Virtual population analysis for Atlantic king mackerel

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<u>Virtual Population Analyses of Atlantic King Mackerel</u>

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Executive Summary

The methods and results of the continuity and updated virtual population analyses (VPA) conducted for SEDAR 38 stock assessment of Atlantic King Mackerel are summarized here and presented in detail in the attached report. The continuity VPA updated the previous assessment, SEDAR 16, with revised landings, discards, length composition, age samples, and indices without changing any assumptions about stock structure, catch composition, or model parameterization. Several key revisions were then made from the continuity to a SEDAR 38 base VPA, which included:

- Revision of stock structure and mixing assumptions, and associated reallocation of landings, discards, length samples, age samples, and indices.
- Truncation of the early time period 1981 to 1985, where no age information was available to estimate catch-at-age or fleet partial catch-at-age.
- Revision to the indices of abundance to use the commercial logbook trolling gear index in place of the North Carolina trip ticket index, and exclusion of the MRFSS recreational private and charter index.
- Revision of life history information, including natural mortality, fecundity, maturity, growth, and length-weight relationships.
- Revised age composition of commercial and recreational discard mortalities to be comprised of age-0 individuals, with the exception of recreational tournaments.
- Inclusion of tournament landings, lengths, and age composition information, with landings approximated as 3% of private and charter landings.
- Inclusion of tournament discard mortalities, calculated from a published tournament retention function and the observed size composition of fish caught by the private fleet.
- Revised indices weighting by index coefficient of variation.

The main findings of the assessment included:

- Changes in stock structure and discard assumptions resulted in changes to fleet partial catch-at-ages, total catch-at-age estimates, and indices used in the VPA.
- Comparison of SSB and recruitment estimates between the continuity and base VPAs showed a distinct change in estimated stock trends; the effect of each change in model assumptions is presented as iterative sensitivities.
- The average spawning stock biomass from 2008 to 2012 was estimated to be 4,980 mt; estimates ranged 4,473 to 5,414 mt for that period.
- The average recruitment from 2008 to 2012 was estimated to be 2.79 million fish; estimates ranged 1.68 to 4.56 million fish for that period.
- The average apical fishing mortality from 2008 to 2012 was estimated to be 0.18; estimates ranged 0.12 to 0.25 for that period.
- Stock-recruitment estimates showed a shotgun pattern with no clear functional form or contrast in the range of recruitment across the range of SSB.
- Relatively strong recruitments were observed in 1989, 1994 to 1996, 1998, and 2003 to 2007; and low recruitment years included 1987, 1991 to 1993, 1999, and 2000.
- The Stock Synthesis model was selected as the preferred model over the VPA for estimation of benchmarks, stock projections, and management recommendations, and those determinations are presented in the SEDAR 38 Assessment Workshop Report.

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1. Introduction

SEDAR 38 was a benchmark assessment for Atlantic King Mackerel, which provided the opportunity to update the state of knowledge of the species and revise stock assessment modeling approaches accordingly. After extensive review of available information, several key assumptions were revised during the data workshop. One of the major conclusions of the life-history workgroup was a proposed revision to the definition of stock structure and winter mixing overlap with Gulf of Mexico King Mackerel. The result of this change in stock structure was reallocation of landings, discards, indices of abundance, age and length samples assigned to each stock, and corresponding changes in estimates of fleet partial catch-at-ages, and total catch-at-age, principle inputs to the virtual population analysis (VPA). The base VPA in the previous assessment (SEDAR 16) was constructed in VPA-2BOX version 3.01, and an updated version of the software was used in this assessment, version 3.05.

A primary objective of the Assessment Workshop was to construct a continuity model that represented a strict update of the SEDAR 16 base VPA with landings, discards, indices of abundance, age and length samples updated to 2012; without changing any of the major assumptions of life history parameters, stock distribution model inputs or parameterization. The one primary change between SEDAR16 and the continuity run was a difference in the catch at age construction. Data and indices provided at the data workshop represented the continuity model inputs as these were constructed under the similar assumptions as the previous assessment. Section 2 of this report documents the review of continuity life history assumptions and data, VPA continuity methods, results, and comparison of the continuity VPA with the SEDAR 16 base model. After this objective was accomplished, the VPA was restructured to incorporate the revisions proposed during the Data Workshop and recommendations from the Assessment Panel based on review of the continuity model.

Revisions to the life-history parameters, landings, discards, indices of abundance, age information, and length samples were incorporated based on changes in the definition of stock distribution and discussion of VPA assumptions. Section 3 of this report documents the revisions to the data and model parameterization, results of the base VPA, and comparison with the continuity model. The effects of changing each of the key data inputs and model assumptions from the continuity to the base model are also presented. Time series estimates of fishing mortality, spawning stock biomass, and recruitment from the VPA base model are presented and discussed in detail.

After the VPA base model was reviewed and evaluated, the Assessment Panel compared modeling approaches with the alternative base model, constructed in Stock Synthesis. The Stock Synthesis model was determined to be the preferred modeling platform, owing to the ability to more accurately model King Mackerel life-history, primarily sexually dimorphic growth and size structure, as well as more appropriately incorporate the various sources of data, specifically fleet associated length and age samples. In using Stock Synthesis, the assumptions of the age composition of the catch being known without error were loosened. Therefore, estimates of benchmarks, stock status, and projections were considered unnecessary for the VPA.

2. Continuity VPA

2.1 Continuity VPA Model Inputs

The continuity VPA was a combined sex, single stock model. Twelve age classes were defined as ages 0 to 10 and a plus group of fish age 11 and older. The modeled period was 1981 to 2012, with the annual time-step defined by fishing year, April 1 to March 31 of the following calendar year. All data were summarized by fishing year. A complete documentation of VPA assumptions and parameterization can be found in the SEDAR 16 Complete Assessment Report, available here: http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=16. For comparative purposes and brevity of data summaries, all figures summarizing the continuity model results are presented with the revised base VPA results.

2.1.1 Life History Assumptions

The stock distribution was assumed to be North Carolina to the west coast of Florida at the Collier-Monroe county line during April 1 to October 31, with a winter mixing zone defined along Florida from the Collier-Monroe to the Flagler-Volusia counties lines during November 1 to March 31 (**Figure 1**). The stock mixing assumption was 50% Gulf of Mexico and 50% Atlantic stock composition within the mixing zone during the defined winter mixing season. Natural mortality (M) was assumed to follow a scaled Lorenzen curve, using a base M of 0.16. Maturity remained unchanged from the SEDAR 5 and SEDAR 16 base models. The assumed spawn date was April 1. Fecundity remained unchanged from SEDAR 16 base. The input values are listed in Table 1. The length-weight relationship was a power equation with parameters a=6.1775e-6, b=3.0495.

2.1.2 Landings

Four fishing fleets were defined by sector and mode that included commercial handline, commercial non-handline, recreational headboat, recreational charter, and recreational private/shore. Tournament landings were assumed a negligible proportion of the recreational landings. Landings were provided during the Data Workshop and remained unchanged for the continuity model. Methods for landings estimation are described in the SEDAR 38 Data Workshop Report. Catch unit was number of fish. For the commercial fleets, this required a conversion from landings measured in whole pounds. This conversion was the annual fleet yield in pounds whole weight divided by the average weight of an individual calculated as the mean size of measured fish captured by the fleet and converted to weight using the length-weight conversion equation: $Weight = a \cdot Length^b$, where a and b values are listed in the above section. All landings within the mixing zone were assumed to be comprised of 50% Atlantic stock and 50% Gulf of Mexico stock. The landings data are summarized in **Figure 2**.

2.1.3 Discards

Commercial discards were assumed to be negligible and were not modeled, consistent with SEDAR 16 base. Estimates of total recreational discards were provided at the Data Workshop, and remained unchanged as input to the continuity model. The length composition of recreational headboat discards was assumed to be fish under the legal size limit, and the length composition of recreational charter/private/shore discards was assumed equal to the length composition of the retained catch. Discard mortality was assumed to be 33% of live discards on recreational headboats and 20% of live discards on private boats, charter boats, and shore fishing.

2.1.4 Shrimp Bycatch

Estimates of shrimp bycatch of age-0 King Mackerel were based on catch rates of King Mackerel from the SEAMAP Atlantic Trawl Survey extrapolated by shrimp fishing effort in the Atlantic (see SEDAR 16-DW-05 and addendum for methods). All shrimp bycatch removals were assumed to be age-0 fish. Estimates of shrimp bycatch are shown in **Figure 3**.

2.1.5 Indices of Abundance

Three fishery dependent indices, and one fishery independent survey were included in the continuity VPA. The fishery dependent indices were the North Carolina trip ticket index of the commercial handline fleet, the Recreational Headboat Survey of the recreational headboat fleet, and the Marine Recreational Fisheries Statistics Survey (MRFSS) for the recreational private/charter/shore fleet. The fishery independent index was the SEAMAP South Atlantic Trawl Survey. All indices were provided during the data workshop and the values remained unchanged for the continuity VPA. The indices for the continuity model are listed in **Table 2** and compared graphically in **Figure 4**.

2.1.6 Length Composition Data

Length composition data were provided during the Assessment Workshop and are described and summarized in SEDAR 38-AW06. Note that the tournament length composition data were excluded from the estimation of size composition, age composition, and partial catch-at-age in the continuity model. A principal assumption of the VPA was that the length composition data accurately described the length composition of removals by fleet.

2.1.7 Partial Catch-at-age and Total Catch-at-age

Age-length keys and annual age-frequency distributions by fleet were provided at the Assessment Workshop. Methods of estimation are described in SEDAR 38-AW05. Key changes to the methods of age structure estimation were noted. Specifically, SEDAR 16 used a stochastic aging approach based on the von Bertalanffy growth model and length frequency distributions to fill fleet catch age-composition in years when little or no data were available. This assessment used a combined age-length key for the fleet, aggregated across years to fill missing years. This was agreed upon by the Assessment Panel to be an improvement in aging method. The annual age frequency distributions are compared across stock zones for each fleet in **Figures 5 to 10**. Fleet partial-catch-at-age (PCAA) was estimated as the annual fleet landings in number of fish times the annual fleet age-frequency distributions plus discard mortalities. Estimated fleet PCAA are presented in **Tables 3 to 5**, and **Figures 11 to 14**. Note that the PCAA listed in **Tables 3 to 5** do not include discard mortalities since the standardized indices of abundance were based on retained fish only; however, the PCAA shown in **Figure 11 to 14** include the discard mortalities to show the total estimated fleet removals. The total catch-at-age (CAA) was estimated as the sum of the individual fleet PCAA (including discard mortalities), plus 50% of fleet mixing zone PCAA, plus estimated shrimp bycatch (age-0 discard mortalities). The estimated CAA is shown in **Table 6** and **Figure 15**. A comparison of the annual catch-at-age estimates between SEDAR 16 base and SEDAR 38 continuity VPA is presented in **Figure 16**.

2.2 Continuity VPA Parameterization

2.2.1 Terminal Year Fishing Mortality

Terminal year fishing mortality was estimated using the frequentist method; starting values were set at 0.15, with a lower limit 0.001, and an upper limit of 3.0.

2.2.2 Plus Group Fishing Mortality Ratios

The plus group (ages 11 and older) fishing mortality was assumed equal to the estimated fishing mortality for age 10 fish; the fishing mortality ratio parameter was fixed at one for all years.

2.2.3 Stock-recruitment Parameters

No stock-recruitment relationship was assumed, that is, zero constraints were put on recruitment deviations related to spawning stock biomass. Stock-recruitment parameters were not directly estimated.

2.2.4 Stock Mixing Parameters

A single stock was assumed and stock mixing was not modeled. Landings from the winter mixing zone were assumed to be 50% Atlantic stock composition.

2.2.5 Tagging Data Assumptions

Tagging information was not included in the model.

2.2.6 Index Weighting

Indices were scaled to their respective means. Indices were scaled to their respective means. Indices were weighted according to SEDAR 16 specifications to give all series equal weight overall but to still retain information on year-to-year precision. This was done by initially estimating the additive variance that would then scale each index variance to equal a common mean variance and then fixing this additional variance for successive model runs. (SEDAR 16-AW-09). Additive variance scalars were as follows: N. Carolina Trip Ticket scalar = 0.5745, Headboat scalar = 0.5129, MRFSS scalar = 0, and SEAMAP Trawl scalar = 0.5254.

2.2.7 Index selectivities

The selectivity of the SEAMAP Atlantic Trawl Index was assumed to be fully selective of age-0 individuals and zero selective of ages 1 and older.

2.2.8 Parameter Estimation Options

The terminal year fishing mortality rates were constrained by penalizing annual deviations in the relative vulnerability (fishing mortality at age divided by the maximum fishing mortality rate at age) for ages 3 to 9 over the last three years with a standard deviation of 0.4. Catchability was estimated by the concentrated maximum likelihood routine assuming a lognormal distribution.

2.2.9 Model Diagnostics

Diagnostic criteria used to assess model convergence included goodness-of-fit criteria (likelihood and posterior density values for data components), limitation on the number of iterations to convergence, and model fits to indices of abundance.

2.2.10 Uncertainty and Sensitivity Analyses

The objective of the continuity model was to compare the stock and fishery trends estimated for SEDAR 16, by updating the VPA with current data but strict adherence to the same assumptions and parameterizations. Therefore, bootstraps and sensitivity analyses were not run for the continuity VPA.

2.3 Continuity VPA Results

2.3.1 Fishing Mortality Estimates

Average estimated fishing mortality over the terminal five years (2008 to 2012) ranged 0.02 to 0.03 for age-0 and age-1 fish, 0.17 to 0.32 for fish ages 2 to 9, 0.19 for age-10, and was assumed equal to age 10 for the plus group (**Table 7**). Annual fishing mortality ranged less than 0.15 for ages 0 and 1 across the time series, and ranged 0.1 to 0.4 for ages 2 and older for most years. Noticeable peaks in estimated fishing mortality were observed for ages 4 to 7 throughout the 1980s, and recently in 2007 and 2009 of age 8 fish (**Figure 17**). The estimates of fishing mortality in 2006 from the continuity VPA were very similar to estimates from SEDAR 16 base model across ages for the terminal year.

2.3.2 Fleet Selectivity Estimates

Estimates of commercial handline and recreational headboat fishery indicated a dome-shaped selectivity, with a mode at age 2 for commercial handlines and a mode at age 4 for recreational headboats (**Figure 18**). The recreational charter/private/shore fleet estimates demonstrated an asymptotic selectivity, with fish age 4 to 6 estimated to be approximately 80% selected, and fish age 8 and up to be approximately fully selected (**Figure 18**).

2.3.3 Abundance-at-age Estimates

Abundance-at-age estimates showed a cyclical pattern corresponding to strong cohorts moving through the population (**Table 8, Figure 19**). The estimated decline in abundance of the older age classes over the time series is notable. A similar trend was estimated for SEDAR 16 base model, and no contradiction to previous model estimates was observed for the continuity model.

2.3.4 Spawning Stock Biomass Estimates

Estimates of spawning stock biomass showed a long-term steady decline from the highest estimated biomass in 1981 to the lowest estimated biomass in 2012 (**Table 9**). Modes corresponding to the periods of relatively strong cohorts were also apparent (**Figure 20**). In comparison to estimates from SEDAR 16 base, the continuity model demonstrated a shift in the magnitude of estimates to a lower biomass across the time series; however, the overall trend was similar between the previous base model and updated continuity VPA (**Figure 20**).

2.3.5 Recruitment Estimates

Recruitment estimates ranged between one million and eight million individuals (**Table 9**, **Figure 21**). Relatively high recruitment years included 1985, 1989, 1994, 1995, 1996, 1998 and 2003. Relatively low recruitment years included 1987, 1991, 1992, 1999, 2000, and the recent time period beginning in 2008. Estimates of recruitment were consistent between the SEDAR 16 base and SEDAR 38 continuity VPAs, and demonstrated nearly indistinguishable long-term trends (**Figure 21**).

2.3.6 Spawner-Recruit Relationship

Estimates of spawning stock biomass and recruitment demonstrated a scattered pattern with no clear functional form (**Figure 22**). Linear, hockey-stick, Beverton-Holt, and Ricker models could all be considered candidate models given the distribution of the estimates. A similar pattern was observed in estimates from the previous assessment.

2.3.7 Model Diagnostics

Model convergence statistics indicated a stable solution was reached with relatively few iterations. The model fits to the indices demonstrated a relatively good fit to the N. Carolina trip ticket index, but considerable divergence to the other indices, in comparison (**Figure 23**). The model predicted similar changes in magnitude in recruitment as the SEAMAP age-0 index; however, the model fit was not consistent across years. Overall, the model performance was similar to the previous assessment, specifically the fits to the four indices of abundance.

2.4 Discussion

The continuity VPA demonstrated similar long-term trends in spawning stock biomass and recruitment as the SEDAR 16 base, although a distinct shift in the magnitude of spawning stock biomass was apparent. Recruitment estimates were similar in magnitude as the previous assessment, in contrast. Since the VPA parameterizations were nearly identical between the models, the change in magnitude was expected to be a result of changes in the data. Two specific changes to data inputs were likely to cause the observed shift, as the majority of data methods remained unchanged from the previous assessment. The first change was revision to the estimated landings which incorporated improved methods, documented in the Data Workshop Report. The second was the change in age composition estimation methods for fleets and years lacking adequate age samples from a stochastic aging based on the growth model to a combined age-length key for the fleet across years. At the Assessment Workshop, a continuity sensitivity was presented that demonstrated that the change in biomass estimates was a direct result of the change in aging method which generally estimated a higher proportion of younger fish ages 1 to 3 and lower proportion of ages 4 and older fish in the catch. Substitution of the SEDAR 16 base model age-frequency scaled to the updated landings in the continuity model demonstrated that changes in the age structure density resulted in the observed shift in spawning stock biomass. Substitution of the SEDAR 16 base landings had little effect, in comparison. Therefore, it was concluded that the methods of estimation of the age structure resulted in the change in magnitude of spawning stock biomass, and that the revised methods represented an improvement in modeling approach. The recommendation was to use the revised aging method and associated age-frequency distributions for the data inputs to the base VPA.

3. Base VPA

3.1 VPA Model Inputs

Similar to the continuity model, the base VPA was a combined sex, single stock model. Twelve age classes were defined as ages 0 to 10 and a plus group of fish age 11 and older. The modeled period was 1986 to 2012, with the annual time-step defined by fishing year, April 1 to March 31 of the following calendar year. All data were summarized by fishing year. For comparative purposes and brevity of data summaries, all figures summarizing the continuity model results are presented with the revised base VPA results.

3.1.1 Life History Assumptions

The stock distribution was assumed to be North Carolina to Monroe County, Florida, including Monroe County south of U.S. highway 1 during April 1 to October 31, with a winter mixing zone defined to be Monroe County, Florida, south of U.S. highway 1, during November 1 to March 31 (**Figure 1**). Note that Monroe County, north of U.S. highway 1 was assumed to be Gulf of Mexico stock. This represented a significant change in stock distribution assumptions from the continuity model. The stock mixing assumption was 50% Gulf of Mexico and 50% Atlantic stock composition within the mixing zone during the defined winter mixing season. Natural mortality (M), maturity, and fecundity estimates were reviewed and updated during the Assessment Workshop based on all available and current information. A detailed description of methods and assumptions applied to the revised life-history schedules can be found in the SEDAR 38 Assessment Workshop Report, Section 2.1. The assumed spawn date was April 1. The revised life-history input values are listed in **Table 10**. The length-weight relationship was updated with all available information, and was assumed to be a power equation with estimated parameters a=7.31e-6, b=3.0009.

3.1.2 Landings

Five fishing fleets were defined by sector and mode that included commercial handline, commercial non-handline, recreational headboat, recreational charter/private/shore, and recreational tournaments. Tournament landings were assumed to be 3% of recreational private landings, which represented a change from the continuity model, in which tournament landings were assumed to be negligible and were not modeled. Updated landing estimates were provided after the Data Workshop based on the revised stock structure assumptions, and were presented and reviewed during the pre-assessment webinar. Methods for landings estimation were consistent with continuity landings, but were estimated using the revised stock structure assumptions. The procedures of landings estimation are described in the SEDAR 38 Data Workshop Report. Catch unit was number of fish. For the commercial fleets, this required a conversion from landings measured in whole pounds. This conversion was the annual fleet yield in pounds whole weight divided by a weight frequency distribution calculated as the size frequency distribution converted to weight using the length-weight conversion equation: $Weight = a \cdot Length^b$, where a and b values are listed in the above section. This represented a change in methods from the continuity model, where commercial landings in numbers were calculated from the mean weight rather than the weight frequency. A comparison of the proportions of landings assigned to the Gulf of Mexico, Atlantic, and winter mixing zones between the continuity and revised stock structures is shown in **Figure 24**. All landings within the mixing zone were assumed to be comprised of 50% Atlantic stock and 50% Gulf of Mexico stock. The landings data are summarized in **Figure 2**.

3.1.3 Discards

Commercial discards were included in the model, which represented a change in methods from the continuity which excluded commercial discards. Estimates of total recreational discards were revised based on the updated stock distributions. The length composition of recreational discards was evaluated during the Assessment Workshop based on observer data provided by the Florida Fish and Wildlife Conservation Commission (unpublished data). Based on this evaluation, the discard size assumptions of recreational fleets was changed to be comprised of fish less than 50cm, and all age-0 (**Figure 25**). This represented a change in the continuity methods in which the length composition of recreational charter/private/shore discards was assumed equal to the length composition of the retained catch. Discard mortality was assumed to be 22% of live discards on recreational headboats and 20% of live discards on private boats, charter boats, and shore fishing. The discard mortality rate assumption of headboats was changed from the continuity model which assumed 33% mortality.

3.1.4 Shrimp Bycatch

The methods for estimation of shrimp bycatch of age-0 King Mackerel were evaluated extensively during the Assessment Workshop, and the assumptions were revised considerably from the continuity methods. Shrimp bycatch for the revised VPA were based on catch rates of observed shrimping trips extrapolated by shrimp fishing effort in the Atlantic. This represented a change from the continuity methods which used the mean catch rates from the SEAMAP Trawl survey opposed to the observer data. This change was based on feedback from workshop participants and stakeholders that indicated that the catch rates from the survey were not representative of the bycatch rate of King Mackerel in the shrimp fishery. A complete description of the revised methods can be found in SEDAR 38-RW-03. Similar to the continuity model, all shrimp bycatch removals were assumed to be age-0 fish. Estimates of shrimp bycatch are shown in **Figure 3**.

3.1.5 Indices of Abundance

Two fishery dependent indices and one fishery independent survey were included in the base VPA. The fishery dependent indices were the commercial logbook index of the handline fleet and the Recreational Headboat Survey of the recreational headboat fleet. The fishery independent index was the SEAMAP South Atlantic Trawl Survey. Changes in indices from the continuity methods included: (1) replacement of the N. Carolina trip ticket index with the commercial logbook index based on trolling gear only, (2) exclusion of the Marine Recreational Fisheries Statistics Survey (MRFSS) survey for the recreational private/charter/shore fleet, and (3) revision to the spatial coverage of the recreational headboat index to include samples from the east coast of Florida, excluding Monroe County. All revised indices were provided after the Data Workshop and were presented and reviewed during the pre-assessment webinar. The indices for the base VPA are listed in **Table 11** and compared graphically in **Figure 4**.

3.1.6 Length Composition Data

Length composition data were provided during the Assessment Workshop and are described and summarized in SEDAR 38-AW06. Note that the tournament length composition data were included in the estimation of size composition, age composition, and partial catch-at-age in the base model; the continuity model excluded tournament information. A principal assumption of the VPA was that the length composition data accurately described the length composition of removals by fleet.

3.1.7 Partial Catch-at-age and Total Catch-at-age

Age-length keys and annual age-frequency distributions by fleet were revised based on the updated stock structure definitions and were provided at the Assessment Workshop. Methods of estimation are described in SEDAR 38-AW05. Key changes to the methods of age structure estimation from the previous assessment, documented above in Section 2.1.7, were consistent for the continuity and base models. The annual age frequency distributions are presented for each fleet in **Figures 26 to 31**. Fleet partial-catch-at-age (PCAA) was estimated as the annual fleet landings in number of fish times the annual fleet age-frequency distributions plus fleet discard mortalities. Note that discards for all fleets except tournaments were assumed to be age-0 fish. Estimated fleet PCAA are presented in **Tables 12** and **13** for the commercial handline and recreational headboat indices respectively, and **Figures 11 to 14**. Note that the PCAA listed in **Tables 12** and **13** do not include discard mortalities since the standardized indices of abundance were based on retained fish only; however, the PCAA shown in **Figure 11 to 14** include the discard mortalities to show the total estimated fleet removals in comparison to the continuity PCAAs. The total catch-at-age (CAA) was estimated as the sum of the individual fleet PCAA including discard mortalities, plus 50% of fleet mixing zone PCAA, plus estimated shrimp bycatch (age-0 discard mortalities). The estimated CAA is shown in **Table 14** and **Figure 15**.

3.2 Base VPA Parameterization

3.2.1 Terminal Year Fishing Mortality

No change was made from the continuity model parameters. Terminal year fishing mortality was estimated using the frequentist method; starting values were set at 0.15, with a lower limit 0.001, and an upper limit of 3.0.

3.2.2 Plus Group Fishing Mortality Ratios

No change was made from the continuity model parameters. The plus group (ages 11 and older) fishing mortality was assumed equal to the estimated fishing mortality for age 10 fish; the fishing mortality ratio parameter was fixed at one for all years.

3.2.3 Stock-recruitment Parameters

No change was made from the continuity model parameters. No stock-recruitment relationship was assumed, that is, zero constraints were put on recruitment deviations related to spawning stock biomass. Stock-recruitment parameters were not directly estimated.

3.2.4 Stock Mixing Parameters

No change was made from the continuity model parameters. A single stock was assumed and stock mixing was not modeled. Landings from the winter mixing zone were assumed to be 50% Atlantic stock composition.

3.2.5 Tagging Data Assumptions

No change was made from the continuity model parameters. Tagging information was not included in the model.

3.2.6 Index Weighting

Indices were scaled by their respective means. Indices were weighted by the estimated coefficients of variation, representing a change from continuity methods which used additive variance scalars to achieve an equal index weighting.

3.2.7 Index selectivities

No change was made from the continuity model parameters. The selectivity of the SEAMAP Atlantic Trawl Index was assumed to be fully selective of age-0 individuals and zero selective of ages 1 and older.

3.2.8 Parameter Estimation Options

The terminal year fishing mortality rates were constrained by penalizing annual deviations in the relative vulnerability (fishing mortality at age divided by the maximum fishing mortality rate at age) for ages 3 to 9 over the last three years with a standard deviation of 0.4. Catchability was estimated by the concentrated maximum likelihood routine assuming a lognormal distribution.

3.2.9 Model Diagnostics

Diagnostic criteria used to assess model convergence included goodness-of-fit criteria (likelihood and posterior density values for data components), limitation on the number of iterations to convergence, and model fits to indices of abundance.

3.2.10 Uncertainty and Sensitivity Analyses

Uncertainty in estimates of fishing mortality and spawning stock biomass was assessed by parametric bootstrapping, and sensitivity analyses were conducted by changing key model assumptions and comparing the results with the base run. Sensitivities presented in this report include an indices jackknife analysis in which each index of abundance was iteratively removed to evaluate the influence on model results, and a retrospective analysis in which the terminal 10 years of data were sequentially removed to evaluate the influence of individual terminal year data on the results.

3.3 Base VPA Results

3.3.1 Fishing Mortality Estimates

Average estimated fishing mortality over the terminal five years (2008 to 2012) ranged 0.02 to 0.05 for age-0 and age-1 fish, 0.08 to 0.16 for fish ages 2 to 9, 0.04 for age-10, and was assumed equal to age 10 for the plus group (**Table 15**). Annual fishing mortality ranged less than 0.12 for ages 0 and 1 across the time series, and ranged 0.05 to 0.4 for ages 2 and older for most years. Noticeable peaks in estimated fishing mortality were observed for ages 4 to 7 throughout the 1990s, and recently in 2003 to 2007 (**Figure 17**).

3.3.2 Fleet Selectivity Estimates

The selectivity of the commercial handline and recreational headboat fleets was estimated to be dome-shaped, with modes at ages 2 and 4 for handlines and headboats, respectively (**Figure 18**). Estimates from the base VPA showed a distinct shift in the estimated modes from the continuity model, with an estimated increase in the selectivity of older fish estimated for handlines and decreased selectivity of older fish estimated for headboats.

3.3.3 Abundance-at-age Estimates

Abundance-at-age estimates showed a cyclical pattern corresponding to strong cohorts moving through the population (**Table 16, Figure 19**). In general, the estimated abundance of older age classes declined during the middle of the time series, but more recently demonstrated a rebuilding period corresponding to multiple years of relatively high recruitment during 2003 to 2007. This pattern was in contrast to estimates from the continuity model which demonstrated a long-term decline of the stock, particularly the older age classes, and no indication of stock rebuilding.

3.3.4 Spawning Stock Biomass Estimates

Estimates of SSB showed a decline during the first 9 years from a peak spawning stock biomass in 1986 to a low in 1994, a relatively stable SSB from 1995 to 2003, a period of stock increase during 2003 to 2007, and a decline in recent years. (**Table 17, Figure 20**). Modes corresponding to the periods of relatively strong cohorts were consistent with those observed for the continuity model (**Figure 20**). Similar to the estimates of abundance, the overall stock trend was in contrast to the continuity model that demonstrated a long-term decline across the time series versus a relatively flat long-term trend in estimates from the base model, with the exception of strong cohorts resulting in peak abundances.

3.3.5 Recruitment Estimates

Recruitment estimates ranged between two million and ten million individuals (**Table 17**, **Figure 21**). Relatively high recruitment years included 1989, 1994, 1995, 1996, 1998 and 2003 to 2007. Relatively low recruitment years included 1987, 1991, 1992, 1993, 1999, 2000, and the recent time period beginning in 2008. Recruitment trends were consistent with those observed for the continuity model. The primary difference was the magnitude of recruitment estimates, which were generally lower for the continuity VPA compared to the base VPA (**Figure 21**).

3.3.6 Spawner-Recruit Relationship

Similar to the continuity VPA, estimates of spawning stock biomass and recruitment from the base VPA demonstrated a scattered pattern with no clear functional form (**Figure 22**). Comparison of spawner-recruitment patterns with the continuity model demonstrated a considerable difference in the range of estimated SSB and recruitment. The base VPA estimated a greater SSB, nearly double for some years, as well as higher recruitment across the time series compared to the continuity model (**Figure 22**).

3.3.7 Model Diagnostics and Sensitivities

The base VPA demonstrated stable convergence with relatively few iterations, and across different starting values for terminal F parameters. Fits to the indices of abundance were considerably better than the observed fits of the continuity model (**Figure 23**). The model predictions demonstrated similar long-term trends to the observed values, and this was true for both the fishery dependent indices and fishery independent surveys. The magnitude of inter-annual change in indices was underestimated, especially for the headboat index. Bootstrap and sensitivity analyses indicated a lack of stability in estimates of fishing mortality, abundance and biomass for the terminal years. The overall long-term trends in fishing mortality-at-age and abundance-at-age did not vary greatly across bootstrap iterations (**Figures 32 and 33**). The indices jackknife sensitivity showed that estimates of recruitment were not sensitive to individual indices (**Figure 34**). In fact, trends in recruitment estimates were well determined and stable across most model sensitivities (**Figures 33 to 36**). The retrospective analysis demonstrated a positive bias in model estimates of spawning stock biomass (**Figure 35**), as the removal of sequential years of data resulted in considerably higher biomass estimates. The effects of changing each of the model assumptions from the continuity to the base model are shown in **Figure 36**. Each change to the life-history parameters, data, and model parameterizations resulted in a change in estimated spawning stock biomass; however, estimates of recruitment were more stable in comparison. Each of the revisions to the model resulted in a more optimistic or similar trend in spawning stock biomass, with the exception of truncating the early period, 1981 to 1985, which had little effect on estimates. In summary, the base VPA resulted in a different picture of long-term trends compared to the continuity model. The model produced relatively stable long-term trends across some parameter estimates, namely recruitment, but indicated considerable uncertainty in the estimates of fishing mortality, abundance, and biomass for recent years.

3.4 Discussion

The base VPA of Atlantic King Mackerel indicated a relatively flat long-term trend in spawning stock biomass, with periods of relatively good recruitment resulting in pulses of increased abundance in following years and higher spawning stock biomass as the fish mature. It was clear from the observed age-frequency distributions and estimated selectivities that these cohorts supported the fisheries for multiple years, from younger ages in commercial fisheries and recreational headboats, to older ages captured by recreational charter, private and tournament fleets. Periods of low recruitment were also apparent which resulted in higher fishing mortality on these relatively weak year classes, and decreased abundance-at-age over time. Although estimates of fishing mortality and spawning stock biomass were sensitive to model assumptions, the long-term trends in recruitment were fairly robust. The causes of these cyclical patterns in recruitment remain obscured, particularly since recruitment appeared to be independent of spawning stock biomass across the range of estimates. Further work is recommended to determine the principle factors leading to strong versus weak recruitment in the Atlantic, which support multiple fisheries and result in changes in spawning stock abundance and biomass.

Estimates of spawning stock biomass were not well determined, as demonstrated by the sensitivity analyses and divergence in stock trends from the continuity VPA which indicated a long-term decline compared to the base VPA which indicated a relatively flat trend. Several of the revisions to the model altered the long-term perception of the spawning stock. Results from the retrospective analysis were particularly disconcerting, as they demonstrated that the addition of information over time could result in very different trends compared to current estimates.

Given this result, caution is warranted in using current estimates of spawning stock biomass for future projection of stock status. One sensitivity that was not conducted but could help elucidate the accurateness of stock projections in determining future stock status is a retrospective projection analysis in which the model is projected forward from one to 10 years in the past and the predictions are compared with estimates using all available information up to the current year. This analysis is recommended if the VPA is to be used for management advice.

Stock benchmarks, and associated stock and fishery status were not estimated from the base VPA, as the Stock Synthesis base model was selected as the preferred model by the Assessment Panel. The reasons for this decision were (1) the Stock Synthesis model more accurately modeled the known life-history of King Mackerel, estimation of specifically the observed differences in sex-specific growth between males and females, (2) Stock Synthesis was thought to more appropriately model shrimp bycatch the various data sources, including fleet specific age and length composition data, (3) Stock Synthesis more appropriately accounted for information gaps, such as missing age-frequency information for a given fleet or year.

4. Tables

Table 1. Life history assumptions in the continuity VPA of Atlantic King Mackerel.

Age	0	1	2	3	4	5	6	7	8	9	10	11+
M	0.67	0.26	0.22	0.20	0.19	0.18	0.17	0.16	0.16	0.16	0.16	0.15
Maturity	0.00	0.55	0.86	0.92	0.95	0.97	0.99	1.00	1.00	1.00	1.00	1.00
Fecundity	0.00	0.13	0.25	0.39	0.53	0.66	0.78	0.89	0.98	1.06	1.12	1.29

Table 2. Indices of Abundance of Atlantic King Mackerel used in the Continuity VPA.

	Headboat		MRFSS		NC_Trip_Ticket		SEAMAP_Trawl	
units	number		number		biomass		number	
GLM	delta-lognormal		delta-lognormal		delta-lognormal		delta-lognormal	
ages	1-11+		1-11+		2-11+		0	
	Index	CV	Index	CV	Index	CV	Index	CV
1980	0.60	0.45	-	-	-	-	-	-
1981	1.45	0.50	1.36	0.75	-	-	-	-
1982	0.63	0.53	1.57	0.68	-	-	-	-
1983	1.58	0.38	1.56	0.70	-	-	-	-
1984	0.91	0.31	1.70	0.67	-	-	-	-
1985	0.57	0.31	1.57	0.64	-	-	-	-
1986	0.60	0.25	5.18	0.55	-	-	-	-
1987	0.81	0.25	1.90	0.60	-	-	-	-
1988	0.83	0.25	1.36	0.60	-	-	-	-
1989	0.49	0.30	1.10	0.60	-	-	-	-
1990	0.65	0.31	1.00	0.62	-	-	2.86	0.17
1991	1.32	0.25	1.38	0.59	-	-	0.62	0.22
1992	1.71	0.24	1.09	0.61	-	-	0.86	0.24
1993	0.76	0.25	0.63	0.69	-	-	0.50	0.22
1994	0.60	0.26	0.40	0.74	0.80	0.17	0.75	0.22
1995	0.70	0.25	0.44	0.74	0.83	0.17	1.32	0.22
1996	0.48	0.27	0.39	0.73	1.24	0.17	2.10	0.19
1997	1.08	0.25	1.32	0.59	1.16	0.17	0.56	0.24
1998	1.36	0.23	0.64	0.65	1.09	0.17	1.91	0.23
1999	1.04	0.24	1.09	0.62	0.97	0.17	1.26	0.19
2000	1.91	0.22	0.94	0.64	1.04	0.17	0.84	0.24
2001	1.43	0.23	0.46	0.71	1.12	0.17	0.46	0.25
2002	0.91	0.26	0.21	0.87	0.97	0.17	0.51	0.20
2003	0.98	0.25	0.30	0.79	0.87	0.17	0.82	0.20
2004	1.03	0.25	0.51	0.70	1.29	0.17	1.13	0.22
2005	1.34	0.27	0.96	0.61	1.15	0.17	1.45	0.20
2006	1.25	0.24	0.69	0.66	1.02	0.17	1.03	0.22
2007	1.49	0.23	0.69	0.65	1.23	0.17	1.31	0.19
2008	1.20	0.24	0.66	0.67	1.06	0.17	1.04	0.22
2009	1.27	0.24	0.46	0.73	0.88	0.17	0.55	0.22
2010	0.87	0.28	0.20	0.89	0.62	0.18	0.29	0.23
2011	0.70	0.28	0.08	1.32	0.73	0.18	0.55	0.29
2012	0.44	0.30	0.15	0.98	0.91	0.18	0.28	0.22

Table 3. Commercial Handline Partial Catch-at-age Input to the Continuity VPA of Atlantic King Mackerel.

FishingYear	Fleet	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1981	HL	36	9,375	14,323	9,371	7,695	6,131	4,141	2,542	1,869	1,271	977	2,693
1982	HL	51	13,440	20,534	13,435	11,033	8,790	5,936	3,644	2,680	1,823	1,401	3,858
1983	HL	48	12,591	19,237	12,586	10,335	8,234	5,561	3,414	2,511	1,708	1,312	3,614
1984	HL	44	11,567	17,672	11,563	9,495	7,565	5,109	3,136	2,307	1,569	1,206	3,322
1985	HL	56	12,347	23,409	15,906	14,342	11,529	7,212	4,056	2,731	1,734	1,338	3,079
1986	HL	0	33,140	38,670	12,930	22,640	1,946	1,761	11,798	2,939	2,382	1,068	4,974
1987	HL	95	8,025	45,017	24,729	36,913	17,319	9,302	2,399	3,950	2,304	1,272	10,009
1988	HL	0	3,202	25,237	32,382	12,996	1,432	1,655	3,937	1,321	4,777	863	4,622
1989	HL	0	17,479	22,326	28,571	18,568	8,249	4,823	1,529	1,559	1,075	4,053	3,276
1990	HL	0	46,441	67,456	22,326	19,465	12,178	6,860	3,206	1,274	1,726	1,013	4,563
1991	HL	0	17,221	82,557	32,165	6,918	9,538	5,644	2,685	1,515	295	142	1,966
1992	HL	0	7,635	52,343	59,454	12,375	4,568	2,935	2,935	1,345	832	462	2,024
1993	HL	0	7,221	21,037	19,135	17,029	6,378	4,176	3,456	4,126	2,127	1,522	3,288
1994	HL	0	16,699	27,069	11,889	15,319	15,814	6,829	2,295	2,773	3,439	2,056	3,028
1995	HL	0	11,012	30,161	15,345	8,653	9,258	9,744	3,021	1,502	2,248	1,797	2,319
1996	HL	0	36,658	87,944	25,101	10,065	4,686	3,918	4,270	598	493	149	409
1997	HL	0	10,735	23,608	9,804	13,549	9,852	7,226	9,679	11,707	4,434	255	2,881
1998	HL	177	14,679	71,909	51,939	12,862	5,828	1,621	843	1,738	2,181	217	840
1999	HL	0	43,329	47,786	28,935	18,845	4,889	1,876	527	503	890	780	506
2000	HL	9	4,632	43,334	16,195	21,435	12,158	2,974	1,103	250	377	1,082	1,408
2001	HL	0	4,357	24,910	34,687	16,255	13,361	6,385	1,582	655	335	590	1,825
2002	HL	2,339	70,872	22,658	9,518	12,588	2,425	1,662	1,039	572	88	101	324
2003	HL	0	656	31,187	7,665	7,894	10,360	2,522	2,629	1,251	375	138	427
2004	HL	0	37,025	62,829	32,403	5,362	3,542	4,922	543	883	168	52	108
2005	HL	56	26,737	120,676	6,726	6,545	1,374	1,161	1,879	589	702	192	229
2006	HL	0	12,186	81,819	45,297	7,103	3,861	545	447	1,640	138	500	730
2007	HL	0	15,108	120,512	25,930	15,161	3,475	1,004	181	338	199	57	148
2008	HL	36	1,813	68,192	20,054	16,004	9,281	4,676	1,191	548	84	280	367
2009	HL	0	11,866	52,399	10,063	9,939	5,865	3,031	1,212	850	167	41	896
2010	HL	0	261	746	4,248	5,397	3,136	2,417	1,041	265	117	36	353
2011	HL	0	2,786	13,665	4,054	10,844	8,776	3,770	1,501	1,210	387	39	272
2012	HL	1	4,544	6,940	2,668	2,961	3,501	2,158	921	961	724	179	621

Table 4. Recreational Headboat Partial Catch-at-age Input to the Continuity VPA of Atlantic King Mackerel.

FishingYear	Fleet	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1981	HB	4	2,243	9,009	8,036	6,811	5,302	3,381	1,954	1,332	878	693	1,586
1982	HB	3	1,140	4,440	6,216	6,614	5,697	3,699	2,112	1,398	896	721	1,406
1983	HB	63	4,549	11,253	6,258	5,370	4,253	2,703	1,559	1,042	663	525	1,220
1984	HB	3	2,336	10,453	7,395	4,757	3,009	1,699	868	582	361	270	749
1985	HB	46	5,037	6,096	4,406	3,314	2,218	1,186	583	367	221	163	367
1986	HB	0	7,177	11,699	7,200	14,557	1,173	818	6,202	1,708	1,573	660	3,608
1987	HB	0	1,609	9,019	4,042	6,125	3,738	1,824	492	611	408	247	1,694
1988	HB	0	469	5,088	5,933	2,988	469	562	1,237	341	1,941	376	2,725
1989	HB	0	6,491	4,424	4,932	3,378	1,571	912	318	315	212	828	678
1990	HB	0	3,261	6,863	3,699	4,549	3,958	2,283	906	387	446	223	1,307
1991	HB	0	9,715	16,707	5,880	1,645	2,562	1,971	1,008	591	124	62	1,057
1992	HB	0	2,110	6,410	6,911	2,161	1,159	1,048	1,153	582	359	243	1,047
1993	HB	0	5,255	4,966	4,359	3,721	1,148	717	506	484	313	156	293
1994	HB	0	7,368	7,790	2,589	2,780	2,416	862	256	324	332	178	242
1995	HB	0	4,191	5,337	2,608	1,419	1,494	1,671	481	278	423	380	512
1996	HB	0	3,842	12,583	5,599	3,605	1,595	1,623	1,874	320	254	101	315
1997	HB	0	7,294	9,291	2,879	1,199	529	301	479	381	112	30	301
1998	HB	275	2,387	7,612	6,277	2,639	1,418	424	256	513	554	75	271
1999	HB	0	7,281	8,053	6,592	6,118	2,079	909	401	391	545	592	466
2000	HB	0	681	16,367	4,964	6,597	3,669	1,071	432	140	133	393	657
2001	HB	0	1,697	9,689	12,737	6,017	4,775	2,175	482	243	123	135	504
2002	HB	299	8,262	5,931	5,363	5,853	1,818	1,828	1,273	756	185	153	746
2003	HB	0	1,722	11,893	2,692	3,044	4,132	1,088	1,147	561	223	75	285
2004	HB	0	1,953	4,207	5,439	1,366	1,654	2,368	372	587	169	86	145
2005	HB	0	2,401	20,198	5,163	6,256	1,450	1,255	2,017	583	696	182	287
2006	HB	0	748	8,662	10,899	2,558	1,866	220	223	762	77	231	290
2007	HB	0	1,350	9,703	7,704	8,360	3,038	1,463	287	663	745	202	666
2008	HB	0	149	4,966	3,123	3,851	3,046	1,632	484	219	54	158	249
2009	HB	0	793	5,743	2,360	2,502	1,727	1,069	394	328	77	17	455
2010	HB	0	473	2,184	2,988	3,489	1,783	1,235	559	118	124	19	247
2011	HB	0	205	972	394	1,409	1,317	697	362	305	114	8	112
2012	HB	0	753	1,516	644	818	929	655	295	286	215	71	236

Table 5. Recreational Charter, Private, and Shore Fleet Partial Catch-at-age Input to the Continuity VPA of Atlantic King Mackerel.

FishingYear	Fleet	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1981	CPS	49	39,432	225,365	160,462	99,021	65,020	42,942	26,474	20,808	15,157	13,087	51,663
1982	CPS	1,803	39,176	153,432	121,823	89,603	62,240	37,413	21,511	15,711	10,849	8,478	24,522
1983	CPS	684	81,767	175,332	137,800	105,634	77,954	51,455	33,237	26,755	20,782	17,190	74,417
1984	CPS	1,067	50,531	136,195	113,042	95,400	74,970	49,480	30,259	21,969	15,701	12,885	39,259
1985	CPS	163	45,947	187,990	181,622	164,183	130,639	82,932	48,000	33,781	21,949	17,188	43,443
1986	CPS	0	126,142	241,315	92,277	183,863	17,213	12,503	94,715	24,524	23,917	9,302	56,661
1987	CPS	0	79,586	191,694	49,903	81,491	58,379	32,162	11,547	18,569	10,572	6,768	59,591
1988	CPS	0	35,056	182,502	152,755	60,768	10,104	12,393	23,000	8,985	46,298	7,901	65,539
1989	CPS	0	36,699	61,043	89,333	64,671	34,797	22,323	10,802	10,755	6,686	27,863	35,092
1990	CPS	0	139,771	90,548	36,993	44,581	37,964	26,194	12,010	6,613	10,077	6,802	35,887
1991	CPS	0	81,532	265,270	111,814	34,465	59,951	57,769	35,040	23,061	9,943	7,124	60,462
1992	CPS	183	72,231	177,389	197,974	61,687	31,919	31,188	38,420	17,802	12,959	11,607	58,595
1993	CPS	564	23,256	47,698	71,470	72,054	27,590	19,959	18,848	24,868	13,627	10,224	32,407
1994	CPS	0	45,200	90,402	39,908	54,653	62,676	28,149	10,733	14,045	17,821	12,038	23,929
1995	CPS	0	77,246	127,019	63,473	45,167	51,637	68,517	22,287	16,387	22,503	23,615	42,458
1996	CPS	0	32,930	132,088	71,648	55,738	27,940	38,760	47,886	13,480	7,955	8,309	19,138
1997	CPS	0	103,499	184,086	104,863	65,454	36,236	23,024	32,612	32,448	12,616	3,387	33,158
1998	CPS	2,028	29,943	118,373	116,044	65,516	37,771	13,592	12,471	21,849	27,254	4,009	24,647
1999	CPS	0	44,144	61,527	73,914	80,764	34,242	16,659	6,501	7,255	11,198	13,004	9,511
2000	CPS	0	6,726	169,064	73,211	119,046	71,740	29,499	12,771	6,008	8,359	19,065	35,110
2001	CPS	0	11,256	63,672	86,588	45,740	53,526	33,805	14,201	5,396	3,996	8,533	48,183
2002	CPS	1,222	41,923	47,014	54,738	67,506	19,802	22,006	14,907	9,868	2,805	1,701	12,397
2003	CPS	0	19,065	147,346	45,836	64,190	94,383	27,485	33,674	17,691	6,752	2,500	11,164
2004	CPS	0	36,742	85,043	113,999	29,409	36,631	54,296	14,599	23,789	13,025	8,335	14,105
2005	CPS	0	22,754	193,575	41,089	51,253	14,310	12,430	19,590	6,439	9,625	3,009	6,170
2006	CPS	0	12,709	93,628	155,625	48,761	50,970	8,107	6,839	21,236	977	8,333	11,425
2007	CPS	0	44,200	213,289	151,829	164,930	63,073	31,183	9,308	15,135	20,074	5,673	22,898
2008	CPS	0	2,986	96,034	60,991	68,459	59,994	34,771	12,695	5,290	2,113	6,451	11,646
2009	CPS	0	11,508	111,158	50,334	58,058	46,430	35,229	12,195	12,120	3,602	912	19,083
2010	CPS	0	2,896	21,829	44,011	53,114	29,511	23,214	12,201	2,964	2,892	917	6,515
2011	CPS	0	3,716	18,873	7,997	29,149	28,362	16,692	10,021	9,771	4,608	821	3,520
2012	CPS	0	10,787	23,357	10,022	14,160	17,919	12,201	6,029	7,049	5,863	1,421	5,779

Table 6. Total Catch-at-age input to the continuity VPA of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1981	1,982	51,592	115,926	618,195	452,607	201,603	93,839	22,091	6,478	3,180	10,527	19,547
1982	40,640	102,802	65,472	319,438	458,726	198,253	78,572	41,909	14,897	10,230	35,456	18,380
1983	69,175	262,967	196,656	249,653	238,249	127,497	104,650	18,534	4,875	1,309	4,799	34,467
1984	63,824	64,115	35,845	270,921	267,235	149,415	102,447	22,246	2,328	3,803	34,286	23,075
1985	256,984	76,952	149,587	186,297	377,542	229,121	69,038	21,489	9,834	6,964	1,117	18,767
1986	3,084	192,467	366,235	149,527	296,892	33,398	22,499	149,058	38,714	36,402	15,533	84,377
1987	113,124	164,492	293,443	97,723	154,815	107,630	59,844	21,571	35,940	20,057	11,974	104,564
1988	16,437	49,117	265,681	263,783	122,473	23,244	29,892	49,134	17,032	83,602	19,304	120,670
1989	22,232	98,841	131,504	178,865	130,073	70,566	44,808	21,603	21,331	12,724	52,492	62,654
1990	17,118	227,575	225,848	103,249	115,178	93,468	62,266	27,500	15,314	20,559	13,457	67,302
1991	25,414	133,476	444,960	210,729	63,061	98,812	95,419	53,510	33,665	12,817	9,030	78,246
1992	22,441	104,549	374,153	380,850	122,447	67,117	53,483	55,716	30,985	20,107	14,387	71,722
1993	53,021	71,298	141,883	177,728	158,406	58,350	39,254	36,112	43,354	23,423	16,343	51,153
1994	53,574	122,680	229,514	107,941	138,942	138,316	60,142	22,021	28,417	33,052	21,518	39,881
1995	109,617	104,357	263,672	143,897	97,804	89,877	110,083	36,106	22,529	31,909	32,071	52,586
1996	32,157	76,753	437,539	175,513	119,197	57,508	62,356	75,852	23,325	11,549	10,908	25,436
1997	66,360	140,251	378,713	287,944	127,229	71,007	38,978	49,917	48,190	18,335	6,151	47,813
1998	50,566	123,156	278,420	270,719	144,235	72,258	25,884	20,548	32,234	39,631	6,043	31,535
1999	41,629	109,455	180,766	166,755	167,544	73,752	31,156	14,253	12,626	20,671	21,116	15,066
2000	37,227	20,872	310,771	183,343	206,082	118,750	46,761	19,613	8,431	11,558	24,587	44,052
2001	47,845	25,442	159,424	205,795	117,686	105,939	59,758	23,565	9,600	6,728	10,763	56,688
2002	51,915	112,992	210,706	138,582	146,172	57,313	46,349	28,624	19,083	5,205	3,017	22,411
2003	29,818	54,642	289,164	108,816	106,013	145,514	47,509	50,102	25,379	10,494	4,133	14,719
2004	35,789	81,348	299,586	238,706	67,535	71,371	99,034	23,151	34,443	15,994	10,047	16,737
2005	23,420	39,960	458,411	140,010	120,099	36,882	31,055	42,045	17,728	17,304	5,849	10,866
2006	21,184	21,899	261,154	346,469	121,500	101,783	19,624	13,752	41,241	5,071	14,395	19,828
2007	31,227	83,052	396,178	274,480	295,552	122,761	53,035	16,851	23,628	28,970	8,749	30,375
2008	19,193	38,680	341,958	168,962	178,472	147,705	85,173	27,915	11,905	5,009	11,190	18,746
2009	13,313	30,926	289,073	148,741	179,064	131,176	89,742	31,581	26,272	6,339	1,625	30,672
2010	20,532	15,190	108,013	168,121	208,862	105,963	79,992	31,064	10,853	5,042	1,779	11,339
2011	19,346	14,240	88,388	43,204	110,284	103,744	51,626	28,205	23,708	11,419	1,676	8,001
2012	15,348	26,720	65,148	45,960	50,130	55,158	42,132	19,187	18,463	12,826	6,126	13,219

Table 7. Continuity VPA Estimated Fishing Mortality-at-age of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1981	0.00	0.02	0.04	0.38	0.49	0.40	0.50	0.02	0.07	0.01	0.13	0.13
1982	0.01	0.05	0.04	0.14	0.53	0.41	0.26	0.41	0.02	0.14	0.11	0.11
1983	0.03	0.15	0.12	0.21	0.14	0.27	0.38	0.09	0.07	0.00	0.09	0.09
1984	0.02	0.04	0.03	0.25	0.35	0.12	0.34	0.13	0.01	0.07	0.07	0.07
1985	0.06	0.04	0.13	0.20	0.65	0.57	0.08	0.11	0.07	0.05	0.03	0.03
1986	0.00	0.07	0.26	0.19	0.54	0.10	0.09	0.22	0.28	0.39	0.14	0.14
1987	0.06	0.08	0.16	0.10	0.31	0.37	0.26	0.12	0.07	0.21	0.20	0.20
1988	0.01	0.05	0.19	0.21	0.18	0.07	0.16	0.34	0.12	0.23	0.31	0.31
1989	0.00	0.06	0.18	0.19	0.15	0.14	0.17	0.16	0.23	0.12	0.21	0.21
1990	0.00	0.07	0.20	0.21	0.18	0.15	0.18	0.15	0.16	0.35	0.18	0.18
1991	0.01	0.06	0.18	0.30	0.19	0.23	0.22	0.22	0.26	0.18	0.25	0.25
1992	0.01	0.09	0.24	0.24	0.29	0.30	0.18	0.19	0.18	0.23	0.31	0.31
1993	0.02	0.06	0.18	0.17	0.15	0.21	0.28	0.17	0.21	0.19	0.29	0.29
1994	0.02	0.09	0.29	0.20	0.19	0.18	0.33	0.24	0.19	0.23	0.26	0.26
1995	0.03	0.05	0.28	0.30	0.28	0.18	0.21	0.33	0.40	0.32	0.35	0.35
1996	0.01	0.04	0.32	0.31	0.43	0.26	0.18	0.21	0.35	0.36	0.16	0.16
1997	0.03	0.06	0.25	0.36	0.39	0.49	0.28	0.20	0.19	0.49	0.31	0.31
1998	0.01	0.09	0.18	0.29	0.31	0.40	0.32	0.22	0.19	0.22	0.28	0.28
1999	0.02	0.05	0.19	0.16	0.29	0.25	0.29	0.28	0.20	0.17	0.17	0.17
2000	0.03	0.02	0.18	0.29	0.30	0.34	0.25	0.28	0.25	0.27	0.30	0.30
2001	0.02	0.03	0.21	0.18	0.31	0.24	0.27	0.18	0.21	0.31	0.40	0.40
2002	0.02	0.07	0.35	0.29	0.19	0.24	0.15	0.20	0.21	0.16	0.21	0.21
2003	0.01	0.03	0.25	0.31	0.38	0.28	0.31	0.23	0.26	0.16	0.18	0.18
2004	0.01	0.03	0.25	0.35	0.33	0.47	0.30	0.23	0.24	0.24	0.22	0.22
2005	0.01	0.02	0.23	0.18	0.30	0.29	0.37	0.20	0.27	0.17	0.13	0.13
2006	0.01	0.01	0.16	0.27	0.24	0.43	0.24	0.27	0.29	0.11	0.20	0.20
2007	0.01	0.04	0.29	0.26	0.39	0.39	0.40	0.32	0.94	0.32	0.26	0.26
2008	0.02	0.02	0.24	0.20	0.27	0.34	0.50	0.37	0.38	0.49	0.19	0.19
2009	0.01	0.04	0.27	0.16	0.33	0.32	0.35	0.33	0.67	0.34	0.28	0.28
2010	0.03	0.02	0.22	0.25	0.35	0.32	0.31	0.19	0.17	0.24	0.14	0.14
2011	0.01	0.03	0.13	0.13	0.25	0.29	0.25	0.17	0.21	0.27	0.11	0.11
2012	0.02	0.03	0.20	0.10	0.21	0.19	0.18	0.13	0.15	0.16	0.21	0.21

Table 8. Continuity VPA Estimated Abundance-at-age of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1981	5,025,024	2,523,319	3,524,961	2,157,656	1,263,504	662,359	259,154	995,975	104,365	444,357	90,909	168,448
1982	4,371,103	2,565,045	1,908,945	2,723,933	1,212,442	640,603	372,027	133,218	824,384	82,868	376,312	194,664
1983	3,630,177	2,203,976	1,896,383	1,472,755	1,943,498	592,900	356,854	242,156	74,649	687,964	61,303	439,350
1984	4,806,525	1,805,594	1,476,803	1,345,775	981,680	1,397,793	380,940	205,672	188,347	59,051	585,949	393,512
1985	6,418,814	2,410,128	1,342,137	1,152,575	858,679	573,436	1,035,496	227,962	154,004	158,170	46,892	786,157
1986	4,683,625	3,098,611	1,799,068	943,193	776,411	372,980	272,958	810,676	173,599	122,030	128,571	696,941
1987	2,548,152	2,389,909	2,231,102	1,117,276	637,990	376,870	282,205	209,758	550,843	112,215	70,725	616,326
1988	3,679,494	1,222,347	1,706,767	1,528,119	827,132	389,650	218,070	183,470	158,087	435,769	77,314	482,309
1989	8,028,184	1,867,707	903,597	1,132,413	1,014,333	575,809	305,439	156,684	110,615	118,889	294,997	351,375
1990	5,314,482	4,084,637	1,359,830	607,647	766,576	724,338	418,351	216,774	113,058	74,555	89,744	447,896
1991	2,705,701	2,702,270	2,963,921	889,650	404,816	532,140	521,986	296,094	158,602	82,148	44,745	386,921
1992	2,755,775	1,364,077	1,975,799	1,981,082	539,341	278,989	356,073	353,272	202,043	104,081	58,311	290,101
1993	3,336,283	1,391,726	964,842	1,251,870	1,280,136	336,997	172,795	251,572	248,493	143,487	70,331	219,681
1994	4,789,353	1,666,807	1,015,338	647,528	865,401	919,355	229,335	109,962	180,218	171,666	100,901	186,623
1995	5,119,070	2,408,515	1,183,402	610,378	433,254	592,677	644,618	138,631	73,070	127,272	116,102	189,985
1996	5,100,358	2,537,704	1,773,809	714,793	370,646	271,212	414,918	443,337	84,511	41,545	79,297	184,523
1997	3,364,397	2,582,373	1,898,030	1,034,036	427,794	200,076	174,991	293,115	306,418	50,538	24,848	192,758
1998	5,519,775	1,671,823	1,877,016	1,185,521	588,470	240,209	103,265	112,065	202,803	216,513	26,321	137,073
1999	2,436,128	2,783,675	1,186,873	1,257,583	727,735	358,111	135,690	63,510	76,199	142,988	148,320	105,603
2000	2,095,620	1,215,045	2,059,869	791,008	879,939	452,615	233,040	86,048	40,802	53,253	103,002	184,169
2001	3,927,378	1,044,223	922,693	1,375,454	483,137	544,125	271,403	153,926	55,006	26,986	34,821	183,032
2002	3,946,358	1,972,306	786,395	598,186	941,384	294,671	359,645	174,439	108,922	37,997	16,848	124,891
2003	6,510,044	1,979,154	1,428,451	443,672	365,425	649,206	194,819	261,099	121,683	75,174	27,636	98,216
2004	5,014,639	3,303,986	1,484,857	888,556	265,643	207,585	411,758	121,020	175,499	80,264	54,495	90,594
2005	4,480,885	2,536,051	2,487,458	924,526	513,463	159,472	109,212	257,035	81,409	117,738	53,789	99,717
2006	4,653,181	2,272,112	1,929,011	1,587,252	631,251	317,649	100,114	63,826	179,420	53,014	84,553	116,223
2007	3,592,366	2,361,677	1,740,441	1,314,605	988,641	414,105	173,813	66,549	41,527	114,854	40,572	140,570
2008	1,653,577	1,812,843	1,756,188	1,043,841	829,986	553,762	235,554	98,306	41,008	13,839	71,400	119,364
2009	2,028,840	831,084	1,370,041	1,104,411	702,949	527,580	329,868	121,194	57,824	23,988	7,218	135,966
2010	1,067,723	1,026,858	616,524	841,843	770,701	421,681	322,909	196,464	73,866	25,220	14,649	93,171
2011	2,023,586	530,939	781,933	398,374	538,358	451,040	257,081	199,457	138,120	52,894	16,886	80,443
2012	1,066,551	1,019,946	398,701	548,408	287,395	347,150	283,671	169,768	143,275	95,775	34,642	74,597

Table 9. Continuity VPA Estimated Spawning Stock Biomass (SSB) and Recruitment of Atlantic King Mackerel.

FishingYear	SSB	Recruits
1981	4,311	5,025,024
1982	4,162	4,371,103
1983	4,041	3,630,177
1984	3,880	4,806,525
1985	3,718	6,418,814
1986	3,489	4,683,625
1987	3,246	2,548,152
1988	3,013	3,679,494
1989	2,752	8,028,184
1990	2,779	5,314,482
1991	2,853	2,705,701
1992	2,719	2,755,775
1993	2,487	3,336,283
1994	2,337	4,789,353
1995	2,194	5,119,070
1996	2,110	5,100,358
1997	2,076	3,364,397
1998	1,982	5,519,775
1999	1,989	2,436,128
2000	2,012	2,095,620
2001	1,852	3,927,378
2002	1,764	3,946,358
2003	1,745	6,510,044
2004	1,787	5,014,639
2005	1,914	4,480,885
2006	2,049	4,653,181
2007	2,078	3,592,366
2008	1,973	1,653,577
2009	1,840	2,028,840
2010	1,634	1,067,723
2011	1,452	2,023,586
2012	1,350	1,066,551

Table 10. Revised life-history assumptions for the Base VPA.

Age	0	1	2	3	4	5	6	7	8	9	10	11+
M	0.66	0.25	0.22	0.21	0.20	0.19	0.18	0.17	0.17	0.16	0.16	0.16
Maturity	0.00	0.87	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fecundity	0.00	0.20	0.29	0.40	0.51	0.62	0.73	0.83	0.92	1.01	1.09	1.37

Table 11. Indices of Abundance of Atlantic King Mackerel used in the Base VPA.

	Headboat		Commercial Logbook		SEAMAP_Trawl	
units	number		biomass		number	
GLM	delta-lognormal		delta-lognormal		delta-lognormal	
ages	1-11+		2-11+		0	
	Index	CV	Index	CV	Index	CV
1980	0.60	0.45	-	-	-	-
1981	1.45	0.50	-	-	-	-
1982	0.63	0.53	-	-	-	-
1983	1.58	0.38	-	-	-	-
1984	0.91	0.31	-	-	-	-
1985	0.57	0.31	-	-	-	-
1986	0.60	0.25	-	-	-	-
1987	0.81	0.25	-	-	-	-
1988	0.83	0.25	-	-	-	-
1989	0.49	0.30	-	-	-	-
1990	0.65	0.31	-	-	2.86	0.17
1991	1.32	0.25	-	-	0.62	0.22
1992	1.71	0.24	-	-	0.86	0.24
1993	0.76	0.25	-	-	0.50	0.22
1994	0.60	0.26	0.80	0.17	0.75	0.22
1995	0.70	0.25	0.83	0.17	1.32	0.22
1996	0.48	0.27	1.24	0.17	2.10	0.19
1997	1.08	0.25	1.16	0.17	0.56	0.24
1998	1.36	0.23	1.09	0.17	1.91	0.23
1999	1.04	0.24	0.97	0.17	1.26	0.19
2000	1.91	0.22	1.04	0.17	0.84	0.24
2001	1.43	0.23	1.12	0.17	0.46	0.25
2002	0.91	0.26	0.97	0.17	0.51	0.20
2003	0.98	0.25	0.87	0.17	0.82	0.20
2004	1.03	0.25	1.29	0.17	1.13	0.22
2005	1.34	0.27	1.15	0.17	1.45	0.20
2006	1.25	0.24	1.02	0.17	1.03	0.22
2007	1.49	0.23	1.23	0.17	1.31	0.19
2008	1.20	0.24	1.06	0.17	1.04	0.22
2009	1.27	0.24	0.88	0.17	0.55	0.22
2010	0.87	0.28	0.62	0.18	0.29	0.23
2011	0.70	0.28	0.73	0.18	0.55	0.29
2012	0.44	0.30	0.91	0.18	0.28	0.22

Table 12. Commercial Handline Partial Catch-at-age Input to the Base VPA of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1986	0	15,898	81,267	49,740	102,336	7,641	8,335	58,963	13,892	12,618	6,213	28,942
1987	245	49,772	99,740	52,224	82,724	62,962	34,276	12,112	20,938	12,946	7,503	54,971
1988	115	11,680	70,692	96,228	51,340	9,390	10,764	23,475	6,604	36,720	8,398	56,415
1989	0	20,743	58,182	81,418	61,073	33,608	22,152	10,191	10,661	6,180	26,959	30,175
1990	0	51,585	102,545	58,067	70,404	58,201	36,476	16,137	7,242	10,460	6,571	29,413
1991	0	44,758	157,775	79,470	22,897	33,677	31,866	18,714	11,901	4,053	2,760	23,328
1992	115	18,560	94,405	127,583	41,175	22,463	18,789	19,937	9,949	6,505	4,056	19,172
1993	0	26,113	63,092	68,241	66,001	24,274	19,392	15,748	20,161	9,964	7,456	13,910
1994	0	35,865	102,494	45,957	62,914	58,487	24,235	7,991	10,017	11,030	7,128	9,117
1995	430	23,521	96,765	61,599	40,228	30,071	34,471	11,380	5,756	8,502	7,642	10,452
1996	0	41,520	258,591	87,244	40,891	14,935	11,794	13,534	4,930	2,417	2,272	5,266
1997	0	37,572	162,372	150,141	49,411	25,195	12,671	16,438	15,802	5,332	1,468	12,720
1998	1,977	90,120	160,414	148,003	68,867	27,898	9,885	6,810	11,862	13,839	1,812	7,690
1999	0	60,541	111,999	100,134	86,705	36,377	12,213	5,433	3,825	6,432	6,867	4,042
2000	0	18,158	90,427	144,740	71,987	38,132	16,867	5,488	2,058	2,623	5,407	7,666
2001	0	13,697	77,001	102,336	63,338	41,504	22,417	7,758	2,884	1,682	2,369	8,239
2002	195	58,890	133,582	60,836	60,486	25,689	19,306	11,288	7,123	1,790	1,090	8,913
2003	0	19,387	107,214	49,899	39,945	54,941	16,590	18,769	9,303	3,546	1,139	4,555
2004	0	48,132	185,129	120,451	34,116	30,952	42,535	7,397	10,658	3,358	1,557	2,336
2005	0	11,256	175,758	83,405	61,623	16,357	13,240	21,944	5,992	8,421	2,834	3,967
2006	0	9,601	141,048	174,008	64,437	49,045	11,333	5,741	22,419	1,930	6,681	8,660
2007	167	52,081	202,742	108,795	101,650	42,480	20,486	5,917	5,415	8,429	2,344	7,646
2008	0	29,043	179,695	102,967	106,823	83,273	46,925	14,083	6,487	1,987	5,084	8,005
2009	0	16,690	159,473	108,790	142,415	87,805	56,082	18,837	11,842	2,025	430	9,266
2010	0	15,728	96,552	134,834	150,016	72,687	46,801	17,585	4,915	1,966	437	4,533
2011	0	10,321	59,720	44,167	81,608	82,035	33,241	19,290	15,410	5,516	605	3,986
2012	0	18,988	39,571	27,040	36,498	36,045	28,279	15,676	12,650	10,006	3,836	9,601

Table 13. Recreational Headboat Partial Catch-at-age Input to the Base VPA of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1986	0	14,296	30,287	10,935	18,312	1,507	1,049	7,808	2,153	1,957	824	4,485
1987	234	5,698	9,567	3,835	5,766	3,710	1,762	457	569	437	254	1,588
1988	0	1,430	7,159	6,803	3,212	549	581	1,305	358	1,997	390	2,738
1989	0	8,827	13,981	7,466	4,811	2,203	1,248	456	452	289	1,172	968
1990	0	9,442	13,725	5,595	6,040	4,848	2,739	1,103	454	515	255	1,637
1991	0	14,840	26,910	7,755	1,529	2,181	1,708	883	531	150	81	1,114
1992	0	5,745	12,738	11,241	3,217	1,756	1,539	1,654	800	501	353	1,500
1993	0	9,538	10,921	7,394	5,999	1,755	1,098	796	777	511	258	580
1994	0	11,127	15,425	3,662	3,988	3,287	1,156	330	431	395	209	273
1995	77	5,070	11,488	4,973	2,423	1,718	1,866	566	255	388	341	454
1996	0	4,558	30,302	10,629	4,783	1,629	1,073	1,200	275	182	116	306
1997	0	10,863	18,474	6,414	1,336	492	236	318	275	77	23	218
1998	299	5,374	7,739	6,567	2,836	1,070	363	223	420	438	56	213
1999	0	7,645	9,174	6,674	5,428	1,947	599	339	204	289	332	261
2000	0	2,545	10,529	9,138	3,555	1,706	711	230	96	84	186	338
2001	0	1,002	5,086	5,132	2,800	1,507	723	215	76	45	42	159
2002	17	3,334	6,739	2,301	2,029	827	564	332	210	50	45	225
2003	0	2,072	7,137	1,998	1,177	1,506	414	423	206	86	29	103
2004	0	3,870	10,982	5,432	1,568	1,570	2,163	375	517	139	70	118
2005	0	2,216	22,995	6,746	3,758	818	584	919	261	374	109	167
2006	0	645	10,096	9,638	2,481	1,421	241	143	507	59	143	230
2007	114	2,712	8,858	6,691	6,906	2,965	1,451	434	383	478	136	549
2008	0	1,548	6,522	2,631	2,855	2,057	1,062	297	154	49	108	211
2009	0	964	6,981	3,856	4,451	2,322	1,398	492	288	61	8	363
2010	0	754	4,073	4,203	4,514	2,079	1,361	617	166	137	25	275
2011	0	568	2,546	969	1,562	1,589	678	411	350	129	14	118
2012	0	1,031	1,481	837	919	779	588	308	246	203	87	208

Table 14. Total Catch-at-age input to the Base VPA of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1986	426,163	119,463	452,308	172,351	502,609	27,946	23,638	174,437	43,346	41,979	17,874	99,878
1987	273,329	189,015	263,785	107,651	337,993	133,118	71,216	24,912	41,330	25,824	15,993	121,009
1988	292,856	69,365	291,600	285,392	308,236	24,631	26,856	53,555	17,854	95,721	18,508	141,209
1989	205,679	66,893	173,457	202,291	278,693	80,103	51,702	24,189	24,730	14,887	63,152	74,685
1990	679,597	252,734	248,068	119,111	612,274	116,481	76,297	34,425	17,162	24,949	16,300	80,691
1991	198,402	169,107	520,802	226,664	147,092	89,607	89,367	54,663	37,126	15,125	11,029	94,226
1992	183,021	118,289	352,318	402,484	215,388	68,085	61,157	69,267	33,027	23,454	18,742	92,958
1993	110,429	70,180	152,874	181,399	221,808	66,519	50,030	44,568	58,026	30,574	22,583	62,622
1994	190,797	115,573	273,092	112,157	263,429	158,047	68,376	23,960	31,764	37,270	24,772	45,594
1995	310,302	116,006	324,657	179,871	288,819	91,885	111,070	38,272	21,652	28,581	29,827	51,941
1996	547,084	85,172	568,188	232,075	472,038	55,207	51,846	61,081	24,608	11,165	12,752	29,543
1997	218,438	152,910	434,342	392,289	225,832	78,644	41,300	53,176	53,347	19,365	5,731	52,799
1998	393,967	187,676	328,053	311,306	373,278	67,910	25,923	20,467	34,741	42,296	5,838	34,001
1999	277,891	139,642	216,148	212,497	353,814	87,889	30,753	14,457	10,635	17,286	20,077	14,183
2000	157,428	56,679	246,380	345,606	249,369	104,782	54,045	20,085	9,595	12,075	23,884	44,987
2001	132,651	36,318	170,433	208,434	156,231	98,191	60,711	26,686	9,963	6,751	11,284	59,971
2002	235,315	141,041	300,382	150,103	190,192	67,076	51,825	31,353	21,010	6,186	3,598	29,310
2003	252,883	73,634	282,631	129,715	190,180	152,605	47,930	55,752	28,413	11,680	4,103	17,981
2004	306,483	95,334	349,677	258,200	186,458	76,129	105,126	25,429	36,679	17,222	10,298	17,425
2005	321,703	34,745	435,639	199,268	264,729	41,349	32,969	48,467	14,891	21,269	7,497	13,742
2006	267,310	38,051	321,539	395,873	199,235	111,495	28,474	15,384	46,533	4,767	16,364	24,618
2007	391,212	140,332	448,851	281,451	377,665	128,228	67,983	23,082	19,147	29,756	8,488	35,971
2008	192,154	62,679	335,614	190,578	248,679	163,286	94,488	30,570	13,480	5,540	13,324	23,984
2009	112,403	28,755	269,058	183,454	264,856	152,041	108,180	37,571	25,931	6,652	773	30,576
2010	88,605	22,428	140,224	198,573	240,401	111,593	77,411	34,991	9,926	5,744	1,818	13,409
2011	72,774	22,590	109,439	63,068	135,324	117,370	50,985	31,327	27,848	11,748	2,236	10,262
2012	37,183	42,221	70,836	46,301	79,777	58,699	44,949	25,045	21,134	17,395	6,445	17,392

Table 15. Base VPA Estimated Fishing Mortality-at-age of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1986	0.08	0.04	0.22	0.15	0.68	0.07	0.08	0.21	0.28	0.33	0.14	0.14
1987	0.11	0.06	0.11	0.08	0.47	0.38	0.26	0.11	0.07	0.26	0.19	0.19
1988	0.09	0.05	0.12	0.17	0.33	0.06	0.12	0.30	0.10	0.21	0.29	0.29
1989	0.03	0.03	0.18	0.12	0.25	0.13	0.15	0.15	0.22	0.11	0.20	0.20
1990	0.13	0.06	0.18	0.18	0.62	0.16	0.18	0.14	0.14	0.34	0.17	0.17
1991	0.07	0.06	0.17	0.25	0.35	0.17	0.17	0.18	0.22	0.17	0.23	0.23
1992	0.05	0.07	0.17	0.19	0.40	0.27	0.16	0.19	0.15	0.20	0.32	0.32
1993	0.03	0.03	0.12	0.12	0.15	0.20	0.32	0.16	0.23	0.19	0.28	0.28
1994	0.03	0.06	0.18	0.13	0.27	0.16	0.32	0.24	0.16	0.21	0.23	0.23
1995	0.06	0.03	0.24	0.18	0.54	0.14	0.15	0.29	0.34	0.21	0.25	0.25
1996	0.09	0.03	0.24	0.28	0.95	0.18	0.11	0.11	0.30	0.29	0.13	0.13
1997	0.06	0.04	0.18	0.26	0.48	0.39	0.20	0.15	0.13	0.39	0.22	0.22
1998	0.06	0.08	0.13	0.19	0.42	0.26	0.21	0.14	0.13	0.14	0.19	0.19
1999	0.12	0.04	0.13	0.12	0.35	0.16	0.17	0.17	0.10	0.09	0.09	0.09
2000	0.06	0.04	0.09	0.32	0.19	0.16	0.14	0.16	0.15	0.15	0.16	0.16
2001	0.03	0.02	0.18	0.10	0.24	0.11	0.13	0.09	0.11	0.15	0.19	0.19
2002	0.05	0.05	0.26	0.24	0.13	0.15	0.08	0.09	0.09	0.09	0.11	0.11
2003	0.03	0.02	0.15	0.17	0.54	0.14	0.15	0.11	0.11	0.07	0.07	0.07
2004	0.05	0.02	0.16	0.20	0.39	0.42	0.13	0.11	0.09	0.08	0.07	0.07
2005	0.06	0.01	0.13	0.13	0.33	0.14	0.32	0.08	0.08	0.07	0.05	0.05
2006	0.04	0.01	0.12	0.16	0.19	0.22	0.13	0.24	0.10	0.03	0.07	0.07
2007	0.09	0.04	0.18	0.14	0.23	0.18	0.20	0.15	0.50	0.09	0.07	0.07
2008	0.06	0.02	0.12	0.11	0.18	0.15	0.19	0.13	0.12	0.25	0.05	0.05
2009	0.05	0.02	0.14	0.09	0.22	0.16	0.14	0.10	0.15	0.07	0.05	0.05
2010	0.07	0.02	0.10	0.14	0.17	0.13	0.11	0.06	0.03	0.04	0.03	0.03
2011	0.04	0.03	0.11	0.06	0.14	0.12	0.08	0.06	0.06	0.05	0.02	0.02
2012	0.03	0.04	0.12	0.06	0.10	0.08	0.06	0.05	0.05	0.05	0.03	0.03

Table 16. Base VPA Estimated Abundance-at-age of Atlantic King Mackerel.

FishingYear	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10	Age11+
1986	7,979,814	3,741,673	2,504,152	1,398,969	1,105,112	442,956	336,306	997,510	189,923	162,705	153,383	855,864
1987	3,472,007	3,836,620	2,817,550	1,599,748	981,597	459,098	342,375	259,897	680,497	121,041	99,753	753,700
1988	4,729,577	1,607,777	2,830,501	2,017,250	1,202,616	503,907	260,762	221,729	196,033	537,896	79,143	602,993
1989	10,137,155	2,245,708	1,194,810	2,002,894	1,382,442	711,877	395,989	193,749	137,823	149,502	369,113	435,907
1990	7,575,236	5,109,930	1,695,289	800,781	1,445,149	886,135	518,318	284,289	141,011	93,971	113,330	560,229
1991	4,198,750	3,449,791	3,769,028	1,134,480	543,579	640,105	630,004	364,276	207,879	103,585	56,971	486,049
1992	4,947,846	2,036,838	2,545,867	2,549,430	718,397	314,814	450,140	445,830	256,744	141,897	74,112	367,078
1993	4,529,736	2,435,912	1,486,917	1,721,599	1,709,791	397,303	199,690	320,997	312,066	186,973	99,018	274,191
1994	7,957,161	2,270,272	1,840,969	1,052,435	1,235,460	1,206,494	269,534	121,634	229,524	210,919	130,776	240,361
1995	7,899,368	3,990,342	1,671,645	1,228,688	754,115	779,023	858,259	163,411	80,530	165,104	144,979	252,115
1996	8,596,794	3,876,271	3,014,823	1,047,831	836,630	361,208	563,379	617,061	102,660	48,345	114,029	263,798
1997	5,587,922	4,071,610	2,952,859	1,905,086	643,288	267,294	249,812	424,220	463,664	64,354	30,833	283,663
1998	8,890,985	2,742,784	3,045,807	1,974,047	1,195,981	326,379	150,795	171,455	308,553	343,426	36,939	214,834
1999	3,378,201	4,331,447	1,977,327	2,142,571	1,324,209	648,302	209,438	102,596	125,642	229,234	252,905	178,403
2000	3,947,026	1,556,002	3,260,458	1,388,130	1,549,437	770,956	458,497	147,263	73,166	96,560	178,858	336,412
2001	6,062,427	1,935,158	1,165,535	2,386,672	818,258	1,049,794	545,001	334,457	105,628	53,115	70,940	376,494
2002	6,972,935	3,049,142	1,479,627	780,075	1,751,296	532,336	782,424	400,773	257,181	80,242	38,923	316,620
2003	10,688,820	3,448,799	2,257,611	915,966	499,104	1,269,130	381,093	607,546	308,744	198,347	62,484	273,434
2004	8,624,288	5,362,584	2,629,108	1,553,089	627,606	239,926	915,172	275,259	460,525	235,191	157,770	266,575
2005	8,066,321	4,254,692	4,104,941	1,790,438	1,029,964	348,615	130,387	670,092	208,493	356,036	183,977	336,742
2006	8,584,341	3,954,794	3,292,888	2,893,396	1,275,346	609,013	251,903	79,147	519,837	162,760	282,920	425,011
2007	6,494,823	4,261,540	3,055,704	2,345,803	1,994,921	869,508	404,549	184,864	52,589	397,192	133,892	566,596
2008	4,569,636	3,091,544	3,205,241	2,043,341	1,652,702	1,300,736	605,572	276,658	134,542	27,029	310,086	557,365
2009	3,176,442	2,233,457	2,359,690	2,263,268	1,488,497	1,135,336	931,733	420,740	204,975	101,484	17,880	706,215
2010	1,839,423	1,567,407	1,719,297	1,646,701	1,673,478	985,763	804,641	681,166	319,872	149,673	80,101	589,943
2011	2,667,261	891,130	1,204,605	1,249,377	1,159,271	1,159,882	717,126	602,830	541,485	261,559	121,875	558,525
2012	1,683,340	1,331,352	676,194	865,413	958,070	831,601	856,423	553,667	478,884	432,637	211,409	569,665

Table 17. Base VPA estimated spawning stock biomass (SSB, in million eggs) and recruitment of Atlantic king mackerel.

FishingYear	SSB	Recruits
1986	5,001	7,979,814
1987	4,804	3,472,007
1988	4,395	4,729,577
1989	4,033	10,137,155
1990	4,245	7,575,236
1991	4,179	4,198,750
1992	3,912	4,947,846
1993	3,682	4,529,736
1994	3,561	7,957,161
1995	3,650	7,899,368
1996	3,736	8,596,794
1997	3,852	5,587,922
1998	3,786	8,890,985
1999	4,000	3,378,201
2000	3,943	3,947,026
2001	3,789	6,062,427
2002	3,862	6,972,935
2003	4,019	10,688,820
2004	4,478	8,624,288
2005	4,850	8,066,321
2006	5,178	8,584,341
2007	5,448	6,494,823
2008	5,414	4,569,636
2009	5,315	3,176,442
2010	5,015	1,839,423
2011	4,685	2,667,261
2012	4,473	1,683,340

5. Figures

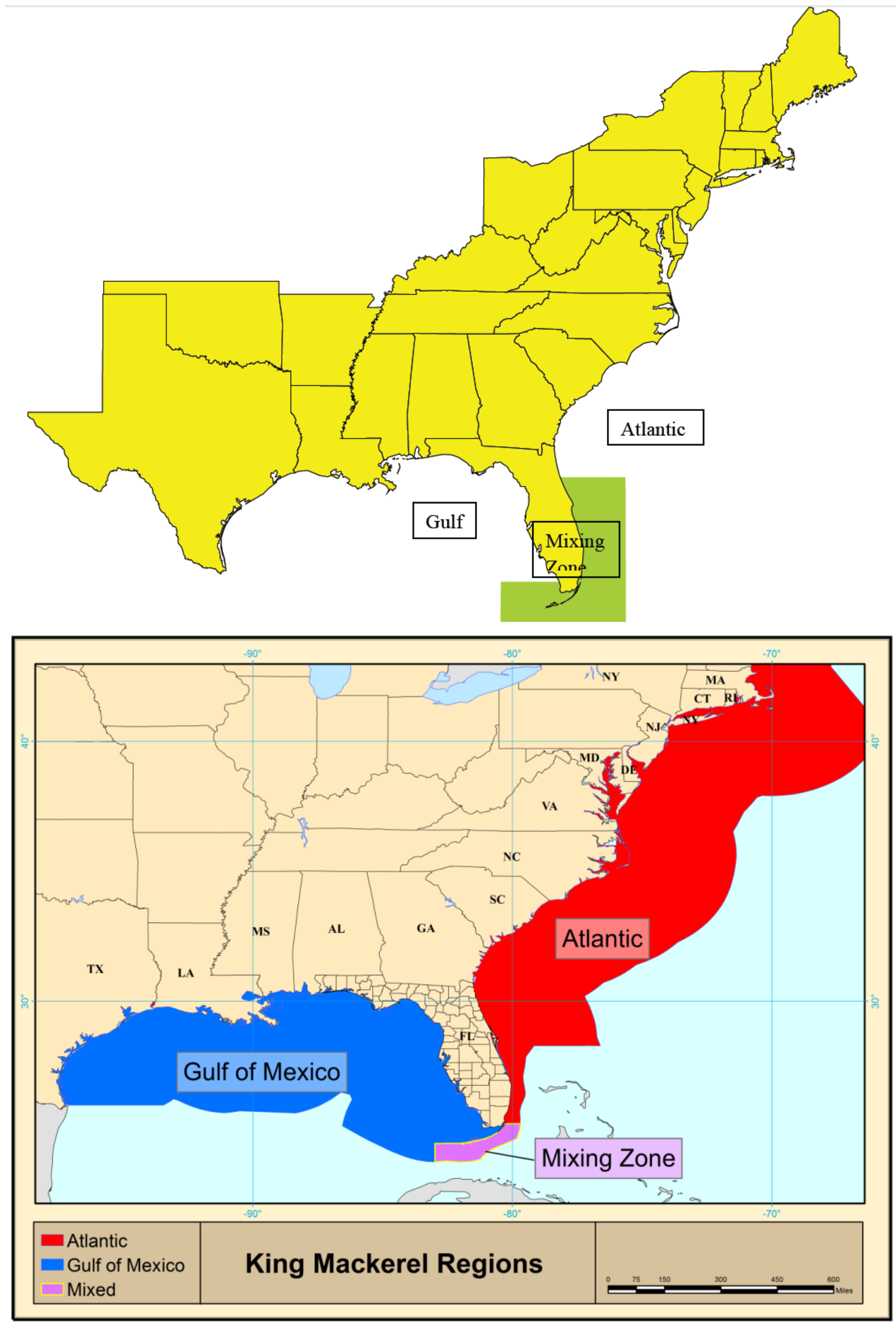
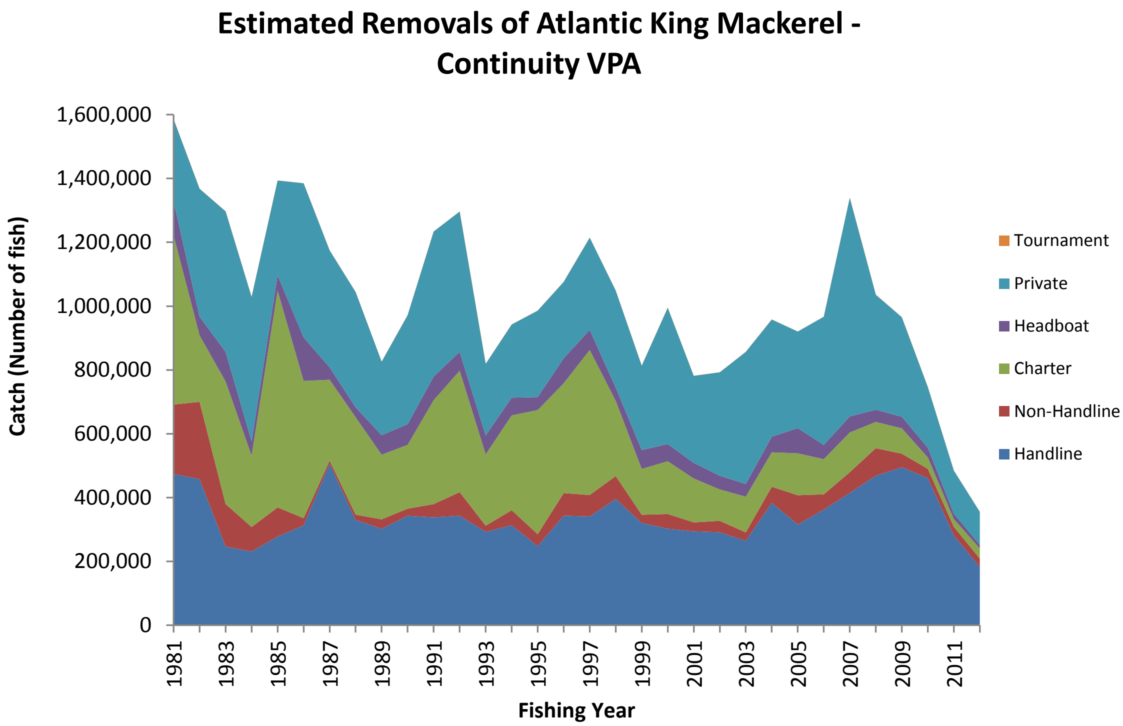


Figure 1. Stock distribution assumptions for the continuity VPA (upper figure) and base VPA (lower figure).



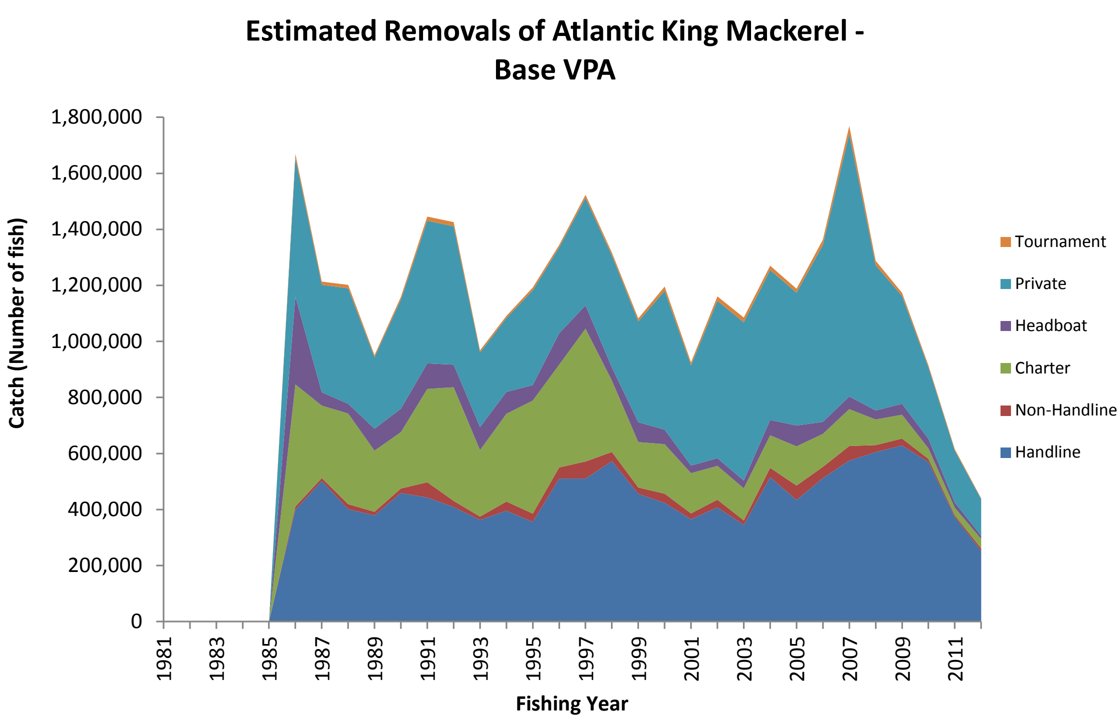
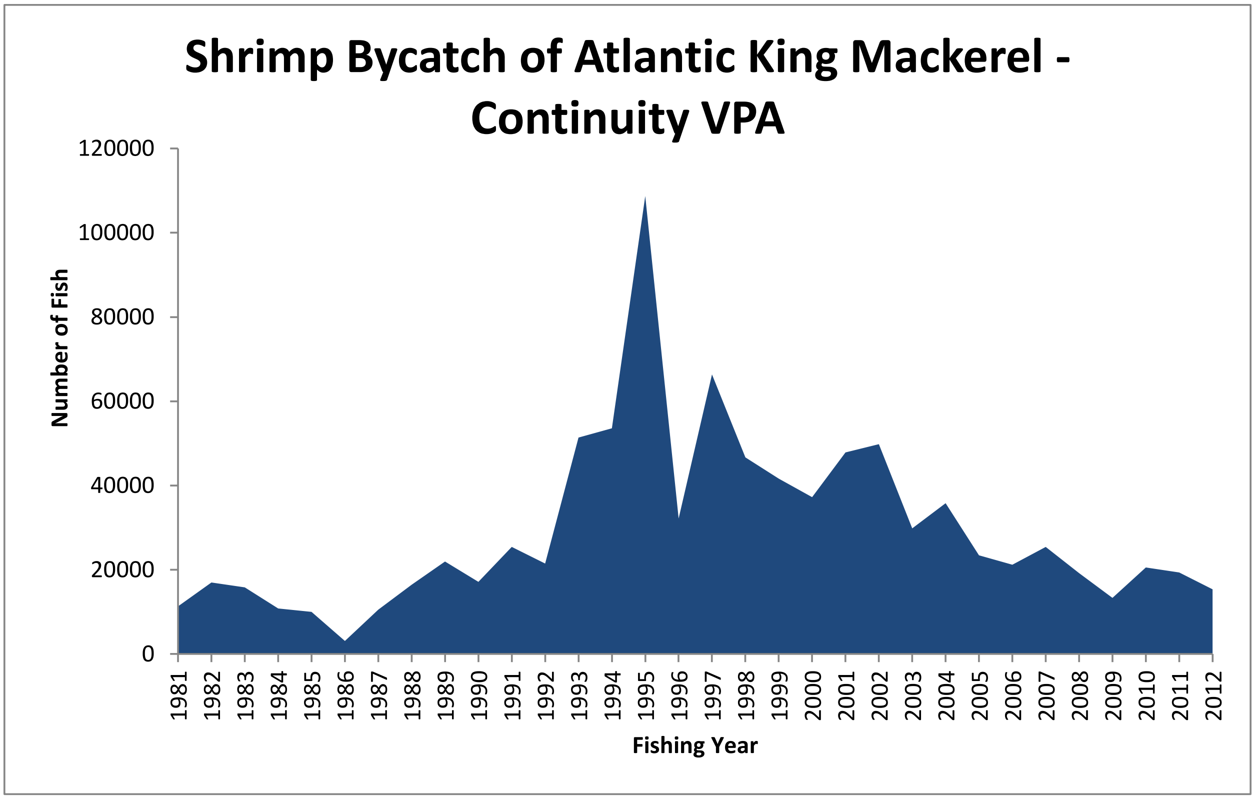


Figure 2. Estimated removals (catch plus discard mortalities) of Atlantic King Mackerel by fishery for the continuity VPA (upper figure) and base VPA (lower figure).



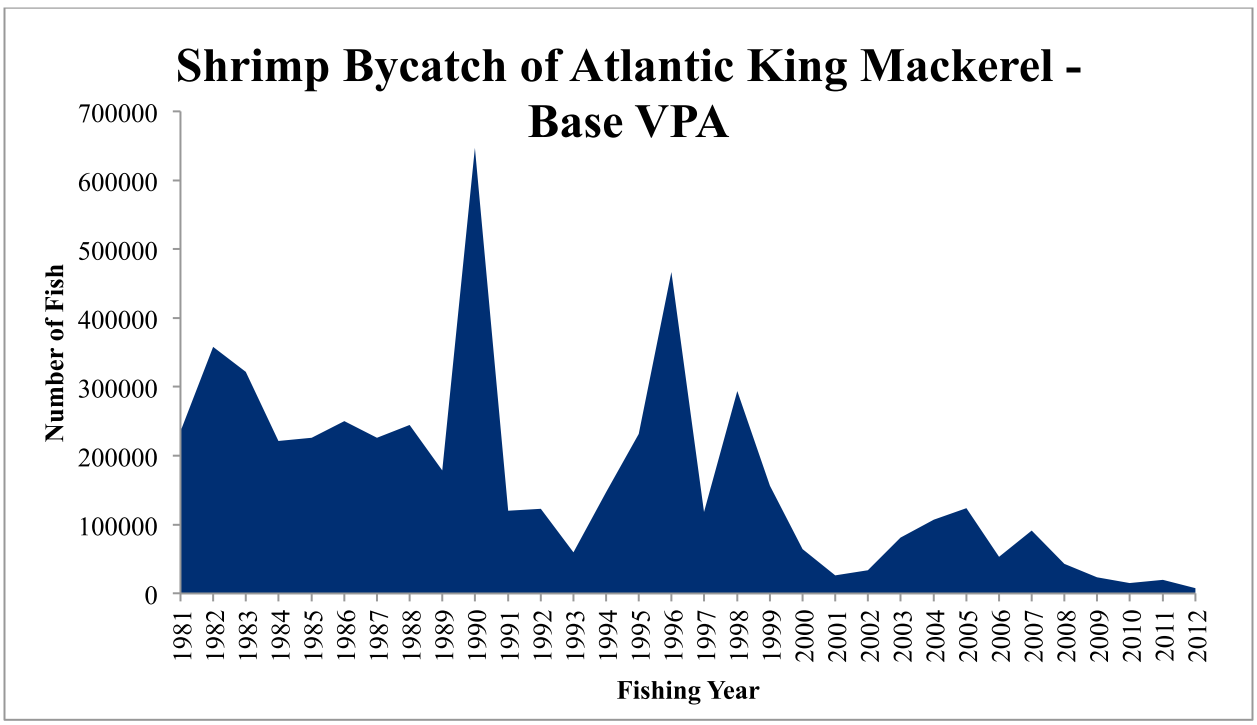


Figure 3. Discard mortalities of age-0 Atlantic King Mackerel from the shrimp fishery, estimated in numbers of fish for the continuity VPA (upper figure) and base VPA (lower figure).

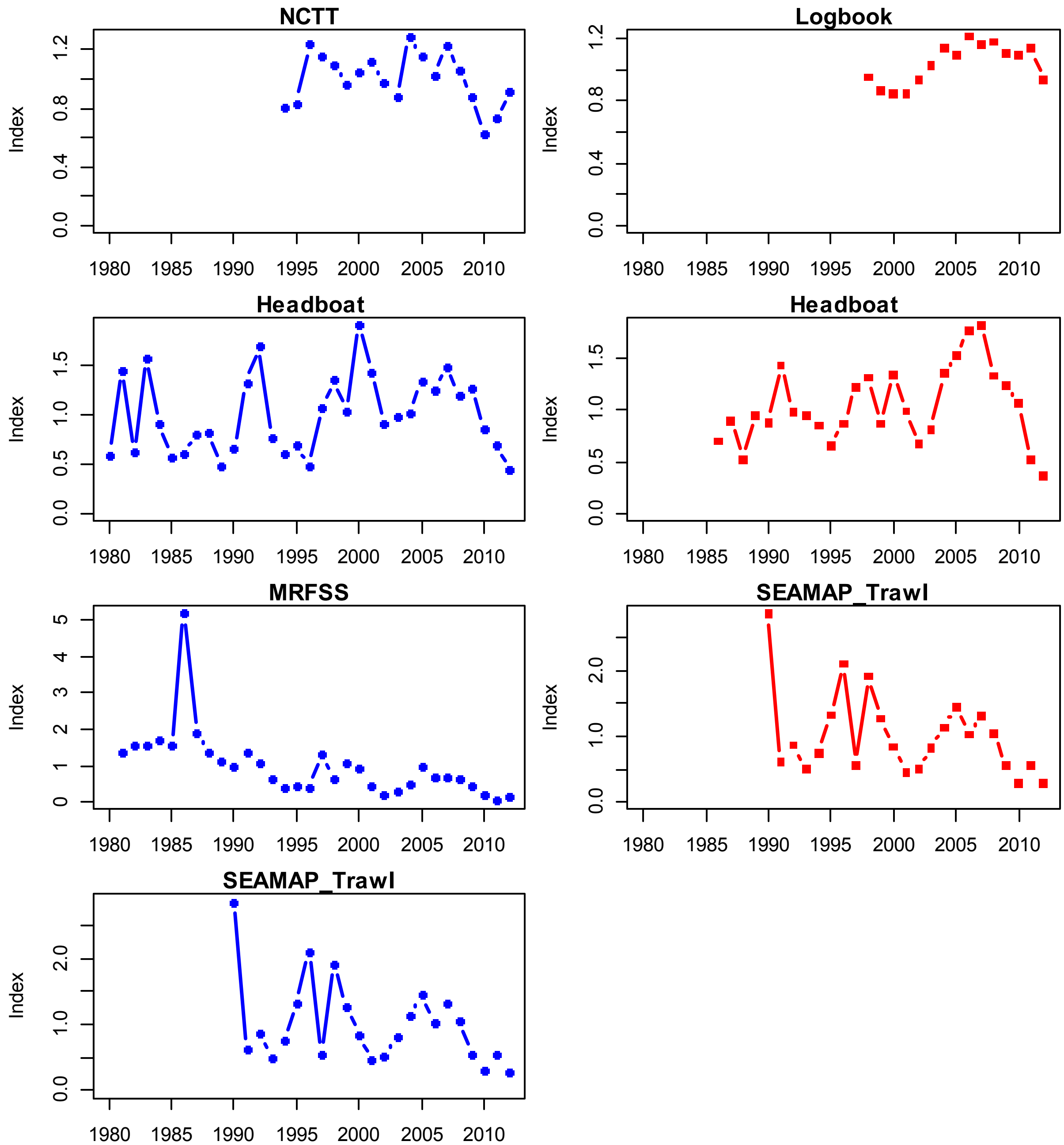


Figure 4. Indices of abundance of Atlantic King Mackerel used in the continuity VPA (left panels with indices shown in blue) and the base VPA (right panels with indices shown in red).

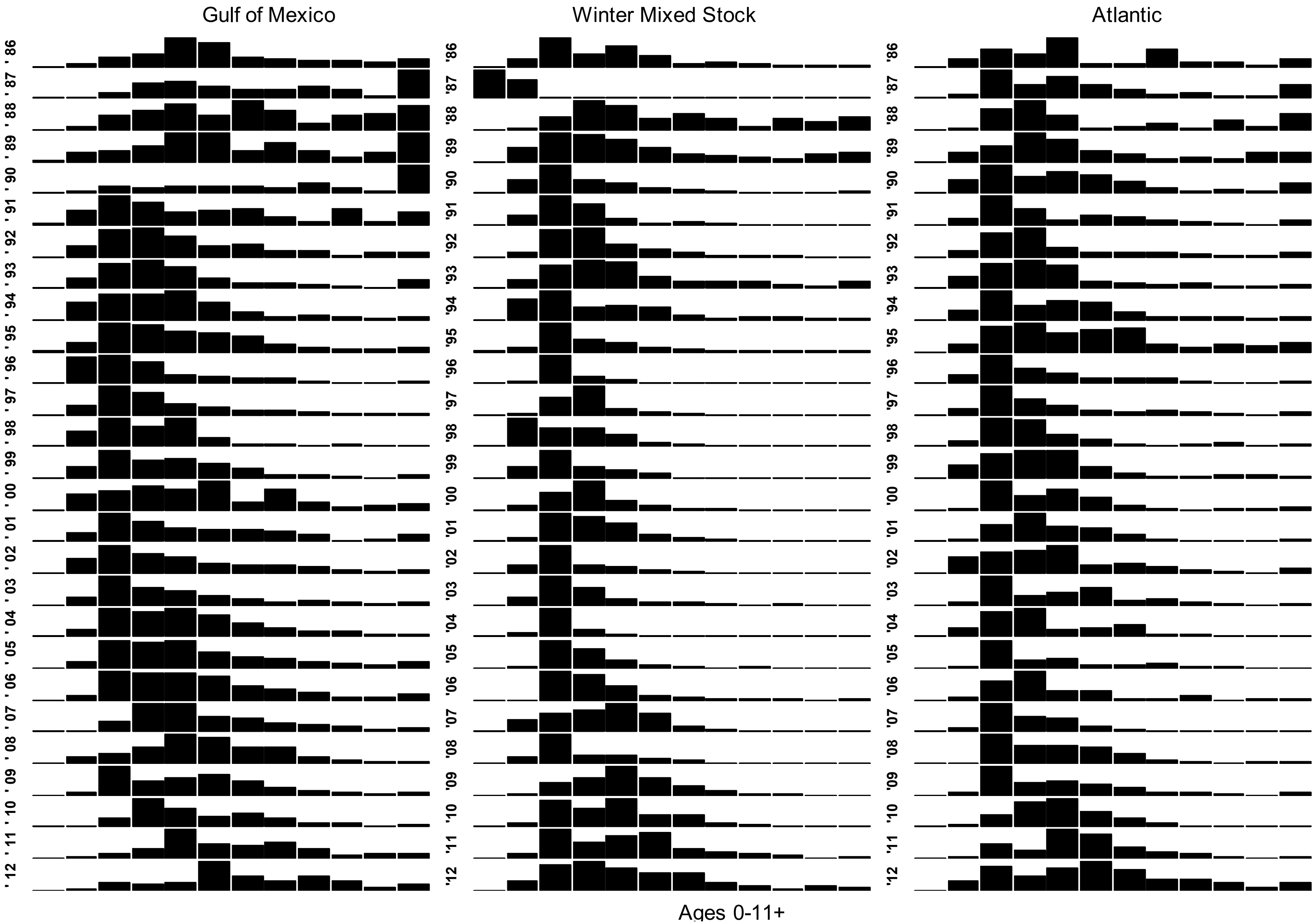


Figure 5. Age frequency distribution of King Mackerel caught in the commercial handline fleet, continuity model.

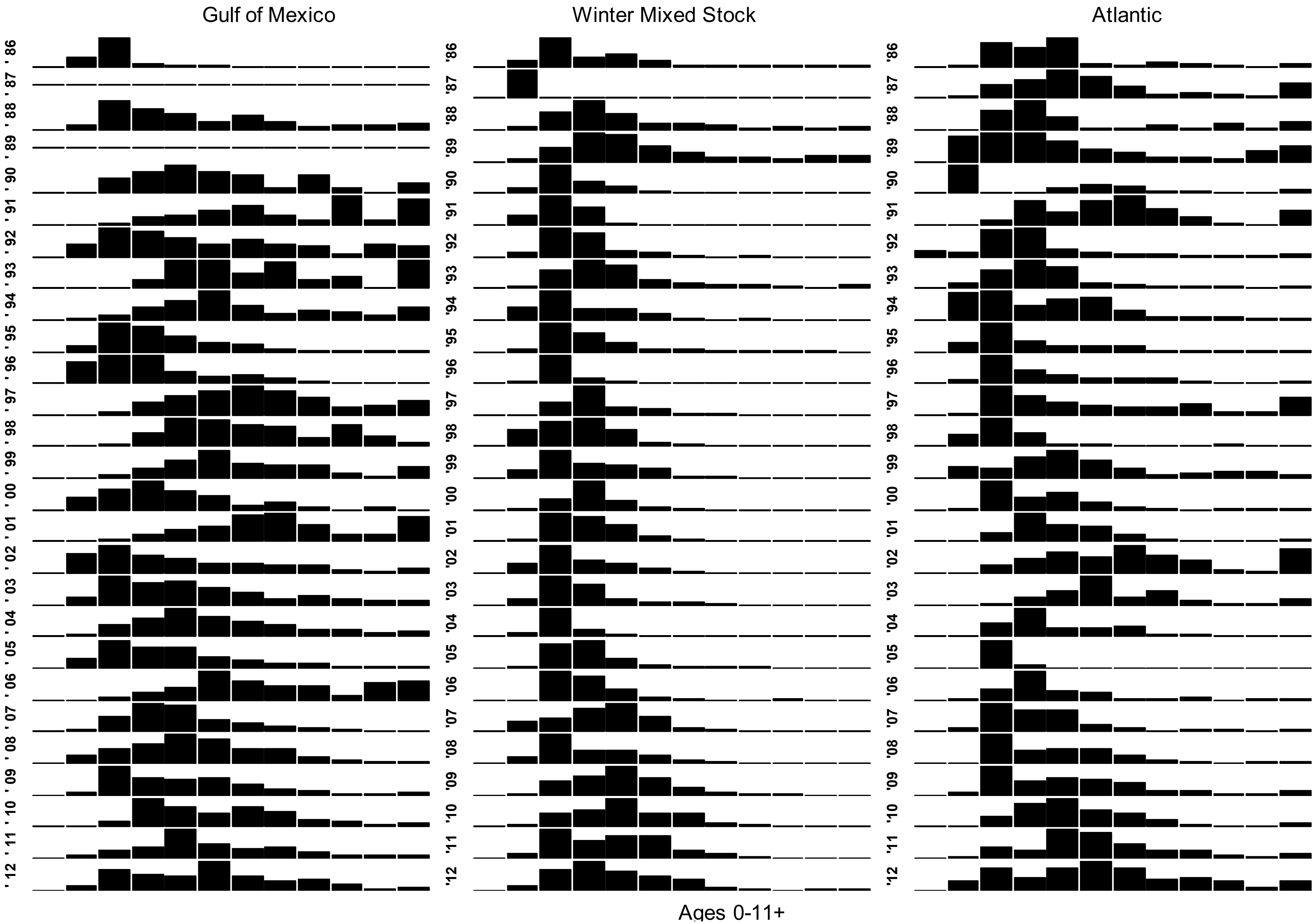


Figure 6. Age frequency distribution of King Mackerel caught in the other commercial fleets combined, continuity model.

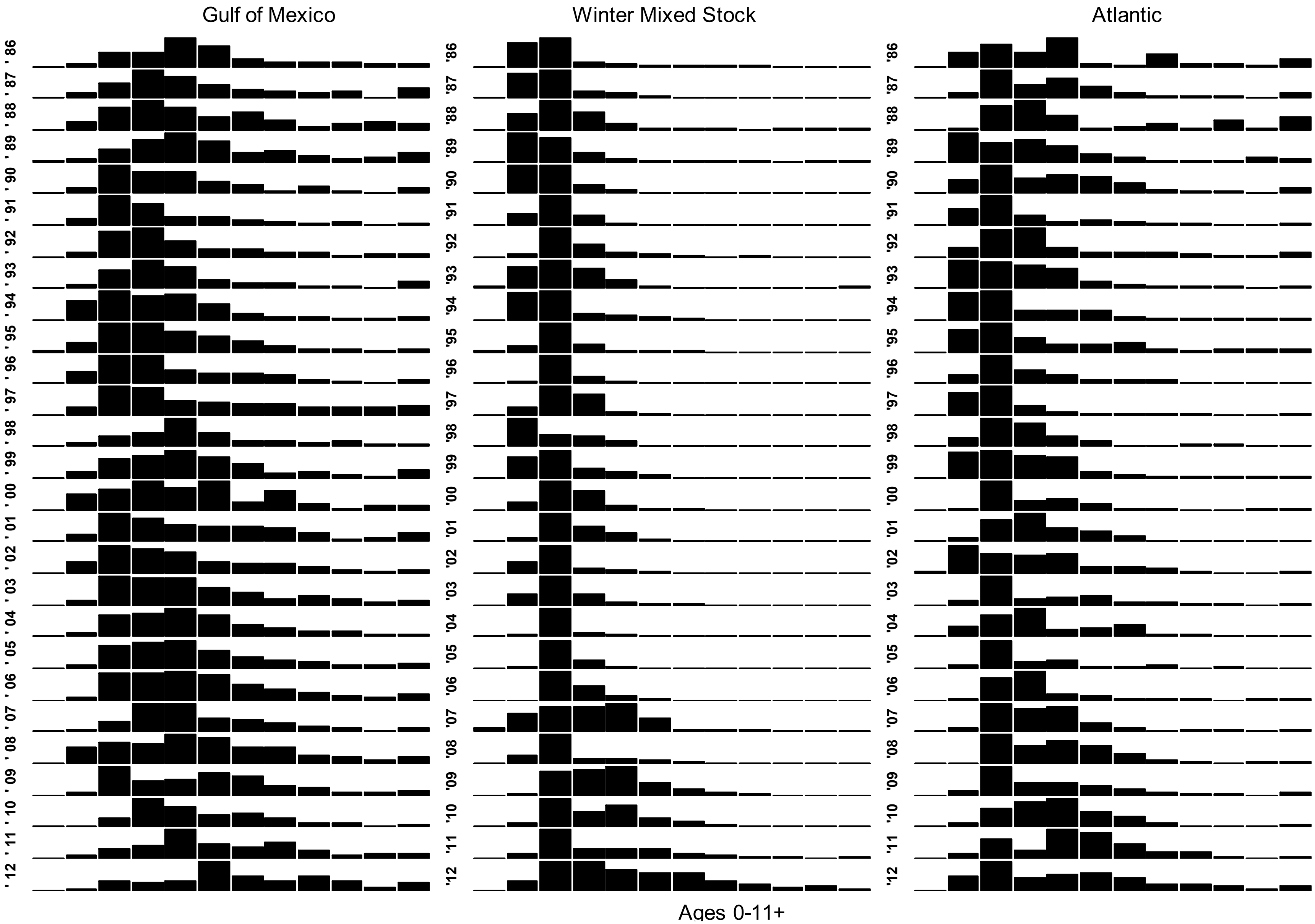


Figure 7. Age frequency distribution of King Mackerel caught in the recreational headboat fleet, continuity model.

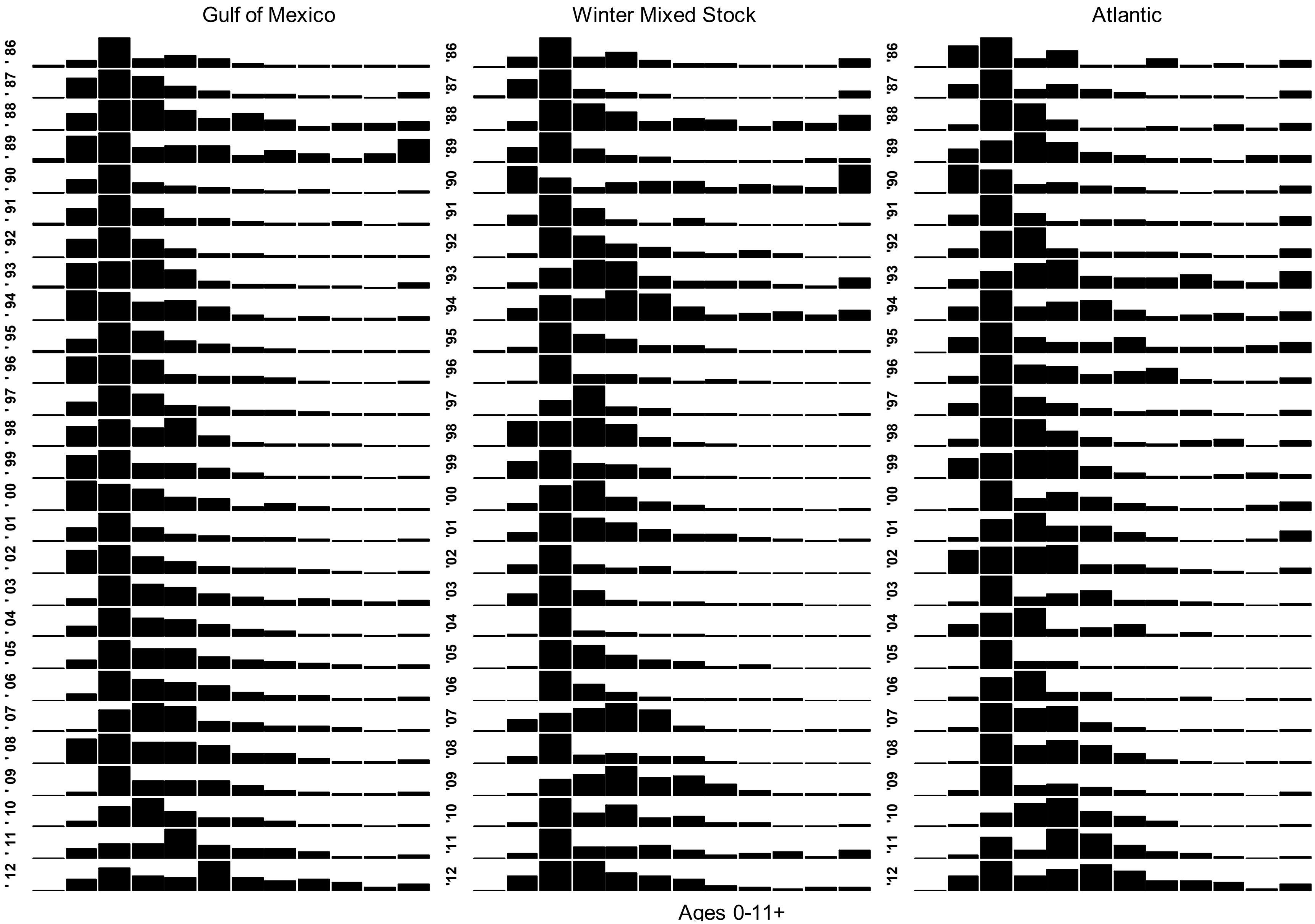


Figure 8. Age frequency distribution of King Mackerel caught in the recreational charter fleet, continuity model.

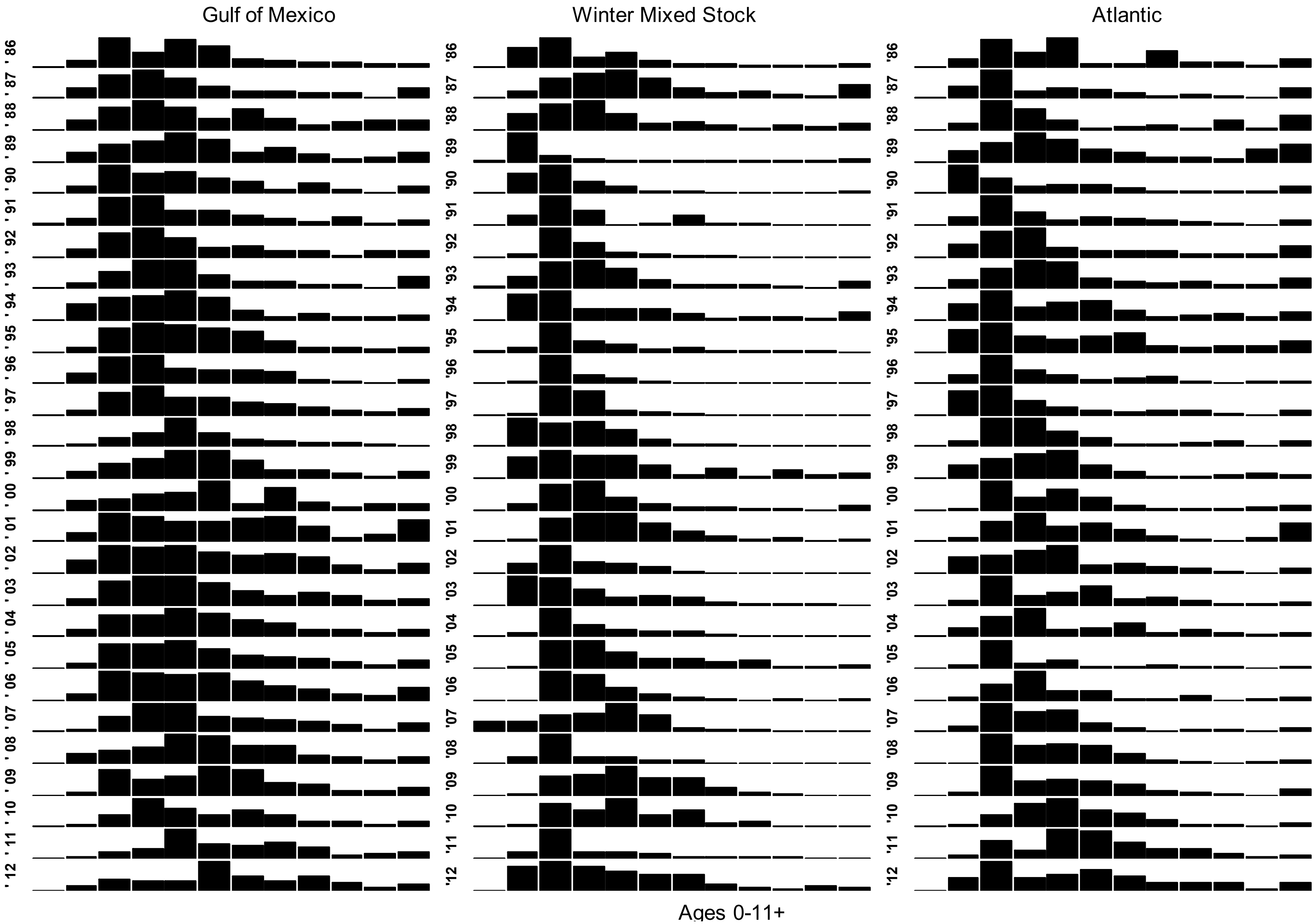


Figure 9. Age frequency distribution of King Mackerel caught in the recreational private fleet, continuity model.

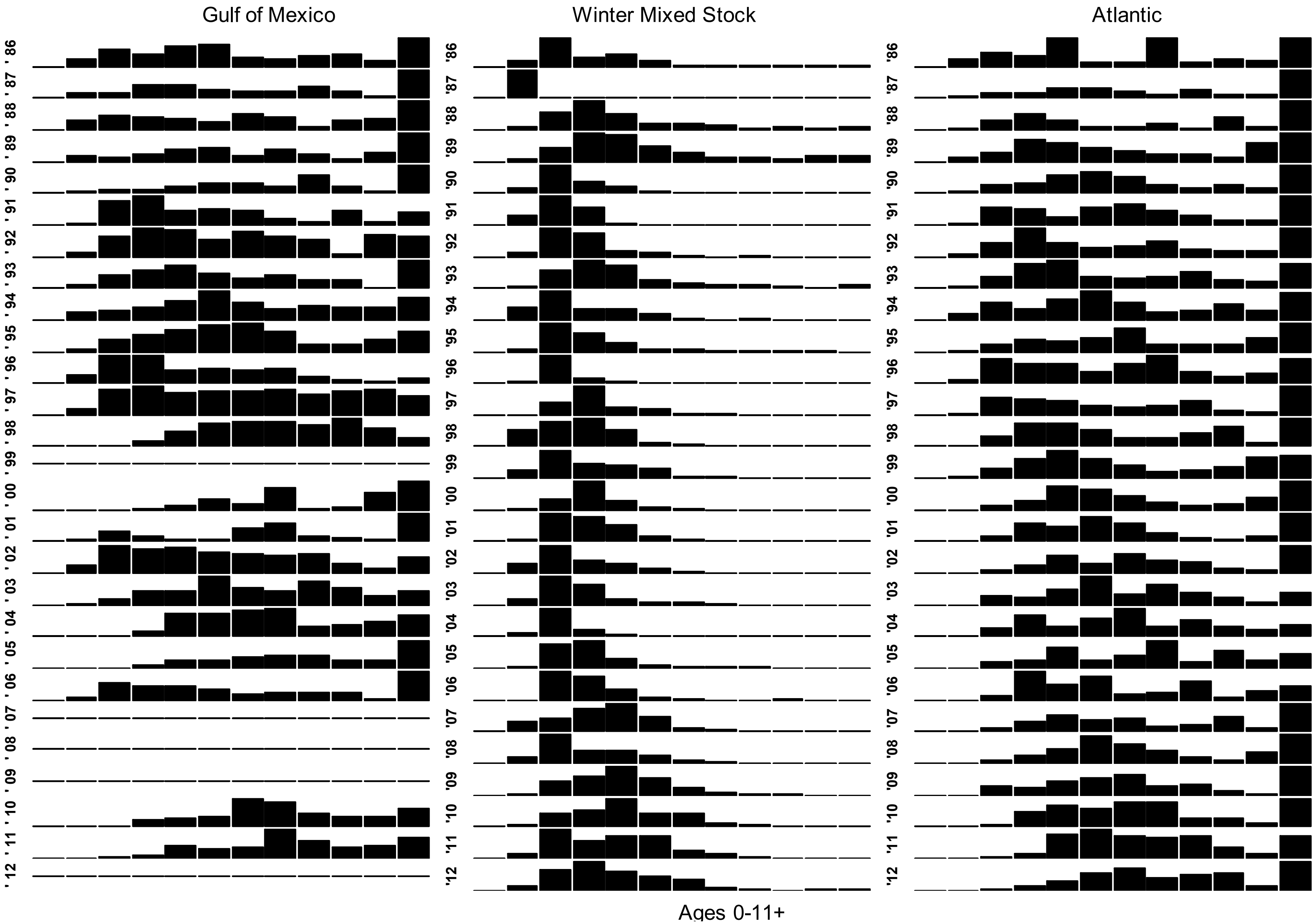


Figure 10. Age frequency distribution of King Mackerel caught in the recreational tournament fleet, continuity model.

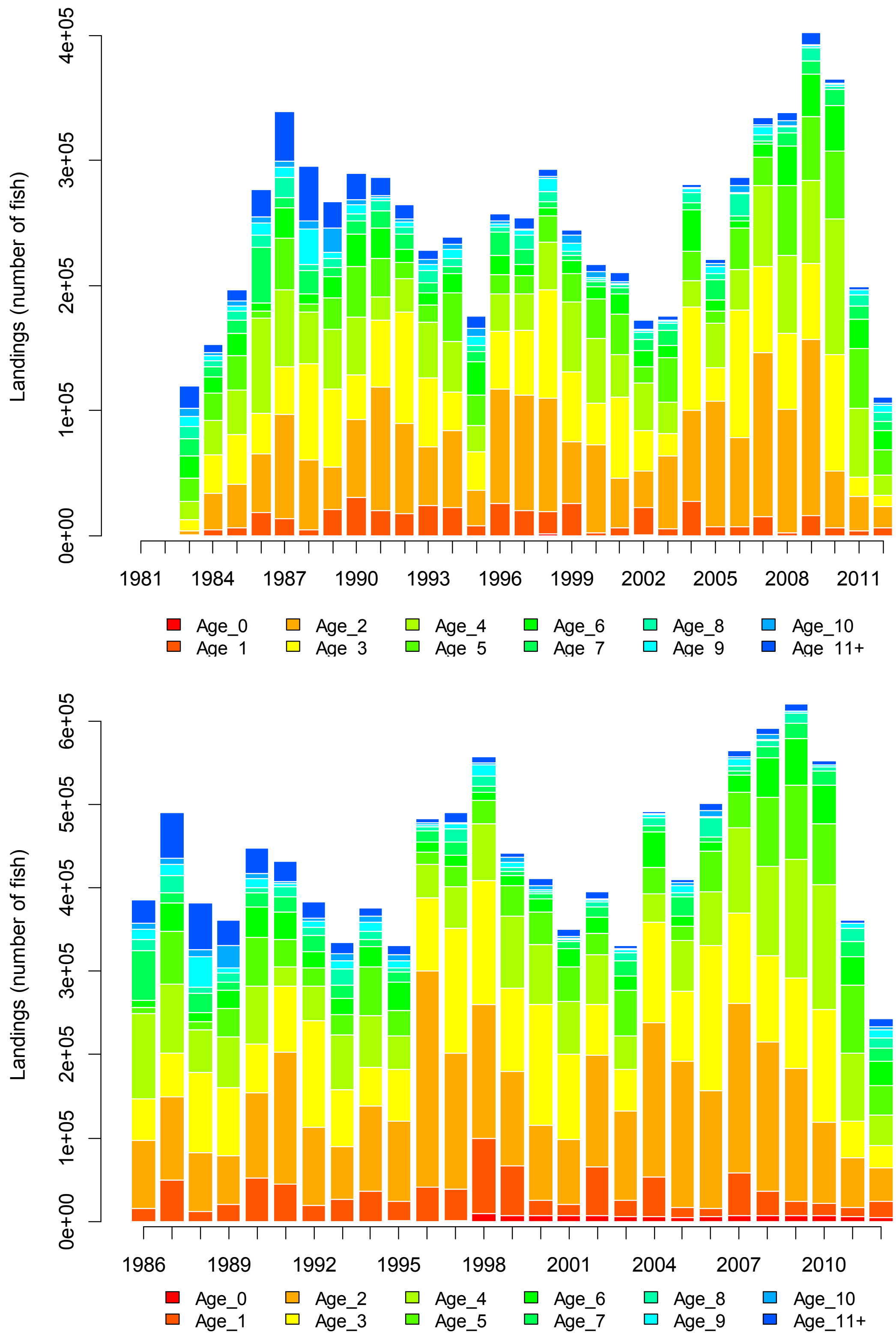


Figure 11. Partial catch-at-age of the commercial handline fleet for the continuity VPA (upper figure) and base VPA (lower figure).

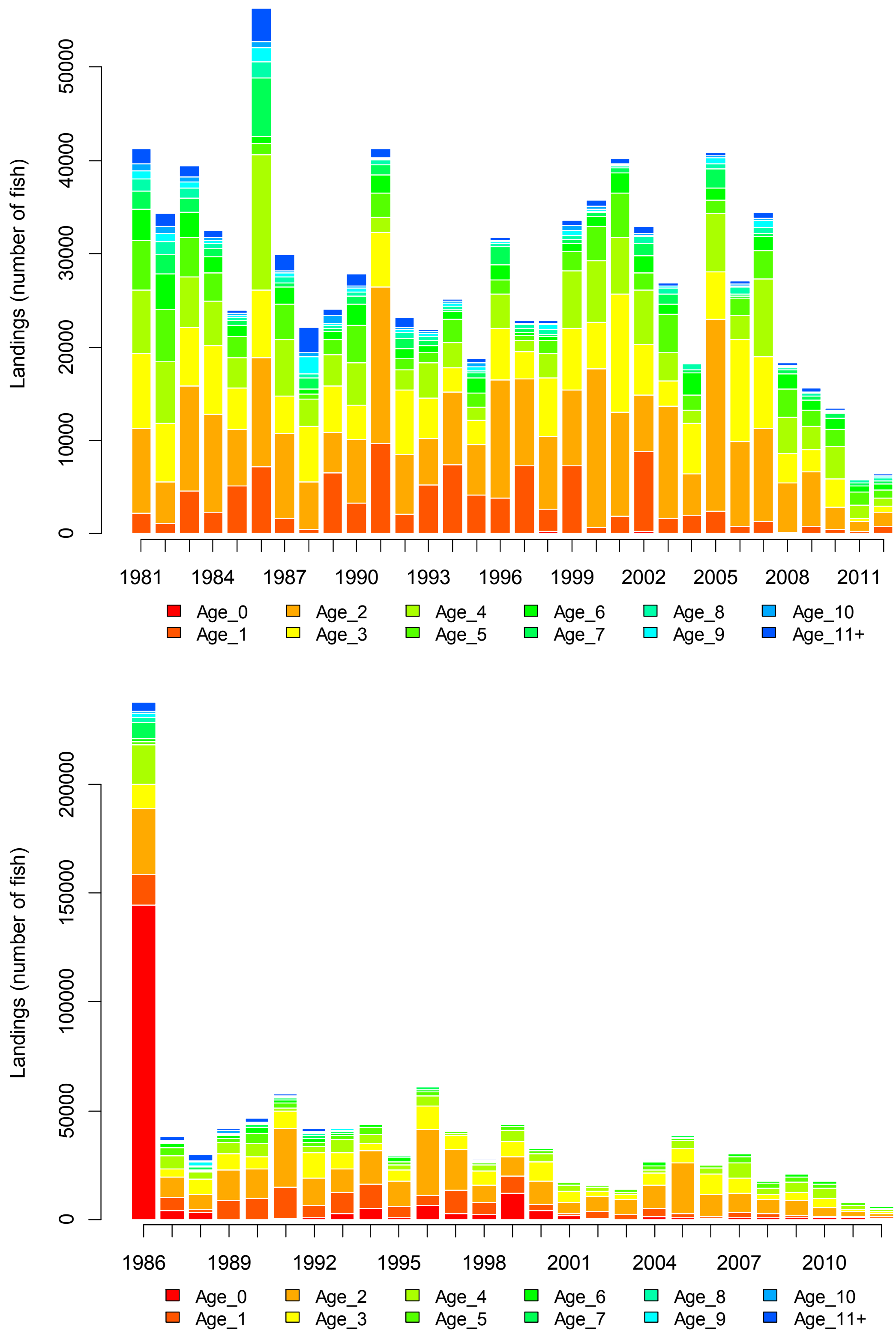


Figure 12. Partial catch-at-age of the recreational headboat fleet for the continuity VPA (upper figure) and base VPA (lower figure).

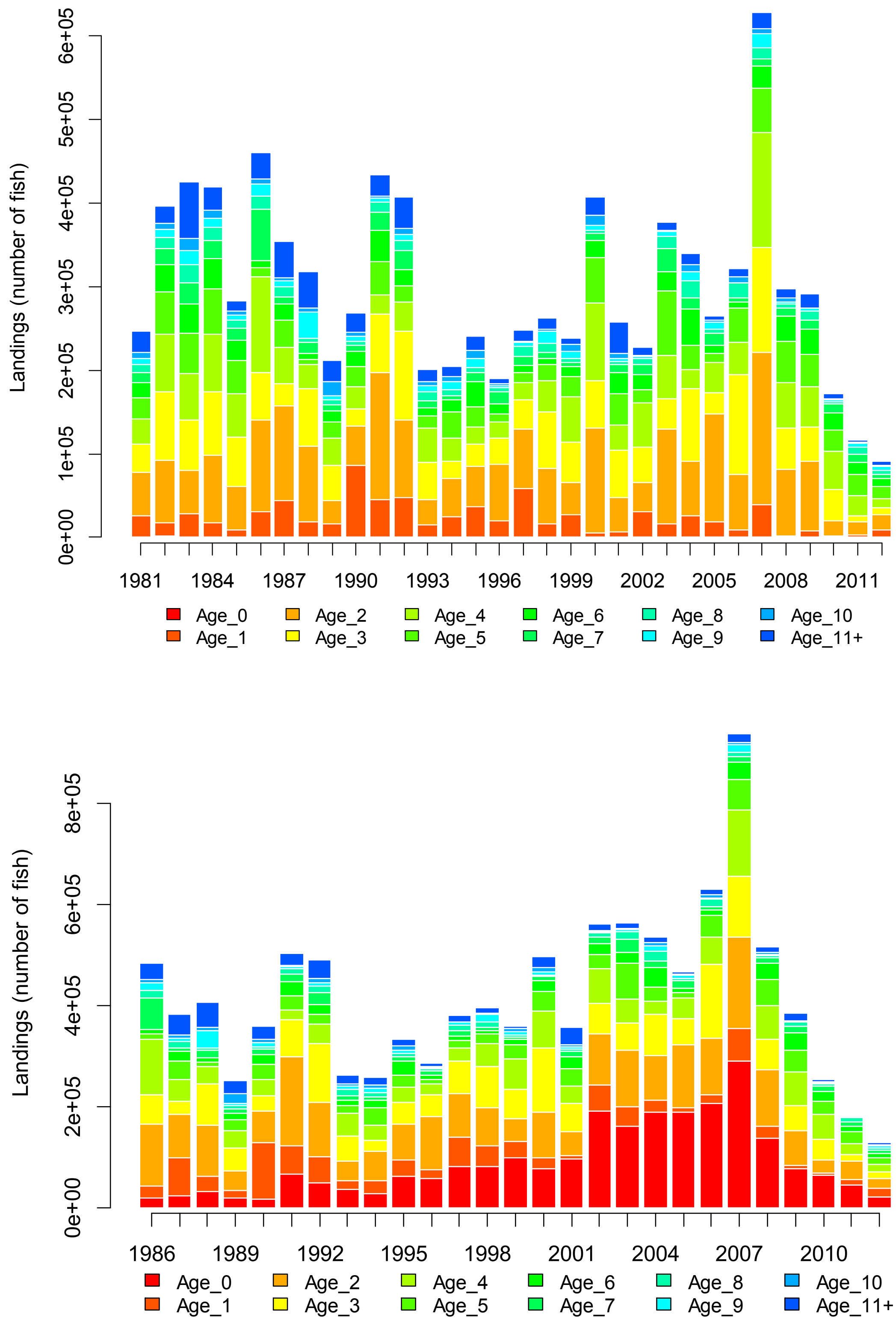


Figure 13. Partial catch-at-age of the recreational private and shore fleet for the continuity VPA (upper figure) and base VPA (lower figure).

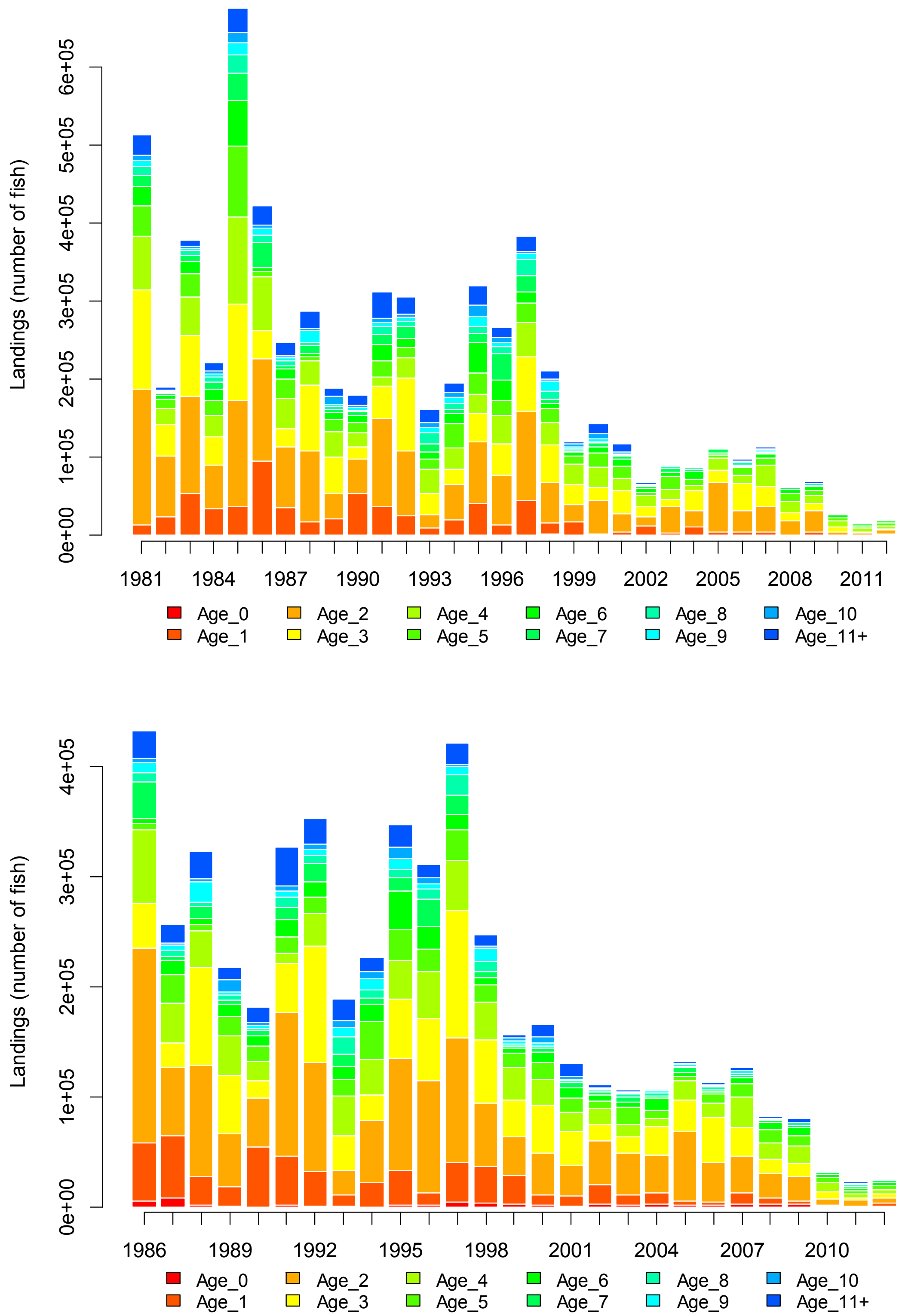


Figure 14. Partial catch-at-age of the recreational charter fleet for the continuity VPA (upper figure) and base VPA (lower figure).

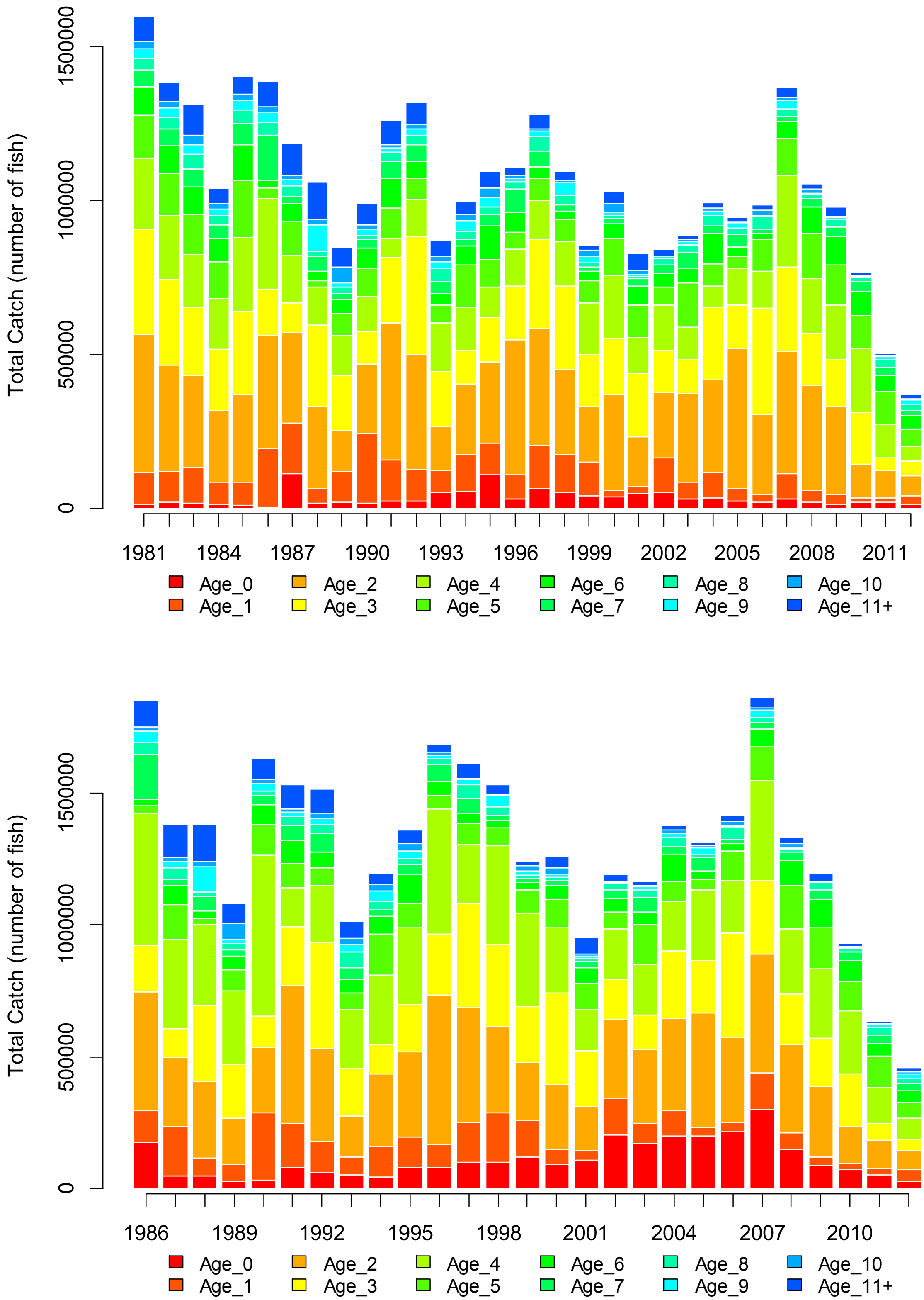
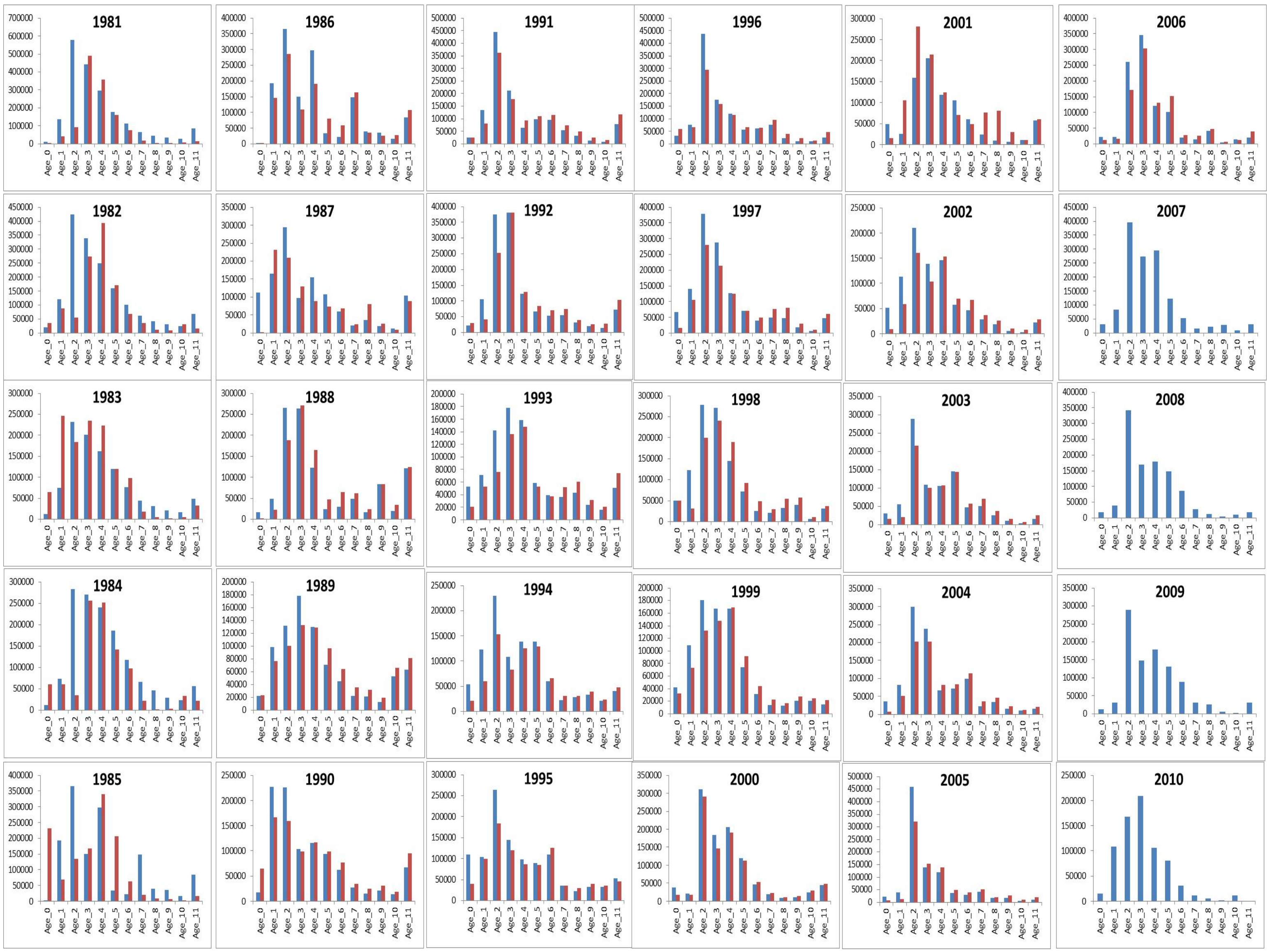


Figure 15. Total catch-at-age of Atlantic King Mackerel for the continuity VPA (upper figure) and base VPA (lower figure).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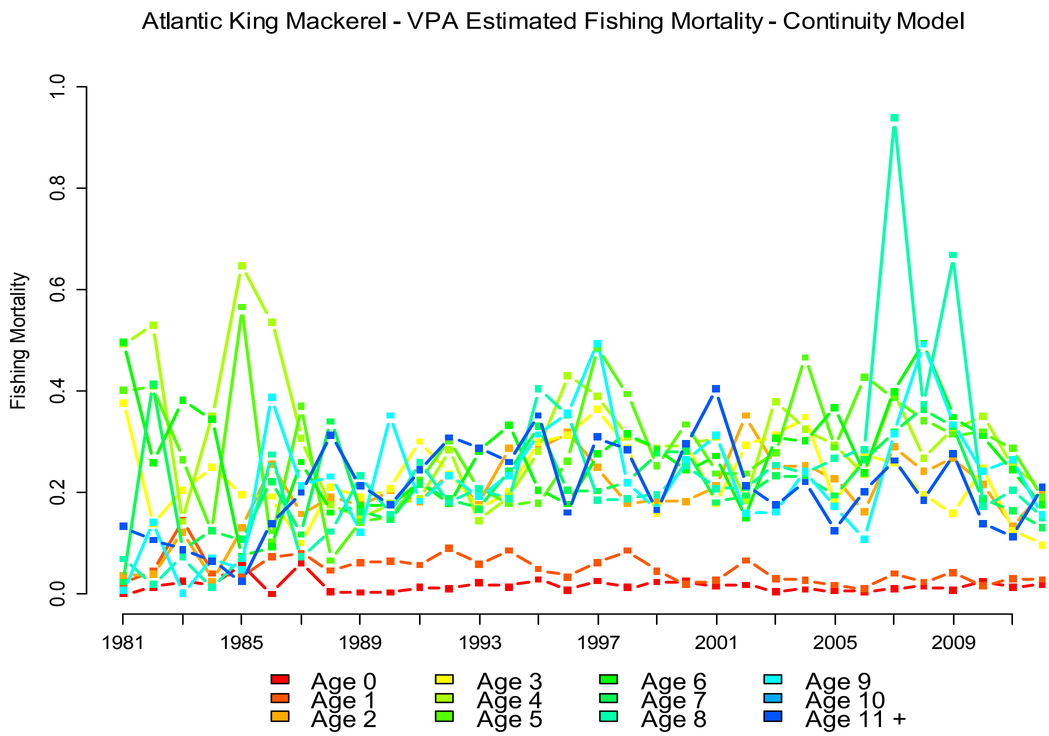


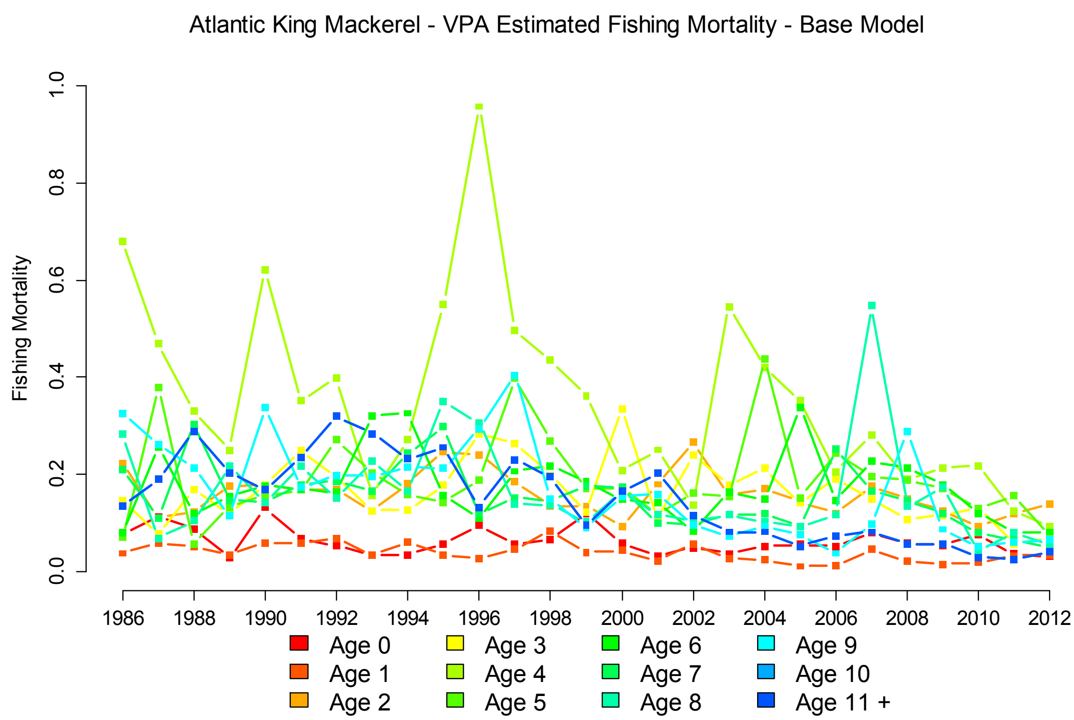


Figure 17. Estimated fishing mortality-at-age of Atlantic King Mackerel from the continuity VPA (upper figure) and base VPA (lower figure).

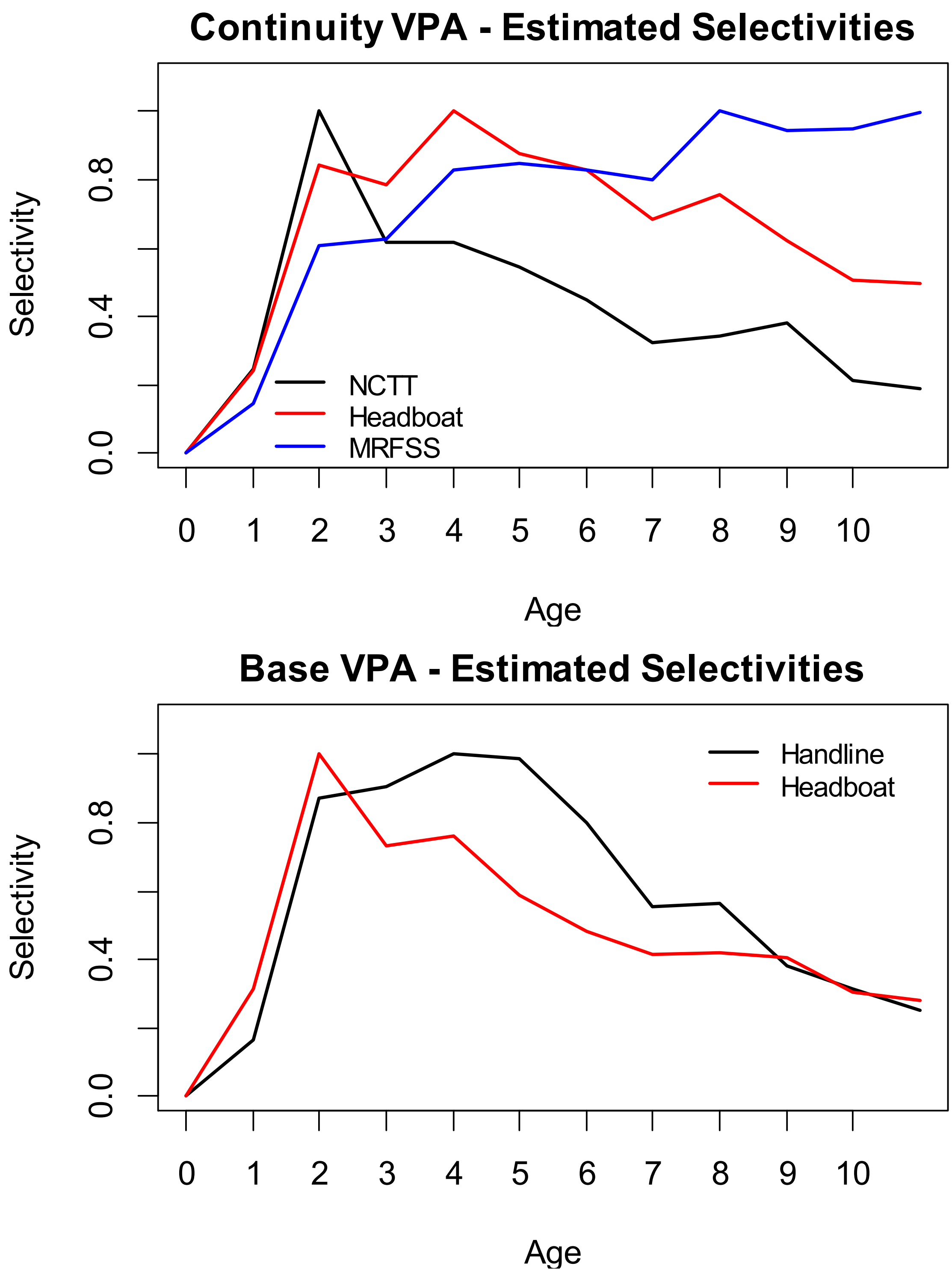


Figure 18. VPA estimated selectivity-at-age of commercial and recreational fleets from the continuity (upper figure) and base models (lower figure).

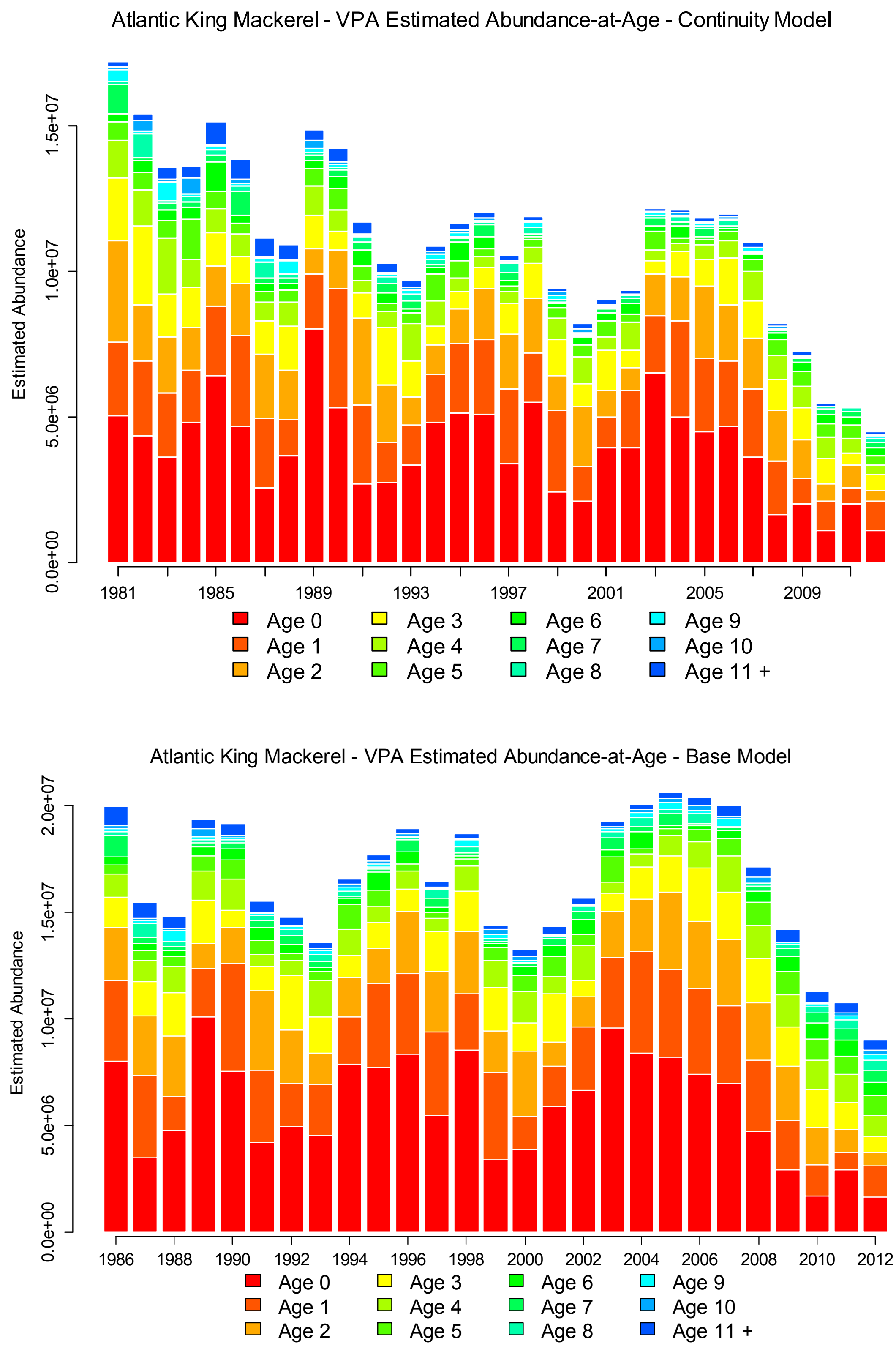


Figure 19. Estimated abundance-at-age of Atlantic King Mackerel from the continuity VPA (upper figure) and base VPA (lower figure).

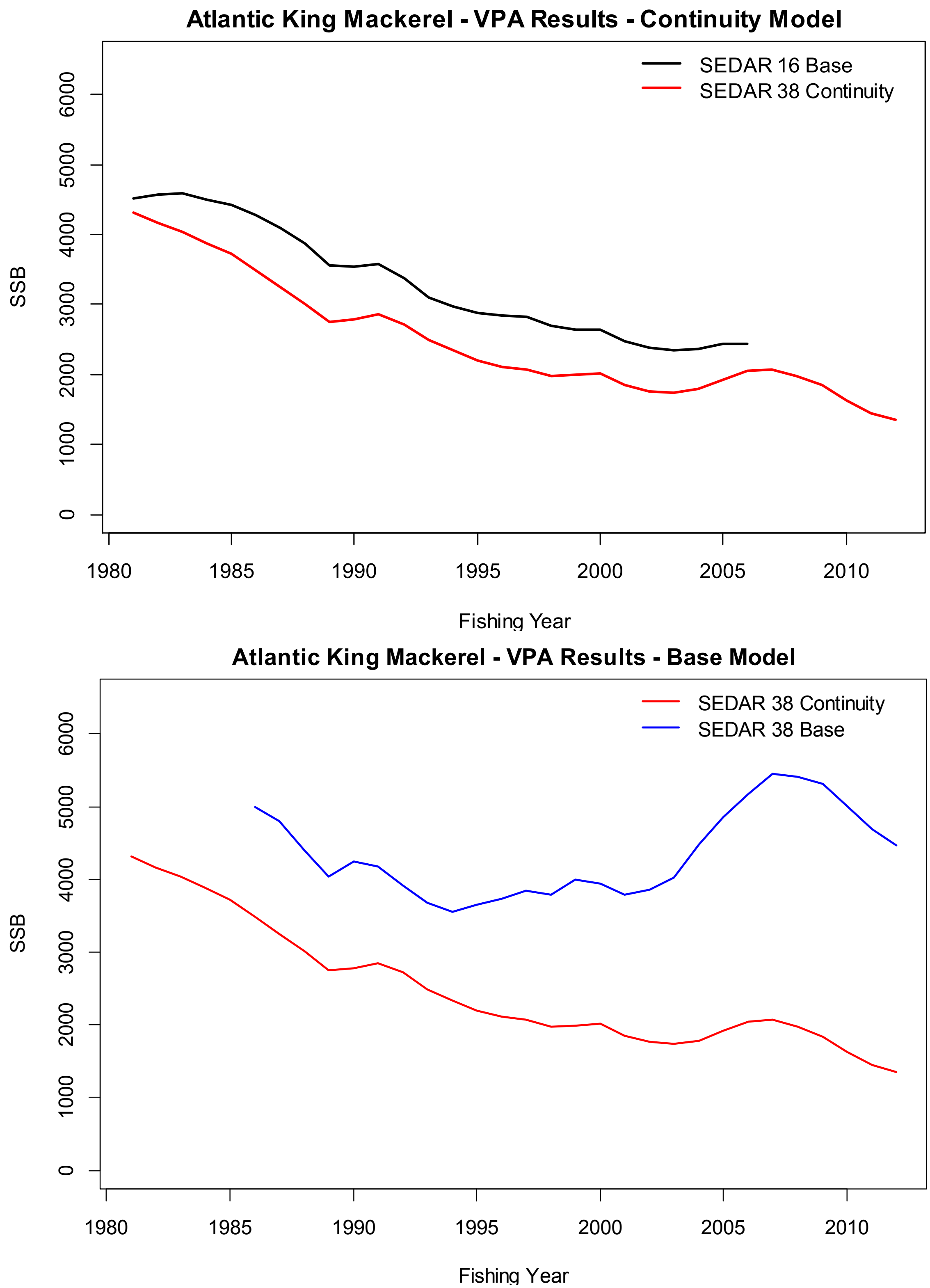
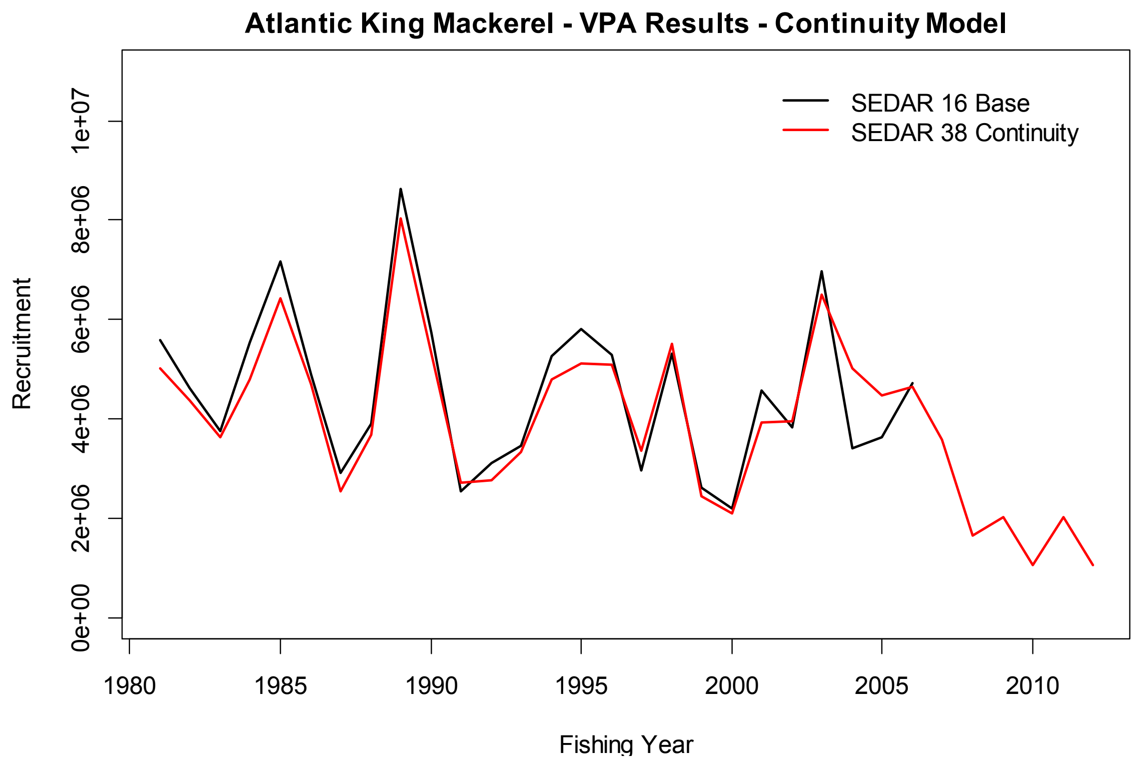


Figure 20. Estimated spawning stock biomass of Atlantic King Mackerel from the continuity VPA and base VPA.



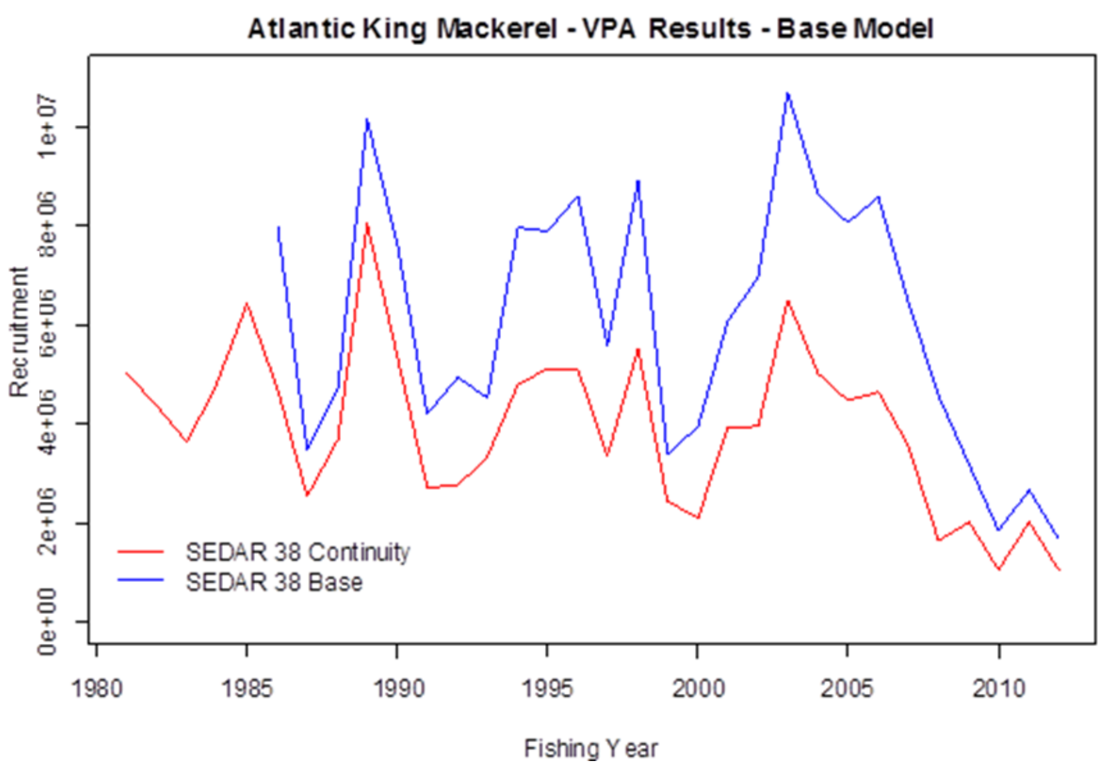


Figure 21. Estimated recruitment of Atlantic King Mackerel from the continuity VPA (upper figure) and base VPA (lower figure).

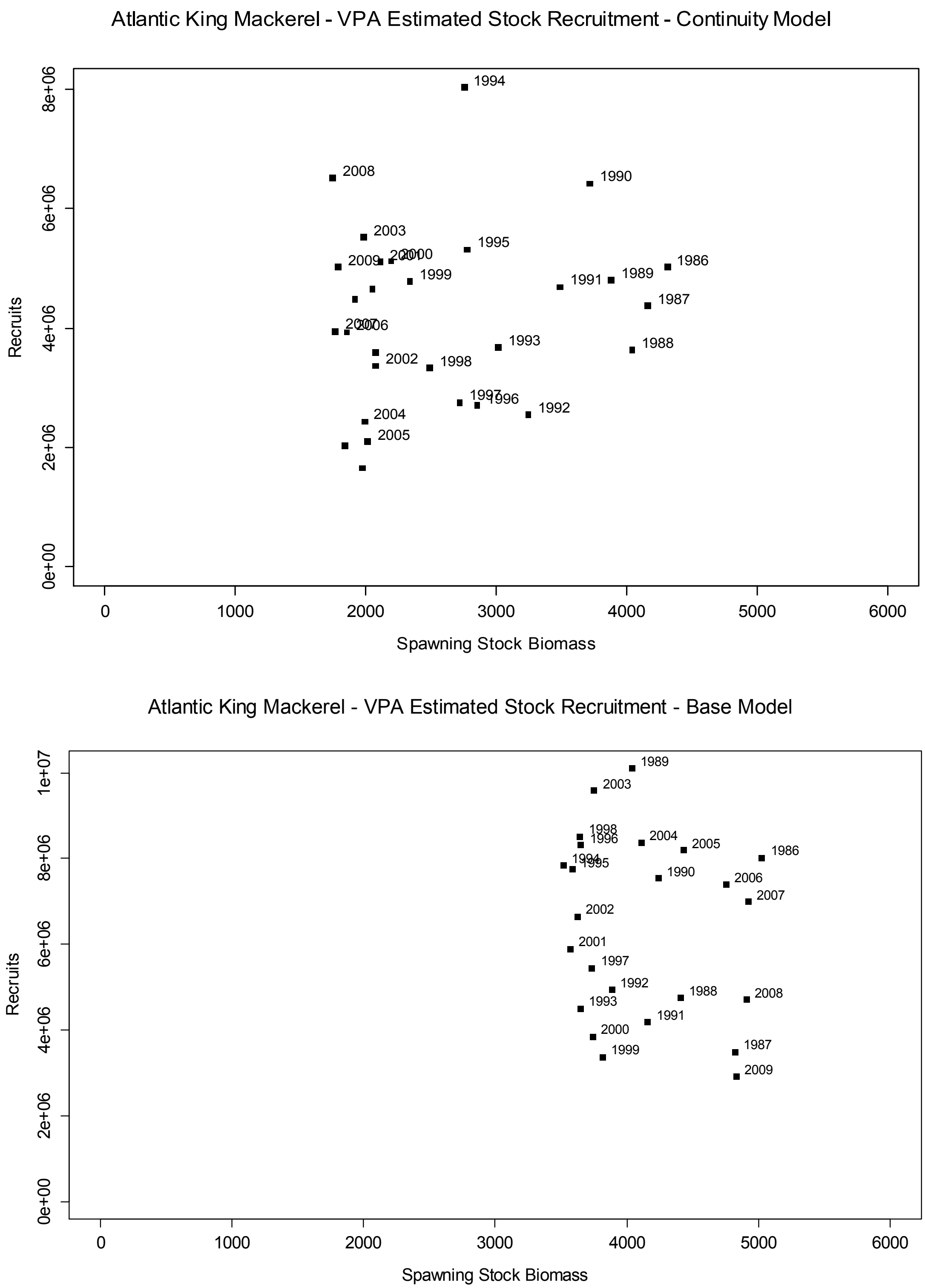


Figure 22. Relationship between estimated recruitment and spawning stock biomass of Atlantic King Mackerel, estimated by the continuity VPA (upper figure) and base VPA (lower figure).

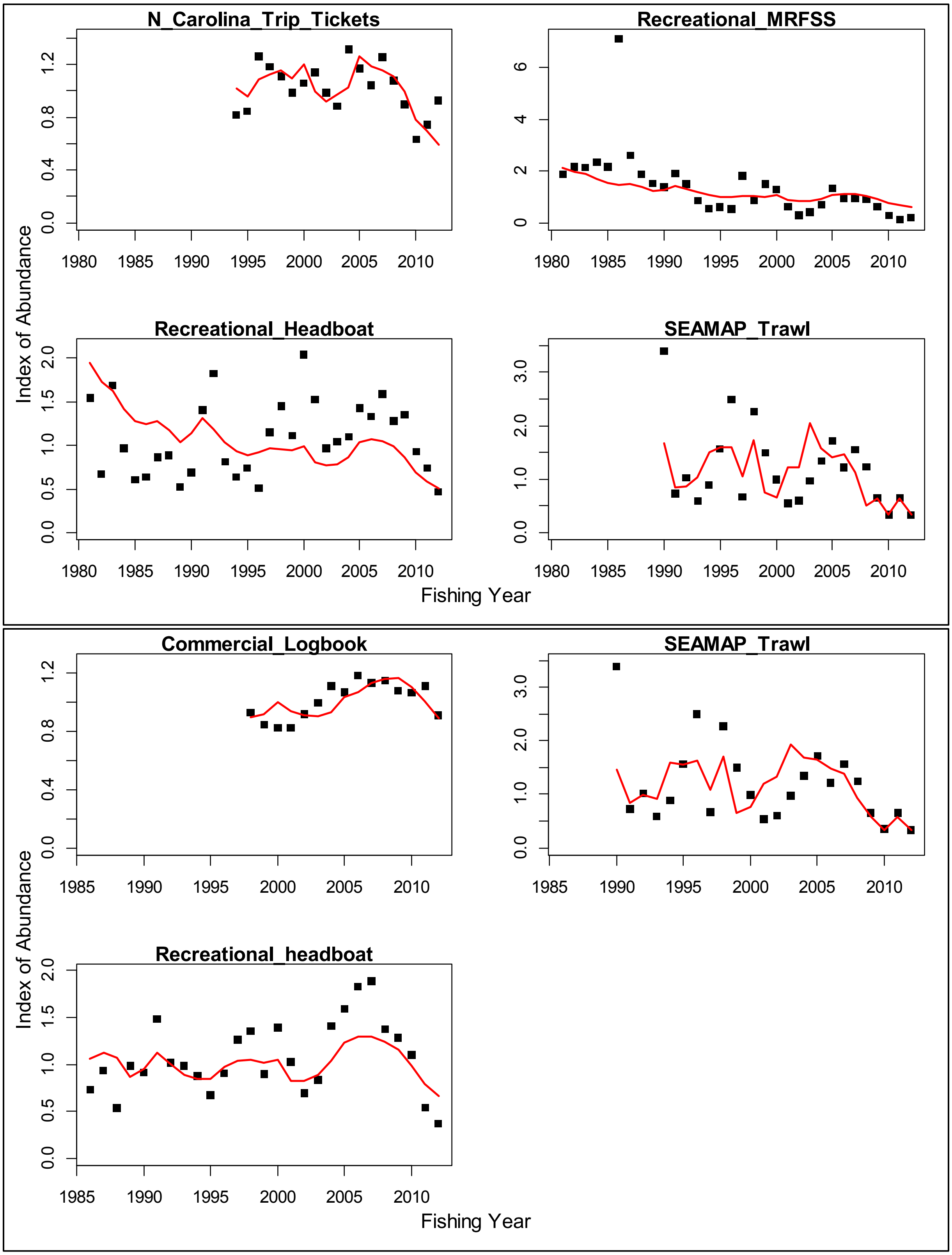
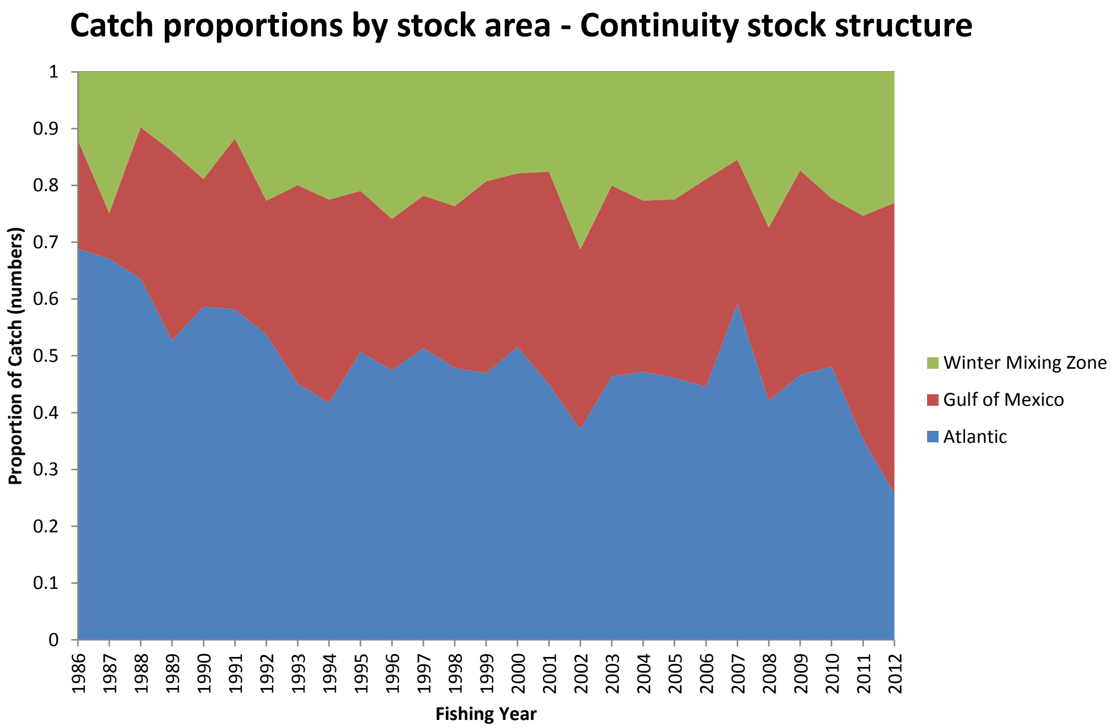


Figure 23. Model fits to indices of abundance of Atlantic King Mackerel for the continuity VPA (upper set of figures) and base VPA (lower set of figures).



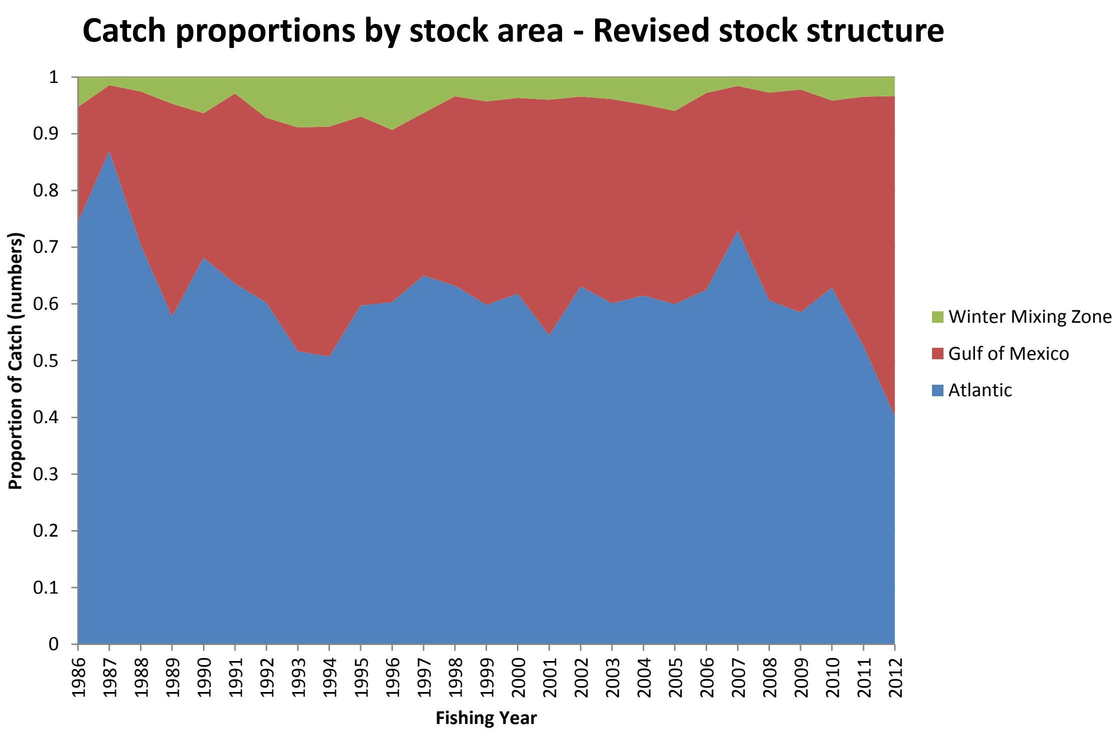


Figure 24. Estimated catch proportions by stock under the continuity (upper figure) and revised (lower figure) stock structure assumptions.

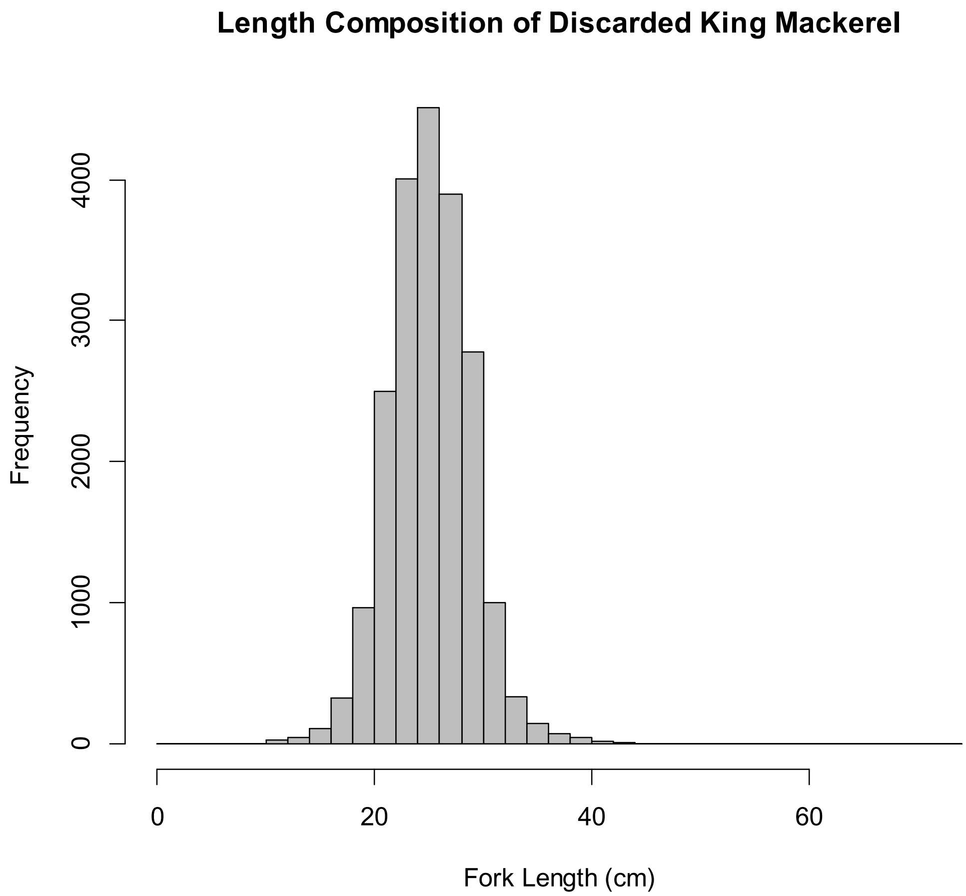


Figure 25. Size frequency distribution of King Mackerel discarded on observer reported recreational trips in Florida. Data provided by the Florida Fish and Wildlife Conservation Commission (unpublished) at the SEDAR 38 Assessment Workshop.

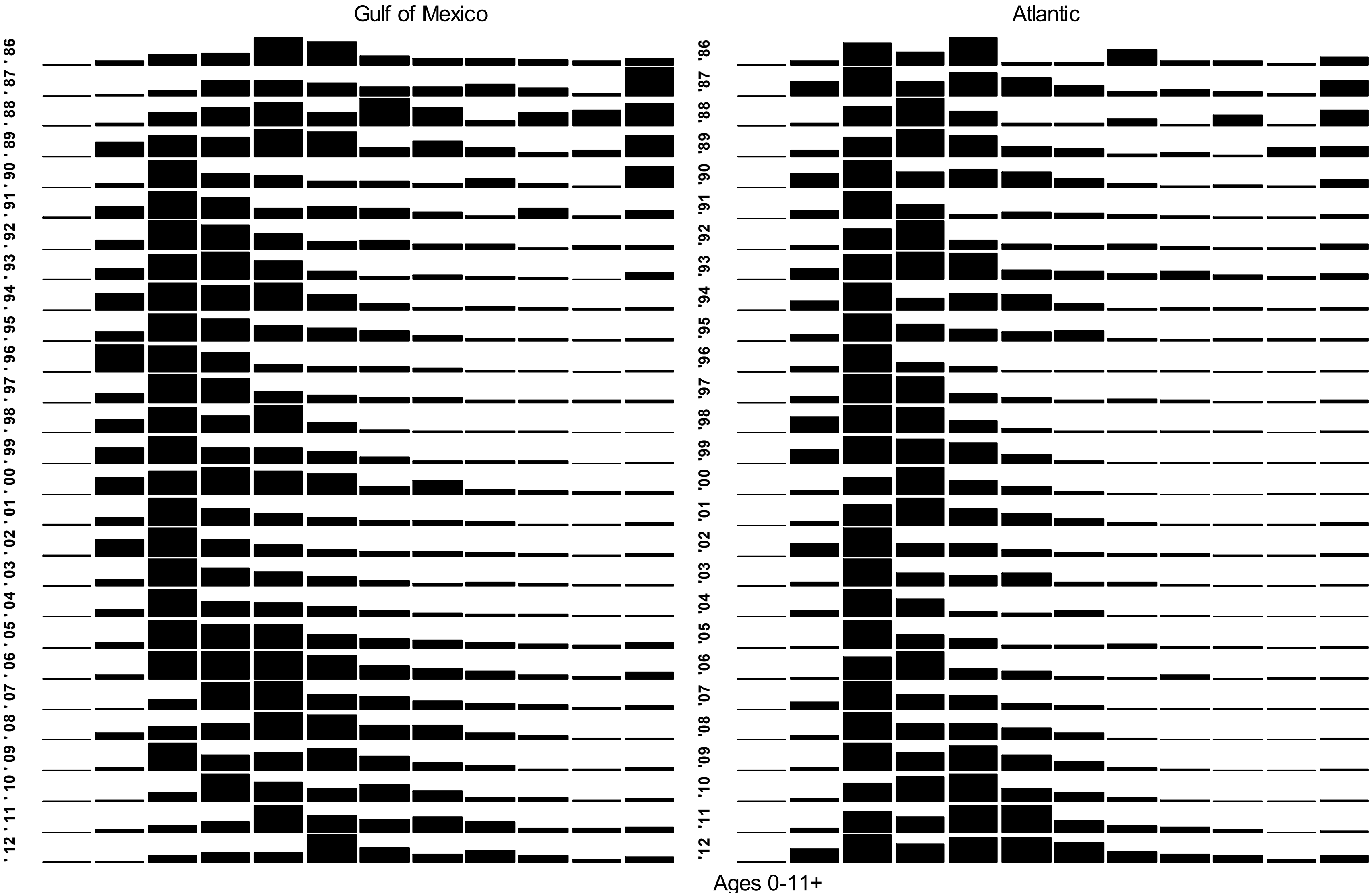


Figure 26. Age-frequency distributions of Gulf of Mexico and Atlantic King Mackerel in the commercial handline fishery under the revised stock structure assumptions. Note that the sample sizes in the redefined mixing zone were minimal and distributions are not shown.

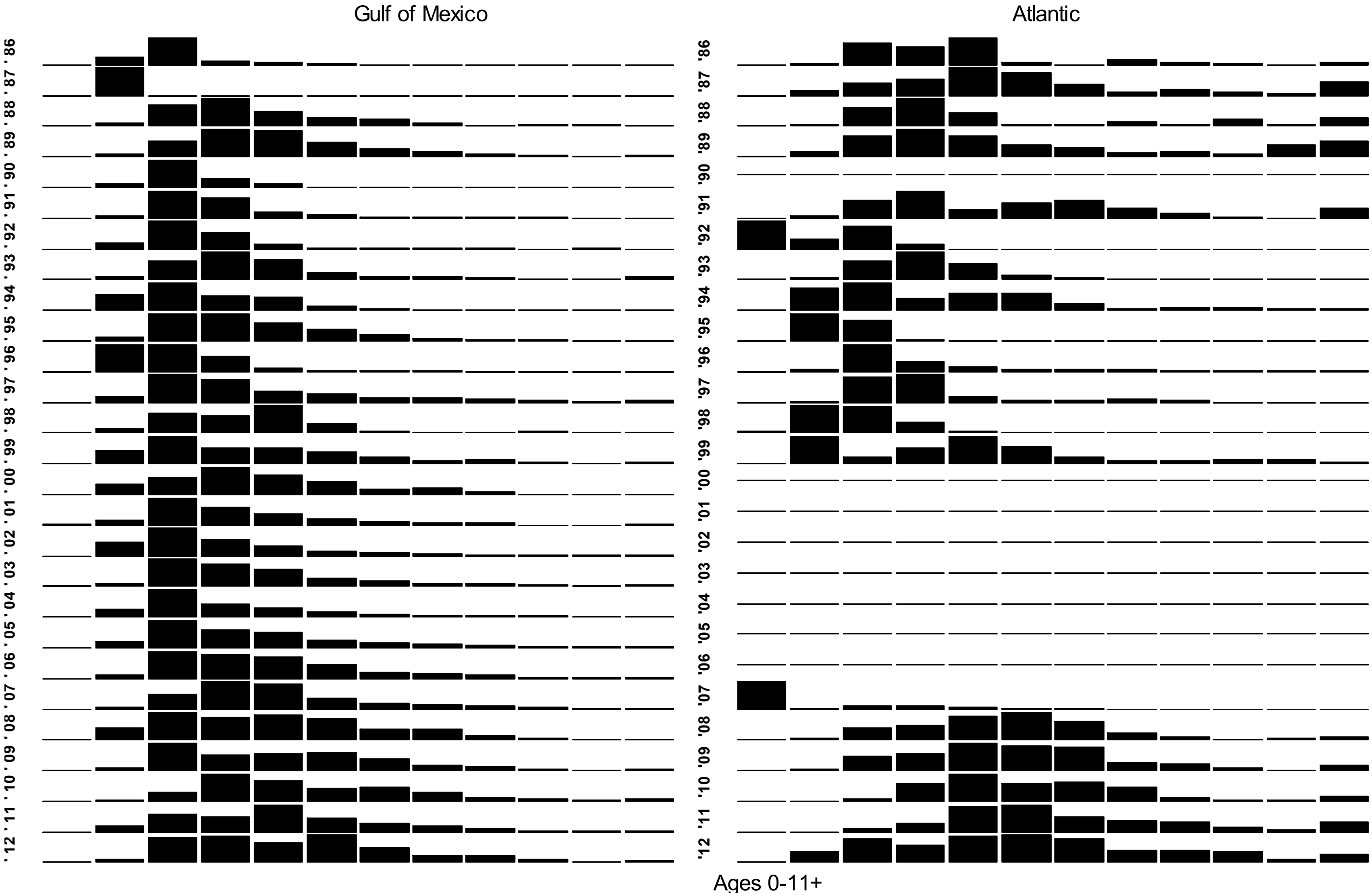


Figure 27. Age-frequency distributions of Gulf of Mexico and Atlantic King Mackerel in the commercial gillnet fishery under the revised stock structure assumptions. Note that the sample sizes in the redefined mixing zone were minimal and distributions are not shown.

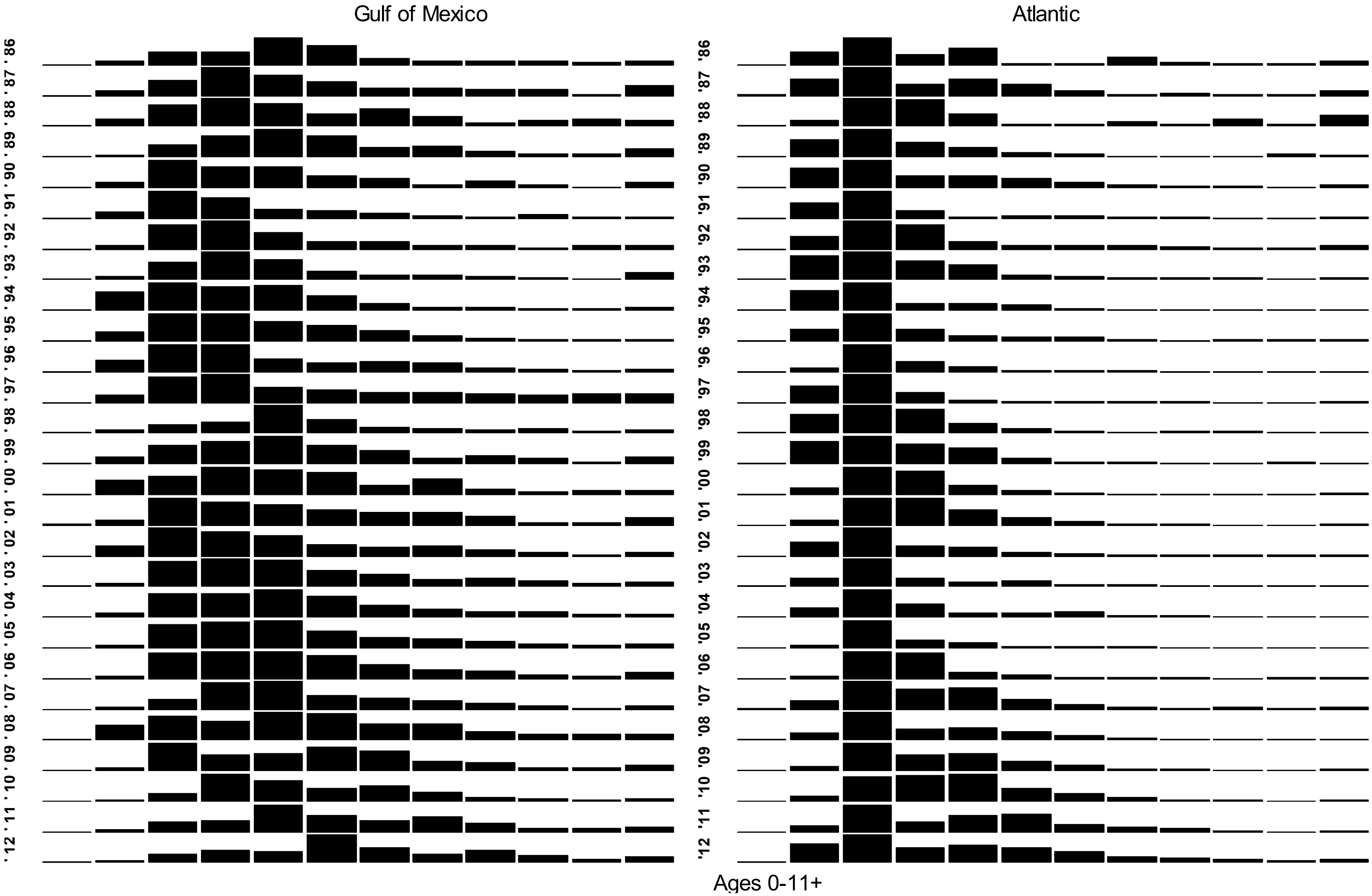


Figure 28. Age-frequency distributions of Gulf of Mexico and Atlantic King Mackerel in the recreational headboat fishery under the revised stock structure assumptions. Note that the sample sizes in the redefined mixing zone were minimal and distributions are not shown.

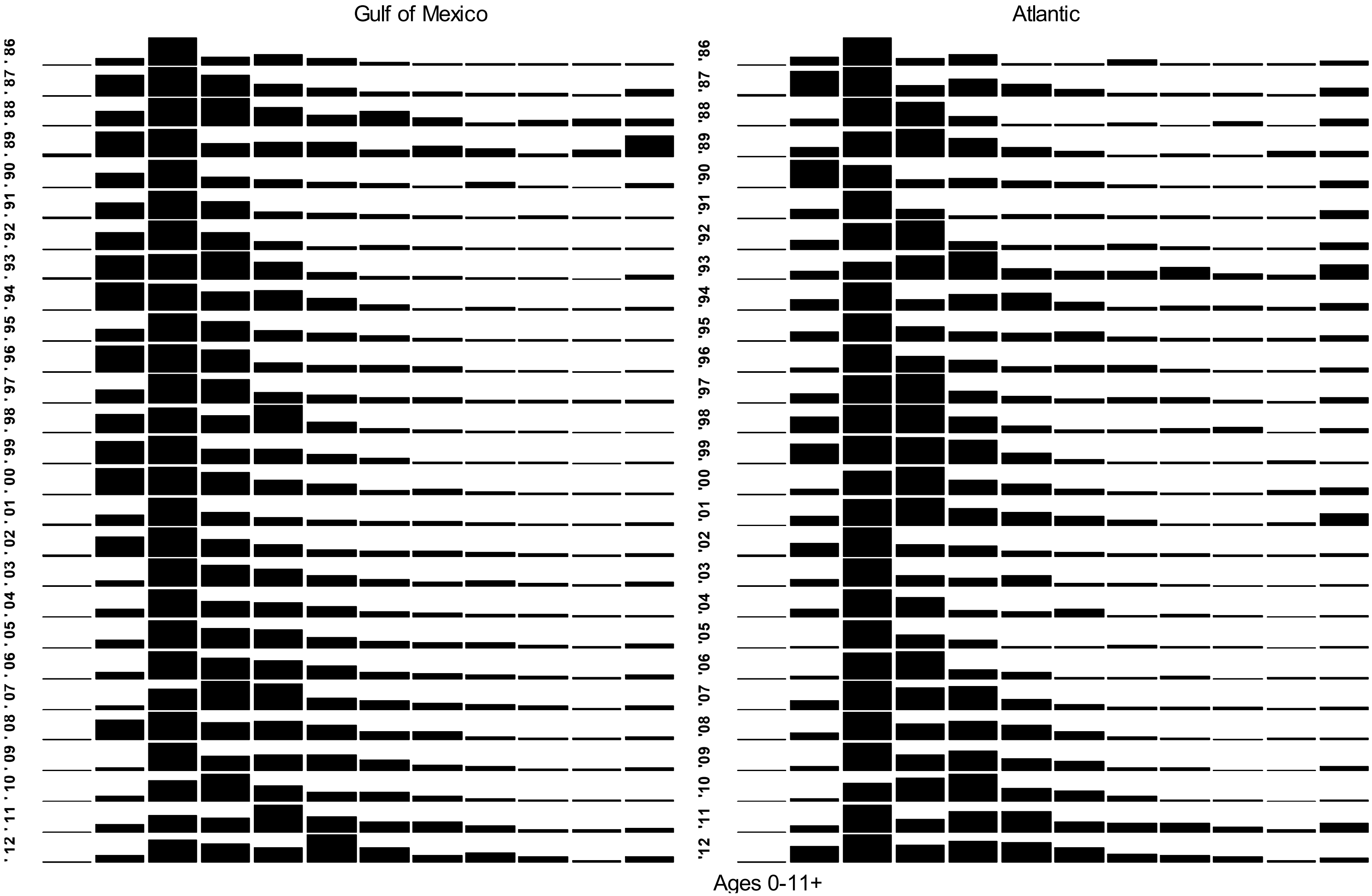


Figure 29. Age-frequency distributions of Gulf of Mexico and Atlantic King Mackerel in the recreational charter boat fishery under the revised stock structure assumptions. Note that the sample sizes in the redefined mixing zone were minimal and distributions are not shown.

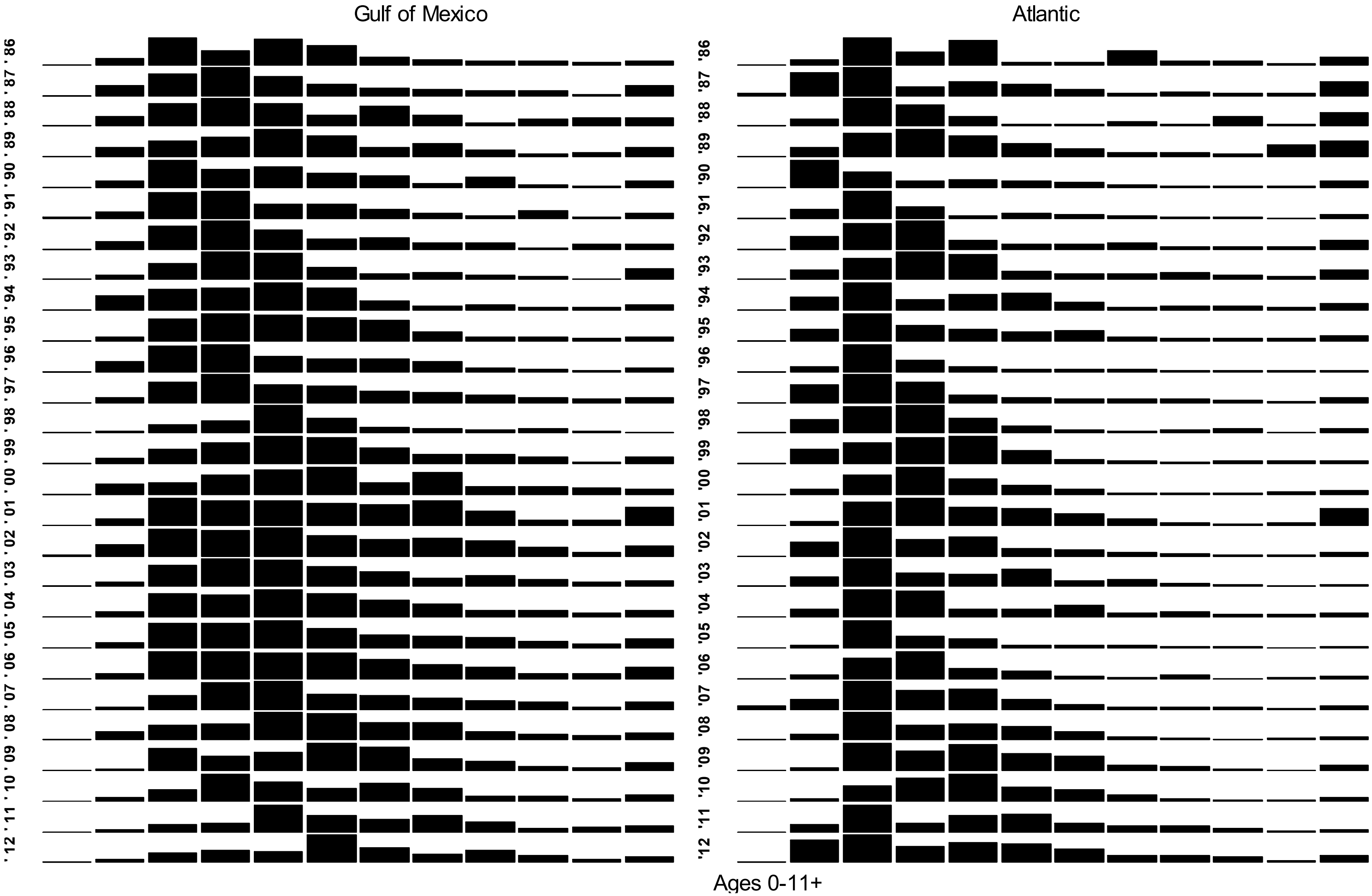


Figure 30. Age-frequency distributions of Gulf of Mexico and Atlantic King Mackerel in the recreational private boat fishery under the revised stock structure assumptions. Note that the sample sizes in the redefined mixing zone were minimal and distributions are not shown.

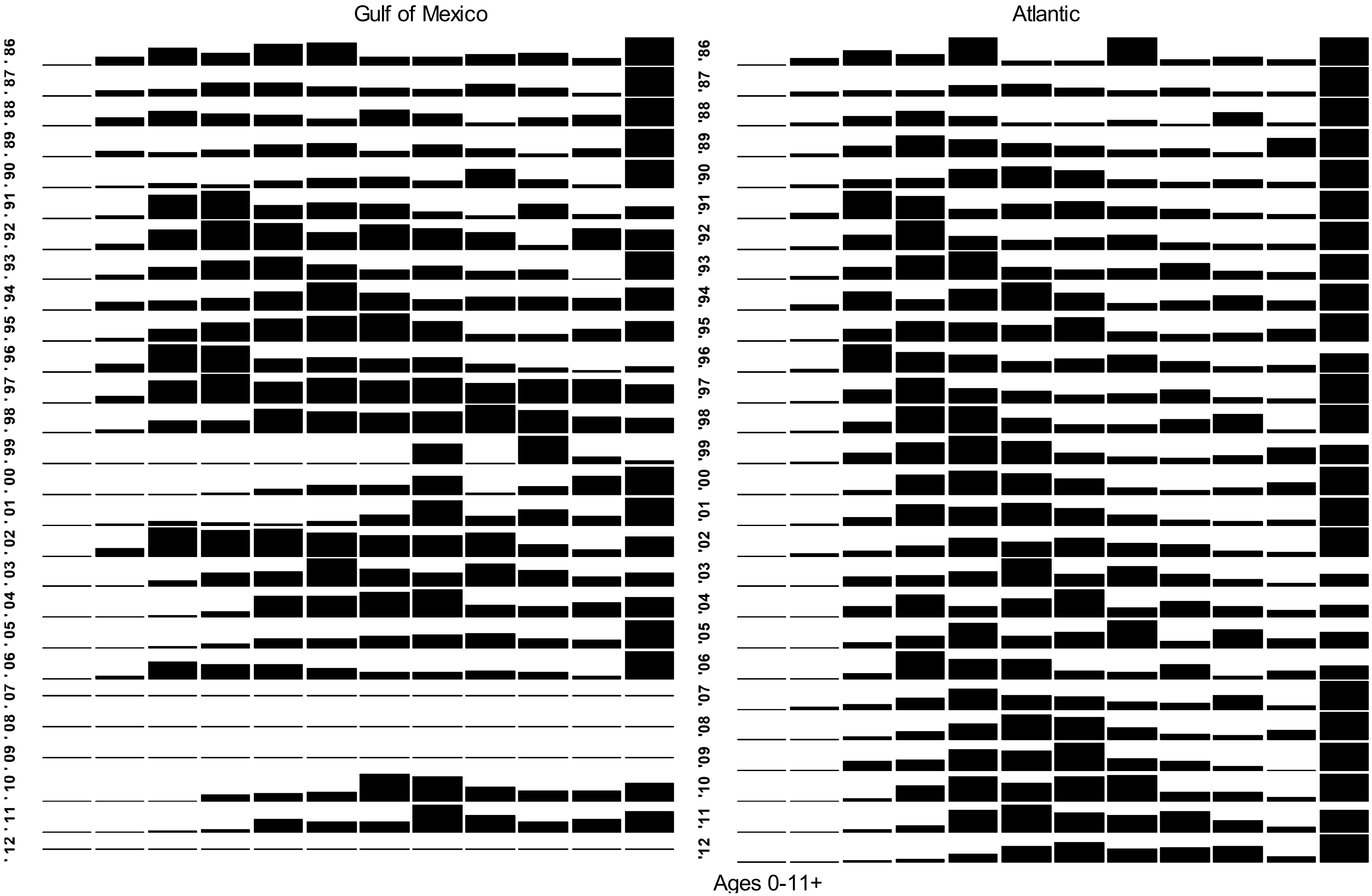


Figure 31. Age-frequency distributions of Gulf of Mexico and Atlantic King Mackerel in the recreational tournament fishery under the revised stock structure assumptions. Note that the sample sizes in the redefined mixing zone were minimal and distributions are not shown.

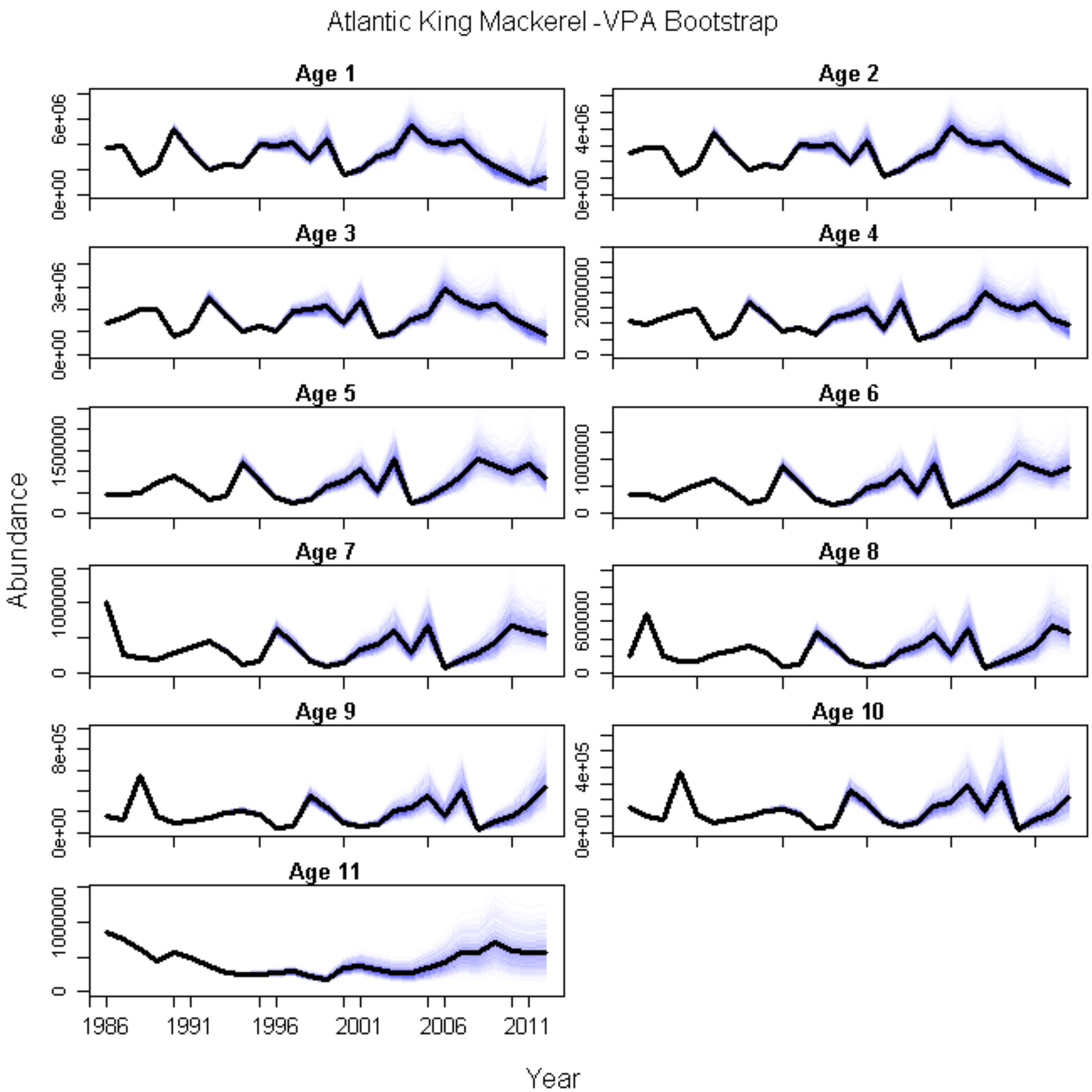


Figure 32. Parametric bootstrap analysis of the Base VPA for Atlantic King Mackerel. The estimates of abundance-at-age are shown for 500 bootstrap iterations, and the density of estimates is represented in blue shading.

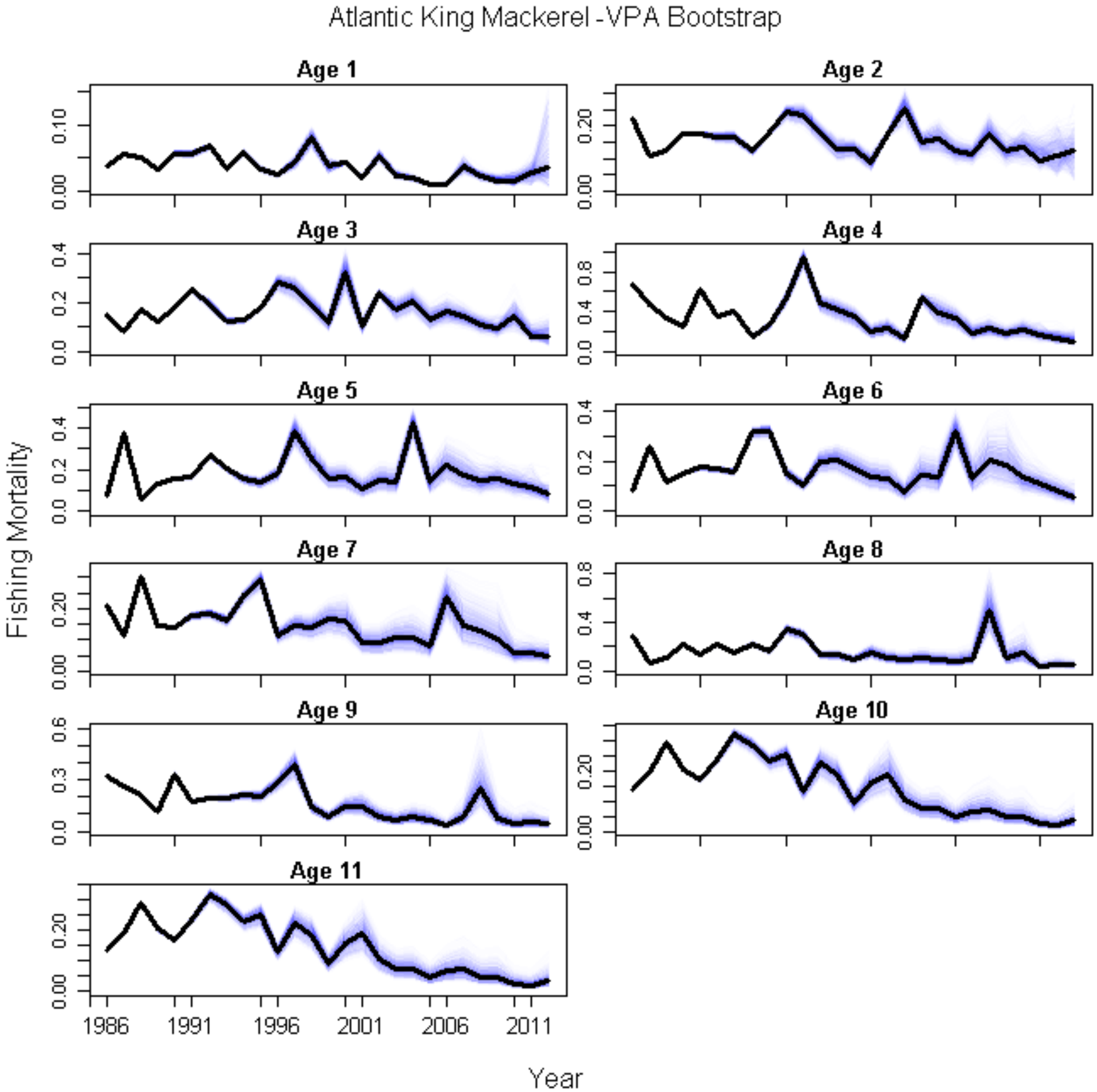


Figure 33. Parametric bootstrap analysis of the Base VPA for Atlantic King Mackerel. The estimates of fishing mortality-at-age are shown for 500 bootstrap iterations, and the density of estimates is represented in blue shading.

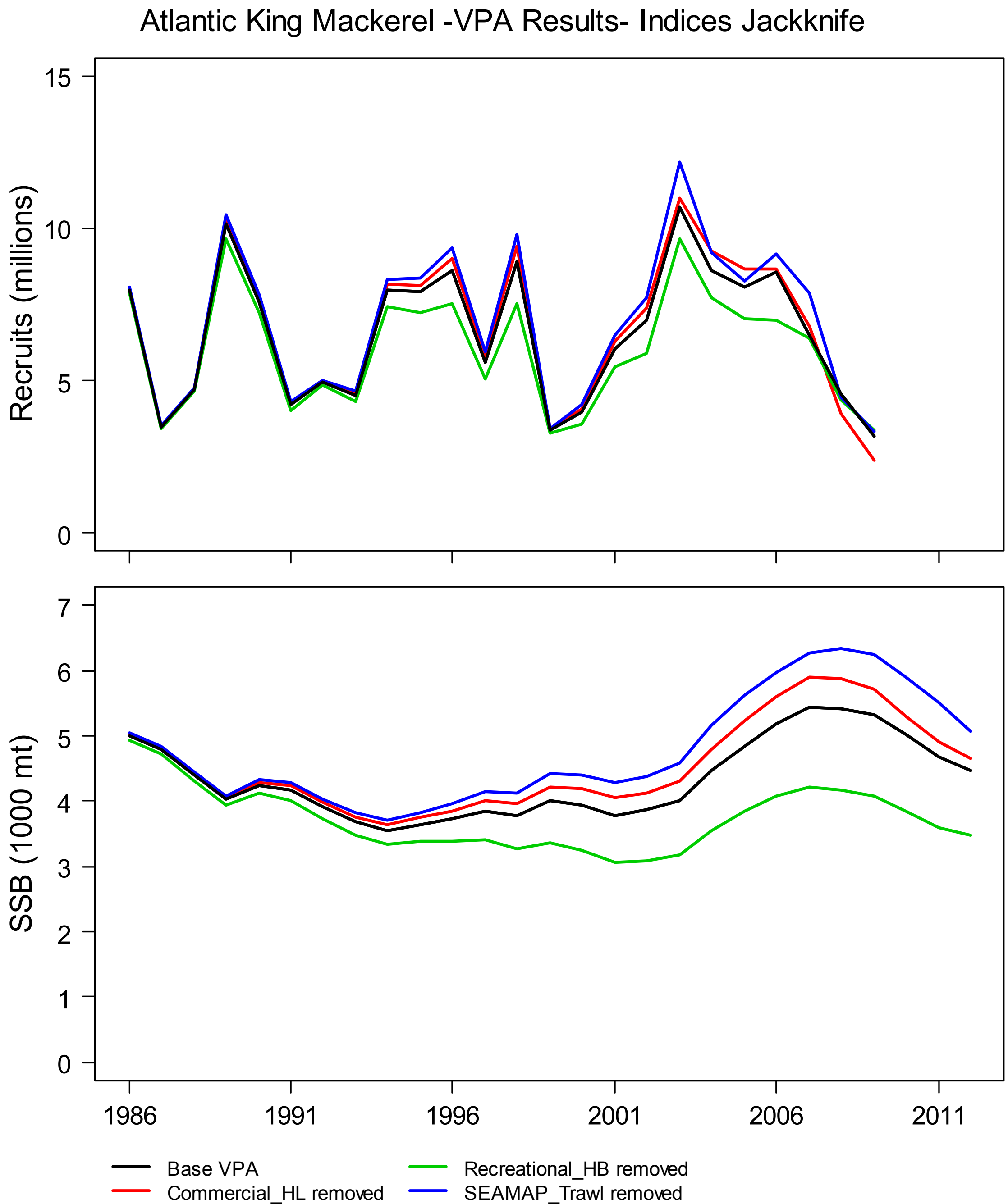


Figure 34. Indices jackknife sensitivity showing the effects of removing each index from the Base VPA on estimates of recruitment and spawning stock biomass (SSB).

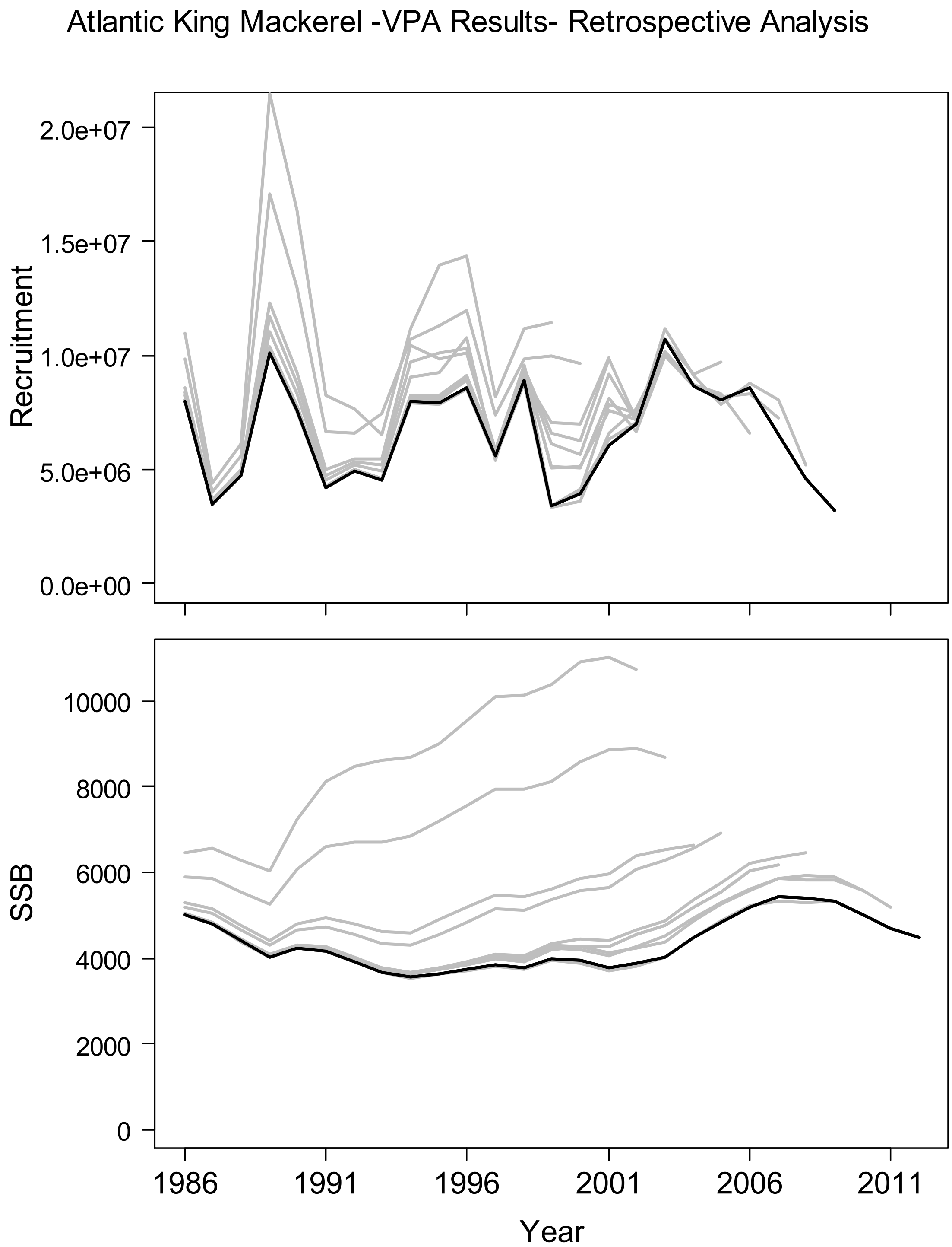


Figure 35. Retrospective analysis sensitivity demonstrating the effect of sequentially removing up to 10 years of data on estimates of recruitment and spawning stock biomass (SSB) from the Base VPA.

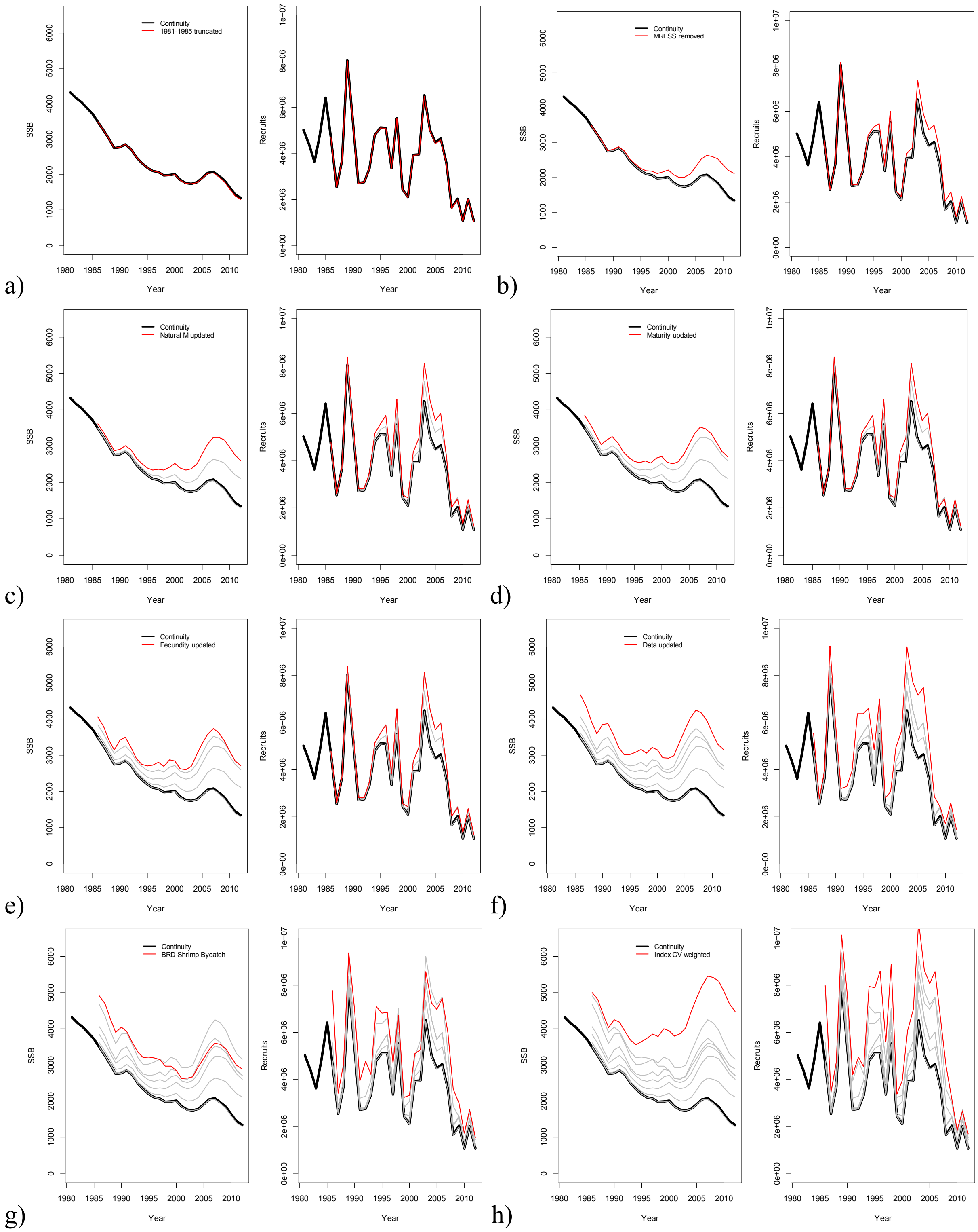


Figure 36. Effects on spawning stock biomass and recruitment shown for iterative revisions to the continuity VPA. Shown are (a) truncation of the early time period 1981 to 1985, (b) removal of the recreational MRFSS index, (c) revised natural mortality, (d) revised maturity, (e) revised fecundity, (f) changes to data resulting from stock distributions, discard, and estimation assumptions, and (g) changes to shrimp bycatch estimates, and (h) indices weighting by coefficient of variation.