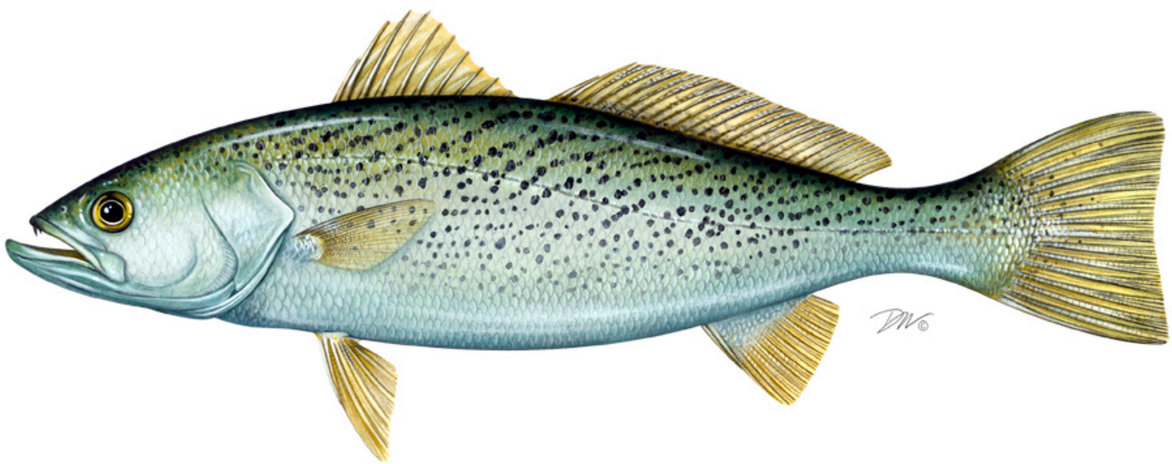
Atlantic States Marine Fisheries Commission

Weakfish Stock Assessment Update Report



October 2019

Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Executive Summary

The Bayesian statistical catch-at-age assessment model for weakfish was updated with data through 2017. This included the new, calibrated MRIP estimates of recreational catch for the entire time series.

Calibrated estimates of weakfish recreational landings were 72% higher overall, and calibrated estimates of recreational live releases were 96% higher overall. The percent difference between calibrated and uncalibrated estimates increased over the time series, so that in recent years, calibrated harvest estimates were 152% - 267% higher, and calibrated live release estimates were 130% - 314% higher than uncalibrated estimates. Despite the increase in percent difference, the overall trend in landings and live releases was the same between the calibrated and uncalibrated time series, with both sets of estimates peaking early in the time series and declining to low levels in recent years.

Commercial landings remained low and stable in the most recent three years; estimates of commercial discards were somewhat higher in the most recent three years and made up a slightly larger proportion of total removals than in the past.

Seven fishery independent age-1+ indices, seven fishery independent young-of-year indices, and one fishery dependent index of age-1+ abundance were used in the model. Indices were generally flat over the three years of new data.

For the assessment update, all four candidate Bayesian models considered during the last benchmark assessment were run with the new MRIP estimates to compare the model performance. The preferred model from the last benchmark, model M4 which included time-varying M and spatial heterogeneity, again performed the best.

Overall, the new MRIP numbers did not cause a significant change between the results of the 2016 benchmark assessment and this assessment update.

Estimates of recruitment, spawning stock biomass, and total abundance remained low in recent years. Estimates of fishing mortality were moderately high in recent years, although not near the time-series highs of the mid- to late-2000s, or the earliest years. Natural mortality remained high, averaging 0.92 in the most recent 10 years, compared to 0.16 over the first 10 years of the time series.

Spawning stock biomass in 2017 was estimated at 1,922 mt, below the SSB threshold of 6,170 mt, indicating the stock is depleted. SSB has shown a slight increasing trend in recent years, but is still well below the SSB threshold.

Total mortality in 2017 was estimated at 1.45, above both the Z target = 1.03 and the Z threshold = 1.43, indicating total mortality on the stock is too high.

Table of Contents

List of Tables

List of Figures

1.0 Life History

Stock Definitions

Weakfish (*Cynoscion regalis*) can be found along the Atlantic coast from Florida through Massachusetts, but the core of their distribution is from North Carolina to New York. Genetic data suggest weakfish are a single stock (Graves et al. 1992; Cordes and Graves 2003), but tagging data and meristic/life history information suggest there may be spatial structure or sub-stock structure in the population (Crawford et al. 1988). However, since stock boundaries could not be determined with confidence from the available literature, weakfish continued to be assessed and managed as a single species within this range (ASMFC 2016). Tringali et al. (2011) found that there was an active zone of introgressive hybridization between weakfish and sand seatrout (*C. arenarius*) in Florida, centered in the Nassau and St. Johns Rivers, with the genome proportions of "pure" weakfish estimated at 48% in Nassau County and 17% in Duval County, and that "pure" weakfish were rare southward.

Migration Patterns

Weakfish exhibit a north-inshore/south-offshore migration pattern, although in the southern part of their range they are considered resident. Shepherd and Grimes (1983) observed that migrations occur in conjunction with movements of the 16-24^{o} C isotherms. Warming of coastal waters during springtime triggers a northward and inshore migration of adults from their wintering grounds on the continental shelf from Chesapeake Bay to Cape Lookout, North Carolina (Mercer 1985). The spring migration brings fish to nearshore coastal waters, coastal bays, and estuaries where spawning occurs. Weakfish move southward and offshore in waves as temperatures decline in the fall (Manderson et al. 2014, Turnure et al. 2015).

Age and Growth

The historical maximum age recorded using otoliths is 17 years for a fish collected from Delaware Bay in 1985 (ASMFC 2016). Weakfish growth is rapid during the first year, and age-1 fish typically cover a wide range of sizes, a result of the protracted spawning season. Lowerre-Barbierri et al. (1995) found length at age to be similar between sexes, with females attaining slightly greater length at age than males. Estimates of L_{∞} ranged from 89.3 cm – 91.7 cm depending on study area (Hawkins 1988; Villoso 1990; Lowerre-Barbierri et al. 1995).

Maturity and Fecundity

Weakfish mature early, with 90-97% of age-1 fish estimated to be mature (Lowerre-Barbieri et al. 1996; Nye et al. 2008). Although the majority of age-1 fish were mature, age-1 weakfish spawned less frequently, arrived later to the estuary, and had lower batch fecundity than did older fish (Nye et al. 2008). Batch fecundity ranged from 75,289 to 517,845 eggs/female and significantly increased with both total length and somatic weight (Lowerre-Barbieri et al. 1996). Weakfish have a protracted spawning season and individual fish spawn multiple times in a season; spawning occurs from March to September in North Carolina (peaking from April to June) (Merriner 1976), but the season is shorter (May to mid-July/August) in Chesapeake Bay and Delaware Bay (Shepherd and Grimes 1984; Lowerre-Barbieri et al. 1996).

Natural Mortality

Recent assessments of weakfish indicated natural mortality has increased over time (NEFSC 2009; ASMFC 2016). Catch has declined significantly since the mid-1990s and remained at low levels in recent years under restrictive management, while recruitment indices have been stable over the time series; however, the population has not recovered. ASMFC (2016) used a Bayesian model to estimate time-varying natural mortality, and found that M was low (M=0.14-17) during the 1980s and early 1990s, but began to increase sharply in the late 1990s; it was estimated at 0.92-0.95 from 2003 – 2013. There are several hypotheses about what caused the increase in M, including increasing predation and/or competition from increasing striped bass and spiny dogfish populations and large scale environmental drivers like Atlantic Multidecadal Oscillation, but no definitive conclusions can be made (NEFSC 2009). Krause (2019) also estimated an increasing trend in M from tagging work and suggested that increasing predation was driving that trend. Krause (2019) identified bottlenose dolphin as an important predator on weakfish.

Habitat

Weakfish are found in shallow marine and estuarine waters along the Atlantic coast. They can be found in salinities as low as 6 ppt (Dahlberg 1972) and temperatures ranging from 17^{o} to 26.5^{o} C (Merriner 1976). Weakfish spawn in estuarine and nearshore habitats throughout their range, and larval and juvenile weakfish generally inhabit estuarine rivers, bays, and sounds, commonly associated with sand or sand/grass bottoms (Mercer 1983). Adult weakfish overwinter offshore on the continental shelf from Chesapeake Bay to North Carolina.

2.0 Data

2.1 Recreational Removals

2.1.1. MRIP Calibration

Data on recreational catch for weakfish were collected by the Marine Recreational Information Program (MRIP, formerly the Marine Recreational Fisheries Statistics Survey or MRFSS). MRIP uses a combination of effort surveys, which are designed to estimate the number of fishing trips taken in various regions of the US, and dockside angler intercept surveys, which are designed to estimate catch-per-trip and size frequencies of recreationally caught species. Data from these surveys are used to calculate total catch (broken down by harvest and live releases) and the size frequency of landed fish.

Prior to 2018, the estimates of effort (i.e., angler trips) used to calculate annual recreational catch of weakfish were derived from the Coastal Household Telephone Survey (CHTS), a random-digit-dial telephone survey. The CHTS was replaced in 2018 by the mail-based Fishing Effort Survey (FES), due to concerns about the inefficient design, coverage bias, and declining response rates of the CHTS. The CHTS and FES were conducted simultaneously for three years (2015-2017), and the FES produced much higher estimates of fishing effort, and therefore much higher estimates of recreational catch. The results of these years of "side-by-side" surveys were used to develop a calibration model to convert historic CHTS estimates to the scale of the new FES. Starting in 2013, design improvements were also made to the access-point angler intercept survey (APAIS) that is used to estimate catch-per-trip. A separate calibration model was used to account for these changes back in time. The final estimates of recreational landings and live releases used in this assessment update included both the APAIS and FES calibrations for the entire time series.

Over the entire time series, the new, calibrated estimates of weakfish landings and live releases were higher than the old, uncalibrated estimates (Figure 1). The APAIS calibration had a minimal effect on the estimates; the majority of the change was driven by the FES effort calibration. Calibrated estimates of weakfish landings were 72% higher overall, and calibrated estimates of live releases were 96% higher overall (Figure 2). The percent difference between calibrated and uncalibrated estimates increased over the time series, so that in recent years, calibrated harvest estimates were 152% - 267% higher, and calibrated live release estimates were 130% - 314% higher than uncalibrated estimates (Figure 2). Despite the increase in percent difference, the overall trend in landings and live releases was the same between the calibrated and uncalibrated time series, with both sets of estimates peaking early in the time series and declining to low levels in recent years (Figure 1).

The MRIP length frequencies were also revised as part of the MRIP calibration process; although there were some changes to annual mean length as a result of the calibration process, mean length did not show the same strong directional change as effort and catch did.

2.1.2. Recreational Landings

MRIP estimates of landings and live releases for Florida were adjusted to account for hybridization of weakfish with sand seatrout. Only data from Nassau and Duval counties were used, and the estimates were adjusted by the county-specific proportion of “pure” weakfish from Tringali et al. (2011).

Weakfish recreational landings peaked in 1987 at 13.1 million fish (9,232 mt) before declining through the early 1990s (Table 1, Figure 1). There was a small increase in landings in the mid to late 1990s, but landings have declined steadily since 2000, to a time-series low of 0.07 million fish (46.4 mt) in 2011. Landings increased slightly after that, with 0.28 million fish (198 mt) landed in 2017.

2.1.3 Recreational Live Releases

The number of weakfish released alive increased from the beginning of the time series to a high of 10.2 million fish (4,004 mt) in 1996 before declining to 0.96 million fish (18.2 mt) in 2013. The number of fish released alive increased somewhat after that, averaging 2.6 million fish (446 mt) from 2015-2017, with 2017 live releases at 1.45 million fish (286 mt). Over the entire time series, about 53% of recreationally caught weakfish were released alive. That proportion has increased over time; in the last 10 years, 88% of weakfish were released alive.

A ten percent release mortality rate was assumed for fish that were released alive, so that total recreational removals equal recreational landings plus ten percent of live releases (Table 1). Total recreational removals in 2017 were 421,433 fish (226 mt).

2.2 Commercial Removals

2.2.1 Commercial Landings

Weakfish commercial landings data came from state-specific harvest records collected through a mandatory reporting system where available, or from the NMFS commercial landings database. As with the recreational data, landings data from Florida were corrected to account for hybrization.

Commercial weakfish landings peaked in the late 1970s and early 1980s, and have declined steadily since then (Figure 3). Landings declined from 8,835 mt (28.1 million fish) in 1982 to a time-series low of 65 mt (0.13 million fish) in 2015; commercial landings in 2017 were 82 mt (0.16 million fish) (Table 1, Figure 3).

2.2.2 Commercial Discards

Commercial discards were estimated using data from the Northeast Fishery Observer Program (NEFOP). The discard estimation method used in the 2016 benchmark assessment and this assessment update was a hybrid of the Standardized Bycatch Reporting Methodology (SBRM; Wigley et al 2014) and de Silva's (2004) guild approach. Like de Silva (2004), the analysis included only species that are likely to co-occur with weakfish. But to minimize the potential for double counting associated with the de Silva method, ratios were developed using a combined ratio method similar to the SBRM. The suite of indicator species associated with weakfish discards was identified using the Jaccard index of similarity (Jaccard 1912).

Discard ratios were calculated over management time blocks (pre-1995, 1995-1996, 1997-2002, 2003-2009, 2010-2017). The one exception was the northern region otter trawl fishery which showed seasonal differences and had sufficient samples to develop separate seasonal ratios by time block. Sample sizes for observed hauls and observed hauls that had weakfish discards are shown in Table 2 and Table 3, respectively. Species guilds utilized in the current assessment were the same as those developed using the Jaccard method for each region-gear combination in the 2016 benchmark assessment (Table 4). The Jaccard method applied to the most recent harvest data (2015-2017) yielded some differences in species compositions, but the WTC supported the use of the species guilds from the 2016 assessment for the sake of continuity between the benchmark and update assessments, especially as management has remained unchanged since 2010. The species guild differences may have arisen due to increased observer sampling after 2014, especially of the southern otter trawl fishery.

Discard ratios were estimated for each stratum (Table 5) as the sum of weakfish discards divided by combined harvest of all guild species in observed hauls (d_{target} / k_{guild}). Prior to 1994 (the first year in the NEFOP database), there were few commercial regulations for weakfish, so it was assumed that all discards were for non-regulatory reasons. A ratio of non-regulatory discards was developed for each stratum for the years 1994-2000 and applied to landings for 1982-1993 to estimate discards in the years prior to the observer program. Variance of the ratios was estimated using equation 6.13 of Cochran (1977)

$$\hat{V}(\hat{R}) = (1-f/n\bar{x}^2)\,[(s_y)^2 + \hat{R}^2(s_x)^2 - 2\hat{R}s_{yx}]$$

with the assumption that the sampling fraction *f* (*i.e.* n/N) approached zero. Ratios were expanded to estimates of total discards using combined harvest of the appropriate guild species pulled from the ACCSP commercial landings database. Minor revisions to the ACCSP harvest data completed since 2015 were incorporated in this update as the revised landings were considered to be more accurate. Ratio values remained the same as those used for the benchmark assessment for the years through 2014. Discard ratios for the years 2015-2017 were calculated using the data from 2010 through 2017 since there were no changes in management during this time period. The WTC approved this method of discard ratio calculation since estimates from only the 2015-2017 data yielded an abnormally high value for the southern region's otter trawl fishery. The high discard ratio estimate was consistent with anecdotal reports of increased discarding in this region, but the estimate had such large uncertainty bounds that the WTC did not consider it reliable. A 100% mortality rate was assumed for commercial discards.

Commercial discards peaked in 1990 at 592 mt (5.9 million fish) and have generally declined since then (Table 1, Figure 3). Commercial discards were lowest from 2004-2014, averaging 43.3 mt (0.21 million fish), and have increased somewhat in recent years. Commercial discards in 2017 were estimated at 77.2 mt (0.40 million fish).

Total commercial removals were calculated as landings plus discards. Total commercial removals have declined over the time series, with total commercial removals in 2017 being 158 mt (0.56 million fish). The percent of commercial removals that are discards has increased over the time series, from 3-5% of the commercial removals in weight at the beginning of the time series to nearly 50% from 2015-2017.

2.3 Total Removals

Total removals include recreational landings, recreational release mortalities, commercial landings, and commercial discards (Table 1, Figure 4). Weakfish landings have declined significantly over the time series; total landings in 2017 were 391 mt, just 2% of their peak value of 19,515 mt, which occurred in 1985. The proportion of removals coming from the recreational sector has increased over time, increasing from about 10% of total removals at the beginning of the time series to approximately 50% of total removals in recent years.

2.4 Biosampling and Age-Length Keys

MRIP length frequencies were used to describe the size structure of the recreational landings. Data on the size structure of released alive fish were more limited. From 2004-2017, Type 9 data from MRIP's at-sea headboat sampling program was used to describe the size structure of released alive weakfish; however, this program did not exist before 2004, so direct observations of released alive fish were not available for those years. The pooled Type 9 from 2004-2008 was used for 2000-2003. From 1982-1999, the size structure of the released alive fish was assumed to be the same as the size structure of the landed fish, due to the limited regulations on the coast for most of this time period. Florida length frequency data were excluded due to concerns about hybridization. Recreational catch-at-length was constructed by year, region (North = MA through VA; South = NC through FL), season (Early = January – June; Late = July – December), and disposition (landed or released alive). In 2015-2017, no samples of released alive fish were available from the southern region, so the northern region released alive length frequencies were used for the southern region.

North Carolina and Florida were the only states in the southern region to report commercial landings in 2015-2017; North Carolina commercial length frequencies were used to describe Florida commercial landings, as Florida had no commercial samples. Due to limited sample sizes at the state level in the northern region, lengths from commercial sampling were pooled into sub-regions with similar minimum sizes for weakfish (MA-NY, NJ-MD, and VA). Length frequencies of commercial discards came from lengths collected by observers through NEFOP, and were stratified by year, region, and season.

Traditional age length keys (ALKs) were developed for this update by pooling data from fishery dependent (FD) and fishery-independent (FI) data sources from 2015 - 2017 to develop keys by year, region, and season for a total of twelve keys. Number of samples by year, season, region and source are given in Table 6.

Ages used were derived from otolith samples and the length used was fork length (cm). Gaps in ALKs were filled in between minimum and maximum observed fork lengths by year, region and season (Table 7, Table 8). Gaps were filled by adding values from length bins at age from the bin above and below wherever possible. When filling at either the lower range or higher range of length bins the nearest bin value was used to fill in gaps to the minimum or maximum observed length. When there were large expanses of gaps in ALKs values and these first two options were not available the following methods were employed (in order of priority):

1. Values were borrowed from the same bin in the opposite region within the same year and season,
2. Values in the same region and season in the year before and after were used,
3. Values were taken from the other season in the same year,
4. Pooled ALKs from the last assessment were used as a last resort.

The maximum age observed was 6 years old and only encountered in the early sampling season in the northern region; maximum observed age in the south was no more than 5 years old in either early or late samples during 2015 – 2017 (Table 8). In 2016 in the late sampling season in the south the oldest fish observed was only 3 years old. Both regions encountered young of year weakfish only in the late sampling season.

2.5 Indices of Abundance

2.5.1 North Carolina Independent Gill Net Survey (NC PSIGNS)

The Independent Gill Net Survey is designed to characterize the size and age distribution for key estuarine species in Pamlico Sound and its major river tributaries. Sampling began in Pamlico

Sound in 2001 and occurs monthly from February to December. Each array of nets consists of floating gill nets in 30-yard segments of 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, and 6.5-inch stretched mesh, for a total of 240 yards of nets. Catches from an array of gill nets comprise a single sample; two samples (one shallow, one deep) totaling 480 yards of gill net are completed each trip. Gill nets are typically deployed within an hour of sunset and fished the following morning. Efforts are made to keep all soak times within 12 hours. Gill net sets are determined using a random stratified survey design, based on area and water depth. All fish are sorted by species. A count and a total weight to the nearest 0.01 kg are recorded. Length, sex, age samples are taken from selected target species, including weakfish.

The index of relative abundance was based on all core samples collected during the calendar year that occurred within the Pamlico Sound portion of the survey only. Available variables for standardization included year, depth, area, surface temperature, surface salinity, dissolved oxygen, pH, wind direction, and wind speed. The best-fitting generalized linear model (GLM) for NC PSIGNS used a negative binomial distribution and included year, depth, and area as significant covariates.

The NC PSIGNS index is comprised mainly of age 2-4 fish (Figure 6). The index has generally declined since the beginning of the time series (Table 9, Figure 6). In 2015, weakfish abundance declined to a time-series low, and remained low for the subsequent two years.

2.5.2 North Carolina Pamlico Sound Survey (NC P195)

The North Carolina Pamlico Sound Survey (Program 195) was instituted in 1987. Sampling is conducted during the middle two weeks of June and September in Pamlico Sound and the Pamlico, Pungo, and Neuse rivers and bays. One hundred and four stations are randomly selected each year from strata based upon depth and geographic location. Tow duration is 20 minutes at 2.5 knots, pulling double rigged demersal mongoose trawls. Environmental and habitat data are recorded during the haul back of each trawl. The entire catch is sorted by species; each species is enumerated and a total weight of each species is taken. Individuals of each target species are measured. If present in large numbers, a subsample of 30–60 individuals of each target species is measured and a total weight of the measured individuals for each species is taken. Weakfish are measured to the nearest millimeter fork length.

An index of relative abundance of age-0 (young-of-year or YOY) weakfish was calculated using the GLM approach. Data were limited to those collected during September, when age-0 weakfish are most prevalent in the survey, and all weakfish 200 mm fork length or less were considered age-0. Available covariates for standardization of the age-0 index were year, depth, surface temperature, surface salinity, dissolved oxygen, and wind speed. The best-fitting GLM for the P195 index of age-0 weakfish abundance included year, depth, surface temperature, and surface salinity as significant covariates and had a negative binomial distribution.
Overall, the index varied without trend over the time series, although there was a period of generally higher values from the mid-1990s until 2000 (Table 10, Figure 7). Weakfish YOY abundance declined in 2015 to a time-series low and then increased in 2016 to the highest abundance observed since 2000.

2.5.3 SEAMAP

Sampling cruises were conducted seasonally: spring (mid-April – May), summer (July-August) and fall (October-November), in established strata between Cape Canaveral, Florida (28° 30.0'N) and Cape Hatteras, North Carolina (35° 13.2'N). Stations were allocated to strata according to results of an Optimal Allocation Analysis. Sampling was conducted during daylight hours. Operations at each site used paired 22.9 m mongoose-type Falcon trawls (designed and constructed by Beaufort Marine Supply) with tickler chains. These were towed for 20 minutes bottom time from the R/V Lady Lisa, a 22.9 m St. Augustine shrimp trawler. Nets did not contain TEDs or BRDs so that density estimates for all sizes of each species could be calculated, and to maintain comparability with previous survey data. Contents of each net were processed independently. Weakfish were measured to the nearest centimeter. Large or complex samples were subsampled by weight with a randomly selected subsample from each net processed. Large numbers of individuals of a species were subsampled and only 30 to 60 individuals measured, when appropriate.

Following trawl collections, hydrographic and meteorological data (air and water temperature, salinity, wind speed and direction, wave height, and barometric pressure) were recorded. Water temperature and salinity was measured and recorded with a SEABIRD Conductivity, Temperature, and Depth (CTD). Abundance, biomass, and length-frequency data was recorded on a computer utilizing electronic measuring boards.

The SEAMAP catch data was spatially (North Carolina to Georgia) and temporally (only fall collections) restricted to provide a comparable index to the other coastwide indices. Florida catches were omitted due to issues of hybridization and overall catches accounting for a small portion of the total survey catch. Dates used for this assessment update were 1990-2017. The SEAMAP weakfish index (catch per tow) was standardized using a zero-inflated negative binomial generalized linear model and the final model selected was the same that was run for the Benchmark Assessment in 2016:

Number of Fish Caught ~ Year + Bottom Temperature (°C) + Surface Salinity (ppt) + Average Depth + Air Temperature (°C) + offset (LogEffort) | Bottom Temperature (°C) + Surface Salinity

The SEAMAP index is dominated by age-0 and age-1 fish, although it has captured fish up to age-6+ (Figure 8). Overall catch per tow was highest by far in 2015 (110.7 weakfish/tow) followed by 2016 (51.3 weakfish/tow) (Figure 9). These indices reflect fall catches greater than 1000 weakfish/tow. Out of 17 catches that contained 1000 or more weakfish/tow in the fall survey since 1990, 9 of those came from 2015 (ranging from 1,371 – 4,132 weakfish). The 2015 value was driven by an unusually high proportion of age-0 weakfish in the catch (97% age-0 fish, compared to the time series mean of 70% age-0 fish). When the index is adjusted to reflect only age-1+ weakfish, 2015 is actually one of the lowest index values on record, but 2016 and 2017 show an increasing trend as that strong recruitment event moves through the population (Table 9, Figure 9).

2.5.4 Virginia Institute of Marine Science Chesapeake Bay Juvenile Fish Trawl Survey

The Virginia Institute of Marine Science (VIMS) has conducted a trawl survey in lower Chesapeake Bay since 1955. A trawl net with a 5.8-m head line, 40 mm stretch-mesh body, and a 6.4-mm liner is towed along the bottom for 5 minutes. Sampling in the Bay occurs monthly except January, February, and March, when few target species are available. Sampling in the tributaries occurs monthly, except during January and February, at both the random stratified and historical fixed (mid-channel) stations. Between two and four trawling sites are randomly selected for each Bay stratum each month, and the number varies seasonally. The weakfish index is calculated using data from all stations sampled from August (0 - 150 mm TL), September (0 – 180 mm TL), and October (0 – 200 mm TL). Using catch data from area-time combinations, an annual juvenile index is calculated as the weighted geometric mean catch per tow. Because stratum areas are not uniform, a weighted mean provides an index that more closely approximates actual population abundance.

In 2015, the VIMS Juvenile Fish Trawl Survey transitioned to a new vessel and trawl gear. As a result, calibration factors comparing the new survey vessel and gear to historical catches were developed. In 2014 and 2015, VIMS conducted a comparison survey between the old research vessel (R/V *Fish Hawk*) and net and the new R/V *Tidewater* and net to calculate calibration factors based on 221 paired tows for young-of-the-year weakfish. The calibration factor is the model-based ratio of R/V *Fish Hawk* catches to R/V *Tidewater* catches and represents the relative catch efficiency of the *Fish Hawk* to the *Tidewater*. The calibration factor was applied at the individual tow-level and provided catches of fish from the R/V *Tidewater* in R/V *Fish Hawk* units; thus, the indices reported for 2015 and thereafter are comparable to the historic indices reported previously.

The VIMS Juvenile Fish Trawl index has varied without trend over the time series; 2015 – 2017 were below average (Table 10, Figure 10).

2.5.5 Maryland Coastal Bays Juvenile Trawl Survey

The Maryland Department of Natural Resources has conducted the Coastal Bays Fisheries Trawl Survey with consistent methodology since 1989. Trawl sampling was conducted at 20 fixed sites throughout Maryland's Coastal Bays on a monthly basis from April through October. A standard 4.9 m (16 ft) semi-balloon trawl net was used in areas with a depth of greater than 1.1 m (3.5 ft). The trawl was towed for six minutes (0.1 hr) at a speed of approximately 2.8 knots. Fishes and invertebrates were identified, counted, and measured for total length in millimeters. At each site, a sub-sample of the first 20 fish (when applicable) of each species were measured and the remainder counted.

A standardized index of juvenile abundance per tow was developed for 1989 - 2017 using a negative binomial distribution including year, start depth, surface salinity, and water temperature as covariates.

Index values generally increased through the late 1990s, declined to moderate levels through most of the 2000s, then declined again, remaining very low from 2011 through 2017 (Table 10, Figure 11).

2.5.6 Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP)

The ChesMMAP Trawl Survey has been sampling the mainstem of the Chesapeake Bay, from Poole's Island, MD to the Virginian Capes at the mouth of the Bay since 2002. ChesMMAP conducts 5 cruises annually, during the months of March, May, July, September, and November; only the fall data were used to develop the weakfish index. The ChesMMAP survey area is stratified into five latitudinal regions, and each region is comprised of three depth strata. Depth strata bounds are consistent across regions, and correspond to shallow (3.0m to 9.1m), middle (9.1m to 15.2m), and deep (>15.2m) waters in the bay. Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A total of 80 sites are sampled per cruise, and a four-seam, two-bridle, semi-balloon bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.5kts. A number of hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation), atmospheric data, and station identification information are recorded at each sampling site.

The index was standardized with a delta-GAM model that used latitude, longitude, water temperature and year as explanatory variables.

The ChesMMAP age-1+ index has declined nearly continuously over the entire time-series, reaching a time-series low in 2014 (Table 9, Figure 12). The age-structure of the index is dominated by age-0 and age-1 fish, and the proportion of age-4, 5, and 6+ fish in the index has been near zero since the mid-2000s (Figure 12).

2.5.7 Delaware Fish and Wildlife Delaware Bay 30' Trawl Survey

The Delaware Division of Fish and Wildlife (DEDFW) has conducted a trawl survey within the Delaware Bay since 1966 (1966-1971, 1979-1984, and 1990 – present), with consistent gear and design used since 1990. The survey collects monthly samples from March through December at nine fixed stations throughout the Delaware portion of the Bay. The net used has a 30.5 foot headrope and 2" stretch mesh codend. Surface and bottom temperature (°C), dissolved oxygen (ppm) and salinity (ppt) are measured at the conclusion of each tow. Aggregate weights are taken for each species. Species represented by less than 50 individuals were measured for fork length to the nearest half-centimeter. Species with more than fifty individuals were randomly sub-sampled (50 measurements) for length with the remainder being enumerated.

The Delaware Weakfish index (catch per tow) was standardized using a zero-inflated negative binomial generalized linear model:

Number of Fish Caught ~ Year + Depth + Month + offset(LogEffort) | Depth + Month

with data from May-September, as this temporal period largely encapsulated when weakfish were present in Delaware Bay.

Since 1991, length frequencies have been aged using survey specific age-length keys.

Relative abundance increased sharply in the early 1990s to a time series high in 1996 (Table 9, Figure 13). The index decreased by more than half in 1997, and has exhibited a generally declining trend since that time. Relative abundance in 2016 and 2017 was near the time-series mean.

Age structure advanced from primarily age 1 and 2 fish in the early 1990s to include ages 7 and 8 in 1998-2000 (Figure 13). Abundance of age 4+ fish accounted for 30 to 35% of the total index in 1997 and 1998 as the large 1993 year class moved through. Abundance of older ages has since declined to levels observed in the early 1990s, with 3+ fish accounting for less than 3% of the total number caught.

2.5.8 Delaware Fish and Wildlife Delaware Bay Juvenile Trawl Survey

In addition to the 30-foot trawl survey, the DEDFW has conducted a fixed station trawl survey in Delaware Bay targeting juvenile finfish from 1980-present. The Delaware young of year survey occurs within the core area of weakfish abundance and encompasses a major spawning/nursery area for the species during months when weakfish are present. Sampling is conducted monthly from April through October using a semi-balloon otter trawl. The net has a 5.2 m headrope and a 12.7 mm stretch mesh codend liner. Weakfish are a significant component of the catch, with the greatest majority of these weakfish (more than 99% in some years) being young of the year.

The DE Juvenile Weakfish index (catch per tow) was standardized using a zero-inflated negative binomial generalized linear model:

Number of Fish Caught ~ Year + Month + offset(LogEffort) | Depth + Month

with data from May-September, as this temporal period largely encapsulated when weakfish were present in Delaware Bay.

The index showed a period of strong recruitment from 1992 – 2000, followed by a period of below average recruitment (Table 10, Figure 14). The index was slightly above average in 2016, but below average in 2015 and 2017.

2.5.9 New Jersey Ocean Trawl Program

New Jersey has conducted a stratified random trawl survey in nearshore ocean waters since August 1988. The survey originated as bi-monthly cruises, but since 1990, the survey has been conducted five times per year (January, April, June, August and October) in the coastal waters from the entrance of New York Harbor south, to the entrance of the Delaware Bay. The survey area is stratified into 5 areas north to south that are further divided into 3 depth zones (<5, 5-10, 10-20 fathoms) for a total of 15 strata. The sampling gear is a two-seam trawl with a 25m head rope, 30.5m footrope, forward netting of 4.7 inch stretch mesh, rear netting of 3.0 inch stretch mesh, cod end of 3.0 inch stretch mesh, and a cod end liner of 0.25-inch bar mesh. Water quality and temperature readings are generally taken before each tow. All fish and most macro-invertebrates taken during these surveys are counted and weighed to obtain abundance and biomass totals per species by tow, with individual lengths measured to the nearest centimeter. This program has consistently contributed weakfish specimens for growth and age analysis since 2007.

A GLM-based index was derived using a negative binomial distribution of the August and October sample data with mean depth and bottom salinity as the covariates. This index fluctuated without a general trend with a surge in numbers for 1994 and 1995 (time series high), followed by smaller peaks in 2002, 2004 and 2011 through 2012 (Table 9, Figure 15). The index values since 2014 show a moderate stabilization at levels near the time-series average. Consistent with many of the other surveys, there has been a truncation of the age structure of the weakfish catch in recent years with no age-6+ fish seen since 2005 (Figure 15).

2.5.10 New York Peconic Bay Juvenile Trawl Survey

The New York Division of Fish, Wildlife and Marine Resources has conducted a juvenile trawl survey in the Peconic Bay estuary of Long Island since 1985. Weakfish was the primary target species when the survey was initiated, and Peconic Bay was selected for the survey area because of its importance as a weakfish spawning ground. Random sampling occurs weekly between May and October using a semi-balloon shrimp trawl with a 4.9 m headrope and 12.7 mm stretch mesh codend liner. The survey samples mainly young of year weakfish, and a YOY index has historically been calculated using all sampling months. In 2005 and 2006, technical difficulties constrained sampling to May – July (2005) and July – October (2006), so a revised index using only July and August has been calculated. The two indices (all months and July-August) show a similar increasing trend and are well correlated ($r = 0.96$).

The index showed a high degree of interannual variability, although the period of 2000 – 2007 was generally above average (Table 10, Figure 16). Strong year classes occurred in 1991, 1996, and 2005 (time series high). The index has shown an increasing trend since 2012, and was above average in 2017.

2.5.11 Connecticut Long Island Sound Trawl Survey (CT LISTS)

Since 1984, the Connecticut Department of Energy and Environmental Protection has conducted spring and fall trawl surveys in the Connecticut portion of Long Island Sound between the New York/Connecticut border in the west and New London, CT in the east. Survey effort consists of three spring cruises conducted during April, May and June, and three fall cruises during September/October. Stratified random sampling is employed based on four depth zones and three bottom types. Survey gear consists of a 14 x 9.1 m high-rise otter trawl with 5 mm codend mesh. The survey catches mostly YOY and age 1 weakfish as defined by examination of length frequencies. For the fall survey, a 30 cm length cutoff is used to separate YOY and age 1 fish. Only the YOY component of the index was used.

Because environmental covariates were not consistently collected until 1992, the geometric mean index was used instead of the GLM-standardized index, to preserve the longer time series.

The YOY index showed a period of lower recruitment at the beginning of the time series and a period of higher but more variable recruitment from 2000 – 2014 (Table 10, Figure 17).

2.5.12 Rhode Island Seasonal Trawl Survey

The Rhode Island Department of Environmental Management's (RIDEM) seasonal trawl survey was initiated in 1979 to monitor recreationally important finfish stocks in Narragansett Bay, Rhode Island Sound, and Block Island Sound.

The survey employs a stratified random and fixed design defined by 12 fixed stations in Narragansett Bay, 14 random stations in Narragansett Bay, 6 fixed stations in Rhode Island Sound, and 12 fixed stations in Block Island Sound.

In 2005, RIDEM replaced the research vessel and survey gear that has been utilized by the survey since its inception. The R/V *Thomas J. Wright* was replaced with a 50' research vessel, the R/V *John H. Chafee*. In 2012, new doors were installed on the R/V *John H. Chafee.* Calibration experiments were conducted in both cases to ensure the index time series are comparable before and after the gear and vessel changes.

The fall component of the Rhode Island seasonal trawl survey is predominantly comprised of YOY weakfish which are present in at least 10% of all tows in any given year of the survey. The RI YOY weakfish index was standardized using a negative binomial GLM with year and bottom temperature as covariates in the final model.

The index varied without trend over the time-series, with extreme highs in 1996 and 2003; 2017 was above the time-series mean (Table 10, Figure 18).

2.5.13 Northeast Fisheries Science Center Bottom Trawl Survey

The National Marine Fisheries Service (NMFS) Northeast Fishery Science Center (NEFSC) conducts seasonal trawl surveys between Nova Scotia and Cape Hatteras. Stratified random sampling is conducted using a #36 Yankee otter trawl equipped with roller gear and a 1.25 cm mesh codend liner. The survey covers a large portion of the geographic range of weakfish, including their "core" distribution area (NEFSC 2000) of New Jersey to North Carolina. In 2009, the NEFSC changed survey vessels. The new R/V Bigelow is larger and cannot sample the innermost inshore strata that the previous vessel did. Instead, those strata are now sampled by the Northeast Area Monitoring and Assessment Program (NEAMAP), described in Section 2.5.14. As few weakfish were ever observed in the offshore strata, 2008 is the terminal year of the NEFSC index for weakfish.

The NEFSC index is generally stable at low numbers (< 20 fish per tow) during the 1980s and 1990s (Table 9, Figure 19). Two notable exceptions are 1984 and 1994, with peaks of 116 and 60 fish per tow, respectively. Evaluation of the index at age data does not indicate that these peaks were the result of strong year classes (Figure 19), and may instead represent increased availability of weakfish based on the timing of migration and the survey. Between 1998 and 2003, the index rose sharply, from less than 5 fish to more than 170 fish per tow, before declining rapidly back to previous levels by 2007.

2.5.14 Northeast Area Monitoring and Assessment Program (NEAMAP)

The Northeast Area Monitoring and Assessment Program, Mid-Atlantic/Southern New England Nearshore Trawl Survey (NEAMAP) has been sampling the coastal ocean from Martha's Vineyard, MA to Cape Hatteras, NC since the fall of 2007. NEAMAP conducts two cruises per year, one in the spring and one in the fall, mirroring the efforts of the Northeast Fisheries Science Center (NEFSC) Bottom Trawl Surveys offshore. The survey area is stratified by both latitudinal/longitudinal region and depth. Sampling sites are selected for each cruise using a stratified random design; site allocation for a given stratum is proportional to the surface area of that stratum. A four-seam, three-bridle, 400x12cm bottom trawl is towed for 20 minutes at each sampling site with a target speed-over-ground of 3.0kts. Hydrographic variables (profiles of water temperature, salinity, dissolved oxygen, and photosynthetically active radiation), atmospheric data, and station identification information are recorded at each sampling site.

A delta-GAM with 6 variables (depth, water temperature, percentage of oxygen saturation, dissolved oxygen, latitude, and year) was used to standardize the index.

The age-1+ index varied without trend over the time-series (Table 9, Figure 20). The age-structure of the index is dominated by age-0 and age-1, with almost no age-4 -6+ fish present in the catch (Figure 20). The time-series is short for this index, but its utility will increase with future updates as the time-series gets longer and it provides important information in areas formerly covered by the NEFSC survey.

2.5.15 Composite Young-of-Year Index

States from Rhode Island through North Carolina conduct trawl surveys for juvenile finfish that capture YOY weakfish, as described above. These surveys are noisy and cover small geographical areas compared to the population range of weakfish. Bayesian hierarchical modeling was used to combine these indices into a single composite index, using the method developed by Conn (2010), that represents the coastwise recruitment dynamics of weakfish. Although the composite YOY was not included in the base run of the assessment model, it was updated for this assessment.

The composite YOY generally varied without a strong trend, being below average in the 1980s and most recent years, and above average from 1992-2006 (Table 10, Figure 21).

2.5.16 MRIP Harvest per Unit Effort

A guild-based approach was used to identify potential weakfish trips from the MRIP intercept data. The Jaccard (1912) coefficient of similarity was used to identify which species most commonly co-occurred with weakfish in the recreational catch. Species guilds were composed of the target species and the five species with the highest similarity coefficients. Any trip that caught any one of the guild species was considered a potential weakfish trip. Species guilds, and therefore effort estimates, were developed for each state individually. Massachusetts, Rhode Island, and Connecticut had no strong species associations and were outside of the core range of the species, so those states were not included in the HPUE index; Florida was excluded because of hybridization concerns.

Because limited information was available to describe the length frequency (and therefore age distribution) of discarded fish prior to 2004, the WTC decided to use an index of harvested fish only (HPUE) coupled with a selectivity curve as input for the population model.

Trip specific HPUE was then modeled using a negative binomial GLM. Full models for the positive and binomial components are as follows.

$$\ln CPUE \sim YEAR + AREA + WAVE + STATE$$
$$success \sim YEAR + STATE + MODE$$

The MRIP index peaked in 1985 and declined steadily until the early 1990s, when it began to increase. It never reached the levels early in the time series, and from the late 1990s, it declined steadily (Table 9, Figure 22). It remained at low levels through 2017.

3.0 Model Description

During the last benchmark assessment, a Bayesian statistical catch-at-age model was developed to assess weakfish. Several different configurations of the model were explored, but the best model was one that allowed natural mortality (M) as well as fishing mortality (F) to be estimated, and that included spatial heterogeneity in the model (that is, allowed the proportion of the population available to each index to vary over time).

Two fleets, commercial and recreational catch were modeled; the selectivities of the two fleets were assumed to be age specific, and recreational fishery selectivity was assumed to change in 1996 because of the implementation of a coastwide minimum size. Time-varying M was estimated as a random-walk process. A Bayesian approach was used to estimate parameters, while performance of the models was compared by goodness-of-fit and the retrospective patterns of the models.

For the assessment update, all four candidate Bayesian models considered during the last benchmark assessment (Table 11) were run with the new MRIP estimates to verify that the preferred model was still the best performing model.

4.0 Results

4.1 Model Selection and Goodness of Fit

The preferred model from the last benchmark, model M4 which included time-varying M and spatial heterogeneity, again performed better in both DIC and retrospective errors (Table 12). It also had the lowest DIC across a range of data sensitivity runs with new MRIP or old MRIP data (Table 13). The DIC value of M4 is much lower than the other 3 models, and the retrospective error, both one year retro and Mohn's retrospective error are much smaller than the other 3 models. This suggested that M4 is still the most appropriate model and the weakfish population is nonstationary as reflected in M variation over time, and spatial asynchrony (Figure 28, Figure 31, and Figure 32).

See Appendix 1 for diagnostic plots and tables for the Bayesian model.

4.2 Selectivity and Catchability

In the fully stationary model (M1), commercial fishery selectivity increases rapidly, with over 50% selectivity by age 2, and remains high across ages 3+ (Figure 24). When time-varying M is estimated (models 2 and 4), selectivity estimates of ages 2 and 3 are lower than in M1 (Figure 24).

Similarly, selectivity in the first block of the recreational fishery, i.e., 1982-1995, reaches a high at age 2 in model M1 and remains high, but peaks at older ages for models M2 and M4; all models show a pattern of a decrease in selectivity from age 4 to age 5, followed by an increase or flattening for age 6+ in the second selectivity block, i.e., 1996-2017 (Figure 25).

4.3 Mortality Rates

The estimated fishing mortality rates in the 2010s were low in all four models. The relative magnitude of F estimates over time among the four models were not the same although similar patterns were observed (Table 14; Figure 26 and Figure 27). This was related to differences in the selectivity patterns estimated by the different models.

The natural mortality rates estimated by the preferred model (M4) are shown in Table 15. The estimated M over time from M2 and M4 showed a similar trend (Figure 28). M was low in 1980s, averaging 0.16, but began to increase in the mid-1990s and remained high after mid-2000s. M has averaged 0.92 since 2007. M in 2016 and 2017 decreased slightly but this may be because of new cohorts joining the population rather than a true decrease in M, because a fast decline of those cohorts would not be shown in the data yet.

4.4 Population Size

The estimated total abundance and spawning stock biomass of Atlantic weakfish has been low in recent years (Table 16 and Table 17). The four models all showed a recent decrease in population size but differed in the early part of the time series differently (Figure 29). M1 and M2, which both assumed no spatial heterogeneity in the population, showed a large decrease in 1985-1990 but recovered in mid-1990s. M3 and M4, which both assumed spatial heterogeneity, also showed a decrease in 1985-1990 but the recovery in mid-1990s was not as significant as in models 1 and 2.

Recruitment in recent years was lower in all model scenarios, but the models with spatial heterogeneity (M3 and M4) showed a more pronounced declining trend over the entire time series (Table 16; Figure 30).

4.5 Sensitivity Analyses

All the models showed robustness with data scenarios and the results can be seen in Figure 33 - Figure 39. Model M4 always yielded the lowest DIC values among the 2 data scenarios (with the new, calibrated MRIP estimates of recreational catch and with the old, uncalibrated estimates).

The use of the new, calibrated MRIP estimates did cause differences in the data sensitivity runs. By using the new MRIP numbers, the estimated selectivity for recreational fishery changed quite significantly (Figure 33). The change of the estimated selectivity for recreational fishery is largely because of the non-proportional changes of the estimated new MRIP across ages and years (Figure 34). The change of selectivity patterns also caused the estimated fishing mortality changes; the estimates of recreational fishing mortality were higher and the commercial fishing mortality estimates were lower in recent years with the new MRIP numbers, but the overall estimates of Z were similar (Figure 35). The new MRIP numbers did not have a significant effect on the estimates of M (Figure 37).

When new MRIP estimates were used, the estimates of total abundance and recruitment were higher (Figure 38 and Figure 39).

4.6 Retrospective Analyses

Retrospective analyses results are shown in Figure 40 - Figure 45 and Table 12. Models M2 and M4 were more robust to retrospective analysis. All the models tended to overestimate total abundance (Figure 44) and recruitment (Figure 45) and underestimate F (Figure 41 - Figure 42). The estimated key parameters of selectivity (Figure 40), and M (Figure 43) were more robust, although the M in the terminal year was consistently underestimated. The retrospective pattern can further be explored through the age specific mortality especially in recent years.

4.7 Historical Retrospective

Overall, the new MRIP numbers did not cause a significant change between the results of the 2016 benchmark assessment and this assessment update.

Estimates of abundance were generally very similar between the benchmark and the update, with slightly higher estimates from the mid-1990s to the mid-2000s (Figure 46). Estimates of recruitment were slightly higher in the assessment update for the early part of the time series, from the mid-1980s to the late 1990s, but were very similar after that. Estimates of total abundance and recruitment were higher in the last few years of the benchmark compared to the same years in the assessment update; however, this is driven by the retrospective pattern in the model rather than the new MRIP data, since the results with the old, uncalibrated MRIP data updated through 2019 were lower than the assessment update results with the new MRIP data.

Estimates of F for the commercial fleet were generally lower across the time series for both the assessment update with the new MRIP data and the update with the old MRIP data, while estimates of F for the recreational fleet were generally similar between the benchmark and the assessment update (Figure 48). Both commercial and recreational F were higher at the end of the time series in the assessment update.

Estimates of natural mortality were also very similar between the benchmark assessment and the assessment update, except for the last year of the benchmark assessment, when M was estimated higher during the assessment update (Figure 49). This is consistent with the direction of the retrospective bias for this model. The overall time-series average M was higher for the assessment update (M=0.46) than for the benchmark assessment (0.43), although this is due to more years at the end of the time series with a higher M value, rather than a difference across the entire time series.

5.0 Stock Status

5.1. Biological Reference Points

Under conditions of time-varying natural mortality, there is no long-term stable equilibrium population size, so an SSB target is not informative for management. The SSB threshold is defined as $SSB_{30\%}$, equivalent to 30% of the projected SSB under the time-series average natural mortality and no fishing. When SSB is below that threshold, the stock is considered depleted.

Currently, total mortality (Z) benchmarks are used to prevent an increase in fishing pressure when F is low but M is high. When Z is below the Z target, F reference points can be used to assess overfishing status. The Z and F targets and thresholds were calculated based on the time-series average natural morality estimate. The Z target is $Z_{30\%SPR}$ and the Z threshold is $Z_{20\%SPR}$. $F_{30\%SPR}$ and $F_{20\%SPR}$ are the F target and threshold, respectively.

The biological reference point estimates were updated for this assessment based on the results of the preferred model using the new MRIP estimates (Table 18). The SSB threshold was estimated at 6,170 mt. The Z target was estimated at 1.03, and the Z threshold was 1.43. The equivalent F target was 0.57 and the F threshold was 0.97.

The updated SSB threshold was slightly lower than the estimate from the 2016 benchmark assessment (Table 18), due to the higher average M value estimated for the assessment update. The F and Z reference points were slightly higher than estimated during the 2016 benchmark assessment (Table 18).

5.2 Stock Status

Spawning stock biomass in 2017 was estimated at 1,922 mt, below the SSB threshold, indicating the stock is depleted (Figure 50). SSB has shown a slight increasing trend in recent years, but is still well below the SSB threshold.

Total mortality in 2017 was estimated at 1.45, above both the Z target and the Z threshold, indicating total mortality on the stock is too high.

Fishing mortality in 2017 was estimated at 0.62, above the F target but below the F threshold.

6.0 Research Recommendations

The TC continued to support the research recommendations from the benchmark assessment; the highest priority recommendations are listed here.

- Increase observer coverage to identify the magnitude of discards for all commercial gear types from both directed and non-directed fisheries.
- Evaluate predation of weakfish with a more advanced multispecies model (e.g., the ASMFC MSVPA or Ecopath with Ecosim).
- Develop a bioenergetics model that encompasses a broader range of ages than Hartman and Brandt (1995) and use it to evaluate diet and growth data.
- Analyze the spawner-recruit relationship and examine the effects of the relationship between adult stock size and environmental factors on year class strength.
- Develop a coastwide tagging program to identify stocks and determine migration, stock mixing, and characteristics of stocks in over wintering grounds. Determine the relationship between migratory aspects and the observed trend in weight at age.
- Monitor weakfish diets over a broad regional and spatial scale.
- Continue to investigate the geographical extent of weakfish hybridization.

In addition, the TC also recommended exploring age- as well as time-varying natural mortality in the Bayesian model for the next benchmark assessment.

7.0 Literature Cited

ASMFC. 2016. Weakfish Benchmark Stock Assessment and Peer Review Report. Arlington, VA. 270 p.

Cochran, W. G. 1977. Sampling Techniques. New York: John Wiley & Sons.

Cordes, J.F. and Graves, J.E. 2003. Investigation of congeneric hybridization in and stock structure of weakfish (*Cynoscion regalis*) inferred from analyses of nuclear and mitochondrial DNA loci. Fish Bull US. 101: 443-450.

Crawford, M.K., Grimes, C.B., and Buroker, N.E. 1988. Stock identification of weakfish, *Cynoscion regalis*, in the middle Atlantic region. Fish Bull US. 87:205-211.

Dahlberg, M.D. 1972. An ecological study of Georgia coastal fishes. Fish Bull US. 70: 323-353.

De Silva, J. A. 2004. Estimating At-Sea discards of weakfish using NEFSC Observer database. A report to the Weakfish Technical Committee of the Atlantic States Marine Fisheries Commission. Florida Fish and Wildlife Commission, Florida Marine Research Institute, St. Petersburg.

Graves, J.E., McDowell, J.R., and Jones, M.L. 1992. A genetic analysis of weakfish *Cynoscion regalis* stock structure along the mid-Atlantic coast. Fish Bull US. 90: 469-475.

Hawkins, J.H. III. 1988. Age, growth and mortality of weakfish, *Cynoscion regalis*, in North Carolina with a discussion on population dynamics [thesis]. Greenville (NC): East Carolina University. 86 p.

Jaccard. 1912. The distribution of the flora of the alpine zone. New Phytologist, 11:37-50.

Krause, J.R. 2019. Sources, Magnitude, and Timing of Weakfish Mortality across the U.S. East Coast [dissertation]. Raleigh, NC. 224 p.

Lowerre-Barbieri, S.K., Chittenden, M.E., and Barbieri, L.R. 1995. Age and growth of weakfish, *Cynoscion regalis*, in the Chesapeake Bay region with a discussion of historical changes in maximum size. Fish Bull. 93: 643-656.

Lowerre-Barbieri, S.K., Chittenden, M.E., and Barbieri, L.R. 1996. The multiple spawning pattern of weakfish, *Cynoscion regalis*, in the Chesapeake Bay and Middle Atlantic Bight. Can J Fish Aquat Sci. 55: 2244-2254.

Manderson, J.P., Stehlik, L.L., Pessutti, J., Rosendale, J., and Phelan, B. 2014. Residence time and habitat duration for predators in a small mid-Atlantic estuary. Fisheries Bulletin 112: 144-158.

Mercer, L.P. 1985. Fishery Management Plan for Weakfish. Washington (DC): Atlantic States Marine Fisheries Commission. Fish Manage Rep. No 7.

Merriner, J.V. 1976. Aspects of the reproductive biology of weakfish, *Cynoscion regalis* (Scianidae), in North Carolina. Fish Bull US. 74:18-26.

NEFSC. 2009. 48th Northeast Regional Stock Assessment Workshop (48th SAW) Assessment Summary Report. US Dept Commerce, Northeast Fisheries Science Center Ref Doc. 09-10; 50 p. Available online at http://www.nefsc.noaa.gov/nefsc/puglications/

Nye, J.A., Targett, T.E., and Helser, T.E. 2008. Reproductive characteristics of weakfish in Delaware Bay: implications for management. N Am J Fish Manage. 27: 1-11.

Shepherd, G.R., and Grimes, C.B. 1983. Geographic and historic variations in growth of weakfish, *Cynoscion regalis*, in the Middle Atlantic Bight. Fish Bull. US 81:803-813.

Tringali, M.D, Seyoum, S., Higham, M., Wallace, E.M. 2011.A dispersal-dependent zone of introgressive hybridization between weakfish, *Cynoscion regalis*, and sand seatrout, *C. arenarius*, (Sciaenidae) in the Florida Atlantic. Journal of Heredity 102: 416-432.

Turnure, J. T., Able, K. W., and Grothues, T. M. 2014. Patterns of intra-estuarine movement of adult weakfish (*Cynoscion regalis*): evidence of site affinity at seasonal and diel scales. Fishery Bulletin, 113(2): 167-179.

Villoso EP. 1990. Reproductive biology and environmental control of spawning cycle of weakfish, *Cynoscion regalis* (Bloch and Schneider), in Delaware Bay [dissertation]. Newark (DE): University of Delaware.

Wigley, S. E., Baylock, J., Rago, P. J., and Shield, G. 2014. 2014 Discard Estimation, Precision, and Sample Size Analyses for 14 Federally Managed Species Groups in the Waters off the Northeastern United States. U.S. Dep. Commer., Northeast Fish. Sci. Cent. Ref Soc. 14-05.

8.0 Tables

Table 1. Total removals by sector for weakfish.

	Commercial (mt)		Recreational (mt)	
Year	Landings	Discards	Landings	Release Mortalities
1982	8,835.3	310.4	7,163.9	20.5
1983	7,926.6	385.6	7,694.7	12.3
1984	8,969.3	340.3	3,391.6	9.5
1985	7,690.0	395.9	4,234.2	13.0
1986	9,610.7	316.9	8,365.8	73.9
1987	7,744.0	301.0	9,232.2	32.7
1988	9,310.7	259.6	3,278.1	29.7
1989	6,424.0	211.6	1,807.1	12.4
1990	4,281.0	592.5	965.0	20.8
1991	3,943.1	495.8	1,958.2	76.6
1992	3,381.0	464.2	1,653.1	63.1
1993	3,108.8	512.2	938.0	54.0
1994	2,808.0	356.1	1,198.4	176.7
1995	3,219.9	404.8	1,711.2	205.1
1996	3,147.8	498.5	2,455.7	400.4
1997	3,310.1	270.0	3,201.2	286.7
1998	3,820.9	280.4	3,238.2	293.3
1999	3,132.1	231.7	3,208.6	396.4
2000	2,449.6	156.2	3,806.2	143.1
2001	2,267.7	128.6	2,125.4	187.2
2002	2,165.0	126.1	1,957.1	117.1
2003	907.7	105.4	882.8	85.1
2004	691.2	37.9	1,008.2	77.8
2005	520.4	48.1	1,170.0	94.6
2006	481.6	38.6	822.4	147.8
2007	413.1	42.1	541.7	97.0
2008	212.7	44.1	486.8	135.5
2009	173.8	55.9	194.0	27.9
2010	93.4	40.2	78.4	44.2
2011	66.0	51.9	46.4	29.5
2012	139.4	44.1	304.3	62.3
2013	161.8	28.4	211.4	18.2
2014	92.9	44.7	98.8	34.9
2015	65.4	80.4	204.6	46.5
2016	82.5	66.2	103.5	58.7
2017	81.9	77.2	197.5	28.6

Table 2. Number of NEFOP observed hauls by gear, region, and season.

Year	Gillnet				Otter Trawl			
	North		South		North		South	
	Early	Late	Early	Late	Early	Late	Early	Late
1989	3	223			909	924		
1990	208	195			806	696		
1991	448	1555			942	1539		16
1992	1260	940	21		1156	770		
1993	827	750	25		671	583		27
1994	396	1121	281	19	885	363	117	85
1995	1169	1001	374	119	1177	994	166	
1996	803	845	384	168	894	767	52	
1997	764	688	384	13	710	665	8	
1998	916	505	465	252	422	252	19	21
1999	381	438	190	52	410	616	102	
2000	364	425	126	95	946	776	95	
2001	368	314	93	26	1003	1150		
2002	273	390	31	5	752	2867	92	
2003	619	1202	53	15	2799	2649	55	14
2004	1248	2801		15	3444	5358	194	93
2005	945	2423	4	20	11975	10149	149	59
2006	508	342	2		6457	4552	110	13
2007	341	862	28	6	5249	6567	216	114
2008	471	584	31		6417	7792	218	79
2009	773	612	9	4	6972	7146	239	114
2010	580	870	24		5772	3798	373	152
2011	805	979	9	33	4942	5028	301	84
2012	780	789	5		3924	2845	72	22
2013	300	617	8	47	2984	3978		41
2014	641	905	9	28	4925	4187	192	33
2015	802	1372	160	288	3843	4376	133	30
2016	1185	1622	424	408	3383	4024	101	374
2017	1400	2119	942	277	4924	6729	247	196

Table 3. Number of NEFOP observed hauls with weakfish discards by gear, region, and season.

Year	Gillnet				Otter Trawl			
	North		South		North		South	
	Early	Late	Early	Late	Early	Late	Early	Late
1989					1	59		
1990					2	33		
1991					10	61		1
1992	1					11		
1993		46			1	10		6
1994	5	90	48	2	15	2	2	2
1995	56	67	28	7	14	124	2	
1996	17	51	30	1	24	113		
1997	18	38	17		11	22		
1998	19	4	29	16	4			1
1999	6	7	13		3	22	4	
2000		8	8	6	5	5	1	
2001	4	8	16	2	7	55		
2002	3	15	1			41	2	
2003		2	1	1	4	44	5	
2004		9			31	88	6	1
2005		5			9	24	2	
2006		3			8	28	5	3
2007	2	5			3	81	7	7
2008		1			8	35	6	12
2009		1			6	70	20	26
2010		8	3		39	64	6	15
2011				2	34	142	8	2
2012					19	80	10	
2013		3		2	61	66		9
2014	1	1			35	75	14	1
2015	3	14	10	37	70	96	2	3
2016	1	30	25	36	65	197	8	279
2017		44	125	26	213	278	16	138

Table 4. Jaccard species guilds used for the 2016 benchmark assessment and with the addition of 2015 – 2017 data. GN=Gillnet OTB=Otter trawl, bottom

Region	Gear	Species Guild for 2016 Benchmark Assessment	Region	Gear	Species Guild with additional 2015-2017
North	GN	BUTTERFISH	North	GN	BLUEFISH
North	GN	CROAKER, ATLANTIC	North	GN	BUTTERFISH
North	GN	DOGFISH, SMOOTH	North	GN	CROAKER, ATLANTIC
North	GN	MENHADEN, ATLANTIC	North	GN	MENHADEN, ATLANTIC
North	GN	SPOT	North	GN	SPOT
North	GN	WEAKFISH (SQUETEAGUE SEA TROUT)	North	GN	WEAKFISH (SQUETEAGUE SEA TROUT)
North	OTB	BLUEFISH	North	OTB	BLUEFISH
North	OTB	CRAB, HORSESHOE	North	OTB	CRAB, HORSESHOE
North	OTB	CROAKER, ATLANTIC	North	OTB	CROAKER, ATLANTIC
North	OTB	SCUP	North	OTB	SCUP
North	OTB	SPOT	North	OTB	SPOT
North	OTB	WEAKFISH (SQUETEAGUE SEA TROUT)	North	OTB	WEAKFISH (SQUETEAGUE SEA TROUT)
South	GN	BLUEFISH	South	GN	BLUEFISH
South	GN	BUTTERFISH	South	GN	BUTTERFISH
South	GN	CROAKER, ATLANTIC	South	GN	CROAKER, ATLANTIC
South	GN	DOGFISH, SPINY	South	GN	MENHADEN, ATLANTIC
South	GN	MENHADEN, ATLANTIC	South	GN	WEAKFISH (SQUETEAGUE SEA TROUT)
South	GN	WEAKFISH (SQUETEAGUE SEA TROUT)			
South	OTB	BUTTERFISH	South	OTB	CROAKER, ATLANTIC
South	OTB	CROAKER, ATLANTIC	South	OTB	FISH, NK
South	OTB	DOGFISH, SMOOTH	South	OTB	SHRIMP, PENAEID (SOUTHERN)
South	OTB	MENHADEN, ATLANTIC	South	OTB	SPOT
South	OTB	SPOT			

Table 5. Weakfish discard ratios by stratum.NR=ratio of non-regulatory discards from the period 1994-2000. T5+=ratio of discards for the additional years (2015-2017) covered in the assessment update. GN=Gillnet, OTB=Otter trawl, bottom.

Block	Years	Region	Gear	Season	Ratio	Variance	Lower CI	Upper CI
NR	1982-1993	North	GN	All	0.0068	1.29E-06	0.0046	0.0090
T1	1994	North	GN	All	0.0099	1.50E-05	0.0023	0.0174
T2	1995-1996	North	GN	All	0.0034	3.37E-07	0.0023	0.0046
T3	1997-2002	North	GN	All	0.0078	2.90E-06	0.0045	0.0111
T4	2003-2009	North	GN	All	0.0005	2.28E-08	0.0002	0.0008
T5	2010-2014	North	GN	All	0.0002	3.97E-09	0.0000	0.0003
T5+	2015-2017	North	GN	All	0.0019	3.68E-07	0.0007	0.0030
NR	1982-1993	North	OTB	All	0.0603	1.26E-04	0.0384	0.0822
T1	1994	North	OTB	Early	0.0018	2.00E-06	0.0000	0.0046
T1	1994	North	OTB	Late	0.0297	7.69E-05	0.0126	0.0468
T2	1995-1996	North	OTB	Early	0.0155	4.01E-05	0.0031	0.0278
T2	1995-1996	North	OTB	Late	0.0765	3.04E-04	0.0425	0.1105
T3	1997-2002	North	OTB	Early	0.0023	6.31E-07	0.0008	0.0038
T3	1997-2002	North	OTB	Late	0.0208	4.21E-05	0.0082	0.0335
T4	2003-2009	North	OTB	Early	0.0004	6.35E-09	0.0002	0.0005
T4	2003-2009	North	OTB	Late	0.0275	4.26E-05	0.0148	0.0402
T5	2010-2014	North	OTB	Early	0.0025	5.58E-07	0.0011	0.0040
T5	2010-2014	North	OTB	Late	0.0109	7.87E-06	0.0055	0.0164
T5+	2015-2017	North	OTB	Early	0.0064	2.48E-06	0.0088	0.0094
T5+	2015-2017	North	OTB	Late	0.0118	2.29E-06	0.0088	0.0147
NR	1982-1993	South	GN	All	0.0007	8.96E-09	0.0005	0.0009
T1	1994	South	GN	All	0.0008	4.71E-08	0.0004	0.0012
T2	1995-1996	South	GN	All	0.0005	1.69E-08	0.0003	0.0008
T3	1997-2002	South	GN	All	0.0009	2.57E-08	0.0006	0.0012
T4	2003-2009	South	GN	All	0.0002	1.77E-08	0.0000	0.0004
T5	2010-2014	South	GN	All	0.0003	4.83E-08	0.0000	0.0008
T5+	2015-2017	South	GN	All	0.0037	5.26E-07	0.0023	0.0052
NR	1982-1993	South	OTB	All	0.0089	4.21E-05	0.0000	0.0215
T1	1994	South	OTB	All	0.0277	4.54E-04	0.0000	0.0692
T2	1995-1996	South	OTB	All	0.0001	2.68E-08	0.0000	0.0005
T3	1997-2002	South	OTB	All	0.0022	2.31E-06	0.0000	0.0051
T4	2003-2009	South	OTB	All	0.0066	3.89E-06	0.0028	0.0105
T5	2010-2014	South	OTB	All	0.0124	1.65E-05	0.0045	0.0203
T5+	2015-2017	South	OTB	All	0.0991	4.02E-04	0.0600	0.1382

Table 6. Number of samples used to develop age-length keys by Year, Season, Region and Source. FD=Fishery dependent; FI=Fishery independent

Year	Season	Region	Source	# of Samples
2015	Early	North	FD	215
2015	Early	North	FI	426
2015	Early	South	FD	159
2015	Early	South	FI	248
2015	Late	North	FD	179
2015	Late	North	FI	1153
2015	Late	South	FD	257
2015	Late	South	FI	505
2016	Early	North	FD	199
2016	Early	North	FI	445
2016	Early	South	FD	221
2016	Early	South	FI	284
2016	Late	North	FD	261
2016	Late	North	FI	824
2016	Late	South	FD	340
2016	Late	South	FI	524
2017	Early	North	FD	150
2017	Early	North	FI	246
2017	Early	South	FD	166
2017	Early	South	FI	131
2017	Late	North	FD	194
2017	Late	North	FI	1308
2017	Late	South	FD	187
2017	Late	South	FI	165

Table 7. Size range of weakfish observed in the catch by region and season for 2015-2017.

	South		North	
	Early	Late	Early	Late
2015	22 - 70 cm	20 - 58 cm	19 - 73cm	15 - 69cm
2016	23 - 52 cm	23 - 60 cm	21 - 74cm	19 - 69cm
2017	22 - 70 cm	22 - 54 cm	18 - 76cm	19 - 64cm

Table 8. Minimum and maximum observed ages and lengths in the age-length key samples by year, season and region.

Year	Season	Region	# Samples	Min-Max Age	Min-Max Length
2015	Early	North	641	1 - 6	17 - 73 cm
2015	Late	North	1332	0 - 5	10 - 71 cm
2015	Early	South	407	1 - 4	12 - 50 cm
2015	Late	South	762	0 - 4	10 - 51 cm
2016	Early	North	644	1 - 6	18 - 77 cm
2016	Late	North	1085	0 - 4	19 - 69 cm
2016	Early	South	505	1 - 5	11 - 54 cm
2016	Late	South	864	0 - 3	9 - 54 cm
2017	Early	North	396	1 - 6	17 - 76 cm
2017	Late	North	1502	0 - 5	6 - 60 cm
2017	Early	South	297	1 - 4	13 - 60 cm
2017	Late	South	352	0 - 5	10 - 55 cm

Table 9. Age-1+ indices of abundance for weakfish.

	SEAMAP	NC P915	ChesMMAP	DE 30'	NJ OT	NEFSC Trawl	NEAMAP	MRIP
1982						7.29		0.08
1983						15.37		0.23
1984						116.00		0.18
1985						2.40		0.13
1986						20.51		0.56
1987						0.42		0.21
1988					1.08	9.14		0.34
1989					24.61	3.32		0.12
1990	3.42				23.19	2.58		0.10
1991	8.15			91.36	18.34	7.54		0.13
1992	2.15			93.67	25.85	3.12		0.07
1993	18.03			305.86	16.28	12.35		0.10
1994	2.55			448.29	197.56	60.64		0.13
1995	0.69			458.47	289.84	14.59		0.24
1996	0.93			1147.41	8.01	23.76		0.24
1997	2.40			324.08	8.72	8.04		0.24
1998	4.99			362.14	1.59	4.87		0.25
1999	5.57			304.06	16.25	19.19		0.15
2000	2.04			825.47	46.63	39.96		0.16
2001	1.13	1.92		450.19	29.40	84.54		0.09
2002	9.23	1.53	5.32	343.55	105.93	111.83		0.10
2003	6.04	1.30	3.54	290.43	56.58	170.27		0.04
2004	2.84	1.31	8.83	257.57	148.80	57.35		0.07
2005	17.32	1.27	8.50	75.30	10.80	48.39		0.08
2006	15.85	1.07	4.48	365.81	5.09	89.84		0.05
2007	12.15	0.47	2.83	107.19	30.20	22.47	83.33	0.02
2008	11.44	0.56	2.21	124.94	37.38	29.21	112.39	0.03
2009	17.68	0.35	0.79	108.78	30.68		91.82	0.01
2010	14.07	0.46	2.13	171.62	38.44		64.26	0.03
2011	3.41	0.39	2.80	347.79	130.02		253.36	0.01
2012	28.17	0.94	3.47	150.90	171.19		314.12	0.03
2013	7.55	0.73	1.23	95.32	16.48		29.91	0.02
2014	9.80	0.53	0.11	55.15	83.64		51.85	0.01
2015	2.83	0.33	1.30	108.71	37.83		65.90	0.02
2016	6.46	0.30	1.80	288.61	63.91		267.38	0.02
2017	10.36	0.33	0.65	215.13	34.80		49.48	0.01

Table 10. Recruitment indices for weakfish.

	Composite YOY	RI Fall Trawl	CT LISTS	NY Peconic Bay	DE Bay 16' Trawl	MD Coastal Bay Trawl	VIMS Juv Trawl	NC P195
1982	0.94	19.26			55.35			
1983	0.37	1.28			20.35			
1984	1.50	4.74	1.00		158.54			
1985	0.71	28.35	6.19		37.10			
1986	0.94	3.50	13.16		59.57			
1987	0.47	0.58	0.63	0.51	43.24			20.19
1988	0.94	1.29	3.49	0.11	26.02		28.98	79.74
1989	0.80	0.86	8.69	1.38	35.85	1.66	24.00	24.78
1990	0.80	12.51	5.56	0.55	50.89	1.95	6.94	51.00
1991	0.95	12.80	11.95	20.44	63.43	5.91	5.09	33.19
1992	1.34	10.75	3.05	3.01	102.41	9.01	17.20	42.35
1993	0.90	9.12	4.08	0.96	110.85	10.78	9.56	10.03
1994	1.20	32.38	11.19	8.24	125.71	4.62	5.91	34.51
1995	1.04	0.22	5.22	1.60	138.00	18.90	8.41	21.97
1996	2.02	336.69	15.23	25.13	119.57	6.41	12.02	108.97
1997	1.71	66.65	12.38	15.28	180.20	10.18	10.25	39.22
1998	1.39	5.97	5.02	0.98	79.68	8.11	11.91	123.74
1999	1.54	3.44	30.93	7.90	78.03	24.27	12.39	77.03
2000	1.90	28.59	63.31	15.87	115.98	11.17	12.24	81.94
2001	1.00	5.98	40.09	16.11	50.93	8.54	12.12	19.87
2002	0.73	3.69	41.35	12.17	35.24	2.04	10.54	15.36
2003	1.28	128.17	49.41	6.08	49.17	7.41	20.55	35.65
2004	0.90	1.26	58.98	5.68	49.69	4.16	9.03	29.21
2005	1.13	24.56	25.86	30.76	68.03	5.81	6.80	36.32
2006	0.66	0.44	1.05	8.63	29.75	4.69	8.26	37.72
2007	1.04	8.40	63.93	12.22	45.55	11.14	8.16	38.98
2008	0.76	0.08	9.03	7.93	33.22	0.40	12.64	49.72
2009	0.71	1.16	6.48	1.73	46.66	1.49	9.93	25.10
2010	0.94	7.94		2.51	45.31	5.88	15.65	30.27
2011	0.62	19.53	11.64	3.47	29.43	1.79	7.14	21.58
2012	0.58	9.70	21.96	2.15	31.71	0.34	6.86	24.10
2013	1.06	2.13	7.01	8.41	65.89	1.13	12.59	52.30
2014	1.07	6.42	41.53	7.67	86.22	1.90	7.12	36.56
2015	0.52	5.19		7.54	41.72	1.13	6.22	7.42
2016	0.98	12.65		10.93	70.42	0.71	5.60	71.06
2017	0.58	33.82		14.38	29.59	0.13	6.53	23.57

Table 11. Descriptions of data (S1-S2) and model (M1-M4) sensitivity runs in the Bayesian age- structured model.

Scenario		Description
Data Sensitivity	S1	Base model run: multinomial ALK, 2 fleets, reconstructed historical catch-at- age with scale ages converted to otolith ages, new MRIP estimates of recreational catch
	S2	same as S1 but with old MRIP estimates
Model Configuration	M1	Constant M, no spatial heterogeneity
	M2	Time-varying M, no spatial heterogeneity
	M3	Constant M, spatial heterogeneity in population available to surveys
	M4	Time-varying M and spatial heterogeneity

Table 12. Estimates of DICs, and retrospective errors. Based on data S1, i.e., with new MRIP estimates. E1_t=(N_t|data to year t -N_t|data to year t+1) /(N_t|data to year t+1); E2_t=(N_t|data to year t - N_t|data to year 2017) /(Nt|data to year t) .

Models	DIC	E1	E2
M1	233.74	1.75	1.45
M2	-72.39	0.86	1.00
M3	-2656.67	4.04	2.37
M4	-2760.66	1.18	1.39

Table 13. DIC values for sensitivity runs S1-S2 for models M1-M4. See Table 11 for a description of the sensitivity runs.

Data scenarios	M1	M2	M3	M4
S1	233.74	-72.39	-2656.67	-2760.66
S2	-18.89	-351.28	-2977.26	-3129.84

Table 14. Full fishing mortality rates estimated by the base run of the Bayesian age-structured model.

Year	Commercial	Recreational	Maximum total F-at-Age
1982	1.08	0.35	1.36
1983	1.22	0.60	1.66
1984	1.59	0.47	1.92
1985	1.21	0.60	1.66
1986	1.55	0.74	2.06
1987	0.77	0.48	1.15
1988	1.58	0.55	1.97
1989	1.50	0.29	1.70
1990	1.35	0.29	1.57
1991	1.25	0.57	1.67
1992	1.41	0.55	1.81
1993	1.23	0.34	1.49
1994	0.61	0.22	0.79
1995	0.39	0.20	0.55
1996	0.38	0.20	0.58
1997	0.37	0.22	0.60
1998	0.48	0.25	0.74
1999	0.49	0.25	0.75
2000	0.51	0.47	0.99
2001	0.45	0.42	0.87
2002	0.85	0.63	1.47
2003	0.86	0.64	1.49
2004	0.53	0.77	1.28
2005	0.47	0.59	1.06
2006	0.69	0.84	1.49
2007	1.32	0.84	2.10
2008	1.08	0.67	1.73
2009	1.38	0.89	2.20
2010	1.53	0.26	1.76
2011	0.39	0.11	0.51
2012	0.34	0.62	0.96
2013	0.75	0.13	0.90
2014	0.56	0.84	1.38
2015	0.42	0.71	1.11
2016	0.46	0.75	1.19
2017	0.19	0.40	0.62

Table 15. Natural mortality (M) and total mortality (Z) rates estimated by the base run of the Bayesian age-structured model.

Year	M	Z
1982	0.17	1.53
1983	0.17	1.83
1984	0.17	2.09
1985	0.17	1.83
1986	0.17	2.24
1987	0.17	1.31
1988	0.16	2.13
1989	0.16	1.86
1990	0.15	1.72
1991	0.15	1.82
1992	0.14	1.95
1993	0.14	1.63
1994	0.14	0.92
1995	0.14	0.69
1996	0.15	0.73
1997	0.17	0.77
1998	0.20	0.93
1999	0.24	0.98
2000	0.29	1.28
2001	0.36	1.23
2002	0.42	1.89
2003	0.48	1.97
2004	0.55	1.83
2005	0.66	1.72
2006	0.80	2.29
2007	0.91	3.01
2008	0.94	2.68
2009	0.94	3.14
2010	0.94	2.70
2011	0.94	1.45
2012	0.95	1.91
2013	0.95	1.84
2014	0.93	2.31
2015	0.90	2.01
2016	0.88	2.07
2017	0.83	1.45

Table 16. Total abundance estimated by the base run of the Bayesian age-structured model in millions of fish.

Year	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Total
1982	25.44	16.62	6.83	3.02	1.43	1.52	54.86
1983	27.09	17.05	7.66	2.13	0.70	0.78	55.41
1984	27.06	17.37	6.94	1.96	0.37	0.29	53.99
1985	36.16	16.49	6.23	1.43	0.26	0.11	60.69
1986	47.56	23.19	6.72	1.60	0.25	0.07	79.39
1987	39.54	28.55	7.90	1.28	0.19	0.04	77.51
1988	23.34	27.86	14.79	2.99	0.37	0.07	69.42
1989	21.53	14.29	9.90	2.99	0.39	0.06	49.15
1990	18.21	13.78	5.70	2.40	0.50	0.08	40.68
1991	19.05	12.00	5.88	1.54	0.46	0.12	39.04
1992	26.52	12.49	4.99	1.53	0.28	0.11	45.91
1993	30.04	17.06	4.89	1.17	0.24	0.06	53.45
1994	31.57	20.41	7.69	1.43	0.25	0.07	61.41
1995	17.27	24.17	12.59	3.79	0.59	0.13	58.55
1996	18.75	13.68	16.00	6.60	1.80	0.38	57.21
1997	16.88	14.79	9.10	8.56	3.21	1.15	53.69
1998	12.86	13.04	9.59	4.69	4.01	2.25	46.44
1999	11.01	9.44	7.72	4.30	1.86	2.85	37.18
2000	15.73	7.74	5.34	3.30	1.63	2.15	35.88
2001	5.94	10.22	3.75	1.74	0.93	1.37	23.95
2002	8.83	3.67	4.89	1.26	0.51	0.86	20.02
2003	10.61	4.67	1.26	0.94	0.19	0.31	17.98
2004	15.88	5.31	1.51	0.22	0.13	0.11	23.16
2005	7.08	7.72	1.76	0.29	0.04	0.05	16.94
2006	7.64	3.17	2.52	0.37	0.05	0.02	13.77
2007	4.20	2.80	0.74	0.32	0.04	0.01	8.12
2008	5.64	1.24	0.44	0.05	0.02	0.00	7.40
2009	5.67	1.70	0.23	0.04	0.00	0.00	7.65
2010	8.50	1.61	0.25	0.01	0.00	0.00	10.38
2011	6.93	2.50	0.29	0.02	0.00	0.00	9.75
2012	6.30	2.50	0.78	0.07	0.01	0.00	9.66
2013	4.04	2.16	0.64	0.13	0.01	0.00	6.98
2014	7.44	1.35	0.56	0.12	0.02	0.00	9.50
2015	5.47	2.45	0.29	0.07	0.01	0.00	8.29
2016	6.60	1.92	0.62	0.05	0.01	0.00	9.19
2017	7.05	2.36	0.48	0.09	0.01	0.00	9.99

Table 17. Spawning stock biomass (mt) estimated by the base run of the Bayesian age-structured model.

Year	SSB (mt)
1982	15,405
1983	12,858
1984	10,815
1985	12,817
1986	20,768
1987	15,740
1988	15,714
1989	11,397
1990	10,681
1991	12,339
1992	10,586
1993	7,971
1994	12,465
1995	12,448
1996	14,250
1997	19,197
1998	15,114
1999	14,107
2000	11,540
2001	12,821
2002	8,259
2003	5,621
2004	4,746
2005	3,782
2006	4,103
2007	3,457
2008	2,060
2009	1,866
2010	1,764
2011	1,556
2012	2,064
2013	1,133
2014	1,263
2015	1,522
2016	1,621
2017	1,922

Table 18. Estimates of biological reference points from the 2016 benchmark assessment and the 2019 assessment updated.

Threshold		
	2016	2019
SSB	6,880 mt	6,170 mt
Z	1.36	1.43
F	0.93	0.97

Target		
	2016	2019
SSB	n.a.	n.a.
Z	0.93	1.03
F	0.55	0.57

Table 19. Updated reference points, terminal year values, and stock status from the base run of the Bayesian age-structured model. The F target and threshold are only applicable when Z is at or below the Z target.

	Threshold	Target	2017 Value	Status
SSB	6,170 mt	n.a.	1,922 mt	Depleted
Z	1.43	1.03	1.45	Exceeding the Z threshold
F	0.97	0.57	0.62	n.a.

9.0 Figures

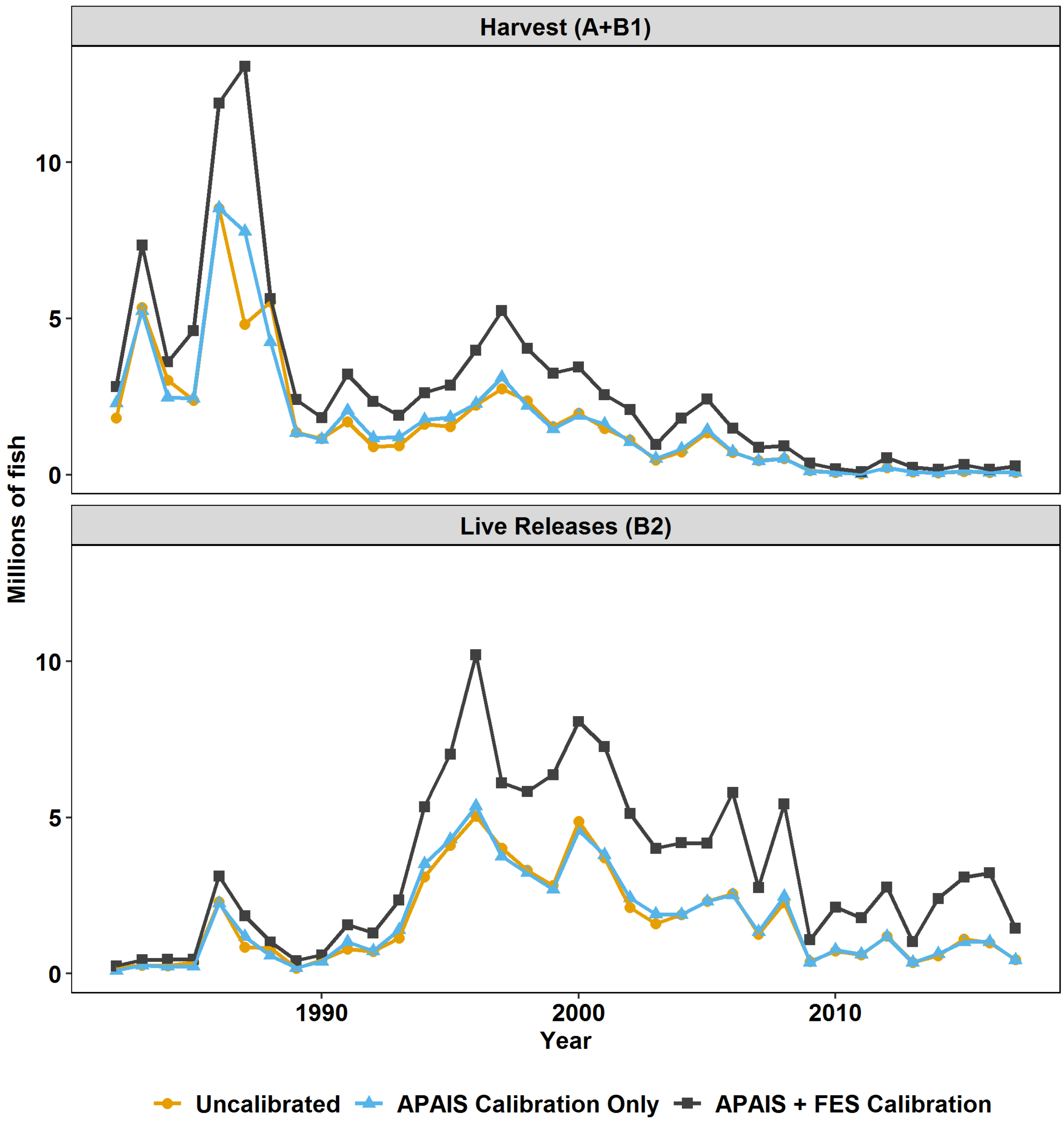


Figure 1. Comparison of calibrated and uncalibrated MRIP estimates of recreational weakfish harvest (top) and live releases (bottom). The APAIS + FES calibration was used to develop the estimates of recreational catch for the assessment update.

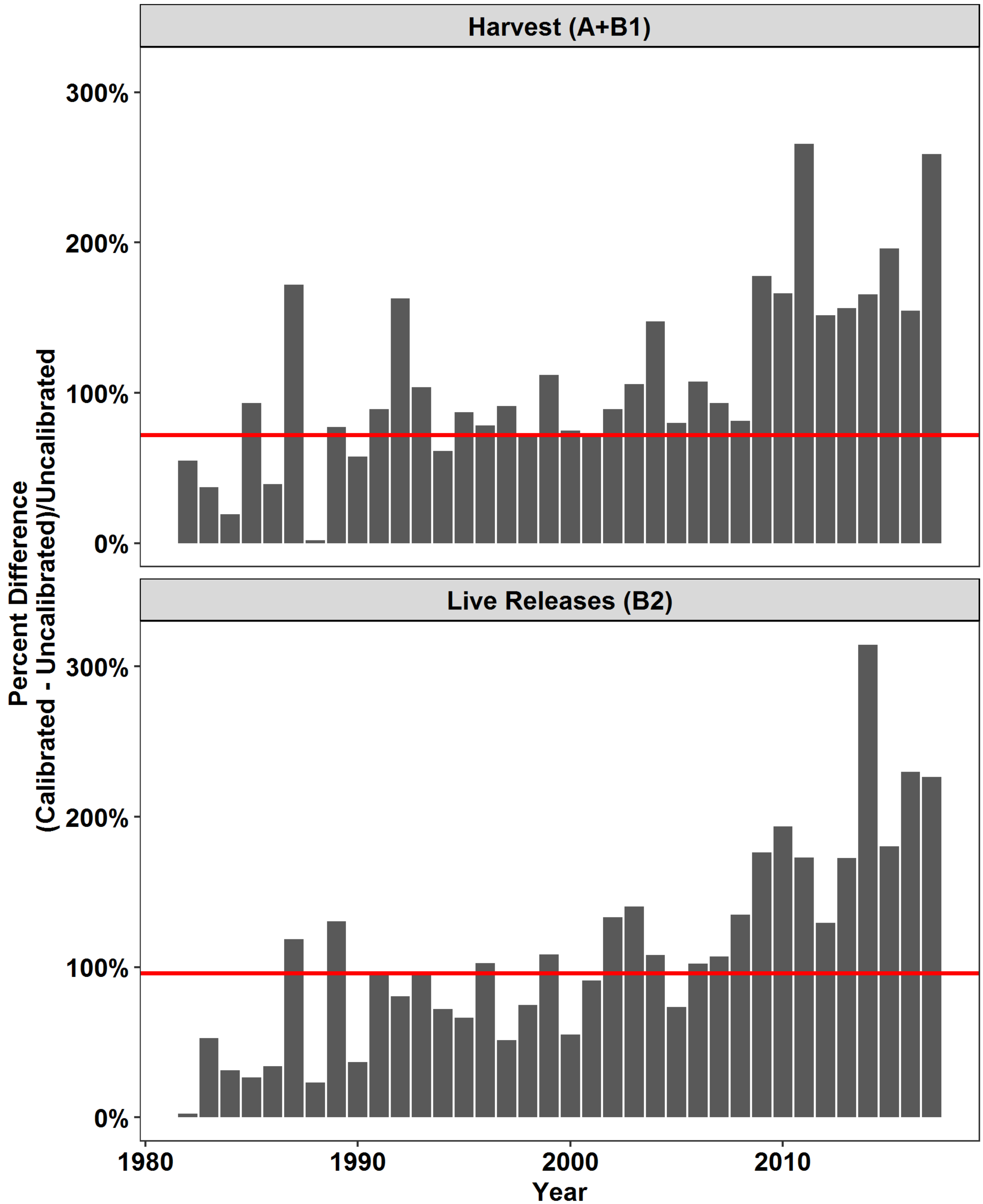


Figure 2. **Percent difference between calibrated and uncalibrated MRIP estimates of recreational weakfish harvest (top) and live releases (bottom). Red line indicates the time series mean percent difference.**

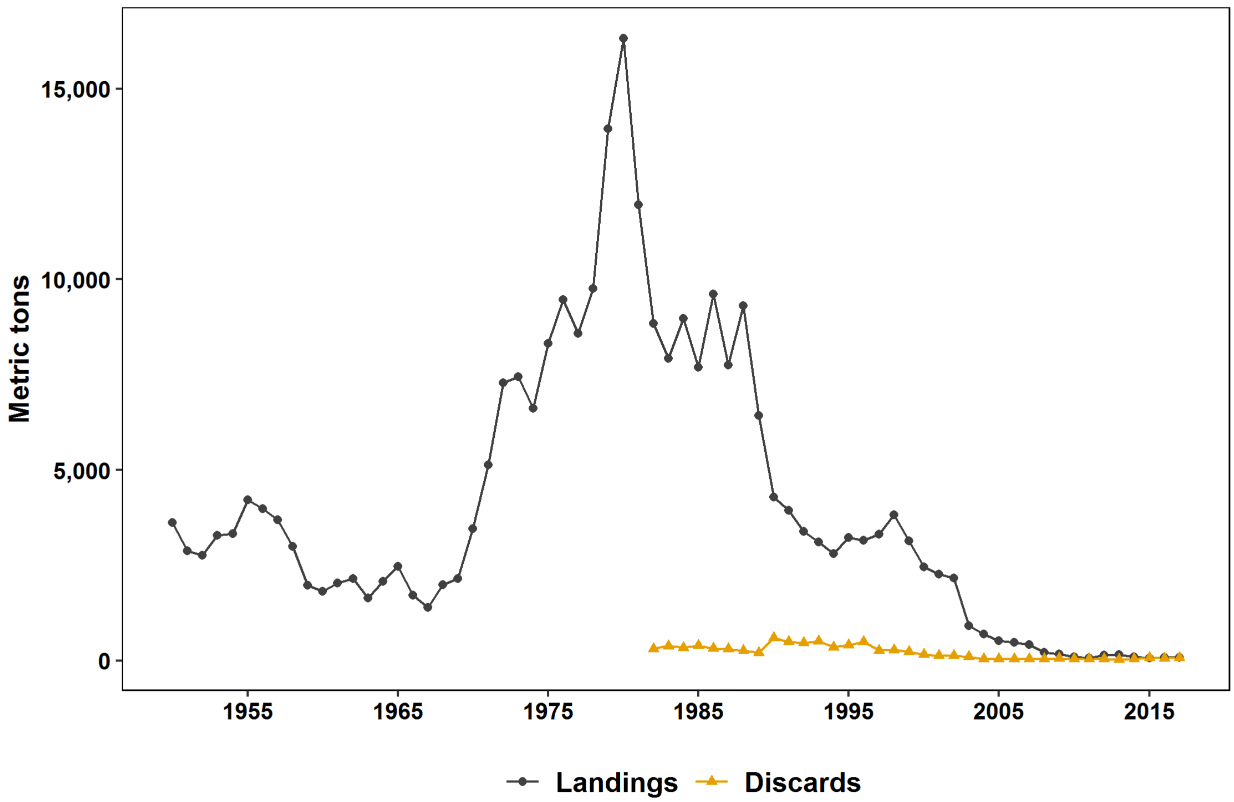


Figure 3. **Commercial landings and discards of weakfish in weight, 1950-2017. Estimates of commercial discards are not available prior to 1982.**

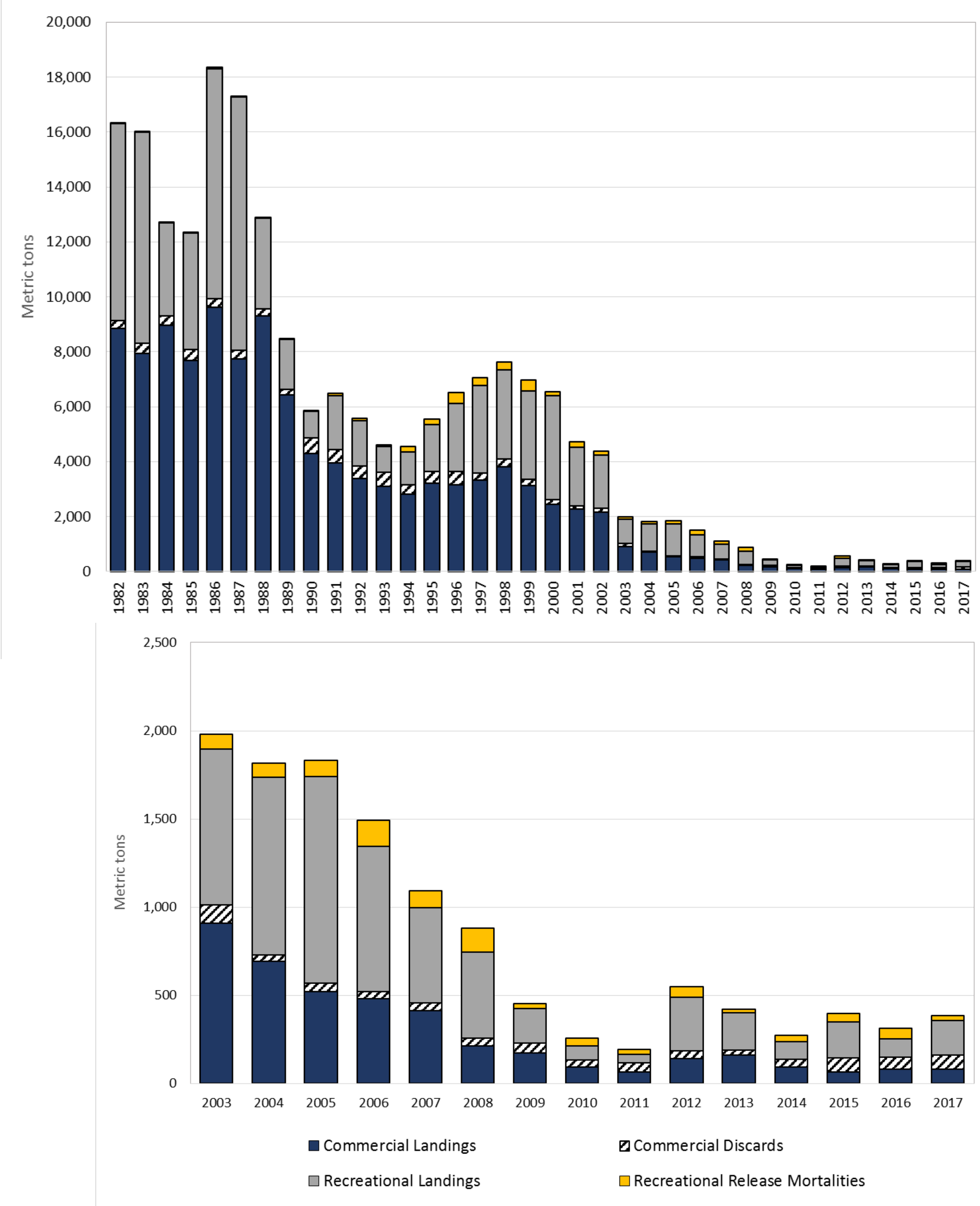


Figure 4. Total annual weakfish removals by sector used in the assessment. Top figure is 1982-2017, bottom figure is 2003 – 2017 to show detail in recent years.

Figure 5. **Weakfish catch-at-age by sector in millions of fish.**

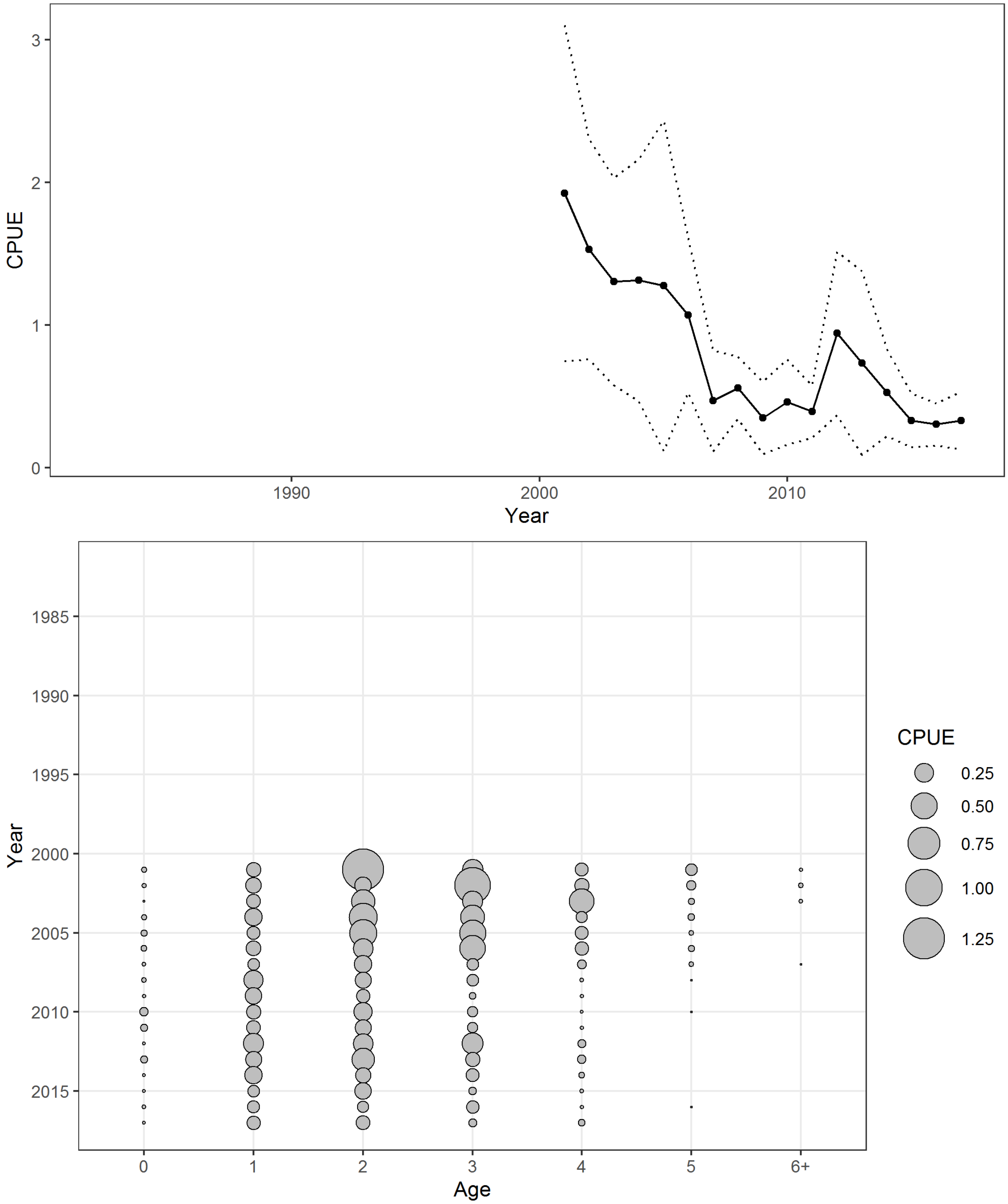


Figure 6. **NC Independent Gillnet Survey age-1+ index plotted with 95% confidence intervals (top) and index-at-age (bottom).**

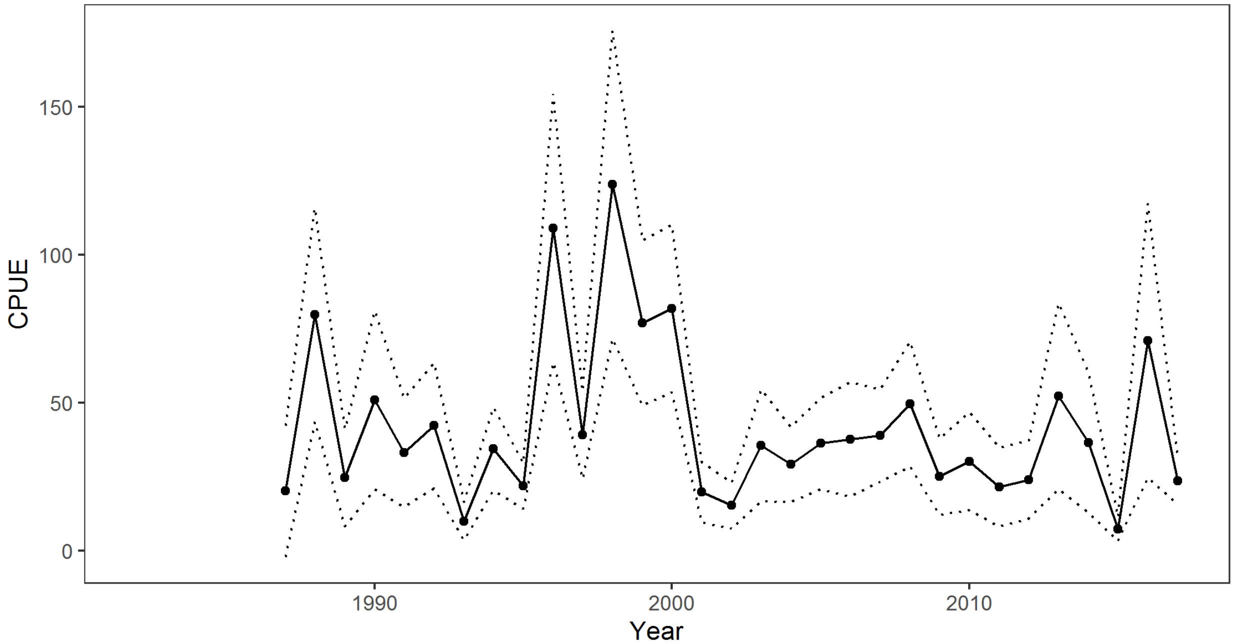


Figure 7. NC Pamlico Sound Survey (P195) recruitment index plotted with 95% confidence intervals.

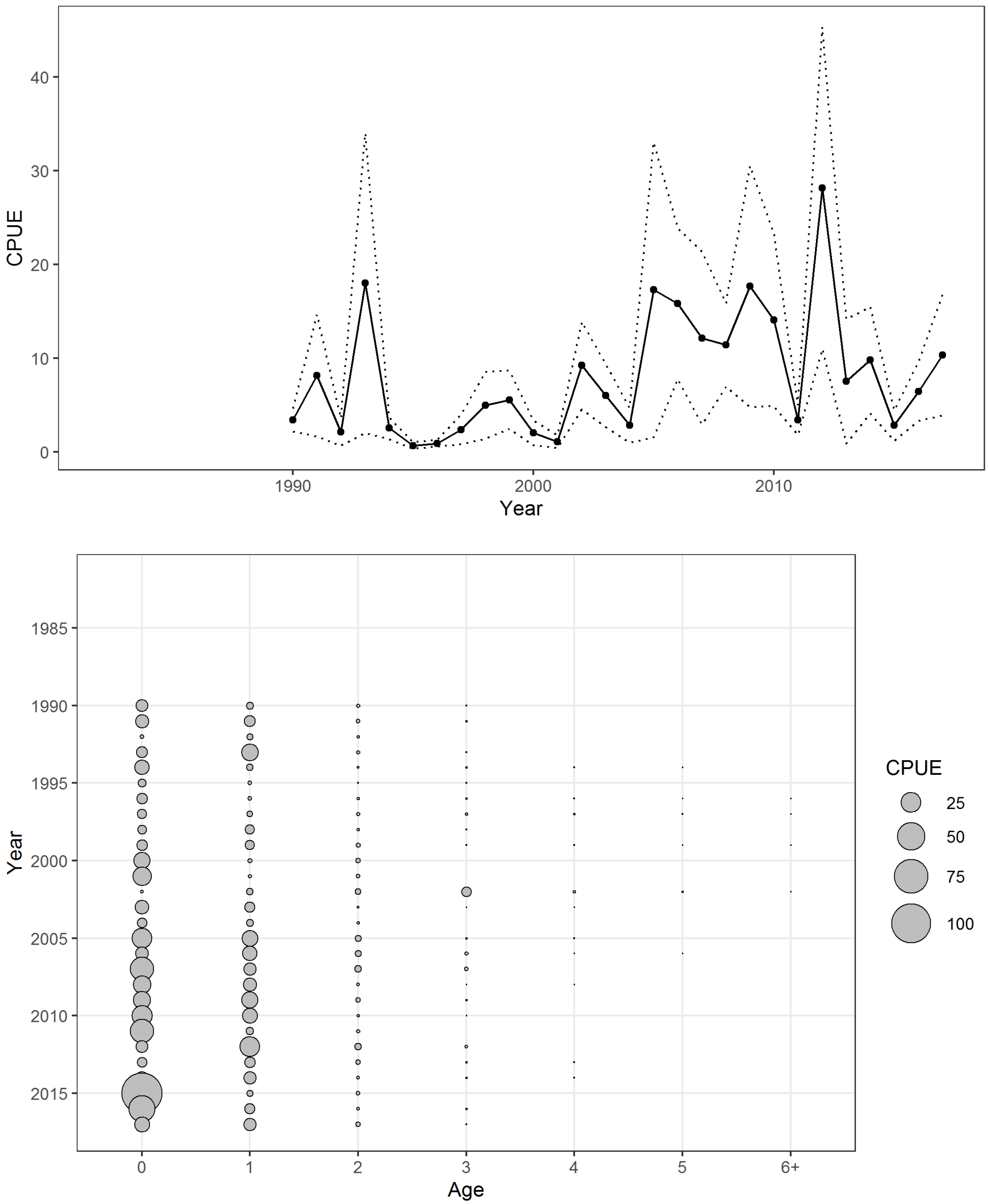


Figure 8. **SEAMAP age-1+ index with 95% confidence intervals (top) and SEAMAP index-at-age (bottom).**

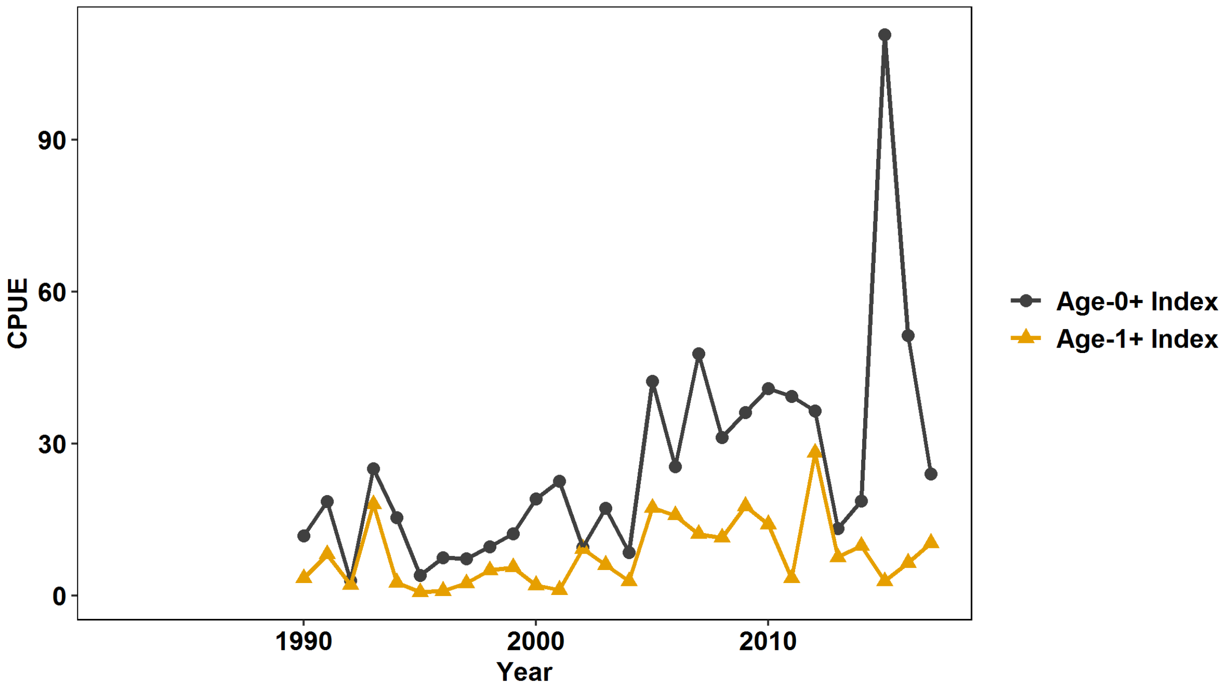


Figure 9. **Comparison of age-0+ and age-1+ index from SEAMAP survey.**

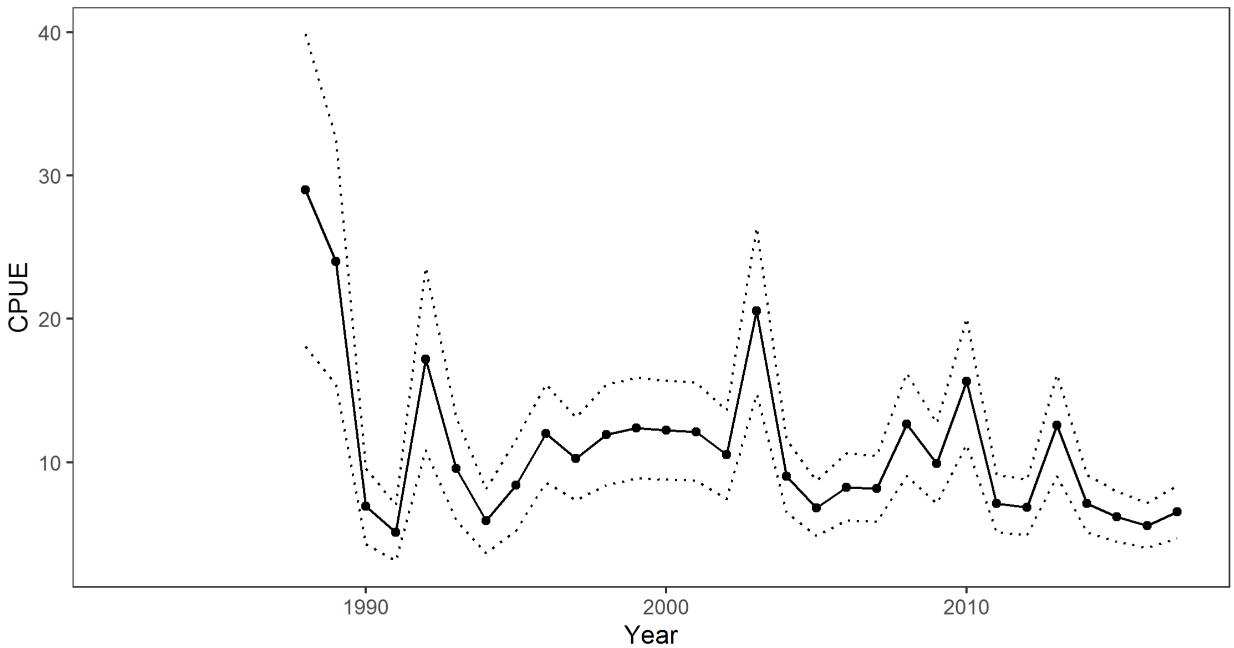


Figure 10. VIMS Juvenile Trawl Survey recruitment index plotted with 95% confidence intervals.

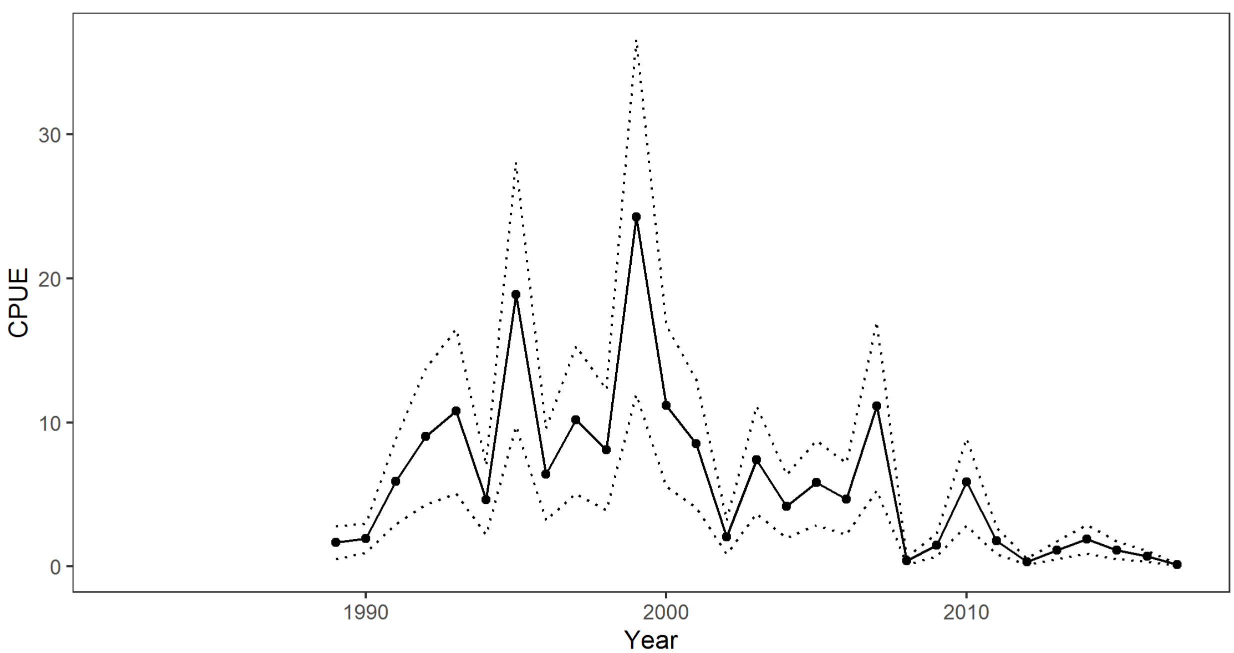


Figure 11. MD Coastal Bays Trawl Survey recruitment index plotted with 95% confidence intervals.

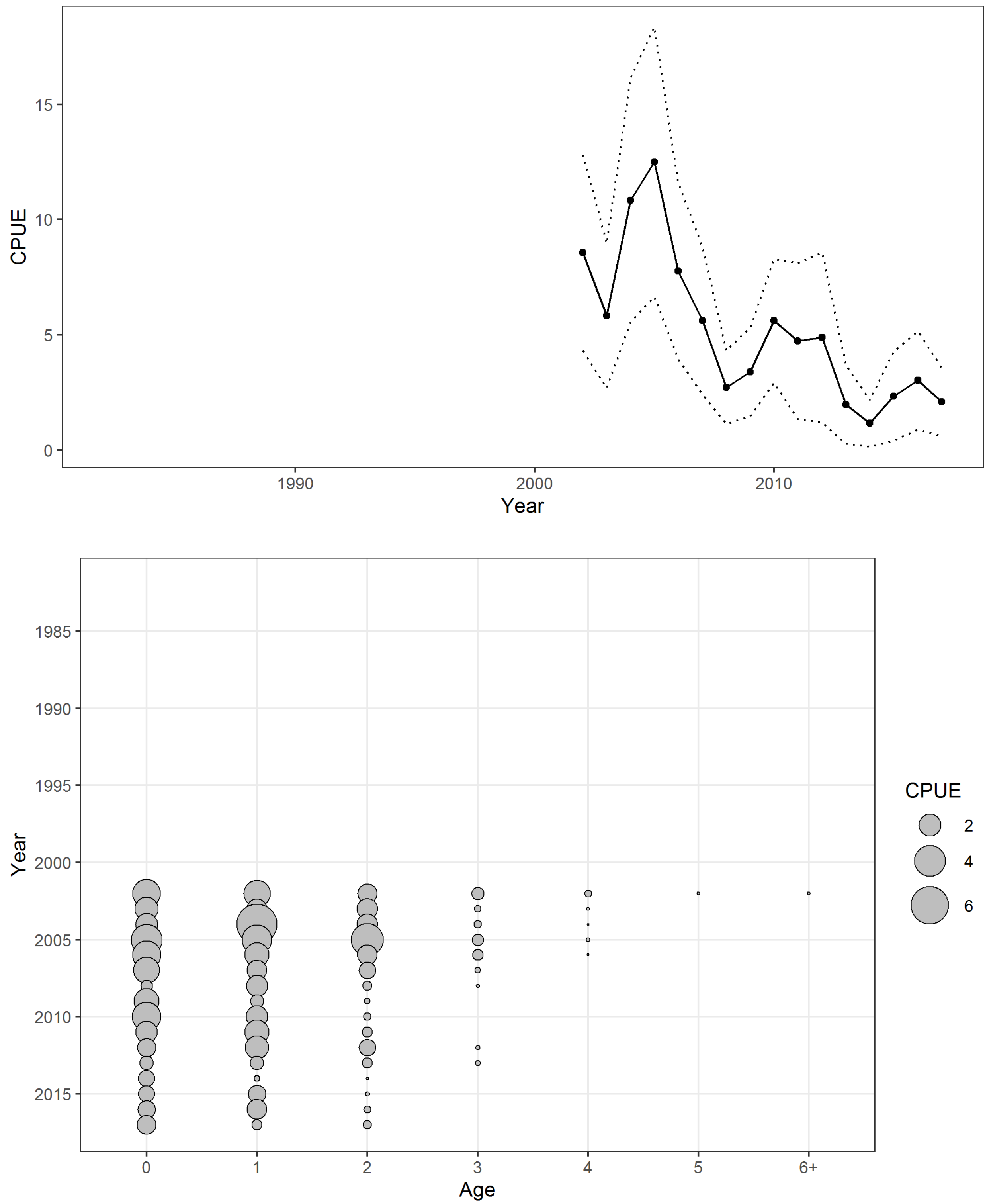


Figure 12. ChesMMAP age-1+ index with 95% confidence intervals (top) and ChesMMAP index-at-age (bottom).

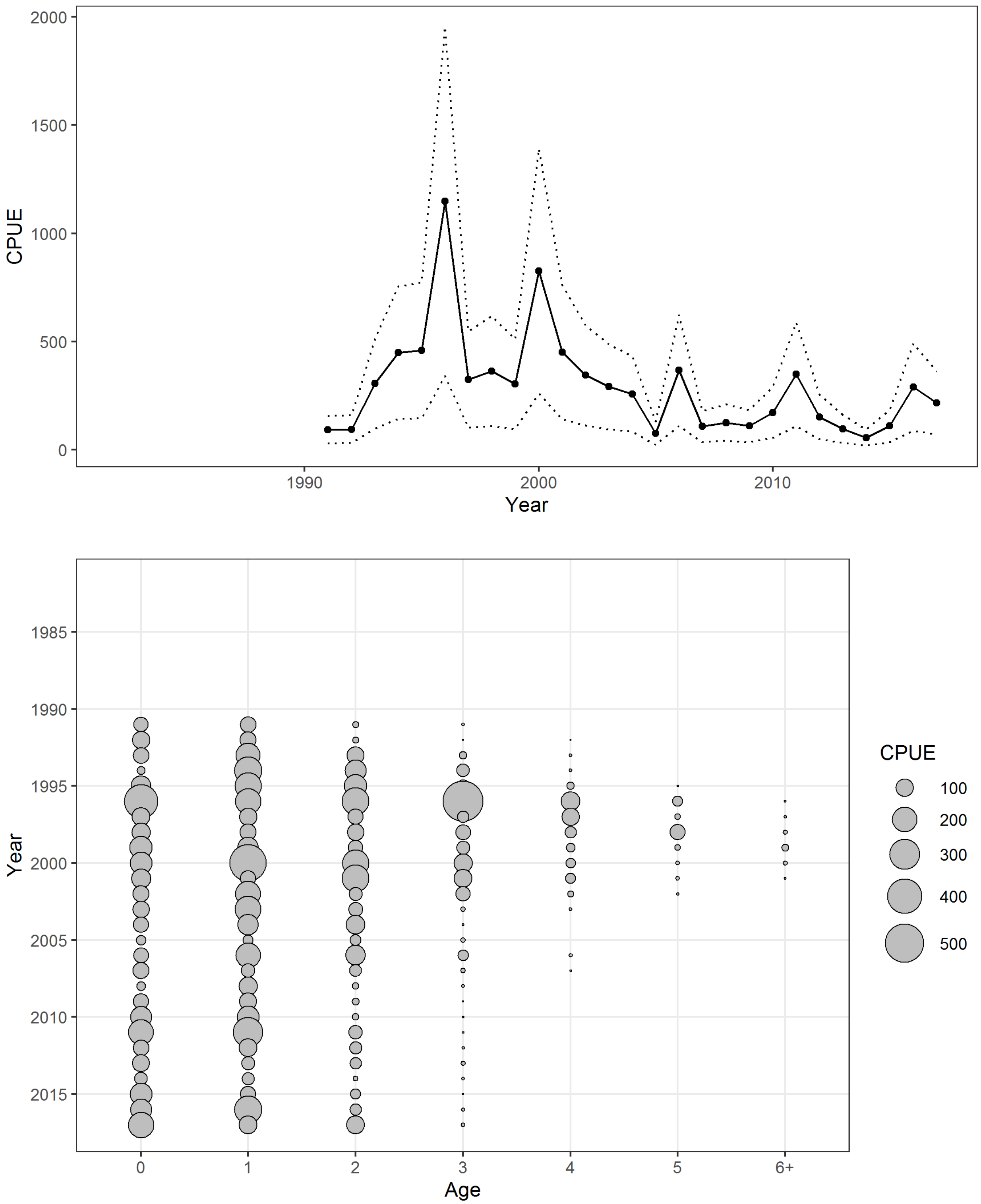


Figure 13. DE Bay 30’ Trawl Survey age-1+ index with 95% confidence intervals (top) and DE Bay 30’ Trawl Survey index-at-age (bottom)

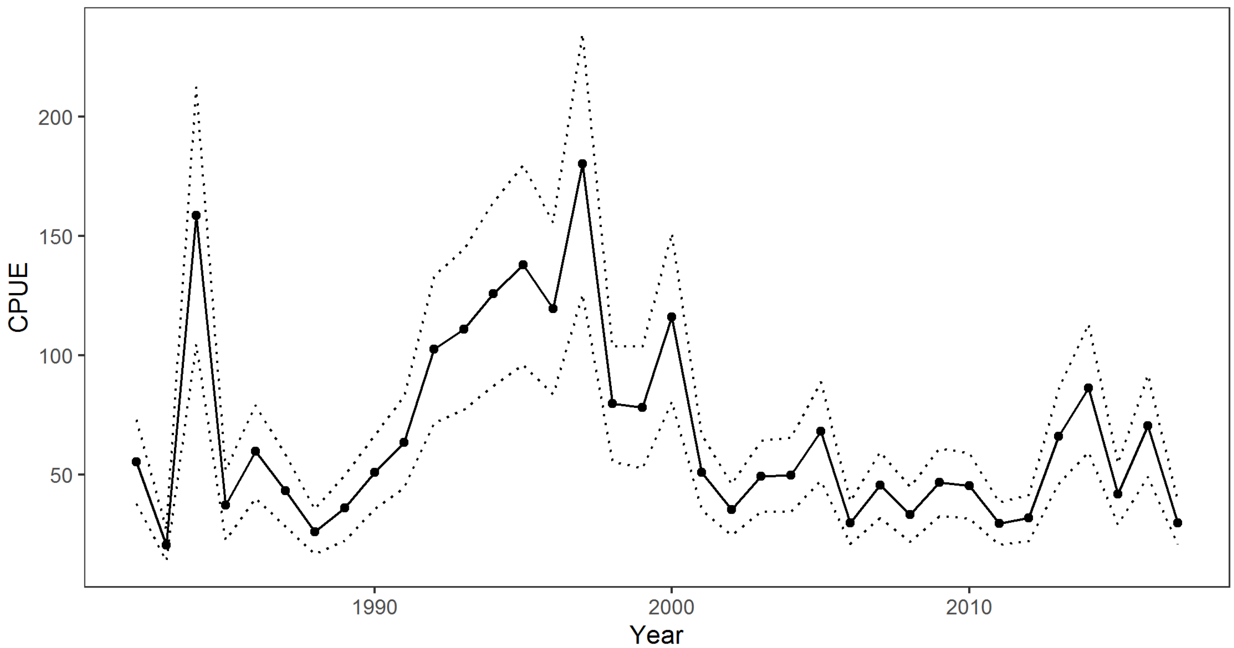
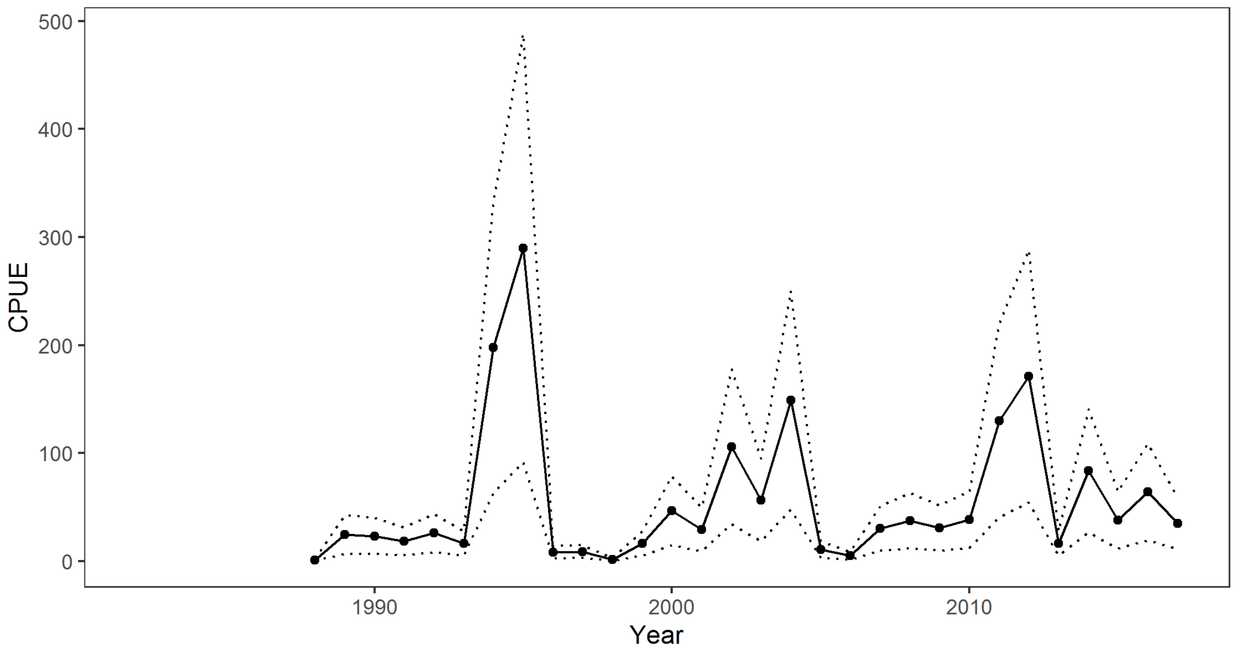


Figure 14. DE Bay Juvenile Trawl Survey recruitment index plotted with 95% confidence intervals.



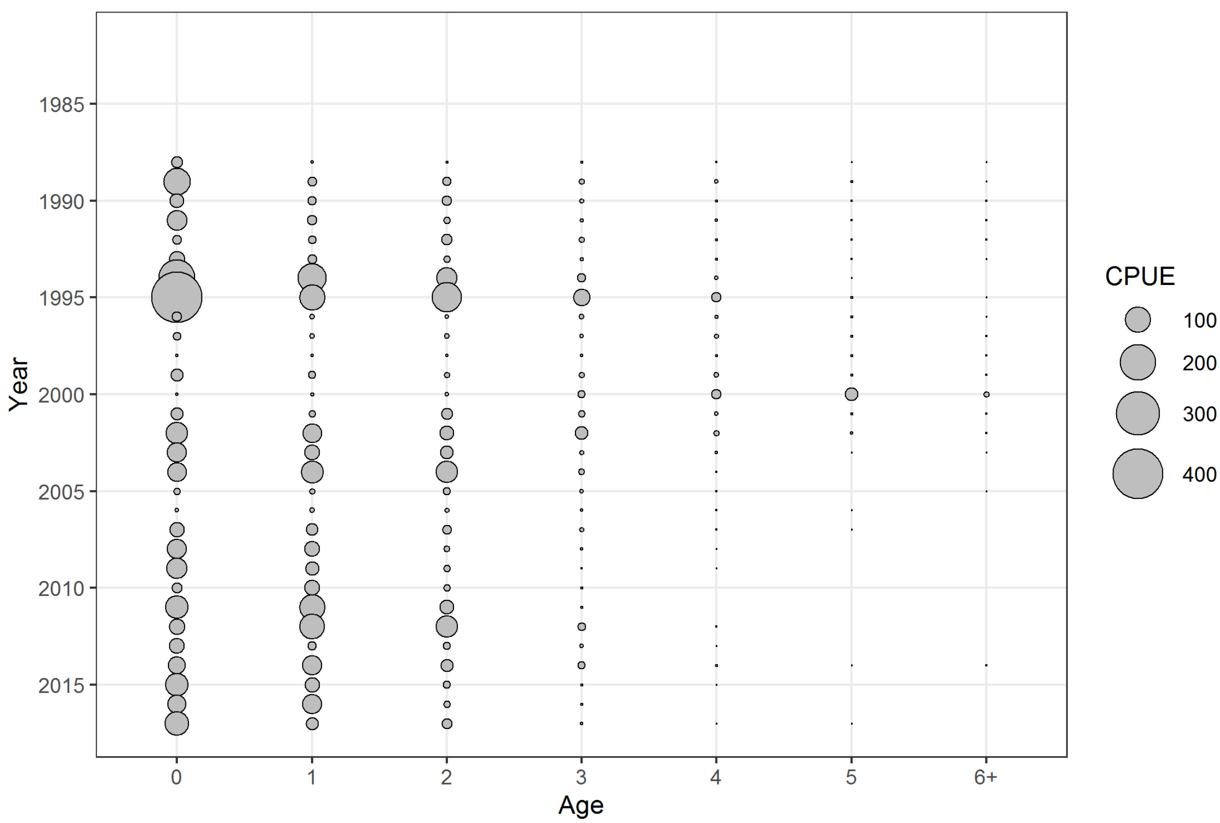


Figure 15. NJ Ocean Trawl Survey age-1+ index with 95% confidence intervals (top) and NJ Ocean Trawl Survey index-at-age (bottom).

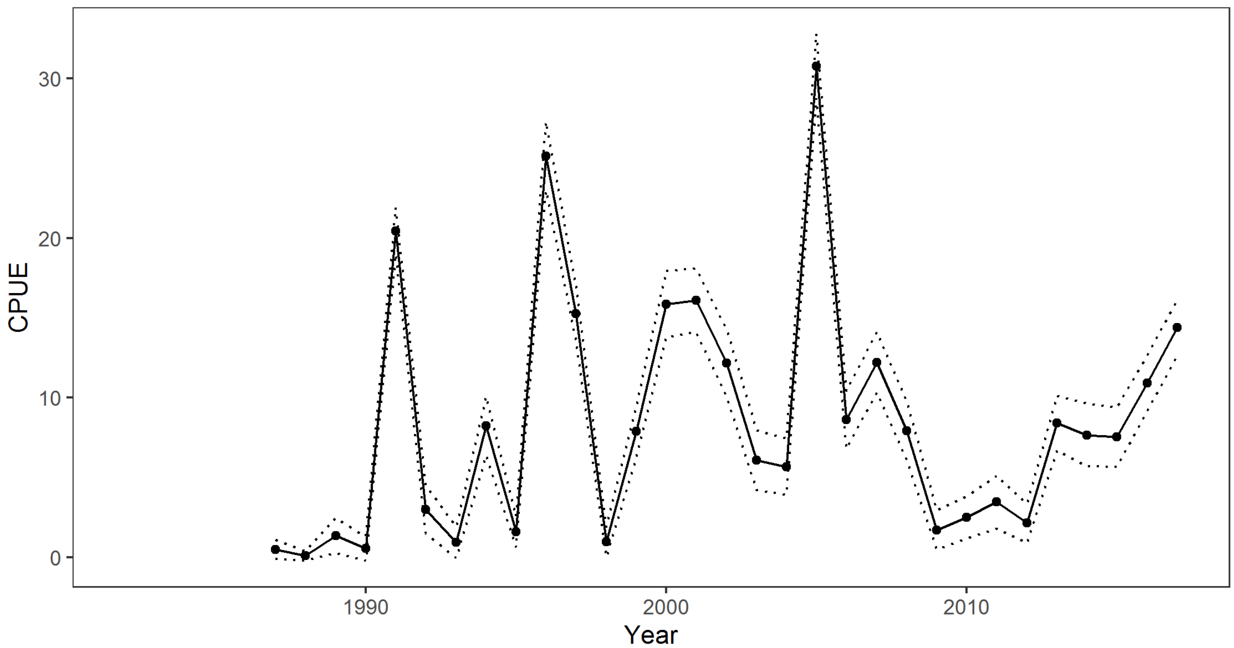


Figure 16. **NY Peconic Bay recruitment index plotted with 95% confidence intervals.**

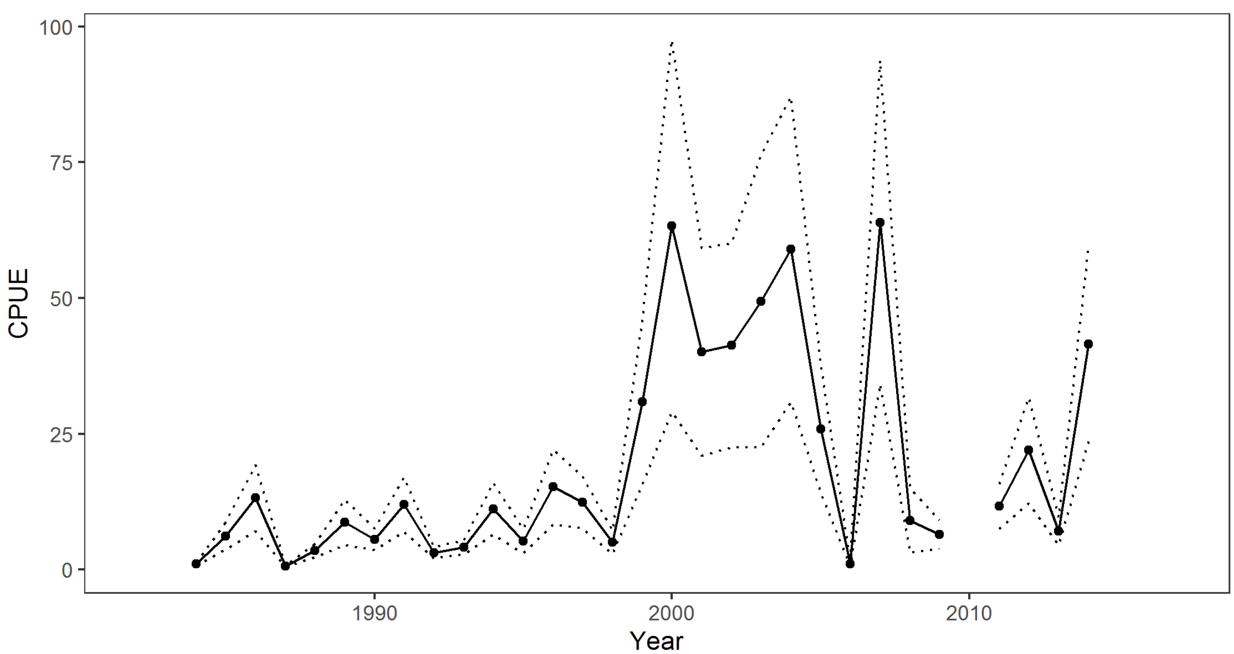


Figure 17. **CT LISTS recruitment index plotted with 95% confidence intervals.**

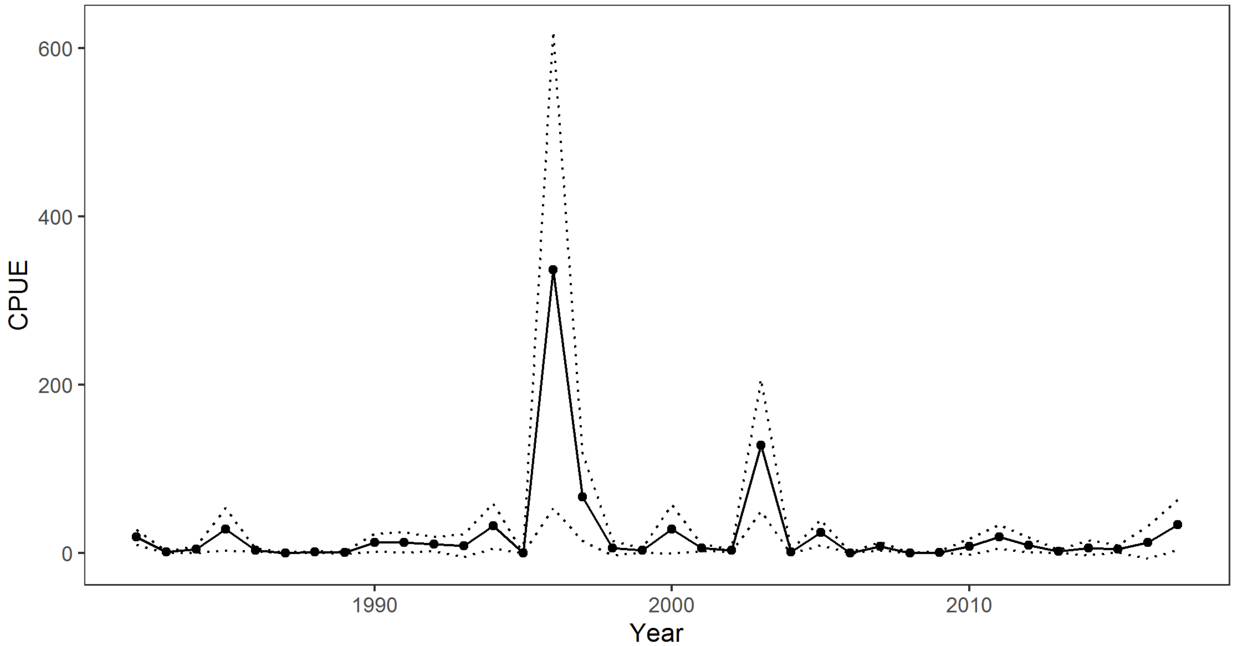


Figure 18. RI Seasonal Trawl recruitment index plotted with 95% confidence intervals.

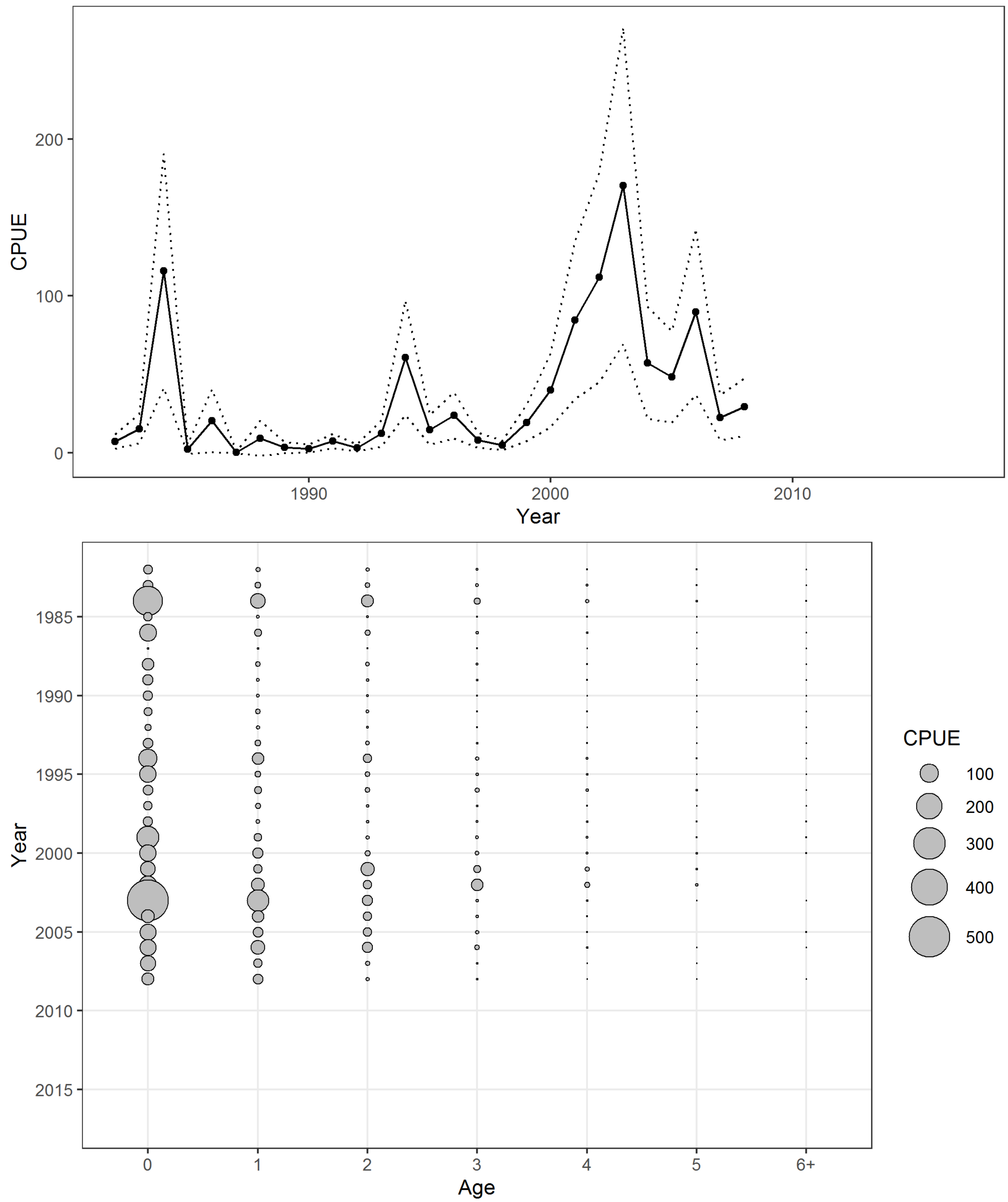


Figure 19. **NEFSC Fall Trawl Survey age-1+ index plotted with 95% confidence intervals (top) and the NEFSC survey index-at-age (bottom).**

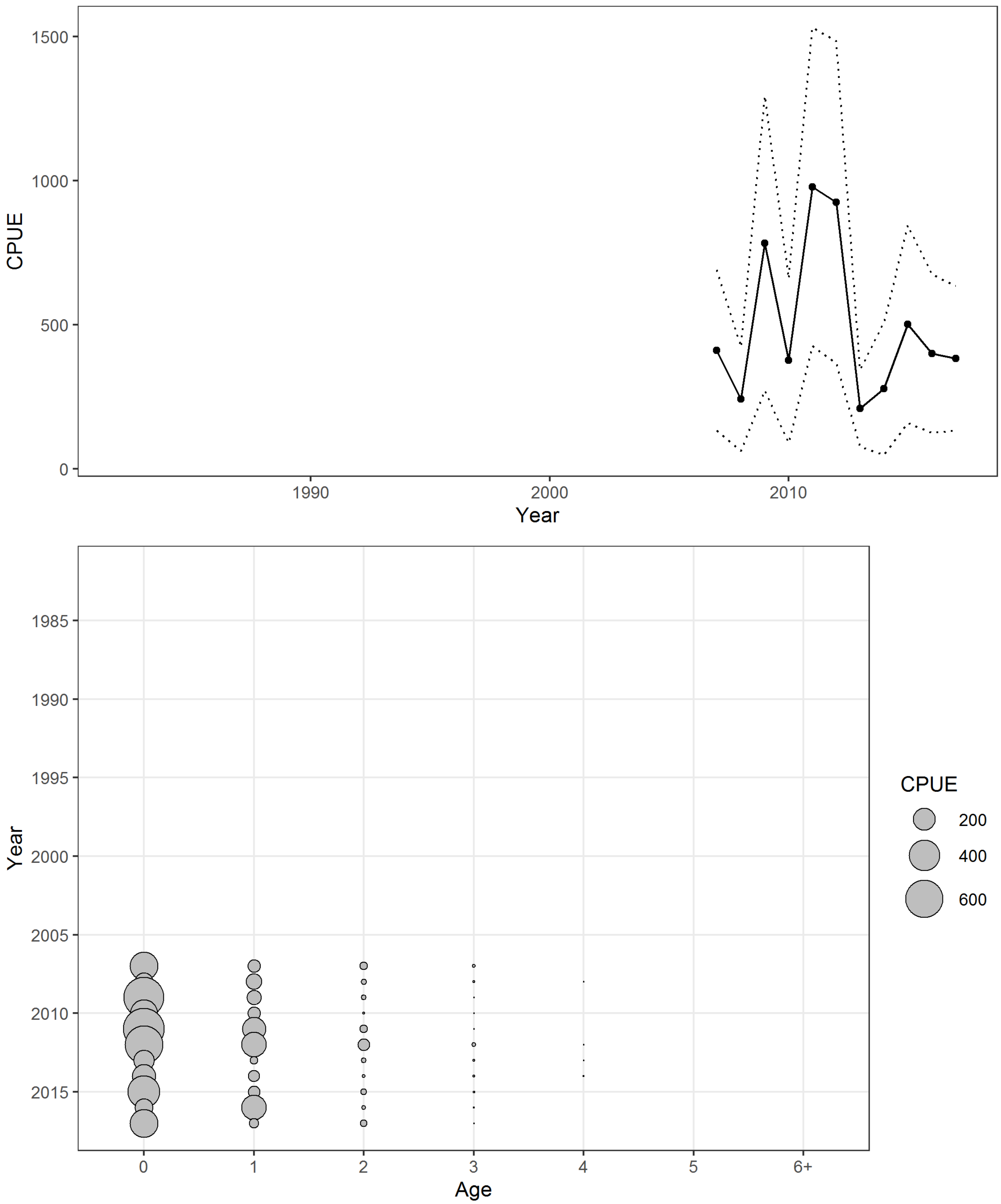


Figure 20. NEAMAP age-1+ index plotted with 95% confidence intervals (top) and the NEAMAP index-at-age (bottom).

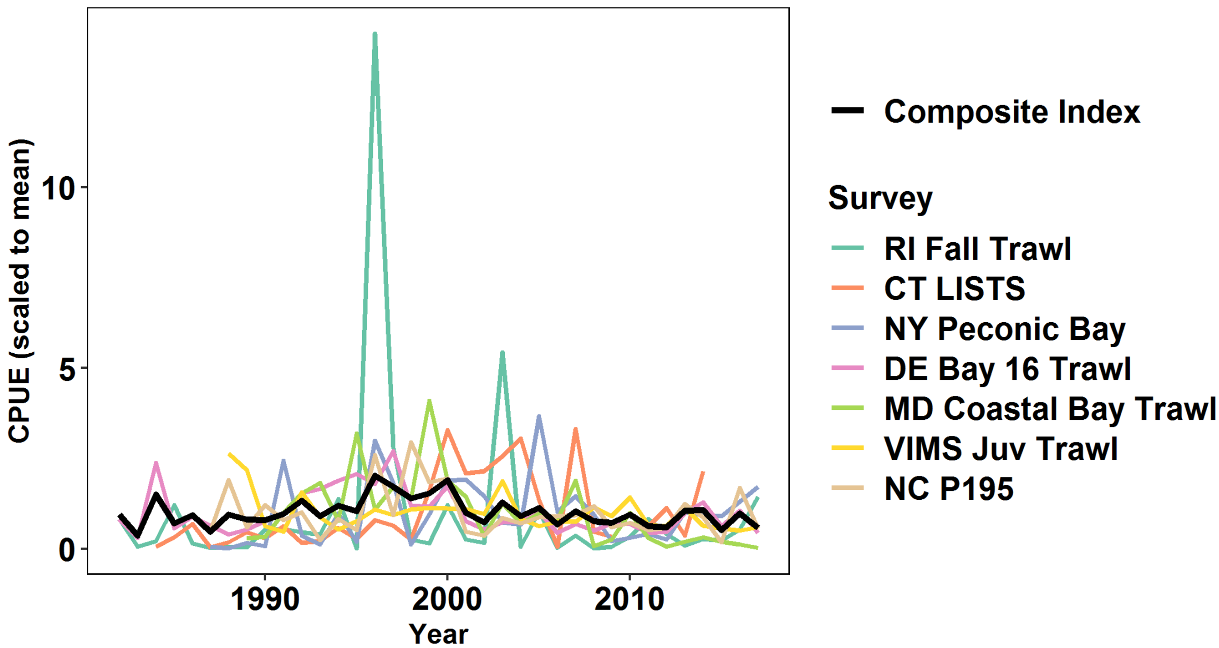


Figure 21. Composite YOY plotted with individual survey indices used to develop it.

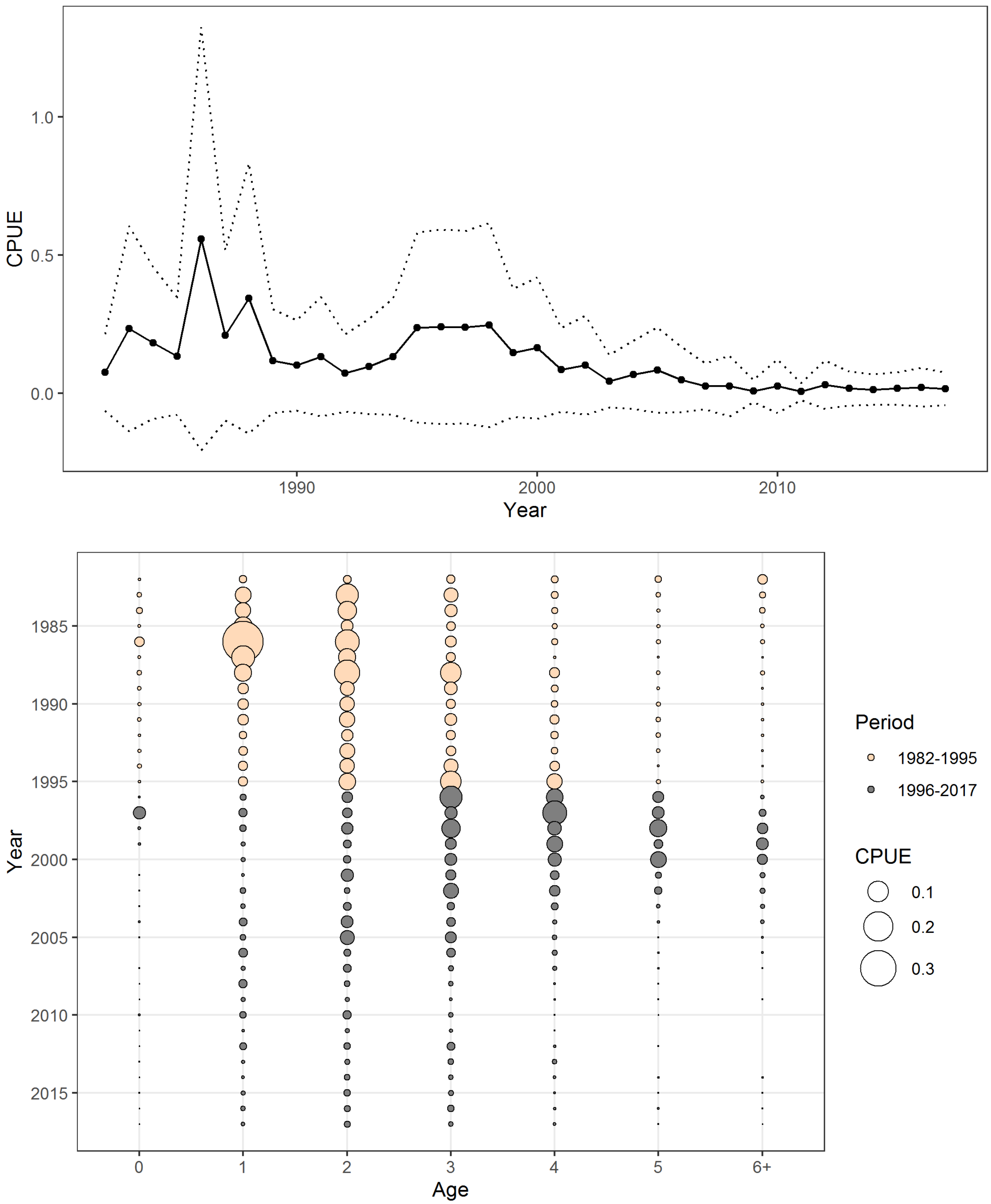


Figure 22. **MRIP HPUE age-1+ index plotted with 95% confidence intervals (top) and MRIP HPUE index-at-age (bottom).**

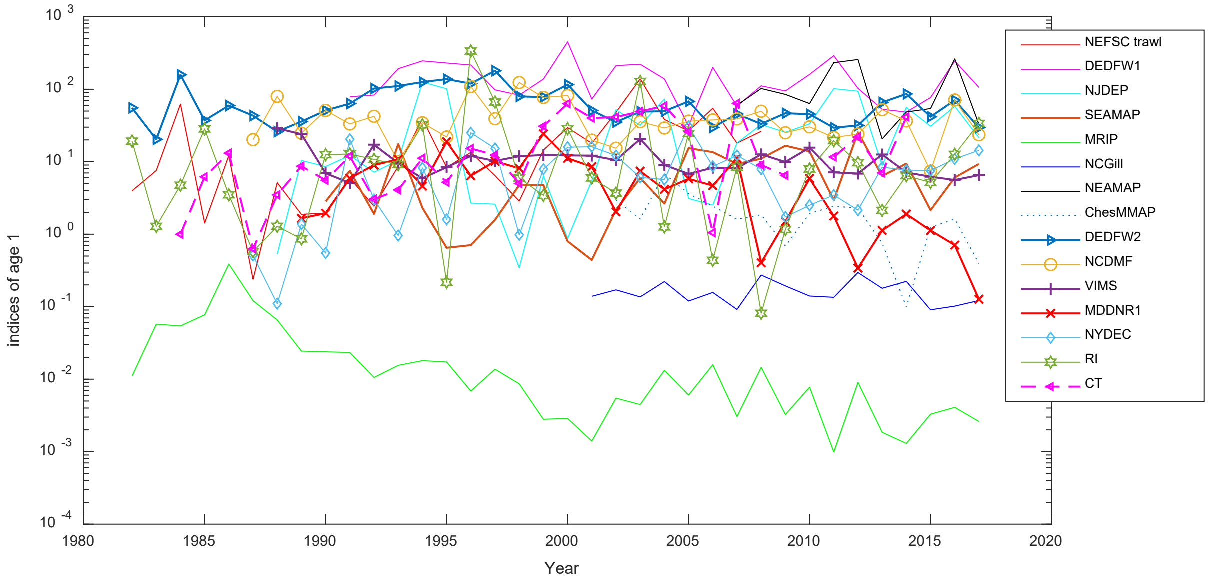


Figure 23. Relative abundance indices of young-of-year and age-1 weakfish used to calibrate the Bayesian model, plotted on the log scale.

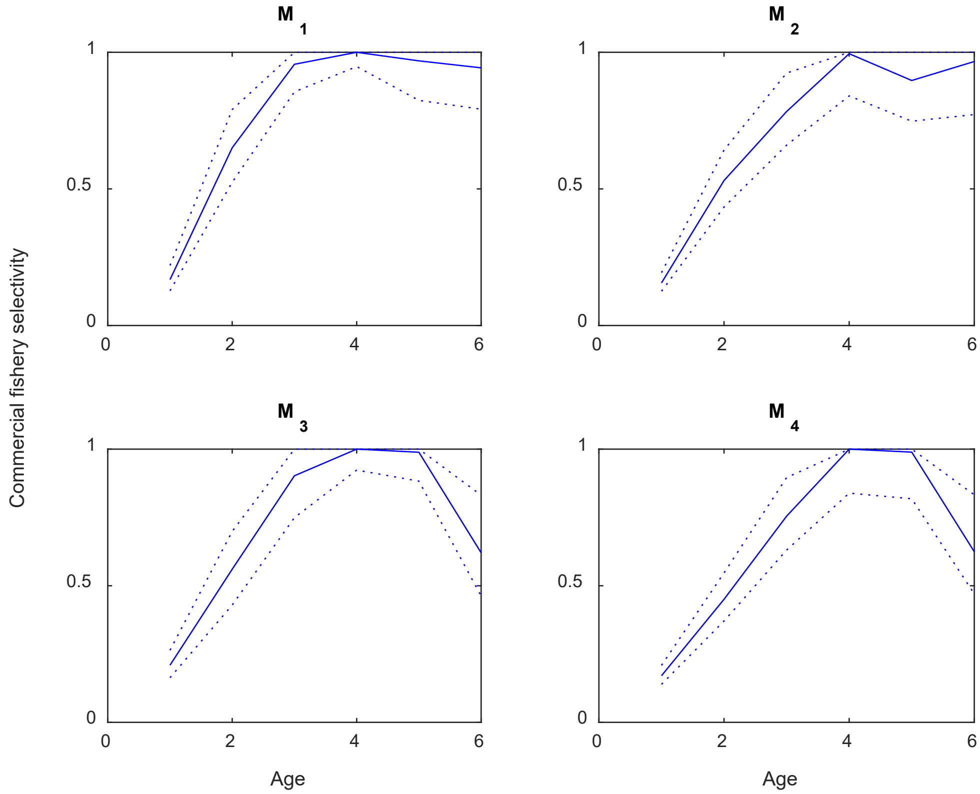


Figure 24. Commercial selectivity-at-age estimated by the Bayesian age-structured models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.

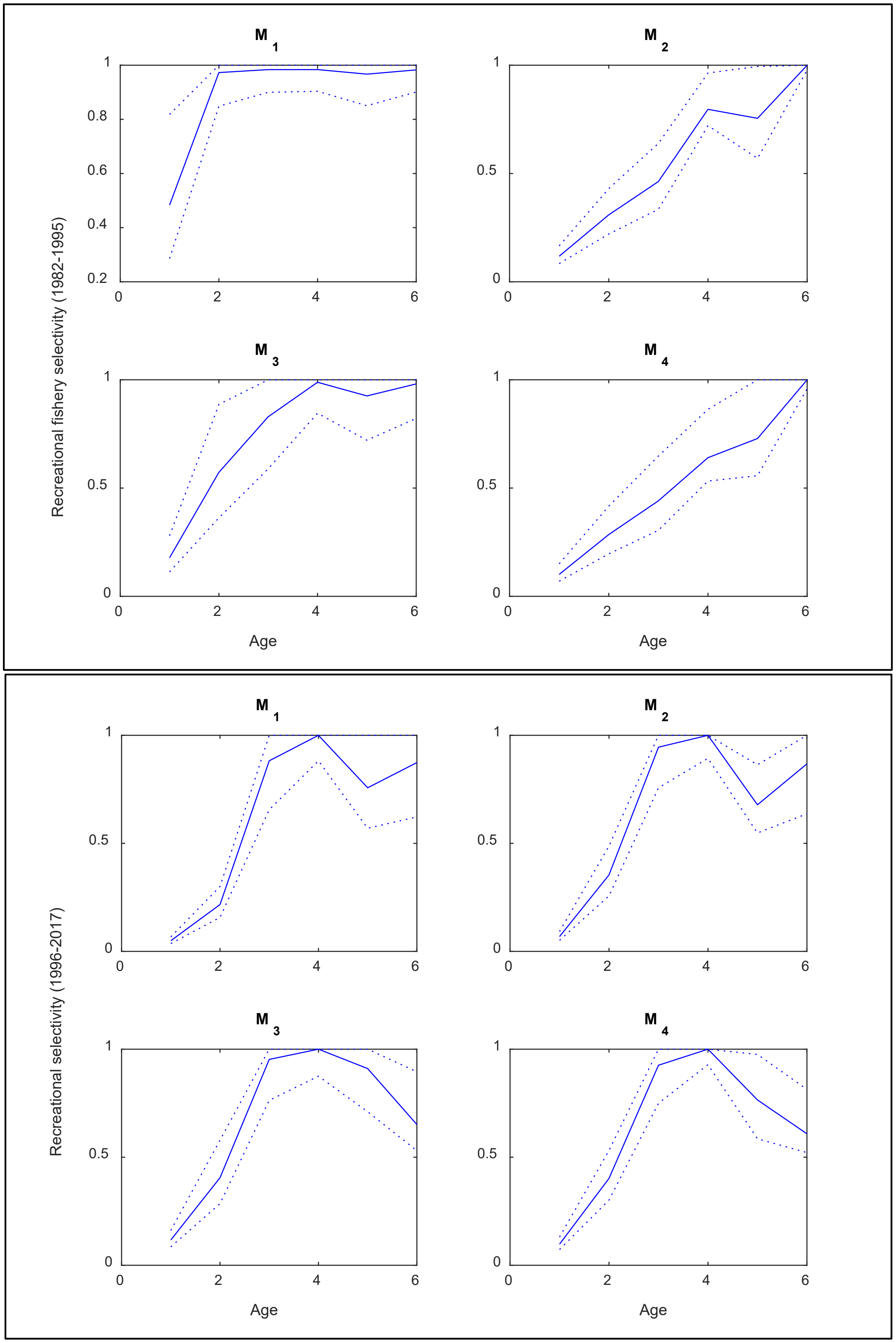


Figure 25. Recreational selectivity-at-age by period estimated by the Bayesian age-structured model. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.

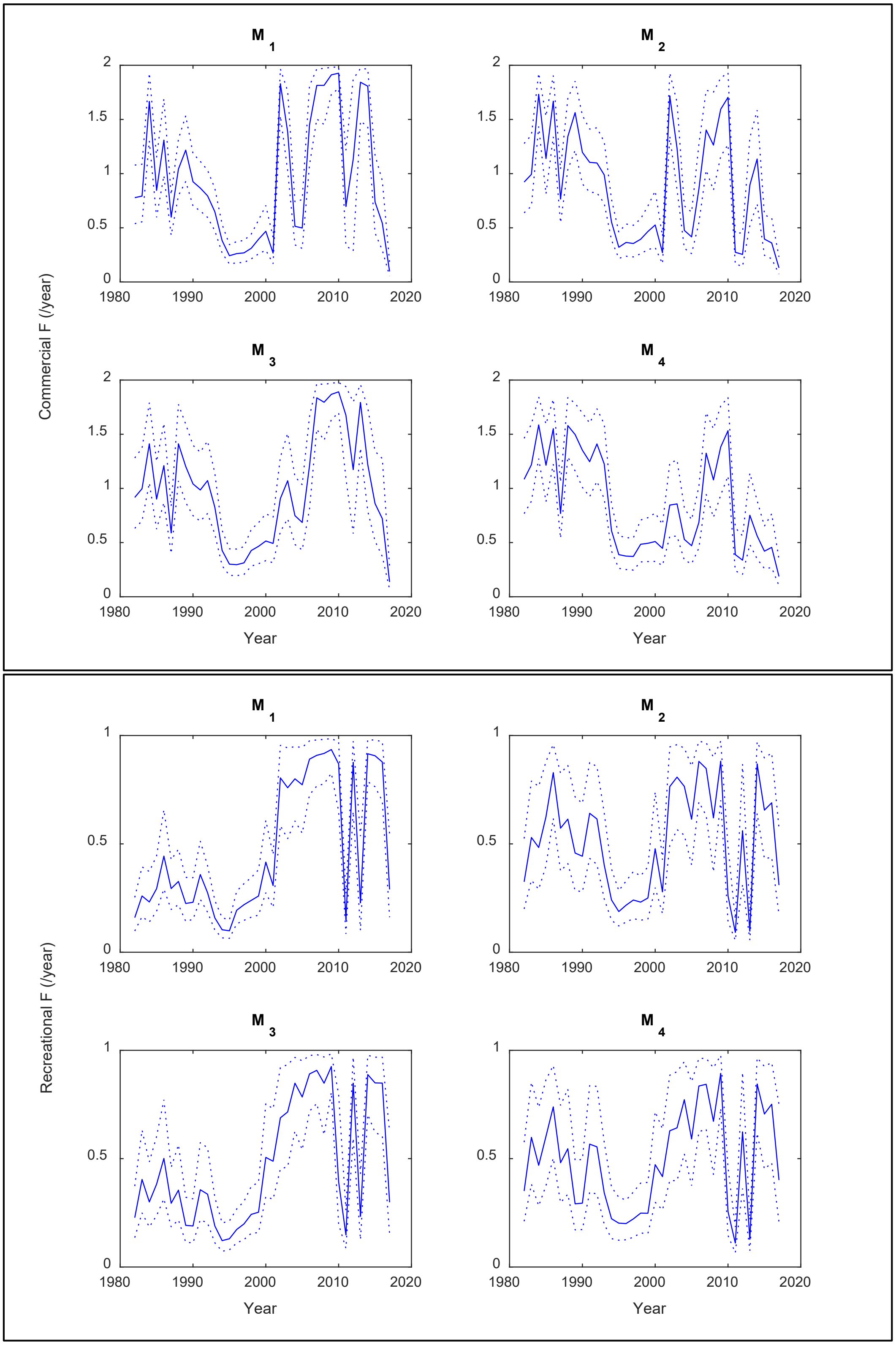


Figure 26. **Posterior fishing mortality for the commercial (top) and recreational (bottom) fleets estimated by the Bayesian age-structured models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.**

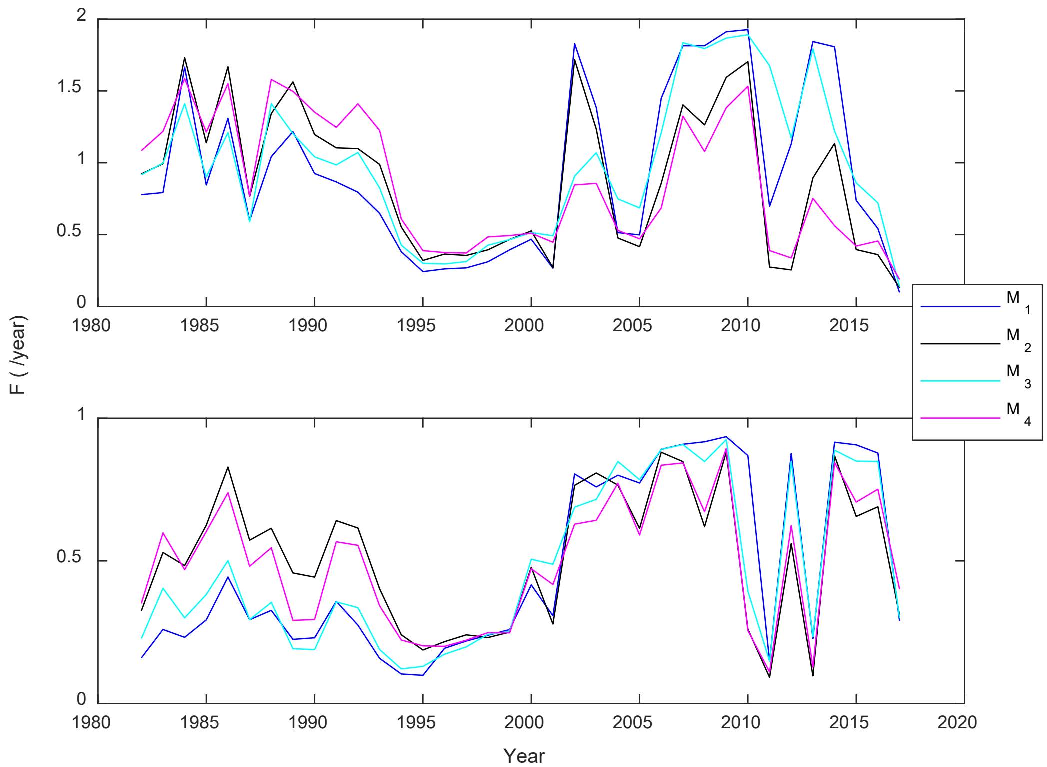


Figure 27. Posterior fishing mortality, for the commercial (top) and recreational (bottom) fleets estimated by the Bayesian age-structured model with all models plotted together.

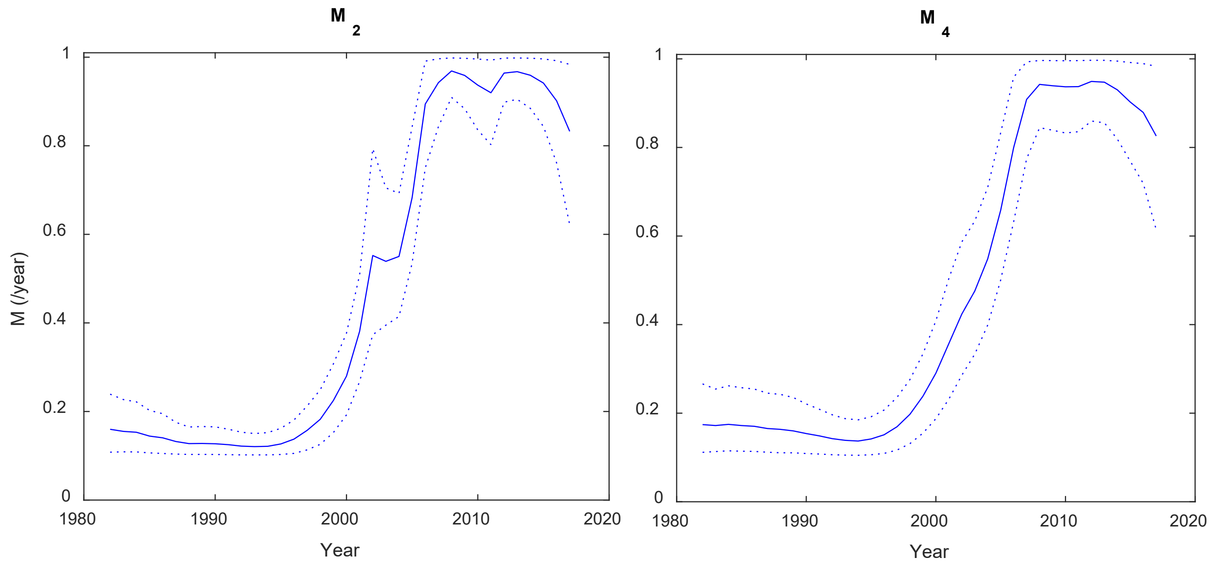


Figure 28. M estimates from the nonstationary Bayesian statistical age structured models M2 and M4. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.

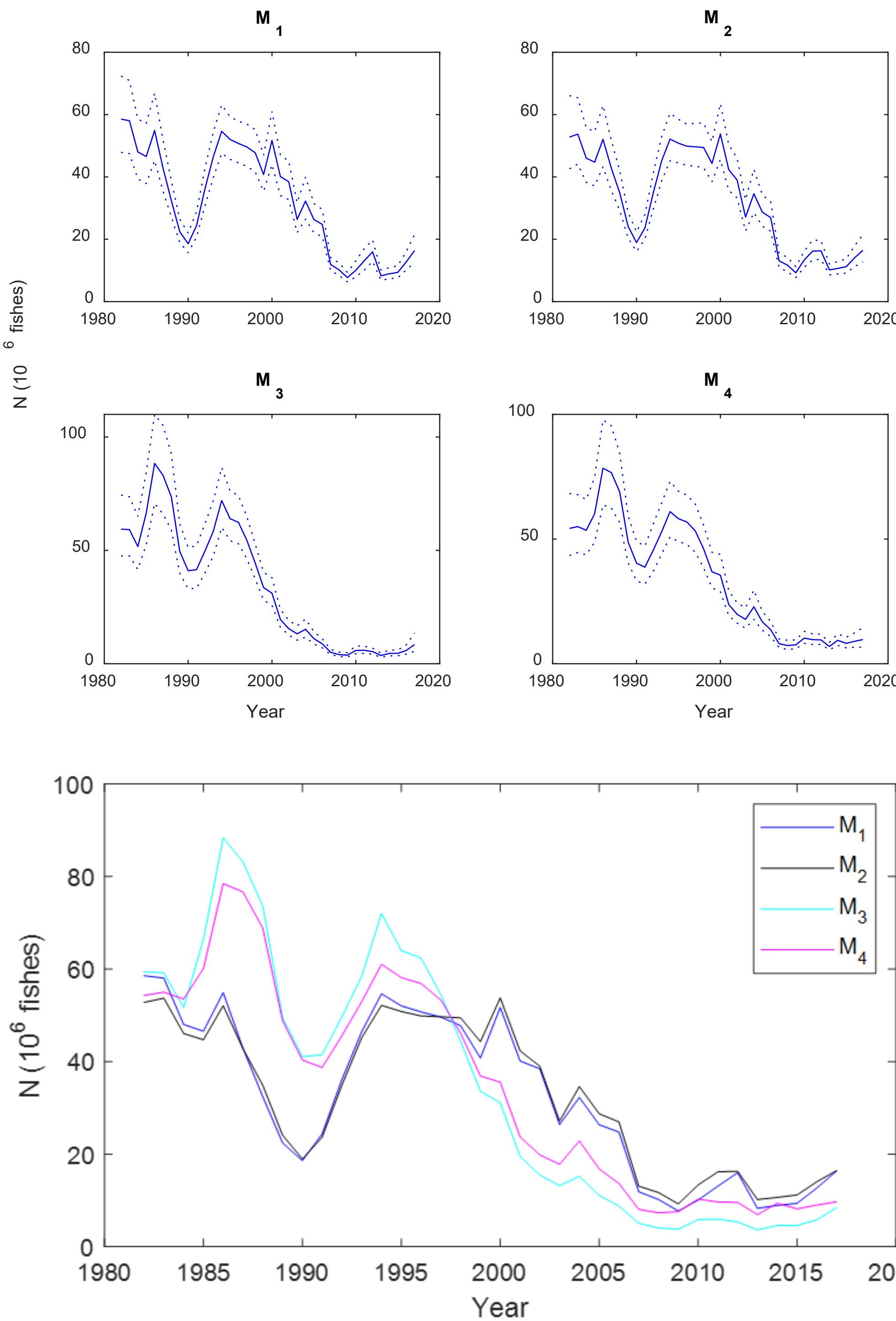


Figure 29. **Posterior population total abundance in millions of fish estimated by the Bayesian age-structured models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.**

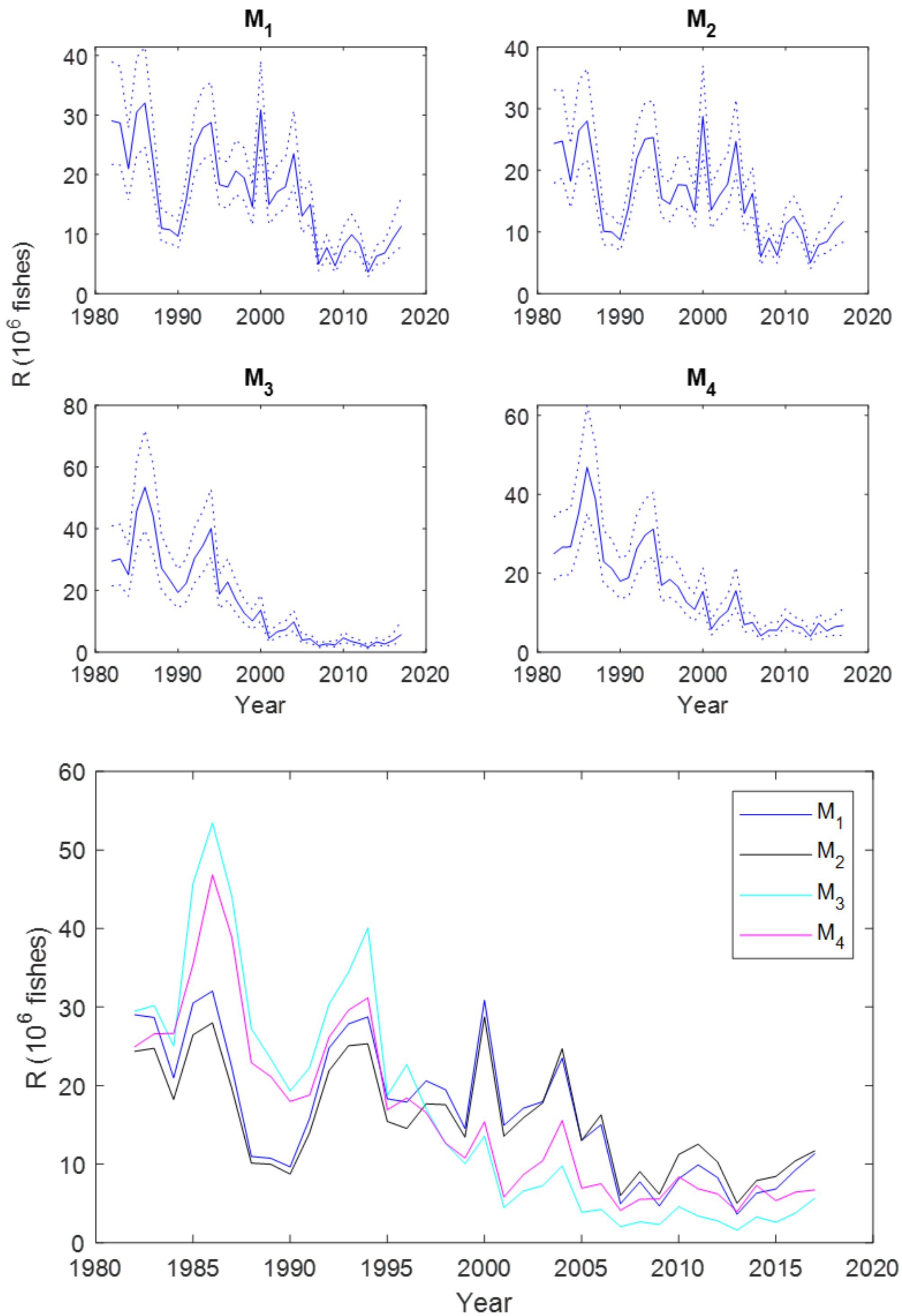


Figure 30. **Posterior recruitment in millions of age-1 fish estimated by the Bayesian age-structured models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.**

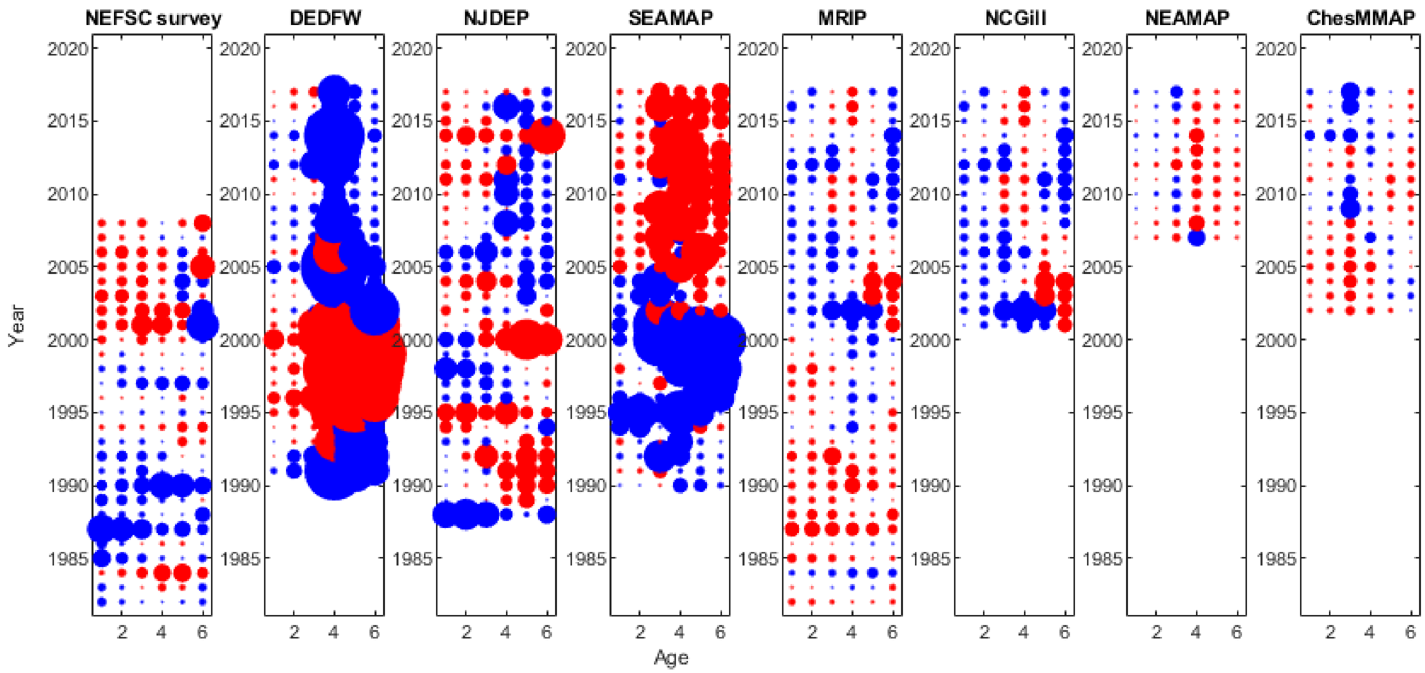


Figure 31. **Spatial heterogeneity reflected from age-1+ surveys shown as differences from the mean population size. Positive values were plotted in red, while negative values were plotted in blue.**

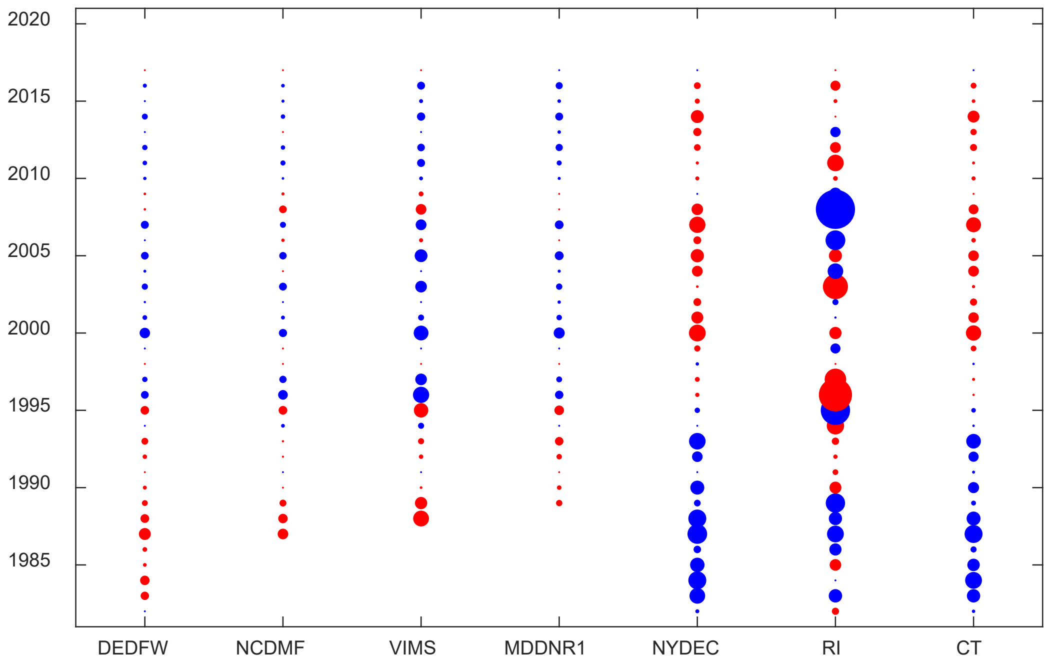


Figure 32. Spatial heterogeneity reflected from young-of-year surveys shown as differences from the mean population size. Positive values were plotted in red, while negative values were plotted in blue.

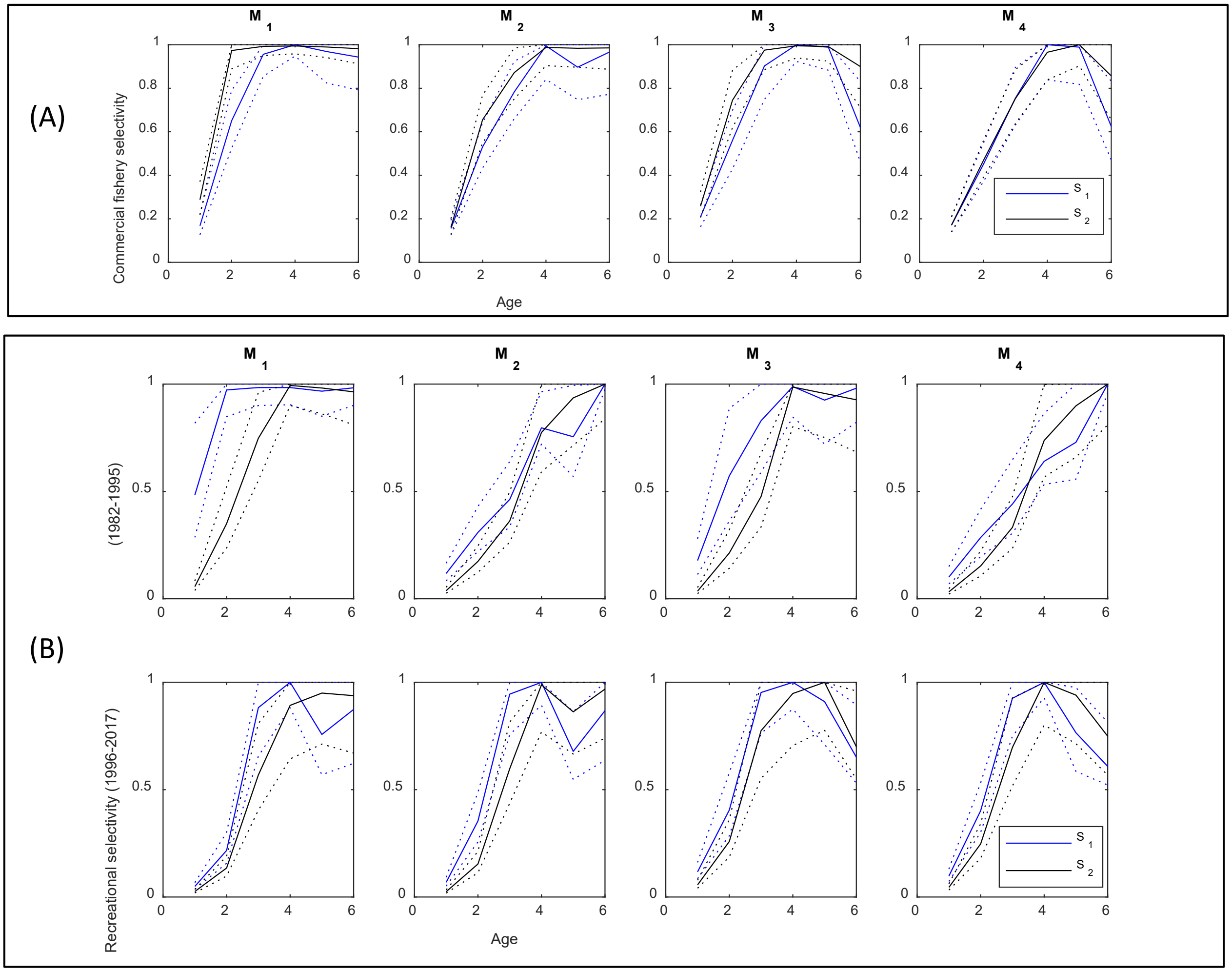
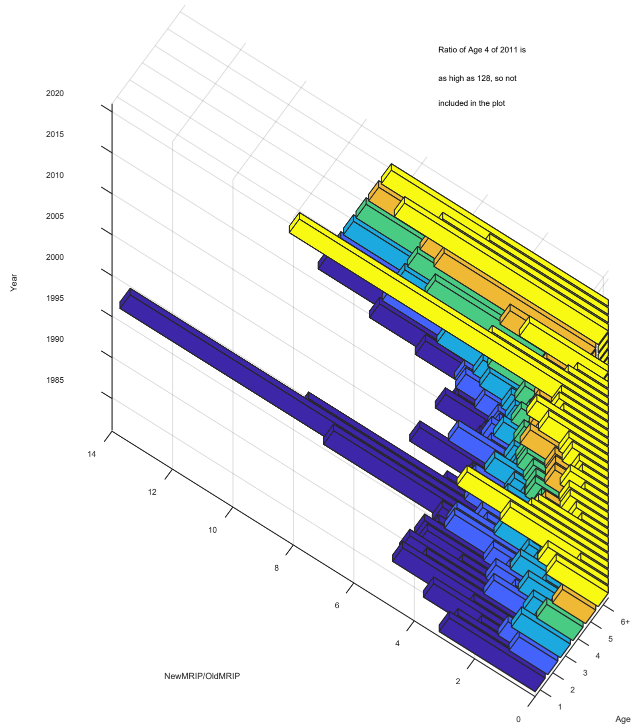


Figure 33. **Sensitivity results for the commercial (A) and recreational (B) selectivity patterns estimated by Bayesian age-structured models when new (S1) and old (S2) MRIP estimates are used.**



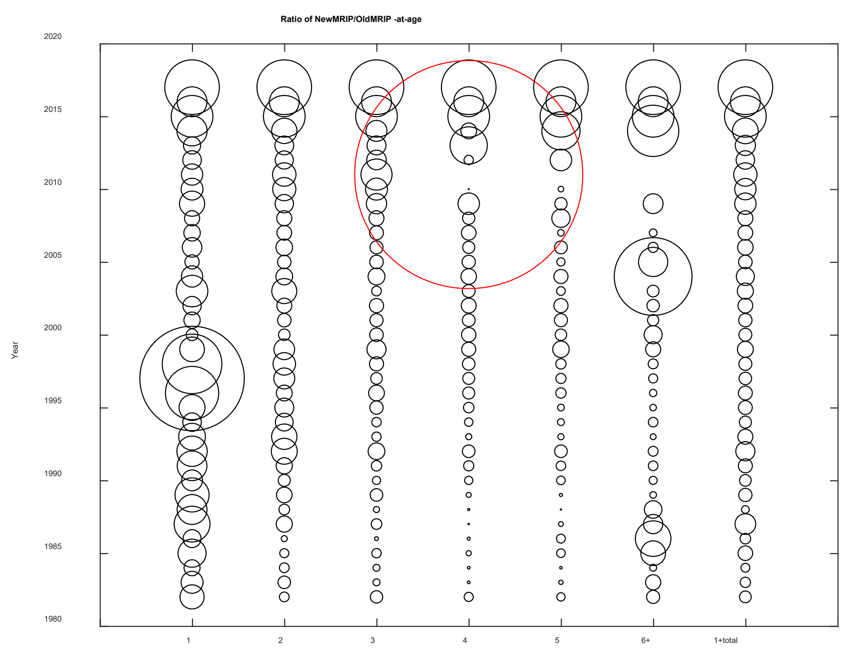


Figure 34. **Differences in the changes of the newly estimated MRIP (New MRIP/Old MRIP) among ages and year shown as 3D bar plot (top) and bubble plot (bottom). The red circle in the bottom plot is the ratio of age 4 of 2011 recreational catch.**

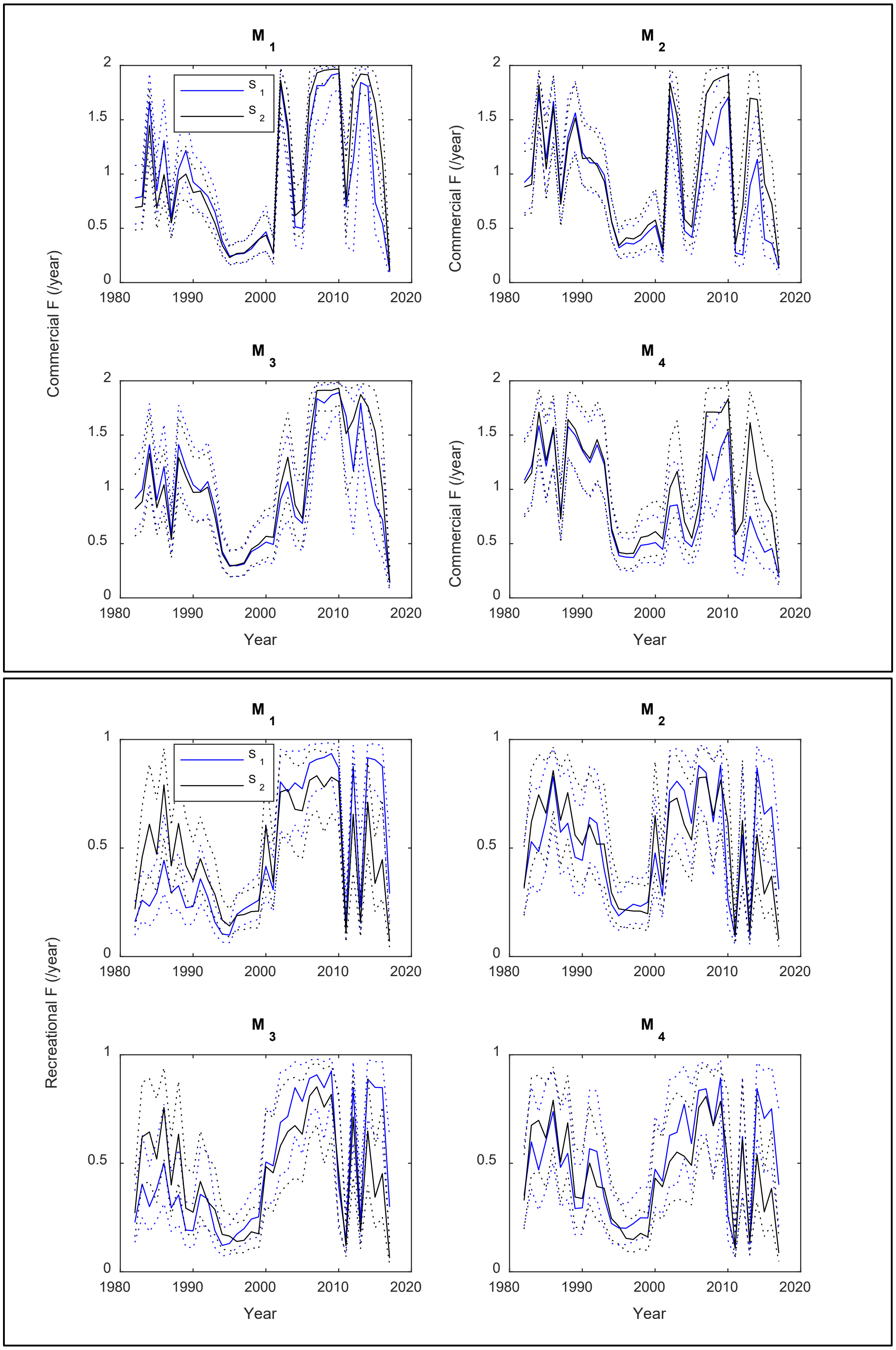


Figure 35. Estimates of F for the commercial (top) and recreational (bottom) fleets using the new (S1) and old (S2) MRIP estimates from the Bayesian age structured models. M4 is the preferred model. Solid line= posterior mean; dashed lines= 95% credible interval.

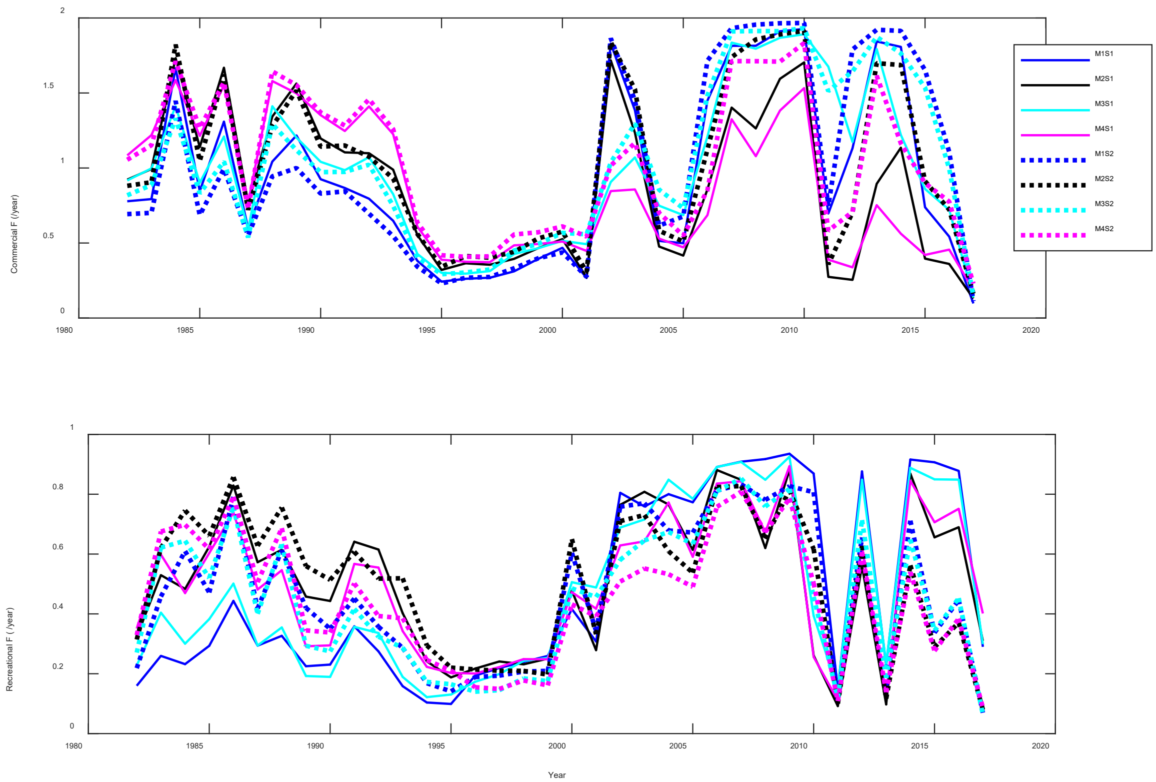


Figure 36. Sensitivity results for commercial (top) and recreational (bottom) fishing mortality estimated by Bayesian age- structured models using the new (S1, solid lines) and old (S2, dashed lines) MRIP estimates, plotted together. M4 is the preferred model.

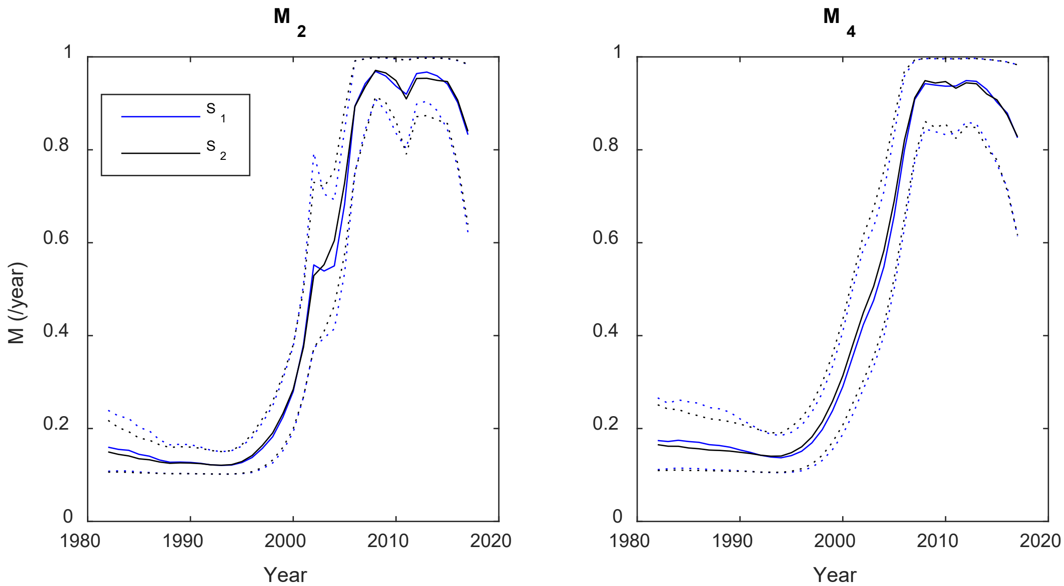


Figure 37. Sensitivity results of M estimates from the nonstationary Bayesian statistical catch-at-age models M2 and M4 using the new (S1) and old (S2) MRIP estimates. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.

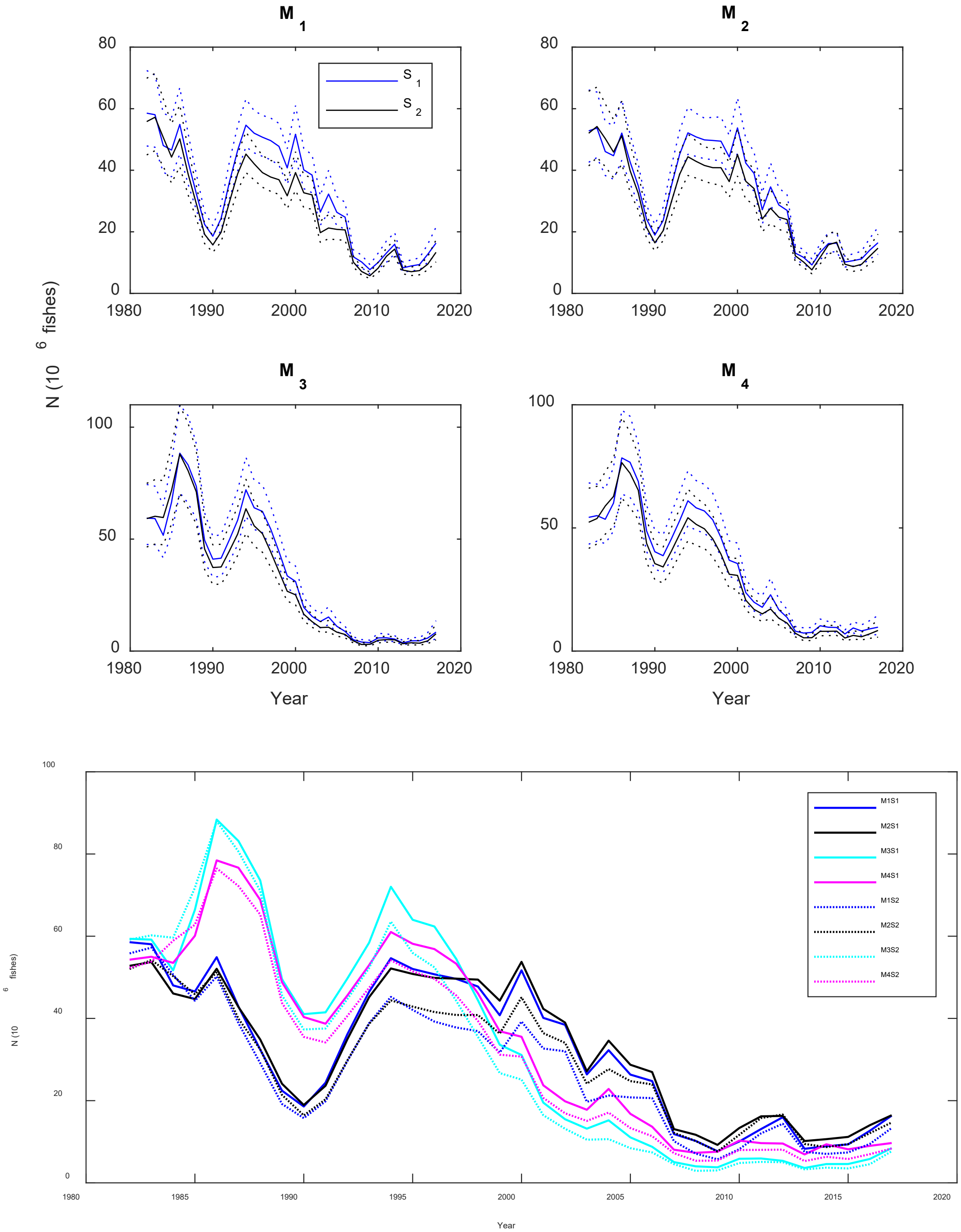
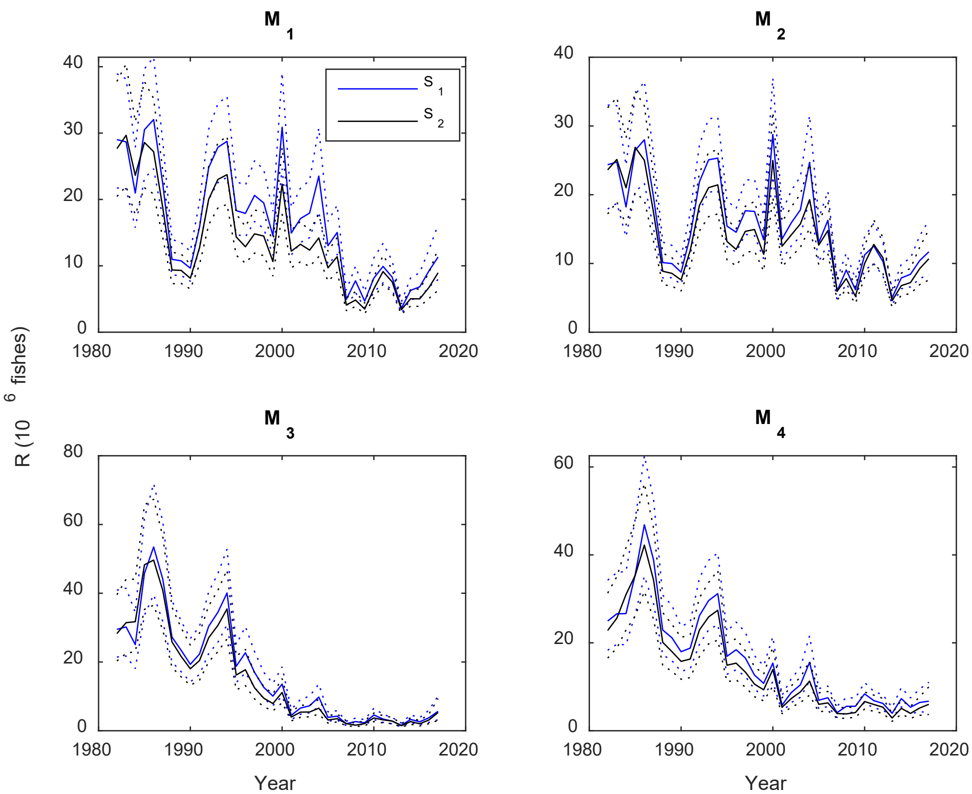


Figure 38. Sensitivity results for weakfish total abundance estimated by Bayesian age- structured models using the new (S1) and old (S2) MRIP estimates. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.



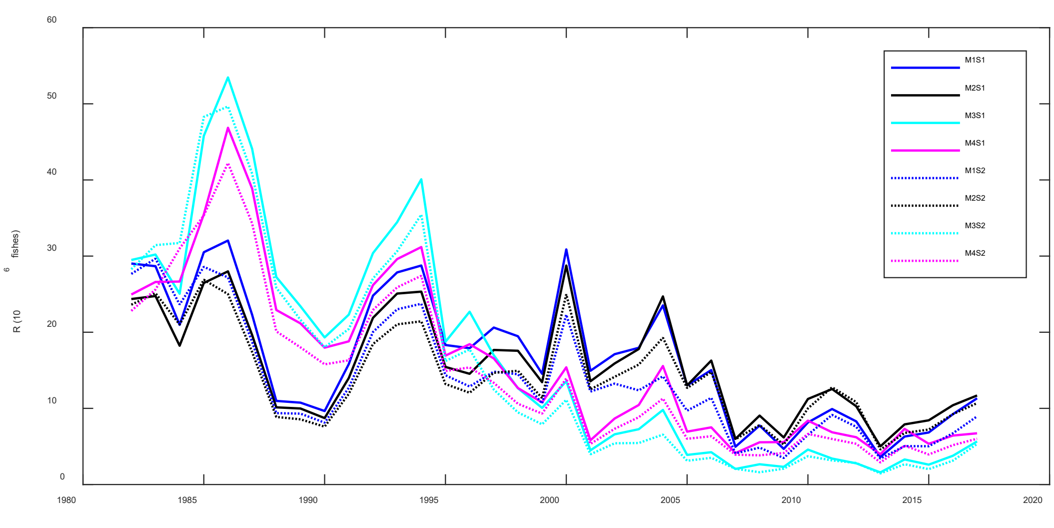


Figure 39. **Sensitivity results for recruitment estimated by the age-structured Bayesian models using the new (S1) and old (S2) MRIP estimates. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.**

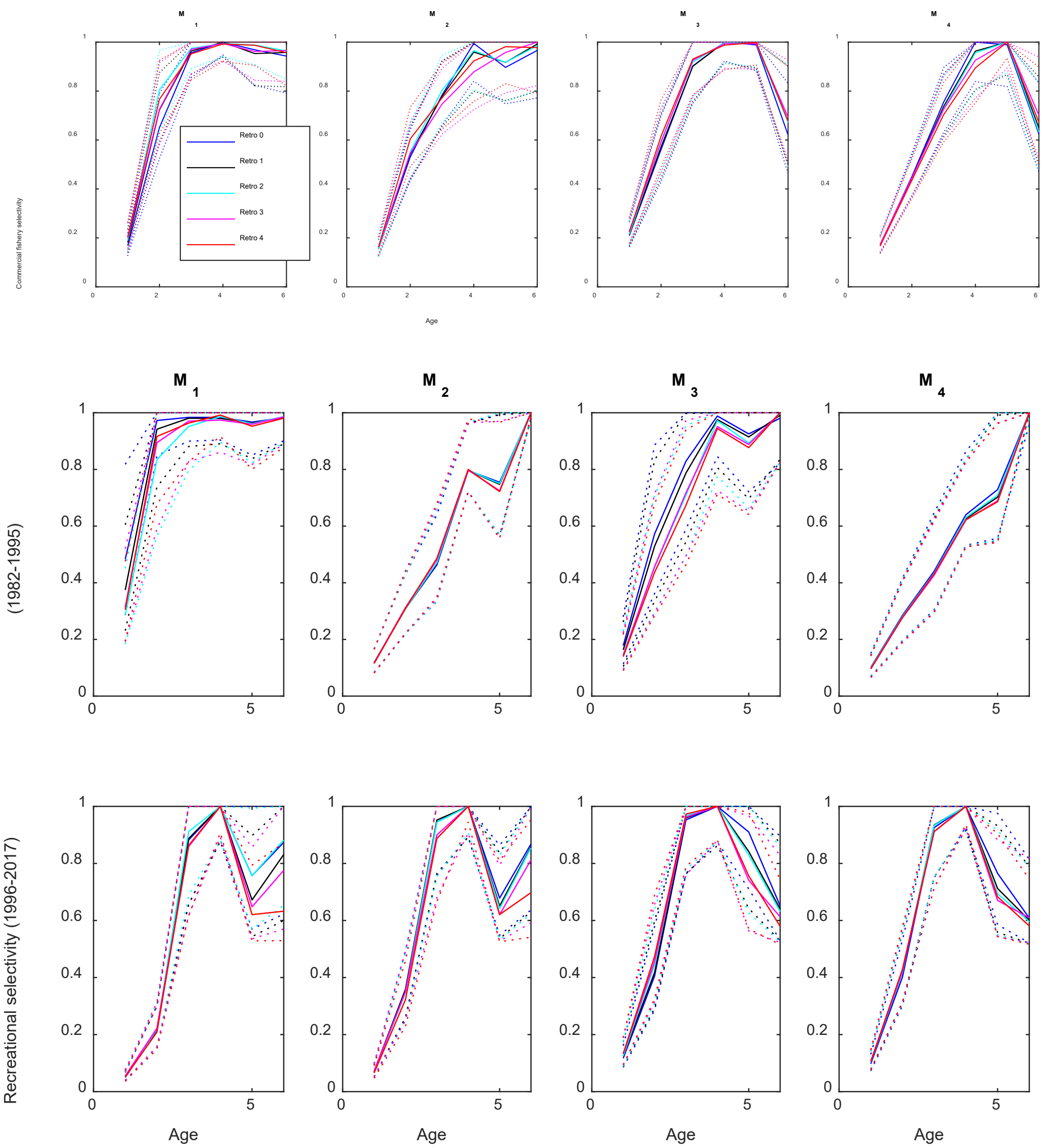


Figure 40. Retrospective analysis results for commercial (top row) and recreational (middle and bottom rows) selectivity patterns estimated by the Bayesian age-structured models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.

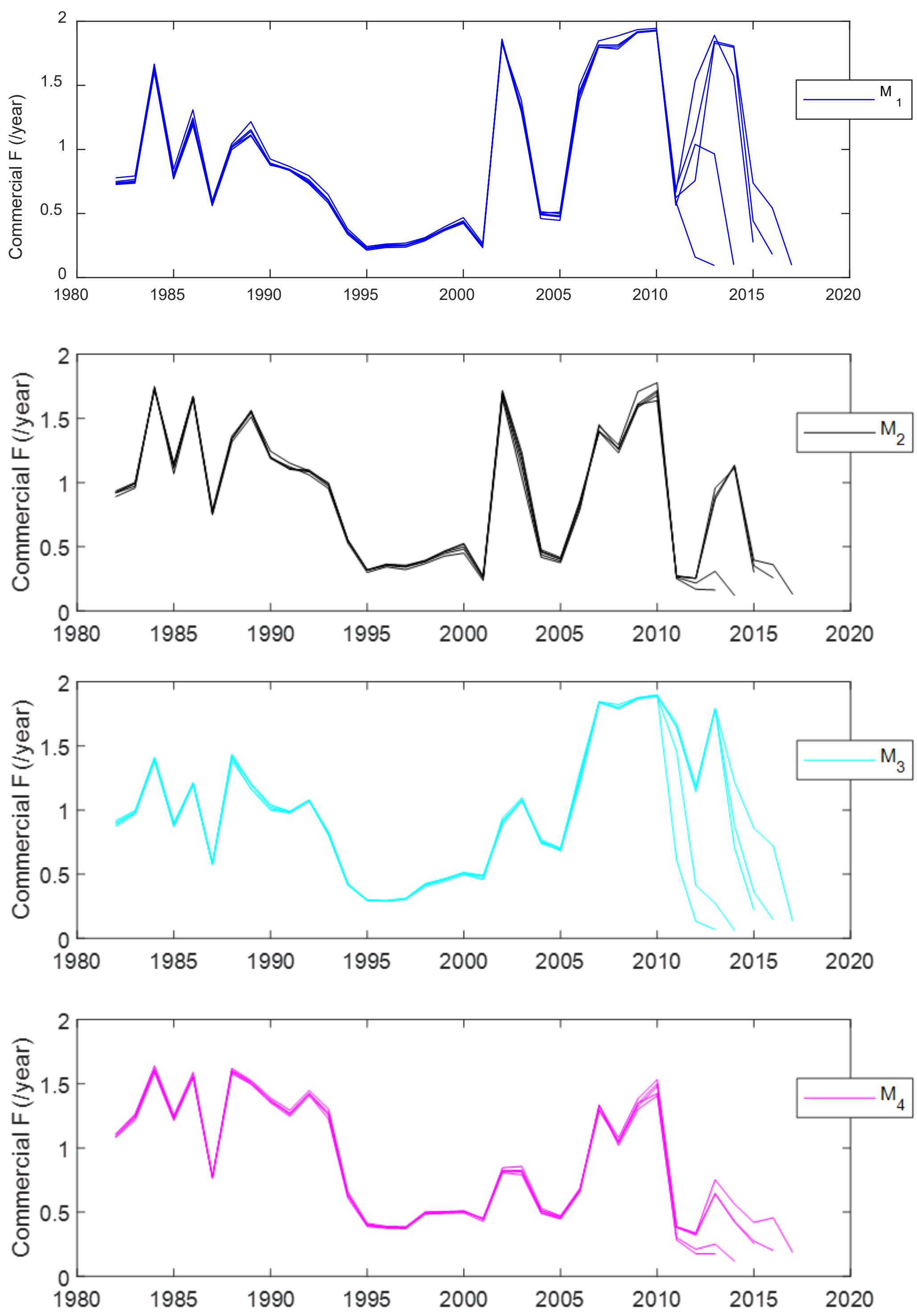


Figure 41. Retrospective analysis results for commercial fishing mortality estimated by each of the Bayesian age-structured models. M4 is the preferred model.

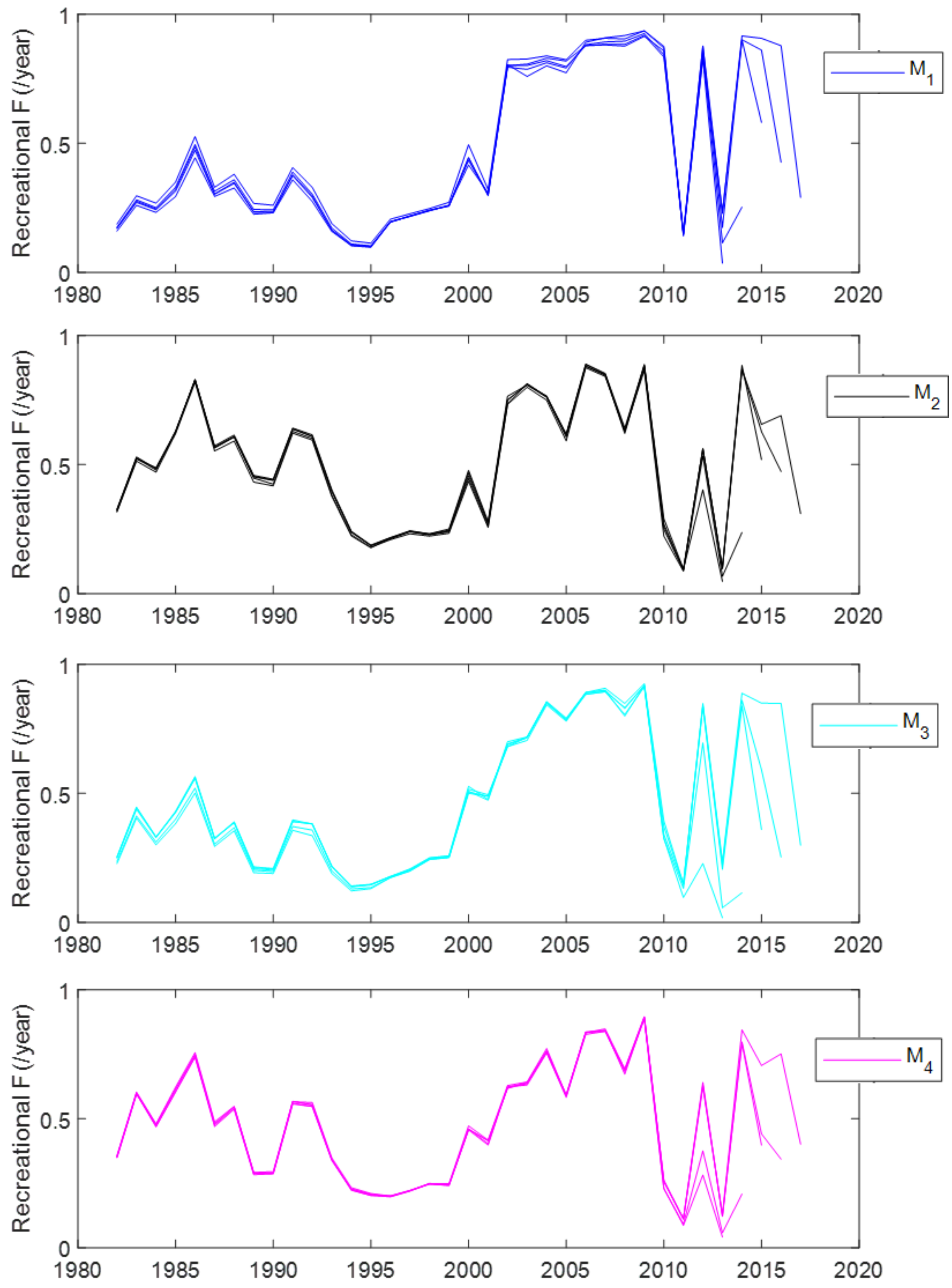


Figure 42. **Retrospective analysis results for recreational fishing mortality estimated by each of the Bayesian age-structured models. M4 is the preferred model.**

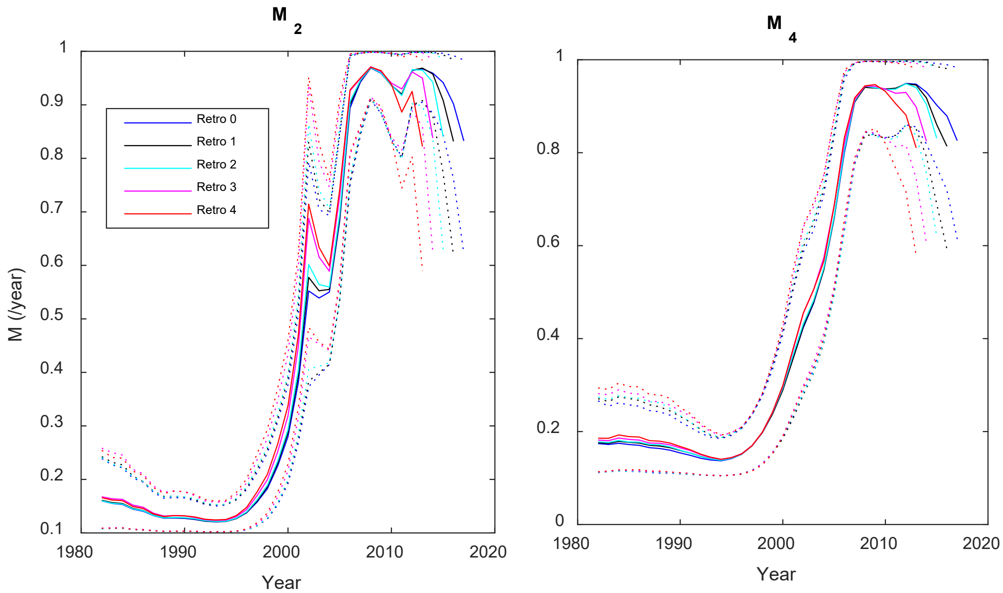


Figure 43. Retrospective analysis results of M estimates from the nonstationary Bayesian statistical catch- at-age models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.

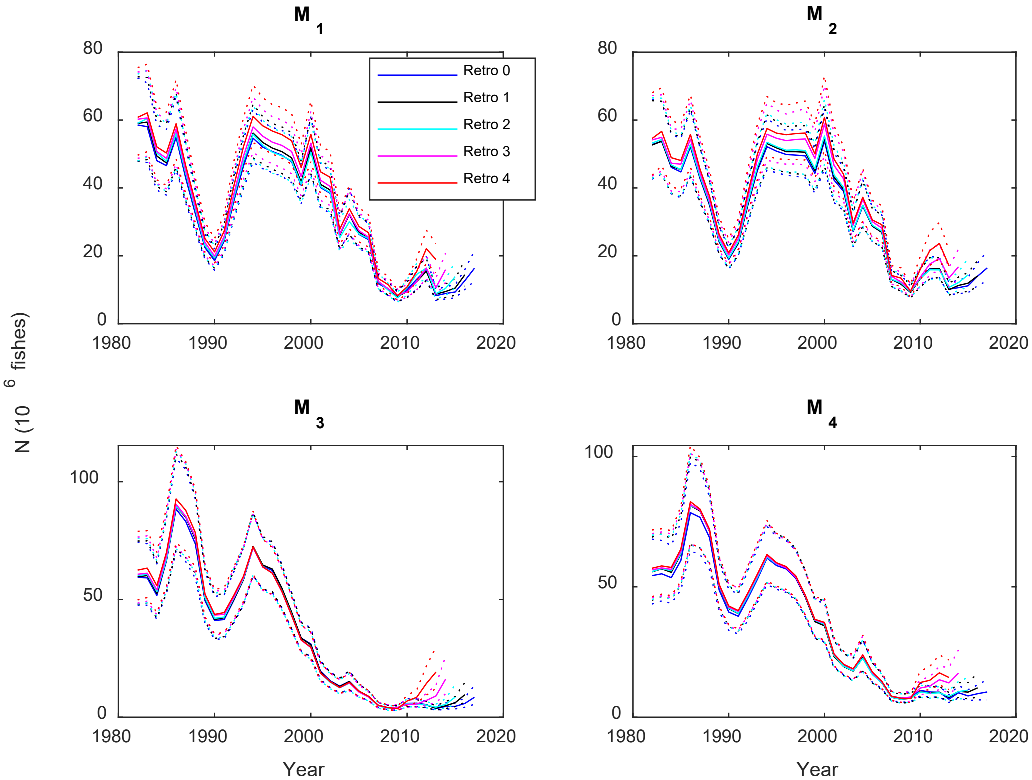


Figure 44. **Retrospective analysis results for population abundance estimated by the Bayesian age-structured models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.**

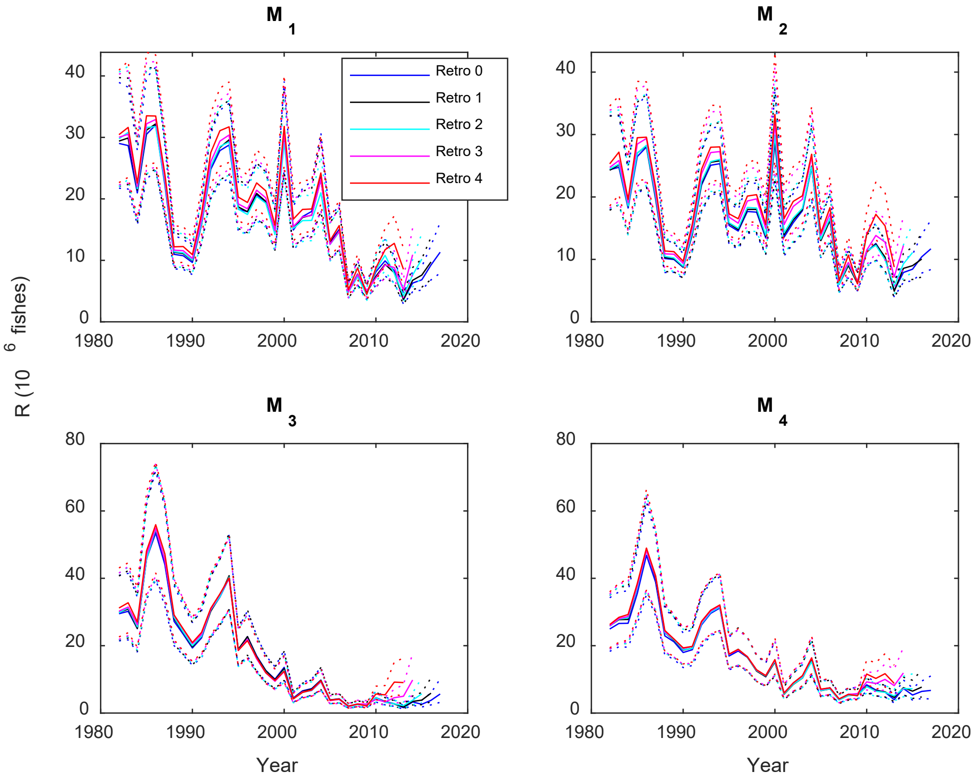


Figure 45. **Retrospective analysis results of recruitment estimated by the Bayesian age-structured models. M4 is the preferred model. Solid line = posterior mean; dashed lines = 95% credible interval.**

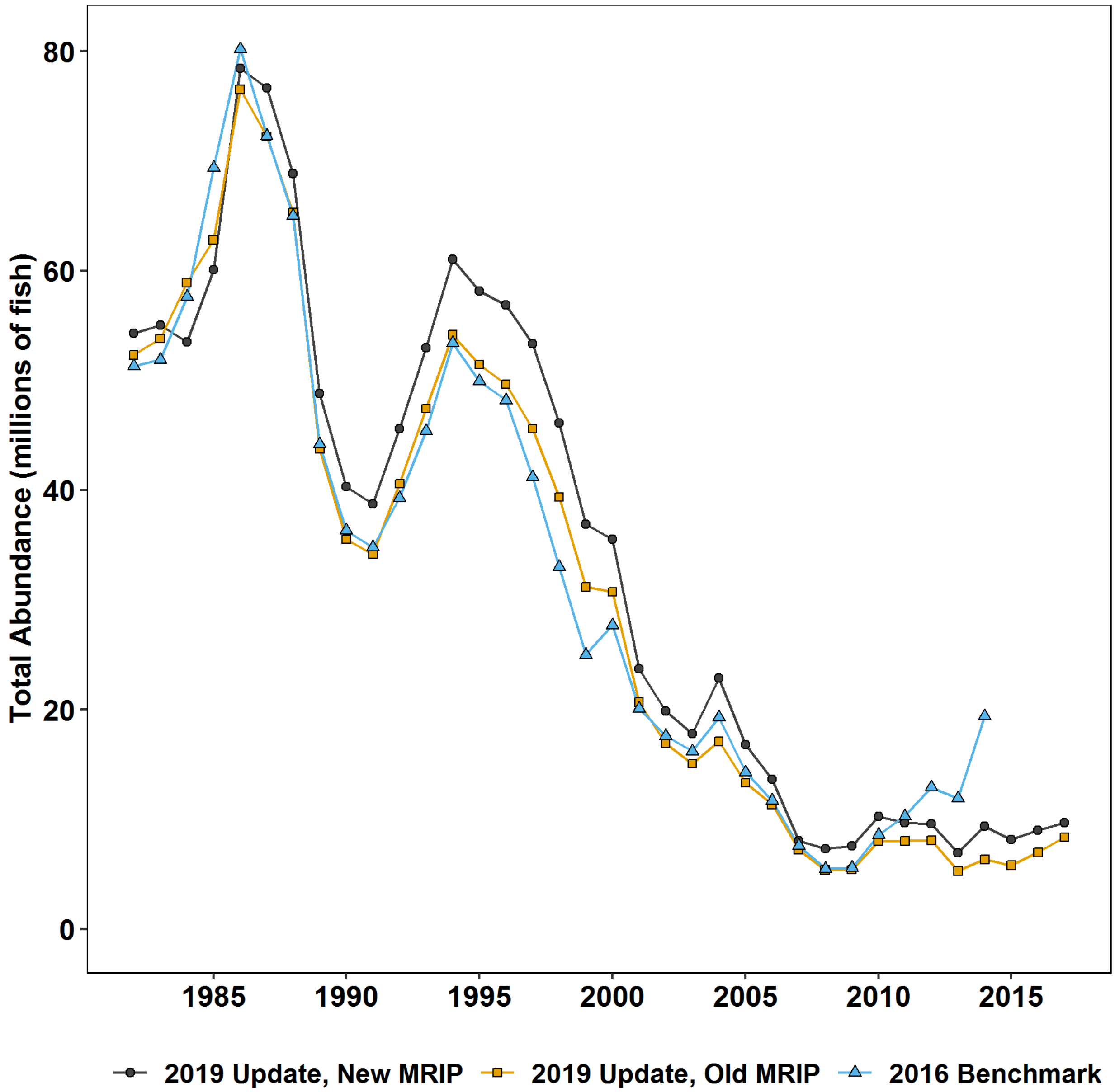


Figure 46. Comparison of total abundance estimates from the 2016 benchmark assessment, the 2019 assessment update with the old, uncalibrated MRIP estimates, and the 2019 assessment update with the new, calibrated MRIP estimates.

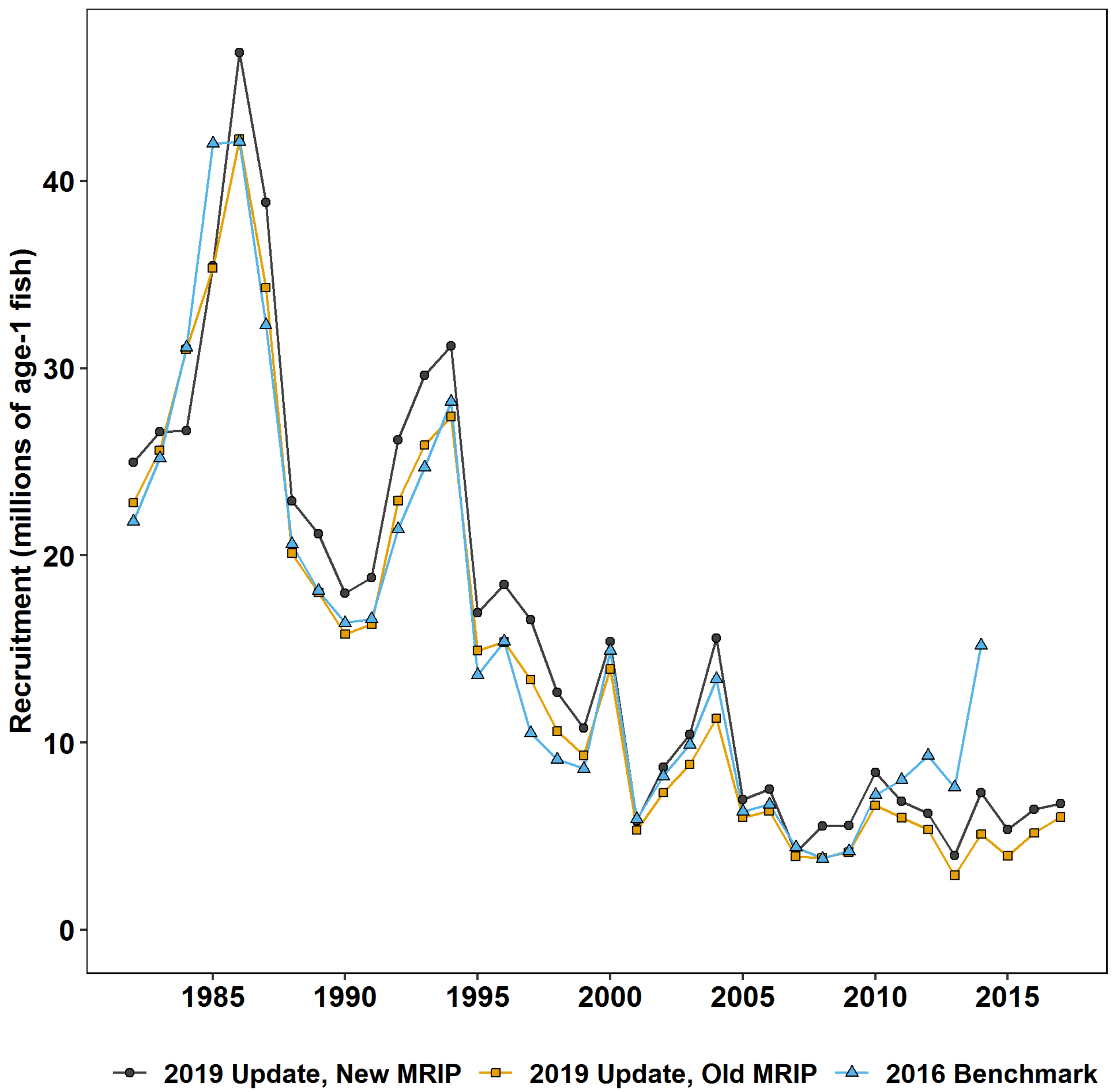


Figure 47. Comparison of recruitment estimates from the 2016 benchmark assessment, the 2019 assessment update with the old, uncalibrated MRIP estimates, and the 2019 assessment update with the new, calibrated MRIP estimates.

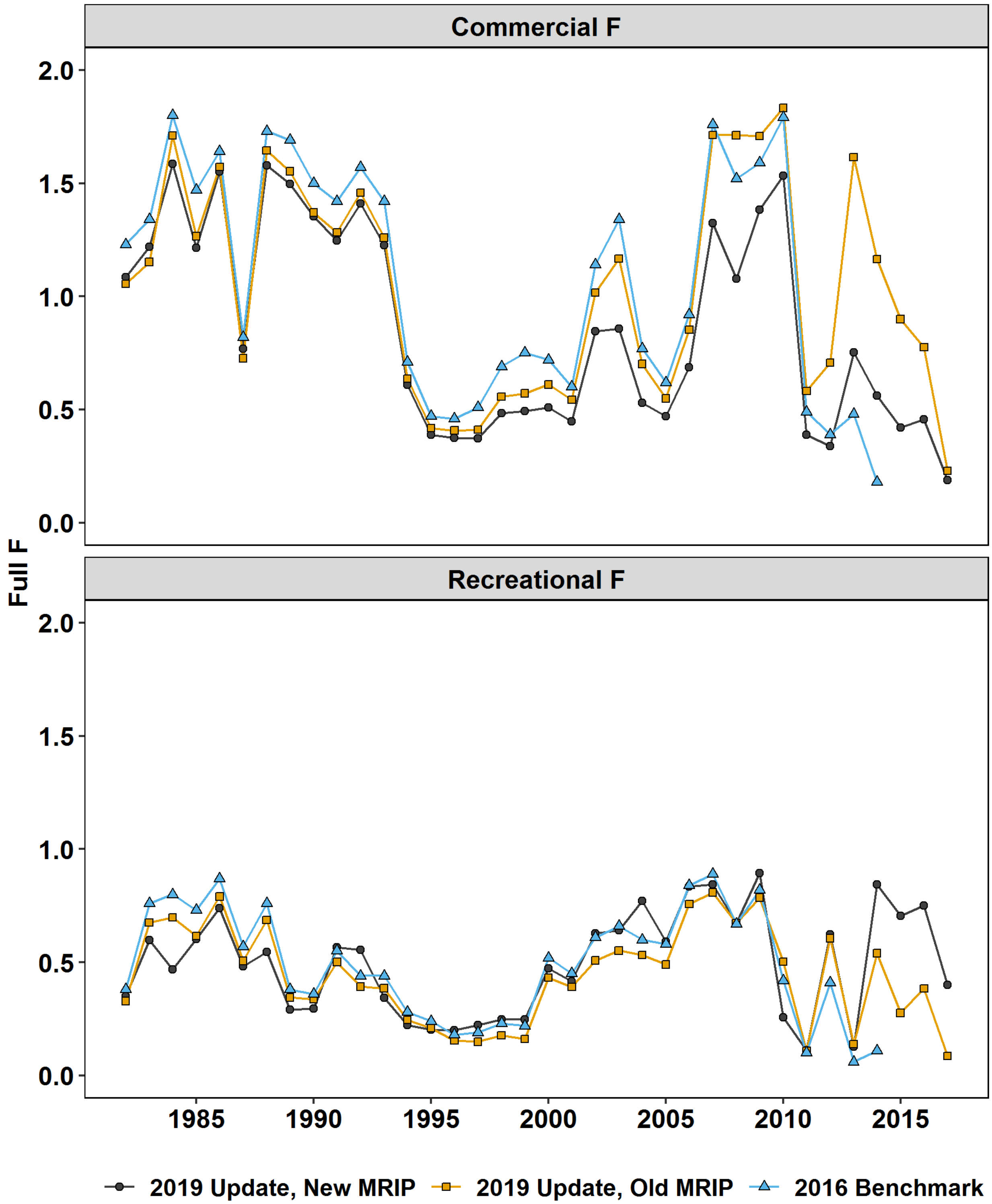


Figure 48. **Comparison of commercial (top) and recreational (bottom) fishing mortality estimates from the 2016 benchmark assessment, the 2019 assessment update with the old, uncalibrated MRIP estimates, and the 2019 assessment update with the new, calibrated MRIP estimates.**

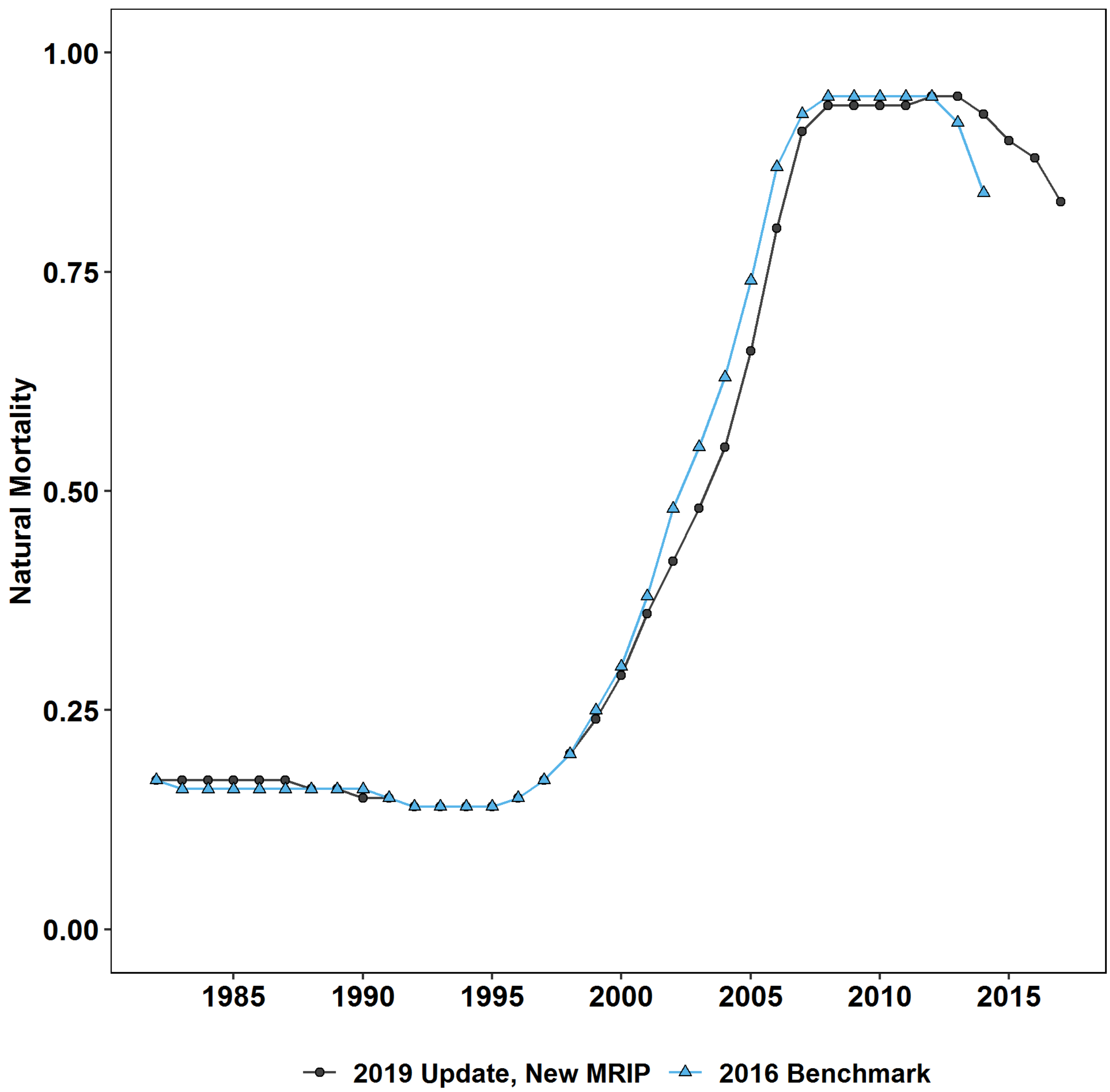


Figure 49. Comparison of natural mortality estimates from the 2016 benchmark assessment and the 2019 assessment updated.

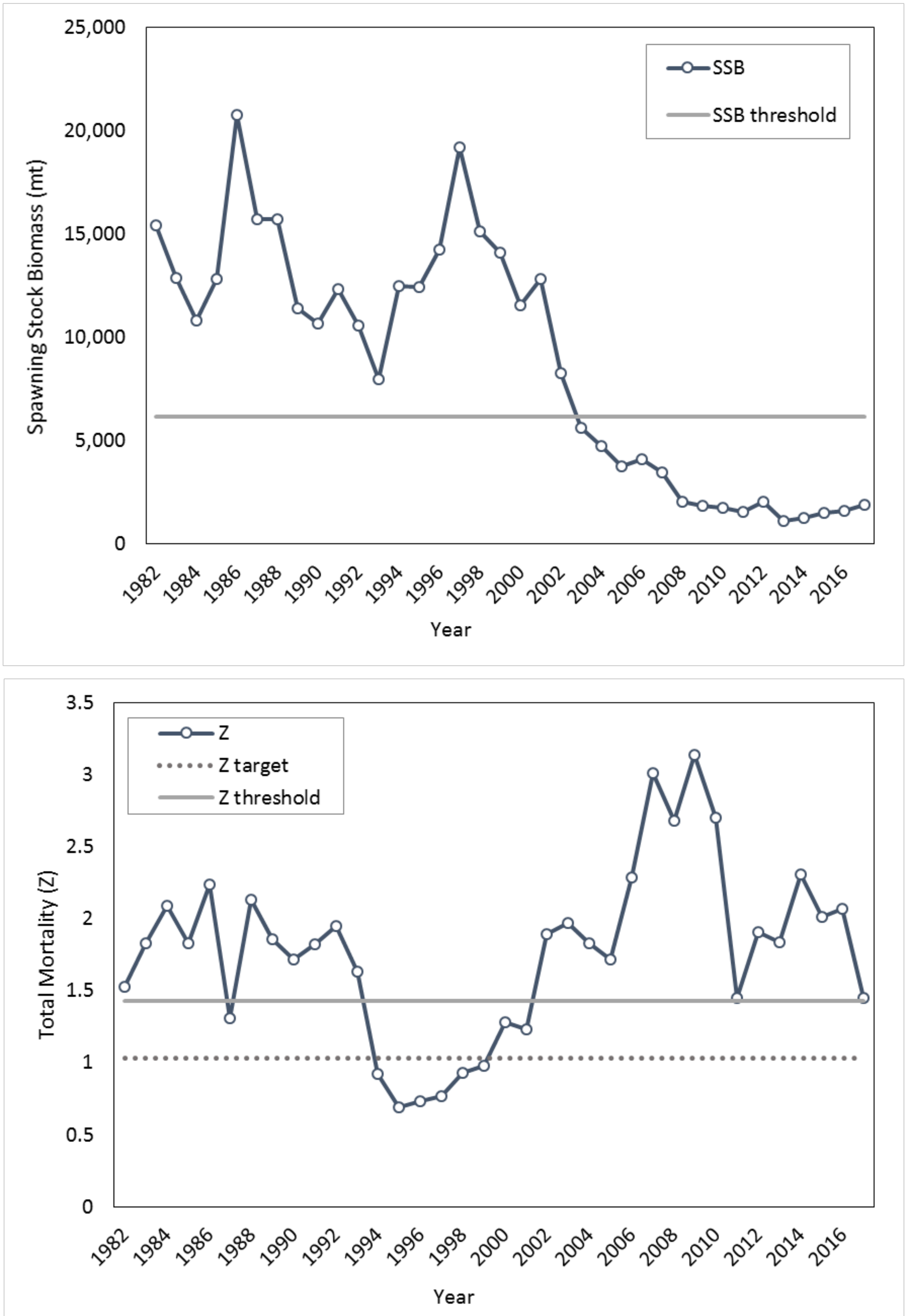


Figure 50. Spawning stock biomass (top) and total mortality (bottom) plotted with their respective targets and thresholds, where defined.