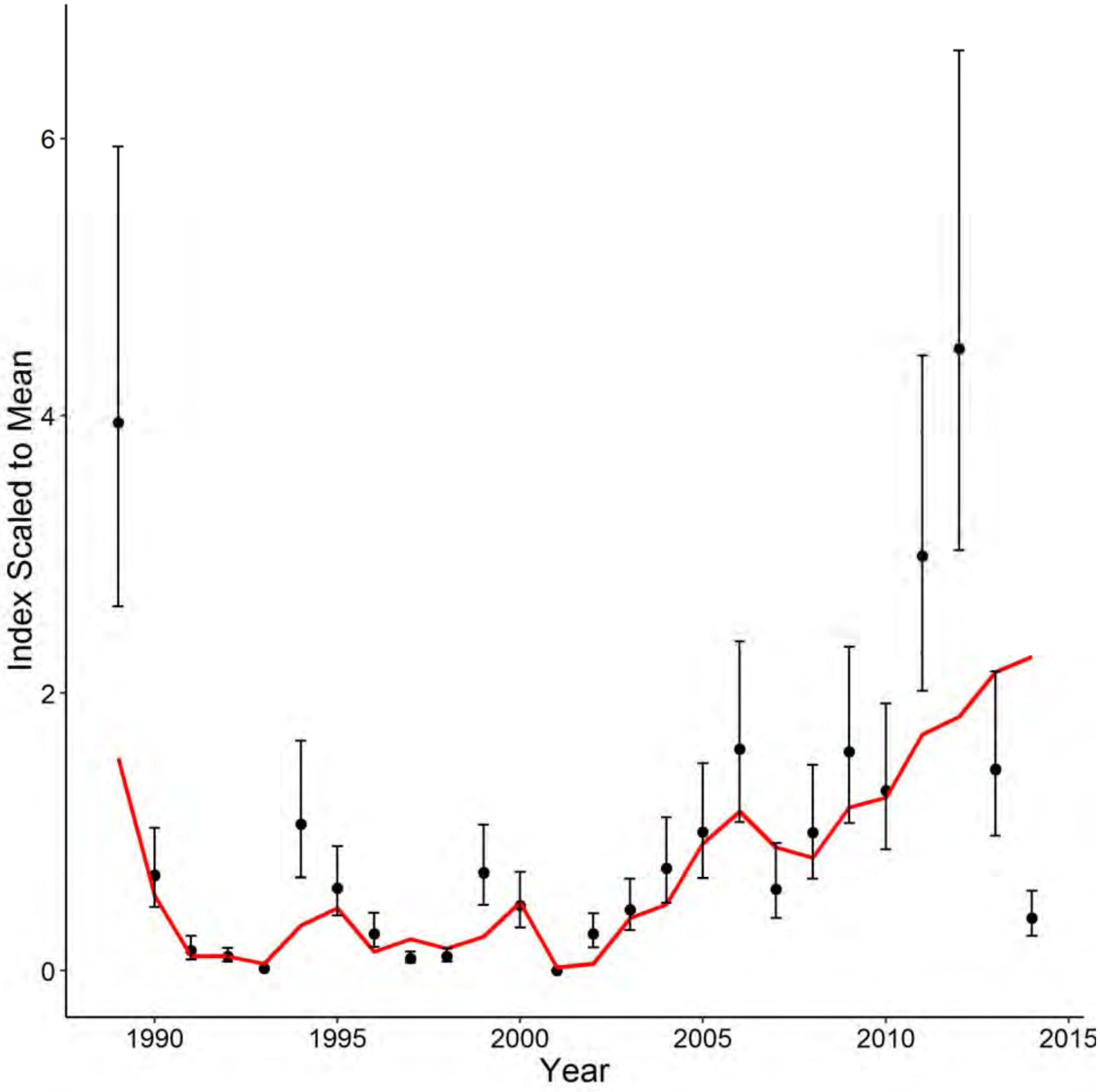


Figure 86. Base modified-CSA model fit to NMFS Trawl Survey post-recruit index. The red line is the model predicted index, the black circles are observed index values, and error bars indicate 95% confidence intervals of the observed index values based on the input CVs.

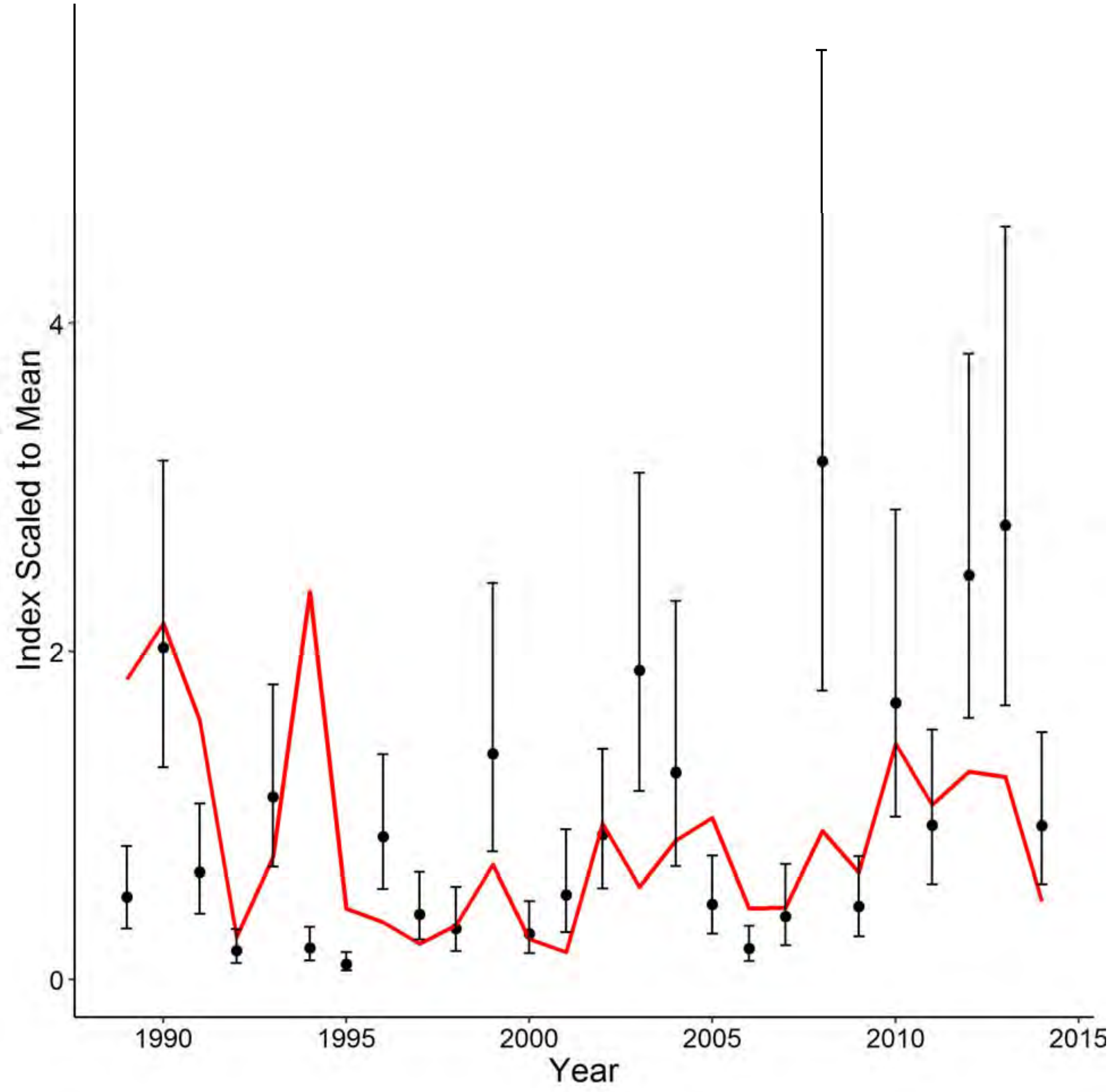


Figure 87. Base modified-CSA model fit to NCDMF Trawl Survey recruit index. The red line is the model predicted index, the black circles are observed index values, and error bars indicate 95% confidence intervals of the observed index values based on the input CVs.

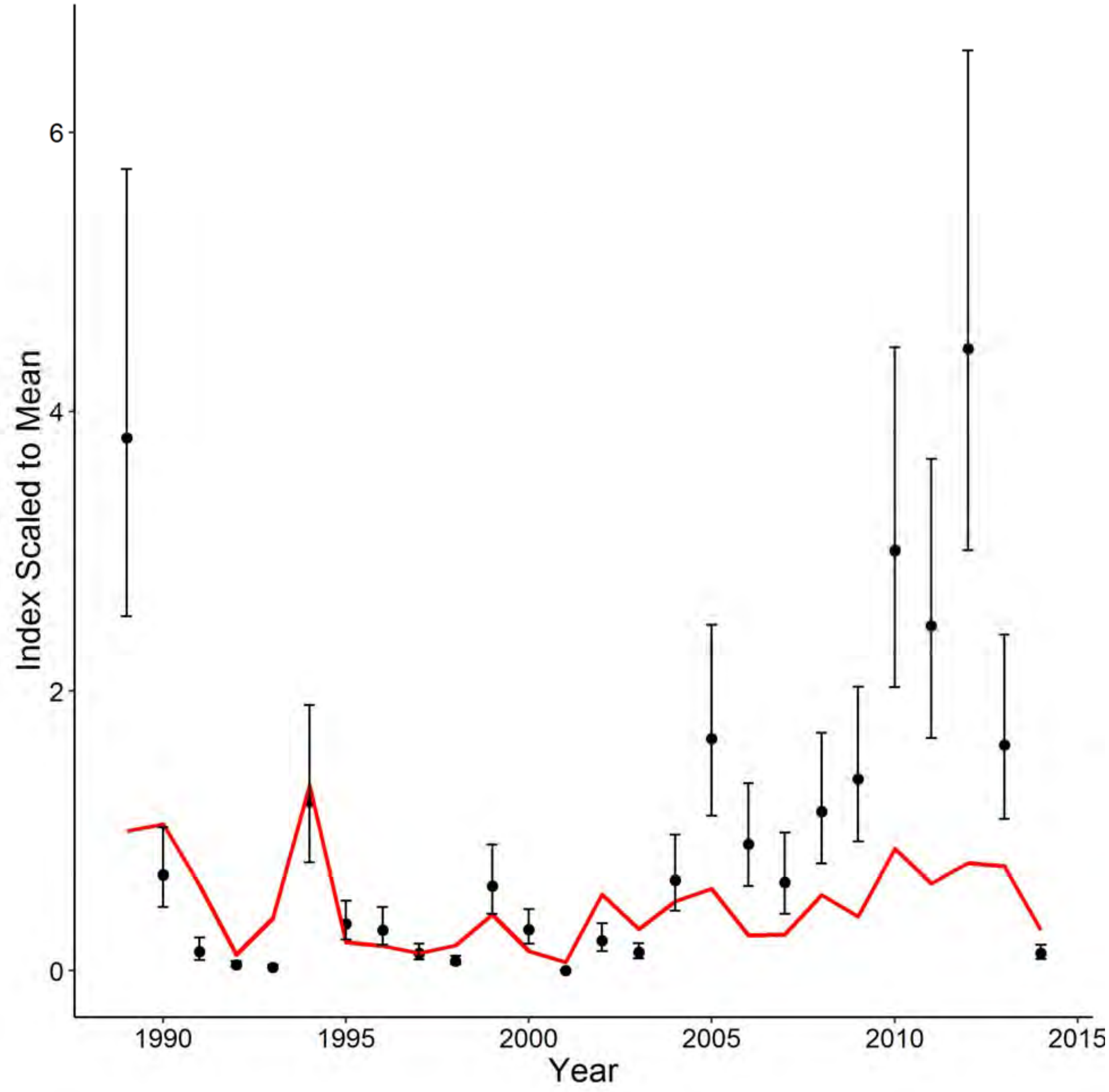


Figure 88. Base modified-CSA model fit to NMFS Trawl Survey recruit index. The red line is the model predicted index, the black circles are observed index values, and error bars indicate 95% confidence intervals of the observed index values based on the input CVs.

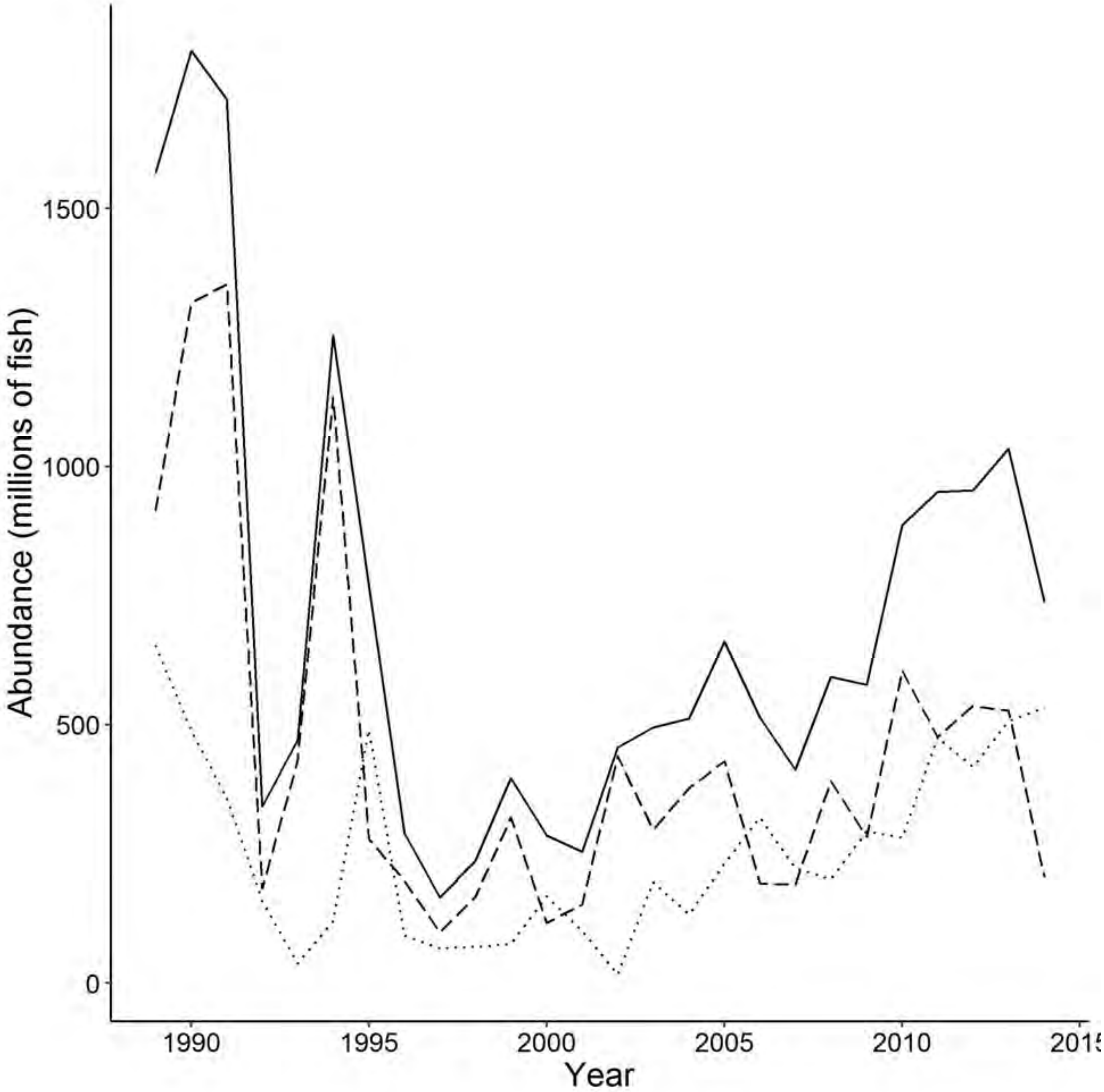


Figure 89. Base modified-CSA model recruitment (dashed line), post-recruit (dotted line), and total abundance (solid line) estimates for spot (millions of fish).

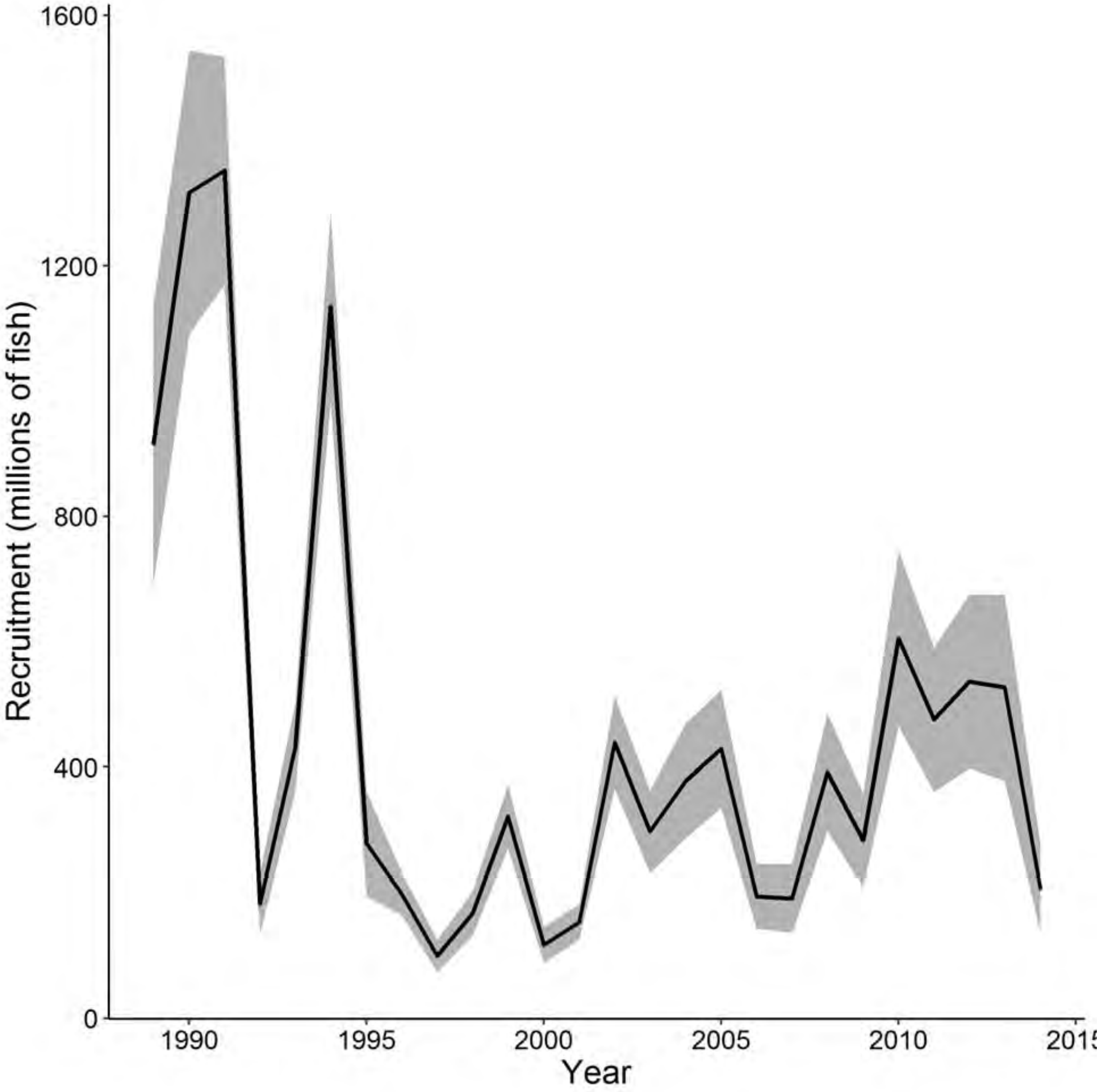


Figure 90. Base modified-CSA model recruitment estimates for spot (millions of fish) with 95% confidence intervals derived from asymptotic standard errors.

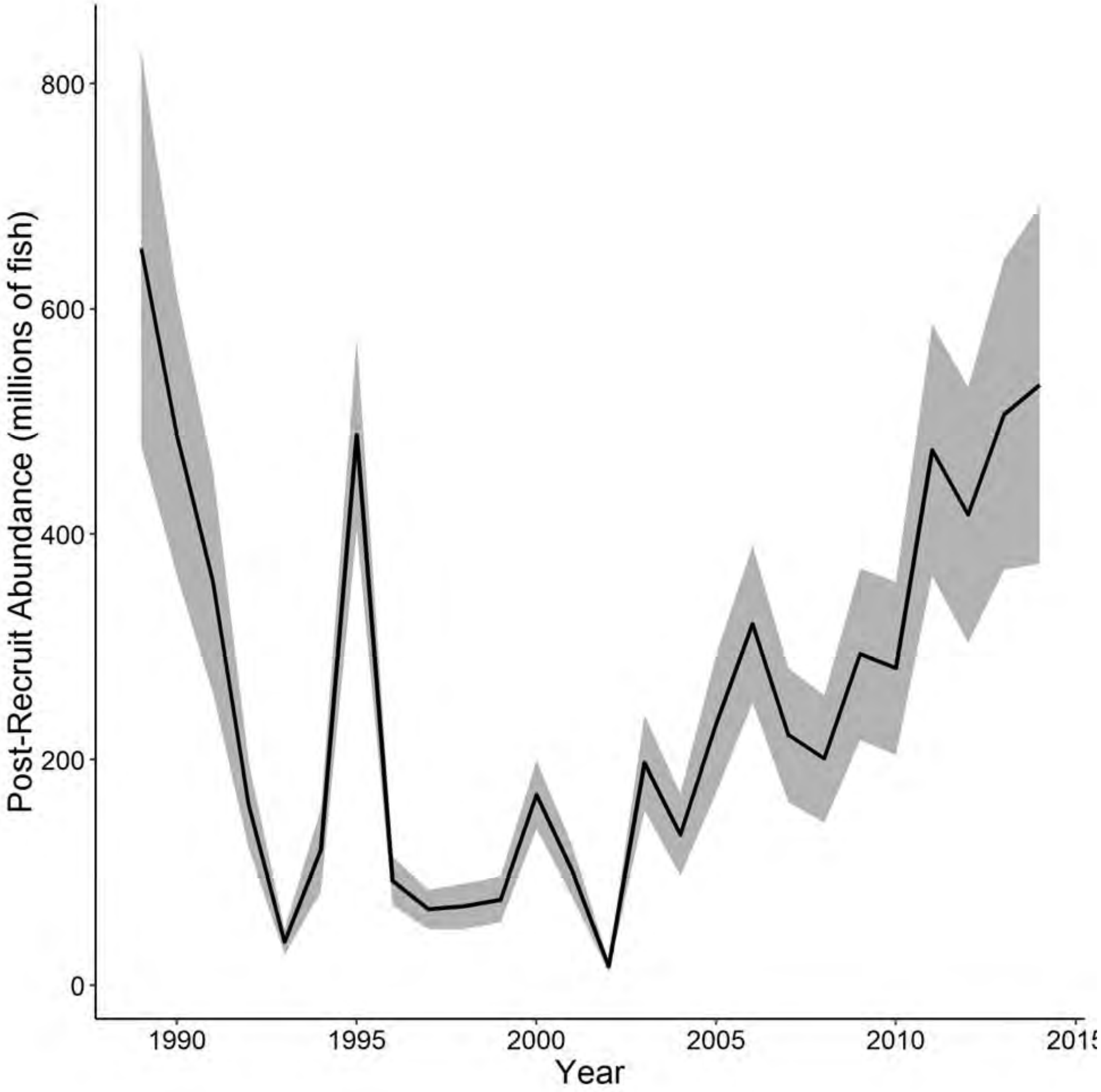


Figure 91. Base modified-CSA model post-recruit abundance estimates for spot (millions of fish) with 95% confidence intervals derived from asymptotic standard errors.

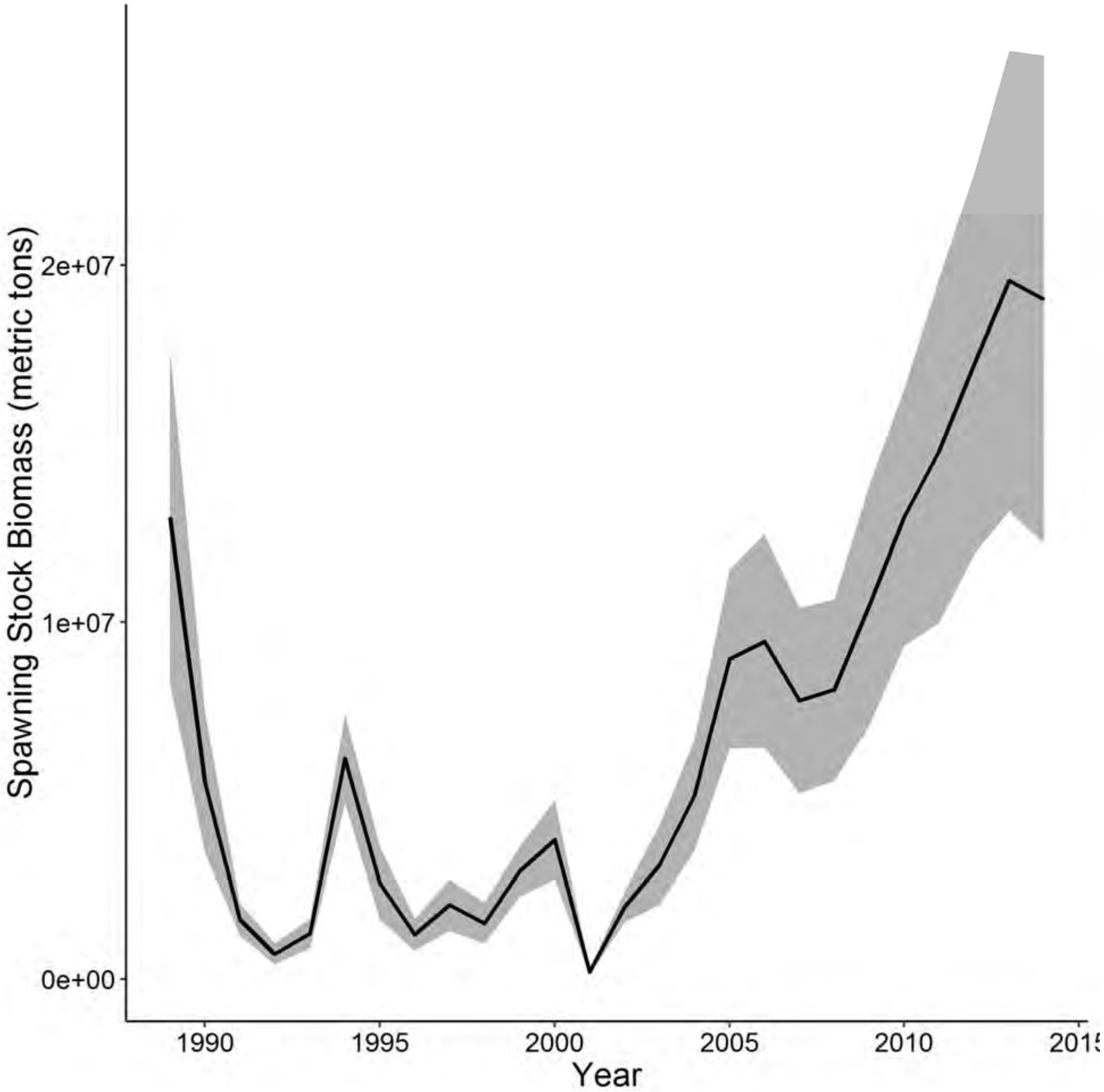


Figure 92. **Base modified-CSA model end-year spawning stock biomass estimates for spot (metric tons) with 95% confidence intervals derived from asymptotic standard errors.**

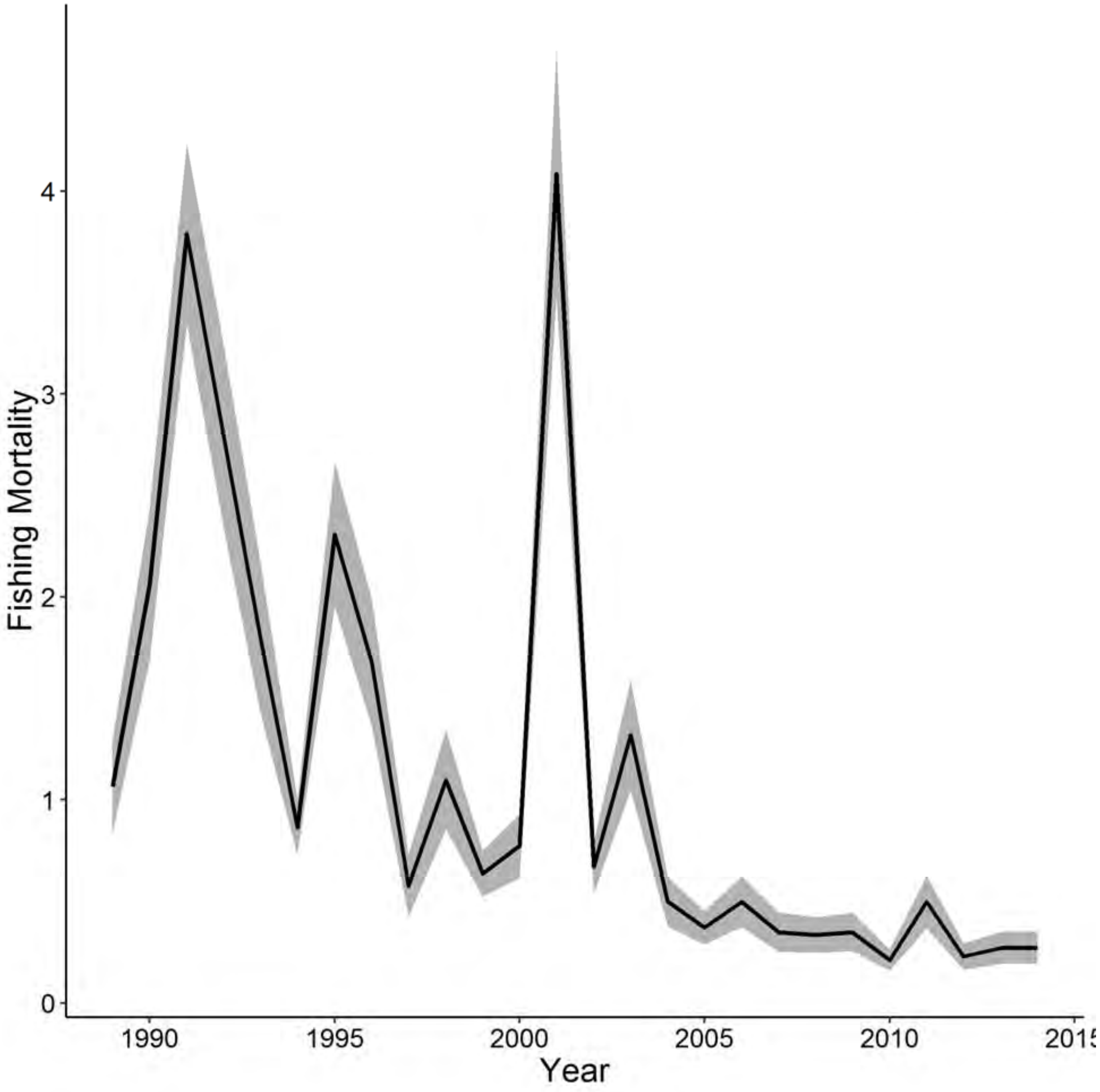


Figure 93. Base modified-CSA model full fishing mortality estimates for spot with 95% confidence intervals derived from asymptotic standard errors. Terminal year (2014) fishing mortality is the geometric mean of the previous two years (2012-2013).

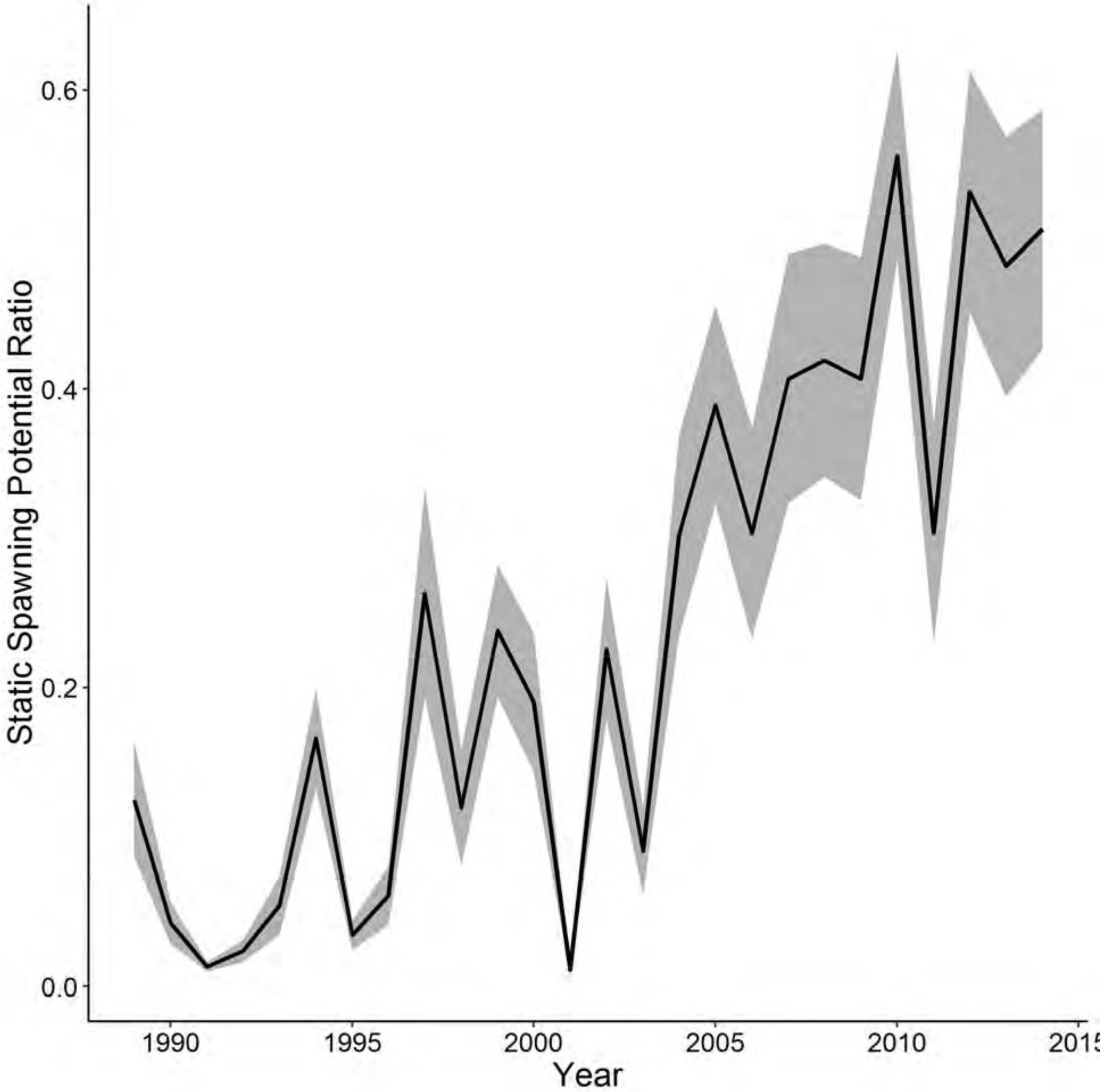


Figure 94. Base modified-CSA model static spawning potential ratio estimates for spot with 95% confidence intervals derived from asymptotic standard errors. Terminal year (2014) sSPR is estimated from the geometric mean of the previous two years (2012-2013) fishing mortality estimates.

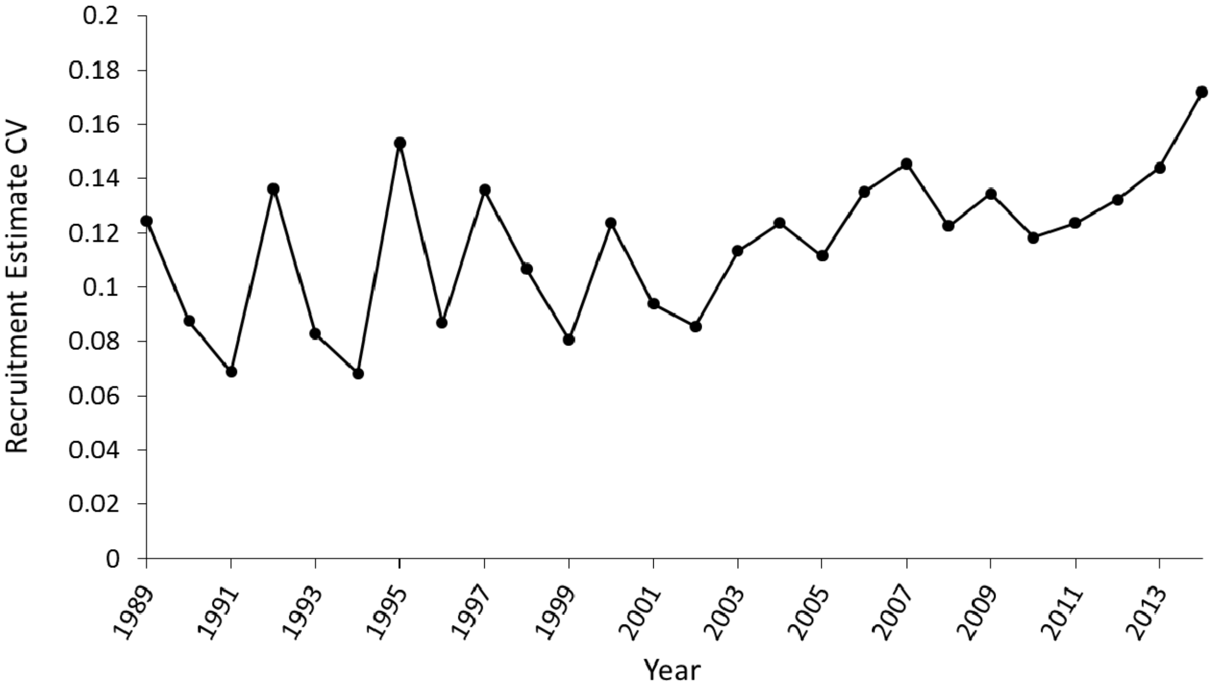


Figure 95. Base modified-CSA model recruitment estimate CVs for spot derived from asymptotic standard errors.

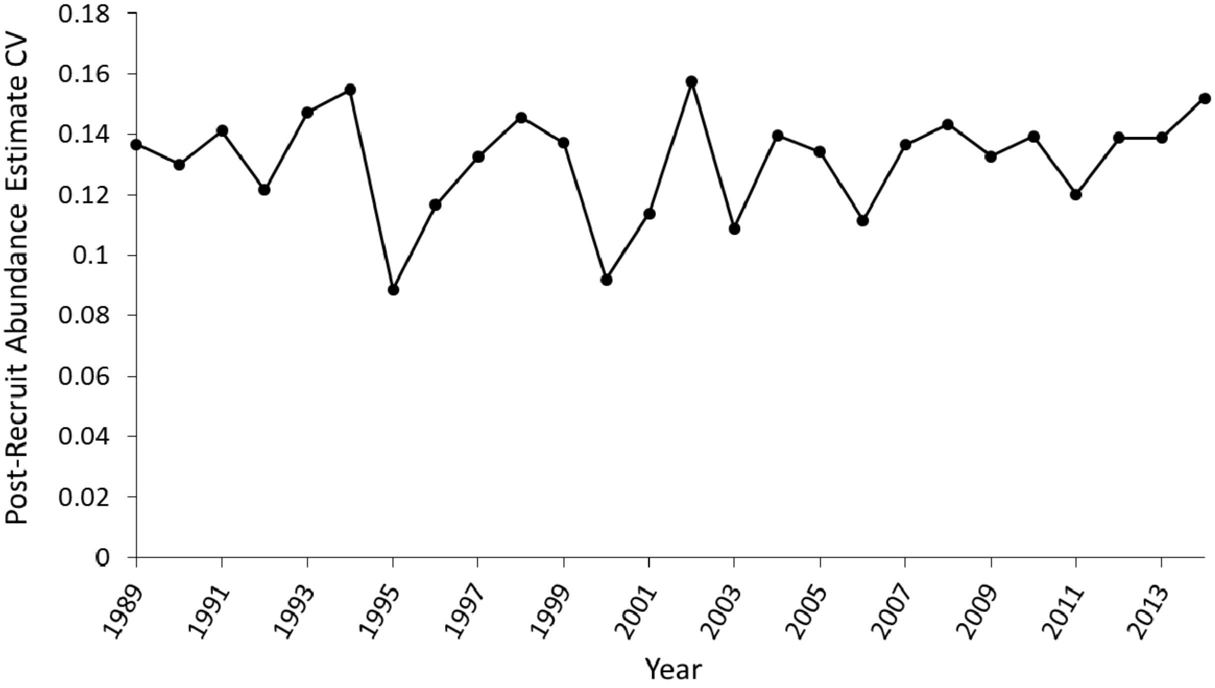


Figure 96. Base modified-CSA model post-recruit abundance estimate CVs for spot derived from asymptotic standard errors.

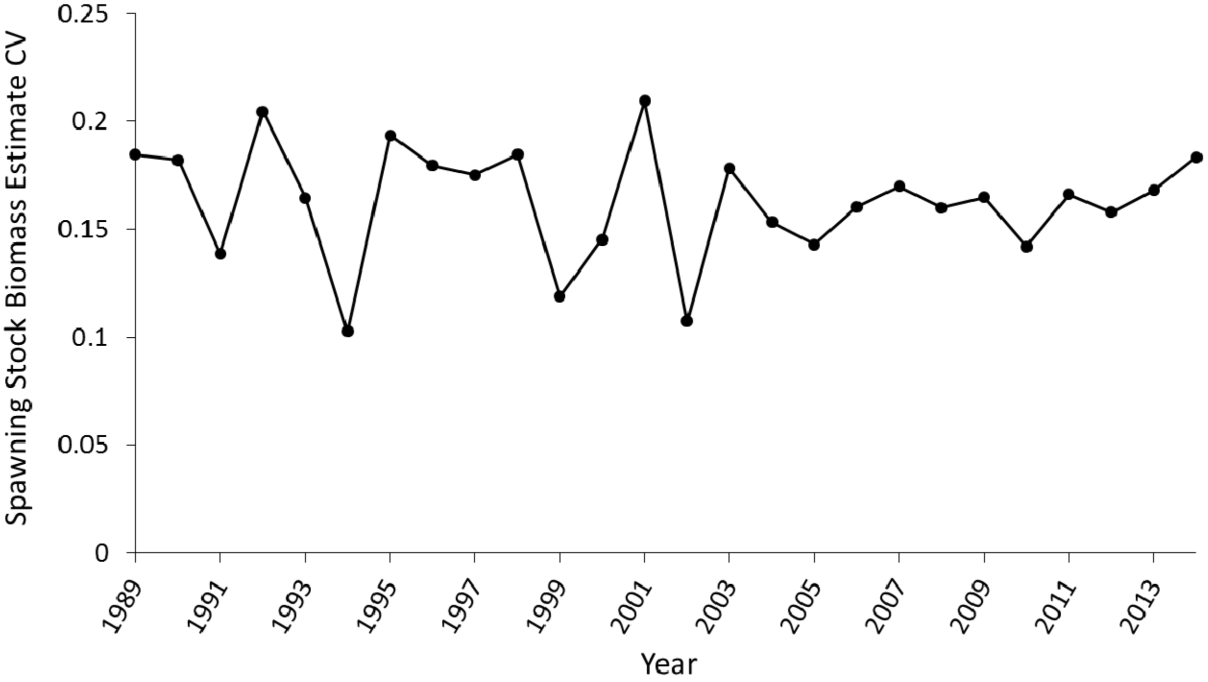


Figure 97. Base modified-CSA model spawning stock biomass estimate CVs for spot derived from asymptotic standard errors.

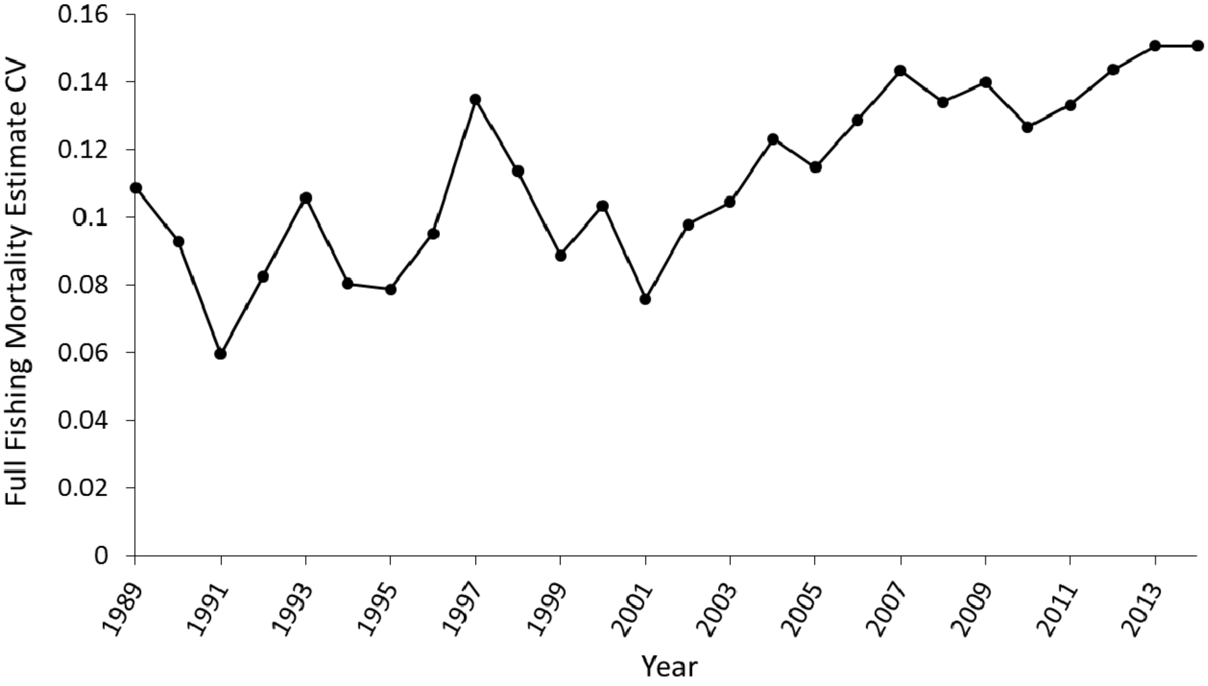


Figure 98. Base modified-CSA model full fishing mortality estimate CVs for spot derived from asymptotic standard errors.

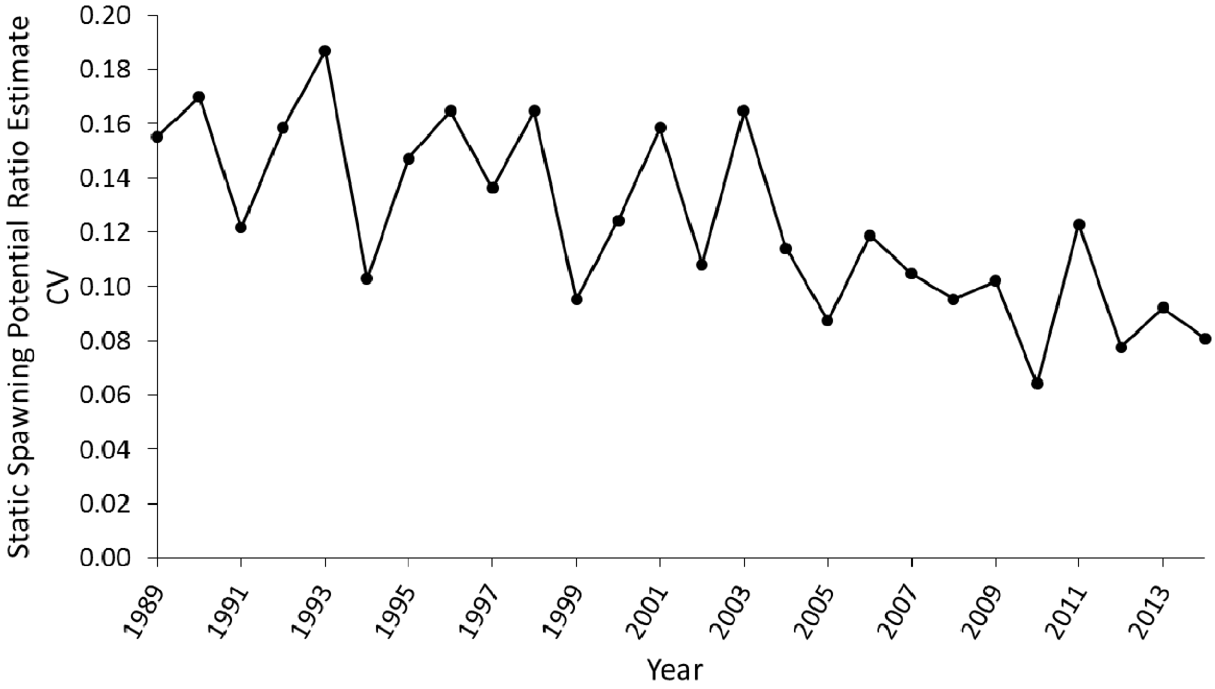


Figure 99. Base modified-CSA model static spawning potential ratio estimate CVs for spot derived from asymptotic standard errors.

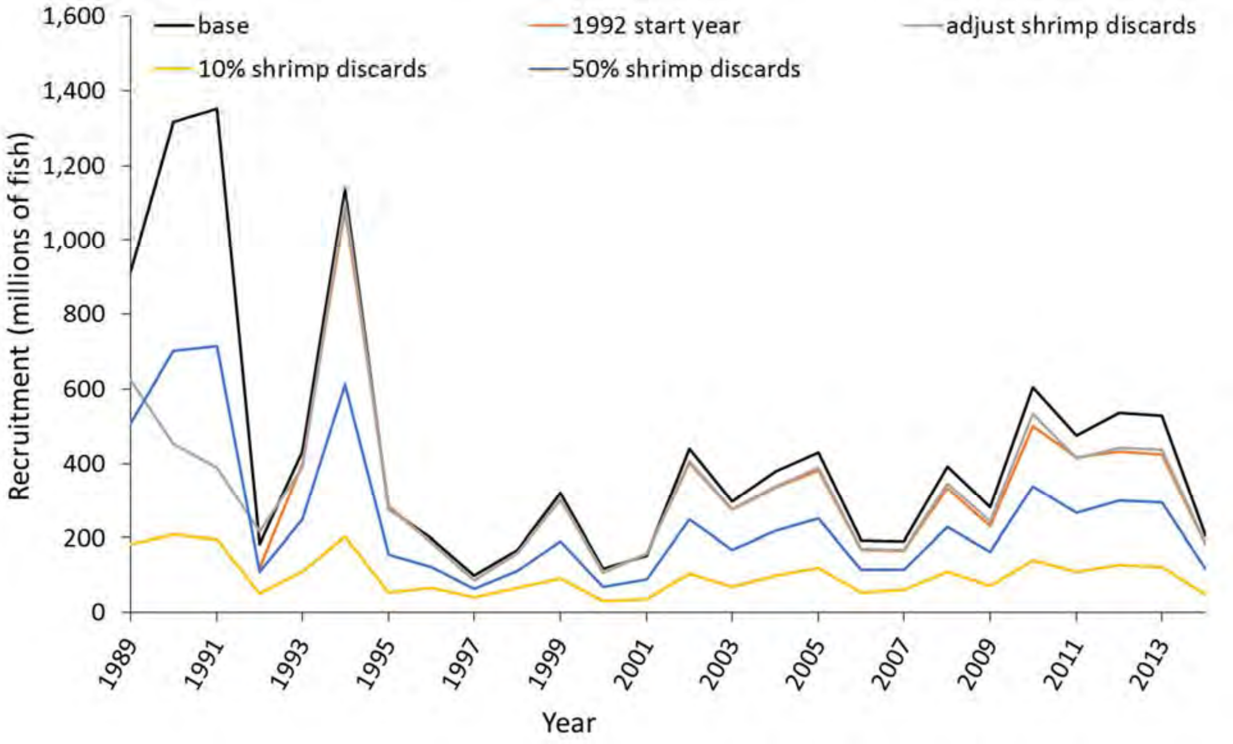


Figure 100. Recruitment estimates for spot from the base modified-CSA model and sensitivity configurations focusing on shrimp trawl discard estimates (see Table 95 for description of sensitivity configurations).

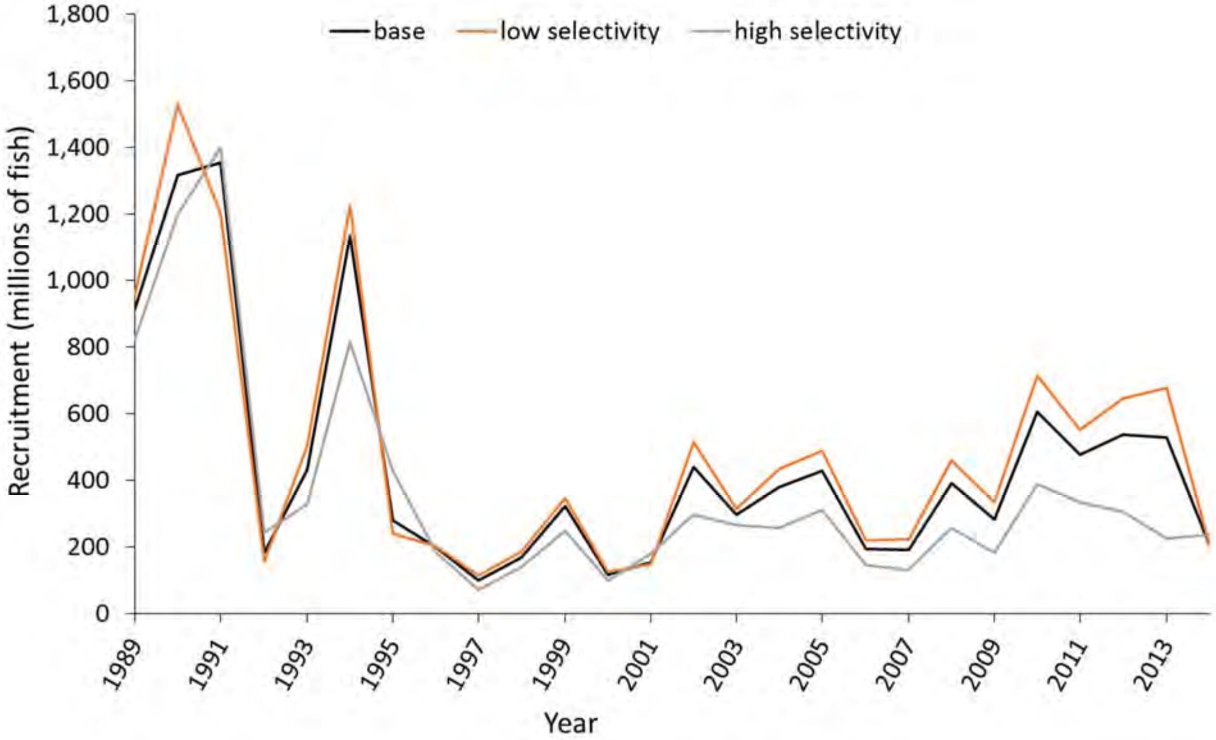


Figure 101. Recruitment estimates for spot from the base modified-CSA model and sensitivity configurations focusing on recruit selectivity assumptions (see Table 95 for description of sensitivity configurations).

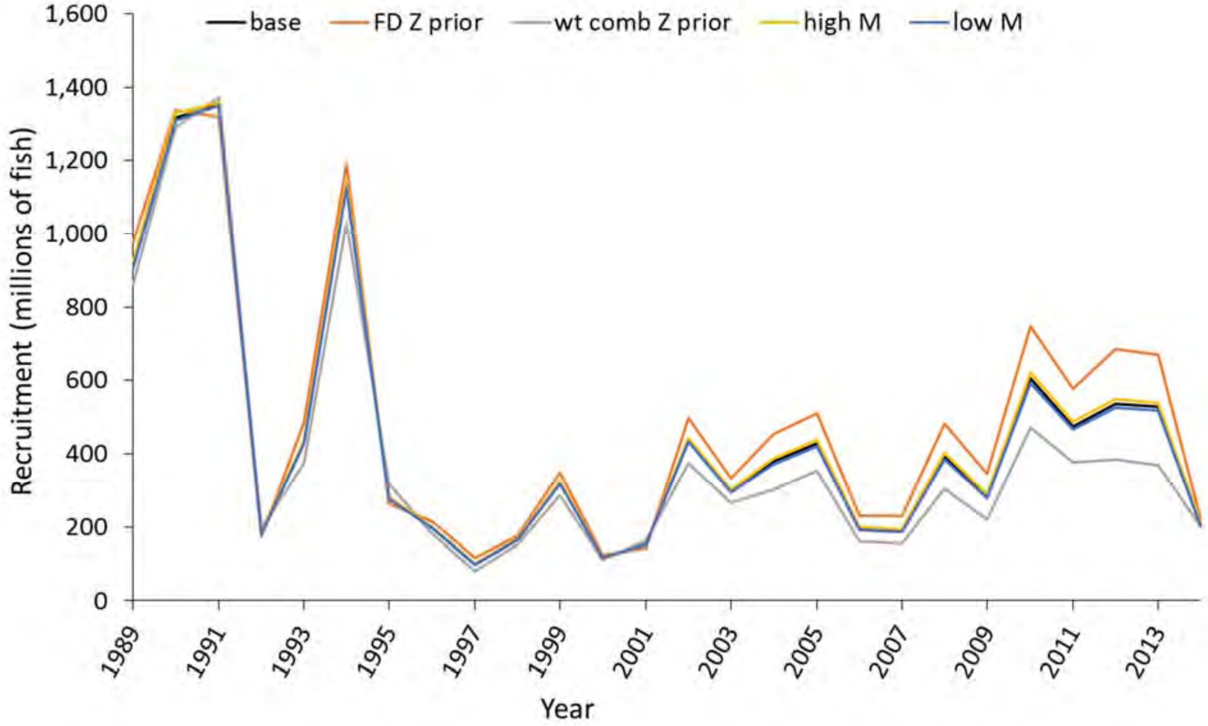


Figure 102. Recruitment estimates for spot from the base modified-CSA model and sensitivity configurations focusing on assumptions about mortality (see Table 95 for description of sensitivity configurations).

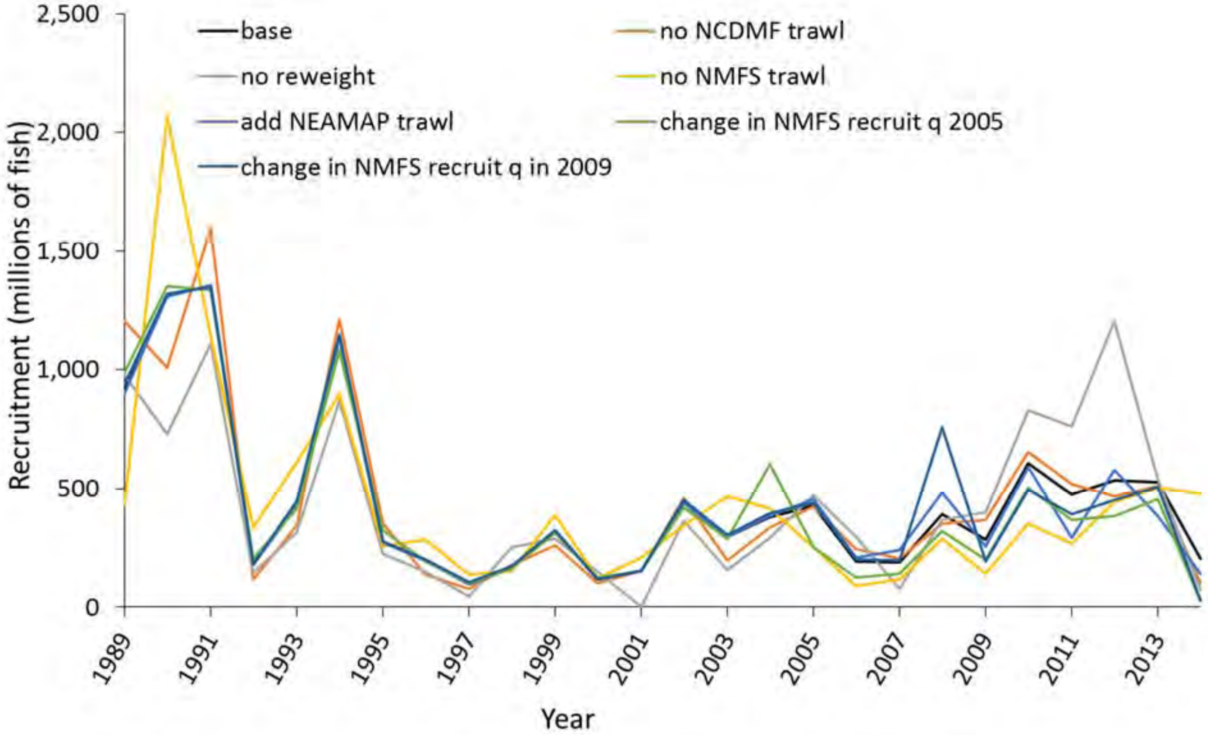


Figure 103. Recruitment estimates for spot from the base modified-CSA model and sensitivity configurations focusing on choices and treatment of index data (see Table 95 for description of sensitivity configurations).

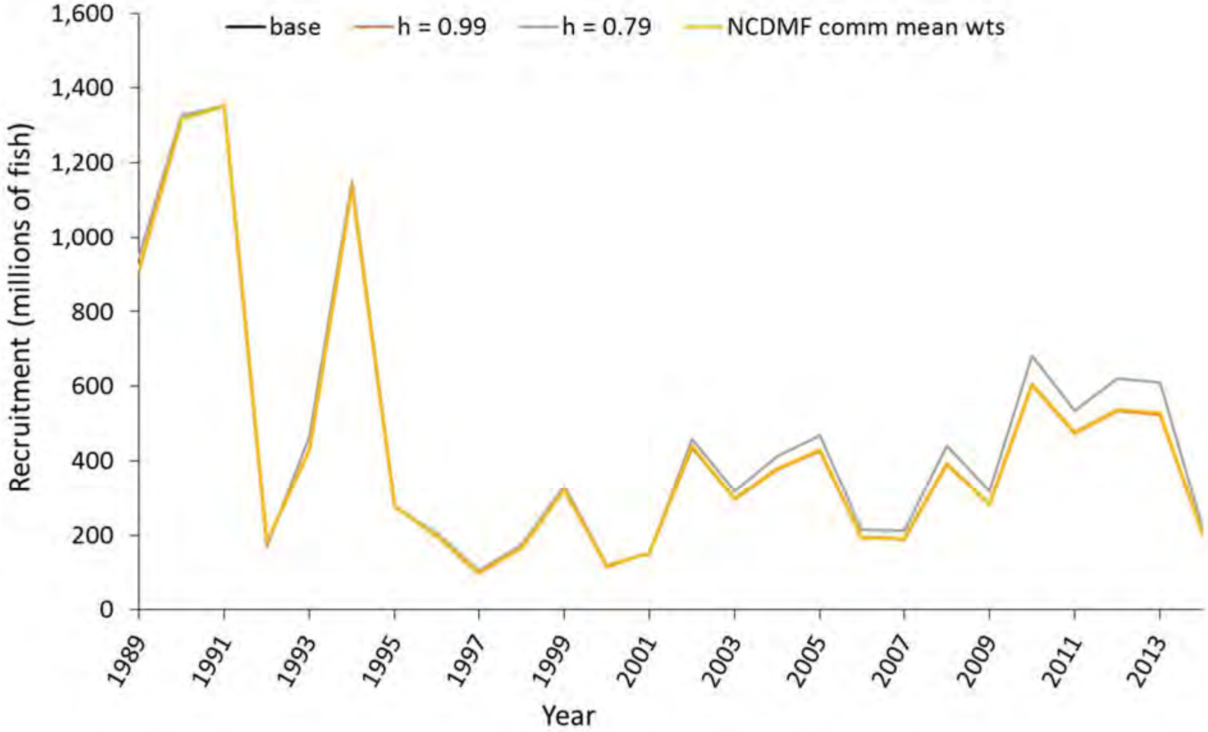


Figure 104. Recruitment estimates for spot from the base modified-CSA model and sensitivity configurations focusing on aspects relating to the stock-recruit relationship (see Table 95 for description of sensitivity configurations).

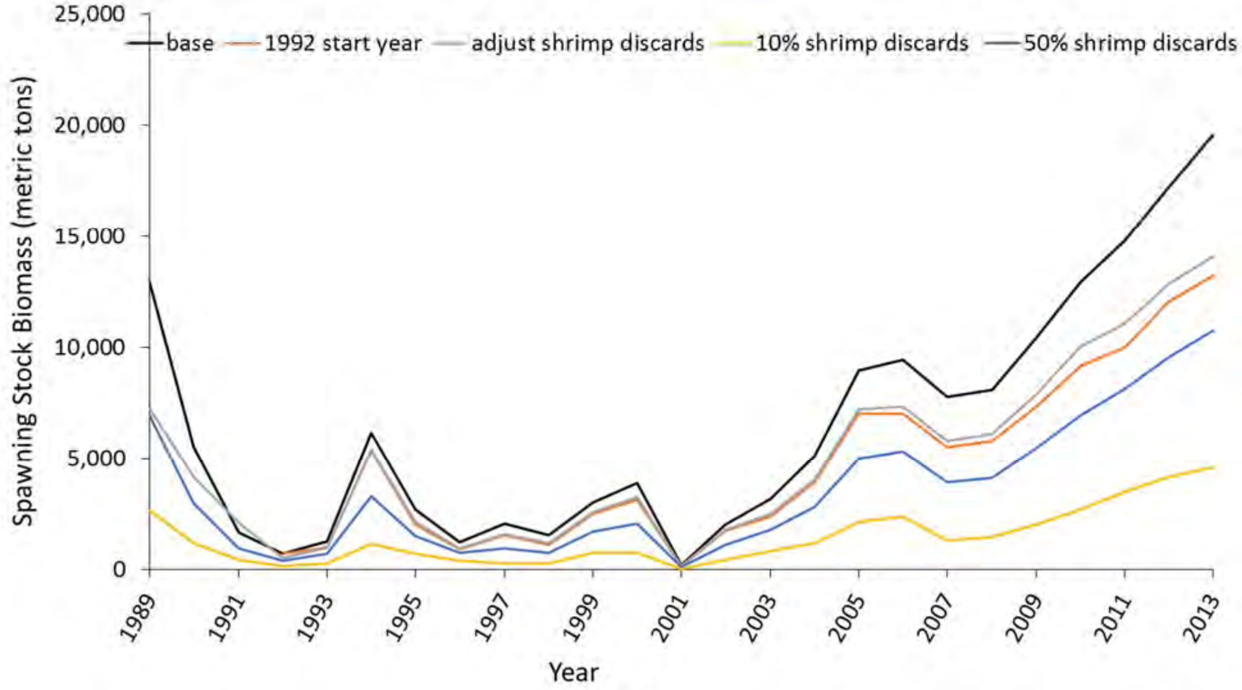


Figure 105. End-year spawning stock biomass estimates for spot from the base modified-CSA model and sensitivity configurations focusing on shrimp trawl discard estimates (see Table 95 for description of sensitivity configurations).

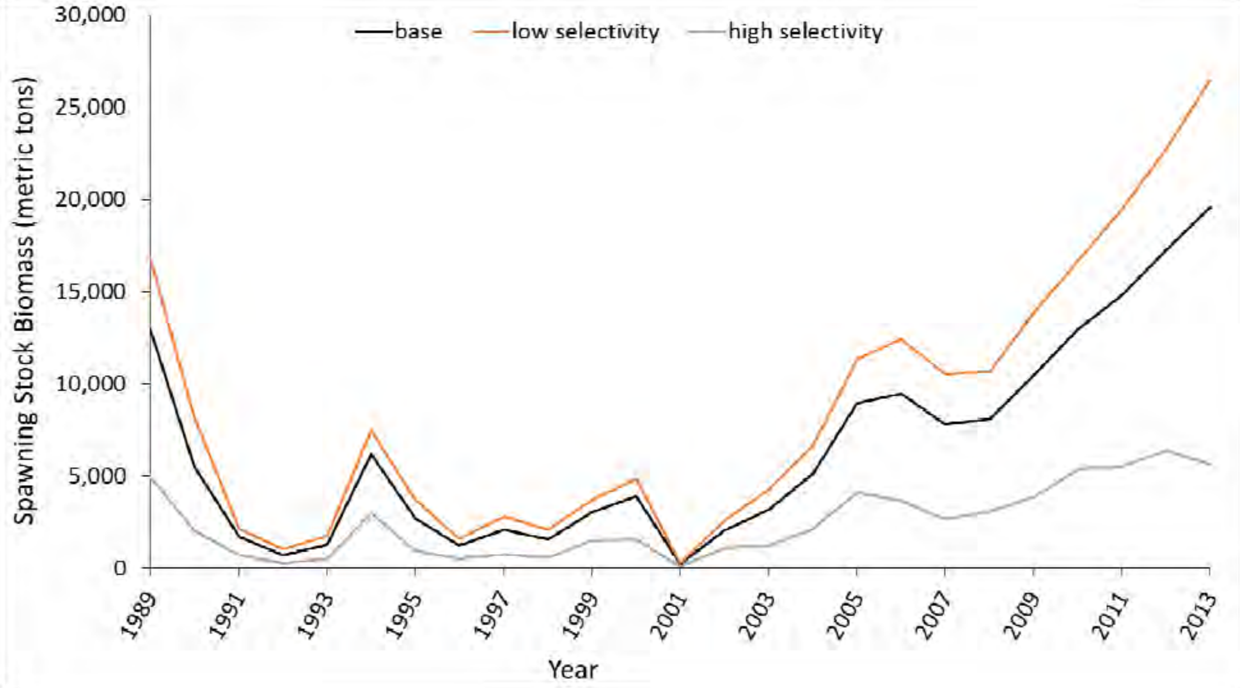


Figure 106. End-year spawning stock biomass estimates for spot from the base modified-CSA model and sensitivity configurations focusing on recruit selectivity assumptions (see Table 95 for description of sensitivity configurations).

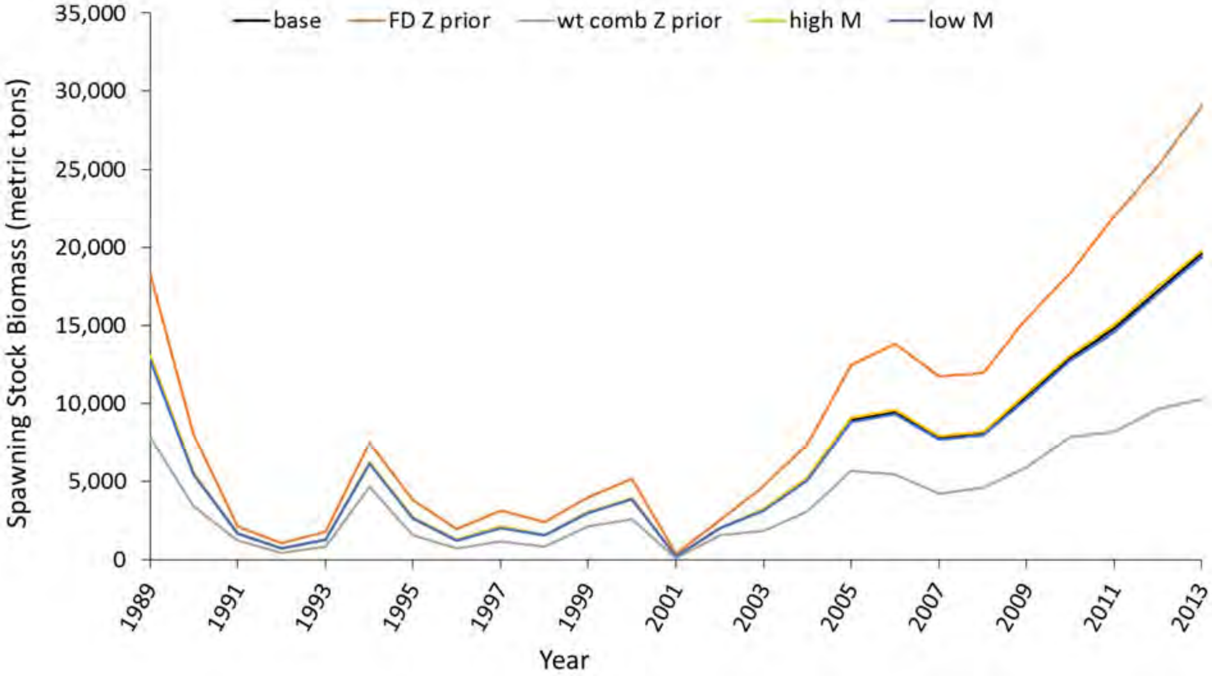


Figure 107. End-year spawning stock biomass estimates for spot from the base modified-CSA model and sensitivity configurations focusing on assumptions about mortality (see Table 95 for description of sensitivity configurations).

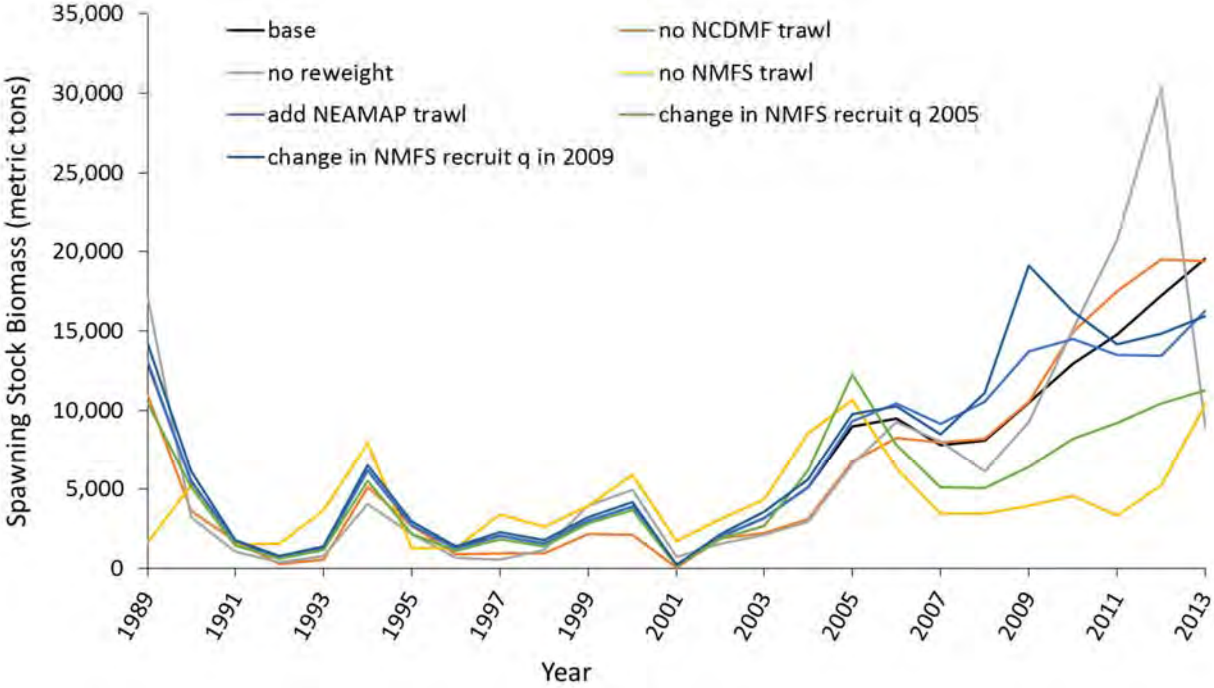


Figure 108. End-year spawning stock biomass estimates for spot from the base modified-CSA model and sensitivity configurations focusing on choices and treatment of index data (see Table 95 for description of sensitivity configurations).

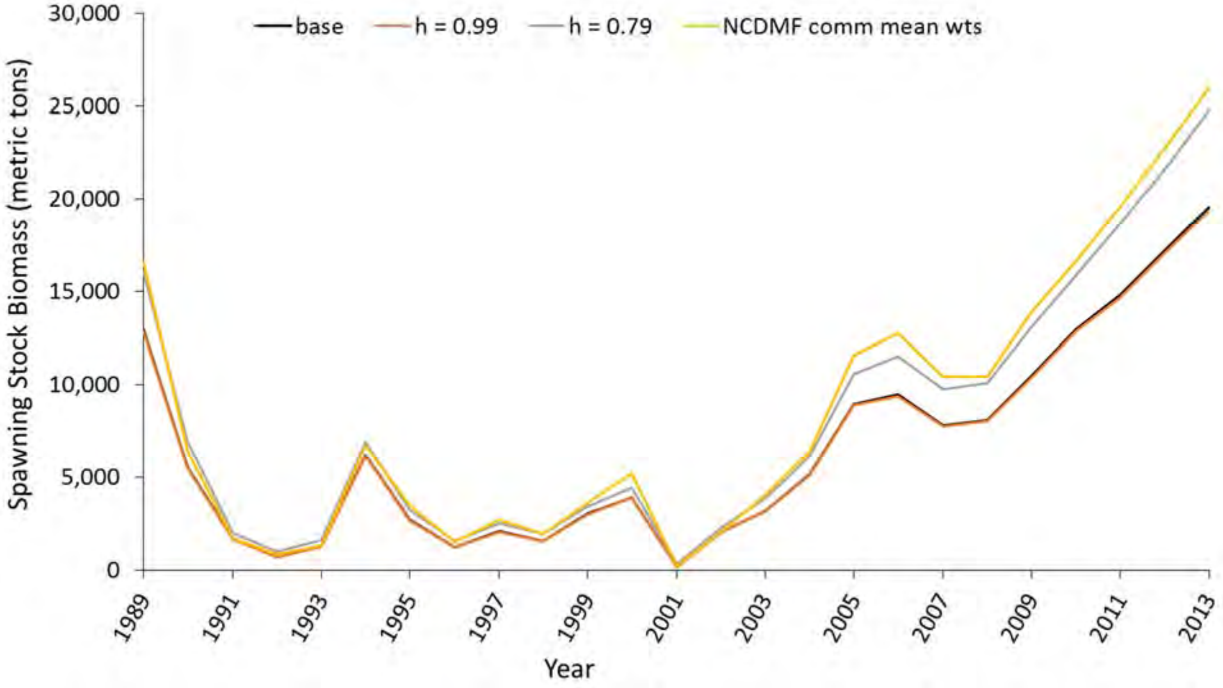


Figure 109. End-year spawning stock biomass estimates for spot from the base modified-CSA model and sensitivity configurations focusing on aspects relating to the stock-recruit relationship (see Table 95 for description of sensitivity configurations).

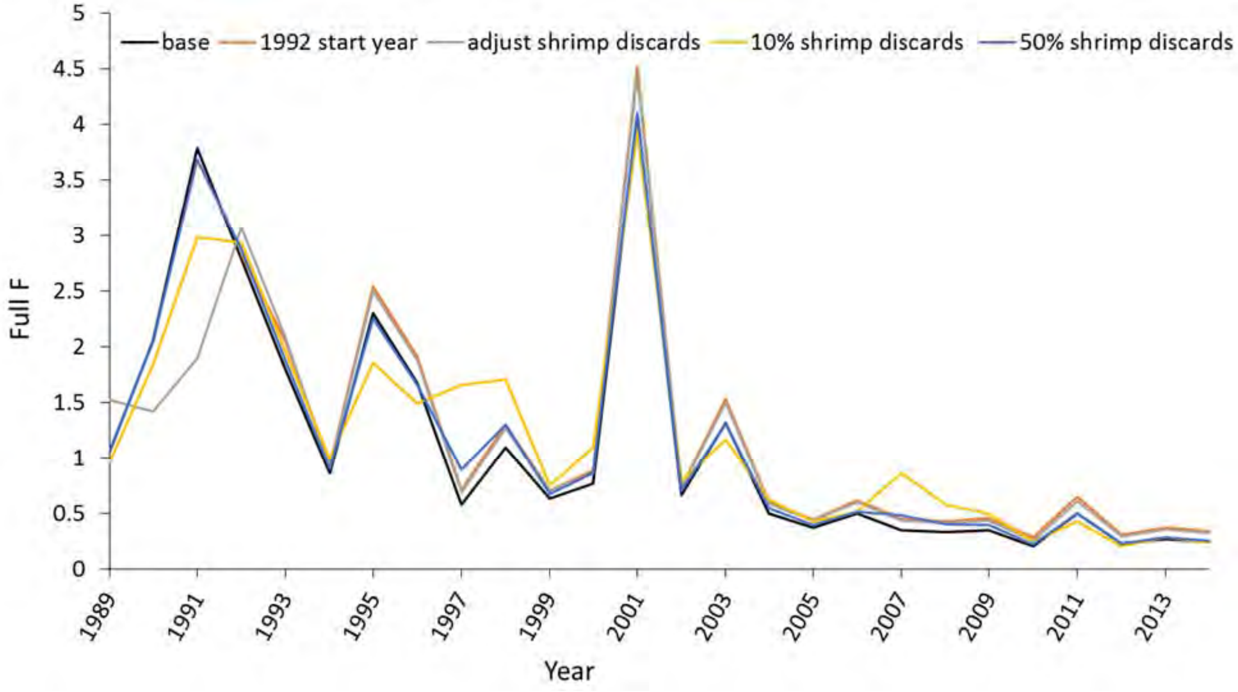


Figure 110. Full fishing mortality estimates for spot from the base modified-CSA model and sensitivity configurations focusing on shrimp trawl discard estimates (see Table 95 for description of sensitivity configurations).

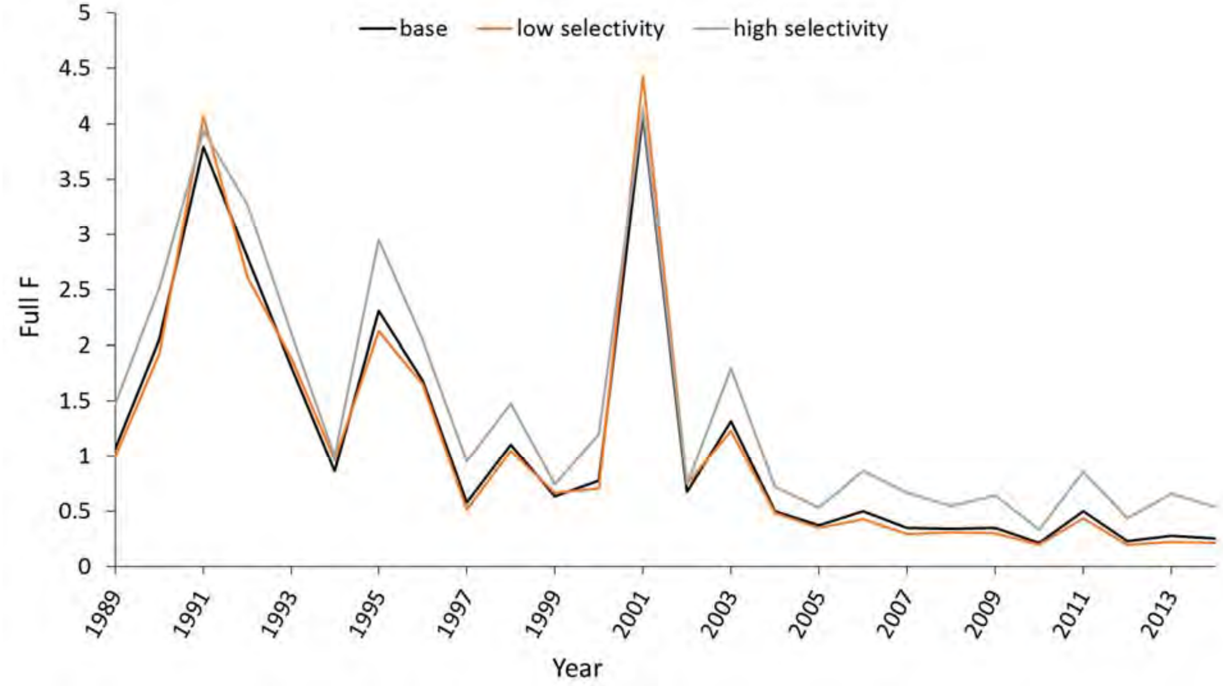


Figure 111. Full fishing mortality estimates for spot from the base modified-CSA model and sensitivity configurations focusing on recruit selectivity assumptions (see Table 95 for description of sensitivity configurations).

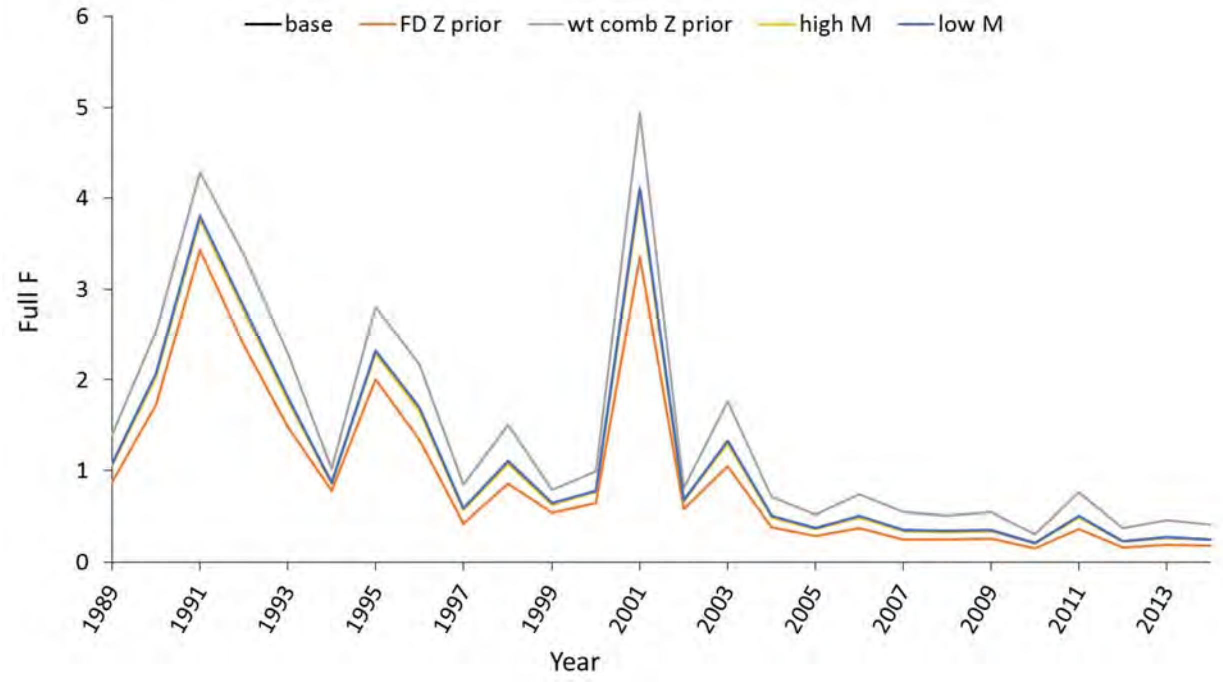


Figure 112. Full fishing mortality estimates for spot from the base modified-CSA model and sensitivity configurations focusing on assumptions about mortality (see Table 95 for description of sensitivity configurations).

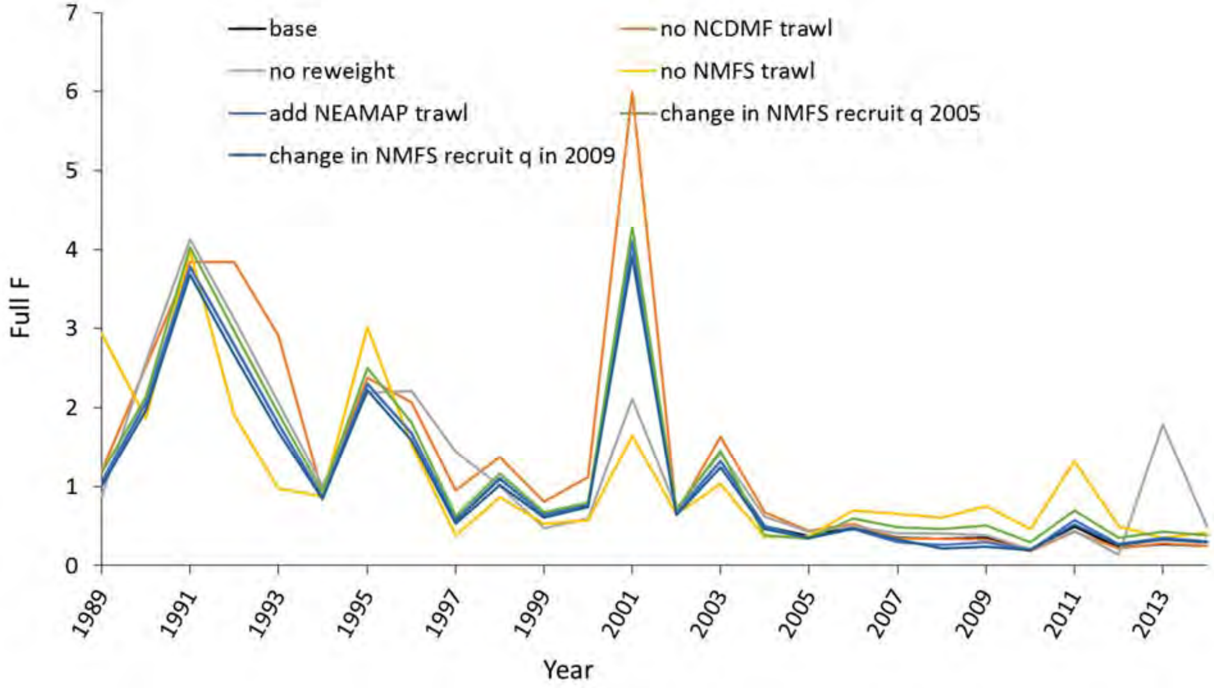


Figure 113. Full fishing mortality estimates for spot from the base modified-CSA model and sensitivity configurations focusing on choices and treatment of index data (see Table 95 for description of sensitivity configurations).

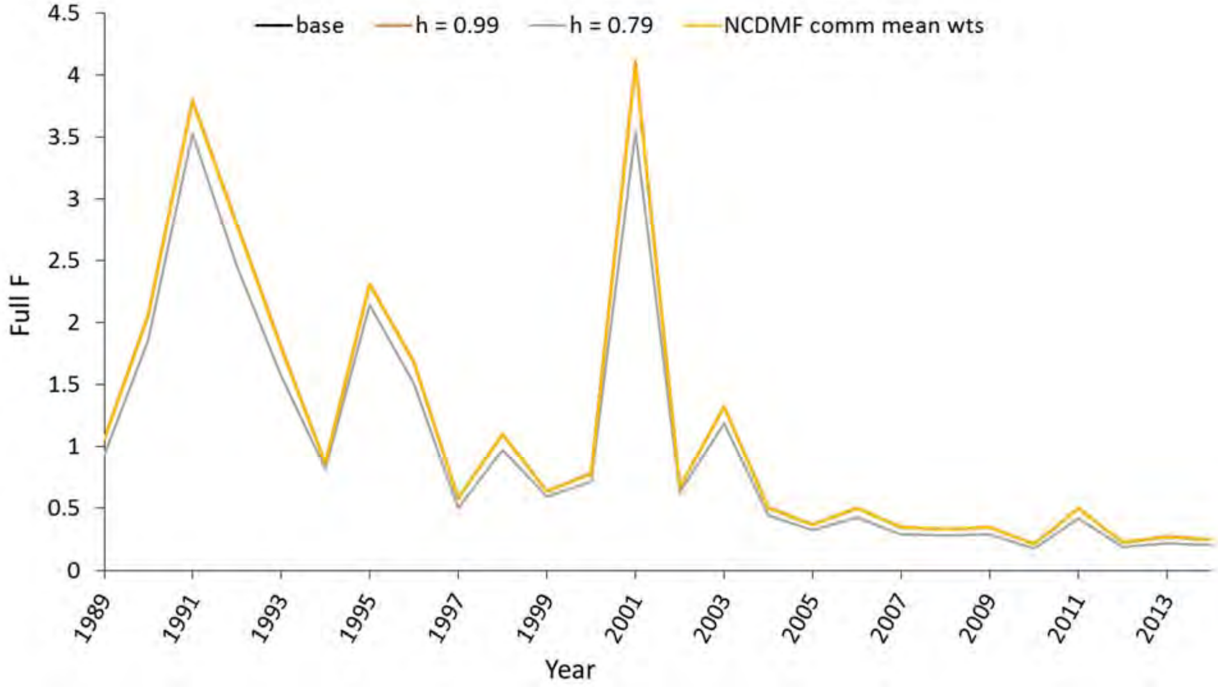


Figure 114. Full fishing mortality estimates for spot from the base modified-CSA model and sensitivity configurations focusing on aspects relating to the stock-recruit relationship (see Table 95 for description of sensitivity configurations).

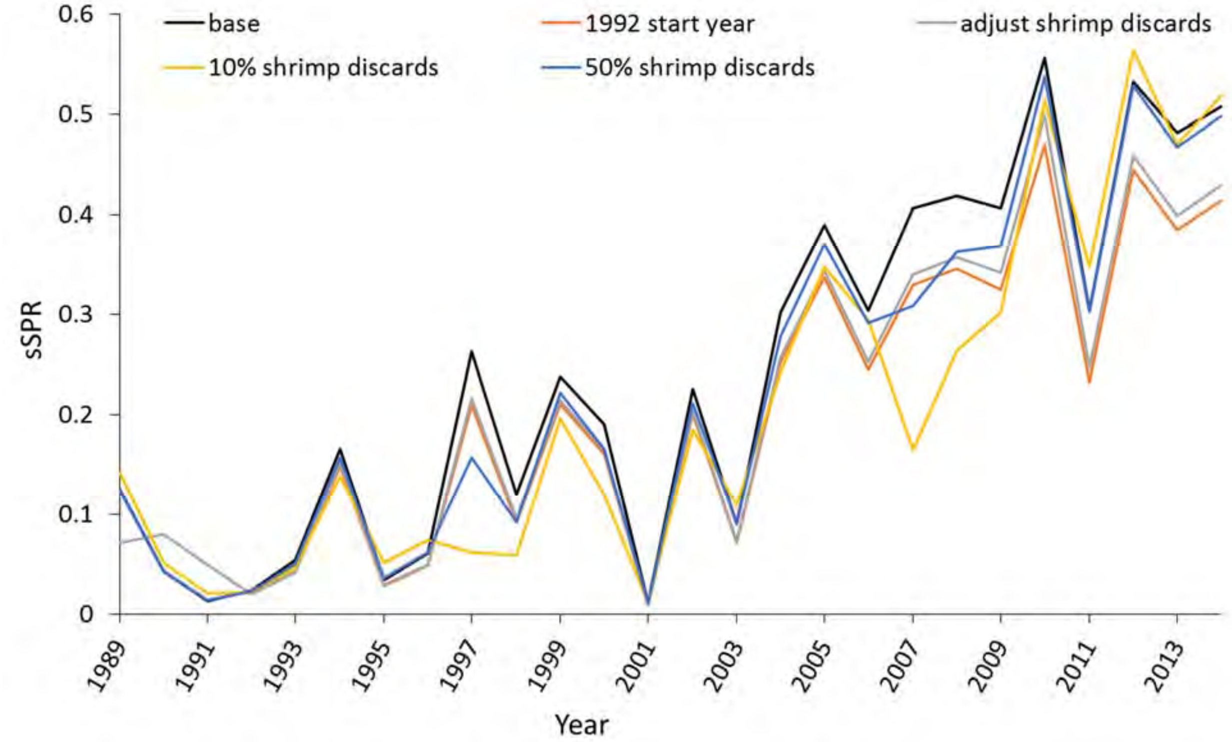


Figure 115. Static spawning potential ratio estimates for spot from the base modified-CSA model and sensitivity configurations focusing on shrimp trawl discard estimates (see Table 95 for description of sensitivity configurations).

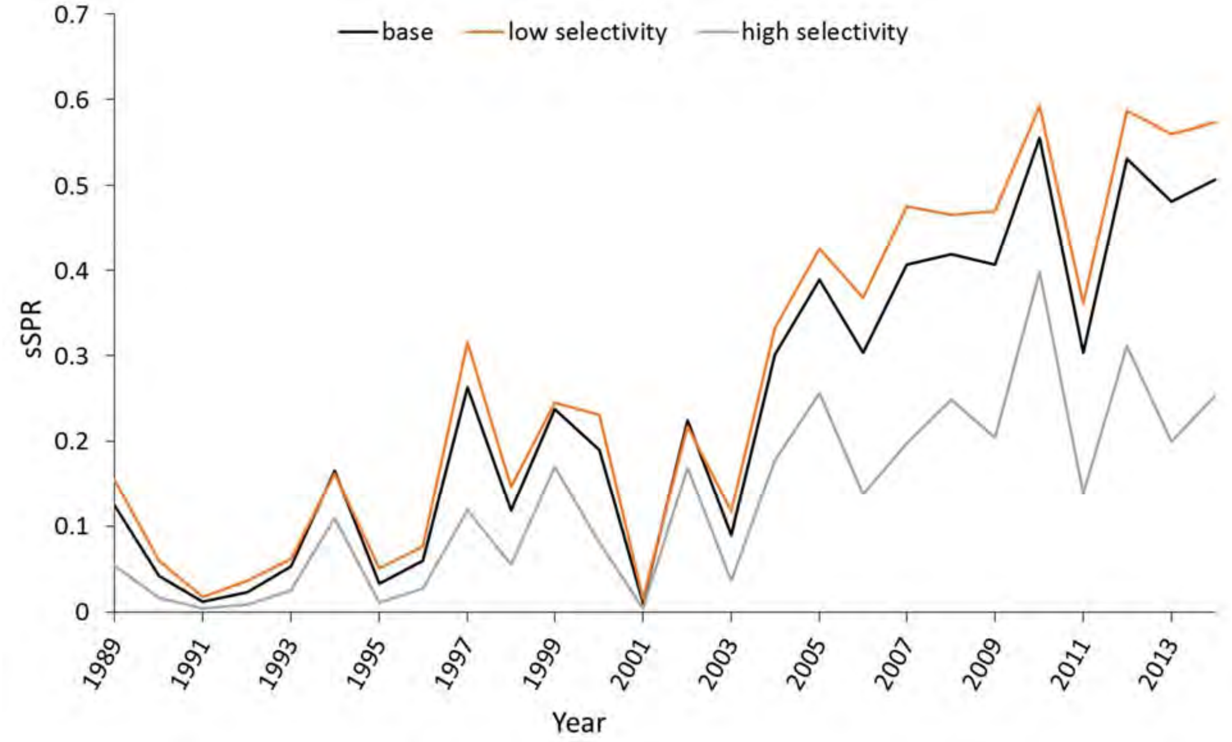


Figure 116. Static spawning potential ratio estimates for spot from the base modified-CSA model and sensitivity configurations focusing on recruit selectivity assumptions (see Table 95 for description of sensitivity configurations).

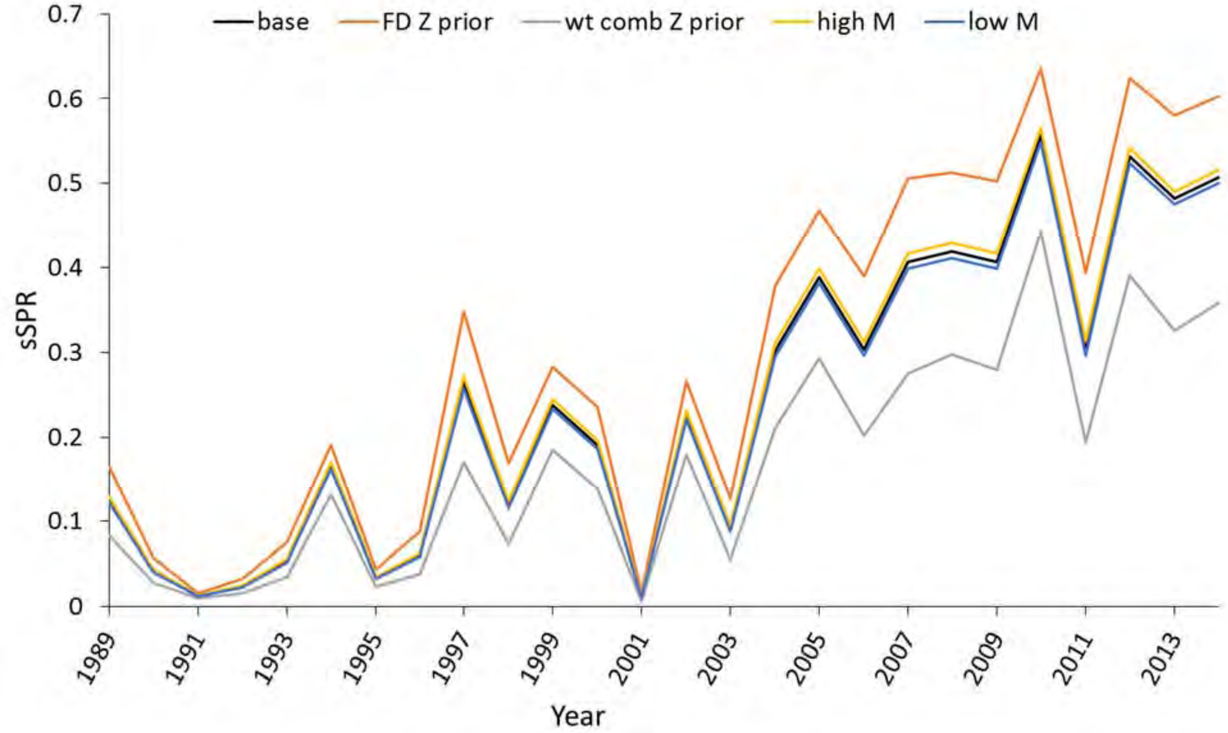


Figure 117. Static spawning potential ratio estimates for spot from the base modified-CSA model and sensitivity configurations focusing on assumptions about mortality (see Table 95 for description of sensitivity configurations).

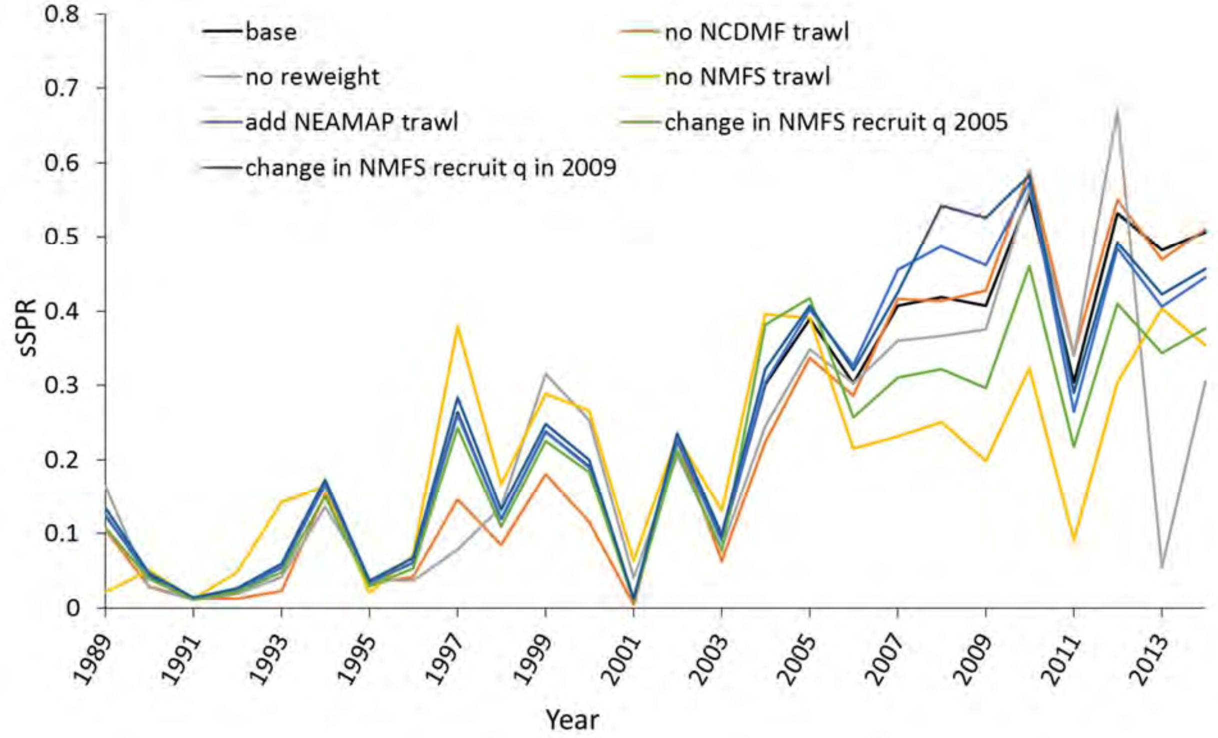


Figure 118. Static spawning potential ratio estimates for spot from the base modified-CSA model and sensitivity configurations focusing on choices and treatment of index data (see Table 95 for description of sensitivity configurations).

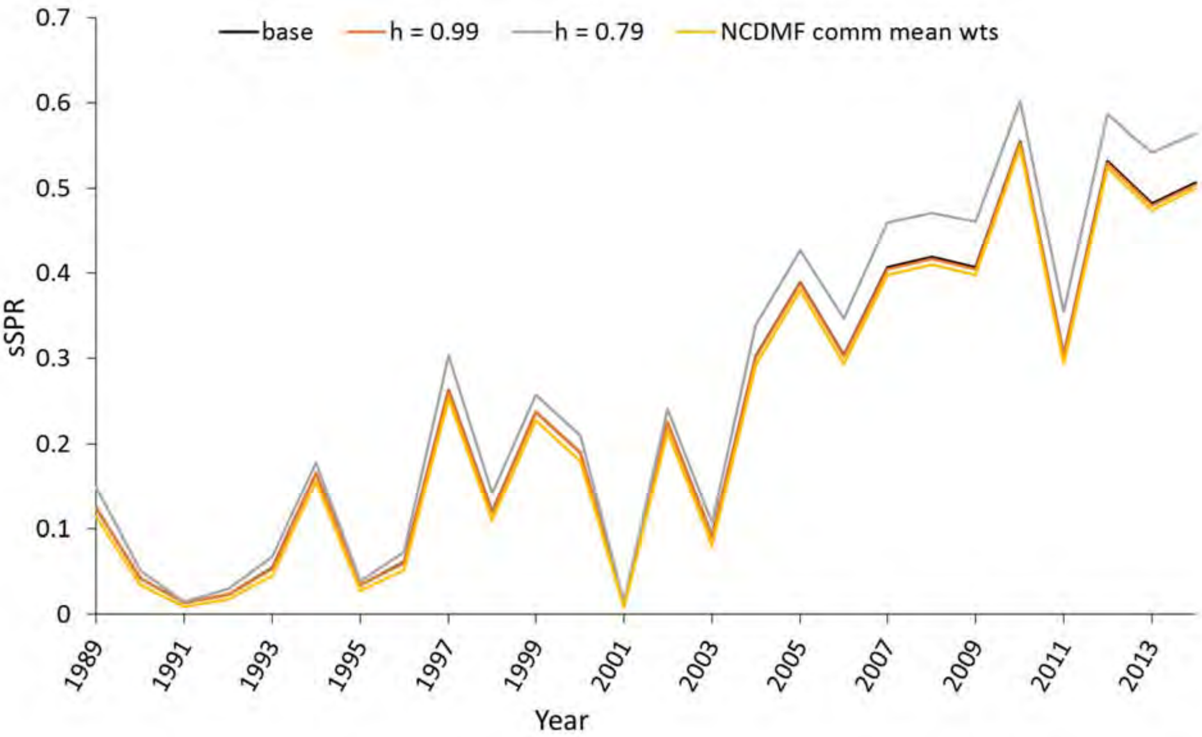


Figure 119. Static spawning potential ratio estimates for spot from the base modified-CSA model and sensitivity configurations focusing on aspects relating to the stock-recruit relationship (see Table 95 for description of sensitivity configurations).

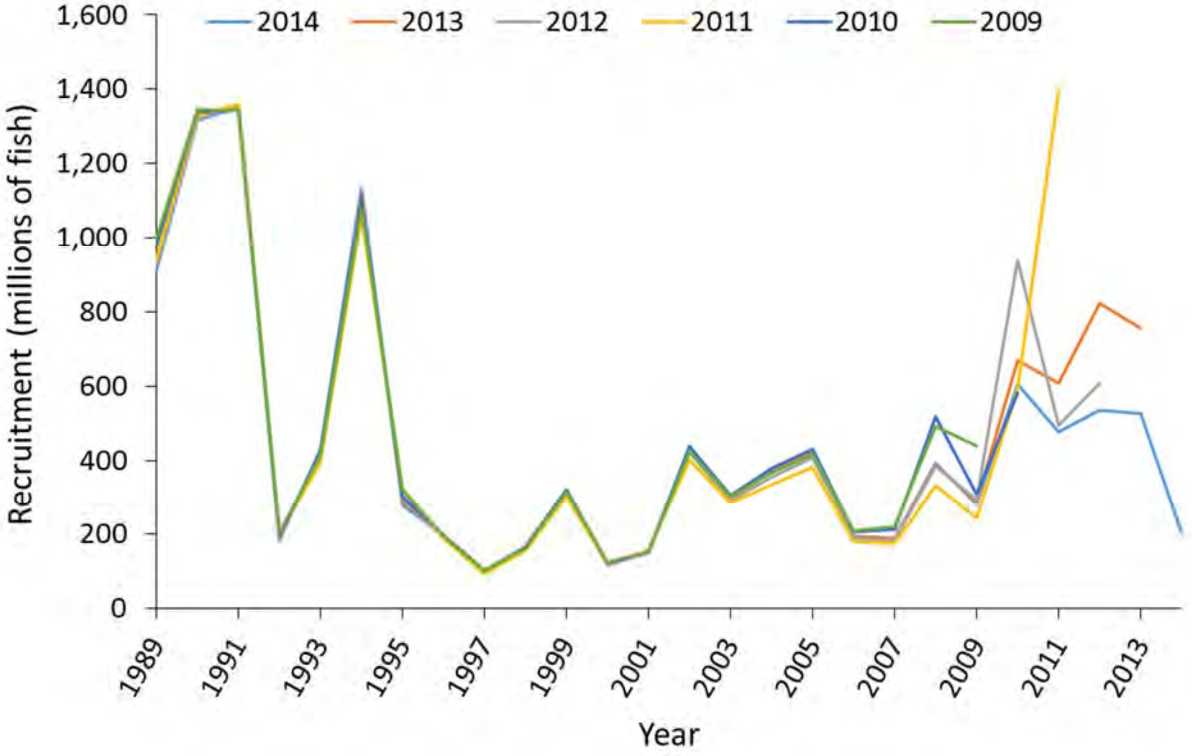


Figure 120. Retrospective plot of recruitment estimates for spot from the base modified-CSA model (2014) and five year peel.

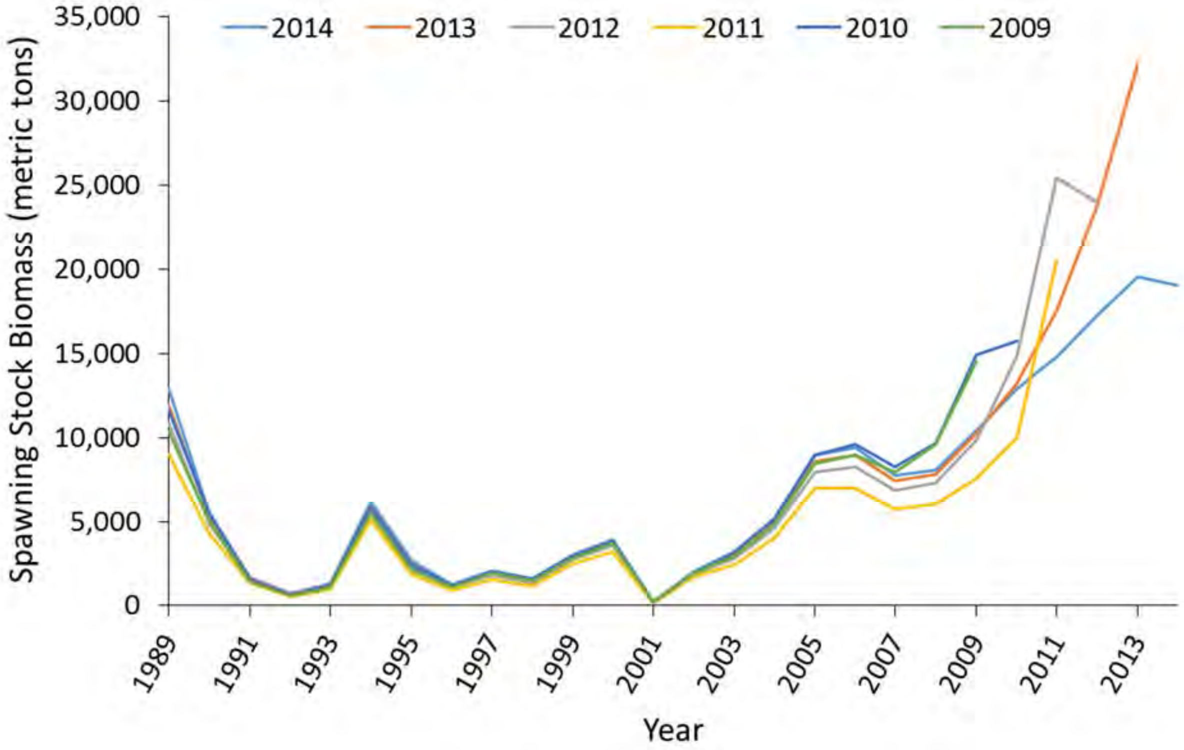


Figure 121. Retrospective plot of end-year spawning stock biomass estimates for spot from the base modified-CSA model (2014) and five year peel.

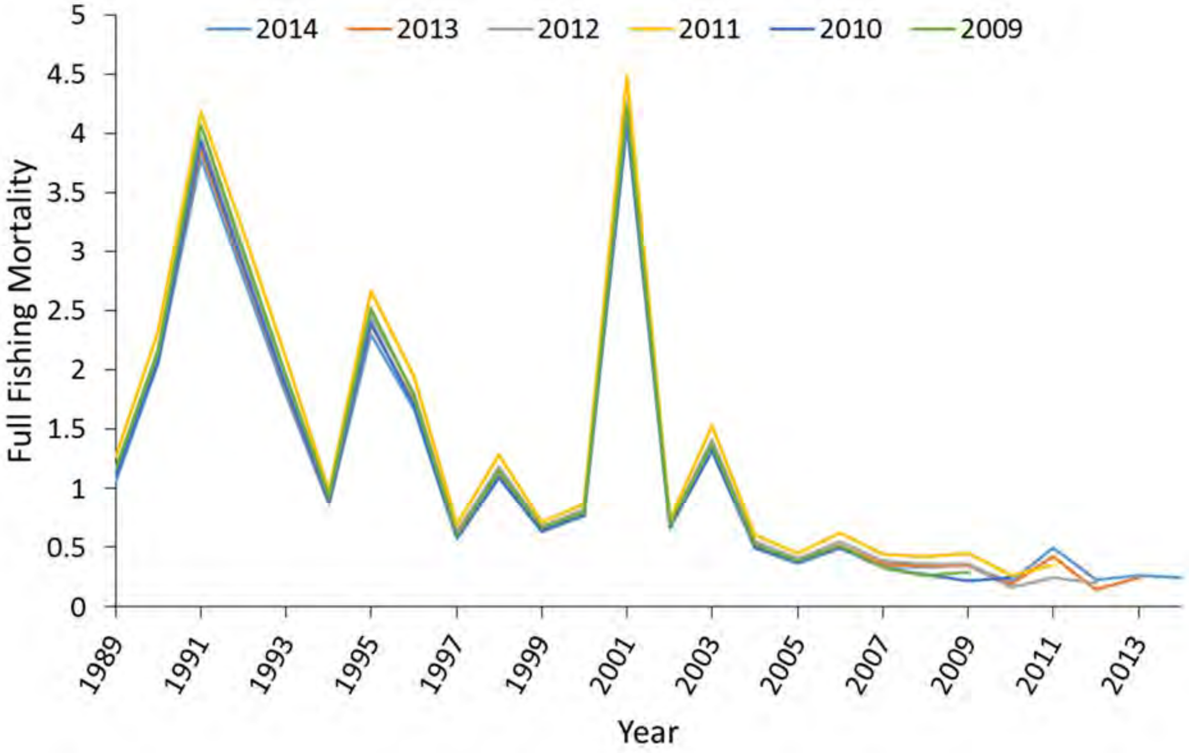


Figure 122. Retrospective plot of full fishing mortality estimates for spot from the base modified-CSA model (2014) and five year peel.

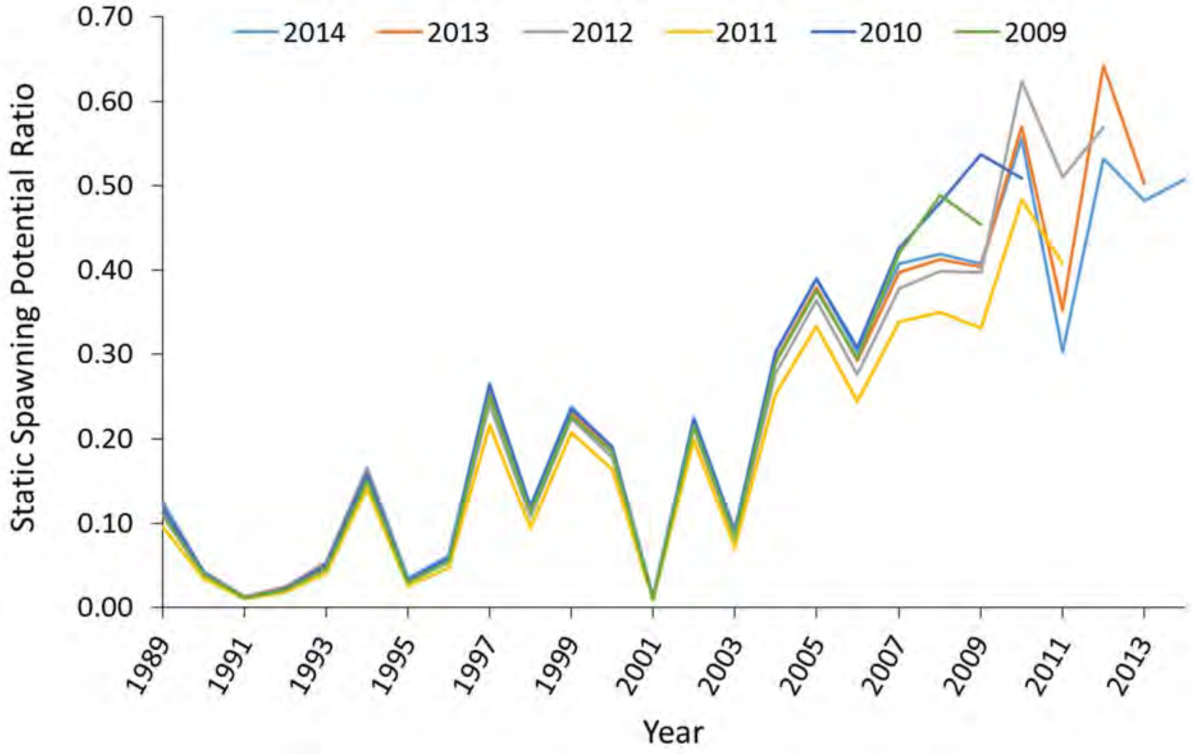


Figure 123. Retrospective plot of static spawning potential ratio estimates for spot from the base modified-CSA model (2014) and five year peel.

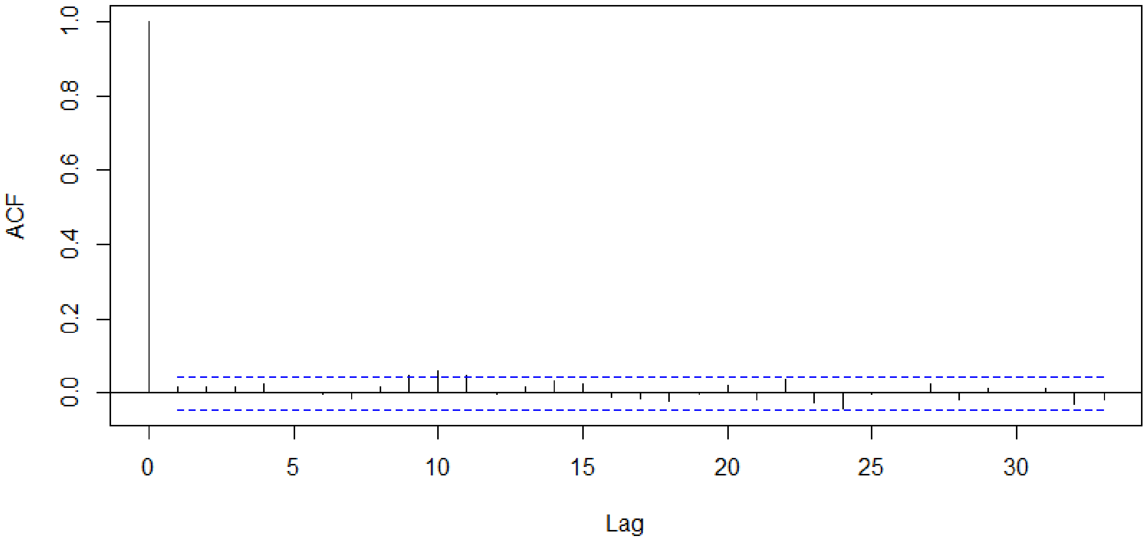


Figure 124. Autocorrelation of MCMC samples for the initial recruitment parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.

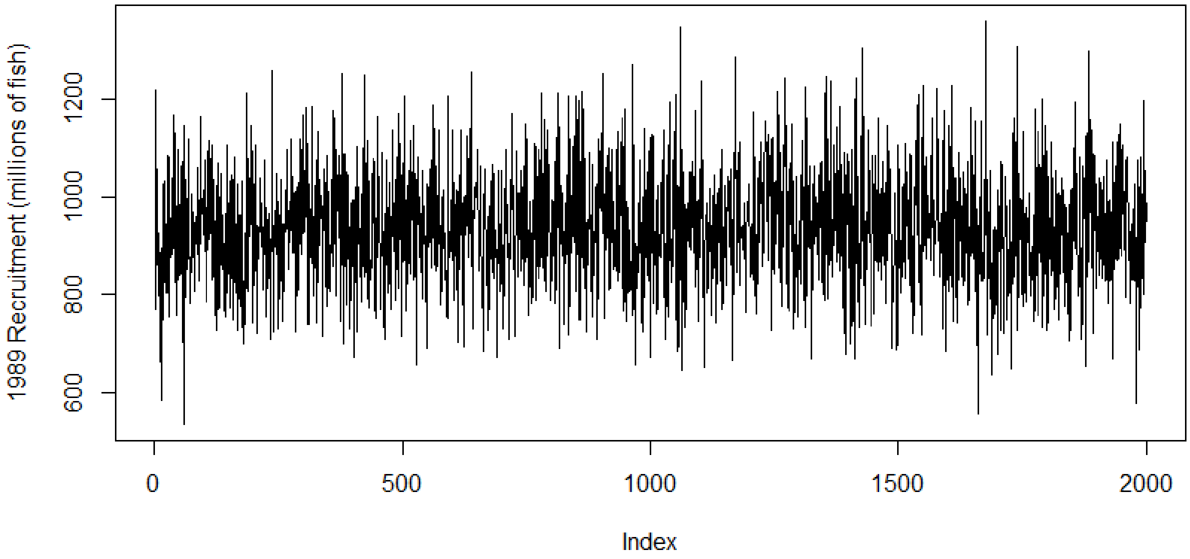


Figure 125. Trace plot of MCMC samples for the initial recruitment parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).

Figure 126. Density of the base modified-CSA model initial recruitment parameter estimate for spot from MCMC draws (solid line) compared to the maximum likelihood estimate and asymptotic standard errors (dashed line). Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).

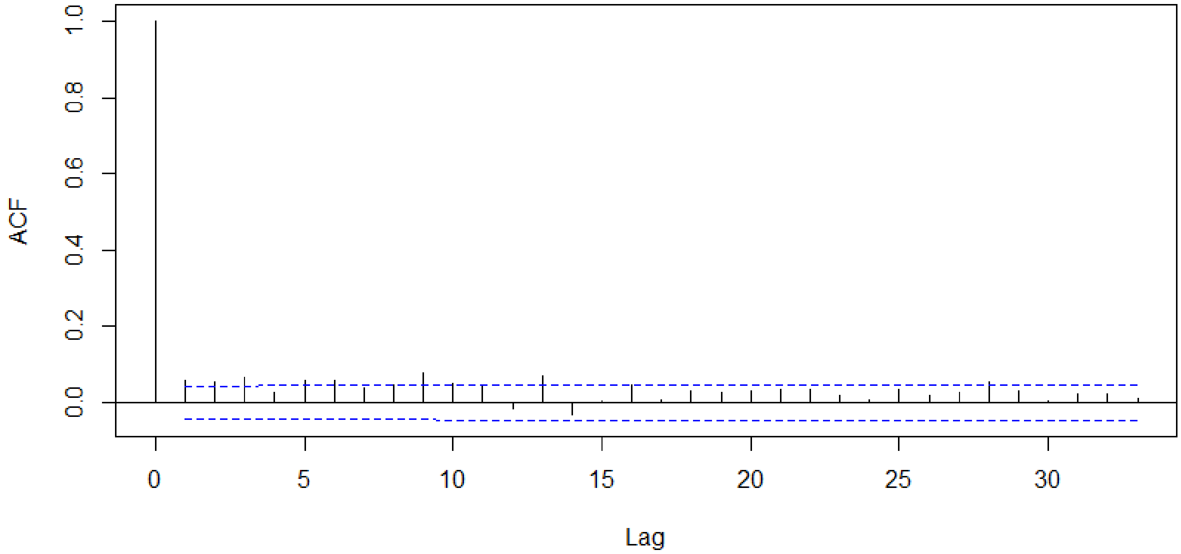


Figure 127. Autocorrelation of MCMC samples for the initial post-recruit abundance parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.

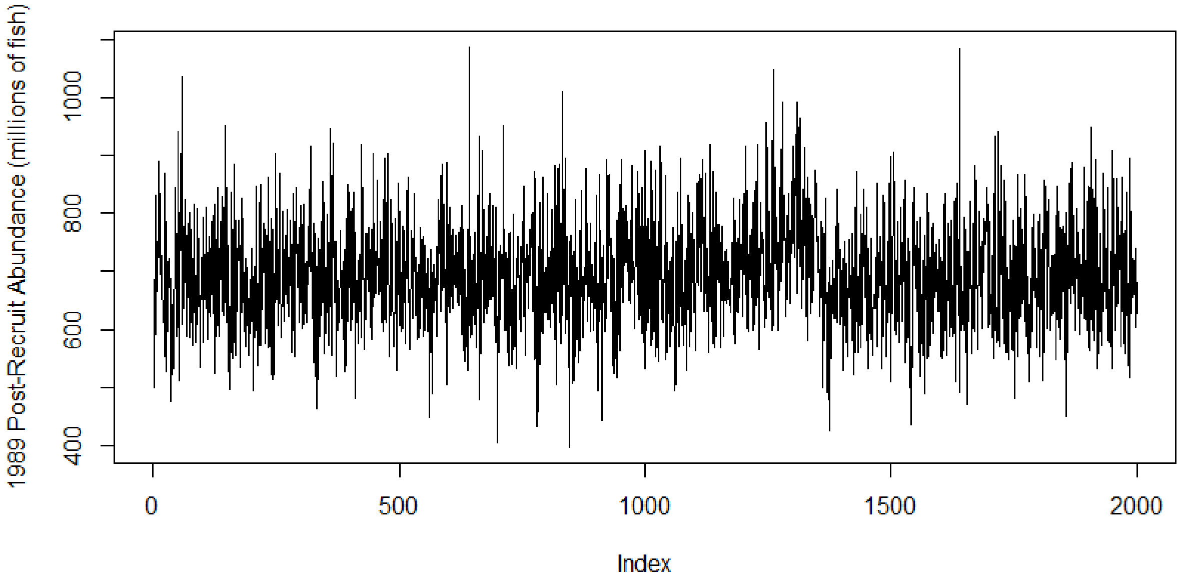


Figure 128. Trace plot of MCMC samples for the initial post-recruit abundance parameter for spot from the base modified-CSA model. Two million MCMC samples were

drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).

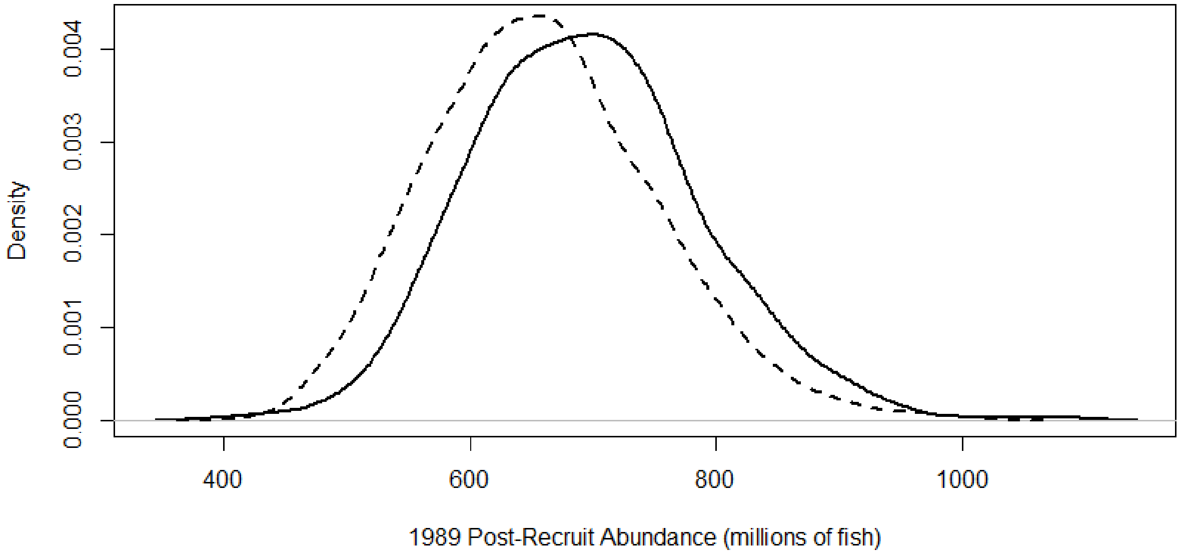


Figure 129. Density of the base modified-CSA model initial post-recruit abundance parameter estimate for spot from MCMC draws (solid line) compared to the maximum likelihood estimate and asymptotic standard errors (dashed line). Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).

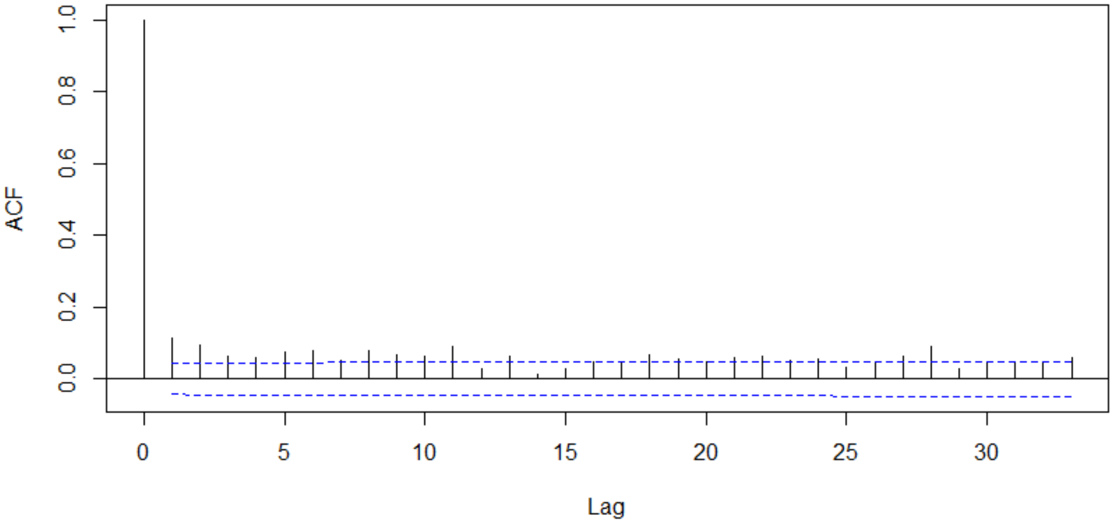


Figure 130. Autocorrelation of MCMC samples for the initial fishing mortality parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one

thousand samples (final n = 2,000). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.

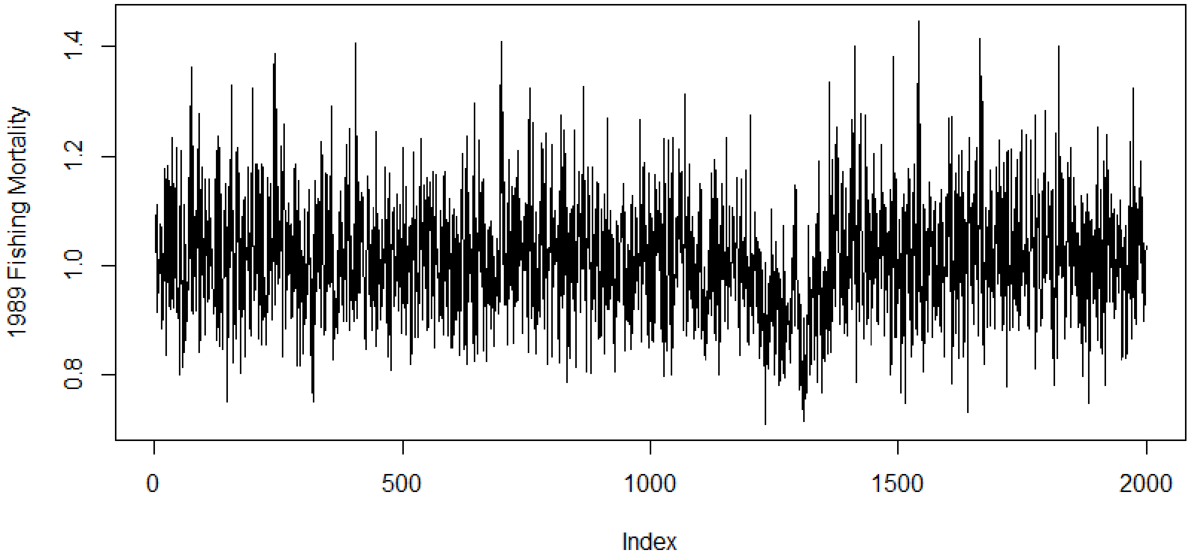


Figure 131. **Trace plot of MCMC samples for the initial fishing mortality parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).**

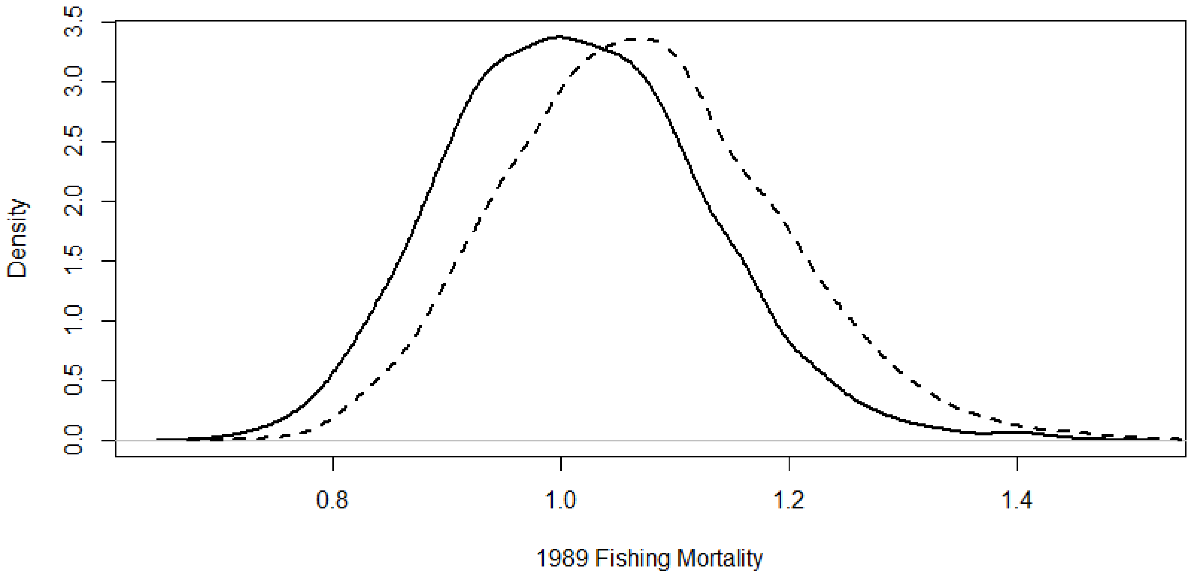


Figure 132. **Density of the base modified-CSA model initial fishing mortality parameter estimate for spot from MCMC draws (solid line) compared to the maximum likelihood estimate and asymptotic standard errors (dashed line). Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).**

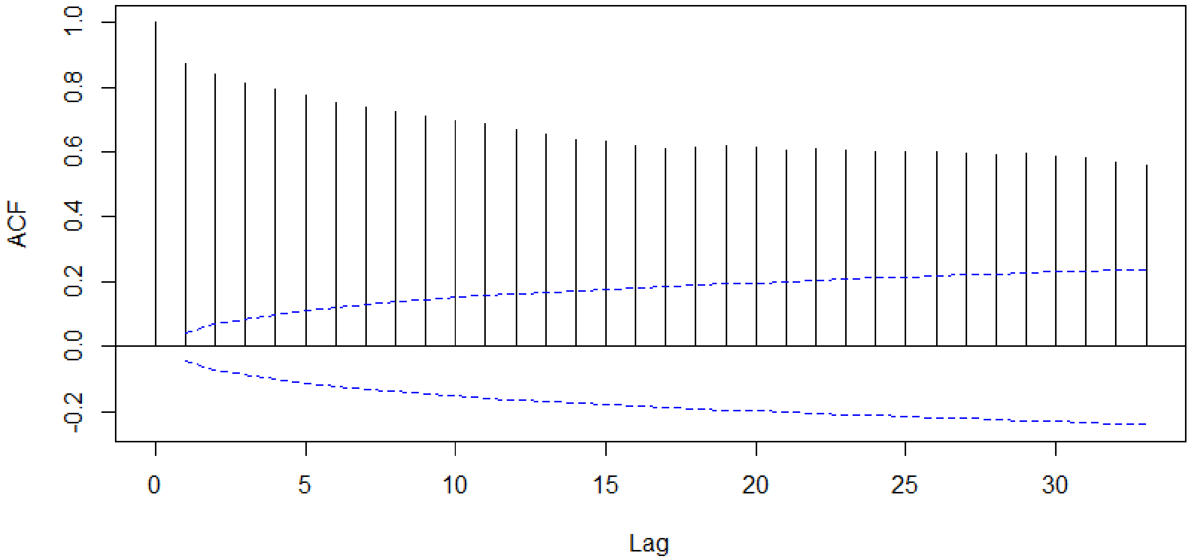


Figure 133. **Autocorrelation of MCMC samples for the unfished spawning stock biomass parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.**

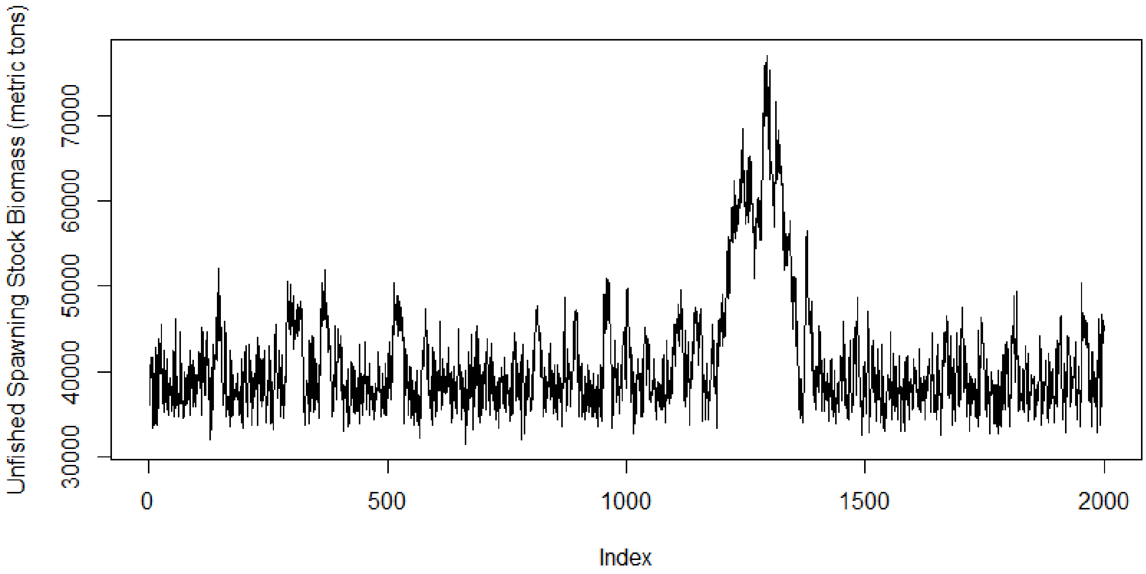


Figure 134. **Trace plot of MCMC samples for the unfished spawning stock biomass parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).**

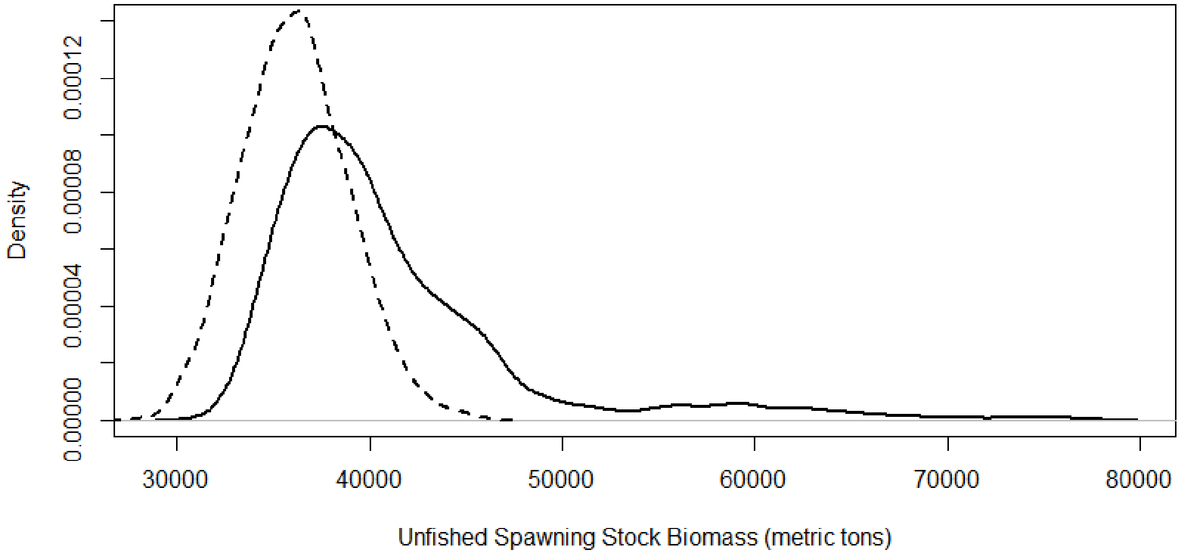


Figure 135. **Density of the base modified-CSA model unfished spawning stock biomass parameter estimate for spot from MCMC draws (solid line) compared to the maximum likelihood estimate and asymptotic standard errors (dashed line). Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).**

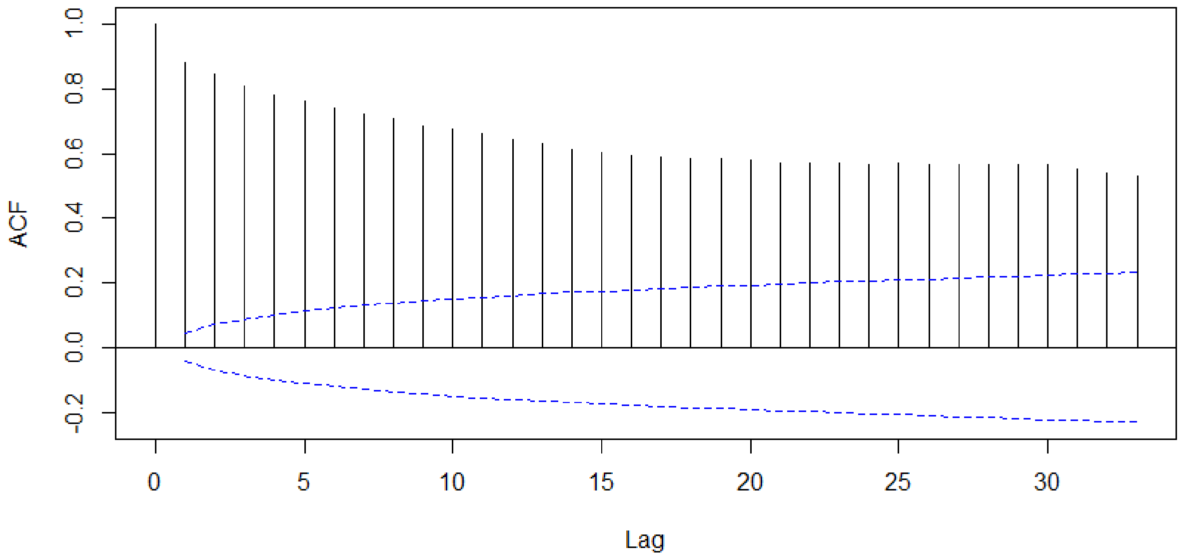


Figure 136. Autocorrelation of MCMC samples for the steepness parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.

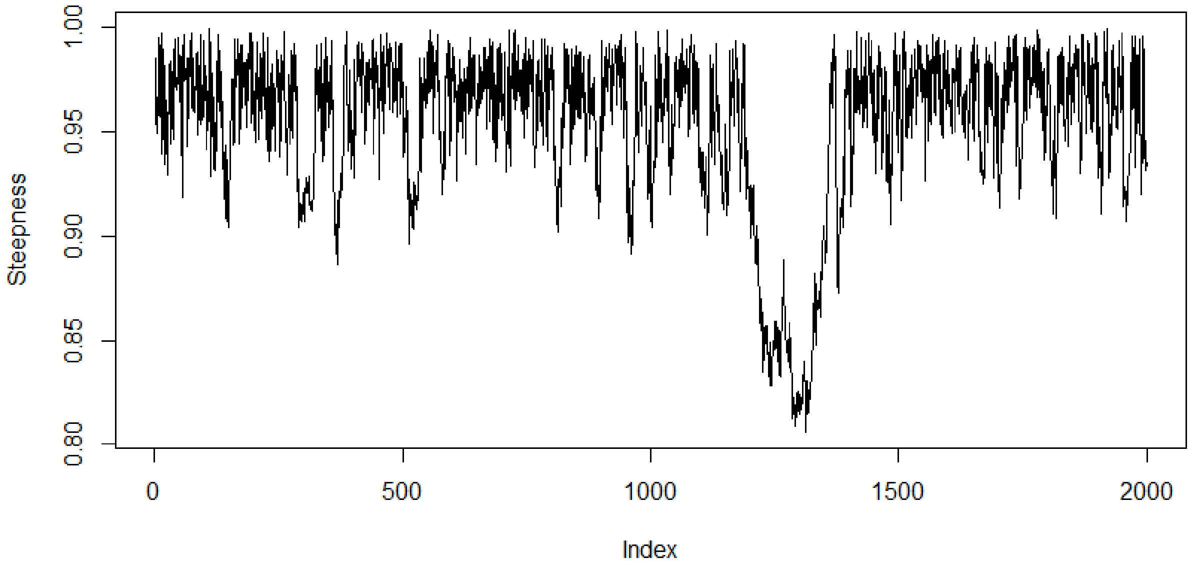


Figure 137. Trace plot of MCMC samples for the steepness parameter for spot from the base modified-CSA model. Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).

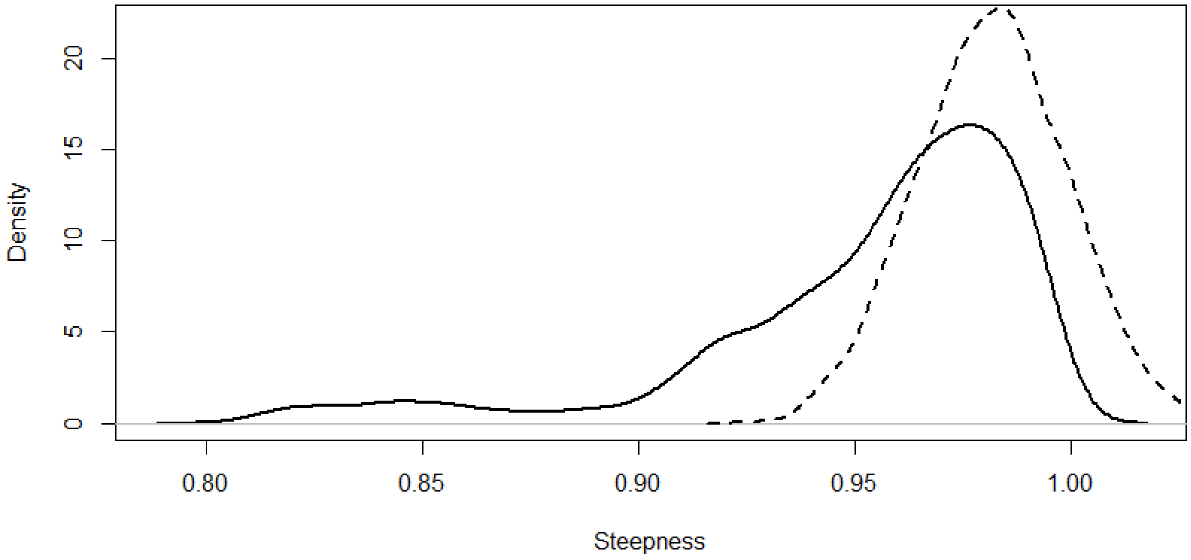


Figure 138. Density of the base modified-CSA model steepness parameter estimate for spot from MCMC draws (solid line) compared to the maximum likelihood estimate and asymptotic standard errors (dashed line). Two million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 2,000).

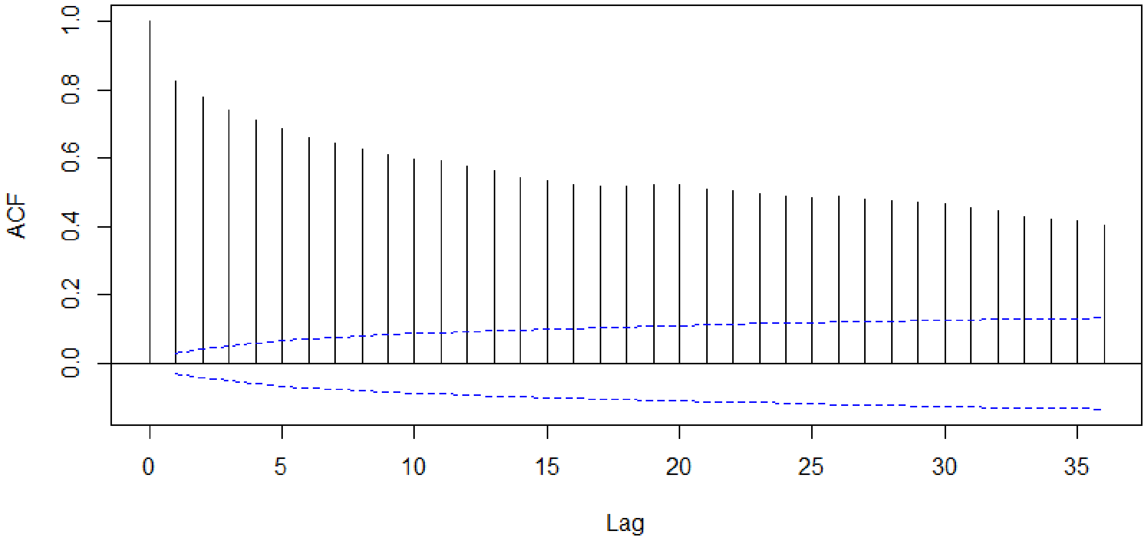


Figure 139. Autocorrelation of MCMC samples for the unfished spawning stock biomass parameter for spot from the base modified-CSA model. Five million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 5,000). Dashed blue lines are 95%

confidence intervals with values exceeding these lines being statistically different than zero.

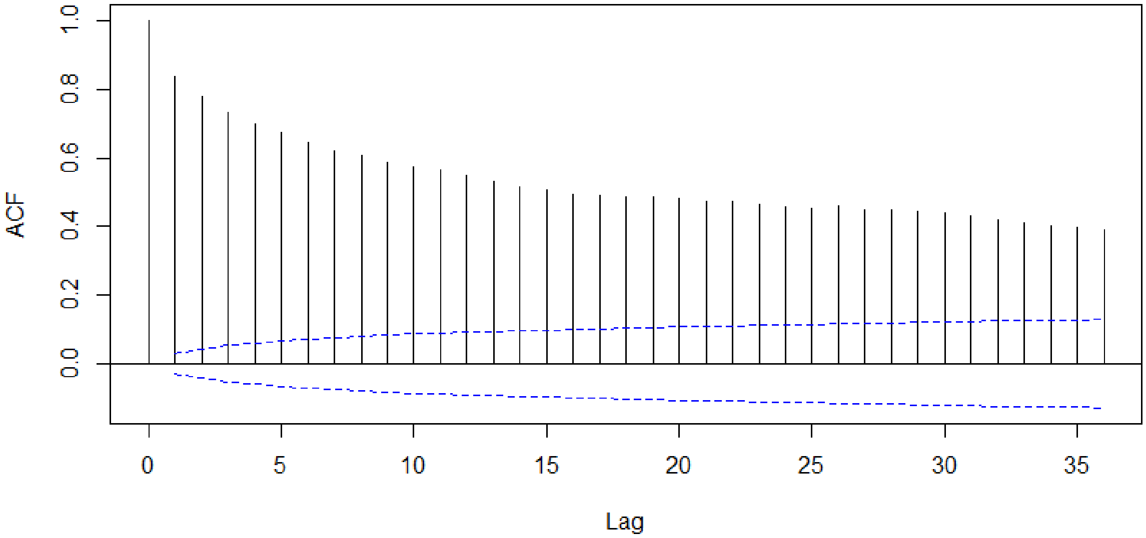


Figure 140. **Autocorrelation of MCMC samples for the steepness parameter for spot from the base modified-CSA model. Five million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of one thousand samples (final n = 5,000). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.**

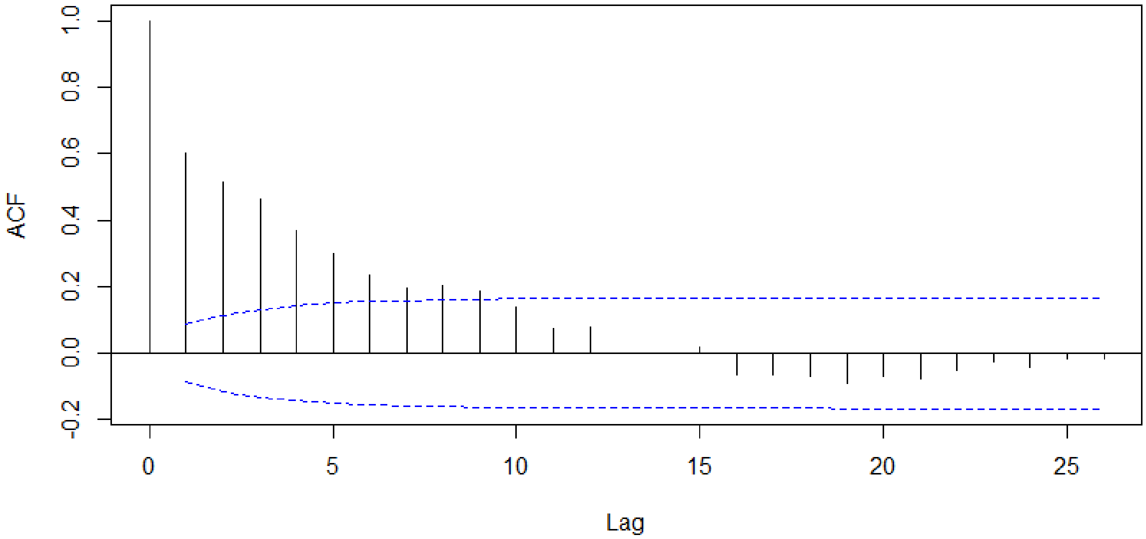


Figure 141. **Autocorrelation of MCMC samples for the unfished spawning stock biomass parameter for spot from the base modified-CSA model. Five million MCMC samples were drawn with a burn-in of one thousand samples and a thinning**

rate of ten thousand samples (final n = 500). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.

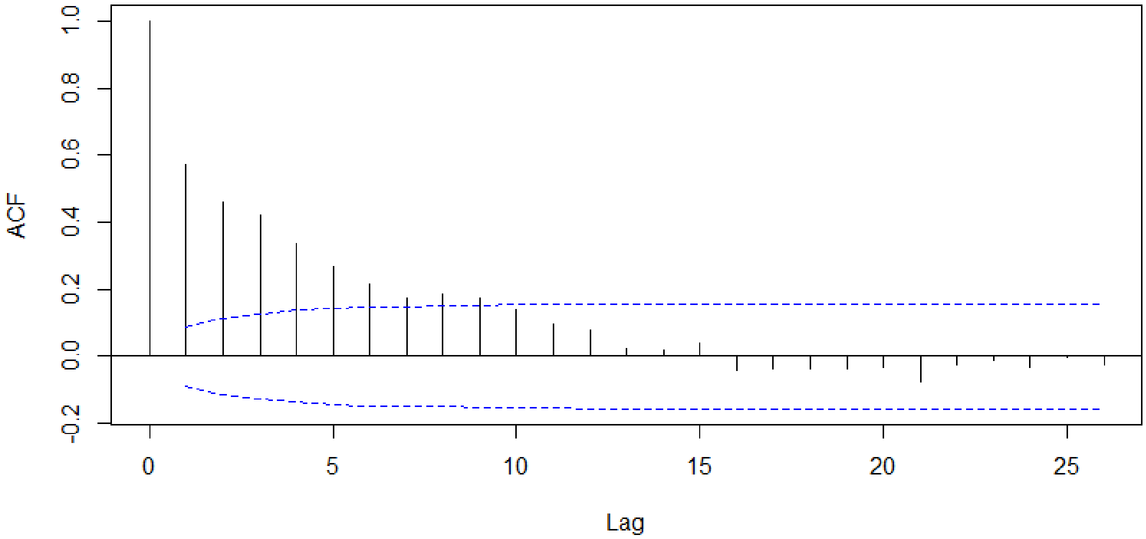


Figure 142. **Autocorrelation of MCMC samples for the steepness parameter for spot from the base modified-CSA model. Five million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of ten thousand samples (final n = 500). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.**

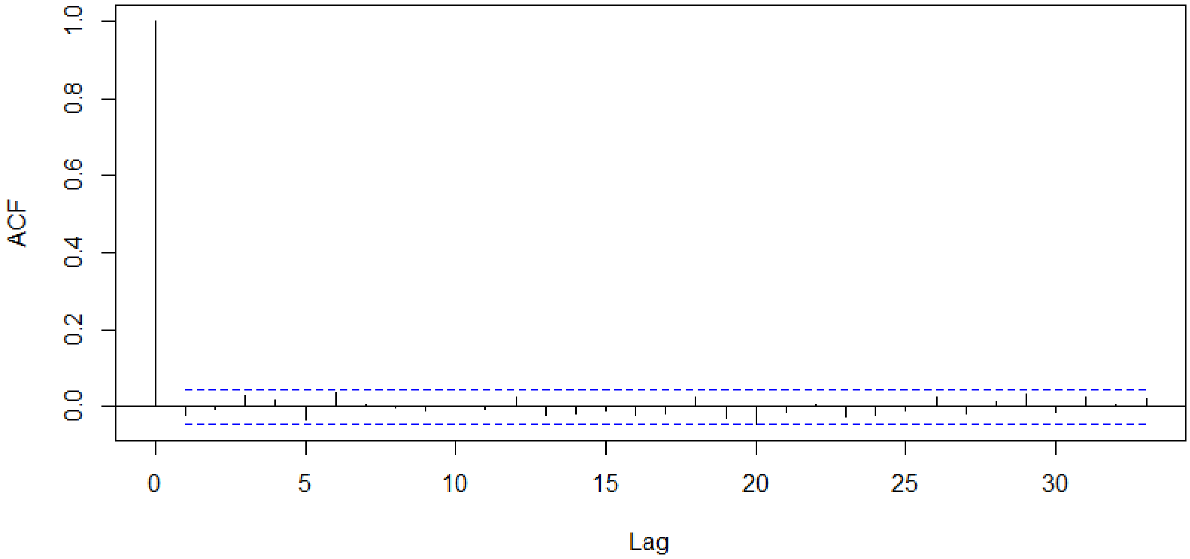


Figure 143. Autocorrelation of MCMC samples for the unfished spawning stock biomass parameter for spot from the modified-CSA model with the steepness parameter fixed at 0.99. Five million MCMC samples were drawn with a burn-in of one thousand samples and a thinning rate of ten thousand samples (final n = 500). Dashed blue lines are 95% confidence intervals with values exceeding these lines being statistically different than zero.

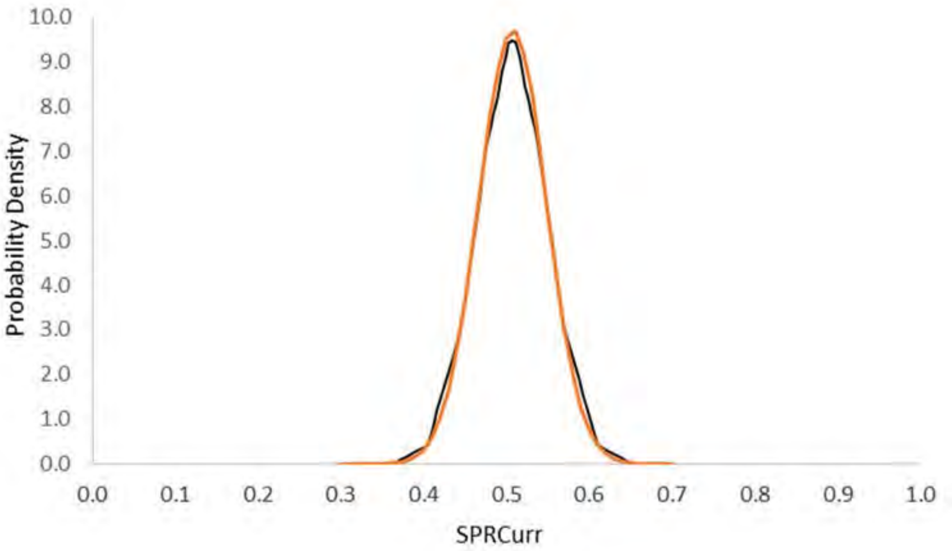


Figure 144. Likelihood profile of terminal year (2014) static spawning potential ratio estimate for spot from the base modified-CSA model.

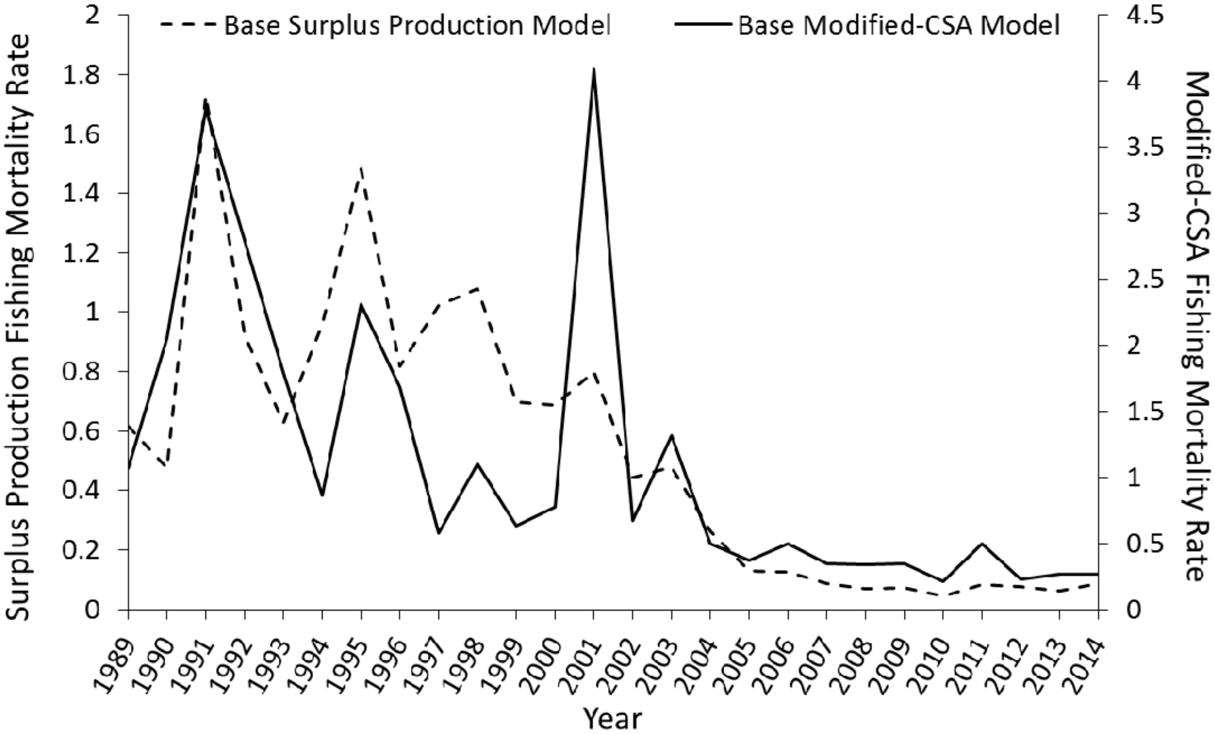


Figure 145. Fishing mortality estimates for spot from the base surplus production model and modified-CSA model.

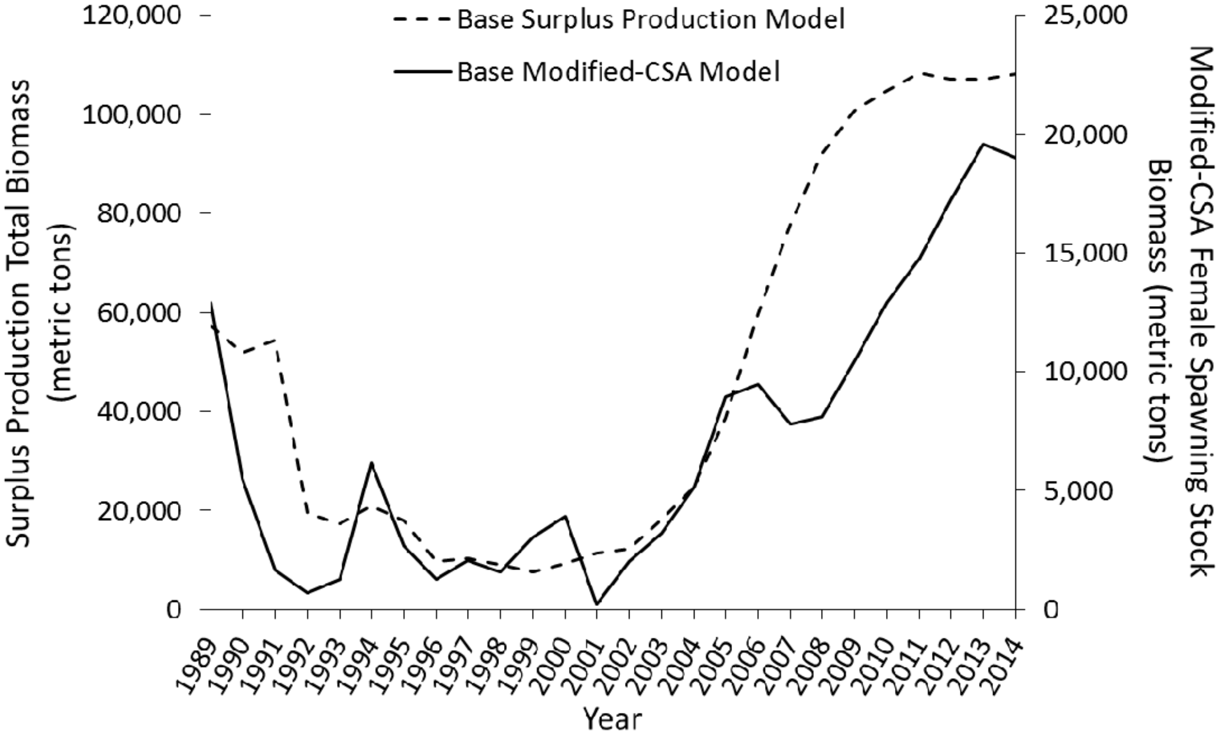


Figure 146. Total biomass (metric tons) and end-year spawning stock biomass (metric tons) estimates for spot from the base surplus production model and base modified-CSA model, respectively.

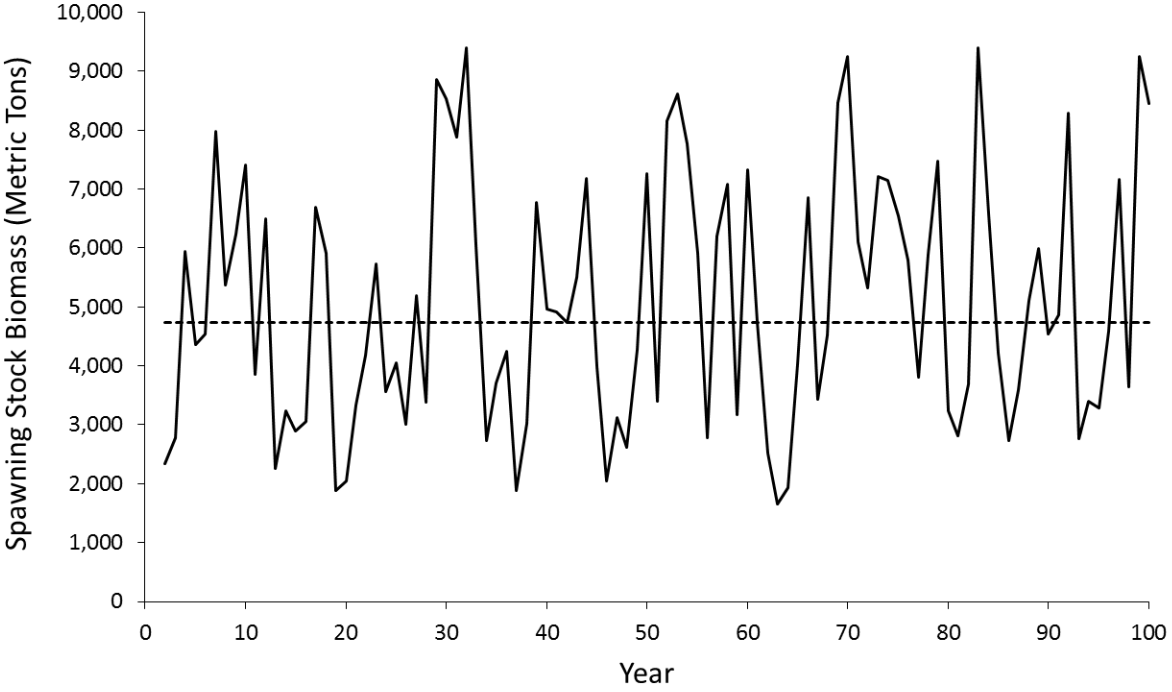


Figure 147. Projected end-year spawning stock biomass estimates (solid black line) for threshold spawning stock biomass estimate. The median (dashed black line; 4,730 metric tons) estimate is the point estimate for the spawning stock biomass threshold.

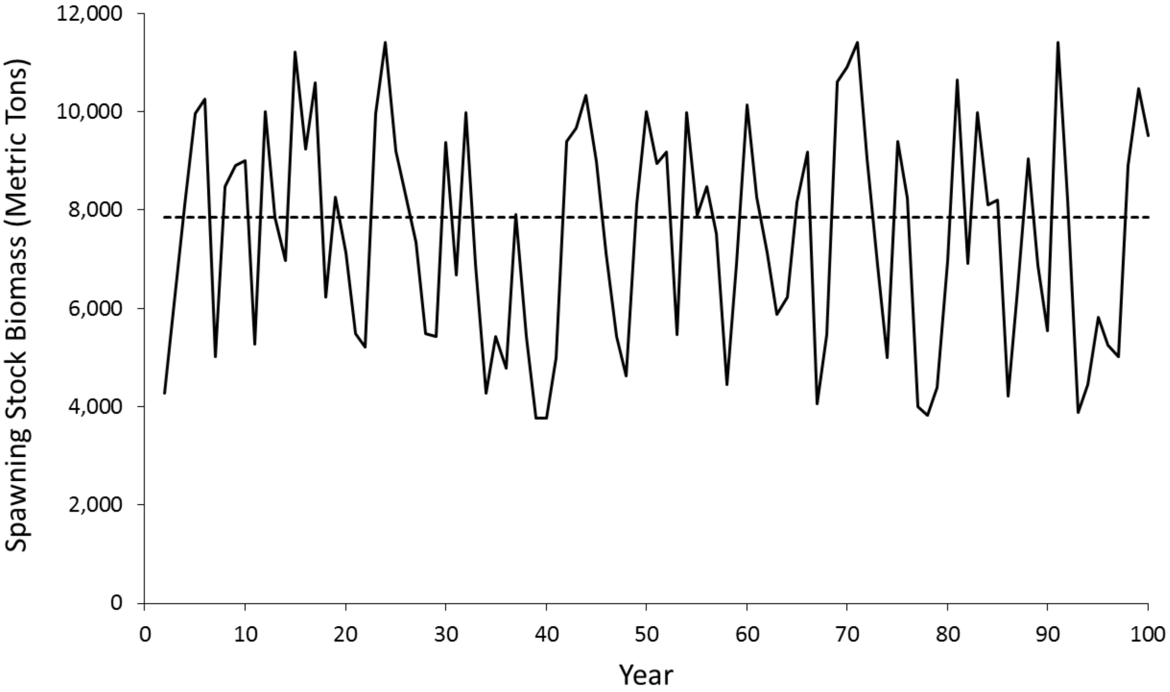


Figure 148. Projected end-year spawning stock biomass estimates (solid black line) for target spawning stock biomass estimate. The median (dashed black line; 7,854

metric tons) estimate is the point estimate for the spawning stock biomass target.

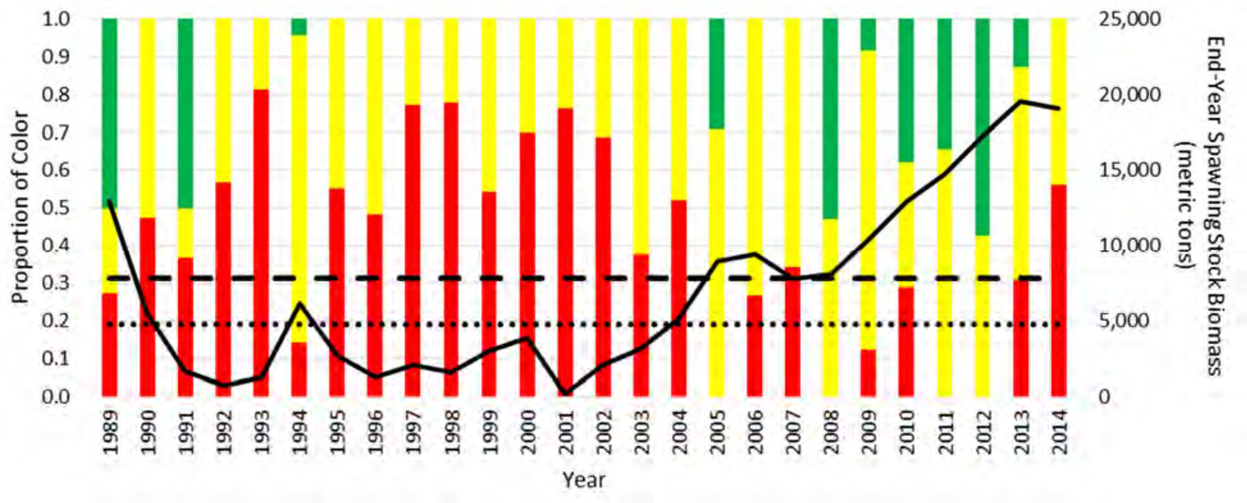


Figure 149. Proportion colors from the spot TLA of the adult abundance metric and end-year spawning stock biomass (solid black line), spawning stock biomass threshold (dotted black line), and spawning stock biomass target (dashed black line) estimates from the base modified-CSA model.

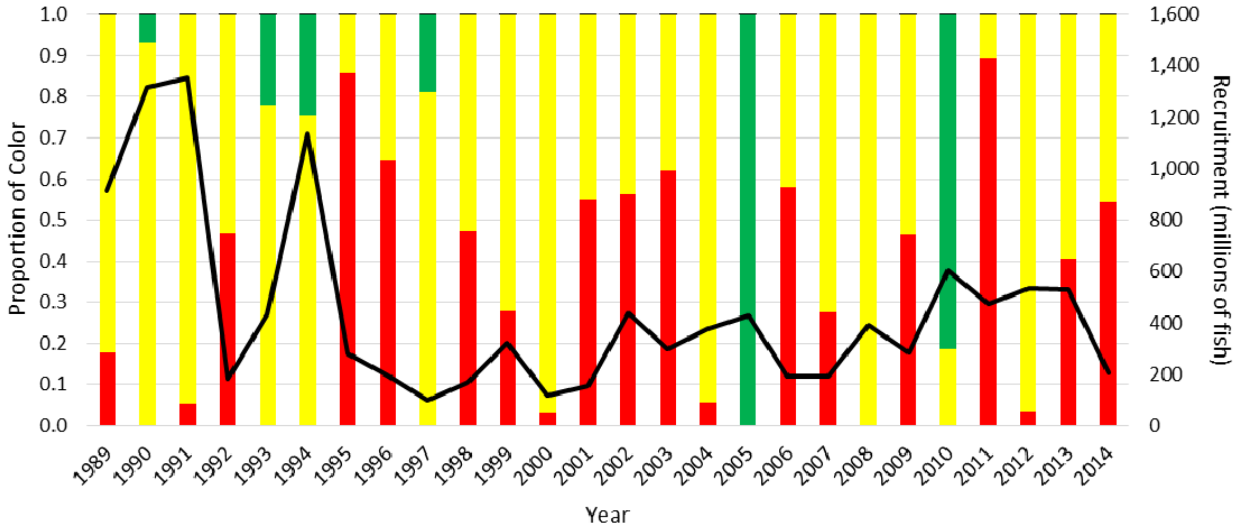


Figure 150. Proportion colors from the spot TLA of the YOY metric and recruitment estimates (solid black line) from the base modified-CSA model.

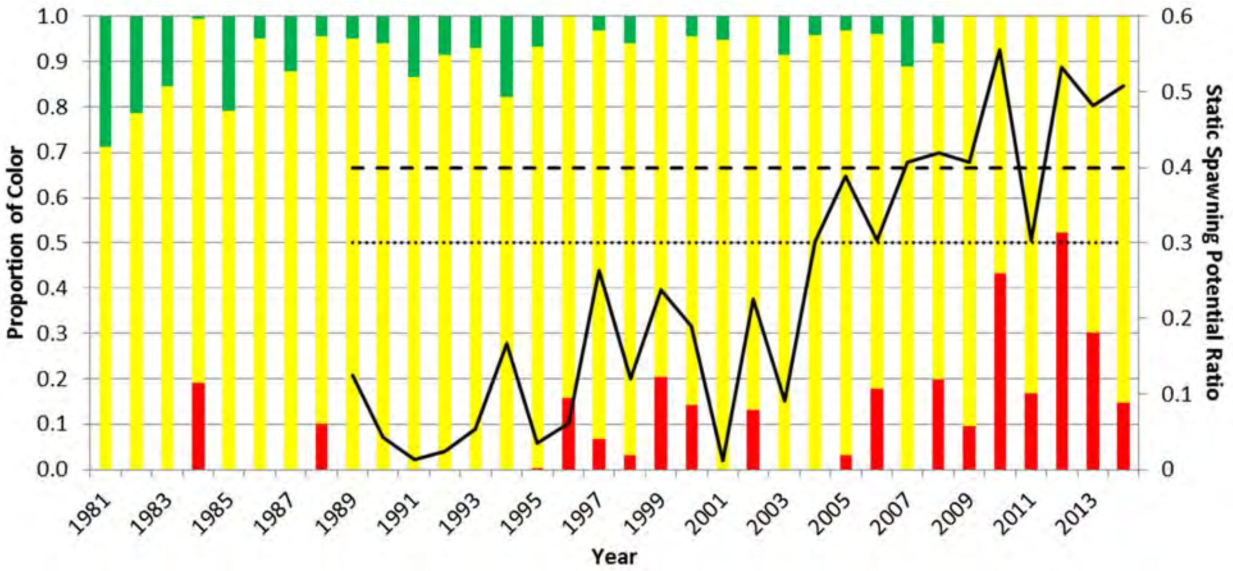


Figure 151. Proportion colors from the spot TLA of the harvest metric, static spawning potential ratio estimates from the base modified-CSA model (solid black line), and the static spawning potential ratio threshold (dotted black line) and target (dashed black line) recommended in this assessment.

14. Appendices

Appendix 1. Traffic Light Analysis of Spot: Alternate Model for 2017 ASMFC Stock Assessment

C. McDonough (SCDNR)

The Traffic Light method (TLA) was originally developed (Caddy and Mahon, 1995; Caddy, 1998, 1999) as a precautionary management framework for data poor fisheries whereby reference points could be developed that would allow for a reasonable level of resource management. The name comes from assigning a color (red, yellow, or green) to categorize relative levels of different indicators of the state of either a fish population or a fishery. These indicators can be combined to form composite characteristics within similar categories and can include biological indicators such as growth and reproduction, population level indicators such as abundance and stock biomass estimates, or fishery indicators such as harvest/landings and fishing mortality. However, each indicator must be evaluated separately in order to determine its appropriateness for use in a management scheme.

The purpose of developing the TLA for spot within the assessment was to allow for comparisons to be made to the assessment modelling results and determine how the two approaches would inform understanding of stock condition. It is important to note that while the TLA does provide a management guidance framework based on different index metrics, it does not provide population level parameters such as biomass (B_{msy}) spawning potential ratios (SPR) or fishing mortality (F_{msy}), so its utility for providing stock specific fishery parameters is limited. However, the ability to illustrate trends in different fishery or population parameters (abundance, landings, etc) is useful to compare to more rigorous population models such as the modified-CSA model used in the assessment.

The specific TLA model used is the fuzzy traffic light model. In the fuzzy traffic light model, we use boundary reference points to determine the relative proportion of each color that includes the buffer (yellow) zone based on the upper and lower 95% confidence intervals from the index values for either the entire data series or a pre-determined reference period (Halliday et al., 2001). In the case of this assessment we are using the 1989-2012 as the reference time period as this is the time frame of the data used for the annual management trigger exercises to determine stock status. The current assessment time period covered two more years, 1989-2014. The TLA color proportions were determined by setting the mean index value at 1.0 for yellow and 0.0 for both red and green as this is the exact center of the buffer zone. The 0.5 proportion value for all three colors is set at the mean index value minus the lower 95% confidence interval (CI) (red and left yellow leg) and the mean index value plus the upper CI (green and the right yellow leg). Finally, the value of 1.0 is set for red at the mean index value minus 2X the lower CI or zero, if the index mean minus 2X the lower CI is a negative number. For green the 1.0 value is set at 2X the upper 95% confidence limit. Once the known index values at the proportion values for each color are determined, the relative color proportions for each year can be estimated via linear regression using the annual values of the index. Any negative values are reset to zero and the proportion of yellow are set at 1 minus the color proportion for either red or green in that year. This allows a better illustration of the annual trends within a given color and whether or not values are approaching levels of concern about the reference boundaries.

Composite figures of combined indices can then be created using the color proportion tables from each individual index. These indexes are additive and the total index is re-scaled to 0-1. It is possible to add weighting factors to each index via the color proportion tables if necessary, although in practice indexes are commonly weighted prior to being run through the TLA. This type of composite index is what Halliday et al. (2001) referred to as a Characteristic, while the individual indices that make it up are the Indicators.

For the fishery dependent data there were two separate sets of indicator data. The first was harvest or landings data by weight (in metric tons) and the second was discard data, also by weight in metric tons. The landings data indicators included commercial landings, recreational harvest and scrap fishery landings (NC and VA only). In addition to the data sets used in the annual management trigger exercise, there were also discard indicator data sets that included the south Atlantic shrimp trawl fishery, commercial discards (mid-Atlantic gill net fishery and mid-Atlantic trawl fishery), and recreational discards that became available through the assessment process. These indicator data were included in this exercise to examine the effects on the TLA in relation to the modified-CSA model output. Mortality for the shrimp trawl, gill net and mid-Atlantic trawl fisheries was set at 100% as bycatch discard were typically released dead in these fisheries and there was no other available estimate of discard mortality. The recreational discard mortality was set at 15% as determined by the Stock Assessment Subcommittee at the Assessment workshop. The recreational discard index used was the estimated annual discards lost through mortality. All of the discard indices were treated as part of the total removals from the stock, along with the harvest landings.

The fishery independent indicator data included survey data from the MDDNR, NMFS, and SEAMAP. The modified-CSA model broke each of these indices into two separate components by age for age 0s and age 1+, however the TLA broke them down by adult (NMFS, SEAMAP) and juvenile (MDDNR) surveys. The reference time period (1989-2012) was the same as that used for the fishery dependent data sets. The data sets were split into the different age groups because while spot were considered fully recruited to the fishery at age 1, a certain proportion reach a large enough size each fall to enter into the fishery while still considered age 0 juveniles prior to spawning for the first time. Because of this, the TLA was run on each index for each age group as well as a combined model for all ages.

RESULTS

The majority of removals (95-99% annually) came from commercial landings, recreational harvest, and the southeast shrimp trawl discards (Fig. 1). Annual shrimp trawl discards varied widely, ranging from 22-89% of total removals with a long term mean of 52% annually for 1989-2014. Thus, trends in the TLA were largely driven by these three indices.

The harvest landings data characteristic (commercial and recreational harvest) showed a decline in landings since the mid 1990s, indicated by the increasing proportions of red through 2012 (Fig. 2). Recent years (since 2013) have shown a slight decline in red indicating an increase in harvest. Under the current management trigger guidelines for spot (ASMFC

Omnibus Amendment, 2012) the landings characteristic would not have triggered in 2014 with the three year average proportion of red being below the 30% threshold indicating moderate management concern.

The fishery discard annual total was dominated by the south Atlantic shrimp trawl fishery, accounting for ≤ 97% of all discards in any given year. Annual discards from the shrimp trawl and commercial fisheries have declined since the early 1990s, while recreational discards have been more variable annually. The discard composite characteristic reflected the decline in discards with high proportions of red in the early years and higher proportions of green in later years (indicating declining bycatch (Fig. 3). High discards in the first three years of the series (1989-1991) had red proportions in excess of the 30% threshold.

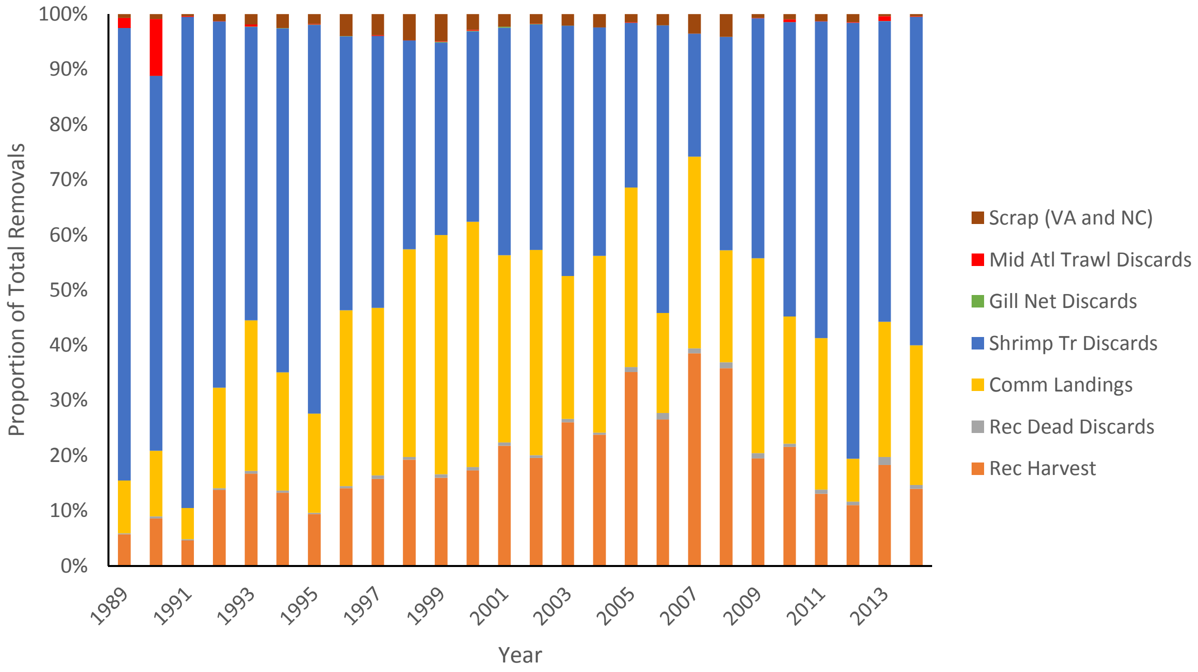


Figure 1. Proportion of annual removals by weight (metric tons) of spot for fishery dependent data by fishery type on the Atlantic coast of the USA from 1989-2014.

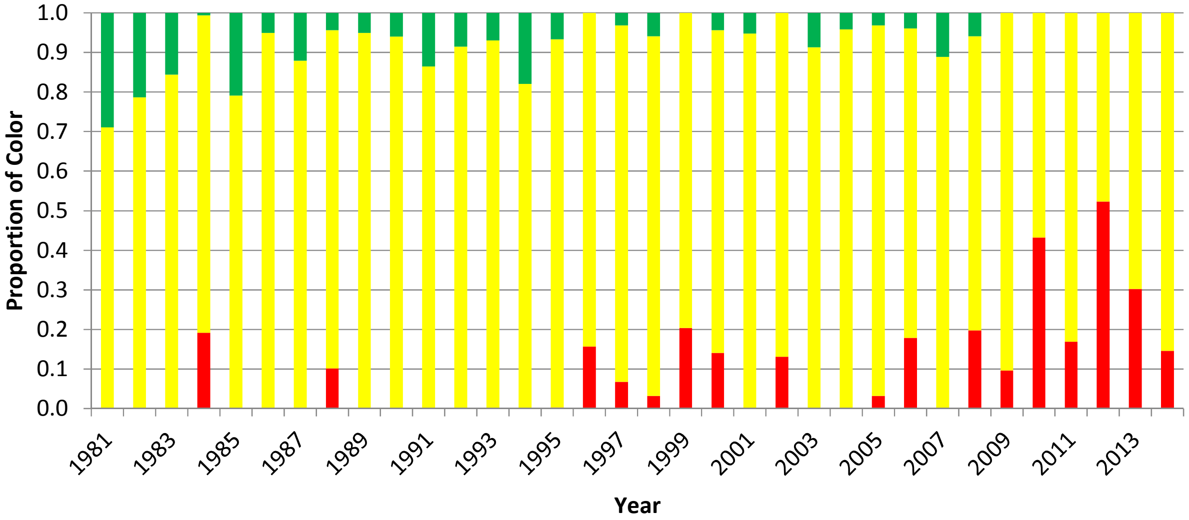


Figure 2. Annual fishery dependent TLA harvest characteristic (commercial, recreational, and scrap fishery landings) for spot on the Atlantic coast of the USA for 1989-2014.

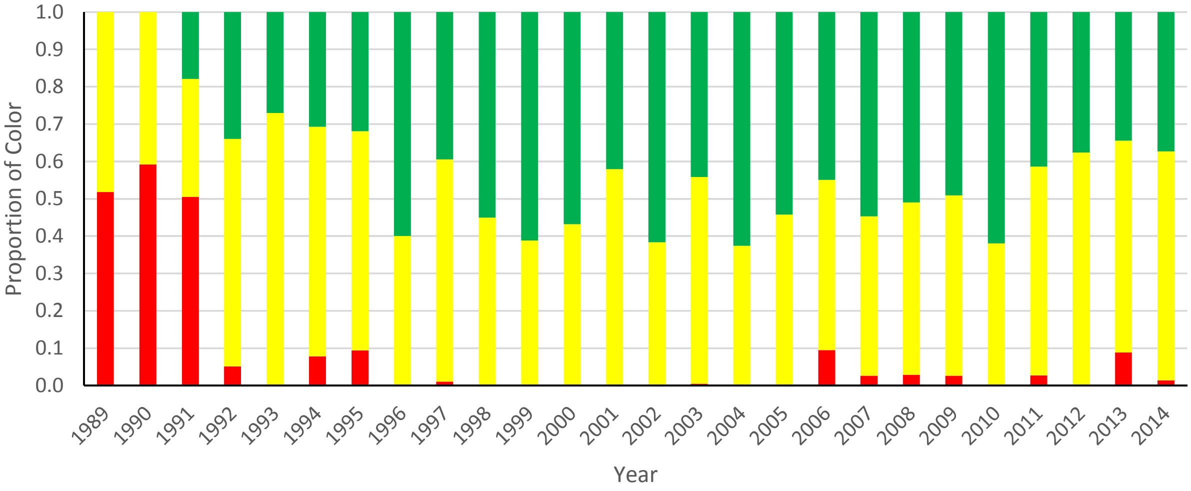


Figure 3. Annual fishery dependent TLA fishery discards characteristic (shrimp trawl fishery, commercial discards and recreational dead discards) for spot on the Atlantic coast of the USA for 1989-2014.

When the landings characteristic was combined with the discards characteristic to form a total removals characteristic, the resulting TLA (Fig. 4) indicated elevated red proportions in the early part of the time series (likely driven by high discards) and an increasing proportion of red since the late 2000s (likely driven by the increase in annual harvest). While this in and of itself was not direct indication of whether spot were being overfished or overfishing was occurring, it does show an increased impact of total removals on spot on the Atlantic coast.

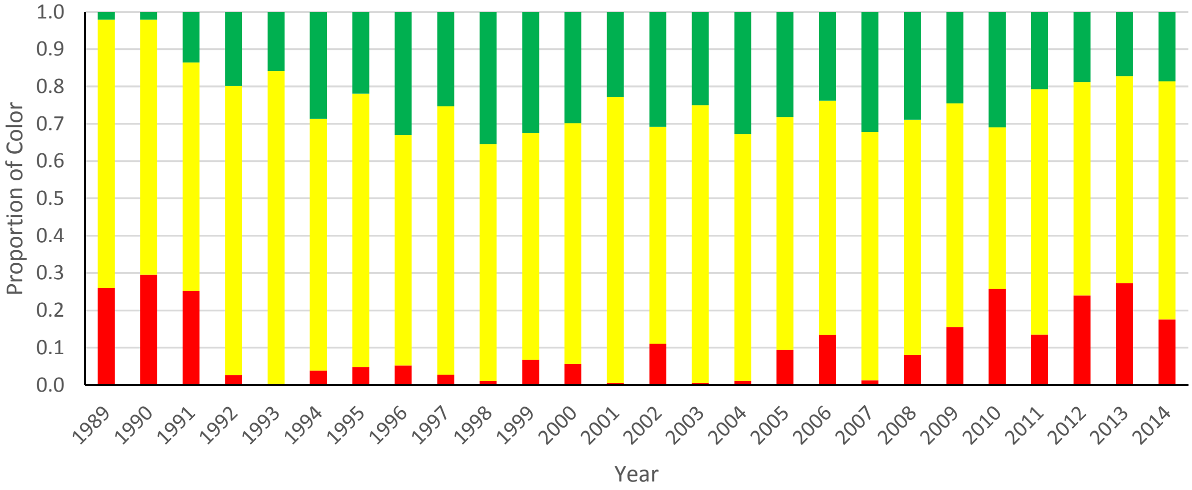


Figure 4. Combined composite TLA characteristic of total annual removals by harvest or fishery discards for spot on the Atlantic coast of the USA for 1989-2014.

The fishery independent survey (NMFS and SEAMAP) characteristic (Fig. 5) indicated high red proportions throughout the 1990s with an increase in green through the 2000s. The last two years showed an increase in red proportions with no triggering of the index since 2005, although it would have triggered in 2014.

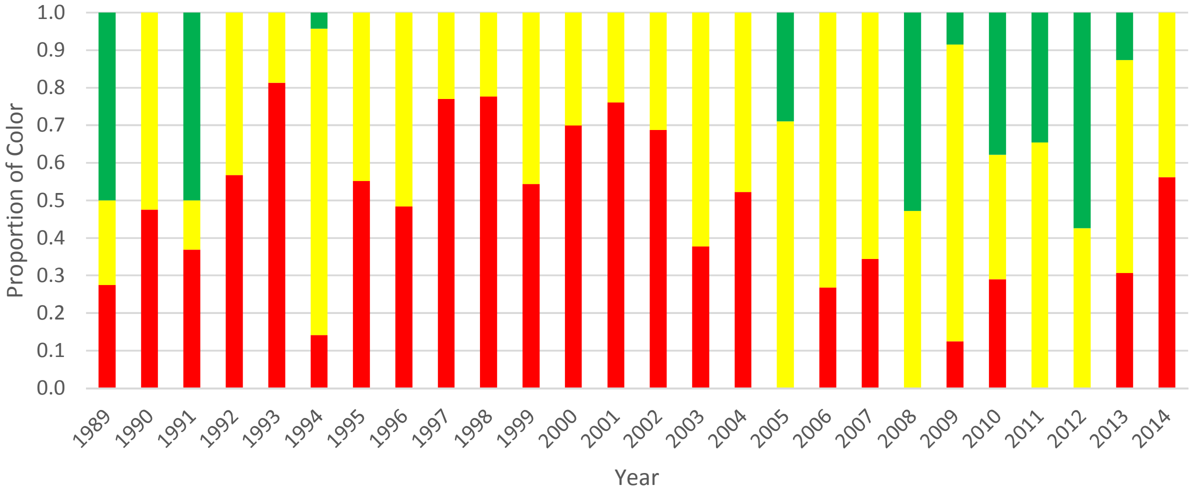


Figure 5. Annual fishery independent TLA composite characteristic for adult (age 1+) spot on the Atlantic coast of the USA using survey data from NMFS and SEAMAP.

The survey index characteristic young of the year spot (Fig.6) showed higher year to year variability in color proportions, likely due to recruitment variability. The higher degree of variability made it more likely that the red proportions would exceed the 30% threshold compared to the adult spot. The MDDNR survey used in the current trigger exercise was the only young of the year survey and increasing proportions of red in this survey reflect the longer term decline in juvenile abundance seen in that survey.

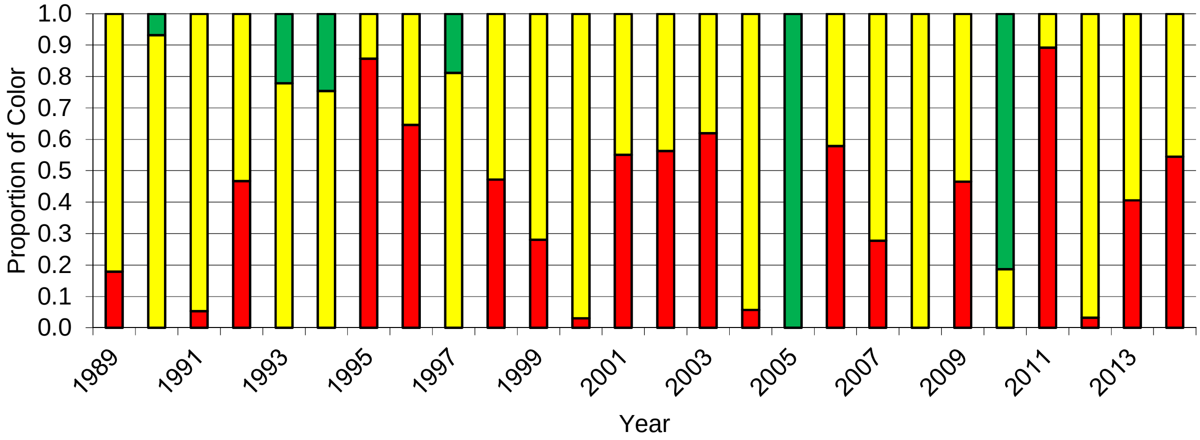


Figure 6. Annual fishery independent TLA composite characteristic for young of the year (age 0) spot on the Atlantic coast of the USA using survey data from MDDNR

FUTURE CONSIDERATIONS

After the current assessment has been completed, the traffic light analysis will have to be reexamined with regards to adjusting the reference period to the time frame of the current assessment and the consideration of adding additional indices to the TLA process. The additional metrics should possibly include the different by-catch estimates (shrimp trawl fishery, commercial discards and recreational discards) as well as possibly including the scrap fishery from Virginia and North Carolina. These indices, coupled with the harvest indicators would produce a characterization of total annual removals from fishery dependent sources. This would be particularly important for the shrimp trawl fishery given the magnitude of the bycatch compared to all other removal sources. For the fishery independent indices, consideration of including the VIMS juvenile trawl survey and NCDMF Program 195 survey might improve the young of the year recruitment characteristic which currently uses just the MDDNR juvenile fish survey. For the adult indices, ChesMMAP and NEAMAP should also be considered. Although, the time series for NEAMAP is still relatively short compared to all the other surveys. A full evaluation of modifying the TLA to improve its representation of both abundance and fishery trends should be considered after completion of the assessment and undertaken by a Spot Technical Committee.

Cited Literature

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ASMFC, 2012. Omnibus Amendment to the Interstate Fishery Management Plans For Spanish Mackerel, Spot, and Spotted Seatrout. http://www.asmfc.org/uploads/file/omnibusAmendment_TechAdd1A_Feb2012.pdf

Caddy, J.F. 1998. A short review of precautionary reference points and some proposals for their use in data-poor situations. FAO Fisheries Technical Paper No. 379, 30pp

Caddy, J.F. 1999. Deciding on precautionary management measures for a stock based on a suite of Limit Reference Points (LRPs) as a basis for a multi-LRP harvest law. NAFO Sci. Council Studies, 32:55-68.

Caddy, J.F. 2002. Limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. Fisheries Research 56:133-137.

Halliday, R.G; L.P. Fanning; and R.K. Mohn. 2001. Use of the Traffic Light Method in Fishery Management Planning. Canadian Science Advisory Secretariat, Research Document No. 108, 41pp.

Seijo, J.C. and J.F. Caddy 2000. Uncertainty in bio-economic reference points and indicators of marine fisheries. Marine and Freshwater Research, 51:477-483.

Appendix 2. Shrimp trawl observer database net performance operation codes.

A - Nets not spread; typically doors are flipped or doors hung together so net could not spread.
B - Gear bogged; the net has picked up a large quantity of sand, clay, mud, or debris in the tail bag possibly affecting trawl performance.
C - Bag obstructed; the catch in the net is prevented from getting into the bag by something (i.e. grass, sticks, turtle, tires, metal/plastic containers etc.) or constriction of net (i.e. twisting of the lazy-line around net).
D - Gear not digging; the net is fishing off the bottom due to insufficient weight or not enough cable let out (etc.).
E - Twisted warp or line; the cables composing the bridle get twisted (from passing over blocks which occasionally must be removed before continuing to fish). Use this code if catch was affected.
F - Gear fouled; the gear has become entangled in itself or with another net. Typically this involves the webbing and some object like a float or chains or lazy line (etc.).
G -Bag untied; bag of net not tied when dragging net.
H - Rough weather. Bags mixed due to rough seas (too dangerous to separate); if the weather is so bad fishing is stopped, then the previous tow should receive this code if the rough conditions affected the catch.
I - Torn, damaged, or lost net; usually results from hanging the net and tearing it loose. The net comes back with large tears etc. if at all. Do not use this code if there are only a few broken meshes. Continue using this code until net is repaired or replaced
J - Dumped catch; tow was made but catch was discarded, perhaps because of too mud. Give reason in comments.
SEDAR38RW01 18
K - Catch not emptied on deck; nets brought to surface, boat changes location, nets redeployed. (explain in comments)
L - Hung up; untimely termination of a tow by a hang. Specify trawl(s) which were hung and caused lost time in Comments.
M - Bags dumped together, catches could not be kept separate.
N - Net did not fish; no apparent cause. Describe reasoning in comments.
O - Gear fouled on submerged object but tow was not terminated. Performance of tow could be affected. Give specifics in Comments.
P - No measurement taken of shrimp and/or total catch.
Q - Main cable breaks and entire rigging lost. Describe in Comments.
R - Net caught in wheel.
S - Tickler chain heavily fouled, tangled, or broken.
T - Other problems. Describe in comments.
U - Turtle excluder gear intentionally disabled.
V – Unknown operation code.
W - Damaged (i.e., bent or broken) excluder gear.
X - BRD intentionally disabled or non-functional. (Damaged) Describe in comments.
Y - Net trailing behind try net.
Z - Successful tow.

Appendix 3. SAS Code for Standardized Shrimp Effort (Trips) Query

```
/******Data for Jennifer Lee**********/
libname SASDATA V8 "N:\FMB\DATA REQUESTS\2016\JEFF KIPP SHRIMP EFFORT";
/***** output directory and year requested *************/



/***********************************/
/*EXTRACT STATE TRIP TICKET DATA  FROM ACCSP FOR TRIPS LANDING SHRIMP*/
PROC SQL         ;
        connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                          ;
        create table sasdata.ACCSP_TRIPS_SHRIMP_TEMP as

        select * from connection to oracle
 (SELECT A.CONS_RPT_ID, A.TRIP_ID, A.DATA_SUPPLIER,'ACCSP' as FORM_VERSION,
A.UNLOAD_YEAR, A.UNLOAD_MONTH, A.UNLOAD_DAY,A.STATE_CODE, A.COUNTY_CODE,
C.IDENT, C.SUPPLIER_PA_ID,D.COAST_GUARD_NBR, D.STATE_REG_NBR,
A.GEAR_CODE,E.GEAR_NAME, A.AREA_CODE, A.SUB_AREA_CODE, A.DISTANCE_CODE,
B.SPECIES_ITIS, G.COMMON_NAME, B.DISPOSITION_CODE, B.MARKET_CODE, B.GRADE_CODE,
B.LIVE_POUNDS, B.DOLLARS, F.START_YEAR, F.START_MONTH, F.START_DAY,
F.TRIP_NBR, F.SPLIT_TRIP,F.DAYS_AT_SEA, F.FISHING_HOURS, F.SOAK_TIME, F.gear_quantity,
F.COUNTY_CODE AS COUNTY_CODE2,
F.STATE_CODE AS STATE_CODE2, F.AREA_CODE AS AREA_CODE2, F.SUB_AREA_CODE AS
SUB_AREA_CODE2, F.DISTANCE_CODE AS DISTANCE_CODE2, F.GEAR_CODE AS GEAR_CODE2
FROM ACCSPREC.CONSOLIDATED_REPORTS@ACCSP_DBLK A
LEFT JOIN ACCSPREC.CONSOLIDATED_LANDINGS@ACCSP_DBLK B ON (A.CONS_RPT_ID =
B.CONS_RPT_ID)
LEFT JOIN ACCSPREC.PARTICIPANTS@ACCSP_DBLK C ON (A.DEALER_ID = C.PARTICIPANT_ID)
LEFT JOIN ACCSPREC.VESSELS@ACCSP_DBLK D ON (A.VESSEL_ID = D.VESSEL_ID)
LEFT JOIN ACCSPREC.GEARS@ACCSP_DBLK E ON (A.GEAR_CODE = E.GEAR_CODE)
LEFT JOIN ACCSPREC.SPECIES@ACCSP_DBLK G ON (B.SPECIES_ITIS = G.SPECIES_ITIS)
LEFT JOIN (SELECT *
FROM (SELECT A.CONS_RPT_ID, A.DATA_SUPPLIER, B.START_YEAR, B.START_MONTH,
B.START_DAY, B.TRIP_NBR, B.SPLIT_TRIP,
B.DAYS_AT_SEA, C.FISHING_HOURS, C.SOAK_TIME, c.gear_quantity, B.COUNTY_CODE,
B.STATE_CODE, C.AREA_CODE, C.SUB_AREA_CODE,
C.DISTANCE_CODE, C.GEAR_CODE, ROW_NUMBER() OVER (PARTITION BY  A.TRIP_ID,
A.DATA_SUPPLIER ORDER BY A.TRIP_ID, A.DATA_SUPPLIER,
B.TRIP_NBR DESC NULLS LAST,B.DAYS_AT_SEA DESC NULLS LAST, C.FISHING_HOURS DESC
NULLS LAST,D.LIVE_POUNDS DESC NULLS LAST ) AS COUNTS
FROM ACCSPREC.CONSOLIDATED_REPORTS@ACCSP_DBLK A
LEFT JOIN ACCSPREC.TRIPS@ACCSP_DBLK B ON (A.TRIP_ID = B.TRIP_ID)
LEFT JOIN ACCSPREC.EFFORTS@ACCSP_DBLK C ON (A.TRIP_ID = C.TRIP_ID)
LEFT JOIN ACCSPREC.CATCHES@ACCSP_DBLK D ON (A.TRIP_ID = D.TRIP_ID AND C.EFFORT_SEQ =
D.EFFORT_SEQ)) E WHERE E.COUNTS = 1) F ON (A.CONS_RPT_ID = F.CONS_RPT_ID)
WHERE (A.DATA_SUPPLIER = '0013' and a.unload_year between 2004 and 2014 or A.DATA_SUPPLIER =
'0012' and a.unload_year between 1994 and 2014
or A.DATA_SUPPLIER = '0014' and a.unload_year between 1989 and 2014)
AND B.CONS_RPT_ID IN (SELECT CONS_RPT_ID FROM
ACCSPREC.CONSOLIDATED_LANDINGS@ACCSP_DBLK WHERE SPECIES_ITIS IN
            (SELECT SPECIES_ITIS
             FROM ACCSPREC.SPECIES@ACCSP_DBLK
             WHERE COMMON_NAME LIKE '%SHRIMP%'))
union
SELECT A.CONS_RPT_ID, A.TRIP_ID, A.DATA_SUPPLIER,'ACCSP' as FORM_VERSION,
A.UNLOAD_YEAR, A.UNLOAD_MONTH, A.UNLOAD_DAY,A.STATE_CODE, A.COUNTY_CODE,
C.IDENT, C.SUPPLIER_PA_ID,D.COAST_GUARD_NBR, D.STATE_REG_NBR,
A.GEAR_CODE,E.GEAR_NAME, A.AREA_CODE, A.SUB_AREA_CODE, A.DISTANCE_CODE,
```

```
B.SPECIES_ITIS, G.COMMON_NAME, B.DISPOSITION_CODE, B.MARKET_CODE, B.GRADE_CODE,
B.LIVE_POUNDS, B.DOLLARS, F.START_YEAR, F.START_MONTH, F.START_DAY,
F.TRIP_NBR, F.SPLIT_TRIP,F.DAYS_AT_SEA, F.FISHING_HOURS, F.SOAK_TIME, F.gear_quantity,
F.COUNTY_CODE AS COUNTY_CODE2,
F.STATE_CODE AS STATE_CODE2, F.AREA_CODE AS AREA_CODE2, F.SUB_AREA_CODE AS
SUB_AREA_CODE2, F.DISTANCE_CODE AS DISTANCE_CODE2, F.GEAR_CODE AS GEAR_CODE2
FROM ACCSPREC.CONSOLIDATED_REPORTS@ACCSP_DBLK A
LEFT JOIN ACCSPREC.CONSOLIDATED_LANDINGS@ACCSP_DBLK B ON (A.CONS_RPT_ID =
B.CONS_RPT_ID)
LEFT JOIN ACCSPREC.PARTICIPANTS@ACCSP_DBLK C ON (A.DEALER_ID = C.PARTICIPANT_ID)
LEFT JOIN ACCSPREC.VESSELS@ACCSP_DBLK D ON (A.VESSEL_ID = D.VESSEL_ID)
LEFT JOIN ACCSPREC.GEARS@ACCSP_DBLK E ON (A.GEAR_CODE = E.GEAR_CODE)
LEFT JOIN ACCSPREC.SPECIES@ACCSP_DBLK G ON (B.SPECIES_ITIS = G.SPECIES_ITIS)
LEFT JOIN (SELECT *
FROM (SELECT A.CONS_RPT_ID, A.DATA_SUPPLIER, B.START_YEAR, B.START_MONTH,
B.START_DAY, B.TRIP_NBR, B.SPLIT_TRIP,
B.DAYS_AT_SEA, C.FISHING_HOURS, C.SOAK_TIME, c.gear_quantity, B.COUNTY_CODE,
B.STATE_CODE, C.AREA_CODE, C.SUB_AREA_CODE,
C.DISTANCE_CODE, C.GEAR_CODE, ROW_NUMBER() OVER (PARTITION BY  A.TRIP_ID,
A.DATA_SUPPLIER ORDER BY A.TRIP_ID, A.DATA_SUPPLIER,
B.TRIP_NBR DESC NULLS LAST,B.DAYS_AT_SEA DESC NULLS LAST, C.FISHING_HOURS DESC
NULLS LAST,D.LIVE_POUNDS DESC NULLS LAST ) AS COUNTS
FROM ACCSPREC.CONSOLIDATED_REPORTS@ACCSP_DBLK A
LEFT JOIN ACCSPREC.TRIPS@ACCSP_DBLK B ON (A.TRIP_ID = B.TRIP_ID)
LEFT JOIN ACCSPREC.EFFORTS@ACCSP_DBLK C ON (A.TRIP_ID = C.TRIP_ID)
LEFT JOIN ACCSPREC.CATCHES@ACCSP_DBLK D ON (A.TRIP_ID = D.TRIP_ID AND C.EFFORT_SEQ =
D.EFFORT_SEQ)) E WHERE E.COUNTS = 1) F ON (A.CONS_RPT_ID = F.CONS_RPT_ID)
WHERE (A.DATA_SUPPLIER = '0015' and a.unload_year between 1986 and 2014)
AND B.CONS_RPT_ID IN (SELECT CONS_RPT_ID FROM
ACCSPREC.CONSOLIDATED_LANDINGS@ACCSP_DBLK WHERE SPECIES_ITIS IN
                (SELECT SPECIES_ITIS
                 FROM ACCSPREC.SPECIES@ACCSP_DBLK
                 WHERE COMMON_NAME LIKE '%SHRIMP%')) and (a.area_code between '630'
 and '799' and a.area_code not in ('777', '750', '747') and a.area_code||a.sub_area_code not in ('7440001', '7480001')
 or a.area_code||a.sub_area_code in ('0010000','0010009','0020002', '0020009') or a.area_code in ('000') and
a.state_code
  in ('37','45','13') or a.area_code in ('000') and a.state_code
  in ('12') and a.county_code in ('107',
'127',
'035',
'069',
'097',
'007',
'111',
'109',
'095',
'085',
'031',
'011',
'009',
'061',
'099',
'089',
'003',
'093',
'125',
'117',
'025',
```

```
'019')));
disconnect from oracle                                                   ;
QUIT ;
/*SC EFFORT DATA NOT AT ACCSP YET, SO SC SENT US TRIP TICKET DATA FOR 2004-2014 IN A .CSV
FILE*/
/*DATA SASDATA.SCDNR_Shrimp_Data;                    ;
/*     %let _EFIERR_ = 0; /* set the ERROR detection macro variable */
/*     infile 'Z:\SEFSC\SHRIMP\STANDARD EXTRACT\SCDNR_Shrimp_Data_2004-2014_051415.csv'
delimiter = ',' MISSOVER DSD
 lrecl=32767 firstobs=2 ;
        FORMAT
          CONS_RPT_ID     10.
          TRIP_ID         10.
          DATA_SUPPLIER    $4.
          FORM_VERSION     $5.
          UNLOAD_YEAR      4.
          UNLOAD_MONTH     $2.
          UNLOAD_DAY       $2.
          STATE_CODE       $2.
          COUNTY_CODE      $3.
          IDENT            $15.
          SUPPLIER_PA_ID   $30.
          COAST_GUARD_NBR  $11.
          STATE_REG_NBR    $14.
          GEAR_CODE        $3.
          GEAR_NAME        $30.
          AREA_CODE        $3.
          SUB_AREA_CODE    $4.
          DISTANCE_CODE    $1.
          SPECIES_ITIS     $11.
          COMMON_NAME      $50.
          DISPOSITION_CODE $3.
          MARKET_CODE      $2.
          GRADE_CODE       $2.
          LIVE_POUNDS      11.2
          DOLLARS          11.2
          START_YEAR       4.
          START_MONTH      $2.
          START_DAY        $2.
          TRIP_NBR         3.
          SPLIT_TRIP       $1.
          DAYS_AT_SEA      5.
          COUNTY_CODE2     $3.
          STATE_CODE2      $2.
          AREA_CODE2       $3.
          SUB_AREA_CODE2   $4.
          DISTANCE_CODE2   $1.
          GEAR_CODE2       $3.
          Nets_Towed       10.
          Head_Rope_Length_Ft 3.
          Number_Of_Tows   5.
         Tow_Time_Hrs     12.2
          Pots_Pulled      5.
          Soak_Time_Hrs    12.2
          Hrs_Fished       12.2;
        INFORMAT
          CONS_RPT_ID     10.
          TRIP_ID         10.
```

```
    DATA_SUPPLIER    $4.
    FORM_VERSION     $5.
    UNLOAD_YEAR      4.
    UNLOAD_MONTH     $2.
    UNLOAD_DAY       $2.
    STATE_CODE       $2.
    COUNTY_CODE      $3.
    IDENT            $15.
    SUPPLIER_PA_ID   $30.
    COAST_GUARD_NBR  $11.
    STATE_REG_NBR    $14.
    GEAR_CODE        $3.
    GEAR_NAME        $30.
    AREA_CODE        $3.
    SUB_AREA_CODE    $4.
    DISTANCE_CODE    $1.
    SPECIES_ITIS     $11.
    COMMON_NAME      $50.
    DISPOSITION_CODE $3.
    MARKET_CODE      $2.
    GRADE_CODE       $2.
    LIVE_POUNDS      best11.
    DOLLARS          best11.
    START_YEAR       4.
    START_MONTH      $2.
    START_DAY        $2.
    TRIP_NBR         3.
    SPLIT_TRIP       $1.
    DAYS_AT_SEA      5.
    COUNTY_CODE2     $3.
    STATE_CODE2      $2.
    AREA_CODE2       $3.
    SUB_AREA_CODE2   $4.
    DISTANCE_CODE2   $1.
    GEAR_CODE2       $3.
    Nets_Towed       10.
    Head_Rope_Length_Ft 3.
    Number_Of_Tows   best12.
   Tow_Time_Hrs     best12.
    Pots_Pulled      best12.
    Soak_Time_Hrs    best12.
    Hrs_Fished       best12.;
 INPUT
    CONS_RPT_ID
    TRIP_ID
    DATA_SUPPLIER    $
    FORM_VERSION     $
    UNLOAD_YEAR
    UNLOAD_MONTH     $
    UNLOAD_DAY       $
    STATE_CODE       $
    COUNTY_CODE      $
    IDENT            $
    SUPPLIER_PA_ID   $
    COAST_GUARD_NBR  $
    STATE_REG_NBR    $
    GEAR_CODE        $
    GEAR_NAME        $
```

```
          AREA_CODE       $
          SUB_AREA_CODE    $
          DISTANCE_CODE    $
          SPECIES_ITIS     $
          COMMON_NAME      $
          DISPOSITION_CODE $
          MARKET_CODE      $
          GRADE_CODE       $
          LIVE_POUNDS
          DOLLARS
          START_YEAR
          START_MONTH      $
          START_DAY        $
          TRIP_NBR
          SPLIT_TRIP       $
          DAYS_AT_SEA
          COUNTY_CODE2     $
          STATE_CODE2      $
          AREA_CODE2       $
          SUB_AREA_CODE2   $
          DISTANCE_CODE2   $
          GEAR_CODE2       $
          Nets_Towed
          Head_Rope_Length_Ft
          Number_Of_Tows
         Tow_Time_Hrs
          Pots_Pulled
          Soak_Time_Hrs
          Hrs_Fished
  ;
  if _ERROR_ then call symput('_EFIERR_',1);
   RUN;

/*STRUCTURE SC DATA FOR MERGE WITH ACCSP DATA*/
/*DATA SASDATA.SCDNR_Shrimp_Data2;
SET SASDATA.SCDNR_Shrimp_Data;
CONS_RPT_ID = TRIP_ID;
IF '0' < STATE_REG_NBR < '2000000' THEN COAST_GUARD_NBR = STATE_REG_NBR;
IF '0' < STATE_REG_NBR < '2000000' THEN STATE_REG_NBR = '';
FORMAT FISHING_HOURS 10.2;
FORMAT SOAK_TIME 10.2;
FORMAT GEAR_QUANTITY 5.;
IF Tow_Time_Hrs > 0 THEN FISHING_HOURS = Tow_Time_Hrs;
IF FISHING_HOURS = . AND Hrs_Fished > 0 THEN FISHING_HOURS = Hrs_Fished;
IF FISHING_HOURS = . AND Soak_Time_Hrs > 0 THEN FISHING_HOURS = Soak_Time_Hrs;
SOAK_TIME = Soak_Time_Hrs;
GEAR_QUANTITY = Nets_Towed;
IF NETS_TOWED = . THEN GEAR_QUANTITY = POTS_PULLED;
DROP NETS_TOWED HEAD_ROPE_LENGTH_FT TOW_TIME_HRS POTS_PULLED SOAK_TIME_HRS
HRS_FISHED Number_Of_Tows;
RUN;



/*CHECK ACCSP DATA FOR DISTRIBUTION OF YEARS*/
/*proc sql;
select unload_year, data_supplier, state_code, sum(live_pounds)
from SASDATA.ACCSP_TRIPS_SHRIMP_TEMP
```

```
group by unload_year, data_supplier, state_code
order by unload_year,  state_code, data_supplier;
quit;

/*1992 AND 1993 INCOMPLETE IN SAS SYSTEM SO USE ALS RECORDS IN ACCSP TO GENERATE
ESTIMATED EFFORT*/
/*PROC SQL      ;
            connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                                  ;
            create table sasdata.ACCSP_TRIPS_SHRIMP_TEMP_NC as

            select * from connection to oracle
 (                SELECT A.CONS_RPT_ID, A.CONS_RPT_ID AS TRIP_ID, A.DATA_SUPPLIER_ID AS
DATA_SUPPLIER,'ACCSP' as FORM_VERSION,
A.YEAR AS UNLOAD_YEAR, A.MONTH_IN_YEAR AS UNLOAD_MONTH, A.DAY_IN_MONTH AS
UNLOAD_DAY,A.STATE_CODE, A.COUNTY_CODE,
(A.DATA_SOURCE||A.DEALER_ID) AS IDENT, A.CF_LICENSE_NBR AS
SUPPLIER_PA_ID,A.VESSEL_CG_OR_ST_REG AS COAST_GUARD_NBR,A.VESSEL_CG_OR_ST_REG
AS STATE_REG_NBR,
A.GEAR_CODE,E.GEAR_NAME, A.AREA_CODE, A.SUB_AREA_CODE, A.DISTANCE_CODE,
A.SPECIES_ITIS, G.COMMON_NAME, A.DISPOSITION_CODE, A.MARKET_CODE, A.GRADE_CODE,
A.LIVE_POUNDS, A.DOLLARS
FROM accsp_inf2.mv_landings@accsp_dblk A
LEFT JOIN ACCSPREC.GEARS@ACCSP_DBLK E ON (A.GEAR_CODE = E.GEAR_CODE)
LEFT JOIN ACCSPREC.SPECIES@ACCSP_DBLK G ON (A.SPECIES_ITIS = G.SPECIES_ITIS)
WHERE A.state_code = '37' and a.year between 1992 and 1993 AND A.CONS_RPT_ID IN (SELECT
CONS_RPT_ID FROM accsp_inf2.mv_landings@accsp_dblk WHERE SPECIES_ITIS IN
               (SELECT SPECIES_ITIS
                FROM ACCSPREC.SPECIES@ACCSP_DBLK
                WHERE COMMON_NAME LIKE '%SHRIMP%')));
disconnect from oracle                                                          ;
QUIT ;
/*
PROC APPEND BASE =  sasdata.ACCSP_TRIPS_SHRIMP_TEMP DATA =
sasdata.ACCSP_TRIPS_SHRIMP_TEMP_NC FORCE;
RUN;*/
/*DELETE WEST COAST OF FL*/
proc sql;
delete
from sasdata.ACCSP_TRIPS_SHRIMP_TEMP
where (STATE_CODE = '12' and county_code not in ('107',
'127',
'035',
'069',
'097',
'007',
'111',
'109',
'095',
'085',
'031',
'011',
'009',
'061',
'099',
'089',
'003',
'093',
'125',
```

```
'117',
'025',
'019')) or state_code = '00';
quit;
/*DELETE SC*/
/*proc sql;
delete
from sasdata.ACCSP_TRIPS_SHRIMP_TEMP
where DATA_SUPPLIER = '0013';
quit;
/*APPEND ACCSP DATA AND SC FILE*/
/*PROC APPEND BASE =  sasdata.ACCSP_TRIPS_SHRIMP_TEMP DATA =
SASDATA.SCDNR_Shrimp_Data2 FORCE;
RUN;

libname SASDATA V8 "N:\FMB\DATA REQUESTS\2016\JEFF KIPP SHRIMP EFFORT";
/*CREATE LOOKUP TABLES FROM ACCSP*/
/*CREATE SPECIES LOOKUP*/
PROC SQL;
connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                    ;
          create table sasdata.ACCSP_SPECIES_TEMP AS
select * from connection to oracle
(SELECT * FROM ACCSPREC.SPECIES@ACCSP_DBLK);
disconnect from oracle;
QUIT;
/*CREATE GEAR LOOKUP*/
PROC SQL;
connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                    ;
          create table sasdata.ACCSP_GEARS_TEMP AS
select * from connection to oracle
(SELECT * FROM ACCSPREC.GEARS@ACCSP_DBLK);
disconnect from oracle                                                    ;
QUIT;
/*CREATE PARTICIPANT LOOKUP*/
PROC SQL;
connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                    ;
CREATE TABLE sasdata.ACCSP_PARTICIPANTS_TEMP AS
select * from connection to oracle
(SELECT * FROM ACCSPREC.PARTICIPANTS@ACCSP_DBLK);
disconnect from oracle                                                    ;
QUIT;
/*CREATE VESSEL LOOKUP*/
PROC SQL;
connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                    ;
          create table sasdata.ACCSP_VESSELS_TEMP AS
select * from connection to oracle
(SELECT * FROM ACCSPREC.VESSELS@ACCSP_DBLK);
disconnect from oracle                                                    ;
QUIT;
/*CREATE LOOKUP OF NON-FOOD SHRIMP SPECIES*/
PROC SQL;
connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                    ;
          create table sasdata.ACCSP_SHRIMP_DROP_SPECIES_XREF AS
select * from connection to oracle
(SELECT *  FROM
DGLOECKN.ACCSP_SHRIMP_DROP_SPECIES_XREF);
disconnect from oracle                                                    ;
QUIT;
```

```
/*DELETE WHERE SPECIES NOT FOOD SHRIMP*/
proc sql;
DELETE FROM sasdata.ACCSP_TRIPS_SHRIMP_TEMP
WHERE SPECIES_ITIS IN (SELECT SPECIES_ITIS FROM
sasdata.ACCSP_SHRIMP_DROP_SPECIES_XREF);
quit;
/*ADD TEXT DISPOSITION DESCRIPTOR*/
data sasdata.ACCSP_TRIPS_SHRIMP_TEMP;
set sasdata.ACCSP_TRIPS_SHRIMP_TEMP;
format disposition $20.0;
run;
/*SET DISPOSITION TO BAIT IF CODED AS BAIT, FOOD FOR ALL OTHERS*/
proc sql;

UPDATE sasdata.ACCSP_TRIPS_SHRIMP_TEMP
SET disposition = 'BAIT'
WHERE DISPOSITION_CODE = '008' OR MARKET_CODE = 'BT' OR GRADE_CODE = '02' or species_itis =
'095603';

UPDATE sasdata.ACCSP_TRIPS_SHRIMP_TEMP
SET DISPOSITION = 'FOOD'
WHERE disposition IS NULL;

/*INSERT DISTINCT TRIP ID IF BLANK*/
UPDATE sasdata.ACCSP_TRIPS_SHRIMP_TEMP
SET TRIP_ID = CONS_RPT_ID WHERE TRIP_ID IS NULL;
quit;

DATA sasdata.ACCSP_TRIPS_SHRIMP_TEMP1;
SET sasdata.ACCSP_TRIPS_SHRIMP_TEMP;
RUN;
/*SORT ACCSP DATA TO DETERMINE TARGET SPECIES*/
PROC SORT DATA = SASDATA.ACCSP_TRIPS_SHRIMP_TEMP1;
BY CONS_RPT_ID IDENT SUPPLIER_PA_ID TRIP_ID UNLOAD_YEAR UNLOAD_DAY
UNLOAD_MONTH STATE_CODE COUNTY_CODE DATA_SUPPLIER DESCENDING LIVE_POUNDS;
RUN;
/*REMOVE DUPLICATE EFFORTS ACROSS SINGLE TRIP*/
PROC SORT IN=SASDATA.ACCSP_TRIPS_SHRIMP_TEMP1
OUT=SASDATA.ACCSP_TRIPS_SHRIMP_TEMP2 NODUPKEY ;
BY UNLOAD_YEAR UNLOAD_DAY UNLOAD_MONTH SUPPLIER_PA_ID IDENT TRIP_ID
CONS_RPT_ID STATE_CODE COUNTY_CODE DATA_SUPPLIER;
RUN ;
/*REMOVE NON-FOOD SHRIMP TARGETED TRIPS*/
PROC SQL;
DELETE FROM SASDATA.ACCSP_TRIPS_SHRIMP_TEMP2
WHERE SPECIES_ITIS NOT IN (SELECT SPECIES_ITIS FROM sasdata.ACCSP_SPECIES_TEMP WHERE
COMMON_NAME LIKE '%SHRIMP%');
QUIT;
/*DETERMINE DISTRIBUTION OF DATA ACROSS STATE, YEAR AND DATA SOURCE*/
/*proc sql;
select distinct state_code,unload_year,  data_supplier
from SASDATA.ACCSP_TRIPS_SHRIMP_TEMP2
order by state_code,unload_year,  data_supplier;
quit;

/*CREATE EFFORT ANALYSIS VARIABLES FROM RECORDED EFFORT*/
DATA SASDATA.ACCSP_TRIPS_SHRIMP_TEMP3;
SET SASDATA.ACCSP_TRIPS_SHRIMP_TEMP2;
```

```
FORMAT NO_START_DATE $1.;/*FORMAT NEW VARIABLE*/
FORMAT TRIPS 10.0; /*FORMAT NEW VARIABLE*/
FORMAT TIME_FISHED 10.2;/*FORMAT NEW VARIABLE*/
FORMAT TIME_UNITS $1.0;/*FORMAT NEW VARIABLE*/
FORMAT DAYS_FISHED 10.2;/*FORMAT NEW VARIABLE*/
FORMAT DAYS_AWAY 10.0;  /*FORMAT NEW VARIABLE*/
IF START_YEAR = . THEN NO_START_DATE = 'Y'; /*insert flag if start date is missing*/
ELSE NO_START_DATE = 'N';/*FLAG IF START DATE PRESENT*/
IF UNLOAD_DAY = '00' THEN UNLOAD_DAY = '01'; /*CORRECT DAY FOR SUMMARY RECORDS*/
IF START_DAY = '00' THEN START_DAY = '01';/*CORRECT DAY FOR SUMMARY RECORDS*/
IF START_month = '00' THEN START_MONTH = UNLOAD_MONTH; /*CORRECT START MONTH IF
SUMMARY DATA*/
FORMAT START_DATE MMDDYY10.; /*FORMAT START DATE VARIABLE*/
FORMAT UNLOAD_DATE MMDDYY10.;/*FORMAT UNLOAD DATE VARIABLE*/
START_DATE = mdy(START_month,START_DAY,START_year); /*CREATE START DATES*/
UNLOAD_DATE = mdy(UNLOAD_month,UNLOAD_DAY,UNLOAD_year);/*CREATE UNLOAD DATES*/
IF STATE_CODE = '12' AND GEAR_CODE = '110' THEN GEAR_NAME = 'SHRIMP
TRAWL';/*STANDARDIZE GEAR NAME*/
IF STATE_CODE = '12' AND GEAR_CODE = '000' THEN GEAR_NAME = 'SHRIMP
TRAWL';/*STANDARDIZE GEAR NAME*/
TRIPS = 1;/*INDICATE EACH TRIP TICKET AS 1 TRIP*/
IF SPLIT_TRIP = 'Y' THEN TRIPS = TRIPS/2; /* IF TRIP IS DIVIDED BETWEEN FISHERMEN THEN
EFFORT IS REPORTED TWICE, SO MUST DIVIDE # TRIPS*/
IF SPLIT_TRIP = 'Y' THEN DAYS_AT_SEA = DAYS_AT_SEA/2; /* IF TRIP IS DIVIDED BETWEEN
FISHERMEN THEN EFFORT IS REPORTED TWICE, SO MUST DIVIDE DAYS AT SEA*/
IF SPLIT_TRIP = 'Y' THEN FISHING_HOURS = FISHING_HOURS/2;/* IF TRIP IS DIVIDED BETWEEN
FISHERMEN THEN EFFORT IS REPORTED TWICE, SO MUST DIVIDE FISHING HOURS*/
IF FISHING_HOURS > 0 AND FISHING_HOURS > DAYS_AT_SEA THEN TIME_UNITS = 'H';/*IF FISHING
HOURS > DAYS AT SEA ASSUME TIME UNITS IS IN HOURS*/
IF FISHING_HOURS > 0 AND FISHING_HOURS > DAYS_AT_SEA THEN TIME_FISHED =
FISHING_HOURS;/*IF FISHING HOURS > DAYS AT SEA ASSUME TIME FISHED IS IN HOURS*/
ELSE TIME_UNITS = 'D';/*IF FISHING HOURS <= DAYS AT SEA THEN TIME UNITS IS IN DAYS*/
IF TIME_UNITS = 'D' AND DAYS_AT_SEA > 0 THEN TIME_FISHED = DAYS_AT_SEA;
IF TIME_FISHED > 0 AND FISHING_HOURS > 0 AND TIME_UNITS = 'H' THEN DAYS_FISHED =
ROUND(((TIME_FISHED/12)+.4),1); /*IF HOURS FISHED IS COLLECTED, USE HOURS FISHED TO
DETERMINE DAYS FISHED*/
IF TIME_UNITS = 'D' THEN DAYS_FISHED = DAYS_AT_SEA;/*IF TIME UNITS IN DAYS THEN DAYS
FISHED IS DAYS AT SEA*/
DAYS_AWAY = (unload_date-start_date)+1; /*DETERMINE DAYS AWAY FROM START AND UNLOAD
DAY*/
IF SPLIT_TRIP = 'Y' THEN DAYS_AWAY = DAYS_AWAY/2;/* IF TRIP IS DIVIDED BETWEEN
FISHERMEN THEN EFFORT IS REPORTED TWICE, SO MUST DIVIDE DAYS AWAY*/
IF DAYS_FISHED = . AND TIME_UNITS = 'D' THEN DAYS_FISHED = DAYS_AWAY; /*IF DAYS FISHED
AND HOURS FISHED NOT COLLECTED, USE DAYS AWAY FOR DAYS FISHED*/
IF TIME_UNITS = 'D' AND TIME_FISHED = . AND DAYS_AWAY > 0 THEN TIME_FISHED =
DAYS_AWAY;/*IF DAYS FISHED AND HOURS FISHED NOT COLLECTED, USE DAYS AWAY FOR
TIME FISHED*/
IF TIME_UNITS = 'D' AND TIME_FISHED = 0 AND DAYS_AWAY > 0 THEN TIME_FISHED =
DAYS_AWAY;/*IF DAYS FISHED AND HOURS FISHED NOT COLLECTED, USE DAYS AWAY FOR
TIME FISHED*/
IF DAYS_FISHED > 45 THEN DAYS_FISHED = 1*TRIPS;/*IF DAYS AT SEA > 45 THEN ASSUME ERROR
IN HOURS AND SET DAYS AT SEA TO 1*/
IF DISPOSITION = 'BAIT' THEN DELETE;/*DELETE BAIT TRIPS*/
IF UNLOAD_MONTH = '12' OR UNLOAD_MONTH = '01' OR UNLOAD_MONTH = '02' THEN SEASON =
'WINTER';/*SET SEASON TO WINTER*/
ELSE SEASON = 'SUMMER';/*SET OTHER MONTHS TO SUMMER*/
RUN;
```

```
/*CREATE STANDARD TABLE STRUCTURE*/
proc sql;
CREATE TABLE SASDATA.ACCSP_LANDINGS_SHRIMP
(DEALER_RPT_ID          NUM,
TRIP_ID         NUM,
DATA_SUPPLIER           CHAR(4),
FORM_VERSION            CHAR(10),
UNLOAD_YEAR             NUM,
UNLOAD_MONTH            CHAR(2),
UNLOAD_DAY CHAR(2),
STATE_CODE      CHAR(2),
COUNTY_CODE             CHAR(3),
IDENT   CHAR(15),
SUPPLIER_PA_ID          CHAR(30),
VESSEL_ID       CHAR(11),
STATE_REG_NBR           CHAR(11),
GEAR_CODE       CHAR(3),
GEAR_NAME       CHAR(50),
AREA_CODE       CHAR(3),
SUB_AREA_CODE           CHAR(4),
DISTANCE_CODE           CHAR(1),
SPECIES_ITIS    CHAR(11),
COMMON_NAME             CHAR(50),
LANDED_LBS      NUM,
DOLLARS         NUM,
TIME_FISHED     NUM,
TIME_UNITS      CHAR(1),
TRIP_START_DATE DATE,
SEASON          CHAR(10),
INSHORE_OFFSHORE        CHAR(10),
SHRIMP_ZONE CHAR(2),
GEAR_CATEGORY           CHAR(50),
START_YEAR      NUM,
START_MONTH             CHAR(2),
START_DAY       CHAR(2),
START_DATE      DATE,
UNLOAD_DATE             DATE,
DAYS_FISHED     NUM,
DAYS_FISHED_CALC        NUM,
TRIPS NUM,
ZONE CHAR(10),
INSHORE_OFFSHORE2 CHAR(10),
DISPOSITION CHAR(10));
quit;
/*INSERT ACCSP DATA INTO STANDARD TABLE STRUCTURE*/
proc sql;
INSERT INTO SASDATA.ACCSP_LANDINGS_SHRIMP
select a.CONS_RPT_ID,
a.TRIP_ID,
a.DATA_SUPPLIER,
a.FORM_VERSION,
a.UNLOAD_YEAR           ,
a.UNLOAD_MONTH,
a.UNLOAD_DAY,
a.STATE_CODE,
a.COUNTY_CODE,
a.IDENT         ,
a.SUPPLIER_PA_ID,
```

```
a.COAST_GUARD_NBR ,
a.STATE_REG_NBR        ,
a.GEAR_CODE,
a.GEAR_NAME  ,
a.AREA_CODE   ,
a.SUB_AREA_CODE,
a.DISTANCE_CODE        ,
a.SPECIES_ITIS,
a.COMMON_NAME,
a.LIVE_POUNDS ,
a.DOLLARS,
A.TIME_FISHED,
A.TIME_UNITS,
a.START_DATE,
A.SEASON ,
'',
'' ,
B.CATEGORY_CODE ,
a.START_YEAR,
a.START_MONTH,
a.START_DAY   ,
a.START_DATE,
a.UNLOAD_DATE,
A.DAYS_FISHED ,
. ,
a.TRIPS,
'',
'' ,
a.DISPOSITION
from SASDATA.ACCSP_TRIPS_SHRIMP_TEMP3 a LEFT JOIN sasdata.ACCSP_GEARS_TEMP B ON
(A.GEAR_CODE = B.GEAR_CODE);
  quit;
/*CREATE SHRIMP DATA FROM SOUTH ATLANTIC SHRIMP (SAS) SYSTEM*/
PROC SQL;
        connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                              ;
        CREATE TABLE SASDATA.SAS_MAIN_DATA_EFFORT AS

        select * from connection to oracle
(SELECT TO_NUMBER((A.DATE_LANDED||A.DEALER_NUMBER||A.SCHEDULE_NUMBER)) AS
TEMPID1,
TO_NUMBER((A.DATE_LANDED||A.DEALER_NUMBER||A.SCHEDULE_NUMBER)) AS TEMPID2,
DECODE(A.STATE_LANDED,43,'0013',13,'0014',36, '0012',10,'0015','NONE') AS DATA_SUPPLIER,
'SAS' AS FORM_VERSION,
TO_NUMBER(SUBSTR(A.DATE_LANDED,1,4)) AS UNLOAD_YEAR,
SUBSTR(A.DATE_LANDED,5,2) AS UNLOAD_MONTH,
SUBSTR(A.DATE_LANDED,7,2) AS UNLOAD_DAY,
LPAD(LTRIM(SUBSTR(TO_CHAR(A.STATE_LANDED,'99'),2)),2,'0') AS STATE_LANDED,
LPAD(LTRIM(SUBSTR(TO_CHAR(A.COUNTY_LANDED,'99'),2)),2,'0') AS COUNTY_LANDED,
LPAD(LTRIM(SUBSTR(TO_CHAR(A.COUNTY_LANDED,'999'),2)),3,'0')||TRIM(dealer_number) AS IDENT,
A.SCHEDULE_NUMBER,
TRIM(A.dealer_number) AS DEALER_NUMBER,
A.VESSEL_ID_NUMBER AS VESSEL_ID,
A.VESSEL_ID_NUMBER AS BOAT_ID,
A.GEAR_CODE,
UPPER(B.DESCRIPTION) AS GEAR_NAME,
A.AREA_FISHED,
A.SUBAREA_FISHED AS SUB_AREA,
NULL AS DISTANCE_CODE,
```

```
A.SPECIES_CODE,
UPPER(C.COMMON_NAME) AS SPECIES_NAME,
A.POUNDS_CAUGHT AS LANDED_LBS,
TO_NUMBER((A.UNIT_COST/100)) AS DOLLARS,
NULL AS SEASON,
NULL AS INSHORE_OFFSHORE,
NULL AS SHRIMP_ZONE,
NULL AS GEAR_CATEGORY,
TO_NUMBER(SUBSTR(A.DATE_LANDED,1,4)) AS START_YEAR,
SUBSTR(A.DATE_LANDED,5,2) AS START_MONTH,
SUBSTR(A.DATE_LANDED,7,2) AS START_DAY,
A.CALENDAR_DAYS_FISHED AS DAYS_FISHED,
0 AS DAYS_FISHED_CALC,
((nvl(boat_trips, 0) + nvl(vessel_trips, 0))/10) AS SAS_TRIPS,
DECODE(STATE_LANDED,'36','37','43','45','13','13','10','12','00') AS STATE_LANDED2,
LPAD(LTRIM(E.FIPS_COUNTY_CODE,'0'),3,'0') AS COUNTY_LANDED2,
DECODE(A.GEAR_CODE,'A','090','B','075','C','118','D','110',
'E','110','F','110','G','750','H','020','I','116','J','143','Z','801','000') AS GEAR_CODE2,
LPAD(LTRIM(F.accsp_area,'0'),3,'0') AS AREA_FISHED2,
LPAD(LTRIM(F.accsp_SUBarea,'0'),4,'0') AS SUBAREA_FISHED2,
C.SPECIES_ITIS AS SPECIES_CODE2,
DECODE(nvl(A.SPECIES_CODE,'0'),'0','NONE','B','BAIT','FOOD') AS DISPOSITION
FROM SAS.SAS_MAIN_DATA A
LEFT JOIN SAS.SAS_GEAR_CODE B ON (A.GEAR_CODE = B.GEAR_CODE)
LEFT JOIN SAS.SPECIES_CODE_SAS C ON (A.SPECIES_CODE = C.SAS_CODE)
LEFT JOIN SAS.SAS_ALS_FIPS_COUNTY_XREF E ON (E.ALSSTATE= A.STATE_LANDED
    AND LPAD(E.SASCOUNTY, 2, '0') = LPAD(A.COUNTY_LANDED, 2, '0'))
LEFT JOIN SAS.SAS_AREA_code F ON (to_number(F.area_code) = TO_NUMBER(a.area_fished)
and to_number(F.subarea_code)= TO_NUMBER(a.SUBAREA_FISHED)));
disconnect from oracle                                                              ;
QUIT;
/*DELETE BAIT TRIPS AND YEARS WHERE TRIP TICKET DATA EXIST IN ACCSP and format and
populate trip start and end dates*/
DATA SASDATA.SAS_MAIN_DATA_EFFORT1;
SET SASDATA.SAS_MAIN_DATA_EFFORT;
FORMAT START_DATE MMDDYY10.;
FORMAT UNLOAD_DATE MMDDYY10.;
START_DATE = mdy(START_month,START_DAY,START_year);
UNLOAD_DATE = mdy(UNLOAD_month,UNLOAD_DAY,UNLOAD_year);
IF SPECIES_CODE = '6' THEN DELETE;
IF DISPOSITION = 'BAIT' THEN DELETE;
IF BOAT_ID NE '000000' THEN BOAT_ID = '';
IF BOAT_ID NE '000000' THEN VESSEL_ID = '';
IF STATE_LANDED = '43' AND UNLOAD_YEAR > 2003 THEN DELETE;
IF STATE_LANDED = '13' AND UNLOAD_YEAR > 2000 THEN DELETE;
RUN;
/*SORT SAS DATA BY PRIMARY CATCH AND EFFORT*/
PROC SORT DATA = SASDATA.SAS_MAIN_DATA_EFFORT1;
BY  TEMPID1 SAS_TRIPS DESCENDING DAYS_FISHED DESCENDING LANDED_LBS DESCENDING
UNLOAD_YEAR UNLOAD_MONTH UNLOAD_DAY IDENT DATA_SUPPLIER SCHEDULE_NUMBER;
RUN;
/*REMOVE DUPLICATE EFFORTS FOR A SINGLE TRIP*/
PROC SORT IN=SASDATA.SAS_MAIN_DATA_EFFORT1 OUT=SASDATA.SAS_MAIN_DATA_EFFORT2
NODUPKEY ;
BY TEMPID1 UNLOAD_YEAR UNLOAD_MONTH UNLOAD_DAY IDENT DATA_SUPPLIER
SCHEDULE_NUMBER;
RUN ;
/*REMOVE DATA FROM ACCSP DATA WHERE SAS DATA EXIST*/
```

```
DATA SASDATA.ACCSP_LANDINGS_SHRIMP2;
SET SASDATA.ACCSP_LANDINGS_SHRIMP;
IF STATE_CODE = '12' AND 1980 < UNLOAD_YEAR < 1993 THEN DELETE;
IF STATE_CODE = '37' AND 1977 < UNLOAD_YEAR < 1992 THEN DELETE;
IF STATE_CODE = '13' AND 1977 < UNLOAD_YEAR < 2001 THEN DELETE;
IF STATE_CODE = '45' AND 1977 < UNLOAD_YEAR < 2004 THEN DELETE;
RUN;
/*INSERT SAS DATA INTO STANDARDIZED STRUCTURE*/
PROC SQL;
INSERT INTO SASDATA.ACCSP_LANDINGS_SHRIMP2
SELECT
TEMPID1,
TEMPID2,
DATA_SUPPLIER,
FORM_VERSION,
UNLOAD_YEAR,
UNLOAD_MONTH,
UNLOAD_DAY,
STATE_LANDED2,
COUNTY_LANDED2,
IDENT,
DEALER_NUMBER,
VESSEL_ID,
BOAT_ID,
GEAR_CODE2,
GEAR_NAME,
AREA_FISHED2,
SUBAREA_FISHED2,
DISTANCE_CODE,
SPECIES_CODE2,
SPECIES_NAME,
LANDED_LBS,
DOLLARS,
.,
'',
.,
SEASON,
INSHORE_OFFSHORE,
SHRIMP_ZONE,
GEAR_CATEGORY,
START_YEAR,
START_MONTH,
START_DAY,
START_DATE,
UNLOAD_DATE,
DAYS_FISHED,
DAYS_FISHED_CALC,
SAS_TRIPS,
'',
'',
DISPOSITION
FROM SASDATA.SAS_MAIN_DATA_EFFORT2;
QUIT;

/*CODE STATE OF LANDING AND REMOVE OUT OF STATE PURCHASES AND ADD SEASON TO SAS
DATA*/
DATA SASDATA.ACCSP_LANDINGS_SHRIMP3;
SET SASDATA.ACCSP_LANDINGS_SHRIMP2;
```

```
FORMAT STATE_POSTAL $2.0;
STATE_POSTAL = 'UN';
IF STATE_CODE = '37' THEN STATE_POSTAL = 'NC';
IF STATE_CODE = '45' THEN STATE_POSTAL = 'SC';
IF STATE_CODE = '13' THEN STATE_POSTAL = 'GA';
IF STATE_CODE = '12' THEN STATE_POSTAL = 'FL';
if state_code = '00' and data_supplier = '0015' then delete;
if state_code = '00' and data_supplier = '0014' then delete;
if state_code = '00' and data_supplier = '0013' then delete;
if state_code = '00' and data_supplier = '0012' then delete;
IF UNLOAD_MONTH = '12' OR UNLOAD_MONTH = '01' OR UNLOAD_MONTH = '02' THEN SEASON =
'WINTER';/*SET SEASON TO WINTER*/
ELSE SEASON = 'SUMMER';/*SET OTHER MONTHS TO SUMMER*/
RUN;
/*PULL IN DISTANCE CODES BY AREA FISHED*/
PROC SQL;
connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                              ;
            create table SASDATA.ACCSP_SHRIMP_WATER_LOOKUP AS
select * from connection to oracle
(SELECT *  FROM
DGLOECKN.ACCSP_SHRIMP_WATER_LOOKUP);
disconnect from oracle                                                                   ;
QUIT;
/*UPDATE DISTANCE CODE BASED ON AREA FISHED*/
PROC SQL;
UPDATE SASDATA.ACCSP_LANDINGS_SHRIMP3
SET INSHORE_OFFSHORE = (SELECT distinct INSHORE_OFFSHORE FROM
SASDATA.ACCSP_SHRIMP_WATER_LOOKUP
WHERE AREA = Accsp_landings_shrimp3.area_CODE
  AND sub = accsp_landings_shrimp3.sub_area_code)
WHERE EXISTS (SELECT * FROM SASDATA.accsp_shrimp_water_lookup
WHERE accsp_landings_shrimp3.area_Code = accsp_shrimp_water_lookup.area
  AND accsp_landings_shrimp3.sub_area_code= accsp_shrimp_water_lookup.sub);

/*SET CORRECT AREA FOR AREA||SUB AREA IF DISTANCE CODE IS PROVIDED*/

UPDATE SASDATA.ACCSP_LANDINGS_SHRIMP3
SET INSHORE_OFFSHORE = 'OFFSHORE'
   WHERE AREA_CODE = '' and DISTANCE_CODE IN ('2','3','4','5','8');

UPDATE SASDATA.ACCSP_LANDINGS_SHRIMP3
SET INSHORE_OFFSHORE = 'INSHORE'
   WHERE AREA_CODE = '' and DISTANCE_CODE in ('1', '0');


update SASDATA.accsp_landings_shrimp3
set inshore_offshore = 'OFFSHORE'
where area_code = '711' and sub_area_code in ('9998') and data_supplier = '0013';


update SASDATA.accsp_landings_shrimp3
set inshore_offshore = 'OFFSHORE'
where area_code = '635' and sub_area_code in ('0021','0023');

update SASDATA.accsp_landings_shrimp3
set inshore_offshore = 'OFFSHORE'
where inshore_offshore = '' and state_code not = '37';
```

```
update SASDATA.accsp_landings_shrimp3
set inshore_offshore = 'INSHORE'
where inshore_offshore = '' and state_code = '37';
QUIT;

/*Shrimp zone designations are required IN the output tables.  We assign
    these codes based on (1) the area code, AND (2) by the county of landing*/
/*PULL IN SHRIMP ZONE AND COUNTY XREF TABLE*/
PROC SQL;
connect to oracle  (user=dgloeckn orapw="gadus6674"  path="SECPR")                                    ;
              create table SASDATA.ACCSP_SHRIMP_COUNTY_ZONE_XREF AS
select * from connection to oracle
(SELECT *  FROM
DGLOECKN.ACCSP_SHRIMP_COUNTY_ZONE_XREF);
disconnect from oracle                                                                                ;
QUIT;
/*ASSIGN SHRIMP ZONE BASED ON AREA FISHED*/
PROC SQL;
UPDATE SASDATA.ACCSP_LANDINGS_SHRIMP3
SET SHRIMP_ZONE = (SELECT distinct SHRIMP_ZONE FROM
SASDATA.ACCSP_SHRIMP_WATER_LOOKUP
WHERE AREA = Accsp_landings_shrimp3.area_CODE
  AND sub = accsp_landings_shrimp3.sub_area_code)
WHERE EXISTS (SELECT * FROM SASDATA.accsp_shrimp_water_lookup
WHERE accsp_landings_shrimp3.area_Code = accsp_shrimp_water_lookup.area
  AND accsp_landings_shrimp3.sub_area_code= accsp_shrimp_water_lookup.sub);

/*ASSIGN SHRIMP ZONE BASED ON COUNTY IF WATERBODY IS UNKNOWN*/
UPDATE SASDATA.ACCSP_LANDINGS_SHRIMP3
SET SHRIMP_ZONE = (SELECT distinct SHRIMP_ZONE FROM
SASDATA.ACCSP_SHRIMP_COUNTY_ZONE_XREF
WHERE COUNTY_CODE = ACCSP_LANDINGS_SHRIMP3.COUNTY_CODE
AND STATE_CODE = ACCSP_LANDINGS_SHRIMP3.STATE_CODE)
WHERE shrimp_zone IN ('00','99')
AND (STATE_cODE||COUNTY_CODE) IN (SELECT STATE_cODE||COUNTY_cODE FROM
SASDATA.ACCSP_SHRIMP_COUNTY_ZONE_XREF);

/*ASSIGN S OF HATTERAS TO PROPER WATERBODY*/
UPDATE SASDATA.ACCSP_LANDINGS_SHRIMP3
SET SHRIMP_ZONE = '34'
WHERE SHRIMP_ZONE='00'
  AND (AREA_CODE||SUB_AREA_CODE) IN (SELECT AREA||SUB FROM
SASDATA.ACCSP_SHRIMP_WATER_LOOKUP
  WHERE SUB_AREA_NAME LIKE '%SOUTH%' AND SUB_AREA_NAME LIKE '%HATTERAS%');
  QUIT;

/*ASSIGN TEXT TO ZONE DESIGNATION*/
DATA SASDATA.ACCSP_LANDINGS_SHRIMP4;
SET SASDATA.ACCSP_LANDINGS_SHRIMP3;
FORMAT ZONE $7.0;
IF SHRIMP_ZONE = '24' THEN ZONE = 'SOUTH';
IF SHRIMP_ZONE ='25' THEN ZONE ='SOUTH';
IF SHRIMP_ZONE ='26' THEN ZONE ='SOUTH';
IF SHRIMP_ZONE ='27' THEN ZONE ='SOUTH';
IF SHRIMP_ZONE ='28' THEN ZONE ='SOUTH';
IF SHRIMP_ZONE ='29' THEN ZONE = 'SOUTH';
IF SHRIMP_ZONE ='30' THEN ZONE = 'SOUTH';
IF SHRIMP_ZONE ='31' THEN ZONE = 'CENTRAL';
```

```
IF SHRIMP_ZONE ='32' THEN ZONE = 'CENTRAL';
IF SHRIMP_ZONE = '33' THEN ZONE ='CENTRAL';
IF SHRIMP_ZONE ='34' THEN ZONE = 'NORTH';
IF SHRIMP_ZONE ='35' THEN ZONE ='NORTH';
IF SHRIMP_ZONE = '36' THEN ZONE ='NORTH';
IF ZONE = '' THEN ZONE = 'UNKNOWN';
RUN;
/*ASSIGN ZONE WHERE UNKNOWN*/
PROC SQL;

UPDATE SASDATA.accsp_landings_shrimp4
SET ZONE = 'SOUTH'
WHERE  zONE ='UNKNOWN'  or zone = ''
  AND DATA_SUPPLIER='0015';

UPDATE SASDATA.accsp_landings_shrimp4
SET ZONE = 'CENTRAL'
WHERE  ZONE ='UNKNOWN'  or zone = ''
  AND DATA_SUPPLIER IN ('0014','0013');

UPDATE SASDATA.accsp_landings_shrimp4
SET  ZONE = 'NORTH'
WHERE  ZONE ='UNKNOWN' or zone = ''
  AND DATA_SUPPLIER = '0012' ;
QUIT;
/*ONLY DATA FROM 2001 AND LATER ARE REQUIRED, SO DELETE PREVIOUS YEARS*/
data SASDATA.accsp_landings_shrimp5;
set SASDATA.accsp_landings_shrimp4;
/*if unload_year < 2001 then delete;
/*if state_code = 37 and unload_year < 1994 then delete;*/
run;
/*DETERMINE AVERAGE DAYS FISHED BY YEAR, STATE, ZONE, SEASON, DISTANCE*/
proc sql;
create table sasdata.mean_days as
select unload_year, state_code, zone, season, inshore_offshore, mean(days_fished) as days, min(days_fished) as
lower, max(days_fished) as upper, count(*) as N
from SASDATA.accsp_landings_shrimp5
where days_fished is not null and days_fished > 0
group by unload_year, state_code, zone, season, inshore_offshore;
quit;
/*USE MEAN DAYS FISHED IF DAYS FISHED IS MISSING*/
proc sql;
update SASDATA.accsp_landings_shrimp5
set days_fished = (select round(days+.5)  from sasdata.mean_days where unload_year =
accsp_landings_shrimp5.unload_year and
state_code = accsp_landings_shrimp5.state_code and zone = accsp_landings_shrimp5.zone and
season = accsp_landings_shrimp5.season and inshore_offshore = accsp_landings_shrimp5.inshore_offshore)
where days_fished = . or days_fished = 0;
quit;
/*DETERMINE AVERAGE DAYS FISHED BY STATE, ZONE, SEASON, DISTANCE*/
proc sql;
create table sasdata.mean_days2 as
select state_code, zone, season, inshore_offshore, mean(days_fished) as days, min(days_fished) as lower,
max(days_fished) as upper, count(*) as N
from SASDATA.accsp_landings_shrimp5
where days_fished is not null and days_fished > 0
group by state_code, zone, season, inshore_offshore;
quit;
```

```
/*USE MEAN DAYS FISHED IF DAYS FISHED IS MISSING AND WASN'T FILLED BY STRATA IN
MEAN_DAYS TABLE*/
proc sql;
update SASDATA.accsp_landings_shrimp5
set days_fished = (select round(days+.5) from sasdata.mean_days2 where state_code =
accsp_landings_shrimp5.state_code
and zone = accsp_landings_shrimp5.zone and season = accsp_landings_shrimp5.season
and inshore_offshore = accsp_landings_shrimp5.inshore_offshore)
where days_fished = . or days_fished = 0;
quit;
/*DETERMINE AVERAGE DAYS FISHED BY ZONE, SEASON, DISTANCE*/
proc sql;
create table sasdata.mean_days3 as
select zone, season, inshore_offshore, mean(days_fished) as days, min(days_fished) as lower, max(days_fished) as
upper, count(*) as N
from SASDATA.accsp_landings_shrimp5
where days_fished is not null and days_fished > 0
group by zone, season, inshore_offshore;
quit;
/*USE MEAN DAYS FISHED IF DAYS FISHED IS MISSING AND WASN'T FILLED BY STRATA IN
MEAN_DAYS OR MEAN_DAYS2 TABLES*/
proc sql;
update SASDATA.accsp_landings_shrimp5
set days_fished = (select round(days+.5) from sasdata.mean_days3 where zone = accsp_landings_shrimp5.zone
and season = accsp_landings_shrimp5.season
and inshore_offshore = accsp_landings_shrimp5.inshore_offshore)
where days_fished = . or days_fished = 0;
quit;
/*CHECK DATA TO MAKE SURE THERE ARE NO CELLS NOT FILLED FOR DAYS_FISHED*/
proc sql;
select zone, season, inshore_offshore, count(dealer_rpt_id) as reports
from SASDATA.accsp_landings_shrimp5
where days_fished = . or days_fished = 0
group by zone, season, inshore_offshore;
quit;
/*SET HOURS BY HOURS IF RECORDED, ELSE ASSUME 12 HOURS PER DAY FISHED*/
DATA SASDATA.accsp_landings_shrimp6;
SET SASDATA.accsp_landings_shrimp5;
FORMAT HOURS_FISHED 10.2;
IF TIME_UNITS = 'H' THEN HOURS_FISHED = TIME_FISHED;
ELSE HOURS_FISHED = DAYS_FISHED*12;
RUN;
/*EXPORT COMPLETE EFFORT FILE*/
PROC EXPORT DATA= sasdata.accsp_landings_shrimp6
            OUTFILE= "N:\FMB\DATA REQUESTS\2016\JEFF KIPP SHRIMP
EFFORT\SA_SHRIMP_EFFORT_all_04182016.csv"
   DBMS=csv REPLACE;
run;
/*CREATE EFFORT BY MONTH*/
PROC SQL;
CREATE TABLE sasdata.SA_SHRIMP_EFFORT_MONTH AS
SELECT UNLOAD_YEAR, UNLOAD_MONTH, STATE_POSTAL, GEAR_NAME,  sum(hours_fished) as
HOURS, SUM(TRIPS) AS TRIPS, SUM(DAYS_FISHED) AS DAYS, COUNT(DISTINCT SUPPLIER_PA_ID)
AS DEALERS
FROM sasdata.accsp_landings_shrimp6
GROUP BY UNLOAD_YEAR, UNLOAD_MONTH, STATE_POSTAL, GEAR_NAME;
QUIT;
/*EXPORT EFFORT BY MONTH*/
```

```
PROC EXPORT DATA= sasdata.SA_SHRIMP_EFFORT_MONTH
            OUTFILE= "N:\FMB\DATA REQUESTS\2016\JEFF KIPP SHRIMP
EFFORT\SA_SHRIMP_EFFORT_MONTH_04182016.csv"
   DBMS=csv REPLACE;
run;
/*CREATE ANNUAL EFFORT*/
PROC SQL;
CREATE TABLE sasdata.SA_SHRIMP_EFFORT_ANNUAL AS
SELECT UNLOAD_YEAR, STATE_POSTAL, GEAR_NAME,  sum(hours_fished) as HOURS, SUM(TRIPS) AS
TRIPS, SUM(DAYS_FISHED) AS DAYS, COUNT(DISTINCT SUPPLIER_PA_ID) AS DEALERS
FROM sasdata.accsp_landings_shrimp6
GROUP BY UNLOAD_YEAR, STATE_POSTAL, GEAR_NAME;
QUIT;
/*EXPORT ANNUAL EFFORT*/
PROC EXPORT DATA= sasdata.SA_SHRIMP_EFFORT_ANNUAL
            OUTFILE= "N:\FMB\DATA REQUESTS\2016\JEFF KIPP SHRIMP
EFFORT\SA_SHRIMP_EFFORT_ANNUAL_04182016.csv"
   DBMS=csv REPLACE;
run;
```

Appendix 4. Modified-CSA ADMB Code

```
//###########################################################################
//###########################################################################
//Originally adapted from Chesapeake Bay 2010 blue crab assessment (M. Wilberg 2/28/2011)
//By: W Cooper 2012
//Major changes for GDAR 01:
// 1) Pulled out sex-specific due to limited biostatistical sampling of landings in Gulf
// 2) Added stage-specific mortality, including in ref points
// 3) Added environmental influences on S-R and stage-specific M
// 4) Added retrospective analyses and projections
//Further adapted from GDAR 01 Blue Crab Assessment
//By: J Kipp 2016
//Major changes for ASMFC spot assessment:
// 1) Allow for recruit survey(s) that occur after fish become vulnerable to fisheries
// 2) Added option for spawning stock estimates to be in either biomass (metric tons) or numbers and recruitment
to be a function of spawning stock biomass or spawning stock numbers
// 3) Added beta prior on SR steepness
// 4) Hardwired average Z prior to be over a subset of model years
//###########################################################################
//###########################################################################
TOP_OF_MAIN_SECTION
  //increase number of estimated parameters
  gradient_structure::set_NUM_DEPENDENT_VARIABLES(2000);
  gradient_structure::set_GRADSTACK_BUFFER_SIZE(2000400);
  gradient_structure::set_CMPDIF_BUFFER_SIZE(10000000);
  arrmblsize = 10000000;
  //###########################################################################
  //###########################################################################
DATA_SECTION
  !!USER_CODE ad_comm::change_datafile_name("Spot.dat");  //read in data file
  init_int testing //toggle to turn on/off console output for testing
  init_int fyear //first year of the model run
  init_int lyear //last year of the model run
  init_int retroYears
  init_int projYears
  int timeSteps //number of time steps in a year
  int stages //number of stages/ages to model
  !! timeSteps=1;
  !! stages=2;
  int retroSteps
  int projSteps
  !! retroSteps=retroYears*timeSteps;
  !! projSteps=projYears*timeSteps;
  //Because coded to be multiple time steps per year, need to define an indexing scheme that isn't year-based
  int mTimeSteps // total model time steps for population dynamics
  int startIndex //starting index for the model
  int endIndex //ending index for the model
  !!mTimeSteps = (lyear-fyear+1)*timeSteps; //calculate the time steps in the model
  !!startIndex=1000; //set a value, can be anything > the lag of environment time series
  //substract off the retrospective period
  !!endIndex=startIndex+mTimeSteps-1-retroSteps; //substract 1 since startIndex is first step
  //########################################
  //#Catch Data
  //########################################
  init_int ftcyear //first year of total catch
```

```
 init_int ltcyear //last year of total catch
 int cStartIndex
 int cTimeSteps //catch time steps based on catch years
 !!cTimeSteps = (ltcyear-ftcyear+1)*timeSteps;
 !!cStartIndex = (ftcyear-fyear)*timeSteps+startIndex;
 init_vector com_TC_obs(cStartIndex,cStartIndex+cTimeSteps-1) //total catch
 init_vector C_wgt_obs(cStartIndex,cStartIndex+cTimeSteps-1) //total catch in weight (metric tons) - not currently
included in the objective function
 init_vector C_cv(cStartIndex,cStartIndex+cTimeSteps-1) //catch data CV
 init_int effFlag //flag to use effort time series
 init_vector com_Eff_obs(cStartIndex,cStartIndex+cTimeSteps-1) //total catch
 //##################################
 //#Survey data
 //##################################
 //Adults
 init_int numAdSurv
 init_int fsayear //first year of adult surveys
 init_int lsayear //last year of adult surveys
 int adTimeSteps
 int adStartIndex
 !!adTimeSteps=(lsayear-fsayear+1)*timeSteps;
 !!adStartIndex = (fsayear-fyear)*timeSteps+startIndex;
 init_matrix ad_survey_obs(1,numAdSurv,adStartIndex,adStartIndex+adTimeSteps-1) //Adult survey CPUE
 init_matrix ad_survey_cv(1,numAdSurv,adStartIndex,adStartIndex+adTimeSteps-1) //Survey CVs for adults
 init_vector sa_time(1,numAdSurv) //survey time
 //Recruits
 init_int numRecSurv
 init_int fsryear
 init_int lsryear
 int recTimeSteps
 int recStartIndex
 !!recTimeSteps=(lsryear-fsryear+1)*timeSteps;
 !!recStartIndex = (fsryear-fyear)*timeSteps+startIndex;
 init_matrix re_survey_obs(1,numRecSurv,recStartIndex,recStartIndex+recTimeSteps-1) //Recruit survey CPUE
 init_matrix re_survey_cv(1,numRecSurv,recStartIndex,recStartIndex+recTimeSteps-1) //survey SDs for recruits
 init_vector sr_time(1,numRecSurv)
 //##################################
 //#Fishery params
 //##################################
 init_number p_rec //Proportion of recreational harvest per region
 init_number p_under //Proportion of harvest underreporting per region
 init_number maxF //Max F for F_pen calculation
 init_number maxM //Max M for F_pen calculation
 //##################################
 //#Adult Z estimates as prior
 //##################################
 init_number aveZ
 init_number Z_cv
 //##################################
 //#Life History params
 //##################################
 init_number sratio //Sex ratio
 init_vector M(1,stages) //mortality at age for each stage (e.g., for CS: recruits, post-recruits)
 vector Myr(1,stages) //M rate on per year basis (for ref points)
```

```
  init_vector pSpawn(1,stages) //proportion of females spawning in each season for differential spawning
throughout the year
  init_number sp_time //proportion of the time step before spawning occurs
  init_number h_prior //prior for steepness
  //init_number h_cv //cv of steepness prior
  init_number h_sd //sd of steepness prior
  init_int SRSwitch //switch for recruit function formulation; 1=bev holt, 2=ricker

  init_int fwtyear //first year of mean weights
  init_int lwtyear //last year of mean weights
  int wtTimeSteps
  int wtStartIndex
  !!wtTimeSteps=(lwtyear-fwtyear+1)*timeSteps;
  !!wtStartIndex = (fwtyear-fyear)*timeSteps+startIndex;
  init_matrix mean_wgt(1,stages,wtStartIndex,wtStartIndex+wtTimeSteps-1) //mean weight in kg
  matrix mean_wgt_mt(1,stages,wtStartIndex,wtStartIndex+wtTimeSteps-1) //mean weight in metric tons
  init_number wgt_time //timing for SSB estimates (0=beginning of the year, 1=end of the year)
  init_int SPSwitch //switch for the desired spawning stock units (1=numbers,2=biomass)
 LOCAL_CALCS
  //convert M to the appropriate time frame from per year basis
  Myr=M;
  M=M/timeSteps;
  //convert individual mean_wgt from kg to metric tons so population estimates are in metric tons; numbers are in
millions, hence the conversion of kg*1000
  mean_wgt_mt=mean_wgt*1000;
 END_CALCS
  //###################################
  //#Environmental time series params/data
  //###################################
  init_int numEnvTS
  init_int feyear //first year of the model
  init_int leyear //last year of the model
  int eTimeSteps
  int eStartIndex //this should be less than the startIndex
  !!eTimeSteps = (leyear-feyear+1)*timeSteps;
  !!eStartIndex = (feyear-fyear)*timeSteps+startIndex;
  init_matrix envObs(1,numEnvTS,eStartIndex,eStartIndex+eTimeSteps-1) //environmental time series (regions,
season,timesteps)
  init_vector env_cv(1,numEnvTS) //environmental time series (regions, season,timesteps)
  init_int envRecTS //time series # that influences recruitment
  init_int envRecLag //lag of recruitment influence
  init_vector envMTS(1,stages) //time series # that influences mortality
  init_vector envMLag(1,stages) //lag in mortality influence
  matrix env(1,numEnvTS,eStartIndex,endIndex+projSteps+1) //add on one for the forward stepping recruitment
  //###################################
  //#Projections
  //###################################
  init_matrix envProj(1,numEnvTS,endIndex+1,endIndex+projSteps+1)
  init_vector effProj(endIndex+1,endIndex+projSteps+1) //START with terminal year since non-estimable F
  //###################################
  //#Parameters (initial val, min, max, phase)
  //###################################
  init_number init_NIni //initial abundance of second stage
  init_vector init_NParams(1,3) //lower bound, upper bound, and phase of estimation for initial abundance
  init_number init_RIni //initial abundance of recruit stage
```

```
init_vector init_RParams(1,3) //lower bound, upper bound, and phase of estimation for initial recruitment
//F params
init_number F_qIni
init_vector F_qParams(1,3)
init_number F_devIni
init_vector F_devParams(1,3)
init_number eff_cvIni
init_vector eff_cvParams(1,3)
//recruitment param
init_number rec_devIni
init_vector rec_devParams(1,3)
init_number rec_cvIni
init_vector rec_cvParams(1,3)
init_number S0Ini
init_vector S0Params(1,3)
init_number steepIni
init_vector steepParams(1,3)
init_number sr_beta_envIni
init_vector sr_beta_envParams(1,3)
init_vector M_beta_envIni(1,stages)
init_vector M_beta_envParams(1,3)
init_number M_cvIni
init_vector M_cvParams(1,3)
init_number selIni_r
init_vector selParams_r(1,3)
init_number selIni_a
init_vector selParams_a(1,3)
//#################################
//#Likelihood Weights
//#################################
init_number com_lambda //survey weight
init_vector sa_lambda(1,numAdSurv) //survey weight
init_vector sr_lambda(1,numRecSurv)
init_number recDev_lambda //survey weight
init_number effort_lambda //survey weight
init_number aveZ_lambda //survey weight
init_number h_lambda //steepness prior weight
//#################################
//#Additional param control flags not addressed in data section
//#################################
init_number biasAdj //Adjustment multiplier for bias correction factor
//#################################
//#Reference point calcs
//#################################
//number for reference point explorations
init_number Fval_init //lowest value of F used in SPR calcs
init_number Fval_max //highest value of F used in SPR calcs
init_number Fval_inc //increment for F
int Fval_num
!!Fval_num=(Fval_max-Fval_init)/Fval_inc+1;
init_int nspr //number of values F-%SPR will be calculated at
init_vector SPR_targ(1,nspr) //Values of SPR for Fval reference point calculations
//#################################
//#EOF Test
//#################################
```

```
 init_int test //check that data read in appropriately
 //##################################
 //#Additional Variables
 //##################################
 //Total harvest including recreational
 vector TC_obs(cStartIndex,cStartIndex+cTimeSteps-1) //total catch
 //Variances for data sets
 vector C_var(cStartIndex,cStartIndex+cTimeSteps-1) //variances of catch
 number Z_var //variance of Z
 matrix ad_survey_var(1,numAdSurv,adStartIndex,adStartIndex+adTimeSteps-1) //variances for adult surveys
 matrix re_survey_var(1,numRecSurv,recStartIndex,recStartIndex+recTimeSteps-1) //variances for recruitment
surveys
 //Define index varaibles
 int y //index variable for time step
 int s //index variable for season
 int r //index variable for region
 int i //index variable
 number year //for report section
 int ispr
 int iter
 int iterMCMC
 !!iterMCMC=0;
 int index
LOCAL_CALCS
 if (SRSwitch==2) steepParams(2)=5.0; //make sure to bound steepness appropriately for Ricker
 for (y=cStartIndex; y<=cStartIndex+cTimeSteps-1; y++){
 C_var(y)=log(C_cv(y)*C_cv(y)+1); //variances of catch
 }
 Z_var=log(Z_cv*Z_cv+1); //variance of Z
 //commercial + recreational catch+prop. underreported
 TC_obs=com_TC_obs*(1.+p_rec+p_under);
 //Calculate variances from CVs
 for (i=1; i<=numAdSurv; i++){
 for (y=adStartIndex; y<=adStartIndex+adTimeSteps-1; y++){
 ad_survey_var(i,y)=log(ad_survey_cv(i,y)*ad_survey_cv(i,y)+1); //variances for adult surveys
 }
 }
 for (i=1; i<=numRecSurv; i++) {
 for (y=recStartIndex; y<=recStartIndex+recTimeSteps-1; y++){
 re_survey_var(i,y)=log(re_survey_cv(i,y)*re_survey_cv(i,y)+1); //variances for recruitment surveys
 }
 }
 for (i=1; i<=numEnvTS; i++){
 for (y=eStartIndex; y<=endIndex; y++){
 env(i,y)=envObs(i,y);
 }
 for (y=endIndex+1; y<=endIndex+projSteps; y++){
 env(i,y)=envProj(i,y);
 }
 }
 if(test!=12345) //check to make sure end of file number is correct
 {
 //if not correct, output the data and exit.
 cout << "Data not reading properly" << endl;
 cout << "Commercial\t" << com_TC_obs << endl;
```

```
  cout << "adults\t" <<ad_survey_obs << endl;
  cout << "recruits\t" <<re_survey_obs << endl;
  cout << "environment\t" <<env << endl;
  cout << "max F\t" <<maxF << endl;
  cout << "max M\t" <<maxM << endl;
  cout << "envMTS\t" <<envMTS << endl;
  cout << "env Lag\t" <<envMLag << endl;
  cout << "ini N\t" <<init_NIni << endl;
  cout << "steepIni\t" <<steepIni << endl;
  cout << "sel params r\t" <<selParams_r<< endl;
  cout << "sel params a\t" <<selParams_a<< endl;
  cout << "EOF test: " << test << endl;
  exit(1);
  }
 END_CALCS
  //######################################################################
  //######################################################################
PARAMETER_SECTION
  //Copy the Parameter estimates to double vals so can put as bounds,phases below
 LOCAL_CALCS
  //template: double xxxMin=log(xxxParams(1)); double xxxMax=log(xxxParams(2)); double
xxxPhase=log(xxxParams(2));
  double log_init_NMin=log(init_NParams(1)); double log_init_NMax=log(init_NParams(2));
  double init_NPhase=init_NParams(3);
  double log_init_RMin=log(init_RParams(1)); double log_init_RMax=log(init_RParams(2));
  double init_RPhase=init_RParams(3);
  double log_F_qMin=log(F_qParams(1)); double log_F_qMax=log(F_qParams(2)); double
  F_qPhase=F_qParams(3);
  double log_F_devMin=log(F_devParams(1)); double log_F_devMax=log(F_devParams(2));
  double F_devPhase=F_devParams(3);
  double log_eff_cvMin=log(eff_cvParams(1)); double log_eff_cvMax=log(eff_cvParams(2));
  double eff_cvPhase=eff_cvParams(3);
  double log_rec_devMin=log(rec_devParams(1)); double log_rec_devMax=log(rec_devParams(2)); double
  rec_devPhase=rec_devParams(3);
  double log_rec_cvMin=log(rec_cvParams(1)); double log_rec_cvMax=log(rec_cvParams(2));
  double rec_cvPhase=rec_cvParams(3);
  double log_S0Min=log(S0Params(1)); double log_S0Max=log(S0Params(2));
  double S0Phase=S0Params(3);
  double log_steepMin=log(steepParams(1)); double log_steepMax=log(steepParams(2));
  double steepPhase=steepParams(3);
  double sr_beta_envMin=sr_beta_envParams(1); double sr_beta_envMax=sr_beta_envParams(2); double
  sr_beta_envPhase=sr_beta_envParams(3);
  double M_beta_envMin=M_beta_envParams(1); double M_beta_envMax=M_beta_envParams(2); double
  M_beta_envPhase=M_beta_envParams(3);
  double log_M_cvMin=log(M_cvParams(1)); double log_M_cvMax=log(M_cvParams(2));
  double M_cvPhase=M_cvParams(3);
  double log_sel_r_Min=log(selParams_r(1)); double log_sel_r_Max=log(selParams_r(2));
  double sel_r_Phase=selParams_r(3);
  double log_sel_a_Min=log(selParams_a(1)); double log_sel_a_Max=log(selParams_a(2));
  double sel_a_Phase=selParams_a(3);
 END_CALCS
  //initial R and N
  //template: (Min,Max,Phase)
  init_bounded_number log_init_N(log_init_NMin,log_init_NMax,init_NPhase)
  init_bounded_number log_init_R(log_init_RMin,log_init_RMax,init_RPhase)
```

```
 //Fishing mortality for each year
 init_bounded_number log_F_q(log_F_qMin,log_F_qMax,F_qPhase)
 init_bounded_vector log_F_dev(startIndex+1,endIndex-1,log_F_devMin,log_F_devMax,F_devPhase) //don't
bother with terminal year deviation
 init_bounded_number log_eff_cv(log_eff_cvMin,log_eff_cvMax,eff_cvPhase)
 //Recruitment params
 init_bounded_dev_vector log_rec_dev(startIndex+1,endIndex,log_rec_devMin,log_rec_devMax,rec_devPhase)
 init_bounded_number log_rec_cv(log_rec_cvMin,log_rec_cvMax,rec_cvPhase)
 //Stock-recruitment parameters
 init_bounded_number log_S0(log_S0Min,log_S0Max,S0Phase)
 init_bounded_number log_steep(log_steepMin,log_steepMax,steepPhase)
 //S-R environmental link parameter
 init_bounded_number sr_beta_env(sr_beta_envMin,sr_beta_envMax,sr_beta_envPhase)
 //Adult environmental link parameter
 init_bounded_vector M_beta_env(1,stages,M_beta_envMin,M_beta_envMax,M_beta_envPhase)
 init_bounded_number log_M_cv(log_M_cvMin,log_M_cvMax,M_cvPhase)
 //Vulnerability at each stage
 init_bounded_number log_sel_r(log_sel_r_Min,log_sel_r_Max,sel_r_Phase)
 init_bounded_number log_sel_a(log_sel_a_Min,log_sel_a_Max,sel_a_Phase)
 //############### Derived parameters ###############//
 //sdreport_matrix for some of these
 sdreport_vector N(startIndex,endIndex+1+projSteps) //abundance
 sdreport_vector R(startIndex,endIndex+1+projSteps) //recruitment
 sdreport_vector SSB(startIndex,endIndex+projSteps) //spawning stock biomass
 vector SP(startIndex,endIndex+projSteps) //number of spawners
 vector TC(startIndex,endIndex+projSteps) //total catch
 vector C_wgt(startIndex,endIndex+projSteps) //catch of recruits in weight
 vector u(startIndex,endIndex+projSteps) //total exploitation rate
 sdreport_vector F(startIndex,endIndex+projSteps) //fishing mortality rate
 vector effort(startIndex,endIndex+projSteps) //fishing mortality rate
 number sel_r //selectivity (partial recruitment) of recruits to the fishery
 number sel_a //selectivity
 matrix Mt(1,stages,startIndex,endIndex+projSteps) //M at time t; don't do for years to account for seasonal M
 vector Z(startIndex,endIndex+projSteps) //total Z
 matrix ad_survey_est(1,numAdSurv,startIndex,endIndex) //estimated adult survey indices
 matrix re_survey_est(1,numRecSurv,startIndex,endIndex) //estimated recruitment survey indices
 vector qa(1,numAdSurv) //catchability for adult surveys
 vector qr(1,numRecSurv) //catchability for recruitment surveys
 number S0
 number mu
 number tau
 number Bprior
 number Aprior
 number steep
 number R0
 number A0
 number alpha //Alpha of the S-R relationship
 number beta //Beta of the S-R relationship
 number rec_var //variance for recruitment deviations
 number eff_var //variance for effort residuals
 number M_var //variance for F deviations
 //Derived variables for reference point calculations
 number Fval //F for SPR calculations
 vector SPR(1,Fval_num) //spawners per recruit (NOT spawning potential ratio)
 number SPR0 //virgin SPR
```

```
number SPR1 //spawner per recruit per year
vector SPR_y(startIndex,endIndex+projSteps) //annual SSB/R
sdreport_vector sSPR(startIndex,endIndex+projSteps) //static SPR
vector NPR(1,Fval_num) //numbers per reruit
vector YPR(1,Fval_num) //yield per recruit
vector SPRatio(1,Fval_num) //spawning potential ratio
vector N_eq(1,Fval_num) //equilibruim numbers
vector SSB_eq(1,Fval_num) //equilibrium SSB
vector R_eq(1,Fval_num) //equilibrium recruitment
vector C_eq(1,Fval_num) //equilibrium catch
vector C_eqSort(1,Fval_num) //sorted equilibrium catch
//Reference points
vector u0_eq(1,Fval_num) //equilibrium explotation rate for age0+
vector u1_eq(1,Fval_num) //equilibrium explotation rate for age1+
vector uAll_eq(1,Fval_num) //equilibrium explotation rate for age0+
vector FSPR_ref(1,nspr) //F%SPR reference points
vector SPRDiff(1,nspr) //temporary array to check if at proper F for SPR calcs
vector Fvec(1,Fval_num) //equilibrium explotation rate for age0+
likeprof_number MSY //MSY estimate
number OFL //Overfishing Limit (Ncurrent*uMSY)
number u0MSY //exploitation rate at MSY for age 0
number u1MSY //exploitation rate at MSY for age 1+
number uMSY //exploitation rate at MSY for age 0+
number FMSY //F rate at MSY
number RMSY //equilibrium recruitment at msy
number NMSY //Number at MSY
number SSBMSY //SSB at MSY
number FLim //F Limit (target)
number NLim //N Limit (target)
number SSBLim //SSB Limit (target)
number cLim //c used in calculation of targets
number FCurr //Current F (geometric mean of last 3 years of model run, not including terminal year)
vector MCurr(1,stages) //Current M (geometric mean of last 3 years of model run)
number NCurr //Current N (geometric mean of last 3 years of model run)
number SSBCurr //Current SSB (geometric mean of last 3 years of model run)
likeprof_number SPRCurr //Current SPR using FCurr and MCurr
number FMSYRatio //Fcurr/FMSY
number NMSYRatio //Ncurr/NMSY
number SSBMSYRatio //SSBCurr/SSBMSY
number UMSYRatio //Ncurr/NMSY
number FFLimRatio //Fcurr/FLimit
number NNLimRatio //Ncurr/NLim
number termToMSY //for F calcs
//variables for likelihood function
vector Lsr(1,numRecSurv) //likelihood components for recruit surveys
vector Lsa(1,numAdSurv) //likelihood components for adult surveys
number Lc //likelihood components for catch time series
number Lz //likelihood components for adult Z estimate (anchors F/N0/R0)
number Lh //likelihood component for steepness prior
number Lrdev //likelihood for recruitment deviations
number Leff //likelihood for effort residuals
number F_pen //penalty for F above the max F
number M_pen //penalty for M above the max M
objective_function_value negLL //negative log-liklihood
//############### Starting parameter values ###############//
```

```
 LOCAL_CALCS
  log_init_N=log(init_NIni);
  log_init_R=log(init_RIni);
  log_F_q=log(F_qIni);
  log_F_dev=log(F_devIni);
  log_M_cv=log(M_cvIni);
  log_rec_cv=log(rec_cvIni);
  log_rec_dev=log(rec_devIni);
  log_S0=log(S0Ini);
  log_steep=log(steepIni);
  sr_beta_env=sr_beta_envIni;
  M_beta_env=M_beta_envIni;
  log_sel_r=log(selIni_r);
  log_sel_a=log(selIni_a);
 END_CALCS
  //######################################################################
  //######################################################################
PROCEDURE_SECTION
  set_initial_conditions();
  if (testing==1) cout << "End set_initial_conditions()" << endl;
  calculate_abundance_and_catch();
  if (testing==1) cout << "End calculate_abundance_and_catch()" << endl;
  calculate_predicted_indices();
  if (testing==1) cout << "End calculate_predicted_indices()" << endl;
  calculate_objective_function();
  if (testing==1) cout << "End calculate_objective_function()" << endl;
  mcmc();
  if (testing==1) cout << "End mcmc()" << endl;
  if (testing==1) {
  //calculate_sSPR();
  obs_pred();
  MSY_estimates();
  HPD_estimates();
  general_report();
  cout << "Procedure section completed first cycle, now exiting"<< endl;
  exit(1); //exit if in testing phase -- runs model at initial parameter values
  }
  //############### Main Functions ###############
FUNCTION set_initial_conditions
  //convert parameters from the log scale
  S0=exp(log_S0);
  steep=exp(log_steep);
  negLL=0.0;
  M_var=log(exp(log_M_cv)*exp(log_M_cv)+1);
  rec_var=log(exp(log_rec_cv)*exp(log_rec_cv)+1);
  eff_var=log(exp(log_eff_cv)*exp(log_eff_cv)+1);
  sel_r=exp(log_sel_r);
  sel_a=exp(log_sel_a);
  F_pen=0;
  M_pen=0;
  //######## S-R Params ########
  //Calculate virgin SPR, including proportion of recruits spawning
  if(SPSwitch==1){
		A0=sratio*pSpawn(2)*exp(-(M(1)+sp_time*M(2)))/(1.-exp(-(M(2)))) + sratio*pSpawn(1)*exp(-
(sp_time*M(1)));
```

```
 }
 if(SPSwitch==2){
	A0=sratio*pSpawn(2)*mean_wgt_mt(2,startIndex)*exp(-(M(1)+sp_time*M(2)))/(1.-exp(-(M(2)))) + 
sratio*pSpawn(1)*mean_wgt_mt(1,startIndex)*exp(-(sp_time*M(1)));
 }
 R0=S0/A0;
 if (SRSwitch==1) { //Beverton-Holt
 alpha = S0*(1-steep)/(4*steep*R0);
 beta = (5*steep-1)/(4*steep*R0);
 }
 if (SRSwitch==2) { //Ricker
 beta = log(5*steep)/(0.8*S0);
 alpha =(exp((5.*log(5.*steep))/4.)*R0)/S0;
 }
 //calculate reference points after setting S-R params so can get FMSY for F projections
 calculate_reference_points();
 //######## M ########
 //compute the yearly M accounting for seasonal differences and environmental differences
 //leave this here to deal with seasonality
 for(y=startIndex; y<=endIndex+projSteps; y++) {
 //only apply deviation + bias correction if active
 Mt(1,y)=M(1);
 if (active(M_beta_env)) Mt(1,y)=M(1)*exp(M_beta_env(1)*env(envMTS(1),y-envMLag(1)))*exp(-0.5*M_var);
 if (y<=endIndex) {
 posfun(maxM-(timeSteps*Mt(1,y)),.000001,M_pen);
 negLL+=100.*M_pen;
 }
 Mt(2,y)=M(2);
 if (active(M_beta_env)) Mt(2,y)=M(2)*exp(M_beta_env(2)*env(envMTS(2),y-envMLag(2)))*exp(-0.5*M_var);
 if (y<=endIndex) {
 posfun(maxM-(timeSteps*Mt(2,y)),.000001,M_pen);
 negLL+=100.*M_pen;
 }
 }
 //######## F ########
 if (effFlag==0) effort=1.0;
 else {
 //set up effort to average and replace all missing data with average
 double avg_effort=mean(com_Eff_obs);
 //for any year prior to effort data, set to avg of all other years
 for (i=startIndex; i<=endIndex; i++) effort(i)=com_Eff_obs(i);
 for (i=endIndex+1; i<=endIndex+projSteps; i++) effort(i)=avg_effort; //effort(endIndex)+effProj(i)*termToMSY; 
//deviation off the last year
 effort/=avg_effort; //scale to observed years and not including projected years
 }
 //If want to estimate ave. q instead of 1st year q: change F_dev to bounded_dev_vector and adjust here
 F(startIndex)=exp(log_F_q+log(effort(startIndex)));
 posfun(maxF-(timeSteps*F(startIndex)),.000001,F_pen);
 negLL+=100.*F_pen;
 for(y=startIndex+1; y<endIndex; y++) { //don't include terminal year estimate
 //Computed as F=q*Eff*exp(dev)
 F(y)=exp(log_F_q+log(effort(y))+log_F_dev(y));
 posfun(maxF-(timeSteps*F(y)),.000001,F_pen);
 negLL+=100.*F_pen;
 }
```

```
 //for terminal year, use estimated deviation from previous year to keep scaled together
 F(endIndex)=exp(log_F_q+log(effort(endIndex))+log_F_dev(endIndex-1));
 termToMSY=FMSY-F(endIndex); //effort range from terminal year to MSY; negative if FMSY<termF
 //no F deviations on terminal year or projected years
 for(y=endIndex+1; y<=endIndex+projSteps; y++) {
 F(y)=(F(endIndex)+effProj(y)*termToMSY);
 effort(y)=exp(log(F(y)))/exp(log_F_q);
 }
 F=F/timeSteps;
 //######## Adult Z ########
 for(y=startIndex; y<=endIndex+projSteps; y++) Z(y)=F(y)+Mt(2,y);
FUNCTION calculate_abundance_and_catch
 N(startIndex)=exp(log_init_N);
 R(startIndex)=exp(log_init_R);
 for(y=startIndex; y<=endIndex+projSteps; y++) {
 //spawners also include some animals that were recruits in the beginning of the year
 if(SPSwitch==1){
        SP(y)=sratio*(N(y)*exp(-sp_time*(Mt(2,y)+sel_a*F(y))))*pSpawn(2)+ sratio*(R(y)*exp(-sp_time*(Mt(1,y)+sel_r*F(y))))*pSpawn(1);
                if (SRSwitch==1) { //Beverton-Holt
                // don't use recruit deviations for projection years
                        if (y<endIndex) R(y+1)=(SP(y)/(SP(y)*beta+alpha))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag))*exp(log_rec_dev(y+1)-biasAdj*0.5*rec_var);
                        else R(y+1)=(SP(y)/(SP(y)*beta+alpha))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag));
                }
                if (SRSwitch==2) { //Ricker
                // don't use recruit deviations for projection years
                        if (y<endIndex) R(y+1)=(alpha*SP(y)*exp(-beta*SP(y)))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag))*exp(log_rec_dev(y+1)-biasAdj*0.5*rec_var);
                        else R(y+1)=(alpha*SP(y)*exp(-beta*SP(y)))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag));
                }
 }
 if(SPSwitch==2){
        SSB(y)=sratio*(N(y)*mean_wgt_mt(2,y)*exp(-wgt_time*(Mt(2,y)+sel_a*F(y))))*pSpawn(2)+ sratio*(R(y)*mean_wgt_mt(1,y)*exp(-wgt_time*(Mt(1,y)+sel_r*F(y))))*pSpawn(1);
                if (SRSwitch==1) { //Beverton-Holt
                // don't use recruit deviations for projection years
                        if (y<endIndex) R(y+1)=((SSB(y)/(SSB(y)*beta+alpha))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag))*exp(log_rec_dev(y+1)-biasAdj*0.5*rec_var));
                        else R(y+1)=((SSB(y)/(SSB(y)*beta+alpha))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag)));
                }
                if (SRSwitch==2) { //Ricker
                // don't use recruit deviations for projection years
                        if (y<endIndex) R(y+1)=((alpha*SSB(y)*exp(-beta*SSB(y)))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag))*exp(log_rec_dev(y+1)-biasAdj*0.5*rec_var));
                        else R(y+1)=((alpha*SSB(y)*exp(-beta*SSB(y)))*exp(sr_beta_env*env(envRecTS,y+1-envRecLag)));
                }
 }
 //abundance for the next year
 N(y+1)=R(y)*exp(-(Mt(1,y)+sel_r*F(y)))+N(y)*exp(-(Mt(2,y)+sel_a*F(y)));
```

```
  //Baranov catch equation
  TC(y)=N(y)*((sel_a*F(y))/(sel_a*F(y)+Mt(2,y))*(1.-exp(-(sel_a*F(y)+Mt(2,y))))) +
R(y)*((sel_r*F(y))/(sel_r*F(y)+Mt(1,y))*(1.-exp(-(sel_r*F(y)+Mt(1,y)))));
  C_wgt(y)= N(y)*mean_wgt_mt(2,y)*((sel_a*F(y))/(sel_a*F(y)+Mt(2,y))*(1.-exp(-(sel_a*F(y)+Mt(2,y))))) +
R(y)*mean_wgt_mt(1,y)*((sel_r*F(y))/(sel_r*F(y)+Mt(1,y))*(1.-exp(-(sel_r*F(y)+Mt(1,y)))));
        if(SPSwitch==1){
                u(y)=TC(y)/(R(y)*((1-exp(-sel_r*F(y)))/(1-exp(-F(y))))+N(y));
        }
        if(SPSwitch==2){
                u(y)=C_wgt(y)/(R(y)*mean_wgt_mt(1,y)*((1-exp(-sel_r*F(y)))/(1-exp(-
F(y))))+N(y)*mean_wgt_mt(2,y));
        }
        if(SPSwitch==1){
        SPR0=sratio*pSpawn(2)*exp(-(Mt(1,y)+sp_time*Mt(2,y)))/(1.-exp(-(Mt(2,y)))) + sratio*pSpawn(1)*exp(-
(sp_time*Mt(1,y)));
        SPR_y(y)=sratio*pSpawn(2)*exp(-(Mt(1,y)+sel_r*F(y)+sp_time*(Mt(2,y)+sel_a*F(y))))/(1.-exp(-
(Mt(2,y)+sel_a*F(y)))) + sratio*pSpawn(1)*exp(-sp_time*(Mt(1,y)+sel_r*F(y)));
   }
   if(SPSwitch==2){
        SPR0=sratio*pSpawn(2)*mean_wgt_mt(2,startIndex)*exp(-(Mt(1,y)+sp_time*Mt(2,y)))/(1.-exp(-
(Mt(2,y)))) + sratio*pSpawn(1)*mean_wgt_mt(1,startIndex)*exp(-(sp_time*Mt(1,y)));
        SPR_y(y)=sratio*pSpawn(2)*mean_wgt_mt(2,y)*exp(-
(Mt(1,y)+sel_r*F(y)+sp_time*(Mt(2,y)+sel_a*F(y))))/(1.-exp(-(Mt(2,y)+sel_a*F(y)))) +
sratio*pSpawn(1)*mean_wgt_mt(1,y)*exp(-sp_time*(Mt(1,y)+sel_r*F(y)));
  }
  sSPR=SPR_y/SPR0;
  }
  //Calculate year-dependent F/N Reference Point components (i.e., ratios)
  NCurr=mfexp((log(N(endIndex))+log(N(endIndex-1))+log(N(endIndex-2)))/3);
  SSBCurr=mfexp((log(SSB(endIndex-1))+log(SSB(endIndex-2)))/2);
  FCurr=mfexp((log(F(endIndex-1))+log(F(endIndex-2)))/2);
  FMSYRatio=FCurr/FMSY;
  NMSYRatio=NCurr/NMSY;
  SSBMSYRatio=SSBCurr/SSBMSY;
  UMSYRatio=mfexp((log(u(endIndex))+log(u(endIndex-1))+log(u(endIndex-2)))/3)/uMSY;
  cLim=max(1-M(2),0.5);
  if(SPSwitch==1){
        OFL=uMSY*mfexp((log(N(endIndex))+log(N(endIndex-1))+log(N(endIndex-2)))/3); //N is by region, so
need to take mean if more
  }
  if(SPSwitch==2){
        OFL=uMSY*mfexp((log(SSB(endIndex))+log(SSB(endIndex-1))+log(SSB(endIndex-2)))/3);
        SSBLim=cLim*SSBMSY;
  }
  NLim=cLim*NMSY;
  FLim=FMSY;
  if (NCurr <= NLim) FLim=(FMSY*NCurr)/(cLim*NMSY);
  FFLimRatio=FCurr/FLim;
  NNLimRatio=NCurr/NLim;
  MCurr(1)=mfexp((log(Mt(1,endIndex))+log(Mt(1,endIndex-1))+log(Mt(1,endIndex-2)))/3);
  MCurr(2)=mfexp((log(Mt(2,endIndex))+log(Mt(2,endIndex-1))+log(Mt(2,endIndex-2)))/3);
  if(SPSwitch==1){
        SPR0=sratio*pSpawn(2)*exp(-(MCurr(1)+sp_time*MCurr(2)))/(1.-exp(-(MCurr(2)))) +
sratio*pSpawn(1)*exp(-(sp_time*MCurr(1)));
```

```
	SPR1=sratio*pSpawn(2)*exp(-(MCurr(1)+sel_r*FCurr+sp_time*(MCurr(2)+sel_a*FCurr)))/(1.-exp(-
(MCurr(2)+sel_a*FCurr))) + sratio*pSpawn(1)*exp(-sp_time*(MCurr(1)+sel_r*FCurr));
 }
 if(SPSwitch==2){
	SPR0=sratio*pSpawn(2)*mean_wgt_mt(2,startIndex)*exp(-(MCurr(1)+sp_time*MCurr(2)))/(1.-exp(-
(MCurr(2)))) + sratio*pSpawn(1)*mean_wgt_mt(1,startIndex)*exp(-(sp_time*MCurr(1)));
	SPR1=sratio*pSpawn(2)*mean_wgt_mt(2,endIndex)*exp(-
(MCurr(1)+sel_r*FCurr+sp_time*(MCurr(2)+sel_a*FCurr)))/(1.-exp(-(MCurr(2)+sel_a*FCurr))) +
sratio*pSpawn(1)*mean_wgt_mt(1,endIndex)*exp(-sp_time*(MCurr(1)+sel_r*FCurr));
 }
 SPRCurr=SPR1/SPR0;
FUNCTION calculate_predicted_indices
 //########## Recruits #########
 for (i=1; i<=numRecSurv; i++){
 qr(i)=0.0;
 double counter=0.0;
 for(y=startIndex; y<=endIndex; y++) {
 if (y<recStartIndex) continue;
 if(re_survey_obs(i,y)!=-999.) { //check to make sure year is not missing
 if(!last_phase()) {
 //small constant added to recruitment in earlier stages to
 //increase numerical stability
 //NOTE: this formulation now allows for surveys that occur after fish become vulnerable to fisheries
 qr(i)+=log(re_survey_obs(i,y))-log(R(y)*exp(-sr_time(i)*(Mt(1,y)+sel_r*F(y)))+.000001);
 }
 else { //small constant not included in last estimation stage
 qr(i)+=log(re_survey_obs(i,y))-log(R(y)*exp(-sr_time(i)*(Mt(1,y)+sel_r*F(y))));
 }
 counter++;
 }
 }
 //calculate geometric mean
 qr(i)=exp(qr(i)/counter);
 //Calculate predicted index of abundance
 //NOTE: this formulation now allows for surveys that occur after fish become vulnerable to fisheries
 for(y=startIndex; y<=endIndex; y++) {
 re_survey_est(i,y)=qr(i)*(R(y)*exp(-sr_time(i)*(Mt(1,y)+sel_r*F(y))));
 }
 }
 //########## Adults #########
 for (i=1; i<=numAdSurv; i++){
 //calculate catchability for each sex-index combination
 double counter=0.0;
 qa(i)=0.0;
 for(y=startIndex; y<=endIndex; y++) {
 if (y<adStartIndex) continue;
 if(ad_survey_obs(i,y)!=-999.) { //check to make sure year is not missing
 qa(i)+=log(ad_survey_obs(i,y))-log(N(y)*exp(-sa_time(i)*(Mt(2,y)+sel_a*F(y))));
 counter++;
 }
 }
 //calculate geometric mean
 qa(i)=exp(qa(i)/counter);
 //Calculate each predicted index of abundance
 for(y=startIndex; y<=endIndex; y++) {
```

```
 ad_survey_est(i,y)=qa(i)*(N(y)*exp(-sa_time(i)*(Mt(2,y)+sel_a*F(y))));
 }
 }
FUNCTION calculate_objective_function
 double pi=3.141593;
 //calculate adult survey likelihood component
 for (i=1; i<=numAdSurv; i++){
 Lsa(i)=0.0;
 for(y=startIndex; y<=endIndex; y++) {
 if (y<adStartIndex) continue;
 if(ad_survey_obs(i,y)!=-999.) { //check to make sure year is not missing -- some holes

Lsa(i)+=0.5*log(2.*pi)+0.5*log(ad_survey_var(i,y))+log(ad_survey_obs(i,y))+square(log(ad_survey_obs(i,y)+.00000
1)-log(ad_survey_est(i,y)+.000001))/(2*ad_survey_var(i,y));
 }
 }
 Lsa(i)=sa_lambda(i)*Lsa(i);
 }
 //calculate recruit survey likelihood component
 for (i=1; i<=numRecSurv; i++){
 Lsr(i)=0.0;
 for(y=startIndex; y<=endIndex; y++) {
 if (y<recStartIndex) continue;
 if(re_survey_obs(i,y)!=-999.) { //check to make sure year is not missing

Lsr(i)+=0.5*log(2.*pi)+0.5*log(re_survey_var(i,y))+log(re_survey_obs(i,y))+square(log(re_survey_obs(i,y)+.000001)
-log(re_survey_est(i,y)+.000001))/(2*re_survey_var(i,y));
 }
 }
 Lsr(i)=sr_lambda(i)*Lsr(i);
 }
 //calculate total catch likelihood component
 Lc=0.0;
 for(y=startIndex; y<=endIndex; y++) {
 if (y<cStartIndex) continue;
 if(TC_obs(y)!=-999.) { //check to make sure year is not missing
 Lc+=0.5*log(2.*pi)+0.5*log(C_var(y))+log(TC_obs(y))+square(log(TC_obs(y)+.000001)-
log(TC(y)+.000001))/(2*C_var(y));
 }
 }
 Lc=com_lambda*Lc;
 //calculate likelihood component for recruitment deviations

Lrdev=recDev_lambda*(0.5*log(2.*pi)*size_count(log_rec_dev)+0.5*log(rec_var)*size_count(log_rec_dev)+sum(lo
g_rec_dev)+0.5*norm2(log_rec_dev)/rec_var);
 //calculate likelihood component for effort residuals if effort time series is included
 Leff=0.0;
 if (effFlag==1) {
 for(y=startIndex; y<endIndex; y++) {
 Leff+=0.5*log(2.*pi)+0.5*log(eff_var)+log(effort(y))+0.5*square(log(effort(y))-(log(F(y))-log_F_q))/eff_var;
 }
 Leff=effort_lambda*Leff;
 }
 //calculate likelihood component for total Z of adults as prior, read from independent Z estimate
```

```
  Lz=aveZ_lambda*(0.5*log(2.*pi)+0.5*log(Z_var)+log(aveZ)+0.5*square(log(aveZ)-log(mean(Z(startIndex+7,endIndex-1))))/Z_var); //hardwired (i.e., startIndex+7 instead of just startIndex) for spot avg Z from 1996-2013
  //calculate likelihood component for SR steepness prior
  mu=(steep-steepParams(1)) / (steepParams(2)-steepParams(1));  // CASAL's v   //borrowed beta prior code from SS3 which borrowed from CASAL
  tau=(steep-steepParams(1))*(steepParams(2)-steep)/square(h_sd)-1.0;
  Bprior=tau*mu;  Aprior=tau*(1.0-mu);  // CASAL's m and n
  Lh =h_lambda*((1.0-Bprior)*log(0.0001+h_prior-steepParams(1)) + (1.0-Aprior)*log(0.0001+steepParams(2)-h_prior)-(1.0-Bprior)*log(0.0001+steep-steepParams(1)) - (1.0-Aprior)*log(0.0001+steepParams(2)-steep));
  negLL+=sum(Lsa)+sum(Lsr)+Lc+Lrdev+Leff+Lz+Lh;
FUNCTION calculate_reference_points
  //Reference point variables
  MSY=0.0;
  u1MSY=0.0;
  u0MSY=0.0;
  uMSY=0.0;
  i=0;
  OFL=0.0;
  SPRDiff=1e10;
  //With recruit spawners
  if(SPSwitch==1){
	SPR0=sratio*pSpawn(2)*(exp(-(Myr(1)+sp_time*Myr(2)))/(1.-exp(-(Myr(2))))) + sratio*pSpawn(1)*(exp(-((sp_time*Myr(1)))));
  }
  if(SPSwitch==2){
	SPR0=sratio*pSpawn(2)*mean_wgt_mt(2,startIndex)*(exp(-(Myr(1)+sp_time*Myr(2)))/(1.-exp(-(Myr(2))))) + sratio*pSpawn(1)*mean_wgt_mt(1,startIndex)*(exp(-((sp_time*Myr(1)))));
  }
  Fval=Fval_init;
  for(i=1; i<=Fval_num; i++)
  {
  Fvec(i)=Fval; //record the F values
  if(SPSwitch==1){
	SPR(i)=sratio*pSpawn(2)*(exp(-(Myr(1)+sel_r*Fval+sp_time*(Myr(2)+sel_a*Fval)))/(1.-exp(-(Myr(2)+sel_a*Fval)))) + sratio*pSpawn(1)*(exp(-(sp_time*(Myr(1)+sel_r*Fval))));
  }
  if(SPSwitch==2){
	SPR(i)=sratio*pSpawn(2)*mean_wgt_mt(2,startIndex)*(exp(-(Myr(1)+sel_r*Fval+sp_time*(Myr(2)+sel_a*Fval)))/(1.-exp(-(Myr(2)+sel_a*Fval)))) + sratio*pSpawn(1)*mean_wgt_mt(1,startIndex)*(exp(-(sp_time*(Myr(1)+sel_r*Fval))));
  }
  NPR(i)=exp(-(Myr(1)+sel_r*Fval))/(1.-exp(-(Myr(2)+sel_a*Fval)));
  if(SPSwitch==1){
	YPR(i)=(sel_r*Fval)/(sel_r*Fval+Myr(1))*(1.-exp(-(sel_r*Fval+Myr(1)))) + ((sel_a*Fval)/(sel_a*Fval+Myr(2))*(1.-exp(-(sel_a*Fval+Myr(2)))))*NPR(i);
  }
  if(SPSwitch==2){
	YPR(i)=((sel_r*Fval)/(sel_r*Fval+Myr(1))*(1.-exp(-(sel_r*Fval+Myr(1)))))*mean_wgt_mt(1,startIndex) + (((sel_a*Fval)/(sel_a*Fval+Myr(2))*(1.-exp(-(sel_a*Fval+Myr(2)))))*mean_wgt_mt(2,startIndex))*NPR(i);
  }
  if (SRSwitch==1) R_eq(i)=(SPR(i)-alpha)/(SPR(i)*beta);
  if (SRSwitch==2) R_eq(i)=(log(alpha)+log(SPR(i)))/(beta*SPR(i));
  N_eq(i) = NPR(i)*R_eq(i);
  SSB_eq(i) = SPR(i)*R_eq(i);
```

```
 C_eq(i)=YPR(i)*R_eq(i);
 //calculate exploitation rate
 //age 0+
 u0_eq(i)=(sel_r*Fval)/(sel_r*Fval+Myr(1))*(1.-exp(-(sel_r*Fval+Myr(1))));
 //age 1+
 u1_eq(i)=(sel_a*Fval)/(sel_a*Fval+Myr(2))*(1.-exp(-(sel_a*Fval+Myr(2))));
 //all ages
 if (SPSwitch==1){
 if (i>1) uAll_eq(i)=C_eq(i)/(N_eq(i)+R_eq(i)*((1-exp(-sel_r*Fval))/(1-exp(-Fval))));
 }
 if (SPSwitch==2){
 if (i>1) uAll_eq(i)=C_eq(i)/(N_eq(i)*mean_wgt_mt(2,startIndex)+R_eq(i)*mean_wgt_mt(1,startIndex)*((1-exp(-
sel_r*Fval))/(1-exp(-Fval))));
 }
 //MSY
 if (C_eq(i)>MSY) {
 MSY=C_eq(i);
 FMSY=Fval;
 NMSY=N_eq(i);
 SSBMSY=SSB_eq(i);
 RMSY=R_eq(i);
 u0MSY=u0_eq(i);
 u1MSY=u1_eq(i);
 uMSY=uAll_eq(i);
 }
 //loop through SPR targets and see if at the correct F for each target
 for (ispr=1; ispr<=nspr; ispr++){
 if (square(SPR(i)/SPR0-SPR_targ(ispr)) < SPRDiff(ispr)) {
 SPRDiff(ispr)=square(SPR(i)/SPR0-SPR_targ(ispr));
 FSPR_ref(ispr)=Fval;
 }
 }
 //increment the female F for the SPR
 Fval+=Fval_inc;
 }
 //############### Reporting functions ###############//
FUNCTION mcmc
 //Code to write results of MCMC to file so we can access the chains
 if(mceval_phase()) {
 //Define output file stream for MCMC results
 if(iterMCMC==0) {
 ofstream mcmcout("cmsa_refs.mcmc");
 mcmcout
<<"MSY\t"<<"FMSY\t"<<"NMSY\t"<<"SSBMSY\t"<<"uMSY\t"<<"FLim\t"<<"NLim\t"<<"FMSYRatio\t"<<"NMSYRatio
\t"<<"SSBMSYRatio\t"<<"UMSYRatio\t"<<"FFLimRatio\t"<<"NNLimRatio\t"<<"SPRCurrent"<<endl;
 //print out yearly F and N
 ofstream mcmcout2("cmsa_yearly.mcmc");
 year=fyear;
 for(y=startIndex;y<=endIndex;y++){
 mcmcout2 <<"N"<<year<<"\t";
 year=year+1.0/timeSteps;
 }
 year=fyear;
 for(y=startIndex;y<=endIndex;y++){
 mcmcout2 <<"R"<<year<<"\t";
```

```
 year=year+1.0/timeSteps;
 }
 year=fyear;
 for(y=startIndex;y<=endIndex;y++){
 if( y<endIndex) mcmcout2 <<"F"<<year<<"\t";
 else mcmcout2 <<"F"<<year << endl;
 year=year+1.0/timeSteps;
 }
 ofstream mcmcout3("cmsa_pars.mcmc");
 mcmcout3 <<"N0\t"<<"R0\t"<< "Fq\t"<<"S0\t"<<"h"<<endl;
 iterMCMC++;
 }
 ofstream mcmcout("cmsa_refs.mcmc",ios::app);
 mcmcout

<<MSY<<"\t"<<FMSY<<"\t"<<NMSY<<"\t"<<SSBMSY<<"\t"<<uMSY<<"\t"<<FLim<<"\t"<<NLim<<"\t"<<FMSYRatio<
<"\t"<<NMSYRatio<<"\t"<<SSBMSYRatio<<"\t"<<UMSYRatio<<"\t"<<FFLimRatio<<"\t"<<NNLimRatio<<"\t"<<SPRC
urr<<endl;
 //print out yearly F and N
 ofstream mcmcout2("cmsa_yearly.mcmc",ios::app);
 for(y=startIndex;y<=endIndex;y++){
 mcmcout2 <<N(y) << "\t";
 }
 for(y=startIndex;y<=endIndex;y++){
 mcmcout2 <<R(y) << "\t";
 }
 for(y=startIndex;y<=endIndex;y++){
 if (y<endIndex) mcmcout2 <<F(y) << "\t";
 else mcmcout2 <<F(y) <<endl;
 }
 //print out yearly F and N
 ofstream mcmcout3("cmsa_pars.mcmc",ios::app);
 mcmcout3 <<exp(log_init_N)<<"\t"<<exp(log_init_R)
<<"\t"<<exp(log_F_q)<<"\t"<<exp(log_S0)<<"\t"<<exp(log_steep) << endl;
 }
FUNCTION obs_pred
 ofstream ofs_op("obs_pred_results.dat");
 ofs_op << "survey year sex a_r s_c snum obs cv pred" << endl;
 year=fyear;
 for(y=startIndex; y<=endIndex; y++) {
 //total observed and predicted catch
 ofs_op << "0 "<< year << " t a c 0 " << TC_obs(y) << " " << C_cv(y) << " " << TC(y) << endl;
 //total observed and predicted catch in weight (metric tons)
 ofs_op << "0 "<< year << " t a c_wgt 0 " << C_wgt_obs(y) << " " << "NA" << " " << C_wgt(y) << endl;
 //adult surveys
 for (i=1; i<=numAdSurv; i++)
 ofs_op << i << " "<< year << " 0 a s 0 " << ad_survey_obs(i,y) << " " << ad_survey_cv(i,y) << " " <<
ad_survey_est(i,y) << endl;
 //recruit surveys
 for (i=1; i<=numRecSurv; i++)
 ofs_op << i << " "<< year << " 0 r s 0 " << re_survey_obs(i,y) << " " << re_survey_cv(i,y) << " " << re_survey_est(i,y)
<< endl;
 if (y==startIndex) ofs_op << "0 "<< year << " r r r 0 " << R(y) << " " << "NA" << " " << "NA" << endl;
 else {
	if (SPSwitch==1){
```

```
                if (SRSwitch==1) ofs_op << "0 "<< year << " r r r 0 " << R(y)<< " " << "NA" << " " <<SP(y-1)/(SP(y-
1)*beta+alpha) << endl;
                if (SRSwitch==2) ofs_op << "0 "<< year << " r r r 0 " << R(y)<< " " << "NA" << " " << alpha*SP(y-
1)*exp(-beta*(SP(y-1))) << endl;
        }
        if (SPSwitch==2){
                if (SRSwitch==1) ofs_op << "0 "<< year << " r r r 0 " << R(y)<< " " << "NA" << " " << (SSB(y-
1)/(SSB(y-1)*beta+alpha)) << endl;
                if (SRSwitch==2) ofs_op << "0 "<< year << " r r r 0 " << R(y)<< " " << "NA" << " " << (alpha*SSB(y-
1)*exp(-beta*(SSB(y-1)))) << endl;
        }
 } //recruitment deviations
 year=year+1.0/timeSteps;
 }
FUNCTION HPD_estimates
 ofstream ofs_hpd("HPD_results.dat");
 ofs_hpd << "year Adult Spawners Rec RecSurvey1 TC recM adM F FMSYRatio NMSYRatio SSBMSYRatio FFLimRatio
NNLimRatio u0 u1 uAll SREnv MEnvRec MEnvAd" << endl;
 year=fyear; //for outputting the year if multiple time steps per year
 for(y=startIndex;y<=endIndex+projSteps;y++){
        if(SPSwitch==1){
                ofs_hpd << year << " " << N(y) << " "<< SP(y)<< " " << R(y) << " " <<R(y)*exp(-sr_time(1)*Mt(1,y))
<< " " << TC(y) << " " << Mt(1,y) << " " << Mt(2,y) << " " << F(y)<< " " << F(y)/FMSY<< " " << N(y)/NMSY<< " "<<
F(y)/FLim<< " " << N(y)/NLim<< " "<<
                (sel_r*F(y))/(sel_r*F(y)+Mt(1,y))*(1.-exp(-(sel_r*F(y)+Mt(1,y)))) << " "<<
(sel_a*F(y))/(sel_a*F(y)+Mt(2,y))*(1.-exp(-
                (sel_a*F(y)+Mt(2,y)))) << " "<< u(y) << " " << env(envRecTS,y-envRecLag) << " "<<
env(envMTS(1),y-envMLag(1)) << " " <<
                env(envMTS(2),y-envMLag(2)) << endl;
        }
        if(SPSwitch==2){
                ofs_hpd << year << " " << N(y) << " "<< SSB(y)<< " " << R(y) << " " <<R(y)*exp(-sr_time(1)*Mt(1,y))
<< " " << TC(y) << " " << Mt(1,y) << " " << Mt(2,y) << " " << F(y)<< " " << F(y)/FMSY<< " " << N(y)/NMSY<< " "<<
F(y)/FLim<< " " << N(y)/NLim<< " "<<
                (sel_r*F(y))/(sel_r*F(y)+Mt(1,y))*(1.-exp(-(sel_r*F(y)+Mt(1,y)))) << " "<<
(sel_a*F(y))/(sel_a*F(y)+Mt(2,y))*(1.-exp(-
                (sel_a*F(y)+Mt(2,y)))) << " "<< u(y) << " " << env(envRecTS,y-envRecLag) << " "<<
env(envMTS(1),y-envMLag(1)) << " " <<
                env(envMTS(2),y-envMLag(2)) << endl;
        }
 year=year+1.0/timeSteps;
 }
FUNCTION MSY_estimates
 ofstream ofs_msy("MSY_results.dat");
 {
 //Column headings
 ofs_msy << "Fval\t" << "C_eq\t" << "N_eq\t" << "R_eq\t" << "YPR\t" << "SPR\t" << "SPRatio\t" << "u0_eq\t" <<
"u1_eq\t" << "uAll_eq\t" << endl;
 Fval=Fval_init;
 for(i=1; i<=Fval_num; i++) {
 ofs_msy << Fval << "\t" << C_eq(i) << "\t" << N_eq(i) << "\t" << R_eq(i) << "\t" <<YPR(i) << "\t" << SPR(i) << "\t" <<
 SPR(i)/SPR0 << "\t" << u0_eq(i) << "\t" << u1_eq(i)<< "\t" << uAll_eq(i) << endl;
 Fval+=Fval_inc;
 }
 }
```

```
FUNCTION general_report
 ofstream ofs_gen("gen_results.dat");
 {
 ofs_gen << "Name Value" << endl;
 ofs_gen << "negLL " << negLL <<endl;
 ofs_gen << "Lsa "<< Lsa <<endl;
 ofs_gen << "Lsr "<< Lsr << endl;
 ofs_gen << "Lc "<< Lc << endl;
 ofs_gen << "Lz "<< Lz << endl;
 ofs_gen << "Lh "<< Lh << endl;
 ofs_gen << "Lrdev "<< Lrdev << endl;
 ofs_gen << "Leff "<< Leff << endl;
 ofs_gen << "init_N "<< exp(log_init_N) << endl;
 ofs_gen << "init_R " << exp(log_init_R) << endl;
 for (i=1; i<=numAdSurv; i++) ofs_gen << "qa_i"<<i <<" " << qa(i) << endl;
 for (i=1; i<=numRecSurv; i++) ofs_gen << "qr_i"<<i <<" " << qr(i) << endl;
 ofs_gen << "F_q "<< exp(log_F_q) << endl;
 ofs_gen << "rec_cv "<< exp(log_rec_cv) << endl;
 ofs_gen << "p_rec "<< p_rec << endl;
 ofs_gen << "p_under " << p_under << endl;
 ofs_gen << "SRType " << SRSwitch << endl;
 ofs_gen << "S0 " << exp(log_S0) << endl;
 ofs_gen << "steepness " << exp(log_steep) << endl;
 ofs_gen << "alpha " << alpha << endl;
 ofs_gen << "beta " << beta << endl;
 ofs_gen << "sr_beta_env " << sr_beta_env << endl;
 ofs_gen << "M_beta_env_1 " << M_beta_env(1) << endl;
 ofs_gen << "M_beta_env_2 " << M_beta_env(2) << endl;
 ofs_gen << "sel_1 " << exp(log_sel_r) << endl;
 ofs_gen << "sel_2 " << exp(log_sel_a) << endl;
 ofs_gen << "Mr " << Myr(1) << endl;
 ofs_gen << "Ma " << Myr(2) << endl;
 ofs_gen << "Ma " << Myr(2) << endl;
 ofs_gen << "sp_time " << sp_time <<endl;
 ofs_gen << "MSY " << MSY << endl;
 ofs_gen << "FMSY " << FMSY << endl;
 ofs_gen << "FMSYRatio " << FMSYRatio << endl;
 ofs_gen << "NMSY " << NMSY << endl;
 ofs_gen << "SSBMSY" << SSBMSY << endl;
 ofs_gen << "NMSYRatio " << NMSYRatio << endl;
 ofs_gen << "SSBMSYRatio " << SSBMSYRatio << endl;
 ofs_gen << "RMSY " << RMSY << endl;
 ofs_gen << "u0MSY " << u0MSY << endl;
 ofs_gen << "u1MSY " << u1MSY<< endl;
 ofs_gen << "uMSY " << uMSY<< endl;
 ofs_gen << "UMSYRatio " << UMSYRatio << endl;
 ofs_gen << "FLim " << FLim << endl;
 ofs_gen << "FFLimRatio " << FFLimRatio << endl;
 ofs_gen << "NLim " << NLim << endl;
 ofs_gen << "NNLimRatio " << NNLimRatio << endl;
 ofs_gen << "cLim " << cLim << endl;
 ofs_gen << "OFL " << OFL<< endl;
 ofs_gen << "projYears " << projYears<< endl;
 for(ispr=1; ispr<=nspr; ispr++) {
 ofs_gen << "F"<<SPR_targ(ispr) << "% " << FSPR_ref(ispr)<< endl;
```

```
 }
 }
 //######################################################################
 //######################################################################
REPORT_SECTION
 //Call reporting functions
 //  calculate_sSPR();
 obs_pred();
 MSY_estimates();
 HPD_estimates();
 general_report();
 report << "Likelihood Components" <<endl;
 report << "negLL\t" << negLL <<endl;
 report << "Lsa\t" << Lsa <<endl;
 report << "Lsr\t" << Lsr << endl;
 report << "Lc\t" << Lc << endl;
 report << "Leff\t" << Leff << endl;
 report << "Lz\t" << Lz << endl;
 report << "Lh\t" << Lh << endl;
 report << "Lrdev\t" << Lrdev << endl;
 report << "F_pen\t" << F_pen << endl;
 report << "\nParameter Estimates (NOT log space unless marked)" <<endl;
 report << "init_N\t" << exp(log_init_N) << endl;
 report << "init_R\t" << exp(log_init_R) << endl;
 report << "F\t" << F << endl;
 report << "M_rec\t" << Mt(1) << endl;
 report << "M_ad\t" << Mt(2) << endl;
 report << "AveF\t" << mean(F(startIndex,endIndex-1)) << endl;
 report << "AveZ\t" << mean(Z(startIndex+7,endIndex-1)) << endl;
 report << "AveU\t" << mean(u(startIndex,endIndex)) << endl;
 report << "F_q "<< exp(log_F_q) << endl;
 report << "log_F_dev\t" << log_F_dev << endl;
 report << "mean(log_F_dev)\t" << mean(log_F_dev) << endl;
 report << "rec_dev\t" << exp(log_rec_dev) << endl;
 report << "mean(log_rec_dev)\t" << mean(log_rec_dev) << endl;
 report << "mean(rec_dev)\t" << mean(exp(log_rec_dev)) << endl;
 report << "rec_cv\t" << exp(log_rec_cv) << endl;
 for (i=1; i<=numAdSurv; i++) report << "qa_i"<<i <<"\t" << qa(i) << endl;
 for (i=1; i<=numRecSurv; i++) report << "qr_i"<<i <<"\t" << qr(i) << endl;
 if (SRSwitch==1) //Beverton-Holt
 report << "SR=Beverton-Holt\t" << endl;
 if (SRSwitch==2) //Ricker
 report << "SR=Ricker\t" << endl;
 report << "S0\t" << exp(log_S0) << endl;
 report << "R0\t" << R0 << endl;
 report << "steepness\t" << exp(log_steep) << endl;
 report << "alpha\t" << alpha << endl;
 report << "beta\t" << beta << endl;
 report << "sr_beta_env\t" << sr_beta_env << endl;
 report << "M_beta_env\t" << M_beta_env << endl;
 report << "M_beta_env_rec\t" << M_beta_env(1) << endl;
 report << "M_beta_env_ad\t" << M_beta_env(2) << endl;
 report << "sel\t" << exp(log_sel_r) <<"\t"<< exp(log_sel_a) << endl;
 report << "p_rec\t" << p_rec << endl;
 report << "p_under\t" << p_under << endl;
```

```
 report << "M\t" << Myr << endl;
 report << "rec_cv\t" << exp(log_rec_cv) << endl;
 report << "sp_time\t" << sp_time <<endl;
 report << "mean_wgt_recruits\t" << mean_wgt(1) <<endl;
 report << "mean_wgt_adults\t" << mean_wgt(2) <<endl;
 report << "\nReference Point Calculations" <<endl;
 report << "negLL\t" << negLL <<endl;
 report << "MSY\t" << MSY << endl;
 report << "uMSY\t" << uMSY<< endl;
 report << "NMSY " << NMSY << endl;
 report << "SSBMSY " << SSBMSY << endl;
 report << "UMSYRatio " << UMSYRatio << endl;
 report << "NMSYRatio " << NMSYRatio << endl;
 report << "SSBMSYRatio " << SSBMSYRatio << endl;
 report << "FMSY\t" << FMSY << endl;
 report << "FMSYRatio " << FMSYRatio << endl;
 report << "RMSY\t" << RMSY << endl;
 report << "u0MSY\t" << u0MSY << endl;
 report << "u1MSY\t" << u1MSY<< endl;
 report << "FLim\t" << FLim << endl;
 report << "FFLimRatio\t" << FFLimRatio << endl;
 report << "NLim\t" << NLim << endl;
 report << "NNLimRatio\t" << NNLimRatio << endl;
 report << "cLim\t" << cLim << endl;
 report << "OFL\t" << OFL << endl;
 report << "SPRCurr\t" << SPRCurr<< "\n"<< endl;
 for(ispr=1; ispr<=nspr; ispr++) {
 report << "F"<<SPR_targ(ispr) << "%\t" << FSPR_ref(ispr)<< endl;
 }
 //#####################################################################
 //#####################################################################
GLOBALS_SECTION
 #include "admodel.h"
 //define constant variable
 const double MathPI = 3.141592654; //or using MI_PI
 const double MathE = 2.71828183;
 //#####################################################################
 //#####################################################################
RUNTIME_SECTION
 maximum_function_evaluations 25000,25000,20000,20000,20000,20000
 convergence_criteria 1.0e-8
 //Leave space below this line
```

Appendix 5. Modified-CSA Data Input File

```
# Data sources
############################################################
############################################################
#Run in testing mode: runs model at initial values and output some values to console (0=off, 1=on)
 0
#first year / last year for the model simulation (should be same as catch)
 1989 2014
#Retrospective NumYears
 0
#Projection NumYears
 0

##################################
#Removal Data
##################################
#first / last year of total removal time series
 1989 2014
#Total removals (in millions of fish)
#Commercial Landings+Commercial Shrimp Trawl Discards+Mid-Atlantic Gillnet and Trawl Discards+Scrap
Landings+Recreational Harvest+Recreational Dead Releases
 640.34  999.087 1324.14 250.646 218.705 355.827 573.627 144.522 40.546  89.201  92.001  98.869  177.471
         97.162  226.63  101.344 108.398 131.881 73.402  86.931  100.43  83.356  220.493 107.162 114.575
         150.239
#Total removals (in metric tons) - not currently included in the objective function
#Commercial Landings+Commercial Shrimp Trawl Discards+Mid-Atlantic Gillnet and Trawl Discards+Scrap
Landings+Recreational Harvest+Recreational Dead Releases
 33570   25314   57236   16878   11973   18580   19720   8144    9862    8924    5841    7044    9332
         6646    10184   8240    6238    8519    7490    6777    7301    4622    9106    8193    6516
         9471
#Total removals CV (i.e., catch SE/mean catch) applied to likelihood - this value is converted to SE of log(catch)
within the model for the likelihood function
 0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05
         0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05    0.05
         0.05
#Flag to include effort time series in calcs (adds negLL component for F-deviations) - 0 to exclude, 1 to include
 0
#Effort (if don't have an effort time series, set all equal to 1 for the total number of years)
 1       1       1       1       1       1       1       1       1       1       1       1       1
         1       1       1       1       1       1       1       1       1       1       1       1
         1

##################################
#Survey Data
##################################
###Post-recruit surveys AND CVs###
#Number of post-recruit surveys
 5
#first / last year in post-recruit surveys
#Note: if catch are different lengths of time, use -999. for missing values
# Therefore, this is min and max year for any data
 1989 2014
#Standardized (x/mu)
#Do all surveys as rows first, then all CVs as rows 2nd
#NCDMF Trawl Survey (Program 195; June, >=120mm)
 0.8602  0.4149  0.8793  0.4639  0.8786  0.9277  1.5358  0.3939  0.6283  0.4781  0.7560  1.7494  0.6035
         0.5230  1.2830  0.9074  1.3612  4.2081  0.9282  0.5587  0.6613  0.6246  1.0763  0.7906  1.3604
         1.1479
```

```
#SEAMAP Trawl Survey (Fall)
 0.2930  0.4260  2.9393  0.6342  1.1321  0.8969  0.2904  0.6332  0.0892  0.1318  0.3033  0.5276  0.1289
         0.3614  0.5989  0.5996  4.2248  0.5699  0.3726  1.9167  1.1684  1.5220  0.6718  1.7912  2.6558
         1.1214
#NMFS Trawl Survey (Fall, NEAMAP Aggregate ALK)
 3.9494  0.6895  0.1446  0.1046  0.0163  1.0548  0.5982  0.2674  0.0886  0.1045  0.7080  0.4713  0.0004
         0.2652  0.4425  0.7368  0.9991  1.5952  0.5910  0.9939  1.5753  1.2970  2.9900  4.4850  1.4494
         0.3823
#ChesMMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         0.5862  0.6730  0.8006  1.8229  3.9015  1.3534  0.6614  1.4423  0.0976  1.1048  0.0105  0.4441
         0.1017
#NEAMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         -999    -999    -999    -999    -999    1.0820  0.6773  1.0868  0.9530  1.9066  0.0121  2.2049
         0.0772
#CV(i.e., index SE/mean index) - these value are converted to SE of log(index) within the model for the likelihood
function
#NCDMF Trawl Survey (Program 195; June, >=120mm) CV
#0.1757 0.222    0.1032  0.1408  0.0978  0.1227  0.1334  0.1673  0.1433  0.2664  0.1639  0.2053  0.1573
         0.1953  0.1671  0.2671  0.2895  0.1248  0.1939  0.319   0.2073  0.1417  0.1432  0.2175  0.2086
         0.1873
 0.2662  0.2988  0.2251  0.2446  0.2226  0.2346  0.2404  0.2607  0.2460  0.3331  0.2586  0.2866  0.2544
         0.2795  0.2606  0.3337  0.3519  0.2357  0.2786  0.3765  0.2881  0.2451  0.2460  0.2955  0.2890
         0.2740
#SEAMAP Trawl Survey (Fall)
 0.3342  0.1849  0.1959  0.2480  0.4129  0.2547  0.1644  0.1751  0.2576  0.2084  0.3830  0.4089  0.2244
         0.2269  0.4688  0.2759  0.3407  0.1264  0.2627  0.5379  0.2732  0.3420  0.2156  0.1819  0.4163
         0.3872
#NMFS Trawl Survey (Fall, NEAMAP Aggregate ALK)
#0.0664 0.0553   0.2101  0.1228  0.1661  0.1197  0.0592  0.1165  0.1019  0.1065  0.0363  0.0730  0.3110
         0.1152  0.0666  0.0620  0.0538  0.0421  0.1104  0.0487  0.0333  0.0368  0.0374  0.0263  0.0452
         0.0697
 0.2107  0.2075  0.2901  0.2347  0.2600  0.2331  0.2086  0.2315  0.2245  0.2266  0.2033  0.2129  0.3698
         0.2308  0.2108  0.2094  0.2071  0.2044  0.2284  0.2058  0.2028  0.2034  0.2035  0.2017  0.2050
         0.2118
#ChesMMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         0.3025  0.2909  0.2853  0.2615  0.2577  0.2915  0.3175  0.2671  0.3483  0.2605  0.2800  0.2689
         0.2081
#NEAMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         -999    -999    -999    -999    -999    0.2586  0.2783  0.1507  0.2697  0.1477  0.2556  0.2384
         0.1125
#post-recruit survey time(s)
# NCDMF=0.46 (mid June); SEAMAP=0.83 (end of Oct); NMFS=0.75 (end of Sep); ChesMMAP=0.66 (beg of
Sep); NEAMAP=0.79 (mid Oct)
 0.46    0.83    0.75    0.66    0.79
###recruitment surveys AND CVs###
#Number of recruit surveys
 5
#first /last year in recruit surveys
#Note: if catch are different lengths of time, use -999. for missing values
# Therefore, this is min and max year for any data
 1989 2014
#Standardized (x/mu)
#Do all surveys as rows first, then all CVs as rows 2nd
#NCDMF Trawl Survey (Program 195; June, <120mm)
```

```
 0.505   2.022   0.657   0.177   1.114   0.195   0.096   0.872   0.4     0.314   1.375   0.279   0.517
         0.884   1.885   1.262   0.461   0.192   0.385   3.159   0.447   1.685   0.942   2.467   2.769
         0.937
#SEAMAP Trawl Survey (Fall)
 0.1918  0.2627  0.3704  0.1281  0.1500  1.2351  0.0719  0.5658  0.1010  0.1505  0.7167  0.0847  0.1527
         0.3398  0.7943  0.2174  9.2655  0.3094  0.1511  0.5208  0.7962  6.8526  0.6487  0.7748  0.6494
         0.4987
#NMFS Trawl Survey (Fall, NEAMAP Aggregate ALK)
 3.8123  0.6849  0.1366  0.0428  0.0258  1.2107  0.3357  0.2916  0.1243  0.0699  0.6070  0.2933  0.0005
         0.2169  0.1322  0.6477  1.6572  0.9031  0.6352  1.1398  1.3698  3.0071  2.4664  4.4506  1.6139
         0.1245
#ChesMMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         0.6630  0.7769  1.2951  1.7277  5.2776  0.7931  1.0832  0.2582  0.6741  0.0215  0.2060  0.1876
         0.0362
#NEAMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         -999    -999    -999    -999    -999    0.5228  1.3452  0.1634  0.5291  0.0938  5.0683  0.2195
         0.0580
#CV(i.e., index SE/mean index) - these value are converted to SE of log(index) within the model for the likelihood
function
#NCDMF Trawl Survey (Program 195; June, <120mm)
#0.1455  0.1159  0.1561  0.2103  0.1474  0.1689  0.2106  0.1216  0.1613  0.2354  0.2152  0.196   0.2223
         0.1318  0.1601  0.244   0.1601  0.1928  0.2424  0.2301  0.1822  0.1895  0.1477  0.1047  0.1697
         0.1437
 0.2473  0.2312  0.2537  0.2902  0.2484  0.2618  0.2904  0.2341  0.2569  0.3089  0.2938  0.2800  0.2990
         0.2395  0.2562  0.3155  0.2562  0.2778  0.3143  0.3049  0.2705  0.2755  0.2486  0.2257  0.2623
         0.2463
#SEAMAP Trawl Survey (Fall)
 0.3342  0.1849  0.1959  0.2480  0.4129  0.2547  0.1644  0.1751  0.2576  0.2084  0.3830  0.4089  0.2244
         0.2269  0.4688  0.2759  0.3407  0.1264  0.2627  0.5379  0.2732  0.3420  0.2156  0.1819  0.4163
         0.3872
#NMFS Trawl Survey (Fall, NEAMAP Aggregate ALK)
#0.0664  0.0553  0.2101  0.1228  0.1661  0.1197  0.0592  0.1165  0.1019  0.1065  0.0363  0.0730  0.3110
         0.1152  0.0666  0.0620  0.0538  0.0421  0.1104  0.0487  0.0333  0.0368  0.0374  0.0263  0.0452
         0.0697
 0.2107  0.2075  0.2901  0.2347  0.2600  0.2331  0.2086  0.2315  0.2245  0.2266  0.2033  0.2129  0.3698
         0.2308  0.2108  0.2094  0.2071  0.2044  0.2284  0.2058  0.2028  0.2034  0.2035  0.2017  0.2050
         0.2118
#ChesMMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         0.3025  0.2909  0.2853  0.2615  0.2577  0.2915  0.3175  0.2671  0.3483  0.2605  0.2800  0.2689
         0.2081
#NEAMAP Trawl Survey (Annual ALK)
 -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999    -999
         -999    -999    -999    -999    -999    0.2586  0.2783  0.1507  0.2697  0.1477  0.2556  0.2384
         0.1125
#Recruit survey time
# NCDMF=0.46 (mid June); SEAMAP=0.83 (end of Oct); NMFS=0.75 (end of Sep); ChesMMAP=0.66 (beg of
Sep); NEAMAP=0.79 (mid Oct)
#NOTE: now allows for recruit surveys that occur after fish become vulnerable to fisheries
#E.g., re_survey_est(r,i)=qr(r,i)*(R(r)*mfexp(-sr_time(r,i)*(Mt(1,y)+sel(1)*F(y))));
 0.46    0.83    0.75    0.66    0.79

##################################
#Fishery params
##################################
```

```
#Proportion of recreational harvest per region (from blue crab model, we have recreational removal estimates for
spot)
 .00
#Proportion under reporting per region
 0
#Max F
 10
#Max M
 4
#Ave Z prior
 1.356
#Ave Z CV (i.e., Z SE/mean Z) - this value is converted to SE of log(Z) within the model for the likelihood function
 .05

##################################
#Life History params
##################################
#Sex ratio
 .5
#Natural mortality per stage (1st = Recruits, 2nd = post-recruits)
 0.542    0.396
#Proportion spawning per stage (1st = Recruits, 2nd = post-recruits)
 0.215
 1
#Proportion of the time step before spawning occurs (0=start of year, 1=end of year)
 1
#Steepness for prior
 0.64
#sd for steepness prior (i.e., h SE/mean h) - this value is converted to SE of log(h) within the model for the
likelihood function
 0.20
#SR formulation (Bev Holt=1, Ricker=2)
 1
#First and last years of mean weights - added to allow for retrospective analysis
 1989 2014
#Mean weight per stage in kg (1st = Recruits, 2nd = post-recruits)
 0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801
          0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801   0.0801
          0.0801
 0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324
          0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324   0.1324
          0.1324
#Timing for SSB estimates in the model (0=start of year, 1=end of year)-should match timing of spawning as recruit
estimates are dependent on SSB estimates
 1
#Desired spawning stock units (1=numbers,2=biomass)
 2

##################################
#Environmental time series params/data
##################################
#Number of environmental time series
 1
#first / last year for the environmental time series
 1988 2014
#Environmental time series
```

```
 0 0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	0
#Environment series CV
 .1
#Time series which influences recruitment:
 1
#Lag in environment influence on recruitment (# time steps)
 1
#Time series that influences mortality (one for each stage):
 1 1
#Lag in enviro influence on mortality (one for each stage):
 0 0

##################################
#Projections time series
##################################
#Environmental time series annomolies for projection years +1 (+1 is for recruit calc)
#Note: must be same number of series as in environment section above with mean=0 (average)
#0 0 0 0 0 0 0 0 0 0 0
 0
#Effort Deviation from year before terminal yr (0) to FMSY (1)
#E.g., 0 .25 .5 .75 1 would be step increase from year before terminal yr F -> FMSY
#.25 .5 .75 1 1 1 1 1 1 1 1
 0

############################################################
############################################################
#Parameters and flags
# Format:
# 1st row: initial parameter estimates vector (or stage, e.g., selectivity)
# 2nd row: min bound, max bound, phase of estimatation
# note: if phase <0, then initial value will be held constant
############################################################
############################################################
##################################
#Initial values, bounds, and phase
##################################
#init_N (millions of fish)
 1000
 .01 50000 1
#init_R (millions of fish)
#Note: only used if the SR lag (in years) is >0
 1700
 .01 100000 1
################
# F params
################
## F=(q*Effort)*exp(Fdev) where 1st Fdev=0 so q scales to the initial year F
#F q
 1
 .00001 10 2
#F_dev
 1
 .1 5 5
#effort_cv (i.e., F_dev SE/mean F_dev) - this value is converted to SE of log(F_dev) within the model for the
likelihood function
 .2
```

```
 .01 1 -1
################
# Recruit params
################
#rec_dev (expected: log(rec_dev)=0 / rec_dev=1)
 1
 .001 40 4
#rec_cv (i.e., rec_dev SE/mean rec_dev) - this value is converted to SE of log(rec_dev) within the model for the
likelihood function
 .66
 .3 1 -1
#Stock Recruitment S0
#This value should be in the same units as the desired spawning stock units
 130000
 .1 1000000 3
#S-R steepness
 .79
 0.00001 0.99999 3
########
# Environment params
########
#sr_beta_env (environmental link parameter for recruitment: R=R*exp(sr_beta_env*env) )
 0
 -20 20 -3
#M_beta_env (environmental link parameter for yearly M: Mt=M*exp(M_beta_env*env) )
#note: one for each stage
 0 0
 -20 20 -3
#M_cv
 .1
 .3 1 -1
#Recruit sel (vulnerability)
 0.43
 0.1 1 -1
#Post-recruit sel (vulnerability)
 1.0
 0.1 1 -1

#################################
#Likelihood weights
#################################
#Landings weight lambda
 1.0
#post-recruit survey weight(s) lambda (one value for each)
 1.0 0.0 1.0 0.0 0.0
#Recruit survey weight(s) lambda (one value for each)
 1.0 0.0 1.0 0.0 0.0
#recruitment deviation weight lambda
 1.0
#effort residuals weight lambda
 0.0
#Z prior weight lambda
 1.0
#steepness prior weight lambda
 1.0
#################################
#Additional param control flags not addressed in data section
#################################
```

```
#Bias correction adjustment for predicted recruitment: biasAdj*(0.5*var)
#can turn off by setting=0 or turn on to whatever proportion by setting =1
 1
#################################
#Reference point calcs
#################################
#variables to control F for females used in reference point calculations
#FSPR_init FSPR_max FSPR_increment
 0 6.0 0.01
#SPR targets for calculating F reference points
#number of SPR targets
 5
#targets
 0.05 0.1 0.2 0.3 0.4
#################################
#EOF I/O test
#################################
#EOF number
 12345
```

Appendix 6. What Level of Spawning Potential Ratio (SPR) is a Good Proxy for Spot's MSY? A Report to the ASMFC Spot & Atlantic Croaker Stock Assessment Subcommittee.

Joseph Munyandorero: FWC/FWRI

Overview

When a stage-structured or an age-structured assessment model is completed, biological reference points (BRPs) such as the benchmarks based on the Maximum Sustainable Yield (MSY) should ideally be derived by combining the yield and spawner per-recruit and a spawner–recruit relationship (SRR; Shepherd 1982). Unfortunately, MSY-based prescriptions are seldom trustworthy, largely because they follow from unreliable and nonrobust SRRs. Therefore, BRPs based on age-, stage- or length-structured per-recruit models are often used as proxies of MSY-based BRPs, such F_{MSY}, for both data-rich stocks and data-limited stocks (NMFS 2011; Legault and Brooks 2013; Ault et al. 2008; Hordyk et al. 2015; Munyandorero 2015).

There is a large body of literature on BRPs that are purportedly suitable for precautionary management in terms of either Threshold or Limit Reference Points (LRPs) or Target Reference Points, TRPs (e.g., see Caddy and Mahon 1995; Caddy 1998; Gabriel and Mace 1999; McKown et al. 2008 for reviews). BRPs derived on a cohort or year-class basis typically employ yield per-recruit (YPR) criteria (F_{max}, a fishing mortality maximizing the YPR; and $F_{0.1}$, a fishing mortality at which the marginal increase in YPR is 10% of the marginal increase in YPR when $F = 0$) or spawner per-recruit considerations [typically $F_{x\%}$, a fishing mortality associated with x% (e.g., 40%) of the unfished spawner per-recruit]. The harvest control rules based on them vary according to fisheries jurisdictions (e.g., Caddy 1998). On the U.S. East Coast, Munyandorero (2015) noted that $F_{40\%}$ or $F_{35\%}$ in the US mid-Atlantic and Northeast Atlantic and $F_{15\%}$–$F_{30\%}$ or F_{max} in the US south Atlantic and Gulf of Mexico, have been preferred, respectively, as F_{MSY} proxies. Perhaps that McKown et al.' s (2008) report is the BRPs guideline for the ASMFC managed species.

Since the 1980's, the SRRs became the theoretical basis for BRP derivations in data-rich jurisdictions, but those SRRs are unfortunately unknown or poorly estimated (Fig. A2.1). This is the reason why research in the 1990's especially in the U.S.A focused on combining spawner per-recruit analyses and analyses of (assessment-generated or simulated) stock–recruit data to identify a spawning potential ratio, SPR (i.e., the ratio of the fished spawner per-recruit to the unfished spawner per-recruit), that could be associated with an F level approximating F_{MSY} (Clark 1991, 1993; Goodyear 1993; Mace and Sissenwine 1993; Mace 1994). According to Clark (2002), an ideal SPR target should be devised such that the spawning stock biomass is maintained at a sustainable level, while still providing a reasonable level of catch, perhaps in the form of MSY (Fig. A2.2). Based on these studies, it is generally accepted that:

- A SPR of 35–40% is sustainable for most species (Clark 1993, 2002; Mace and Sissenwine 1993; Mace 1994).
- A SPR of 35–40% may, however, be risk-adverse for species thought to be long-lived and less resilient to fishing (generally with low natural mortality rate M), so a SPR of 50–60% may be appropriate for them (Clark 2002).
- A SPR of 20% may be considered a recruitment-based LRP for average-to-high resilient species (usually short- and moderate-lived species, with moderate-to-high M) and, for little

known stocks, the LRP shout be set at 30% of the unfished spawner per-recruit (Caddy and Mahon 1995).

Case of Spot

Probably that spot is a short-lived species and, therefore, falls into the category of species for which an LRP should be a SPR of 20%. However, this SPR may be risk-adverse, because the corresponding $F_{20\%}$ may be high. For precautionary principle, an LPR between 30 and 40% may be a good option.

Another aspect to be considered relates to the type of "spawner" per-recruit analysis to be used for the LPR derivation. As indicated above, a spawner per-recruit analysis can be age-structured, stage-structured or length-structured and each approach may employ egg production or mass variables. For a given species, each of these analysis combinations may lead to different $F_{x\%}$ (say $F_{40\%}$). In any case, when a full assessment model is conducted, an LPR should be consistent with that model. This is the reason why a composite (i.e., stage-structured) spawning stock per-recruit analysis is recommended (see Munyandorero 2015). The CSA has that flexibility.

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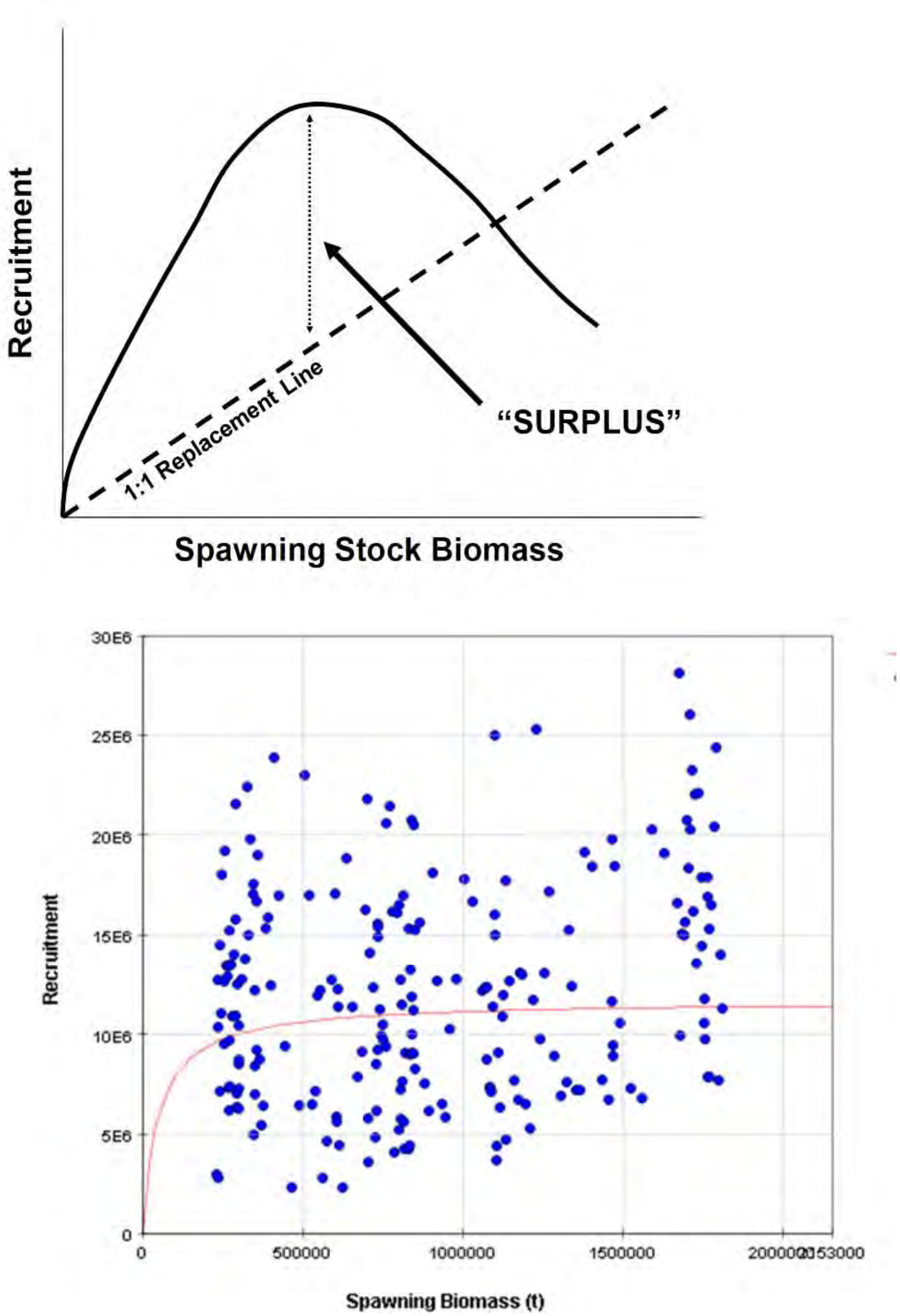

Fig. A2.1 – Theory (top) and reality (bottom) of stock – recruit relationships and stock productivity.

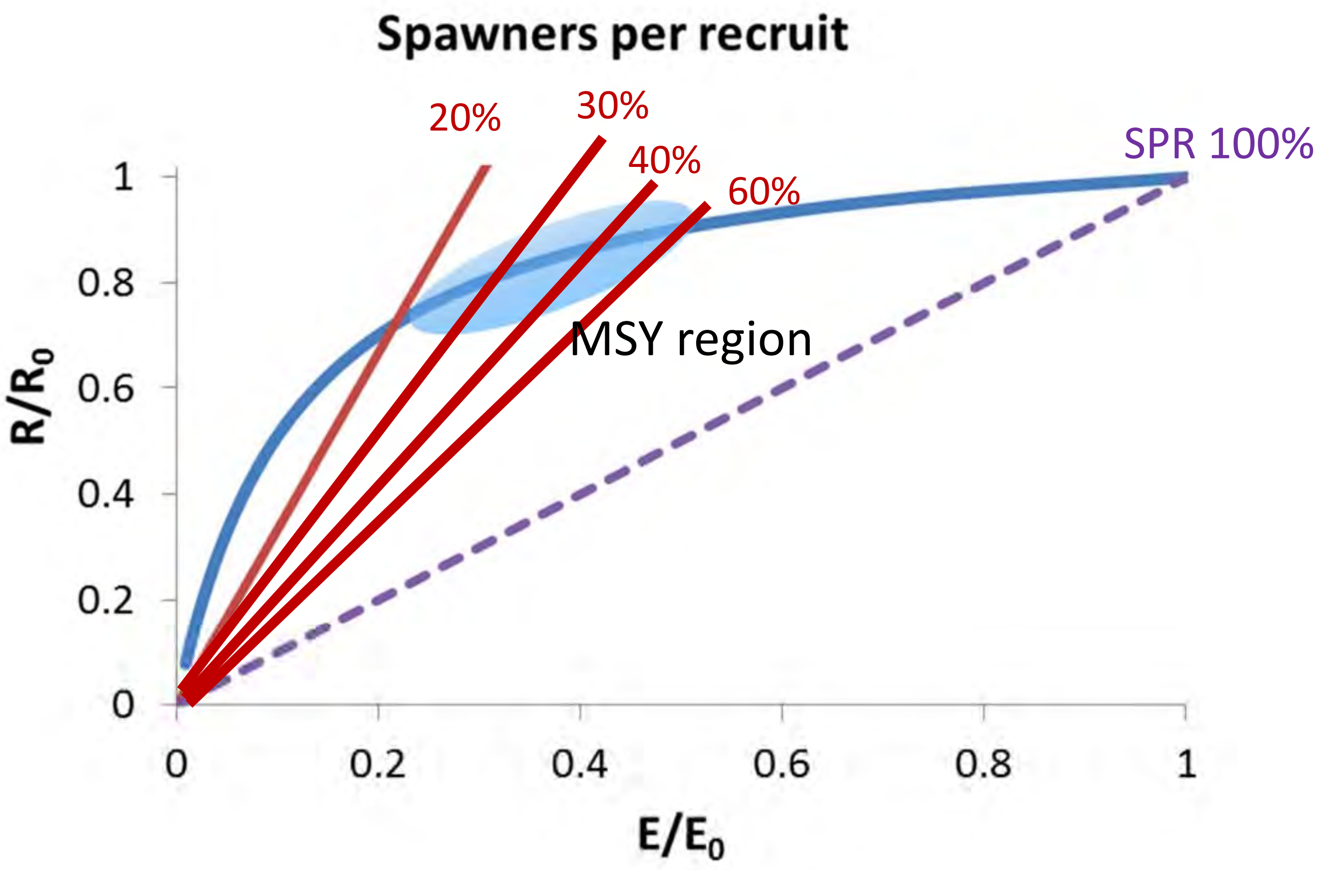

Fig. A2.2 – Theoretical representations of SPR levels for different life-history patterns.

Appendix 7. Selectivity of Age Zero Spot

The proportion of age zero spot available to removal sources was determined by comparing the length frequencies of spot from the removals to the length frequency of age zero spot from fishery independent samples. Only fishery independent lengths from specimens that were determined to be age zero using otolith ages were included in the analysis. All lengths were converted to total length in millimeters where necessary, and length frequencies were constructed using 5mm length bins. Removal types included commercial haul seines, commercial trawls, commercial gill nets, commercial fixed nets, commercial other gear, recreational harvest, recreational release discards, shrimp trawl discards, finfish trawl discards and finfish gill net discards. The length group at which the upper 95% of the removal length frequency remained was used as the cut off value for comparison to the fishery independent age zero length frequency. This was done to eliminate lengths at which incidental catch occurs, but the vast majority of spot at those lengths would not be selected by the gear.

In the first several months of the year, age zero spot are small enough to avoid capture in fishery independent gear, as indicated by 97% of age zero spot being sampled from July through December. The percentage of reported or estimated removals occurring July through December were 70% for the shrimp trawl discards, 91% for combined commercial landings and 90% for recreational harvest. These three removal categories represent 99.6% of total removals. The vast majority of shrimp trawl discards prior to July are likely age one, based on the monthly length frequency distribution.

The selectivity was calculated using length frequencies from July through December combined and dividing this value in half. This assumes age zero spot are not available in the first half of the year. The SAS acknowledges that a very small percentage of age zero spot are selected in the first half of the year. However, it is highly likely a small percentage of age zero spot are not recruited to the fishery independent gears during the July through December timeframe, leading to a slight over estimate of age zero selectivity. The assumption is that these two small errors are equal and offsetting, result in a reliable estimate of the proportion of age zero spot removed by the various fisheries.

Selectivity was calculated for each removal type, and weighted against the average landings from 1994-2014 by removal type. These years represented a timeframe in which removal estimates in numbers were available for all removal types by gear. The weighted portions by removal type were summed to generate a total selectivity from July through December of 0.86. This value was dived by two, yielding an annual age zero spot selectivity value of 0.43.

Cutoff length group in mm, number of lengths, average annual removals in numbers, percentage of total landings and proportion of age zero spot selected by removal type.

	July Through December				July Through December
Removal Type	95% Length Group Cutoff	Number of Lengths	Average Removals	Percentage of Total	Proportion of Age Zero Spot Selected
Commercial Haul Seines	180	20,338	4,012,154	2.70%	0.2528
Commercial Gill Nets	210	78,475	8,045,291	5.41%	0.0290
Commercial Trawls	135	934	518,254	0.35%	0.7303
Commercial Fixed Nets	185	24,005	801,017	0.54%	0.1891
Commercial Other	190	309	207,236	0.14%	0.5390
Shrimp Trawl Discards	90	26,705	124,942,995	84.08%	0.9767
Recreational Landings	170	83,101	9,461,346	6.37%	0.3753
Recreational Discards	110	2,246	528,692	0.36%	0.9226
Finfish Trawl Discards	125	64	75,577	0.05%	0.8258
Finfish Gill Net Discards	225	973	10,062	0.01%	0.0050

Appendix 8. Catch Curve Analysis of Spot for 2017 Stock Assessment

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Catch curve analysis was used to estimate total annual mortality of spot for fishery dependent, fishery independent and the combined data sets where direct age and length data was available. In addition, separate catch curve analysis was also run on model index data from SEAMAP, NEFSC (NMFS) and MRIP using age length keys to convert available length data to age composition data. The catch curve analysis for the MRIP data was performed using the age length key from the fishery dependent data to convert annual length frequency distributions to annual age distributions. Catch curve analysis for SEAMAP and NEFSC were estimated using coastwide ALK'S within each year. The annual total mortality estimates for each data permutation can be seen in Table X. The time period used covered 1996 through 2014 as this represented years where age data was present in the most data sets.

Table A1.1 Estimated annual total mortality from catch curve analysis by data set or type for spot on the Atlantic coast of the United States. *Total number for SEAMAP, NEFSC, and MRIP were based on length frequency expansions of total number with age distributions estimated using age length key conversions.

Year	SEAMAP Z	NEFSC Z	MRIP Z	Fishery Independent	Fishery Dependent	All Data Combined
1996	2.715	2.030	2.133	1.179	1.204	1.379
1997	4.227	1.579	1.396	1.156	1.098	1.303
1998	2.912	1.698	1.305	1.048	1.088	1.237
1999	3.209	2.208	1.511	1.111	1.231	1.339
2000	3.353	2.130	1.754	1.248	1.209	1.401
2001	3.581	2.180	1.860	1.431	1.287	1.527
2002	3.087	2.179	2.065	1.318	1.158	1.370
2003	3.182	1.892	1.679	1.223	1.111	1.298
2004	3.992	2.284	1.806	1.100	0.911	1.071
2005	2.789	2.411	1.457	1.197	0.977	1.139
2006	3.101	2.435	1.820	1.211	1.114	1.303
2007	2.730	2.378	2.284	1.272	1.151	1.331
2008	4.321	2.409	2.678	1.319	1.214	1.445
2009	3.170	2.497	2.433	1.284	1.291	1.466
2010	3.285	2.471	2.342	1.315	1.284	1.464
2011	3.480	2.736	3.507	1.384	1.163	1.467
2012	2.722	2.913	1.482	1.162	1.258	1.385
2013	2.570	2.545	3.548	1.404	1.082	1.478
2014	2.823	2.150	2.244	0.954	1.259	1.328
Z-Range	2.57 - 4.32	1.57 - 2.91	1.31 – 3.55	0.95 -1.43	0.91 – 1.29	1.07 – 1.53
COV	0.305	0.190	0.282	0.098	0.122	0.146
Mean	3.224	2.271	2.069	1.227	1.163	1.354
Median	3.445	2.240	2.43	1.190	1.10	1.30
Age Range	0-4	0-6	0-6	0-6	0-6	0-6
Number	*817,871	*83,440	*138,548,315	9,870	12,460	22,593

In the fishery independent data sets, SEAMAP data had higher Z values than the NEFSC and MRIP data due to a smaller age range (0-4) found in this data set (Figure X.1). Annual Z values were significantly different between SEAMAP and MRIP (paired t-test, P_{MRIP} =0.339) but not with NEFSC (paired t-test, $P_{NEFSC} < 0.001$). The NEFSC and MRIP estimates had similar trends except for two large peaks in the MRIP data in 2011 and 2013 and were not significantly different (pair t-test, P = 0.143).. The peaks in the Z estimate for MRIP in 2011 and 2013 was likely due to the lack of ages 5 and 6 in the age range for those two years.

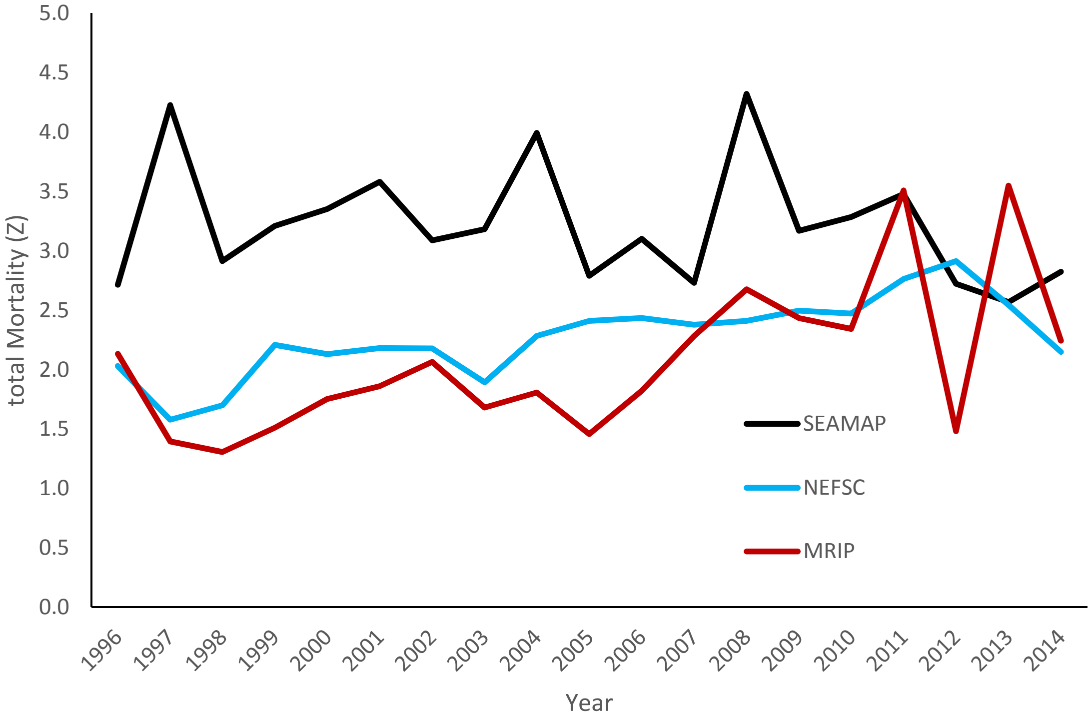

Figure A1.1 Estimated annual total mortality by data set (SEAMAP, NEFSC, MRIP) for spot on the Atlantic coast of the U.S. from assessment data.

The full fishery independent age data set (which also included age data from ChesMMAP, NEAMAP, FWC, and NCDMF) had lower range and mean value than the fishery dependent and full combined age data sets (Table A1.1). Annual trends were very similar across the FI, FD and combined data sets (Figure A1.2), with the mean values and range of Z for the combined data set higher than either the FI or FD data. The annual Z values for FI and FD were not significantly different (paired t-test, $P = 0.068$), so the combined data set was used to set the Z prior levels in the CSA model. However, because there was a significant difference in annual Z values between the combined data with both FI ($P < 0.001$) and FD ($P < 0.001$), separate sensitivity runs were made in the CSA model using the FI and FD values to determine if it effected the model.

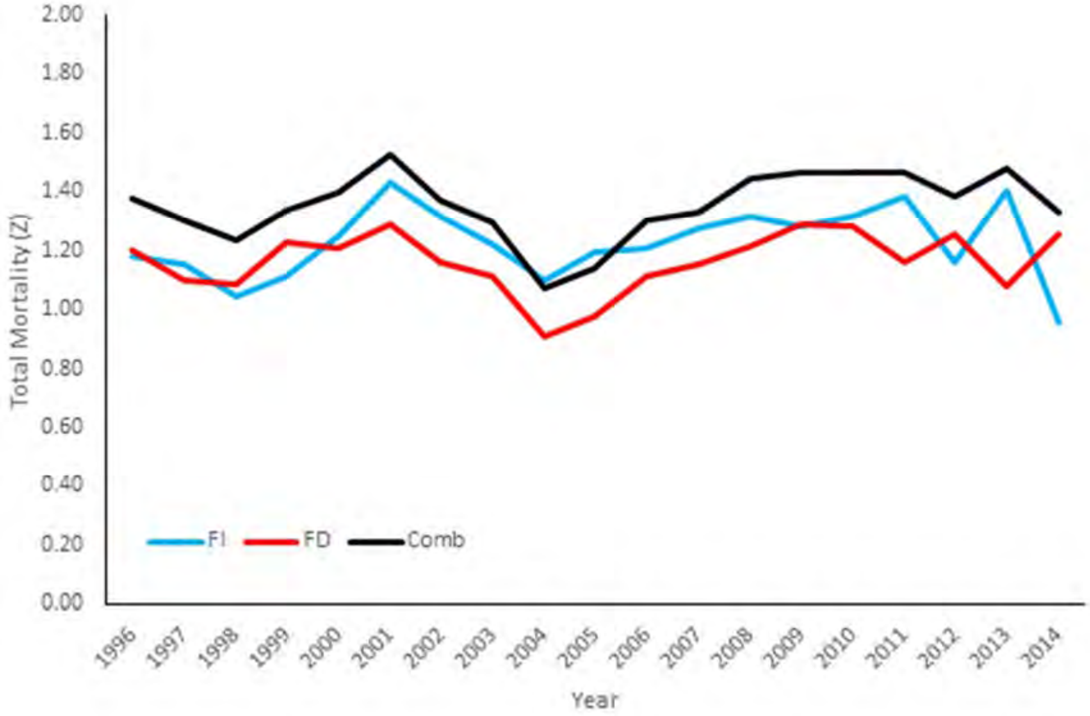

Figure A1.2 Estimated annual total mortality by data type (fishery independent, fishery dependent, combined) for spot on the Atlantic coast of the U.S. from available assessment age data.

Appendix 9. Prior distributions of stock–recruit steepness for the Atlantic croaker (*Micropogonias undulatus*) and Spot (*Leiostomus xanthurus*) populations in the U.S. Atlantic Ocean

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Abstract: The stock–recruit steepness is difficult to estimate. Estimation difficulties are often reduced upon fixing steepness at a "reasonable" value or assigning it a prior distribution. This contribution is devoted to the development of steepness prior distributions for Atlantic croaker and spot inhabiting the U.S. Atlantic coast. To this end, a relationship between slopes at the origin of stock–recruit curves (α) and asymptotic sizes is constructed to infer the plausible values of α, which in turn are combined with species-specific unfished spawning biomass per-recruit (Φ_0). Monte Carlo (MC) simulations are used to propagate uncertainty in growth parameters into natural mortality, Φ_0 and steepness. Under assumptions of Beverton–Holt stock–recruit dynamics, median steepness is 0.78 (80% probable range: 0.68–0.84, mean = 0.76 and mode = 0.79) for Atlantic croaker and 0.66 (80% probable range: 0.33–0.89, mean = 0.64 and mode = 0.79) for spot. If Ricker stock–recruit relationships were assumed, mean and median steepness are 1.68 (80% probable range: 1.1–2.25, mode = 1.78) for Atlantic croaker; for spot, median steepness is 1.58 (80% probable range: 0.35–3.28, mean = 1.03 and mode = 0.52). Two-parameter beta functions are fitted to empirical distributions of the Beverton–Holt stock–recruit steepness for both species. A normal function and a gamma function appear appropriate for fitting the Ricker stock–recruit steepness of Atlantic croaker and spot, respectively. The previous tendency statistics or probable ranges of steepness can guide its estimation. Alternatively, the fitted parameters can be used to select parametric prior for stock–recruit steepness of Atlantic croaker and spot.

Introduction

Contemporary assessments and management of data-rich stocks largely infer from stock–recruit relationships (SRRs). Inferences are made at two levels. First, assessment models include stock-recruit functions designed to govern the recruitment production. Second, nominally sustainable levels (i.e., maximum sustainable yield (MSY)-based benchmarks) and the determination of stock status in principle follow from the combination of (reliable) SRR and per-recruit models (Shepherd, 1982).

Since about the mid-1980s, data-rich stock assessments focused on recasting the stock–recruitment parameters (i.e., maximum recruits per spawner as spawner abundance approaches zero and the degree of compensation) in terms of "steepness" (*h*; i.e., the fraction of the unexploited recruitment produced by 20% of the unexploited parental stock). This move was adopted because the definition of *h* was considered biologically meaningful (Hilborn and Mangel, 1997; Haddon, 2001). The previous definition of steepness and related biological and management interpretations are, however, intelligible for and suited to the Bevertion–Holt SRR (BH–SRR). They are difficult to comprehend for other SRRs.

Steepness measures the degree of dependence of average recruitment on the parental stock. For the BH–SRR, it reflects the stock's productivity, whereby its higher values are thought to be associated with highly productive populations, especially at lower density (Beddington and Kirkwood, 2005; Lee et al., 2012; Maunder, 2012; Shertzer and Conn, 2012). In those cases, the stocks are considered to be resilient to harvest. In theory, therefore, intense exploitation and growth-overfishing associated with higher steepness would not affect recruitment or lead to recruitment-overfishing!

Unfortunately, steepness is difficult to estimate. Estimation difficulties arise from reasons such as changes of steepness over time, uninformative fishery data, large fluctuations in recruitment at low stock size, and lack of contrast (i.e., how well the possible range is covered) for the stock–recruit data (Walters and Martell, 2004; Conn et al., 2010; Shertzer and Conn, 2012). For example, in most assessments involving the BH–SRR where steepness is bounded between 0.2 and 1.0, the steepness estimates tend to hit the upper bound irrespective of whether the stock is or is not productive (e.g., Conn et al., 2010; Lee et al., 2012).

Strategies commonly adopted to reduce the estimation difficulties of steepness include: (i) fixing *h* to an assumed "reasonable" value in a base-model run and conduct sensitivity runs involving alternative values of *h*; (ii) constraining *h* between selected lower and upper bounds (e.g., Conn et al., 2010; Anonymous, 2011; Rademeyer et al., 2012); or (iii) developing a prior distribution (penalty function in a maximum likelihood context) for *h*. The first strategy, along with a fixed natural mortality rate (*M*), fixes biological reference points, BRPs (Mangel et al., 2013). The second strategy basically is a uniform distribution for *h*, a "reasonable" estimate of which depends on information contained in fishery data and on possible contrasts that the spawning stock may have exhibited. The third strategy relies on met-population analyses (Myers et al., 1999, 2002; Rose et al., 2001; Shertzer and Conn, 2012; Punt and Dorn, 2014), persistence principles (He et al., 2006), or uncertainty in reproductive and life history parameters (Mangel et al., 2010; Simon et al., 2012; Brodziak et al., 2015). This strategy is somewhat similar to the first strategy when *M* is fixed, but differ from it in that: (i) given a long and comprehensive time series of fishery data and variable spawning stock, the prior distribution of *h* can be updated, usually through Bayes' rule, into a posterior distribution; and (ii) the resulting BRPs have distributions.

For the current benchmark assessments of the Atlantic croaker (*Micropogonias undulatus*) and spot (*Leiostomus xanthurus*) stocks in the U.S. Atlantic coast, this note aims to construct plausible prior distributions for stock–recruit steepness of the stocks in question. Analyses combine: (i) the relationship between published stock productivity levels at low stock size and asymptotic lengths; (ii) species-specific parameters on growth and maturity/fecundity (the estimation of *M* follows from a nonlinear empirical equation in Then et al., 2015); and (iii) the unfished spawning biomass (or number of eggs) per-recruit (Φ_0).

Materials and methods

Basic parameters, relationships and assumptions

The construction of prior distributions of the stock–recruit steepness (*h*) for Atlantic croaker and spot relies on two main characteristics. First, the slopes at the origin of spawner-recruit curves (α, the maximum recruits per-spawner at lower spawner abundance) is negatively and significantly related to the parameters L_∞ and W_∞ of the von Bertlanffy growth (VBG) equation (Denney et al., 2002; Goodwin et al., 2006; Hall et al, 2006). Therefore, given species-specific values of L_∞ and longevity or W_∞ falling in the range of meta-analytic relationships $\alpha \sim L_\infty$ or $\alpha \sim W_\infty$, plausible species-specific values of α can be estimated. Second, the definition of *h* reduces to a nonlinear function *h* of α and the unfished spawning biomass (or number of eggs) per-recruit (Φ_0): $h = f(\alpha, \Phi_0)$ (Mangel et al., 2010, 2013 and references therein).

The previous aspects are accounted for by compiling estimates of α, L_∞, and Φ_0 that have preferably been estimated and published simultaneously. Otherwise, when only α is available, L_∞ values are compiled from various sources including FishBase (http://fishbase.org). Most α values were estimated employing the Ricker SRR (R–SRR)—Myers et al. (1999, 2002) argue that at the limit of small population size, the BH–SRR and R–SRR coincide, having the same α, although they produce different estimates of α once fitted to the same data (Michielsens and McAllister, 2004; Forrest et al., 2010; Galindo-Cortes et al., 2010). In this note, all compiled α values are used irrespective of the standard BH–SRR or standard R–SRR they were derived with, provided the BH–SRR was of the form similar to the equation used below for defining steepness. Furthermore, α estimates for the BH–SRR are preferred over those for R–SRR if they are available for the same stock. The relationship between α and L_∞ is (Fig. 1a, b; $r^2 = 0.67$, $P < 0.001$):

$$\alpha = 856213.7L_\infty^{-2.9393} \quad (1)$$

The VBG parameters (L_∞, K year^{-1}, and age_0 (years)) and the length–growth scales (a) and exponents (b) for females of Atlantic croaker[1] include those in ASMFC (2010a) and those that have been updated during this assessment benchmark. The growth parameters for females of spot are available during this assessment benchmark only, so they also include those values that have been estimated for both sexes in ASMFC (2010b). Estimated growth parameters are treated as “observed data.” Then, the variability in these parameters is considered reflective of scientific uncertainty, but note that the majority of them are linearly and significantly related (Fig. 1c–h). No unique combination made up of each point estimate from their respective sets is preferred *a priori* over other combinations in calculating composite life history metrics, such as M and Φ_0.

Characterizing uncertainty through random samples of growth parameters

Because at least two sets of the observed growth parameters are linearly and significantly related (Fig. 1c–h), the VBG parameters on the one hand, and the length-weight scales and exponents on the other, are jointly simulated as multivariate normal distributions given their empirical mean vectors and covariance matrices. Sampling is performed (number of iterations n = 10000) with the R package MASS (Venables and Ripley, 2002). (A different sampling scheme such as Monte Carlo (MC) simulations assuming uniform distributions would be appropriate if the previous pairs of growth parameters were not linearly related). Except for Atlantic croaker’s parameter age_0 versus L_∞, stochastic realizations of various growth parameters are expectedly related linearly (Fig. 2a–h). In particular, isopleths have the highest probability density at about (L_∞, K) = (42 cm, 0.2 year^{-1}) and (a, b) = (0.015, 3.0) for Atlantic croaker and at bout (L_∞, K) = (370 mm, 0.35 year^{-1}) and (a, b) = (3.5×10^{-5}, 3.0) for spot.

During the sampling, some iterations can yield negative values for the parameter a and positive values for the parameter age_0. Such random draws are conducive, respectively, to negative mean weights and negative mean lengths at age-0, which are unfeasible. It is therefore necessary to subset the initial iterations, only keeping draws of L_∞, K, and b associated with positive values of a and negative values of age_0. The number of kept draws is denoted $n+$ and, for each of them, the following quantities are derived or calculated through MC simulations.

Natural mortality

Constant M (Figs. 3a, b) is estimated using the Pauly’s nonlinear empirical equation (Then et al., 2015):

$$M = 4.118K^{0.73}L_\infty^{-0.33} \quad (2a)$$

(Hoenig’s updated nonlinear empirical equation can also be used, on the basis of maximum ages that individual studies have recorded). Natural mortality at age (M_{age}) follows from Lorenzen’s

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[1] The triplets (L_∞, K, age_0) equal to (85.4, 0.0638, −0.0016) and (64.5, 0.2, −3.06) are excluded because they appear to be outliers.

(2000, 2005) natural survival equation at age (S_{age}) for the VBG function (L_∞ is treated as reference length and M relates to L_∞):

$$S_{age} = \left[\frac{L_{age}}{L_{age}+L_\infty(e^K-1)}\right]^{\frac{M}{K}} \tag{2b}$$

where L_{age} is mean length at age estimated with the VBG equation. It follows that $M_{age} = -\log(s_{age})$:

$$M_{age} = \frac{M}{K}\log\left[1+\frac{L_\infty}{L_{age}}(e^K-1)\right] \tag{2c}$$

Figures 3c, d show levels (medians and empirical 95% confidence intervals) and trajectories of natural mortality at age.

Mean weights

The asymptotic weight (W_∞) is given by:

$$W_\infty = aL_\infty{}^{b} \tag{3a}$$

Mean weight at age (W_{age}) is calculated as:

$$W_{age} = W_\infty\{1 - \exp[-K(age - age_0)]\}^{b} \tag{3b}$$

The unfished spawning stock biomass per-recruit (SSBR)

The unfished SSBR at age (starting from age-0) for females ($\psi_{age.F=0}$) is calculated as:

$$\Psi_{ageF=0} = l_{age}sr_{age}W_{age}\mu_{age}\frac{\sum_{m=1}^{12}\pi_m exp(-\varphi_m M_{age})}{\sum_{m=1}^{12}\pi_m} \tag{4}$$

where sr_{age} is the sex-ratio at age; μ_{age} is the probability mature at age; π_m is the monthly proportion of spawning-capable females; φ_m is the fraction of the year elapsed at the beginning of the spawning month m (calculated assuming that natural mortality by age is uniformly distributed over the year; by convention, φ_1 for the month of January is zero, $\varphi_2 = 1/12$ for the month of February consistent with the elapsed month of January, and so on); and l_{age} is the unfished survivorship to a given age (note: at age-0, $l_{age} = 1$): $l_{age} = l_{age-1}\, exp(-M_{age-1}) = exp(-\sum_0 M_{age-1})$. Figures 3e, f describe the estimated l_a levels and trajectories.

The sex-ratios and probability mature ate age (s_{age}, μ_{age}) as well as the vector φ_m used in Eq. (4) were developed during this assessment benchmarks. Together with the vector π_m, they are treated as deterministic.

The total unfished SBPR (Φ_0) is given by:

$$\Phi_0 = \sum_{age=0}^{T_{max}}\Psi_{ageF=0} \tag{5}$$

where T_{max} is maximum observed age (17 years for Atlantic croaker, 6 years for spot).

Calculating the steepness parameter

The BH–SRR and R–SRR are commonly used in stock assessment models of population dynamics. Here, the steepness (h) is calculated on the ground that its definition relies on a BH–SRR of the form $R = \alpha S/(1 + \beta S)$, where R is recruitment, S is spawning stock biomass producing R, and α and β are parameters[2]:

$$h = a\Phi_0/(4 + a\Phi_0\,) \tag{6a}$$

If there is evidence for mechanisms supporting the R–SRR, $R = \alpha S\exp(-\beta S)$, then

$$h = 0.2(a\Phi_0\,)^{0.8} \tag{6b}$$

---

[2] If the steepness were defined based on BH–SRRs of the forms $R = \alpha S/(\beta + S)$ and $R = S/(\alpha + \beta S)$, h would be expressed as $h = \alpha\Phi_0/(4\beta + \alpha\Phi_0)$ and $h = \Phi_0/(4\alpha + \Phi_0)$, respectively.

The quantity $\alpha\Phi_0$ is the maximum lifetime reproductive rate at low density (Myers et al., 1999, 2002), i.e., the number of recruits produced by a recruit over its lifespan in the absence of fishing (Brooks et al., 2010). It corresponds to the Goodyear (1977, 1980) compensation ratio and is related to steepness (Walters and Martell, 2004; Martell et al. 2008; Brooks et al., 2010; Fig. 4).

Some properties and estimation considerations of the steepness

The range of h is [0.2, 1) for the BH–SRR and [0.2, ∞) for the R–SRR; its domain (i.e., values of $\alpha\Phi_0$) is [1, ∞). The variation of h against $\alpha\Phi_0$ (Fig. 4) indicates that, for the BH–SRR for example, (i) $h = 0.5$ when $\alpha\Phi_0 = 4$; (ii) for $\alpha\Phi_0 > 4$, $h > 0.5$ (e.g., $h = 0.75$ if $\alpha\Phi_0 = 12$ and $h = 0.95$ if $\alpha\Phi_0 = 76$), but $h < 1$ because $\alpha\Phi_0 < 4 + \alpha\Phi_0$ (i.e., 1 should never upper-bound h); and (iii) for $\alpha\Phi_0 < 4$, $h < 0.5$ and $h = 0.2$ when $\alpha\Phi_0 = 1$.

Although the steepness is dimensionless and is considered a tool for comparison across species (e.g., Beddington and Kirkwood, 2005; Kell et al. 2013, Rossberg et al., 2013), the units chosen to calculate Φ_0 influence its magnitude. For example, given α in number of recruits per spawning biomass, values of h based on Φ_0 in g would be higher than those that would be based on Φ_0 in kg. For the BH–SRR in particular, it may be useful to develop Φ_0 with a unit in such a way that the order of magnitude for the $\alpha\Phi_0$ value is comparable with 4 on the denominator (typical values of $\alpha\Phi_0$ are single-digit and double-digit numbers; Figs. 4). For Φ_0 calculated as SSBR, as is here, use of kg is deemed appropriate and is recommended to facilitate comparisons among life histories. The previous remarks suggest that comparison of species of different life histories on the basis of the stock–recruit steepness make sense when their Φ_0 is in the same unit.

Estimating parameters of prior distributions for steepness

The R ExtDist package is used to estimate the parameters that provide the maximum likelihood fit to the empirical steepness distributions as obtained from MC simulations. Specifically, the fitted probability density functions (pdfs) are: (i) the two-parameter beta pdf for the BH–SRR steepness, and (ii) the normal or gamma pdf for the R–SRR steepness.

The forms of the fitted normal, gamma, and two-parameter beta pdfs are, respectively:

$$f(h) = \frac{e^{-\frac{(h-\mu_h)}{\sigma^2}}}{2\sqrt{2\pi}} \qquad (7a)$$

$$f(h) = \frac{h^{p-1}e^{-\frac{h}{\theta}}}{\Gamma(p)\theta^p} \qquad (7b)$$

$$f(h) = \frac{\Gamma(p+q)}{\Gamma p \Gamma q} h^{p-1}(1-h)^{q-1} \qquad (7c)$$

The parameters are the mean μ_h and the standard deviation σ (> 0) for the normal pdf, the shape p (> 0) and the scale θ (> 0) for the gamma pdf, and the shape parameters p and q (> 0) for the two-parameter beta pdf. The mean and variance are given by $p\theta$ and $p\theta^2$ for the gamma pdf and, for the two-parameter beta pdf, by $p/(p + q)$ and $pq/[(p + q)^2(p + q + 1)]$, respectively.

Results

The distributions of the BH–SRR steepness are left skewed for both the Atlantic croaker and Spot (Fig. 5a, b) with MC sample medians of 0.78 (80% probable range: 0.68–0.84) and 0.66 (80% probable range: 0.33–0.89), respectively. The MC sample mean of the BH–SRR steepness is 0.76 (CV = 0.11) for Atlantic croaker and 0.64 (CV = 0.32) for spot.

The parameters of the fitted beta density (Fig. 5a, b) are p = 22.07 (standard error, SE = 0.324) and q = 6.93 (SE = 0.099) for Atlantic croak and p = 3.05 (SE = 0.05) and q = 1.73 (SE = 0.027) for spot.

The R–SRR steepness for Atlantic croaker is normally distributed (Fig. 5c) with an MC sample mean of 1.68 (CV = 0.28; 80% probable range: 1.1–2.25). For spot, the R–SRR steepness is right skewed (Fig. 5d), with an MC sample median of 1.03 and an MC sample mean of 1.58 (80% probable range: 0.35–3.28). The fitting of a gamma pdf to the MC sampled data for this distribution produces p = 1.42 and θ = 0.91 (mean = 0.61; standard deviation = 0.27).

Shertzer and Conn (2012) argue that, if data are informative, "a prior distribution (for steepness) informs the estimation process in that the best estimate occurs at the mode." If so, the modes of the BH–SRR steepness are 0.79 for both Atlantic croaker and spot. The modes of the R–SRR steepness for these species, respectively, are 1.78 and 0.52.

Discussion

This note builds upon a relationship that exits between the slopes at the origin of stock–recruit curves (α) and asymptotic lengths (L_∞). Empirical inferences of α for Atlantic croaker and spot are then made on the ground that their L_∞ values are in the range of the aforementioned relationship. Finally, the calculated α values are combined with the species-specific unexploited spawning biomass per-recruit (Φ_0) to develop the corresponding stock–recruit steepness. The construction of empirical distributions of steepness is made possible through: (i) Monte Carlo simulations of growth parameters, (ii) calculations of constant M using the realized L_∞ and K, and (iii) the propagation of uncertainty in L_∞, K, constant M and length-weight parameters into M-at-length and Φ_0. Therefore, contrary to fully meta-analytic approaches (Myers et al., 1999, 2002; Rose et al., 2001; Shertzer and Conn, 2012; Punt and Dorn, 2014) and methods exclusively based on reproductive and life history parameters (Mangel et al., 2010; Simon et al., 2012; Brodziak et al., 2015), the methodology used here combines results on α and L_∞ gained from other stocks and life history parameters of the species of interest. As such, the proposed approach is hybrid.

Apart from the relationship α ~ L_∞ (which may change depending on the selected pairs), a key step to estimating the steepness is the calculation of Φ_0 (Eq. (5)). Here, a calculation methodology is proposed to account for the protracted nature of the spawning activity for Atlantic croaker and Spot. However, because the incorporation of the reproductive dynamics into equilibrium per-recruit models is challenging, Eq. (4) attempts to address the protracted spawning season through a weighted average of monthly survival rates (i.e., $\frac{\sum_{m=1}^{12}\pi_m exp(-\varphi_m M_{age})}{\sum_{m=1}^{12}\pi_m}$) themselves based on φ_m values; the weights are monthly proportions of spawning-capable females. Such a procedure implies simplifying assumptions that all age-specific schedules are conserved each month and that females in a cohort can survive at the beginning of any month of a year but spawn only during a single month.

The previous weighting of monthly survival rates is flexible in that it can accommodate various configurations depending on species-specific reproductive dynamics in a year. For example, the proportion π_m should simply be set to zero in months during which a species is reproductively inactive. In that case, the resting months would weigh nothing. At another extreme, π_m would equal one if females reproducing in each month all were spawning-capable (the denominator = 12). It is of note that Gabriel et al.'s (1989) equation, applicable for a single month of peak spawning assuming (π_m = 1), is a special case of Eq. (4).

Parametric density functions (normal, gamma, and beta) for steepness are fitted to the empirical steepness distributions to the estimate their parameters. It is anticipated that the fitted parameters can be used to select parametric prior for stock–recruit steepness of Atlantic croaker and spot assuming either the BH–SRR or the R–SRR.

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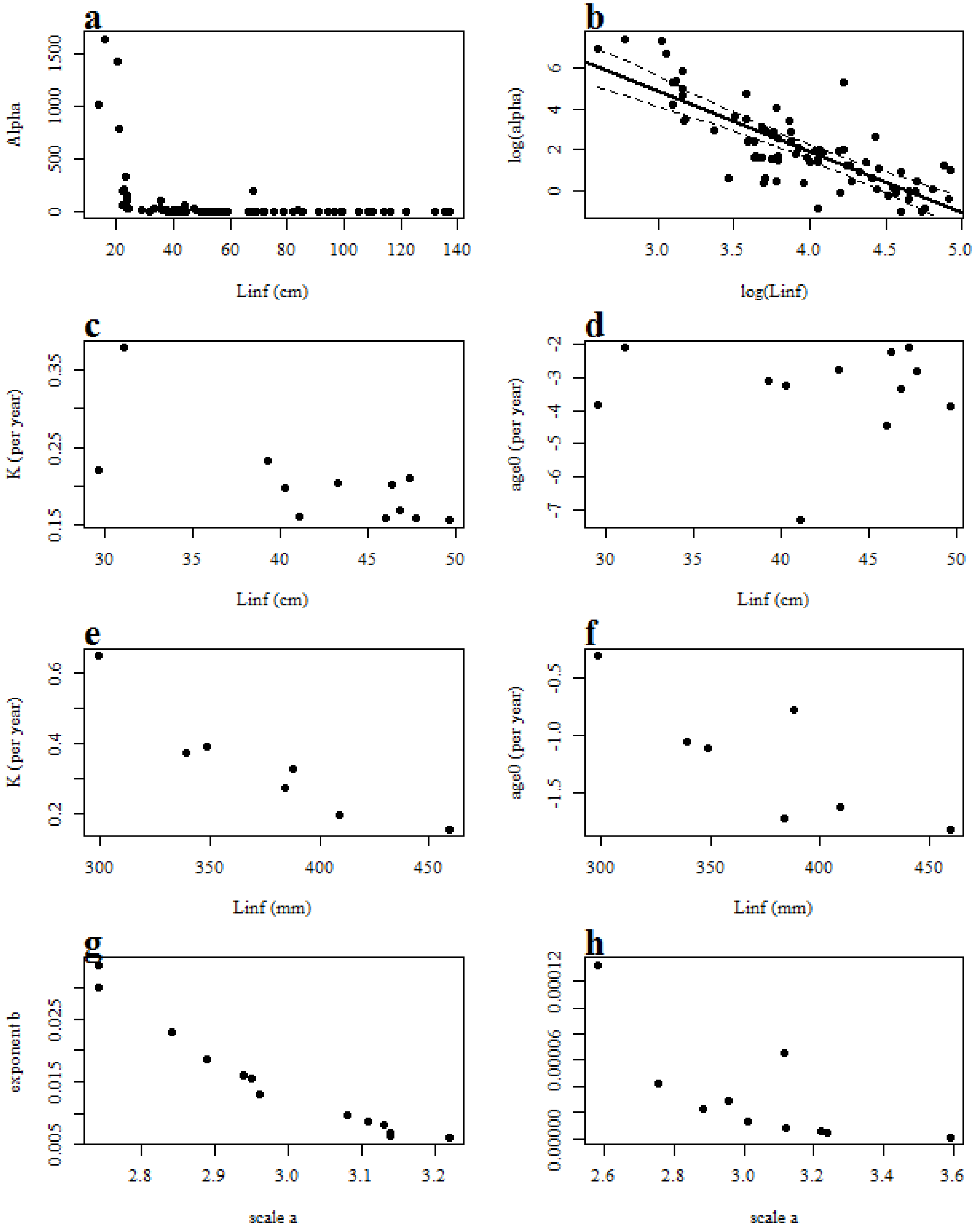

Fig. 1 Relationships between (a, b) “observed” values of alpha and L_∞, on arithmetic and log scale, respectively; (c, d) the VBG parameters *K* and age$_0$ for Atlantic croaker, (e, f) for spot; and (g, h) the exponent and the scale of length-weight for Atlantic croaker and spot, respectively.

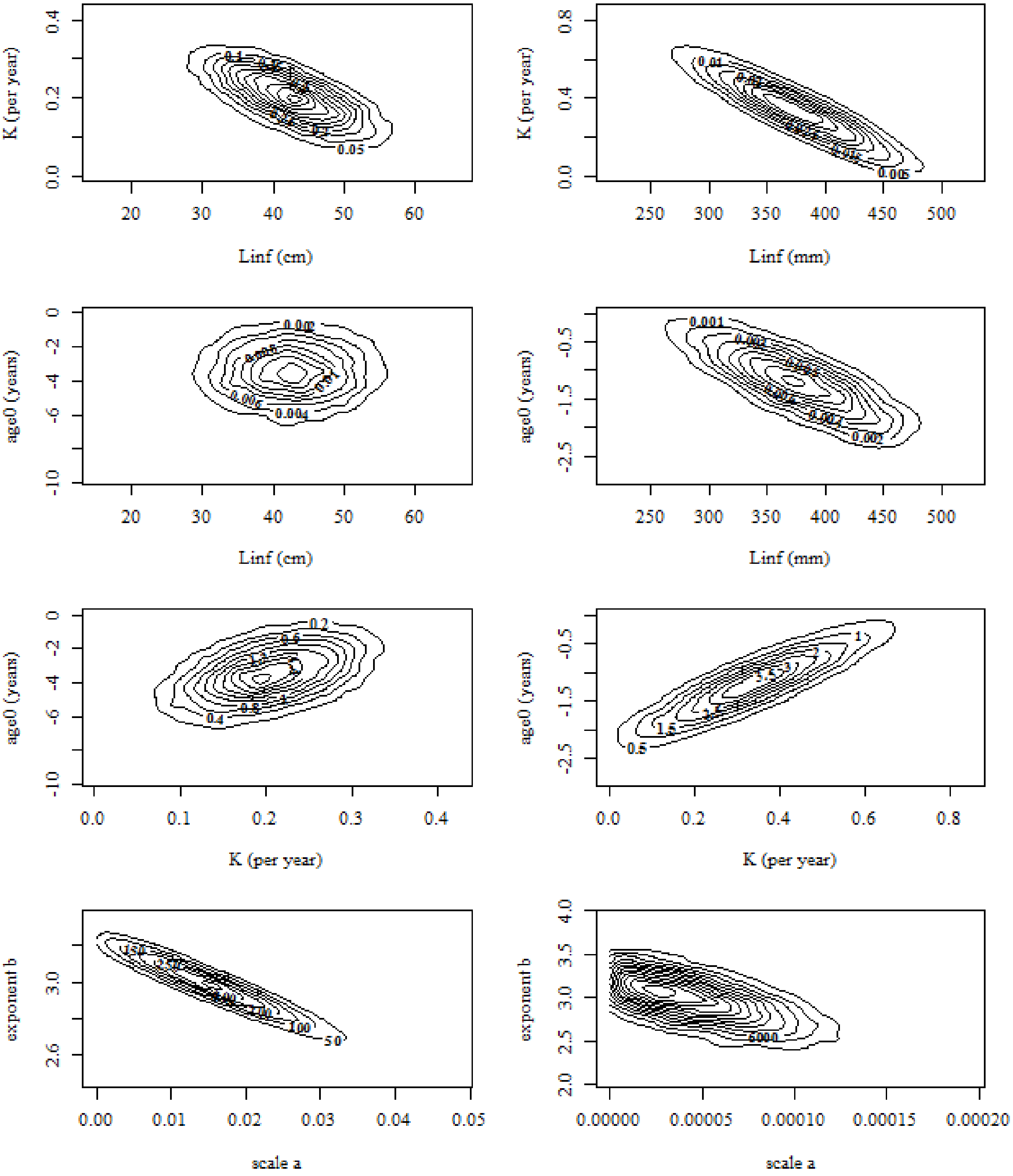

Fig. 2 Isopleth contours showing relationships between the growth parameters for Atlantic croaker (left panel; the number of draws producing the scale *a* > 0 and age-0 < 0, n+, is = 9394) and spot (right panel; n+ = 7632).

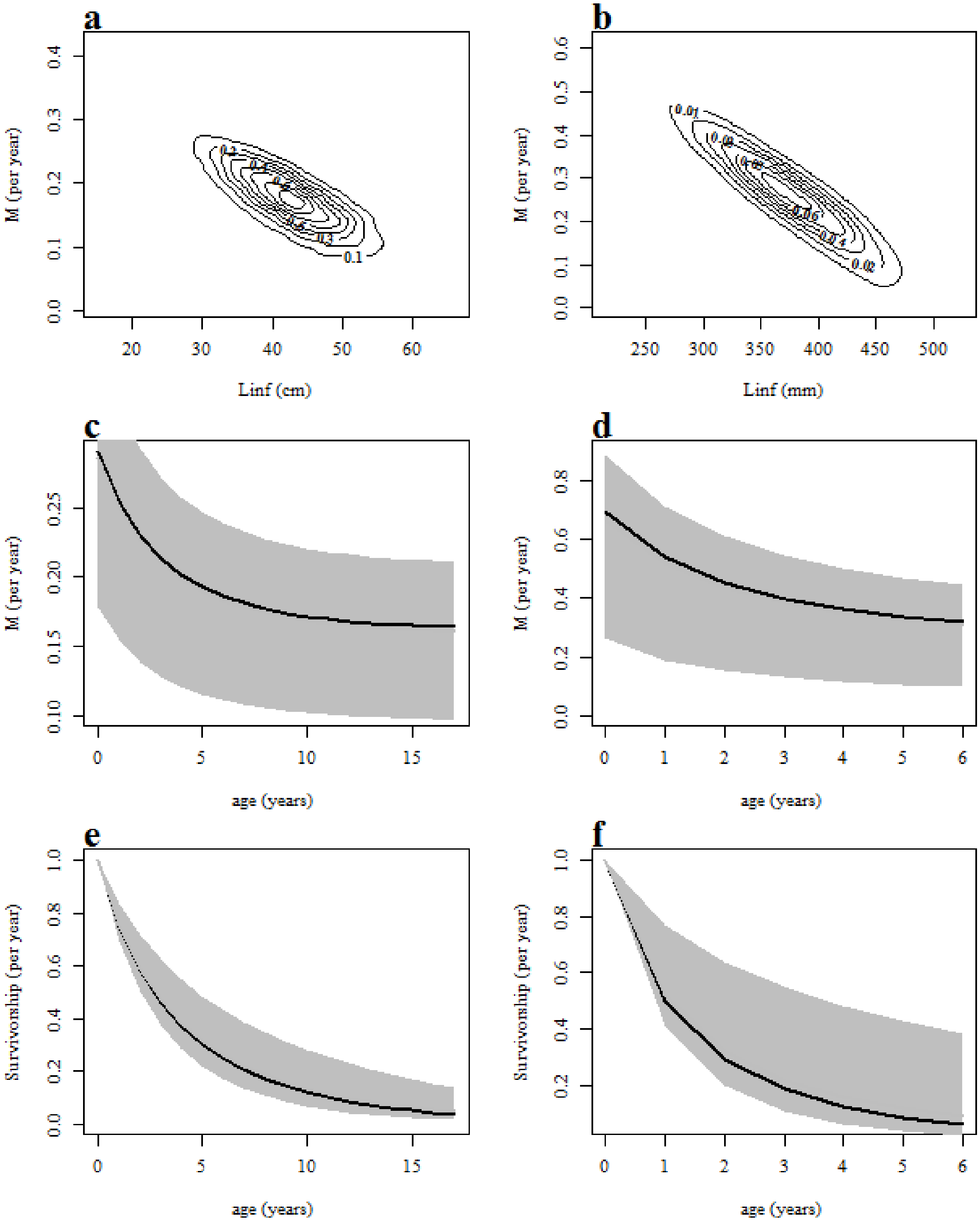

Fig. 3 Relationships between (a, b) the realized natural mortality (*M*) and L_∞; trajectories of median (black line) and 95% confidence intervals (gray color area) of (c, d) age-specific natural mortality and (e, f) survivorship for Atlantic croaker (left panel) and spot (right panel).

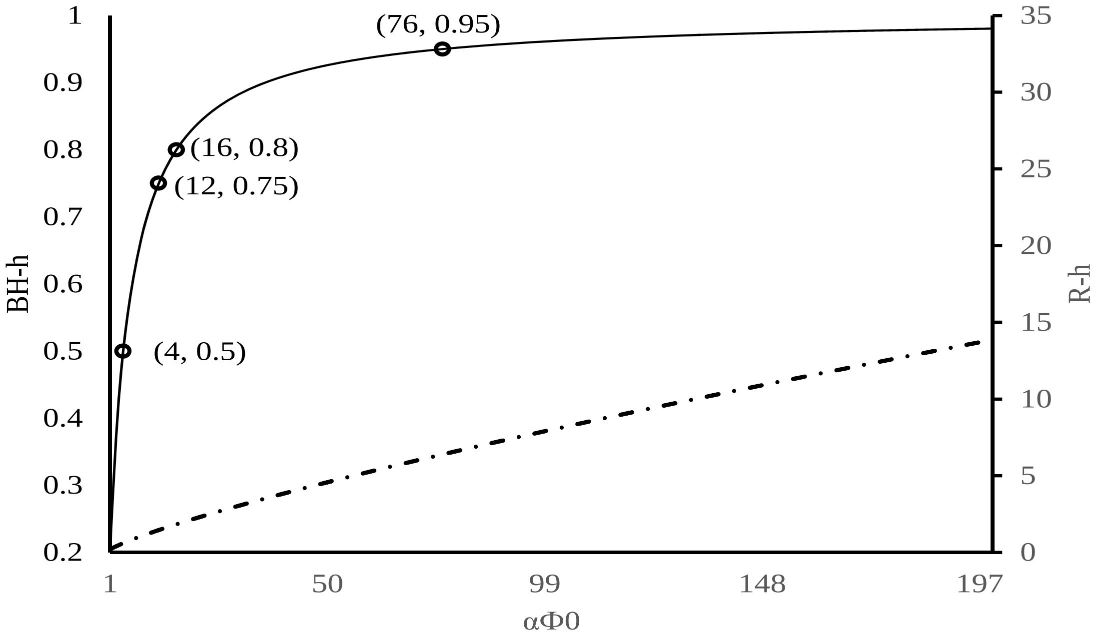

Fig 4 Curves for the BH–SRR steepness (BH–h) and R–SRR steepness (R–h) in relation with the maximum lifetime reproductive rate (a.k.a. Goodyear recruitment compensation ratio), $\alpha\Phi_0$. The selected coordinates for the BH–SRR relate to some commonly-assumed values of steepness.

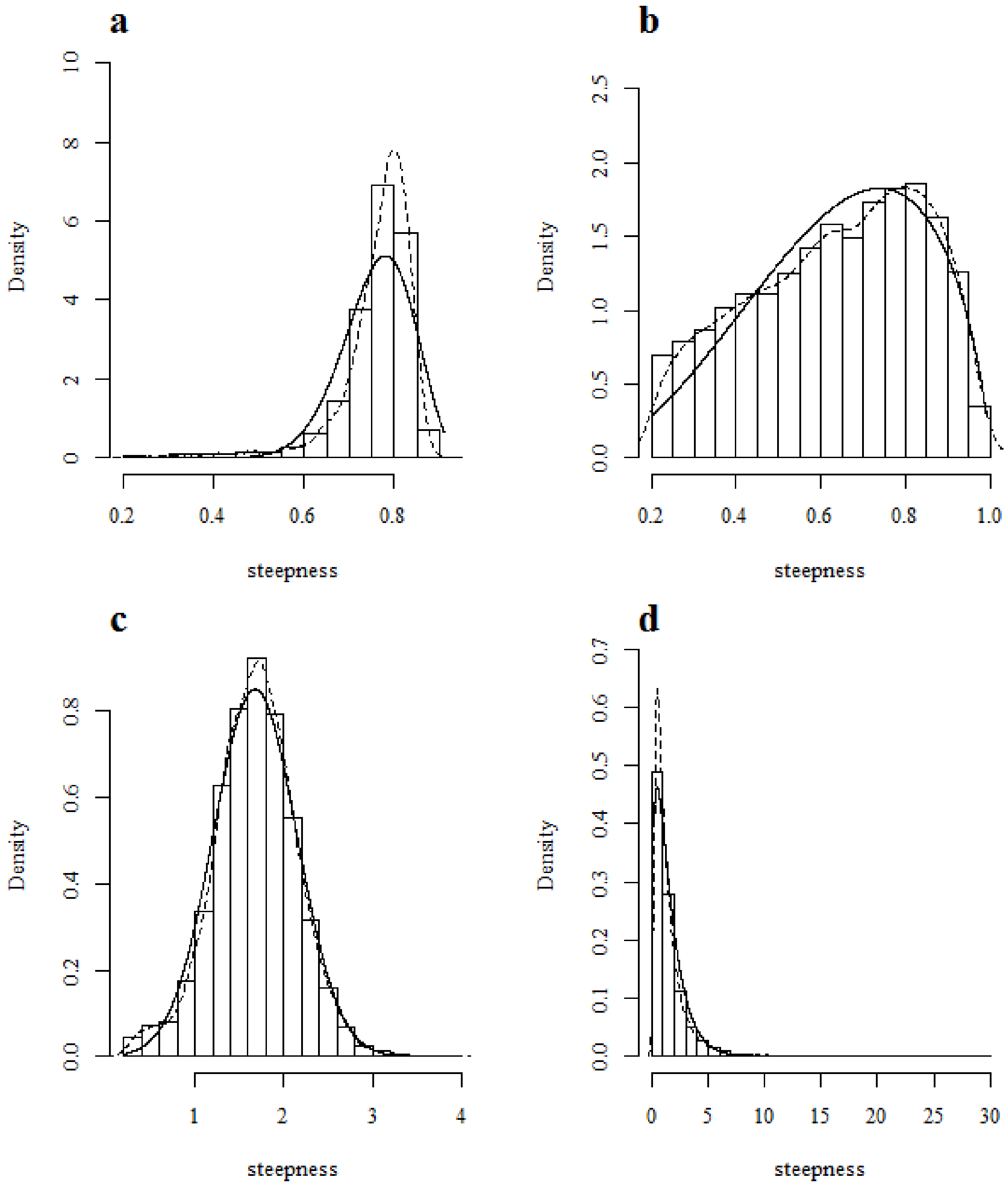

Fig 5 – Frequency histograms of steepness along with empirical (dashed lines) and parametric (solid lines) density functions fitted to those data for (a, b) the BH–SRR and (c, d) the R–SRR for Atlantic croaker (left panel) and spot (right panel) off the U.S. Atlantic coast.