Stock Assessment of Vermilion Snapper off the Southeastern United States

SEDAR Update Assessment

Southeast Fisheries Science Center

National Marine Fisheries Service

Report issued: October 2012

Last revision: November 1, 2012

Document History

October, 2012 Original release.

November 1, 2012 Appendix C added. Appendix C tabulates $P^{\star}$=0.4 projections, as requested by the SSC during their October 2012 review of this assessment.

Contents

List of Tables

List of Figures

1 Executive Summary

This update assessment evaluated the stock of vermilion snapper *Rhomboplites aurorubens* off the southeastern United States[1]. The primary objectives of this assessment were to update the 2008 SEDAR-17 benchmark assessment of vermilion snapper and to conduct fresh stock projections. Data compilation and assessment methods were guided by methods used in SEDAR-17. The benchmark assessment included data through 2007, updated here through 2011. This assessment was conducted by the Southeast Fisheries Science Center in cooperation with regional data providers.

Available data on this stock included indices of abundance, landings, discards, and samples of annual length and age compositions from fishery dependent and fishery independent sources. Five indices of abundance were fitted by the model: one from the NMFS headboat survey, one from general recreational data, one from commercial logbooks (handline), and two fishery-independent indices from MARMAP data. Landings and discards data were available from recreational and commercial fleets.

The primary model used in SEDAR-17—and updated here—was the Beaufort Assessment Model (BAM), a statistical catch-age formulation. A base run of BAM was configured to provide estimates of key management quantities, such as stock and fishery status. Uncertainty in estimates from the base run was evaluated through a mixed Monte Carlo/Bootstrap (MCB) procedure.

Results suggest that spawning stock has generally declined throughout the full assessment period (1946–2011). The terminal (2011) estimate of spawning stock is the lowest value of the time series, slightly below $\mathrm{SSB}_{\mathrm{MSY}}$ ($\mathrm{SSB}_{2011}/\mathrm{SSB}_{\mathrm{MSY}}$ =0.98), but still above MSST (SSB_{2011}/MSST =1.26), using the Council's definition of MSST as $(1-M)\mathrm{SSB}_{\mathrm{MSY}}$. The estimated fishing rate has exceeded the MFMT (represented by F_{MSY}) only rarely, and never since 1992. The terminal estimate is below F_{MSY} ($F_{2009-2011}/F_{\mathrm{MSY}} = 0.67$). Thus, this assessment indicates that the stock is not overfished, nor is it experiencing overfishing.

These status indicators may be in qualitative agreement with management goals, but should be interpreted with two notes of caution. First, the MCB analysis indicated much uncertainty in these estimates of stock and fishery status. Second, estimated trends of decreasing biomass and (slowly) increasing F go in the wrong direction for the status indicators to hold indefinitely.

The estimated trends of this update assessment are quite similar to those from the SEDAR-17 benchmark. However, the two assessments did show some differences in results, which was not surprising, given several modifications made to both the data and model (described throughout the report). Of those modifications, an updated value of steepness was the primary driver of any differences in results. In SEDAR-17, steepness was not considered estimable, and it was fixed at $h = 0.56$. Modifications in this update allowed estimation of steepness, and in the base run, its value was $\hat{h} = 0.71$. Compared to SEDAR-17, this assessment suggests higher values of SSB/$\mathrm{SSB}_{\mathrm{MSY}}$ and lower values of F/F_{MSY}.

[1] Abbreviations and acronyms used in this report are defined in Appendix A

2 Data Review and Update

In the SEDAR-17 benchmark assessment, the assessment period was 1946–2007. In this update, the terminal year was extended to 2011. For most data sources, the data were simply updated with the additional four years, using the same methods as in the benchmark assessment (SEDAR 2008). However, for some sources, it was necessary to update data prior to 2007 as well. The input data for this assessment are described below, with focus on the data that required modification beyond just the addition of years.

2.1 Data Review

In this update assessment, the Beaufort assessment model (BAM) was fitted to the same data sources as in SEDAR-17.

- Landings: Commercial handline; Commercial historic trawl, Commercial combined gears, Headboat, General recreational
- Discards: Commercial handline, Headboat, General recreational
- Indices of abundance: MARMAP Florida snapper trap, MARMAP chevron trap, Commercial handline, Headboat, General recreational
- Length compositions of surveys or landings: MARMAP Florida snapper trap, Commercial handline, Commercial combined gears, Headboat, General recreational
- Length compositions of discards: Commercial handline, Headboat
- Age compositions of surveys or landings: MARMAP chevron trap, Commercial handline, Headboat, General recreational

In addition to data fitted by the model, SEDAR-17 utilized life-history information that was treated as input. Such inputs remained the same for this assessment, including natural mortality, fecundity at age, female maturity at age, sex ratio (71.5% female), and somatic growth. Discard mortality rates were also unchanged for this assessment.

2.2 Data Update

In several cases, SEDAR-17 data did not require updating. For example, landings from commercial historic trawl (1961–1962) were unchanged. MARMAP Florida trap snapper data (1983–1987) were also unchanged.

In most cases, data were updated simply by adding the four additional years (2008–2011) at the end of the time series. The exceptions are described below in more detail.

The landings and discards from the general recreational fleet were estimated in SEDAR-17 using MRFSS. Here, estimates from MRIP were available for 2004–2011. Thus, for this assessment, estimates from MRIP were used for 2004–2011, replacing the previous MRFSS estimates for 2004–2007.

All of the indices of abundance with data through the terminal year (2011) were re-evaluated. Methods of computation were the same as in SEDAR-17, but with updated data. Because annual values of these indices are model-based (e.g., from delta-GLMs), years prior to 2007 were updated as well as any additional years. The index from the general recreational fleet used MRFSS data for 1987–2003, and MRIP data starting in 2004.

The fishery dependent indices were also evaluated in light of new management measures effected since the last assessment. In July of 2009, the recreational season was closed November 1 through March 31, and the recreational bag limit per angler was changed from ten fish to five fish. In SEDAR-17, the ten-fish bag limit was shown to be met infrequently and to have little influence on the indices of abundance. However, since implementation, the current five-fish bag limit was met in approximately 18% of angler-trips in both the headboat and general recreational fleets. This upper bound on the catch clearly affects catch per effort, and it likely invalidates catch per effort as a meaningful index of abundance. Thus, the headboat and recreational indices of abundance were modeled only through 2008. Similarly, the commercial fishery has become subject to new regulations. In July of 2009, split-season ACLs were implemented and have since led to fishery closures twice per year. In addition, a commercial trip limit of 1500 lb gutted weighted was implemented in July of 2011. These new regulations make CPUE a questionable measure of relative abundance, and thus the commercial handline index of abundance was modeled only through 2008. The fishery independent data from MARMAP are not subject to fishery regulations; therefore the MARMAP chevron trap index extends to the terminal year of 2011.

Data available for this update assessment are summarized in Tables 1–4.

3 Stock Assessment Methods

This assessment updates the primary model applied during SEDAR-17 to South Atlantic vermilion snapper. The methods are reviewed below, and any changes since SEDAR-17 are flagged.

3.1 Overview

The primary model in this assessment was the Beaufort assessment model (BAM), which applies a statistical catch-age formulation. The model was implemented with the AD Model Builder software (Fournier et al. 2012). In essence, the model simulates a population forward in time while including fishing processes (Quinn and Deriso 1999; Shertzer et al. 2008*a*). Quantities to be estimated are systematically varied until characteristics of the simulated populations match available data on the real population. Statistical catch-age models share many attributes with ADAPT-style tuned and untuned VPAs.

The method of forward projection has a long history in fishery models. It was introduced by Pella and Tomlinson (1969) for fitting production models and then, among many applications, used by Fournier and Archibald (1982), by Deriso et al. (1985) in their CAGEAN model, and by Methot (1989; 2009) in his Stock Synthesis model. The catch-age model of this assessment is similar in structure to the CAGEAN and Stock Synthesis models. Versions of this assessment model have been used in previous SEDAR assessments of reef fishes in the U.S. South Atlantic, such as red porgy, black sea bass, tilefish, snowy grouper, gag grouper, greater amberjack, Spanish mackerel, red grouper, and red snapper, as well as in previous SEDAR assessments of vermilion snapper (SEDAR 2003; 2008).

3.2 Data Sources

The catch-age model included data from five fleets that caught vermilion snapper in southeastern U.S. waters: recreational headboat, general recreational, commercial historic trawl (1961–1962), commercial hook-and-line (handline), and commercial combined (recent trawl, trap, spears, longline, and other miscellaneous gears). The model was fitted to data on annual landings (in whole weight for commercial fleets, in numbers for recreational fleets); annual discard mortalities (in numbers for commercial handline and recreational fleets); annual length compositions of landings, discards, and surveys; annual age compositions of landings and surveys; three fishery dependent indices of abundance (commercial handline, general recreational, and headboat); and two fishery independent indices of abundance. Data used in the model are tabulated in §2 of this report.

The general recreational fleet has been sampled since 1981 by the MRFSS, but for previous years, landings values were obtained by interpolating data reported in saltwater angling surveys (Clark 1962; Deuel and Clark 1968; Deuel 1973), adjusted to account for recall bias (SEDAR 2008). Unlike in SEDAR-17, the more recent (2004–2011) general recreational estimates are from MRIP. Starting with the headboat survey in 1972, headboat landings were separated from the general recreational fleet.

Data on annual discard mortalities, as fitted by the model, were computed by multiplying total discards (tabulated in §2) by the fleet-specific release mortality rates of 0.41 in the commercial sector and 0.38 in the recreational (SEDAR 2008).

3.3 Model Configuration and Equations

Model structure and equations of the BAM are detailed in Table 3.1 of the SEDAR-17 report (SEDAR 2008). The assessment time period was 1946–2011. A general description of the assessment model follows.

Stock dynamics In the assessment model, new biomass was acquired through growth and recruitment, while abundance of existing cohorts experienced exponential decay from fishing and natural mortality. The population was assumed closed to immigration and emigration. The model included age classes $1 - 12^+$, where the oldest age class 12^+ allowed for the accumulation of fish (i.e., plus group).

Initialization The initial stock (in 1946) was assumed to be at the unfished (virgin) biomass and age structure.

Natural mortality rate The natural mortality rate (M) was assumed constant over time, but decreasing with age. The form of M as a function of age was based on Lorenzen (1996). The Lorenzen (1996) approach inversely relates the natural mortality at age to mean weight at age W_a by the power function $\mathrm{M}_a = \alpha W_a^\beta$, where α is a scale parameter and β is a shape parameter. Lorenzen (1996) provided point estimates of $\hat{\alpha} = 3.69$ and $\hat{\beta} = -0.305$ for oceanic fishes, which were used for this assessment. As in previous SEDAR assessments, the Lorenzen estimates of M_a were rescaled to provide the same fraction of fish surviving from age 1 through the oldest observed age (19 yr) as would occur with constant $M = 0.22$ from the DW. This approach using cumulative mortality allows that fraction at the oldest age to be consistent with the findings of Hoenig (1983) and Hewitt and Hoenig (2005).

Growth Mean total length (TL, in units of mm) at age of the population was modeled with the von Bertalanffy equation, and weight at age (whole weight, WW) and fork length (FL) were modeled as functions of total length (Table 1, Figure 1). Parameters of growth and conversions (TL-WW, TL-FL) were estimated by the SEDAR-17 DW and were treated as input to the assessment model. The von Bertalanffy parameter estimates from the DW were $L_\infty = 506$, $K = 0.12$, and $t_0 = -3.5$. For fitting length composition data, the distribution of size at age was assumed normal with CV estimated by the assessment model ($\widehat{\mathrm{CV}} = 22.25\%$). For fishery length composition data collected under a size limit regulation, the normal distribution of size at age was truncated at the size limit, such that predicted length compositions of landings included only fish of legal size. Similarly, predicted length compositions of discards included only fish below the size limit, except for those of commercial discards in 2009–2011, which also included legal-size fish discarded during closed seasons (see Selectivities description below). Mean length at age of landings and discards were computed from these truncated distributions, and thus average weight at age of landings and discards may differ from that in the population at large.

Female maturity and fecundity Maturity at age of females was modeled as 80% at age 1 and 100% at ages 2^+. For spawning females, annual egg production was computed as eggs spawned per batch, a function of fork length, multiplied by the number of batches per year (31). Maturity and fecundity parameters were provided by the SEDAR-17 DW and treated as input to the assessment model.

Spawning stock Spawning biomass was modeled as the population egg production, assuming a sex ratio of 71.5% female, as estimated by the DW. Spawning biomass was computed each year from number at age when spawning peaks. For vermilion snapper, peak spawning was considered to occur at the midpoint of the year.

Recruitment Expected recruitment of age-1 fish was predicted from spawning stock (population egg production) using the Beverton–Holt spawner-recruit model. Annual variation in recruitment was assumed to occur with lognormal deviations starting in 1976, when composition data could provide information on year-class strength. In years prior, recruitment followed the Beverton–Holt model precisely, similar to an age-structured production model.

For modeling recruitment, this update assessment implemented two changes to the SEDAR-17 model. In the previous assessment, a parameter for autocorrelation of recruitment residuals was estimated to be 1.33E-07, effectively zero. That estimate was upheld in exploratory model runs with the updated data. Thus in this assessment, annual recruitment deviations were treated as independent events (i.e., autocorrelation fixed at 0.0). In addition, the previous assessment was unable to estimate the steepness parameter of the spawner-recruit model. Instead, that assessment fixed steepness at $h = 0.56$, a value chosen to provide consistency between F_{MSY} and the metric that was expected to be its proxy, $F_{40\%}$. In this assessment, steepness appeared to be estimable, and thus h was freely estimated rather than fixed. Estimation of h was facilitated more by modifications to the model than by additional data. A sensitivity run considered the SEDAR-17 value of steepness, $h = 0.56$.

Landings Time series of landing from five fleets were modeled: commercial handline (1958–2011), commercial historic trawl (1961–1962), commercial combined (1971-2011), headboat (1947-2011), and general recreational (1947–2011). Landings were modeled with the Baranov catch equation (Baranov 1918) and were fitted in either weight or numbers, depending on how the data were collected (1000 lb whole weight for commercial fleets, and 1000 fish for recreational).

Discards Commercial handline discard mortalities were modeled starting in 1992 with the implementation of the 12-inch size-limit regulation. Headboat and general recreational discard mortalities were modeled for the entire time series (1946–2007), because MRFSS data indicated that recreational discards occurred prior to when size limits were implemented (1992). As with landings, discard mortalities (in units of 1000 fish) were modeled with the Baranov catch equation (Baranov 1918), which required estimates of discard selectivities (described below) and release mortality rates. In the base model, headboat and recreational release mortality rates were 0.38, and commercial release mortality rates were 0.41, slightly higher to account for some fish reported as discards but actually used as bait (SEDAR 2008).

Fishing For each time series of landings and discard mortalities, the assessment model estimated a separate full fishing mortality rate (F). Age-specific rates were then computed as the product of full F and selectivity at age. In SEDAR-17, the across-fleet annual F was represented by the sum of fleet-specific full Fs. In this assessment, the across-fleet annual F was represented by apical F, computed as the maximum of F at age summed across fleets. The two approaches may differ under the presence of dome-shaped selectivities that peak at different ages. The change in approach here was adopted in response to comments made by the SEDAR-17 review panel, and has been used in SEDAR assessments since.

Selectivities In most cases, selectivities were estimated using a two-parameter logistic model. This parametric approach reduces the number of estimated parameters and imposes theoretical structure on the estimates. Critical to estimating selectivity parameters are age and size composition data.

Selectivity of each fishery was fixed within each period of size-limit regulations, but was permitted to vary among periods. Commercial fisheries experienced two periods of size-limit regulations (no limit prior to 1992, 12-inch limit during 1992–2011), and recreational fisheries experienced four periods (no limit prior to 1992, 10-inch limit during 1992–1998, 11-inch limit during 1999–2006, and 12-inch limit during 2007–2011). Ideally, a model would have sufficient age composition data from each fishery over time to estimate selectivities in each period of regulations. That was not the case here, and thus additional assumptions were applied to define selectivities, as follows. Because the MRFSS collected little age or length composition data on vermilion snapper until recently, headboat and general recreational fisheries were assumed to have the same selectivities in recreational regulation periods 1 and 2. MARMAP Florida snapper trap was assumed to catch only age-1 fish, because length compositions contained relatively small fish and no age compositions were available. MARMAP chevron trap had age composition data and was estimated to be dome-shaped.

Commercial combined gears only had length composition data from the mid-1980s; because of the small size of these fish, it was assumed that this gear had full selectivity for age-1 fish, 0.5 for age-2 fish, and 0 for age-3^+ fish. SEDAR-17 had assumed that only age-1 fish were caught, but this modification to allow some selectivity of age-2 fish provided nearly the same fit to data and avoided the tendency for spiky behavior in estimated F. The commercial combined length composition data came primarily from trawls, which were banned from South Atlantic federal waters in January of 1989. Starting in 1989, with no composition data to estimate selectivity of commercial combined gears, this selectivity was assumed to be the same as that of commercial handline. In SEDAR-17, the change in selectivity was assumed to occur with the change in size-limit regulations in 1992. Here, the change was assumed to occur in 1989, coinciding with the federal ban of trawl gear from South Atlantic waters (Amendment 1, January, 1989).

Selectivities of discards were partially estimated, assuming that discards consisted primarily of undersized fish, as implied by observed length compositions of discards. The general approach taken for discard selectivities was that the value for age-1 fish was fixed at zero, for age-2 fish was estimated, for age-3 fish was assumed full selection, and for ages-4^+ was fixed at the age-specific probability of being below the size limit given a normal distribution of size at age. Given available data on discards, some additional assumptions were necessary: Headboat and general recreational were assumed to have the same discard selectivities. Selectivity of age-2 fish in recreational period 2 was assumed to be the same as the estimate from period 3, because no length composition data were available before period 3. Recreational discard selectivity in period 1 was assumed to be the same as that during period 2. Starting in 2009, the descending limb of commercial discard selectivity (ages-4^+) was estimated using a negative exponential function, described below. This modification was adopted to account for a shift toward legal-sized fish in the length compositions of commercial discards, presumably resulting from closed periods when split-season quotas were met. Such a shift was not apparent in length compositions of recreational discards, and was therefore not adopted for the recreational discard selectivities.

As described in the SEDAR-17 report, several selectivity parameters were fixed. In this assessment, no selectivity parameters were fixed, but rather normal prior distributions ($CV = 0.2$) were applied during estimation.

In SEDAR-17, dome-shaped selectivity of MARMAP chevron trap gear was estimated using a double logistic model. More recent assessments have found parameters of that model to lack identifiability, likely because it requires re-scaling (to peak at one). Thus in this assessment, dome-shaped selectivity was modeled by 1) estimating free parameters for ages prior to full selection, 2) assuming the age at full selection (a_f), and 3) estimating the descending limb using a negative exponential model:

$$\text{selex}_a = \exp\left(-\left(\frac{(a - a_f)}{\sigma}\right)^2\right) \tag{1}$$

This model was applied to commercial discard selectivity starting in 2009 and to the MARMAP chevron trap selectivity. In both cases, a_f was set equal to age 3. For commercial discards, full selectivity at age 3 was the recommendation of SEDAR-17. For MARMAP chevron trap, the SEDAR-17 model estimated full selectivity to occur at age 3, and in the current model, age 3 was most consistent with MARMAP age composition data (as indicated by likelihood values of model runs using $a_f = 2, 3, \text{or } 4$).

Indices of abundance The model was fitted to two fishery independent indices of abundance (MARMAP Florida snapper trap 1983–1987; chevron trap 1990–2011) and to three fishery dependent indices of abundance (headboat 1976–2008; MRFSS 1987–2008; and commercial handline 1993–2008). A sensitivity run modeled fishery dependent indices through 2011. Predicted indices were computed from numbers at age at the midpoint of the year or, in the case of commercial handline, weight at age.

Catchability In the BAM, catchability scales indices of relative abundance to the estimated population at large. As in SEDAR-17, catchability coefficients of fishery independent indices were assumed constant, and those of fishery dependent indices were assumed to increase linearly with a slope of 2% per year, to account for technological improvements in fishing efficiency. This trend reflects the belief that catchability has generally increased over time as a result of improved technology (SEDAR Procedural Guidance 2009) and as estimated for reef fishes in the Gulf of Mexico (Thorson and Berkson 2010).

A sensitivity run adopted a slightly different form of increasing catchability for fishery dependent indices. In this formulation, catchability was assumed to increase linearly with a slope of 2%, but was constant after 2003. Choice of the year 2003 was based on recommendations from fishermen at the SEDAR-19 DW regarding when the effects of Global Positioning Systems might have saturated in the southeast U.S. Atlantic (SEDAR 2009).

Biological reference points Biological reference points (benchmarks) were calculated based on maximum sustainable yield (MSY) estimates from the Beverton–Holt spawner-recruit model with bias correction (expected values in arithmetic space). Computed benchmarks included MSY, fishing mortality rate at MSY (F_{MSY}), and spawning stock at MSY ($\mathrm{SSB}_{\mathrm{MSY}}$). In this assessment, spawning stock measures population fecundity of mature females. These benchmarks are conditional on the estimated selectivity functions and the relative contributions of each fleet's fishing mortality. The selectivity pattern used here was the effort-weighted selectivities at age, with effort from each fishery (including discard mortalities) estimated as the full F averaged over the last three years of the assessment.

Fitting criterion The fitting criterion was a likelihood approach in which observed landings and discards were fit closely, and observed composition data and abundance indices were fit to the degree that they were compatible. Landings, discards, and index data were fit using lognormal likelihoods. Length and age composition data were fit using multinomial likelihoods, and only from years that met a minimum sample size criterion ($n \geq 400$ for length compositions of landings, $n \geq 170$ for length compositions of discards, $n \geq 45$ for age compositions).

SEDAR-17 also included a least-squares penalty term for log deviations of annual recruitment, permitting estimation of the Beverton–Holt spawner-recruit parameters internal to the assessment model. This assessment did not apply a least-squares penalty, but instead applied the lognormal likelihood:

$$\Lambda_6 = n \log(\widehat{\sigma}_R) + \sum_{y \geq 1976} \frac{[(R_y + (\widehat{\sigma}_R^2/2)]^2}{2\widehat{\sigma}_R^2} \tag{2}$$

where Λ_6 is the spawner-recruit likelihood component, R_y are annual recruitment deviations in log space, n is the number of years of recruitment deviations (here starting in 1976), and $\widehat{\sigma}_R$ is the estimated standard deviation. As in SEDAR-17, the total likelihood included a least-squares penalty term to discourage large deviation from zero in recruitment residuals during the last three assessment years.

The influence of each dataset on the overall model fit was determined by the specification of the error terms in each likelihood component. In the case of lognormal likelihoods, error was quantified by the inverse of the annual coefficient of variation, and for the multinomial components, by the annual sample sizes (Table 4). These terms determine the influence of each year of data relative to other years of the same data source. However, in SEDAR-17 the relative influence of different datasets and penalty terms was also influenced by external weights (ω_i) chosen by the AW. In this assessment, those external weights were reduced by a factor of 10, with the exception of the spawner-recruit lognormal likelihood, which had no external weight. The intent of this modification was to allow estimation of steepness, while maintaining the same relative influence of datasets that was specified by the AW. Here, the external weights were $\omega_1 = 0.001$ for length compositions, $\omega_2 = 0.1$ for age compositions, $\omega_3 = \omega_4 = 100$ for landings and discards, respectively, $\omega_5 = 10$ for indices, and $\omega_7 = 100$ for the penalty on the last three years of recruitment deviations. A sensitivity run applied the data component weights of SEDAR-17, along with the assumed value of steepness ($h = 0.56$).

For parameters defining selectivities, CV of size at age, and σ_R, normal priors were applied to maintain parameter estimates near reasonable values, and to prevent the optimization routine from drifting into parameter space with negligible gradient in the likelihood. For σ_R, the prior mean (0.6) and standard deviation (0.15) were based on Beddington and Cooke (1983) and Mertz and Myers (1996). No prior distribution was applied for the estimation of steepness.

Configuration of base run The base run was configured as described above. This configuration does not necessarily represent reality better than all other possible configurations, and thus this assessment attempted to portray uncertainty in point estimates through sensitivity analyses and through a Monte-Carlo/bootstrap approach (described below).

Sensitivity analyses SEDAR-17 included many sensitivity runs, and not all of them were repeated here. Instead, sensitivity runs were chosen to investigate issues that arose specifically with this update. They were not intended to be an extensive evaluation of model inputs and assumptions. These model runs vary from the base run as follows.

- S1: Steepness $h = 0.56$, the value used in SEDAR-17
- S2: Steepness $h = 0.56$ and external data component weights as in SEDAR-17
- S3: Steepness $h = 0.71$ as estimated in the base run, fishery dependent indices extended to 2011
- S4: Linearly increasing catchability with slope of 2% until 2003 and constant thereafter

In S1 and S2, the recruitment standard deviation was fixed at the value estimated by the base run ($\widehat{\sigma}_R = 0.57$).

3.4 Parameters Estimated

The model estimated annual fishing mortality rates of each fleet, selectivity parameters, catchability coefficients associated with indices, parameters of the spawner-recruit model, annual recruitment deviations, and CV of size at age. Estimated parameters are described mathematically in Table 3.1 of the SEDAR-17 report (SEDAR 2008).

3.5 Per Recruit and Equilibrium Analyses

Static spawning potential ratio (static SPR) of each year was computed as the asymptotic spawners (population fecundity) per recruit given that year's fishery-specific Fs and selectivities, divided by spawners per recruit that would be obtained in an unexploited stock. In this form, static SPR ranges between zero and one, and it represents SPR that would be achieved under an equilibrium age structure given the year-specific F (hence the word *static*).

Yield per recruit and spawning potential ratio were computed as functions of F, as were equilibrium landings and spawning biomass. Equilibrium landings and discards were also computed as functions of biomass B, which itself is a function of F. As in computation of MSY-related benchmarks (described in §3.6), per recruit and equilibrium analyses applied the most recent selectivity patterns averaged across fleets, weighted by each fleet's F from the last three years (2009–2011).

3.6 Benchmark/Reference Point Methods

In this assessment of vermilion snapper, the quantities F_{MSY}, $\mathrm{SSB}_{\mathrm{MSY}}$, B_{MSY}, and MSY were estimated by the method of Shepherd (1982). In that method, the point of maximum yield is identified from the spawner-recruit curve and parameters describing growth, natural mortality, maturity, and selectivity. The value of F_{MSY} is the F that maximizes equilibrium landings.

On average, expected recruitment is higher than that estimated directly from the spawner-recruit curve, because of lognormal deviation in recruitment. Thus, in this assessment, the method of benchmark estimation accounted for lognormal deviation by including a bias correction in equilibrium recruitment. The bias correction (ς) was computed from the variance (σ_R^2) of recruitment deviation in log space: $\varsigma = \exp(\sigma_R^2/2)$. Then, equilibrium recruitment (R_{eq}) associated with any F is,

$$R_{eq} = \frac{R_0\left[\varsigma 0.8h\Phi_F - 0.2(1-h)\right]}{(h-0.2)\Phi_F} \tag{3}$$

where R_0 is virgin recruitment, h is steepness, and $\Phi_F = \phi_F/\phi_0$ is spawning potential ratio given growth, maturity, and total mortality at age (including natural, fishing, and discard mortality rates). The R_{eq} and mortality schedule imply an equilibrium age structure and an average sustainable yield (ASY). The estimate of F_{MSY} is the F giving the highest ASY (excluding discards), and the estimate of MSY is that ASY. The estimate of $\mathrm{SSB}_{\mathrm{MSY}}$ follows from the corresponding equilibrium age structure, as does the estimate of discard mortalities (D_{MSY}), here separated from ASY (and consequently, MSY).

Estimates of MSY and related benchmarks are conditional on selectivity pattern. The selectivity pattern used here was an average of terminal-year selectivities from each fleet, where each fleet-specific selectivity was weighted in proportion to its corresponding estimate of F averaged over the last three years (2009–2011). If the selectivities or relative fishing mortalities among fleets were to change, so would the estimates of MSY and related benchmarks.

The maximum fishing mortality threshold (MFMT) is defined by the SAFMC as F_{MSY}, and the minimum stock size threshold (MSST) as $\mathrm{MSST} = (1-M)\mathrm{SSB}_{\mathrm{MSY}}$ (Restrepo et al. 1998), with constant M here equated to 0.22. Overfishing is defined as $F > \mathrm{MFMT}$ and overfished as $\mathrm{SSB} < \mathrm{MSST}$. Current status of the stock is represented by SSB in the latest assessment year (2011), and current status of the fishery is represented by the geometric mean of F from the latest three years (2009–2011). Although SEDAR-17 used only the terminal-year F to gauge the fishing status, more recent SEDAR assessments have considered the mean over the terminal three years to be a more appropriate metric.

In addition to the MSY-related benchmarks, the assessment considered proxies based on per recruit analyses (e.g., $F_{40\%}$). The values of $F_{X\%}$ are defined as those Fs corresponding to X% spawning potential ratio, i.e., spawners (population fecundity) per recruit relative to that at the unfished level. These quantities may serve as proxies for F_{MSY}, if the spawner-recruit relationship cannot be estimated reliably. Mace (1994) recommended $F_{40\%}$ as a proxy; however, later studies have found that $F_{40\%}$ is too high of a fishing rate across many life-history strategies (Williams and Shertzer 2003; Brooks et al. 2009) and can lead to undesirably low levels of biomass and recruitment (Clark 2002).

3.7 Uncertainty and Measures of Precision

In SEDAR-17, uncertainty was examined in part through use of multiple models and sensitivity runs, and for the base catch-age model, by bootstrapping recruitment residuals and refitting the spawner-recruit curve many times. However, SEDAR-17 reviewers noted that this bootstrapping method captured uncertainty only partially. Indeed, more recent SEDAR assessments have applied the more thorough method of a mixed Monte Carlo and bootstrap (MCB) approach. Because of reviewers comments, and because of the increased emphasis on accounting for uncertainty in SEDAR assessments, this update applied the MCB approach.

Monte Carlo and bootstrap methods (Efron and Tibshirani 1993; Manly 1997) are often used to characterize uncertainty in ecological studies, and the mixed approach has been applied successfully in stock assessment (Restrepo et al. 1992; Legault et al. 2001; SEDAR 2004; 2009; 2010; 2011). The approach is among those recommended for use in SEDAR assessments (SEDAR Procedural Guidance 2010).

The approach translates uncertainty in model input into uncertainty in model output, by fitting the model many times with different values of "observed" data and key input parameters. A chief advantage of the approach is that the results describe a range of possible outcomes, so that uncertainty is characterized more thoroughly than it could be by any single fit or handful of sensitivity runs. A minor disadvantage of the approach is that computational demands are relatively high.

In this assessment, the BAM was successively re-fit in $n = 3600$ trials that differed from the original inputs by bootstrapping on data sources, and by Monte Carlo sampling of several key input parameters. The value of $n = 3600$ was chosen because a minimum of 3000 runs were desired, and it was anticipated that not all runs would converge or otherwise be valid. Of the 3600 trials, approximately 6.4% were discarded, because the model did not properly converge (in most cases, an estimated quantity was at or exceeded its upper bound). This left $n = 3368$ trials used to characterize uncertainty, which was sufficient for convergence of standard errors in management quantities.

The MCB analysis should be interpreted as providing an approximation to the uncertainty associated with each output. The results are approximate for two related reasons. First, not all combinations of Monte Carlo parameter inputs are equally likely, as biological parameters might be correlated. Second, all runs are given equal weight in the results, yet some might provide better fits to data than others.

3.7.1 **Bootstrap of observed data**

To include uncertainty in time series of observed landings, discards, and indices of abundance, multiplicative lognormal errors were applied through a parametric bootstrap. To implement this approach in the MCB trials, random variables ($x_{s,y}$) were drawn for each year y of time series s from a normal distribution with mean 0 and variance $\sigma^2_{s,y}$ [that is, $x_{s,y} \sim N(0, \sigma^2_{s,y})$]. Annual observations were then perturbed from their original values ($\hat{O}_{s,y}$),

$$O_{s,y} = \hat{O}_{s,y}[\exp(x_{s,y} - \sigma^2_{s,y}/2)] \tag{4}$$

The term $\sigma^2_{s,y}/2$ is a bias correction that centers the multiplicative error on the value of 1.0. Standard deviations in log space were computed from CVs in arithmetic space, $\sigma_{s,y} = \sqrt{\log(1.0 + CV^2_{s,y})}$. As used for fitting the base run, CVs of landings and discards were assumed to be 0.05, and CVs of indices of abundance were those provided by, or modified from, the DW (tabulated in Table 3 of this assessment report).

Uncertainty in age and length compositions were included by drawing new distributions for each year of each data source, following a multinomial sampling process. Ages (or lengths) of individual fish were drawn at random with replacement using the cell probabilities of the original data. For each year of each data source, the number of fish sampled was the same as in the original data.

3.7.2 Monte Carlo sampling

In each successive fit of the model, several parameters were fixed (i.e., not estimated) at values drawn at random from distributions described below.

Natural mortality Point estimates of natural mortality ($M = 0.22$) were provided by the SEDAR-17 DW, but with some uncertainty. To carry forward this source of uncertainty, Monte Carlo sampling was used to generate deviations from the point estimate. A new M value was drawn for each MCB trial from a truncated normal distribution (DW range [0.16, 0.28]) with mean equal to the point estimate ($M = 0.22$) and standard deviation set to provide 95% confidence limits at the DW bounds. Each realized value of M was used to scale the age-specific Lorenzen M, as in the base run.

Discard mortalities Similarly, discard mortalities δ were subjected to Monte Carlo variation as follows. A new value for commercial lines discard mortality was drawn for each MCB trial from a truncated normal distribution (DW range [0.24, 0.53]) with mean equal to the point estimate ($\delta = 0.41$) and standard deviation set to provide an upper 95% confidence limit at 0.53 (the upper bound). A new value for recreational (headboat and general recreational) discard mortality was drawn for each MCB trial from a truncated normal distribution (DW range [0.2, 0.5]) with mean equal to the point estimate ($\delta = 0.38$) and standard deviation set to provide an upper 95% confidence limit at 0.5 (the upper bound).

Spawner-recruit parameters In initial trials of the MCB analysis, steepness approached its upper bound in a minority but non-negligible proportion of model fits. This was more likely a result of poor estimation than an indication that steepness is high (Conn et al. 2010). Consequently, steepness was fixed in the MCB analysis, drawn from a truncated normal distribution [0.52, 0.9], with mean equal to the point estimate ($h = 0.71$) from the base run and standard deviation equal to 0.19 (Shertzer and Conn 2012). The range represented plus/minus one standard deviation and was in general agreement with the range indicated by likelihood profiling. Similarly, the standard deviation of recruitment, σ_R, was drawn from a truncated normal distribution [0.45, 0.75], with mean (0.6) and standard deviation (0.15) the same as in the prior distribution used for estimation in the base run (Beddington and Cooke 1983; Mertz and Myers 1996).

Catchability The base model included a linear increase in catchability of 2% per year. In MCB runs, the level of increase was drawn from a uniform distribution spanning [0%, 4%]. This range has been considered in previous SEDAR assessments of snapper-grouper stocks, including in SEDAR-17. The lower bound of the range was chosen to represent the assumption of constant catchability; the range itself is consistent with increases in total factor productivity estimated for New England groundfish (4.4%) and for Norwegian stocks (1.7–4.3%) (Jin et al. 2002; Hannesson 2007).

Historic recreational landings Prior to the introduction of MRFSS in 1981, recreational landings values were obtained by interpolating data reported in saltwater angling surveys (Clark 1962; Deuel and Clark 1968; Deuel 1973), adjusted to account for recall bias (SEDAR 2008). For the base model, the adjustment for recall bias reduced the values from saltwater angling surveys to 75% of their original values. In MCB runs, that adjustment was drawn from a uniform distribution spanning [50%, 100%].

3.8 Projections—Probabilistic Analysis

Acceptable biological catch (ABC) was computed using the sequential PASCL approach of Shertzer et al. (2010), a refinement of the probability-based approach described in Shertzer et al. (2008*b*). In short, this approach solves for annual levels of projected landings that are consistent with a preset, acceptable probability of overfishing ($P^{\star}$) in each year. The method considers uncertainty in F_{MSY}, computed through the MCB analysis (§3.7), and described by the probability density function, $\phi_{F_{\text{MSY}}}$. It also considers uncertainty in annual fishing mortality, computed by stochastic projection, and described by the probability density function, ϕ_{F_t}. Given the distributions $\phi_{F_{\text{MSY}}}$ and ϕ_{F_t}, the probability of overfishing associated with catch C can be computed as,

$$\Pr(F_t > F_{\text{MSY}}) = \int_0^{\infty} \left[\int_F^{\infty} \phi_{F_t}(\theta) d\theta \right] \phi_{F_{\text{MSY}}}(F) dF \tag{5}$$

where θ is a dummy integration variable. The value of C is then adjusted until the distribution of F_t is positioned to achieve $\Pr(F_t > F_{\text{MSY}}) = P^{\star}$. This value of C is that year's ABC.

No implementation uncertainty was included, and annual catch targets were considered to be centered on the ABC. Two values of $P^{\star}$ were considered: $P^{\star} = 0.5$ and $P^{\star} = 0.275$. After SEDAR-17, the SSC recommended ABCs based on interpolation of results from $P^{\star} = 0.25$ and $P^{\star} = 0.30$. Here, $P^{\star}$ was set equal to 0.275, so no interpolation is necessary.

In this application, projections were run for five years past the end of the assessment. The structure of the projection model was as described in SEDAR (2008). Two modifications in this update were the initialization of projections (in 2012) and the characterization of projection uncertainty, both described in more detail below.

3.8.1 **Initialization of projections**

In the assessment, the terminal three years of recruitment were penalized for deviation from the spawner-recruit curve, which influenced the estimated abundances of ages 1–3 (N_{1-3}) in 2011. In the projections, lognormal stochasticity was applied to these abundances, based on recruitment variation σ_R. Thus, the initial abundance in year one (2012) of projections included this variability in N_{2-4}, as well as in the SSB_{2011} used to compute initial recruits, N_1.

In $P^{\star}$ projections, the first year of new management was assumed to be 2013, which is the earliest year management could react to this assessment. Because the assessment period ended in 2011, the projections required an interim period of harvest (2012). The level of landings in 2012 was assumed equal to the average of the last two years of harvest. That average was estimated to be $L_{\text{current}} = 1,320,531$ lb whole weight.

3.8.2 **Uncertainty of projections**

To characterize uncertainty in future stock dynamics, stochasticity was included in replicate projections, each an extension of a single MCB assessment model fit. Thus, projections carried forward uncertainties in steepness, natural mortality, and discard mortality, as well as in estimated quantities such as remaining spawner-recruit parameters, selectivity curves, and in initial (start of 2012) abundance at age.

Initial and subsequent recruitment values were generated with stochasticity using a Monte Carlo procedure, in which the estimated Beverton–Holt model of each MCB fit was used to compute mean annual recruitment values ($\bar{R}_y$). Variability was added to the mean values by choosing multiplicative deviations at random from a lognormal distribution,

$$R_y = \bar{R}_y \exp(\epsilon_y). \tag{6}$$

Here ϵ_y was drawn from a normal distribution with mean 0 and standard deviation σ_R, where σ_R is the standard deviation from the relevant MCB fit.

The procedure generated 10,000 replicate projections of MCB model fits drawn at random (with replacement) from the MCB runs. In cases where the same MCB run was drawn, projections would still differ as a result of stochasticity in projected recruitment streams.

4 Stock Assessment Results

4.1 Measures of Overall Model Fit

The Beaufort assessment model (BAM) fit well to the available data. In general, the fits were quite similar to those from SEDAR-17.

Predicted length compositions from each fishery were reasonably close to observed data in most years, as were predicted age compositions (Figure 2). The model was configured to fit observed commercial and recreational landings closely (Figures 3–7), as well as observed discards (Figures 8–10). Fits to indices of abundance generally captured the observed trends but not all annual fluctuations (Figures 11–15).

4.2 Parameter Estimates

Estimates of all parameters from the catch-age model are shown in Appendix B. Estimates of management quantities and some key parameters, such as those of the spawner-recruit model, are reported in sections below.

4.3 Stock Abundance and Recruitment

In general, estimated abundance at age showed truncation of the older ages mostly through the 1980s, and more stable values since (Figure 16; Table 5). Total estimated abundance was at its lowest values at the end of the assessment period. Annual number of recruits is shown in Table 5 (age-1 column) and in Figure 17. In the most recent decade, the strongest year class (age-1 fish) was predicted to have occurred in 2006.

4.4 Total and Spawning Biomass

Estimated biomass at age followed a similar pattern as abundance at age (Figure 18; Table 6). Total biomass and spawning biomass showed similar trends—general decline throughout the assessment period, with the lowest predicted values at the end of the time series (Figure 19; Table 7).

4.5 Selectivity

Selectivities of the two MARMAP trap gears are shown in (Figure 20), and selectivities of landings from commercial and recreational fleets are shown in Figures 21–25. In the most recent years, full selection occurred near age-3 or age-4, depending on the fleet.

By design, selectivities of discard mortalities were dome-shaped for all fleets (Figures 26–27). However, the commercial discards included relatively more older fish starting when the seasonal closures went into place in 2009. Despite similar seasonal closures for recreational fleets, length compositions did not indicate such a shift toward older fish.

Average selectivities of landings and of discard mortalities were computed from F-weighted selectivities in the most recent period of regulations (Figure 28). These average selectivities were used to compute point estimates of benchmarks. All selectivities from the most recent period, including average selectivities, are tabulated in Table 8.

4.6 Fishing Mortality, Landings, and Discards

The estimated fishing mortality rates (F) have shown a general pattern of increase over time, with much variability across years (Figure 29). In recent decades, the commercial handline fleet has been the largest contributor to total F (Table 9).

Similarly, in recent decades, the majority of estimated landings were from the commercial sector (Figures 30, 31; Tables 10, 11). Estimated discard mortalities occurred on a smaller scale than landings (Figure 32; Tables 12, 13)

4.7 Spawner-Recruitment Parameters

The estimated Beverton–Holt spawner-recruit curve is shown in Figure 33, along with the effect of density dependence on recruitment, depicted graphically by recruits per spawner as a function of spawners (population fecundity). Values of recruitment-related parameters were as follows: steepness $\hat{h} = 0.71$, unfished age-1 recruitment $\widehat{R_0} = 3,921,597$, unfished spawners (eggs) per recruit $\phi_0 = 5.168\text{E}6$, and standard deviation of recruitment residuals in log space $\widehat{\sigma}_R = 0.57$ (which resulted in bias correction of $\varsigma = 1.18$). Uncertainty in these quantities was estimated through the Monte Carlo/bootstrap (MCB) analysis (Figure 34).

4.8 Per Recruit and Equilibrium Analyses

Static spawning potential ratio (static SPR) showed a general trend of decline until the late-1980s, followed by an increase in 1992, and then stable or slowly decreasing trend since then (Figure 35, Table 7). Values near the end of the time series were slightly higher than those expected at MSY.

Yield per recruit and spawning potential ratio were computed as functions of F (Figure 36). As in computation of MSY-related benchmarks, per recruit analyses applied the most recent selectivity patterns averaged across fisheries, weighted by F from the last three years (2009–2011). The yield per recruit curve was strictly increasing, but was not well defined in the sense that a wide range of F provided nearly identical yield per recruit. The F that provides 50% SPR is $F_{50\%} = 0.24$, $F_{40\%} = 0.40$, and $F_{30\%} = 0.83$. For comparison, F_{MSY} corresponds to about 31% SPR.

As in per recruit analyses, equilibrium landings and spawning biomass were computed as functions of F (Figure 37). By definition, the F that maximizes equilibrium landings is F_{MSY}, and the corresponding landings and spawning biomass are MSY and SSB_{MSY}. Equilibrium landings and discards could also be viewed as functions of biomass B, which itself is a function of F (Figure 38).

4.9 Benchmarks / Reference Points

As described in §3.6, biological reference points (benchmarks) were derived analytically assuming equilibrium dynamics, corresponding to the expected spawner-recruit curve (Figure 33). Reference points estimated were F_{MSY}, MSY, B_{MSY} and SSB_{MSY}. Based on F_{MSY}, three possible values of F at optimum yield (OY) were considered—$F_{\text{OY}} = 65\% F_{\text{MSY}}$, $F_{\text{OY}} = 75\% F_{\text{MSY}}$, and $F_{\text{OY}} = 85\% F_{\text{MSY}}$—and for each, the corresponding yield was computed. Standard errors of benchmarks were approximated as those from Monte Carlo/bootstrap analysis (§3.7).

Estimates of benchmarks are summarized in Table 14. Point estimates of MSY-related quantities were $F_{\text{MSY}} = 0.75$ (y^{-1}), $\text{MSY} = 1563$ (1000 lb), $B_{\text{MSY}} = 2252$ (mt), and $\text{SSB}_{\text{MSY}} = 5.98$ (1E12 eggs). Distributions of these benchmarks from the MCB analysis are shown in Figure 39.

4.10 Status of the Stock and Fishery

Estimated time series of stock status ($\mathrm{SSB/MSST}$ and $\mathrm{SSB/SSB_{MSY}}$) showed general decline throughout the assessment period (Figure 40, Table 7). Base-run estimates of spawning biomass have remained above the threshold of MSST throughout the time series. Current stock status was estimated in the base run to be $\mathrm{SSB_{2011}/MSST} = 1.26$ and $\mathrm{SSB_{2011}/SSB_{MSY}} = 0.98$ (Table 14), indicating that the stock is not overfished and is quite close to $\mathrm{SSB_{MSY}}$. The MCB analysis suggested much uncertainty in the terminal estimate of stock status (Figures 41, 42). Of the MCB runs, approximately 25% indicated the stock to be overfished. Age structure estimated by the base run generally showed more older fish than the (equilibrium) age structure expected at MSY (Figure 43).

The estimated time series of F/F_{MSY} suggests that overfishing has been rare throughout most of the assessment period (Table 7), but with much uncertainty demonstrated by the MCB analysis (Figure 40). Current fishery status in the terminal year, with current F represented by the geometric mean from 2009–2011, was estimated by the base run to be $F_{2009-2011}/F_{\mathrm{MSY}} = 0.67$ (Table 14), but again with much uncertainty in that estimate (Figures 41, 42). Of the MCB runs, approximately 30% indicated the stock to be undergoing overfishing.

4.10.1 Comparison to previous assessment

Stock and fishery status estimated by this assessment show trends similar to those from the previous, SEDAR-17 assessment (Figure 44). However, this update assessment estimates lower levels of F/F_{MSY} and higher levels of $\mathrm{SSB/MSST}$. Most of the difference in results is due to higher steepness estimated by the update ($\hat{h} = 0.71$) than was assumed in SEDAR-17 ($h = 0.56$). Very little of the difference is due to updates in data or to modifications in the model.

4.11 Sensitivity Analyses

Sensitivity runs, described in §3.3, were used here to examine some topics related to updating the assessment. They were not as extensive as those of SEDAR-17, in which many model inputs were considered. Time series of F/F_{MSY} and $\mathrm{SSB/MSST}$ are plotted to demonstrate sensitivity to steepness and data weighting (Figure 45), terminal year of fishery dependent indices (Figure 46), and trends in catchability (Figure 47). Two of these runs suggested the stock to be overfished and undergoing overfishing, and two agreed with the status indicated by the base run (Figure 48, Table 15). The difference in results was primarily driven by the value of steepness.

4.12 Projections—Probabilistic Analysis

The distribution of F_{MSY} in Figure 39 was used to compute annual ABC (landings plus discard mortalities in 1000 lb whole weight). In general, the ABC tends to increase with higher acceptable probability of overfishing ($P^{\star}$), whereas stock size tends to decrease. Projected values from this assessment are shown in Tables 16 and 17.

Values of ABC were computed given uncertainties in F_{MSY}, initial abundance at age (2012), selectivities, natural mortality, discard mortalities, spawner-recruit parameters, and future recruitment deviations. Uncertainty in management implementation was not considered. Thus, these ABC values should be considered as possible catch limits, and implementation uncertainty might be considered when setting annual catch targets (ACTs).

The projection method applied here assumed that the catch taken from the stock was the ABC. If the projection had applied a catch level lower than the ABC, say at ACT $<$ ABC, then the corresponding reduction in applied F would have resulted in higher stock sizes, and higher ABCs in subsequent years. In this sense, the values presented here are conservative.

5 Discussion

5.1 Comments on the Assessment

Estimated benchmarks played a central role in this assessment. Values of $\mathrm{SSB}_{\mathrm{MSY}}$ and F_{MSY} were used to gauge the status of the stock and fishery. Computation of benchmarks was conditional on selectivity. If selectivity patterns change in the future, for example as a result of new size limits or different relative catch allocations among sectors, estimates of benchmarks would likely change as well.

The base run of the BAM indicated that the stock is not overfished ($\mathrm{SSB}_{2011}/\mathrm{MSST} = 1.26$), and that overfishing is not occurring ($F_{2009-2011}/F_{\mathrm{MSY}} = 0.67$). Although these status indicators may be in qualitative agreement with management goals, they should be interpreted with two notes of caution. First, the MCB analysis indicated much uncertainty in these estimates of stock and fishery status. Second, estimated trends of decreasing biomass and (slowly) increasing F go in the wrong direction for the status indicators to hold indefinitely.

In addition to more years of data, this update assessment included several modifications to previous data, such as the use of MRIP (instead of MRFSS) starting in 2004 and the re-evaluation (delta-GLM modeling) of indices of abundance. Furthermore, the assessment model itself included some modifications. In sum, these modifications allowed for the estimation of steepness in this update assessment. In the previous SEDAR-17 assessment, steepness was not estimable and was therefore fixed at $h = 0.56$, somewhat lower than the estimate from this assessment, $\hat{h} = 0.71$. This update in the value of steepness was the primary reason for differences between results of this assessment and the SEDAR-17 benchmark.

One major methodological change in this update was the use of MCB analysis to quantify uncertainty. The SEDAR-17 assessment did not take this approach, but rather applied a simple bootstrap procedure toward estimation of the spawner-recruit curve and management benchmarks. That procedure was not nearly as comprehensive as the MCB analysis. This change was implemented because of the increased emphasis placed on quantifying uncertainty since SEDAR-17 (SEDAR Procedural Guidance 2010).

In general, fishery dependent indices of abundance may not track actual abundance well, because of factors such as hyperdepletion or hyperstability. Furthermore, this issue can be exacerbated by management measures. In this assessment, fishery dependent indices were not extended beyond 2008, because of the implementation of restrictive bag or trip limits, along with seasonal closures. As such management measures become more common in the southeast U.S., the continued utility of fishery dependent indices in SEDAR stock assessments will be questionable. This situation amplifies the importance of fishery independent sampling.

Although additional management measures were enacted after the last assessment, their effect on overall fishing rate appears to have been small. This may in part be due to landings exceeding the quota. In 2009–2011, the commercial quota was 618,046 lb gutted weight (sum of two split-season quotas). Observed commercial landings (Table 2), converted to gutted weight using the SEDAR-17 relationship WW = 1.068GW, exceeded the quota in each of those three years by 35%, 43%, and 79%, respectively.

Projections suggested ABC values near 1,150,000 lb whole weight, if $P^{\star} = 0.275$ is again chosen as the preferred probability of overfishing (Table 16). That value of ABC includes landings and discard mortalities. For reference, the sum of landings and discard mortalities (lb whole weight) across fleets in recent years has been approximately 1,487,000 in 2009, 1,267,000 in 2010, and 1,472,000 in 2011.

5.2 Comments on the Projections

As usual, projections should be interpreted in light of the model assumptions and key aspects of the data. Some major considerations are the following:

- In general, projections of fish stocks are highly uncertain, particularly in the long term (e.g., beyond 5–10 years).
- Although projections included many major sources of uncertainty, they did not include structural (model) uncertainty. That is, projection results are conditional on one set of functional forms used to describe population dynamics, selectivity, recruitment, etc.
- Fisheries were assumed to continue fishing at their estimated current proportions of total effort, using the estimated current selectivity patterns. New management regulations that alter those proportions or selectivities would likely affect projection results.
- The projections assumed that the estimated spawner-recruit relationship applies in the future and that past residuals represent future uncertainty in recruitment. If future recruitment is characterized by runs of large or small year classes, possibly due to environmental or ecological conditions, stock trajectories may be affected.
- Projections apply the Baranov catch equation to relate F and landings using a one-year time step, as in the assessment. The catch equation implicitly assumes that mortality occurs throughout the year. This assumption is violated when seasonal closures are in effect, introducing additional and unquantified uncertainty into the projection results.

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7 Tables

Table 1. Life-history characteristics at age, including average body length and weight (mid-year), annual fecundity per mature female (number batches X eggs per batch), proportion females mature, and natural mortality at age. The CV of length was estimated by the assessment model; other values were treated as input.

Age	Total length (mm)	Total length (in)	CV length	Whole weight (kg)	Whole weight (lb)	Fecundity (million eggs)	Female maturity	Natural mortality
1	228.3	9.0	0.22	0.15	0.33	0.86	0.8	0.341
2	259.7	10.2	0.22	0.22	0.48	1.18	1.0	0.304
3	287.6	11.3	0.22	0.29	0.65	1.53	1.0	0.278
4	312.3	12.3	0.22	0.37	0.83	1.88	1.0	0.258
5	334.2	13.2	0.22	0.46	1.01	2.22	1.0	0.243
6	353.6	13.9	0.22	0.54	1.19	2.56	1.0	0.231
7	370.8	14.6	0.22	0.62	1.36	2.89	1.0	0.222
8	386.1	15.2	0.22	0.69	1.53	3.19	1.0	0.214
9	399.7	15.7	0.22	0.77	1.69	3.48	1.0	0.208
10	411.7	16.2	0.22	0.84	1.85	3.75	1.0	0.202
11	422.4	16.6	0.22	0.90	1.99	4.00	1.0	0.198
12	431.8	17.0	0.22	0.96	2.12	4.23	1.0	0.194

Table 2. Observed time series of landings (L) and discards (D) for commercial lines (c.hal), commercial historic trawl (c.htr), commercial combined (c.cmb), recreational headboat (hb), and general recreational (rec). Commercial landings are in units of 1000 lb whole weight. Recreational landings and all discards are in units of 1000 fish. Discards include all released fish, live or dead.

Year	L.c.hal	L.c.htr	L.c.cmb	L.hb	L.rec	D.c.hal	D.hb	D.rec
1947	.	.	.	14.632	9.013	.	0.903	1.953
1948	.	.	.	30.581	17.077	.	1.887	3.701
1949	.	.	.	46.801	25.099	.	2.888	5.439
1950	.	.	.	63.431	33.059	.	3.915	7.165
1951	.	.	.	80.610	40.935	.	4.975	8.871
1952	.	.	.	98.478	48.707	.	6.078	10.556
1953	.	.	.	117.175	56.352	.	7.231	12.213
1954	.	.	.	136.839	63.851	.	8.445	13.838
1955	.	.	.	157.611	71.182	.	9.727	15.426
1956	.	.	.	179.629	78.325	.	11.086	16.974
1957	.	.	.	203.033	85.257	.	12.530	18.477
1958	0.194	.	.	227.963	91.959	.	14.069	19.929
1959	1.262	.	.	254.558	98.409	.	15.710	21.327
1960	1.747	.	.	282.957	104.587	.	17.463	22.666
1961	19.317	24.025	.	312.783	110.447	.	19.303	23.936
1962	10.822	42.582	.	341.589	115.852	.	21.081	25.107
1963	20.967	.	.	366.412	120.640	.	22.613	26.145
1964	6.792	.	.	384.289	124.651	.	23.716	27.014
1965	22.009	.	.	392.256	127.722	.	24.208	27.680
1966	3.397	.	.	388.652	129.749	.	23.986	28.119
1967	14.172	.	.	377.023	130.858	.	23.268	28.359
1968	31.936	.	.	362.218	131.230	.	22.354	28.440
1969	31.348	.	.	349.083	131.049	.	21.544	28.401
1970	19.511	.	.	342.467	130.497	.	21.135	28.281
1971	66.321	.	0.396	345.461	129.728	.	21.320	28.114
1972	68.794	.	11.790	402.814	128.788	.	24.860	27.911
1973	86.192	.	6.112	383.908	127.693	.	23.693	27.673
1974	119.387	.	2.728	421.690	126.461	.	26.025	27.406
1975	218.655	.	2.825	477.319	125.109	.	29.458	27.113
1976	212.410	.	7.521	399.737	123.653	.	24.670	26.798
1977	273.322	.	11.297	317.303	122.112	.	19.582	26.464
1978	345.076	.	1.046	487.529	120.503	.	30.088	26.115
1979	430.888	.	54.161	425.382	118.841	.	26.252	25.755
1980	482.636	.	268.613	322.990	117.146	.	19.933	25.388
1981	500.886	.	242.894	270.987	115.008	.	16.724	33.350
1982	672.796	.	215.666	362.321	230.532	.	22.361	41.312
1983	645.732	.	142.782	399.040	304.266	.	24.627	31.903
1984	734.077	.	117.956	324.429	366.589	.	20.022	22.494
1985	920.506	.	24.984	529.803	420.894	.	32.697	24.091
1986	896.379	.	23.977	533.101	307.370	.	32.900	24.091
1987	697.928	.	51.631	731.007	202.196	.	45.114	24.091
1988	854.227	.	131.537	740.891	179.117	.	45.724	25.687
1989	1041.509	.	90.065	661.251	202.690	.	40.809	63.855
1990	1141.190	.	148.713	655.859	190.929	.	40.476	71.476
1991	1332.693	.	61.418	600.501	164.798	.	37.060	42.392
1992	764.936	.	0.278	345.266	136.442	73.294	67.499	79.547
1993	866.361	.	8.552	327.027	116.230	82.115	63.934	48.160
1994	948.426	.	9.734	369.720	85.881	101.527	72.280	66.768
1995	928.497	.	2.877	354.766	81.076	118.203	69.357	121.089
1996	743.692	.	1.394	340.340	93.301	158.378	66.536	41.777
1997	759.005	.	2.012	364.742	104.549	147.861	71.307	41.445
1998	708.112	.	2.394	341.563	120.203	113.581	66.775	59.409
1999	876.584	.	4.510	381.936	165.514	96.871	86.492	257.553
2000	1348.519	.	1.592	428.235	209.669	97.493	96.977	215.610
2001	1633.594	.	3.230	418.876	212.669	113.911	94.858	137.247
2002	1334.418	.	1.338	335.543	191.314	243.983	75.986	108.259
2003	727.859	.	6.970	251.796	204.084	105.165	57.021	183.324
2004	1086.300	.	2.676	329.081	237.865	50.349	87.969	140.602
2005	1100.916	.	0.871	275.450	154.037	81.069	52.502	77.108
2006	827.160	.	1.460	344.724	254.878	47.428	76.340	78.973
2007	1012.612	.	7.693	507.970	150.821	52.539	127.773	204.794
2008	1158.340	.	34.330	262.851	187.293	106.470	132.593	283.348
2009	856.434	.	37.252	225.311	188.061	71.686	139.720	172.150
2010	910.715	.	34.002	138.405	70.952	88.534	94.715	80.834
2011	1145.114	.	37.722	133.402	60.656	75.683	90.902	20.718

Table 3. Observed indices of abundance and CVs from MARMAP Florida snapper trap (fst), MARMAP chevron trap (cvt), commercial lines (cl), headboats (hb), and general recreational (rec).

Year	fst	fst CV	cvt	cvt CV	cl	cl CV	hb	hb CV	rec	rec CV
1976	.	.	.	.	.	.	1.25	0.21	.	.
1977	.	.	.	.	.	.	1.06	0.23	.	.
1978	.	.	.	.	.	.	1.65	0.18	.	.
1979	.	.	.	.	.	.	1.59	0.20	.	.
1980	.	.	.	.	.	.	0.92	0.24	.	.
1981	.	.	.	.	.	.	1.05	0.24	.	.
1982	.	.	.	.	.	.	0.88	0.23	.	.
1983	1.43	0.30	.	.	.	.	1.32	0.17	.	.
1984	0.72	0.28	.	.	.	.	1.10	0.20	.	.
1985	1.18	0.27	.	.	.	.	1.34	0.18	.	.
1986	1.18	0.24	.	.	.	.	1.10	0.16	.	.
1987	0.50	0.25	.	.	.	.	1.36	0.16	1.21	0.30
1988	.	.	.	.	.	.	1.45	0.16	0.83	0.19
1989	.	.	.	.	.	.	1.15	0.21	0.98	0.16
1990	.	.	0.64	0.23	.	.	1.16	0.20	1.86	0.25
1991	.	.	2.53	0.20	.	.	1.06	0.21	1.50	0.20
1992	.	.	1.43	0.22	.	.	0.50	0.25	0.95	0.16
1993	.	.	1.10	0.19	0.65	0.28	0.49	0.26	0.93	0.14
1994	.	.	2.10	0.18	0.73	0.25	0.49	0.28	0.65	0.11
1995	.	.	1.02	0.20	0.85	0.22	0.53	0.28	0.83	0.20
1996	.	.	1.27	0.20	0.74	0.25	0.57	0.27	1.20	0.20
1997	.	.	0.64	0.22	0.85	0.25	0.82	0.29	0.68	0.15
1998	.	.	0.71	0.21	0.83	0.26	0.68	0.25	0.90	0.12
1999	.	.	0.98	0.24	1.02	0.26	0.81	0.25	1.14	0.09
2000	.	.	0.95	0.23	1.22	0.26	1.02	0.25	1.14	0.10
2001	.	.	0.99	0.23	1.25	0.24	1.06	0.24	1.07	0.09
2002	.	.	1.23	0.22	1.18	0.24	1.19	0.23	0.91	0.10
2003	.	.	0.70	0.30	0.95	0.30	0.74	0.30	1.09	0.10
2004	.	.	0.54	0.23	1.09	0.30	1.04	0.21	1.16	0.13
2005	.	.	0.55	0.23	1.29	0.28	0.94	0.27	0.68	0.21
2006	.	.	0.39	0.26	1.07	0.30	1.00	0.24	0.97	0.17
2007	.	.	0.73	0.23	1.08	0.27	0.89	0.25	0.56	0.12
2008	.	.	1.12	0.24	1.18	0.27	0.80	0.26	0.74	0.15
2009	.	.	1.21	0.21	.	.	.	.	.	.
2010	.	.	0.67	0.18	.	.	.	.	.	.
2011	.	.	0.49	0.24	.	.	.	.	.	.

Table 4. Sample sizes (number fish) of length compositions (len) or age compositions (age) by survey or fleet, including those of discards (D). Data sources are MARMAP Florida snapper trap (fst), MARMAP chevron trap (cvt), commercial lines (c.hal), commercial combined gears (c.cmb), headboats (hb), and general recreational (rec).

Year	len.fst	len.c.hal	len.c.cmb	len.hb	len.rec	len.c.hal.D	len.hb.D	age.c.hal	age.cvt	age.hb	age.rec
1976	.	.	.	1146	.	.	.	.	.	.	.
1977	.	.	.	1036	.	.	.	.	.	.	.
1978	.	.	.	1768	.	.	.	.	.	.	.
1979	.	.	.	1389	.	.	.	.	.	.	.
1980	.	.	.	1348	.	.	.	.	.	12	.
1981	.	.	.	1335	10	.	.	.	.	112	.
1982	.	.	.	2777	90	.	.	.	.	38	.
1983	469	391	.	4482	124	.	.	.	.	2	.
1984	354	7976	196	4545	581	.	.	.	.	.	.
1985	608	9800	.	5894	165	.	.	.	.	.	.
1986	471	7888	650	6159	19	.	.	.	.	89	.
1987	290	7315	616	6327	36	.	.	.	.	8	.
1988	.	5577	692	4759	32	.	.	.	.	2	.
1989	.	5625	.	4768	80	.	.	.	.	.	.
1990	.	6007	.	5308	66	.	.	.	.	.	.
1991	.	10525	.	4029	50	.	.	.	.	166	.
1992	.	6161	.	2823	114	.	.	82	.	46	.
1993	.	8286	.	3323	75	.	.	183	.	48	.
1994	.	7488	.	5724	77	.	.	164	.	252	.
1995	.	13246	.	4799	74	.	.	317	.	192	.
1996	.	6718	.	3858	16	.	.	.	.	73	.
1997	.	6793	64	4133	68	.	.	55	.	14	.
1998	.	6644	.	4239	76	.	.	104	.	2	.
1999	.	11961	.	4306	194	.	.	136	.	.	.
2000	.	18712	.	4469	261	.	.	209	.	.	.
2001	.	18034	.	3387	398	.	.	244	.	22	83
2002	.	12024	.	3895	393	.	.	181	765	10	217
2003	.	11977	.	3824	578	.	23	122	215	103	366
2004	.	13458	.	3324	888	.	176	512	305	331	102
2005	.	8604	.	2206	1835	.	652	727	481	486	299
2006	.	11124	.	3209	1209	.	514	938	272	597	230
2007	.	6769	.	3995	1274	395	853	1011	536	721	31
2008	.	182	.	2624	512	11	1090	3656	676	352	18
2009	.	178	.	2737	337	151	1484	2320	973	640	11
2010	.	180	.	1623	488	475	737	3784	596	672	87
2011	.	196	.	1370	208	337	708	4251	871	216	36

Table 5. Estimated total abundance at age (1000 fish) at start of year.

Year	1	2	3	4	5	6	7	8	9	10	11	12	Total
1946	4694.38	3337.98	2462.97	1865.20	1441.04	1130.17	897.06	718.47	580.05	471.12	384.95	1790.86	19774.25
1947	4694.38	3337.98	2462.97	1865.20	1441.04	1130.17	897.06	718.47	580.05	471.12	384.95	1790.86	19774.25
1948	4694.04	3337.36	2459.42	1861.42	1438.32	1128.05	895.38	717.13	578.98	470.25	384.24	1787.54	19752.14
1949	4693.07	3336.49	2455.38	1854.94	1432.66	1123.77	892.00	714.43	576.80	468.49	382.80	1780.86	19711.70
1950	4691.53	3335.17	2451.10	1848.03	1424.87	1117.16	886.90	710.36	573.52	465.83	380.63	1770.79	19655.90
1951	4689.48	3333.42	2446.40	1840.87	1416.72	1108.88	879.93	704.89	569.13	462.27	377.73	1757.30	19587.00
1952	4686.93	3331.28	2441.29	1833.30	1408.31	1100.26	871.61	697.93	563.59	457.79	374.07	1740.35	19506.72
1953	4683.94	3328.78	2435.76	1825.30	1399.50	1091.39	863.00	689.86	556.84	452.37	369.66	1719.91	19416.31
1954	4680.51	3325.92	2429.82	1816.84	1390.27	1082.14	854.13	681.52	549.18	445.96	364.48	1695.94	19316.72
1955	4676.66	3322.71	2423.43	1807.89	1380.57	1072.48	844.92	672.95	541.29	438.81	358.48	1668.41	19208.62
1956	4672.41	3319.18	2416.60	1798.43	1370.36	1062.37	835.32	664.06	533.17	431.44	351.87	1637.24	19092.44
1957	4667.75	3315.30	2409.28	1788.41	1359.61	1051.77	825.29	654.81	524.76	423.87	345.07	1602.57	18968.47
1958	4662.67	3311.09	2401.47	1777.79	1348.27	1040.62	814.79	645.16	516.02	416.03	338.08	1564.83	18836.82
1959	4657.16	3306.52	2393.12	1766.52	1336.27	1028.87	803.77	635.07	506.92	407.90	330.85	1524.39	18697.36
1960	4651.19	3301.58	2384.19	1754.54	1323.50	1016.39	792.11	624.44	497.37	399.40	323.33	1481.39	18549.43
1961	4644.73	3296.25	2374.64	1741.80	1310.01	1003.21	779.81	613.27	487.37	390.54	315.51	1436.12	18393.28
1962	4637.08	3250.69	2350.06	1727.98	1294.16	987.59	765.50	600.46	476.05	380.61	306.83	1386.29	18163.30
1963	4627.98	3213.08	2300.02	1703.49	1279.79	972.80	751.40	587.74	464.76	370.69	298.17	1336.13	17906.05
1964	4618.77	3276.26	2292.29	1660.94	1256.24	957.54	736.71	574.24	452.80	360.23	289.06	1283.73	17758.79
1965	4610.60	3268.89	2332.87	1651.08	1222.88	938.86	724.36	562.40	441.92	350.58	280.59	1234.07	17619.09
1966	4602.71	3262.58	2324.89	1677.31	1212.22	910.86	707.82	551.09	431.34	341.00	272.15	1184.44	17478.42
1967	4595.69	3256.89	2319.80	1671.23	1232.80	904.50	687.95	539.48	423.44	333.43	265.19	1141.07	17371.47
1968	4589.87	3252.11	2316.74	1668.41	1227.99	919.22	682.65	523.96	414.21	327.09	259.12	1100.84	17282.20
1969	4584.78	3248.32	2315.09	1667.70	1225.39	914.60	692.94	519.31	401.82	319.58	253.89	1063.33	17206.74
1970	4580.64	3245.05	2314.16	1668.30	1226.15	913.62	690.19	527.69	398.67	310.34	248.32	1030.97	17154.11
1971	4577.76	3242.30	2312.76	1668.76	1228.44	915.99	690.83	526.64	405.92	308.53	241.63	1003.28	17122.83
1972	4574.65	3239.46	2309.84	1666.25	1223.40	911.97	688.19	523.76	402.52	312.13	238.68	970.08	17060.94
1973	4569.59	3216.45	2291.19	1654.05	1213.98	902.47	680.83	518.47	397.79	307.56	239.94	935.95	16928.27
1974	4563.85	3222.74	2280.65	1642.83	1204.90	894.70	673.09	512.42	393.39	303.65	236.20	909.59	16838.01
1975	4557.48	3222.96	2280.11	1627.66	1188.03	880.28	661.42	502.14	385.38	297.65	231.14	878.50	16712.74
1976	1433.48	3216.22	2269.43	1614.69	1158.48	850.47	637.46	483.35	369.92	285.63	221.94	833.40	13374.48
1977	11626.94	1006.48	2267.81	1616.65	1155.72	833.93	619.30	468.42	358.05	275.69	214.16	797.00	21240.17
1978	1741.21	8199.95	713.38	1621.82	1156.36	828.93	604.96	453.36	345.70	265.85	205.94	760.78	16898.24
1979	1378.55	1230.60	5802.52	507.47	1143.34	814.10	590.04	434.52	328.26	251.82	194.83	713.58	13389.64
1980	3910.93	893.06	834.09	4124.31	353.43	790.41	568.78	415.96	308.80	234.70	181.14	658.13	13273.73
1981	2845.94	2193.88	561.12	589.66	2864.68	243.59	550.62	399.86	294.82	220.20	168.38	606.46	11539.21
1982	8308.87	1629.60	1392.16	396.25	407.49	1960.05	168.44	384.23	281.31	208.67	156.81	555.77	15849.65
1983	6850.38	5380.84	1072.32	942.44	254.59	254.92	1237.84	107.34	246.88	181.86	135.72	466.82	17131.94
1984	3791.45	4598.10	3618.28	728.17	595.58	155.30	156.86	768.51	67.19	155.46	115.20	384.45	15134.53
1985	5972.85	2516.92	3098.86	2473.97	446.50	345.78	90.82	92.55	457.11	40.20	93.58	302.94	15932.08
1986	6432.32	4146.58	1686.56	2021.33	1398.53	234.53	182.74	48.42	49.74	247.18	21.87	217.25	16687.05
1987	2694.64	4482.30	2807.55	1114.60	1159.43	745.83	125.84	98.92	26.43	27.31	136.53	133.10	13552.50
1988	2165.34	1834.13	2980.05	1842.54	648.73	634.82	411.21	70.00	55.47	14.91	15.50	153.97	10826.66
1989	15001.18	1315.06	1132.07	1895.23	999.07	323.77	318.59	208.20	35.73	28.49	7.70	88.24	21353.33
1990	1005.39	10502.29	857.57	686.22	914.25	428.31	139.30	138.31	91.14	15.74	12.63	42.86	14834.00
1991	2239.50	707.57	7163.44	526.46	272.64	293.17	136.87	44.89	44.93	29.79	5.18	18.37	11482.82
1992	5757.58	1574.10	478.03	4254.12	141.09	47.99	50.70	23.85	7.89	7.94	5.30	4.22	12352.80
1993	1372.17	4080.80	1099.57	289.42	2481.45	83.57	28.82	30.77	14.61	4.86	4.93	5.94	9496.92
1994	6245.68	972.49	2880.99	647.27	156.98	1364.90	46.58	16.23	17.48	8.35	2.80	6.29	12366.03
1995	1004.76	4426.17	683.07	1676.05	347.71	85.55	753.99	26.00	9.14	9.90	4.76	5.22	9032.31
1996	3681.29	711.95	3091.44	384.89	865.32	182.25	45.48	405.15	14.10	4.99	5.44	5.53	9397.82
1997	5900.04	2608.81	500.57	1836.64	215.31	491.46	104.97	26.47	237.98	8.34	2.97	6.57	11940.13
1998	4099.41	4177.64	1806.93	280.10	960.25	114.41	265.14	57.28	14.59	132.06	4.66	5.37	11917.83
1999	5539.68	2904.05	2934.33	1046.23	149.32	519.20	62.71	146.81	32.00	8.20	74.74	5.72	13422.98
2000	4761.60	3923.70	1969.51	1684.68	568.96	82.65	291.63	35.60	84.13	18.46	4.76	46.96	13472.67
2001	3146.41	3370.97	2641.70	1041.08	800.59	275.02	40.54	144.59	17.82	42.39	9.37	26.46	11556.94
2002	4947.04	2227.18	2273.60	1322.69	447.85	349.98	121.96	18.17	65.40	8.11	19.43	16.55	11817.97
2003	4484.14	3502.55	1498.29	1159.54	602.43	207.86	165.06	58.21	8.76	31.76	3.97	17.72	11740.27
2004	1100.25	3177.58	2391.22	864.26	633.85	335.23	117.39	94.24	33.54	5.08	18.55	12.77	8783.96
2005	4701.57	779.09	2155.99	1304.40	426.81	318.06	170.55	60.33	48.87	17.51	2.67	16.56	10002.40
2006	5639.17	3329.39	529.64	1181.60	650.37	216.37	163.55	88.63	31.64	25.80	9.30	10.30	11875.76
2007	3346.30	3987.55	2207.69	277.64	563.81	315.48	106.45	81.30	44.46	15.98	13.11	10.03	10969.79
2008	3244.55	2376.50	2764.68	1032.37	111.67	230.92	131.33	44.85	34.61	19.07	6.90	10.07	10007.51
2009	2668.16	2305.49	1675.09	1367.32	443.50	48.93	102.96	59.32	20.48	15.93	8.84	7.93	8723.95
2010	3079.23	1895.96	1630.98	883.84	646.50	213.77	24.00	51.19	29.83	10.39	8.14	8.64	8482.47
2011	3121.28	2188.63	1359.37	908.41	436.75	325.18	109.30	12.43	26.81	15.76	5.53	9.01	8518.45
2012	3141.94	2218.46	1570.49	706.89	394.07	192.51	145.58	49.54	5.69	12.39	7.34	6.82	8451.72

Table 6. Estimated biomass at age (1000 lb) at start of year

Year	1	2	3	4	5	6	7	8	9	10	11	12	Total
1946	1560.7	1614.0	1601.4	1541.0	1450.0	1340.4	1221.8	1100.3	982.2	869.5	765.2	3797.0	17843.6
1947	1560.7	1614.0	1601.4	1541.0	1450.0	1340.4	1221.8	1100.3	982.2	869.5	765.2	3797.0	17843.6
1948	1560.7	1613.8	1599.2	1537.9	1447.3	1337.8	1219.4	1098.3	980.4	868.0	763.9	3790.0	17816.2
1949	1560.2	1613.3	1596.6	1532.7	1441.6	1332.7	1214.7	1094.2	976.6	864.7	761.0	3775.6	17764.0
1950	1559.8	1612.7	1593.7	1526.9	1433.9	1325.0	1207.9	1088.0	971.1	859.8	756.6	3754.5	17689.5
1951	1559.1	1611.8	1590.6	1521.0	1425.5	1315.1	1198.4	1079.6	963.6	853.2	750.9	3725.8	17594.7
1952	1558.2	1610.9	1587.3	1514.8	1417.1	1304.9	1187.0	1069.0	954.2	844.8	743.6	3689.9	17481.6
1953	1557.1	1609.6	1583.8	1508.2	1408.3	1294.3	1175.3	1056.7	942.9	834.9	734.8	3646.4	17352.1
1954	1556.0	1608.3	1579.8	1501.1	1399.1	1283.3	1163.2	1043.9	929.9	823.0	724.7	3595.7	17207.7
1955	1554.7	1606.7	1575.6	1493.6	1389.1	1271.8	1150.6	1030.7	916.5	809.8	712.8	3537.3	17049.7
1956	1553.4	1605.0	1571.2	1485.9	1379.0	1259.9	1137.6	1017.0	902.8	796.3	699.5	3471.2	16878.8
1957	1551.8	1603.2	1566.6	1477.5	1368.2	1247.4	1123.9	1002.9	888.5	782.2	686.1	3397.8	16695.8
1958	1550.1	1601.0	1561.5	1468.9	1356.7	1234.1	1109.6	988.1	873.7	767.9	672.2	3317.7	16501.4
1959	1548.3	1598.8	1556.0	1459.5	1344.6	1220.3	1094.6	972.7	858.3	752.9	657.6	3232.0	16295.7
1960	1546.3	1596.4	1550.3	1449.5	1331.8	1205.5	1078.7	956.4	842.2	737.0	642.9	3140.7	16077.7
1961	1544.1	1593.9	1544.1	1439.2	1318.1	1189.8	1062.0	939.2	825.2	720.7	627.2	3044.8	15848.4
1962	1541.7	1571.9	1528.0	1427.7	1302.3	1171.3	1042.6	919.5	806.0	702.4	610.0	2939.2	15562.4
1963	1538.6	1553.6	1495.4	1407.4	1287.7	1153.7	1023.4	900.1	786.8	684.1	592.8	2832.7	15256.9
1964	1535.5	1584.2	1490.5	1372.4	1264.1	1135.6	1003.3	879.4	766.8	664.9	574.7	2721.6	14993.0
1965	1532.9	1580.7	1516.8	1364.2	1230.6	1113.3	986.6	861.3	748.2	647.1	557.8	2616.4	14755.8
1966	1530.2	1577.6	1511.7	1385.8	1219.8	1080.3	964.1	844.2	730.4	629.4	541.0	2511.3	14525.2
1967	1527.8	1574.8	1508.4	1380.8	1240.5	1072.8	937.0	826.3	716.9	615.3	527.1	2419.4	14347.0
1968	1526.0	1572.6	1506.4	1378.6	1235.7	1090.2	929.7	802.5	701.3	603.6	515.2	2334.0	14195.3
1969	1524.3	1570.8	1505.3	1377.9	1233.0	1084.7	943.8	795.4	680.3	589.7	504.6	2254.4	14064.2
1970	1523.0	1569.0	1504.7	1378.3	1233.7	1083.6	940.1	808.2	675.1	572.8	493.6	2185.9	13967.8
1971	1521.9	1567.7	1503.8	1378.8	1236.1	1086.2	940.9	806.7	687.2	569.5	480.4	2127.0	13906.3
1972	1521.0	1566.4	1501.8	1376.8	1231.1	1081.6	937.2	802.3	681.4	576.1	474.4	2056.7	13806.7
1973	1519.2	1555.4	1489.7	1366.6	1221.6	1070.3	927.3	794.1	673.5	567.7	477.1	1984.4	13646.6
1974	1517.2	1558.4	1482.8	1357.4	1212.5	1061.1	916.7	784.8	666.0	560.4	469.6	1928.4	13515.4
1975	1515.2	1558.4	1482.6	1344.8	1195.3	1043.9	900.8	769.0	652.6	549.4	459.4	1862.5	13334.2
1976	476.6	1555.1	1475.6	1334.0	1165.8	1008.6	868.2	740.3	626.3	527.1	441.1	1767.0	11985.9
1977	3865.4	486.8	1474.5	1335.8	1162.9	989.0	843.5	717.4	606.3	508.8	425.7	1689.8	14105.8
1978	578.9	3965.0	463.9	1340.0	1163.6	983.0	823.9	694.5	585.3	490.5	409.4	1612.9	13111.1
1979	458.3	595.0	3772.8	419.3	1150.6	965.4	803.6	665.6	555.8	464.7	387.4	1512.8	11751.3
1980	1300.3	431.9	542.3	3407.7	355.6	937.4	774.7	637.1	522.9	433.2	360.0	1395.3	11098.1
1981	946.2	1060.9	364.9	487.2	2882.5	288.8	749.8	612.4	499.1	406.3	334.7	1285.7	9918.8
1982	2762.4	787.9	905.2	327.4	410.1	2324.6	229.3	588.4	476.2	385.1	311.7	1178.4	10686.9
1983	2277.4	2601.9	697.3	778.7	256.2	302.3	1685.9	164.5	418.0	335.5	269.8	989.7	10777.1
1984	1260.6	2223.4	2352.6	601.6	599.2	184.1	213.6	1177.0	113.8	286.8	229.1	815.0	10057.0
1985	1985.7	1217.0	2014.8	2044.1	449.3	410.1	123.7	141.8	774.0	74.3	186.1	642.2	10063.0
1986	2138.5	2005.1	1096.6	1670.0	1407.2	278.2	248.9	74.1	84.2	456.1	43.4	460.5	9963.1
1987	896.0	2167.4	1825.4	920.9	1166.7	884.5	171.3	151.5	44.8	50.5	271.4	282.2	8832.6
1988	719.8	886.9	1937.6	1522.3	652.8	752.9	560.0	107.1	93.9	27.6	30.9	326.5	7618.3
1989	4987.3	635.8	736.1	1565.9	1005.3	384.0	433.9	318.8	60.4	52.5	15.2	187.2	10382.7
1990	334.2	5078.3	557.5	567.0	920.0	507.9	189.6	211.9	154.3	29.1	25.1	90.8	8665.9
1991	744.5	342.2	4657.7	435.0	274.3	347.7	186.5	68.8	76.1	54.9	10.4	39.0	7236.9
1992	1914.1	761.3	310.9	3514.8	142.0	56.9	69.0	36.6	13.4	14.6	10.6	9.0	6852.9
1993	456.1	1973.4	715.0	239.2	2497.0	99.2	39.2	47.2	24.7	9.0	9.7	12.6	6122.0
1994	2076.5	470.2	1873.3	534.8	157.9	1618.6	63.5	24.9	29.5	15.4	5.5	13.4	6883.5
1995	334.0	2140.2	444.2	1384.7	349.9	101.4	1026.9	39.9	15.4	18.3	9.5	11.0	5875.5
1996	1223.8	344.4	2010.2	317.9	870.8	216.1	61.9	620.6	23.8	9.3	10.8	11.7	5721.2
1997	1961.5	1261.5	325.4	1517.4	216.7	582.9	142.9	40.6	403.0	15.4	6.0	13.9	6487.1
1998	1362.9	2020.1	1174.8	231.5	966.3	135.6	361.1	87.7	24.7	243.6	9.3	11.5	6629.1
1999	1841.7	1404.3	1907.9	864.4	150.4	615.8	85.3	224.9	54.2	15.2	148.6	12.1	7324.6
2000	1583.1	1897.3	1280.7	1392.0	572.5	98.1	397.3	54.5	142.4	34.2	9.5	99.6	7560.8
2001	1046.1	1630.1	1717.6	860.2	805.6	326.1	55.1	221.6	30.2	78.3	18.5	56.0	6845.4
2002	1644.6	1077.0	1478.4	1092.8	450.6	415.1	166.0	27.8	110.7	15.0	38.6	35.1	6551.9
2003	1490.8	1693.6	974.2	958.1	606.3	246.5	224.9	89.1	14.8	58.6	7.9	37.5	6402.2
2004	365.7	1536.6	1554.7	714.1	637.8	397.5	159.8	144.4	56.9	9.5	36.8	27.1	5641.0
2005	1563.1	376.8	1401.9	1077.6	429.5	377.2	232.4	92.4	82.7	32.4	5.3	35.1	5706.2
2006	1874.8	1609.8	344.4	976.2	654.3	256.6	222.7	135.8	53.6	47.6	18.5	21.8	6216.4
2007	1112.5	1928.2	1435.4	229.5	567.2	374.1	145.1	124.6	75.2	29.5	26.0	21.2	6068.7
2008	1078.7	1149.0	1797.6	853.0	112.4	273.8	178.8	68.8	58.6	35.3	13.7	21.4	5641.0
2009	887.1	1114.9	1089.1	1129.6	446.2	58.0	140.2	90.8	34.6	29.3	17.6	16.8	5054.5
2010	1023.8	916.7	1060.4	730.2	650.6	253.5	32.6	78.5	50.5	19.2	16.1	18.3	4850.6
2011	1037.7	1058.2	883.8	750.5	439.4	385.6	148.8	19.0	45.4	29.1	11.0	19.2	4828.1
2012	1044.6	1072.8	1021.2	584.0	396.6	228.4	198.2	75.8	9.7	22.9	14.6	14.6	4683.1

Table 7. Estimated time series of status indicators, fishing mortality, and biomass. Fishing mortality rate is apical F, which includes discard mortalities. Total biomass (B, mt) is at the start of the year, and spawning biomass (SSB, population fecundity, 1E12 eggs) at the time of peak spawning (mid-year). The MSST *is defined by* $\text{MSST} = (1 - M)\text{SSB}_{\text{MSY}}$, *with constant* $M = 0.22$. *SPR is static spawning potential ratio.*

Year	F	F/F_{MSY}	B	B/B_{unfished}	SSB	$\text{SSB}/\text{SSB}_{\text{MSY}}$	SSB/MSST	SPR
1946	0.00000	0.00000	8094	1.000	24.26	4.057	5.20	1.000
1947	0.00202	0.00270	8094	1.000	24.24	4.054	5.20	0.989
1948	0.00408	0.00543	8081	0.998	24.18	4.044	5.18	0.978
1949	0.00616	0.00821	8058	0.996	24.09	4.029	5.17	0.967
1950	0.00830	0.01105	8024	0.991	23.97	4.008	5.14	0.955
1951	0.01050	0.01399	7981	0.986	23.82	3.984	5.11	0.944
1952	0.01278	0.01703	7930	0.980	23.65	3.955	5.07	0.933
1953	0.01516	0.02020	7871	0.972	23.45	3.922	5.03	0.921
1954	0.01765	0.02352	7805	0.964	23.23	3.886	4.98	0.909
1955	0.02027	0.02700	7734	0.956	23.00	3.847	4.93	0.897
1956	0.02303	0.03068	7656	0.946	22.75	3.804	4.88	0.885
1957	0.02596	0.03458	7573	0.936	22.48	3.759	4.82	0.872
1958	0.02907	0.03872	7485	0.925	22.19	3.712	4.76	0.858
1959	0.03239	0.04315	7392	0.913	21.89	3.661	4.69	0.844
1960	0.03594	0.04788	7293	0.901	21.57	3.608	4.63	0.829
1961	0.03989	0.05314	7189	0.888	21.21	3.547	4.55	0.796
1962	0.04376	0.05829	7059	0.872	20.79	3.476	4.46	0.774
1963	0.04753	0.06332	6920	0.855	20.37	3.407	4.37	0.781
1964	0.05012	0.06676	6801	0.840	20.02	3.348	4.29	0.775
1965	0.05191	0.06915	6693	0.827	19.69	3.293	4.22	0.765
1966	0.05211	0.06942	6589	0.814	19.41	3.245	4.16	0.769
1967	0.05161	0.06875	6508	0.804	19.17	3.207	4.11	0.768
1968	0.05164	0.06879	6439	0.796	18.98	3.173	4.07	0.766
1969	0.05059	0.06739	6379	0.788	18.82	3.147	4.03	0.770
1970	0.04896	0.06523	6336	0.783	18.71	3.129	4.01	0.776
1971	0.05493	0.07318	6308	0.779	18.59	3.109	3.99	0.760
1972	0.06129	0.08164	6263	0.774	18.40	3.078	3.95	0.733
1973	0.06225	0.08293	6190	0.765	18.20	3.043	3.90	0.736
1974	0.07110	0.09471	6130	0.757	17.97	3.005	3.85	0.715
1975	0.09174	0.12220	6048	0.747	17.61	2.945	3.78	0.671
1976	0.08620	0.11482	5437	0.672	15.96	2.670	3.42	0.681
1977	0.09000	0.11989	6398	0.791	18.33	3.065	3.93	0.683
1978	0.10895	0.14513	5947	0.735	17.62	2.947	3.78	0.652
1979	0.12759	0.16996	5330	0.659	15.50	2.592	3.32	0.558
1980	0.23710	0.31584	5034	0.622	14.18	2.372	3.04	0.457
1981	0.21656	0.28847	4499	0.556	12.64	2.113	2.71	0.462
1982	0.22861	0.30452	4847	0.599	13.15	2.200	2.82	0.451
1983	0.25466	0.33924	4888	0.604	13.65	2.283	2.93	0.460
1984	0.30558	0.40706	4562	0.564	12.89	2.156	2.76	0.435
1985	0.40693	0.54207	4565	0.564	12.47	2.085	2.67	0.406
1986	0.39169	0.52176	4519	0.558	12.49	2.088	2.68	0.417
1987	0.36452	0.48558	4006	0.495	11.25	1.881	2.41	0.409
1988	0.45858	0.61087	3456	0.427	9.23	1.543	1.98	0.326
1989	0.61244	0.81583	4709	0.582	12.26	2.050	2.63	0.349
1990	0.91040	1.21273	3931	0.486	10.92	1.826	2.34	0.334
1991	1.52512	2.03160	3283	0.406	8.48	1.418	1.82	0.301
1992	0.28104	0.37438	3108	0.384	8.67	1.450	1.86	0.445
1993	0.35476	0.47258	2777	0.343	7.87	1.317	1.69	0.413
1994	0.36402	0.48491	3122	0.386	8.51	1.424	1.83	0.406
1995	0.40310	0.53696	2665	0.329	7.48	1.250	1.60	0.387
1996	0.32289	0.43012	2595	0.321	7.14	1.195	1.53	0.425
1997	0.39050	0.52018	2943	0.364	8.05	1.347	1.73	0.388
1998	0.37191	0.49542	3007	0.372	8.53	1.426	1.83	0.403
1999	0.35113	0.46774	3322	0.410	9.26	1.549	1.99	0.399
2000	0.48599	0.64738	3429	0.424	9.32	1.558	2.00	0.351
2001	0.58555	0.78000	3105	0.384	8.23	1.376	1.76	0.329
2002	0.52845	0.70395	2972	0.367	7.88	1.319	1.69	0.339
2003	0.34597	0.46087	2904	0.359	8.18	1.368	1.75	0.403
2004	0.44754	0.59616	2559	0.316	7.03	1.175	1.51	0.364
2005	0.43795	0.58339	2588	0.320	6.88	1.150	1.47	0.368
2006	0.48190	0.64194	2820	0.348	7.66	1.280	1.64	0.346
2007	0.65278	0.86956	2753	0.340	7.43	1.242	1.59	0.320
2008	0.58692	0.78182	2559	0.316	6.84	1.143	1.47	0.338
2009	0.49104	0.65411	2293	0.283	6.23	1.042	1.34	0.363
2010	0.44692	0.59534	2200	0.272	6.03	1.009	1.29	0.383
2011	0.57716	0.76883	2190	0.271	5.86	0.981	1.26	0.349
2012	.	.	2124	0.262	.	.	.	.

Table 8. Selectivity at age for MARMAP Florida snapper traps (fst), MARMAP chevron traps (cvt), commercial lines (c.hal), headboat (hb), recreational (rec), commercial discard mortalities (D.c.hal), headboat discard mortalities (D.hb), selectivity of landings averaged across fisheries (L.avg), and selectivity of discard mortalities averaged across fisheries (D.avg). Selectivity of landings from the commercial combined was assumed equal to that from commercial lines, and selectivity of discards from the general recreational fleet was assumed equal to that from the headboat fleet. TL is total length. For time-varying selectivities, values shown are from the terminal assessment year.

Age	TL(mm)	TL(in)	fst	cvt	c.hal	hb	rec	D.c.hal	D.hb	L.avg	D.avg	L.avg+D.avg
1	228.3	9.0	1	0.003	0.000	0.007	0.002	0.000	0.000	0.001	0.000	0.001
2	259.7	10.2	0	0.015	0.009	0.260	0.064	0.268	0.262	0.041	0.023	0.064
3	287.6	11.3	0	1.000	0.573	0.946	0.705	1.000	1.000	0.599	0.086	0.685
4	312.3	12.3	0	0.991	0.995	0.999	0.988	0.962	0.455	0.949	0.051	1.000
5	334.2	13.2	0	0.966	1.000	1.000	1.000	0.856	0.343	0.954	0.041	0.995
6	353.6	13.9	0	0.926	1.000	1.000	1.000	0.704	0.264	0.954	0.033	0.987
7	370.8	14.6	0	0.872	1.000	1.000	1.000	0.536	0.207	0.954	0.025	0.979
8	386.1	15.2	0	0.808	1.000	1.000	1.000	0.377	0.168	0.954	0.019	0.973
9	399.7	15.7	0	0.735	1.000	1.000	1.000	0.246	0.139	0.954	0.014	0.968
10	411.7	16.2	0	0.658	1.000	1.000	1.000	0.148	0.117	0.954	0.011	0.965
11	422.4	16.6	0	0.579	1.000	1.000	1.000	0.082	0.101	0.954	0.008	0.962
12	431.8	17.0	0	0.501	1.000	1.000	1.000	0.042	0.089	0.954	0.007	0.961

Table 9. Estimated time series of fully selected fishing mortality rates for commercial lines (F.c.hal), commercial historic trawl (F.c.htr), commercial combined (F.c.cmb), headboat (F.hb), general recreational (F.rec), commercial discard mortalities (F.c.hal.D), headboat discard mortalities (F.hb.D), general recreational discard mortalities (F.rec.D). Also shown is apical F, the maximum F at age summed across fleets, which may not equal the sum of fully selected F's because of dome-shaped selectivities.

Year	F.c.hal	F.c.htr	F.c.cmb	F.hb	F.rec	F.c.hal.D	F.hb.D	F.rec.D	Apical F
1947	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.002
1948	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.004
1949	0.000	0.000	0.000	0.004	0.002	0.000	0.000	0.000	0.006
1950	0.000	0.000	0.000	0.005	0.003	0.000	0.000	0.001	0.008
1951	0.000	0.000	0.000	0.006	0.003	0.000	0.000	0.001	0.011
1952	0.000	0.000	0.000	0.008	0.004	0.000	0.000	0.001	0.013
1953	0.000	0.000	0.000	0.009	0.005	0.000	0.001	0.001	0.015
1954	0.000	0.000	0.000	0.011	0.005	0.000	0.001	0.001	0.018
1955	0.000	0.000	0.000	0.013	0.006	0.000	0.001	0.001	0.020
1956	0.000	0.000	0.000	0.015	0.006	0.000	0.001	0.001	0.023
1957	0.000	0.000	0.000	0.017	0.007	0.000	0.001	0.001	0.026
1958	0.000	0.000	0.000	0.019	0.008	0.000	0.001	0.002	0.029
1959	0.000	0.000	0.000	0.022	0.008	0.000	0.001	0.002	0.032
1960	0.000	0.000	0.000	0.024	0.009	0.000	0.001	0.002	0.036
1961	0.002	0.012	0.000	0.027	0.010	0.000	0.002	0.002	0.040
1962	0.001	0.022	0.000	0.030	0.010	0.000	0.002	0.002	0.044
1963	0.002	0.000	0.000	0.033	0.011	0.000	0.002	0.002	0.048
1964	0.001	0.000	0.000	0.035	0.011	0.000	0.002	0.002	0.050
1965	0.003	0.000	0.000	0.037	0.012	0.000	0.002	0.002	0.052
1966	0.000	0.000	0.000	0.037	0.012	0.000	0.002	0.002	0.052
1967	0.002	0.000	0.000	0.036	0.012	0.000	0.002	0.002	0.052
1968	0.004	0.000	0.000	0.035	0.013	0.000	0.002	0.002	0.052
1969	0.004	0.000	0.000	0.034	0.013	0.000	0.002	0.002	0.051
1970	0.002	0.000	0.000	0.033	0.013	0.000	0.002	0.002	0.049
1971	0.008	0.000	0.000	0.033	0.013	0.000	0.002	0.002	0.055
1972	0.009	0.000	0.006	0.039	0.013	0.000	0.002	0.002	0.061
1973	0.011	0.000	0.003	0.038	0.013	0.000	0.002	0.002	0.062
1974	0.016	0.000	0.001	0.042	0.013	0.000	0.002	0.002	0.071
1975	0.030	0.000	0.001	0.048	0.013	0.000	0.002	0.002	0.092
1976	0.030	0.000	0.007	0.042	0.013	0.000	0.002	0.002	0.086
1977	0.040	0.000	0.003	0.036	0.014	0.000	0.002	0.003	0.090
1978	0.053	0.000	0.000	0.045	0.011	0.000	0.002	0.002	0.109
1979	0.072	0.000	0.088	0.043	0.012	0.000	0.002	0.002	0.128
1980	0.074	0.000	0.232	0.041	0.015	0.000	0.004	0.005	0.237
1981	0.081	0.000	0.211	0.039	0.017	0.000	0.003	0.006	0.217
1982	0.135	0.000	0.084	0.057	0.036	0.000	0.003	0.006	0.229
1983	0.161	0.000	0.048	0.053	0.040	0.000	0.002	0.003	0.255
1984	0.223	0.000	0.060	0.039	0.044	0.000	0.001	0.001	0.306
1985	0.283	0.000	0.012	0.069	0.055	0.000	0.003	0.002	0.407
1986	0.281	0.000	0.009	0.070	0.040	0.000	0.003	0.002	0.392
1987	0.243	0.000	0.032	0.095	0.026	0.000	0.003	0.002	0.365
1988	0.313	0.000	0.143	0.117	0.028	0.000	0.004	0.003	0.459
1989	0.427	0.000	0.029	0.119	0.036	0.000	0.007	0.012	0.612
1990	0.731	0.000	0.077	0.079	0.023	0.000	0.002	0.004	0.910
1991	1.390	0.000	0.022	0.089	0.024	0.000	0.002	0.003	1.525
1992	0.159	0.000	0.000	0.082	0.032	0.013	0.013	0.015	0.281
1993	0.231	0.000	0.002	0.085	0.030	0.013	0.007	0.005	0.355
1994	0.236	0.000	0.002	0.096	0.022	0.014	0.009	0.008	0.364
1995	0.269	0.000	0.001	0.100	0.023	0.021	0.007	0.013	0.403
1996	0.195	0.000	0.000	0.093	0.026	0.021	0.008	0.005	0.323
1997	0.226	0.000	0.001	0.115	0.033	0.034	0.012	0.007	0.390
1998	0.232	0.000	0.001	0.097	0.034	0.017	0.006	0.005	0.372
1999	0.232	0.000	0.001	0.071	0.034	0.012	0.008	0.022	0.351
2000	0.353	0.000	0.000	0.077	0.043	0.013	0.008	0.019	0.486
2001	0.450	0.000	0.001	0.079	0.045	0.014	0.008	0.012	0.586
2002	0.387	0.000	0.000	0.073	0.046	0.036	0.008	0.012	0.528
2003	0.228	0.000	0.002	0.053	0.049	0.017	0.006	0.019	0.346
2004	0.318	0.000	0.001	0.067	0.054	0.007	0.008	0.013	0.448
2005	0.313	0.000	0.000	0.071	0.042	0.014	0.008	0.012	0.438
2006	0.308	0.000	0.001	0.088	0.076	0.011	0.010	0.011	0.482
2007	0.407	0.000	0.003	0.154	0.067	0.008	0.018	0.029	0.653
2008	0.401	0.000	0.012	0.075	0.071	0.015	0.017	0.037	0.587
2009	0.300	0.000	0.013	0.071	0.077	0.010	0.023	0.028	0.491
2010	0.333	0.000	0.012	0.047	0.031	0.013	0.017	0.014	0.447
2011	0.465	0.000	0.015	0.049	0.029	0.012	0.018	0.004	0.577

Table 10. Estimated time series of landings in numbers (1000 fish) for commercial lines (L.c.hal), commercial historical trawl (L.c.htr), commercial combined (L.c.cmb), headboat (L.hb), and general recreational (L.rec).

Year	L.c.hal	L.c.htr	L.c.cmb	L.hb	L.rec	Total
1947	.	.	.	14.63	9.01	23.64
1948	.	.	.	30.58	17.08	47.66
1949	.	.	.	46.80	25.10	71.90
1950	.	.	.	63.43	33.06	96.49
1951	.	.	.	80.61	40.94	121.55
1952	.	.	.	98.48	48.71	147.19
1953	.	.	.	117.17	56.35	173.53
1954	.	.	.	136.84	63.85	200.69
1955	.	.	.	157.61	71.18	228.79
1956	.	.	.	179.63	78.33	257.95
1957	.	.	.	203.03	85.26	288.29
1958	0.14	.	.	227.96	91.96	320.06
1959	0.89	.	.	254.56	98.41	353.86
1960	1.23	.	.	282.96	104.59	388.78
1961	13.69	64.53	.	312.78	110.45	501.45
1962	7.69	114.48	.	341.59	115.85	579.62
1963	14.95	.	.	366.41	120.64	502.00
1964	4.85	.	.	384.29	124.65	513.79
1965	15.78	.	.	392.26	127.72	535.76
1966	2.45	.	.	388.65	129.75	520.85
1967	10.26	.	.	377.02	130.86	518.15
1968	23.23	.	.	362.22	131.23	516.68
1969	22.90	.	.	349.08	131.05	503.03
1970	14.30	.	.	342.47	130.50	487.27
1971	48.76	.	1.06	345.46	129.73	525.02
1972	50.72	.	31.69	402.82	128.79	614.01
1973	63.70	.	16.44	383.91	127.69	591.74
1974	88.43	.	7.33	421.70	126.46	643.92
1975	162.42	.	7.60	477.33	125.11	772.46
1976	158.49	.	18.24	399.74	123.65	700.13
1977	204.95	.	33.35	317.30	122.11	677.71
1978	258.29	.	2.39	487.53	120.50	868.71
1979	320.17	.	142.62	425.39	118.84	1007.02
1980	393.96	.	770.37	323.00	117.15	1604.47
1981	389.43	.	646.10	270.99	115.01	1421.52
1982	488.38	.	623.23	362.32	230.53	1704.46
1983	466.94	.	380.66	399.04	304.27	1550.91
1984	557.43	.	302.65	324.43	366.59	1551.11
1985	806.90	.	69.71	529.81	420.90	1827.31
1986	822.00	.	64.99	533.10	307.37	1727.47
1987	634.70	.	128.87	730.97	202.19	1696.73
1988	801.97	.	348.31	740.87	179.12	2070.27
1989	990.39	.	93.30	661.27	202.69	1947.65
1990	1055.02	.	152.22	655.85	190.93	2054.02
1991	1466.52	.	84.73	600.51	164.80	2316.57
1992	591.72	.	0.21	345.30	136.45	1073.69
1993	631.02	.	6.23	327.06	116.23	1080.54
1994	705.27	.	7.24	369.73	85.88	1168.12
1995	665.63	.	2.06	354.74	81.07	1103.50
1996	554.56	.	1.04	340.35	93.30	989.25
1997	542.79	.	1.44	364.76	104.55	1013.54
1998	511.50	.	1.73	341.57	120.20	975.01
1999	661.14	.	3.40	381.95	165.52	1212.00
2000	1008.12	.	1.19	428.22	209.67	1647.20
2001	1234.66	.	2.44	418.85	212.66	1868.61
2002	1011.59	.	1.01	335.53	191.31	1539.45
2003	542.80	.	5.20	251.79	204.08	1003.88
2004	818.41	.	2.02	329.06	237.85	1387.35
2005	828.86	.	0.66	275.40	154.02	1258.94
2006	594.83	.	1.05	344.64	254.82	1195.34
2007	758.03	.	5.76	507.90	150.81	1422.50
2008	902.85	.	26.75	262.87	187.30	1379.77
2009	657.27	.	28.57	225.35	188.09	1099.28
2010	690.29	.	25.76	138.42	70.96	925.42
2011	857.95	.	28.25	133.41	60.66	1080.27

Table 11. Estimated time series of landings in whole weight (1000 lb) for commercial lines (L.c.hal), commercial historical trawl (L.c.htr), commercial combined (L.c.cmb), headboat (L.hb), and general recreational (L.rec).

Year	L.c.hal	L.c.htr	L.c.cmb	L.hb	L.rec	Total
1947	.	.	.	16.24	10.00	26.24
1948	.	.	.	33.92	18.94	52.87
1949	.	.	.	51.89	27.83	79.71
1950	.	.	.	70.26	36.62	106.87
1951	.	.	.	89.16	45.28	134.44
1952	.	.	.	108.73	53.78	162.51
1953	.	.	.	129.10	62.09	191.18
1954	.	.	.	150.38	70.17	220.54
1955	.	.	.	172.70	78.00	250.69
1956	.	.	.	196.18	85.54	281.72
1957	.	.	.	220.94	92.78	313.72
1958	0.19	.	.	247.10	99.68	346.97
1959	1.26	.	.	274.75	106.21	382.22
1960	1.75	.	.	303.99	112.36	418.10
1961	19.32	24.02	.	334.45	118.10	495.89
1962	10.82	42.58	.	363.88	123.41	540.70
1963	20.97	.	.	388.60	127.94	537.51
1964	6.79	.	.	404.39	131.17	542.35
1965	22.01	.	.	409.58	133.36	564.96
1966	3.40	.	.	402.98	134.53	540.91
1967	14.17	.	.	388.57	134.87	537.61
1968	31.94	.	.	371.27	134.51	537.72
1969	31.35	.	.	356.10	133.68	521.13
1970	19.51	.	.	348.05	132.63	500.19
1971	66.32	.	0.40	349.95	131.41	548.08
1972	68.79	.	11.79	406.69	130.03	617.31
1973	86.19	.	6.11	386.37	128.51	607.18
1974	119.39	.	2.73	422.56	126.72	671.39
1975	218.66	.	2.83	475.10	124.53	821.11
1976	212.41	.	7.52	401.79	124.29	746.01
1977	273.32	.	11.30	319.69	123.03	727.34
1978	345.08	.	1.05	434.08	107.29	887.50
1979	430.90	.	54.16	405.25	113.21	1003.52
1980	482.65	.	268.61	336.20	121.94	1209.40
1981	500.89	.	242.89	287.70	122.10	1153.58
1982	672.79	.	215.66	366.14	232.96	1487.55
1983	645.74	.	142.78	337.18	257.10	1382.80
1984	734.10	.	117.96	256.56	289.90	1398.52
1985	920.52	.	24.98	421.49	334.84	1701.83
1986	896.40	.	23.98	404.19	233.04	1557.62
1987	697.90	.	51.63	544.79	150.69	1445.01
1988	854.21	.	131.54	589.68	142.56	1717.99
1989	1041.59	.	90.07	488.44	149.72	1769.82
1990	1141.29	.	148.71	396.71	115.49	1802.20
1991	1332.74	.	61.42	405.06	111.16	1910.37
1992	765.08	.	0.28	347.16	137.18	1249.71
1993	866.61	.	8.55	337.34	119.89	1332.39
1994	948.51	.	9.73	382.94	88.95	1430.14
1995	928.34	.	2.88	368.47	84.21	1383.90
1996	743.71	.	1.39	353.41	96.88	1195.40
1997	759.07	.	2.01	386.88	110.89	1258.86
1998	708.16	.	2.39	344.52	121.24	1176.31
1999	876.66	.	4.51	395.11	174.87	1451.15
2000	1348.39	.	1.59	441.03	221.27	2012.29
2001	1633.21	.	3.23	430.95	223.38	2290.77
2002	1334.20	.	1.34	349.35	203.29	1888.18
2003	727.85	.	6.97	258.48	214.94	1208.24
2004	1086.06	.	2.68	340.52	250.91	1680.17
2005	1100.09	.	0.87	298.28	169.32	1568.56
2006	826.41	.	1.46	358.45	274.10	1460.42
2007	1012.11	.	7.69	622.87	195.16	1837.83
2008	1158.61	.	34.33	320.59	235.93	1749.45
2009	857.00	.	37.25	279.31	241.13	1414.68
2010	911.29	.	34.00	173.54	92.05	1210.88
2011	1145.44	.	37.72	167.65	79.37	1430.18

Table 12. Estimated time series of discard mortalities in numbers (1000 fish) for commercial lines (D.c.hal), headboat (D.hb), and general recreational (D.rec).

Year	D.c.hal	D.hb	D.rec	Total
1947	.	0.34	0.74	1.09
1948	.	0.72	1.41	2.12
1949	.	1.10	2.07	3.16
1950	.	1.49	2.72	4.21
1951	.	1.89	3.37	5.26
1952	.	2.31	4.01	6.32
1953	.	2.75	4.64	7.39
1954	.	3.21	5.26	8.47
1955	.	3.70	5.86	9.56
1956	.	4.21	6.45	10.66
1957	.	4.76	7.02	11.78
1958	.	5.35	7.57	12.92
1959	.	5.97	8.10	14.07
1960	.	6.64	8.61	15.25
1961	.	7.34	9.10	16.43
1962	.	8.01	9.54	17.55
1963	.	8.59	9.94	18.53
1964	.	9.01	10.27	19.28
1965	.	9.20	10.52	19.72
1966	.	9.11	10.69	19.80
1967	.	8.84	10.78	19.62
1968	.	8.49	10.81	19.30
1969	.	8.19	10.79	18.98
1970	.	8.03	10.75	18.78
1971	.	8.10	10.68	18.78
1972	.	9.45	10.61	20.05
1973	.	9.00	10.52	19.52
1974	.	9.89	10.41	20.30
1975	.	11.19	10.30	21.50
1976	.	9.37	10.18	19.56
1977	.	7.44	10.06	17.50
1978	.	11.43	9.92	21.36
1979	.	9.98	9.79	19.76
1980	.	7.57	9.65	17.22
1981	.	6.36	12.67	19.03
1982	.	8.50	15.70	24.20
1983	.	9.36	12.12	21.48
1984	.	7.61	8.55	16.16
1985	.	12.42	9.15	21.58
1986	.	12.50	9.15	21.66
1987	.	17.14	9.15	26.30
1988	.	17.38	9.76	27.14
1989	.	15.51	24.26	39.77
1990	.	15.38	27.16	42.54
1991	.	14.08	16.11	30.19
1992	30.05	25.65	30.23	85.93
1993	33.67	24.29	18.30	76.26
1994	41.63	27.47	25.37	94.46
1995	48.46	26.36	46.01	120.83
1996	64.94	25.28	15.88	106.09
1997	60.62	27.10	15.75	103.47
1998	46.57	25.37	22.58	94.52
1999	39.72	32.87	97.87	170.45
2000	39.97	36.85	81.93	158.75
2001	46.70	36.05	52.15	134.90
2002	100.03	28.87	41.14	170.04
2003	43.12	21.67	69.66	134.45
2004	20.64	33.43	53.43	107.50
2005	33.24	19.95	29.30	82.49
2006	19.45	29.01	30.01	78.46
2007	21.54	48.55	77.82	147.92
2008	43.65	50.39	107.68	201.72
2009	29.39	53.09	65.42	147.91
2010	36.30	35.99	30.72	103.01
2011	31.03	34.54	7.87	73.45

Table 13. Estimated time series of discard mortalities in whole weight (1000 lb) for commercial lines (D.c.hal), headboat (D.hb), and general recreational (D.rec).

Year	D.c.hal	D.hb	D.rec	Total
1947	.	0.10	0.21	0.31
1948	.	0.21	0.40	0.61
1949	.	0.32	0.59	0.91
1950	.	0.43	0.78	1.21
1951	.	0.54	0.97	1.51
1952	.	0.66	1.15	1.82
1953	.	0.79	1.33	2.13
1954	.	0.92	1.51	2.44
1955	.	1.06	1.69	2.75
1956	.	1.21	1.86	3.07
1957	.	1.37	2.02	3.39
1958	.	1.54	2.18	3.71
1959	.	1.72	2.33	4.05
1960	.	1.91	2.48	4.38
1961	.	2.11	2.61	4.72
1962	.	2.30	2.74	5.05
1963	.	2.47	2.86	5.33
1964	.	2.59	2.95	5.54
1965	.	2.64	3.02	5.67
1966	.	2.62	3.07	5.69
1967	.	2.54	3.10	5.64
1968	.	2.44	3.10	5.55
1969	.	2.35	3.10	5.45
1970	.	2.31	3.09	5.39
1971	.	2.33	3.07	5.40
1972	.	2.71	3.05	5.76
1973	.	2.59	3.02	5.61
1974	.	2.84	2.99	5.83
1975	.	3.21	2.96	6.17
1976	.	2.69	2.92	5.62
1977	.	2.16	2.92	5.08
1978	.	3.23	2.80	6.04
1979	.	2.90	2.84	5.74
1980	.	2.21	2.81	5.02
1981	.	1.82	3.64	5.46
1982	.	2.45	4.52	6.97
1983	.	2.65	3.43	6.09
1984	.	2.18	2.45	4.62
1985	.	3.58	2.64	6.21
1986	.	3.57	2.61	6.18
1987	.	4.90	2.62	7.52
1988	.	5.02	2.82	7.83
1989	.	4.47	6.99	11.46
1990	.	4.33	7.64	11.97
1991	.	4.09	4.68	8.76
1992	13.29	7.38	8.69	29.36
1993	14.42	6.90	5.20	26.52
1994	18.13	7.95	7.34	33.42
1995	20.59	7.46	13.02	41.07
1996	28.25	7.33	4.60	40.19
1997	26.19	7.70	4.48	38.37
1998	19.74	7.21	6.42	33.37
1999	17.04	11.16	33.22	61.42
2000	17.09	12.42	27.61	57.12
2001	20.00	12.19	17.64	49.83
2002	43.14	9.82	13.99	66.96
2003	18.42	7.29	23.44	49.15
2004	8.84	11.31	18.07	38.21
2005	14.52	6.88	10.11	31.50
2006	8.29	9.70	10.03	28.01
2007	9.11	20.54	32.92	62.56
2008	18.70	21.60	46.15	86.45
2009	21.78	22.83	28.13	72.73
2010	27.49	15.52	13.24	56.25
2011	23.46	14.82	3.38	41.66

Table 14. Estimated status indicators, benchmarks, and related quantities from the Beaufort catch-age model, conditional on estimated current selectivities averaged across fleets. Precision is represented by standard errors (SE) approximated from Monte Carlo/Bootstrap analysis. Estimates of yield do not include discards; D_{MSY} represents discard mortalities expected when fishing at F_{MSY}. Rate estimates (F) are in units of y^{-1}; status indicators are dimensionless; and biomass estimates are in units of metric tons or pounds, as indicated. Spawning stock biomass (SSB) is measured as population fecundity.

Quantity	Units	Estimate	SE
F_{MSY}	y^{-1}	0.75	0.619
$85\%F_{MSY}$	y^{-1}	0.638	0.527
$75\%F_{MSY}$	y^{-1}	0.563	0.465
$65\%F_{MSY}$	y^{-1}	0.488	0.403
$F_{30\%}$	y^{-1}	0.827	0.386
$F_{40\%}$	y^{-1}	0.404	0.123
$F_{50\%}$	y^{-1}	0.238	0.057
B_{MSY}	mt	2252	393
SSB_{MSY}	1E12 eggs	5.98	1.31
MSST	1E12 eggs	4.66	1.08
MSY	1000 lb	1563	224
D_{MSY}	1000 fish	149	70
R_{MSY}	1000 age-1 fish	3718	630
Y at $85\%F_{MSY}$	1000 lb	1559	225
Y at $75\%F_{MSY}$	1000 lb	1551	228
Y at $65\%F_{MSY}$	1000 lb	1535	233
$F_{2009-2011}/F_{MSY}$	—	0.67	0.57
SSB_{2011}/MSST	—	1.26	0.41
SSB_{2011}/SSB_{MSY}	—	0.98	0.30

Table 15. Results from sensitivity runs of the Beaufort assessment model. Current F represented by geometric mean of last three assessment years.

Run	Description	F_{MSY}	SSB_{MSY} (1E12 eggs)	MSY(1000 lb)	$\text{F}_{\text{current}}/F_{\text{MSY}}$	SSB_{2011}/MSST	steep	R0(1000)
Base	—	0.751	5.98	1563	0.67	1.26	0.71	3922
S1	h=0.56	0.353	8.1	1338	1.44	0.85	0.56	4193
S2	h=0.56 + S17 wgts	0.352	7.2	1196	1.55	0.81	0.56	3731
S3	Indices through 2011	0.725	5.87	1512	0.8	1.15	0.71	3905
S4	q saturates 2003	0.862	5.66	1596	0.57	1.35	0.74	3888

Table 16. Acceptable biological catch (ABC) in units of 1000 lb whole weight, based on the annual probability of overfishing $P^{\star} = 0.275$. F = fishing mortality rate (per yr), SSB = mid-year spawning stock (1E12 eggs), Pr(SSB < MSST) = proportion of replicates overfished (i.e., SSB below the base-run point estimate of MSST), R = recruits (1000 age-1 fish), D = discard mortalities (1000 lb whole weight), and L = landings (1000 lb whole weight). ABC (1000 lb whole weight) includes landings and discard mortalities. Annual ABCs are a single quantity among the 10,000 replicate projections; other values presented are medians.

Year	F	$P^{\star}$	SSB	Pr(SSB < MSST)	R	D(1000 lb)	L(1000 lb)	ABC(1000 lb)
2012	0.544	0.355	6.12	0.25	2926	53	1321	–
2013	0.427	0.275	6.32	0.25	2890	44	1079	1123
2014	0.403	0.275	6.55	0.25	2872	44	1112	1156
2015	0.385	0.275	6.81	0.25	2880	43	1128	1171
2016	0.367	0.275	7.06	0.25	2862	42	1128	1171

Table 17. Acceptable biological catch (ABC) in units of 1000 lb whole weight, based on the annual probability of overfishing $P^{\star} = 0.5$. F = fishing mortality rate (per yr), SSB = mid-year spawning stock (1E12 eggs), Pr(SSB < MSST) = proportion of replicates overfished (i.e., SSB below the base-run point estimate of MSST), R = recruits (1000 age-1 fish), D = discard mortalities (1000 lb whole weight), and L = landings (1000 lb whole weight). ABC (1000 lb whole weight) includes landings and discard mortalities. Annual ABCs are a single quantity among the 10,000 replicate projections; other values presented are medians.

Year	F	$P^{\star}$	SSB	Pr(SSB < MSST)	R	D(1000 lb)	L(1000 lb)	ABC(1000 lb)
2012	0.544	0.355	6.12	0.25	2926	53	1321	–
2013	0.72	0.5	5.92	0.32	2890	68	1629	1697
2014	0.693	0.5	5.7	0.36	2800	64	1471	1537
2015	0.681	0.5	5.64	0.39	2722	62	1411	1476
2016	0.667	0.5	5.63	0.4	2648	59	1371	1434

8 Figures

Figure 1. Mean length at age (mm) and estimated upper and lower 95% confidence intervals of the population.

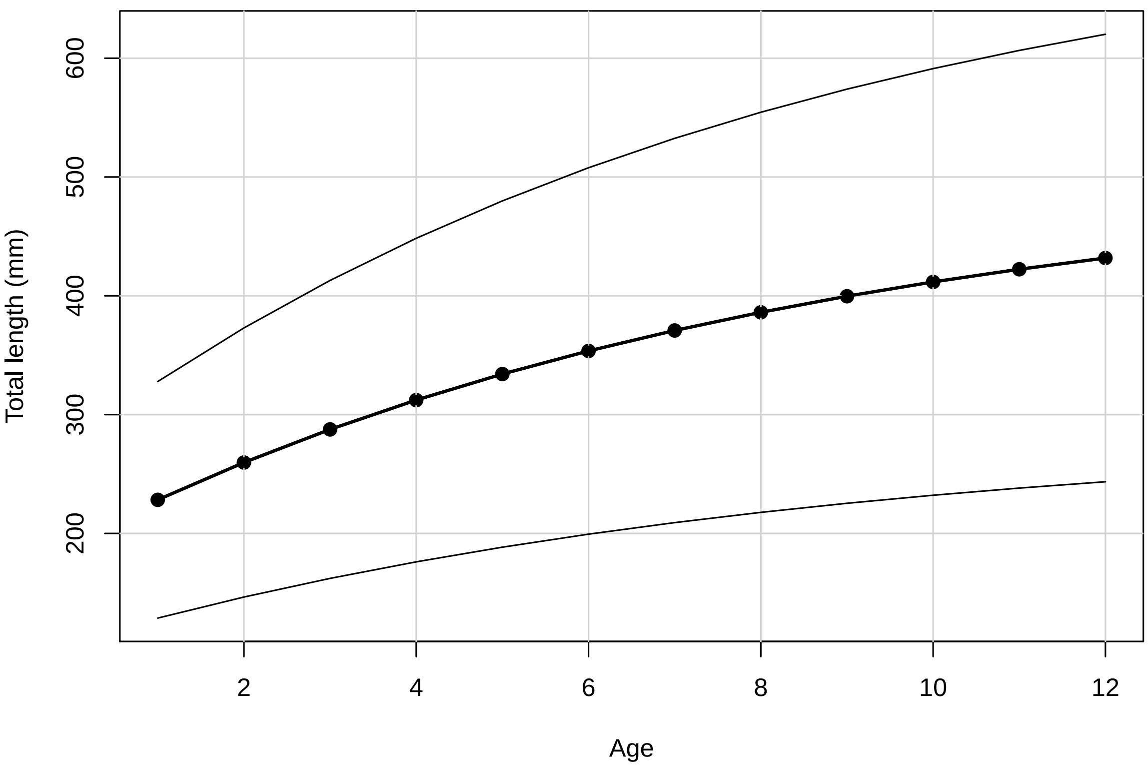


Figure 2. Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey. In panels indicating the data set, lcomp refers to length compositions, acomp to age compositions, fst to MARMAP Florida snapper trap, cvt to MARMAP chevron trap, c.hal to commercial handline, c.cmb to commercial combined, hb to headboat, rec to general recreational, and D to discards. N = −99999 indicates that the composition was not used for fitting, in most cases because the sample size was below the cutoff.

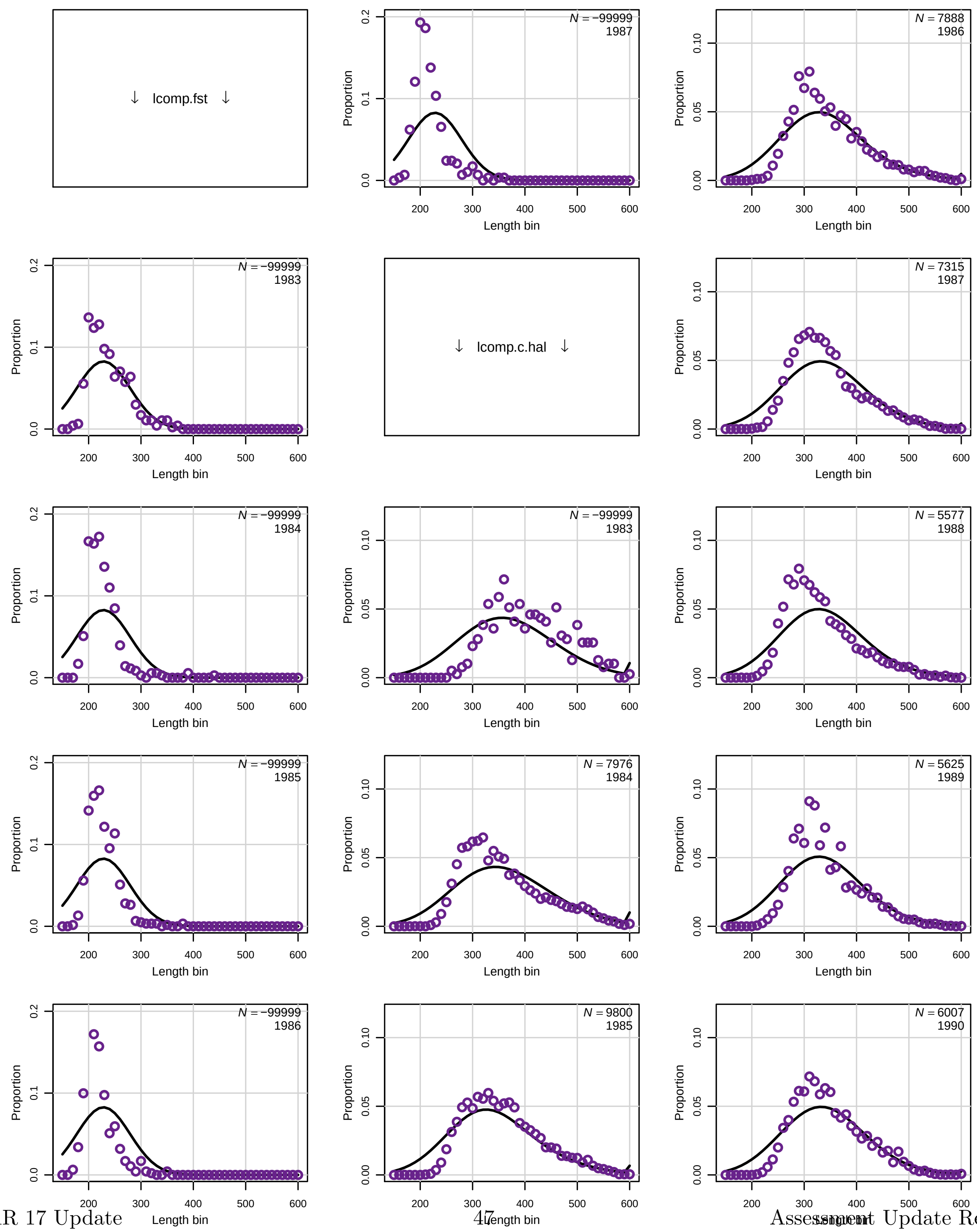


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

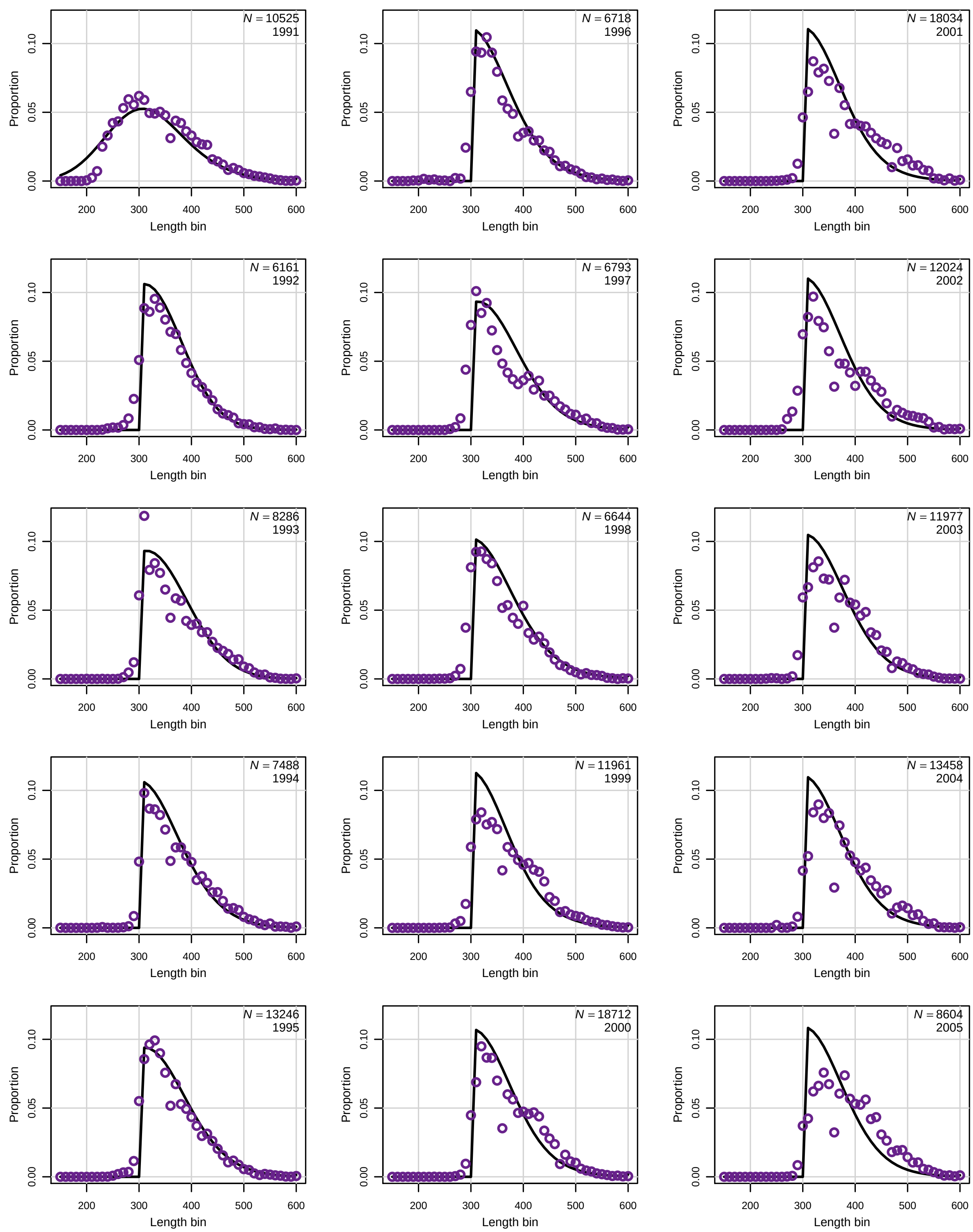


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

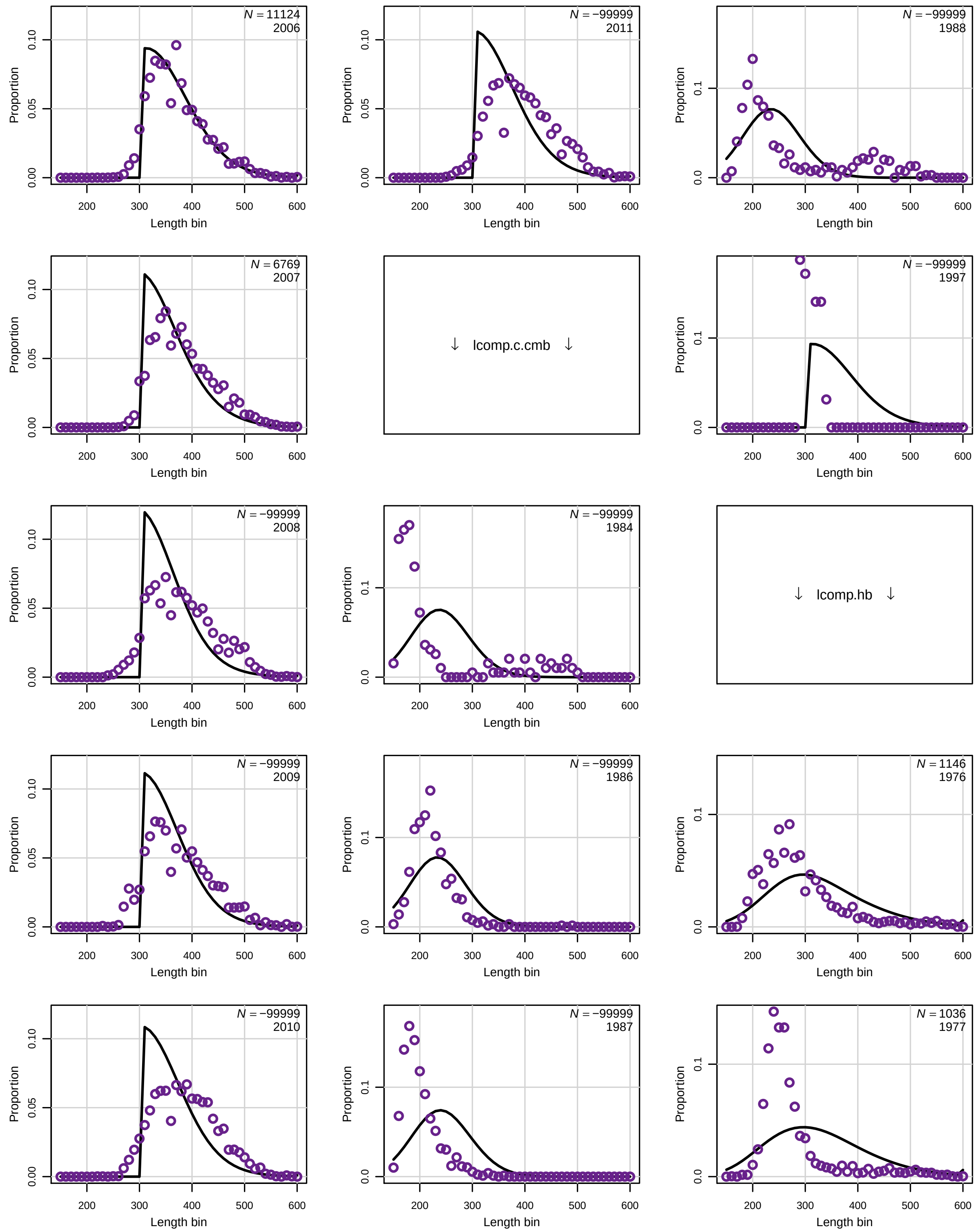


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

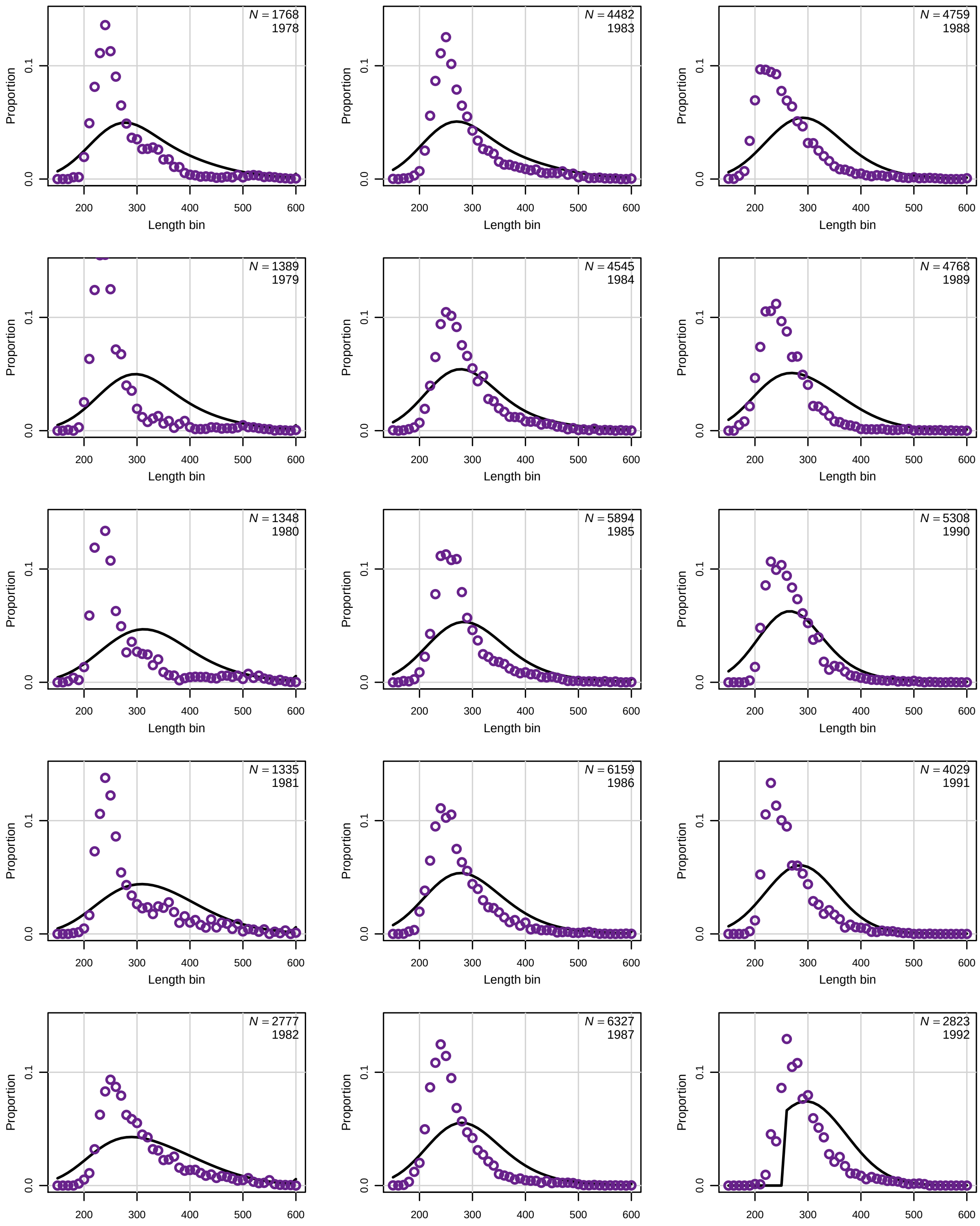


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

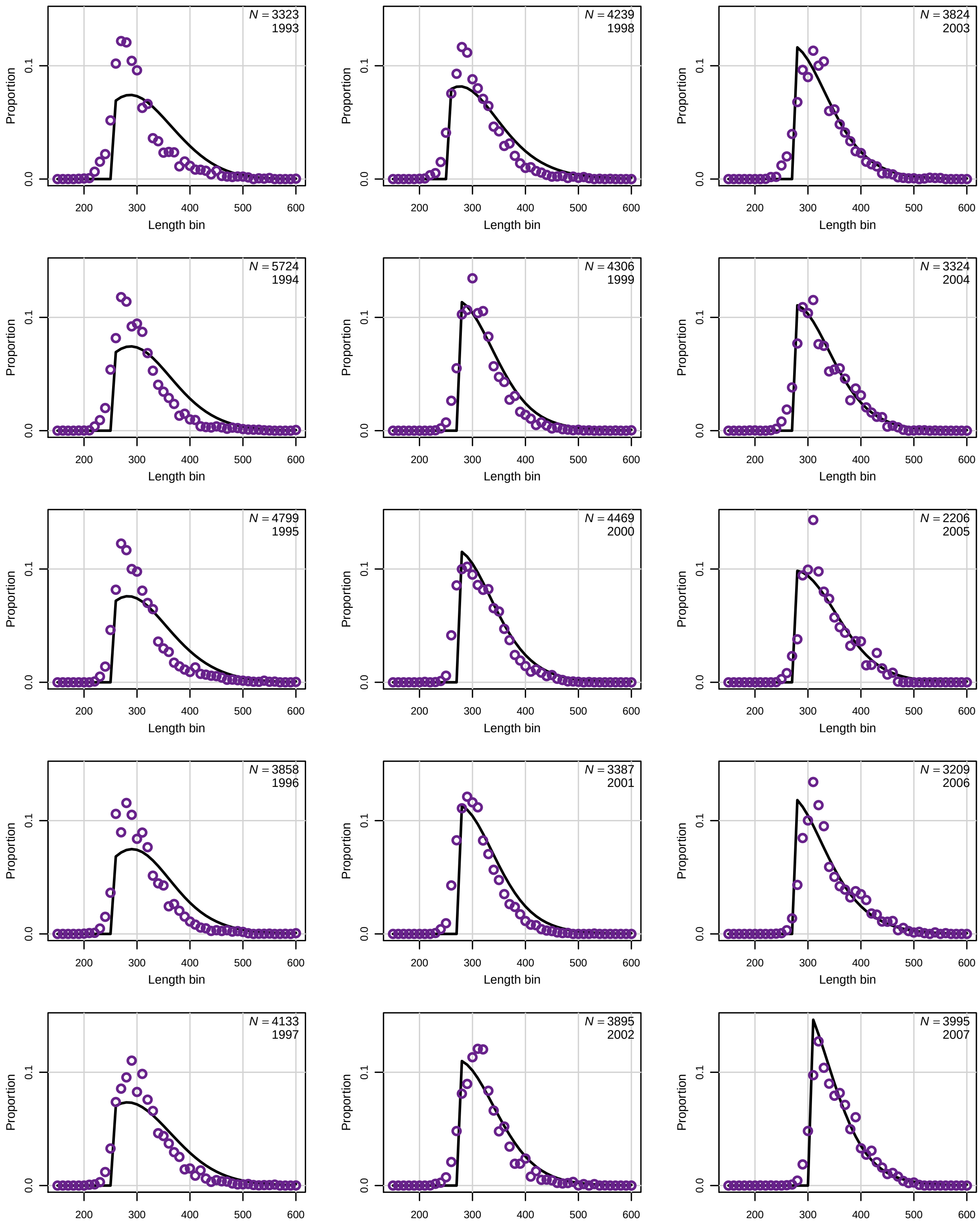


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

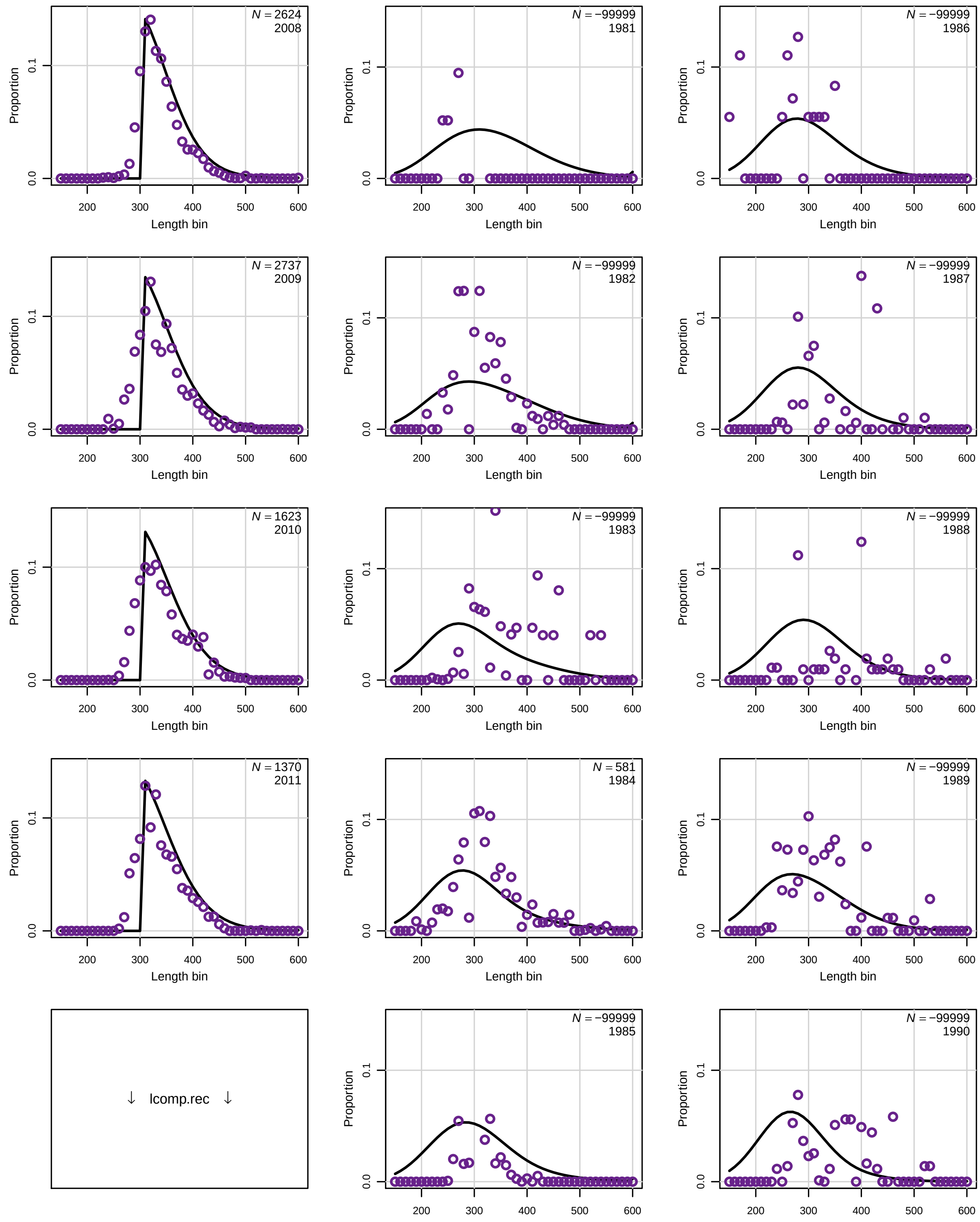


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

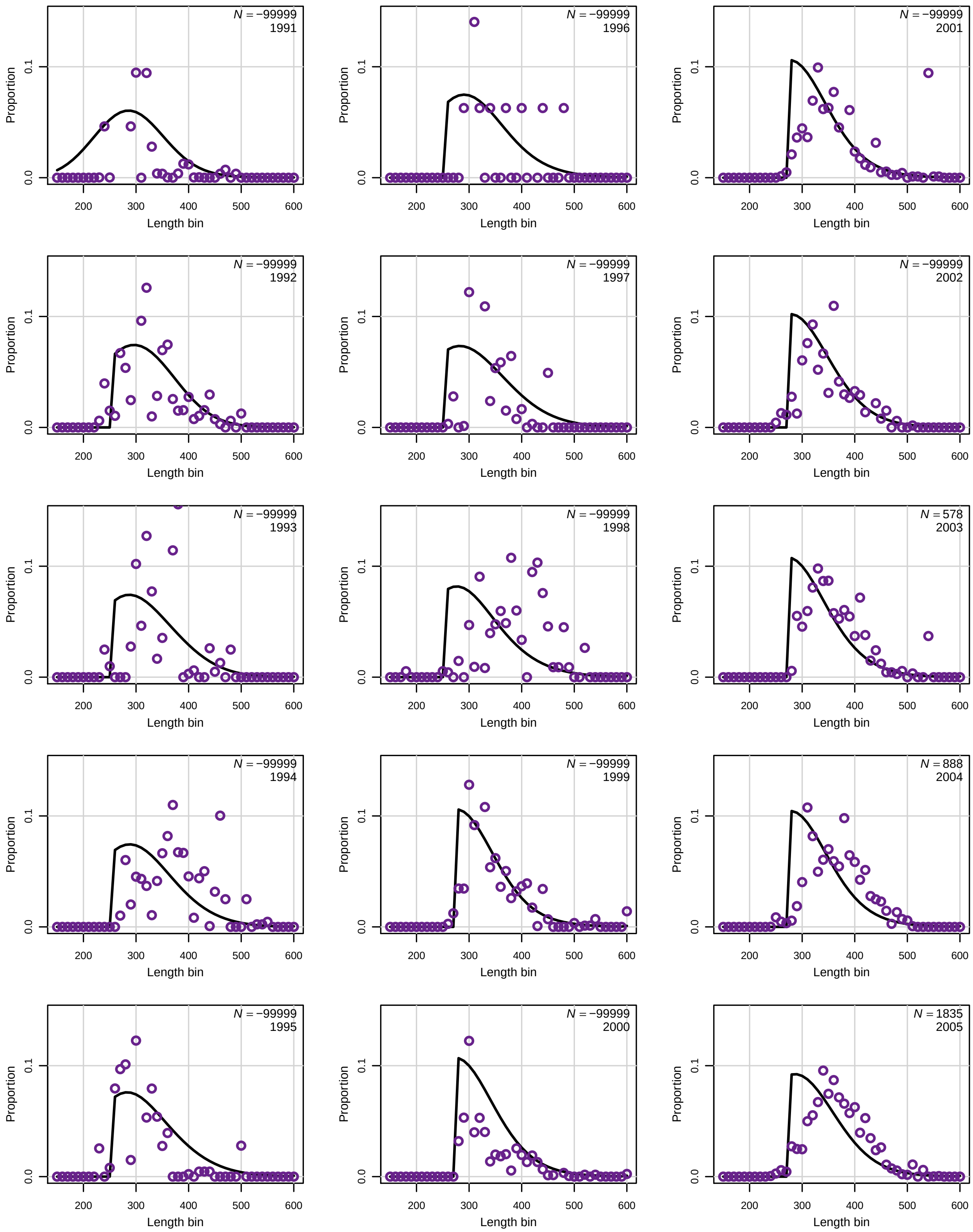


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

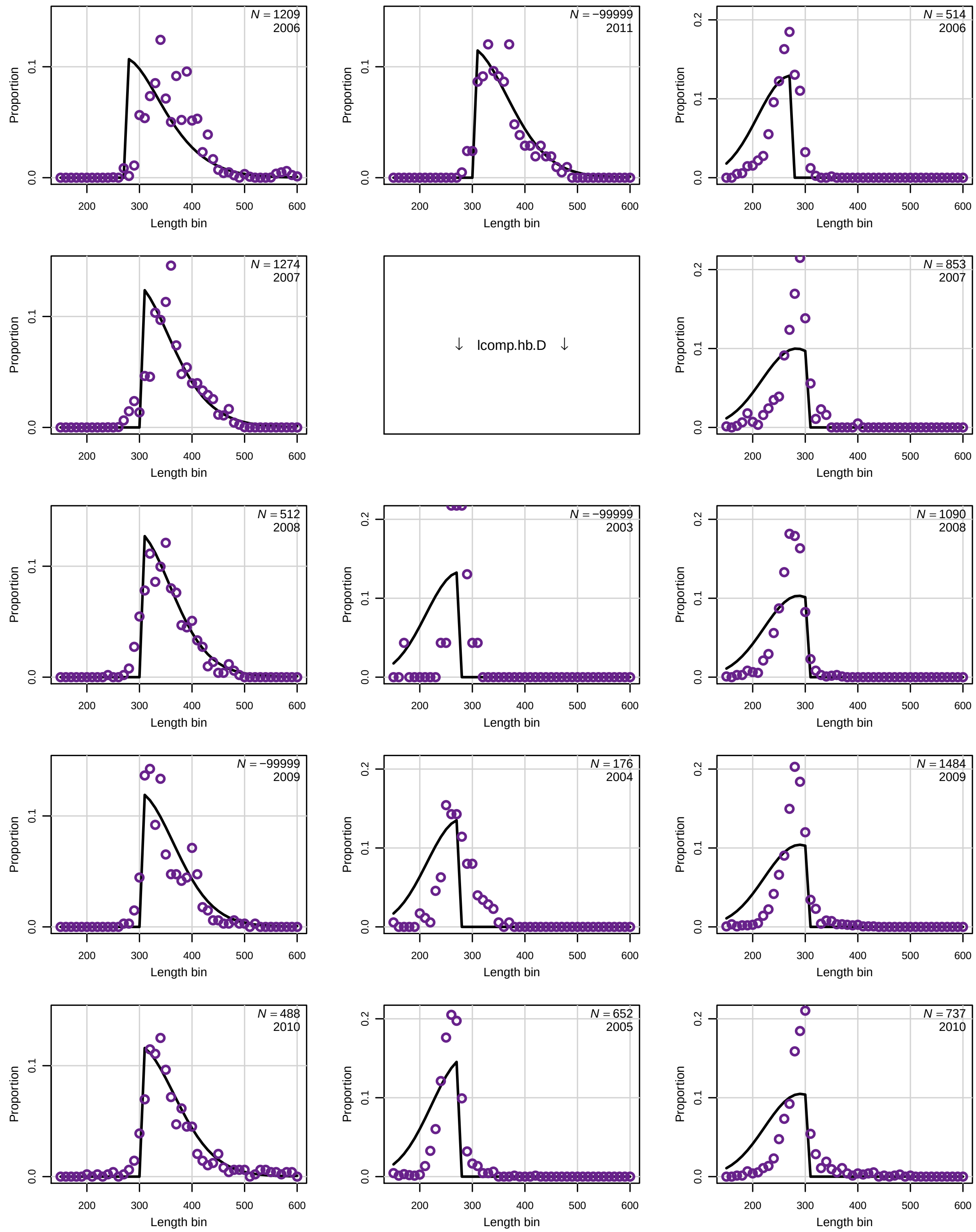


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

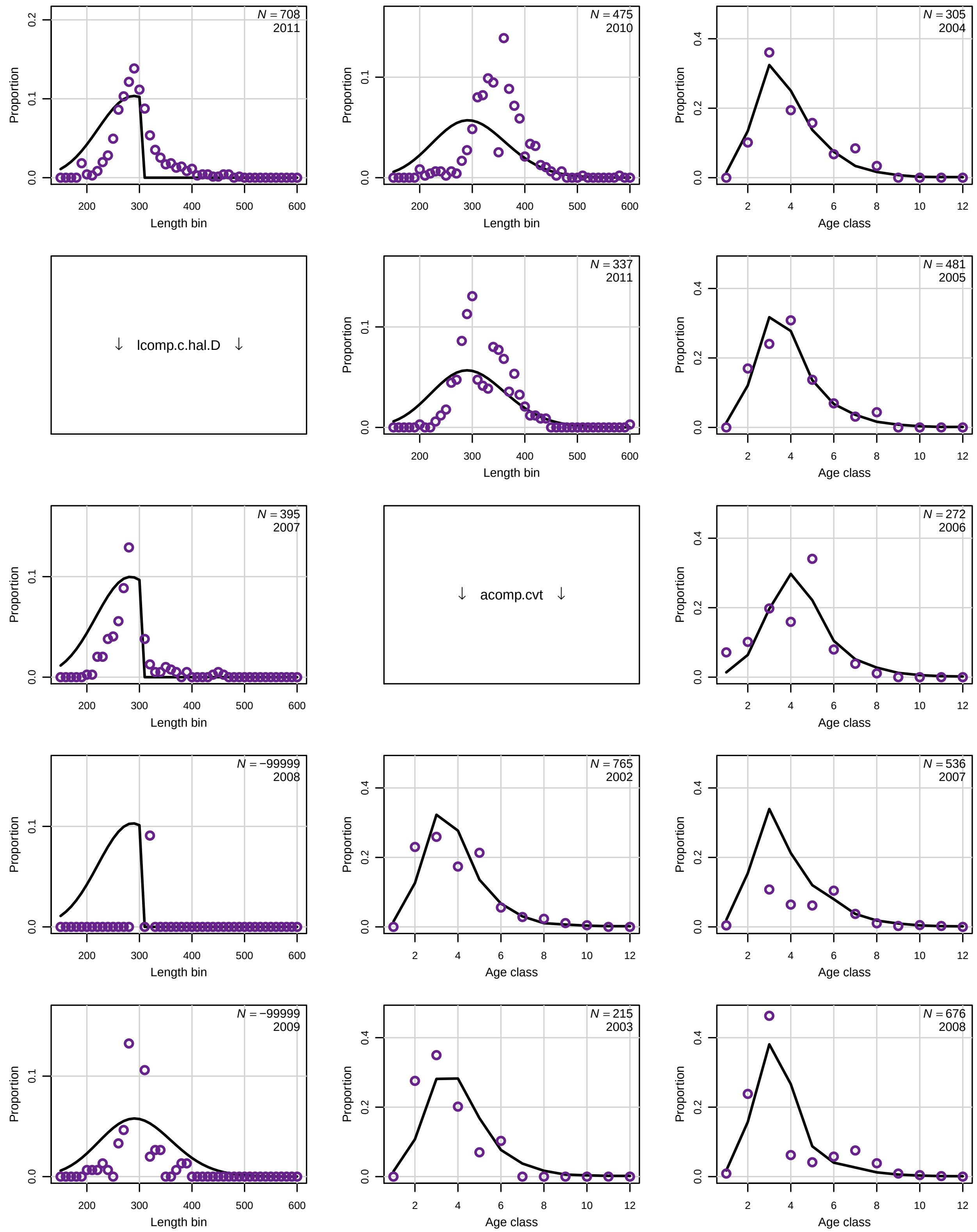


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

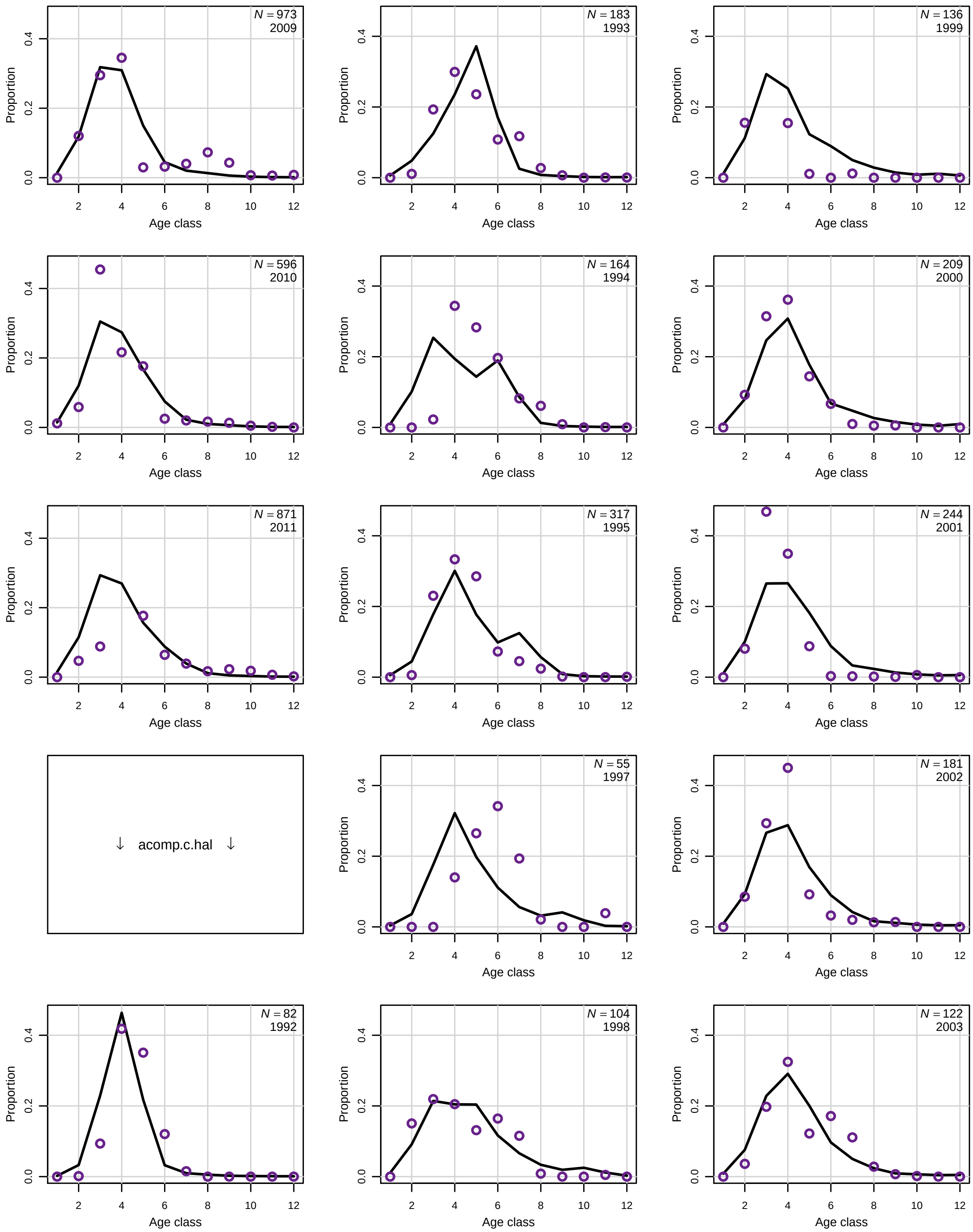


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

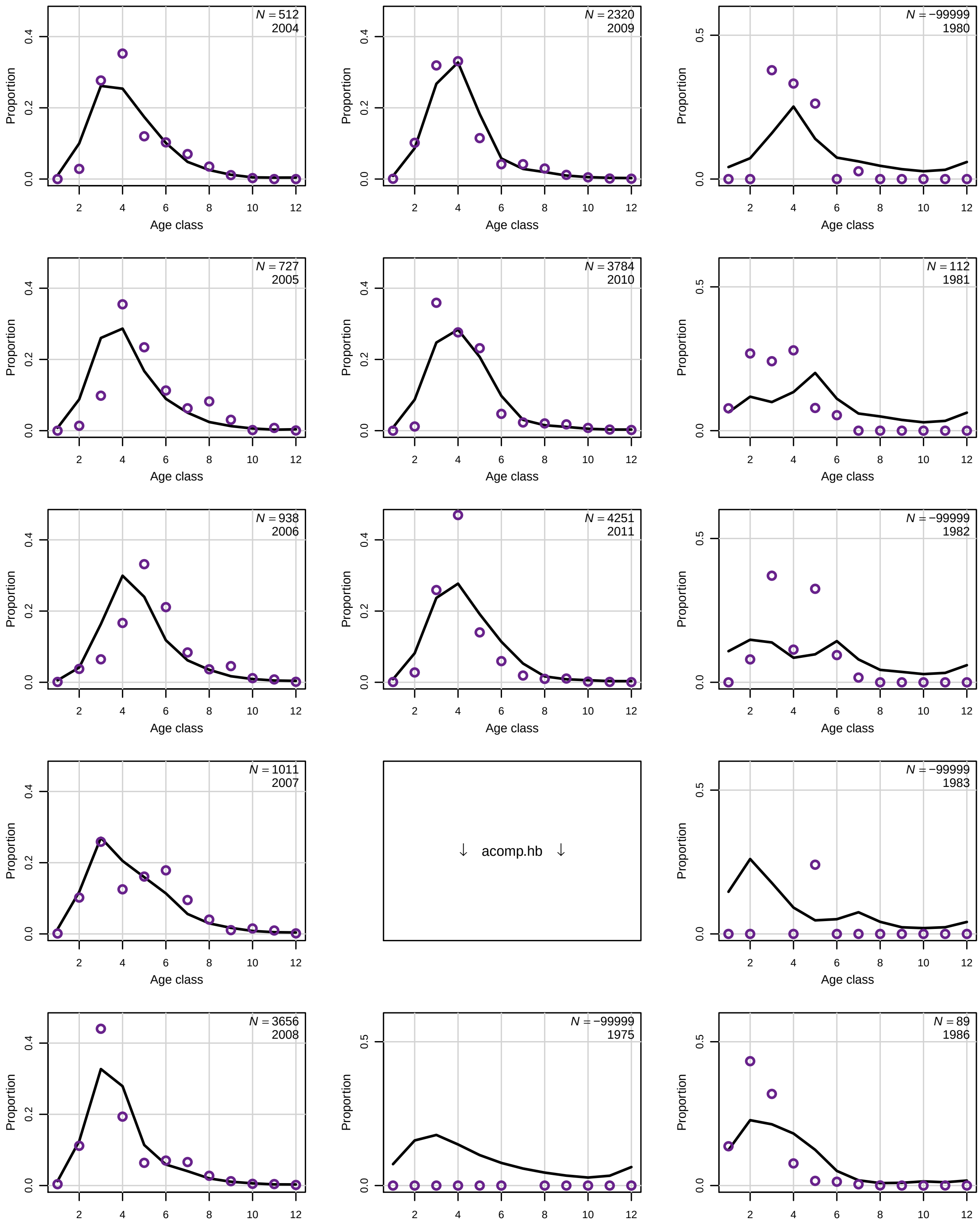


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

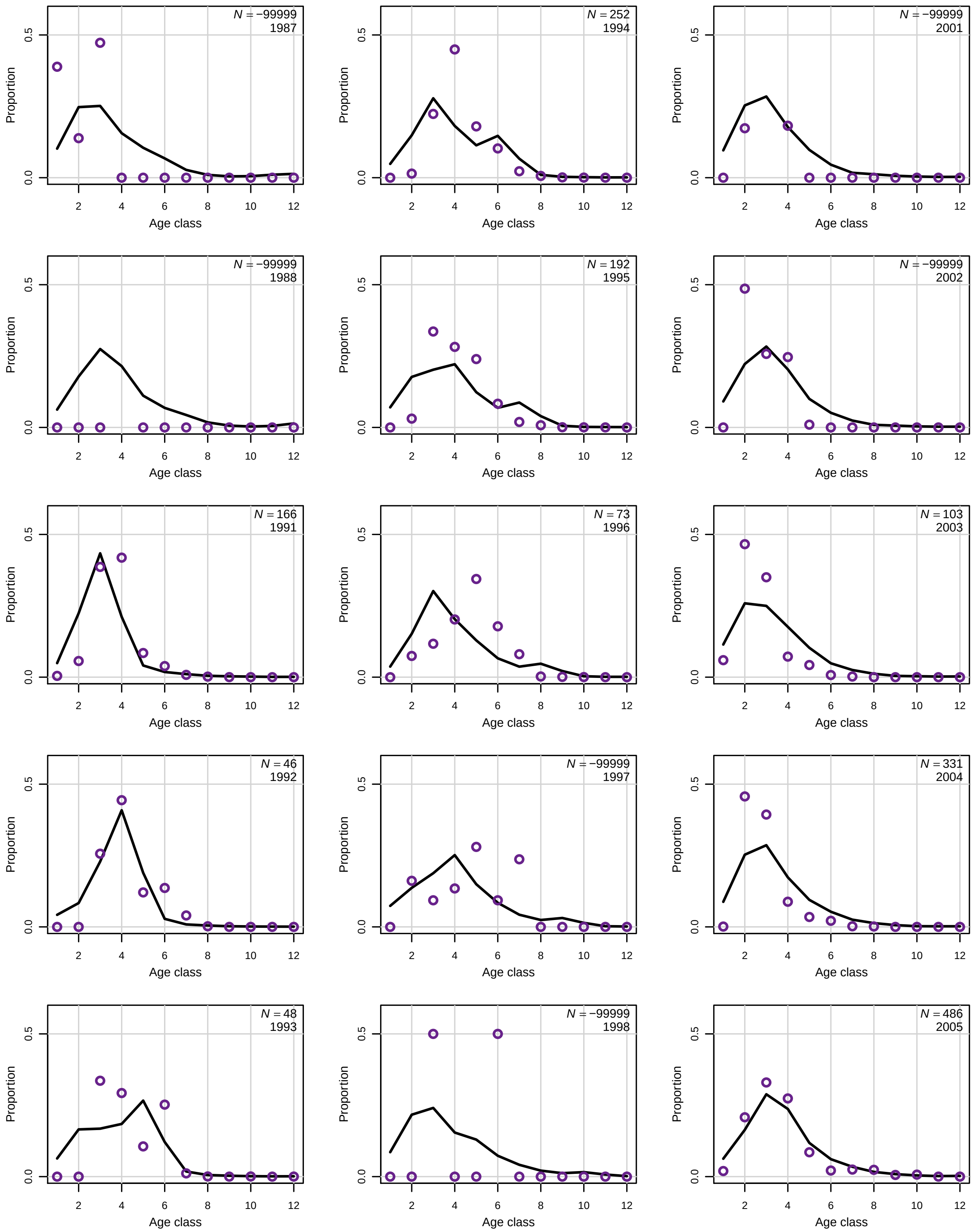


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

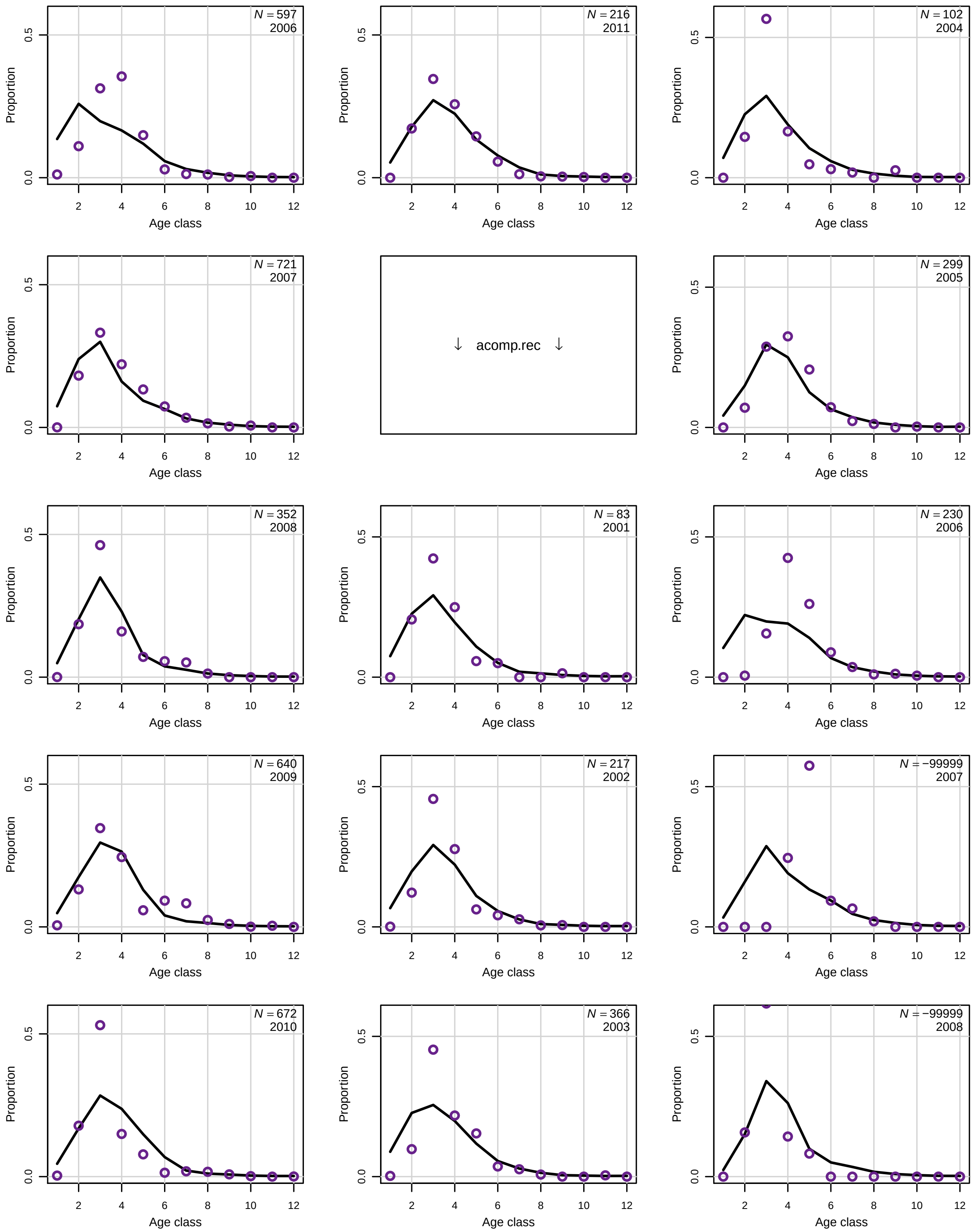


Figure 2. (cont.) Observed (open circles) and estimated (solid line) annual length and age compositions by fleet or survey.

Figure 3. Observed (open circles) and estimated (solid line, circles) commercial handline landings (1000 lb whole weight). Open and solid circles are indistinguishable.

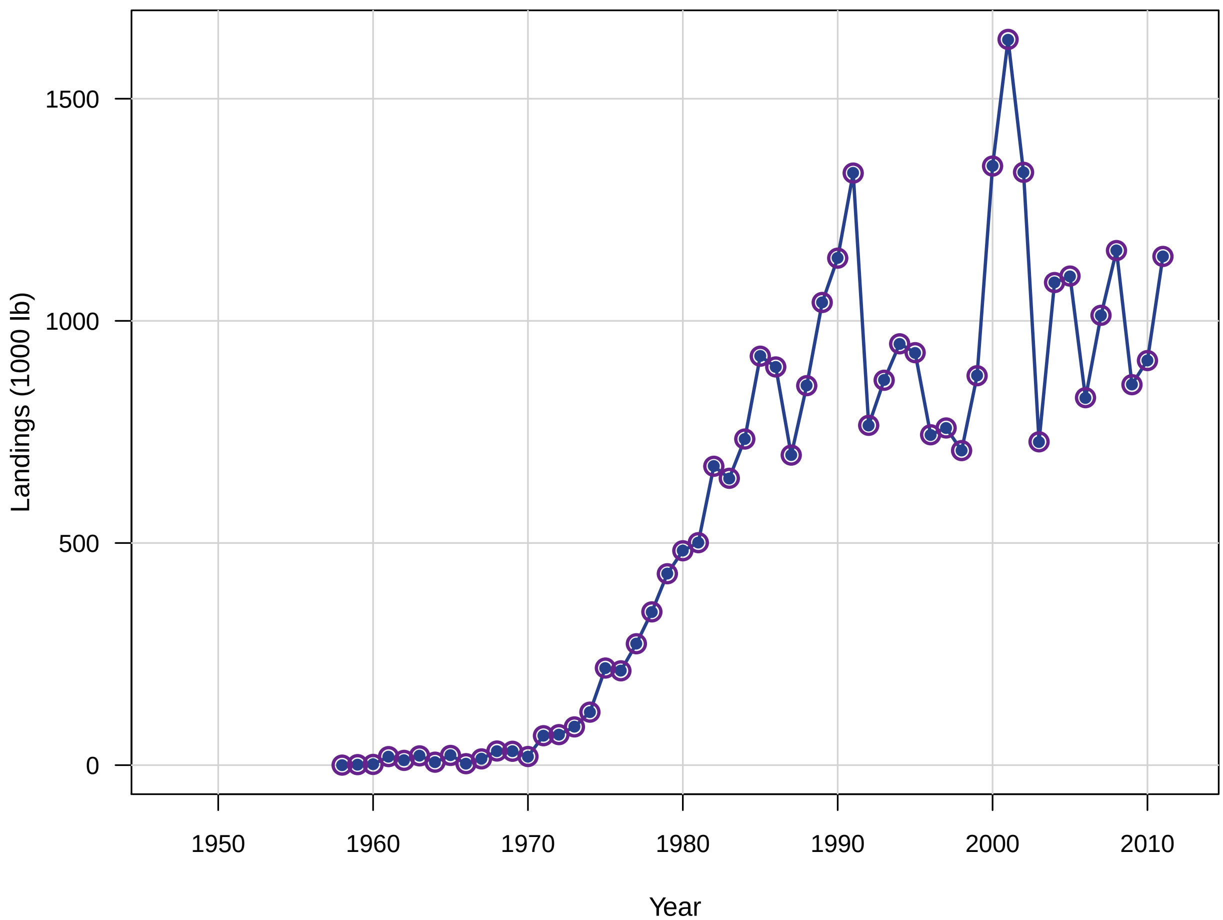


Figure 4. Observed (open circles) and estimated (solid line, circles) commercial historic trawl (1000 lb whole weight). Open and solid circles are indistinguishable.

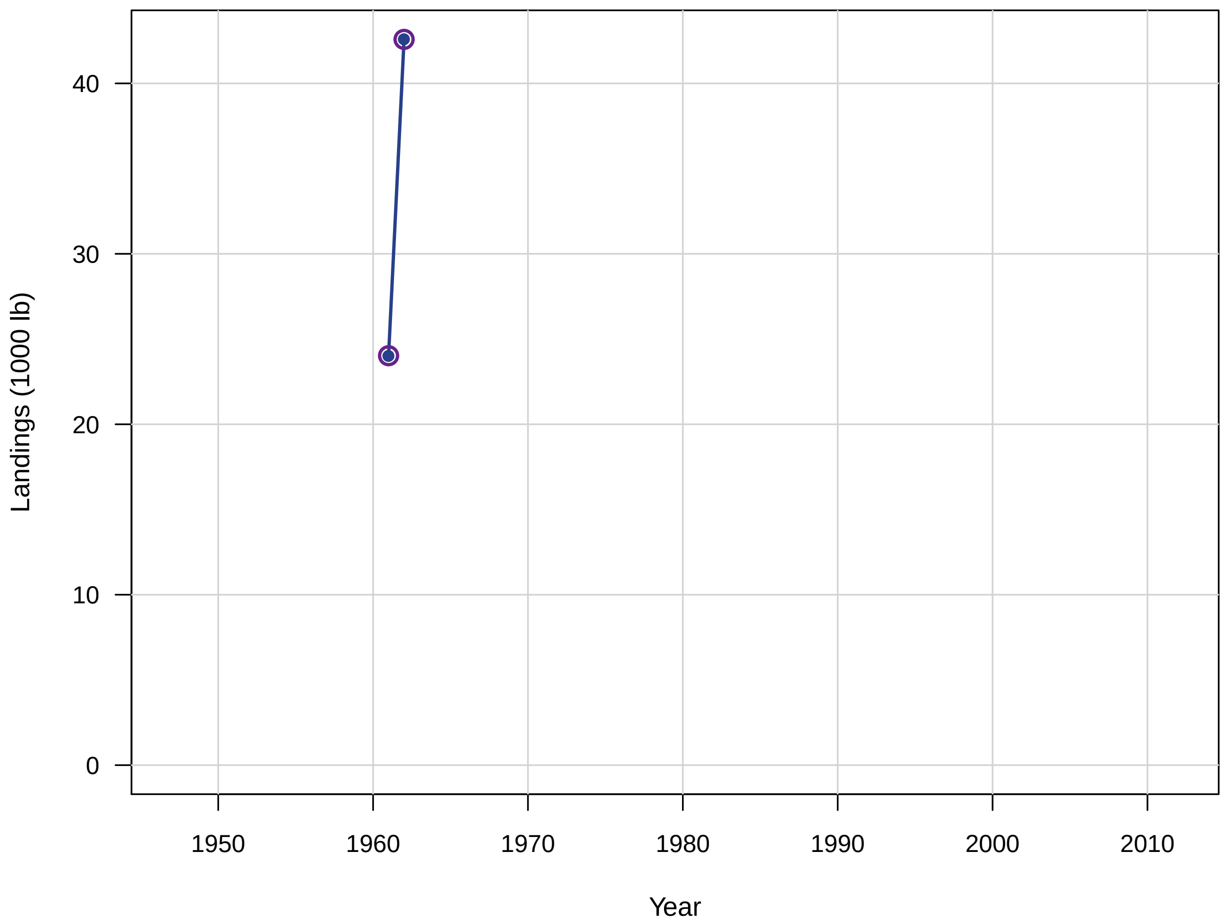


Figure 5. Observed (open circles) and estimated (solid line, circles) commercial combined gears (1000 lb whole weight). Open and solid circles are indistinguishable.

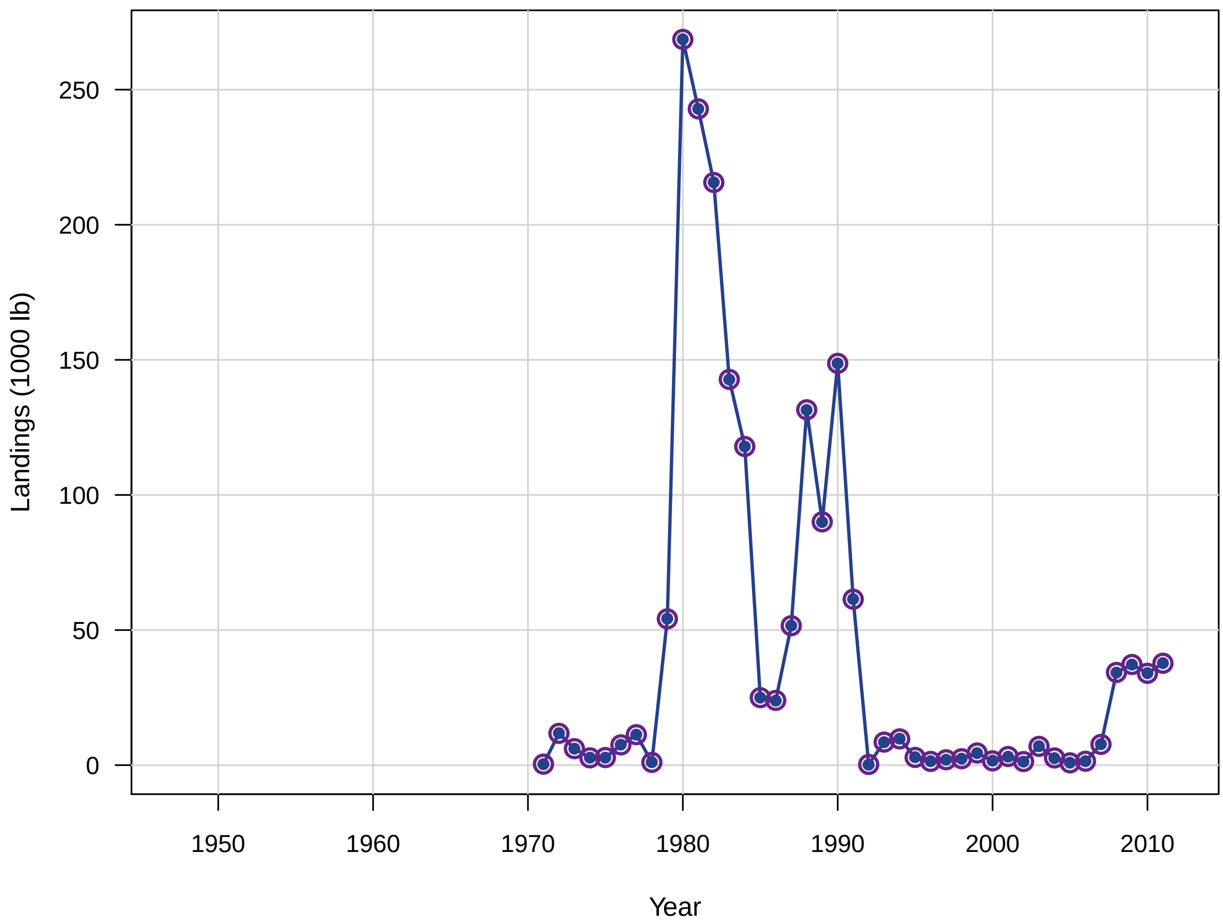


Figure 6. Observed (open circles) and estimated (solid line, circles) headboat landings (1000 fish). Open and solid circles are indistinguishable.

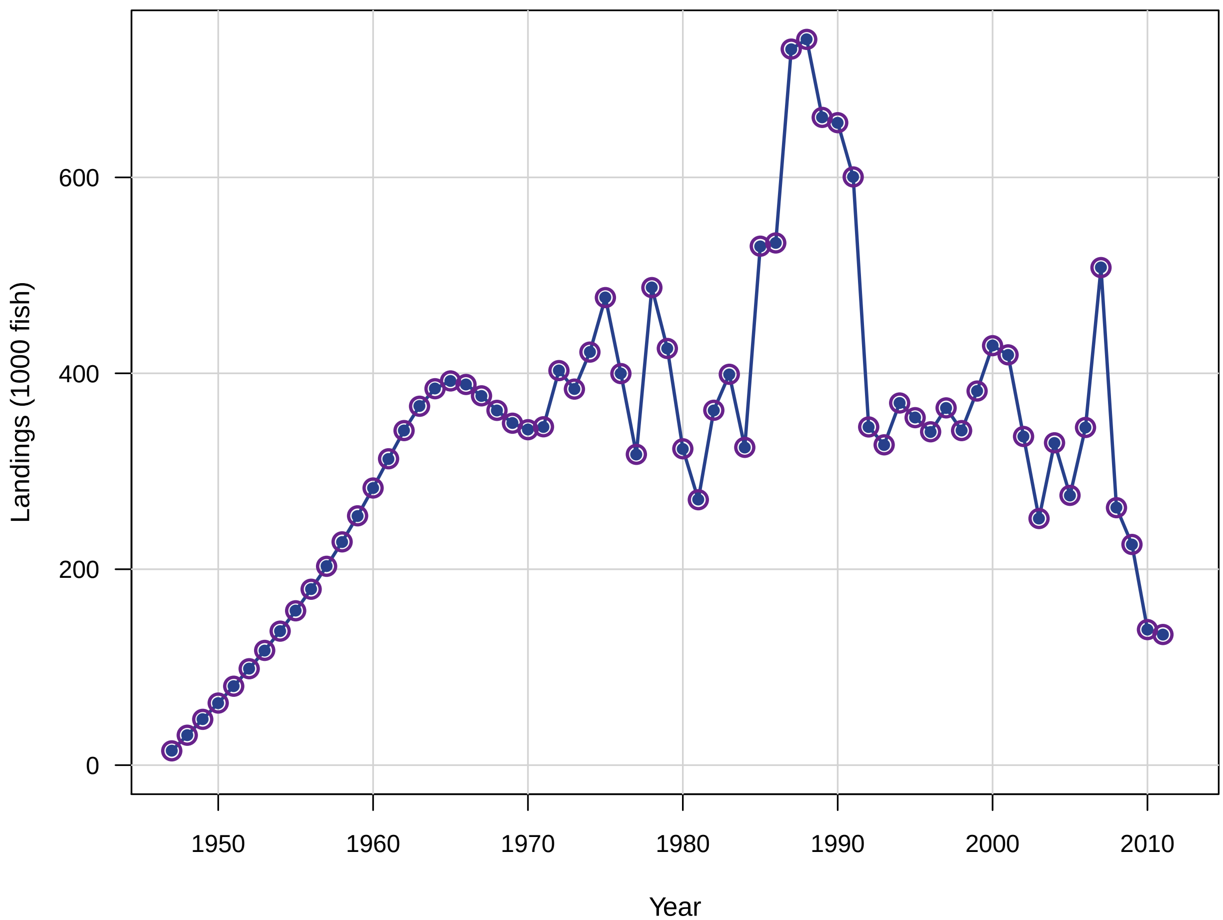


Figure 7. Observed (open circles) and estimated (solid line, circles) general recreational landings (1000 fish). Open and solid circles are indistinguishable.

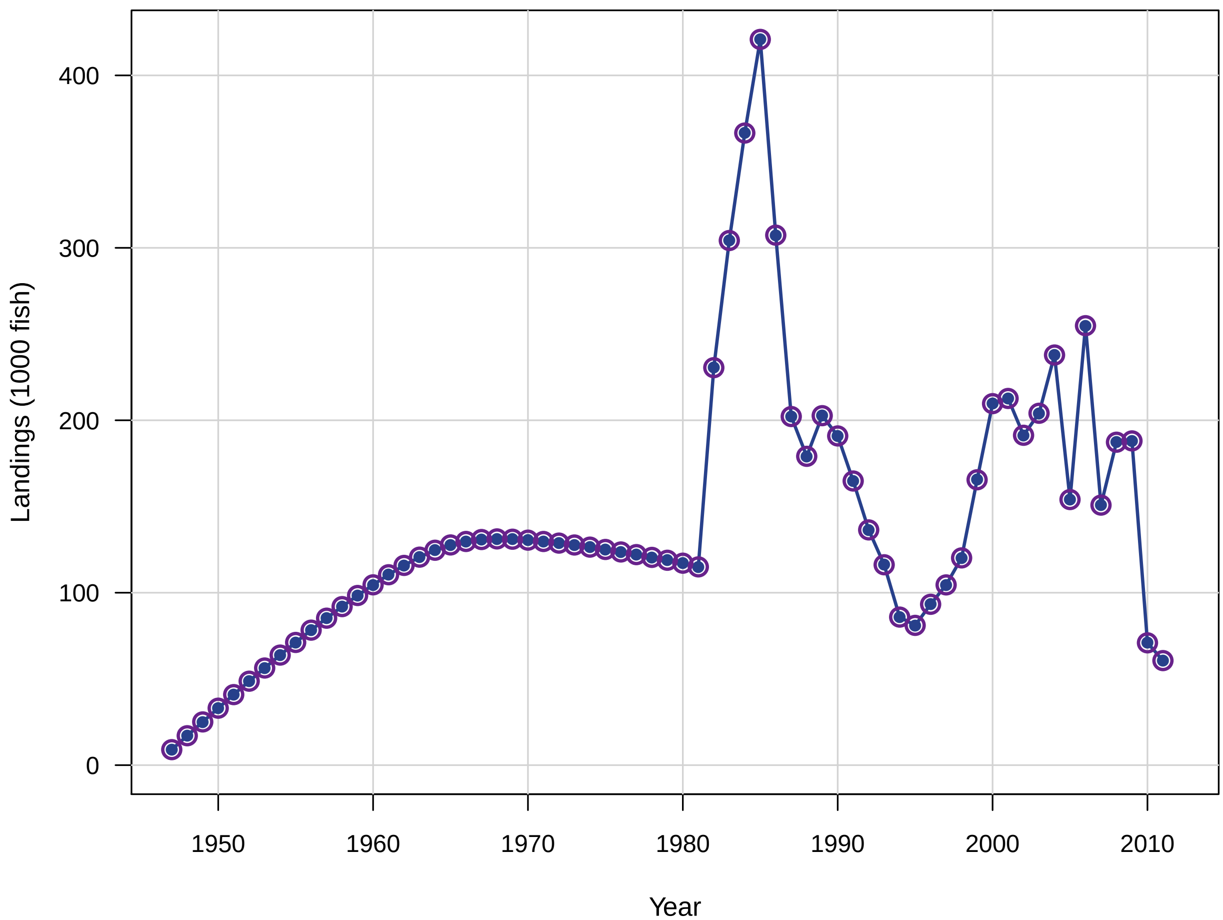


Figure 8. Observed (open circles) and estimated (solid line, circles) commercial handline discard mortalities. Open and solid circles are indistinguishable.

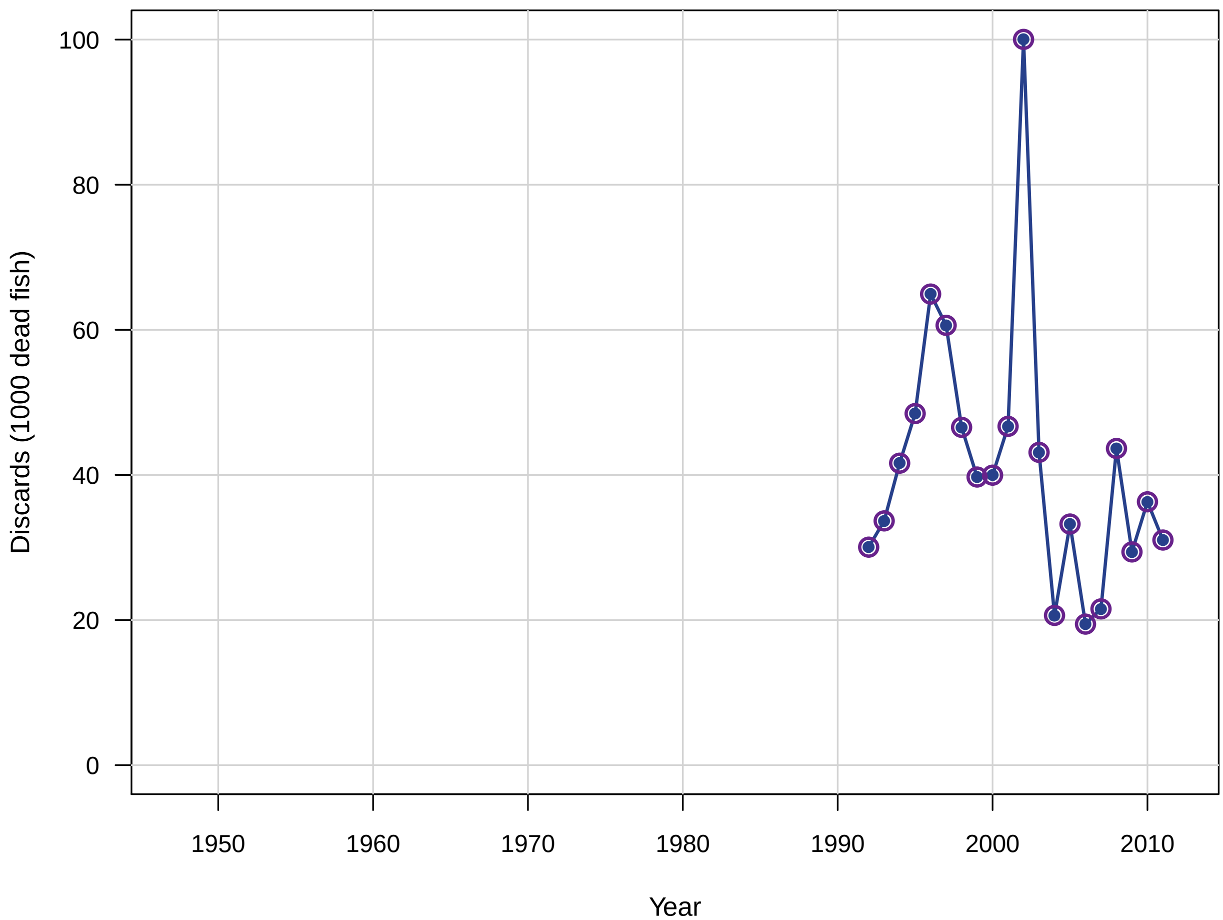


Figure 9. Observed (open circles) and estimated (solid line, circles) headboat discard mortalities. Open and solid circles are indistinguishable.

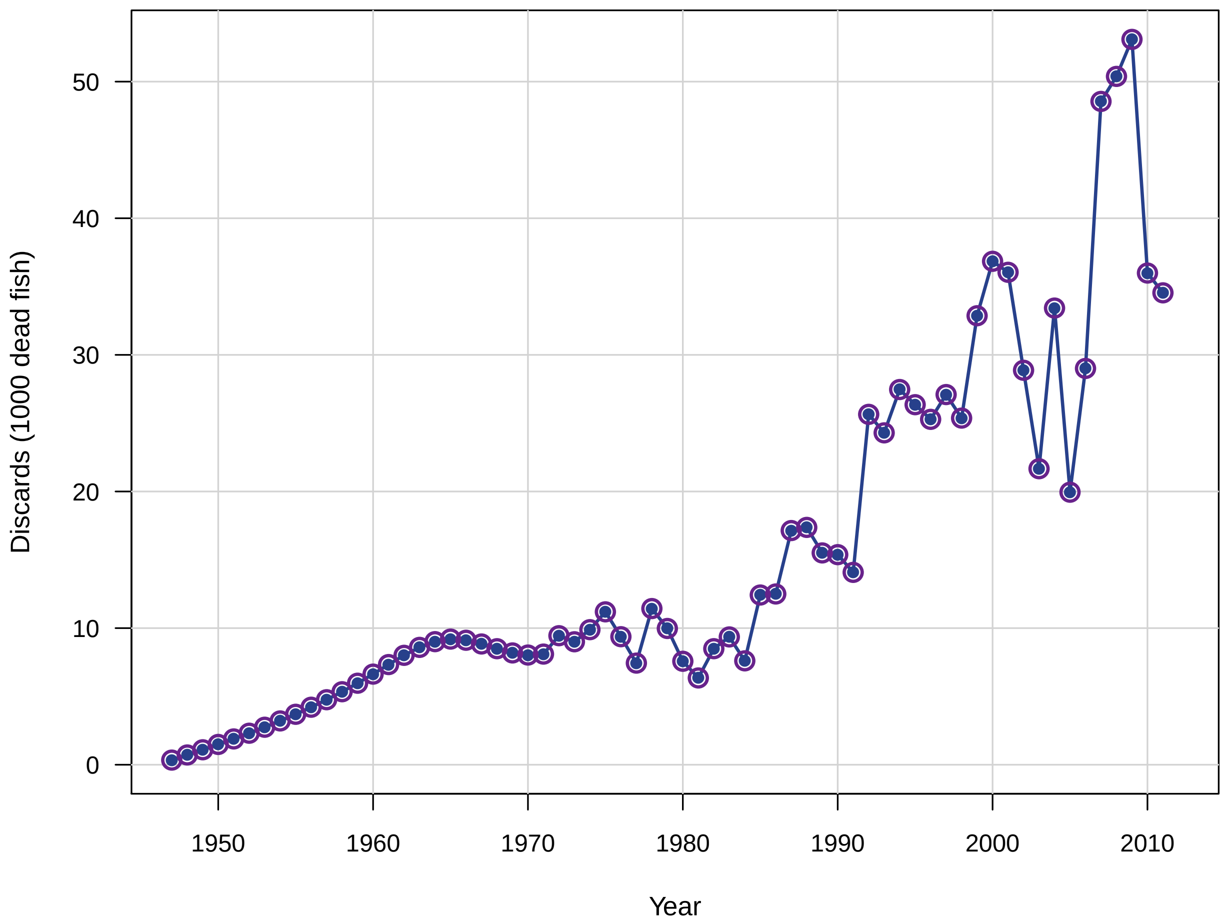


Figure 10. Observed (open circles) and estimated (solid line, circles) general recreational discard mortalities. Open and solid circles are indistinguishable.

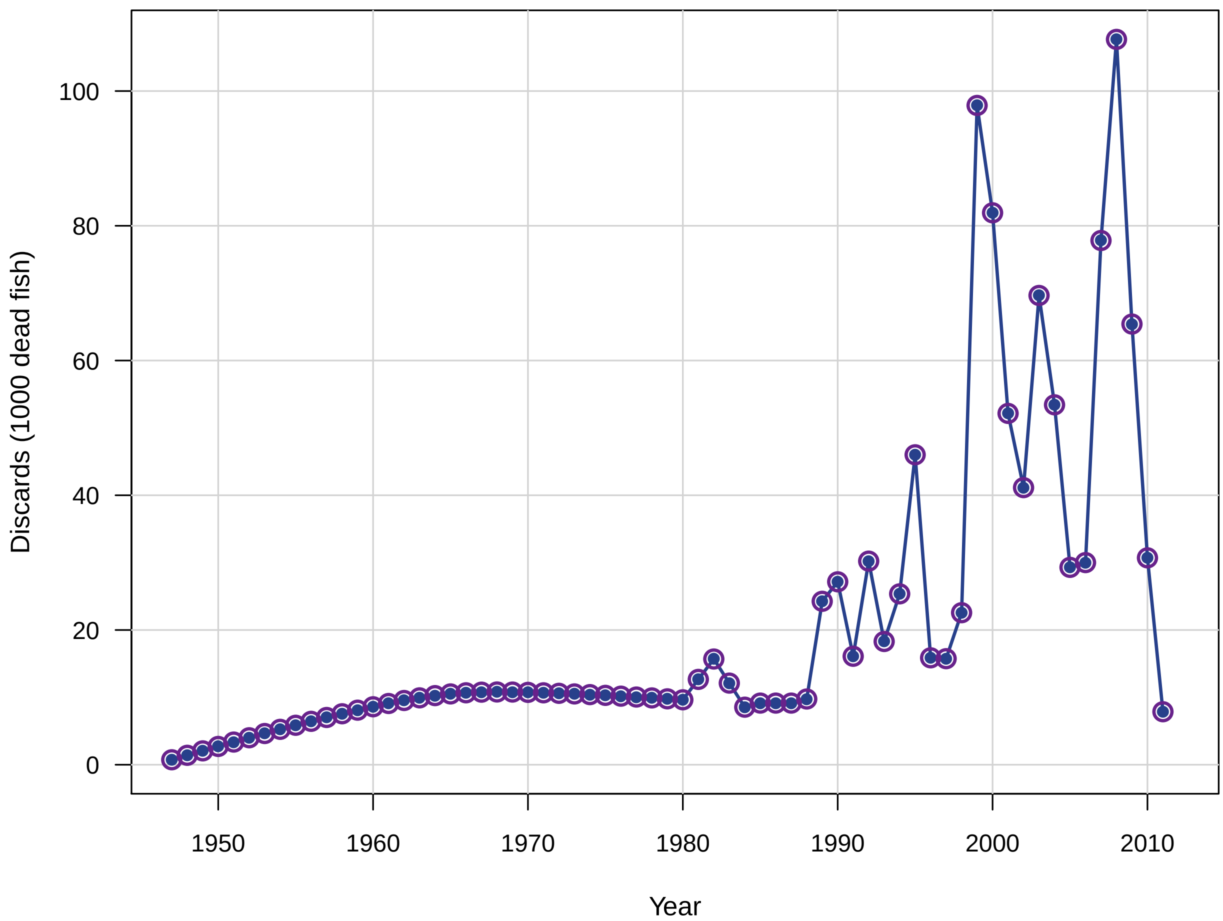


Figure 11. Observed (open circles) and estimated (solid line, circles) index of abundance from MARMAP Florida snapper trap.

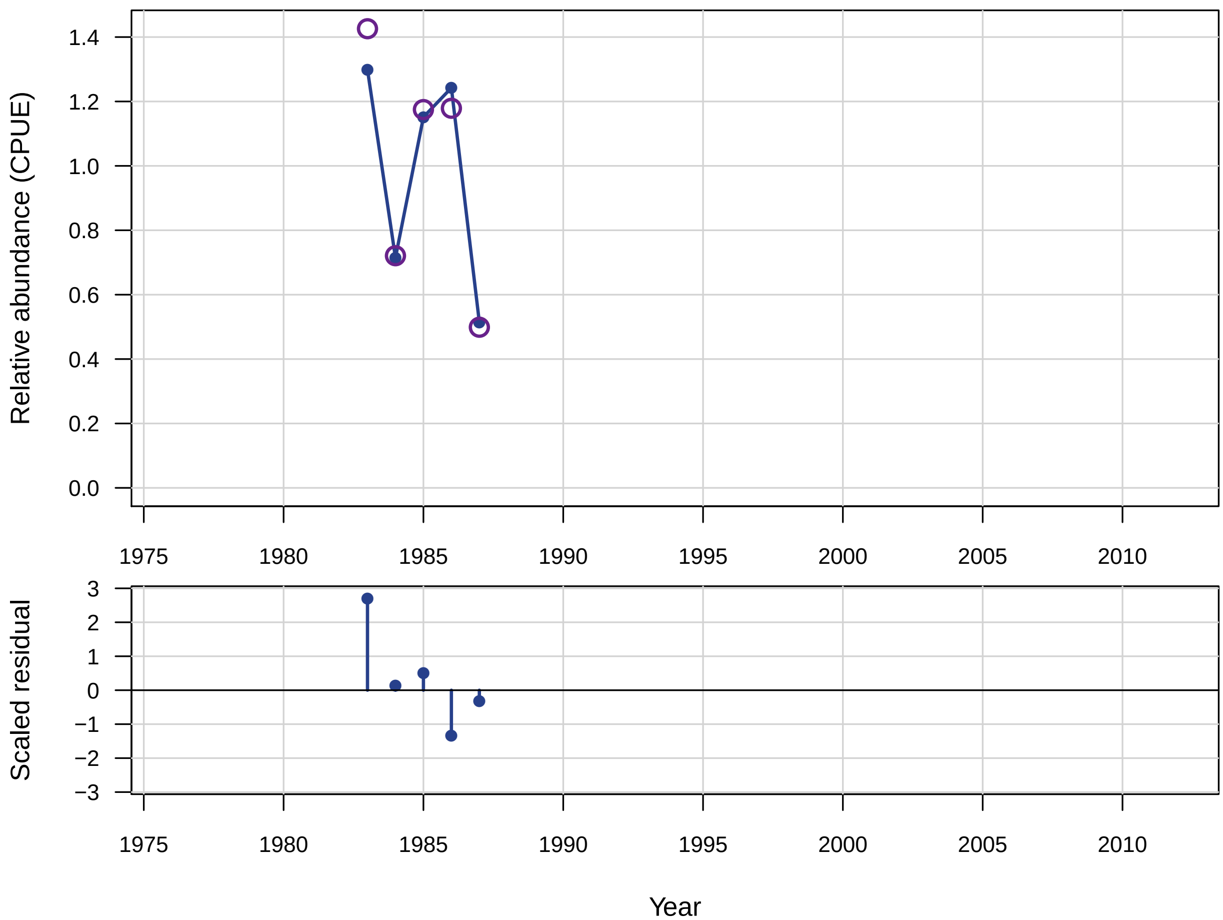


Figure 12. Observed (open circles) and estimated (solid line, circles) index of abundance from MARMAP chevron trap.

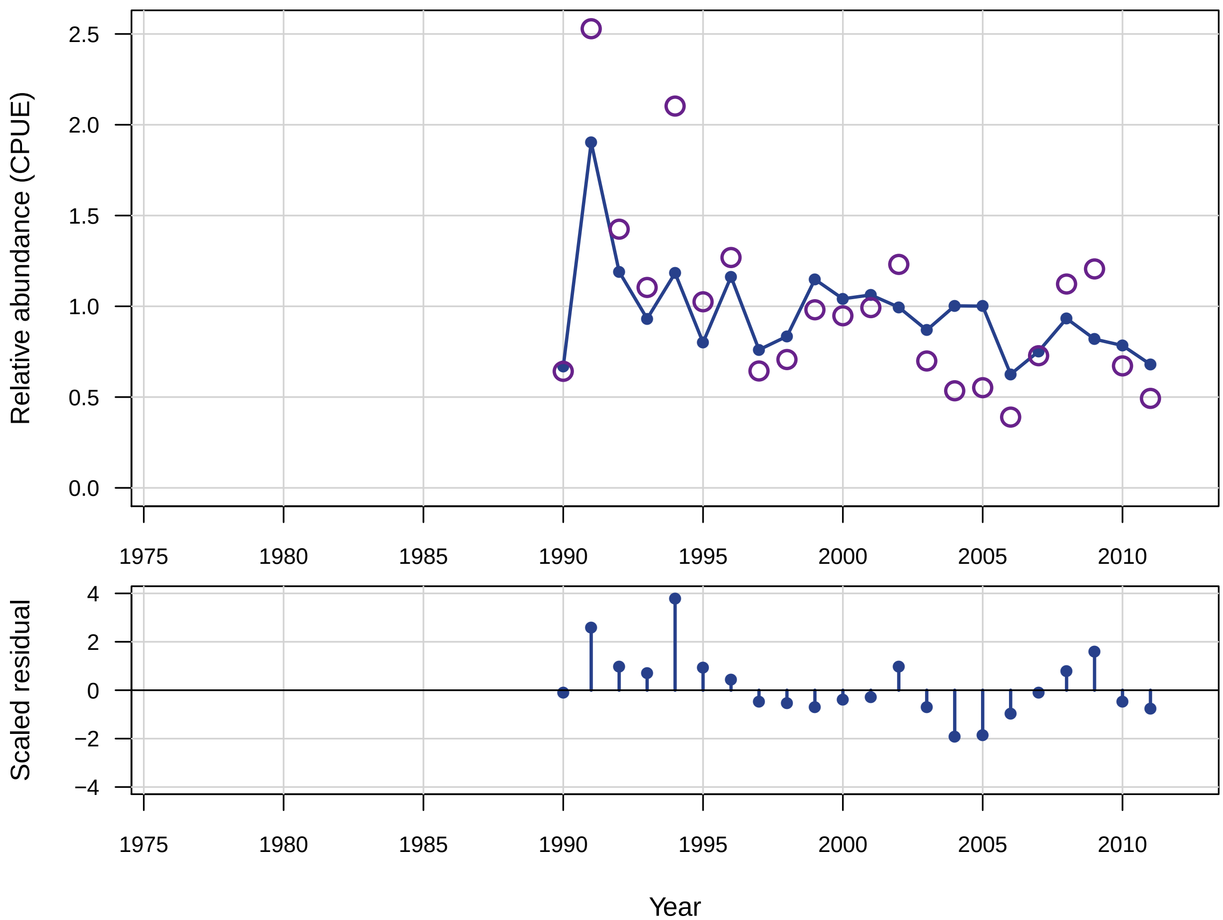


Figure 13. Observed (open circles) and estimated (solid line, circles) index of abundance from commercial handline.

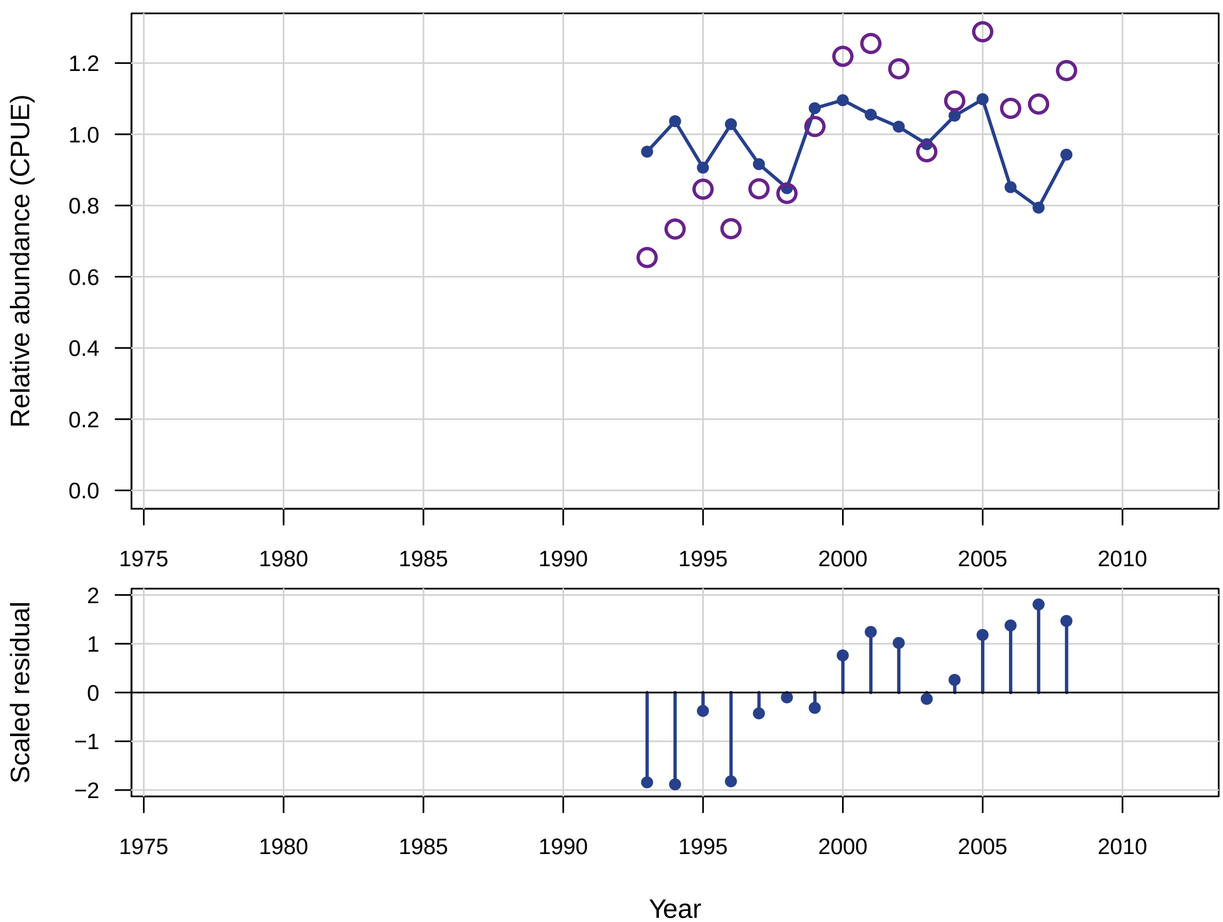


Figure 14. Observed (open circles) and estimated (solid line, circles) index of abundance from headboat.

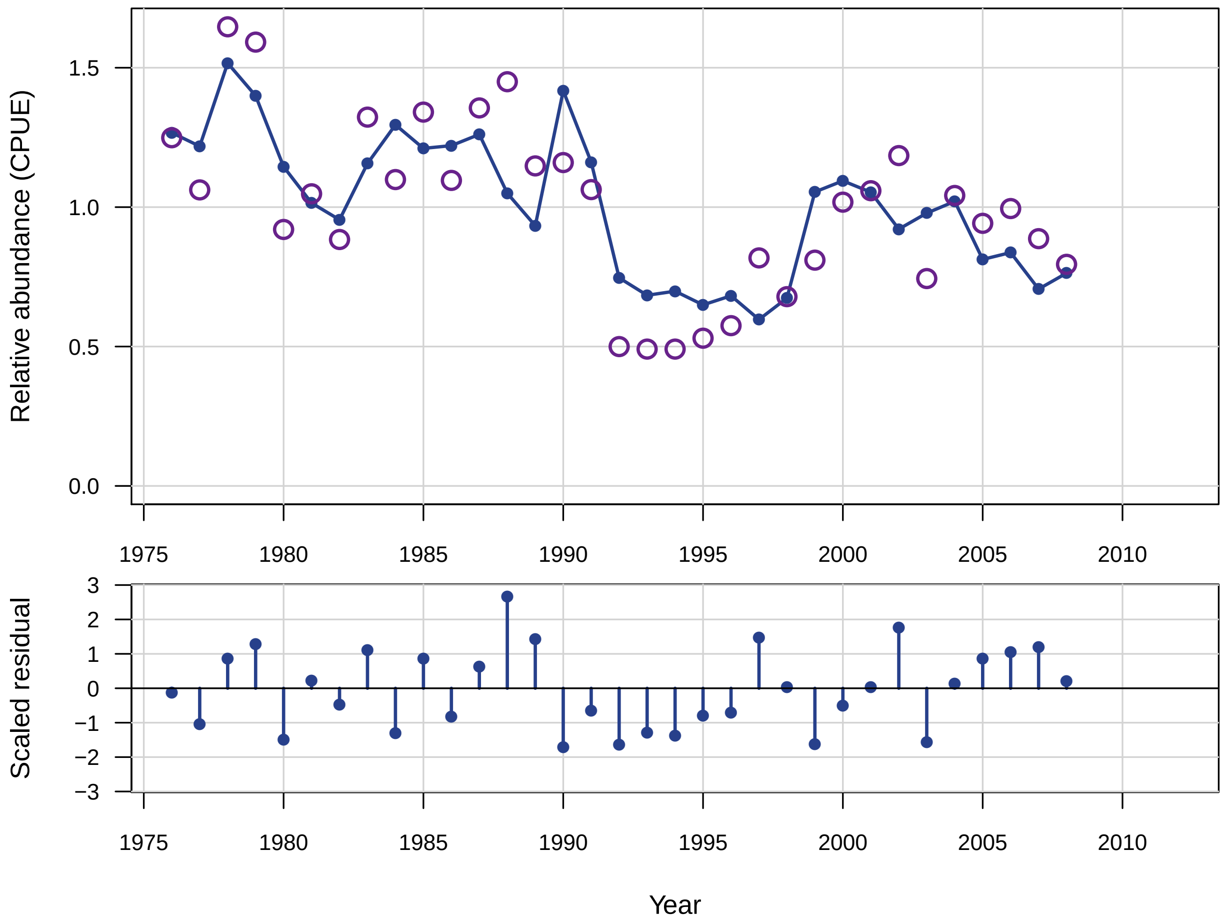


Figure 15. Observed (open circles) and estimated (solid line, circles) abundance from general recreational.

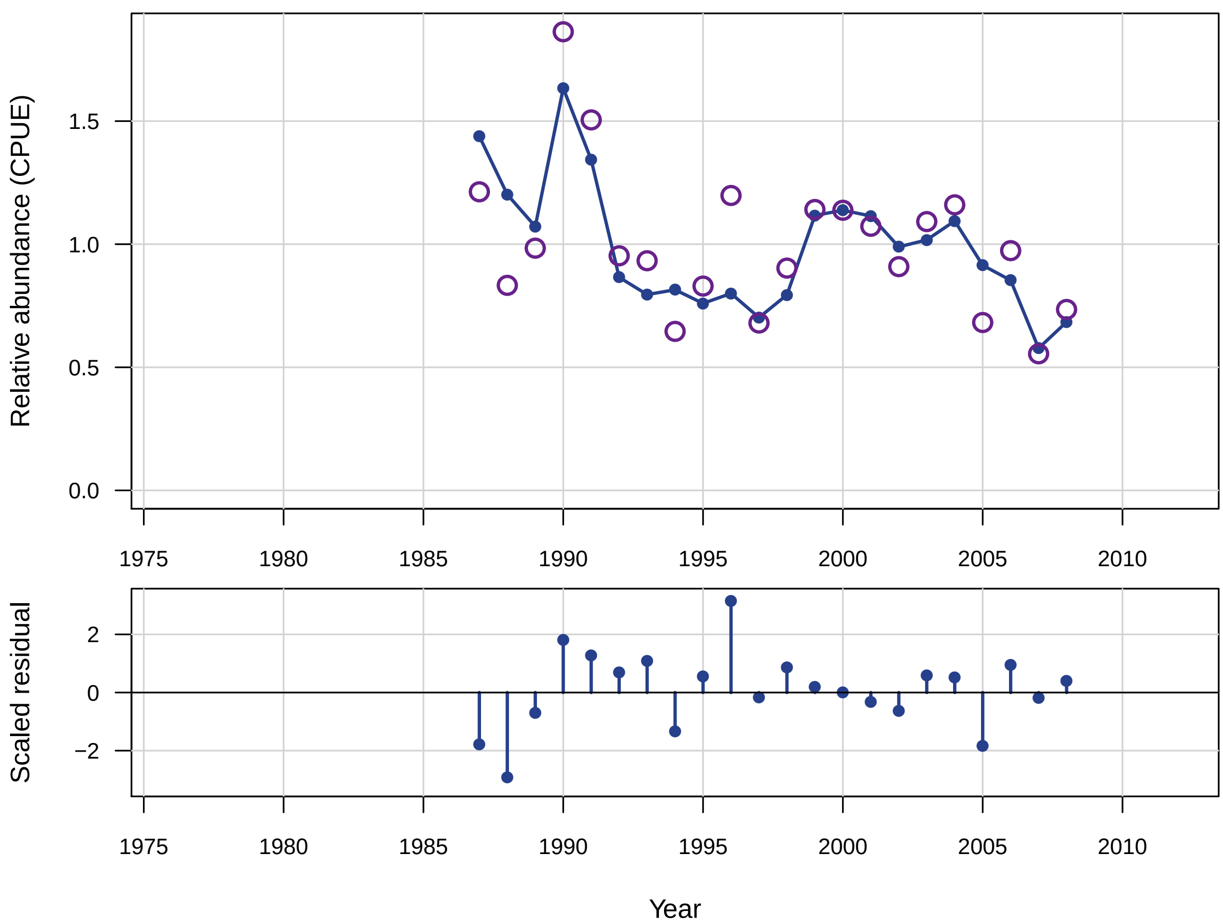


Figure 16. Estimated abundance at age at start of year.

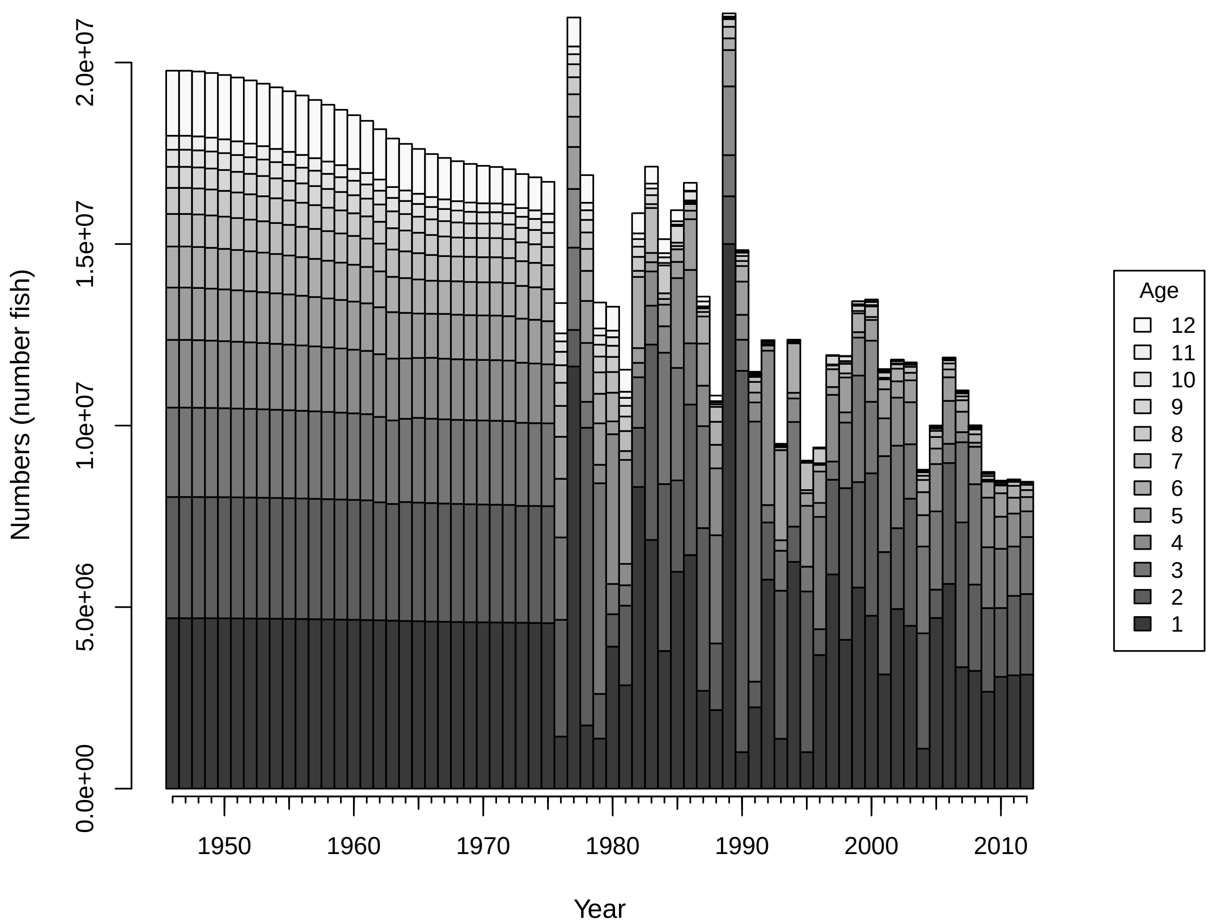


Figure 17. Top panel: Estimated recruitment of age-1 fish. Horizontal dashed line indicates R_{MSY}*. Bottom panel: log recruitment residuals.*

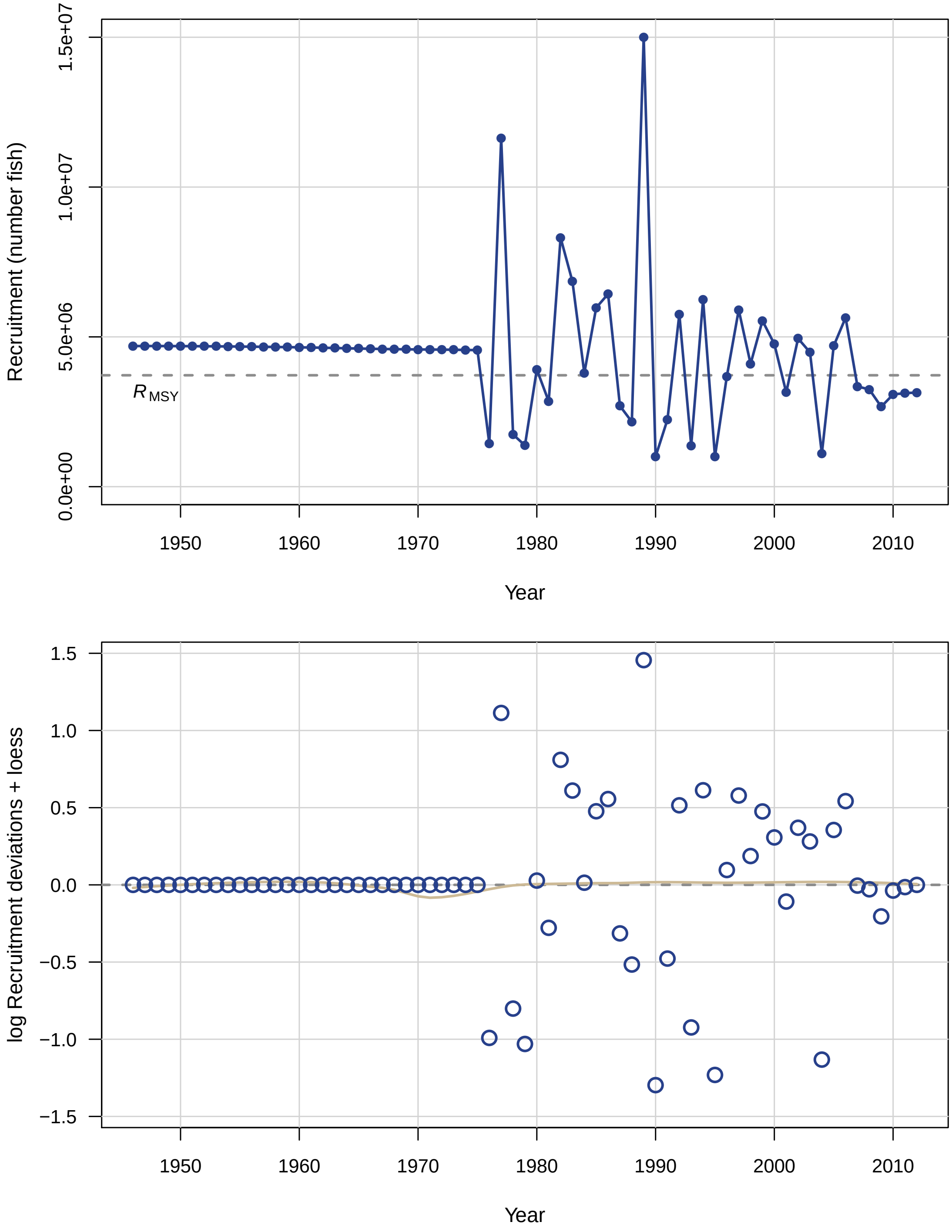


Figure 18. Estimated biomass at age at start of year.

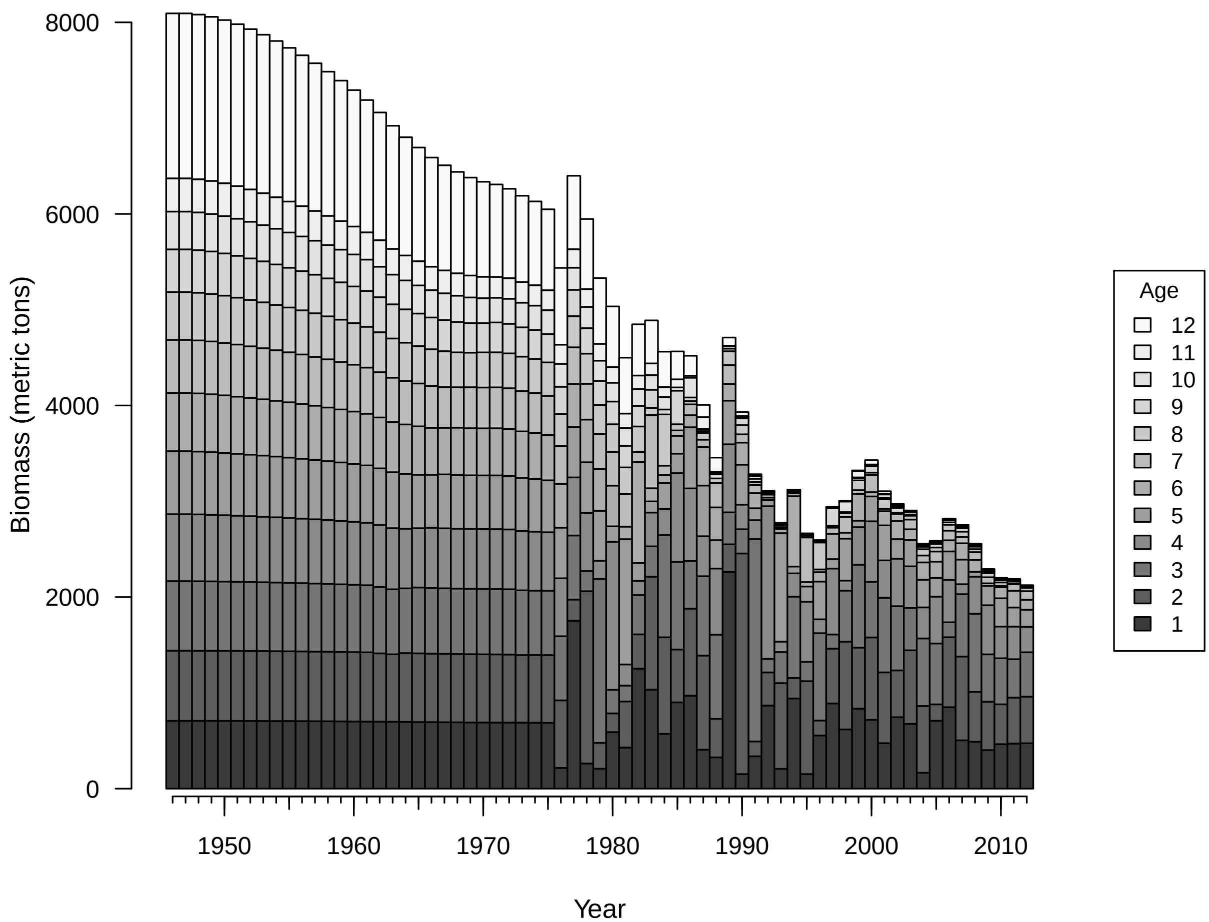


Figure 19. Top panel: Estimated total biomass (metric tons) at start of year. Horizontal dashed line indicates B_{MSY}. Bottom panel: Estimated spawning stock (population fecundity) at time of peak spawning.

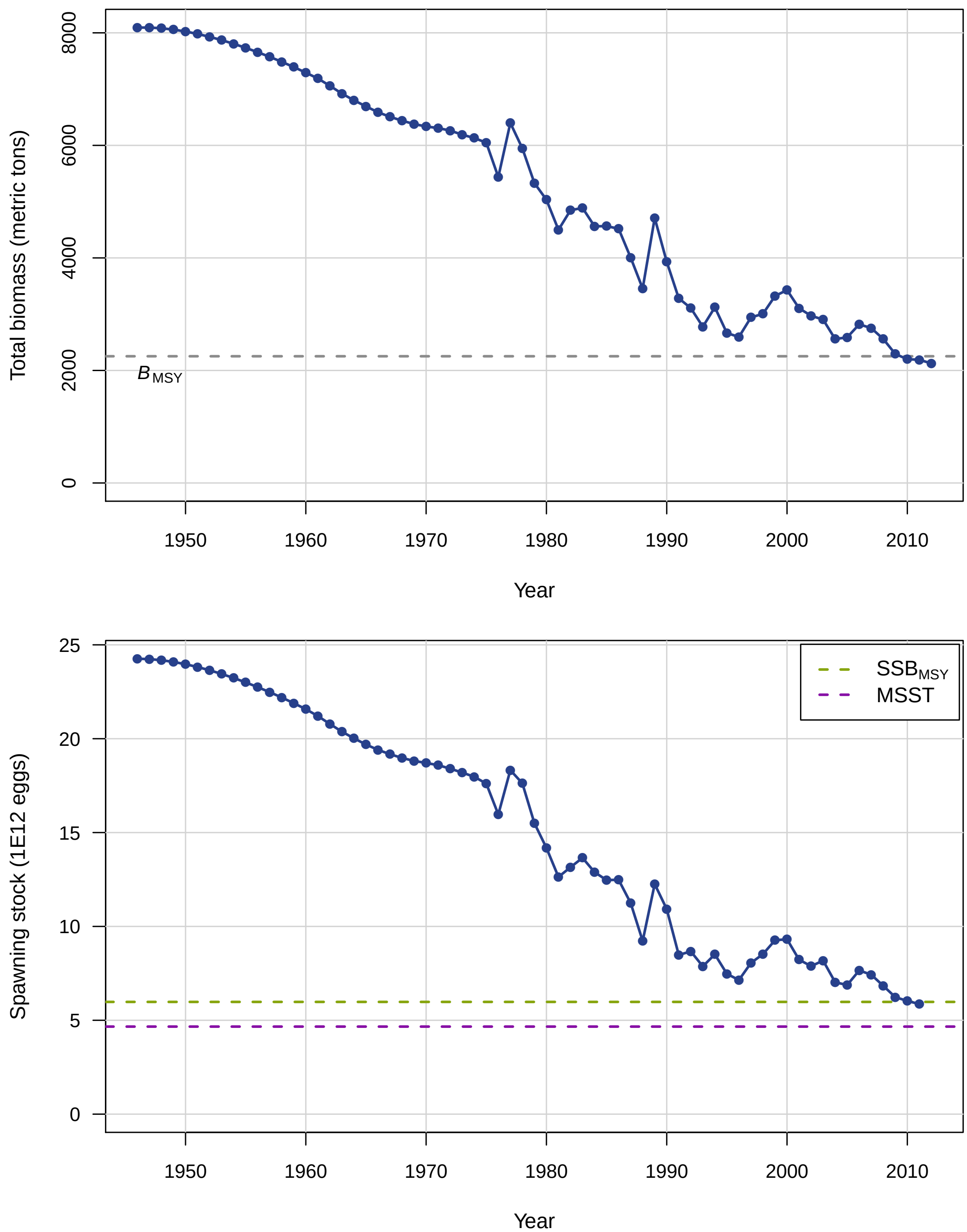


Figure 20. Selectivities of MARMAP gears. Top panel: Florida snapper traps. Bottom panel: chevron traps.

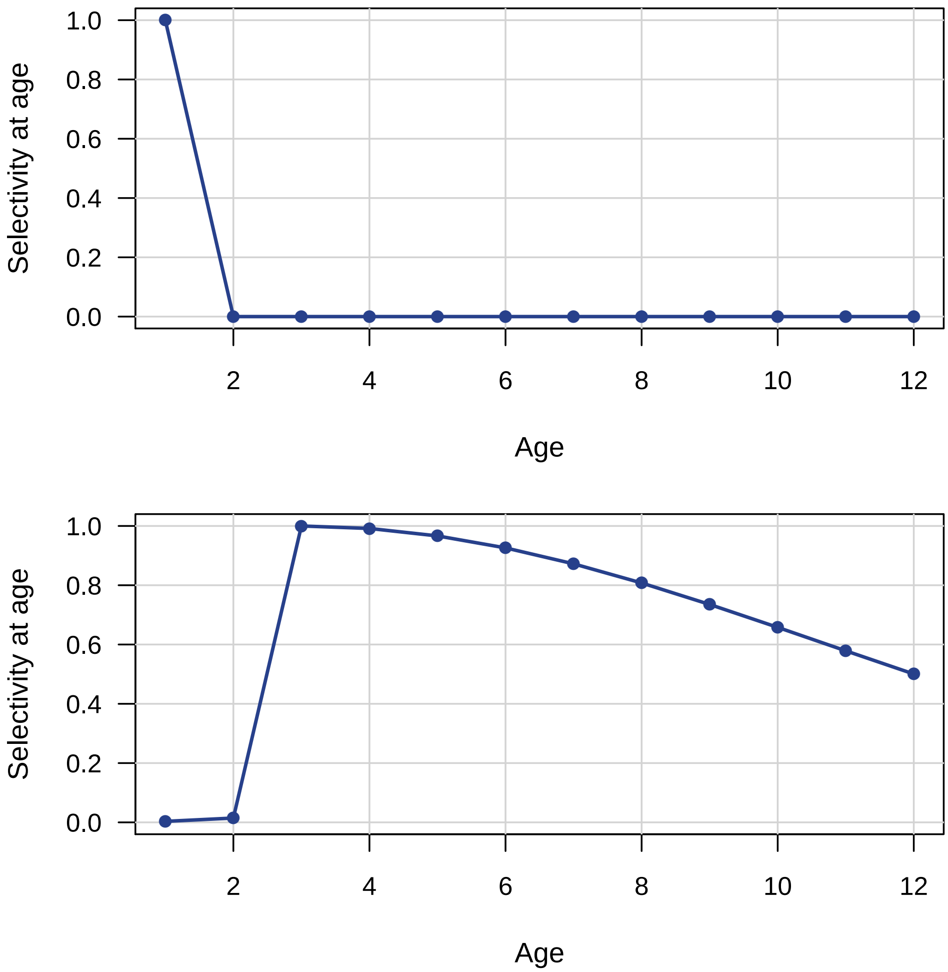


Figure 21. Estimated selectivities of commercial handline. Top panel: commercial period 1 (prior to 1992, no regulations). Bottom panel: period 2 (1992–2011, 12-inch limit).

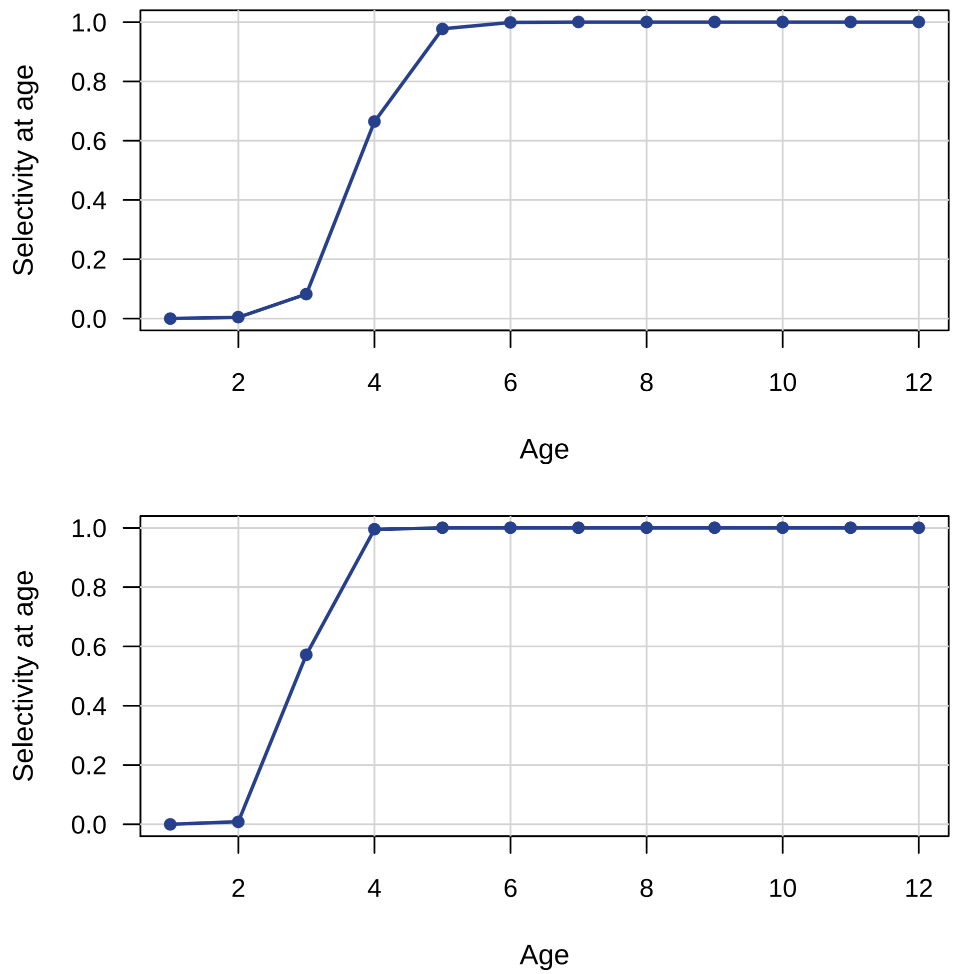


Figure 22. Selectivity of commercial historic trawl (1961, 1962).

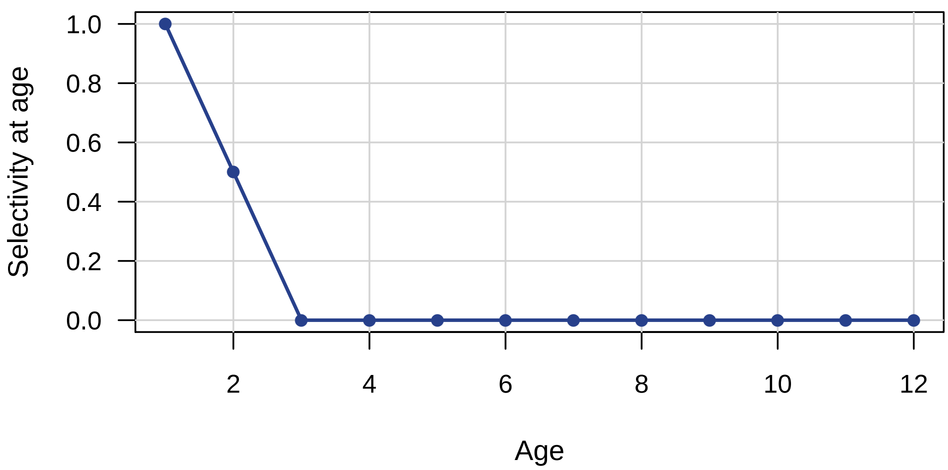


Figure 23. Selectivities of commercial combined gears. Top panel: prior to 1989 (mostly trawl gear). Bottom panel: 1989–2011 (mostly other gears).

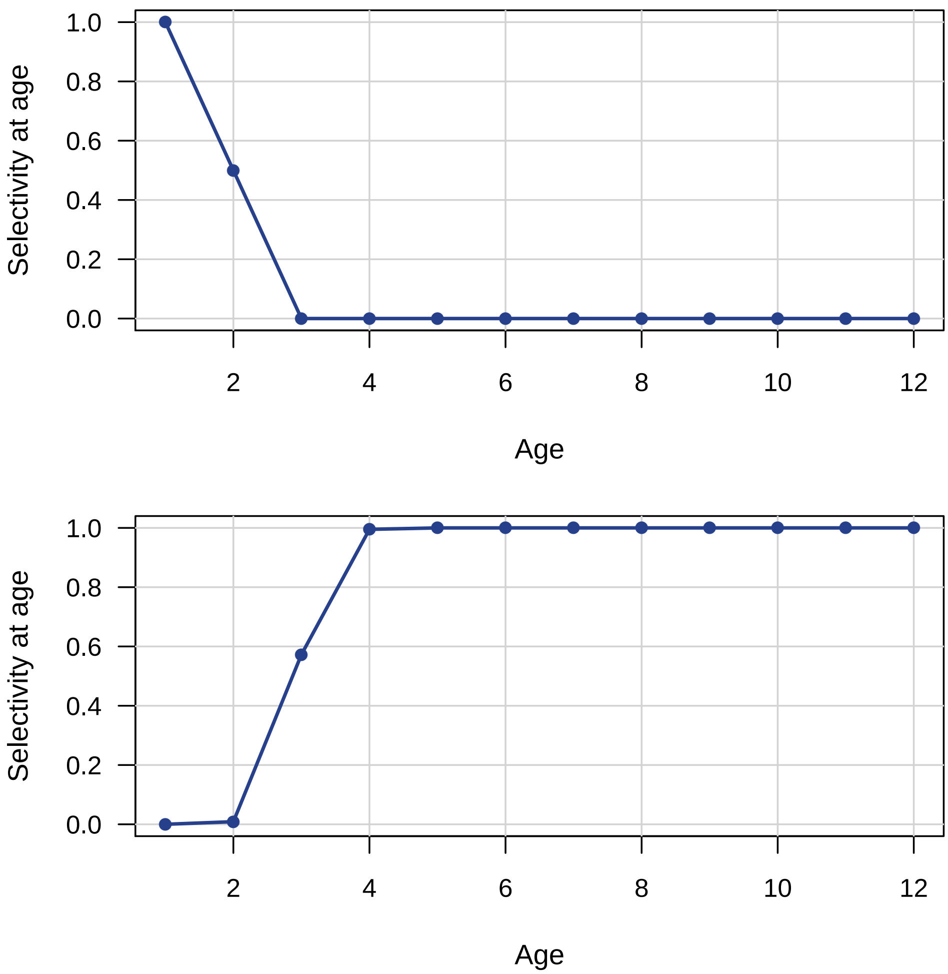


Figure 24. Estimated selectivities of the headboat fleet. Top panel: recreational period 1 (prior to 1992, no regulations). Second panel: period 2 (1992–1998, 10-inch limit). Third panel: period 3 (1999–2006, 11-inch limit). Bottom panel: period 4 (2007–2011, 12-inch limit).

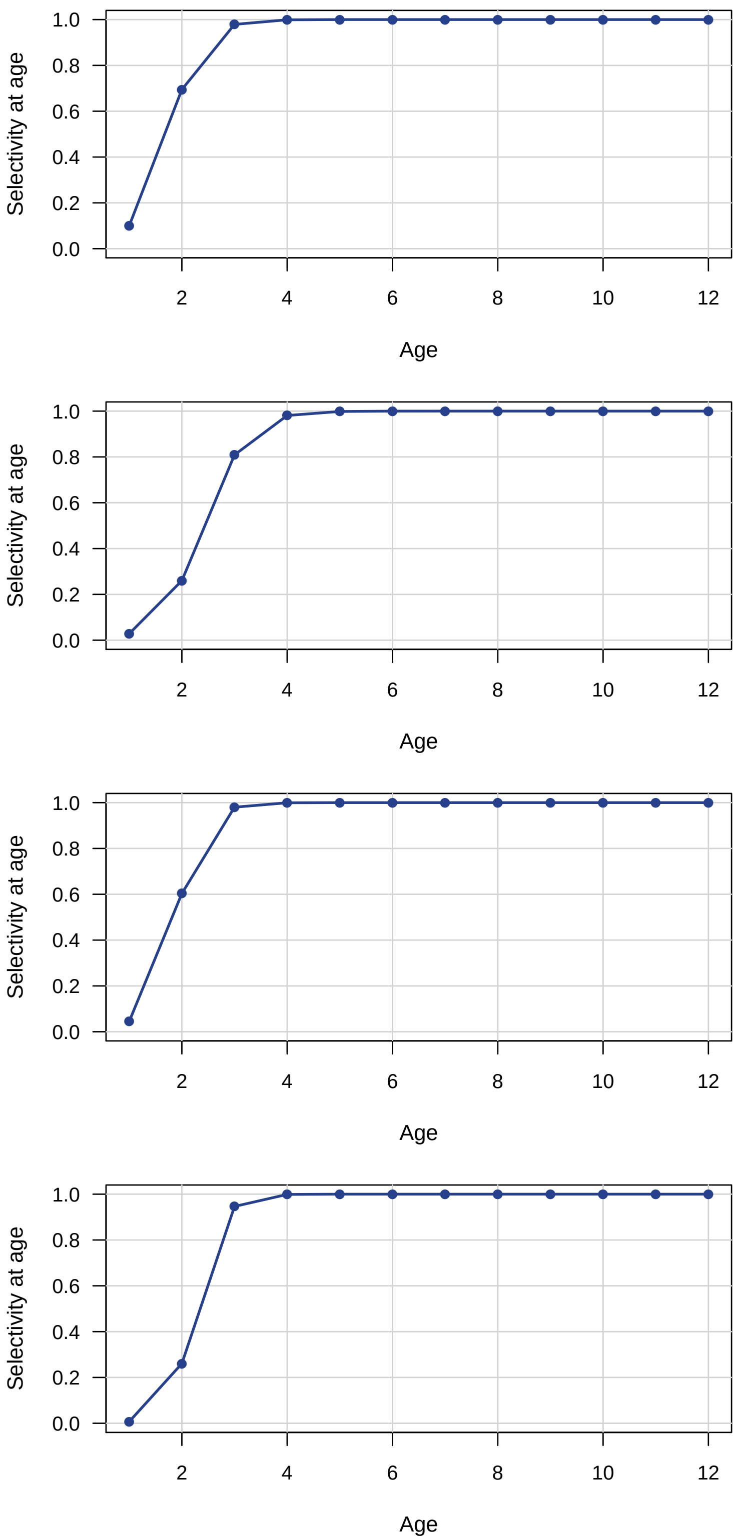


Figure 25. Estimated selectivities of the general recreational fleet. Top panel: recreational period 1 (prior to 1992, no regulations). Second panel: period 2 (1992–1998, 10-inch limit). Third panel: period 3 (1999–2006, 11-inch limit). Bottom panel: period 4 (2007-2011, 12-inch limit).

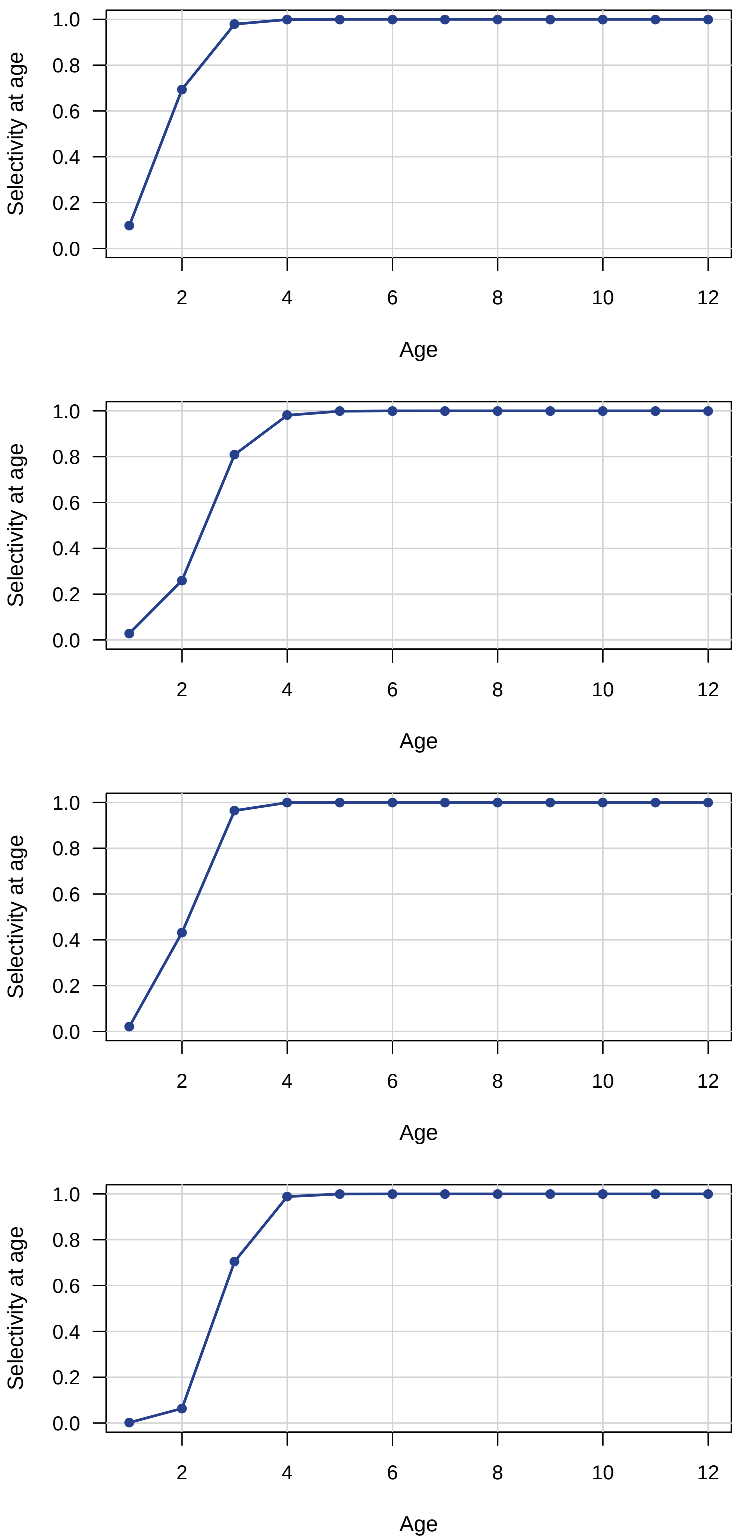


Figure 26. Estimated selectivity of discard mortalities from commercial handline. Prior to 1992, commercial discards were assumed to be zero. Top panel: 1992–2008 (12-inch limit). Bottom panel: 2009–2011 (12-inch limit and closed seasons).

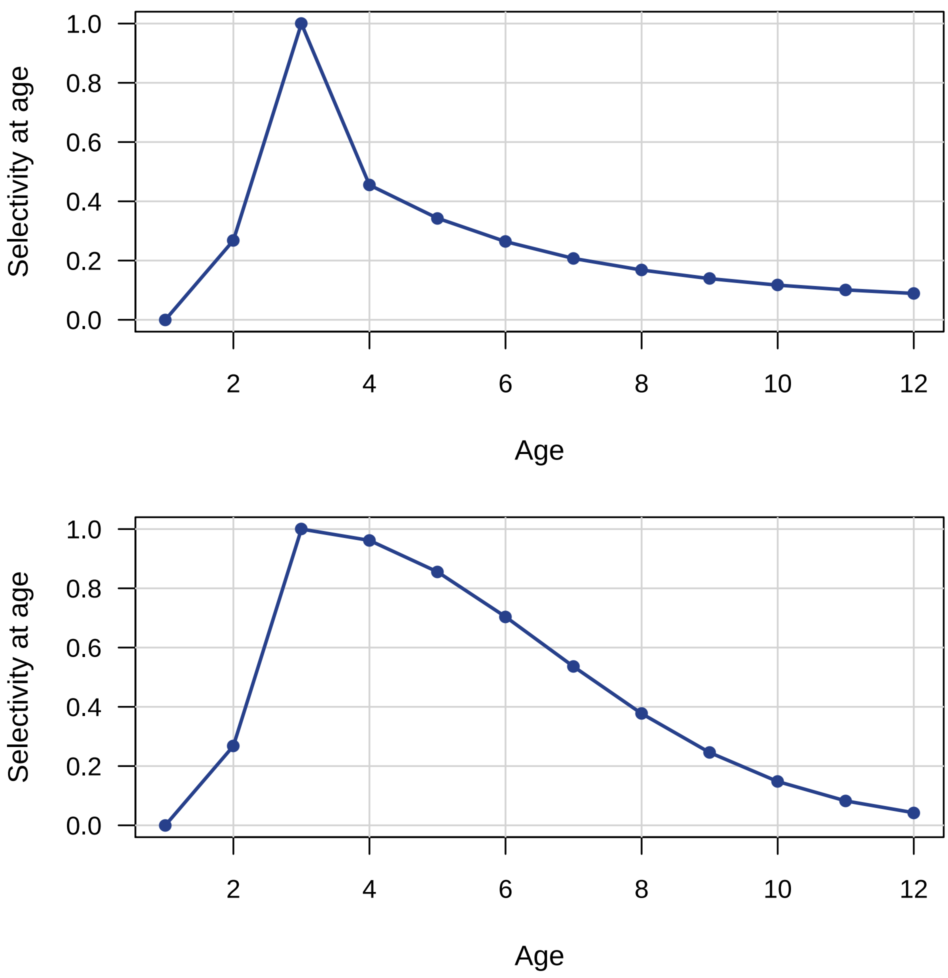


Figure 27. Estimated selectivities of discard mortalities from the headboat and general recreational fleets. The selectivity in recreational period 1 (prior to 1992, no regulations) was assumed equal to that of period 2. Top panel: recreational period 2 (1992–1998, 10-inch limit). Middle panel: period 3 (1999–2006, 11-inch limit). Bottom panel: period 4 (2007-2011, 12-inch limit).

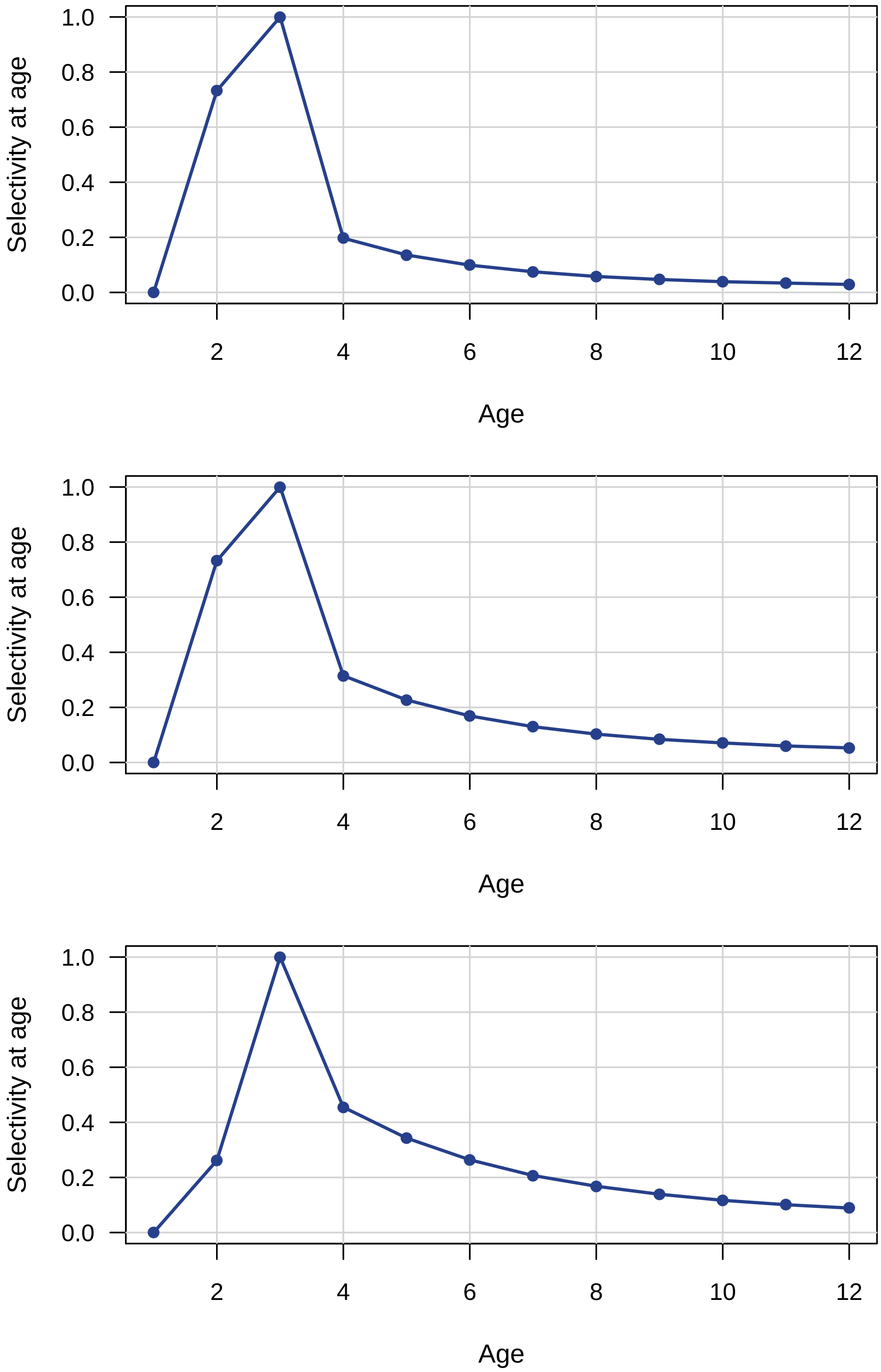


Figure 28. Average selectivities from the terminal assessment years, weighted by geometric mean Fs from the last three assessment years, and used in computation of benchmarks. Top panel: average selectivity applied to landings. Middle panel: average selectivity applied to discard mortalities. Bottom panel: total average selectivity.

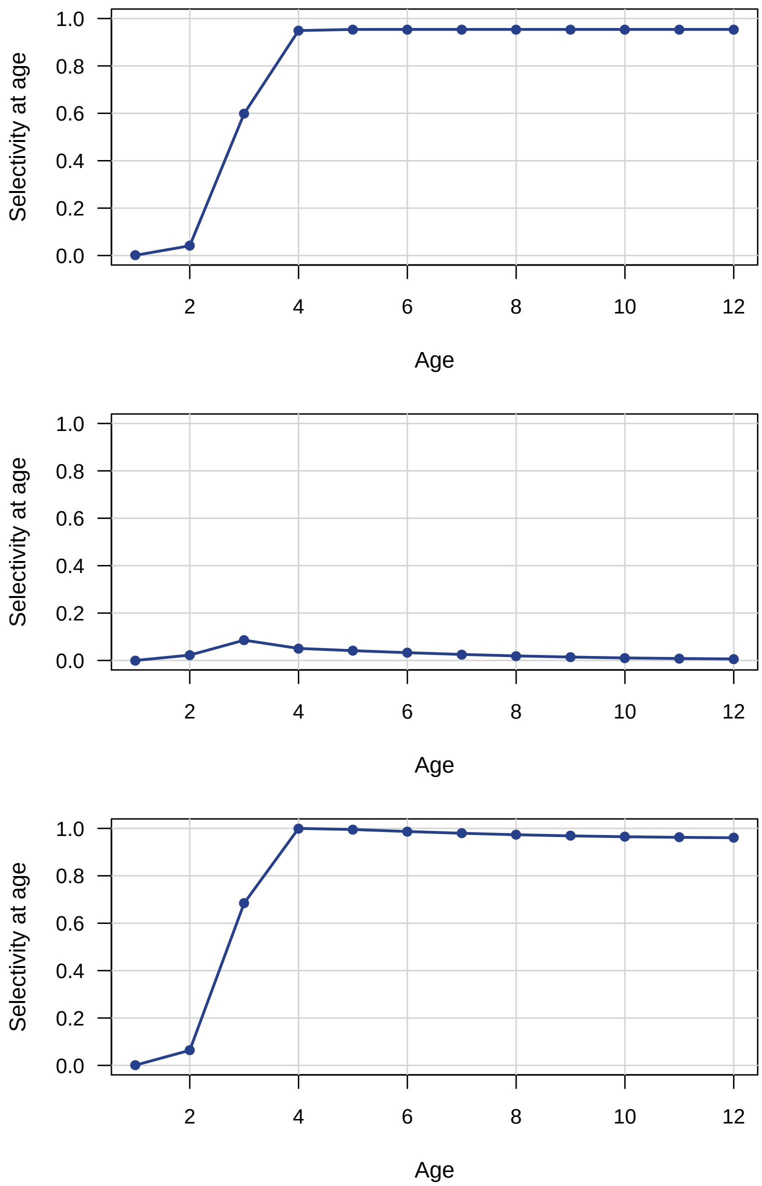


Figure 29. Estimated fully selected fishing mortality rate (per year) by fleet. c.hal refers to commercial lines, c.htr to commercial historic trawl, c.cmb to commercial combined gears, hb to headboat, rec to general recreational, c.hal.D to commercial discard mortalities, hb.D to headboat discard mortalities, and rec.D to general recreational discard mortalities.

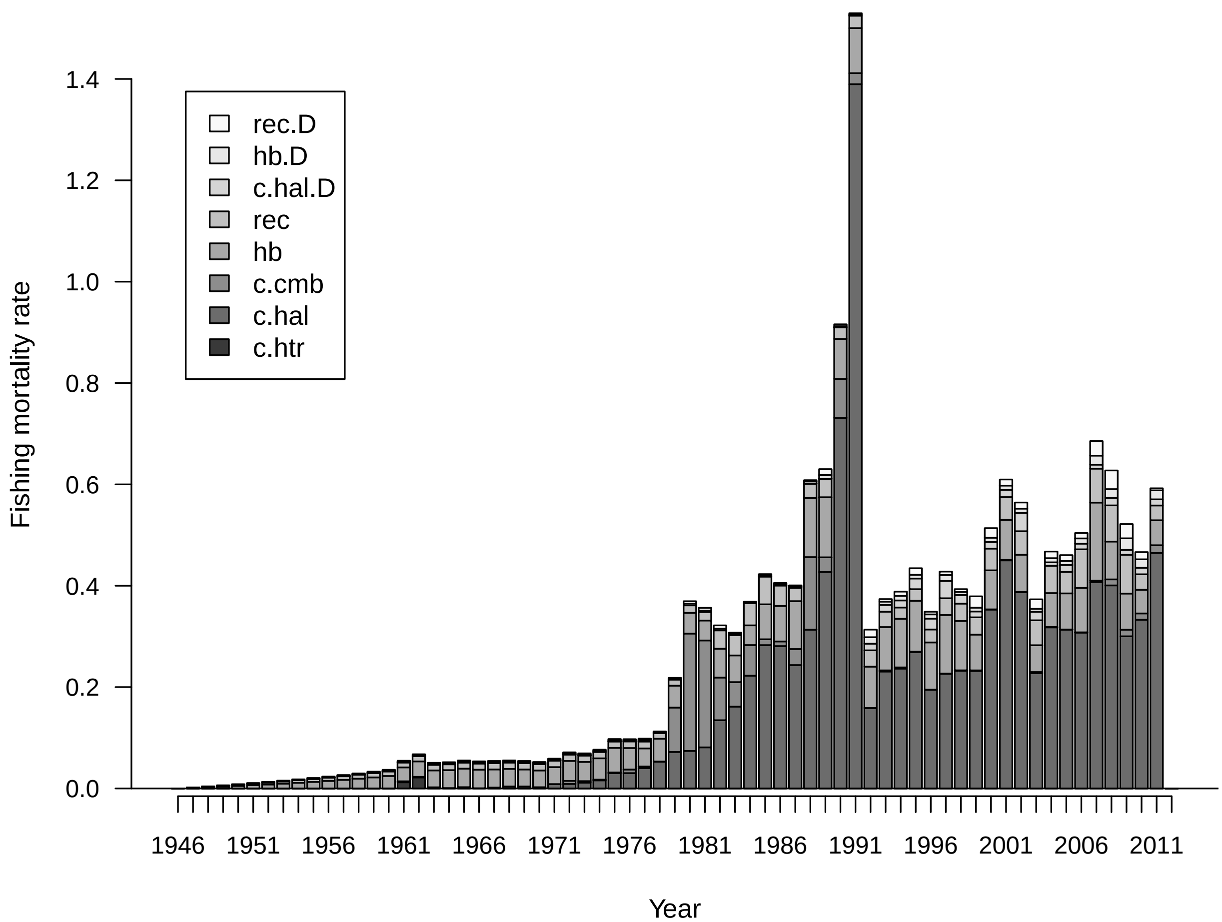


Figure 30. Estimated landings in numbers by fleet from the catch-age model. c.hal refers to commercial lines, c.htr to commercial historic trawl, c.cmb to commercial combined gears, hb to headboat, rec to general recreational.

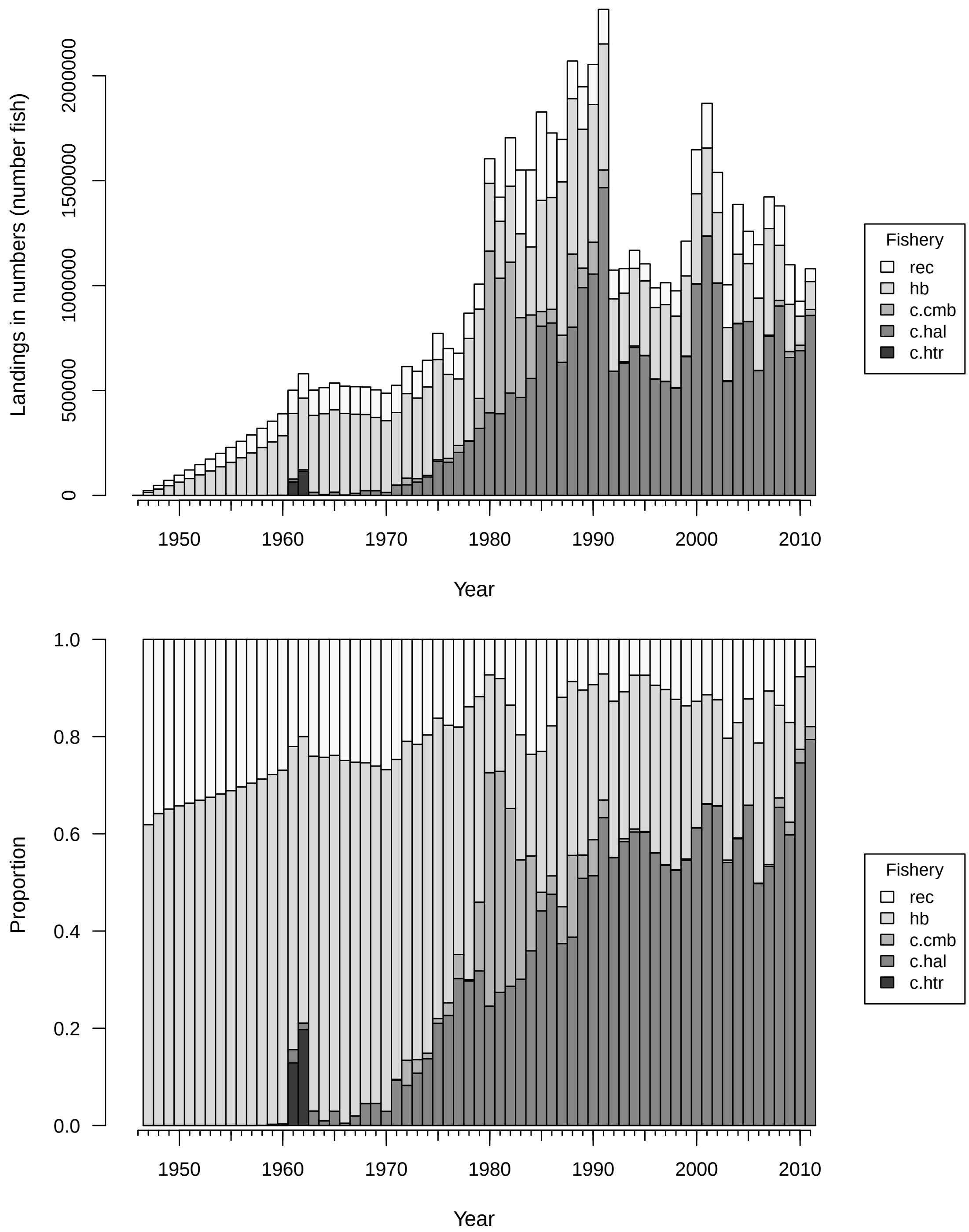


Figure 31. Estimated landings in whole weight by fleet from the catch-age model. c.hal refers to commercial lines, c.htr to commercial historic trawl, c.cmb to commercial combined gears, hb to headboat, rec to general recreational. Horizontal dashed line in the top panel corresponds to the point estimate of MSY.

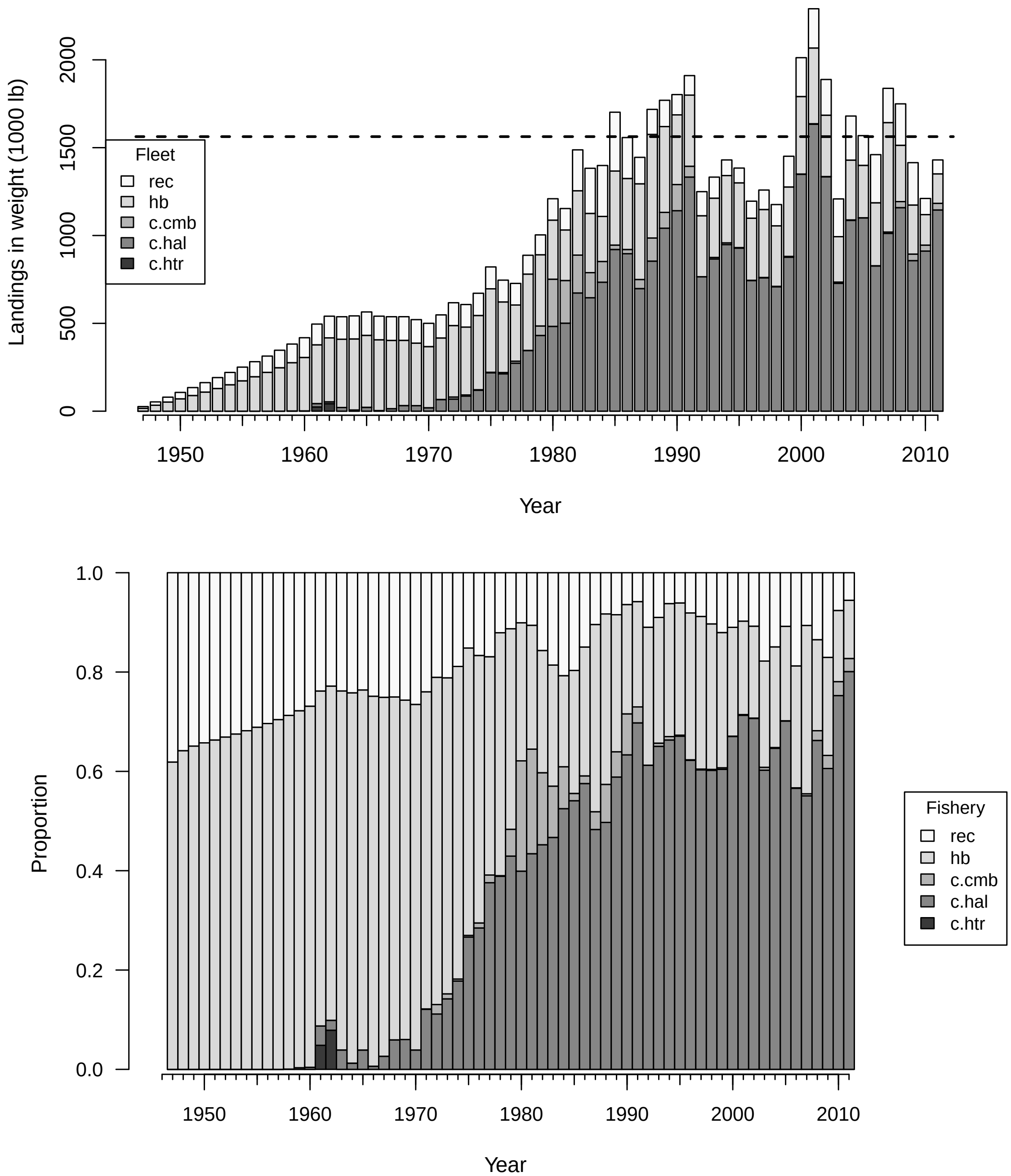


Figure 32. Estimated discard mortalities by fleet from the catch-age model. c.hal refers to commercial lines, hb to headboat, rec to general recreational.

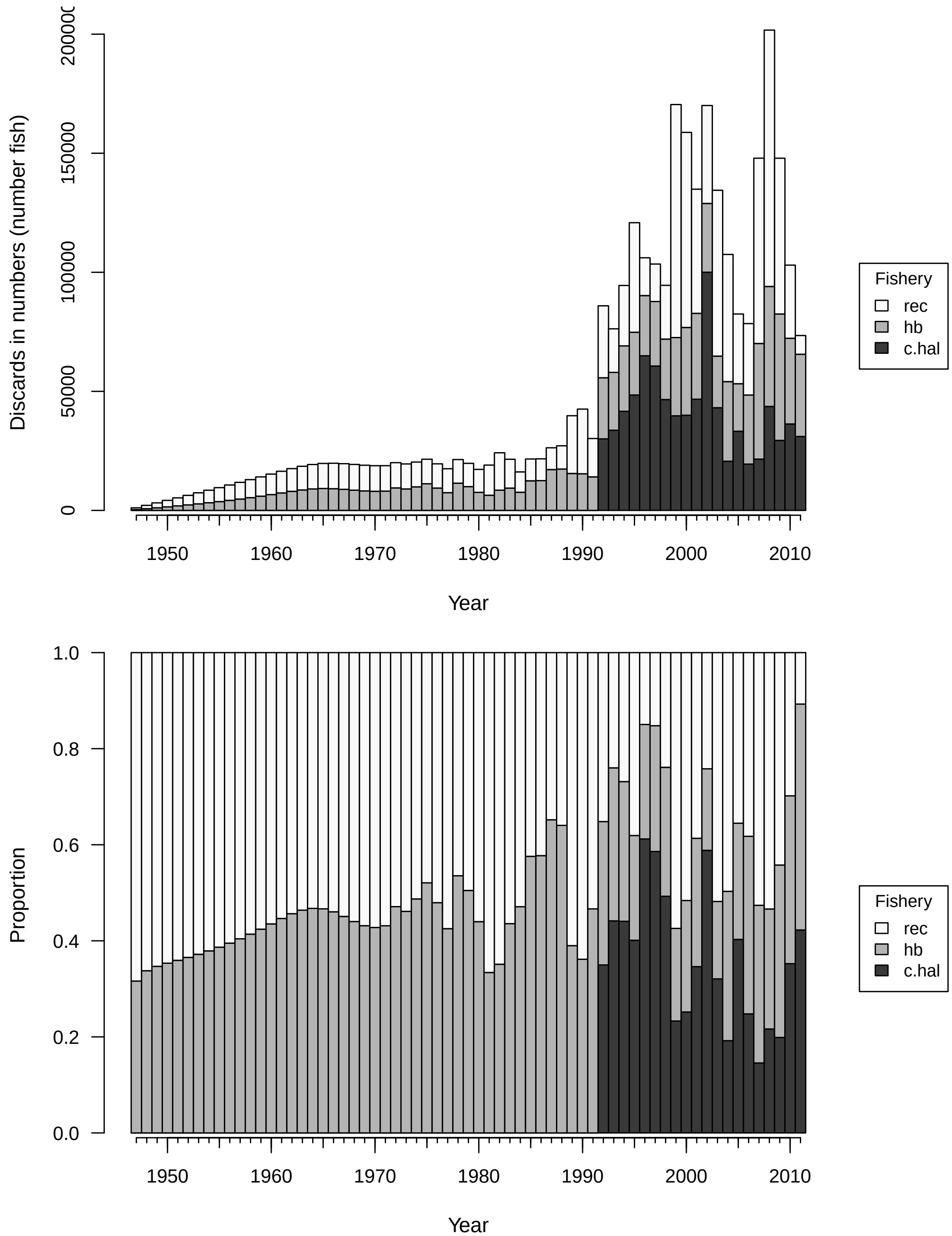


Figure 33. Top panel: Beverton–Holt spawner-recruit curves, with and without lognormal bias correction. The expected (upper) curve was used for computing management benchmarks. Bottom panel: log of recruits (number age-1 fish) per spawner as a function of spawners.

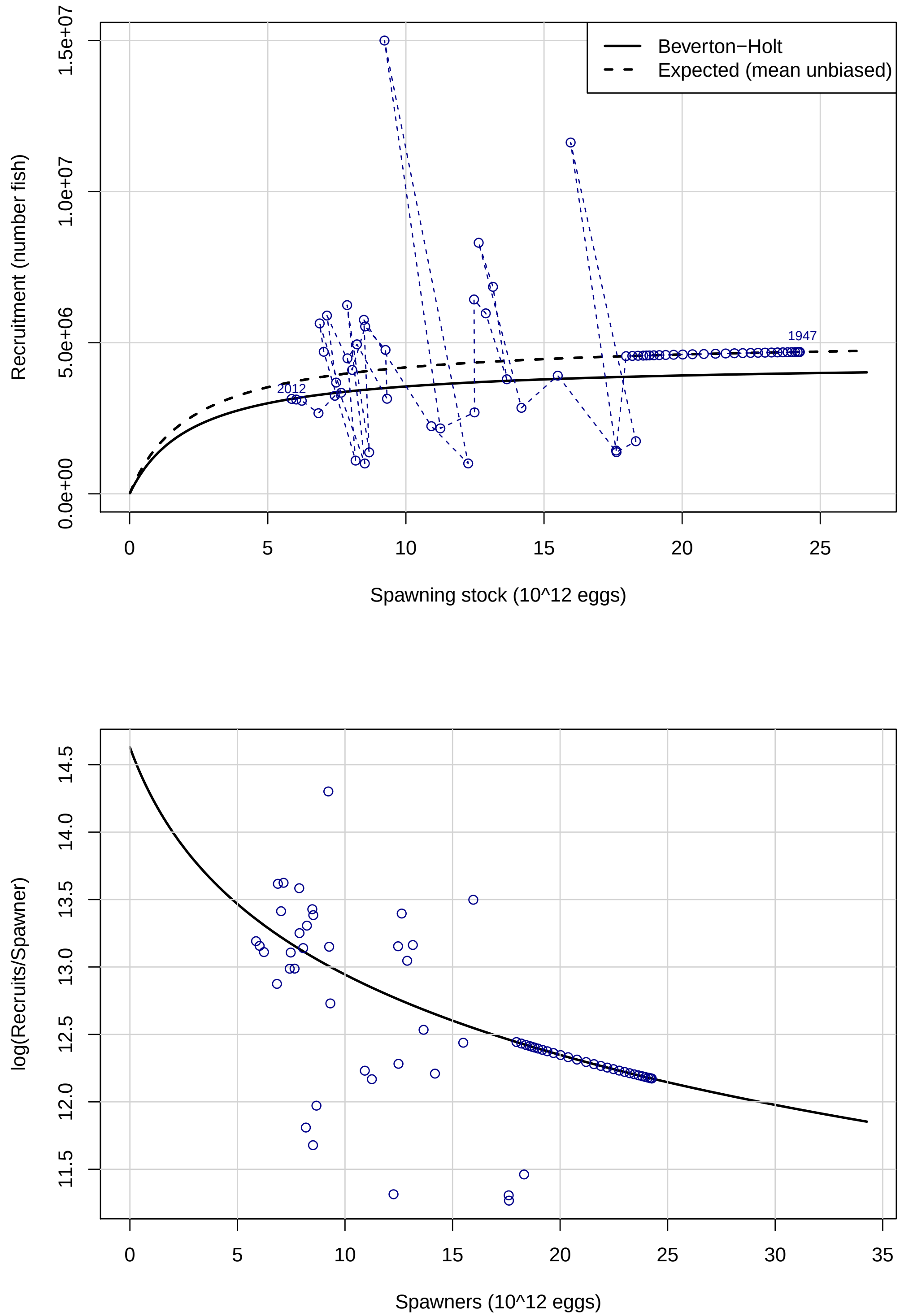


Figure 34. Probability densities of spawner-recruit quantities R0 (unfished recruitment of age-1 fish), steepness, unfished spawners per recruit, and standard deviation of recruitment residuals in log space. Vertical lines represent point estimates or values from the base run of the Beaufort Assessment Model.

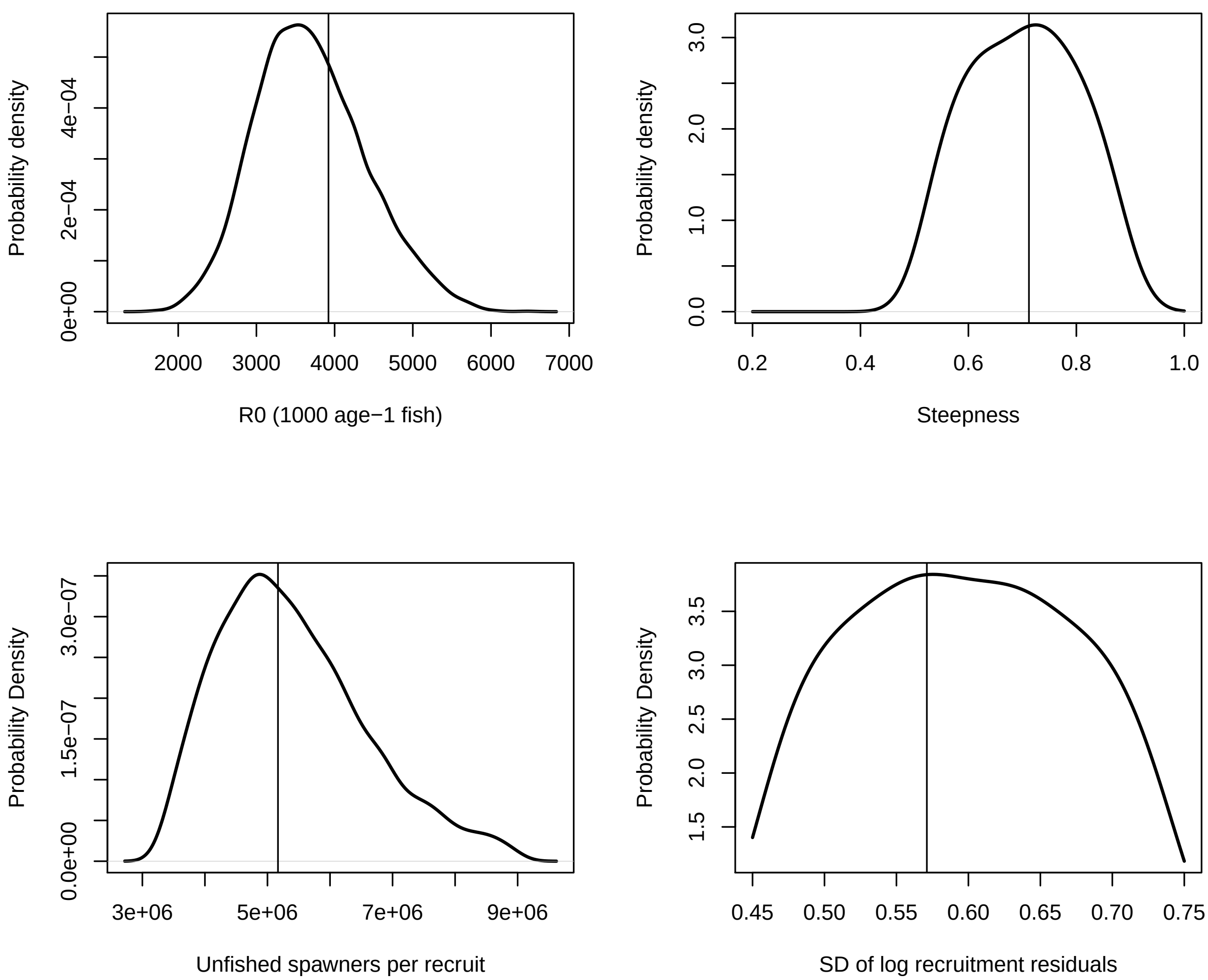


Figure 35. Estimated time series of static spawning potential ratio, the annual equilibrium spawners per recruit relative to that at the unfished level. Horizontal dashed line indicates the equilibrium MSY level, given current selectivity patterns.

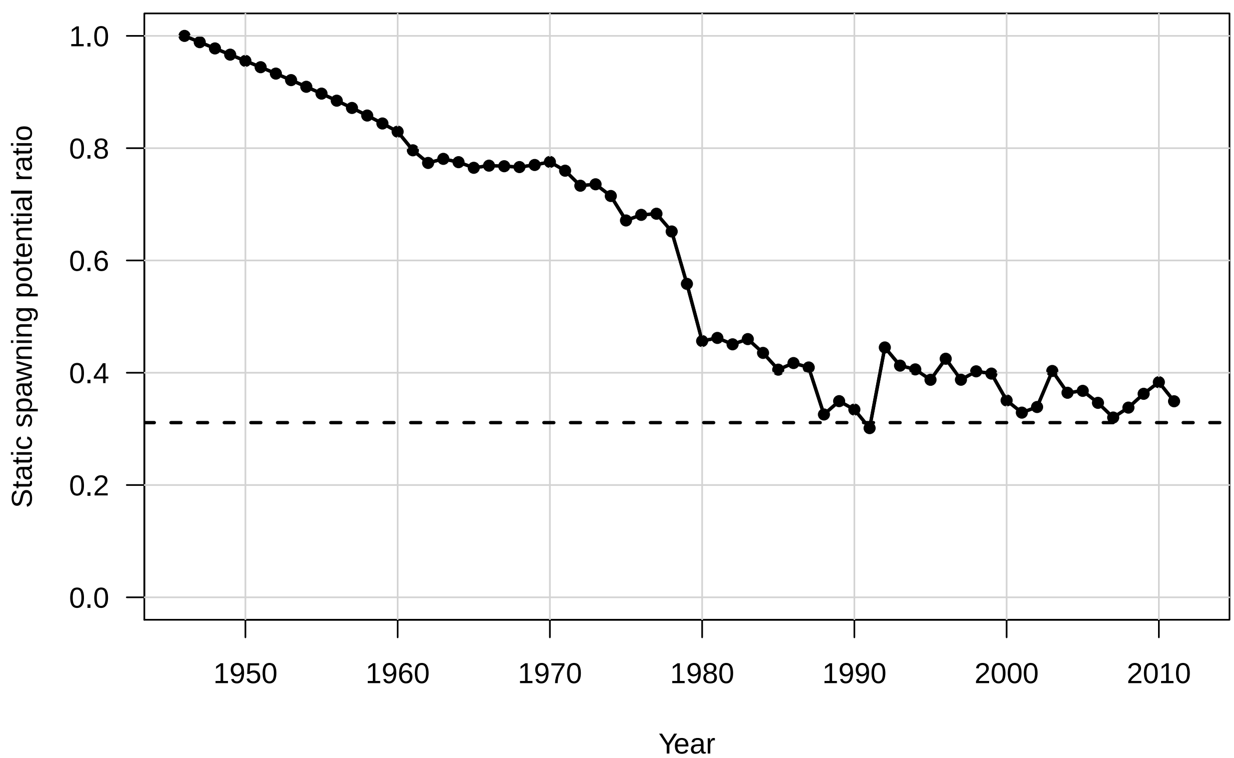


Figure 36. Top panel: yield per recruit. Bottom panel: spawning potential ratio (spawning biomass per recruit relative to that at the unfished level), from which the X% level of SPR provides $F_{X\%}$. Both curves are based on average selectivity from the end of the assessment period.

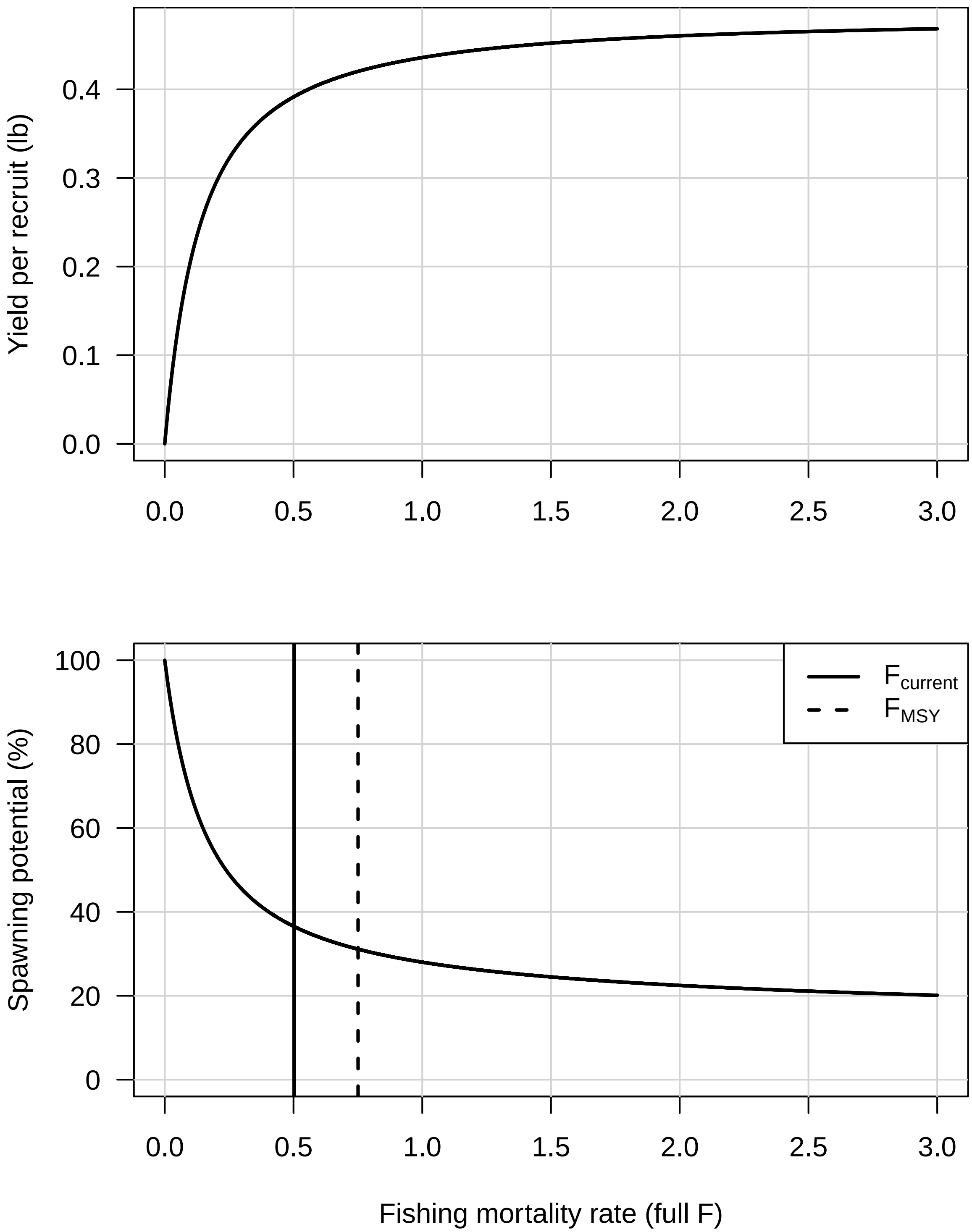


Figure 37. Top panel: equilibrium landings. The peak occurs where fishing rate is $F_{\mathrm{MSY}} = 0.75$ *and equilibrium landings are* $\mathrm{MSY} = 1563$ *(1000 lb). Bottom panel: equilibrium spawning biomass. Both curves are based on average selectivity from the end of the assessment period.*

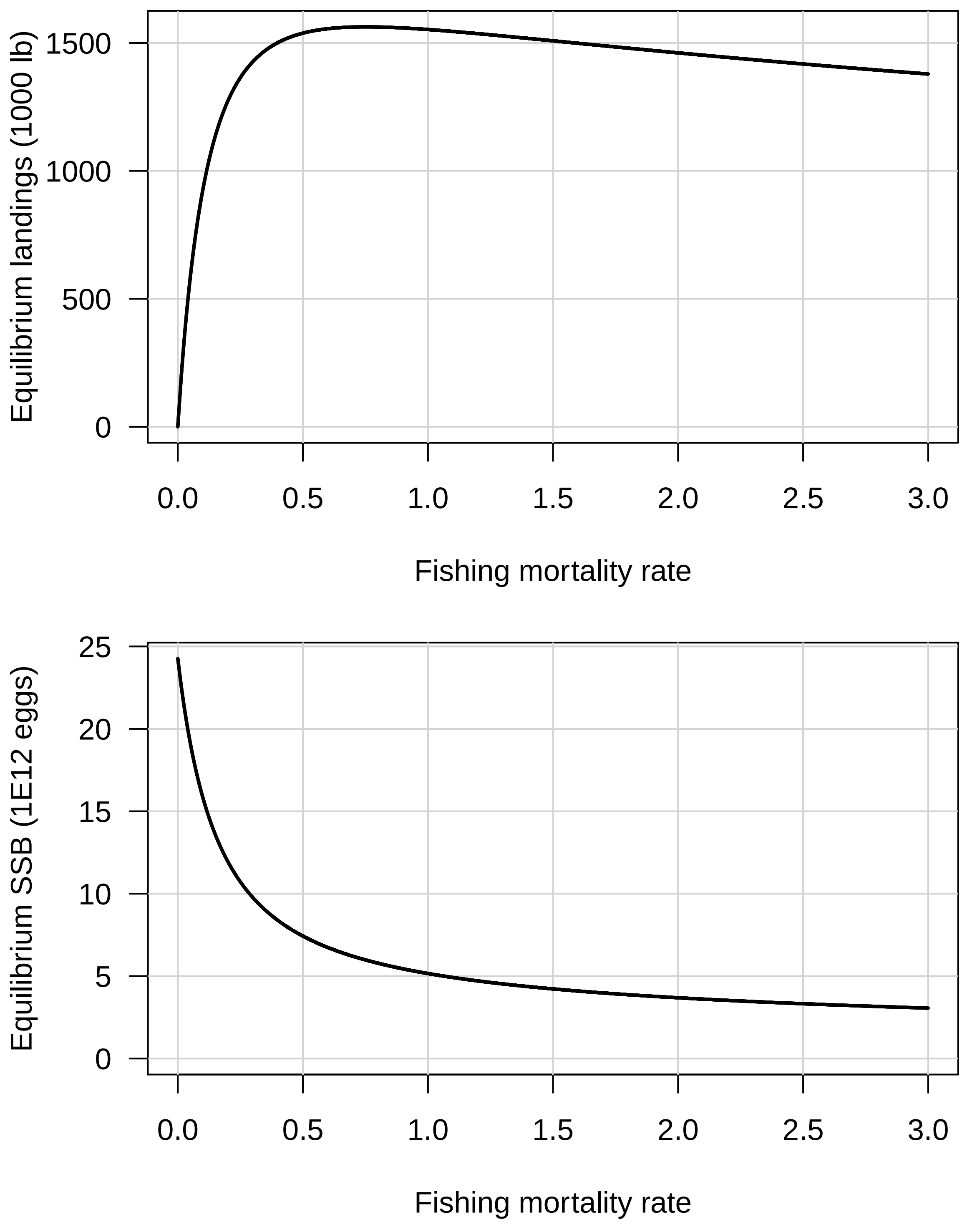


Figure 38. Top panel: equilibrium landings as a function of equilibrium biomass, which itself is a function of fishing mortality rate. The peak occurs where equilibrium biomass is $B_{\text{MSY}} = 2252$ *mt and equilibrium landings are* $\text{MSY} = 1563$ *(1000 lb). Bottom panel: equilibrium discard mortality as a function of equilibrium biomass.*

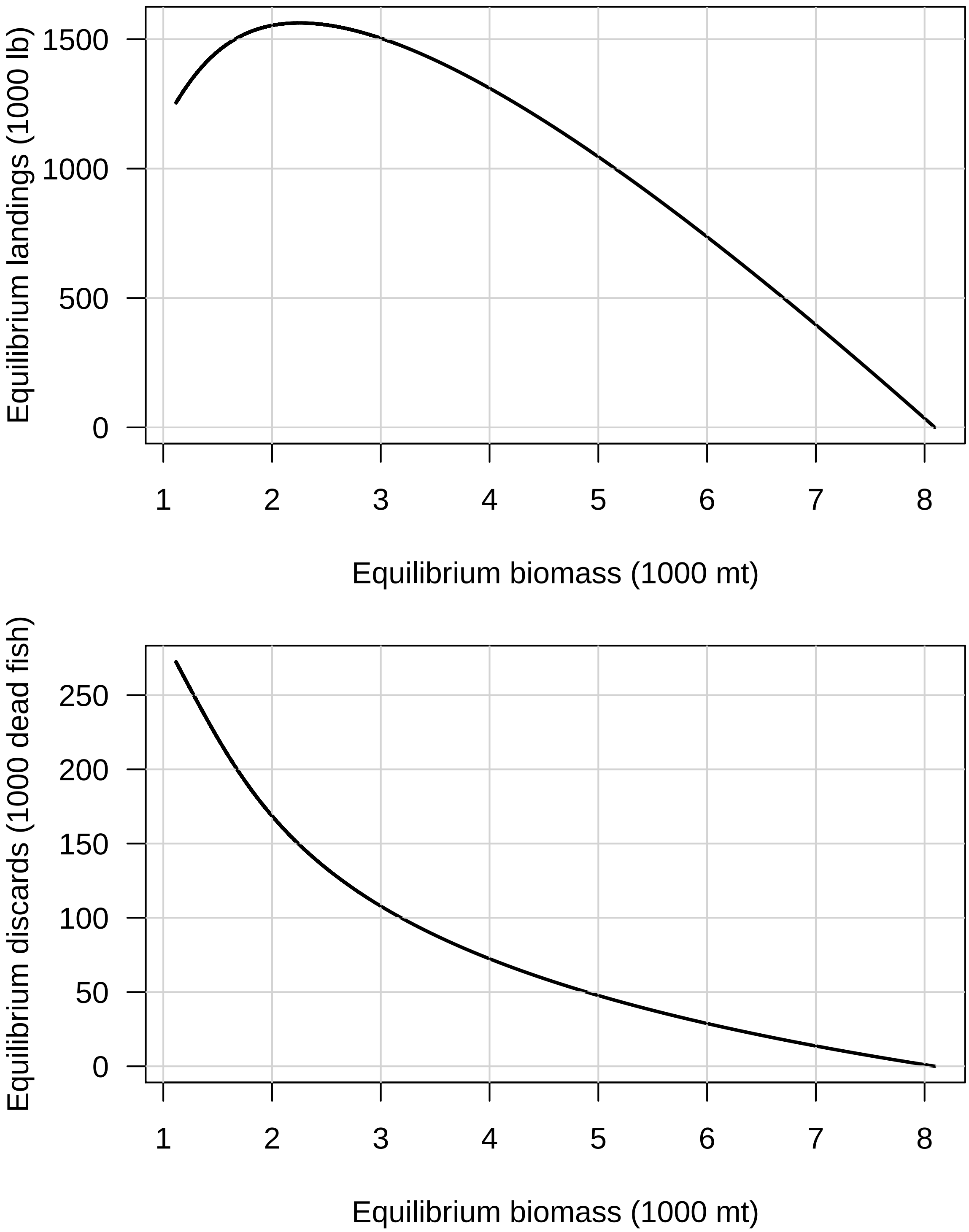


Figure 39. Probability densities of MSY*-related benchmarks from MCB analysis of the Beaufort Assessment Model. Vertical lines represent point estimates from the base run.*

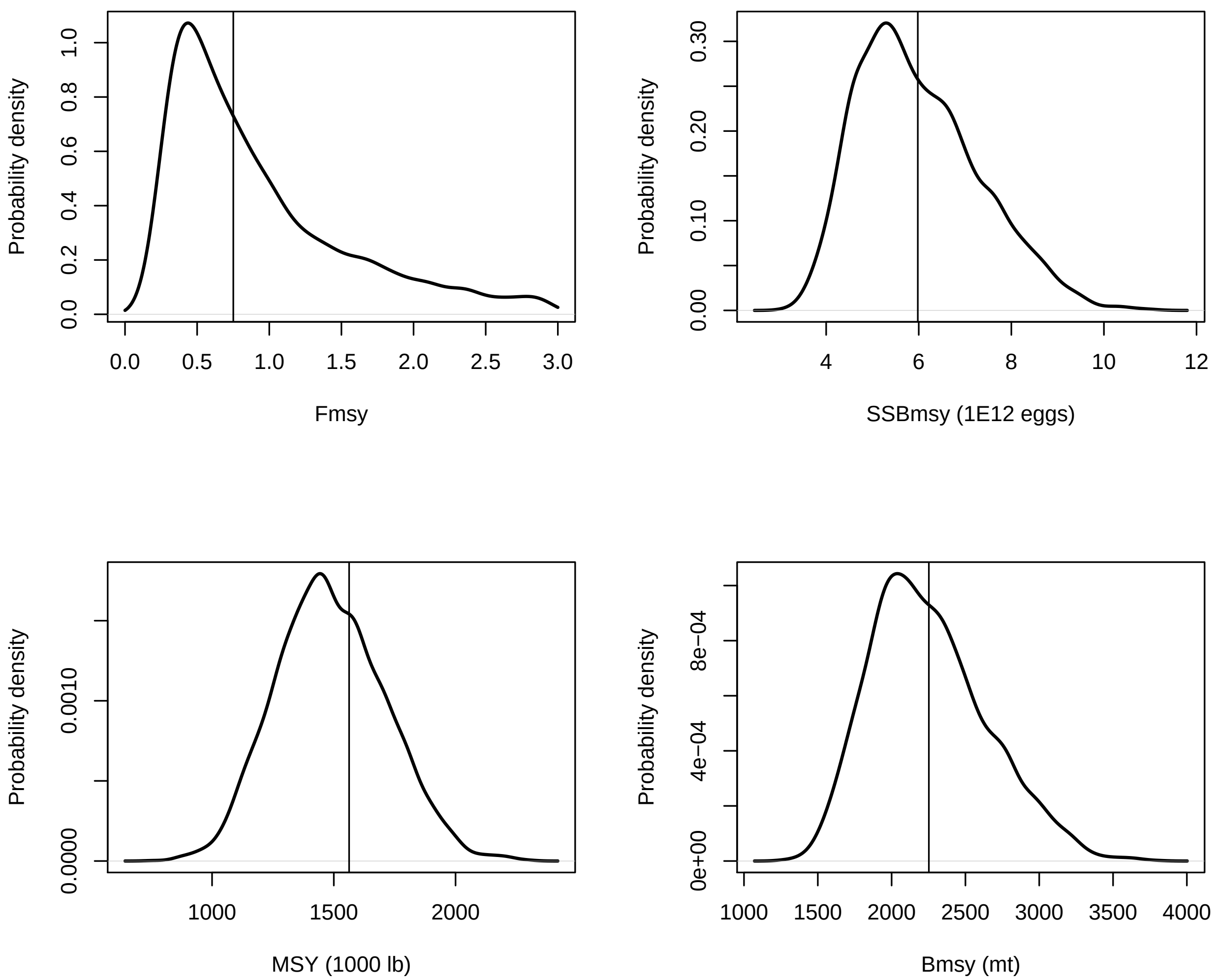


Figure 40. Estimated time series relative to benchmarks. Solid line indicates estimates from base run of the Beaufort Assessment Model; gray error bands indicate 5^{th} *and* 95^{th} *percentiles of the MCB trials. Top panel: spawning biomass relative to the minimum stock size threshold (*MSST*). Middle panel: spawning biomass relative to* $\mathrm{SSB_{MSY}}$*. Bottom panel: F relative to* F_{MSY}*.*

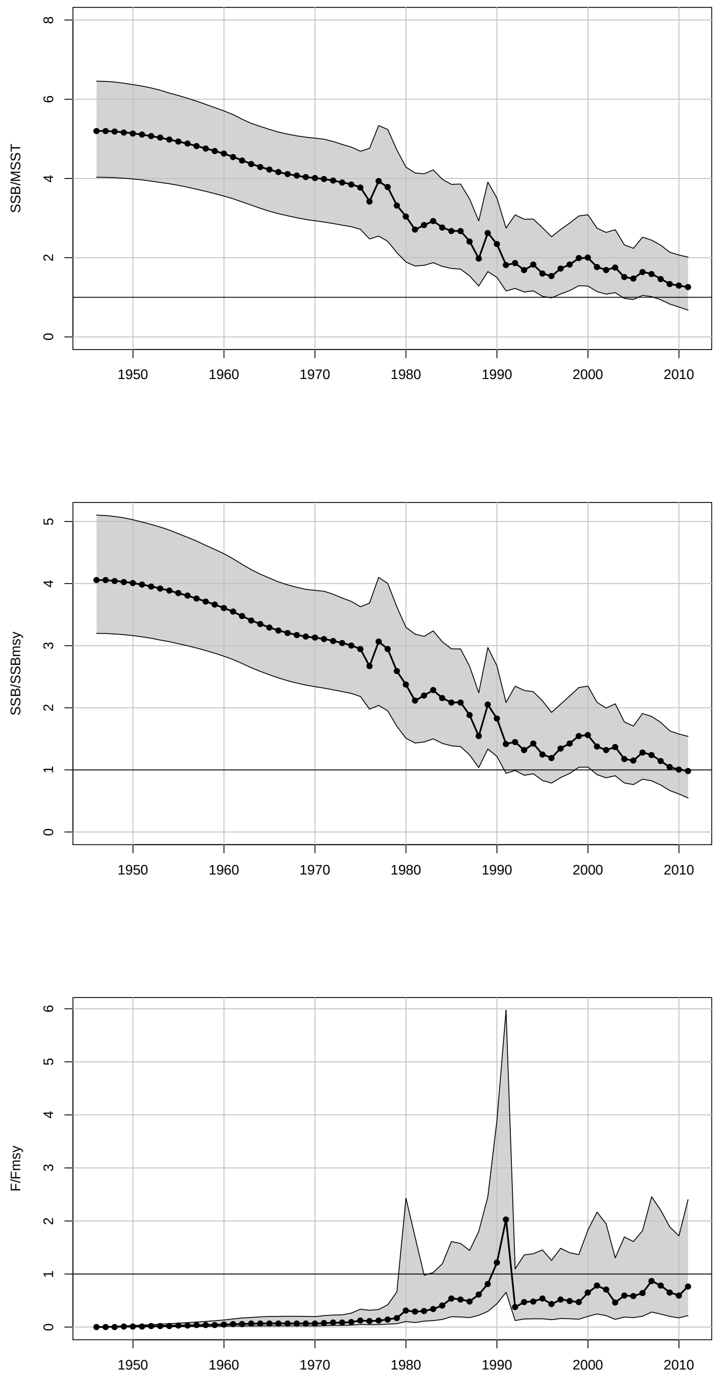


Figure 41. Probability densities of terminal status estimates from MCB analysis of the Beaufort Assessment Model. Vertical lines represent point estimates from the base run.

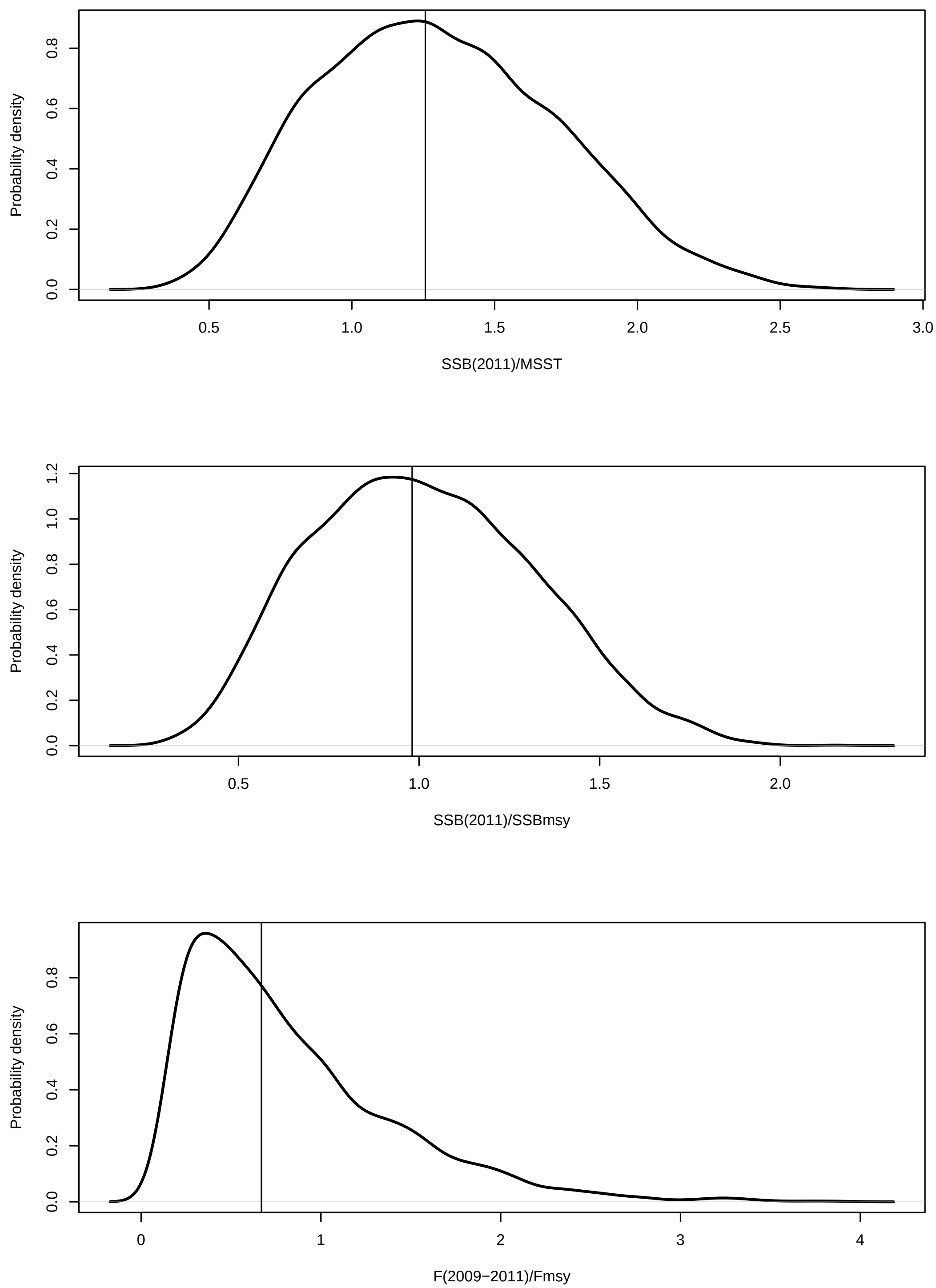


Figure 42. Phase plots of terminal status estimates from MCB analysis of the Beaufort Assessment Model. The intersection of crosshairs indicates estimates from the base run; lengths of crosshairs defined by 5^{th} and 95^{th} percentiles.

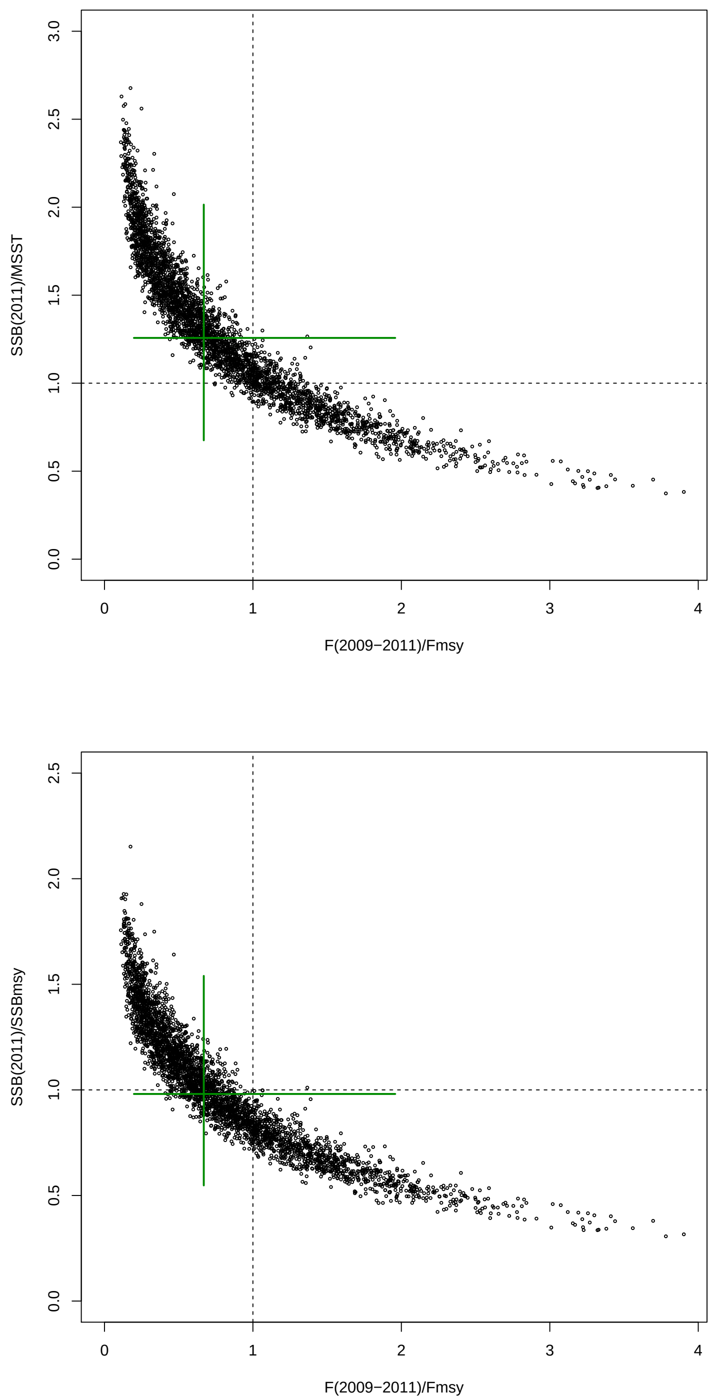


Figure 43. Age structure relative to the equilibrium expected at MSY.

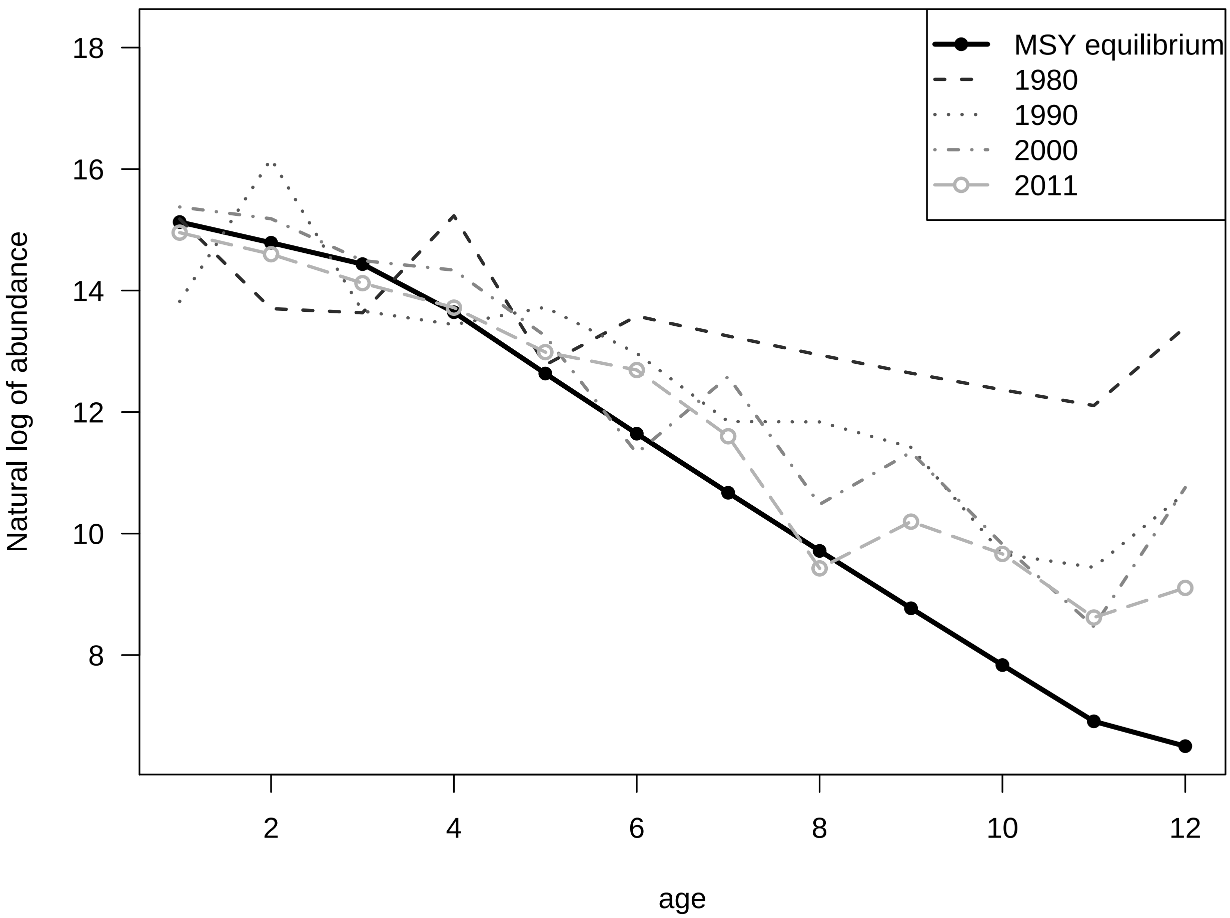


*Figure 44. Comparison of results from this update assessment and from the previous, SEDAR-17 assessment. Top panel: F relative to F_{MSY}. Bottom panel: spawning biomass relative to the minimum stock size threshold (*MSST*).*

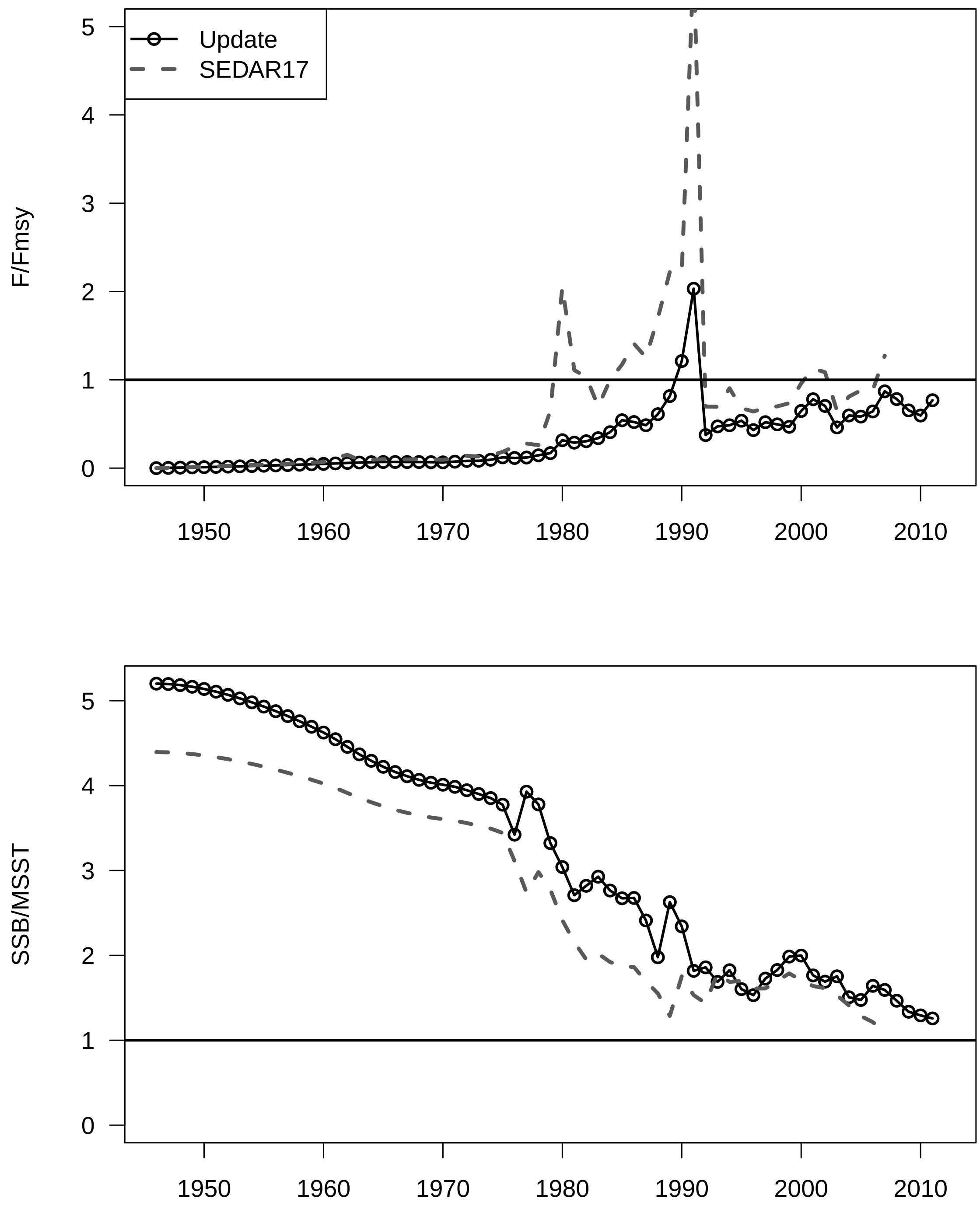


Figure 45. Sensitivity to updated values of steepness and data component weights (sensitivity runs S1–S2). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* MSST.

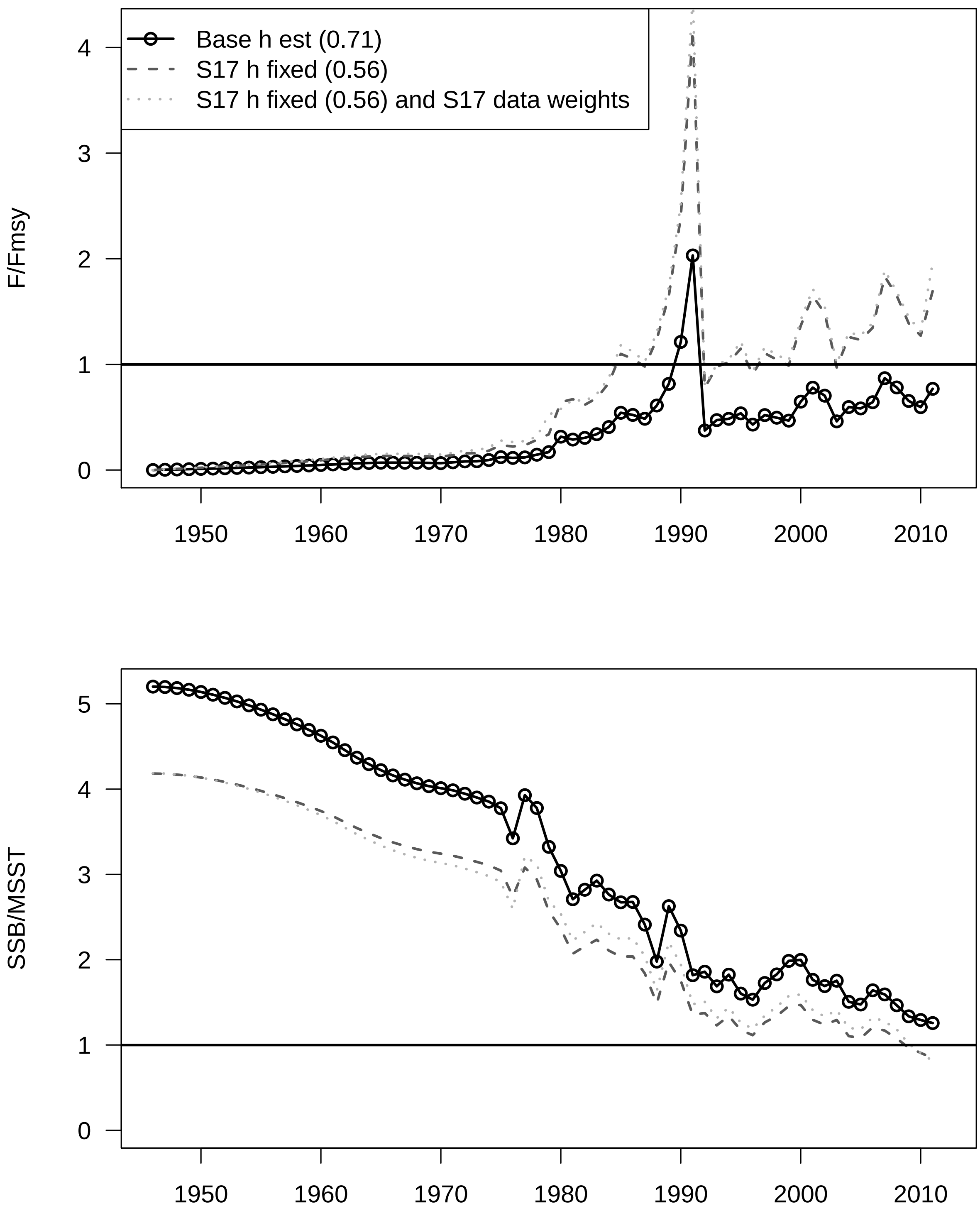
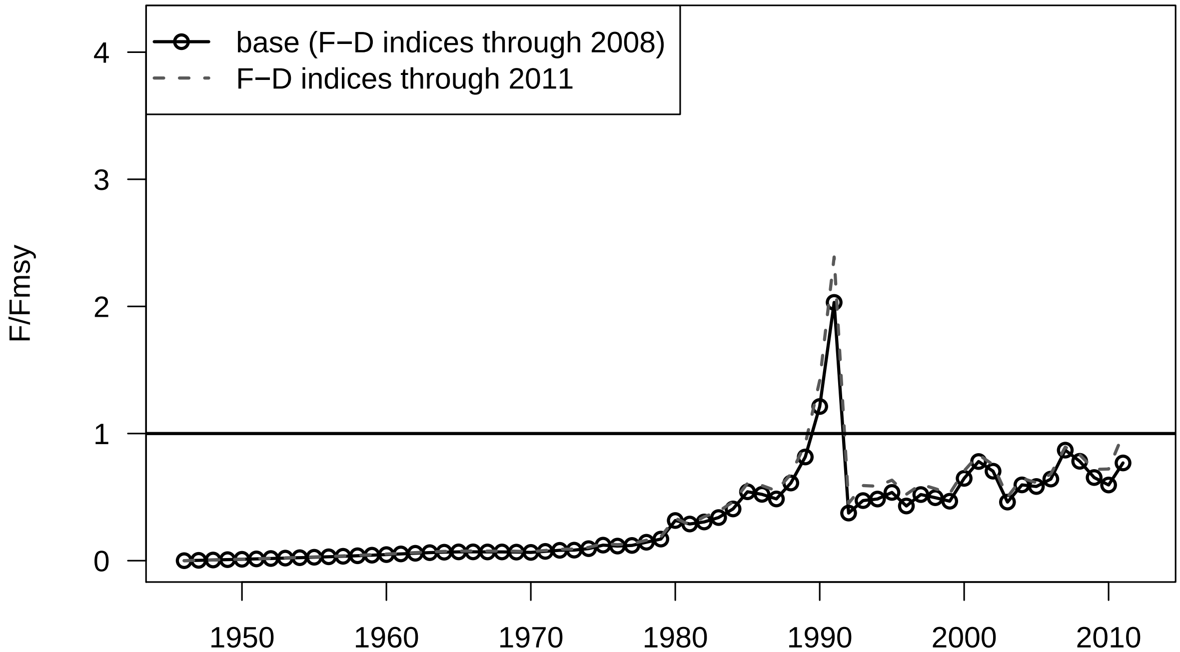


Figure 46. Sensitivity to terminal year of fishery dependent indices of abundance (sensitivity run S3). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* MSST.



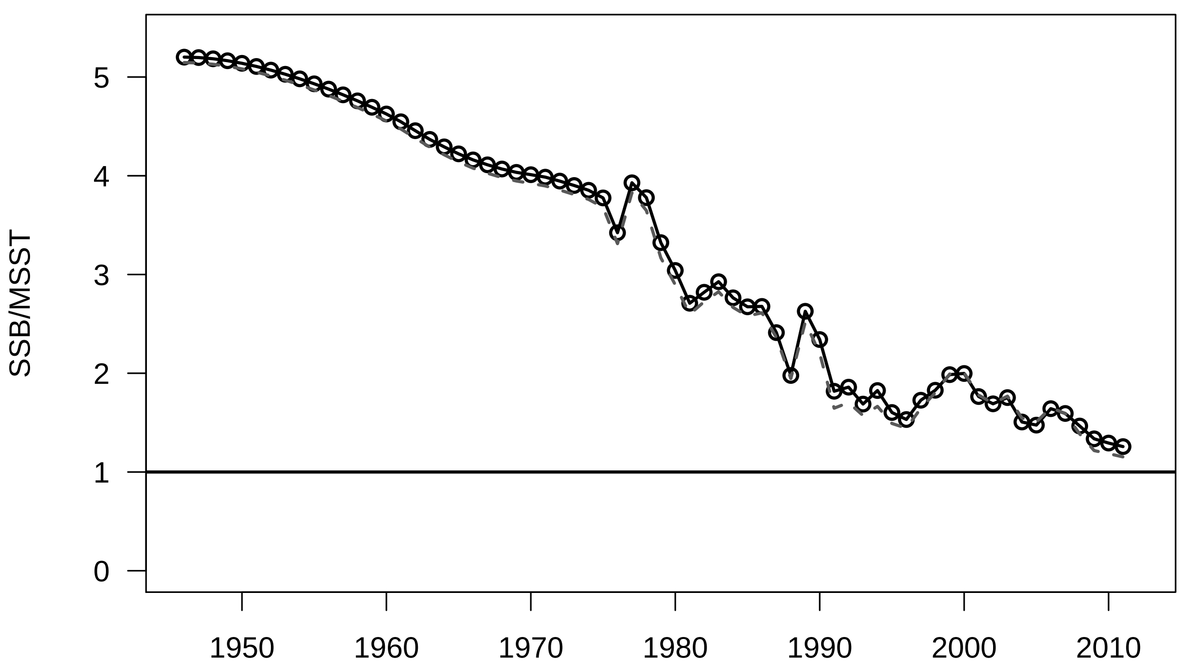


Figure 47. Sensitivity to the increase in fishery dependent catchability saturating in 2003 (sensitivity run S4). Top panel: Ratio of F to F_{MSY}. Bottom panel: Ratio of SSB *to* MSST.

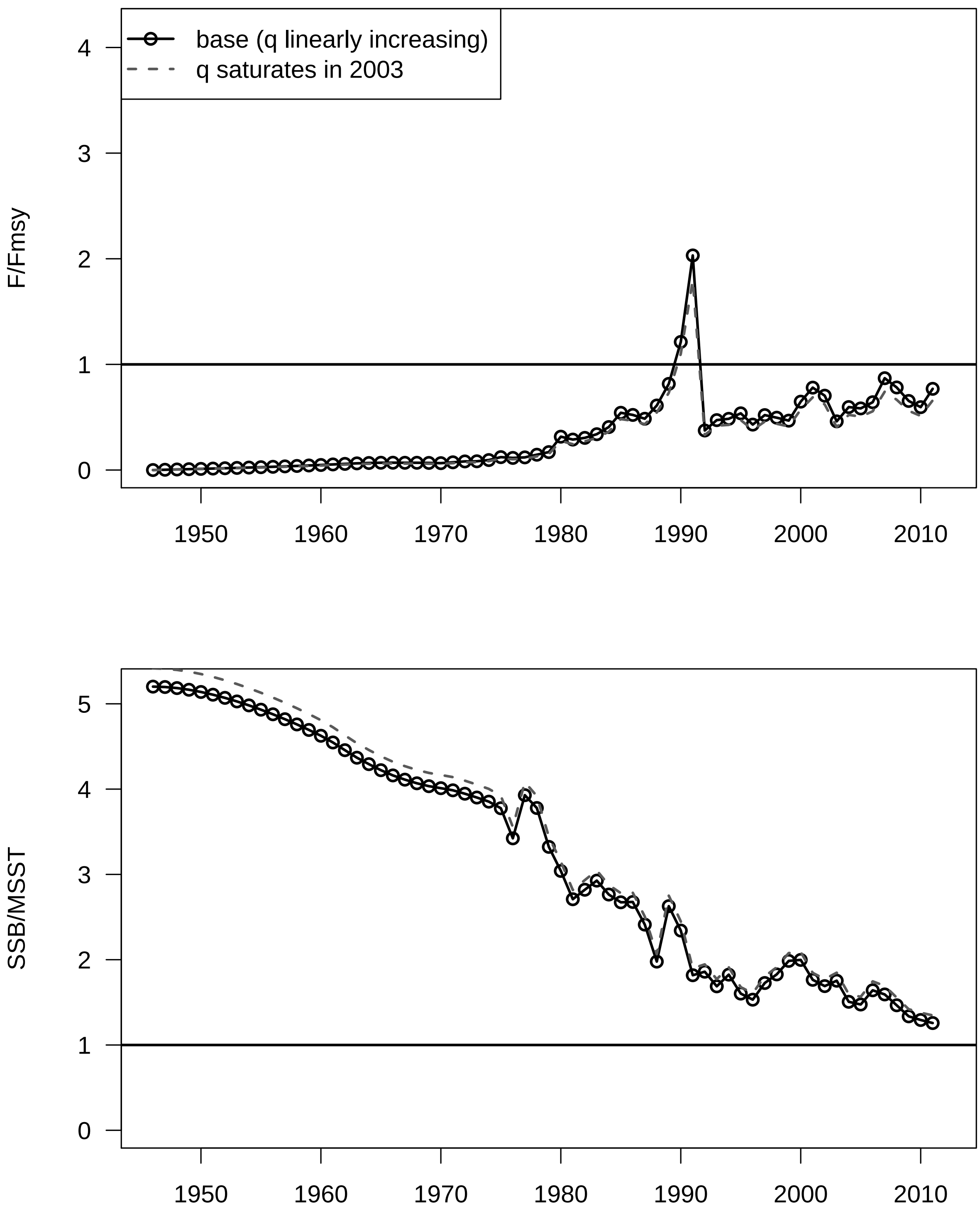
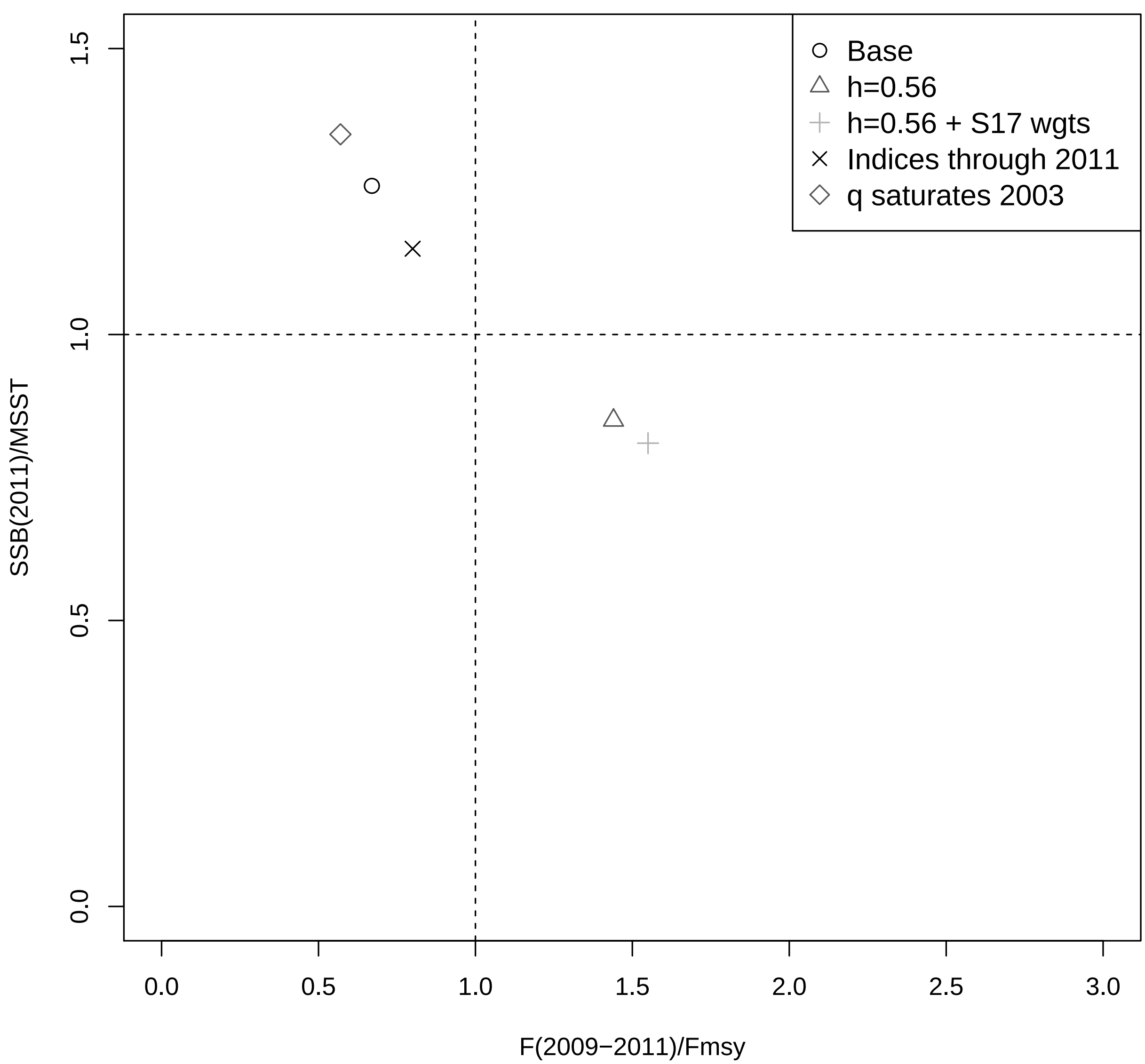


Figure 48. Phase plot of terminal status estimates from sensitivity runs of the Beaufort Assessment Model.



Appendix A Abbreviations and symbols

Table 18. Acronyms and abbreviations used in this report

Symbol	Meaning
ABC	Acceptable Biological Catch
AW	Assessment Workshop (here, for vermilion snapper)
ASY	Average Sustainable Yield
B	Total biomass of stock, conventionally on January 1
BAM	Beaufort Assessment Model (a statistical catch-age formulation)
CPUE	Catch per unit effort; used after adjustment as an index of abundance
CV	Coefficient of variation
DW	Data Workshop (here, for vermilion snapper)
F	Instantaneous rate of fishing mortality
F_{MSY}	Fishing mortality rate at which MSY can be attained
FL	State of Florida
GA	State of Georgia
GLM	Generalized linear model
K	Average size of stock when not exploited by man; carrying capacity
kg	Kilogram(s); 1 kg is about 2.2 lb.
klb	Thousand pounds; thousands of pounds
lb	Pound(s); 1 lb is about 0.454 kg
m	Meter(s); 1 m is about 3.28 feet.
M	Instantaneous rate of natural (non-fishing) mortality
MARMAP	Marine Resources Monitoring, Assessment, and Prediction Program, a fishery-independent data collection program of SCDNR
MCB	Monte Carlo/Bootstrap, an approach to quantifying uncertainty in model results
MFMT	Maximum fishing-mortality threshold; a limit reference point used in U.S. fishery management; often based on F_{MSY}
mm	Millimeter(s); 1 inch = 25.4 mm
MRFSS	Marine Recreational Fisheries Statistics Survey, a data-collection program of NMFS, predecessor of MRIP
MRIP	Marine Recreational Information Program, a data-collection program of NMFS, descended from MRFSS
MSST	Minimum stock-size threshold; a limit reference point used in U.S. fishery management. The SAFMC has defined MSST for vermilion snapper as $(1 - M)\text{SSB}_{\text{MSY}} = 0.7\text{SSB}_{\text{MSY}}$.
MSY	Maximum sustainable yield (per year)
mt	Metric ton(s). One mt is 1000 kg, or about 2205 lb.
N	Number of fish in a stock, conventionally on January 1
NC	State of North Carolina
NMFS	National Marine Fisheries Service, same as “NOAA Fisheries Service”
NOAA	National Oceanic and Atmospheric Administration; parent agency of NMFS
OY	Optimum yield; SFA specifies that OY $\leq$ MSY.
PSE	Proportional standard error
R	Recruitment
SAFMC	South Atlantic Fishery Management Council (also, Council)
SC	State of South Carolina
SCDNR	Department of Natural Resources of SC
SDNR	Standard deviation of normalized residuals
SEDAR	SouthEast Data Assessment and Review process
SFA	Sustainable Fisheries Act; the Magnuson–Stevens Act, as amended
SL	Standard length (of a fish)
SPR	Spawning potential ratio
SSB	Spawning stock biomass; mature biomass of males and females
SSB_{MSY}	Level of SSB at which MSY can be attained
TIP	Trip Interview Program, a fishery-dependent biodata collection program of NMFS
TL	Total length (of a fish), as opposed to FL (fork length) or SL (standard length)
VPA	Virtual population analysis, an age-structured assessment
WW	Whole weight, as opposed to GW (gutted weight)
yr	Year(s)

Appendix B Parameter estimates from the Beaufort Assessment Model

```
# Number of parameters = 453  Objective function value = 1146.21  Maximum gradient component = 0.00288848
# log_len_cv:
-1.50275264728
# log_R0:
15.1820094670
# steep:
0.712181053281
# log_dev_N_rec:
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 0.556131290252 -0.314166810136 -0.516031028018 1.45577781851 -1.29716605752 -0.477325116675 0.515448422824 -0.923390428440 0.613012006522 -1.23115521970
 0.0962320386816 0.578720065669 0.186885720407 0.475720982312 0.307431581132 -0.108058171260 0.370131467061 0.281306750324 -1.13180834176 0.355655811169
 0.542753030964 -0.00470117828538 -0.0286087468126 -0.204041628499 -0.0368012664034 -0.0143886175134
# rec_sigma:
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# selpar_sigma_CVT:
10.8185252970
# selpar_Age1_CVT_logit:
-5.69156402029
# selpar_Age2_CVT_logit:
-4.21359581354
# selpar_L50_cHAL1:
3.77934245231
# selpar_slope_cHAL1:
3.08969448943
# selpar_L50_cHAL2:
2.94158999458
# selpar_slope_cHAL2:
5.00930195905
# selpar_Age2_cHAL_D2_logit:
-1.00583624964
# selpar_sigma_cHAL_D3:
5.06356711708
# selpar_L50_HB1:
1.72831391926
# selpar_slope_HB1:
3.02015741652
# selpar_L50_HB2:
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# selpar_slope_HB2:
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# selpar_L50_HB3:
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# selpar_slope_HB3:
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# selpar_L50_HB4:
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# selpar_slope_HB4:
3.91465531411
# selpar_Age2_HB_D3_logit:
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# selpar_Age2_HB_D4_logit:
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# selpar_L50_MRFSS3:
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# selpar_slope_MRFSS3:
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# selpar_L50_MRFSS4:
2.75561278227
# selpar_slope_MRFSS4:
3.56077154749
# log_q_FST:
-15.2792178080
# log_q_CVT:
-14.9841346924
# log_q_HAL:
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# log_q_HB:
-15.8184298782
# log_q_MRFSS:
-15.4879672771
# log_avg_F_cHAL:
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# log_F_dev_cHAL:
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 1.92993679096 2.23987570025 2.77755737673 3.41962694622 1.25051765721 1.62410473539 1.64860979497 1.77790026291 1.45376414985 1.60392638304 1.63086873533
 1.62881145603 2.04917834073 2.29201242294 2.14223835047 1.61013538113 1.94419424137 1.93055662240 1.91133033825 2.19182396238 2.17590884124
 1.88735260317 1.99069001709 2.32402124225
# log_avg_F_cCMB:
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# log_F_dev_cCMB:
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 3.86044722168 2.94161948014 2.38767873213 2.60991589922 0.954575127520 0.720871851165 1.96229238704 3.47302842753 1.87551925910 2.85220737795 1.58898776366
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 -2.43665399551 -0.712254980350 -1.73555232528 -2.88472359524 -2.10095911095 -0.361606906752 0.983067157783 1.07776160625 1.02835493187 1.23683169428
# log_avg_F_cHTR:
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# log_F_dev_cHTR:
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# log_avg_F_HB:
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# log_F_dev_HB:
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-5.73793298415
# log_F_dev_MRFSS_D:
 -3.08749798679 -2.44641833297 -2.05917363516 -1.78100557168 -1.56459186818 -1.38759410230 -1.23844922923 -1.10994646432 -0.997472560573 -0.897743226411
 -0.808520889414 -0.728196165837 -0.655396678107 -0.589155695233 -0.527546212382 -0.464868212982 -0.408456977537 -0.378461595671 -0.357386719967
 -0.338673682288 -0.327996501453 -0.323633881706 -0.324144975369 -0.327868424311 -0.332508073780 -0.335138533521 -0.336586353717 -0.342042302920
 -0.347129954298 -0.354827662091 -0.00558216782654 -0.709610611176 -0.688459243463 0.348876671780 0.536881547965 0.686031655659 -0.166968676095
 -0.823186224393 -0.463618236435 -0.434150631824 -0.632751094434 -0.245821241562 1.28630774460 0.147679767288 -0.200153186754 1.53777835691 0.432922662485
 0.951348695595 1.38633354807 0.485574517740 0.745704311475 0.526500062356 1.93723636285 1.76724250323 1.31577594871 1.31725648270 1.76179286589
 1.40121849103 1.28158828725 1.19839597359 2.18483256385 2.43609305169 2.16510404475 1.48390605539 0.226351611315
```

Appendix C Projections with $P^{\star}$=0.4.

*Table 19. Acceptable biological catch (ABC) in units of 1000 lb whole weight, based on the annual probability of overfishing $P^{\star} = 0.4$. F = fishing mortality rate (per yr), SSB = mid-year spawning stock (1E12 eggs), Pr(*SSB < MSST*) = proportion of replicates overfished (i.e., SSB below the base-run point estimate of* MSST*), R = recruits (1000 age-1 fish), D = discard mortalities (*1000 lb *whole weight), and L = landings (*1000 lb *whole weight). ABC (*1000 lb *whole weight) includes landings and discard mortalities. Annual ABCs are a single quantity among the 10,000 replicate projections; other values presented are medians.*

Year	F	$P^{\star}$	SSB	Pr(SSB < MSST)	R	D(1000 lb)	L(1000 lb)	ABC(1000 lb)
2012	0.544	0.355	6.12	0.25	2926	53	1321	–
2013	0.574	0.4	6.12	0.29	2890	56	1372	1429
2014	0.543	0.4	6.09	0.31	2836	55	1312	1367
2015	0.524	0.4	6.17	0.32	2800	53	1289	1343
2016	0.506	0.4	6.28	0.33	2740	51	1269	1322