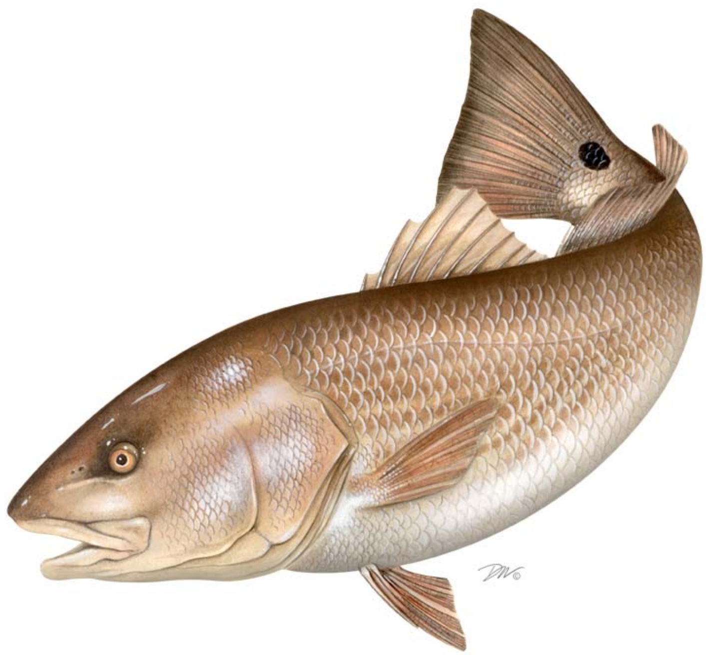
Atlantic States Marine Fisheries Commission

Red Drum Benchmark Stock Assessment & Peer Review Report



Accepted for Management Use

February 2017

Vision: Sustainably Managing Atlantic Coastal Fisheries

Overview

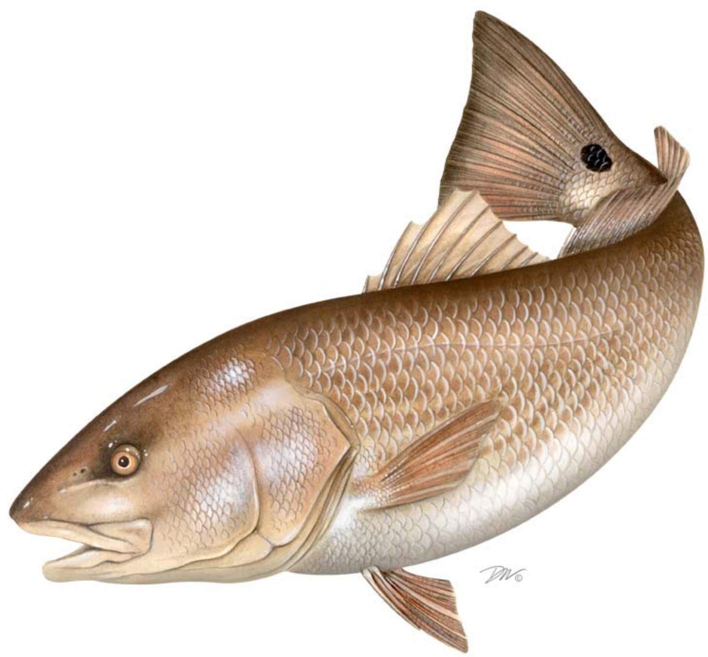
The 2017 Red Drum Benchmark Stock Assessment occurred through an Atlantic States Marine Fisheries Commission (ASMFC) assessment review process. ASMFC organized and held Data and Assessment Workshops with participants from the ASMFC Red Drum Stock Assessment Subcommittee and Technical Committee. SEDAR and ASMFC coordinated two rounds of Review Workshops for the Red Drum Assessment, focusing on model development and final assessment results, respectively. Participants included members of the Red Drum Assessment Subcommittee and Review Panels consisting of reviewers appointed by ASMFC as well as the Center for Independent Experts (CIE).

Red Drum Stock Assessment Peer Review Report (PDF Pages 3-20)
The Peer Review Report provides an evaluation of how each Term of Reference was addressed by the Stock Assessment Subcommittee, including the Panel's findings on stock status and future assessment recommendations.

Red Drum Stock Assessment Report (PDF Pages 21-126)
The Stock Assessment Report describes the data and analytical models used in the assessment submitted by the Stock Assessment Subcommittee to the Review Panel.

Atlantic States Marine Fisheries Commission

Red Drum Benchmark Assessment Peer Review Report



Accepted for Management Use

February 2017

Vision: Sustainably Managing Atlantic Coastal Fisheries

Atlantic States Marine Fisheries Commission

Atlantic Red Drum Benchmark Stock Assessment Peer Review Report of the Statistical Catch-at-Age Model

Conducted January 2017

Prepared by the Red Drum Stock Assessment Desk Review Panel

Dr. Paul Rago, NOAA Fisheries Northeast Fisheries Science Center (retired)
Dr. Matthew Cieri, Maine Department of Marine Resources

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

Acknowledgements

The Review Panel thanks members of the Red Drum Assessment Team (AT) and the many different scientists associated with preparation of the assessment reports we have reviewed. The previous reviewers for SEDAR 44 are also thanked for their lucid summaries. Finally we thank the ASMFC staff for their guidance and support, particularly for initiating a webinar meeting with members of the AT in December 2016.

Executive Summary

Overall the Statistical Catch-at-Age Stock Assessment Report and the SEDAR 44 Data Workshop Report together have met each of the terms of reference. The AT performed their work well, especially given the difficulties red drum life-history and exploitation patterns create for stock assessment analyses.

Examination of the assessment results, as well as corroborating information from the independent indices, suggest that both the Northern and Southern stocks appear to be above their management targets and limits as approved in the FMP.

However, there is a high degree of uncertainty associated with these assessments. The lack of good fishery-dependent and -independent data on the oldest and most fecund age classes, coupled with sensitivity to weightings and initial conditions suggest an overall scaling problem with both regions' assessments. The wide confidence limits in the South and the unrealistic decline in abundance over the time series in the North suggest fundamental assessment and data issues. Given the life-history and pattern of exploitation, it is unclear how these issues can be easily resolved. Certainly further work, as outlined below and highlighted by the AT, is needed.

Given the critical dependency of overfishing status determination on the F estimates for older fish, and the difficulties of estimating F when population size is indeterminate, the assessment only gives a rough measure of stock status. While there are no major signals to suggest the stocks are in trouble, it should be recognized that even small changes in the fishing mortality on age 5 and older fish could lead to rapid overfishing.

Theoretically, the Spawning Potential Ratio (SPR) analysis measures exploitation in an equilibrium context. By that measure, a small increase in F on older fish would lead to an immediate determination of overfishing. In practice, the stock dynamics would depend on the true population size of older fish. Since population size is highly uncertain, and in the North equilibrium is highly improbable, any management changes should be carefully considered. More specifically, measures that might increase fishing mortality rates on older fish should be avoided until the estimates can be verified. Moreover, the assessment cannot provide information on the potential population limits for recruitment failure as scale of the most fecund portion of the population is uncertain.

As a final note, it is important to recognize that the same concerns that were identified with the SS3 model formulation underlie the application of SCA models to the stocks. Despite its nominally less complex analytical structure, the data conflicts and instability of estimates remain in SCA, as in SS3 formulations. These issues would likewise confound any age structured modeling approach. It suggests that the overall problem is one of data and the pattern of exploitation which informs model approaches, rather than the approach itself.

Nonetheless, the SEDAR 44 recommendations to work from a simple model and gradually increase complexity remain valid. Such a process is in and of itself, a major task as model identification relies heavily on deeper insights developed over years of experience by the lead data and assessment analysts. Moreover, there is no guarantee that such a process can derive an optimal model if the underlying causes cannot be identified. More often than not, the problems lie in the data themselves. By that measure the AT and other groups assessing red drum are well poised to move forward because they have a strong understanding of the underlying data.

Evaluation of Terms of Reference (TOR)

1. Evaluate the thoroughness of data collection and the presentation and treatment of fishery-dependent and fishery-independent data in the assessment, including the following but not limited to:

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

The assessment team did an excellent job of summarizing the available data and characterizing the underlying sources of uncertainty. Methods for estimating sampling variance followed accepted methods. For major programs, such as the MRIP, measures of uncertainty followed estimates obtained from official sources. Differences often exist between sample variances and variances implied as data are used in analytical models. These differences are often expressed as "effective sample size". The authors used modern and accepted methods for estimating effective sampling size. It should be noted that these methods (e.g., the Francis method) are conditional on the analytical model used and the data ensemble included in it. Thus, these approaches are objective methods for subjectively estimating the information content of data.

b. Justification for inclusion or elimination of available data sources

The SEDAR 44 Data Workshop Report provided extraordinary details on the advantages and limitations of available data sets. One important feature of their data analyses was development of objective approaches for looking for both internal and external consistency with other data sources. Testing for the ability to follow a year class over multiple years is especially useful for eliminating indices that may be tracking availability to the sampling area rather than true abundance. We affirm the conclusions of the SEDAR panel that the process for reducing the 23 indices for the Northern stock to 5 indices and the 25 indices to 11 for the Southern stock was well done.

The general premise that data sets with "some information" should be included to improve model fit should be applied with caution. Adding marginally informative data streams can increase uncertainty of parameter estimates, as weighting of data sources ultimately undermines the application of likelihood theory in the model and is often ad hoc. This concern is not restricted to the red drum assessment and is in fact, commonly applied in fisheries assessments. While additional data streams can stabilize model performance and improve determination of status, it incurs a cost of stretching the underlying theory and underestimating the uncertainty of the results.

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

As noted above, the AT conducted a detailed evaluation of the myriad data sets available. For the purposes of the SCA assessment, no major changes in data sources or indices estimation occurred. This is consistent with the Terms of Reference given to the AT.

d. Calculation and/or standardization of abundance indices

The analyses of the MRIP data to develop species clusters to improve estimation of the likely trips for red drum by Murphy (SEDAR44-DW12) was novel, thorough, and well done.

Assembling region or state specific abundance indices for smaller and younger fish into a coherent measure of trend is a vexing problem for many assessments of coastal stocks on the East Coast. Habitat, sampling design, and gear differences among indices are compounded by inter-annual variations in availability. Fig. 5.7.4 (pg. 139 in SEDAR 44 report) provides an excellent illustration of this challenge.

e. Estimation of discards and size composition of discards.

One potential concern is the use of the ratio estimator to hind cast historical discards. While this is an appropriate approach given the lack of data, these estimates will likely be sensitive to changes in management. Other than a cautious note about discards, this term of reference was handled very well by the AT via the Data Workshop.

2. Evaluate the definition of stock structure used in the assessment. Is the definition appropriate given the biology and management of red drum?

Stock structure decisions in stock assessments always reflect a mixture of biological and management considerations. Practical considerations such as differences among fleets, user groups, or jurisdictions among areas often are equally important or supersede purely biological determinations. For red drum there appears to be sufficient evidence of a genetic difference between the Northern and Southern stocks. Life history differences also support the genetic distinction. Fortuitously, the boundary also corresponds to changes in ecosystems and management jurisdictions near North Carolina. Mixing of stocks in this area is common for many species owing to its oceanographic conditions. Such localized mixing is relatively unimportant for stock assessments, but should be recognized.

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 red drum?***

The AT did an excellent job of evaluating alternative hypotheses. The approach was rigorous and well executed. Within the constraints of using the SCA model and not altering its configuration drastically, the authors rendered multiple hypotheses into a manageable subset and then examined the joint effects of multiple data weightings. Methods for consideration of alternative data weighting schemes for each stock (Tables 9 and 10) and the results (Tables 11 and 21) are exceptionally lucid and well crafted.

The AT also addressed key life history information appropriately for each stock. Differences in maturation rates, natural mortality, longevity, and growth are well described. How adjacent stocks could have such dramatically different population trajectories, as implied by the model fits, received less attention from the AT. Seeking model formulations that are more consistent with each other could help improve the overall fit of both models.

One possible avenue for future exploration would be to examine a model that can fit both age and length composition data, similar to what was recently developed for Cobia using the Beaufort Assessment Model (BAM). Care would need to be taken however to ensure that appropriate weightings were given in the likelihood profile to ensure that undo weights were not assigned to the catch data.

    a. ***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).***

A critical, if not *the* critical assumption, in the modeling process is the implementation of domed shaped stock-recruitment relationship. As a result, the assessment model consists of two independent populations; an immature but heavily exploited younger group, and a reproductive but minimally exploited plus group. The plus group is essentially unbounded, as catches of fish older than age 6 are uncommon or low. When parametric selectivity curves are employed, the modeled F approaches zero, so that the dynamics of the plus group are governed almost entirely by the assumed level of F of those ages. This is clearly seen in the estimation of age 7+ group in the Northern Stock. Differences between the model estimates and a simple exponential decay curve can be demonstrated, as shown in the following section.

In the Southern Stock the plus group seems to be more consistent with the population biology. For both stocks however, the abundances of age 7+ red drum are very high. This leads to a large fraction of total biomass being essentially static and unavailable to exploitation.

Overall, the externally estimated parameters were handled well. One possible suggestion for natural mortality, in future work, would be to examine Charnov et al. (2013) which examined the descending trend of M at age in light of maturation, as opposed to survival at maximum age (which can be difficult in exploited populations).

Most importantly, the inability to establish scale (i.e., population abundance) in the model outputs is a major problem for the assessment. In theory the rate of change in abundance indices by age class can inform F estimates. It is not clear how much of the F estimate is reliant on the age compositions vs. the relationship between total catches and relative abundance indices. The best model fit for the Northern Stock fully weights the information for the tag based info, the indices of abundance, and total catch, and down weights the recreational age composition relative to the commercial fishery (Table 11). In contrast, the best model for the Southern Stock does not distinguish between the weighting on total catch for commercial and recreational, places a high weight on the MRIP relative abundance index, and also down weights the age composition of live release recreational catch.

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.

The model is highly sensitive to weightings applied to various likelihood components. Generally such sensitivity is symptomatic of conflicting information within the model wherein abundance indices suggest a pattern inconsistent with total catch or age/length compositions. Neither catch time series nor survey indices reveal high abundances of large fish. This leads to estimation of a dome shaped selectivity pattern wherein the size of the population in the plus group is essentially unverifiable. One might call such populations cryptic. This would be merely an intellectual curiosity if it were not a critical component of status determination.

If this were not an "intermediate" assessment, more could be done to explore model performance. Likelihood profile analyses would be helpful for several parameters. An important starting point would be the age-specific F estimates. Given the importance of the estimated F on the oldest fish, it would be valuable to conduct a profile analysis of estimated F for each stock. Such an approach might reveal a broader confidence interval than suggested by the asymptotic errors. More importantly, profile analysis would be valuable to examine the effects on population size and SPR for each fixed value of F in the likelihood profile. The multi-fleet structure of the SCA model might make this computation more difficult because aggregate age specific F is a composite estimate of commercial and recreational fleets. We defer to the lead analysts on how best to implement a reasonable approach.

Further examination of simple parametric relationships for the calculation of SPR would also be useful. A sensitivity analysis of SPR to F on the oldest ages is shown below. At low Fs, SPR reference points will be highly sensitive to the implied biomass in the plus groups. To illustrate this effect, the biomass in the plus group to the total population at equilibrium can be estimated from the parameters for the sSPR.

One effect of the domed-selectivity pattern in the Northern Stock is that the dynamics of the plus group are essentially uncoupled from the age 1 to 4 red drum. A simple illustration of this effect can be demonstrated by noting the trajectory of the plus group from 1989 to 2013. In the model estimates the trajectory is

Model based 7+ Abundance estimate in 1989 =13,962,773; abundance in 2013 = 3,592,926 (Table 13, p. 32).
The annual instantaneous rate of change Z = -ln(3592926/13962773)/(2013-1989)=0.06.

Using this, one can compute the predicted population size for the 7+ group as

N7+_pred(1990)=N7+_model(1989)*exp(-0.06)
....
N7+_pred(t+1)=N7+_pred(t)*exp(-0.06)

This synthetic trajectory, which excludes the effect of recruitment of age 6 fish to the 7+ group, looks surprisingly similar to the actual model predictions shown in Figure 1.

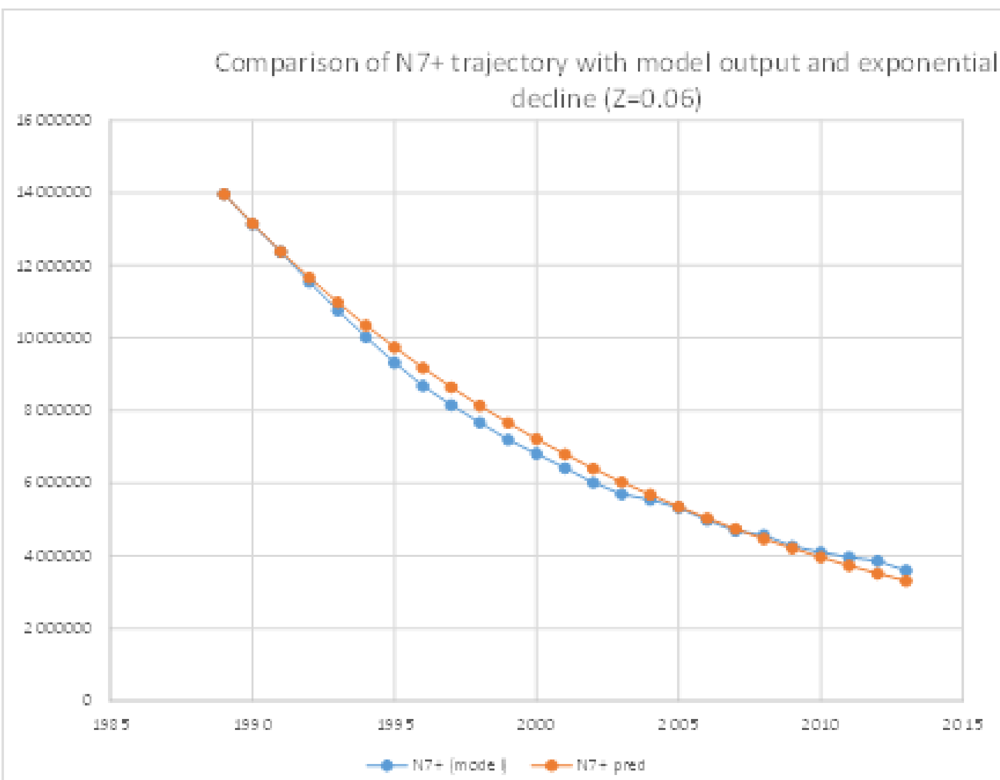


Figure 1. Comparison of SCA model output (blue dots) with predicted estimate based on simple exponential decay of the 1989 abundance estimate at Z=0.06.

This suggests that the exponential decline in 7+ is consistent with a total Z of about 0.06 which is the value used for M in the North. F on 7+ fish is minimal throughout the time series. Incoming recruitment of age 6 fish has relatively little influence on the trajectory but there is some improvement after 2010 as age 6 fish began to increase. The numerical fraction of the plus group to the total population ranges from 96% in 1989 to 62% in 2013. In contrast, the Southern Stock fluctuates around 39% without trend. The expected fraction of a population above 6 years old in a population with Z=0.06 is 0.69. This is just the sum N(a) from a=7 to 62 divided by sum N(a) from a=1 to 62. Hence the average fraction of the population in the 7+ (2011-2013) of 66% is about equal to that expected in an equilibrium population.

Another way of examining the "uncoupling" effect is to consider the ratio of the population numbers in the plus group to the average numbers of recruits (i.e., age 6) to the plus group. In 1989, for the Northern Stock the ratio of the plus group to average age 6 is 132.8. By 2013, this ratio decreases to 34.2. The overall ratio across all years is 69.5. If these numbers are true it would suggest that the initial plus group size is the consequence of a much higher historical average recruitment. Since that hypothetical epoch the stock must have had a reduced recruitment stanza. An alternative hypothesis to the dome is that the larger fish have died.

In contrast, the Southern Stock relationship between the size of the plus group and age 6 recruits reveals an overall ratio of 6.8 and a slightly increasing trend from 1989 (4.1) to 2013 (7.4). Such a pattern is more consistent with the underlying biology and the hypothesized efficacy of management measures. It is difficult to develop a plausible explanation for these differences between stocks. While the model estimates for the Southern Stock are less precise, they have, at least by this metric, greater biological plausibility.

While the above analysis is preliminary it highlights a major concern; that the abundance estimate for age 7+ in the Northern Stock in 1989 is probably an artifact. The model estimates a very high initial population which allows it to minimize the differences between observed and predicted catches, and reduce the effects of incoming recruitment on the subsequent stock dynamics.

Comparison between the estimate of SPR in the SEDAR 18 formulation and the base model reveals large differences in Figure 2 (i.e., Figure 14 from the Assessment Report).

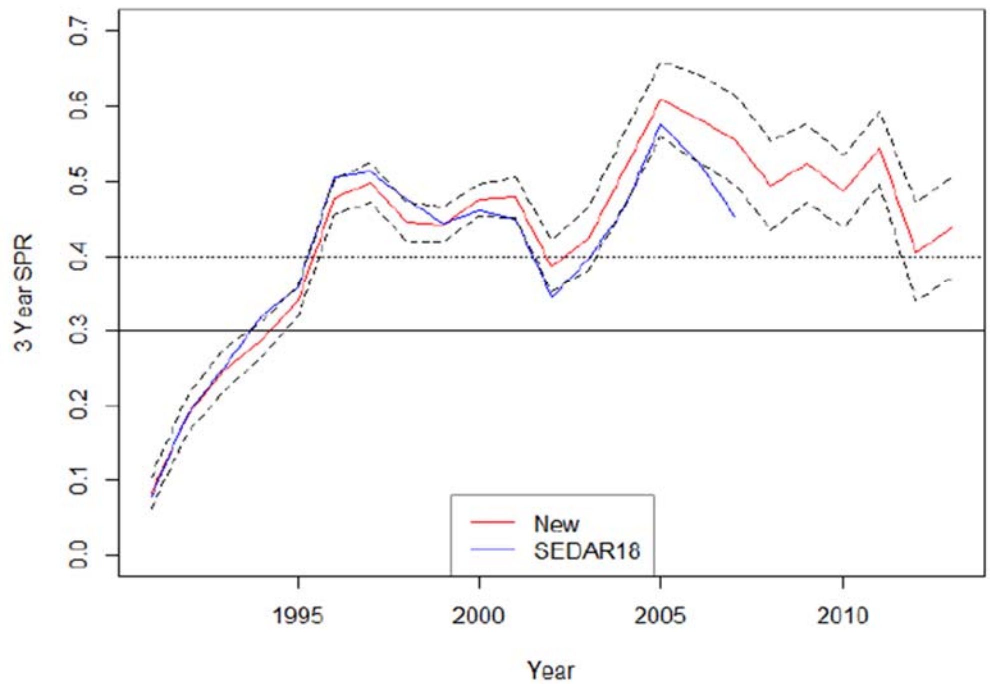


Figure 14. Three year average sSPR for the northern stock with 95% confidence intervals from asymptotic standard errors. Point estimates from the previous benchmark assessment (SEDAR18) are included for comparison. The target sSPR (dashed black line) is 40% and the threshold sSPR (solid black line) is 30%.

Figure 2. Taken from the assessment report.

This suggest that cumulative changes in the SCA assessment vs. SEDAR 18 have had a large impact on the population's trajectory. Given this and if there is time, a full continuity run, or an update of the previous model approach through 2014, is suggested. This would highlight the potential uncertainty for managers.

b. Retrospective analysis

The retrospective pattern in the assessment is particularly interesting as it reveals an apparent bifurcation of estimates with the 2010 peel in the Northern Stock and 2012 and earlier peels in the Southern Stock (Figure 3 and 4) (i.e., Figures 16 and 35, respectively, from the Assessment Report). Because these changes must be due to changes in F, it would be useful to examine the changes in age-specific F estimates for each stock.

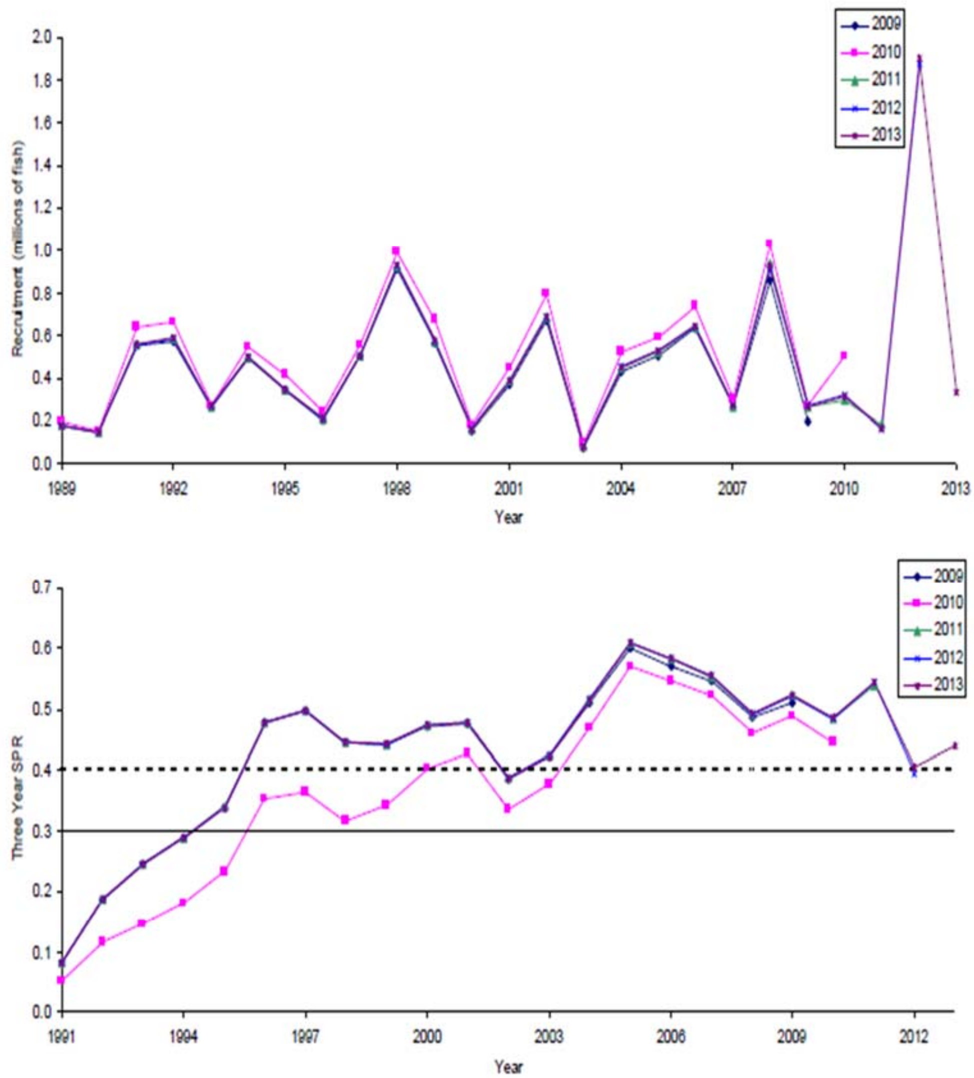


Figure 16. Five year retrospective analysis of the recruitment (top) and three year average sSPR (bottom) for the northern stock.

Figure 3. Taken from the assessment report.

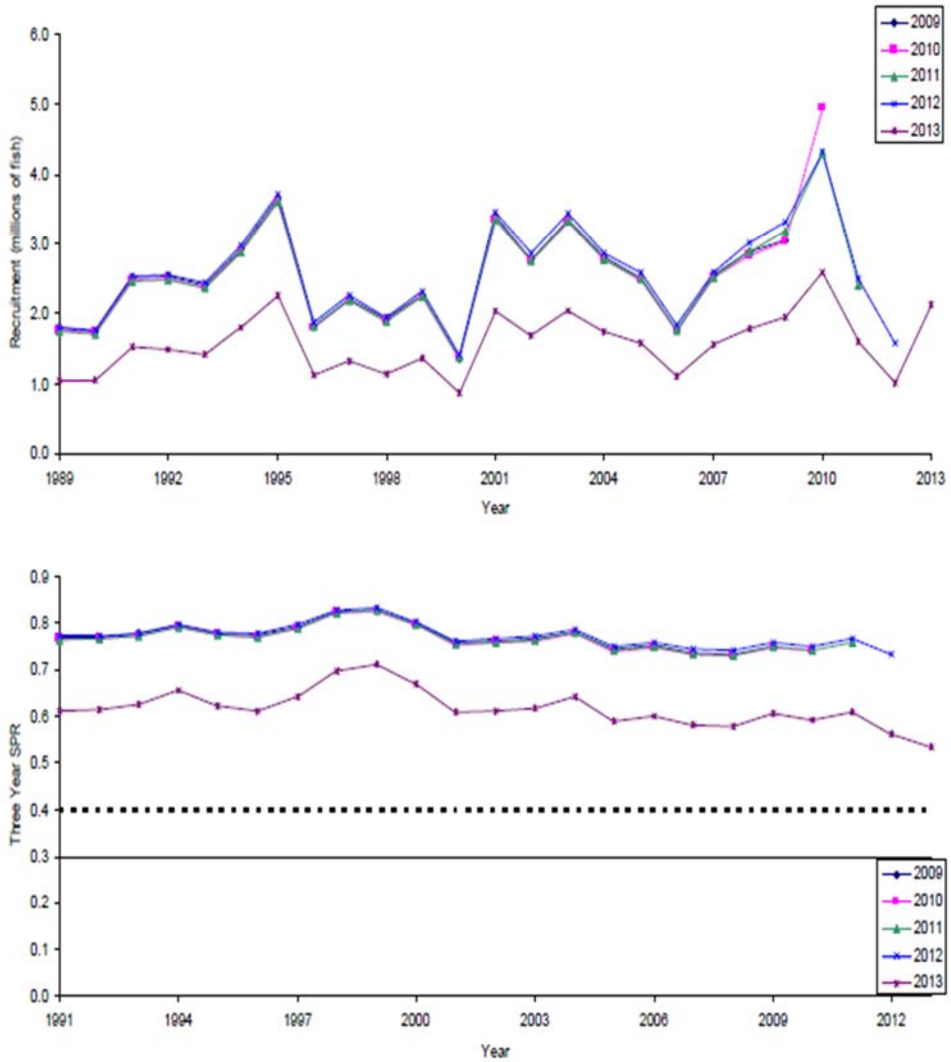


Figure 35. Five year retrospective analysis of the recruitment (top) and three year average sSPR (bottom) for the southern stock.

Figure 4. Taken from the assessment report.

The pattern in the North again highlights the sensitivity of the plus group to changes in the data, particularly with the 2010 peel. This can have implications on potential reference points. For the South, an explanation of the 2013 peel is warranted but again highlights the difficulty the SCA model has in defining population scale appropriately. In both stocks the sensitivity analyses suggest that scale is sensitive to assumptions, and poorly defined.

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

The AT provides estimates of key parameters using asymptotic errors for all and MCMC for some. Both measures of uncertainty probably underestimate the true variance, as acknowledged by the AT.

The high correlation among parameters is expected given the relatively high apparent ratio of parameters to data. It is not clear why 0.9 is chosen as a cutoff for presentation. As a general consideration, it would be helpful to develop some functional equivalents to “condition indices”, a metric used in general linear models to identify poorly specified models. Condition indices are functions of the eigen values and vectors of the design matrix.

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

Increasing trends in several indices suggests management measures may be working. However, the conclusion that stocks are above B_{msy}, or proxies, are tenuous given initial condition effects on plus groups. In the North this suggests that age 4+ abundance is declining throughout the time series. Overall, both stocks appear to be above management targets and limits, though the wide confidence intervals in the South, as well as model performance, suggest a higher degree of uncertainty surrounding stock status.

A relative F approach, though simplistic, may be more useful for examining trends given the model's inability to rectify scale. This approach would examine the ratio of catch to some function of the time series of relative abundance indices and could be either year-specific, or calculated as a moving average.

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.**

A possible alternative is to look at cohort specific SPR. This would limit overfishing definition to completed cohorts from 1989 to 2009. Estimates for cohorts from 2010 to 2013 could be obtained by assuming that the Fs estimated for 2013 continue onward for those cohorts.

The reference points as a whole would benefit from further testing. Static SPR is useful for measuring overfishing but its implementation is compromised by the same factors that led to rejection of biomass determination. If biomass and abundance estimates are unreliable due to problems in resolving scale, one cannot then conclude that the F estimates are reliable. This occurs because the catches are fixed. The Fs are conditional on the ability to generally match the catch based on the estimated abundance indices.

The biological reference points should be evaluated with respect to varying assumptions about the magnitude of F on the plus group. The effect of increasing F(7+) from 0.004 to 0.04 will have a dramatic impact on the current state of the resource (Figure 5 and 6). As a simple illustration we examined the effects of increasing F on the age 4 to 7 range from 0.009 to 0.214 in the South and from 0.004 to 0.065 in the North. The upper bounds correspond to the respective F estimates on age 3 fish in each area. The lower bounds correspond to the F estimates on age 5 fish in the terminal year.

For the northern stock, increasing F from 0.004 to 0.04 drops SPR below 30%.

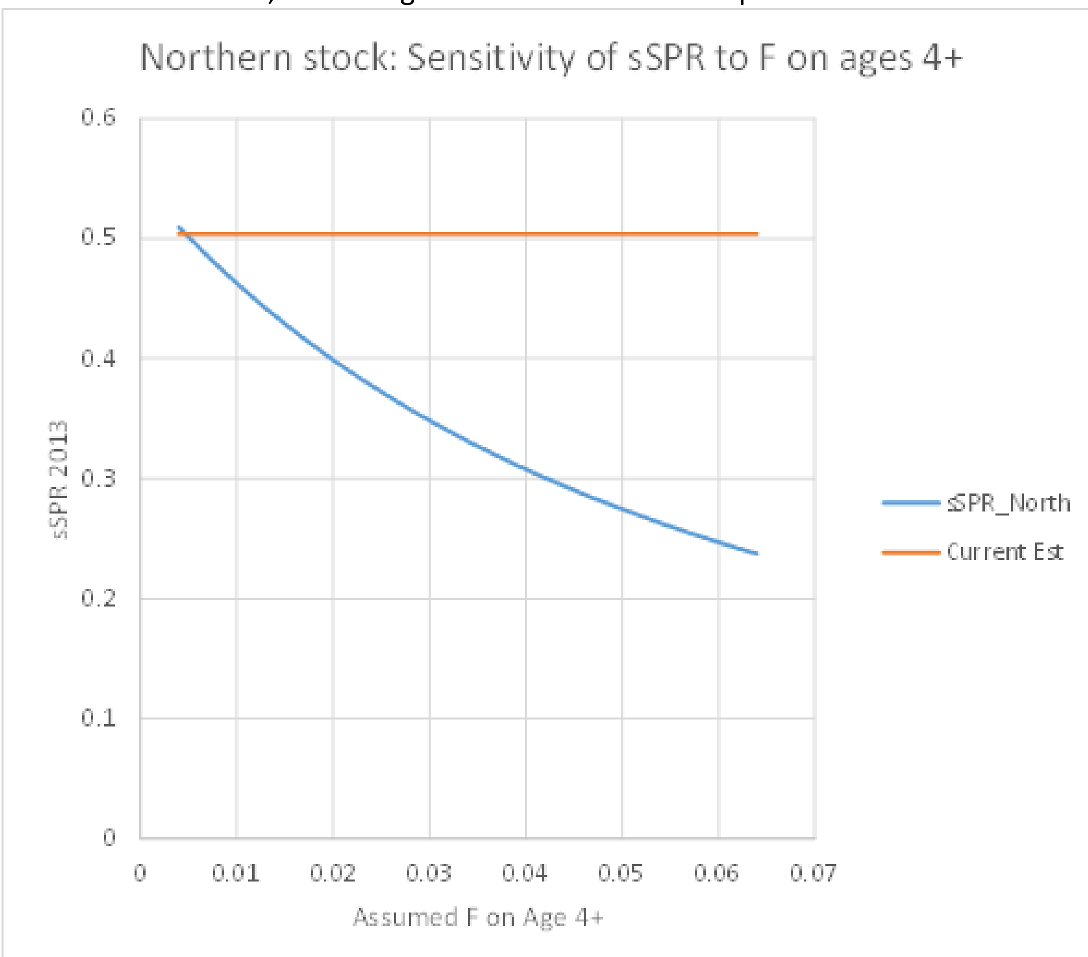


Figure 5. Sensitivity analysis of the current estimate of SPR in the Northern Stock to variation in the assumed fishing mortality estimate on ages 4 and older.

The southern stock is slightly less sensitive but increases in F to 0.06 are sufficient to drive SPR below 30% (Figure 6). Thus the status determination is highly sensitive to the estimated composite F on ages 4 and older. In the vicinity of Fs of about half the estimated M, the stock status can sharply decline. If the current level of recruitment is in fact dependent on an extended age structure implied by the low Z on adults older than 7, resource persistence is conditional on maintenance of minimal harvest of older red drum.

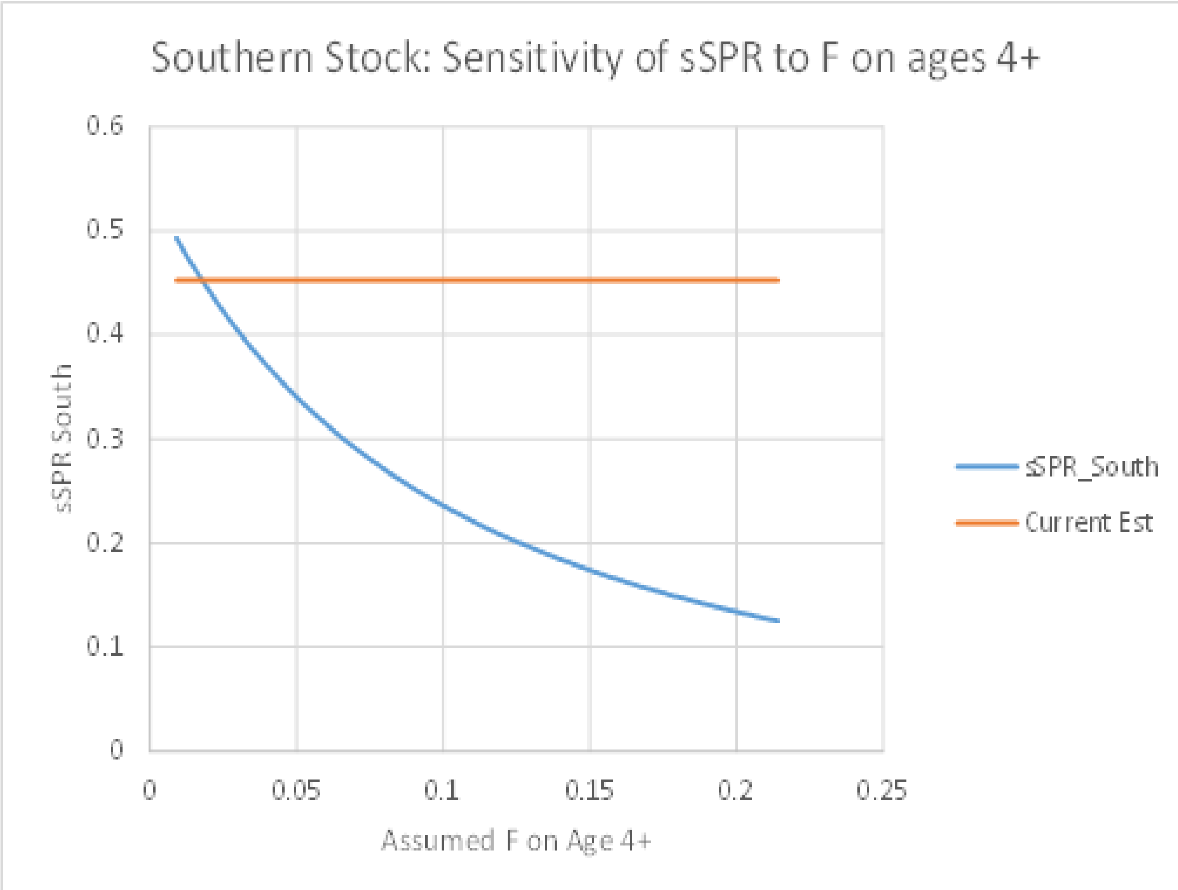


Figure 6. Sensitivity analysis of the current estimate of SPR in the Southern Stock to variation in the assumed fishing mortality estimate on ages 4 and older.

For the southern stock the fraction of sSPR in the 7+ group is 0.82 under current fishing mortality and 0.84 when F is assumed to be zero. For the Northern Stock the fraction of sSPR in the 7+ group is 0.8 under current fishing mortality and the same when F is assumed to be zero. For either stock, most of the SPR is in the plus group, and is therefore relatively unaffected by the F estimates on younger fish. The primary factor is the estimated F on age 7 fish, which is uncertain.

The ability to resolve differences in age specific Fs of less than 0.01 is problematic in any stock assessment. Differences between the current estimate and true value of F of less than 0.04 would lead to an estimate of overfishing in the Northern Stock; differences of less than 0.06 would lead to an estimate of overfishing in the South.

Thus, caution should be applied when examining stock status relative to current reference points. Any biomass or abundance based targets and limits would suffer from difficulties this approach has to estimating scale of the population, particularly, for the plus group. Further, SPR as a benchmark cannot get at minimum stock size needed for sustainable recruitment.

References

ASMFC. 2016. Red Drum Statistical Catch-at-Age Model Stock Assessment Report. November 2016. Arlington, VA.

Murphy, M. 2014. Relative indices of abundance for Red drum (Sciaenops ocellatus) inhabiting inland waters along the Atlantic coast based on 1991-2013 angler catch rate data. SEDAR-DW12.

SEDAR. 2015. SEDAR 44 – Red Drum Section III: Review Workshop. SEDAR, North Charleston SC. 890 pp. available online at: http://sedarweb.org/sedar-44.

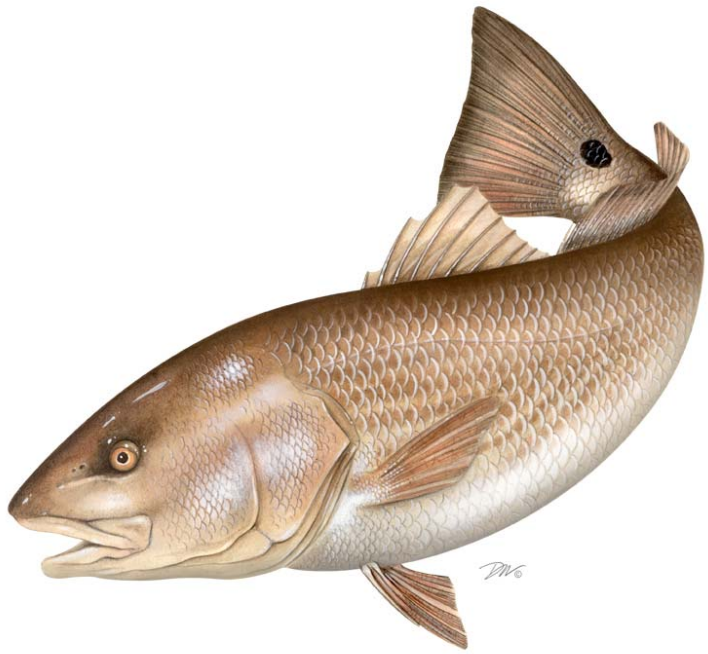
SEDAR. 2015. SEDAR 44 – Atlantic Red Drum Stock Assessment Report. SEDAR, North Charleston SC. 890 pp. available online at: http://sedarweb.org/sedar-44.

Charnov, E. L., H. Gislason, and J. G. Pope. 2013. Evolutionary assembly rules for fish life histories. Fish Fish. 14:212–224

SEDAR, 2013. SEDAR 28: South Atlantic Cobia Stock Assessment Report. SEDAR, North Charleston, SC 29405. Available at http://sedarweb.org/docs/sar/S28_SAR_SACobia_WithAddendumFinal_5.16.2013.pdf

Atlantic States Marine Fisheries Commission

Red Drum Benchmark Stock Assessment



November 2016

Vision: Sustainably Managing Atlantic Coastal Fisheries

Atlantic States Marine Fisheries Commission

Red Drum Benchmark Stock Assessment

November 2016

Prepared by the
ASMFC Red Drum Stock Assessment Subcommittee:

Ms. Angela Giuliano, Maryland Department of Natural Resources
Ms. Carolyn Belcher, Georgia Department of Natural Resources
Dr. Steve Arnott (Chair), South Carolina Department of Natural Resources
Mr. Jeff Kipp, Atlantic States Marine Fisheries Commission
Mr. Lee Paramore, North Carolina Division of Marine Fisheries
Mr. Mike Murphy, Florida Fish and Wildlife Research Institute (Retired)
Mr. Mike Schmidtke, Atlantic States Marine Fisheries Commission
Mr. Ryan Jiorle, Virginia Marine Resources Commission

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award Nos. NA10NMF4740016 and NA15NMF4740069

Acknowledgments

The Atlantic States Marine Fisheries Commission (ASMFC or Commission) thanks all of the individuals who contributed to the development of the red drum stock assessment. The Commission specifically thanks the ASMFC Red Drum Technical Committee (TC) and Stock Assessment Subcommittee (SAS) members who developed the consensus stock assessment report.

Executive Summary

During the SouthEast Data, Assessment, and Review (SEDAR) 44 Benchmark Stock Assessment for red drum (SEDAR 2015b), assessment models were developed with the Stock Synthesis 3 (SS3) integrated analysis framework (SS3, Methot 2013). Models using this framework were not accepted by the South Atlantic State/Federal Fisheries Management Board (Board) due to concerns with the reliability of population parameter estimates. Instead, the Board tasked the TC and SAS to evaluate the utility of the statistical catch-at-age (SCA) models used in the previous benchmark assessment (SEDAR18; SEDAR 2009) for management advice. The SAS explored several potential changes to these models, including data changes, but ultimately recommended models with minimal structural changes for management advice. This report includes results of the SCA models for both the northern and southern red drum stocks. For assessment terms of reference (TORs) and information on red drum life history, management, and data, including model data inputs, see the SEDAR 44 Data Workshop Report (SEDAR 2015b).

The northern and southern red drum stocks were assessed relative to static spawning potential ratio (sSPR) reference points defined in Amendment 2 to the Red Drum Interstate Fisheries Management Plan (ASMFC 2002). The 2011-2013 three year average sSPR was estimated to be 43.8% in the northern stock and 53.5% in the southern stock, both above the sSPR30% threshold and sSPR40% target, indicating that overfishing is not occurring. However, most of the issues that arose with the models during SEDAR18 remained. Abundance estimates of older fish continued to be more uncertain and, particularly in the southern stock, had large standard errors. Similar to SEDAR18, initial abundance estimates of older fish (ages 7^+) were unrealistically large for the northern stock. Abundance estimates in the south were so uncertain that they are likely indicative only of relative trends. Therefore, an abundance or biomass status (overfished/not overfished) could not be determined for either stock. In addition, the estimation of sSPR was much more uncertain in the south. Most of the sensitivity runs that were conducted for the southern model, however, suggested that the sSPR likely is above the threshold.

Table of Contents

1. Methods

A standard statistical catch-at-age (SCA) model was used for red drum, which included special features for capturing some information from tagging programs and restricting the selectivity estimated for older fish. These analyses were defined for the period 1989-2013 and included age-specific data for red drum ages 1 through 7^+.

1.1. Data Sources

The observed data used in the analyses for the southern and northern stock of red drum included the total annual harvest (landings plus release mortalities) attributed to each fishery, the estimated age-proportions in these annual harvests, indices of abundance, and for the northern model, tagging derived instantaneous fishing mortality-at-age (F-at-age) for harvested fish and full instantaneous fishing mortality (F) for released fish. For all observed data, measures of precision were available for use in the models. Data input files are in appendices A and B for the northern and southern stocks, respectively.

In the SCA framework all input data can be considered as “tuning” indices. The inputs included the 1989-2013 total annual kill of red drum by the northern fisheries: commercial gillnet and beach seine, other commercial gears (mostly pound nets and seines), recreational landings, and recreational live release mortalities. Recreational catch estimates were calibrated following methods in working paper SEDAR44-DW04. Since the commercial fishery statistics are considered a complete census of the landings, the coefficients of variation (CV = standard error / mean) for each year’s landings was assumed low, at 0.01. The CVs for the annual recreational harvest and the annual live release mortalities were taken as the proportional standard errors (PSEs) estimated for the Marine Recreational Fisheries Statistics Survey’s (MRFSS) and Marine Recreational Information Program’s (MRIP) Type A+B1 catch (landings) and Type B2 catch (live releases), respectively. The 1989-2013 southern stock’s total annual landings of red drum were grouped as: Florida recreational landings, Georgia recreational landings, South Carolina recreational landings, Florida live release mortalities, and Georgia/South Carolina live release mortalities. The CVs associated with these estimates were derived as explained above for the northern stock recreational catches.

The input data for the age compositions (SEDAR44-DW06) of the catch from the fisheries listed above were generally derived from random fish length samples taken from the catch that were then converted to ages using various age-length keys. The age data were rarely available directly for the recreational live release fisheries, but some information was available from angler-taken measurements of released fish. These data sources included the volunteer logbook program from Florida and reported recaptures of tagged fish which were released alive in North Carolina and South

Carolina. These data were deemed sufficient for the South Carolina and Georgia live release fisheries but not for the northern stock or for the Florida live release fishery where North Carolina tagging study results (Bacheler et al. 2008) were used to infer the catch age-structure. The use of South Carolina tag recapture data, rather than data from a two year log book study conducted by South Carolina, for estimating the age composition of the live release fishery is a data change since SEDAR18 (SEDAR 2009).

The age composition proportions were represented as a multinomial distribution so the number of aged fish in the annual samples indicated the precision of the observed proportions. Because these ages weren't direct random samples from the catch, the SAS used what were assumed to be independent sampling events as sample sizes (e.g., longline set, tow, etc.) with a minimum level of two used for the years when no age-length data were available. This minimum sample size of two was also used for the age composition data estimated for the Georgia/South Carolina live release fishery. These sample sizes were then scaled to a maximum of 50 to avoid assigning too much precision to the composition data relative to other data components.

Indices of abundance are used in the assessment model to "tune" agreement between the model-predicted and observed trends in abundance. For the northern stock, five indices were used to model trends in abundance (Table 1). Two indices measured young-of-the-year (age 1) abundance: the North Carolina Independent Gillnet Survey (IGNS) and the North Carolina bag seine survey, though the former was for late year age-1 red drum and the latter was for the beginning-of-the-year age-1 fish. The other juvenile indices of abundance used in the northern stock were the IGNS catch rates for age-2 red drum (mid-year) and the MRIP total catch rate (assumed to apply to the aggregate late year abundance of ages 1-3). The final index of abundance for the northern stock, which was used for the first time with this benchmark assessment, was the North Carolina longline survey which is assumed to track aggregated relative abundance of age 7^+ fish later in the year.

For the southern stock, there were eleven indices of abundance (Table 2). Four indices measured young-of-the-year trends: the Florida small seine survey, the Georgia monofilament gill net survey, the South Carolina stop net survey, and the South Carolina trammel net survey. The Florida survey was compared to beginning-of-year abundance, the Georgia survey was compared to mid-year abundance, and the last two surveys were compared to late year abundance estimates. Other age-specific surveys included: the Florida haul seine survey used separately for age-2 and age-3 and the South Carolina trammel net survey for age-2, all compared to mid-year abundance. Finally, four pooled-age indices were used: MRIP for ages 1-3, the Georgia longline survey (ages 7^+), the South Carolina 1 mile longline survey (7^+), and the South Carolina 1/3 mile longline survey (ages 7^+). The MRIP survey was used to indicate mid-year abundance; the longline surveys for abundance had survey mid-points 11 months into the calendar year. Estimated annual arithmetic means or standardized year effects and their CVs were used for all indices. Index values were all scaled to means for use in the model. Index choices represent the major data changes since the last benchmark assessment (SEDAR 2009). The South Carolina electrofishing survey was used in SEDAR18 but removed in this assessment. The new indices used included the South Carolina stop net survey, the South Carolina age-1 trammel net survey, the South Carolina 1/3 mile longline survey, and the Georgia longline survey.

Less conventional "tuning" was provided by estimates of age-specific instantaneous F available from a long-term tag-recapture program conducted in North Carolina (Bacheler et al. 2008). In the northern stock, estimates for F-at-age were available for the combined harvest fisheries (commercial and recreational A+B1). These estimates and associated CVs were used to "tune" the model-estimated F-at-age for ages $1\text{-}4^{+}$ during 1989-2004. The 1989-2004, annual fully recruited Fs estimated for the live releases were also used to compare against that fishery's fully recruited Fs estimated within the model. Only the fully recruited Fs were fit, as the selectivity-at-age information was also used to estimate the age composition of the live release fishery mortality in the northern model.

The temporal and age framework for these analyses for both the northern and southern stock models was 1989-2013 and ages $1\text{-}7^{+}$. The assessment model was configured under the separability assumption that there was a year-specific apical F for each fishery and age-specific selectivities as portions of this fully recruited F. Selectivities were estimated for ages $1\text{-}5^{+}$, with selectivity for age 4 and 5^{+} fish estimated as proportions of age-3 selectivity (constrained to the bounds of 0 and 1). These estimated proportions of age-3 selectivity, or selectivity constraints, were assumed to be the same for all fleets and were time invariant. The selectivity blocks used for the northern stock were 1989-1991, 1992-1998, and 1999-2013 for all fisheries, chosen mostly to reflect changes in size limits in North Carolina where the vast majority of landings, on average, occur (Table 3). In the southern stock, where regulatory actions were not as coincidental among the states, constant selectivity within each fishery was assumed to occur during: 1989-2013 for the Florida recreational fisheries (both harvest and live release); 1989-1991, 1992-2001, and 2002-2013 for the Georgia recreational harvest fishery; 1989-1993, 1994-2000, 2001-2013 for the South Carolina recreational harvest fishery; and 1989-1991, 1992-2013 for the Georgia/South Carolina pooled recreational live release fishery (Table 4). Selectivity was not estimated for the Florida recreational live release fishery. The selectivity for this fishery was assumed equal to the North Carolina tagging study findings for the period 1999-2004. During this period there were generally similar size limit regulations in place in North Carolina that corresponded to the Florida selectivity period (1989-2013).

Natural mortality (M) was assumed constant over time, though varying with age, for each stock (Lorenzen 1996). M for the northern stock was the same as estimated in SEDAR18 (SEDAR 2009). For the southern stock, M was updated to match the M estimated in SEDAR44 (SEDAR 2016). In SEDAR18, one maturity schedule was used for both the northern and southern stocks (SEDAR 2009). For this assessment, maturity-at-age was determined separately for the northern and southern stocks using North Carolina and South Carolina data (SEDAR44-DW02). Weights-at-age were estimated in SS3 for each stock (SEDAR44; SEDAR 2016).

1.2. Model Configuration and Equations

The population dynamics models were based on annual fleet- and age-specific separable F :

$$F_{f,y,a} = F^*_{f,y} s_{f,y,a},$$

where $F_{f,y,a}$ is the instantaneous F caused by fleet f in year y on age a fish, F* is the apical F for fleet *f* in year *y*, and *s* is the selectivity, a bounded number ranging from zero to one. Given red drum's inherent reduced vulnerability after age-3 due to their movement from estuarine waters to nearshore waters and more recently to enacted maximum size limits, the selectivity for ages-4 and 5^+ fish were restricted to be between 0-100% of the selectivity at age-3. Selectivity was therefore estimated for ages 1-3 in each of the time periods for which the selectivity was assumed not to have changed for each fishery. Selectivity for ages 4 and 5^+ was derived from the estimated age 3 selectivity for a given time period and the proportional selectivity parameters for ages 4 and 5^+. These proportional selectivity parameters were assumed to be constant across selectivity blocks and fleets.

The abundances of the different age groups in the population are modeled forward in time beginning with estimates for a series of recruits ($N_{y,1}$ in 1989 through 2013) and an initial year's abundance-at-age ($N_{1989,a}$ for ages 2-7^+). These initial conditions were both modeled as lognormally distributed variables. From these starting abundances, older ages are sequentially modeled as:

$$N_{y+1,a+1} = N_{y,a} e^{-\sum_f F_{f,y,a} - M_a},$$

where M_a is the age-specific instantaneous M rate. A "plus" group abundance included survivors from both the previous year's plus group and that year's next-to-oldest age group

$$N_{y+1,A} = N_{y,A-1} e^{-\sum_f F_{f,y,A-1} - M_{A-1}} + N_{y,A} e^{-\sum_f F_{f,y,A} - M_A},$$

where *A* is age 7^+.

The observation model for these analyses involves total catch, the proportion of the fleet- and year-specific catch in each age group, and indices of abundance. The fleet- and year-specific predicted catch-at-age, $C_{f,y,a}$, was calculated using the Baranov catch equation:

$$\hat{C}_{f,y,a} = N_{y,a} \frac{F_{f,y,a}}{\sum_f F_{f,y,a} + M_a} \left(1 - e^{-\sum_f F_{f,y,a} - M_a}\right),$$

with the annual total catch for each fleet determined by summing across ages and the proportion-at-age in the catch determined from the age-specific catch relative to this annual total. The observed catch has an assumed lognormal error, ε_{fya}, from the true catch and the model estimates the true catch.

Indices of abundance were assumed linearly related to the stock abundance of chosen age group(s):

$$\hat{I}_{s,y} = q_s N_y,$$

where $I_{s,y}$ is the predicted index of relative abundance for the age(s) caught by survey s in year y, q_s is the proportionality constant for survey s, and N_y is the abundance for the age(s) included in the index.

The objective function used to confront the observation model predictions with the observed data contained abbreviated lognormal negative log likelihoods for fleet- and year-specific total catch and annual indices of abundance where:

$$negLL\left(\mathrm{T}_f\right) = \sum_y \left(0.5 \frac{\left(\ln\left(\overset{o}{T}_{f,y} + 1.e^{-6} \right) - \ln\left(\sum_a \hat{C}_{f,y,a} + 1.e^{-6} \right) \right)^2}{\sigma^2_{f,y}} + \ln\left(\sigma_{f,y}\right) \right)$$

where $T_{f,y}$ is the observed total number killed each year y by fleet f and $\sigma_{f,y}$ is the standard error of the total catch within each fleet each year. The variance was estimated from the reported CVs using $\sigma^2=\ln(CV^2+1)$. The CVs were available for the recreational fisheries as the proportional standard error (PSE) and were assumed low (0.01) for the commercial fisheries. Likewise, the negative log likelihoods for the indices of abundance were:

$$negLL\left(\mathrm{I}_s\right) = \sum_y \left(0.5 \frac{\left(\ln\left(\overset{o}{I}_{s,y} + 1.e^{-6} \right) - \ln\left(q_s \sum_a \hat{N}_{y,a} + 1.e^{-6} \right) \right)^2}{\sigma^2_{s,y}} + \ln\left(\sigma_{s,y}\right) \right)$$

where $I_{s,y}$ is the observed index for the age(s) in the survey in year y, and $\sigma_{s,y}$ is the standard error of the survey index in year y, estimated from the original data or from a standardization procedure, e.g. delta lognormal method (Lo *et al*. 1992). Of course, in the case of multi-age indices, estimated abundances across these ages would be compared to the index value.

For the catch proportion-at-age, a multinomial negative log likelihood was used:

$$negLL\left(P_{f,y}\right)=-\sum_{a}\left(n_{f,y}\left(\overset{o}{P}_{f,y,a}+1.e^{-6}\right)\ln\left(\frac{\hat{C}_{f,y,a}}{\sum_{a}\hat{C}_{f,y,a}}+1.e^{-6}\right)\right)$$

where $P_{f,y,a}$ is the observed proportion-at-age a in the total catch for fleet f in year y and $n_{f,y}$ is the sample size for aged fish. These components were not included for the fleets where the selectivity estimates based on tagging were used (northern live release recreational fishery and the southern stock's Florida recreational live release fishery).

There were additional observed data derived from a long-term tag-recapture study conducted in North Carolina that was utilized in the northern stock analyses. The estimated F-at-age and their standard errors for the pooled harvest (kept) fisheries in the north during 1989-2004 were included in the northern stock's objective function as:

$$negLL\left(\mathrm{F}_{tag(y)}\right)=\sum_{y}\left(0.5\frac{\left(\ln\left(F_{tag(y,a)}\right)-\ln\left(\sum_{f}\hat{F}_{f,y,a}\right)\right)^{2}}{\sigma^{2}_{tag(y,a)}}+\ln\left(\sigma_{tag(y,a)}\right)\right)$$

where $F_{tag(y,a)}$ and $\sigma_{tag(y,a)}$ are the observed F and its estimated standard deviation for year y and age a. The estimated F-at-age were only tallied for the recreational kept and commercial fisheries. Likewise, F-at-age estimates for the recreational live release fishery were available for the period 1989-2004 from the tagging program. However, since the selectivity vectors from this program were used as input parameters because of the lack of observations for the catch-at-age for this fishery, only the information from its fully-recruited Fs were used in the northern stock's analysis:

$$negLL\left(\mathrm{F}_{full(y)}\right)=\sum_{y}\left(0.5\frac{\left(\ln\left(F_{full(y)}\right)-\ln\left(\hat{F}_{full(y)}\right)\right)^{2}}{\sigma^{2}_{full(y)}}+\ln\left(\sigma_{full(y)}\right)\right)$$

where $F_{full(y)}$ and $\sigma_{full(y)}$ represent the fully recruited Fs for the recreational live release fishery and its standard deviation.

The final component of the objective function included the sum of squares for the log of the unstandardized (to unity) selectivitities for each fleet-specific selectivity period for ages 1 through 3. These values were configured as a deviation vector whose sum equaled zero. This added stability to the solution search routine.

The resulting objective function included input weights (λs) for the different likelihoods that reflected the relative perceived levels of accuracy associated with the estimation equations for the predicted values. The final objective function was:

$$ObjFunction = \sum_{f}\left(\lambda_{TC(f)}\, negLL\left(\mathrm{T}_f\right)\right) + \sum_{f,y}\left(\lambda_{P(f,y)}\, negLL\left(P_{f,y}\right)\right) + \sum_{s}\left(\lambda_{s}\, negLL\left(I_s\right)\right) + \sum_{1989}^{2004}\left(\lambda_{Ftag}\, negLL\left(F_{tag(y)}\right)\right) + \sum_{1989}^{2004}\left(\lambda_{Ffull}\, negLL\left(F_{full(y)}\right)\right).$$

Note that the F_{tag} and F_{full} negative log-likelihoods were not part of the southern stock analyses.

1.3. Parameters Estimated

Parameters were estimated for: age 1-3 selectivity during each block of years within a fishery where selectivity was assumed constant, age 4 and age 5^{+} selectivity as a proportion of age-3 selectivity, the fully recruited instantaneous F (also referred to as apical F) for each fishery each year, the initial abundance for ages 2-7^{+}, annual recruitment (1989-2013), and catchability coefficients for each survey. All parameters were estimated in log space. For the northern stock, 165 parameters were estimated (Table 5) and for the southern stock, 196 parameters were estimated (Table 6).

The observed data for these analyses included: total annual kill by fleet, CVs for total annual kill by fleet, proportion-at-age each year, effective number of ages sampled each year for each fleet, F-at-age for the combined “harvest” fleets during 1989-2004 (northern stock only), CVs for F-at-age for the combined “harvest” fleets during 1989-2004, fully-recruited F for recreational live release fishery during 1989-2004 (northern stock only), CVs for fully-recruited F for the recreational live release fishery during 1989-2004, annual survey catch per unit effort, and CVs for annual survey catch per unit effort. There were 783 observations (data points), not including CVs for many of the data points or aged sample-size observations, in the northern stock (Table 7) and 976 in the southern stock (Table 8).

There were a number of input parameters (part of model structure) that were assumed to be known and without error. These input parameters included: M-at-age, defined periods of constant selectivity, selectivity for all ages for Florida and northern recreational live release fisheries, release mortality, ages selected for each survey, survey time of year, and external weights for likelihoods from fleet-specific total catch.

1.4. Evaluation of Model Fits

The SAS carried over a number of hypotheses in relation to the data sets developed in the previous benchmark assessment (Tables 9 and 10) and used the total standardized residual sum of squares (RSS), visual inspection of data fits, index standardized residual sum of squares, and qualitative evaluation of age 4 and 5^{+} proportional selectivity parameter estimates (i.e., estimates away from the upper bound of 1) as criteria for choosing the most appropriate formulation.

1.5. Uncertainty and Measures of Precision

Estimated CVs (or PSEs) were used as measures of the precision for observed kill, index, and tagging F data. For the proportion-at-age data, the sample sizes and proportion indicated the precision of the observed data. For the model-estimated parameters, asymptotic standard errors were estimated during the model fitting process. The precision of important derived values, e.g., terminal three year average sSPR, was explored by describing their likelihood profiles. The implied precision from likelihood profiles is probably too great (i.e., narrow) given that there were no errors associated with input parameters, e.g., M-at-age, and the standard deviations of the standardized residuals (SDSR) often departed significantly from 1.0. This would suggest that there was additional "process error" that was not included in the model. For these reasons, the precision of the estimated parameters and derived values is almost certainly too great, i.e., confidence bands are too narrow. Iterative reweighting was done in sensitivity runs to acknowledge the additional "process error" not included in the base model and achieve "expected" fits to data (Francis 2011; SEDAR 2015a). SDSRs were calculated for each data component with input precision. Input precision was iteratively adjusted in subsequent model runs for each index and, in the north, tag data component, for those indices that had SDSRs that exceeded the upper bound suggested by Francis (2011) for a given number of observations. This process was repeated until all SDSRs fell below their upper bounds. Additional sensitivity runs were conducted to evaluate the effects model and data assumptions had on model fits and estimates. Additionally, a five year retrospective analysis was completed to determine whether there was any directional bias in the estimates as years were removed from the model.

1.6. Benchmark and Reference Points

The ASMFC (2002) defines the overfishing threshold for red drum to be 30% static spawning potential ratio (sSPR) and a management goal (fishing target) of 40% sSPR. Due to the noisiness of the data and the general imprecision of terminal year F estimates, the reviewers in SEDAR18 recommended using a three year average for management of red drum. The benchmarks estimated for this assessment include the sSPR, three year average sSPR, and escapement rate through age-5.

The sSPR is calculated as the spawning stock biomass per recruit expected under the current year's fishing regime divided by the theoretical spawning stock biomass under no fishing. This was calculated as:

$$sSPR_y = \frac{\sum_a Mat_a B_a \prod_1^a e^{-M_a - F_{y,a}}}{\sum_a Mat_a B_a \prod_1^a e^{-M_a}}$$

where Mat_a and B_a are the maturity- and weight-at-age vectors through the maximum ages (62 years in north and 41 years in south), respectively.

A more readily "observable" metric for red drum, that is very similar to sSPR when there are low levels of F on mature adults, is the escapement rate. Past assessments (Vaughan and Carmichael 2000) presented estimates of escapement through model age-3. During the most recent benchmark assessment (SEDAR 2009), it was determined that it may be more useful to encompass more of the immature portion of the stock in the escapement estimate, so escapement estimates through age-5 are presented in this assessment. Because there are a large number of adult age groups (ages 6-62 in the north and ages 6-41 in the south) assumed to have the same low level of F as for age-5 in the sSPR calculation, escapement rates are always higher than the sSPR. If there was no F on mature adults then escapement would equal sSPR levels. Static, or year-specific, escapement (sEsc) was defined as:

$$sEsc_y = e^{\sum_{a=1}^{T} -F_{y,a}}$$

where *T* is age-5. The cohort- specific escapement (tEsc), which defines the escapement rate for the cohort completing its final "escapement" age that year, is:

$$tEsc_y = e^{\sum_{a=1}^{T} -F_{y-T+a,a}}$$

2. Results

2.1. Northern Stock

The model with the lowest RSS from the data weighting hypotheses was the model with the total catch unity weighted, the indices unity weighted, the recreational harvest proportion-at-age data downweighted by 0.01, and the tagging data unity weighted (Table 11). This was the same model weighting that was chosen as the base model in SEDAR18. The fit of the model was reasonable overall and this model met all other fitting criteria. The fit was very good for the commercial catch data with very low RSS values and low SDSRs (Table 7 and Figures 1 and 2). The fit was not as good to the recreational catch data, particularly the recreational kept fleet which had a SDSR close to 2 and had poor fit in the 1990s. However, most recreational catch estimates were within the errors of the observed recreational data (Figure 1). The SDSR of the proportion-at-age data was low indicating good model fits (Table 7 and Figure 3). The index data were generally fit well (Figures 4 and 5), though all but the adult longline survey were overdispersed (SDSRs >2, Table 7). Most indices were estimated within the errors of the observed indices. The RSS values were highest for the North Carolina JAI and the MRIP indices due to the fitted model missing some of the peaks in the observed data. For the auxiliary tagging data, the fits were relatively good for age-1 and age-2 and not as good for age-3 and age-4 (Table 7 and Figure 6). The fit was very good to the full F of the release fishery (Table 7 and Figure 7).

Recruitment in the north was marked by large year classes in model years 1998, 2008, and 2012, corresponding to the 1997, 2007, and 2011 year classes (Table 12 and Figure 8). The 2012 recruitment was particularly large, approximately twice as large as any other between 1989 and 2013. As in SEDAR18, recruitment in the northern stock was estimated very precisely.

Total abundance in the northern stock shows a marked decline due to the decline in abundance of older ages (Table 13 and Figure 9). As with recruitment, the strong 2011 year class is evident in the estimates of age 1-3 abundance and total abundance in 2012 and 2013. Similar to SEDAR18, this marked decline is due to a decline in age 7^{+} abundance and may be an artifact of the assessment model, particularly the assumption of fixed selectivities for the live release fleet and the North Carolina longline survey time series being so short (only seven years).

The selectivities for each fleet and age for the three selectivity blocks are shown in Figure 10. For the kept fisheries (commercial gill net beach seine (GNBS), commercial other, and recreational harvest), peak selectivity occurred at age-2 across all selectivity blocks. The selectivity curves in the last selectivity block (1999-2013) are the narrowest and the kept selectivities are wider in earlier time blocks (broader slot range prior to 1992). The recreational live release fishery selectivities were fixed based on external tag-based estimates (Bacheler et al. 2008) but as with the kept fisheries, the selectivity in the most recent time block also peaked at age-2 before dropping to low levels.

F by year, age, and fleet are shown in Table 14 and the total F-at-age is shown in Table 15. The highest fleet specific F rates occur in the recreational harvest and commercial GNBS fleets (Figure 11). F rates are generally very low in the commercial other and recreational release fleets. Fs were particularly high in 1989 and 1990 before declining in 1991. The F rates have been generally low in all of the fleets with the exception of peaks as year classes have moved through the fisheries.

Correlation of model parameters with absolute values greater than 0.90 are in Table 16. All correlations above this threshold are between commercial F estimates and subsequent year commercial F estimates or prior year recruitment estimates.

2.1.1. <u>Stock Status</u>

Static and transitional escapement rates for ages 1-5 are shown in Table 17 and Figure 12. Escapement was low in the late 1980s and early 1990s and increased through the mid-1990s. Values have been fairly high and stable since around 2000, though there may be a slight decrease in the most recent years, particularly in 2012.

The sSPR increased throughout the 1990s (Table 18 and Figure 13). While the data is quite noisy, it appears to have been generally high in the 2000s and decreasing in recent years. In 2013, sSPR was estimated at 50.4% in the northern stock. Similar to the sSPR estimates, the average sSPR increased throughout the 1990s and peaked in 2005 before starting to decline (Table 18 and Figure 14). However, the 2011-2013 average sSPR is 43.8%, above the target (40%) and threshold (30%) values. Using ADMB's likelihood profile capabilities, the posterior probability density of the 2013 three year average sSPR was estimated. This estimation suggests that it is likely that the terminal year average sSPR estimate is above the management sSPR threshold of 30% (Figure 15).

2.1.2. Retrospective Analysis

In general, the model was very insensitive to removing years of data and estimates in recruitment and three year average sSPR were very consistent (Figure 16). The only exception was when the model only had data through 2010. In this model run, the recruitment estimates were slightly higher and the three year average sSPR was lower.

2.1.3. Sensitivity Analysis

In SEDAR18, the northern model was very sensitive to the inclusion of the tag-based F data and the TC felt that this necessitated a sensitivity run in this assessment. The removal of the tag-based F data did not affect the estimates of recruitment and resulted in slightly higher three year average sSPR estimates (Figure 17). The main effect the removal of the tagging data had was to increase the confidence intervals of the recruitment and three year average sSPR estimates. As the tagging data only span 1989-2004, it may be that the addition of nine years of data has lessened the impact the tagging data has on the model results.

Sensitivity analysis was conducted to determine the influence of each index of abundance on the model (Figure 18). Most of the model runs converged on a similar three year average sSPR value. The removal of the North Carolina IGNS age-1 index and the North Carolina JAI initially resulted in a lack of model convergence. Convergence was able to be achieved, however, by adjusting the bounds on the selectivity constraint parameters which changed the starting values of these parameters. When either the North Carolina IGNS age-1 or North Carolina JAI were removed, this resulted in lower sSPR values in the early part of the time series but similar sSPRs in the later part of the time series. The removal of the MRIP index, by comparison, gave similar three year average sSPR estimates in the early part of the time series but resulted in lower sSPR values at the end of the time series. The removal of the MRIP index was the only one of these model runs that resulted in the terminal year estimate of three year average sSPR to fall below the management threshold.

A sensitivity run was also conducted using iterative reweighting as suggested by the review panel in SEDAR18. The CVs for all indices except the North Carolina Longline survey and the F-at-age data for ages 2-4 had to be increased to achieve SDSRs below the upper limit suggested by Francis (2011). The adjustments are in Table 19. These adjustments resulted in a better fit to the recreational harvest and age-3 harvest F, particularly in the final selectivity period (after 1998). Conversely, the fit to the age-4 harvest F deteriorated in the final selectivity period (Figure 19). Both changes in fit to the F-at-age data indicate higher F on these ages in the final selectivity period (Figure

20), resulting in higher selectivity estimates and lower sSPR estimates than the base model. Changes in the three year average sSPR are most pronounced from 2009-2013, when they start to fluctuate around the target before falling below the target in the final two years (Figure 21). The estimates do not fall below the threshold. The reweighting acknowledges some process error due to interannual variability of the index catchabilities (i.e., increased input CVs), propagating additional uncertainty into the model estimates (Table 20).

2.2. Southern Stock

The model with the lowest RSS (Table 21) in the south had a very high index RSS value. As Francis (2011) recommends fitting the abundance indices well and this model improved the fit to the total catch and proportion-at-age data at the expense of the index data, this model was not selected as the best model. Models with the next lowest RSS values were evaluated and discarded for the following reasons: high (>700) index RSS, estimated selectivity constraints for ages 4 and 5^{+} greater than 0.9 of the age-3 selectivity, and poor visual fit to the Florida live release catch. The remaining two models under consideration had the total catch and indices unity weighted and differed by how much the Georgia/South Carolina recreational discard proportion-at-age data were downweighted (0.1 vs. 0.001). As these models produced very similar results, the model with the proportion-at-age data downweighted to 0.1 was chosen as the preferred model as it was the preferred model used in SEDAR18 and the weighting was generally consistent with the northern model.

The fit of the preferred model was reasonable overall. The fit was very good for the catch data with very low RSS values and low SDSR values (Table 8 and Figures 22 and 23). All of the catch estimates were within the errors of the observed data (Figure 22). The SDSRs of the proportion-at-age data were also low indicating good model fits, though it was slightly higher for the Georgia/South Carolina release fleet (Table 8 and Figure 24). The index data were generally fit well (Figures 25 and 26) although most were overdispersed, particularly the South Carolina trammel net survey indices and the adult longline indices (Table 8). Most indices were estimated within the errors of the observed indices, though some peaks in the observed data were missed by the model. The correlation of estimated values and parameters was explored using the correlation matrix output by ADMB. A large number of annual estimates of F for the fleets were strongly (>0.90) and positively correlated with annual F estimates from other years and fleets (Appendix C). The Florida recreational harvest fleet F and Florida discard fleet had the most correlations with other fleet and year specific Fs. There was also strong negative correlations between the recruitment estimates in 1989 and 1990 with various annual estimates of F, again particularly with the Florida fleets.

Estimated recruitment showed peaks in model years 1995, 2001, 2003, 2010 and 2013 (Table 22 and Figure 27). However, as in SEDAR18, abundance was very imprecisely estimated. Total abundance for the southern stock showed an upward trend and mirrored the trends seen in the ages 1-3 abundance (Table 23 and Figure 28). Age 4^{+} abundance has been fairly stable and exhibits a slight upward trend.

The selectivities for each fleet and age for the various selectivity blocks are shown in Figure 29. Florida's recreational kept fishery had one selectivity block which peaked at age-3. Florida's recreational release fishery's selectivity was fixed based on tag-based estimates of selectivity from North Carolina (Bacheler et al. 2008). Georgia's kept fleet (commercial and recreational) peaked at age 1 for all time blocks. In the most recent selectivity period (2002-2013), the tail of the curve decreases more rapidly than in the 1989-1991 time block, likely due to the implementation of maximum size regulations. The selectivities for the South Carolina kept fleet was similar across all selectivity blocks with the main differences seen in the age-1 selectivity estimates. The Georgia/South Carolina release fleet selectivity peaked at age-1 in the 1989-1991 time period and stayed high through age-3 while the selectivity in the 1992-2013 time period was slightly lower for ages 1 and 2 and peaked at age-3.

F by year, age, and fleet are shown in Table 24 and the total F-at-age is shown in Table 25. The highest fleet specific F rates occur in the Florida and South Carolina harvest fleets (Figure 30). A large increase in annual F can be seen in the Florida harvest fleet in recent years, though slight increases can also be seen in the Florida and Georgia/South Carolina release fleets.

2.2.1. Stock Status

Static and transitional escapement for ages 1-5 are shown in Table 26 and Figure 31. Escapement has fluctuated mostly between 0.6 and 0.7 since the early part of the time series. Since 2005, however, there has been a slight decrease in static escapement, falling to the lowest value in the time series in terminal year 2013.

Both sSPR (Table 27 and Figure 32) and three year average sSPR (Table 27 and Figure 33) have been stable throughout the early part of the time series and show a slight decrease in recent years. However, as in SEDAR18, the asymptotic confidence bounds on these values are very large making any conclusions on stock status very uncertain. The terminal year three year sSPR for the southern stock is 53.5%, above both the target and threshold values. Using ADMB's likelihood profile capabilities, the posterior probability density of the 2013 three year average sSPR was estimated. This estimation suggests that it is likely that the terminal year average sSPR estimate is above the management sSPR threshold of 30% (Figure 34).

2.2.2. Retrospective Analysis

A five year retrospective analysis was conducted to see how recruitment and the three year average sSPR values changed as years of data were removed (Figure 35). Using the full time series (through 2013) resulted in lower estimates of recruitment and three year sSPR than any other terminal year. All other terminal year model runs using data through 2009-2012 converged on similar solutions.

2.2.3. Sensitivity Analyses

Indices were removed from the model individually to determine how sensitive the model estimates of three year sSPR were to the inclusion of certain indices (Figure 36). Removal of the Florida haul seine surveys resulted in higher three year sSPR values than the base run. Removal of the South Carolina trammel net survey (both ages-1 and 2) and the MRIP survey resulted in much lower estimates of three year average sSPR. Depending on which surveys were included, a very wide range of estimates for three year average sSPR were observed, though most of these point estimates were above the management threshold.

A sensitivity run was also conducted using iterative reweighting as suggested by the review panel in SEDAR18. The CVs for all indices which had SDSR values greater than those suggested by Francis (2011) were increased using the adjustments in Table 28. Following just one iteration, all index and proportion-at-age data had SDSR values around or less than 1 (Table 29) and within the recommended bounds. Additionally, the total standardized residual sum of squares and total negative log-likelihood were reduced and the visual fits of the Georgia/South Carolina release fleet proportion-at-age data were improved. This weighting, while fitting the observed data components better, did not improve the precision of the population estimates (i.e. total abundance, abundance at age, or sSPR). Three year average sSPR values were very similar between the base model and the iteratively reweighted model, with the iteratively re-weighted model estimating slightly higher sSPR (Figure 37). Total abundance estimates between the base run and the iteratively reweighted run were divergent in the early and late parts of the time series (Figure 38). The difference in the early part of the time series was primarily driven by the estimated age 7^{+} abundance (Figure 39). This trend in the iteratively reweighted model shows a greater increase in total abundance as regulations were put in place in the early 1990s.

The M values used for the southern base model were from the SEDAR44 base runs and were estimated in SS3 with the SS3 age-2 M-at-age fixed based on external estimates. A sensitivity run was conducted using the M-at-age values from SEDAR18 to determine what effect this would have on the model results. The SEDAR18 M-at-age values were slightly higher than those estimated by SS3 for ages 1-4 and the same for ages 5-7^{+}. The model run using the SEDAR18 M-at-age values resulted in higher estimates of the three year average sSPR (Figure 40) and higher estimates of total abundance (Figure 41) when compared to the base model.

The weights-at-age used to calculate sSPR in the base model were also updated to match the values estimated by SS3 in SEDAR44. A sensitivity analysis was conducted using the SEDAR18 weights-at-age which were estimated using a spline. As spawning stock biomass was not calculated in this assessment, following the recommendations from SEDAR18, and sSPR is calculated as the ratio of fished spawning potential to unfished spawning potential, the change in the weights-at-age data did not change the three year average sSPR estimated when compared to the base model (Figure 40). Similarly, the estimates of total abundance did not change from the base model (Figure 41).

3. Discussion

The models presented here use essentially the same codes as were used in the previous benchmark assessment (SEDAR 2009) and, other than adding the infinite series correction, the main updates to the models were in the indices used, an updated maturity schedule and M vector for the southern stock, and updated weights-at-age. Additional exploration of the models was conducted based on the SEDAR18 reviewers' comments. These included using iterative reweighting and exploring the correlation of parameters. Iterative reweighting did not change the sSPR estimates for the southern stock much but did result in better fits to the observed data components and a trend in stock abundance that intuitively makes sense. The iterative reweighting of the northern stock model did give different results in the estimated three year average sSPR, estimating a lower terminal three year average sSPR value than the base model. However, the iterative reweighting did result in poorer fits to the F-at-age data for older fish after 1998, suggesting much higher selectivity than the base model even though harvest of fish greater than 27 inches was prohibited in North Carolina starting in 1999. Correlation analysis showed few strong correlations between parameter estimates in the northern model but a large number of correlations in the southern model. Reviewer comments from SEDAR18 suggested that this could show the model is overparameterized and future work should explore how the model could be simplified (e.g. reducing the number of fleets).

Most of the analyses completed in this assessment do indicate that both stocks are being fished above the threshold of 30% sSPR. The three year average sSPR point estimates from the base models for both stocks also indicate that both stocks are being fished above the target of 40% sSPR. However, the models do estimate trends in three year average sSPR in both stocks declining towards the target since about 2005. There are no apparent trends in recruitment estimates in either stock and the largest year class occurred in 2011 and 2009 in the northern and southern stocks, respectively.

One improvement in results from this assessment is the reduced reliance of the northern base model on the externally-derived F estimates. This indicates that the other data components in the base model agree with the F estimated in the Bacheler et al. 2008 tagging study, given the model configuration assumptions. It is important to note, however, that while the northern base model was less sensitive to the exclusion of the tagging data in the base model than it was in SEDAR18, similarly drastic changes were seen in the results when unity weights were used rather than the preferred model weighting. In contrast to SEDAR18 which estimated very large sSPRs when the tagging data were removed, the removal of the tagging data in the model with unity weights resulted in very low sSPRs. Nevertheless, the incorporation of tagging data directly into the model for both stocks, as recommended in SEDAR 18, should still be explored.

The inclusion of an adult index in the northern model and additional adult indices in the south addressed a particular shortcoming of the previous benchmark assessment. However, these indices have short time series, especially when compared to the life span of red drum, and will hopefully become more useful in the future. Despite improved information on mature fish through the new indices, the catch-at-age data are still too sparse to expand the age structure used in the model beyond an age-7 plus group and some of the concerns in the previous benchmark assessment remain in this assessment. The model still seems unable to provide realistic estimates of abundance of older ages. This was particularly true for the northern model which had very large age 7^+ estimates starting in the late 1980s. These northern model estimates for ages 7^+ also did not seem to track changes in regulation that would be expected, particularly the addition of a maximum harvest size in 1999. During SEDAR44, the year class information from the adult surveys were further explored and shown to track large year classes from the 1970s and 1980s well. Future work incorporating the age composition data for the adult indices into the SCA model could be useful.

Estimates of abundance and sSPR in the southern model continue to have very large confidence intervals. This uncertainty around the estimates makes it particularly difficult to reliably determine stock size or stock status in the south and as recommended by the reviewers in SEDAR18, the trends in abundance and sSPR are useful for only relative trends in the south.

Further work on the SCA models could be undertaken to possibly improve the models' stability and its ability to estimate abundance of mature fish. Initial work undertaken as a continuity analysis had focused on adapting the models to more closely resemble the SS3 models. The main change for this was to have the model estimate the selectivities for the release fleets rather than fixing them as was done in SEDAR18 for the northern model and for the Florida release fleet in the south. These runs, however, were found to be less stable and more sensitive to the weighting used, particularly in the south. For this reason, the SAS went back to using the original SEDAR18 codes, with the addition of the infinite series correction. However, this model configuration did show reasonable trends in the ages 7^+ abundance estimates for the northern model and may be worth further consideration. Stability to this model could be increased by estimating only one set of selectivity constraints rather than different ones for kept versus released fish. Another possibility could be coding the selectivities using a parametric equation.

Fishery selectivities remain a major uncertainty of red drum assessments. Selectivities are constrained in the model by several assumptions and directly impact the model sSPR estimates. The Bacheler et al. 2008 tagging study was used to validate these assumptions and allow the model to estimate sSPR. Additionally, more reliable data on the age structure of the removals, particularly the recreational removals, may improve the models' ability to estimate selectivity and adult abundance.

There are some conflicts in the data that result in poor fits to some data points. For example, the indices in the northern model tend to disagree about the relative abundance in some years (i.e., 2001 year class). The MRIP and NC IGNS age-1 indices indicate high relative abundance of this year class, while the NC IGNS age-2 and NC JAI indices indicate low relative abundance of this year class. The model "smoothes" over this conflict by overestimating the NC IGNS age-2 and NC JAI indices and underestimating the NC IGNS age-1 and MRIP indices. These effects should be diminished by using the three year average sSPR for management, unless there is a consistent disagreement between the data sources. There may be some spatial effects that contribute to these conflicts, as the MRIP index is the only index that incorporates relative abundance information from states north of North Carolina and is the only index that spans the entire range of red drum in the south. Spatial dynamics should be an area of focus in future assessments, particularly if additional indices of abundance from states north of North Carolina become available.

4. Literature Cited

ASMFC. 2002. Amendment 2 to the Interstate Fishery Management Plan for Red Drum. ASMFC. Washington, D.C. 142 pp.

Bacheler, N.M., J.E. Hightower, L.M. Paramore, J.A. Buckel, and K.H. Pollock. 2008. Age-dependent tag return model to estimate mortality and selectivity of an estuarine-dependent fish with high rates of catch and release. Transaction of the American Fisheries Society 137: 1422-1432.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Canadian Journal of Fisheries and Aquatic Sciences 68: 1124-1138.

Lo, N.C.H., Jacobson, L.D. and Squire, J.L. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences*, 49: 2515-2526.

Lorenzen, K. 1996. The relationship between body weight and natural mortality in juvenile and adult fish: A comparison of natural ecosystems and aquaculture. J. Fish. Biol. 49:627-647.

Methot, Jr., R. D. and Wetzel, C.R. 2013. Stock Synthesis: A biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research*. http://dx.doi.org/10.1016/j.fishres.2012.10.012

SEDAR. 2009. SEDAR18: Review Workshop Report, Atlantic Red Drum. SEDAR. North Charleston, SC.

SEDAR. 2015a. SEDAR 40 – Atlantic Menhaden Stock Assessment Report. SEDAR, North Charleston SC. 643 pp. available online at: http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=40.

SEDAR. 2015b. SEDAR 44 – Atlantic Red Drum Stock Assessment Report. SEDAR, North Charleston SC. 890 pp. available online at: http://sedarweb.org/sedar-44.

SEDAR. 2016. Addendum II to the SEDAR 44 Red Drum Stock Assessment Report.

Vaughan, D.S. and J.T. Carmichael, 2000. Assessment of Atlantic red drum for 1999: northern and southern regions. NOAA Tech. Memo. NMFS-SEFSC-447.

5. Tables

Table 1. Indices used in the northern stock model.

Index	Years
NC Independent Gill Net Survey—Age 1	2001-2013
NC Independent Gill Net Survey—Age 2	2001-2013
NC Juvenile Abundance Index	1992-2013
MRFSS/MRIP Index	1991-2013
NC Longline Survey	2007-2013

Table 2. Indices used in the southern stock model.

Index	Years
FL Bagged Beach Seine Survey (YOY)	2002-2013
GA Gill Net Survey—Age 1	2003-2013
SC Stop Net Survey (YOY)	1989-1994
SC Trammel Net Survey—Age 1	1994-2013
SC Trammel Net Survey—Age 2	1994-2013
FL Haul Seine Survey—Age 2	1997-2013
FL Haul Seine Survey—Age 3	1997-2013
MRFSS/MRIP Index	1991-2013
SC 1 mile Longline Survey (Adult)	1994-2004
SC 1/3 mile Longline Survey	2007-2013
GA Longline Survey	2007-2013

Table 3. Selectivity blocks used in the northern stock model.

Fleet	Selectivity Block	Years
Commercial Gill Net and Beach Seine	1	1989-1991
Commercial Gill Net and Beach Seine	2	1992-1998
Commercial Gill Net and Beach Seine	3	1999-2013
Commercial Other Gears	1	1989-1991
Commercial Other Gears	2	1992-1998
Commercial Other Gears	3	1999-2013
Recreational Kept	1	1989-1991
Recreational Kept	2	1992-1998
Recreational Kept	3	1999-2013
Recreational Live Release	1	1989-1991
Recreational Live Release	2	1992-1998
Recreational Live Release	3	1999-2013

Table 4. Selectivity blocks used in the southern stock model.

Fleet	Selectivity Block	Years
FL Recreational Kept	1	1989-2013
GA Commercial/Recreational Kept	1	1989-1991
GA Commercial/Recreational Kept	2	1992-2001
GA Commercial/Recreational Kept	3	2002-2013
SC Commercial/Recreational Kept	1	1989-1993
SC Commercial/Recreational Kept	2	1994-2000
SC Commercial/Recreational Kept	3	2001-2013
FL Recreational Live Release	1	1989-2013
GA/SC Recreational Live Release	1	1989-1991
GA/SC Recreational Live Release	2	1992-2013

Table 5. Estimated parameters in the SCA models for red drum population dynamics in the northern stock. Parameters for each stock include those that describe fishing mortality: annual fully recruited F's (log_F) for each fishery, age 1-3 selectivities (log_sel) for each period of assumed constant selectivity, and age 4-5$^+$ selectivities as a proportion of age 3 selectivity (sel04, sel05). Abundance-estimate related parameters include recruitment (log_R), first-year abundance for ages 2-7$^+$ (log_initN), and index-of-abundance proportionality coefficients ('survey scalars' or log_q).

Northern stock

Population dynamic	Parameters estimated		Number
Fishing mortality			
Comm BS&GN	1989-2013 log_F's; 3 sets of age 1-3 log_sel's		34
Comm other	1989-2013 log_F's; 3 sets of age 1-3 log_sel's		34
Rec A+B1	1989-2013 log_F's; 3 sets of age 1-3 log_sel's		34
Rec B2	1989-2013 log_F's		25
Ages 4-5$^+$ sel	constant sel04 and sel05		2
		Total	129
Abundance			
recruitment	log_R 1989-2013		25
initial abundance	log_initN for ages 2-7$^+$		6
survey scalar	log_q's for five surveys		5
		Total	36
Grand Total			165

Table 6. Estimated parameters in the SCA models for red drum population dynamics in the northern stock. Parameters for each stock include those that describe fishing mortality: annual fully recruited F's (log_F) for each fishery, age 1-3 selectivities (log_sel) for each period of assumed constant selectivity, and age 4-5⁺ selectivities as a proportion of age 3 selectivity (sel04, sel05). Abundance-estimate related parameters include recruitment (log_R), first-year abundance for ages 2-7⁺ (log_initN), and index-of-abundance proportionality coefficients ('survey scalars' or log_q).

Southern stock

Population dynamic	Parameters estimated		Number
Fishing mortality			
FL rec A+B1	1989-2013 log_F's; 1 sets of age 1-3 log_sel's		28
GA rec A+B1	1989-2013 log_F's; 3 sets of age 1-3 log_sel's		34
SC rec A+B1	1989-2013 log_F's; 3 sets of age 1-3 log_sel's		34
FL rec B2	1989-2013 log_F's		25
GA/SC rec B2	1989-2013 log_F's; 2 sets of age 1-3 log_sel's		31
Ages 4-5⁺ sel	constant sel04 and sel05		2
		Total	154
Abundance			
recruitment	log_R 1989-2013		25
initial abundance	log_initN for ages 2-7⁺		6
survey scalar	log_q's for eleven surveys		11
		Total	42
Grand Total			196

Table 7. Likelihood components of the northern stock base model.

Components		N	TSS	RSS	NegLL	SDSR
Total Kill						
Comm GN & BS		25	84,705.83	0.12	-115.07	0.07
Comm Other		25	165,558.94	0.00	-115.13	0.01
Rec Kept		25	140.26	110.95	22.05	1.99
Rec Release		25	350.71	43.41	-7.77	1.31
	Totals	100	250,755.74	154.48	-215.92	
Proportion-at-age						
Comm GN & BS		175			359.92	0.08
Comm Other		175			130.07	0.32
Rec Kept		175			486.48	0.12
	Totals	525			976.47	
Indices of Abundance						
NC IGNS age 1		13	207.19	58.26	7.89	2.11
NC IGNS age 2		13	309.64	74.64	19.58	2.38
NC JAI age 1		22	333.08	262.87	98.61	3.45
MRIP ages 1-3		23	855.94	256.21	74.16	3.31
NC Adult Longline		7	4.49	7.08	-8.65	1.01
	Totals	78	1,710.34	659.05	191.58	
Auxiliary Observations						
F kept at age-1		16	840.21	14.83		0.99
F kept at age-2		16	293.06	22.09		0.97
F kept at age-3		16	298.33	315.49		4.59
F kept at age-4$^+$		16	1,816.75	380.74	247.91	5.03
Full F release		16	354.87	10.47	-25.18	0.81
	Totals	80	3,603.22	743.62	222.72	
Other Deviations						
Selectivities					57.99	
	Totals				57.99	
Grand Total					1,232.84	

Table 8. Likelihood components of the southern stock base model.

Components		N	TSS	RSS	NegLL	SDSR
Total Kill						
FL Rec		25	177.51	0.67	-43.80	0.16
GA Comm/Rec		25	116.15	0.32	-38.20	0.11
SC Comm/Rec		25	86.67	1.06	-32.81	0.20
FL Releases		25	198.77	0.07	-43.17	0.05
GA/SC Releases		25	310.38	0.03	-36.83	0.03
	Totals	125	889.47	2.15	-194.81	
Proportion-at-age						
FL Rec		175			547.00	0.13
GA Comm/Rec		175			593.21	0.89
SC Comm/Rec		175			913.69	0.54
GA/SC Releases		175			116.65	1.61
	Totals	700			2170.55	
Indices of Abundance						
FL Bagged Beach Seine Survey		12	26.43	16.76	-0.79	1.17
GA Gill Net Survey—Age 1		11	71.48	34.86	-0.49	1.78
SC Stop Net Survey		6	9.99	12.22	-2.58	1.40
SC Trammel Net Survey—Age 1		20	276.83	99.33	11.90	2.23
SC Trammel Net Survey—Age 2		20	253.44	100.13	12.56	2.24
FL Haul Seine Survey—Age 2		17	28.34	52.85	-2.82	1.76
FL Haul Seine Survey—Age 3		17	20.44	54.54	3.12	1.79
MRIP Index		23	411.08	76.53	-32.81	1.82
SC 1 mile Longline Survey (Adult)		11	44.97	46.95	6.06	2.06
SC 1/3 mile Longline Survey		7	34.19	32.82	2.27	2.15
GA Longline Survey		7	32.48	30.84	5.74	2.10
	Totals	151	1,209.65	557.82	2.14	
Other Deviations						
Selectivities					34.25	
	Totals				34.25	
	Grand Total				2,012.13	

Table 9. The external hypotheses (weights) used to evaluate 'best' model fit in the northern stock. The total catch fleets were the commercial gillnet and beach seine, the other commercial gears, the recreational landed (MRIP Type A+B1) catch, and the recreational live release. The first three of these were included in the proportion-at-age weights (the age composition of the live release fishery was implied from tagging estimates). The indices were the North Carolina independent gill net survey (IGNS) age 1 index, the IGNS age 2 index, the North Carolina juvenile abundance index, the MRFSS total catch rate index, and the North Carolina Longline survey. The tag-based F weights were used for the F-at-age estimates from the recreational landed fish and the fully recruited F's for the live release fishery.

<u>Total Catch by fleet</u>

H_o : default

1. 1. 1. 1.

H_{a1}: live release recreational total catch estimates are suspect

1. 1. 1. 0.1

H_{a2}: live release recreational total catch estimates are really suspect

1. 1. 1. 0.01

<u>Proportion-at-age (excludes the live release fishery)</u>

H_o: default

catch-at-age by fleet and year all year and all fleets 1.0

H_a: the recreational age composition data is less certain than commercial

commercial fleets are 1.0 and recreational fleet is 0.01

<u>Indices of abundance</u>

H_o: default

1. 1. 1. 1. 1.

H_{a1}: the MRIP index is best due to larger spatial coverage

1. 1. 1. 10. 1.

H_{a2}: the YOY indices are best due to scientific design and ease of capture

10. 1. 10. 1. 1.

<u>Tagging based F (for kept F-at-age and then full F live release recreational)</u>

H_o: default

1. 1.

H_a: both less accurate than catch-at-age model

0.1 0.1

Table 10. The external hypotheses (weights) used to evaluate 'best' model fit in the southern stock. The total catch fleets were the Florida recreational landed (MRIP Type A+B1) fishery, the Georgia recreational landed commercial fishery, the South Carolina recreational landed/commercial fishery, the Florida live release fishery, and the Georgia/South Carolina live release fishery. All but the Florida live release fishery (in order) were included in the proportion-at-age weights (the age composition of the Florida live release fishery was implied from tagging estimates). The indices were the Florida small seine survey, the Georgia monofilament gill net survey, the South Carolina stop net survey, the South Carolina age-1 trammel net survey, the South Carolina age-2 trammel net survey, the Florida age-2 haul seine survey, the Florida age-3 haul seine survey, the MRIP index, the South Carolina 1 mile longline survey, the South Carolina 1/3 mile longline survey, and the Georgia longline survey.

<u>Total Catch by fleet</u>

H_o : default

1. 1. 1. 1. 1.

H_{a1}: live release recreational total catch estimates are uncertain

1. 1. 1. 0.1 0.1

H_{a2}: live release recreational total catch estimates are really uncertain

1. 1. 1. 0.01 0.01

<u>Proportion-at-age (excludes the Florida live release fishery)</u>

H_o: default

catch-at-age by fleet and year all year and all fleets 1.0

H_{a1}: the live release recreational age composition data is less certain than other data

landed fisheries are 1.0 and recreational live release fleet is 0.1

H_{a2}: the live release recreational age composition data is <u>much</u> less certain than other data

landed fisheries are 1.0 and recreational live release fleet is 0.01

<u>Indices of abundance</u>

H_o: default

1. 1. 1. 1. 1. 1. 1. 1. 1. 1. 1.

H_{a1}: the MRIP index is best due to larger areal coverage

1. 1. 1. 1. 1. 1. 1. 10. 1. 1. 1.

H_{a2}: the YOY indices are best due to scientific design and ease of capture

10. 10. 10. 10. 1. 1. 1. 1. 1. 1. 1.

Table 11. Total standardized residual sums of squares for the northern stock weighting hypotheses. Weighting combinations with no number entered failed to converge. Bolded value is the model weighting with the lowest RSS.

Tag Based F, H0			Total Catch Hypothesis			
		Indices H0		H0	Ha1	Ha2
		PAA	H0	1,657		2,434
			Ha1	**1,579**	1,605	2,096
			Total Catch Hypothesis			
		Indices Ha1		H0	Ha1	Ha2
		PAA	H0		2,481	3,340
			Ha1	1,948	2,091	2,506
			Total Catch Hypothesis			
		Indices Ha2		H0	Ha1	Ha2
		PAA	H0	1,966		3,855
			Ha1	2,133	2,586	3,264
Tag Based F, Ha1			Total Catch Hypothesis			
		Indices H0		H0	Ha1	Ha2
		PAA	H0			4,040
			Ha1	2,224	2,856	3,688
			Total Catch Hypothesis			
		Indices Ha1		H0	Ha1	Ha2
		PAA	H0	4,027	4,295	
			Ha1	3,720		
			Total Catch Hypothesis			
		Indices Ha2		H0	Ha1	Ha2
		PAA	H0	3,677	5,892	6,569
			Ha1	6,684		7,068

Table 12. Estimated recruitment with 95% confidence intervals (± 1.96 SE) for the northern stock.

Year	Est	LCI	UCI
1989	175,782	91,016	339,650
1990	145,801	101,709	208,812
1991	555,709	445,922	692,509
1992	591,845	479,008	731,285
1993	267,266	186,523	382,833
1994	499,319	414,934	600,850
1995	346,625	268,850	446,799
1996	211,928	164,861	272,257
1997	501,822	391,306	643,484
1998	934,718	817,685	1,069,109
1999	576,079	493,050	673,388
2000	161,781	124,285	210,388
2001	385,771	306,421	486,008
2002	689,002	586,950	809,270
2003	81,308	62,152	106,338
2004	450,449	379,043	535,232
2005	525,445	444,431	621,772
2006	642,422	545,198	756,599
2007	269,682	217,639	334,181
2008	928,198	801,591	1,075,010
2009	265,933	216,674	326,205
2010	310,519	250,976	384,164
2011	167,042	127,584	218,742
2012	1,899,308	1,670,928	2,157,791
2013	330,711	242,990	449,664

Table 13. Estimate beginning-of-the-year abundance of red drum ages 1 – 7^+ in the northern stock during 1989-2013.

Northern	1	2	3	4	5	6	7^+	Total
1989	175,822	82,951	11,711	18,691	173,718	142,063	13,962,773	14,567,728
1990	145,733	18,145	2,401	1,712	15,325	160,129	13,130,891	13,474,335
1991	555,703	26,476	1,211	564	1,444	14,128	12,374,686	12,974,211
1992	591,855	301,275	12,391	779	505	1,332	11,543,832	12,451,969
1993	267,221	400,924	142,784	8,175	698	466	10,758,409	11,578,677
1994	499,313	162,768	141,719	81,594	7,263	644	10,018,501	10,911,802
1995	346,586	323,748	88,300	103,263	73,439	6,686	9,315,883	10,257,905
1996	211,860	241,719	193,478	67,241	93,286	67,684	8,678,335	9,553,604
1997	501,796	158,115	161,069	153,466	60,950	86,068	8,149,807	9,271,272
1998	934,984	350,391	89,925	116,860	138,314	56,205	7,670,214	9,356,892
1999	576,207	626,052	164,312	60,534	104,863	127,552	7,196,352	8,855,873
2000	161,703	448,337	375,572	140,491	55,033	96,584	6,812,266	8,089,987
2001	385,905	124,647	248,479	318,972	127,584	50,647	6,421,222	7,677,456
2002	689,203	288,104	46,575	201,779	288,823	117,377	6,013,468	7,645,328
2003	81,296	516,227	102,316	38,017	182,736	265,672	5,695,017	6,881,281
2004	450,418	64,147	320,701	88,766	34,611	168,419	5,546,430	6,673,493
2005	525,676	353,708	38,298	276,210	80,789	31,903	5,319,139	6,625,723
2006	642,259	409,233	215,033	32,910	251,084	74,376	4,975,518	6,600,414
2007	269,686	494,676	243,199	184,360	29,873	230,797	4,687,830	6,140,420
2008	928,288	207,130	274,639	206,355	167,328	27,476	4,567,248	6,378,463
2009	265,857	694,841	98,013	228,002	186,776	153,639	4,260,964	5,888,092
2010	310,509	207,585	460,355	85,152	207,266	171,826	4,100,645	5,543,338
2011	167,057	232,104	97,805	383,220	77,052	190,215	3,958,810	5,106,262
2012	1,898,819	130,108	138,828	84,186	348,348	70,925	3,855,730	6,526,945
2013	330,551	1,285,364	48,748	111,897	75,198	315,627	3,592,926	5,760,311

Table 14. Instantaneous fishing mortality, by fleet and age, for the northern stock.

	Commercial Gill net and Beach Seine					Commercial 'other' gear fishery				
	1	2	3	4	5	1	2	3	4	5
1989	0.699	1.358	0.658	0.039	0.000	0.142	0.238	0.184	0.011	0.000
1990	0.782	1.518	0.736	0.044	0.000	0.112	0.188	0.146	0.009	0.000
1991	0.107	0.208	0.101	0.006	0.000	0.041	0.069	0.053	0.003	0.000
1992	0.025	0.104	0.040	0.002	0.000	0.004	0.013	0.008	0.000	0.000
1993	0.041	0.167	0.065	0.004	0.000	0.005	0.018	0.011	0.001	0.000
1994	0.032	0.133	0.052	0.003	0.000	0.005	0.019	0.011	0.001	0.000
1995	0.038	0.158	0.062	0.004	0.000	0.010	0.035	0.021	0.001	0.000
1996	0.023	0.095	0.037	0.002	0.000	0.003	0.012	0.007	0.000	0.000
1997	0.011	0.044	0.017	0.001	0.000	0.003	0.011	0.007	0.000	0.000
1998	0.062	0.253	0.099	0.006	0.000	0.009	0.031	0.019	0.001	0.000
1999	0.024	0.222	0.035	0.002	0.000	0.001	0.006	0.004	0.000	0.000
2000	0.021	0.192	0.031	0.002	0.000	0.001	0.006	0.004	0.000	0.000
2001	0.032	0.290	0.046	0.003	0.000	0.001	0.006	0.004	0.000	0.000
2002	0.012	0.114	0.018	0.001	0.000	0.002	0.007	0.004	0.000	0.000
2003	0.007	0.066	0.010	0.001	0.000	0.001	0.005	0.003	0.000	0.000
2004	0.016	0.143	0.023	0.001	0.000	0.001	0.002	0.001	0.000	0.000
2005	0.018	0.162	0.026	0.002	0.000	0.001	0.005	0.003	0.000	0.000
2006	0.014	0.123	0.020	0.001	0.000	0.001	0.006	0.004	0.000	0.000
2007	0.019	0.173	0.027	0.002	0.000	0.002	0.009	0.005	0.000	0.000
2008	0.029	0.264	0.042	0.002	0.000	0.001	0.006	0.004	0.000	0.000
2009	0.012	0.106	0.017	0.001	0.000	0.001	0.005	0.003	0.000	0.000
2010	0.024	0.216	0.034	0.002	0.000	0.001	0.004	0.003	0.000	0.000
2011	0.011	0.104	0.016	0.001	0.000	0.001	0.005	0.003	0.000	0.000
2012	0.012	0.105	0.017	0.001	0.000	0.001	0.006	0.004	0.000	0.000
2013	0.014	0.131	0.021	0.001	0.000	0.002	0.010	0.006	0.000	0.000

Table 14 (con't). Instantaneous fishing mortality, by fleet and age, for the northern stock.

	Recreational Harvest					Recreational Live Release				
	1	2	3	4	5	1	2	3	4	5
1989	1.208	1.811	0.980	0.058	0.001	0.022	0.005	0.000	0.000	0.000
1990	0.575	0.862	0.467	0.028	0.000	0.037	0.008	0.000	0.000	0.000
1991	0.230	0.345	0.187	0.011	0.000	0.034	0.008	0.000	0.000	0.000
1992	0.144	0.492	0.267	0.016	0.000	0.016	0.008	0.001	0.000	0.000
1993	0.207	0.705	0.382	0.023	0.000	0.043	0.020	0.001	0.001	0.001
1994	0.081	0.276	0.150	0.009	0.000	0.115	0.054	0.004	0.003	0.003
1995	0.047	0.161	0.087	0.005	0.000	0.065	0.030	0.002	0.001	0.001
1996	0.047	0.161	0.087	0.005	0.000	0.019	0.009	0.001	0.000	0.000
1997	0.106	0.361	0.196	0.012	0.000	0.039	0.018	0.001	0.001	0.001
1998	0.096	0.326	0.177	0.011	0.000	0.035	0.016	0.001	0.001	0.001
1999	0.008	0.128	0.012	0.001	0.000	0.017	0.025	0.005	0.002	0.002
2000	0.015	0.229	0.022	0.001	0.000	0.023	0.034	0.007	0.003	0.003
2001	0.034	0.521	0.051	0.003	0.000	0.026	0.037	0.008	0.003	0.003
2002	0.048	0.746	0.073	0.004	0.000	0.027	0.039	0.008	0.003	0.003
2003	0.017	0.258	0.025	0.001	0.000	0.012	0.018	0.004	0.002	0.002
2004	0.014	0.224	0.022	0.001	0.000	0.011	0.016	0.003	0.001	0.001
2005	0.011	0.171	0.017	0.001	0.000	0.021	0.030	0.006	0.003	0.003
2006	0.014	0.214	0.021	0.001	0.000	0.032	0.047	0.010	0.004	0.004
2007	0.015	0.237	0.023	0.001	0.000	0.028	0.041	0.008	0.004	0.004
2008	0.019	0.289	0.028	0.002	0.000	0.041	0.060	0.012	0.005	0.005
2009	0.009	0.133	0.013	0.001	0.000	0.026	0.038	0.008	0.003	0.003
2010	0.022	0.337	0.033	0.002	0.000	0.045	0.065	0.014	0.006	0.006
2011	0.016	0.243	0.024	0.001	0.000	0.022	0.032	0.007	0.003	0.003
2012	0.034	0.531	0.052	0.003	0.000	0.143	0.209	0.043	0.019	0.019
2013	0.019	0.288	0.028	0.002	0.000	0.031	0.046	0.009	0.004	0.004

Table 15. Estimated age-1 to age-5 instantaneous fishing mortality for the northern stock during 1989-2013.

	Northern stock				
	1	2	3	4	5
1989	2.071	3.412	1.823	0.109	0.001
1990	1.506	2.577	1.349	0.081	0.001
1991	0.412	0.629	0.341	0.021	0.001
1992	0.189	0.617	0.316	0.019	0.001
1993	0.296	0.910	0.460	0.028	0.001
1994	0.233	0.482	0.217	0.015	0.003
1995	0.160	0.385	0.172	0.012	0.002
1996	0.093	0.276	0.132	0.008	0.001
1997	0.159	0.434	0.221	0.014	0.001
1998	0.201	0.627	0.296	0.018	0.001
1999	0.051	0.381	0.057	0.005	0.002
2000	0.060	0.460	0.063	0.006	0.003
2001	0.092	0.854	0.108	0.009	0.003
2002	0.089	0.905	0.103	0.009	0.004
2003	0.037	0.346	0.042	0.004	0.002
2004	0.042	0.386	0.049	0.004	0.001
2005	0.050	0.368	0.052	0.005	0.003
2006	0.061	0.390	0.054	0.007	0.004
2007	0.064	0.458	0.064	0.007	0.004
2008	0.090	0.618	0.086	0.010	0.005
2009	0.047	0.282	0.041	0.005	0.003
2010	0.091	0.623	0.083	0.010	0.006
2011	0.050	0.384	0.050	0.005	0.003
2012	0.190	0.852	0.116	0.023	0.019
2013	0.067	0.475	0.065	0.007	0.004

Table 16. Correlation coefficients between parameters with a correlation greater than 0.90 or less than -0.90 in the northern stock model.

Parameter 1	Parameter 2	Correlation
Comm Other F 1997	Comm Other F 1998	0.9074
Comm Other F 2000	Comm Other F 2001	0.9151
Comm Other F 2001	Comm Other F 2004	0.9107
Comm Other F 2004	Comm Other F 2010	0.914
Comm GNBS F 2013	Comm Other F 2013	0.942
Comm GNBS F 1999	Recruit 1998	-0.9225
Comm GNBS F 2000	Recruit 1999	-0.9157
Comm GNBS F 2003	Recruit 2002	-0.9389
Comm GNBS F 2005	Recruit 2004	-0.9309
Comm GNBS F 2007	Recruit 2006	-0.9045
Comm GNBS F 2009	Recruit 2008	-0.9611
Comm GNBS F 2011	Recruit 2010	-0.946

Table 17. sEsc, and tEsc (ages 1-5) with asymptotic SEs and CVs for the northern stock.

Year	sEsc			tEsc		
	Est	SE	CV	Est	SE	CV
1989	0.00	0.000	0.73			
1990	0.00	0.003	0.62			
1991	0.25	0.032	0.13			
1992	0.32	0.023	0.07			
1993	0.18	0.017	0.09	0.007	0.003	0.449
1994	0.39	0.018	0.05	0.084	0.018	0.213
1995	0.48	0.016	0.03	0.222	0.015	0.069
1996	0.60	0.023	0.04	0.265	0.016	0.062
1997	0.44	0.025	0.06	0.383	0.013	0.033
1998	0.32	0.017	0.05	0.465	0.012	0.026
1999	0.61	0.017	0.03	0.508	0.015	0.030
2000	0.55	0.019	0.03	0.436	0.017	0.040
2001	0.34	0.026	0.07	0.426	0.016	0.037
2002	0.33	0.037	0.11	0.518	0.014	0.027
2003	0.65	0.037	0.06	0.533	0.016	0.030
2004	0.62	0.044	0.07	0.360	0.024	0.067
2005	0.62	0.041	0.07	0.351	0.035	0.100
2006	0.60	0.055	0.09	0.610	0.031	0.051
2007	0.55	0.049	0.09	0.616	0.039	0.063
2008	0.45	0.043	0.10	0.622	0.036	0.057
2009	0.68	0.029	0.04	0.596	0.047	0.079
2010	0.44	0.038	0.09	0.540	0.042	0.077
2011	0.61	0.046	0.08	0.479	0.040	0.083
2012	0.30	0.087	0.29	0.620	0.024	0.039
2013	0.54	0.044	0.08	0.474	0.035	0.073

Table 18. Annual sSPR and three year sSPR with asymptotic SEs and CVs for the northern stock.

Year	sSPR			3 yr sSPR		
	Est	SE	CV	Est	SE	CV
1989	0.001	0.000	0.73			
1990	0.004	0.002	0.62			
1991	0.243	0.032	0.13	0.083	0.011	0.13
1992	0.316	0.022	0.07	0.188	0.013	0.07
1993	0.180	0.017	0.09	0.246	0.014	0.06
1994	0.369	0.018	0.05	0.288	0.012	0.04
1995	0.469	0.017	0.04	0.339	0.011	0.03
1996	0.596	0.023	0.04	0.478	0.012	0.02
1997	0.429	0.024	0.06	0.498	0.013	0.03
1998	0.313	0.017	0.05	0.446	0.013	0.03
1999	0.586	0.017	0.03	0.443	0.012	0.03
2000	0.525	0.019	0.04	0.475	0.011	0.02
2001	0.325	0.025	0.08	0.479	0.014	0.03
2002	0.311	0.035	0.11	0.387	0.018	0.05
2003	0.633	0.036	0.06	0.423	0.021	0.05
2004	0.602	0.043	0.07	0.515	0.025	0.05
2005	0.593	0.042	0.07	0.609	0.026	0.04
2006	0.556	0.055	0.10	0.584	0.030	0.05
2007	0.518	0.048	0.09	0.556	0.030	0.05
2008	0.408	0.041	0.10	0.494	0.031	0.06
2009	0.647	0.033	0.05	0.524	0.027	0.05
2010	0.403	0.037	0.09	0.486	0.025	0.05
2011	0.583	0.046	0.08	0.544	0.025	0.05
2012	0.228	0.071	0.31	0.405	0.034	0.08
2013	0.504	0.044	0.09	0.438	0.034	0.08

Table 19. Multiplicative weighting factors applied to input error in the northern stock assessment model to achieve SDSRs below the upper limit suggested by Francis (2011).

Data Set	Multiplicative Weighting Factor	SDSR Upper Limit	SDSR
NC Independent Gill Net Survey—Age 1	2.10	1.32	1.10
NC Independent Gill Net Survey—Age 2	2.42	1.32	1.11
NC Juvenile Abundance Index	3.44	1.25	1.02
MRFSS/MRIP Index	4.59	1.24	1.10
NC Longline Survey	1.00	1.45	1.02
Commercial GNBS	1.00	1.23	0.17
Commercial Other	1.00	1.23	0.63
Recreational Harvest	1.00	1.23	0.40
Harvest age-1 F	1.00	1.29	1.25
Harvest age-2 F	1.34	1.29	0.92
Harvest age-3 F	4.31	1.29	0.35
Harvest age-4+ F	8.99	1.29	1.25
Recreational Release Full F	1.00	1.29	0.83

Table 20. Annual sSPR and three year sSPR with asymptotic SEs and CVs for the northern stock iteratively reweighted model.

Year	sSPR			3 yr sSPR		
	Est	SE	CV	Est	SE	CV
1989	0.00	0.001	1.00			
1990	0.01	0.008	0.65			
1991	0.21	0.043	0.21	0.07	0.015	0.20
1992	0.34	0.036	0.11	0.19	0.019	0.10
1993	0.19	0.027	0.14	0.24	0.022	0.09
1994	0.39	0.027	0.07	0.30	0.020	0.06
1995	0.46	0.026	0.06	0.35	0.018	0.05
1996	0.59	0.034	0.06	0.48	0.019	0.04
1997	0.45	0.039	0.09	0.50	0.021	0.04
1998	0.35	0.027	0.08	0.47	0.021	0.05
1999	0.54	0.025	0.05	0.45	0.019	0.04
2000	0.46	0.028	0.06	0.45	0.018	0.04
2001	0.32	0.034	0.11	0.44	0.021	0.05
2002	0.23	0.047	0.20	0.33	0.025	0.07
2003	0.63	0.042	0.07	0.39	0.027	0.07
2004	0.61	0.054	0.09	0.49	0.032	0.07
2005	0.60	0.061	0.10	0.62	0.038	0.06
2006	0.56	0.067	0.12	0.59	0.045	0.08
2007	0.49	0.071	0.14	0.55	0.051	0.09
2008	0.38	0.060	0.16	0.48	0.052	0.11
2009	0.43	0.069	0.16	0.44	0.053	0.12
2010	0.33	0.062	0.19	0.38	0.053	0.14
2011	0.51	0.069	0.14	0.42	0.054	0.13
2012	0.18	0.065	0.37	0.34	0.049	0.14
2013	0.33	0.084	0.25	0.34	0.054	0.16

Table 21. Total standardized residual sums of squares for the southern stock weighting hypotheses. Weighting combinations with no number entered failed to converge. Bolded value is the model weighting with the lowest RSS and italicized number is the model chosen for the preferred base model run.

		Total Catch Hypothesis		
Indices H0		H0	Ha1	Ha2
PAA	H0	1,240	1,168	3,433
	Ha1	*1,210*	1,158	3,544
	Ha2	1,201	1,157	3,583
		Total Catch Hypothesis		
Indices Ha1		H0	Ha1	Ha2
PAA	H0	1,148	1,192	3,877
	Ha1	**850**	1,185	
	Ha2	879	1,273	5,340
		Total Catch Hypothesis		
Indices Ha2		H0	Ha1	Ha2
PAA	H0	951	1,110	7,678
	Ha1	964	2,177	7,872
	Ha2	972	2,200	7,638

Table 22. Estimated recruitment and associated bounds (± 1.96 asymptotic standard errors) for the southern stock.

Year	-1.96SE	Est	+1.96SE
1989	344,376	1,048,558	3,192,654
1990	371,890	1,051,206	2,971,397
1991	561,393	1,523,740	4,135,756
1992	515,633	1,490,653	4,309,360
1993	491,377	1,424,046	4,126,984
1994	666,042	1,794,613	4,835,483
1995	878,402	2,264,207	5,836,321
1996	409,570	1,125,957	3,095,393
1997	456,655	1,322,172	3,828,143
1998	383,079	1,132,098	3,345,642
1999	475,059	1,362,687	3,908,810
2000	326,621	869,824	2,316,427
2001	724,662	2,034,166	5,710,016
2002	592,228	1,690,145	4,823,466
2003	731,270	2,040,881	5,695,837
2004	654,140	1,740,266	4,629,779
2005	594,702	1,579,688	4,196,077
2006	411,877	1,111,477	2,999,394
2007	583,749	1,572,756	4,237,370
2008	632,733	1,782,988	5,024,308
2009	687,894	1,954,106	5,551,042
2010	1,001,036	2,597,568	6,740,375
2011	613,234	1,592,891	4,137,575
2012	386,594	1,011,298	2,645,473
2013	789,232	2,129,962	5,748,293

Table 23. Estimate beginning-of-the-year abundance of red drum ages 1 – 7+ in the southern stock during 1989-2013.

Southern	1	2	3	4	5	6	7+	Total
1989	1,048,558	667,100	329,375	372,344	1,897,098	739,802	1,978,164	7,032,441
1990	1,051,206	786,262	486,995	260,673	313,453	1,661,009	2,421,220	6,980,817
1991	1,523,740	782,510	571,367	380,634	218,212	274,489	3,632,240	7,383,191
1992	1,490,653	1,090,488	534,229	425,208	311,719	190,480	3,476,687	7,519,464
1993	1,424,046	1,123,202	805,684	419,783	356,809	272,840	3,272,935	7,675,298
1994	1,794,613	1,061,257	834,635	644,122	355,011	312,267	3,163,403	8,165,309
1995	2,264,207	1,320,017	763,425	649,999	538,370	310,337	3,096,904	8,943,259
1996	1,125,957	1,634,147	910,247	589,016	540,999	470,662	3,036,156	8,307,185
1997	1,322,172	850,826	1,187,885	709,402	492,459	473,203	3,125,147	8,161,094
1998	1,132,098	1,006,663	633,614	959,584	602,758	430,899	3,207,939	7,973,555
1999	1,362,687	883,239	774,331	510,834	814,602	527,504	3,245,033	8,118,230
2000	869,824	1,041,250	661,546	611,171	429,542	712,367	3,361,035	7,686,735
2001	2,034,166	643,012	741,464	499,364	503,726	374,996	3,621,658	8,418,385
2002	1,690,145	1,520,240	448,040	551,517	408,866	439,567	3,554,733	8,613,108
2003	2,040,881	1,297,397	1,137,316	355,412	464,794	357,654	3,560,681	9,214,135
2004	1,740,266	1,533,199	907,247	873,408	295,195	406,243	3,490,745	9,246,303
2005	1,579,688	1,300,071	1,097,895	712,426	732,747	258,004	3,471,215	9,152,046
2006	1,111,477	1,159,300	880,292	826,375	586,457	638,983	3,315,430	8,518,313
2007	1,572,756	837,538	841,933	684,975	690,456	512,353	3,518,857	8,658,868
2008	1,782,988	1,162,262	582,209	638,212	565,619	603,001	3,587,185	8,921,477
2009	1,954,106	1,301,874	782,505	434,644	523,403	493,766	3,726,439	9,216,736
2010	2,597,568	1,502,790	982,443	626,831	367,904	458,171	3,764,483	10,300,189
2011	1,592,891	1,880,033	1,006,489	739,477	515,979	321,067	3,755,472	9,811,408
2012	1,011,298	1,187,355	1,304,045	769,036	612,809	450,695	3,629,838	8,965,076
2013	2,129,962	764,333	822,511	976,881	631,668	534,995	3,630,363	9,490,714

Table 24. Instantaneous fishing mortality, by fleet and age, for the southern stock.

	FL Rec					GA Comm/Rec				
	1	2	3	4	5	1	2	3	4	5
1989	0.004	0.024	0.028	0.013	0.001	0.025	0.024	0.018	0.008	0.000
1990	0.005	0.029	0.034	0.015	0.001	0.035	0.033	0.024	0.011	0.001
1991	0.010	0.058	0.068	0.031	0.002	0.063	0.059	0.043	0.020	0.001
1992	0.009	0.049	0.058	0.026	0.001	0.035	0.024	0.011	0.005	0.000
1993	0.005	0.028	0.034	0.015	0.001	0.043	0.030	0.014	0.006	0.000
1994	0.009	0.048	0.057	0.026	0.001	0.048	0.034	0.015	0.007	0.000
1995	0.007	0.036	0.043	0.019	0.001	0.042	0.029	0.013	0.006	0.000
1996	0.010	0.057	0.067	0.030	0.002	0.025	0.017	0.008	0.004	0.000
1997	0.005	0.026	0.031	0.014	0.001	0.017	0.012	0.005	0.002	0.000
1998	0.008	0.045	0.054	0.024	0.001	0.012	0.008	0.004	0.002	0.000
1999	0.011	0.059	0.070	0.031	0.002	0.029	0.020	0.009	0.004	0.000
2000	0.016	0.087	0.103	0.046	0.002	0.050	0.035	0.016	0.007	0.000
2001	0.016	0.090	0.107	0.048	0.002	0.035	0.024	0.011	0.005	0.000
2002	0.010	0.053	0.063	0.028	0.001	0.030	0.027	0.006	0.003	0.000
2003	0.010	0.054	0.065	0.029	0.002	0.036	0.032	0.008	0.003	0.000
2004	0.008	0.044	0.052	0.024	0.001	0.046	0.041	0.010	0.004	0.000
2005	0.012	0.066	0.078	0.035	0.002	0.040	0.037	0.009	0.004	0.000
2006	0.010	0.056	0.066	0.030	0.002	0.032	0.029	0.007	0.003	0.000
2007	0.013	0.069	0.082	0.037	0.002	0.048	0.043	0.010	0.005	0.000
2008	0.012	0.068	0.081	0.037	0.002	0.051	0.046	0.011	0.005	0.000
2009	0.006	0.030	0.036	0.016	0.001	0.023	0.021	0.005	0.002	0.000
2010	0.010	0.056	0.067	0.030	0.002	0.056	0.050	0.012	0.005	0.000
2011	0.010	0.055	0.066	0.030	0.002	0.037	0.033	0.008	0.004	0.000
2012	0.014	0.079	0.095	0.042	0.002	0.022	0.019	0.005	0.002	0.000
2013	0.023	0.124	0.148	0.066	0.003	0.028	0.026	0.006	0.003	0.000

Table 24 (con't). Instantaneous fishing mortality, by fleet and age, for the southern stock.

	SC Comm/Rec					FL Releases				
	1	2	3	4	5	1	2	3	4	5
1989	0.048	0.094	0.042	0.019	0.001	0.006	0.009	0.002	0.001	0.001
1990	0.043	0.085	0.038	0.017	0.001	0.002	0.003	0.001	0.000	0.000
1991	0.037	0.072	0.032	0.014	0.001	0.019	0.028	0.006	0.002	0.002
1992	0.028	0.055	0.024	0.011	0.001	0.007	0.010	0.002	0.001	0.001
1993	0.028	0.055	0.025	0.011	0.001	0.011	0.017	0.003	0.001	0.001
1994	0.025	0.055	0.021	0.009	0.000	0.016	0.023	0.005	0.002	0.002
1995	0.051	0.114	0.043	0.019	0.001	0.013	0.019	0.004	0.002	0.002
1996	0.029	0.063	0.024	0.011	0.001	0.011	0.016	0.003	0.001	0.001
1997	0.032	0.070	0.026	0.012	0.001	0.015	0.022	0.005	0.002	0.002
1998	0.012	0.027	0.010	0.004	0.000	0.013	0.019	0.004	0.002	0.002
1999	0.011	0.025	0.009	0.004	0.000	0.015	0.022	0.005	0.002	0.002
2000	0.010	0.022	0.008	0.004	0.000	0.021	0.030	0.006	0.003	0.003
2001	0.008	0.045	0.019	0.008	0.000	0.021	0.031	0.006	0.003	0.003
2002	0.004	0.023	0.009	0.004	0.000	0.014	0.020	0.004	0.002	0.002
2003	0.014	0.077	0.032	0.014	0.001	0.014	0.021	0.004	0.002	0.002
2004	0.009	0.051	0.021	0.009	0.000	0.019	0.027	0.006	0.002	0.002
2005	0.012	0.069	0.028	0.013	0.001	0.029	0.043	0.009	0.004	0.004
2006	0.005	0.029	0.012	0.005	0.000	0.020	0.030	0.006	0.003	0.003
2007	0.009	0.049	0.020	0.009	0.000	0.018	0.027	0.006	0.002	0.002
2008	0.013	0.074	0.030	0.014	0.001	0.019	0.028	0.006	0.002	0.002
2009	0.007	0.038	0.015	0.007	0.000	0.010	0.014	0.003	0.001	0.001
2010	0.014	0.080	0.033	0.015	0.001	0.023	0.034	0.007	0.003	0.003
2011	0.013	0.074	0.030	0.014	0.001	0.019	0.027	0.006	0.002	0.002
2012	0.012	0.067	0.027	0.012	0.001	0.019	0.028	0.006	0.002	0.002
2013	0.012	0.068	0.028	0.012	0.001	0.034	0.050	0.010	0.004	0.004

Table 24 (con't). Instantaneous fishing mortality, by fleet and age, for the southern stock.

	GA/SC Releases				
	1	2	3	4	5
1989	0.004	0.004	0.004	0.002	0.000
1990	0.009	0.009	0.009	0.004	0.000
1991	0.006	0.006	0.006	0.003	0.000
1992	0.004	0.004	0.005	0.002	0.000
1993	0.006	0.007	0.008	0.004	0.000
1994	0.010	0.010	0.012	0.006	0.000
1995	0.013	0.013	0.017	0.007	0.000
1996	0.006	0.006	0.007	0.003	0.000
1997	0.005	0.005	0.006	0.003	0.000
1998	0.003	0.003	0.004	0.002	0.000
1999	0.003	0.003	0.003	0.002	0.000
2000	0.006	0.006	0.008	0.004	0.000
2001	0.010	0.011	0.013	0.006	0.000
2002	0.007	0.007	0.009	0.004	0.000
2003	0.012	0.013	0.016	0.007	0.000
2004	0.010	0.011	0.013	0.006	0.000
2005	0.016	0.016	0.020	0.009	0.000
2006	0.015	0.016	0.019	0.009	0.000
2007	0.015	0.015	0.019	0.009	0.000
2008	0.019	0.020	0.024	0.011	0.001
2009	0.018	0.018	0.022	0.010	0.001
2010	0.020	0.021	0.026	0.012	0.001
2011	0.015	0.016	0.020	0.009	0.000
2012	0.013	0.014	0.017	0.007	0.000
2013	0.017	0.018	0.022	0.010	0.001

Table 25. Estimated age-1 to age-5 instantaneous fishing mortality for the southern stock during 1989-2013.

	Southern stock				
	1	2	3	4	5
1989	0.088	0.155	0.094	0.042	0.003
1990	0.095	0.159	0.106	0.048	0.003
1991	0.135	0.222	0.155	0.070	0.006
1992	0.083	0.143	0.101	0.045	0.003
1993	0.094	0.137	0.084	0.038	0.003
1994	0.107	0.169	0.110	0.049	0.004
1995	0.126	0.212	0.119	0.054	0.004
1996	0.080	0.159	0.109	0.049	0.004
1997	0.073	0.135	0.073	0.033	0.004
1998	0.048	0.102	0.075	0.034	0.003
1999	0.069	0.129	0.097	0.043	0.004
2000	0.102	0.180	0.141	0.063	0.006
2001	0.091	0.201	0.156	0.070	0.006
2002	0.064	0.130	0.092	0.041	0.004
2003	0.086	0.198	0.124	0.056	0.005
2004	0.092	0.174	0.102	0.046	0.005
2005	0.109	0.230	0.144	0.065	0.007
2006	0.083	0.160	0.111	0.050	0.005
2007	0.102	0.204	0.137	0.061	0.005
2008	0.114	0.236	0.152	0.068	0.006
2009	0.063	0.122	0.082	0.037	0.003
2010	0.123	0.241	0.144	0.065	0.006
2011	0.094	0.206	0.129	0.058	0.005
2012	0.080	0.207	0.149	0.067	0.006
2013	0.115	0.286	0.214	0.096	0.009

Table 26. sEsc, and tEsc (ages 1-5) with asymptotic SEs and CVs for the southern stock.

Year	sEsc			tEsc		
	Est	SE	CV	Est	SE	CV
1989	0.683	0.184	0.270			
1990	0.663	0.193	0.291			
1991	0.556	0.223	0.401			
1992	0.687	0.175	0.254			
1993	0.701	0.164	0.234	0.637	0.197	0.309
1994	0.644	0.184	0.286	0.631	0.195	0.308
1995	0.597	0.250	0.418	0.660	0.180	0.273
1996	0.669	0.200	0.298	0.679	0.177	0.260
1997	0.728	0.153	0.210	0.647	0.193	0.298
1998	0.769	0.133	0.173	0.629	0.215	0.342
1999	0.710	0.156	0.219	0.673	0.187	0.278
2000	0.611	0.189	0.310	0.712	0.160	0.225
2001	0.592	0.204	0.344	0.711	0.158	0.223
2002	0.718	0.162	0.226	0.676	0.173	0.256
2003	0.626	0.189	0.301	0.637	0.184	0.288
2004	0.659	0.174	0.264	0.634	0.185	0.292
2005	0.574	0.204	0.356	0.672	0.176	0.262
2006	0.665	0.177	0.266	0.648	0.181	0.280
2007	0.600	0.191	0.318	0.632	0.185	0.293
2008	0.562	0.209	0.371	0.607	0.192	0.316
2009	0.737	0.148	0.201	0.620	0.190	0.307
2010	0.560	0.208	0.372	0.618	0.188	0.304
2011	0.611	0.203	0.332	0.613	0.189	0.309
2012	0.601	0.204	0.339	0.642	0.186	0.290
2013	0.487	0.234	0.482	0.601	0.202	0.336

Table 27. Annual sSPR and three year sSPR with asymptotic SEs and CVs for the southern stock.

Year	sSPR			3 yr sSPR		
	Est	SE	CV	Est	SE	CV
1989	0.665	0.193	0.290			
1990	0.647	0.201	0.312			
1991	0.527	0.232	0.441	0.613	0.204	0.332
1992	0.667	0.184	0.276	0.614	0.202	0.329
1993	0.680	0.174	0.256	0.625	0.195	0.311
1994	0.618	0.194	0.314	0.655	0.182	0.278
1995	0.574	0.258	0.449	0.624	0.203	0.325
1996	0.646	0.211	0.326	0.613	0.214	0.350
1997	0.705	0.165	0.233	0.642	0.205	0.320
1998	0.746	0.145	0.195	0.699	0.171	0.245
1999	0.684	0.168	0.245	0.712	0.158	0.222
2000	0.580	0.201	0.346	0.670	0.170	0.254
2001	0.560	0.215	0.384	0.608	0.193	0.317
2002	0.694	0.174	0.251	0.611	0.195	0.319
2003	0.601	0.199	0.331	0.618	0.195	0.315
2004	0.632	0.185	0.293	0.642	0.185	0.288
2005	0.540	0.215	0.398	0.591	0.198	0.336
2006	0.635	0.189	0.298	0.602	0.195	0.324
2007	0.572	0.201	0.352	0.582	0.201	0.345
2008	0.533	0.218	0.409	0.580	0.202	0.348
2009	0.716	0.158	0.221	0.607	0.191	0.315
2010	0.530	0.218	0.410	0.593	0.197	0.332
2011	0.583	0.214	0.367	0.610	0.196	0.321
2012	0.571	0.215	0.376	0.562	0.214	0.382
2013	0.449	0.242	0.538	0.535	0.222	0.416

Table 28. Multiplicative weighting factors applied to input error in the southern stock assessment model to achieve SDSRs below the upper limit suggested by Francis (2011).

Data Set	Multiplicative Weighting Factor	SDSR Upper Limit	SDSR
FL Bagged Seine Survey	1.00	1.34	1.19
GA Gill Net Survey	1.77	1.35	1.12
SC Stop Net Survey	1.00	1.49	1.12
SC Trammel Net Survey—Age 1	2.20	1.26	1.14
SC Trammel Net Survey—Age 2	2.23	1.26	1.14
FL Haul Seine Survey—Age 2	1.77	1.28	0.91
FL Haul Seine Survey—Age 3	1.80	1.28	0.96
MRFSS/MRIP Index	1.85	1.24	1.08
SC 1 mile Long Line Survey	2.11	1.35	1.34
SC 1/3 mile Long Line Survey	2.13	1.45	0.99
GA Long Line Survey	2.09	1.45	1.04

Table 29. Likelihood components of the southern red drum assessment model following iterative re-weighting.

Components		N	TSS	RSS	NegLL	SDSR
Total Kill						
FL Rec		25	177.51	0.12	-44.07	0.07
GA Comm/Rec		25	116.15	0.05	-38.33	0.05
SC Comm/Rec		25	86.67	0.23	-33.22	0.10
FL Releases		25	198.77	0.01	-43.20	0.02
GA/SC Releases		25	310.38	0.01	-36.84	0.02
	Totals	125	889.47	0.43	-195.67	
Proportion-at-age						
FL Rec		175			543.81	0.13
GA Comm/Rec		175			588.34	0.53
SC Comm/Rec		175			907.00	0.39
GA/SC Releases		175			103.30	0.88
	Totals	700			2142.45	
Indices of Abundance						
FL Bagged Beach Seine Survey		12	26.43	17.27	-0.54	1.19
GA Gill Net Survey—Age 1		11	23.61	13.75	-5.00	1.12
SC Stop Net Survey		6	9.99	7.93	-4.73	1.12
SC Trammel Net Survey—Age 1		20	58.97	25.91	-9.46	1.14
SC Trammel Net Survey—Age 2		20	53.16	25.92	-9.02	1.14
FL Haul Seine Survey—Age 2		17	9.32	14.25	-12.69	0.91
FL Haul Seine Survey—Age 3		17	6.67	15.79	-6.77	0.96
MRIP Index		23	120.34	26.83	-43.54	1.08
SC 1 mile Longline Survey (Adult)		11	10.66	19.93	0.31	1.34
SC 1/3 mile Longline Survey		7	7.76	6.91	-5.52	0.99
GA Longline Survey		7	8.17	7.64	-1.04	1.04
	Totals	151	335.06	182.11	-98.00	
Other Deviations						
Selectivities					37.90	
	Totals				37.90	
	Grand Total				1,886.68	

6. Figures

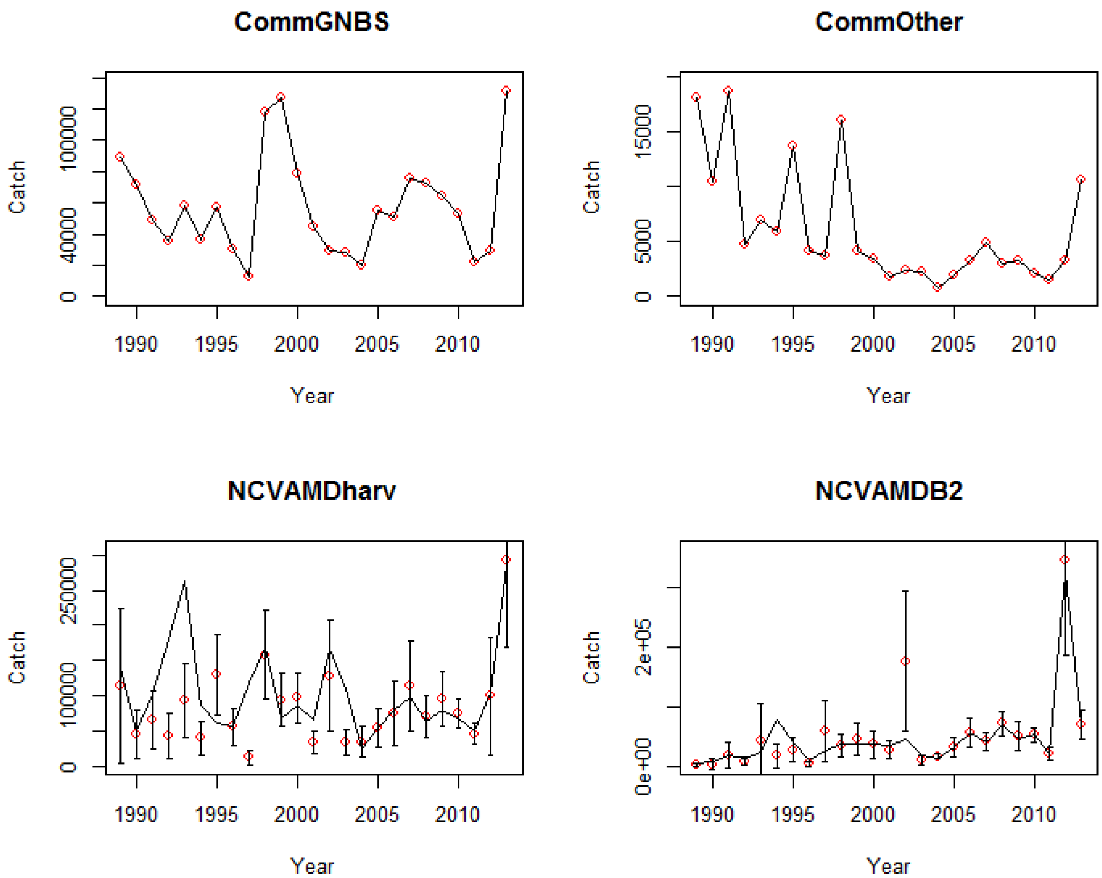


Figure 1. Observed (red circles) and model estimated (solid black line) catch, by fleet, for the northern stock. Error bars show 95% confidence intervals of observed values.

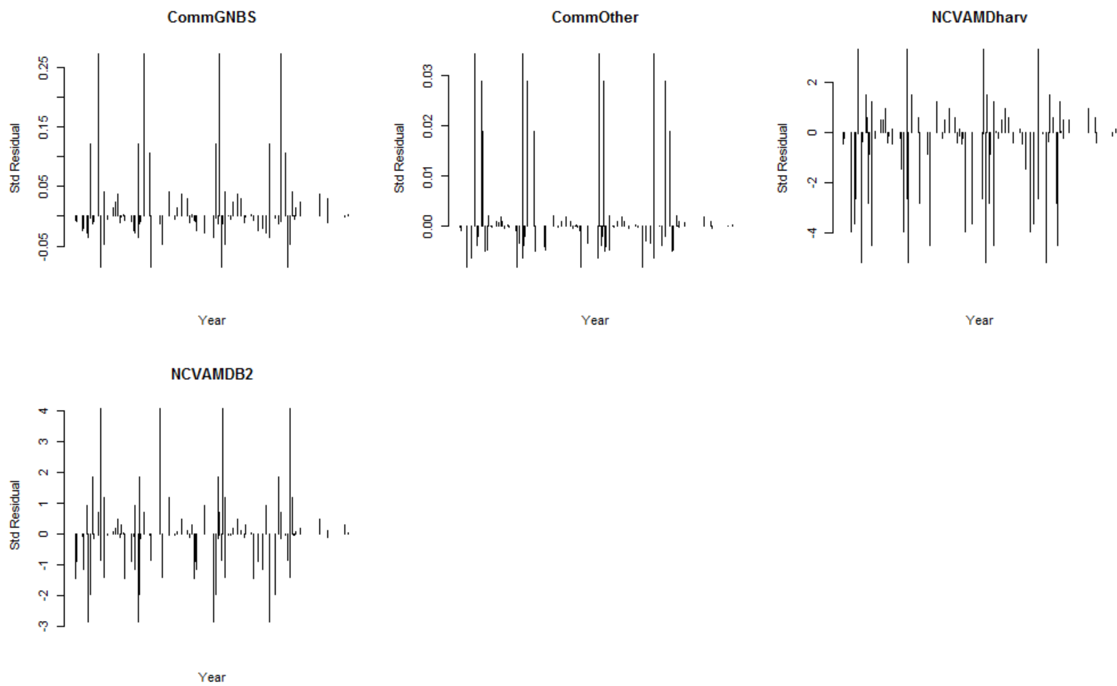


Figure 2. Standardized residuals for model fits to catch, by fleet and year, for the northern stock.

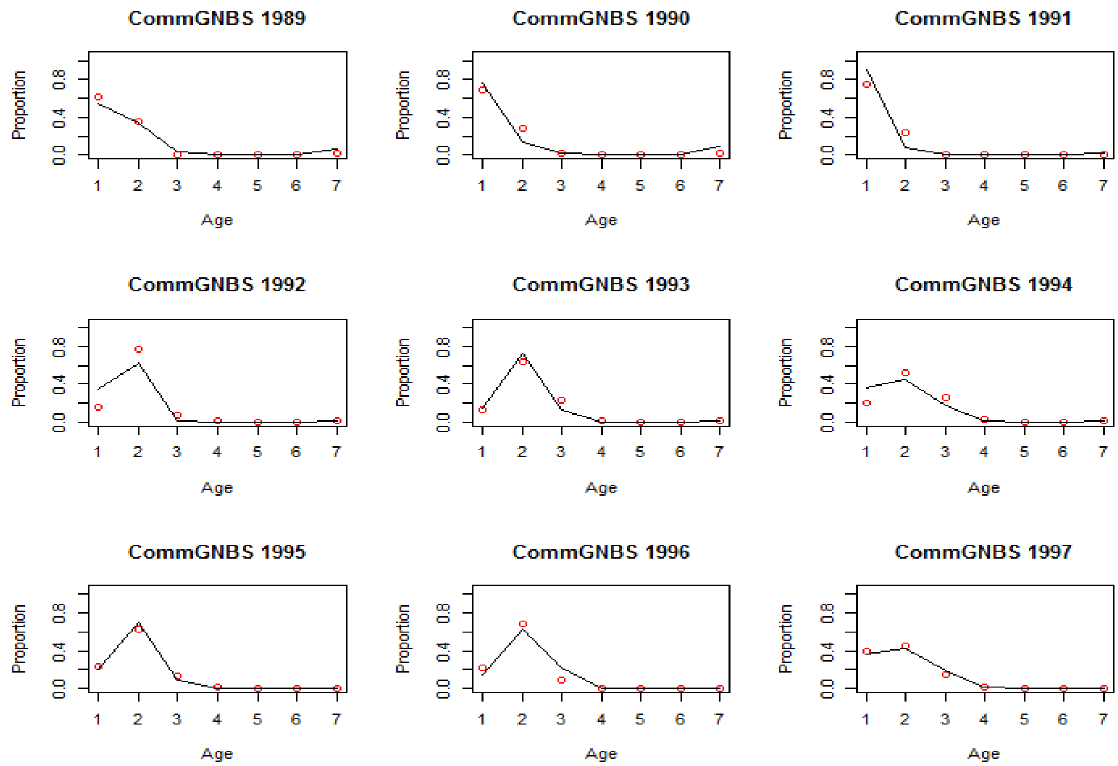


Figure 3. Northern model fits to the proportion-at-age data for each fleet and year. The recreational release fleet is not included as the selectivities were fixed based on external tagging data and the proportion-at-age data were not used in model fitting.

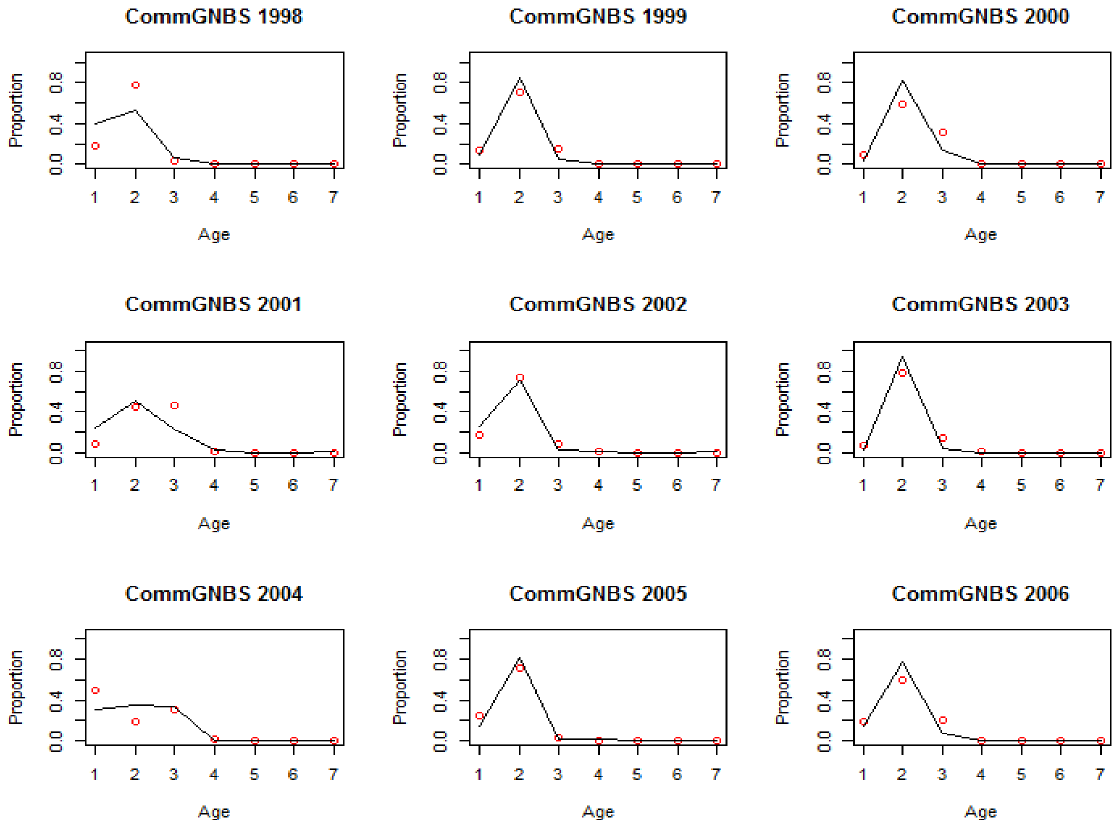


Figure 3 (con't).

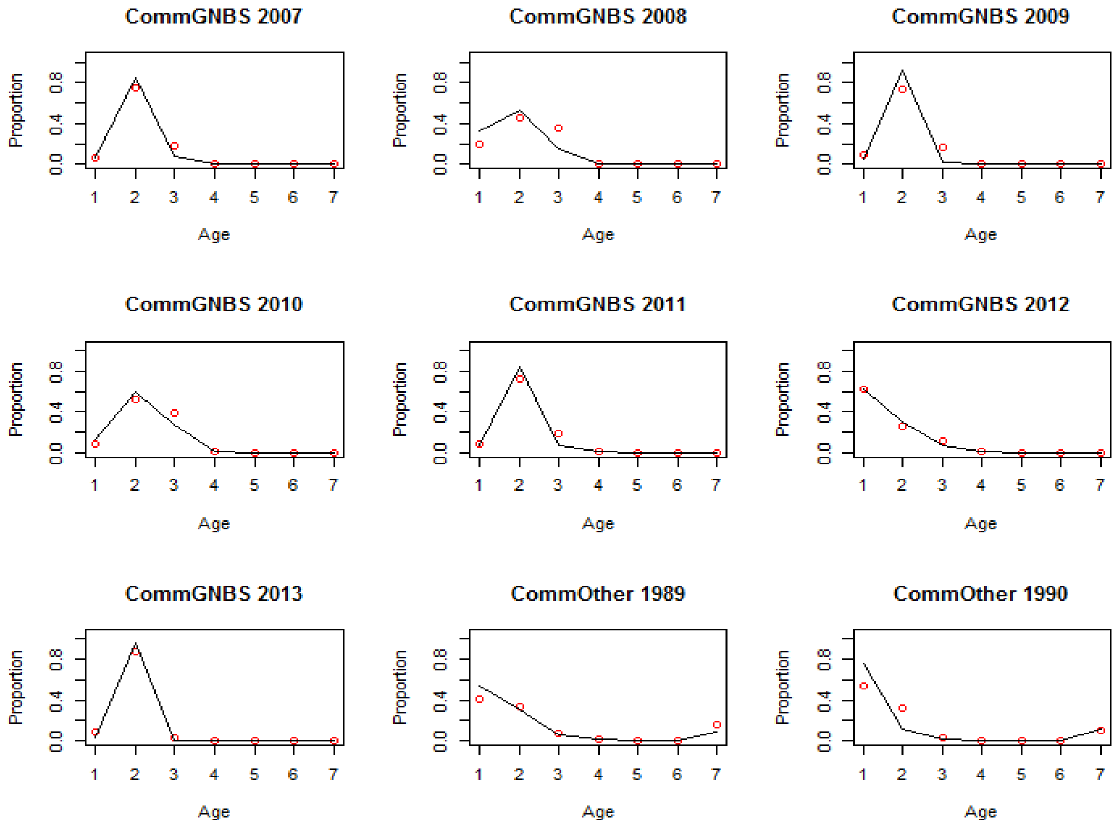


Figure 3 (con't).

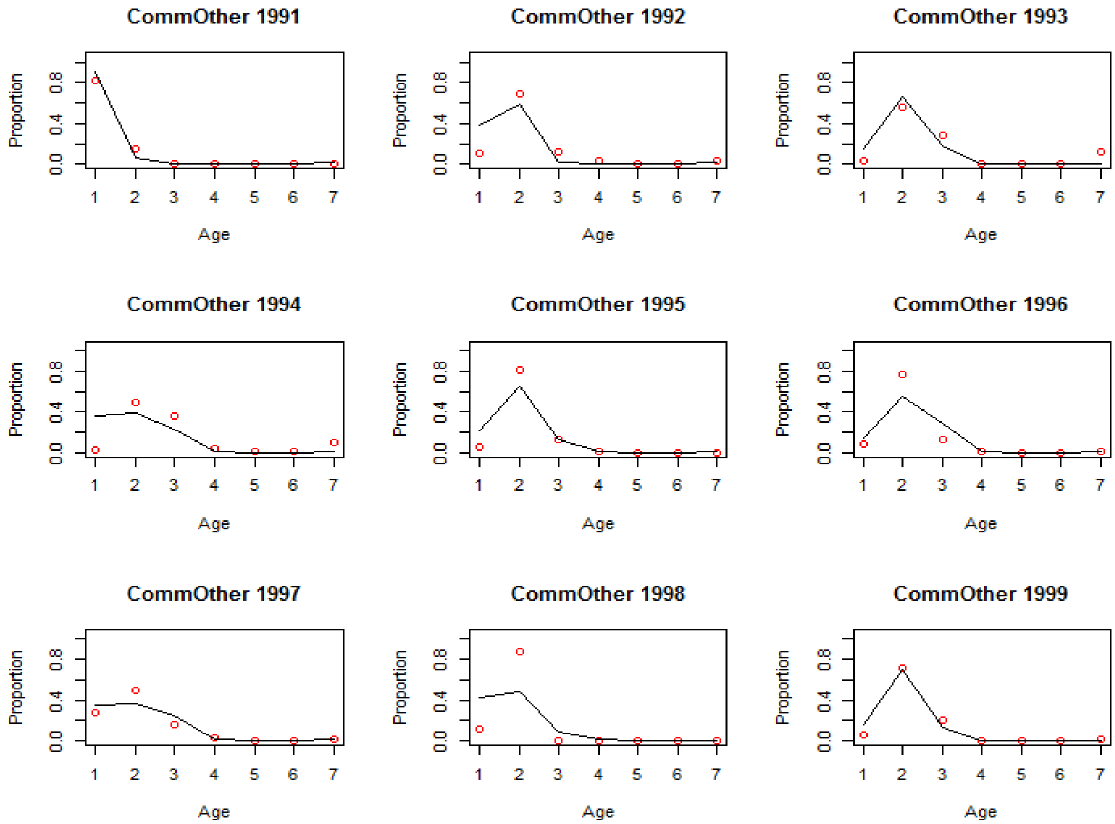


Figure 3 (con't).

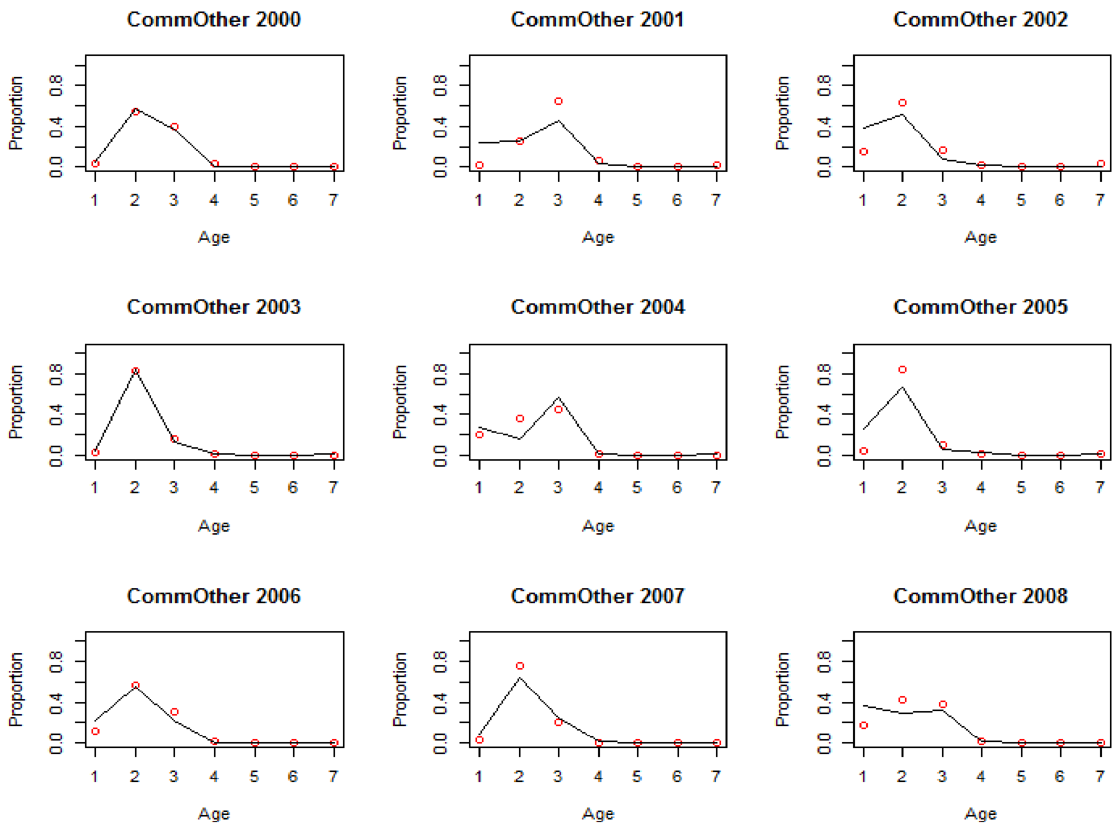


Figure 3 (con't).

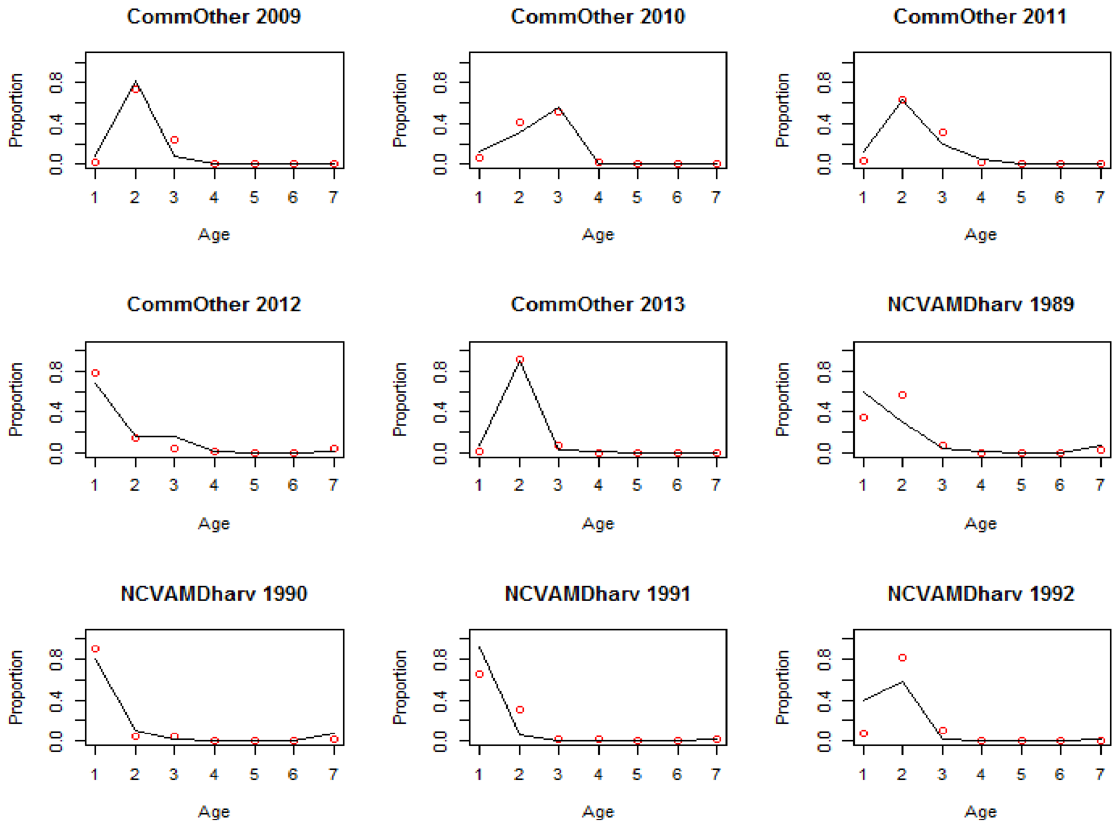


Figure 3 (con't).

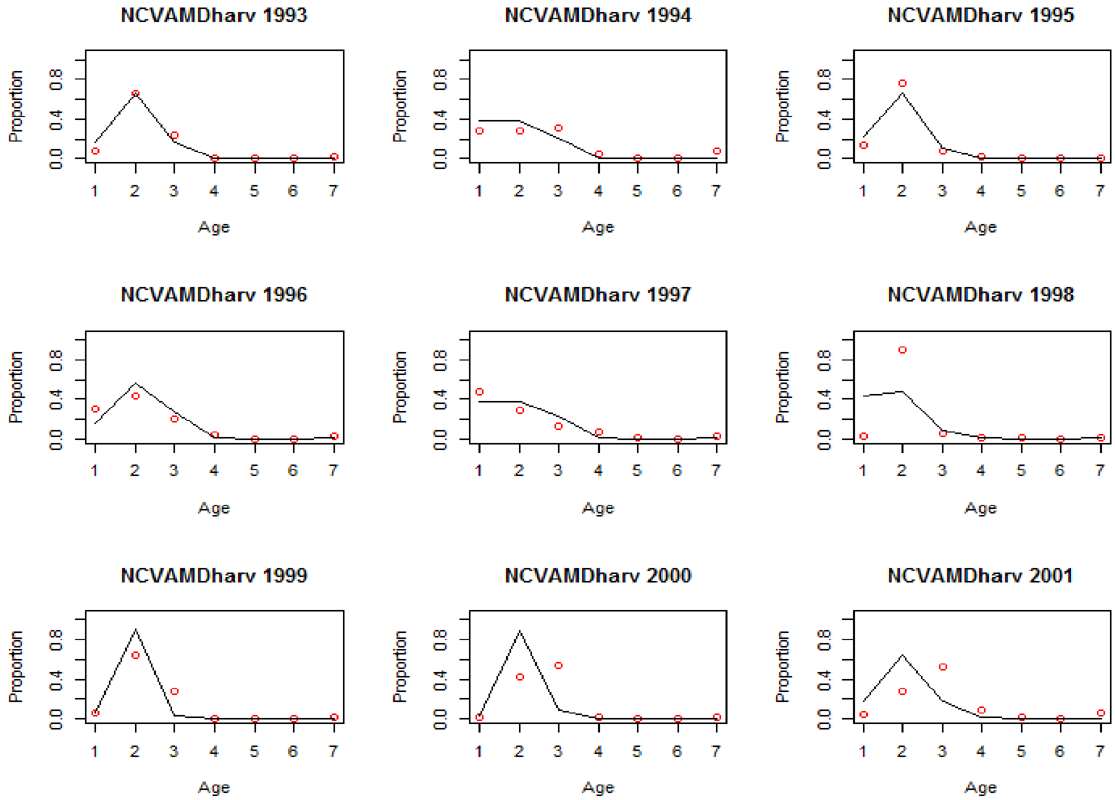


Figure 3 (con't).

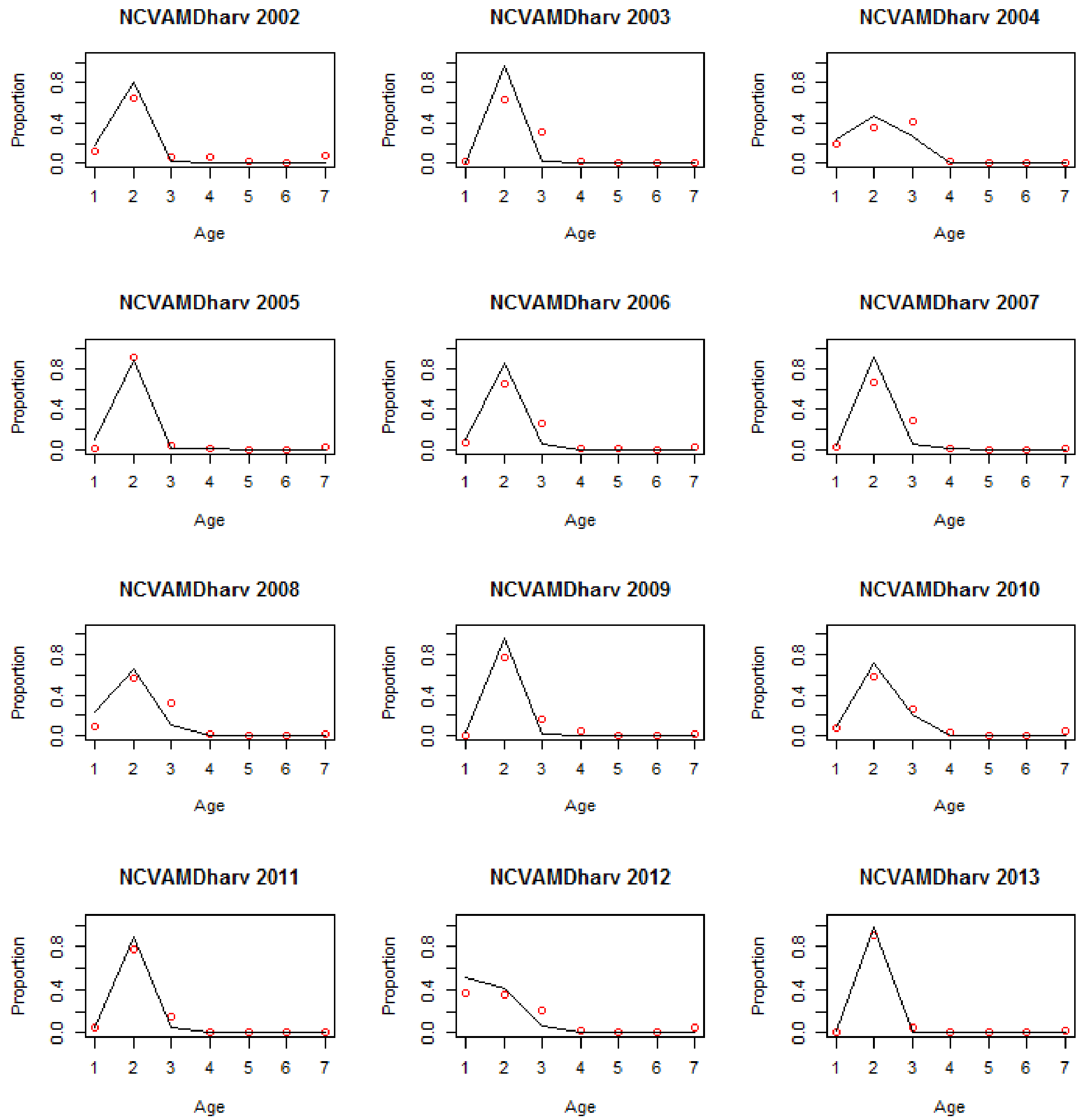


Figure 3 (con't).

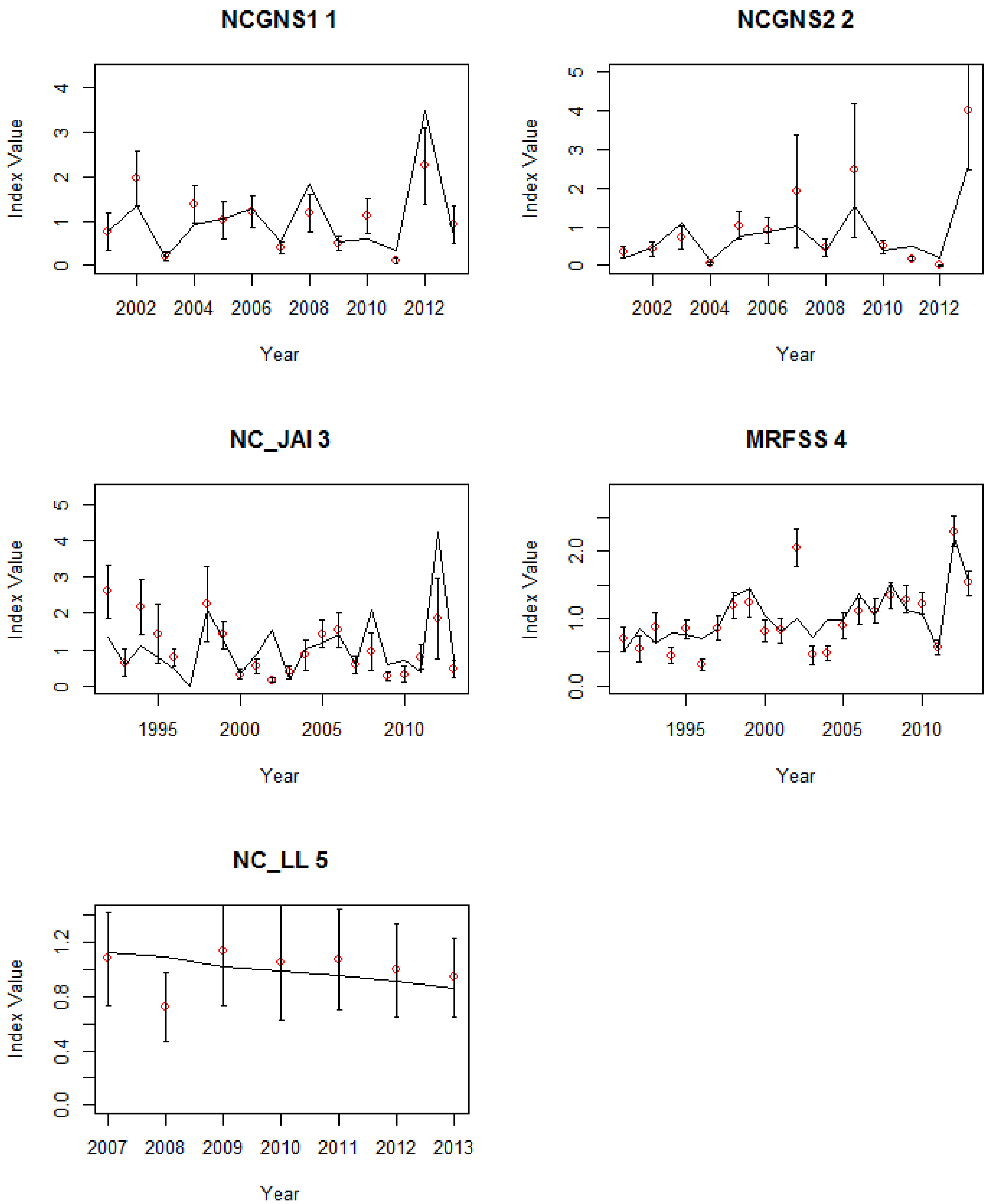


Figure 4. Observed (red circles) and model estimated (solid black line) indices of abundance for the northern stock. Error bars show 95% confidence intervals of observed values.

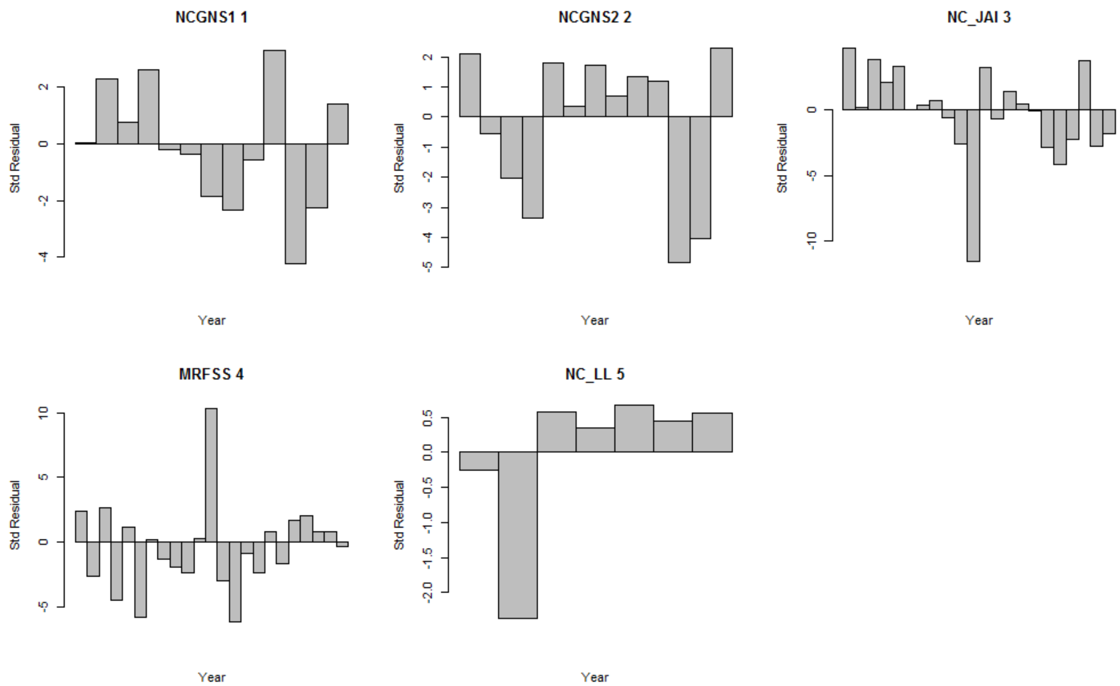


Figure 5. Standardized residuals for model fits to indices of abundance, by year, for the northern stock.

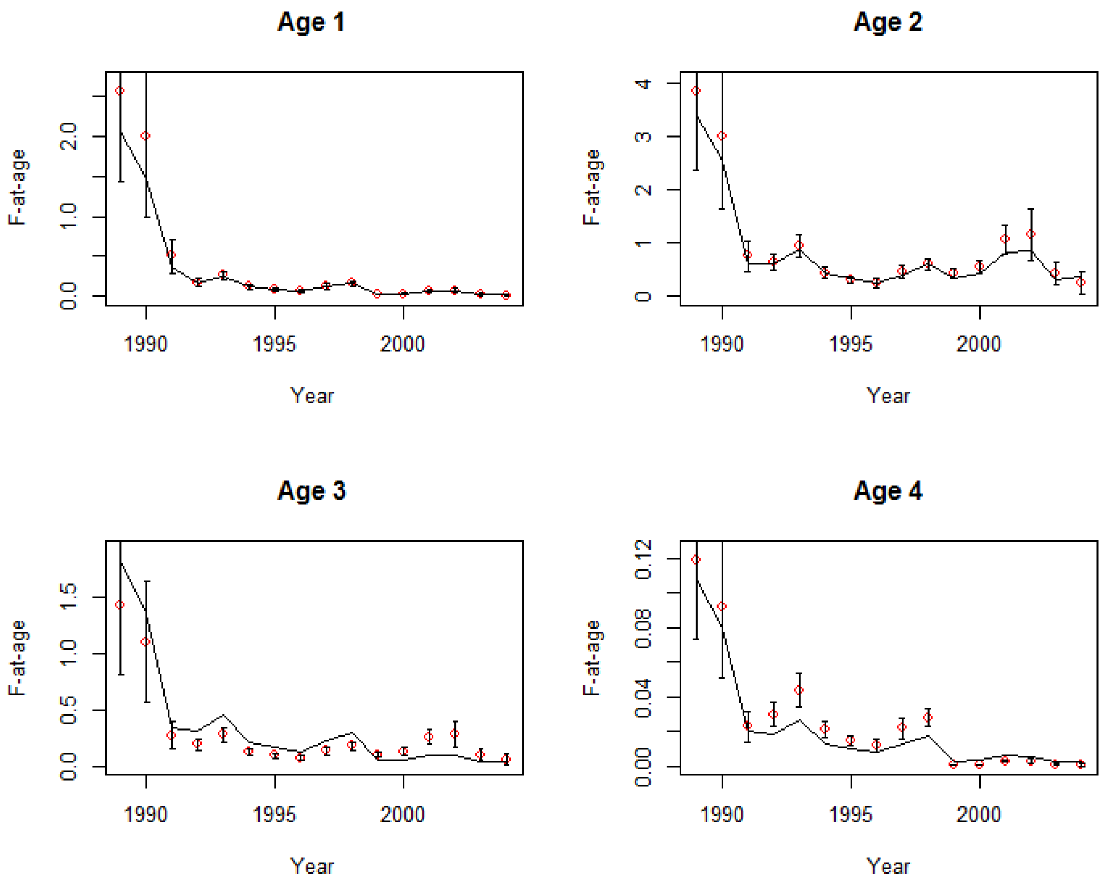


Figure 6. Observed (red circles) and model estimated (solid black line) F-at-age (ages 1-4) for the harvest fleets in the northern stock. Error bars show 95% confidence intervals of observed values.

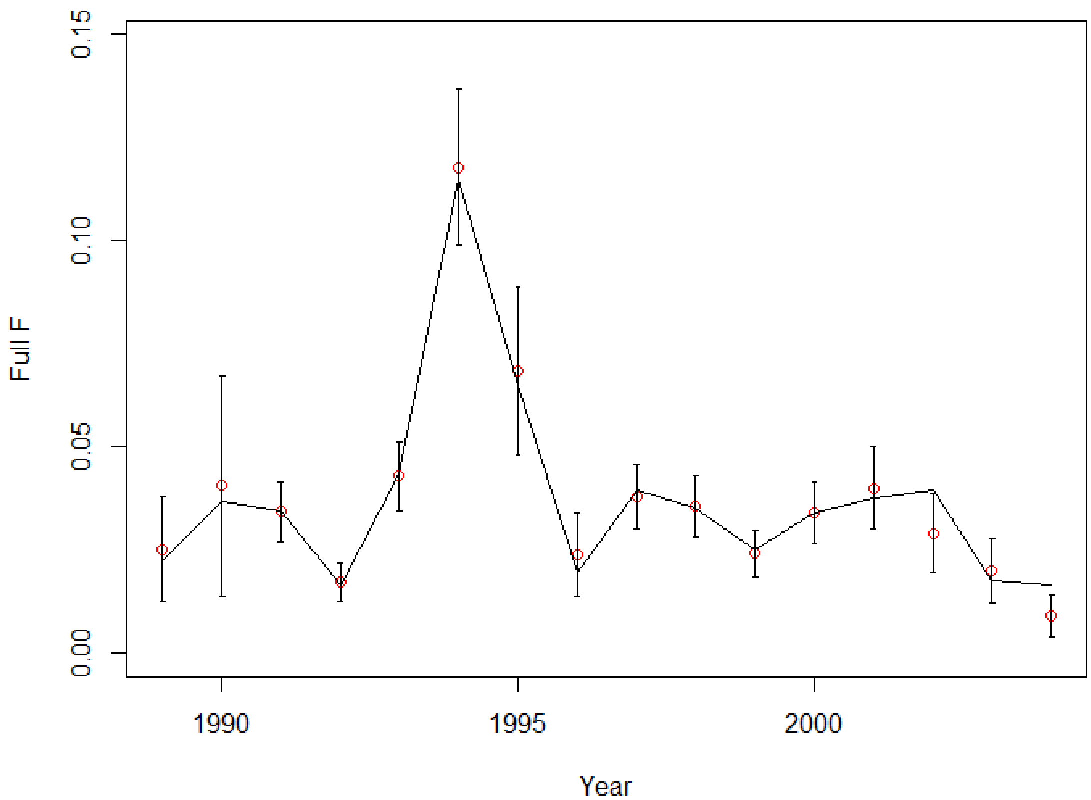


Figure 7. Observed (red circles) and model estimated (solid black line) full F for the recreational live release fleet in the northern stock. Error bars show 95% confidence intervals of observed values.

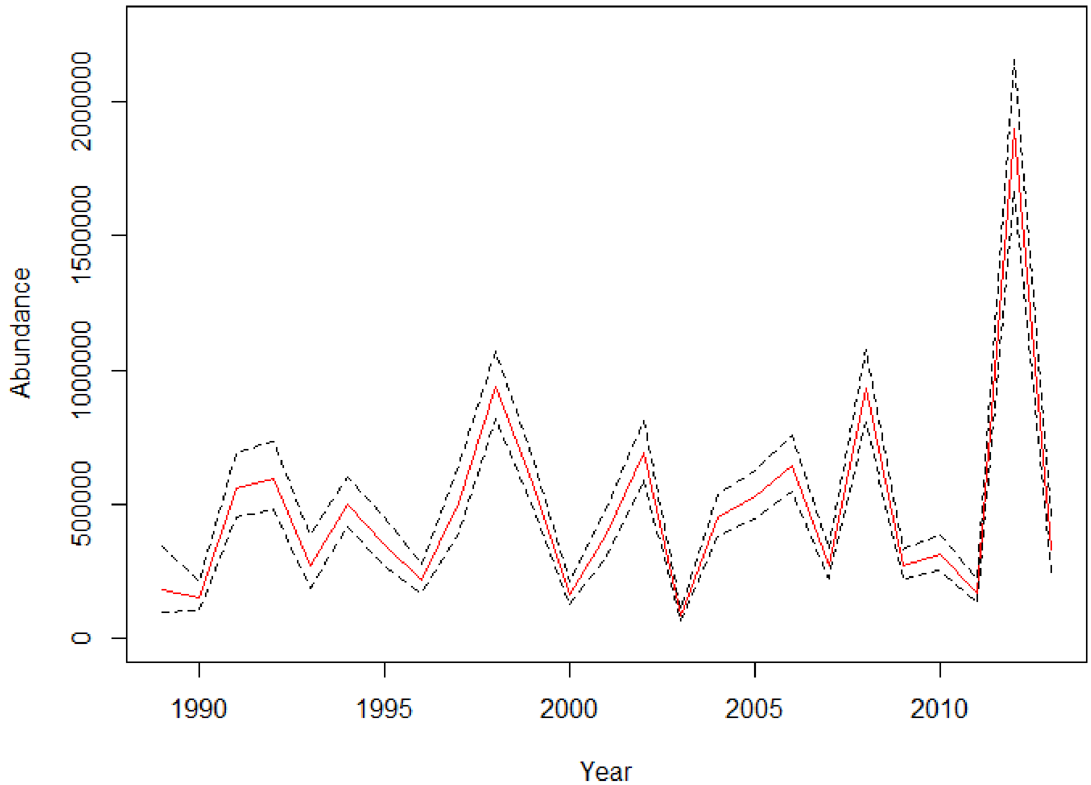


Figure 8. Predicted recruitment for the northern stock with 95% confidence intervals from asymptotic standard errors.

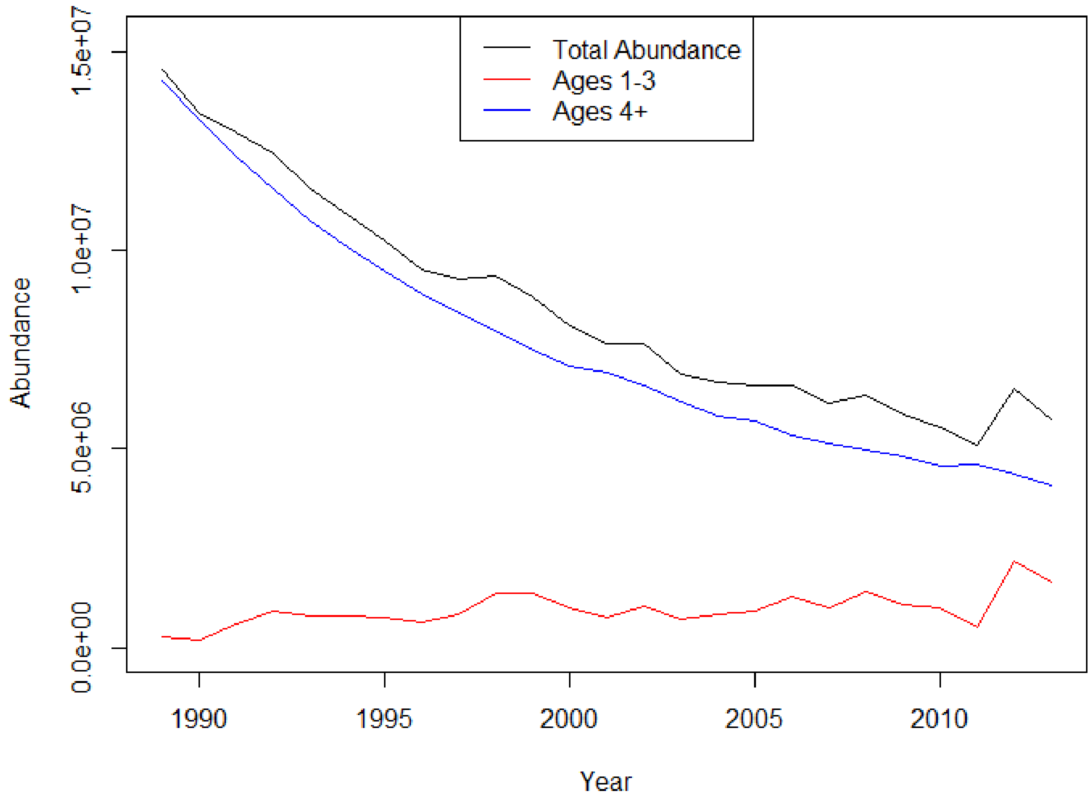


Figure 9. Abundance of red drum at various ages for the northern stock.

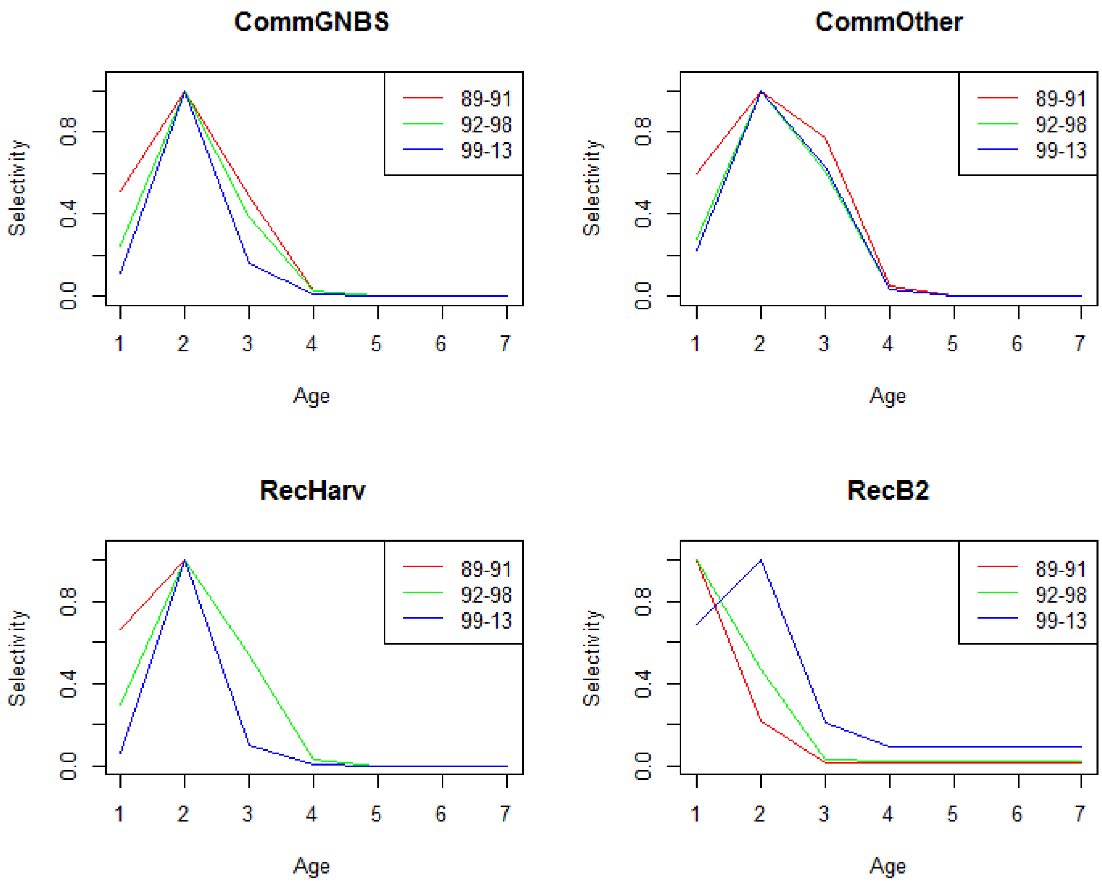


Figure 10. Selectivity curves for each fleet and selectivity block in the northern stock. The recreational live release selectivity is fixed based on external tagging analysis (Bacheler et al. 2008).

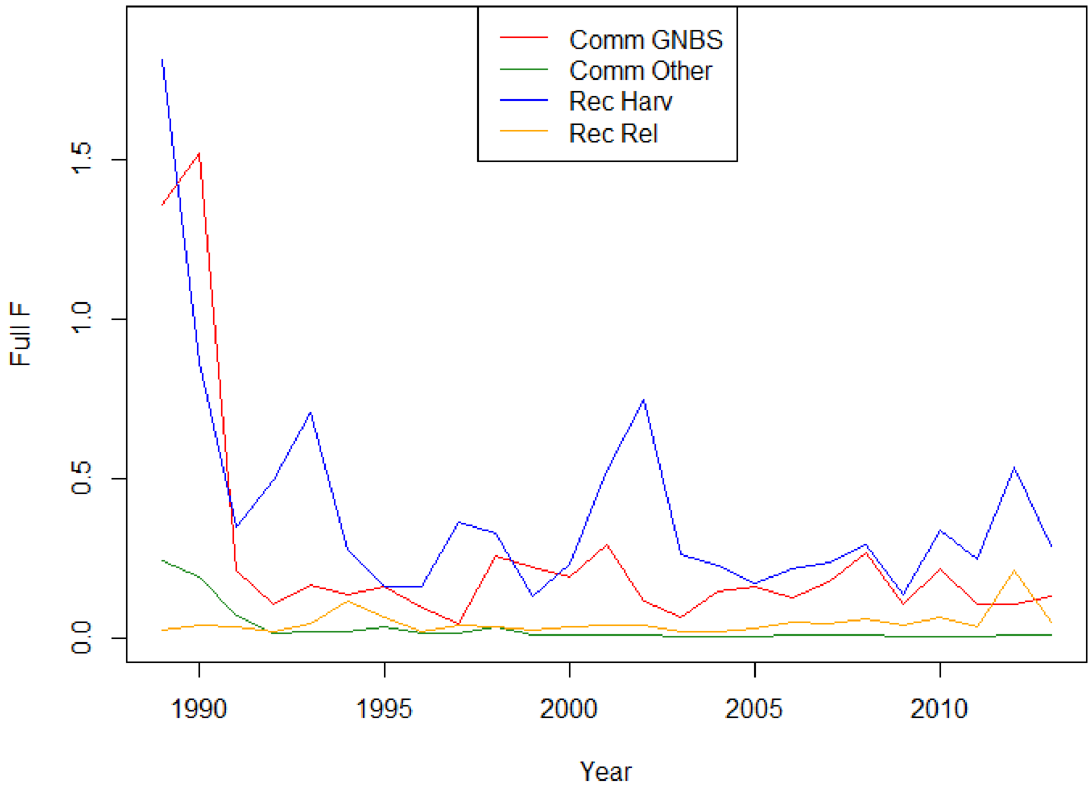


Figure 11. Fleet-specific annual fishing mortality for the northern stock.

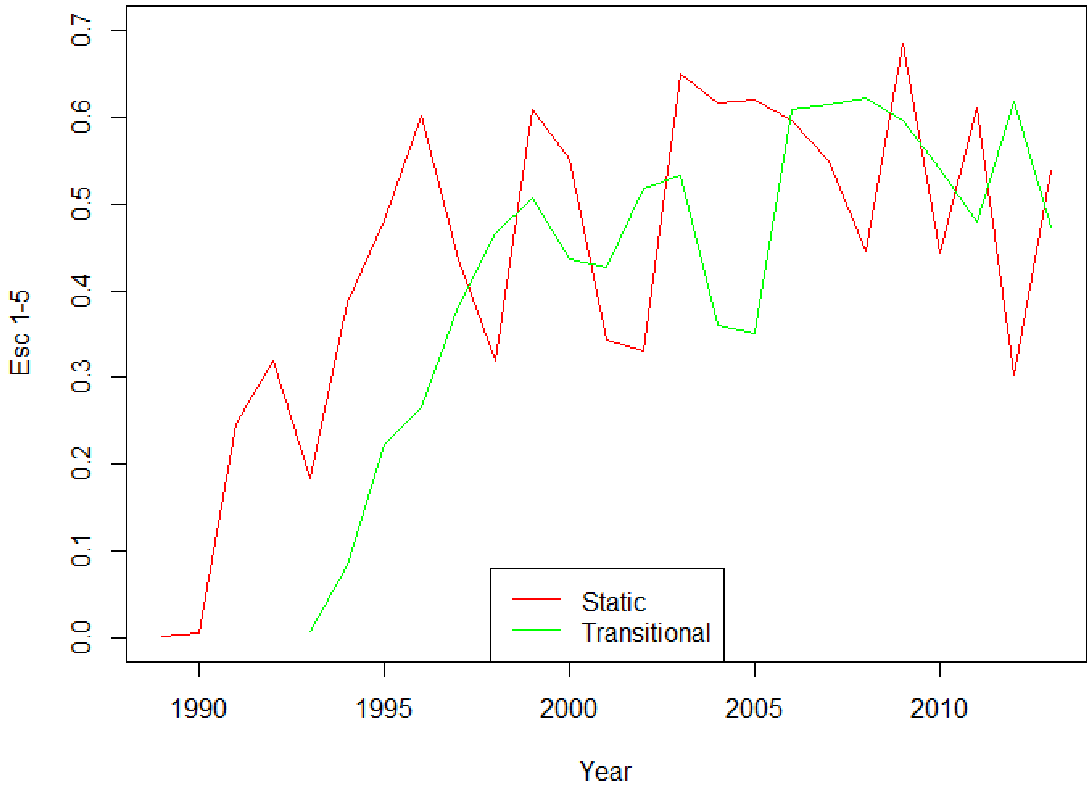


Figure 12. Estimates of static and transitional escapement for ages 1-5 for the northern stock.

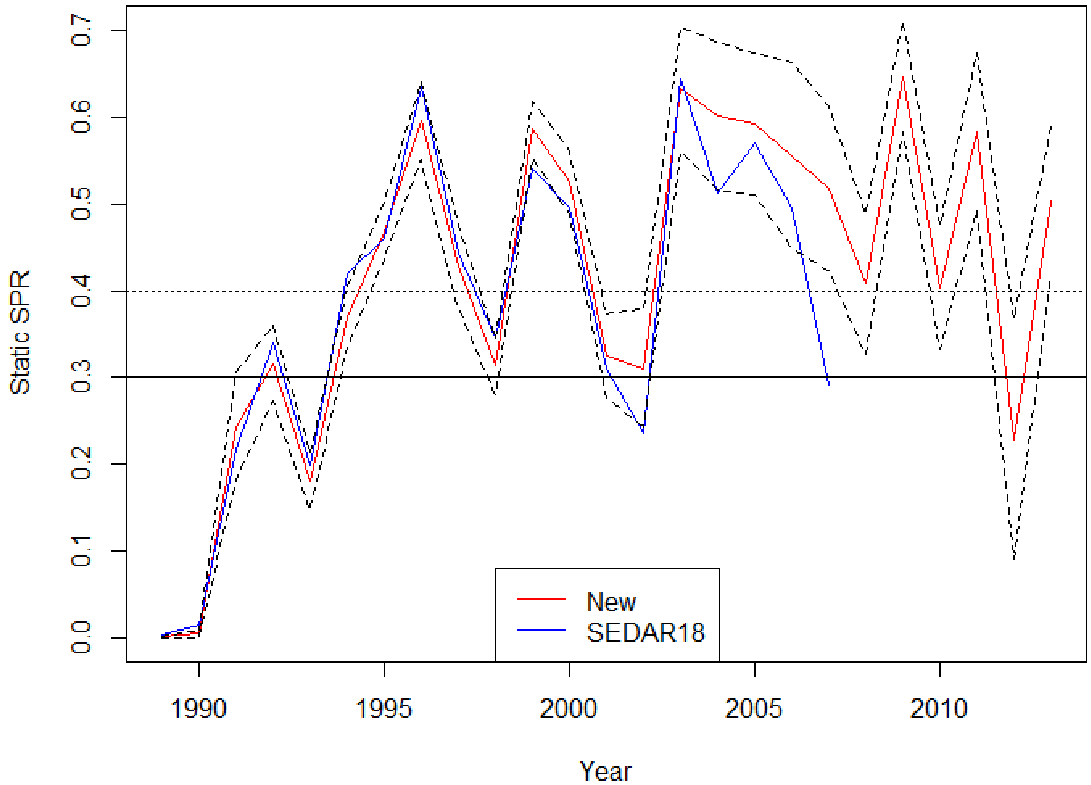


Figure 13. Annual sSPR estimates for the northern stock with 95% confidence intervals from asymptotic standard errors. Point estimates from the previous benchmark assessment (SEDAR18) are included for comparison. The target sSPR (dashed black line) is 40% and the threshold sSPR (solid black line) is 30%.

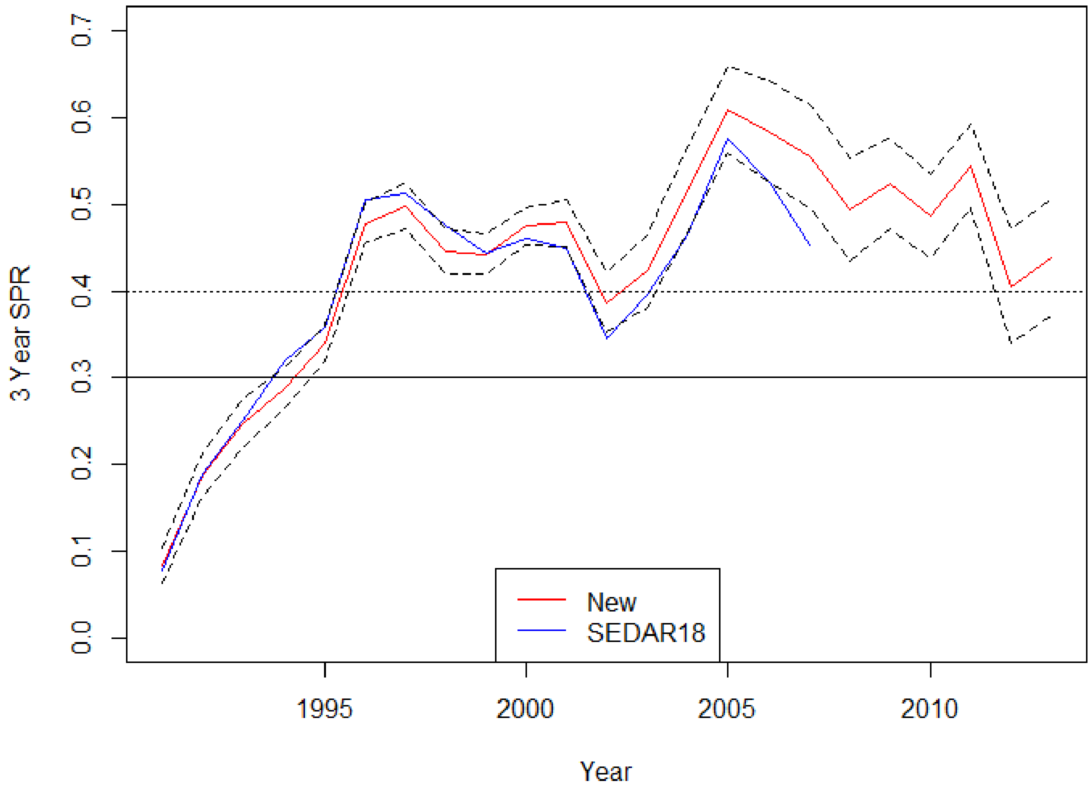


Figure 14. Three year average sSPR for the northern stock with 95% confidence intervals from asymptotic standard errors. Point estimates from the previous benchmark assessment (SEDAR18) are included for comparison. The target sSPR (dashed black line) is 40% and the threshold sSPR (solid black line) is 30%.

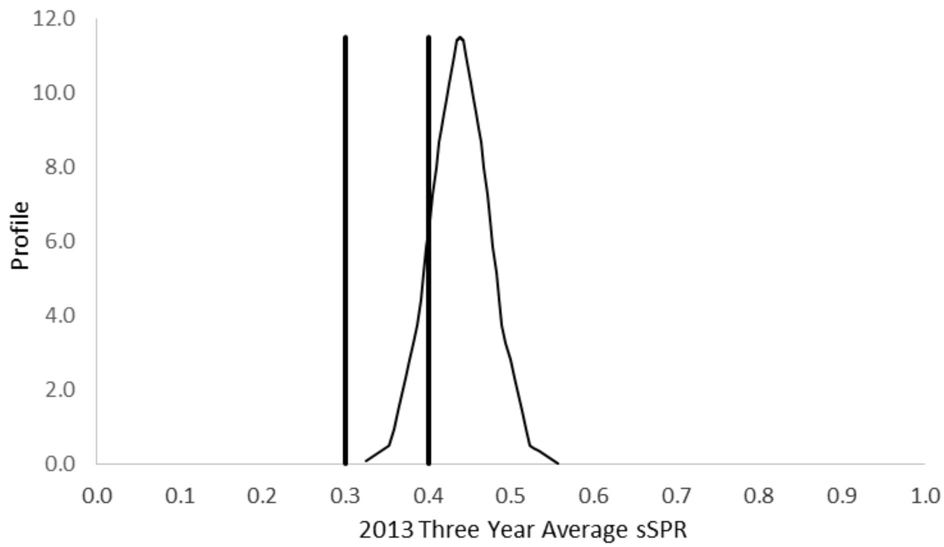


Figure 15. Estimated probability density function of the 2013 three year average sSPR for the northern stock. The target sSPR is 40% and the threshold sSPR is 30%.

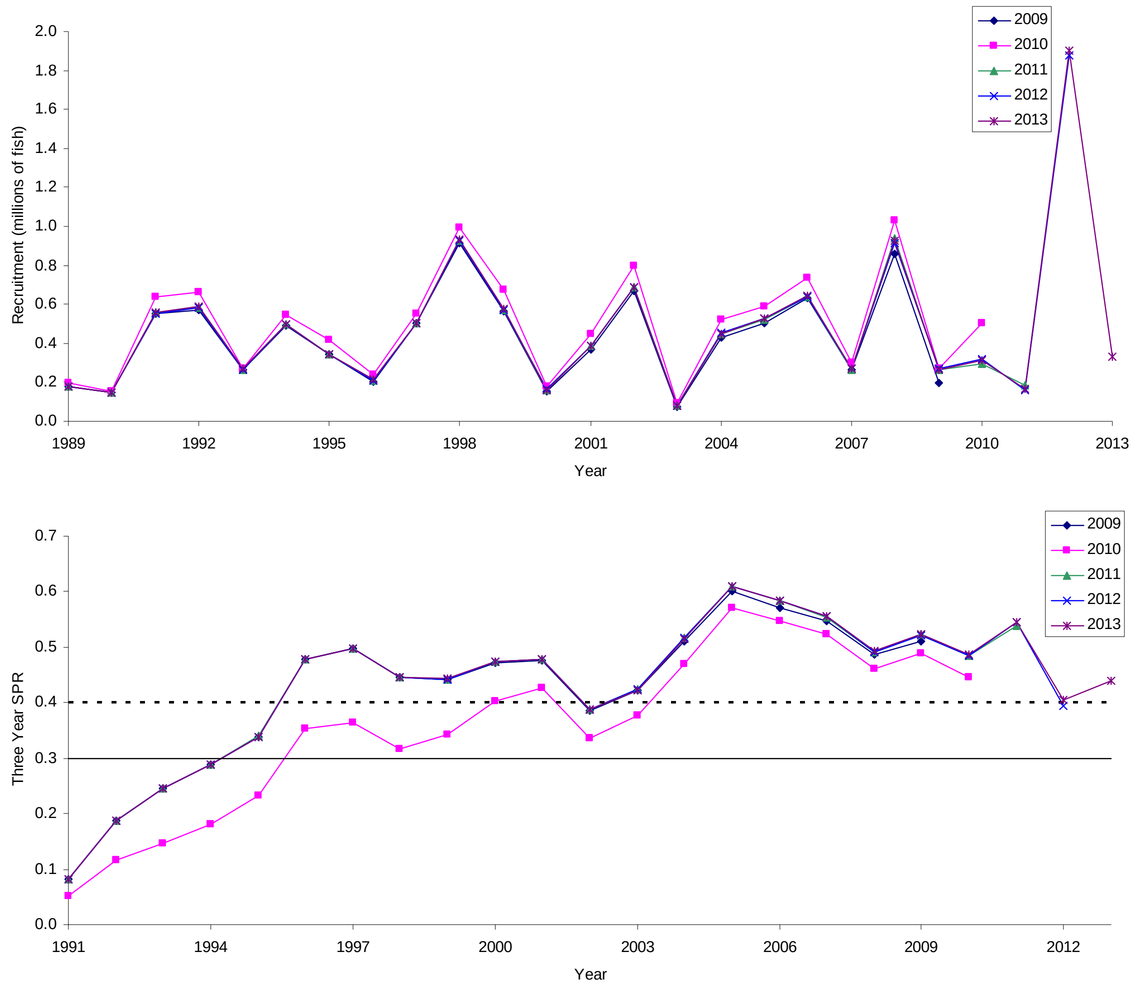


Figure 16. Five year retrospective analysis of the recruitment (top) and three year average sSPR (bottom) for the northern stock.

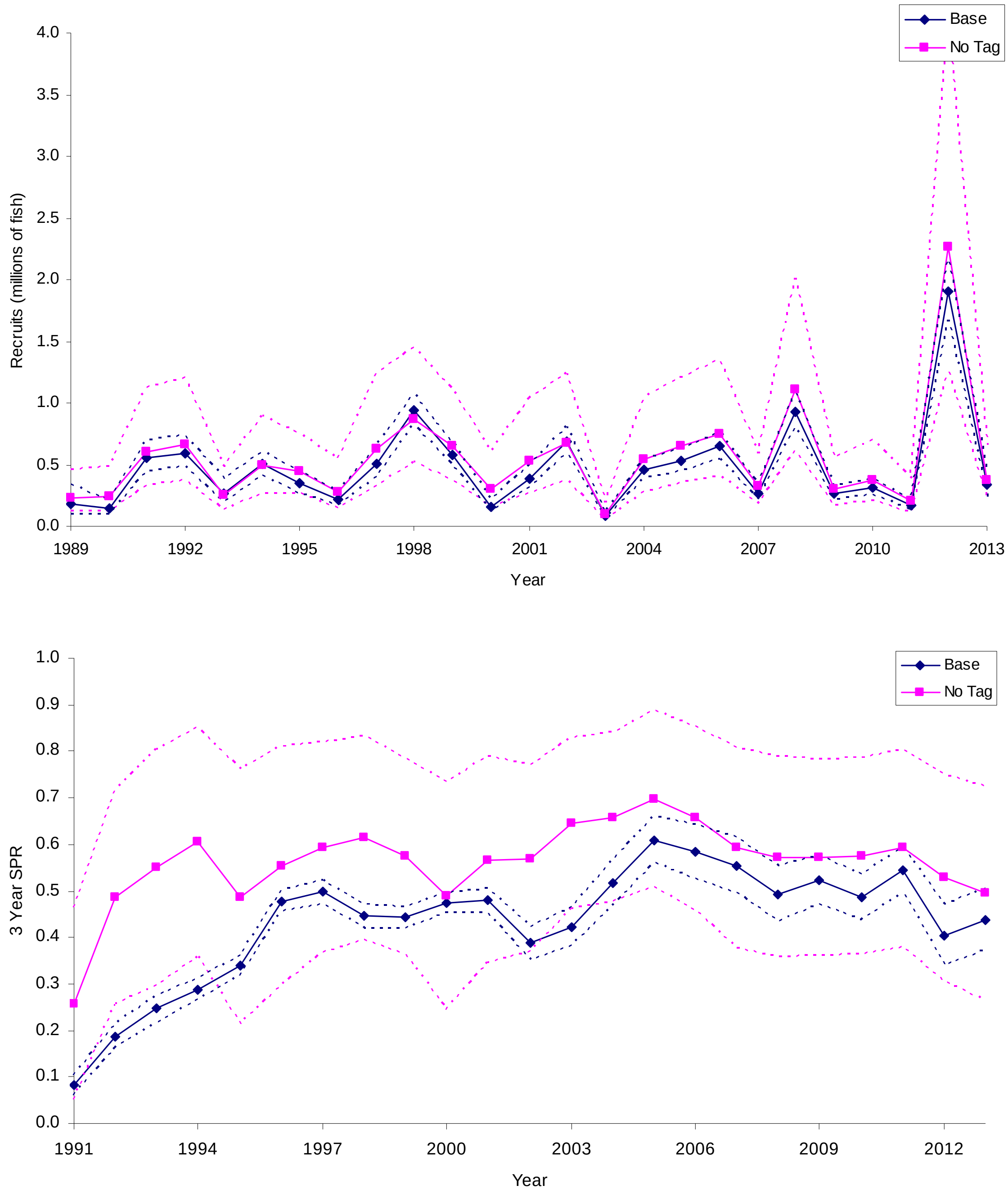


Figure 17. Comparison of the recruitment (top) and three year average sSPR (bottom) for the northern stock between the base model and when the tag-based F estimates (1989-2004) are removed.

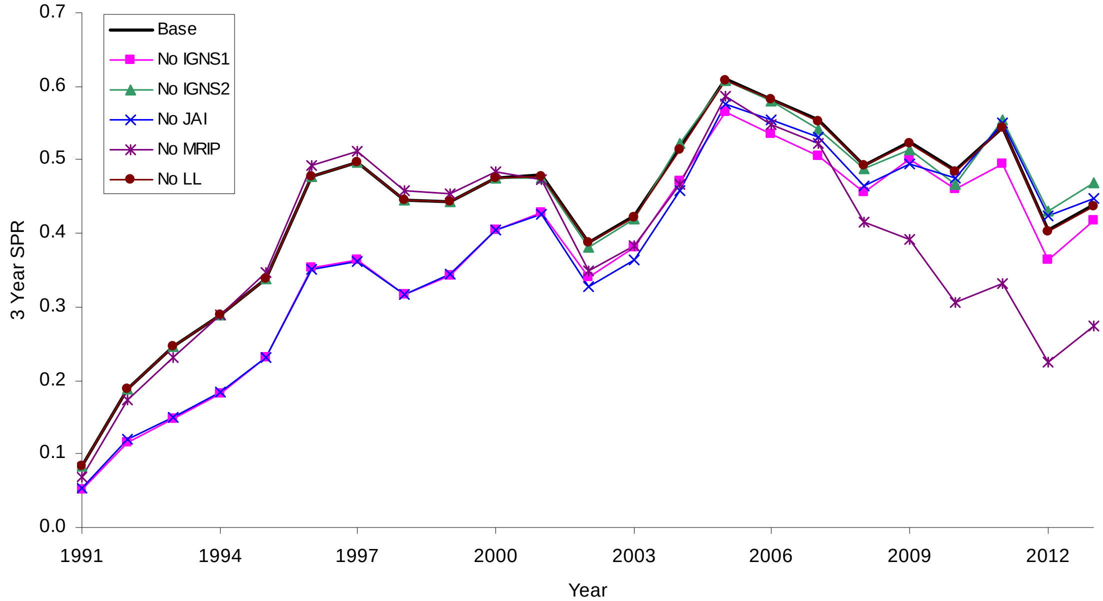


Figure 18. Comparison of the three year average sSPR for the northern stock when individual indices are removed.

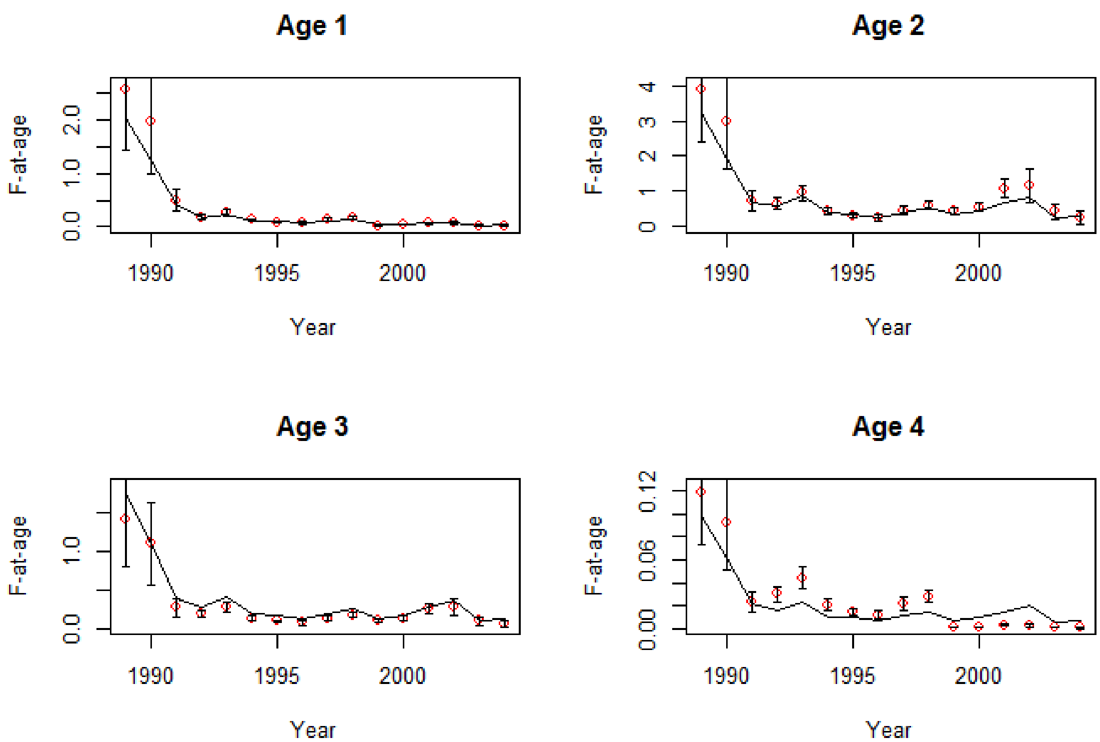


Figure 19. Observed (red circles) and model estimated (solid black line) F-at-age (ages 1-4) for the harvest fleets in the northern stock from the iteratively reweighted model. Error bars show 95% confidence intervals of observed values.

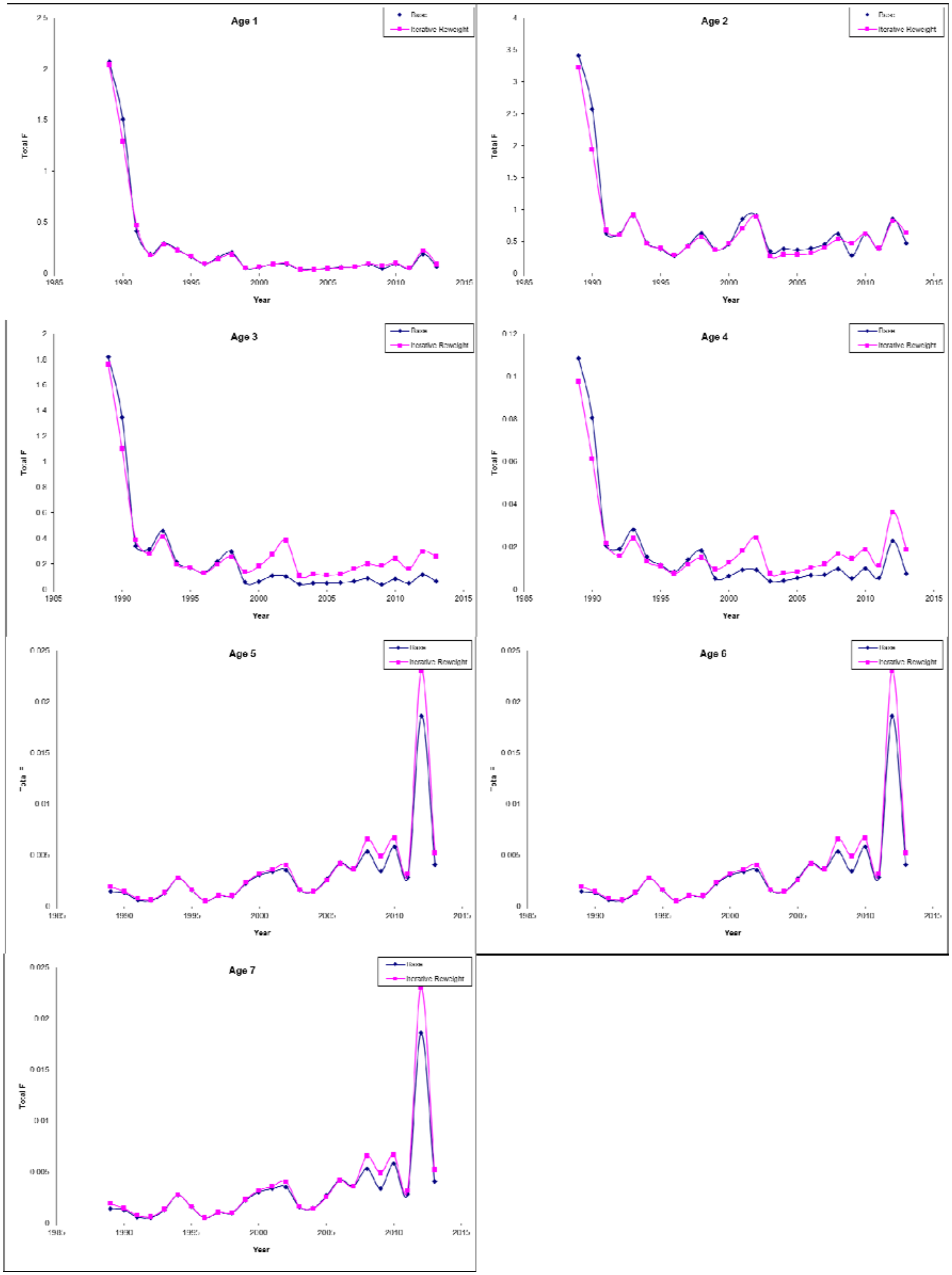


Figure 20. Comparison of the F-at-age for the northern stock for the base model and the iteratively reweighted model.

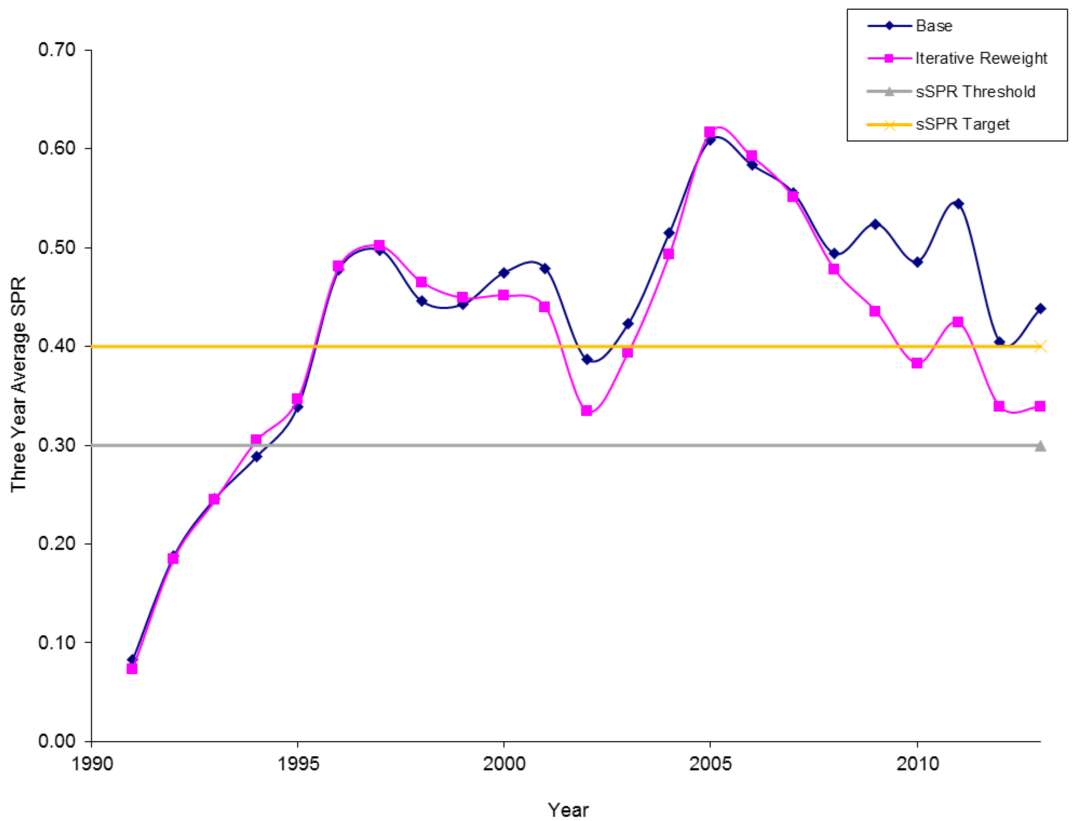


Figure 21. Comparison of the three year average sSPR for the northern stock for the base model and the iteratively reweighted model.

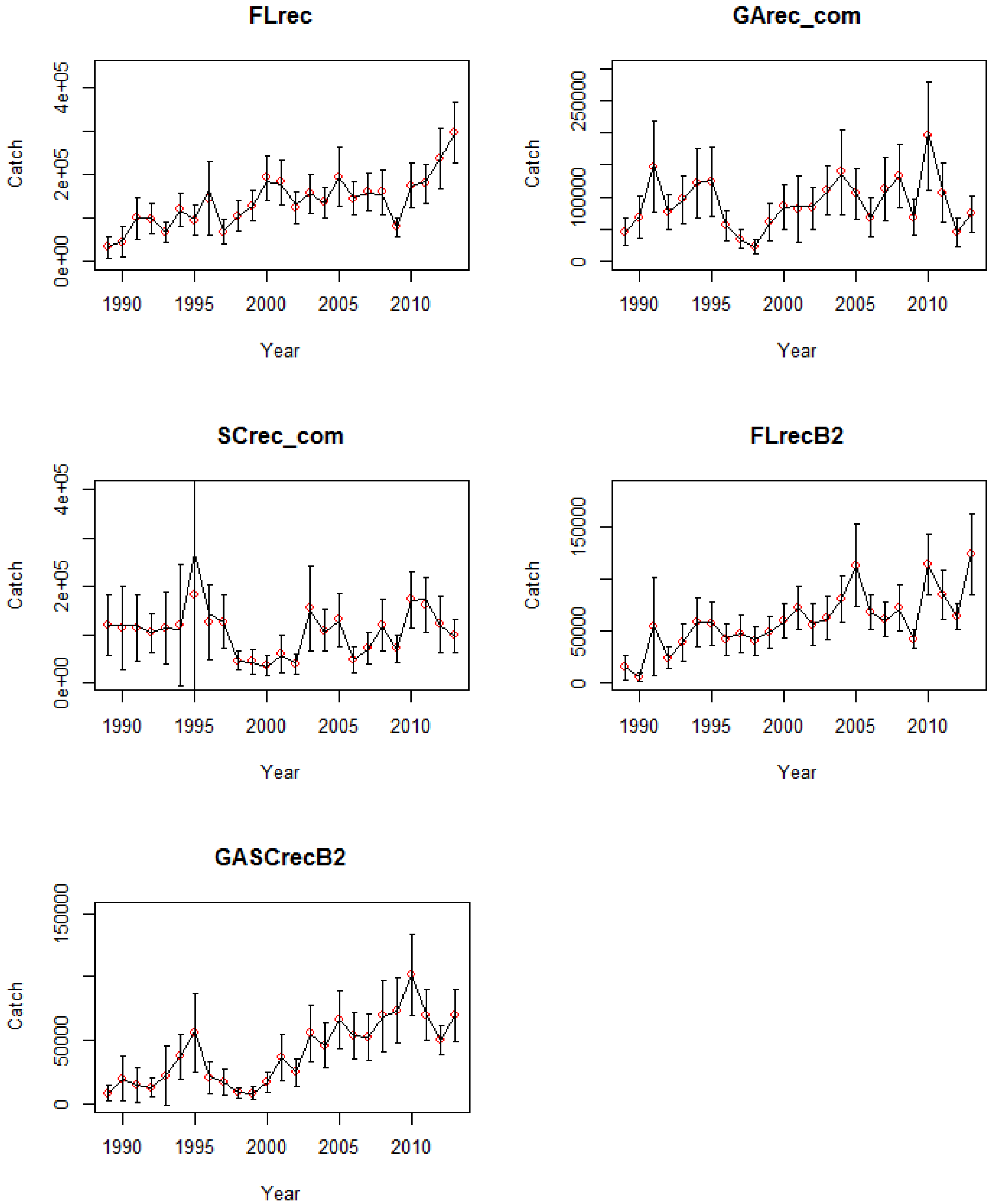


Figure 22. Observed (red circles) and model estimated (solid black line) catch, by fleet, for the southern stock. Error bars show 95% confidence intervals of observed values.

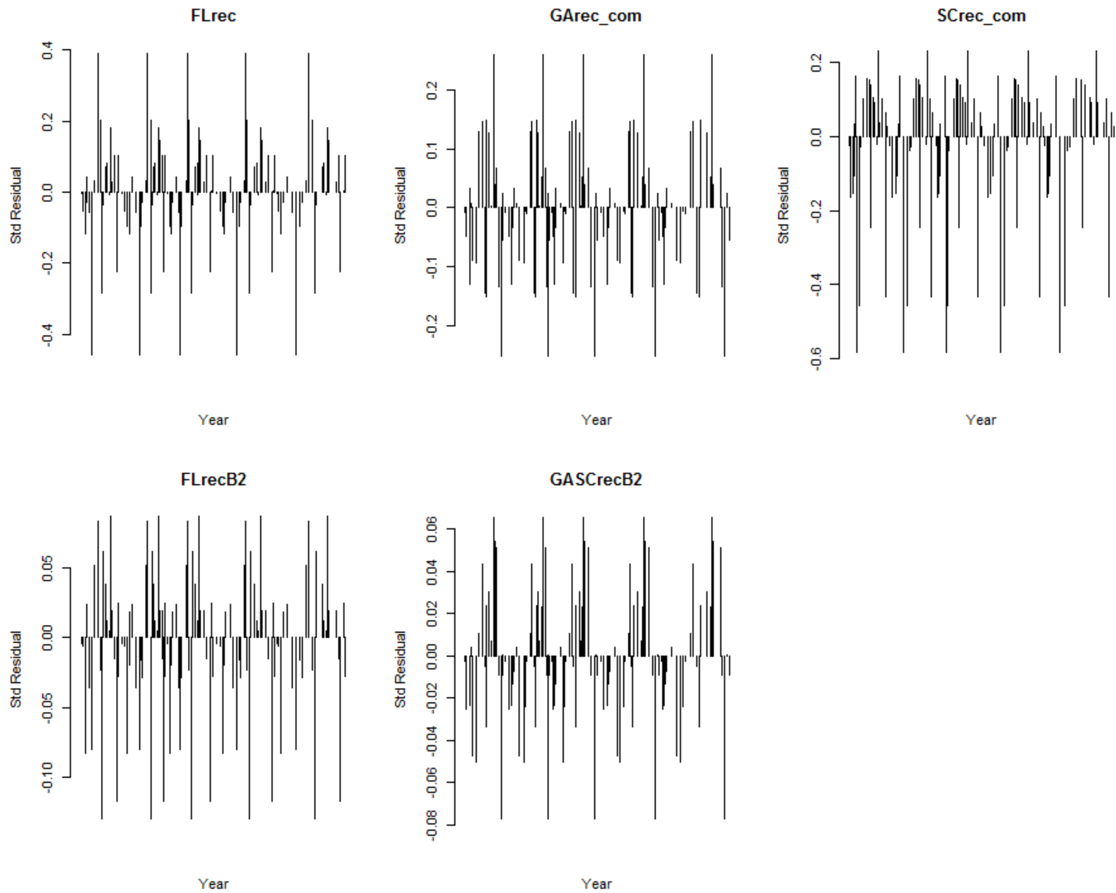


Figure 23. Standardized residuals for model fits to catch, by fleet and year, for the southern stock.

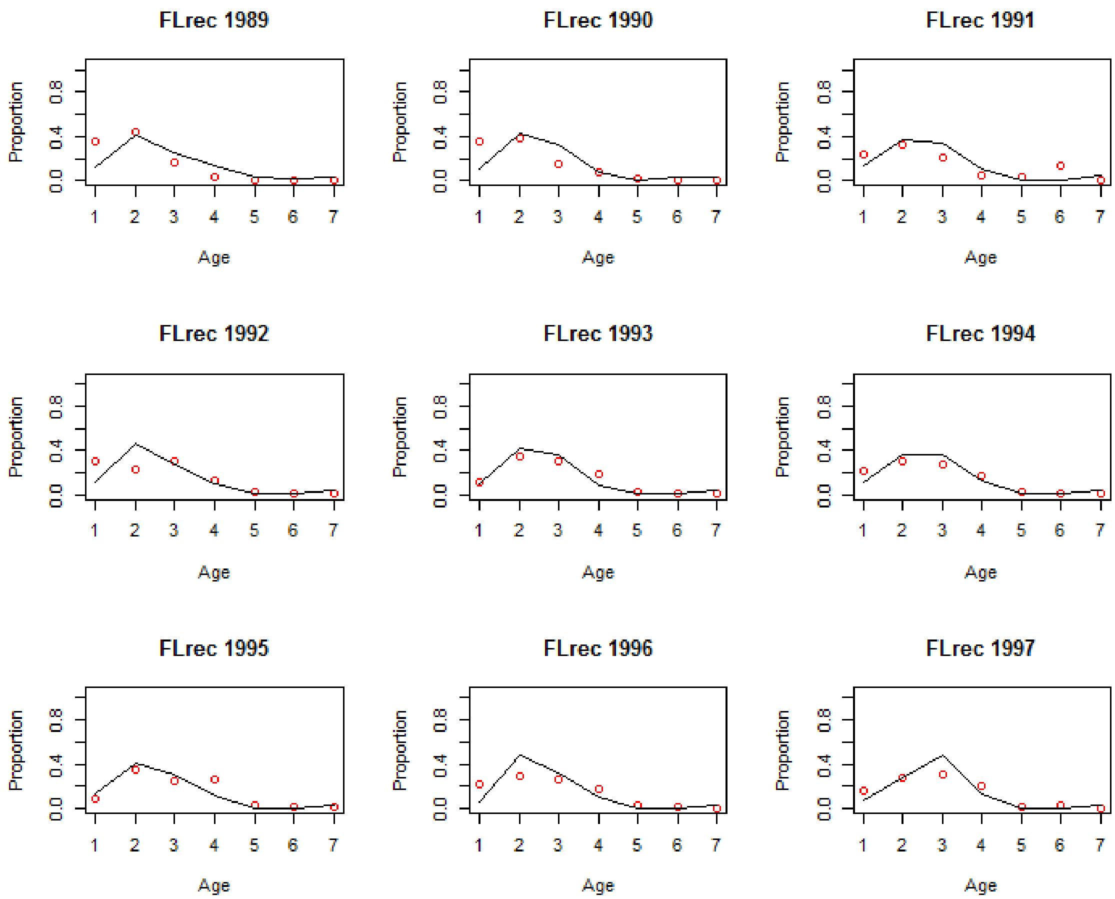


Figure 24. Southern model fits to the proportion-at-age data for each fleet and year. The Florida recreational release fleet is not included as the selectivity-at-age was fixed using tagging data from North Carolina and the proportion-at-age data was not used in model fitting.

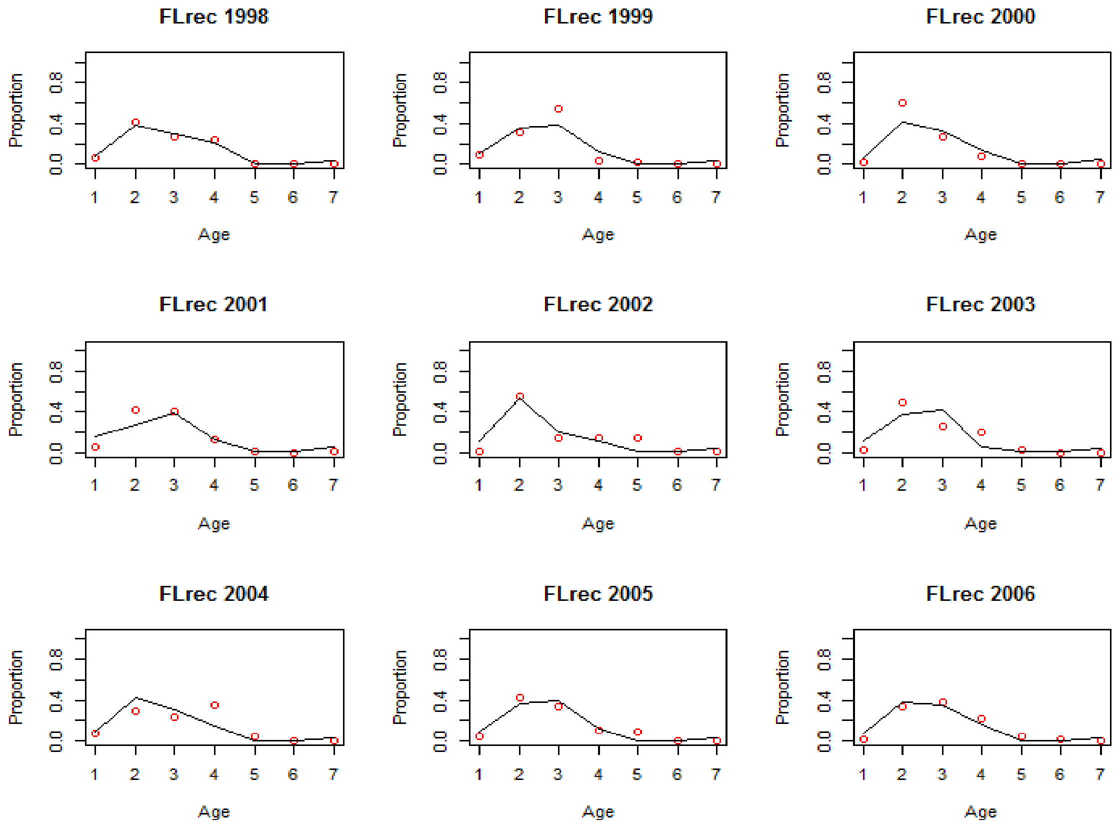


Figure 24 (con't).

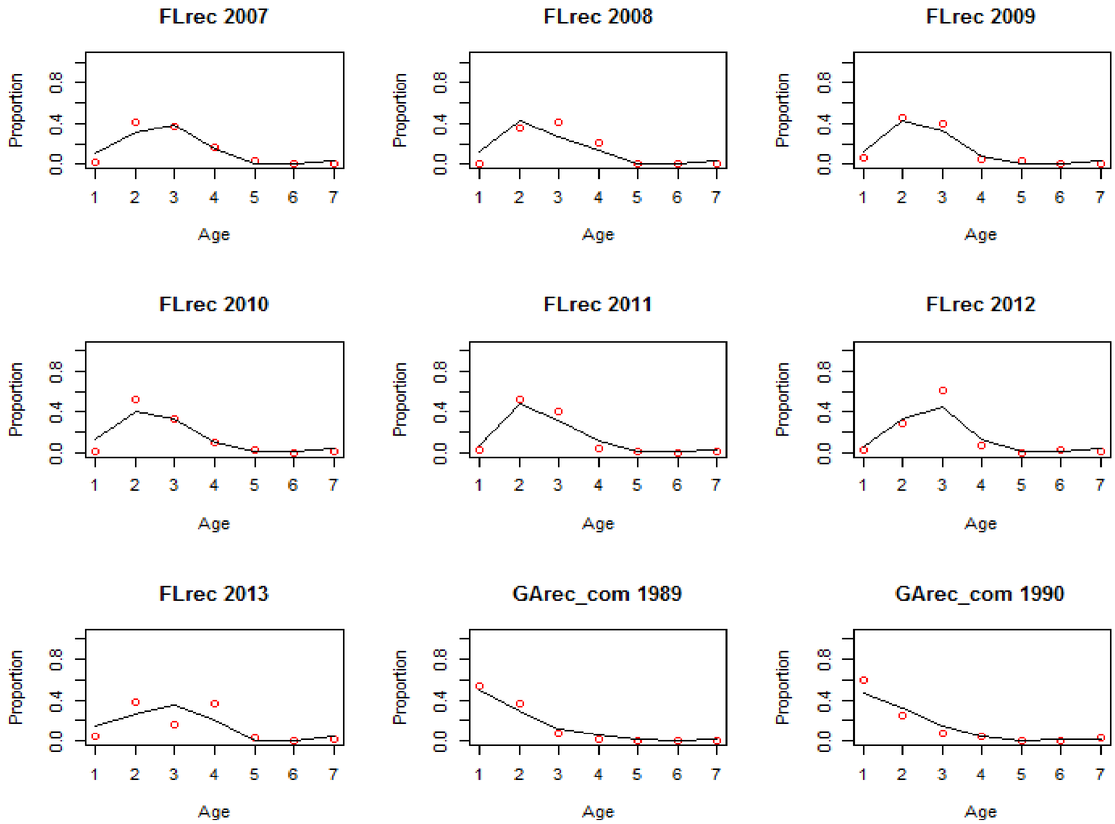


Figure 24 (con't).

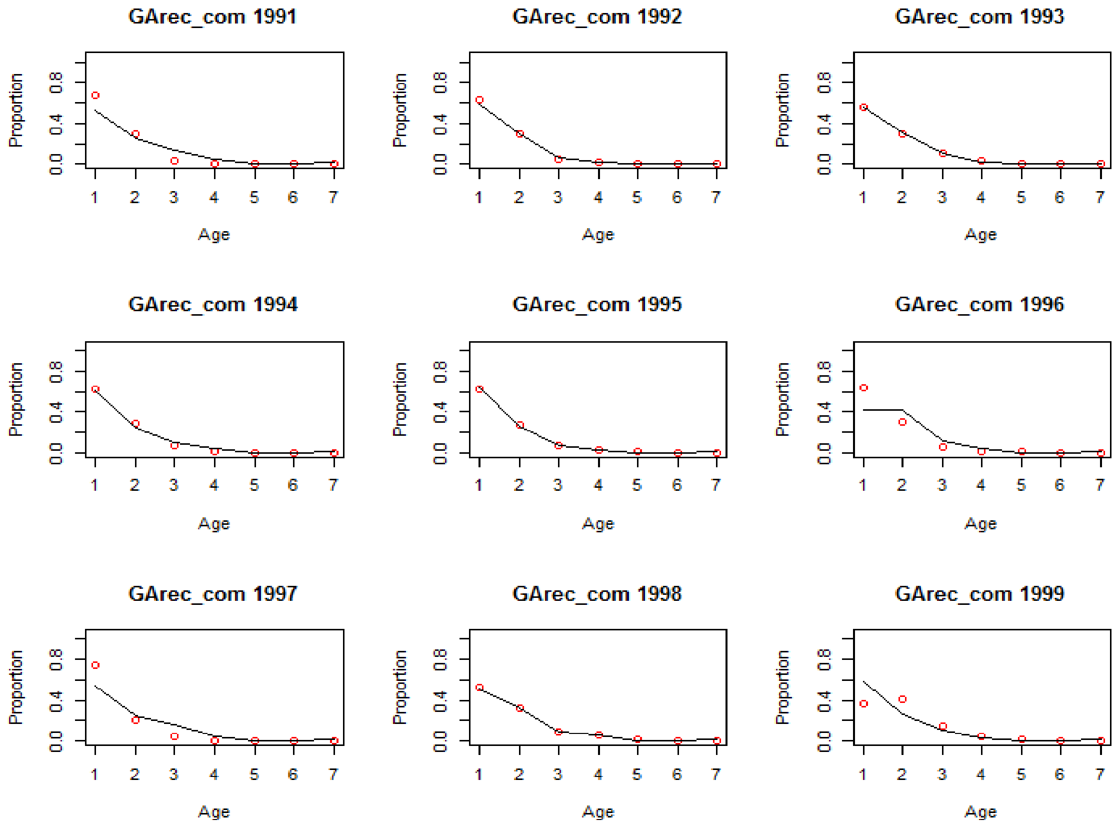


Figure 24 (con't).

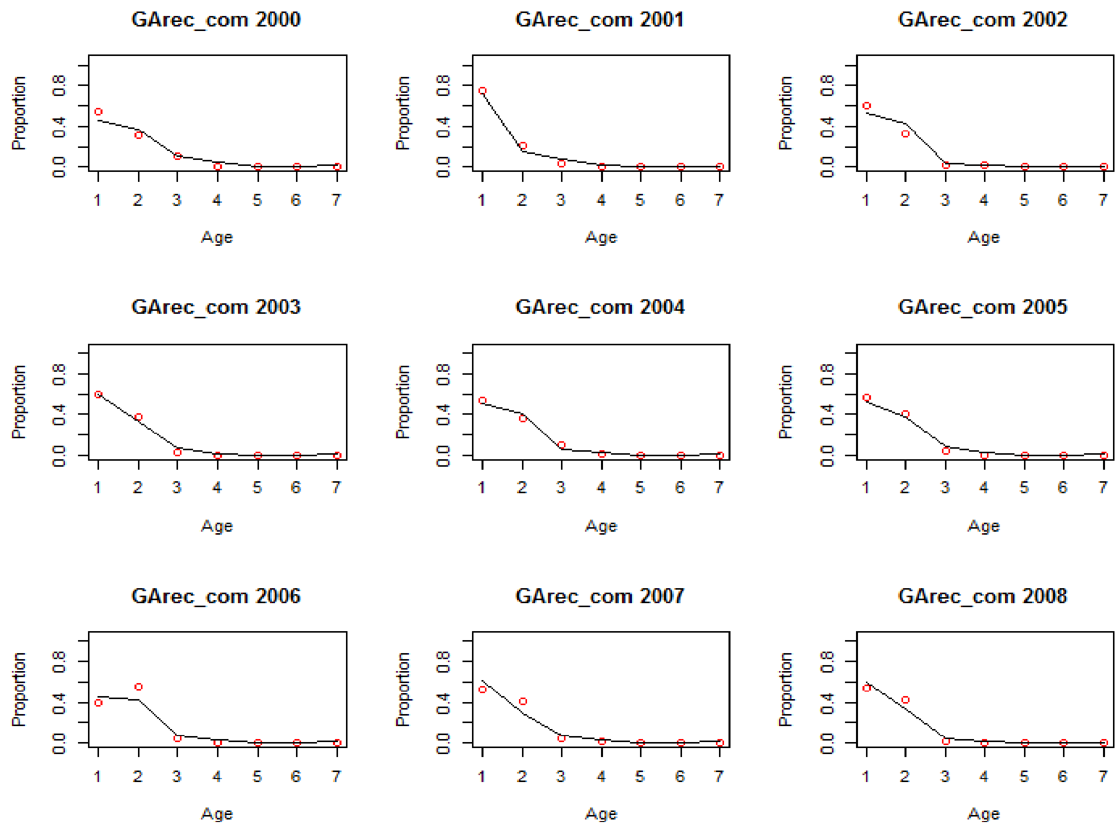


Figure 24 (con't).

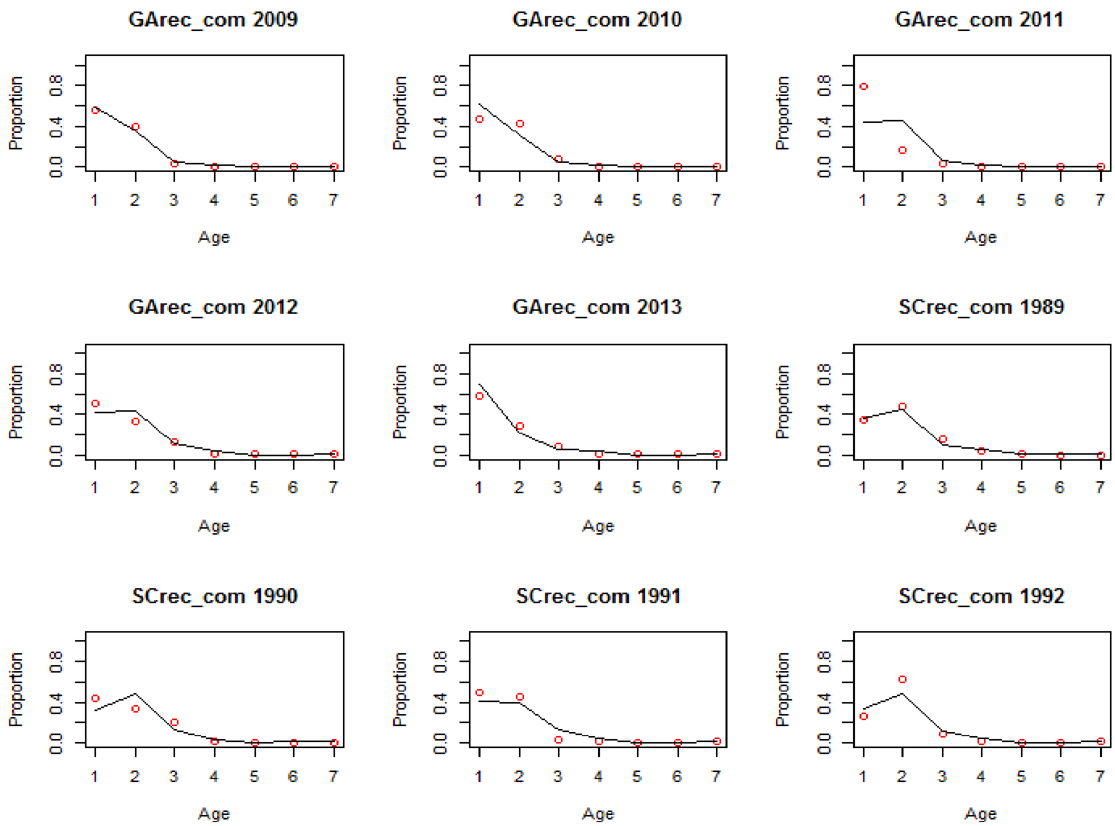


Figure 24 (con't).

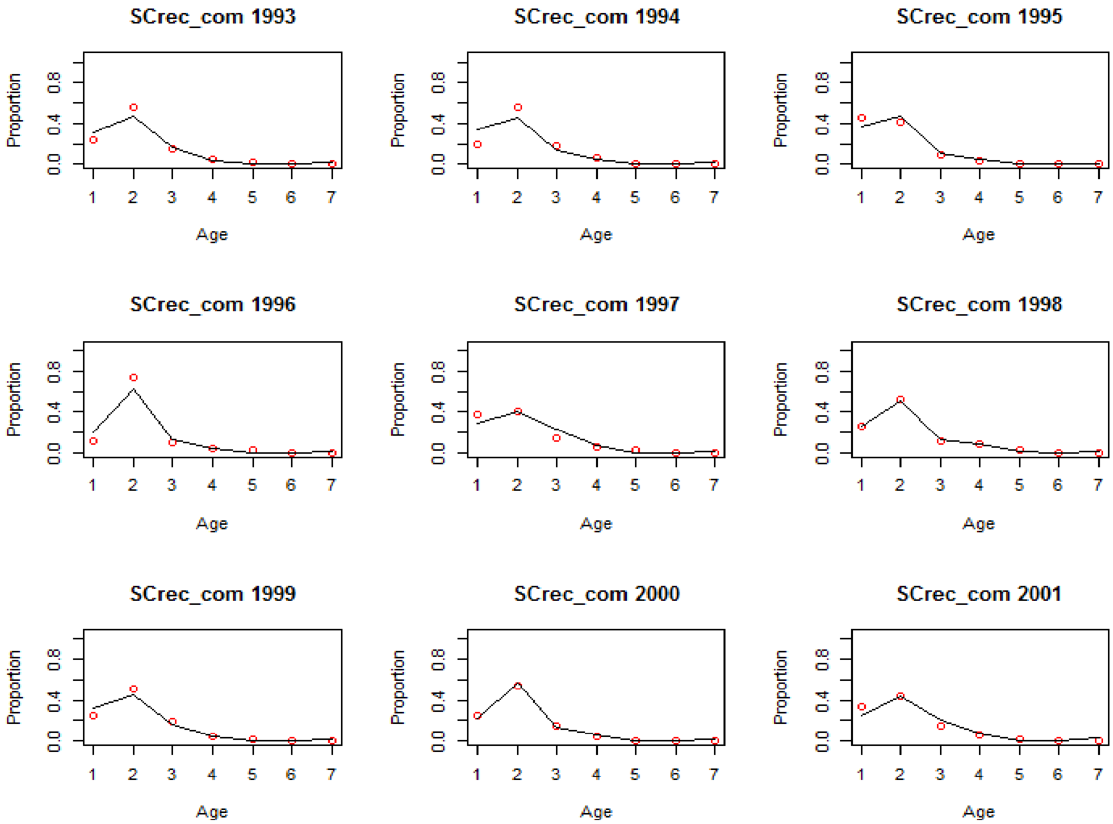


Figure 24 (con't).

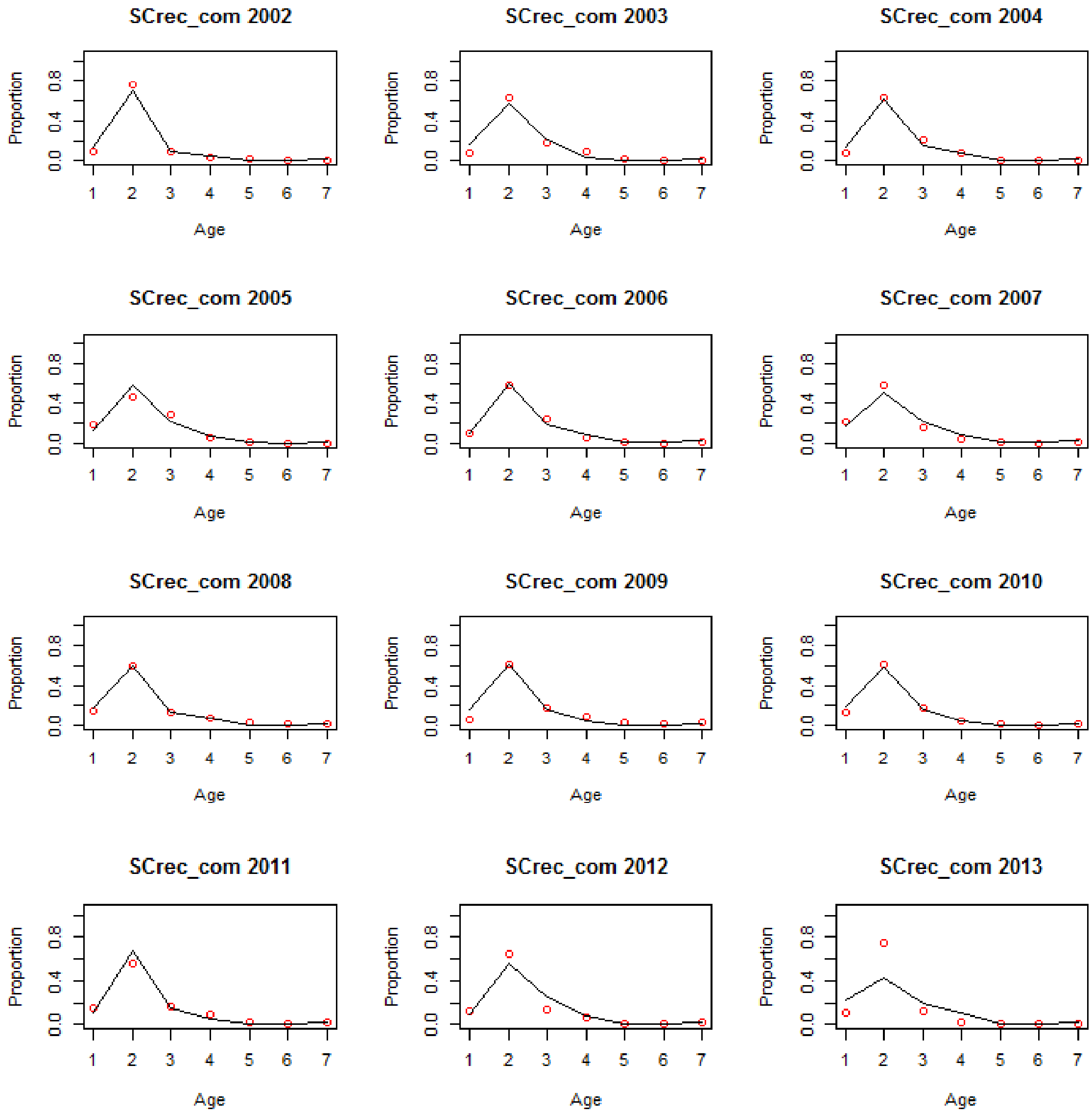


Figure 24 (con't).

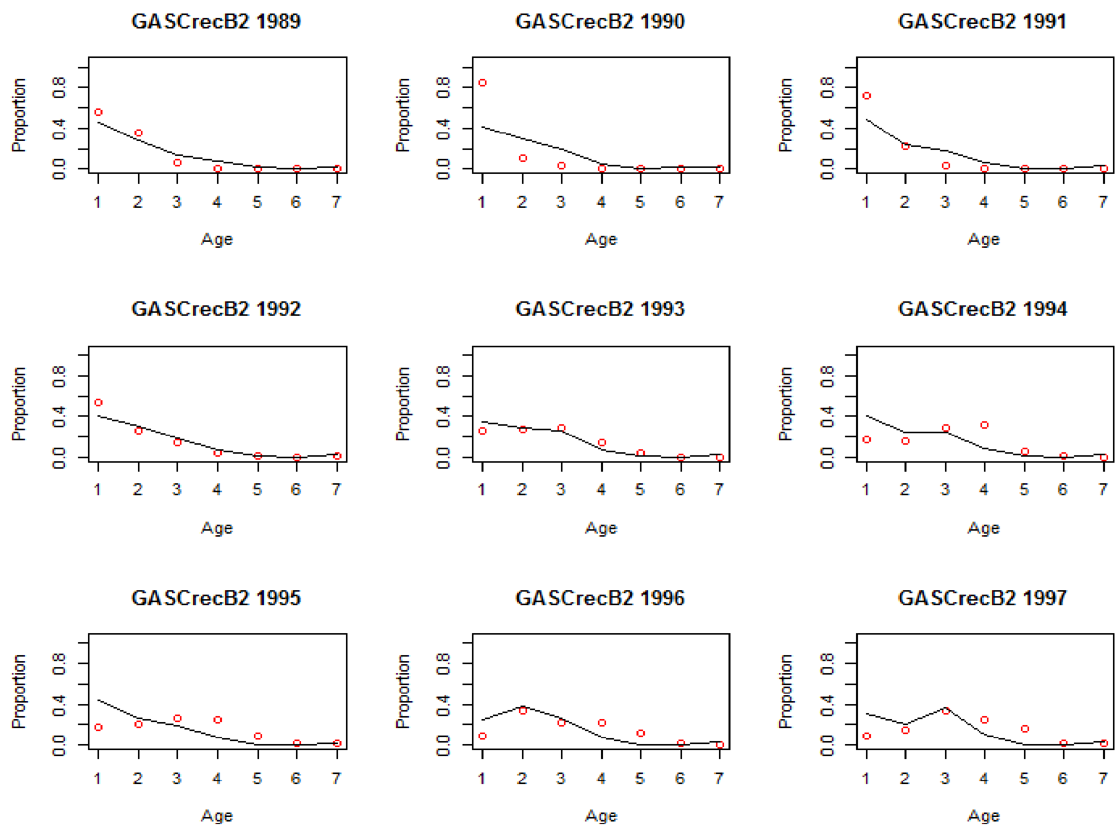


Figure 24 (con't).

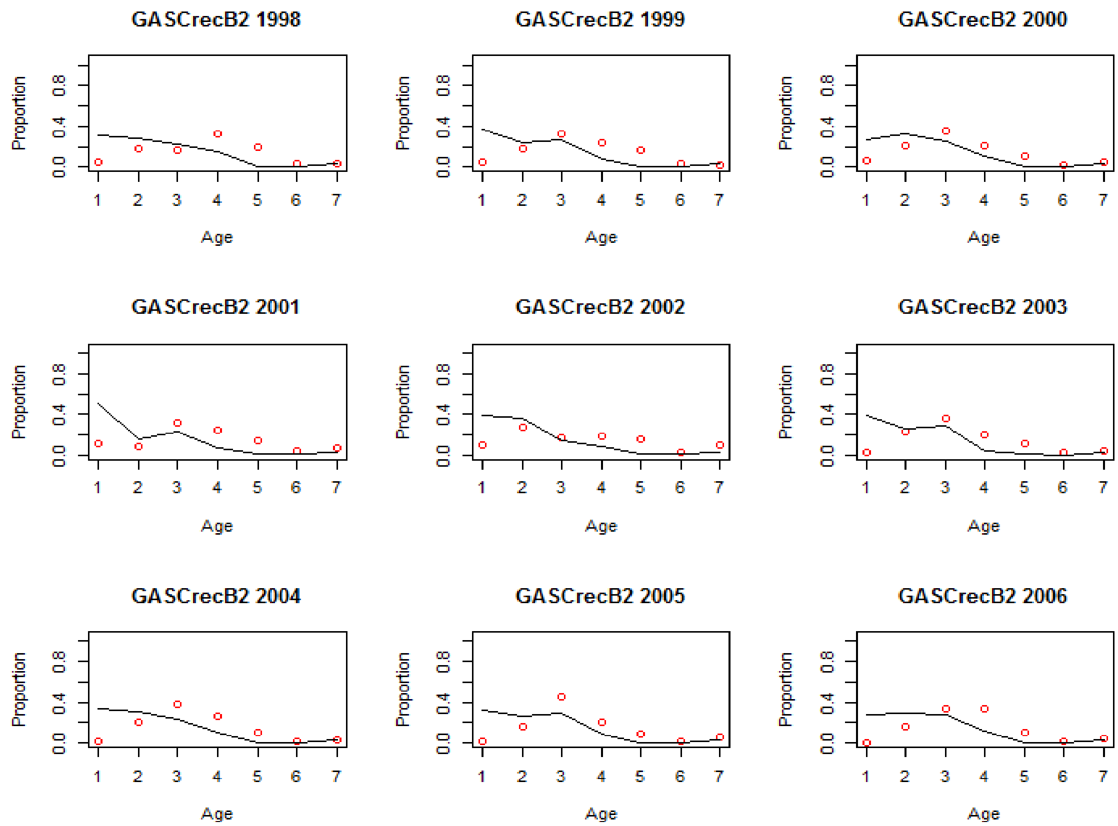


Figure 24 (con't).

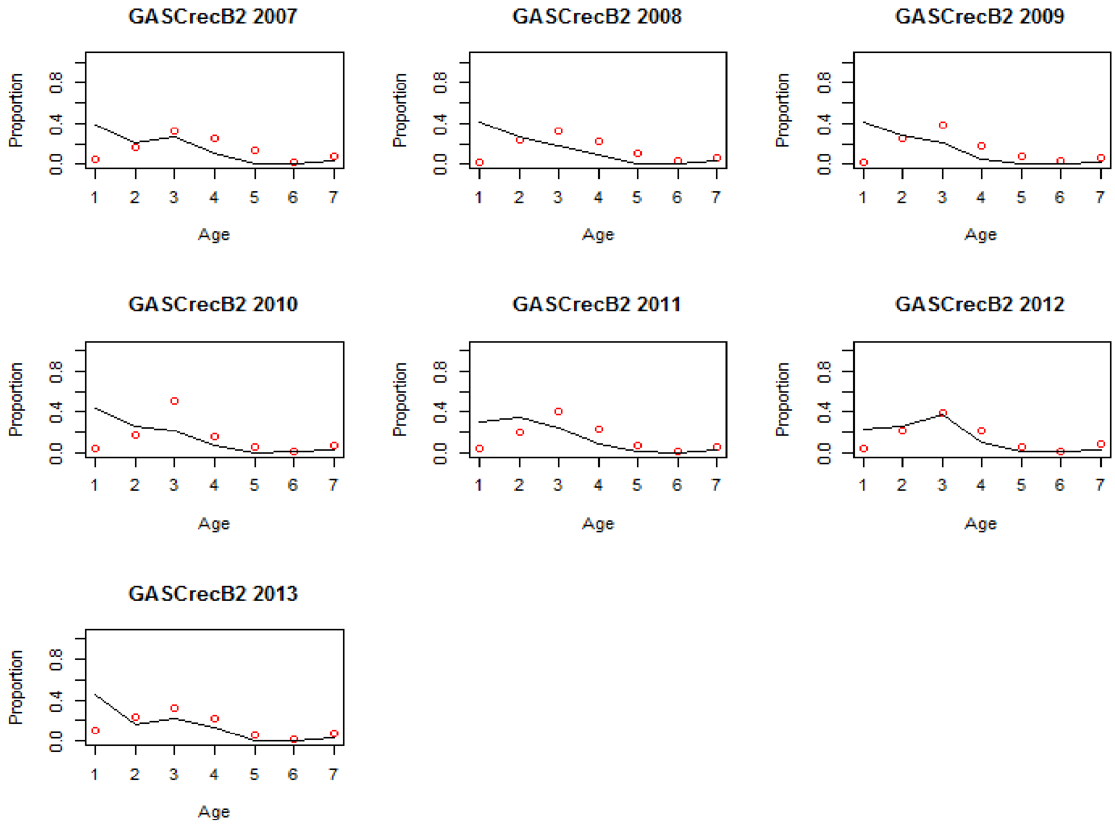


Figure 24 (con't).

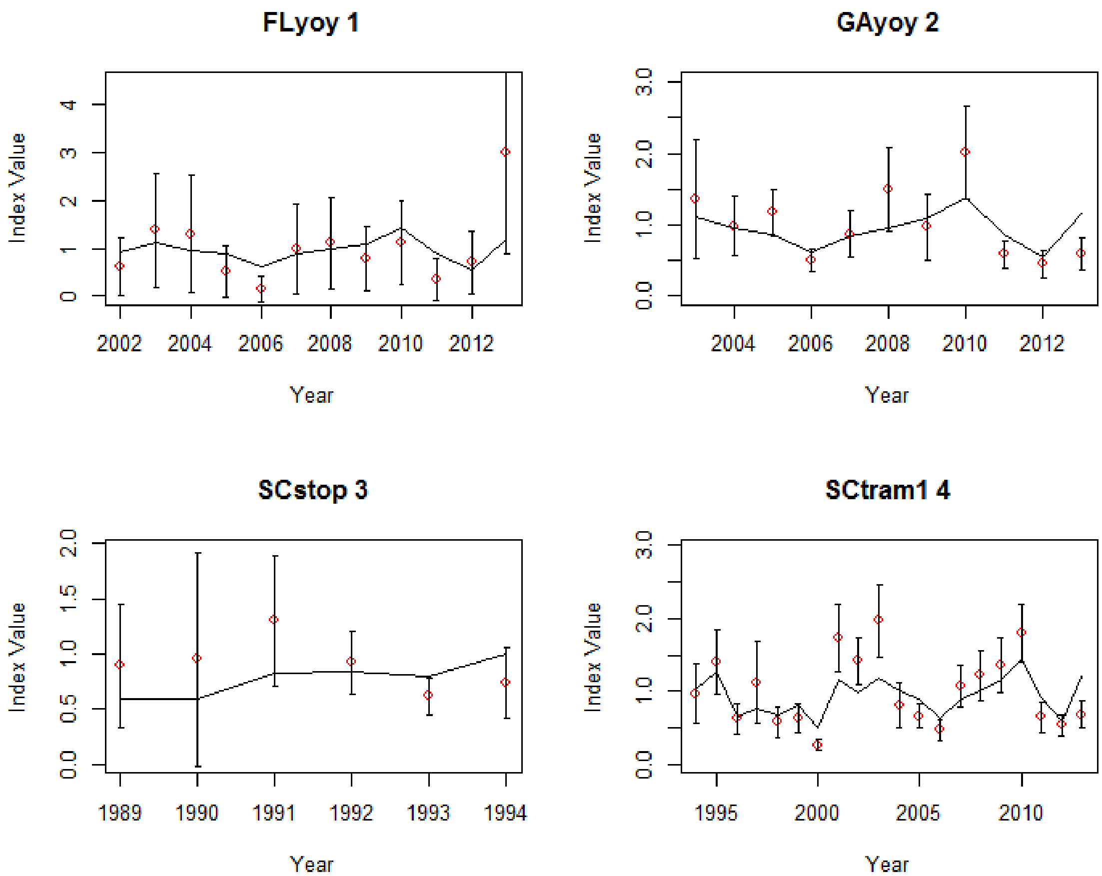


Figure 25. Observed (red circles) and model estimated (solid black line) indices of abundance for the southern stock. Error bars show 95% confidence intervals of observed values.

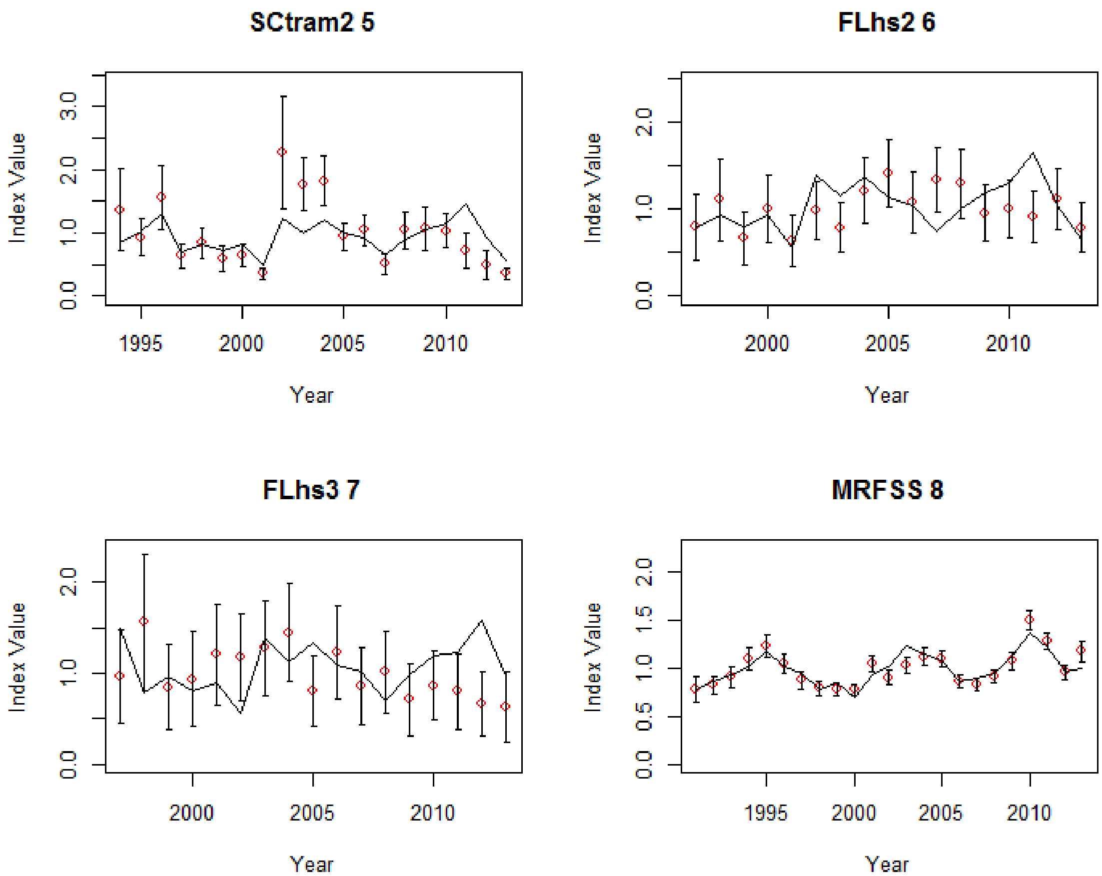


Figure 25 (con't). Index fits for the southern stock.

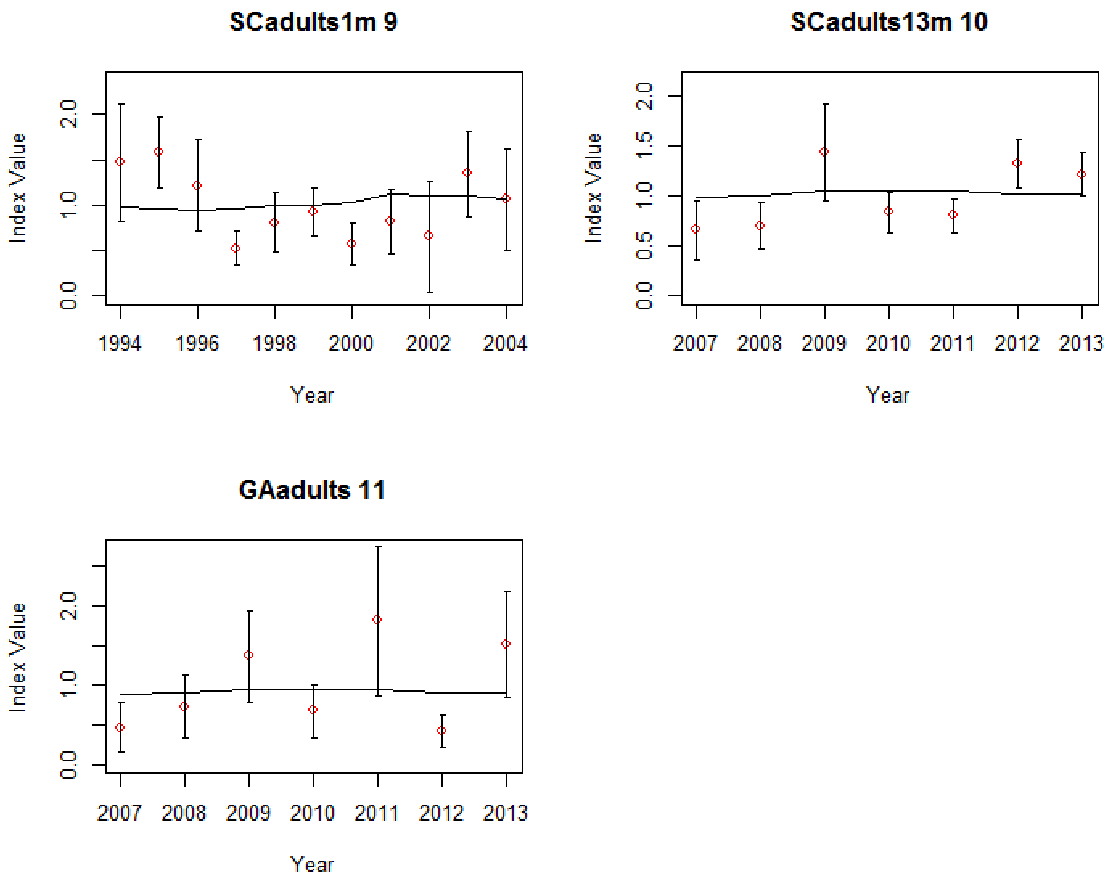


Figure 25 (con't). Index fits for the southern stock.

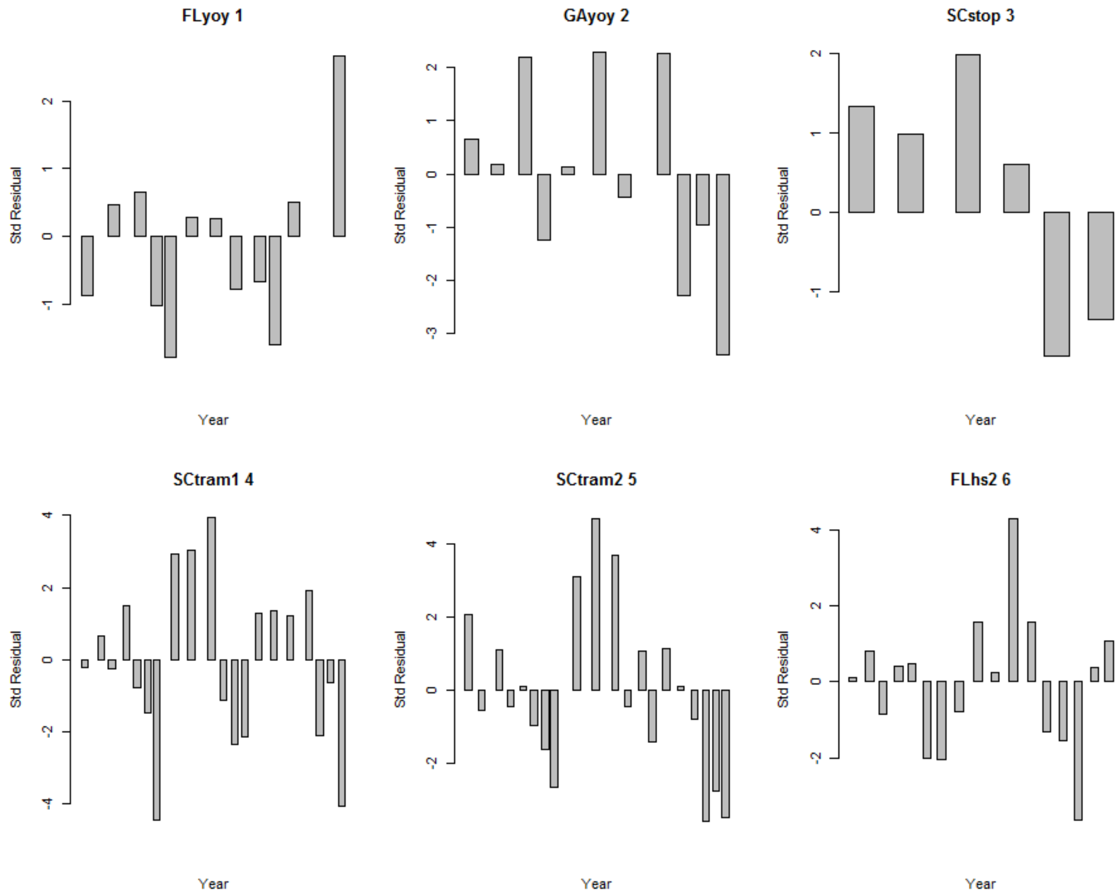


Figure 26. Standardized residuals for model fits to indices of abundance, by year, for the southern stock.

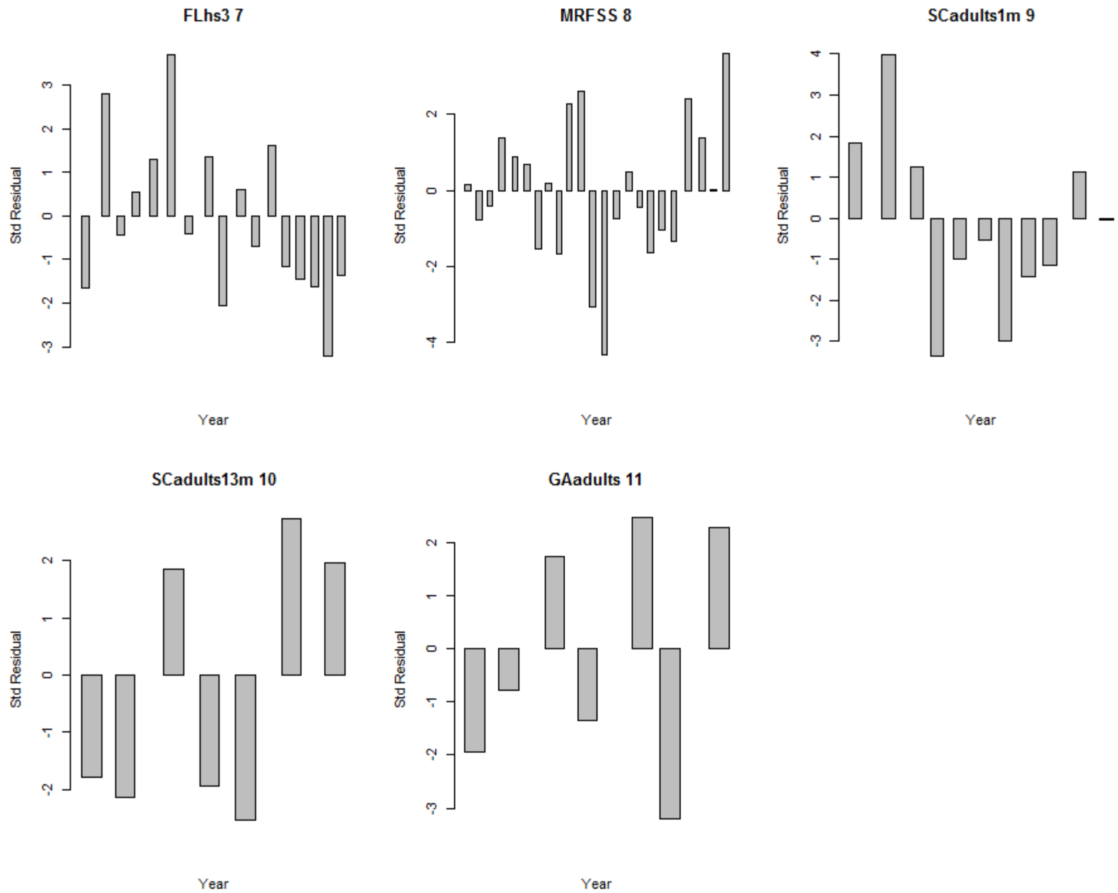


Figure 26 (con't). Standardized residuals for model fits to indices of abundance, by year, for the southern stock.

Figure 27. Predicted recruitment for the southern stock with 95% confidence intervals from asymptotic standard errors.

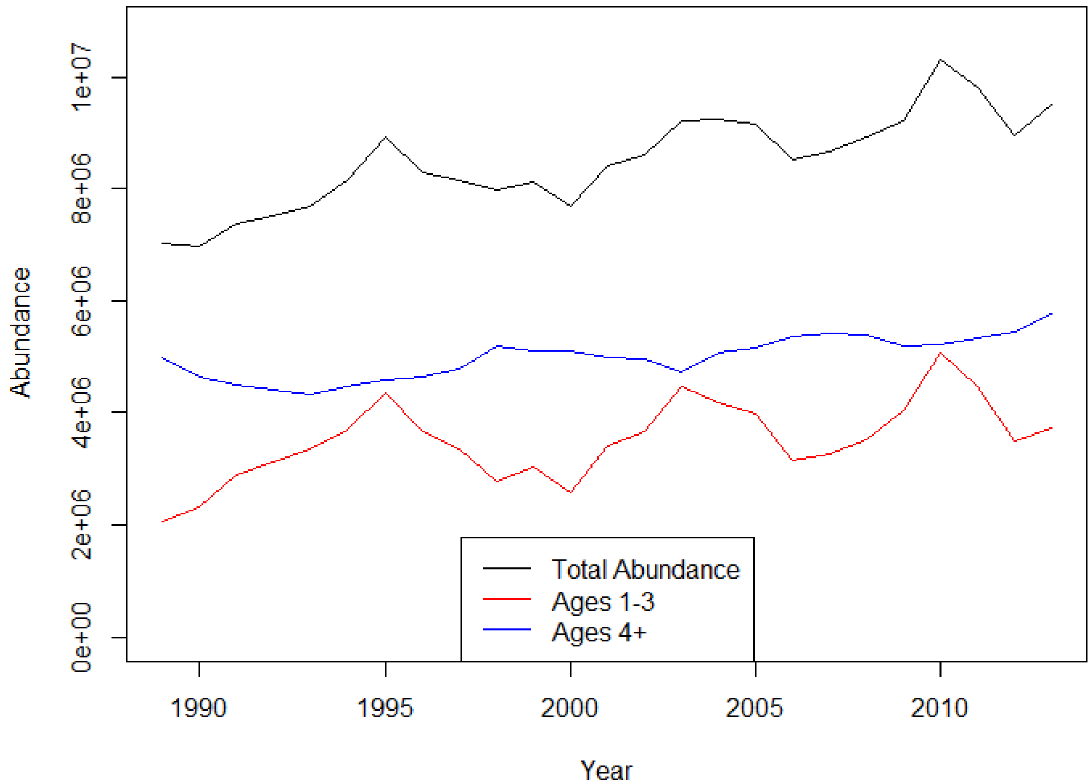


Figure 28. Abundance of red drum at various ages for the southern stock.

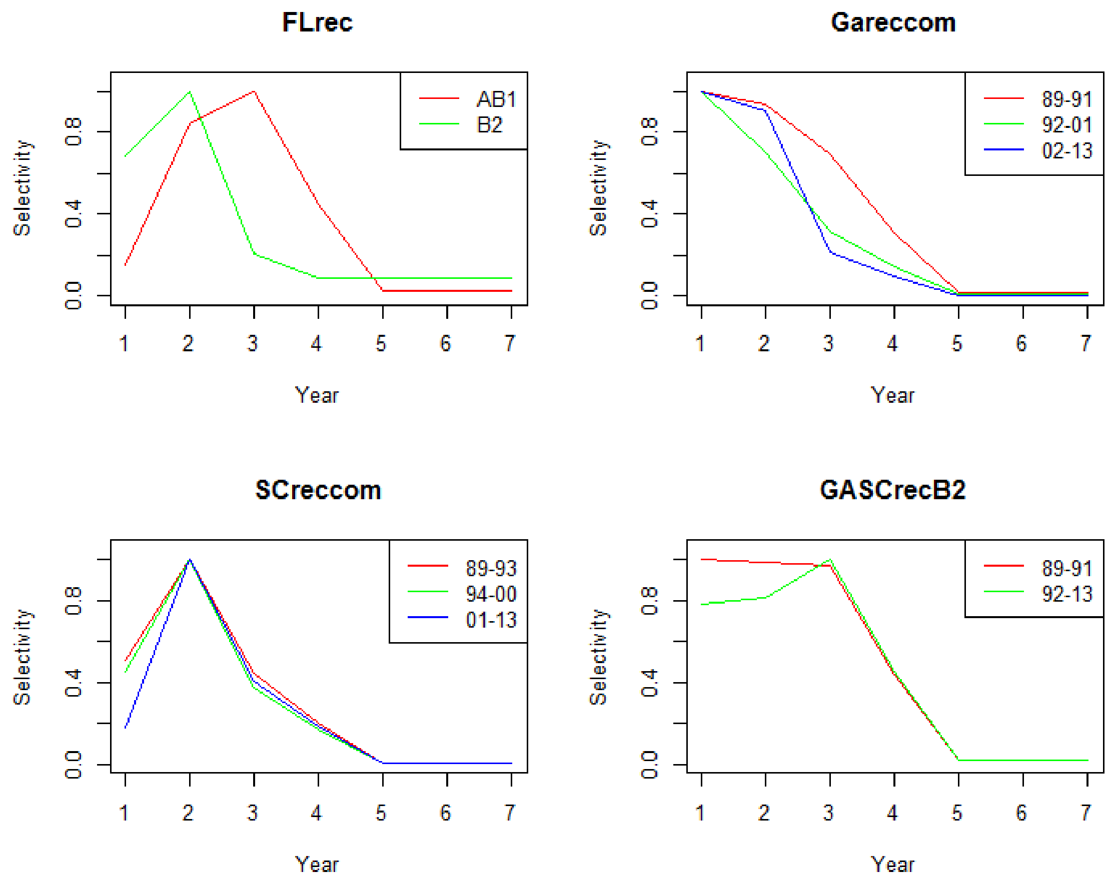


Figure 29. Selectivity curves for each fleet and selectivity block in the southern stock. The FL recreational live release selectivity is fixed based on external tagging analysis for North Carolina (Bacheler et al. 2008).

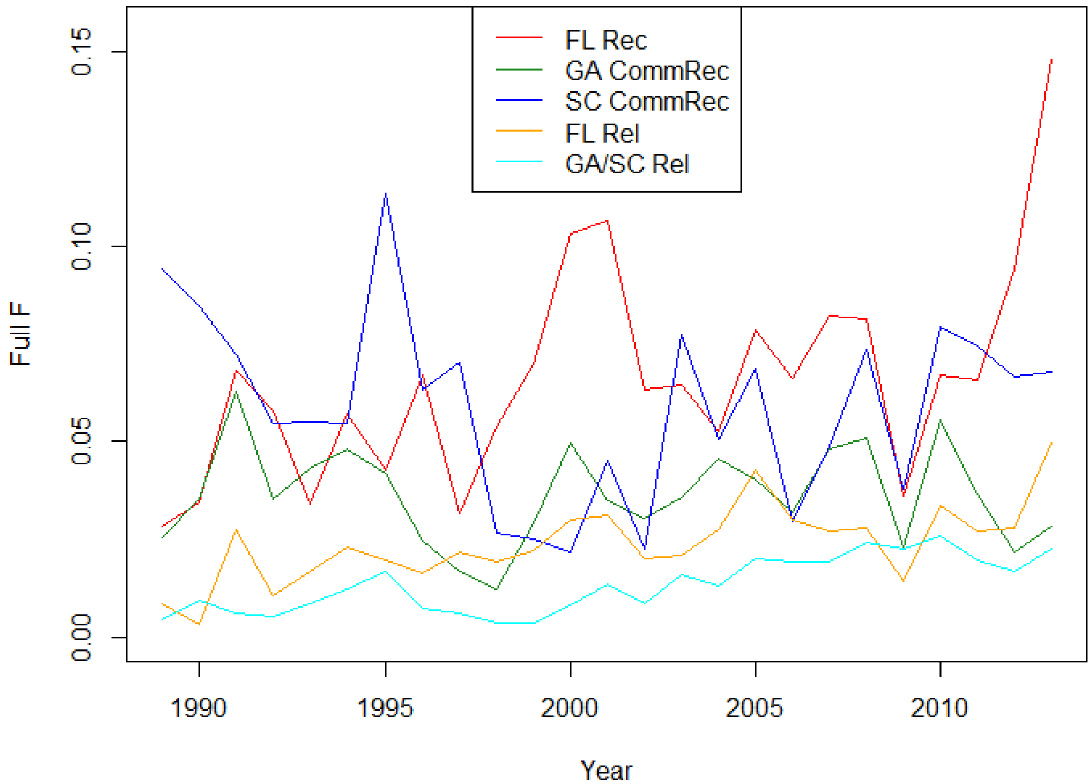


Figure 30. Fleet-specific annual fishing mortality for the southern stock.

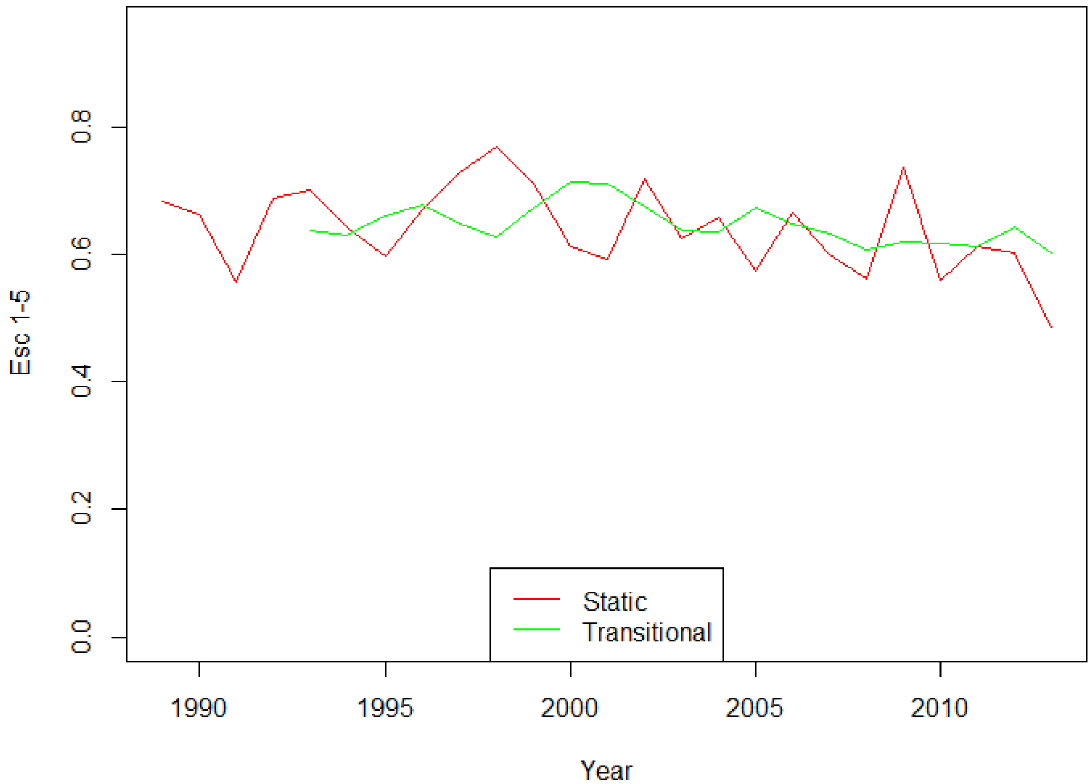


Figure 31. Estimates of static and transitional escapement for ages 1-5 for the southern stock.

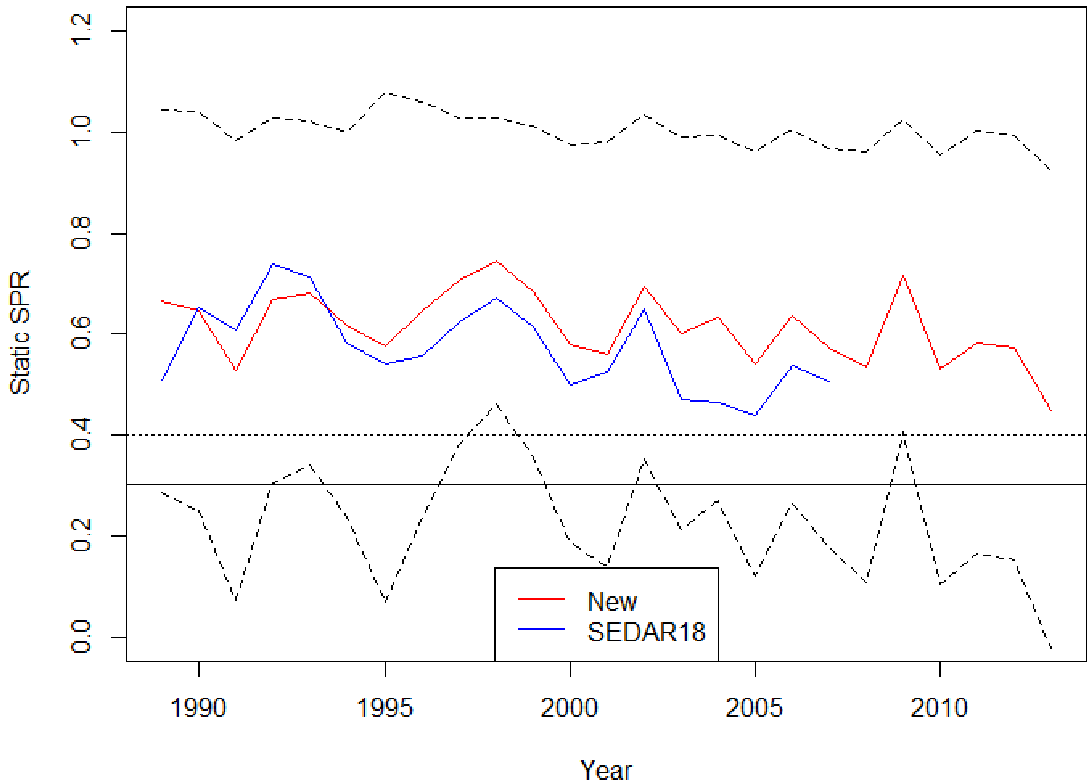


Figure 32. Annual sSPR estimates for the southern stock with 95% confidence intervals from asymptotic standard errors. Point estimates from the previous benchmark assessment (SEDAR18) are included for comparison. The target sSPR (dashed black line) is 40% and the threshold sSPR (solid black line) is 30%.

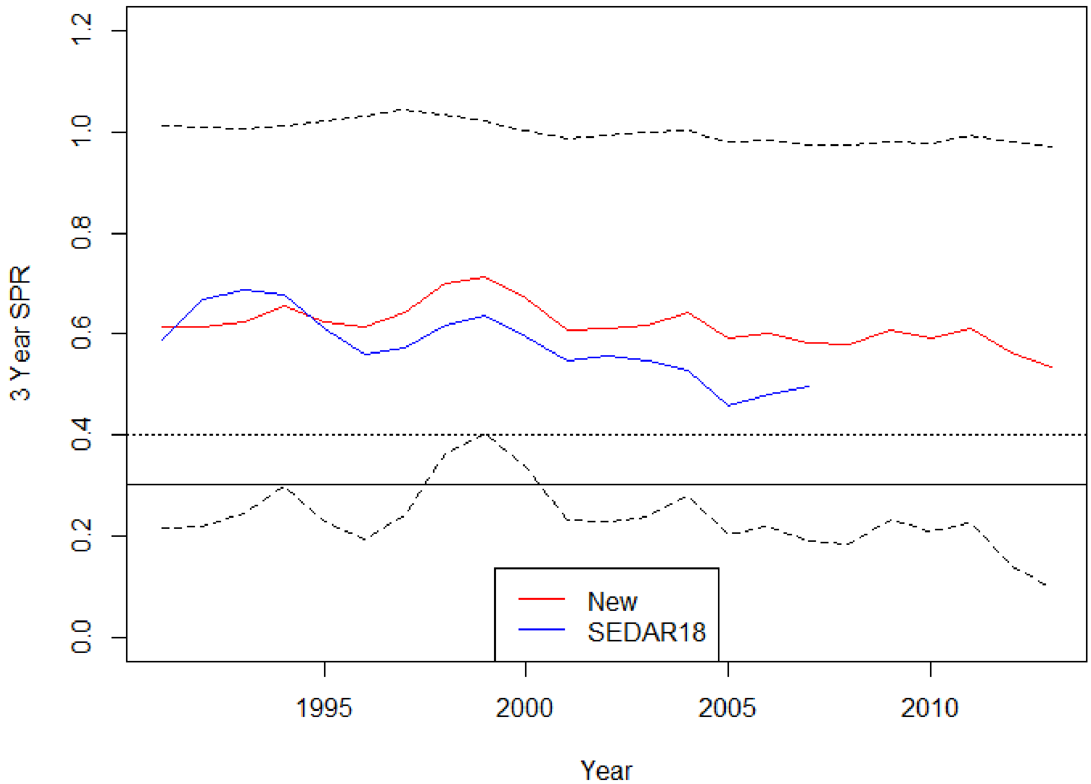


Figure 33. Three year average sSPR for the southern stock with 95% confidence intervals from asymptotic standard errors. Point estimates from the previous benchmark assessment (SEDAR18) are included for comparison. The target sSPR (dashed black line) is 40% and the threshold sSPR (solid black line) is 30%.

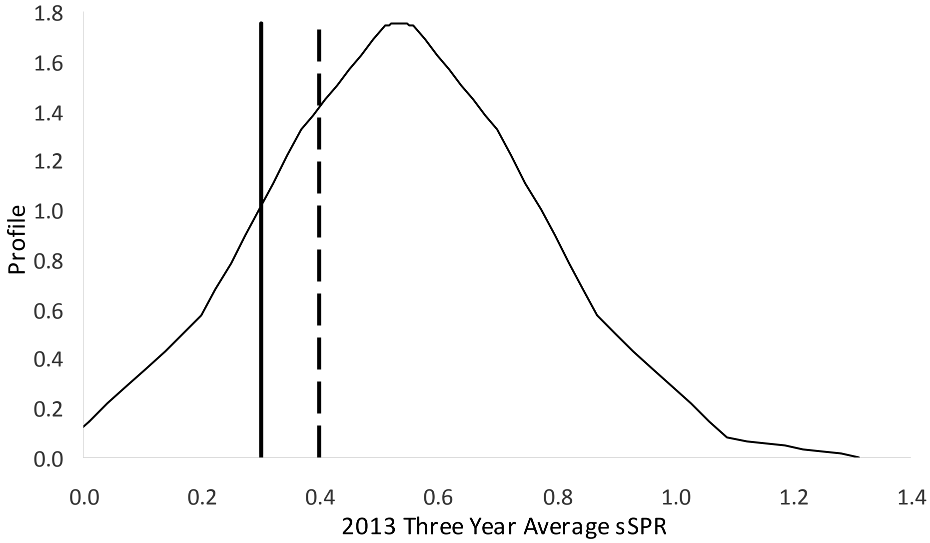
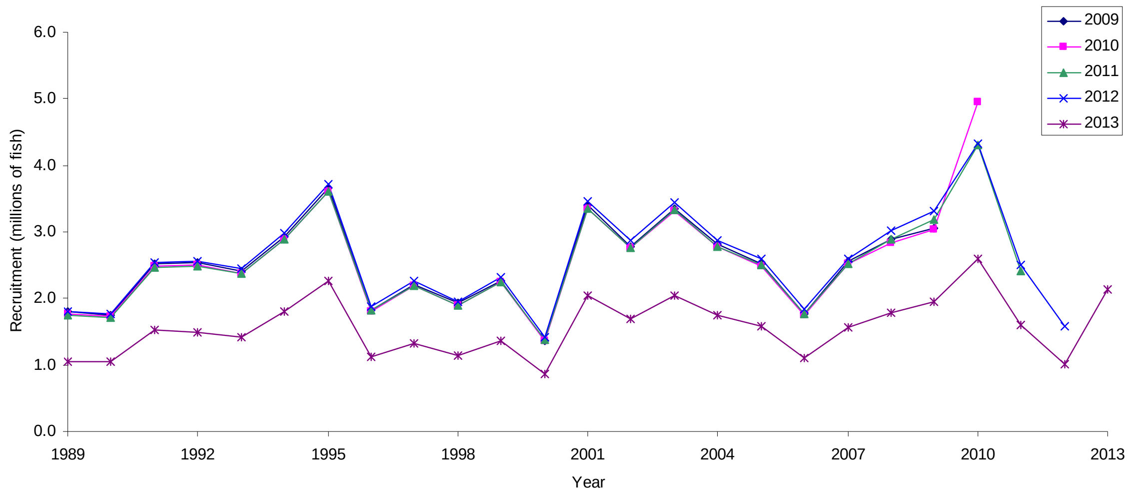


Figure 34. Estimated probability density function of the 2013 three year average sSPR for the southern stock. The target sSPR is 40% and the threshold sSPR is 30%.



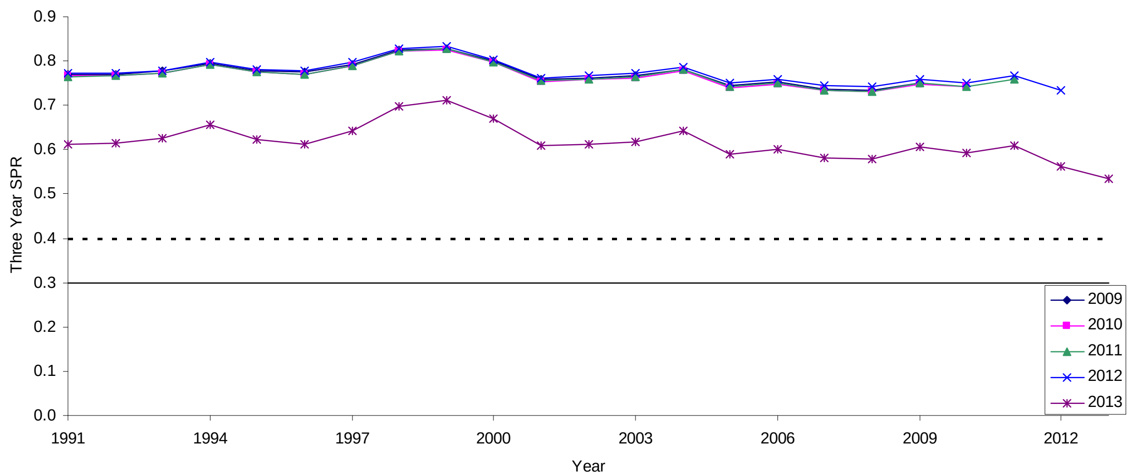


Figure 35. Five year retrospective analysis of the recruitment (top) and three year average sSPR (bottom) for the southern stock.

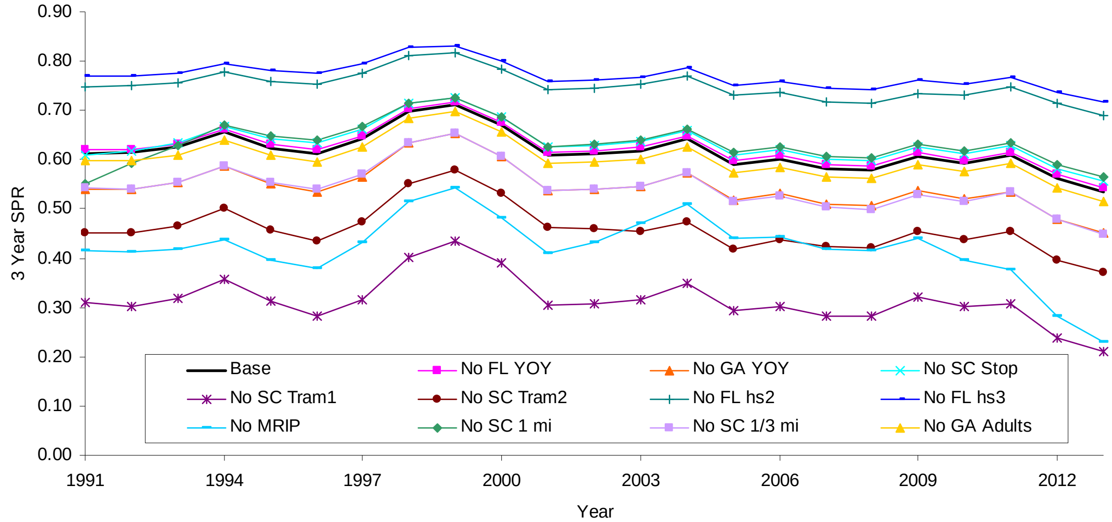


Figure 36. Comparison of the three year average sSPR for the southern stock when individual indices are removed.

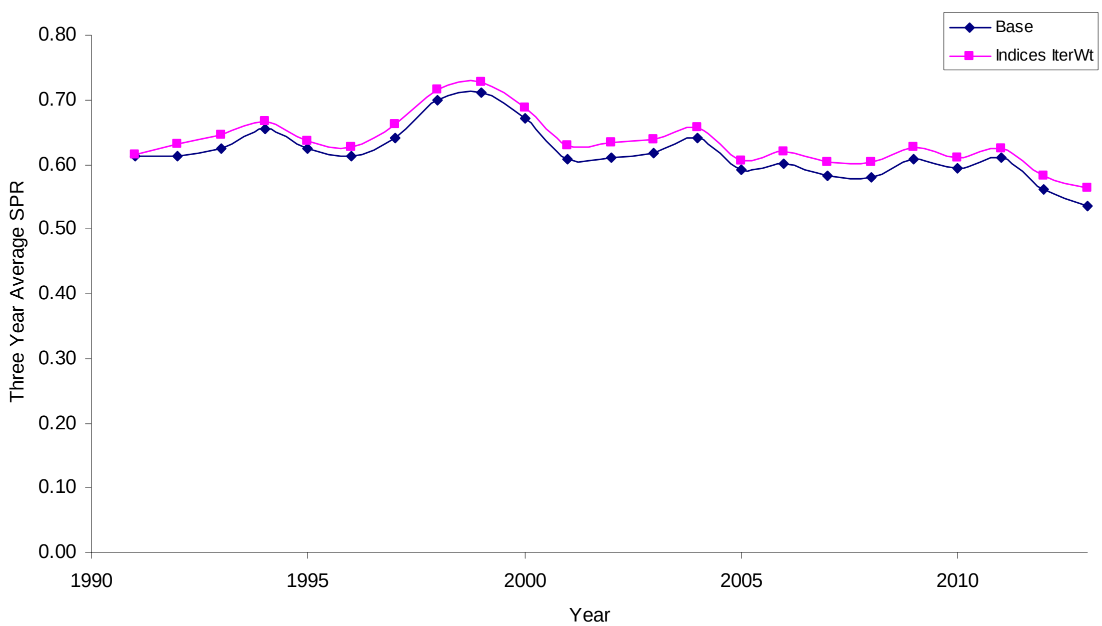


Figure 37. Comparison of the three year average sSPR for the southern stock for the base model and the iteratively reweighted model.

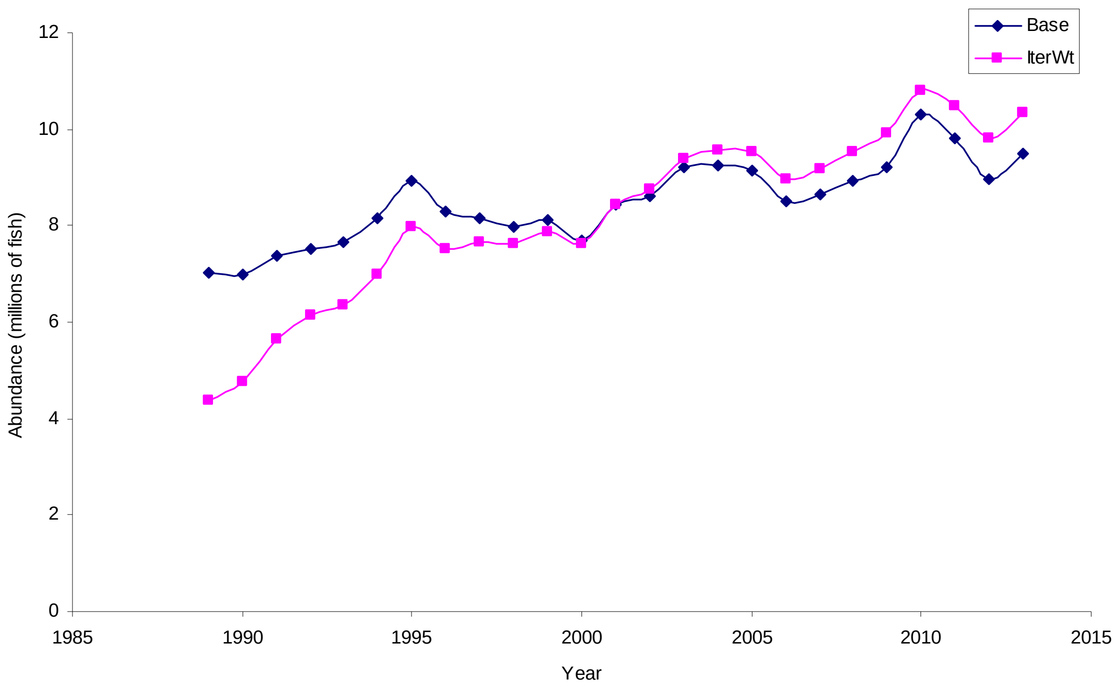


Figure 38. Comparison of the total abundance for the southern stock for the base model and the iteratively reweighted model.

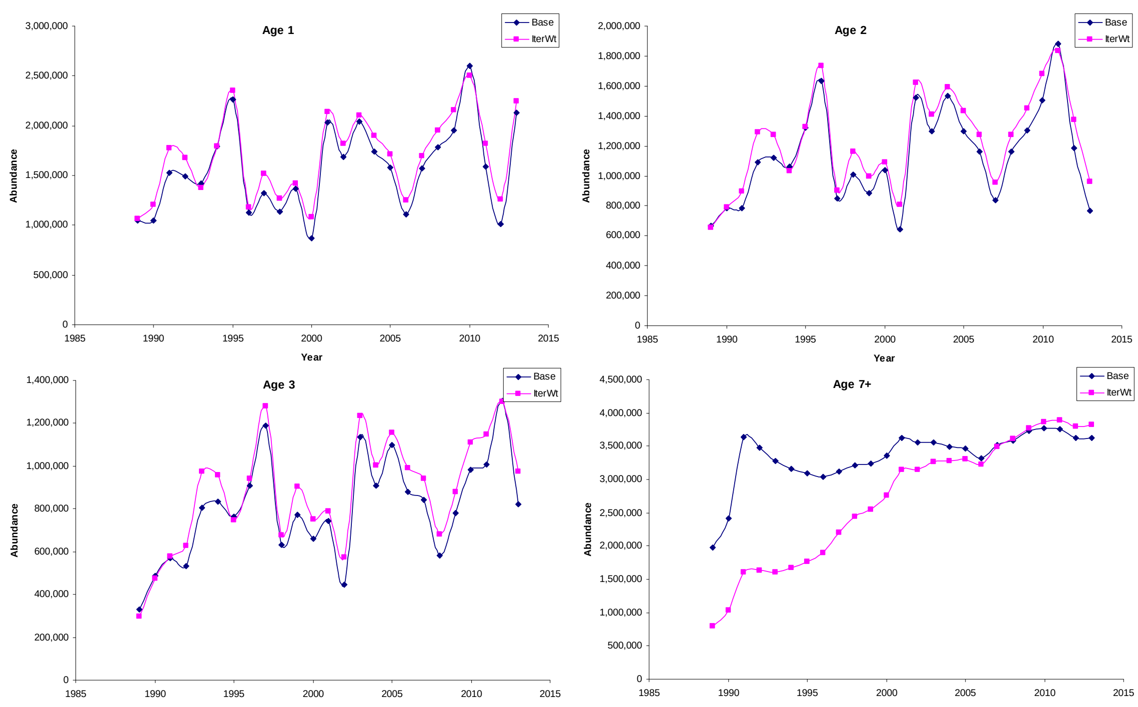


Figure 39. Comparison of the abundance for ages 1, 2, 3, and 7^+ for the southern stock for the base model and the iteratively reweighted model.

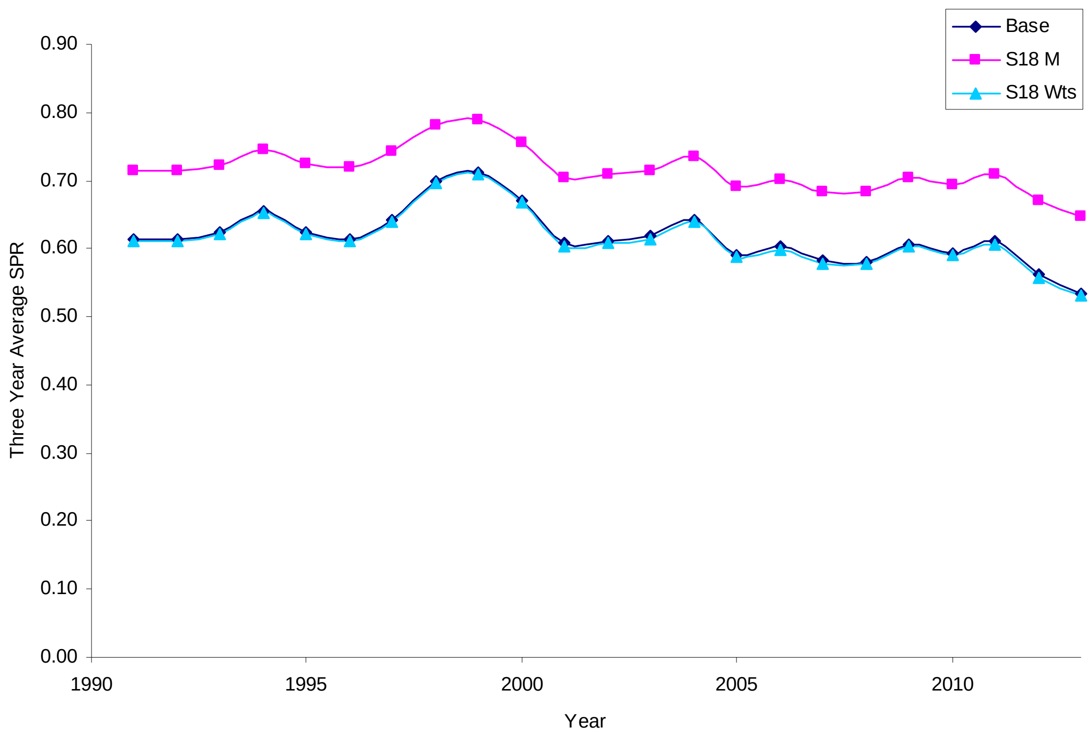


Figure 40. Comparison of the three year average sSPR for the southern stock for the base model, the model run using SEDAR18 estimates of M-at-age, and the model run using the SEDAR18 weights-at-age.

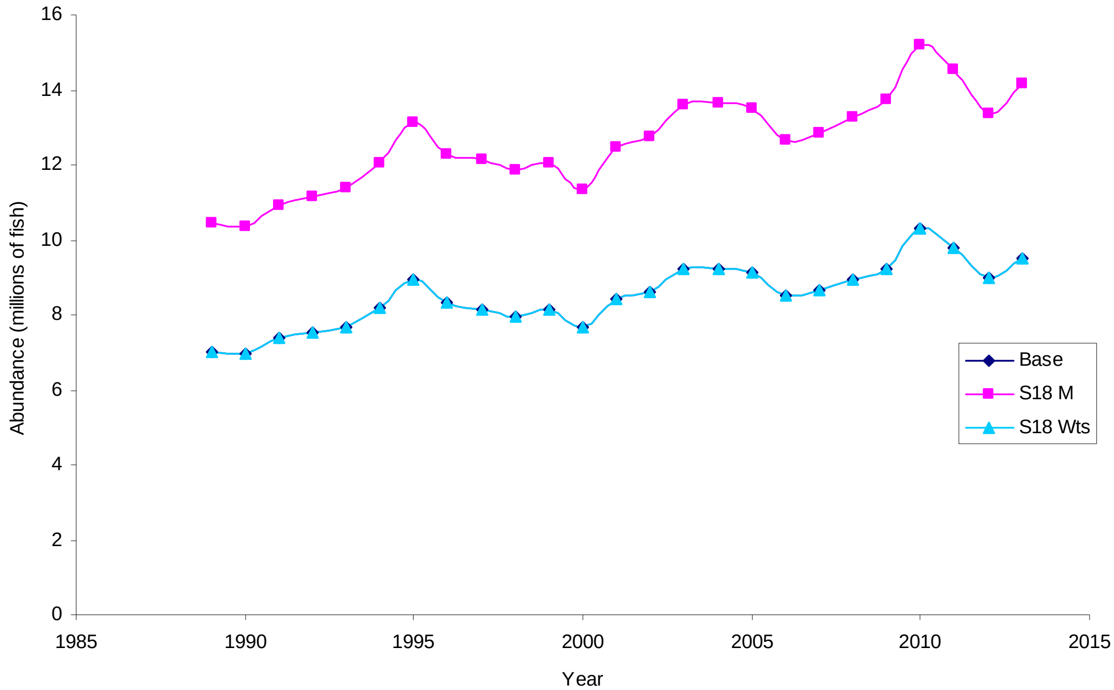


Figure 41. Comparison of the total abundance estimates for the southern stock for the base model, the model run using SEDAR18 estimates of M-at-age, and the model run using the SEDAR18 weights-at-age.