Northeast Fisheries Science Center Reference Document 24-03

Butterfish Research Track Assessment Report

February 2024

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Northeast Fisheries Science Center

NOAA Fisheries Service, Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543

US DEPARTMENT OF COMMERCE
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Northeast Fisheries Science Center (NEFSC) Reference Documents

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BUTTERFISH WORKING GROUP

The butterfish research track (RT) working group (WG) met 15 times between November 2020 and December 2021. All meetings were held remotely via Google Meet. WG members were:

Charles Adams (NEFSC), assessment lead
Carly Bari (GARFO)
Kiersten Curti (NEFSC)
Jonathan Deroba (NEFSC), chair
Jason Didden (MAFMC)
Andrew Jones (NEFSC)
Alyson Pitts (GARFO)
Laurel Smith (NEFSC)
Brian Stock (NEFSC)
Robert Vincent (MIT)

GARFO = Greater Atlantic Regional Fisheries Office
MAFMC = Mid-Atlantic Fishery Management Council
MIT = Massachusetts Institute of Technology
NEFSC = Northeast Fisheries Science Center

In addition to the WG members, the following participated in some of the meetings:

Katie Almeida (The Town Dock)
Alan Bianchi (North Carolina Division of Marine Fisheries)
Russell Brown (NEFSC)
Glenn Chamberlain (NEFSC)
Doug Christel (GARFO)
Greg DiDomenico (Lund's Fisheries)
Alexander Dunn (NEFSC)
James Fletcher (United National Fisherman's Association)
Daniel Hocking (GARFO)
Victoria Kentner (NEFSC)
Kristofer Ketch (NEFSC)
Meghan Lapp (SeaFreeze Ltd.)
Brooke Lowman (NEFSC)
Timothy Miller (NEFSC)
Eric Reid (fisheries consultant)
Eric Robillard (NEFSC)
Brian Smith (NEFSC)
Mark Terceiro (NEFSC)
Michele Traver (NEFSC)
Susan Wigley (NEFSC)
Alissa Wilson (The Marine Stewardship Council)

PEER REVIEW PANEL AND MEETING

Peer review of the butterfish RT was conducted the week of March 7–11, 2022. The meeting was held remotely via Google Meet. Peer review panelists were:

Michael Wilberg, chair
University of Maryland Center for Environmental Science
USA

Yong Chen
SUNY Stonybrook
USA

Robin Cook
University of Strathclyde
Scotland

Robin Thomson
CSIRO
Australia

WORKING PAPERS

All Working Papers (WPs) can be accessed at:
https://www.fisheries.noaa.gov/resource/data/northeast-region-stock-assessment-support-materials

ASSESSMENT HISTORY

The first stock assessment for butterfish (*Peprilus triacanthus*) was conducted in 1977 (Murawski and Waring undated; Murawski and Waring 1979; the assessment was first published as an undated Woods Hole Laboratory Reference Document and was subsequently published in Transactions of the American Fisheries Society in 1979 with minor edits; the latter will be cited for the remainder of this document). A virtual population analysis (VPA; Gulland 1965) was done with natural mortality (*M*) values of 0.6, 0.8, 1.0, and 1.2, and starting fishing mortality (*F*) values for each year class scaled according to total mortality (*Z*) values from National Marine Fisheries Service (NMFS) bottom trawl survey data. The mean stock size (61,762 metric tons [mt]) from the VPA with $M = 0.8$ was closest to the average swept area expansion (61,630 mt) for 1969-1973 (Waring 1975). Thus, it was assumed that *M* was at least 0.8 (Murawski and Waring 1979). This is noteworthy because it was the value of *M* assumed for all future analytical assessments through 2009 (i.e., Waring and Anderson 1983, NEFSC 2004, and NEFSC 2010). Average *F* generally increased over the course of the $M = 0.8$ VPA run from 0.213 in 1968 to 0.788 in 1975, with a peak of 0.872 in 1974 (Murawski and Waring 1979). Stock biomass varied over the period 1968-1976, ranging from a low of 31,896 mt in the terminal year to a high of 70,631 in 1973. Maximum sustainable yield (MSY) was determined to be 21,500 mt at $F_{0.1}$. This value was revised to 21,635 mt the following year (Murawski 1978).

Status of the butterfish stock was then reviewed annually from 1978-1982 (Murawski and Waring 1978; Waring 1979; Waring 1980; Waring and Anderson 1981; Waring and Anderson 1982). These status reviews consisted of updates to the NMFS survey indices and commercial catch data, and a comparison of both with historical patterns.

The second analytical assessment for butterfish was conducted in 1983 (Waring and Anderson 1983). Cohort analysis (Pope 1972) was applied to numbers at age (NAA) catch data partitioned into 6-month intervals (coded ages 0-8). Annual *M* was assumed to be 0.8 (Murawski and Waring 1979), thus $M = 0.4$ was applied to each 6-month interval (Waring and Anderson 1983). Estimated *F* values for each 6-month period were then summed into annual values for ages 0-4. Average *F* (age 2+) ranged from a high of 2.136 in 1976 to a low of 0.773 in 1982. Spawning stock biomass (SSB) varied over the period of 1976-1983, ranging from a high of 24,968 mt in 1976 to a low of 10,373 mt in 1983. Yield per recruit analysis indicated that $F_{0.1}$ was = 1.60, which was higher than any observed in the fishery since 1976. MSY at $F_{0.1} = 1.60$ was 11,500 mt.

After the establishment of the Stock Assessment Workshop (SAW) process, stock assessments for butterfish were conducted annually from 1985-1991 (NEFC 1986, 1987, 1988; NEFSC 1989, 1990, 1991), and the next one after that occurred in 1994 (NEFSC 1994). Similar to the aforementioned status reviews, the primary methodology for these assessments was a comparison of catch data and survey indices with historical patterns.

The butterfish analytical assessment in SAW 38 (NEFSC 2004) utilized the KLAMZ model, which is an implementation of a delay difference model (Deriso 1980; Schnute 1985). Data sources included domestic landings and discards, foreign catch, and Northeast Fisheries Science Center (NEFSC) spring, fall, and winter bottom trawl survey data. *M* was assumed to be 0.8 (Murawski and Waring 1979). New biological reference points were estimated as F_{MSY} proxy = 0.38 and SSB_{MSY} proxy = 22,798 mt. According to these estimates, *F* in 2002 (0.34) was near the overfishing definition, and stock biomass in 2002 was 8700 mt, less than half of the SSB_{MSY} proxy. However, these estimates were considered highly uncertain. It was also noted that discards were estimated to be more than twice the landings.

The next stock assessment for butterfish was completed in 2009 in SAW 49 (NEFSC 2010), again using the KLAMZ model. Data sources again included domestic landings and discards, foreign catch, and NEFSC spring, fall, and winter bottom trawl survey data. It is notable that the recently developed Standardized Bycatch Reporting Methodology (SBRM; Wigley et al. 2007), which combines landings, vessel trip reports (VTRs), and observer sampling data, was used to estimate discards. There were attempts to derive *M* from a variety of methods, but there were inconsistencies among the estimates, and *M* was again assumed to be 0.8 (Murawski and Waring 1979). Consumptive removals by 6 finfish predators was estimated to account for only 0.1 of the assumed *M*. Although *F* and SSB in 2008 were estimated to be 0.02 and 45,000 mt, respectively, these estimates were highly uncertain: CV(F_{2008}) = 0.63; and CV(SSB_{2008}) = 0.60. An F_{MSY} proxy of $F_{0.1}$ = 1.04, with $SSB_{0.1}$ = 16,262 mt, was proposed. However, the Stock Assessment Review Committee (SARC) did not accept any of these equilibrium-based reference points (including those from SAW 38) because the stock did not appear to be in equilibrium and thus reference points would be inappropriate. The panel noted that the stock appeared to be in decline even though fishing mortality had been low relative to *M* for more than 20 years. Stock status was unknown because of uncertainty in the stock size and the lack of an equilibrium-based biomass reference point.

The most recent stock assessment for butterfish in SAW 58 (NEFSC 2014) switched to a statistical catch at age model, the age structured assessment program (ASAP) version 4 (Miller and Legault 2015). Commercial data consisted of domestic landings and discards, and commercial mean weights at age, from 1989-2012. Survey data consisted of swept area abundances and abundance indices (number/tow) at age from 1989-2012 NEFSC fall bottom trawl surveys (inshore and offshore), and swept area abundances and abundance indices at age from 2007-2012 Northeast Area Monitoring and Assessment Program (NEAMAP) fall bottom trawl surveys. As in SAW 49, estimates of consumption by the top 6 finfish predators of butterfish within the NEFSC food habits database appeared to be very low. There were several enhancements to the standard ASAP model in version 4, including 1) catchability of the NEFSC offshore survey was reparameterized as the product of availability and efficiency, which 2) enabled the estimation of *M*. For catchability, an average measure of availability based on bottom temperature was used, while efficiency was based on the relative efficiency of the FRV *Albatross IV* to the FSV *Henry B. Bigelow*, given the assumption that the *Bigelow* was 100% efficient for daytime tows. Results of the model included an estimate of M = 1.22 (CV = 0.05). F_{2012} was 0.02 (CV = 0.33), which was 98% below the accepted overfishing reference point (F_{MSY} proxy = $2M/3 = 2 \times 1.22/3 = 0.81$). The accepted SSB reference point SSB_{MSY} proxy (median SSB based on a 50-year projection at the F_{MSY} proxy) was 45,616 mt (CV = 0.25). SSB_{2012} was estimated to be 79,451 mt, which was 74% above the accepted SSB_{MSY} proxy. The accepted MSY proxy was 36,199 mt (CV = 0.20). Overfishing was not occurring, and the stock was not overfished

An update of the SAW 58 model was done in 2017 (Adams 2018). Biological reference points were recalculated based on advice from the Mid-Atlantic Fishery Management Council (MAFMC) Science and Statistical Committee. This was done because of a revised availability index for 1989-2012, along with new estimates for 2013-2015, and to enable internal consistency with the new estimate of M = 1.25. The stock assessment update was completed by adding catch and indices for 2013-2016 to data from 1989-2012 used in SAW 58. Estimated *F* and SSB in 2016 were 0.05 (CV = 0.28) and 59,041 mt (CV = 0.25), respectively. The 2016 fishing mortality rate was 94% below the revised overfishing reference point F_{MSY} proxy = 0.82. The 2016 SSB was

21% above the revised biomass reference point SSB_{MSY} proxy = 48,681 (CV = 0.25). Stock status was unchanged: overfishing was not occurring, and the stock was not overfished.

An enhanced stock assessment process was initiated in 2020. This process has 2 tracks of assessment work: a management track (MT) that includes the more routine assessments but with more flexibility to make improvements than in the past; and a RT that allows comprehensive research and development of improved assessments on a stock-by-stock or topical basis (analogous to the previous SAW assessments).

A MT assessment for butterfish was conducted in 2020 by adding 3 years of data for 2017-2019 to the 2017 model update (NEFSC 2022). Two changes were made to the assessment model: the time series of discards was reestimated to incorporate changes made to the underlying data; and the NEAMAP indices at age were reestimated using the NEAMAP age-length key instead of the NEFSC age-length key. Biological reference points were recalculated to enable internal consistency with the new estimate of M = 1.29. The availability index was no longer being updated, so the value from the 2017 model update was used. Estimated F and SSB were 0.21 (CV = 0.29) and 29,308 mt (CV = 0.27), respectively. The 2019 fishing mortality was 76% below the revised overfishing reference point F_{MSY} proxy = 0.86. While the 2019 SSB was below the revised biomass reference point SSB_{MSY} proxy = 42,427 (CV = 0.31), it was 38% above $SSB_{Threshold}$ (21,214 mt). Stock status was unchanged: overfishing was not occurring, and the stock was not overfished.

MANAGEMENT HISTORY

Prior to 1976 butterfish fishing was essentially unregulated. The elimination of foreign fisheries began in 1976 with the commencement of federal/council fishery management through the Magnuson-Stevens Fishery Conservation and Management Act. A revised initial Butterfish Fishery Management Plan (FMP) was approved by the MAFMC in June 1979 (MAFMC 1979). The initial FMP set an optimum yield with a foreign fishing allocation, and it initiated registration/permitting and weekly reporting. Around 1983, the Butterfish FMP was merged with Atlantic mackerel (*Scomber scombrus*) and squid (MAFMC 1983) to form the Mackerel, Squid, Butterfish (MSB) FMP. Amendments in the 1990s addressed overfishing definitions; restricted joint ventures (though this was not common for butterfish); eliminated the possibility of foreign fishing; revised overfishing definitions; refined permitting including limited access; and established essential fish habitat (MAFMC 1991a, 1991b, 1996, 1997a, 1997b, 1998). Actions in the 2000s created research set-asides, implemented standardized bycatch reporting, and prohibited bottom trawling by MSB-permitted vessels in Lydonia and Oceanographer Canyons (MAFMC 2001, 2007, 2008). The early 2010s saw the development of a butterfish rebuilding program (since determined to have been unnecessary) that included a butterfish catch restriction (cap) in the longfin squid, *Doryteuthis* (Amerigo) *pealeii*, fishery; a Council risk policy that allowed more direct consideration of assessment uncertainty; and an update of essential fish habitat (MAFMC 2010a, 2010b, 2011). Continuing in the 2010s, the Council clarified the limited circumstances under which catches can be increased for stocks without status determination criteria on overfishing; twice modified the butterfish cap on the longfin squid fishery to improve its operation; modified the standardized bycatch reporting methodology; established closed areas for bottom trawling to protect deep sea corals in areas that could be relevant to butterfish fishing near the shelf/slope break; and decoupled the limited access permits for longfin squid and butterfish as part of an effort to reduce latent capacity in the longfin squid fishery (MAFMC 2012, 2013, 2014, 2015, 2016, 2018). Actions in 2020 required electronic catch reporting by vessels and slightly liberalized the Council's risk policy (and therefore catches) (MAFMC 2020a, 2020b). Presidential Executive Orders prohibited fishing in several relevant canyon areas from September 2016 until June 2020 and again since October 2021.

Some additional detail around the butterfish rebuilding program, its effects on landings, and management changes since its implementation may be useful. Excepting one good year in 2001, landings had steadily declined to around 500 mt by 2003 in the absence of substantial domestic regulatory constraint. SeaFreeze Ltd. landed most of those 2001 butterfish and had trouble getting rid of them, attesting to the market issues hindering utilization of the resource (2012 personal communication from Geir Monsen to Jason Didden). While regulations did not contribute to the demise of the directed fishery in the late 1990s and early 2000s, trip limits and quotas afterward locked the fishery into a bycatch-retention fishery. Low trip limits were implemented in 2005 and made more restrictive in 2008, while a rebuilding plan was developed in MSB Amendment 10 in response to an overfished finding by NMFS[1] in response to SAW 38. A constraining landings quota of 500 mt was implemented in 2008, but the trip limits and availability had been limiting landings to around that amount already.

Regulations and quotas then precluded resumption of a directed fishery until 2013, when a limited directed fishery quota was reestablished based on empirical analyses conducted by NEFSC staff. The directed fishery included a 3-inch (7.62 cm) mesh requirement to possess more than 2,500 pounds (1.1 mt), which was liberalized to more than 5,000 pounds (2.3 mt) in May 2016. A 2014 assessment utilizing data through 2012 found that butterfish had never been overfished, and quotas were substantially increased beginning in 2015. Assessment updates in 2017 and 2020 led to substantial quota reductions in 2018 and 2021, respectively, but quotas were high enough that the fishery has not been restricted by those quotas. A cap on discards in the longfin squid fishery remains in place to ensure annual catch limits are not inadvertently exceeded, but it has been able to be set high enough that it has generally not been constraining on the longfin squid fishery (though fishery participants report that the cap's existence generally discourages targeting of butterfish).

BIOLOGY

Butterfish occur from southern Florida to the Gulf of St. Lawrence and the south and east coasts of Newfoundland (Horn 1970b), but they are primarily found from Cape Hatteras to the Gulf of Maine, where the population is considered to be a unit stock (Brodziak 1995).

Butterfish form loose schools, wintering near the edge of the continental shelf in the Middle Atlantic Bight and migrating inshore in the spring into southern New England and Gulf of Maine waters (Cross et al. 1999). Spawning occurs from May to September, but peaks in June and July (O'Brien et al. 1993). Details of growth and maturity are discussed below.

Butterfish can reach a maximum age of 6 (Draganik and Zukowski 1966), although individuals > 4 years of age are rare (Table 1).

Ages are determined using whole otoliths (Dery 1988). Butterfish are assigned ages based on calendar years. For example, butterfish born in the second half of 2020 reach nominal age 1 on January 1, 2021 at a biological age of no more than 6 months. Age data in this report are nominal ages unless otherwise specified. A recent marginal increment analysis demonstrated that whole

[1] The MAFMC was notified by NMFS on February 11, 2005, that the butterfish stock was designated as overfished.

otoliths can be used to estimate butterfish ages accurately and precisely (Robillard and Dayton working paper [WP]).

Butterfish undergo diel vertical migration, staying relatively close to the bottom during the day and dispersing upward at night (Murawski and Waring 1979).

Juvenile butterfish often shelter beneath jellyfish (Mansueti 1963). This association ends around 75-100 mm standard length, when the swim bladder is completely regressed and they begin to school (Horn 1970a).

The diet of juvenile butterfish includes cnidarians (jellyfish), while the diet of adults includes tunicates and pelagic molluscs, e.g., *Clione* sp. (Bowman et al. 2000). More recent work found that the amphipods *Hyperia* sp. and *Parathemisto* sp. comprised the majority of identifiable stomach contents (Suca et al. 2018). These authors also noted that gelatinous zooplankton were qualitatively very abundant in the diet of butterfish, but they were unable to be incorporated in the prey number and biomass calculations.

Fish predators of butterfish, not in the NEFSC Food Habits Database (B Smith WP), include Atlantic bluefin tuna, *Thunnus thynnus* (Eggleston and Bochenek 1990; Chase 2002; Logan et al. 2011), swordfish, *Xiphias gladius* (Scott and Tibbo 1968; Stillwell and Kohler 1985) and wahoo, *Acanthocybium solandri* (Manooch and Hogarth 1983).

There is confusion regarding longfin squid preying upon butterfish due to inaccurate citations in the literature. For example, Collette and Klein-MacPhee (2002) cite Tibbetts (1977) and Rountree (1999) that butterfish form an important part of the diet of longfin squid. However, Tibbetts (1977) does not say anything about longfin eating butterfish (although her Table 2 does list butterfish as a predator on longfin). The Rountree (1999) citation is actually a website with data from the NEFSC food habits database, which has a single record of longfin squid preying on butterfish from 1989. In another example, Brodziak (1995) states that butterfish are preyed upon by longfin squid but gives no citation; Brodziak (1995) was in turn cited by Cross et al. (1999). In contrast to all this, Hunsicker and Essington (2006) examined stomach contents of 3026 longfin squid; their Table 3 shows that butterfish otoliths were found in only n = 3 individuals.

The common tern (*Sterna hirundo*) has been observed feeding upon butterfish (Duffy 1988). Although the size of the butterfish is not reported, they were commensal with *Cyanea*, suggesting they were juveniles < 10 cm. Other aspects of seabird predation on butterfish are described in the Vincent WP.

Marine mammal predation on butterfish is described in the L Smith WP.

Length-weight relationship

Early estimates of butterfish length-weight parameters were reported in International Commission for Northwest Atlantic Fisheries (ICNAF) documents. Draganik and Zukowski (1966) estimated α = 0.017 and β = 2.94 for butterfish collected during research surveys aboard the M/T *Wieczno* on Georges Bank from August to October 1965. Similarly, Waring (1975) estimated α = 0.01074 and β = 3.2276 for butterfish collected in the fall 1974 NMFS bottom trawl survey. Using 3,850 commercial specimens from Japanese trawlers from October 1970 to July 1976, Kawahara (1977, 1978) estimated ln(α) = -13.3239 and β = 3.492.

DuPaul and McEachran (1973) sampled 140 butterfish from the lower York River (Virginia) in September 1969. They estimated length-weight parameters ln(α) = -11.932 and β = 3.2646

Biological sampling procedures on the NEFSC bottom trawl surveys were expanded to include recording individual fish weight, in addition to recording fish length, in 1992. Wigley et al. (2003) analyzed length-weight parameters for 10,305 butterfish from NEFSC spring, fall, and winter bottom trawl surveys 1992-1999. A significant difference was found between length-weight relationships for winter/spring vs. fall.

For the current assessment, an exploratory regression of NEFSC spring and fall data for 33,983 butterfish from 1992-2019 confirmed a significant effect of season ($p < 2e\text{-}16$). Thus, length-weight parameters were estimated separately for the 2 seasons. For spring, $\ln(\alpha) = -11.8205$ and $\beta = 3.3334$; while for the fall $\ln(\alpha) = -10.8534$ and $\beta = 3.0010$.

Growth

Early estimates of butterfish von Bertalanffy growth parameters were reported in ICNAF documents. Draganik and Zukowski (1966) estimated $L_\infty = 20.5$ cm, $k = 0.468$ and $t_0 = -0.65$ for butterfish collected during research surveys aboard the M/T *Wieczno* on Georges Bank from August to October 1965. Similarly, Waring (1975) estimated $L_\infty = 21.2$ cm, $k = 0.446$ and $t_0 = -1.2$ for butterfish collected in the fall 1974 NMFS bottom trawl survey. Using 3850 commercial specimens from Japanese trawlers from October 1970 to July 1976, Kawahara (1977, 1978) estimated somewhat different growth parameters of $L_\infty = 21.1$ cm, $k = 0.861$ and $t_0 = -0.07$.

Penttila et al. (1989) provided mean lengths at age for butterfish sampled during NEFSC bottom trawl surveys from 1982-1988. Fitting a nonlinear least squares to these values with the `growth` function in the R package `fishmethods` gives von Bertalanffy growth parameter estimates of $L_\infty = 21.0$ cm, $k = 0.855$ and $t_0 = -0.08$.

For the current assessment, butterfish von Bertalanffy growth parameters were estimated for 44,194 individuals from the spring and fall NEFSC surveys from 1982-2019. Estimates were $L_\infty = 21.7$ cm, $k = 0.387$ and $t_0 = -1.46$.

Maturity

DuPaul and McEachran (1973) noted that maturity began in the second summer (age 1).

Morse (1979) examined 796 butterfish from the spring, summer, and fall NEFSC surveys in 1977. Median length at maturity for females was again 12.0 cm, while for males, L_{50} was slightly larger at 12.1 cm.

O'Brien et al. (1993) examined 674 butterfish (333 females, 341 males) from the NEFSC spring bottom trawl survey from 1986-1989. They found that median length at maturity (L_{50}) for female and male butterfish was 12.0 and 11.4 cm, respectively, while median age at maturity (A_{50}) was 0.9 yr for both sexes.

For the current assessment, L_{50} and A_{50} were reevaluated using NEFSC spring bottom trawl survey data from 1985-2019 for 10,775 butterfish (5686 females, 5089 males). For females, L_{50} = 11.3 cm and A_{50} = 0.74 yr, while for males, L_{50} = 11.2 cm and A_{50} = 0.75 yr.

Natural mortality

Estimates of M vary depending on the method. Assuming a maximum age of 6, the method of Hoenig (1983) gives $M = 0.73$, while the preferred t_{max} method from Then et al. (2015) gives $M = 0.95$. Further assuming the value of $k = 0.387$ from the maturity section above, and that the midpoint of the length range = 11 cm, the method of Gislason et al. (2010) results in $M = 1.19$.

As was described above in the assessment history, all assessments through SAW 49 (NEFSC 2010) assumed $M = 0.80$. Beginning in SAW 58 (NEFSC 2014), M was estimated internal to the model as 1.22. This increased slightly to 1.25 for the 2017 model update (Adams 2018) and increased again to 1.29 for the 2020 MT (NEFSC 2022). Relevant to the current assessment, the latter value was revised to M = 1.278 upon re-running the 2020 model after making a minor correction to the discard estimation code.

TOR1: ESTIMATE CATCH FROM ALL SOURCES INCLUDING LANDINGS AND DISCARDS. DESCRIBE THE SPATIAL AND TEMPORAL DISTRIBUTION OF LANDINGS, DISCARDS, AND FISHING EFFORT. CHARACTERIZE THE UNCERTAINTY IN THESE SOURCES OF DATA.

Butterfish catch is comprised of commercial landings and discards. Recreational catch of butterfish is negligible.

Commercial landings

Domestic landings prior to 1965 were obtained from Lyles (1967) as compiled by Murawski et al. (1978). Landings from 1965-1988 were obtained from the NEFSC commercial fisheries state canvas data table, while landings from 1989-2019 were obtained from the NEFSC Commercial Fisheries Database System (CFDBS). Some of the trends in landings described below (e.g., gear types, market categories) only present data from CFDBS as the WG decided that 1989 would be the start year of the catch time series due to concerns associated with the commercial discards (see “Discards” below).

Statistical areas used to report butterfish landings are shown in Figure 1. The statistical area boundaries have been in existence since the mid-1940s, although the current 3-digit numerical coding scheme was not adopted until 1963 (Mayo 1977). Landings are obtained from the weighout reports of commercial dealers and are generally considered a census of total landings. Prior to 1994, commercial landings were allocated to the 3-digit statistical area according to post-trip interviews conducted by NMFS port agents (Burns et al. 1983). Since 1994, fishing vessels have been required to submit a VTR containing statistical area and effort information, which are then matched to dealer reported landings at the trip level using a multi-tiered allocation procedure (Wigley et al. 2008).

During the late 1800s through 1928, butterfish harvested from nearshore weirs and traps between Cape Cod and Virginia ranged between 142 mt and 2794 mt annually (Murawski et al. 1978). Landings increased from 1929 to 1962, ranging between 1033 mt and 7758 mt, and averaging 4315 mt (Figure 2). This was due to trawlers based primarily in Point Judith, RI, and New Bedford, MA, that landed butterfish in mixed-species food and industrial fisheries (Edwards and Lawday 1960). Between 1963 and 1986, landings of butterfish were reported by distant water fleets targeting longfin squid. In many cases, the reported catch included discards; thus, these foreign landings are described in the total catch section below. Domestic landings of butterfish averaged 1976 mt from 1965-1979 without any trend (Table 2; Figures 2 and 3). A domestic fishery was developed to supply the Japanese market, leading to peak landings of 11,715 mt in 1984, but then declined to 1449 mt in 2000. Between 2002 and 2012 there was no directed fishery, and landings, primarily as bycatch in the small mesh (< 4 in = 10.2 cm) bottom trawl longfin squid fishery, averaged 578 mt annually. A directed fishery was gradually reestablished between 2013 and 2015 (see “Management History” above), with landings averaging 2330 mt through 2019.

Most butterfish landings have generally come from statistical areas 526, 537, 539, 613, and 616 off southern New England (Figure 4). Early in the time series, landings were highest from statistical area 537, averaging 1224 mt annually between 1989 and 2001. Since the resumption of the directed fishery in 2013, landings have been highest from statistical area 526, averaging 735 mt annually.

The majority of butterfish landings have been caught with bottom otter trawls, averaging 90% between 1989 and 2019 (Figure 5). Since the resumption of the directed fishery in 2013, this gear type has caught an average of 95% of butterfish landings annually.

By state, Rhode Island has the most annual landings of butterfish (Figure 6), except in 2005. Rhode Island landings have been highest when a directed fishery is operating, averaging 1978 mt between 1989 and 2001 and 1825 mt between 2013 and 2019.

Landings by market category in a given year are highest for either medium, small, or unclassified (Figure 7). The latter category was highest during the early part of the time series, between 1989 and 1997. Small and medium have been the highest market category landed since the resumption of the directed fishery in 2013, with the exception of 2016.

Landings at length

Butterfish are sampled dockside by NMFS port agents. Length samples containing approximately 100 fish are collected per market category, port, and gear. Since 1989, an average of 28 samples have been collected annually (Table 3). Sampling intensity is often expressed in terms of landings (mt) per 100 fish lengths measured; for butterfish, this has ranged from 11 mt per 100 lengths between 2005 and 2008, to 300 mt per 100 lengths in 1995 (Table 3).

There is considerable overlap in the length composition of the medium, small, and extra small market categories (Figure 8). Thus, in the previous benchmark assessment (NEFSC 2014), the WG decided to combine these market categories. This decision was retained for the current assessment.

The same procedure was used to fill holes in the length sampling as in the previous benchmark assessment (NEFSC 2014). Briefly, lengths were summed for each half year (January-June, July-December) by decade and then used for half years within the decade in which no lengths were available (Table 4).

Landings at age

In addition to the dockside length sampling described above, NMFS port agents also set aside 25 butterfish per sample that are then frozen for subsequent otolith extraction. While there was generally adequate age sampling in the early part of the time series, it effectively ceased in 1998 and did not resume until 2014, in conjunction with the reestablished directed fishery (Table 3). Age samples have mostly come from the unclassified, medium, and small market categories (Table 5).

The proportion of butterfish age samples by length has not varied systematically over time (Figures 9 and 10). Grouping age samples by length for the 2 time blocks of the directed fishery (1989-1997 and 2014-2019) shows similar patterns except at the smallest and largest sizes (Figure 11), which is due to a small number of observations (e.g., the proportion of age 0 at 9 cm in the 1989-1997 block is due to a single record).

Given the availability of commercial ages since 2014 (Table 3), the WG reevaluated the decision in the previous benchmark assessment (NEFSC 2014) to calculate commercial landings at age using NEFSC survey age-length keys (ALKs). A comparison of the ALKs by half year for the 2 time blocks of the directed fishery revealed systematic differences, e.g., in half year 1, butterfish ~12-20 cm were more likely to be assigned age 1 based on the survey but would be age 2 or 3 based on the commercial ALKs (Figures 12 and 13); and in half year 2, a similar pattern can be seen for age 0 and age 1/age 2 (Figures 14 and 15). Thus, the WG decided that the use of commercial ALKs would be more appropriate for calculating the landings at age.

Semiannual ALKs were created for years with adequate age sampling: 1989-1993, 1996-1997, and 2014-2019. For 1994 and 1995, semiannual ALKs were created using data for 1989-1997, and for 1998–2013, semiannual ALKs were created using data for the entire time series. The multinomial method of Gerritsen et al. (2006) was used to fill any remaining ALK holes.

Commercial landings at age are shown in Figure 16. Reduced landings of ages 1-3 butterfish during the period of no directed fishery (2002-2012) are readily apparent.

Commercial discards

In addition to CFDBS and the VTR database, an additional source of data is used to estimate discards: the NEFSC Observer Database System (OBDBS). The Northeast Fisheries Observer Program (NEFOP) began in 1989. Thus, in the previous benchmark assessment (NEFSC 2014), the catch time series was started in 1989 because butterfish was considered a discard fishery (Table 2). While landings have accounted for the majority of the catch since the resumption of the directed fishery in 2013 (Table 2), the WG decided to retain the 1989 start year for the current assessment for reasons mostly related to the high uncertainty associated with the distant water fleet discards:

1) In some cases, the reported catch included discards.
2) Discards were estimated by dividing longfin catch by survey ratios to account for butterfish discards of countries reporting only longfin.
3) Foreign catch was likely underestimated because Spain and Italy did not report their butterfish bycatch from the squid fisheries from 1972-1976 (Murawski and Waring 1979).

A related reason for the 1989 start year is that foreign landings in the 1970s were underreported, potentially on the scale of an order of magnitude (Didden WP).

Catch data from 1976-1986 as presented in earlier assessment documents include some estimates of butterfish discards combined with landings (Waring and Anderson 1983; NEFC 1990). In SAW 49 (NEFSC 2010), the portion of the annual total catches in these records attributable to discards was determined by subtracting the landings obtained from the NEFSC commercial fisheries state canvas data table. These values are reproduced here as “historic discards” in Table 2.

Butterfish discards for 1989-2019 were estimated using the SBRM (Wigley et al. 2007). In the SBRM, the sampling unit is an individual fishing trip. For butterfish, trips were stratified by area, time (year and quarter), gear, and mesh. The same statistical areas used to report butterfish landings (Figure 1) were used to estimate discards and were stratified into 2 regions: New England (statistical areas < 600) and Mid-Atlantic (statistical areas ≥ 600). Gear groups included bottom trawls (fish, scallop, twin, Ruhle, haddock separator, and shrimp), midwater trawls (single and paired), beach seine, gill nets, and scallop dredge. Mesh groups for fish and twin bottom trawls were < 4 inches (10.2 cm) and ≥ 4 inches; mesh groups for gillnets were < 5.5 inches (14.0 cm), 5.5–7.99 inches, and ≥ 8.00 inches (20.3 cm). Discards were estimated using the combined (D/K)

ratio estimator (method 2 in Wigley et al. 2007), where *D* = discarded pounds of butterfish and *K* = the kept pounds of all species landed in a trip. Total discards by fleet were derived by multiplying the estimated discard rate for that fleet by the corresponding fleet landings from CFDBS.

Total discard estimates varied from 205 mt in 2005 to a high of 10,178 mt in 1999 (Table 6). In the early part of time series, the precision of these estimates was generally poor, with only 4 years with an estimated CV ≤ 0.30. However, since 2010, the estimated CV has been ≤ 0.20 in all but one year (2012).

Almost all estimated discards are attributable to tows with bottom trawls, either in a single otter trawl configuration or a twin trawl configuration (Table 7). Details for these 2 gear types, with an additional stratification of mesh size < 4 inches vs. ≥ 4 inches (10.2 cm), are shown in Tables 8 and 9.

The number of observed trips for any stratum ranged from a low of 15 in 2002 for mesh size < 4 inches in the Mid-Atlantic (Table 8) to a high of 1591 in 2011 for mesh size ≥ 4 inches in New England waters (Table 9). The average number of observed trips was greater in New England waters (128 for mesh size < 4 inches and 558 for mesh size ≥ 4 inches) relative to the Mid-Atlantic (147 for mesh size < 4 inches and 217 for mesh size ≥ 4 inches). Discards were roughly an order of magnitude higher with small mesh (< 4 inches), averaging 626 mt in New England waters and 953 mt in the Mid-Atlantic, while large mesh discards averaged 332 mt and 247 mt in New England and Mid-Atlantic waters, respectively.

Discards at length

OBDBS data from 1989-2019 were used to examine the length composition of the discarded and kept fraction of trips where butterfish were caught. The number of butterfish measured averaged 5022, ranging from 1176 in 1992 to 18,774 in 2011 (Figures 17-20). Both the discarded and kept fractions ranged in size from 3 cm to 34 cm.

Discards at age

Age data are not collected by NEFOP. Thus, the semiannual commercial ALKs used to calculate butterfish landings at age were used to estimate discards at age. Commercial discards at age are shown in Figure 21.

Total catch

Total catch of butterfish increased from 15,167 mt in 1965 to a peak of 39,896 mt in 1973 and were dominated by catch from distant water fleets (Table 2; Figures 1 and 2). Total catch then declined to 11,863 mt in 1977 following the implementation of the Magnuson-Stevens Fishery Conservation and Management Act of 1976. Foreign landings were completely phased out by 1987.

For the time period used in this assessment (1989-2019), total catch ranged from 883 mt in 2007 to 12,288 in 1999 (Table 10). In the early part of time series, 12 of 20 years had an estimated CV ≤ 0.30. However, since 2009, all catch CVs have been ≤ 0.23.

During the period of no directed fishery (2002-2012), landings and discards averaged 36% and 64%, respectively (Table 11). Since the resumption of the directed fishery in 2013, this situation has reversed, with landings and discards averaging 66% and 44%, respectively.

Total catch at age

Total catch at age is shown in Figure 22. The proportions of catch at age in weight are shown in Figure 23.

TOR 2: PRESENT THE SURVEY DATA AVAILABLE (E.G., INDICES OF RELATIVE OR ABSOLUTE ABUNDANCE, RECRUITMENT, STATE SURVEYS, AGE-LENGTH DATA, ETC.), AND DESCRIBE THE BASIS FOR INCLUSION OR EXCLUSION OF THOSE DATA IN THE ASSESSMENT. CHARACTERIZE THE UNCERTAINTY IN THESE SOURCES OF DATA.

There are a number of fishery-independent bottom trawl surveys available for butterfish, including federal, state, and academic. NEFSC and NEAMAP are presented first, as these were the 2 surveys in the SAW 58 statistical catch at age model and are put forward as the primary surveys in the final model for the current assessment. For the state surveys, the percent positive tows are shown, as this was one of the criteria used to determine whether or not to include a particular survey in a combined coastwide young-of-the-year (YOY) index.

NEFSC

The standardized NEFSC bottom trawl survey began in fall 1963. It uses a stratified random design. Initially, offshore strata 1-40 from the Gulf of Maine to Hudson Canyon off New Jersey were sampled (Figure 24) with depths between 27 m (15 fathoms) and 366 m (200 fathoms). In fall 1967, offshore strata 61-76 were added to sample the Mid-Atlantic. A dedicated spring survey was added in 1968. Inshore strata south of Massachusetts, with depths less than 27 m (15 fathoms), were added in 1972. Inshore strata around Massachusetts were added in 1979 (Johnston and Sosebee 2014). The average number of tows per survey since 1979 is ~ 330. A winter (flatfish) survey was conducted from 1992-2007, but this was not considered for the current assessment as butterfish ages were only collected in 1 year (1992).

Several gear and vessel changes have occurred over the course of the NEFSC time series. From 1963-2008, the primary survey platform was the FRV *Albatross IV* (hereafter Albatross); although some surveys were done with the FRV *Delaware II* (1970-2003) or the FRV *Atlantic Twin* (1972-1975). Calibration coefficients between the Albatross and *Delaware II* were found not to be necessary for butterfish (Byrne and Forrester 1991). In spring 2009, the FSV *Henry B. Bigelow* (hereafter Bigelow) replaced the Albatross. The size, towing power, and fishing gear characteristics of the Bigelow are substantially different from the Albatross (Table 12), resulting in different fishing power and thus different survey catchability (Johnston and Sosebee 2014). Calibration coefficients were calculated for most species, including butterfish (Miller et al. 2010). These calibration coefficients were used to convert Bigelow indices to Albatross units in the previous benchmark assessment (NEFSC 2014) because the Bigelow time series was too short (4 years) to treat as a separate index. For the current assessment, the Albatross and Bigelow were treated as separate time series because there were a sufficient number of years (11) to estimate relatively precise catchability and selectivity parameters.

Because of the deeper draft of the Bigelow, the inshore strata < 18 m are no longer sampled (Figure 24). Thus, in the previous benchmark assessment (NEFSC 2014), these inshore strata were treated as a separate time series. For the current assessment, treating the Albatross and Bigelow as separate time series allowed for the use of different strata sets. Briefly, all strata that were sampled during Albatross years were used for that time series, and all strata that were sampled during Bigelow years were used for that time series (Table 13). For the fall time series, the primary difference in the strata set as compared with the previous benchmark assessment (NEFSC 2014) is the addition of Gulf of Maine strata (offshore 24 and 26-40; inshore 56, 58-61, and 63-66); this change was justified by a range expansion observed over the past decade (Adams WP). Similarly, the decision to include the spring survey was due in part to butterfish being distributed over the shelf during warm years over the same time period (Adams 2017; WP).

There were 2 years of NEFSC survey data the WG considered dropping from the respective times series (spring 2014 and fall 2017). In fall 2017, only 11 of 59 strata from the SAW 58 offshore set were sampled. Thus, in the 2020 MT, fall 2017 data were set to NA. For the current assessment, only 29 of 77 strata for the new set were sampled, and fall 2017 data were again set to NA. As for spring 2014, only 64 of 77 strata were sampled. Given that this was a much smaller proportion of unsampled strata, the following analysis was adapted from NEFSC (2018) to determine whether this would make a difference: a linear regression was fit to the aggregate indices (arithmetic mean numbers per tow) from 2009-2019 estimated with (dependent variable) and without (independent variable) these strata; this regression was used to calibrate the spring 2014 survey observation (aggregate and at age) to a value assumed equivalent to having sampled the entire survey area; the regressions fit to the aggregate indices and indices at age were similar, and the difference between the uncalibrated (121.9) and calibrated (112.2) values were within the 90% confidence interval of the uncalibrated index. Thus, the spring 2014 data were not dropped.

NEFSC survey dates are shown in Figure 25. The average mid-date for the spring survey was 92.3, which corresponds to April 2. The average mid-date for the fall survey was 280.0, which corresponds to October 7. The aforementioned issues with the fall 2017 and spring 2014 surveys are reflected here in the late starts. There was also a late start in spring 2016.

The percent positive tows were always higher in the NEFSC fall survey (Figure 26). Also, the percent positive tows for the Bigelow, in both spring and fall, were generally higher than the Albatross.

The NEFSC spring abundance indices (stratified mean number per tow) for the Albatross ranged from 5.1 in 1990 to 76.9 in 2007, while the Bigelow ranged from 27.6 in 2013 to 135.8 in 2012 (Table 14; Figure 27). CVs for the spring abundance indices averaged 0.47 and 0.33 for the Albatross and Bigelow, respectively (Table 14; Figure 28). The fall abundance indices for the Albatross ranged from 34.6 in 2005 to 321.8 in 1994, while the Bigelow ranged from 65.7 in 2019 to 551.5 in 2018. CVs for the fall abundance indices averaged 0.25 and 0.26 for the Albatross and Bigelow, respectively.

Fitting exploratory trendlines to the abundance indices (Figures 29 and 30) shows conflicting trends during the Albatross years (spring trending upward, fall trending downward) but similar trends during the Bigelow years (both trending upward). This is noteworthy because conflicting trends between the spring and fall were what led the SARC 58 panel to request that the spring indices be dropped from the model.

Survey-specific ALKs were created using age data collected during the respective survey. Missing age-at-length data were filled using the multinomial method of Gerritsen et al. (2006).

Tables 15 and 16 and Figures 31-34 show that the fall survey catches primarily age 0 butterfish while the spring survey catches primarily age 1 butterfish.

NEAMAP

The Virginia Institute of Marine Science (VIMS) conducts the NEAMAP survey, along with 2 other surveys that are discussed below. NEAMAP has spring and fall bottom trawl surveys that began in fall 2007. Each survey samples 150 stations with a stratified random design. The boundaries of the survey are consistent with NEFSC inshore strata < 18 m (from Cape Cod, MA, to Cape Hatteras, NC) that are no longer sampled by the Bigelow (Figure 35). NEAMAP uses the same net as the Bigelow but with some differences (e.g., NEAMAP dyes the codend liner with black Rit-dye), while the wires, trawl doors, and the type of sweep are different. The NEAMAP fall indices were used in the previous benchmark assessment (NEFSC 2014), the 2017 model update (Adams 2018), and the 2020 MT (NEFSC 2022). For the current assessment, both the spring and fall surveys were used.

NEAMAP survey dates are shown in Figure 36. The average mid-date for the spring survey (not including 2017) was 128.8, which corresponds to May 9. The average mid-date for the fall survey was 290.5, which corresponds to October 17. The WG decided to drop the spring 2017 data because the mid-date of that survey corresponded to June 18, and only 63 out of 150 stations (42%) were sampled.

The percent positive tows for NEAMAP are shown in Figure 37. Both spring and fall surveys have a high number of positive tows: 3 years in the spring survey (2009, 2012, and 2016) have positive tows between 98% and 99%; and 1 year in the fall survey (2010) has 98% positive tows.

The NEAMAP spring abundance indices (arithmetic stratified mean number per tow) ranged from 47.3 in 2013 to 987.1 in 2019 (Table 17; Figure 38). CVs for the spring abundance indices averaged 0.26 (Table 17; Figure 39). The fall abundance indices ranged from 352.0 in 2019 to 3769.8 in 2014. CVs for the fall abundance indices averaged 0.25.

NEAMAP aging of butterfish is aligned with NEFSC aging (2020 personal communication from Eric Robillard to Charles Adams). Tables 18 and 19 and Figures 40 and 41 show that the fall survey catches primarily age 0 butterfish and that the spring survey catches primarily age 1 butterfish. However, unlike the NEFSC spring survey, the NEAMAP spring survey does catch age 0 butterfish, and in some years (2008, 2011, and 2017), this index is greater than the age 1 index. There is also 1 year (2008) when the age 2 index is greater than the age 1 index.

Maine-New Hampshire

The Maine-New Hampshire inshore survey (Figure 42) is conducted by the Maine Department of Marine Resources (MEDMR). Spring and fall surveys began in fall 2000. There were no spring surveys from 2003-2005 or in 2009. Positive tows averaged 13.0% and 72.2% for the spring and fall surveys, respectively (Figure 43).

Massachusetts

Spring and fall bottom trawl surveys have been conducted by the Massachusetts Division of Marine Fisheries (MADMF) since spring 1978 (Figure 42), although data are only presented here for 1989-2019. Positive tows averaged 22.0% and 85.0% for the spring and fall surveys, respectively (Figure 44).

Rhode Island

Spring and fall bottom trawl surveys have been conducted by the Rhode Island Department of Fish and Wildlife (RIDFW) since spring 1979 in Narragansett Bay and the state waters of Rhode Island Sound (Figure 42), although data are only presented here for 1989-2019. Positive tows averaged 16.5% and 82.2% for the spring and fall surveys, respectively (Figure 45).

Connecticut

The Connecticut Department of Energy and Environmental Protection (CTDEEP) bottom trawl survey of Long Island Sound (Figure 42) began in 1984, although data are only presented here for 1989-2019. Forty stations are sampled monthly in April, May, June, September, and October; data for April-June are used to provide spring indices, while data for September-October are used to provide fall indices. There was no fall survey in 2010. Positive tows averaged 51.0% and 93.3% for the spring and fall surveys, respectively (Figure 46).

New York

The New York Division of Marine Resources (NYDMR) conducts 2 surveys. The survey of Peconic Bay (Figure 42) began in 1987, although data are only presented here for 1989-2019. Sixteen stations are sampled weekly from May-October. The survey was not conducted from August 2005 to May 2006, May to July 2008, or in May 2010. May and October data are presented because these 2 months have the closest temporal alignment with the NEFSC and NEAMAP spring and fall surveys. Percent positive tows averaged 1.6% and 20.1% for May and October, respectively (Figure 47).

The NYDMR also conducts a nearshore survey in the winter, spring, summer, and fall. The survey ran from 2005-2007 and was restarted in 2018. This survey was not considered for the assessment given that there were only 2 years of recent data.

New Jersey

The New Jersey Division of Fish and Wildlife (NJDFW) bottom trawl survey began in August 1988 (Figure 42). Surveys are conducted in January, April, June, August, and October. There were several vessel changes earlier in the time series, the last of which occurred in 2001. Thus, the WG decided that only data for 2002-2019 would be considered for this survey. April and October data are presented because these 2 months have the closest temporal alignment with the NEFSC and NEAMAP spring and fall surveys. There was no survey in April 2019. Percent positive tows averaged 57.8% and 88.9% for April and October, respectively (Figure 48).

Delaware

The Delaware Division of Fish and Wildlife (DEDFW) conducts 3 surveys. The 30-foot headrope bottom trawl survey of Delaware Bay (Figure 42) was reinstated in 1990. Nine stations are sampled monthly from March-December. Due to an undocumented vessel change in 2003, the WG decided that only data for 2003-2019 would be considered for this survey. April and October data are presented because these 2 months have the closest temporal alignment with the NEFSC and NEAMAP spring and fall surveys. There was no survey in April 2003. Percent positive tows averaged 26.4% and 57.5% for April and October, respectively (Figure 49).

The DEDFW also conducts a 16-foot headrope trawl survey of the Delaware Bay estuary (Figure 42) that began in 1980. Monthly sampling occurs from April-October. Due to a vessel and gear change in 2003, the WG decided that only data for 2003-2019 would be considered for this survey. April and October data are presented because these 2 months have the closest temporal alignment with the NEFSC and NEAMAP spring and fall surveys. There were no positive tows in April from 2003-2019. Positive tows averaged 15.8% for October (Figure 50).

The 16-foot survey was expanded to include the Indian River and Rehoboth Bays (Figure 42) in 1986. These indices are typically provided separately. Percent positive tows averaged 3.2% and 8.8% for April and October, respectively (Figure 51).

VIMS juvenile and ChesMMAP

In addition to NEAMAP, VIMS conducts 2 other surveys. The VIMS juvenile fish and blue crab trawl survey of Chesapeake Bay (Figure 42) began in 1955. Sampling occurs monthly from January-December. April and October data are presented because these 2 months have the closest temporal alignment with the NEFSC and NEAMAP spring and fall surveys. Percent positive tows averaged 3.3% and 13.0% for April and October, respectively (Figure 52).

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) bottom trawl survey began in 2002 (Figure 42). Sampling occurs in March, May, July, September, and November. There was a vessel and gear change in 2019; calibration coefficients are not yet available, so the WG decided that only data through 2018 would be considered for this survey. The ChesMMAP butterfish index is based on September and November data from regions 4 and 5 (Virginia). Percent positive tows averaged 42.2% (Figure 53)

North Carolina

The North Carolina Division of Marine Fisheries (NCDMF) bottom trawl survey of Pamlico Sound (Figure 42) began in 1990. Sampling occurs in June and September, although the latter sometimes extends into October due to vessel repairs, weather delays, and similar events. Only September and October data are presented because these 2 months have reasonable temporal alignment with the NEFSC and NEAMAP fall surveys. Percent positive tows averaged 18.6% (Figure 54).

Combined YOY index

The WG ultimately decided to combine some of the state survey data into a coastwide YOY index using the method of Conn (2010). The following decisions and criteria led to the selection of which state surveys to use in the YOY index. First, the WG chose not to use the spring state survey data because the resource is distributed along the shelf break at that time. This decision had industry support. In the fall, each individual state survey does not cover much spatial area and so is unlikely to be indicative of stockwide abundance. Thus, it was decided to combine the state surveys; however, the WG also did not want to include numerous noisy surveys with little information content. Two criteria were established for a survey to be considered: 1) the survey must occur from September-November for temporal alignment with the NEFSC and NEAMAP fall surveys, and 2) time series mean percent positive tows must be greater than or equal to 50%. For the latter, the NEFSC mean percent positive tows -2SD (50.4%) was initially considered as a threshold, but some WG members had concerns about tying the criteria to any one survey and that the criteria would ultimately change through time. Given that the assessment already had 2 fall surveys thought to be relatively reliable (NEFSC and NEAMAP), it was not “data-poor,” and the WG was not motivated to be inclusive but rather was motivated to include only the state surveys most likely to produce a composite index that reflects changes in coastwide abundance.

Accordingly, a relatively stringent 50% criterion was adopted as a static number not tied to the NEFSC survey. Table 20 shows that 6 state surveys met the September-November and greater than or equal to 50% criteria: MEMDR, MADMF, RIDFW, CTDEEP, NJDFW, and DEDFW.

The state surveys do not collect ages. Thus, the following considerations were what led to the creation of a YOY index rather than indices at age: 1) ALKs from NEFSC and NEAMAP were not used because ALKs can vary temporally and spatially for a variety of reasons (e.g., regional growth differences, schooling behavior) and because there was spatial inconsistency between each state survey and ALK availability; 2) a selectivity curve was not borrowed because it was unclear what the correct selectivity should be for a combination of surveys that catch age 0 and age 1 butterfish for a range of reasons; and 3) developing a YOY index seemed the most reliable because of the ability to distinguish age 0 from other ages based on length frequencies. Although still technically reliant on ALKs, focusing on just age 0 is likely more robust to the concerns described in #1 above. A fall NEAMAP ALK was used as the basis to define length cutoffs because the inconsistent inshore coverage disqualified NEFSC. An aggregate ALK was used because the annual NEAMAP ALKs are noisy, and there were several years that were unable to split the bimodal length frequencies; also, it allowed extension of the ALK back to 2003 (see below). Based on this aggregate ALK, the cutoff was 11.5 cm (i.e., age 0 ≤ 11.5 cm, age 1+ > 11.5 cm).

The start year for the YOY index was 2003 because of the undocumented vessel change in the DEDFW survey in that year. Two other justifications for a more recent start date were: 1) the vessel change in the NJDFW survey in 2001; and 2) the MEDMR survey began in fall 2000. Given the large footprint of the latter relative to the other state surveys (Table 21), the WG did not want to extend the YOY index any further back in time. YOY indices for the 6 state surveys are shown in Figure 55.

Conn (2010) developed a hierarchical model to combine multiple noisy indices into a single index. This method has been used to combine state survey data in the Atlantic menhaden (*Brevoortia tyrannus*) and bluefish (*Pomatomus saltatrix*) assessments (SEDAR 2015; NEFSC 2015a). The approach was adopted in the current assessment to combine the 6 state surveys into a YOY index for butterfish.

Assuming a lognormal error structure, that the indices are subject to process and sampling errors, and that catchability is stationary, each index is related to absolute abundance as:

$$\log(U_{it}) \sim \text{normal}(\log(\mu_t) + \log(q_t), \left(\sigma_{it}^{p}\right)^2 + \left(\sigma_{it}^{s}\right)^2)$$

where q_{it} is the catchability of index i in year t, and σ_{it}^{p} and σ_{it}^{s} are the standard deviations for process and sampling errors, respectively (Conn 2010).

A Bayesian analysis was done to estimate the true trend in relative abundance of recruits, as well as the process error and catchability of each survey. Input parameters and priors were chosen to be the same as Conn (2010), as was done for the Atlantic menhaden and bluefish assessments (SEDAR 2015; NEFSC 2015a). The observed CVs from the respective state surveys were used as the input sampling error.

All posterior simulation was done with OpenBUGS (Lunn et al. 2009) using R2WinBUGS (Sturtz et al. 2005) in the R statistical environment (R Core Team 2019). The model was initialized with 3 chains, ran for 10,000 iterations, had a burn in period of 1,000 iterations, and had a thinning interval of 2. Standard Bayesian diagnostics were used to assess convergence and stability of results.

The combined YOY index is shown in Figure 56.

TOR 3: ESTIMATE ANNUAL FISHING MORTALITY, RECRUITMENT AND STOCK BIOMASS (BOTH TOTAL AND SPAWNING STOCK) FOR THE TIME SERIES, AND ESTIMATE THEIR UNCERTAINTY. INCLUDE RETROSPECTIVE ANALYSES (BOTH HISTORICAL AND WITHIN-MODEL) TO ALLOW A COMPARISON WITH PREVIOUS ASSESSMENT RESULTS AND PROJECTIONS, AND TO EXAMINE MODEL FIT.

Model development was initially done with the Age Structured Assessment Program (ASAP), a statistical catch at age model (Legault and Restrepo, 1999). The "final" ASAP model was then brought into the Woods Hole Assessment Model (WHAM), a state-space model (Stock and Miller 2021), for further development.

ASAP

ASAP is an age-structured model that uses forward computations assuming separability of fishing mortality into year and age components to estimate population sizes given observed catches, catch at age, and indices of abundance. The separability assumption is relaxed by allowing for the selectivity at age to change smoothly over time or in blocks of years. Weights are input for different components of the objective function, which allows for relatively simple age-structured production models to fully parameterized statistical catch at age models. The objective function is the sum of the negative log-likelihood of the fit to various model components. Fishery and survey age compositions are modeled assuming a multinomial distribution, while all other model components are assumed to have lognormal error distributions. Diagnostics include index fits, residuals in catch and catch at age, and effective sample size calculations. ASAP version 3 (https://noaa-fisheries-integrated-toolbox.github.io/ASAP) is widely used for stock assessments in the region.

ASAP version 4 (hereafter ASAP4; Miller and Legault 2015) was developed, in part, for the previous butterfish benchmark assessment (NEFSC 2014). Two of the new features in ASAP4 were: 1) catchability could be modeled as the product of availability and efficiency, the former specified with a thermal habitat availability index based on bottom temperature; and 2) estimation of *M*. Although several other assessments have considered the use of ASAP4, butterfish was the only stock for which it became the accepted assessment model. ASAP4 is no longer supported, as NEFSC resources have been shifted to WHAM.

The WG decided to revert back to ASAP3 for initial model development. There were 2 reasons for this: 1) as noted above, ASAP4 is no longer supported; and 2) the thermal habitat availability index was last updated with data through 2015 and will no longer be updated.

Following a bridge from ASAP4, there were 36 documented model runs in ASAP3 (Table 22). Highlights of the model runs include switching to catch based on commercial ages (run 001); splitting the NEFSC fall Albatross and Bigelow into separate time series (run 002); combining the fall inshore and offshore (run 003); and adding Gulf of Maine strata (run 004). Additional surveys were then added: NEFSC spring Albatross and Bigelow (run 005); spring NEAMAP (run 006); and the YOY index (run 007). Runs 010 to 015 allowed each of the surveys to freely estimate selectivity for ages > 0 in the fall and ages > 1 in the spring. Catch selectivity at age was evaluated in runs 018 to 020 with fixing age 3 (run 019) having the best diagnostics.

All runs up to this point had a strong penalty on the fall Albatross *q* that was carried forward from SAW 58. Runs 021 and 022 relaxed this prior (Table 22), which resulted in many highly correlated scale parameters and an unrealistic increase in SSB. A likelihood profile was done over *M*, ranging from 0.60-1.30, while freely estimating *q* because the WG ideally wanted to eliminate the prior; however, the scale issues remained. Thus, the prior was deemed a necessity. Then a profile on the CV for the *q* penalty was done to find the point where the penalty could be made as weak as possible but still effective. This value (0.2) was incorporated in run 023.

Subsequent runs included a standard data reweighting procedure (Francis 2011) in runs 025 and 026; switching to annual maturity ogives (run 027); and dropping the spring Albatross due to poor diagnostics (run 028).

A model with a start year of 1973 was attempted in run 031; however, the model did not converge, presumably because there was no information on the early recruitment estimates. Several exploratory runs were then tried. To solve non-convergence, under lambdas-2, the recruitment lambda was set to 1 and CV was set to 1 in all years, which imposes a relatively weak penalty on annual recruitments for deviating from the underlying mean. The model converged, but there were many highly correlated parameters and high CVs in the parameter estimates. Another run was tried with the fall Albatross *q* CV penalty set to 0.15; that solved some problems but the gradient was ~ 25. At this point, it was concluded that there would not be a suitable solution, and the WG decided to return to the 1989 start year.

A second selectivity block was considered due to a pattern in the age composition residuals in run 030, being all negative for young ages and positive for older ages in the last 6 years of the time series; this pattern was caused by a shift in the fishery selectivity when the directed fishery resumed in 2013. The second selectivity block was evaluated with 2 start years: 2013-2019 (run 032) and 2014-2019 (run 033). The latter was chosen for several reasons: 1) while the limited directed fishery technically began in 2013, landings did not really increase until 2014 (Table 11); 2) commercial ages resumed in 2014, whereas 1998-2013 data used the average of all commercial ages (see TOR 1); and 3) diagnostics for run 033 were slightly better, e.g., the root mean square error (RMSE) for catch standardized residuals was 0.72 as compared with 0.85 for run 032.

Configuration of the final ASAP3 model

Biological settings for run 036 were as follows: *M* = 1.278 (see "Natural mortality" section above); annual maturity ogives (Table 23); and the fraction of year at spawning = 0.5.

A single fishing fleet was specified, with two selectivity blocks (1989-2013 and 2014-2019). For both blocks, selectivity was fixed at 1 for age 3 and freely estimated for all other ages. Catch mean weight at age is shown in Table 24, and the proportions of catch at age in weight are shown in Table 25. Empirical CVs (Table 10) were used due to the uncertainties in the discards described in TOR 1. Effective sample size was 41 based on a standard data reweighting procedure (Francis 2011).

Six of the survey indices described in TOR 2 made it into the final ASAP3 model: 1) NEFSC fall Albatross; 2) NEFSC fall Bigelow; 3) NEAMAP fall; 4) NEFSC spring Bigelow; 5) NEAMAP spring; and 6) the YOY index. Survey selectivities are summarized in Table 26. Empirical CVs (Tables 14 and 17) were multiplied by the respective RMSEs from the first step of the data reweighting procedure in run 025 (Table 27), with any resulting CVs greater than 0.9 set to that value. Effective sample sizes are summarized in Table 28.

Diagnostics for the final ASAP3 model

Objective function components for the final ASAP3 model are shown in Table 29. RMSEs for data components for the final model were generally close to 1 (Table 30), and survey indices were all within the 95% confidence interval for their respective sample sizes, i.e. number of years (Figure 57).

The aggregate fishery catches predicted by the model closely followed the observed catches (Figure 58). No trends were apparent in the catch age composition data (Figure 59).

Diagnostics for the survey indices are shown in Figures 60-65. The WG noted that the run of negative residuals for the most recent 5 years in the fall NEAMAP survey (Figure 62) should be monitored in the future; otherwise, no other trends in the survey indices were apparent. No trends were observed in the survey age composition data either (Figures 66-70).

Results for the final ASAP3 model

Estimated fishery selectivity was dome-shaped, with butterfish fully selected at age 3 in both blocks (Figure 71). Survey selectivities varied: both fall NEFSC surveys were fully selected at age 0, while the spring Bigelow was fully selected at age 1; for NEAMAP, the fall survey was fully selected at ages 0 and 1, while the spring survey was fully selected at ages 1 and 2 (Figure 72). Catchability (q) was highest for the fall and spring Bigelow surveys (0.57 and 0.53, respectively) and lowest for the YOY index (Figure 73).

SSB was estimated to be 51,801 mt in 2019, and ranged from 32,446 mt in 2008 to 146,300 mt in 1990 (Table 31; Figure 74). Estimates of SSB were mostly precise, with CVs $\leq$ 0.30 in all but the first 3 years of the time series, as well as the last 2 years (Table 31; Figure 75).

Fishing mortality was estimated to be 0.30 in 2019, the highest value in the time series (Table 31; Figure 74). Fishing mortality averaged 0.08 between 1989 and 2013 but has averaged 0.20 since 2014. With the exception of 1998 and 2003, CVs for F varied between 0.30 and 0.58 (Table 31; Figure 75).

Retrospective for the final ASAP3 model

An internal model retrospective analysis was done using the standard 7-year peel, even though the selectivity block changed over the retrospective period. Mohn's rho (Mohn 1999) was -0.091, -0.009, and -0.088 for F, SSB, and recruits, respectively (Figure 76).

WHAM

WHAM is a state-space model that can implement random effects on interannual transitions in NAA, M, and selectivity (Stock and Miller 2021). There is functionality built into WHAM to migrate ASAP input files to R inputs needed for WHAM. Table 33 shows that there are 6 standard NAA models in WHAM (Stock and Miller WP). The "Base" model approximates ASAP by estimating recruitment deviations as independent fixed effect parameters. WHAM can also treat only recruitment (NAA1 and NAA2) or numbers at all ages (NAA3, NAA4, and NAA5) as random effects. Models with only recruitment as random effects are technically state-space models and thus models with all NAA as random effects are referred to as "full state-space models" (i.e., they include process error on the NAA transitions).

Table 5 in the Stock and Miller WP shows that there were 25 model runs in WHAM. Some brief highlights of these model runs include: estimating q of the fall Albatross (same scale issues as in ASAP); estimating M (0.9-1.0 was lower than the ASAP4 estimate of 1.278 but not supported by the Akaike Information Criterion [AIC; Burnham and Anderson 2002]); and exploring different age composition likelihood options (ASAP assumes multinomial likelihood; Dirichlet-multinomial did not converge; logistic-normal converged). Finally, it was possible to estimate Beverton-Holt parameters for some WHAM models; however, this was deemed inappropriate because recruits in the butterfish assessment are age 0, and WHAM assumes age 1 recruits enter the population on January 1.

The best WHAM model for butterfish was 17-NAA5 (Stock and Miller WP). The model selection procedure to determine the best WHAM model is shown in Appendix 1 (which was drafted at the request of the panel during the peer review). Briefly, 17-NAA5 had a much higher convergence rate than competing models in simulation self-tests and did marginally better in prediction skill. It also had some other attractive features related to objectivity and parsimony

Configuration of the best WHAM model

The input data file for 17-NAA5 only differed from ASAP3 run 36 in 2 minor ways: 1) the fall Albatross *q* was fixed at the estimate from ASAP3 run 36 (0.197517), which had lower AIC than the input value (0.21); and 2) the spring NEAMAP age 2 selectivity was fixed at 1. There were 2 key settings of 17-NAA5: 1) it estimated all NAA as random effects with first-order autoregressive, AR(1), correlation by year but independent across ages; and 2) it used a logistic-normal age composition likelihood. WHAM version 1.0.5.9000 was used to generate the diagnostics, results, and retrospectives for 17-NAA5 that are detailed below. It should be noted that WHAM version 1.06, which added the one-step ahead (OSA) prediction quantile residuals for age compositions, was not released until April 8, 2022, 1 month after the butterfish peer review was over. Thus, these diagnostics are not presented in this report as they were not considered during the peer review.

Diagnostics for the best WHAM model

Conditional log-likelihood components for the best WHAM model are shown in Figure 77.

The aggregate fishery catches predicted by the model closely followed the observed catches (Figure 78). With the exception of 1 outlier, the OSA residuals for the aggregate catch are normally distributed (Figure 79). No trends were apparent in the catch age composition data (Figure 80).

Diagnostics for the survey indices are shown in Figures 81-86. Similar to ASAP3 run 36, there was a run of negative residuals for the most recent 5 years in the fall NEAMAP survey (Figure 83). Additionally, there was a run of negative residuals for the most recent 5 years in the YOY index (Figure 86). Both indices should be monitored in the future to see if this persists. OSA residuals for all indices are uncorrelated and normally distributed (Figures 87-92). There was no apparent trend for any of the survey age composition residuals (Figures 93-97).

As noted above, 17-NAA5 was chosen over competing models primarily on the basis of two diagnostics: simulation self-tests and prediction skill. Briefly, simulation self-tests (Deroba et al. 2015) were done by simulating 100 datasets, keeping all fixed effect parameters at the maximum likelihood estimates; then refitting the models to these simulated datasets, and calculating the convergence rate and relative error in SSB, F, recruitment, and predicted catch. The convergence rate for 17-NAA5 was 95%. Figure 98 shows the relative error for 17-NAA5.

Predictive skill was evaluated by sequentially removing aggregate and age composition data for 1 index at a time, refitting the model and predicting the removed data. Mean absolute scaled error (MASE; Carvalho et al. 2021; Kell et al. 2021) of the predictions was calculated over time horizons used to provide butterfish management advice, i.e., 1-3 years. MASE over the 3-year prediction horizon for 17-NAA5 is shown in Figure 99.

Results for the best WHAM model

Estimated fishery selectivity was dome-shaped, with butterfish fully selected at age 3 in both blocks (Figure 100). Survey selectivities varied: both fall NEFSC surveys were fully selected at age 0, while the spring Bigelow was fully selected at age 1; the NEAMAP fall survey was fully selected at ages 0 and 1, while the spring survey was fully selected at ages 1 and 2 (Figure 101).

SSB was estimated to be 78,579 mt in 2019, and ranged from 44,944 mt in 2013 to 120,237 mt in 1993 (Table 32; Figure 102). Estimates of SSB were mostly precise, with CVs ≤ 0.30 in all but the first 2 years of the time series (Table 32).

Fishing mortality was estimated to be 0.24 in 2019, the fourth highest value in the time series (Table 32; Figure 102). Fishing mortality averaged 0.09 during 1989-2013 but has averaged 0.21 since 2014. CVs for *F* were ≤ 0.30 in only 5 years (Table 32).

Recruitment in 2019 was estimated to be 3.9 billion butterfish, the lowest value in the time series (Table 32). Recruitment estimates were generally precise, with CVs ≤ 0.30 in all years except the first year of the time series (Table 31; Figure 75).

Retrospective for the best WHAM model

An internal model retrospective analysis was done using the standard 7-year peel, even though the selectivity block changed over the retrospective period. Mohn’s rho (Mohn 1999) was 0.018, 0.089, and 0.08 for F, SSB, and recruits, respectively (Figures 103-105).

Historical retrospective

Historical retrospectives are shown in Figures 106-108. As a reminder, the terminal year (2019) for the current assessment was the same as the 2020 MT.

The historical retrospective for fishing mortality is shown in Figure 106. *F* increases markedly in 2014, which corresponds to when landings increased after the resumption of the directed fishery.

The historical retrospective for SSB is shown in Figure 107. The WHAM 17-NAA5 model has the highest SSB estimates for the most recent 6 years.

The historical retrospective for recruitment is shown in Figure 108. The WHAM 17-NAA5 model has the highest recruitment estimates for the most recent 5 years. It is worth noting that terminal year estimates of recruitment in the ASAP models were consistently revised upward as additional years of data were added. For example, the terminal year (2012) estimate in SAW 58 was revised upward in the 2017 model update. Similarly, the terminal year (2016) estimate in the 2017 model update was revised upward in the 2020 MT.

TOR4: UPDATE OR REDEFINE STATUS DETERMINATION CRITERIA (SDC POINT ESTIMATES OR PROXIES FOR BMSY, BTHRESHOLD, FMSY AND MSY) AND PROVIDE ESTIMATES OF THEIR UNCERTAINTY. IF ANALYTIC MODEL-BASED ESTIMATES ARE UNAVAILABLE, CONSIDER RECOMMENDING ALTERNATIVE MEASURABLE PROXIES FOR BRPS. COMMENT ON THE SCIENTIFIC ADEQUACY OF EXISTING BRPS AND THE "NEW" (I.E., UPDATED, REDEFINED, OR ALTERNATIVE) BRPS.

The existing F_{MSY} proxy is 2/3*M* based on Patterson (1992). However, the methods used by Patterson (1992) were intended to identify a reference point that would induce stability in biomass and not necessarily identify an F_{MSY} proxy. Furthermore, Patterson (1992) used VPA estimates of biomass and exploitation rate, and VPA estimates are known to produce spurious trends under many circumstances (Lapointe et al. 1989; Lapointe et al. 1992), and the use of stock assessment output as data without due consideration of uncertainty has also been criticized (Brooks and Deroba 2015).

An $F_{40\%}$ proxy was briefly considered but was abandoned because it was unrealistically high (i.e., ~10), and $B_{40\%}$ was less than any biomass in the time series.

The WG also considered a B_{loss} approach (e.g., Hauge et al. 2007) but abandoned this because the stock does not appear to have ever been depleted (Figure 109). Thus, B_{loss} would have equated to using a B_{proxy} near the unfished level.

Ultimately, the WG decided to assume a symmetrical production curve, where $B_{MSY} = 0.5 \times B_0$ (in the absence of a stock-recruit curve, this equates to $B_{50\%SPR}$) and overfished = $0.5 \times B_{MSY}$. Two advantages to this approach were noted: 1) it has classical theoretical underpinnings that make it defensible relative to the previously considered alternatives; and 2) it is generally in line with the MAFMC Ecosystem Approach to Fisheries Management guidance for forage fish. With respect to the latter, ogives for maturity, selectivity, and *M* suggested a stock with MSY levels likely far less than $0.5 \times B_0$ (i.e., an asymmetrical production curve); thus, some forage conservatism is inherent.

$F_{50\%SPR}$ and $B_{50\%SPR}$ were calculated assuming: 1) average recruitment over 2011-2019; and 2) average SSB per recruit over 2015-2019 (selectivity, maturity, weights at age). For assumption 1, 2011 was chosen as the start year based on the analysis of L Smith (WP) that showed a regime shift in butterfish condition starting in that year; for assumption 2, the most recent 5 years is the standard in the region. Further details of the reference point calculations can be found in the Stock and Miller WP.

Reference points are: $B_{MSY} = B_{50\%SPR}$ = 37,597 mt; and $F_{MSY} = F_{50\%SPR}$ = 6.68 (Stock and Miller WP).

TOR 5: MAKE A RECOMMENDED STOCK STATUS DETERMINATION (OVERFISHING AND OVERFISHED) BASED ON NEW MODELING APPROACHES DEVELOPED FOR THIS PEER REVIEW.

Table 34 shows that in 2019, the butterfish stock was not overfished ($B_{2019}/B_{50\%} > 1$) or experiencing overfishing ($F_{2019}/F_{50\%} < 1$). It should be noted that the uncertainty in $B_{2019}/B_{50\%}$ and $F_{2019}/F_{50\%}$ results from uncertainty in F and SSB in 2019 alone. Further details of the status determination calculations can be found in the Stock and Miller WP.

TOR 6: DEFINE THE METHODOLOGY FOR PERFORMING SHORT-TERM PROJECTIONS OF CATCH AND BIOMASS UNDER ALTERNATIVE HARVEST SCENARIOS, INCLUDING THE ASSUMPTIONS OF FISHERY SELECTIVITY, WEIGHTS AT AGE, AND MATURITY.

Details of the projection methodology can be found in the Stock and Miller WP. Briefly, the assumption that the NAA deviations followed an AR(1) process was continued into the projection period for consistency. Projections for catch advice are not typically done in a RT but in a MT that follows shortly thereafter (for butterfish, 3-years projections for catch advice were done in the June 2022 MT). Thus, for the RT, projections were done under 3 scenarios to demonstrate how they might be done in WHAM:

- $F = 0$
- $F = F_{2019}$ (0.237)
- $F = F_{50\%}$

The assumptions of fishery selectivity, weights at age, and maturity were the same as for the reference points.

Projection results are shown in Figures 110-113. The effect of treating projected recruitment as a continuation of the AR(1) process can be seen in all 3 scenarios as it gradually approaches the 2011-2019 average recruitment.

TOR7: REVIEW, EVALUATE AND REPORT ON THE STATUS OF THE STOCK ASSESSMENT REVIEW COMMITTEE (SARC) AND WORKING GROUP RESEARCH RECOMMENDATIONS LISTED IN MOST RECENT SARC REVIEWED ASSESSMENT AND REVIEW PANEL REPORTS, AS WELL AS THE MOST RECENT MANAGEMENT TRACK ASSESSMENT REPORT. IDENTIFY NEW RESEARCH RECOMMENDATIONS.

Research recommendations from the 2014 SARC-reviewed assessment:

1. Encourage field experiments to examine efficiency and catchability of survey gear for the benefit of improving assessment models. Particular emphasis should be on the catchability of the Bigelow net configuration – *This research recommendation has not been completed and has been carried forward in the new research recommendations developed during the 2021 research track assessment.*
2. Explore the possibility of spawning south of Cape Hatteras, NC and potential contribution to the northern stock – *This research recommendation has not been completed and has been carried forward in the new research recommendations developed during the 2021 research track assessment.*
3. Continue development of the modified ASAP model incorporating environmental covariates, particularly the addition of additional survey *q*s – *This research recommendation has not been completed because of the switch to the WHAM model; however, environmental covariates may be considered in the future.*
4. The current estimate of F implies that existing fisheries have little impact on the stock dynamics. The WG recommends no additional assessments be conducted until such time as the fishery has developed to the point that it could influence the total stock biomass – *The current 2021 research track assessment includes 7 years of data since the resumption of the directed fishery in 2013.*

Research recommendations from the 2020 MT assessment:

1. Weights-at-age. As described above, the mean weights-at-age for a cohort indicated fish were not growing between ages 0 and 1 or were shrinking between ages 3 and 4+ in some years. Alternative approaches for estimating mean weights at age should be considered (e.g., averaging across years instead of using individual years). – *This research recommendation has been completed. As noted in the caption for Table 24, the age 4+ values for 1996 and 1997 were interpolated as the previous year's age 3 value plus the time series average change from age 3 to age 4+.*
2. Fishery selectivity. Currently fishery selectivity is specified at 1.0 for ages 2-4+. However, a pattern in the age composition residuals indicates that selectivity for age-2 may be lower than that for age-3. The PRC [Peer Review Committee] recommends reconsidering a selectivity function that estimates the age-2 fishery selectivity. Changing the fishery selectivity may affect the estimated natural mortality rate. – *This research recommendation has been completed. Selectivity*

was freely estimated for all ages as part of model development in ASAP3, with selectivity for age 3 eventually being fixed at 1.

3. Reconsider the fishing mortality rate reference point. Recent research has suggested that using FMSY ≈ 2/3 M may not be a robust approximation. – *This research recommendation has been completed. Several alternatives were considered, and B_0 based reference points were adopted.*
4. Given the observation of declining recruitment with declining stock size, it may be possible to estimate a stock-recruitment function for this stock which could be used for reference point estimation. – *WHAM could not estimate a stock-recruitment function internal to the model for butterfish because it assumes recruits are age 1; however, this may be possible if age 0 functionality is added to the WHAM model in the future.*

New research recommendations developed during the 2021 RT assessment:

1. Encourage field experiments to examine efficiency and catchability of survey gear for the benefit of improving assessment models. Particular emphasis should be on the catchability of the Bigelow net configuration.
2. Explore the possibility of spawning south of Cape Hatteras, NC and potential contribution to the northern stock.
3. Reevaluate the stock-recruitment relationship if age 0 functionality is added to the WHAM model.
4. Consider adding an acoustic index to the model if ongoing Stock Assessment Improvement Plan (SAIP) funded research is able to successfully develop a target strength model for butterfish.
5. Continue to monitor butterfish spatial distribution in response to climate change. The distribution of butterfish on the shelf has changed in recent warm years, likely affecting catchability and selectivity. While work is ongoing (e.g., Kentner WP), this work will be of increasing importance and should continue.
6. The assessment has a scale issue that requires fixing or strongly penalizing a catchability parameter to prevent unrealistically high biomass estimates. The initial work used to derive the input catchability parameter is no longer being supported. Continued work to externally derive scale parameters (e.g., *M*, *q* [see #1 above]) may help address this problem in the future.

TOR 8: DEVELOP A "PLAN B" FOR USE IF THE ACCEPTED ASSESSMENT MODEL FAILS IN THE FUTURE.

The WG recommends the Plan B smooth if the accepted model fails in the future. This peer-reviewed method has been used to set catch advice for Georges Bank cod, *Gadus morhua* (NEFSC 2015b, 2017), and was approved by the Assessment Oversight Panel for use as the backup plan for the butterfish 2020 MT assessment. Briefly, the Plan B approach combines the NEFSC spring and fall surveys into an average index, then a loess smoother is applied to the average index (with a span = 0.3). The predicted loess smoothed values in the final 3 years are used in a log-linear regression to estimate the slope, and this slope (transformed back to the linear scale) is used to adjust the most recent 3-year average catch to generate catch advice.

For butterfish, the proposed Plan B smooth uses 4 surveys: the NEFSC spring and fall Bigelow and the spring and fall NEAMAP indices. All 4 surveys are standardized to their time series mean, and missing years (e.g., NEFSC fall 2017, NEAMAP spring 2017) are removed from the averaging. Results indicate a multiplier of 1.041 for the data used in the current assessment (Figure 113). Average catch for 2017-2019 is 4258 mt (Table 2); thus, catch advice would be 4433 mt.

ADDITIONAL TERMS OF REFERENCE

ATOR1: Describe life history characteristics and the stock's spatial distribution, including any changes over time. Describe ecosystem and other factors that may influence the stock's productivity and recruitment. Consider any strong influences and, if possible, integrate the results into the stock assessment.

Life history characteristics of butterfish are described above in the "Biology" section. Spatial distribution is described in the Adams and Kentner WPs; the latter also included future predicted butterfish distributions under 2 contrasting climate change scenarios. Ecosystem effects on productivity are described in the L Smith WP. Results of the latter were used to set the start year for sampling recruitment for setting reference points and projections.

ATOR2: Evaluate consumptive removals of butterfish by its predators, including (if possible) marine mammals, seabirds, tunas, swordfish and sharks. If possible, integrate results into the stock assessment.

Consumptive removals of butterfish are detailed in several WPs: by finfish (B Smith); marine mammals (L Smith); and seabirds (Vincent). All 3 analyses found the amount of consumptive removals to be negligible. Thus, these results were not integrated into the assessment.

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TABLES AND FIGURES

Table 1. Number of butterfish (*Peprilus triacanthus*) age samples from Northeast Fisheries Science Center spring and fall bottom trawl survey data, 1982-2019.

Age	Spring	Fall
0		19087
1	8388	7034
2	3472	3442
3	1733	645
4	296	58
5	31	3
6	5	1

Table 2. Butterfish (*Peprilus triacanthus*) landings (mt), historic discards (mt), estimated discards (mt), foreign catch (mt), and total catch (mt), 1965-2019. Landings from 1976-1986 include discards, which were assumed by Waring and Anderson (1983) and SAW 10 (NEFSC 1990) to be 10% of landings; these discards were estimated in SAW 49 (NEFSC 2010) and are shown here as historic discards. Foreign catch includes discards, which were estimated by dividing longfin squid (*Doryteuthis* [Amerigo] *pealeii*) catch by survey ratios to account for butterfish discards of countries reporting only longfin (Murawski and Waring 1979; NEFC 1990).

Year	Landings	Historic Discards	Discards	Foreign Catch	Total Catch
1965	2944		11474	749	15167
1966	2461		10997	3865	17323
1967	2245		10174	2316	14735
1968	1585		9856	5437	16878
1969	2198		9421	15378	26997
1970	1731		8760	12450	22941
1971	1566		7977	8913	18456
1972	704		6653	12221	19578
1973	1521		6696	31679	39896
1974	1778		6197	15465	23440
1975	1973		5658	12764	20395
1976	1376	152	6193	14437	22006
1977	1296	152	7255	3312	11863
1978	3615	61	8675	1699	13989
1979	2646	185	9193	1107	12946
1980	5172	184	9956	1392	16520
1981	4855	0	9531	1400	15786
1982	8837	68	11098	1578	21513
1983	4743	162	10911	630	16284
1984	11715	257	10257	429	22401
1985	4633	106	8328	804	13765
1986	4418		7936	164	12518
1987	4578		7351		11929
1988	2107		7352		9459
1989	3203		1432		4635
1990	2298		1116		3414
1991	2189		2308		4496
1992	2754		4916		7671
1993	4608		5370		9978
1994	3634		4680		8315
1995	2067		1611		3678
1996	3555		1395		4949
1997	2795		788		3582
1998	1966		4502		6468
1999	2110		10178		12288
2000	1449		3575		5024
2001	4404		3309		7713
2002	872		2936		3808
2003	536		2616		3152
2004	520		1507		2027
2005	437		781		1218
2006	554		893		1447

Table 2 continued. Butterfish (*Peprilus triacanthus*) landings (mt), historic discards (mt), estimated discards (mt), foreign catch (mt), and total catch (mt), 1965-2019. Landings from 1976-1986 include discards, which were assumed by Waring and Anderson (1983) and SAW 10 (NEFSC 1990) to be 10% of landings; these discards were estimated in SAW 49 (NEFSC 2010) and are shown here as historic discards. Foreign catch includes discards, which were estimated by dividing longfin squid (*Doryteuthis* [Amerigo] *pealeii*) catch by survey ratios to account for butterfish discards of countries reporting only longfin (Murawski and Waring 1979; NEFC 1990).

Year	Landings	Historic Discards	Discards	Foreign Catch	Total Catch
2007	678		205		883
2008	451		976		1428
2009	435		850		1285
2010	576		742		1317
2011	664		1482		2146
2012	640		996		1636
2013	1091		441		1532
2014	3135		1054		4189
2015	2104		830		2934
2016	1194		1537		2731
2017	3681		948		4629
2018	1673		1388		3061
2019	3431		1655		5085

Table 3. Butterfish (*Peprilus triacanthus*) commercial length samples, total number of lengths sampled, age samples, and total number of ages sampled.

	Length		Age	
Year	Samples	Number	Samples	Number
1989	28	2818	24	519
1990	34	3405	29	747
1991	30	3005	30	601
1992	25	2517	19	481
1993	21	2165	18	332
1994	14	1285	2	2
1995	6	688	2	2
1996	16	1727	12	307
1997	31	3075	10	265
1998	25	2361		
1999	28	2725		
2000	9	912		
2001	28	2911		
2002	12	1243	2	50
2003	28	2947		
2004	41	4094		
2005	38	3827		
2006	49	5051		
2007	63	6431		
2008	42	4091		
2009	25	2451		
2010	32	3241		
2011	24	2364		
2012	22	2111		
2013	33	3027		
2014	33	3137	18	450
2015	30	2913	11	275
2016	29	2841	11	271
2017	29	2750	6	152
2018	29	2900	23	575
2019	27	2700	13	313

Table 4. Summary of imputations required to fill holes in the length sampling of butterfish (*Peprilus triacanthus*) landings.

	January-June					July-December				
Year	Unclassified	Medium	Large	Large/mix	Jumbo	Unclassified	Medium	Large	Large/mix	Jumbo
1989	None	None	1990s	1990s	2000s	None	None	1990s	1990s	2000s
1990	None	None	1990s	None	2000s	None	None	1990s	None	2000s
1991	None	None	1990s	None	2000s	None	None	None	1990s	2000s
1992	None	None	None	1990s	2000s	None	None	1990s	1990s	2000s
1993	None	None	1990s	1990s	2000s	None	None	1990s	1990s	2000s
1994	None	1990s	1990s	1990s	2000s	None	None	1990s	1990s	2000s
1995	None	None	1990s	1990s	2000s	None	1990s	1990s	1990s	2000s
1996	None	1990s	1990s	1990s	2000s	None	None	1990s	1990s	2000s
1997	None	None	None	1990s	2000s	None	None	None	1990s	2000s
1998	None	None	None	1990s	2000s	None	None	1990s	1990s	2000s
1999	None	None	None	1990s	2000s	None	None	1990s	1990s	2000s
2000	None	None	2000s	2000s	2000s	None	None	None	2000s	2000s
2001	None	None	None	2000s	2000s	None	2000s	2000s	None	2000s
2002	None	2000s	None	2000s	2000s	None	2000s	None	2000s	None
2003	None	2000s	None	2000s	2000s	None	None	None	None	2000s
2004	None	None	None	None	2000s	None	None	None	2000s	2000s
2005	None	None	None	2000s	2000s	None	None	None	None	2000s
2006	None	None	None	2000s	2000s	None	None	None	2000s	None
2007	None	None	None	None	None	None	None	None	None	None
2008	None	2000s	None	None	None	None	None	None	None	2000s
2009	None	None	None	2000s	2000s	None	2000s	None	2000s	2000s
2010	None	None	None	2000s	2000s	None	None	None	2000s	2000s
2011	None	None	None	2000s	2000s	None	2010s	2010s	2000s	2000s
2012	None	None	None	2000s	2000s	None	2010s	None	2000s	2000s
2013	None	None	None	2000s	2000s	None	None	None	2000s	2000s
2014	None	None	None	2000s	2000s	None	None	None	2000s	2000s
2015	None	None	None	2000s	2000s	None	None	None	2000s	2000s
2016	None	None	None	2000s	2000s	None	None	2010s	2000s	2000s
2017	None	None	None	2000s	2000s	None	None	None	2000s	2000s
2018	None	None	None	2000s	2000s	None	None	None	2000s	2000s
2019	None	None	None	2000s	2000s	None	None	None	2000s	2000s

Table 5. Butterfish (*Peprilus triacanthus*) commercial age samples by market category. There are no age samples for the market category super super small.

Year	Unclassified	Extra small	Small	Medium	Large	Large/mix	Jumbo
1989	92	19	332	76			
1990	118		250	277		102	
1991	263	23	156	122	20	17	
1992	164	43	181	72	21		
1993	160		83	89			
1994	2						
1995	2						
1996	278			29			
1997	126		26	88	25		
1998							
1999							
2000							
2001							
2002					25		25
2003							
2004							
2005							
2006							
2007							
2008							
2009							
2010							
2011							
2012							
2013							
2014	279		25	121	25		
2015	50	77	72	51	25		
2016	171	25	25	25	25		
2017	100		27	25			
2018	424	25		77	49		
2019	238		25	25	25		

Table 6. Estimated butterfish (*Peprilus triacanthus*) discards (mt) and associated coefficients of variation (CV).

Year	Discards	CV
1989	1432	0.36
1990	1116	0.42
1991	2308	0.22
1992	4916	0.27
1993	5370	0.39
1994	4680	0.73
1995	1611	0.91
1996	1395	0.75
1997	788	1.07
1998	4502	1.87
1999	10178	0.36
2000	3575	0.52
2001	3309	0.57
2002	2936	0.70
2003	2616	1.52
2004	1507	0.30
2005	781	0.22
2006	893	0.84
2007	205	0.70
2008	976	0.63
2009	850	0.35
2010	742	0.20
2011	1482	0.16
2012	996	0.36
2013	441	0.20
2014	1054	0.20
2015	830	0.19
2016	1537	0.17
2017	948	0.16
2018	1388	0.14
2019	1655	0.16

Table 7. Butterfish (*Peprilus triacanthus*) estimated discards for bottom trawls fish (OTF) and twin (OTT), total discards (mt), and proportion OTF/OTT.

Year	OTF/OTT	Total	Proportion
1989	1431	1432	0.99996
1990	1115	1116	0.99957
1991	2304	2308	0.99861
1992	4914	4916	0.99950
1993	5369	5370	0.99975
1994	4677	4680	0.99928
1995	1606	1611	0.99685
1996	1390	1395	0.99651
1997	780	788	0.99072
1998	4501	4502	0.99975
1999	10177	10178	0.99989
2000	3574	3575	0.99970
2001	3304	3309	0.99849
2002	2936	2936	0.99987
2003	2614	2616	0.99895
2004	1506	1507	0.99886
2005	779	781	0.99784
2006	892	893	0.99847
2007	204	205	0.99656
2008	971	976	0.99401
2009	849	850	0.99852
2010	739	742	0.99701
2011	1480	1482	0.99848
2012	974	996	0.97799
2013	440	441	0.99695
2014	1052	1054	0.99843
2015	830	830	0.99942
2016	1535	1537	0.99823
2017	947	948	0.99857
2018	1382	1388	0.99547
2019	1654	1655	0.99939

Table 8. Total kept of all species (mt), number of observed trips, discard rate, estimated butterfish (*Peprilus triacanthus*) discards (mt), and coefficient of variation (CV) for bottom trawl (fish and twin) and mesh size < 4 inches in New England and Mid-Atlantic waters.

	New England					Mid-Atlantic				
Year	Kept all	Trips	Ratio	Discards	CV	Kept all	Trips	Ratio	Discards	CV
1989	22495	72	0.03237	728	0.31	28941	29	0.01984	574	0.81
1990	23271	33	0.00610	142	1.38	30465	31	0.02447	745	0.53
1991	21162	84	0.04088	865	0.33	35963	61	0.03442	1238	0.33
1992	20235	56	0.10596	2144	0.51	37601	39	0.06996	2631	0.28
1993	23887	21	0.00772	184	0.64	41655	34	0.03213	1339	0.73
1994	23669	38	0.12071	2857	1.14	37411	23	0.04382	1639	0.65
1995	17469	73	0.00400	70	0.88	31063	60	0.03833	1191	1.20
1996	23673	49	0.01150	272	1.17	35478	71	0.02892	1026	0.79
1997	18546	38	0.00774	144	2.19	37957	42	0.01009	383	2.00
1998	23221	18	0.02536	589	0.80	42115	57	0.00298	126	1.07
1999	21901	38	0.04686	1026	0.63	27577	30	0.15753	4344	0.65
2000	18214	30	0.11769	2144	0.70	27252	28	0.04472	1219	0.89
2001	20196	30	0.03520	711	0.33	18177	42	0.00789	143	4.44
2002	13114	74	0.01681	220	1.22	16772	15	0.14032	2353	0.85
2003	14152	49	0.01725	244	0.52	16318	26	0.14254	2326	1.71
2004	12898	92	0.06155	794	0.41	39468	126	0.01563	617	0.49
2005	11400	87	0.01361	155	0.33	22039	82	0.02645	583	0.27
2006	10635	50	0.01375	146	0.43	42151	106	0.01030	434	1.71
2007	13592	58	0.00945	128	0.48	18670	109	0.00186	35	3.64
2008	10818	46	0.05352	579	0.93	23398	82	0.01493	349	0.84
2009	14414	196	0.02477	357	0.34	25700	191	0.01769	455	0.60
2010	10728	210	0.03148	338	0.28	24265	202	0.01521	369	0.31
2011	12683	164	0.01843	234	0.31	29304	239	0.04200	1231	0.18
2012	14348	138	0.02225	319	0.25	24964	143	0.02541	634	0.56
2013	13121	191	0.01761	231	0.29	21294	220	0.00946	201	0.27
2014	18196	286	0.03154	574	0.21	18838	234	0.02367	446	0.38
2015	15601	243	0.02779	433	0.23	11980	183	0.03076	369	0.32
2016	16912	285	0.04030	682	0.18	17716	393	0.04486	795	0.29
2017	17276	592	0.03306	571	0.15	22024	605	0.01424	314	0.39
2018	12953	361	0.04865	630	0.18	31110	528	0.02264	704	0.22
2019	21427	259	0.04140	887	0.25	24110	526	0.03058	737	0.20

Table 9. Total kept of all species (mt), number of observed trips, discard rate, estimated butterfish (*Peprilus triacanthus*) discards (mt), and coefficient of variation (CV) for bottom trawl (fish and twin) and mesh size ≥ 4 inches in New England and Mid-Atlantic waters.

	New England					Mid-Atlantic				
Year	Kept all	Trips	Ratio	Discards	CV	Kept all	Trips	Ratio	Discards	CV
1989	69161	68	0.00015	10	0.56	13761	21	0.00863	119	0.37
1990	90606	55	0.00239	216	0.74	13775	18	0.00086	12	0.65
1991	88291	91	0.00103	91	0.56	20783	22	0.00531	110	0.46
1992	78026	69	0.00014	11	0.79	25587	24	0.00501	128	1.17
1993	63576	54	0.05491	3491	0.53	14415	19	0.02463	355	0.57
1994	55642	40	0.00244	136	0.78	19146	29	0.00233	45	0.57
1995	49998	69	0.00551	275	1.06	14280	58	0.00493	70	1.14
1996	56171	45	0.00085	48	11.78	14737	27	0.00299	44	1.08
1997	50458	32	0.00129	65	0.58	13349	31	0.01411	188	0.88
1998	53591	28	0.02868	1537	1.51	16976	17	0.13253	2250	3.60
1999	49448	41	0.05686	2812	0.66	15659	43	0.12740	1995	0.63
2000	55503	110	0.00368	204	0.87	12806	38	0.00060	8	0.54
2001	64016	168	0.01117	715	0.67	11688	63	0.14844	1735	0.98
2002	60164	246	0.00594	357	1.22	11553	111	0.00040	5	0.53
2003	61809	408	0.00069	43	1.01	11738	64	0.00006	1	0.68
2004	75169	605	0.00092	69	0.49	14592	249	0.00176	26	0.70
2005	53845	1497	0.00004	2	0.48	18468	194	0.00211	39	0.42
2006	40044	651	0.00015	6	0.75	18032	118	0.01693	305	0.19
2007	39152	638	0.00079	31	0.79	10032	273	0.00098	10	0.50
2008	41616	766	0.00023	9	1.08	8785	203	0.00376	33	0.87
2009	38863	893	0.00032	12	0.49	13495	265	0.00184	25	0.82
2010	37029	1053	0.00031	11	0.43	11822	438	0.00177	21	0.54
2011	35854	1591	0.00009	3	0.33	14018	385	0.00087	12	0.44
2012	38011	1573	0.00007	3	0.31	10898	269	0.00163	18	1.04
2013	33418	1139	0.00008	3	0.29	10033	432	0.00046	5	0.23
2014	31335	1216	0.00017	5	0.32	11047	474	0.00245	27	0.50
2015	27992	926	0.00054	15	0.32	10519	410	0.00119	12	0.32
2016	28224	671	0.00184	52	0.37	11169	558	0.00057	6	0.17
2017	32729	779	0.00138	45	0.30	9369	655	0.00175	16	0.31
2018	29930	739	0.00052	16	0.63	10102	564	0.00311	31	0.46
2019	32254	1045	0.00029	9	0.18	9477	649	0.00211	20	0.33

Table 10. Butterfish (*Peprilus triacanthus*) total catch (mt) and associated coefficients of variation (CV).

Year	Catch	CV
1989	4635	0.11
1990	3414	0.14
1991	4496	0.11
1992	7671	0.17
1993	9978	0.21
1994	8315	0.41
1995	3678	0.40
1996	4949	0.21
1997	3582	0.24
1998	6468	1.30
1999	12288	0.30
2000	5024	0.37
2001	7713	0.24
2002	3808	0.54
2003	3152	1.26
2004	2027	0.22
2005	1218	0.14
2006	1447	0.52
2007	883	0.16
2008	1428	0.43
2009	1285	0.23
2010	1317	0.11
2011	2146	0.11
2012	1636	0.22
2013	1532	0.06
2014	4189	0.05
2015	2934	0.05
2016	2731	0.10
2017	4629	0.03
2018	3061	0.06
2019	5085	0.05

Table 11. Comparison of the percent butterfish (*Peprilus triacanthus*) landings and discards for period of no directed fishery (2002-2012) and the recently resumed directed fishery (2013-2019).

Year	Landings	Discards	Total Catch	% Landings	% Discards
2002	872	2936	3808	22.9%	77.1%
2003	536	2616	3152	17.0%	83.0%
2004	520	1507	2027	25.6%	74.4%
2005	437	781	1218	35.9%	64.1%
2006	554	893	1447	38.3%	61.7%
2007	678	205	883	76.8%	23.2%
2008	451	976	1428	31.6%	68.4%
2009	435	850	1285	33.8%	66.2%
2010	576	742	1317	43.7%	56.3%
2011	664	1482	2146	30.9%	69.1%
2012	640	996	1636	39.1%	60.9%
			average	**36.0%**	**64.0%**
Year	Landings	Discards	Total Catch	% Landings	% Discards
2013	1091	441	1532	71.2%	28.8%
2014	3135	1054	4189	74.8%	25.2%
2015	2104	830	2934	71.7%	28.3%
2016	1194	1537	2731	43.7%	56.3%
2017	3681	948	4629	79.5%	20.5%
2018	1673	1388	3061	54.7%	45.3%
2019	3431	1655	5085	67.5%	32.5%
			average	**66.2%**	**33.8%**

Table 12. Vessel and gear differences between the FSV *Henry B. Bigelow* and FRV *Albatross IV* (adapted from Brooks et al. 2010).

Measure	**FSV *Henry B. Bigelow***	**FRV *Albatross IV***
Tow speed	3.0 knots SOG	3.8 knots SOG
Tow duration	20 min	30 min
Headrope height	3.5-4 m	1-2 m
Ground gear	Rockhopper sweep Total length = 25.5 m Center = 8.9 m length, 16" rockhoppers Wings = 8.2 m each 14" rockhoppers	Roller sweep Total length = 24.5 m Center = 5 m length, 16" rollers Wings = 9.75 m each, 4" cookies
Mesh size	Poly webbing Forward portion of trawl = 12 cm, 4 cm Square aft to codend = 6 cm, 2.5 mm Codend = 12 cm, 4 mm dbl Codend liner = 2.54 cm, knotless	Nylon webbing Body of trawl = 12.7 cm Codend = 11.5 cm Liner (codend and aft portion of top belly) = 1.27 cm knotless
Net design	4 seam, 3 bridle	Yankee 36 (recent years)
Other comments	Wing end to door distance = 36.5 m	Wing end to door distance = 9 m

Table 13. Northeast Fisheries Science Center strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years.

Albatross
Offshore (prefix 01)
1-30, 33-40, 61-76
Inshore (prefix 03)
2-46, 55-56, 58-61, 63-66
Bigelow
Offshore (prefix 01)
1-30, 34-40, 61-76
Inshore (prefix 03)
2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44-46, 56, 59-61, 64-66

Table 14. Butterfish (*Peprilus triacanthus*) stratified mean number per tow and coefficients of variation (CV) from the Northeast Fisheries Science Center spring and fall bottom trawl surveys. Strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years are shown in Table 13.

	Spring		Fall	
Year	Number	CV	Number	CV
1989	18.24	0.80	252.79	0.35
1990	5.13	0.44	231.80	0.22
1991	18.25	0.59	122.07	0.40
1992	10.14	0.21	153.77	0.26
1993	14.78	0.39	163.47	0.23
1994	19.85	0.27	321.77	0.44
1995	22.98	0.59	72.51	0.25
1996	6.39	0.39	55.17	0.19
1997	61.68	0.38	162.57	0.11
1998	22.40	0.61	134.95	0.31
1999	42.39	0.59	158.41	0.35
2000	20.13	0.36	137.59	0.25
2001	33.39	0.37	56.48	0.22
2002	25.74	0.44	66.51	0.19
2003	26.00	0.60	125.37	0.14
2004	69.00	0.32	59.55	0.23
2005	20.79	0.38	34.57	0.20
2006	39.32	0.39	128.41	0.22
2007	76.94	0.54	35.85	0.17
2008	73.71	0.70	85.90	0.21
2009	91.84	0.40	237.45	0.24
2010	71.36	0.27	159.06	0.23
2011	39.19	0.20	324.03	0.28
2012	135.78	0.21	85.62	0.30
2013	27.55	0.21	80.73	0.21
2014	121.86	0.74	123.01	0.19
2015	53.18	0.34	360.28	0.33
2016	123.89	0.20	145.75	0.36
2017	42.42	0.28	NA	NA
2018	101.65	0.28	551.51	0.31
2019	79.83	0.54	65.67	0.18

Table 15. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from the Northeast Fisheries Science Center spring bottom trawl surveys. Strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years are shown in Table 13.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0	14.76	2.88	0.53	0.00
1990	0	4.12	0.74	0.16	0.02
1991	0	16.53	1.17	0.49	0.01
1992	0	8.85	1.15	0.12	0.01
1993	0	12.93	1.56	0.29	0.00
1994	0	16.28	2.92	0.62	0.02
1995	0	14.64	7.03	1.31	0
1996	0	4.25	1.43	0.67	0.03
1997	0	58.65	2.67	0.36	0.00
1998	0	9.87	11.92	0.61	0
1999	0	35.18	6.11	1.10	0
2000	0	19.03	0.93	0.15	0.02
2001	0	26.85	6.12	0.41	0
2002	0	20.83	3.57	1.20	0.14
2003	0	21.57	2.96	1.38	0.09
2004	0	68.33	0.62	0.04	0.01
2005	0	15.49	4.48	0.56	0.25
2006	0	36.45	2.02	0.68	0.18
2007	0	65.95	9.18	1.69	0.12
2008	0	67.34	5.92	0.39	0.06
2009	0	88.11	3.01	0.59	0.13
2010	0	61.03	8.29	1.96	0.08
2011	0	32.29	4.87	1.44	0.58
2012	0	122.56	9.66	2.96	0.55
2013	0	22.14	3.67	1.56	0.19
2014	0	116.65	4.16	0.85	0.20
2015	0	42.58	8.42	1.99	0.19
2016	0	97.98	21.14	4.68	0.08
2017	0	29.91	8.98	3.15	0.37
2018	0	72.20	18.45	10.37	0.62
2019	0	73.75	4.57	1.27	0.15

Table 16. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from the Northeast Fisheries Science Center fall bottom trawl surveys. Strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years are shown in Table 13.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	213.96	28.92	9.32	0.59	0
1990	209.20	19.50	2.47	0.59	0
1991	106.19	13.35	2.31	0.20	0
1992	144.71	6.09	2.91	0.06	0
1993	124.85	31.89	6.23	0.50	0
1994	301.33	13.57	5.95	0.91	0.01
1995	29.35	27.60	15.48	0.08	0
1996	41.38	11.04	2.58	0.18	0
1997	149.94	10.90	1.64	0.09	0
1998	98.21	31.40	4.99	0.34	0
1999	147.35	9.68	1.37	0.02	0
2000	107.18	27.18	3.00	0.21	0
2001	41.27	9.60	5.46	0.15	0
2002	57.68	6.73	1.97	0.14	0
2003	115.70	8.16	1.07	0.25	0.14
2004	43.05	10.49	5.25	0.44	0.32
2005	29.55	3.38	1.11	0.51	0.01
2006	110.28	13.89	3.60	0.59	0.05
2007	25.36	9.23	1.20	0.06	0
2008	80.31	4.85	0.70	0.04	0
2009	209.19	23.54	4.46	0.25	0.01
2010	109.04	40.92	7.74	1.36	0
2011	284.10	33.04	6.22	0.58	0.08
2012	37.75	34.72	11.93	1.13	0.09
2013	71.90	6.63	1.91	0.27	0.02
2014	97.86	20.53	3.92	0.70	0.00
2015	310.53	39.74	9.60	0.38	0.03
2016	97.78	36.02	9.88	1.89	0.16
2017	NA	NA	NA	NA	NA
2018	533.71	13.05	3.97	0.75	0.03
2019	35.12	26.10	3.86	0.56	0.01

Table 17. Butterfish (*Peprilus triacanthus*) arithmetic stratified mean number per tow and coefficients of variation (CV) from the Northeast Area Monitoring and Assessment Program spring and fall bottom trawl surveys.

	Spring		Fall	
Year	Number	CV	Number	CV
2007			1052.53	0.36
2008	342.35	0.21	1028.89	0.17
2009	188.31	0.12	3597.7	0.14
2010	524.26	0.58	1071.53	0.12
2011	458.1	0.15	1647.62	0.16
2012	525.54	0.16	625.29	0.21
2013	47.25	0.13	3547.04	0.43
2014	224.71	0.22	3769.81	0.27
2015	111.6	0.24	1110.78	0.22
2016	323.17	0.17	417.85	0.19
2017	NA	NA	997.34	0.33
2018	456.9	0.51	856.95	0.23
2019	987.13	0.41	352.01	0.37

Table 18. Butterfish (*Peprilus triacanthus*) arithmetic stratified mean number per tow at age from the Northeast Area Monitoring and Assessment Program spring bottom trawl surveys.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
2008	107.9	88.6	133.2	8.8	3.9
2009	14	147.9	12.6	10.6	3.2
2010	3.9	221.7	216.9	68.9	12.9
2011	277.2	108.9	59.1	10.5	2.5
2012	7.4	349.2	147.3	21.3	0.2
2013	1.1	31.6	10.3	2.4	1.8
2014	0	171.1	44.8	8.8	0
2015	0.6	96.9	14.2	0	0
2016	0.1	298.2	24.9	0	0
2017	NA	NA	NA	NA	NA
2018	17.7	322.4	116.5	0.3	0
2019	21	945.1	20.2	0.8	0

Table 19. Butterfish (*Peprilus triacanthus*) arithmetic stratified mean number per tow at age from the Northeast Area Monitoring and Assessment Program fall bottom trawl surveys.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
2007	877.9	155.1	16.2	3.1	0.3
2008	772.5	215.4	36	4.3	0.7
2009	2437	1079.2	62.5	16.8	2.2
2010	376.3	502.3	158.3	31.8	2.8
2011	1290.3	307.1	37.2	11	2
2012	398.9	172.8	50.5	3.1	0
2013	3166.9	353.8	22.5	4	0
2014	3698.9	65.9	4.5	0.5	0
2015	177.4	895.6	35.6	2.2	0
2016	259.1	158.2	0.6	0	0
2017	643.3	344.4	9.6	0	0
2018	729.1	127.7	0.2	0	0
2019	327.5	22.9	1.6	0	0

Table 20. Summary statistics for the percent positive tows for the surveys considered for this assessment. Highlighted cells indicate surveys which had a mean percent positive tows ≥ 50%. The proportion of years when the percent positive tows was ≥ 50% are shown in the column nyear. Survey acronyms are: Northeast Fisheries Science Center (NEFSC); Northeast Area Monitoring and Assessment Program (NEAMAP); Maine Department of Marine Resources (MEDMR); Massachusetts Division of Marine Fisheries (MADMF); Rhode Island Department of Fish and Wildlife (RIDFW); Connecticut Department of Energy and Environmental Protection (CTDEEP); New York Division of Marine Resources (NYDMR); New Jersey Division of Fish and Wildlife (NJDFW); Delaware Division of Fish and Wildlife (DEDFW); Virginia Institute of Marine Science (VIMS); Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP); North Carolina Division of Marine Fisheries (NCDMF).

survey	season	mean	sd	min	median	max	nyear
nefsc	fall	64.8	7.2	51.2	64.4	79.8	1
neamap	fall	89.6	6.9	74.7	91.3	98.0	1
medmr	fall	72.2	12.9	38.5	74.5	93.6	0.95
madmf	fall	85.0	9.0	67.7	85.6	98.9	1
ridfw	fall	82.2	9.7	57.8	84.4	97.9	1
ctdeep	fall	93.3	3.6	85.0	93.1	100.0	1
nydmr	sep/oct	22.8	10.5	4.2	21.4	40.3	0
njdfw	oct	88.9	12.6	48.7	93.6	100.0	0.94
dedfw	sep/oct/nov	59.0	16.6	29.6	63.0	85.2	0.71
estuary	sep/oct	16.9	8.0	0	19.2	28.9	0
bays	sep/oct	17.7	12.6	0	16.7	50.0	0.06
vims	sep/oct/nov	12.9	5.8	1.8	11.3	23.7	0
chesmmap	sep/nov	42.2	13.1	20.0	38.2	62.7	0.29
ncdmf	sep/oct	18.6	11.6	1.9	16.7	48.1	0

Table 21. Area covered by the state surveys used in this assessment. Northeast Fisheries Science Center (NEFSC) and Northeast Area Monitoring and Assessment Program (NEAMAP) are shown for comparison. State survey acronyms are: Maine Department of Marine Resources (MEDMR); Massachusetts Division of Marine Fisheries (MADMF); Rhode Island Department of Fish and Wildlife (RIDFW); Connecticut Department of Energy and Environmental Protection (CTDEEP); New Jersey Division of Fish and Wildlife (NJDFW). Delaware Division of Fish and Wildlife is not shown because it has fixed stations and thus no stratum areas that can be summed.

Survey	nmi^2	km^2
NEFSC	67,345	230,987
NEAMAP	4,429	15,191
MEDMR	4,665	16,001
MADMF	1,833	6,287
RIDEM	134	460
CTDEEP	725	2,488
NJDFW	1,792	6,146
State total	9,149	31,382

Table 22. Summary of age structured assessment program (ASAP) 3 model runs. Note that model ages 1 to 5 correspond to true ages 0 to 4+.

Run	Description	Comments
Bridge	Bridge from ASAP4	M = 1.278 NEFSC fall offshore q = 0.12 & CV for Catchability = 0.01
001	Switch to catch based on CF ages	Includes weights at age fix
002	Split Albatross & Bigelow	
003	Combine SAW 58 NEFSC fall inshore/offshore	New q = 0.13
004	Add NEFSC fall GOM strata	New q = 0.21
005	Add NEFSC spring	
006	Add NEAMAP spring	
007	Add YOY	Model not converged
008	Change Phase for Catchability in First Year to 1	
009	Change CV for F-mult deviations to 0.9	No change
010	NEFSC fall Alb: Initial Guess for ages 2-5 to 1; Phase for ages 4-5 to 1	
011	NEFSC fall Big: Initial Guess for ages 2-5 to 1; Phase for ages 4-5 to 1	
012	NEAMAP fall: Initial Guess for ages 3-5 to 1; Phase for ages 4-5 to 1	
013	NEFSC spring Alb: Initial Guess for ages 3-5 to 1; Phase for age 5 to 1	
014	NEFSC spring Big: Initial Guess for ages 3-5 to 1; Phase for age 5 to 1	
015	NEAMAP spring: Initial Guess for age 1 to 1; Phase for ages 3-5 to 1	
016	NEFSC spring Alb & Big Selectivity Start Age to 2	
017	NEAMAP fall Phase for age 2 to -1	
018	Fix catch selectivity for age 3 (Phase for ages 4-5 to 1)	
019	Run 017; fix catch selectivity for age 4 (Phase for ages 3 and 5 to 1)	Diagnostics slightly better
020	Run 017; fix catch selectivity for age 5 (Phase for ages 3-4 to 1)	
021	Run 019; Index-1 Lambda for Catchability to 0	SSB unrealistically large
022	Index-1 CV for Catchability to 0.9	No change
023	Run 019; Index-1 CV for Catchability to 0.2	
024	Average F Start Age = End Age = 4	
025	All ESS to 100 & CVs to empirical	
026	Run 024; input new ESS & survey CVs multiplied by RMSE from run 025	
027	Switch to annual maturity ogives	
028	Drop spring Albatross	
029	Drop YOY	Sensitivity run
030	Run 028; spring NEAMAP 2017 to -999	
031	Run 028; start year = 1973; Lambdas-1 CV for 1973-1988 set to 0.9	Model not converged
032	Run 030; selectivity block #2 for 2013-2019	
033	Run 030; selectivity block #2 for 2014-2019	Diagnostics slightly better
034	Use surveys fall age 1 and spring age 2 only	Sensitivity run
035	Run 033; catch ESS set to 41 from run 033	
036	Set fall NEAMAP month to 10	

Table 23. Butterfish (*Peprilus triacanthus*) annual maturity ogives.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0	0.438	0.816	1	1
1990	0	0.769	1	1	1
1991	0	0.549	0.982	0.970	1
1992	0	0.612	0.951	1	1
1993	0	0.463	1	1	1
1994	0	0.511	0.926	1	1
1995	0	0.581	0.970	1	1
1996	0	0.389	0.964	1	1
1997	0	0.536	0.972	1	1
1998	0	0.379	0.927	1	1
1999	0	0.504	0.984	1	1
2000	0	0.581	0.859	1	1
2001	0	0.439	1	1	1
2002	0	0.650	0.950	0.981	1
2003	0	0.573	0.884	1	1
2004	0	0.577	0.923	1	1
2005	0	0.625	0.934	1	1
2006	0	0.672	0.944	1	1
2007	0	0.520	0.957	1	1
2008	0	0.521	0.897	0.960	1
2009	0	0.655	0.988	1	1
2010	0	0.587	0.938	1	1
2011	0	0.583	0.945	1	1
2012	0	0.779	1	1	1
2013	0	0.842	0.966	0.982	1
2014	0	0.807	1	1	1
2015	0	0.813	0.989	1	1
2016	0	0.928	0.981	1	1
2017	0	0.673	0.966	0.992	1
2018	0	0.828	1	1	1
2019	0	0.711	1	1	1

Table 24. Butterfish (*Peprilus triacanthus*) total catch mean weight at age (kg). The age 4+ values for 1996 and 1997 were interpolated as the previous year's age 3 value plus the time series average change from age 3 to age 4+. The age 0 value for 2017 was interpolated as the 2018 age 1 value minus the time series average change from age 0 to age 1.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.02	0.05	0.07	0.10	0.11
1990	0.02	0.06	0.09	0.11	0.11
1991	0.03	0.04	0.08	0.11	0.15
1992	0.03	0.05	0.08	0.11	0.13
1993	0.04	0.06	0.09	0.11	0.14
1994	0.03	0.05	0.08	0.11	0.17
1995	0.02	0.05	0.08	0.11	0.37
1996	0.04	0.06	0.08	0.10	0.17
1997	0.03	0.06	0.08	0.11	0.16
1998	0.04	0.05	0.07	0.09	0.17
1999	0.03	0.04	0.07	0.11	0.28
2000	0.02	0.05	0.08	0.13	0.20
2001	0.02	0.05	0.08	0.11	0.18
2002	0.01	0.05	0.07	0.11	0.22
2003	0.03	0.05	0.08	0.11	0.14
2004	0.03	0.04	0.08	0.11	0.19
2005	0.04	0.05	0.07	0.11	0.17
2006	0.03	0.05	0.07	0.11	0.20
2007	0.04	0.06	0.08	0.11	0.14
2008	0.03	0.05	0.07	0.09	0.12
2009	0.03	0.04	0.07	0.10	0.17
2010	0.03	0.06	0.07	0.10	0.13
2011	0.02	0.05	0.07	0.10	0.13
2012	0.03	0.05	0.07	0.11	0.14
2013	0.03	0.05	0.07	0.09	0.12
2014	0.03	0.06	0.09	0.11	0.12
2015	0.04	0.06	0.08	0.10	0.12
2016	0.03	0.05	0.07	0.09	0.15
2017	0.03	0.05	0.07	0.09	0.11
2018	0.03	0.05	0.09	0.10	0.14
2019	0.03	0.05	0.08	0.10	0.12

Table 25. Butterfish (*Peprilus triacanthus*) proportions of catch at age in weight.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.07	0.36	0.43	0.13	0.01
1990	0.07	0.51	0.33	0.09	0.01
1991	0.15	0.38	0.32	0.13	0.02
1992	0.13	0.31	0.44	0.12	0.004
1993	0.12	0.43	0.30	0.14	0.02
1994	0.09	0.43	0.32	0.14	0.02
1995	0.14	0.26	0.37	0.12	0.11
1996	0.12	0.21	0.51	0.16	0
1997	0.05	0.36	0.46	0.13	0
1998	0.10	0.42	0.35	0.11	0.02
1999	0.14	0.42	0.28	0.10	0.06
2000	0.17	0.31	0.29	0.18	0.06
2001	0.12	0.21	0.38	0.22	0.06
2002	0.11	0.37	0.35	0.13	0.04
2003	0.17	0.30	0.32	0.17	0.03
2004	0.10	0.38	0.31	0.16	0.04
2005	0.07	0.43	0.32	0.15	0.03
2006	0.15	0.39	0.30	0.12	0.04
2007	0.03	0.32	0.40	0.21	0.04
2008	0.15	0.36	0.36	0.12	0.01
2009	0.12	0.44	0.29	0.13	0.03
2010	0.09	0.39	0.36	0.14	0.02
2011	0.13	0.40	0.33	0.13	0.02
2012	0.08	0.43	0.33	0.14	0.02
2013	0.11	0.50	0.31	0.07	0.01
2014	0.05	0.42	0.34	0.17	0.03
2015	0.10	0.28	0.41	0.19	0.03
2016	0.04	0.45	0.25	0.25	0.01
2017	0	0.22	0.51	0.21	0.07
2018	0.11	0.30	0.32	0.24	0.03
2019	0.01	0.23	0.40	0.28	0.08

Table 26. Survey selectivities for the final age structured assessment program (ASAP) 3 model (run 036). Selectivity is freely estimated for phase = 1 and fixed for phase = -1. Model ages 1 to 5 correspond to true ages 0 to 4+. Surveys are: Northeast Fisheries Science Center (NEFSC); Northeast Area Monitoring and Assessment Program (NEAMAP); and the combined young-of-the-year (YOY) index.

Survey	Age	Initial Guess	Phase
NEFSC fall Albatross	1	1	-1
	2	1	1
	3	1	1
	4	1	1
	5	1	1
NEFSC fall Bigelow	1	1	-1
	2	1	1
	3	1	1
	4	1	1
	5	1	1
NEAMAP fall	1	1	-1
	2	1	-1
	3	1	1
	4	1	1
	5	1	1
NEFSC spring Bigelow	1	0	-1
	2	1	-1
	3	1	1
	4	1	1
	5	1	1
NEAMAP spring	1	1	1
	2	1	-1
	3	1	1
	4	1	1
	5	1	1
YOY	1	1	-1
	2	0	-1
	3	0	-1
	4	0	-1
	5	0	-1

Table 27. Root mean square errors (RMSE) from age structured assessment program (ASAP) 3 run 025 used as coefficient of variation (CV) multipliers for the final ASAP3 model (run 036). Surveys are: Northeast Fisheries Science Center (NEFSC); Northeast Area Monitoring and Assessment Program (NEAMAP); and the combined young-of-the-year (YOY) index.

Survey	RMSE
NEFSC fall Albatross	1.9174
NEFSC fall Bigelow	2.0632
NEAMAP fall	2.6578
NEFSC spring Bigelow	1.7267
NEAMAP spring	4.1455
YOY	0.8987

Table 28. Survey effective sample sizes (ESS) for the final age structured assessment program (ASAP) 3 model (run 036). Surveys are: Northeast Fisheries Science Center (NEFSC); and Northeast Area Monitoring and Assessment Program (NEAMAP).

Survey	ESS
NEFSC fall Albatross	17
NEFSC fall Bigelow	15
NEAMAP fall	4
NEFSC spring Bigelow	14
NEAMAP spring	3

Table 29. Objective function components for the final age structured assessment program (ASAP) 3 model (run 036).

Component	Value
total	2084.03
catch.total	-53.53
discard.total	0
index.fit.total	-18.33
index.fit.ind01	-7.52
index.fit.ind02	-1.76
index.fit.ind03	0.96
index.fit.ind04	-2.41
index.fit.ind05	4.41
index.fit.ind06	-12.02
catch.age.comp	1722.09
discards.age.comp	0
index.age.comp	435.37
sel.param.total	0
index.sel.param.t	0
q.year1	-1.58
q.devs	0
Fmult.year1.total	0
Fmult.devs.total	0
N.year1	0
Recruit.devs	0
SR.steepness	0
SR.scaler	0
Fmult.Max.penalty	0
F.penalty	0

Table 30. Root mean square errors (RMSE) for the final age structured assessment program (ASAP) 3 model (run 036).

Component	N	RMSE
catch.tot	31	0.0702
discard.tot	0	0
ind01	20	0.9823
ind02	10	1.0298
ind03	13	1.1750
ind04	11	1.0297
ind05	11	1.2768
ind06	17	0.8593
ind.total	82	1.0476
N.year1	0	0
Fmult.year1	0	0
Fmult.devs.total	0	0
recruit.devs	0	0
fleet.sel.params	0	0
index.sel.params	0	0
q.year1	1	4.4926
q.devs	0	0
SR.steepness	0	0
SR.scaler	0	0

Table 31. Estimates of spawning stock biomass (SSB; mt), recruitment (millions), fishing mortality (F) and respective coefficients of variation (CV) from the final age structured assessment program (ASAP) 3 model (run 036).

Year	SSB	CV	Recruitment	CV	F	CV
1989	76,730	0.40	13,065	0.34	0.08	0.45
1990	146,330	0.35	14,169	0.31	0.05	0.41
1991	105,370	0.32	12,409	0.30	0.06	0.37
1992	117,590	0.30	13,183	0.29	0.10	0.37
1993	117,850	0.29	12,705	0.29	0.12	0.38
1994	105,930	0.28	12,131	0.28	0.11	0.50
1995	121,030	0.27	7,448	0.28	0.05	0.49
1996	83,378	0.27	7,470	0.26	0.08	0.36
1997	79,218	0.25	9,851	0.24	0.07	0.36
1998	60,508	0.24	8,297	0.27	0.11	0.91
1999	64,707	0.25	8,058	0.27	0.26	0.39
2000	71,422	0.26	6,188	0.28	0.10	0.44
2001	57,155	0.27	5,194	0.28	0.19	0.37
2002	53,780	0.27	4,933	0.27	0.11	0.58
2003	45,005	0.26	5,668	0.25	0.09	0.95
2004	43,406	0.25	4,418	0.27	0.07	0.35
2005	43,981	0.25	4,362	0.27	0.04	0.30
2006	43,524	0.25	4,781	0.27	0.05	0.55
2007	43,439	0.25	3,736	0.27	0.03	0.31
2008	32,446	0.25	6,188	0.28	0.06	0.49
2009	41,996	0.26	6,904	0.29	0.05	0.36
2010	58,177	0.27	4,673	0.30	0.04	0.31
2011	46,572	0.28	5,866	0.30	0.07	0.31
2012	57,325	0.29	3,846	0.30	0.05	0.38
2013	46,744	0.30	5,711	0.30	0.06	0.31
2014	62,176	0.30	5,344	0.30	0.21	0.36
2015	61,440	0.30	7,198	0.29	0.16	0.37
2016	70,176	0.29	4,162	0.31	0.14	0.36
2017	45,270	0.30	4,865	0.31	0.25	0.36
2018	52,793	0.31	6,014	0.32	0.16	0.35
2019	51,801	0.32	2,315	0.36	0.30	0.36

Table 32. Estimates of spawning stock biomass (SSB; mt), recruitment (millions), fishing mortality (F), and respective coefficients of variation (CV) from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

Year	SSB	CV	F	CV	Recruitment	CV
1989	57,625	0.40	0.106	0.45	10,343	0.36
1990	112,511	0.33	0.065	0.40	10,361	0.26
1991	78,863	0.29	0.091	0.36	12,451	0.30
1992	115,594	0.28	0.116	0.36	12,248	0.25
1993	120,237	0.27	0.125	0.38	11,286	0.24
1994	98,466	0.25	0.121	0.47	9,900	0.25
1995	113,345	0.25	0.060	0.48	7,950	0.23
1996	76,212	0.23	0.092	0.34	7,328	0.21
1997	88,033	0.22	0.065	0.35	10,063	0.18
1998	68,167	0.21	0.134	0.85	9,800	0.23
1999	78,017	0.22	0.247	0.38	9,592	0.24
2000	78,452	0.23	0.103	0.43	8,160	0.23
2001	63,592	0.23	0.182	0.36	6,223	0.22
2002	61,911	0.23	0.112	0.56	6,462	0.21
2003	54,028	0.22	0.109	0.88	7,258	0.19
2004	52,846	0.22	0.061	0.34	5,041	0.22
2005	51,060	0.22	0.038	0.29	5,221	0.21
2006	53,215	0.22	0.052	0.54	5,935	0.22
2007	55,988	0.22	0.026	0.30	4,663	0.21
2008	46,244	0.22	0.048	0.48	8,366	0.20
2009	57,097	0.22	0.039	0.34	10,645	0.24
2010	71,052	0.23	0.033	0.29	6,337	0.23
2011	51,720	0.24	0.068	0.29	8,144	0.24
2012	63,244	0.25	0.057	0.35	5,056	0.25
2013	44,944	0.24	0.066	0.28	7,253	0.24
2014	69,857	0.27	0.279	0.37	7,474	0.24
2015	71,867	0.26	0.181	0.39	8,245	0.24
2016	83,933	0.26	0.157	0.38	5,281	0.25
2017	52,724	0.27	0.273	0.38	7,732	0.26
2018	77,481	0.27	0.147	0.36	9,207	0.27
2019	78,579	0.28	0.237	0.38	3,936	0.28

Table 33. Woods Hole Assessment Model (WHAM) model descriptions, parameters estimated, and the number of parameters estimated. NAA = numbers at age. Other notation includes recruitment in year *y* (R_y), recruitment deviations (σ_R), deviations for age *a* (σ_a), correlation by year (ρ_{year}), and correlation at age (ρ_{age}).

Model	Description	Parms. estimated	No.
Base	As ASAP, recruitment estimated as fixed effects	R_y for $y > 1$	$n_{years} - 1$
NAA1	Recruitment deviations are independent random effects	σ_R	1
NAA2	Recruitment deviations are autocorrelated, AR(1), random effects	σ_R, ρ_{year}	2
NAA3	All NAA deviations are independent random effects	σ_R, σ_a	2
NAA4	All NAA deviations are random effects with correlation by year and age, 2D AR(1)	σ_R, σ_a, ρ_{year}, ρ_{age}	4
NAA5	All NAA deviations are random effects with correlation by year only, AR(1)	σ_R, σ_a, ρ_{year}	3

Table 34. Biological reference points for butterfish (*Peprilus triacanthus*) from Term of Reference (TOR) 4 and stock status in 2019.

$F_{50\%}$	$B_{50\%}$	$F_{2019}/F_{50\%}$	$B_{2019}/B_{50\%}$
6.68	37,597	0.04 (0.02-0.07)	2.09 (1.20-3.64)

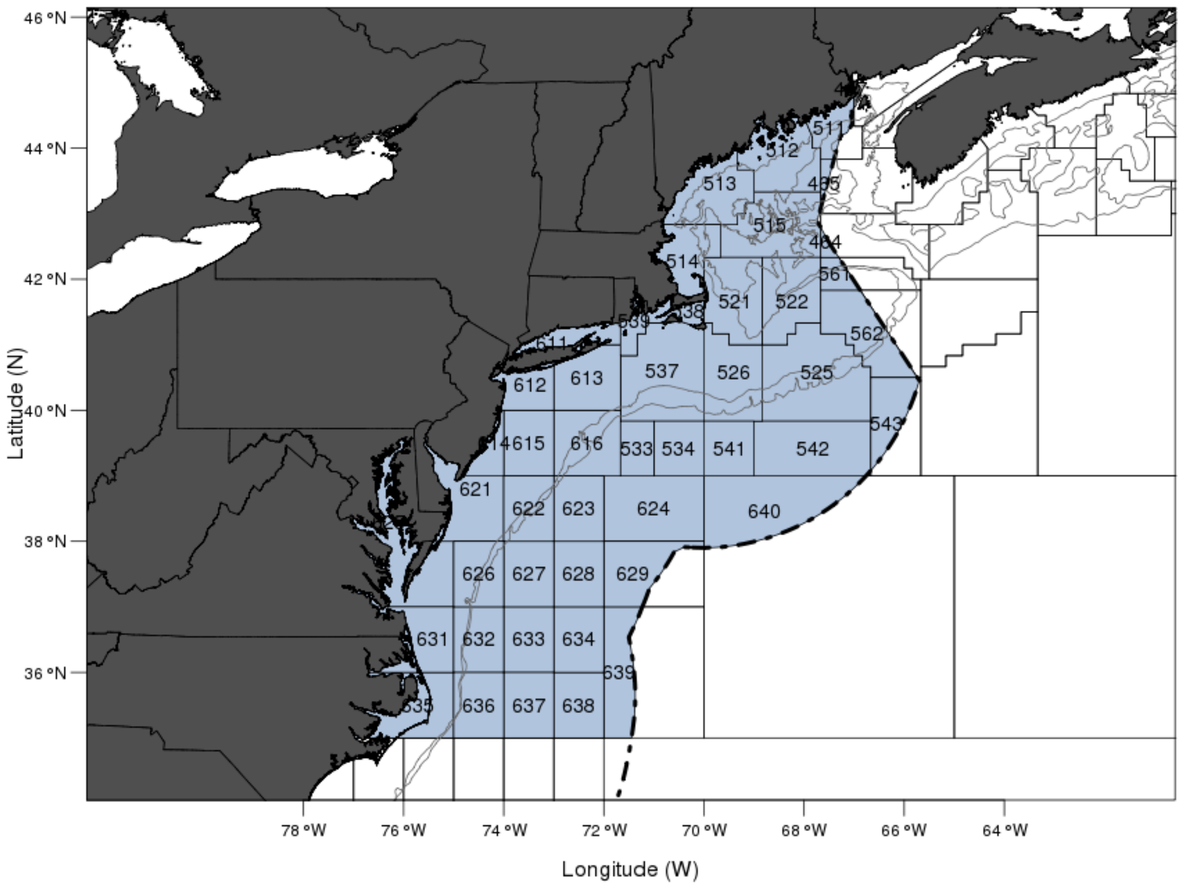

Figure 1. Statistical areas used to calculate butterfish (*Peprilus triacanthus*) landings and discard estimates.

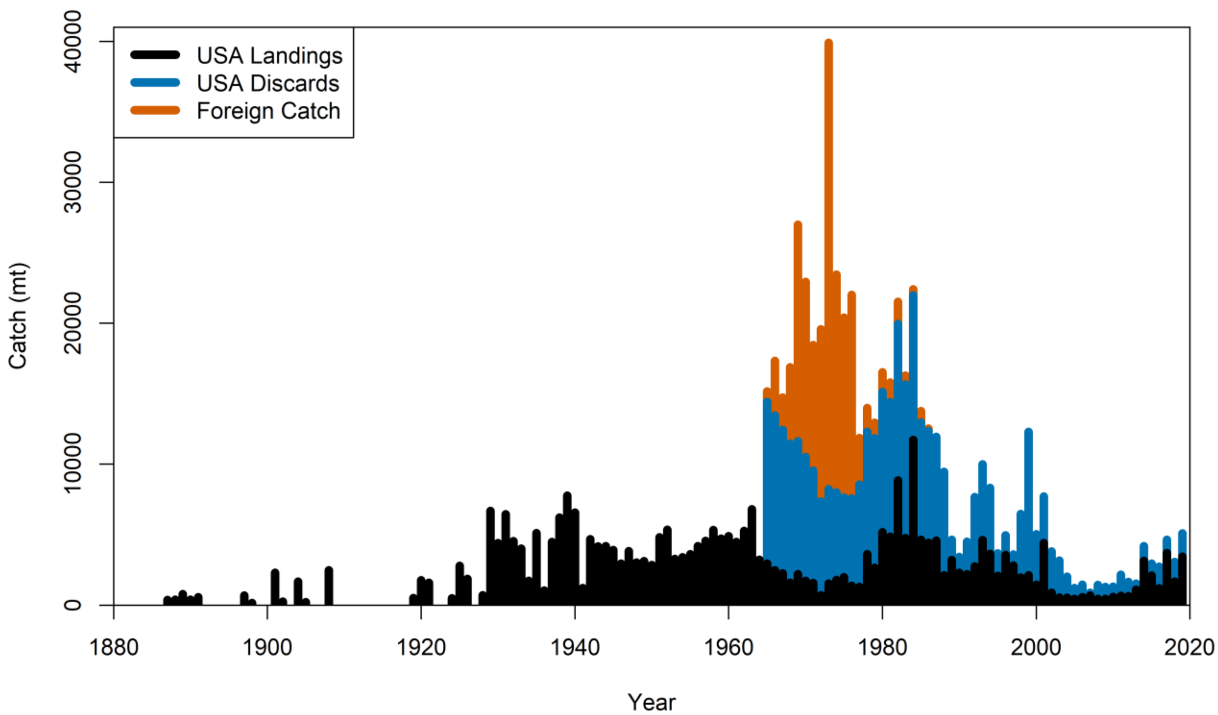

Figure 2. Butterfish (*Peprilus triacanthus*) catch, 1887-2019. Annual catch data are missing for some years prior to 1930. Discards are unavailable prior to 1965. Catch between 1965 and 1988 includes discards estimated by applying an average of discard rates for trawl gear from 1989-1999 to annual landings of all species between 1965 and 1988 by trawl gear.

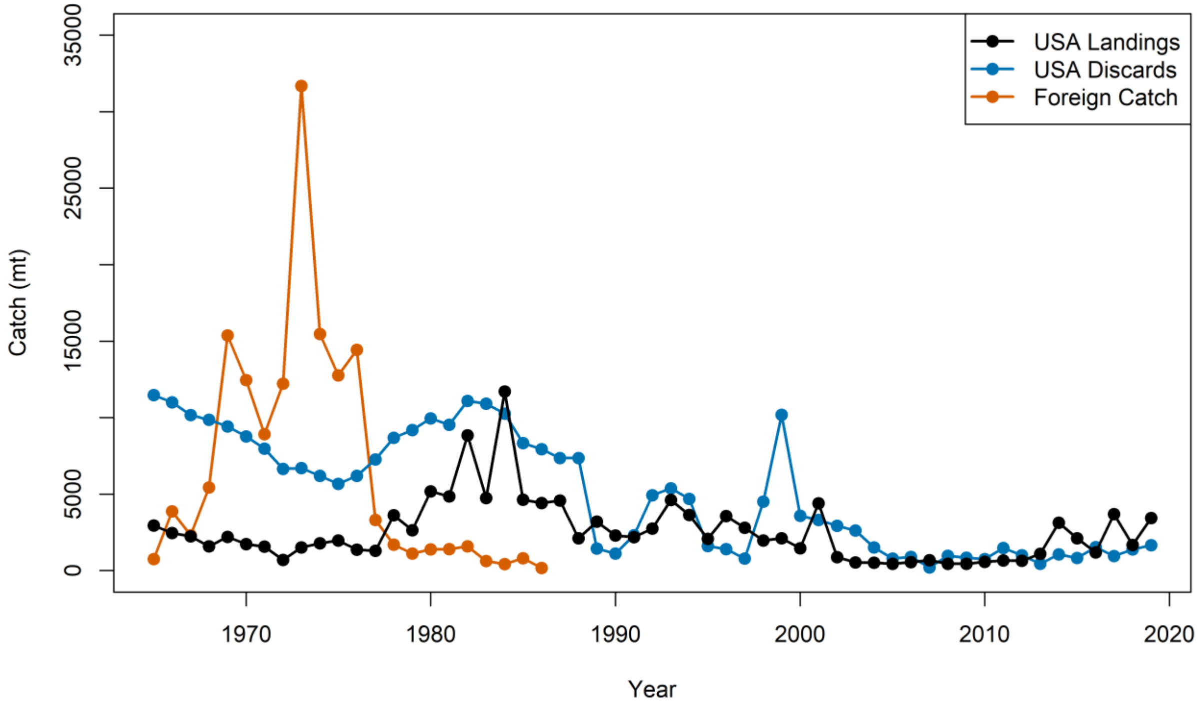

Figure 3. U.S. landings, U.S. discards, and foreign catch of butterfish (*Peprilus triacanthus*), 1965-2019.

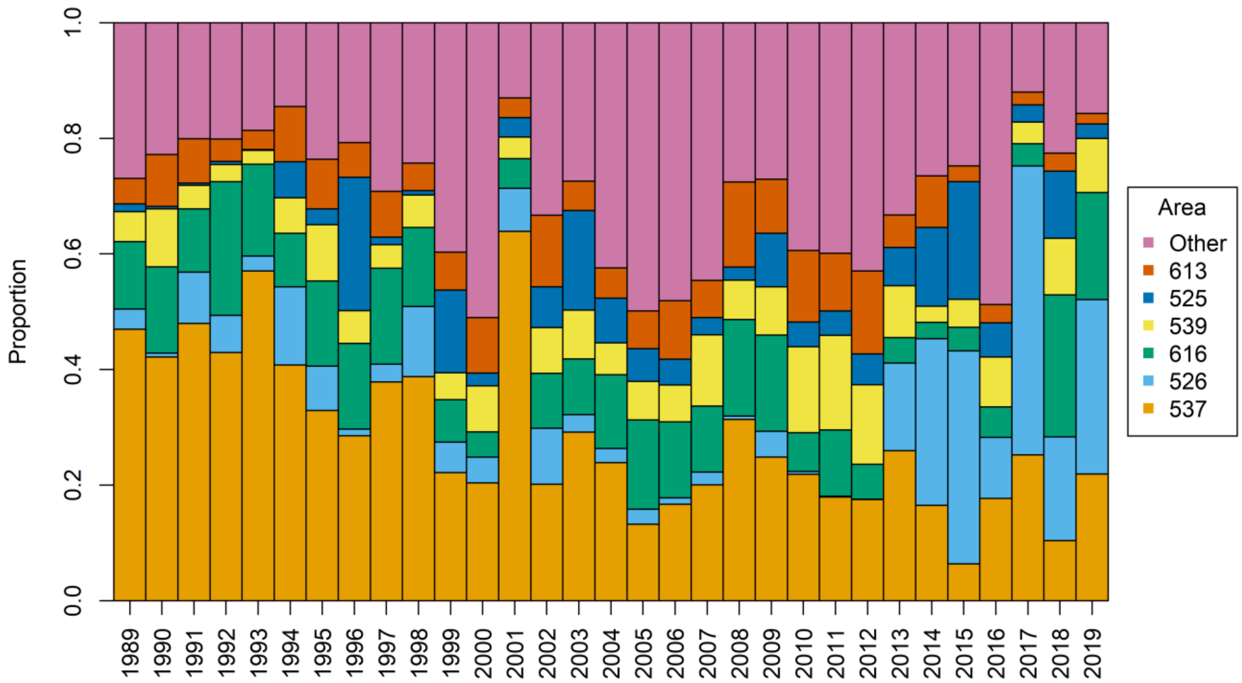

Figure 4. Proportion of annual butterfish (*Peprilus triacanthus*) landings by statistical area.

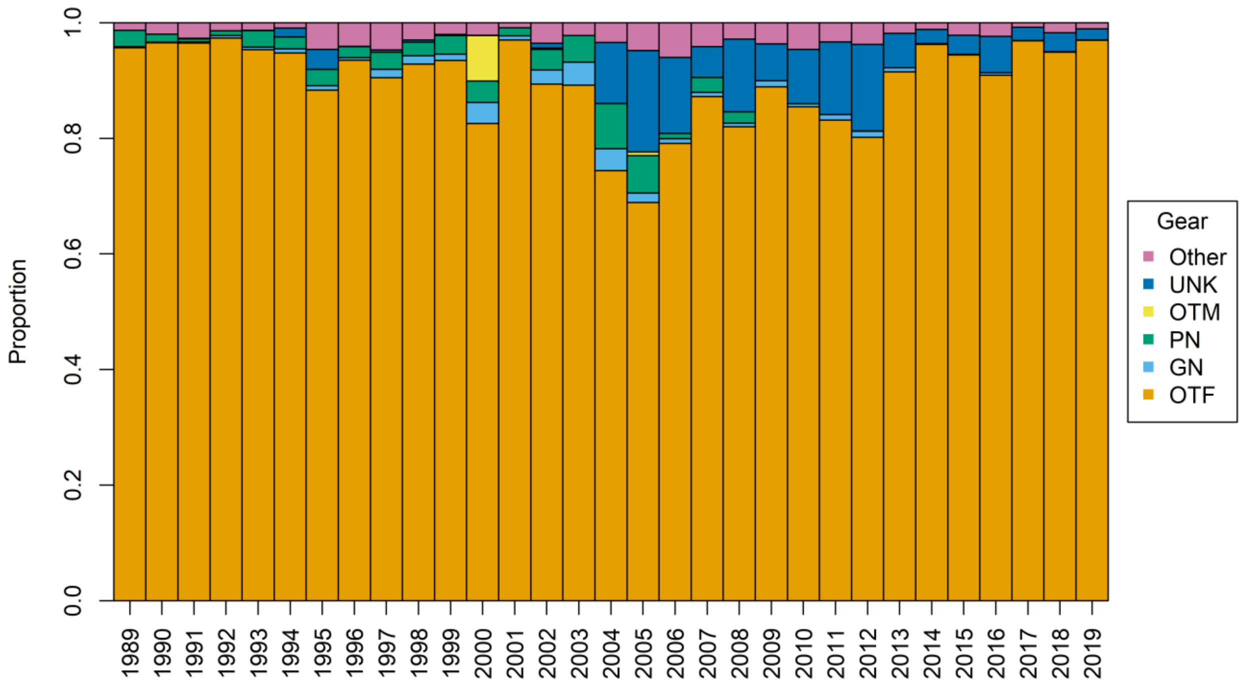

Figure 5. Proportion of annual butterfish (*Peprilus triacanthus*) landings by gear type. Abbreviations are: otter trawl, bottom, fish (OTF); gill net (GN), pound net (PN); otter trawl, midwater (OTM); unknown (UNK).

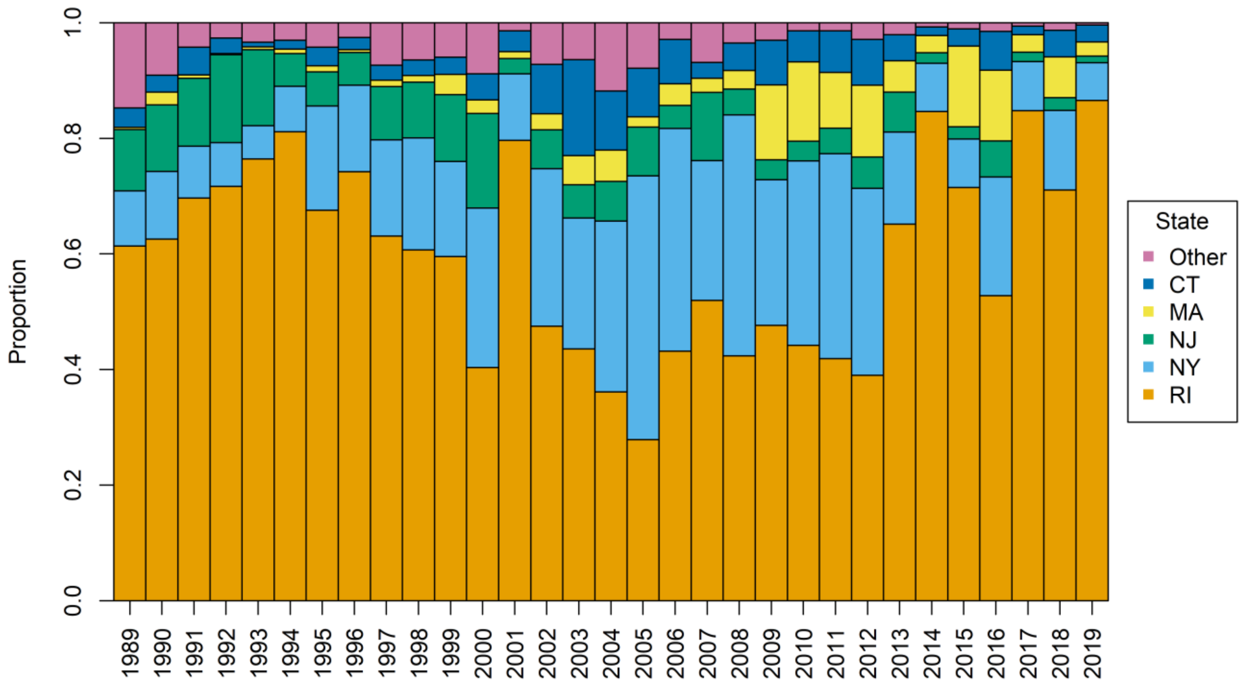

Figure 6. Proportion of annual butterfish (*Peprilus triacanthus*) landings by state. Abbreviations are: Connecticut (CT); Massachusetts (MA); New Jersey (NJ); New York (NY); Rhode Island (RI).

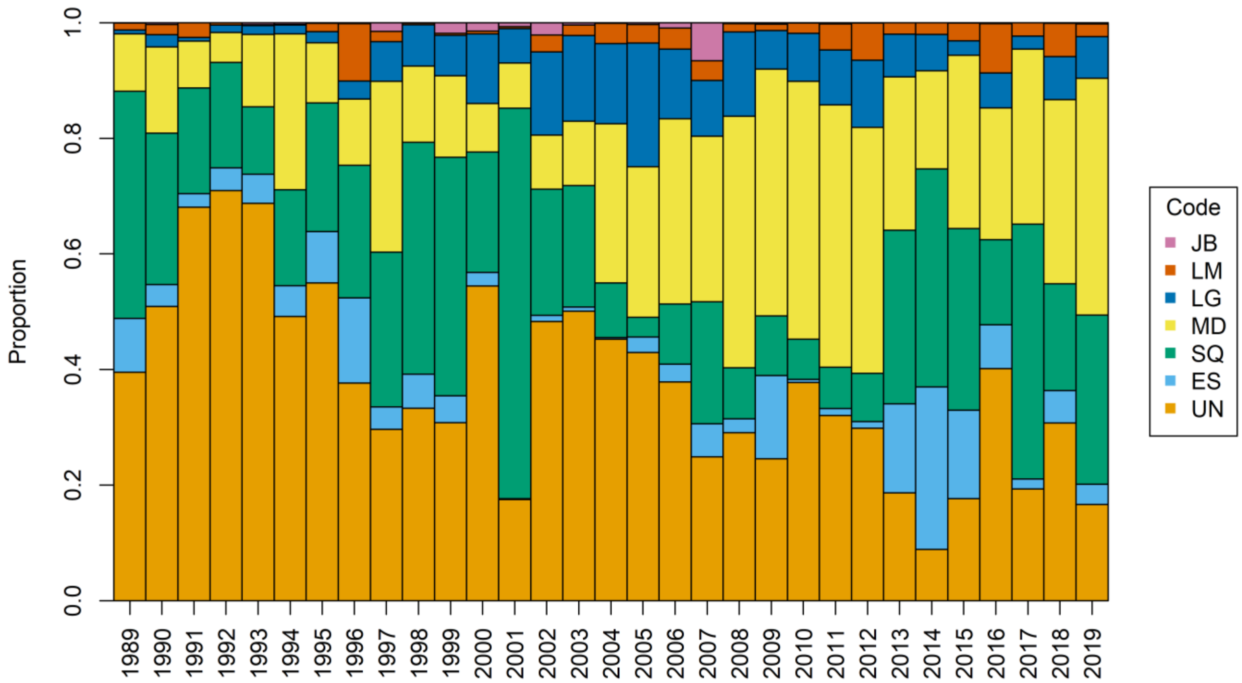

Figure 7. Proportion of annual butterfish (*Peprilus triacanthus*) landings by market category. Abbreviations are: jumbo (JB); large/mix (LM); large (LG); medium (MD); small (SQ); extra small (ES); unclassified (UN). The market category super super small (SV) is combined with ES for this plot.

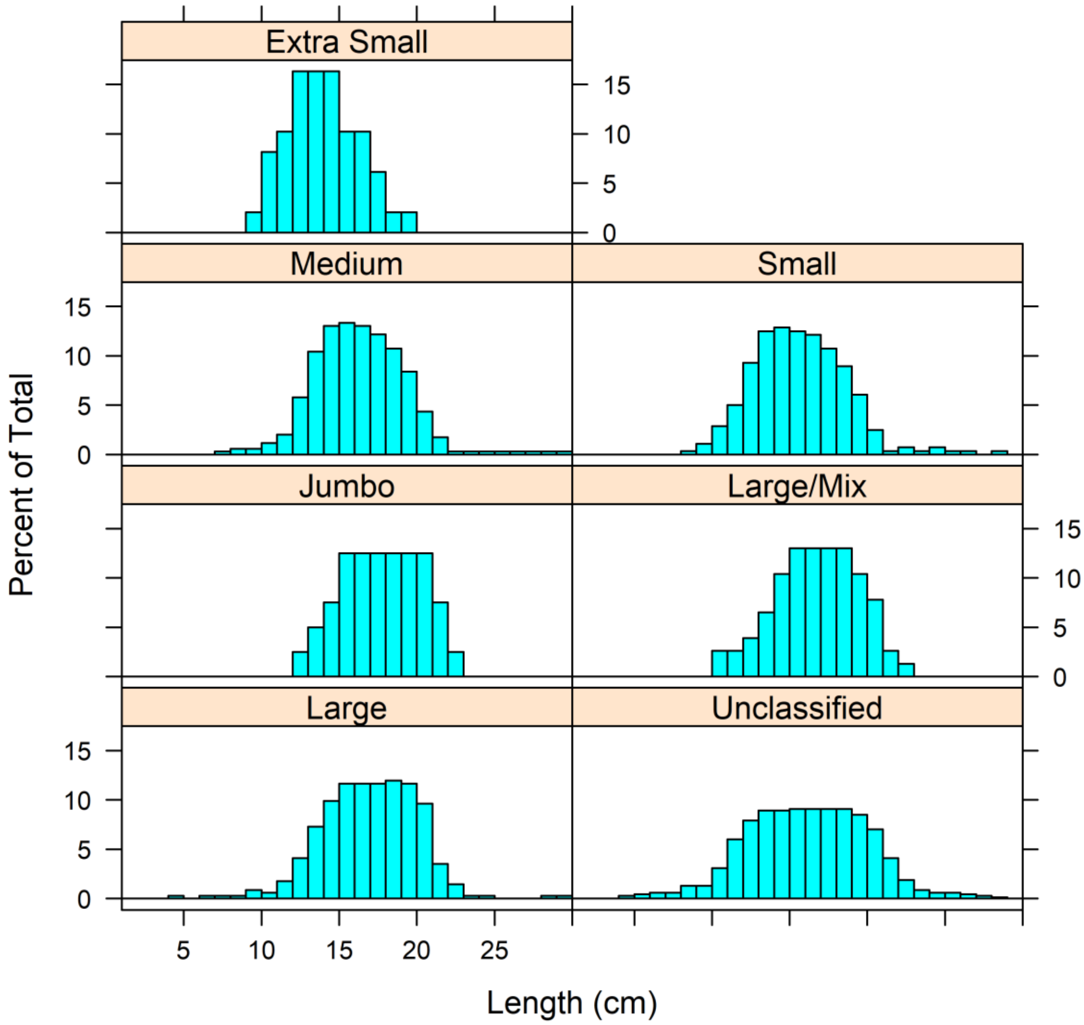

Figure 8. Length composition of butterfish (*Peprilus triacanthus*) landings by market category. There are no length measurements for the market category super super small.

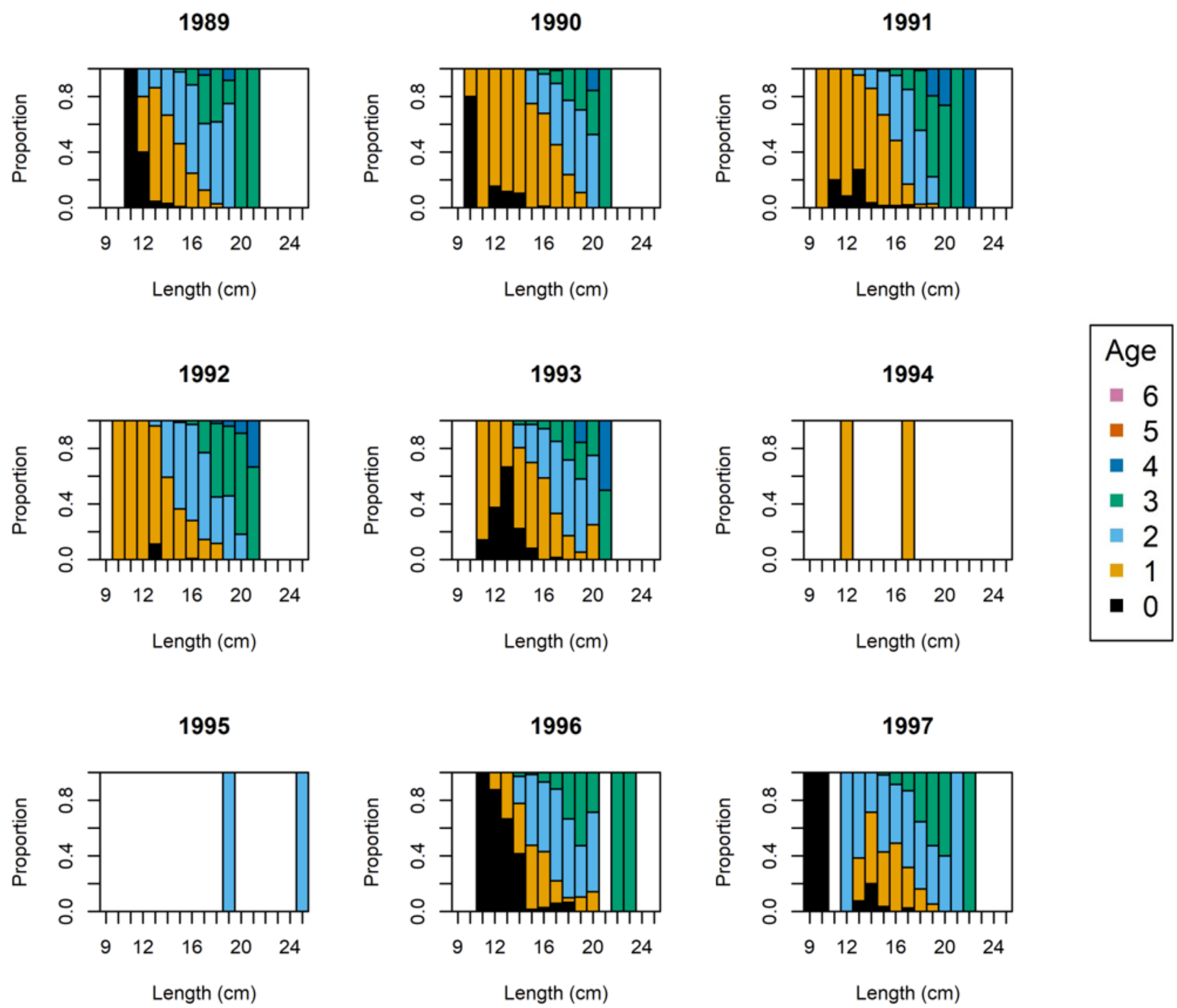

Figure 9. Proportion of butterfish (*Peprilus triacanthus*) commercial age samples by length, 1989-1997.

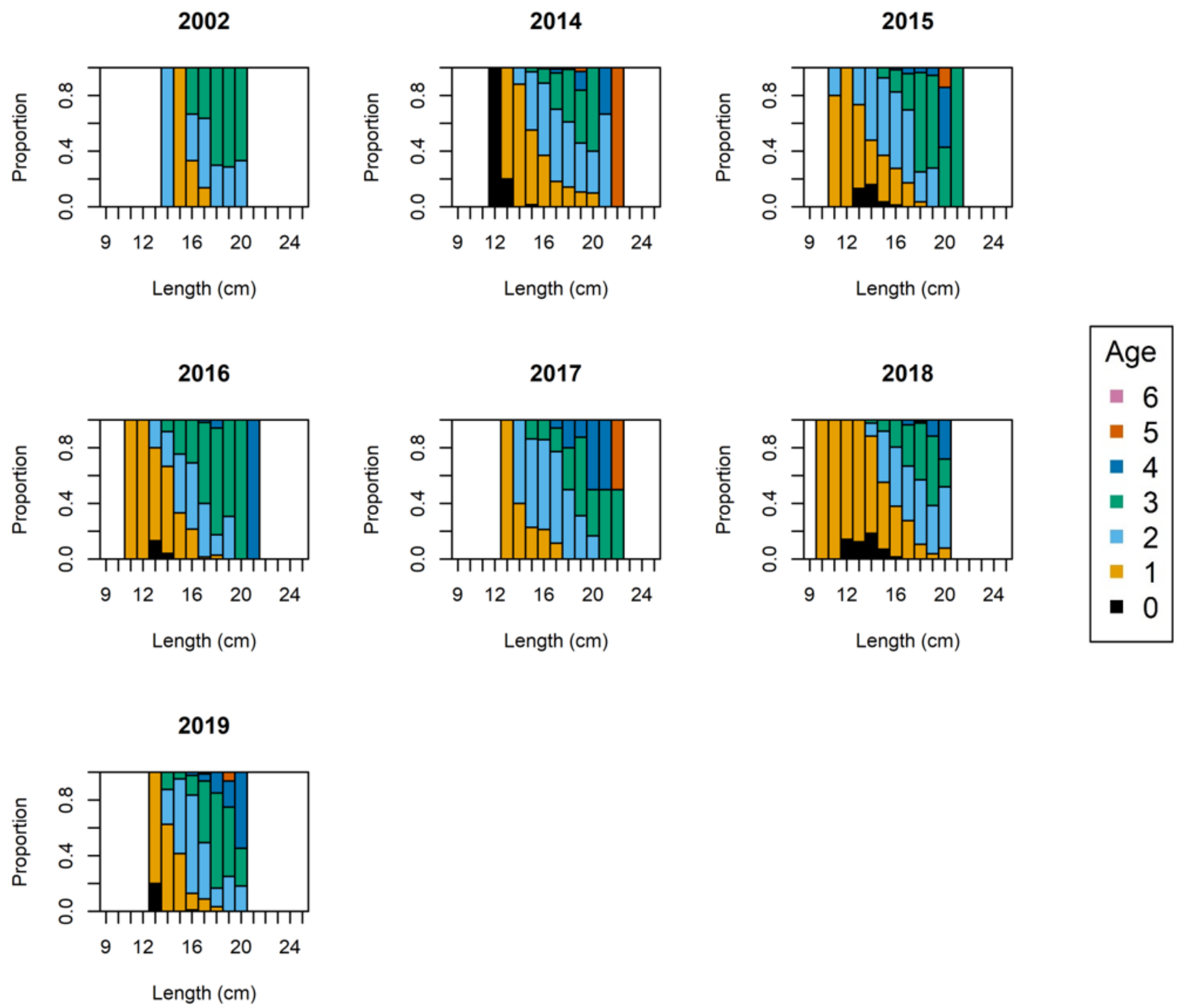

Figure 10. Proportion of butterfish (*Peprilus triacanthus*) commercial age samples by length, 2002 and 2014-2019.

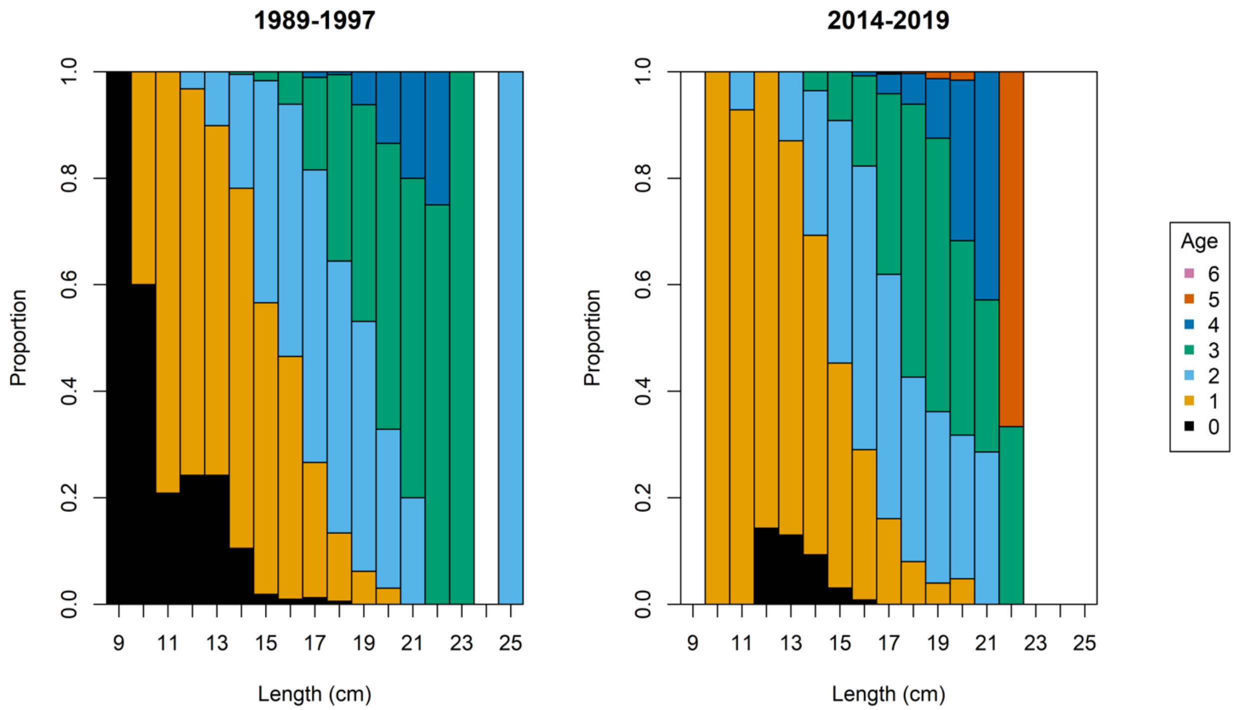

Figure 11. Proportion of butterfish (*Peprilus triacanthus*) commercial age samples by length for the 2 time blocks, 1989-1997 and 2014-2019.

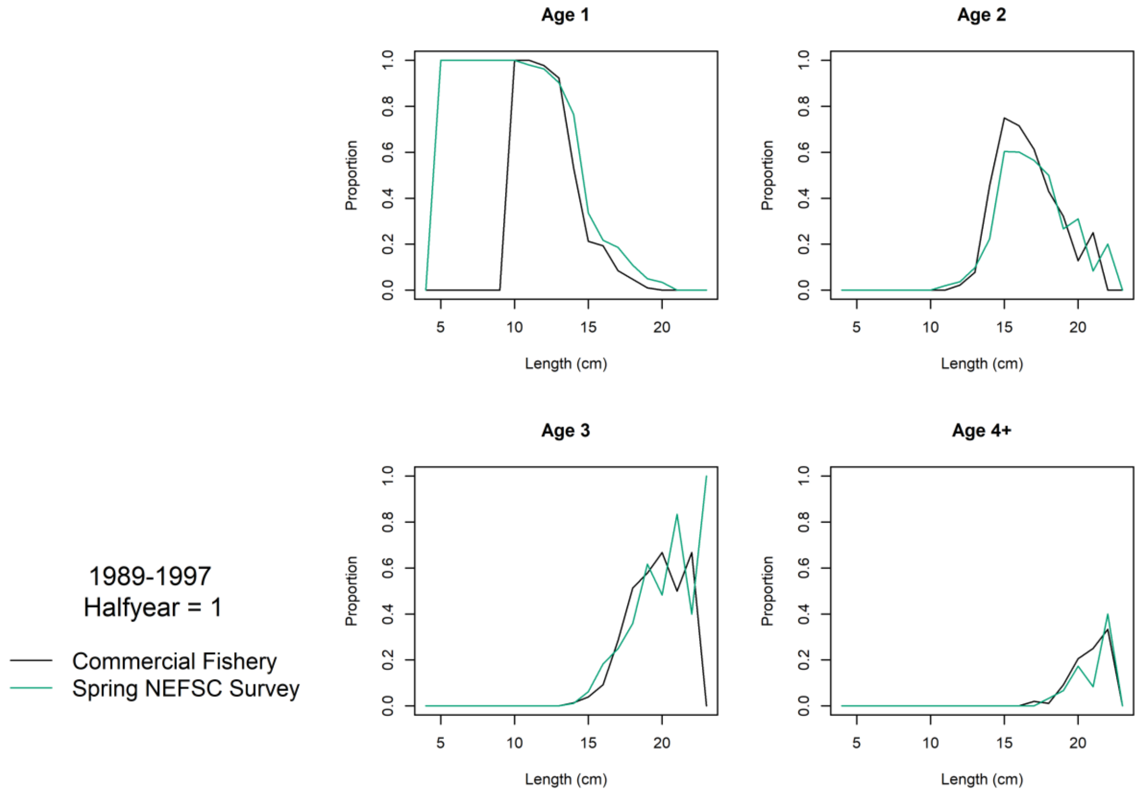

Figure 12. Age-length key proportions for commercial ages and Northeast Fishery Science Center (NEFSC) spring bottom trawl survey ages, January-June, 1989-1997.

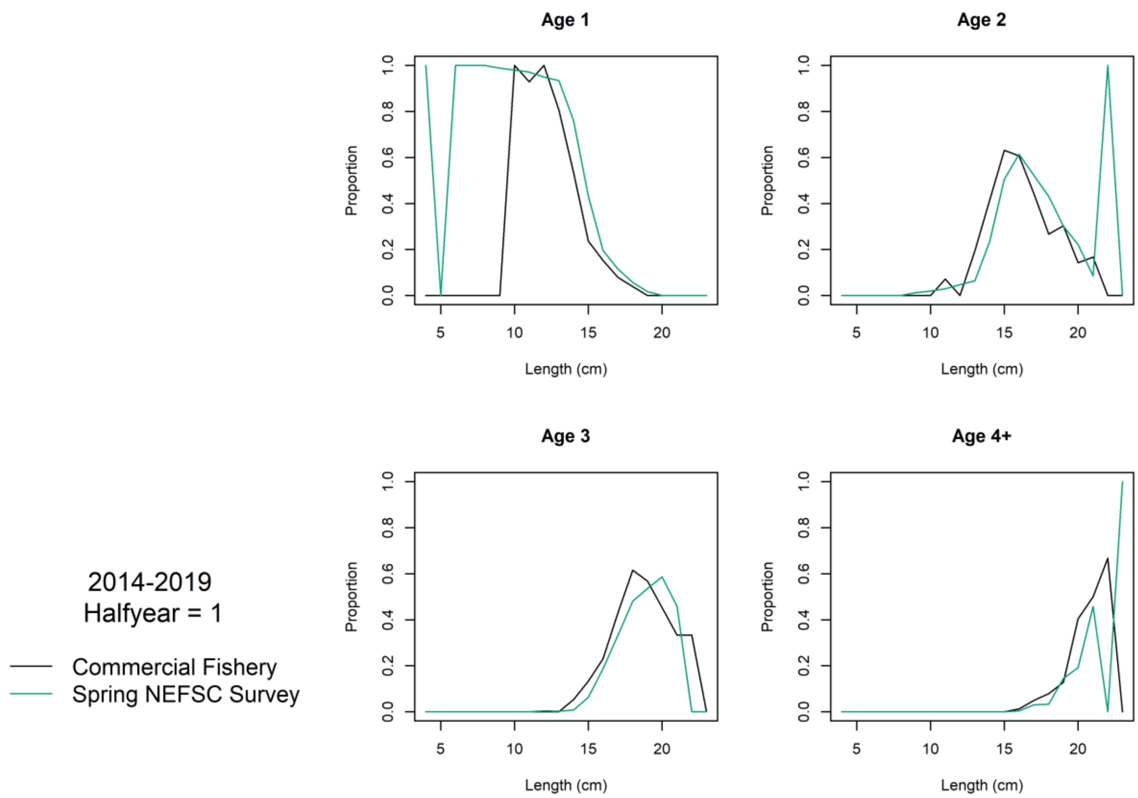

Figure 13. Age-length key proportions for commercial ages and Northeast Fishery Science Center (NEFSC) spring bottom trawl survey ages, January-June, 2014-2019.

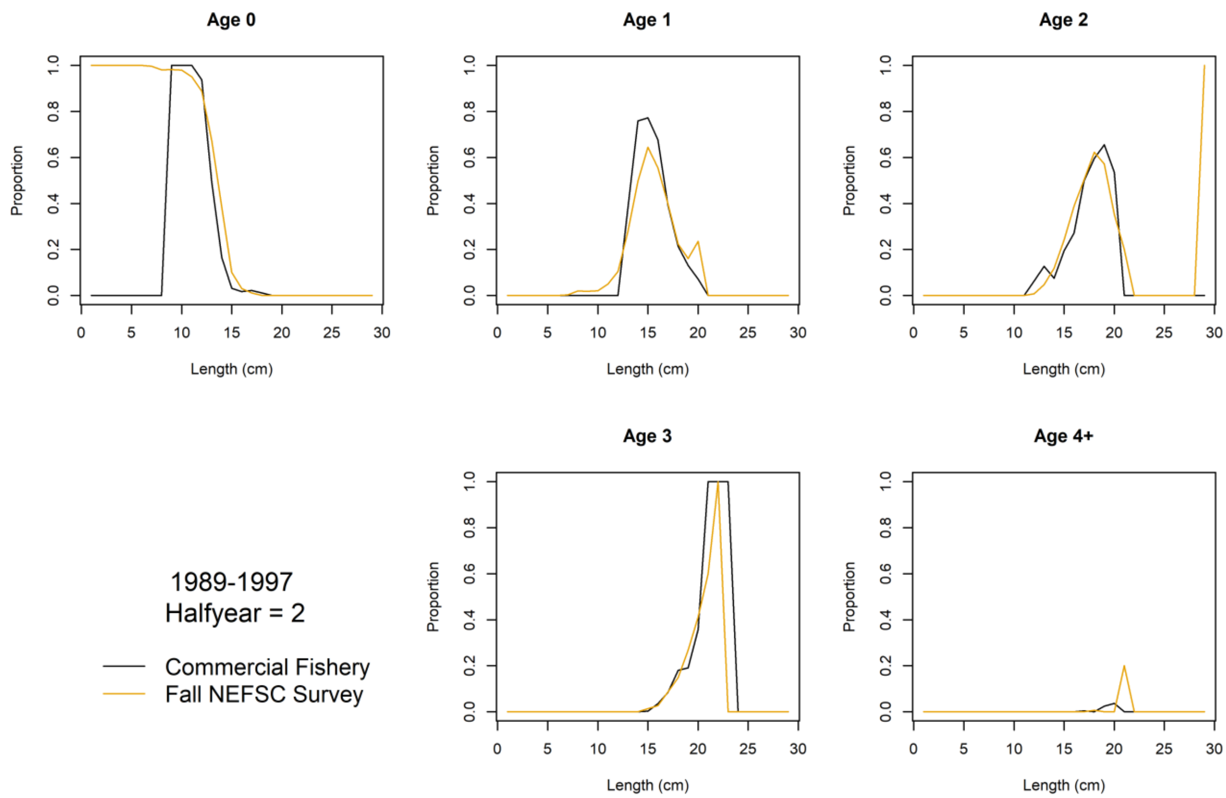

Figure 14. Age-length key proportions for commercial ages and Northeast Fishery Science Center (NESFC) fall bottom trawl survey ages, July-December, 1989-1997.

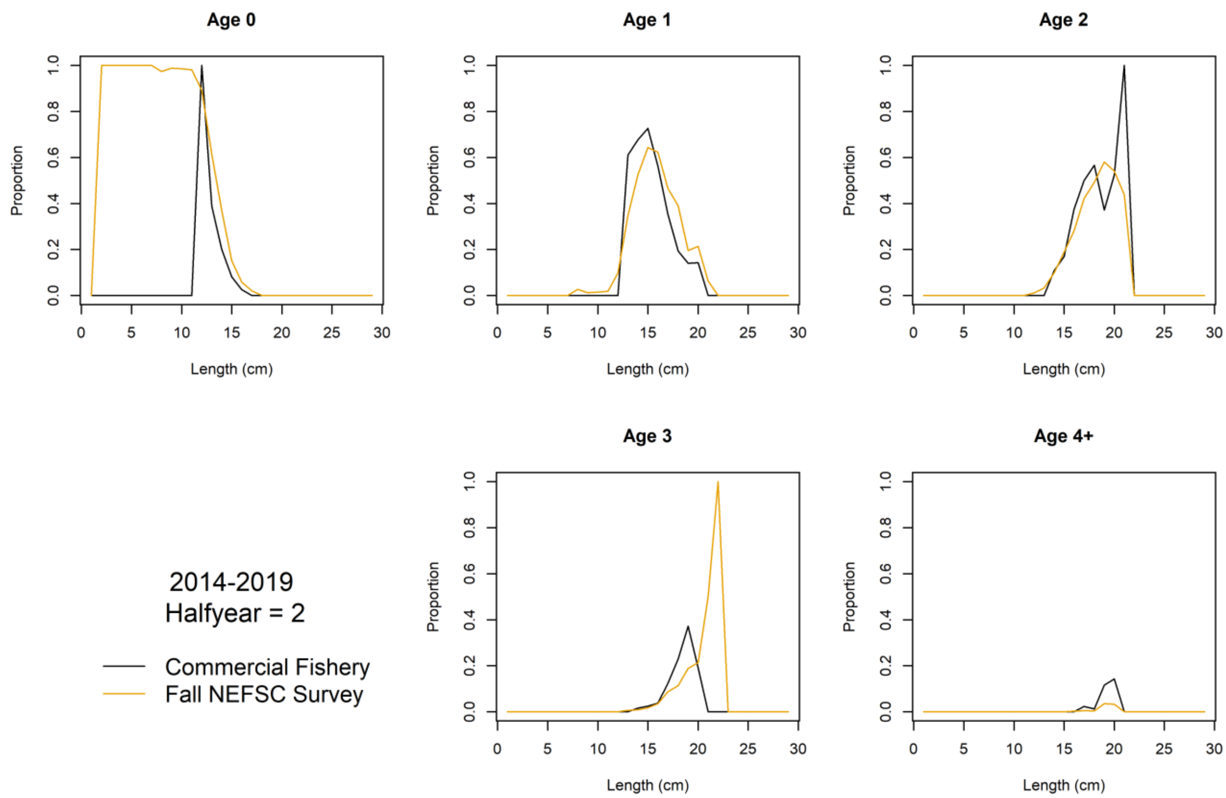

Figure 15. Age-length key proportions for commercial ages and Northeast Fishery Science Center (NEFSC) fall bottom trawl survey ages, July-December, 2014-2019.

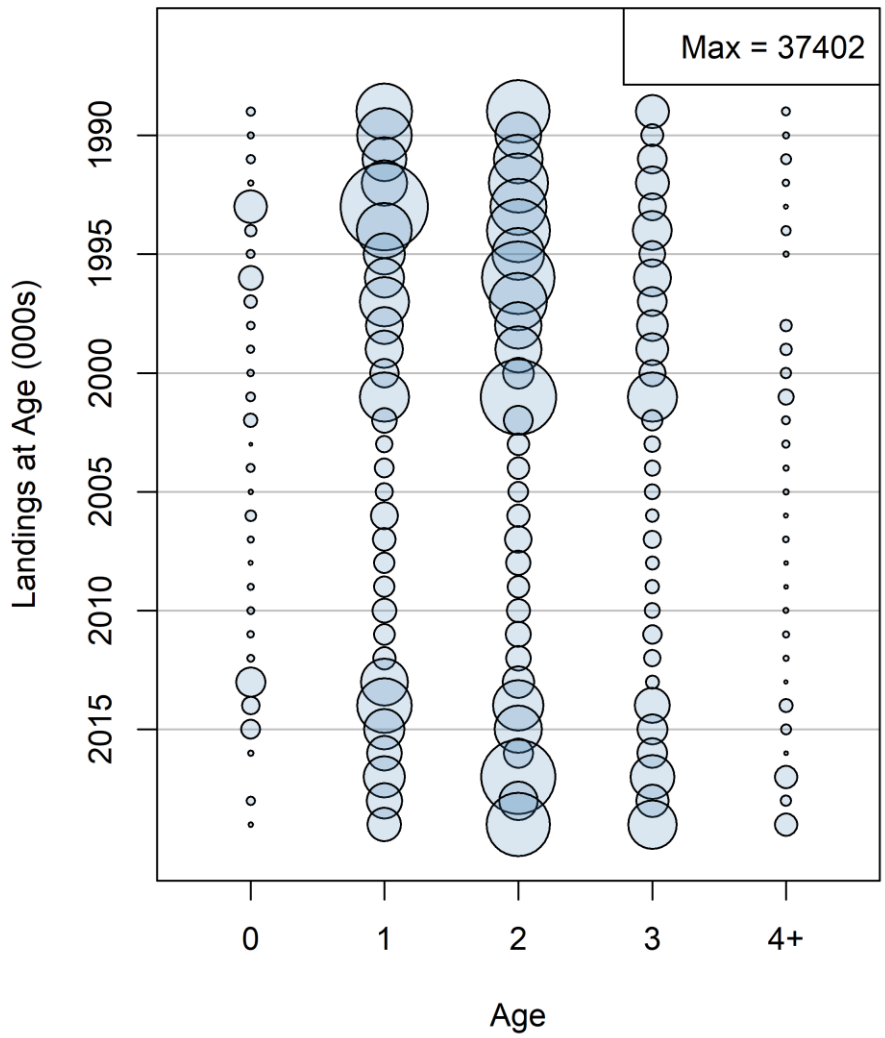

Figure 16. Butterfish (*Peprilus triacanthus*) commercial landings at age.

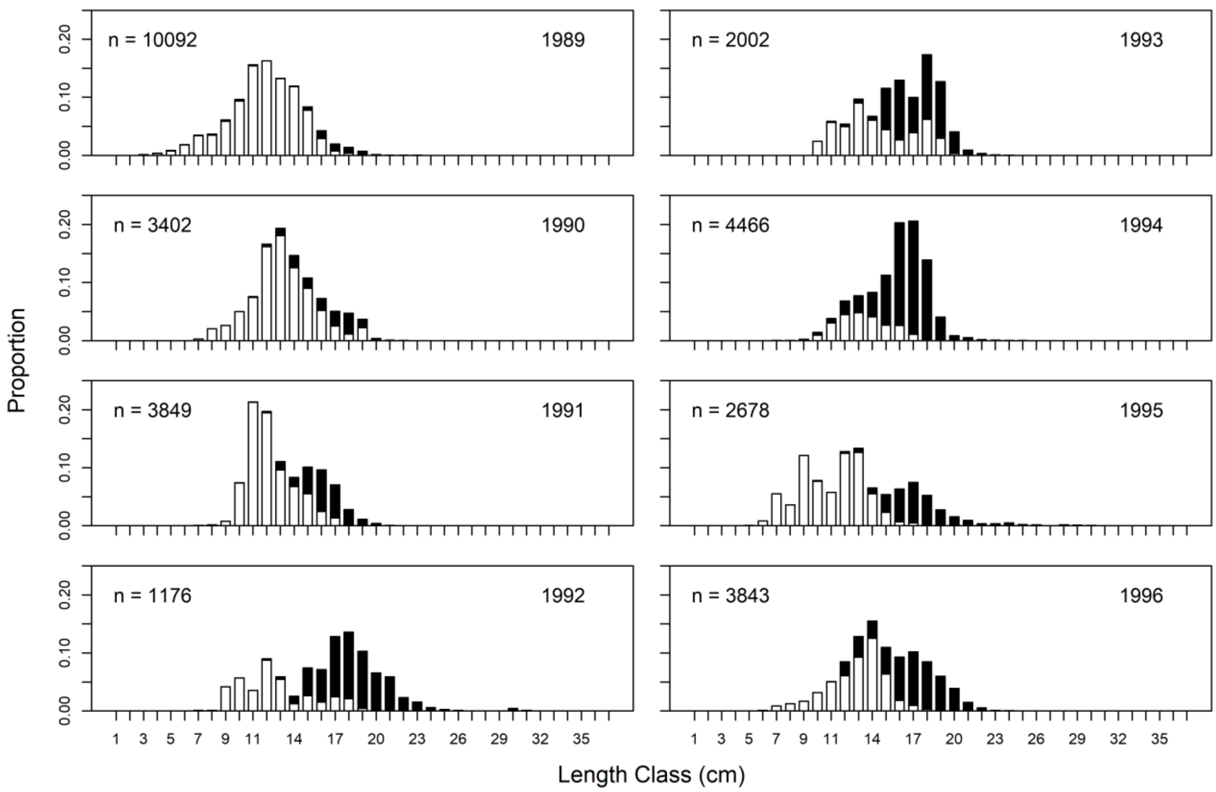

Figure 17. Length composition of butterfish (*Peprilus triacanthus*) from Northeast Fisheries Observer Program, 1989-1996, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

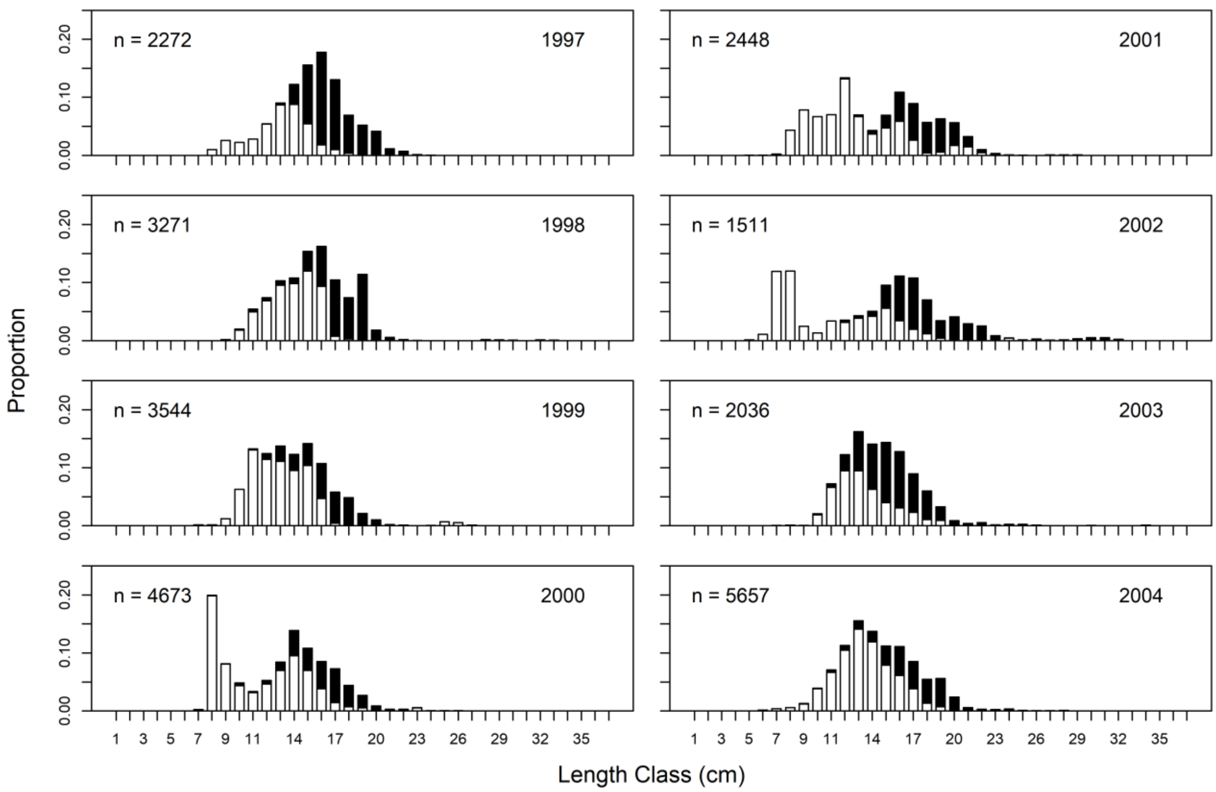

Figure 18. Length composition of butterfish (*Peprilus triacanthus*) from Northeast Fisheries Observer Program, 1997-2004, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

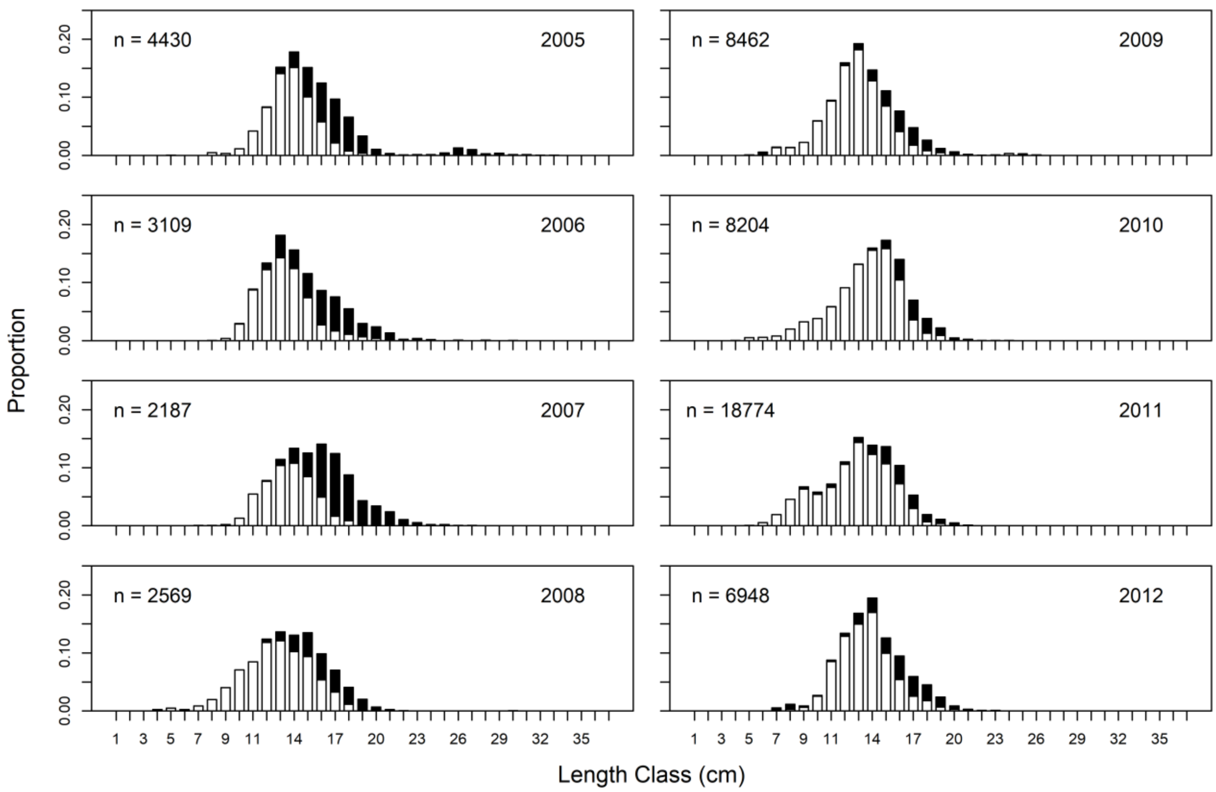

Figure 19. Length composition of butterfish (*Peprilus triacanthus*) from Northeast Fisheries Observer Program, 2005-2012, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

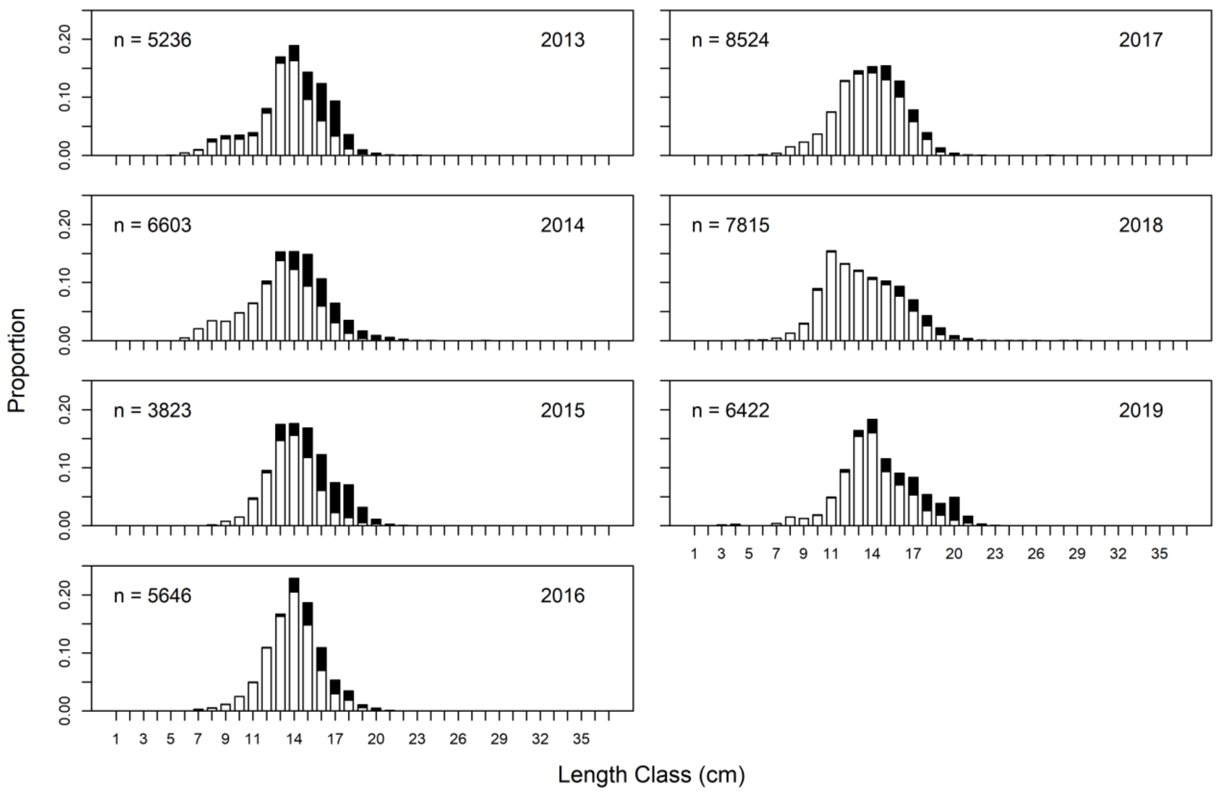

Figure 20. Length composition of butterfish (*Peprilus triacanthus*) from Northeast Fisheries Observer Program, 2013–2019, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

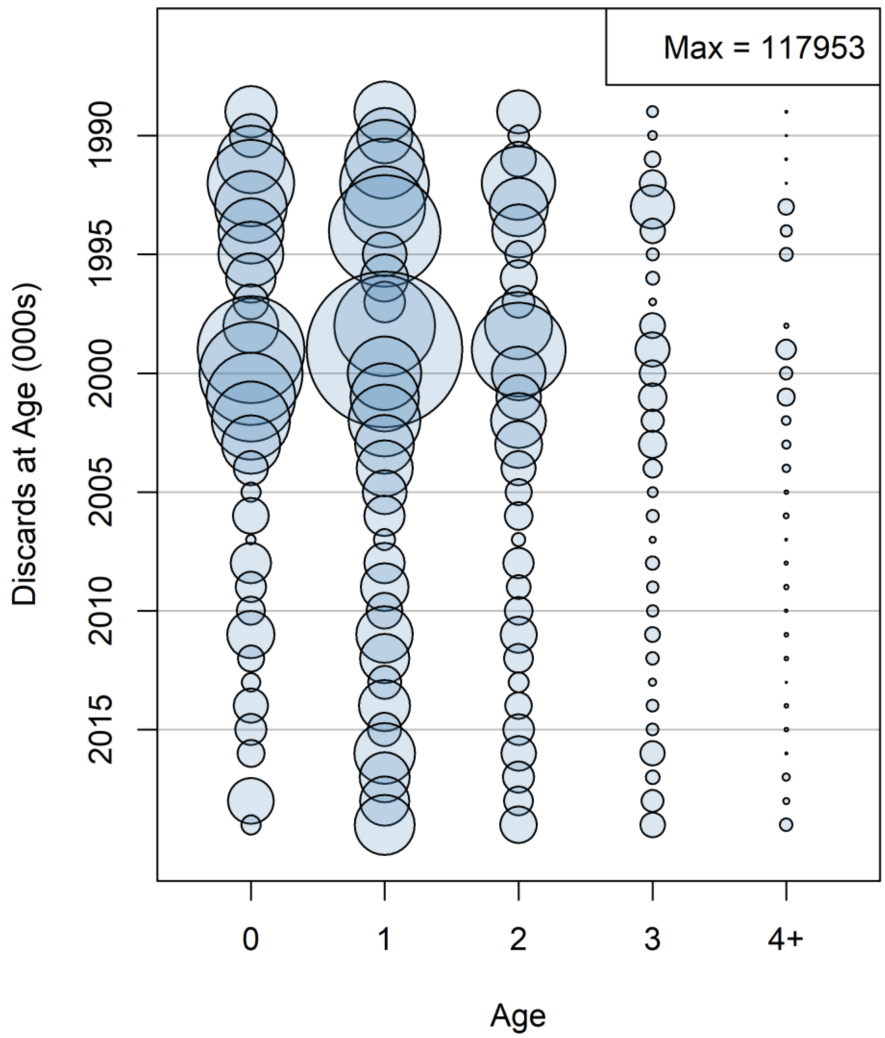

Figure 21. Butterfish (*Peprilus triacanthus*) commercial discards at age.

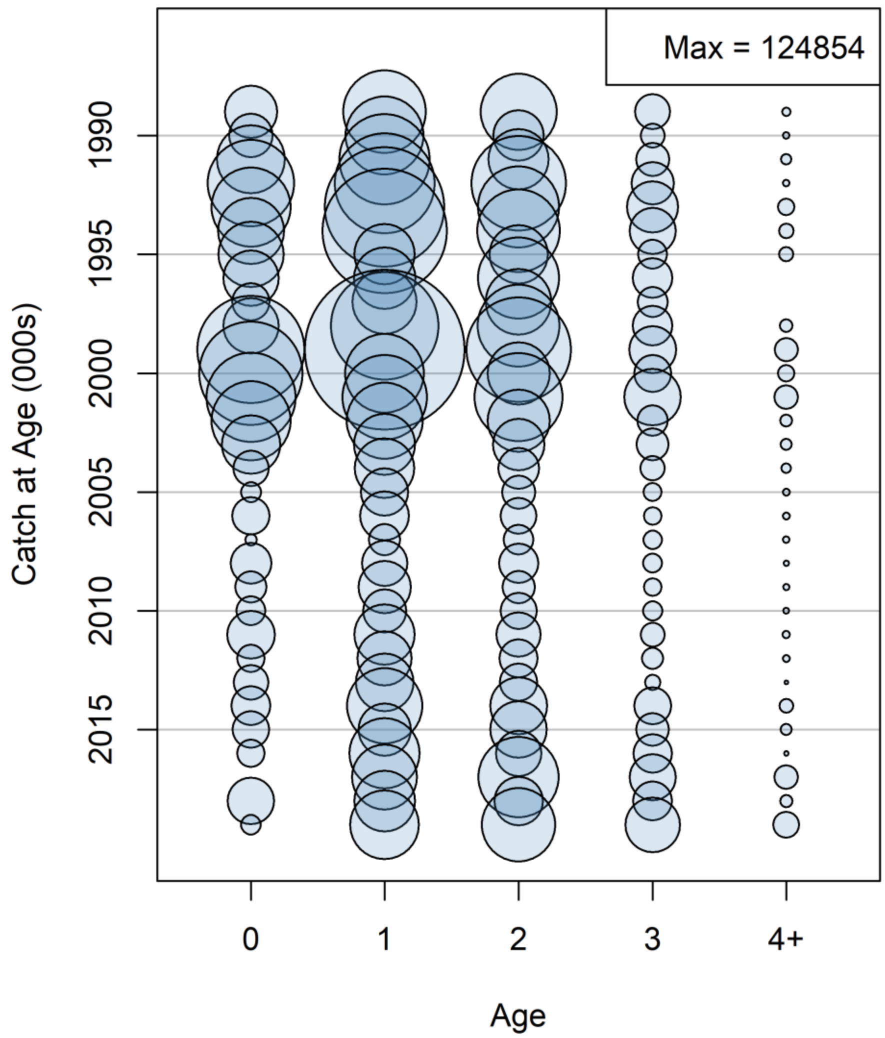

Figure 22. Butterfish (*Peprilus triacanthus*) commercial catch at age.

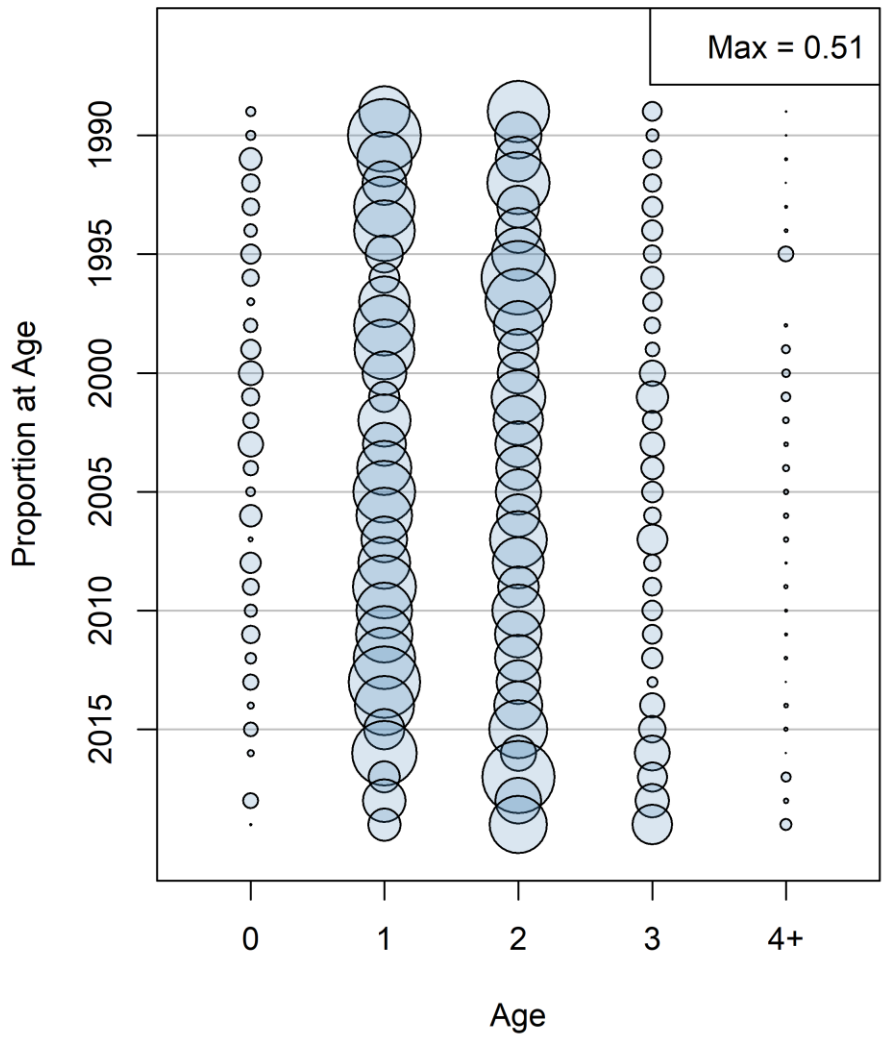

Figure 23. Butterfish (*Peprilus triacanthus*) proportions of catch at age in weight.

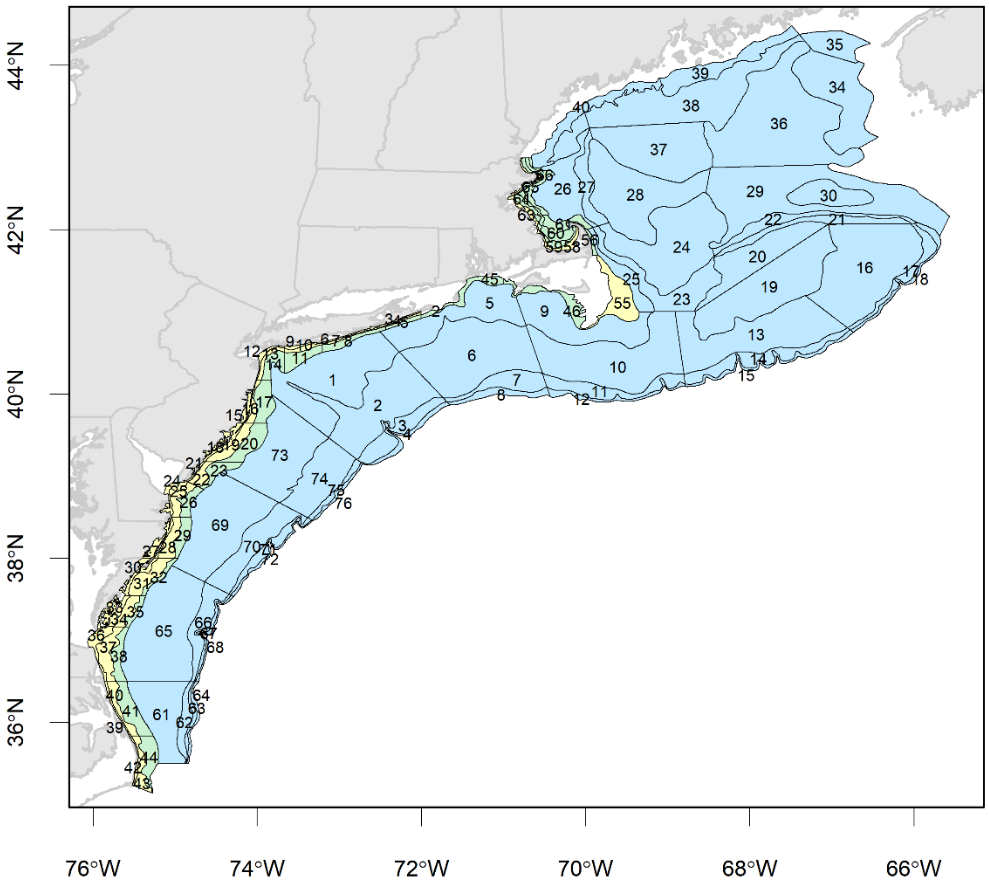

Figure 24. Northeast Fisheries Science Center bottom trawl survey strata. Offshore strata (prefix 01) are in blue, and inshore strata (prefix 03) are in green. The shallow inshore strata (< 18 m) that were sampled by the FRV *Albatross IV* but not sampled by the FSV *Henry B. Bigelow* are in yellow.

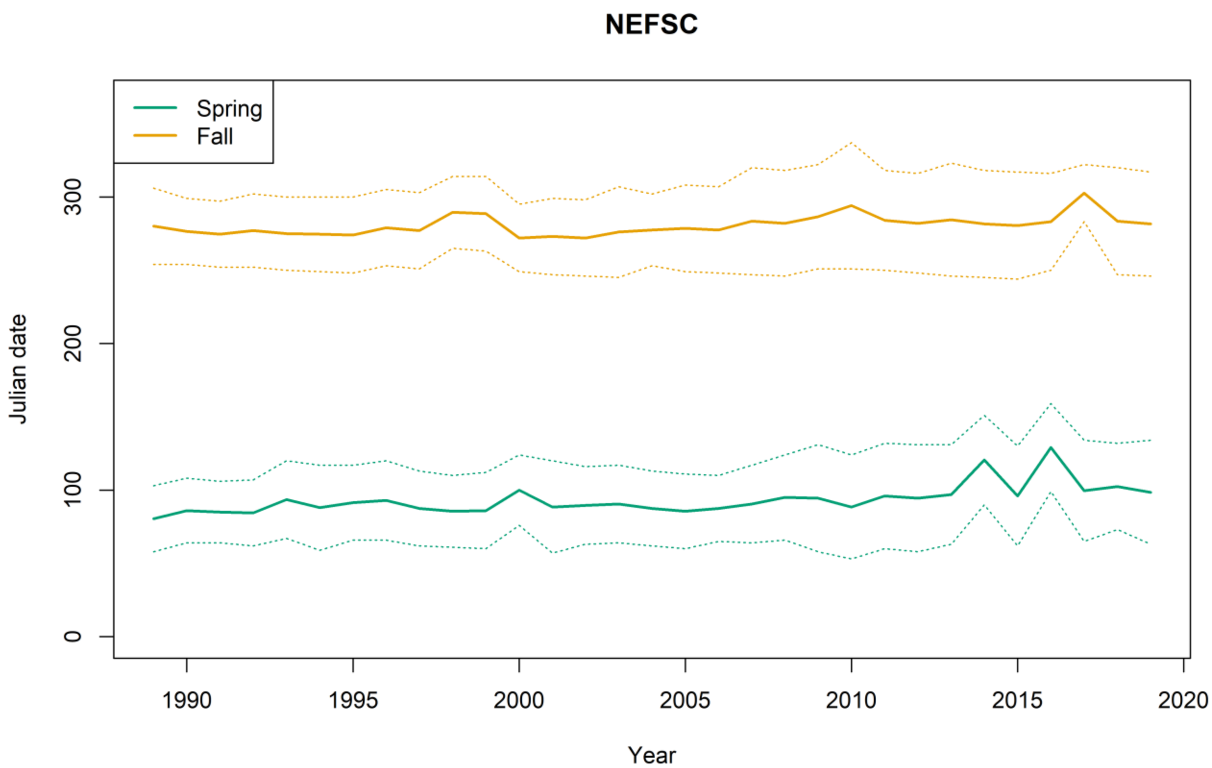

Figure 25. Northeast Fisheries Science Center (NEFSC) bottom trawl survey dates. Solid lines represent the mid-date; lower and upper dotted lines represent the start- and end-dates for the respective survey.

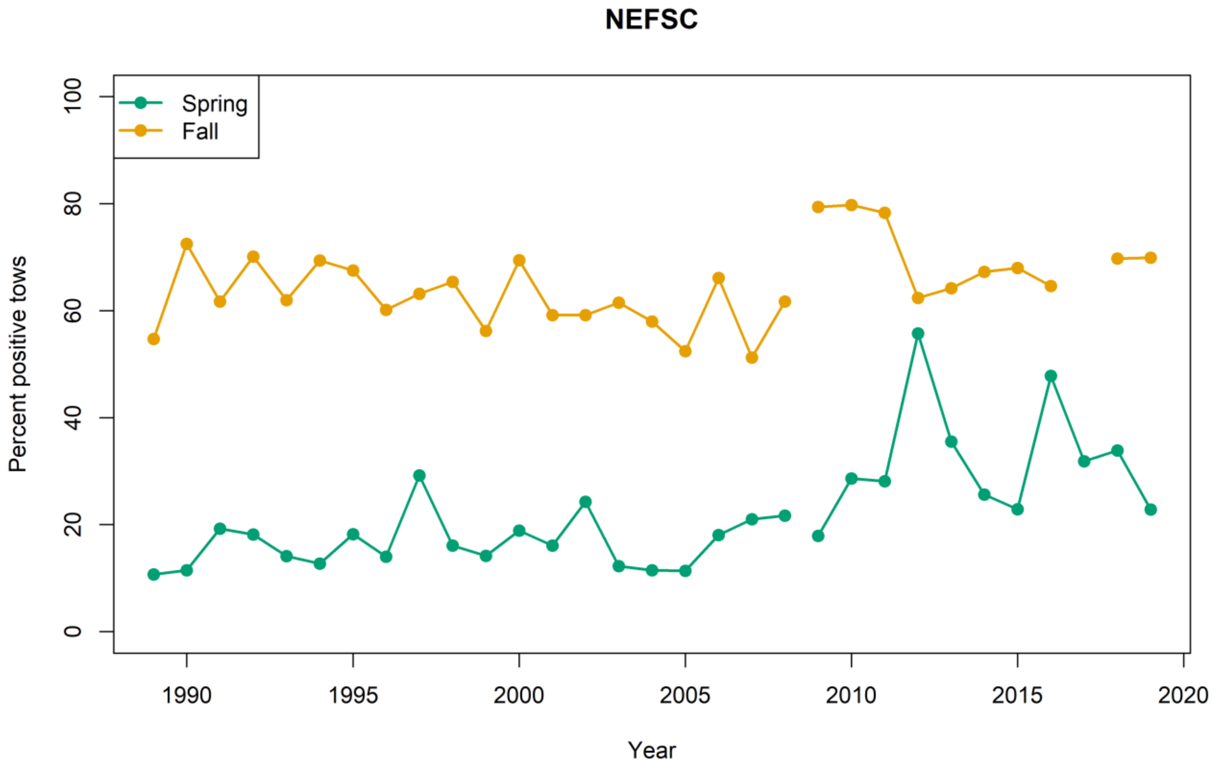

Figure 26. Percent positive tows for the Northeast Fisheries Science Center (NEFSC) bottom trawl survey. Strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years are shown in Table 13.

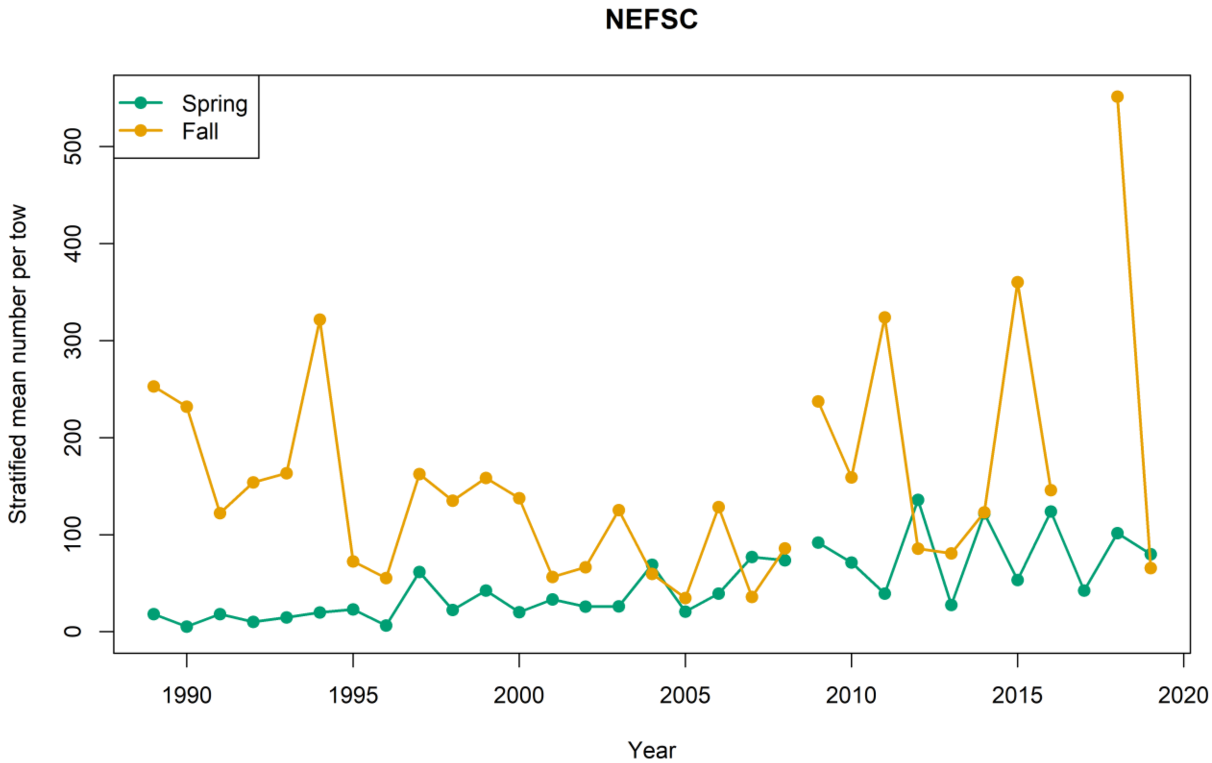

Figure 27. Northeast Fisheries Science Center (NEFSC) bottom trawl survey stratified mean number per tow for butterfish (*Peprilus triacanthus*). Strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years are shown in Table 13.

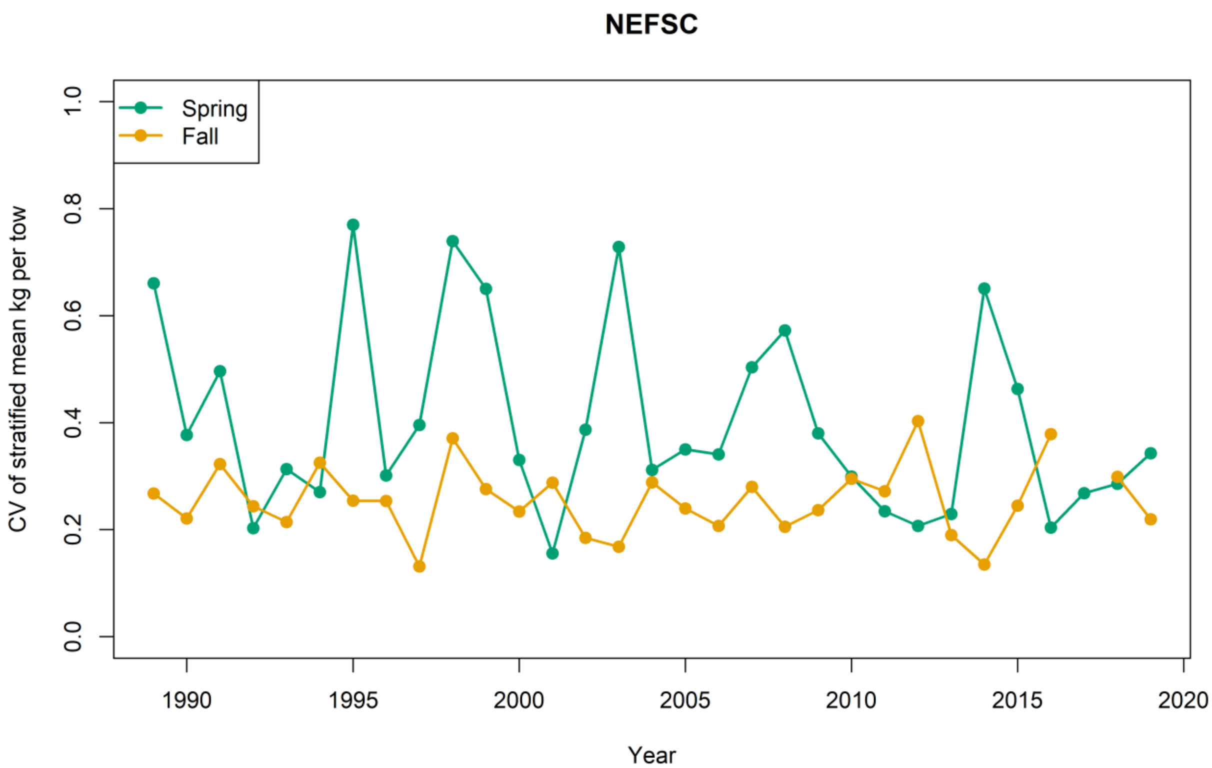

Figure 28. Coefficient of variation (CV) for Northeast Fisheries Science Center (NEFSC) bottom trawl survey stratified mean number per tow for butterfish (*Peprilus triacanthus*).

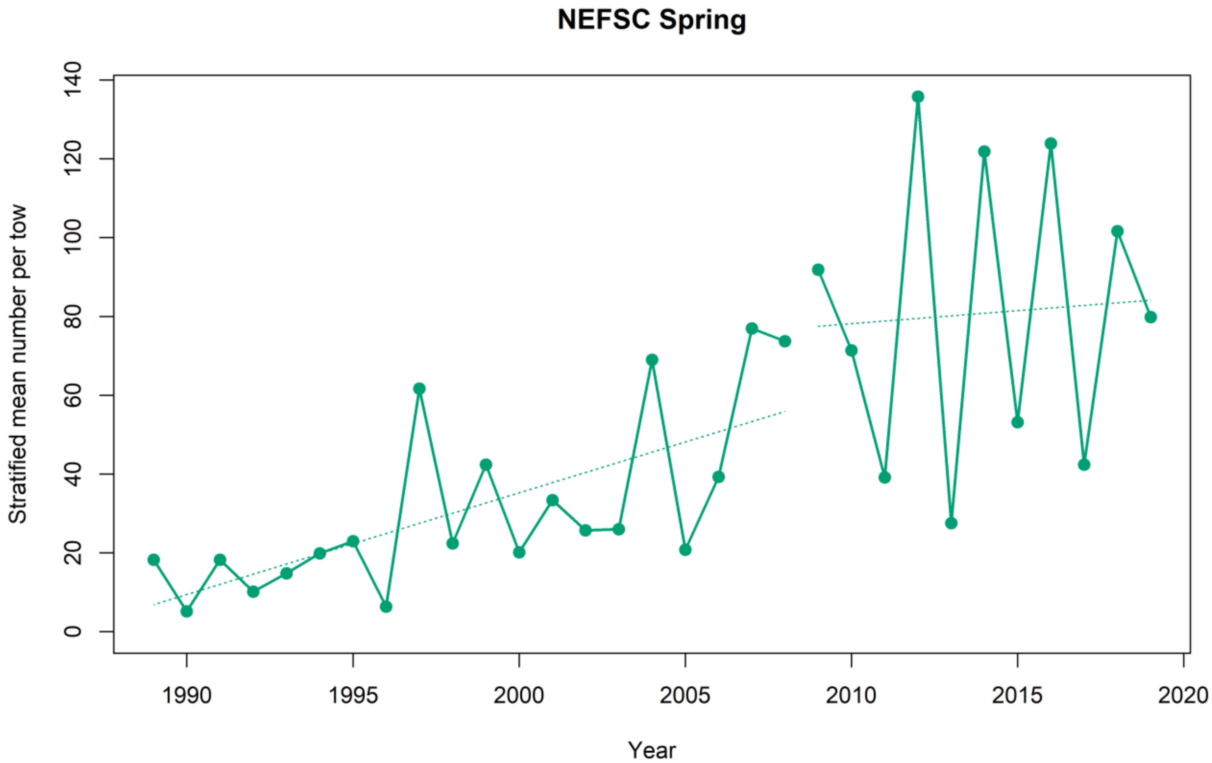

Figure 29. Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey stratified mean number per tow for butterfish (*Peprilus triacanthus*). Dotted lines are linear regressions for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years.

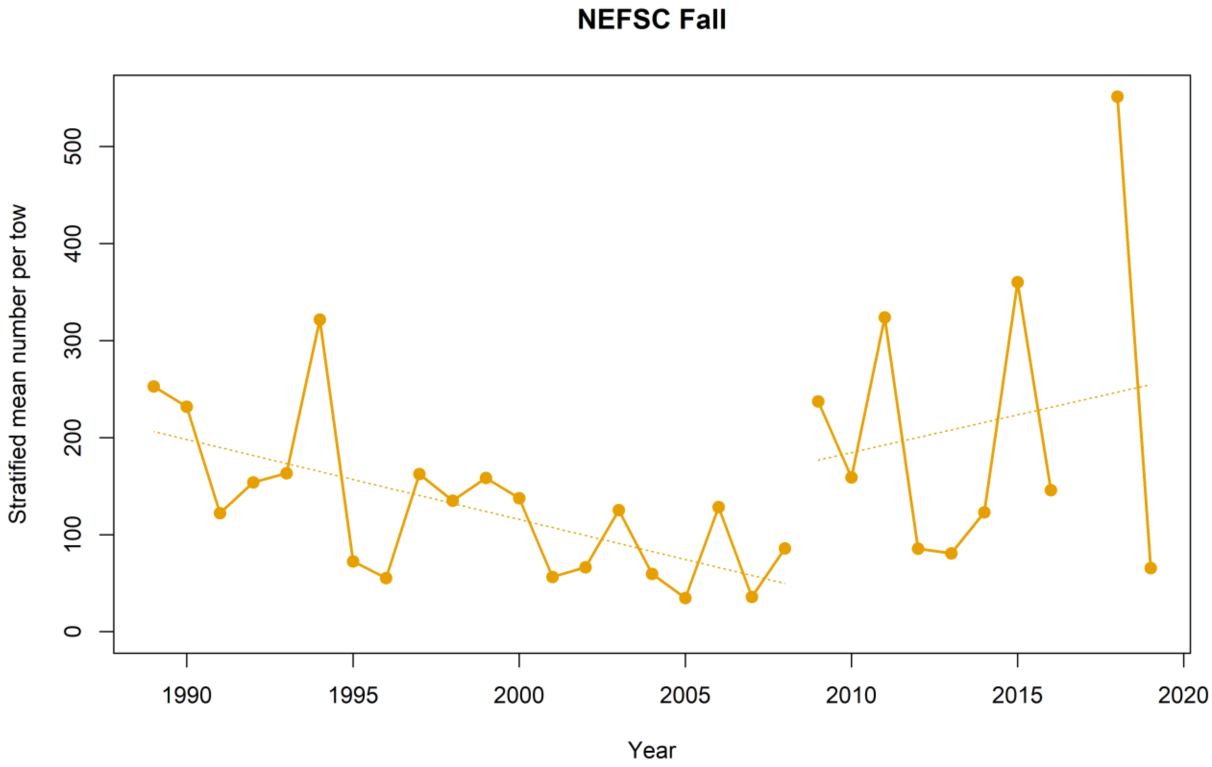

Figure 30. Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey stratified mean number per tow for butterfish (*Peprilus triacanthus*). Dotted lines are linear regressions for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years.

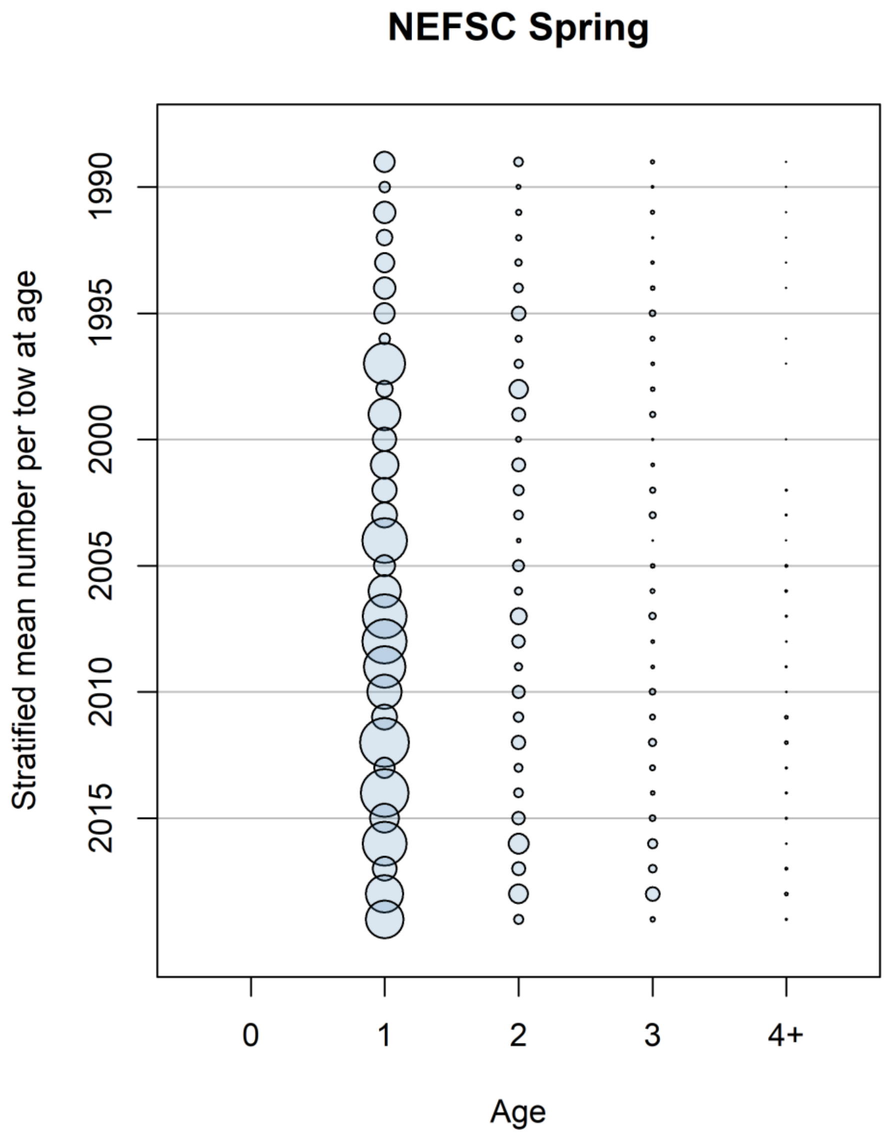

Figure 31. Northeast Fisheries Science Center (NEFSC) spring bottom trawl survey stratified mean number per tow at age for butterfish (*Peprilus triacanthus*). FSV *Henry B. Bigelow* data (2009-2019) are calibrated to FRV *Albatross IV* units using the coefficients in Miller et al. (2010) to facilitate cohort tracking.

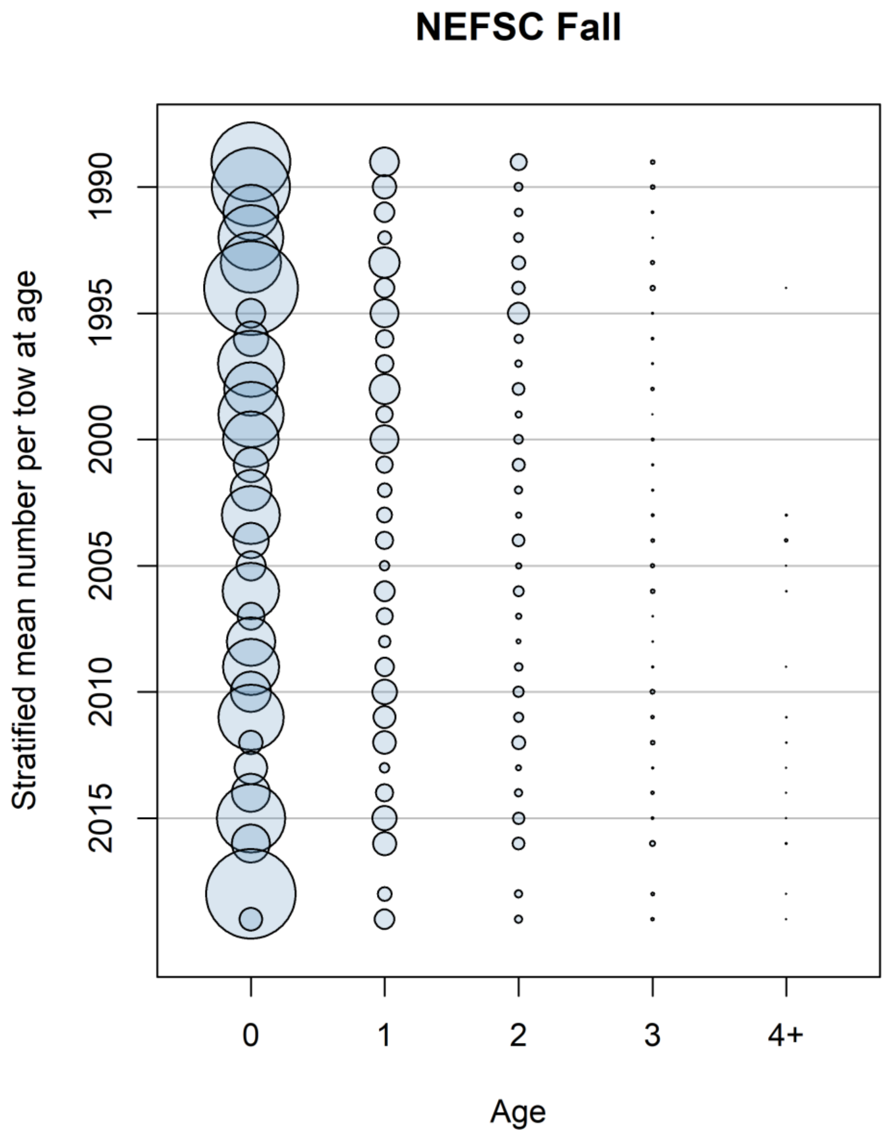

Figure 32. Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey stratified mean number per tow at age for butterfish (*Peprilus triacanthus*). FSV *Henry B. Bigelow* data (2009-2019) are calibrated to FRV *Albatross IV* units using the coefficients in Miller et al. (2010) to facilitate cohort tracking.

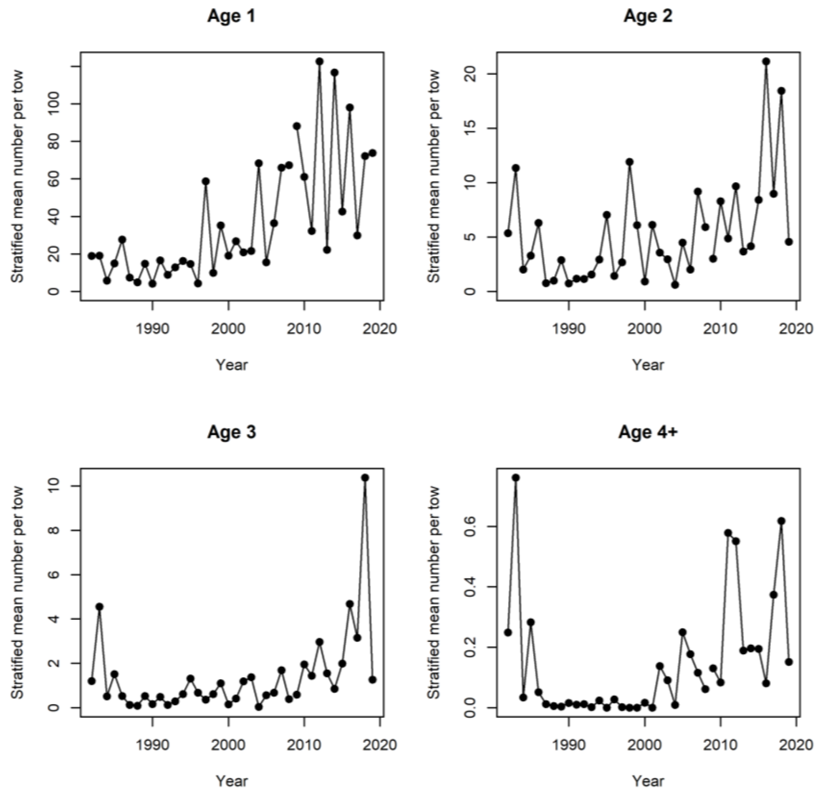

Figure 33. Northeast Fisheries Science Center spring bottom trawl survey stratified mean number per tow at age for butterfish (*Peprilus triacanthus*). Strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years are shown in Table 13.

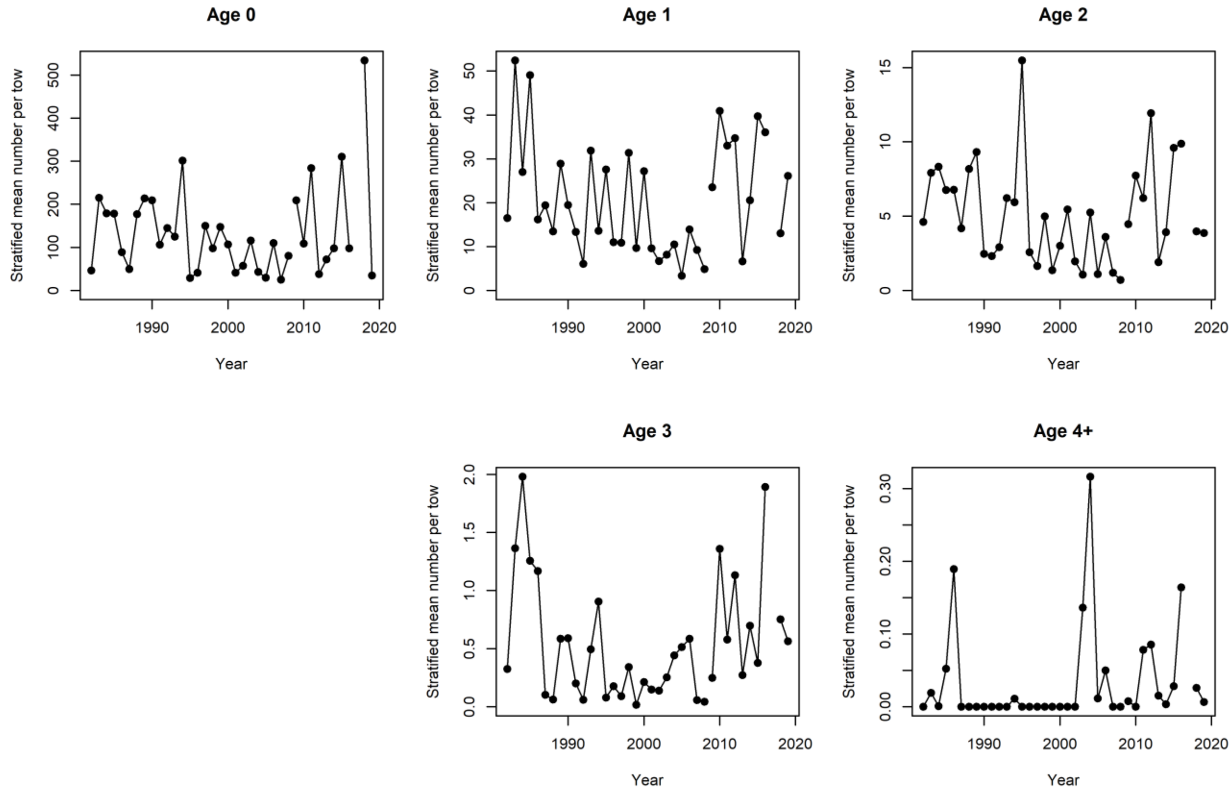

Figure 34. Northeast Fisheries Science Center fall bottom trawl survey stratified mean number per tow at age for butterfish (*Peprilus triacanthus*). Strata for FRV *Albatross IV* (1989-2008) and FSV *Henry B. Bigelow* (2009-2019) years are shown in Table 13.

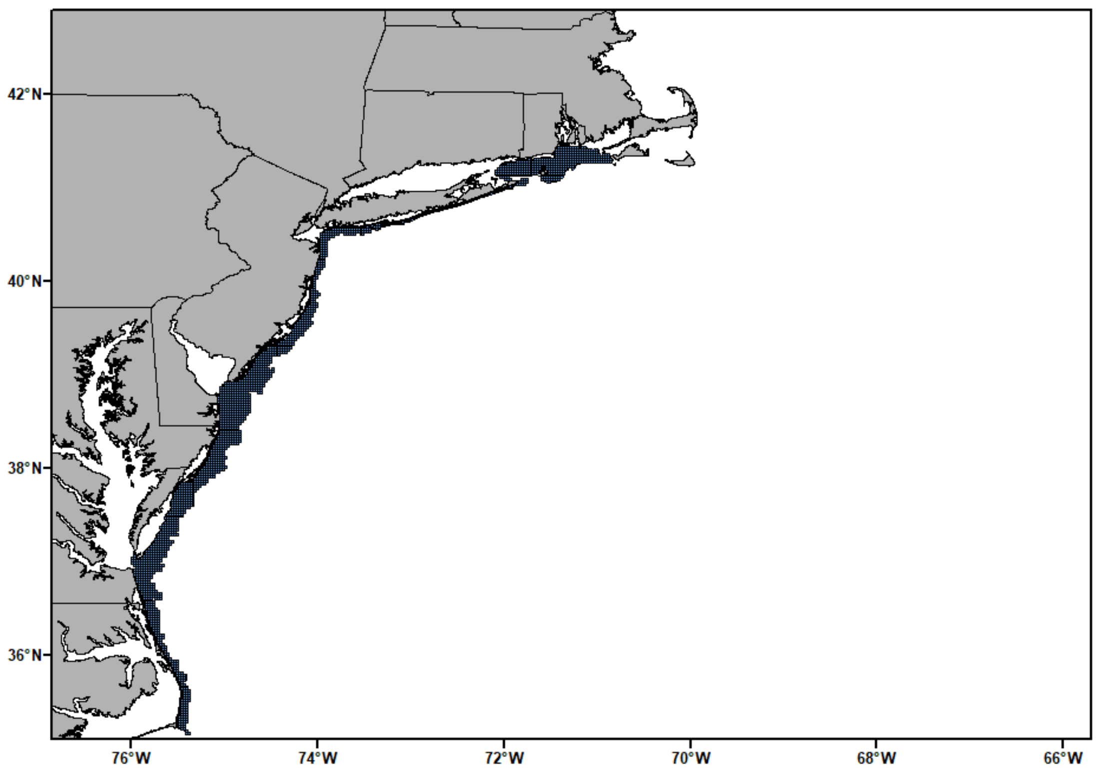

Figure 35. Northeast Area Monitoring and Assessment Program bottom trawl survey cells.

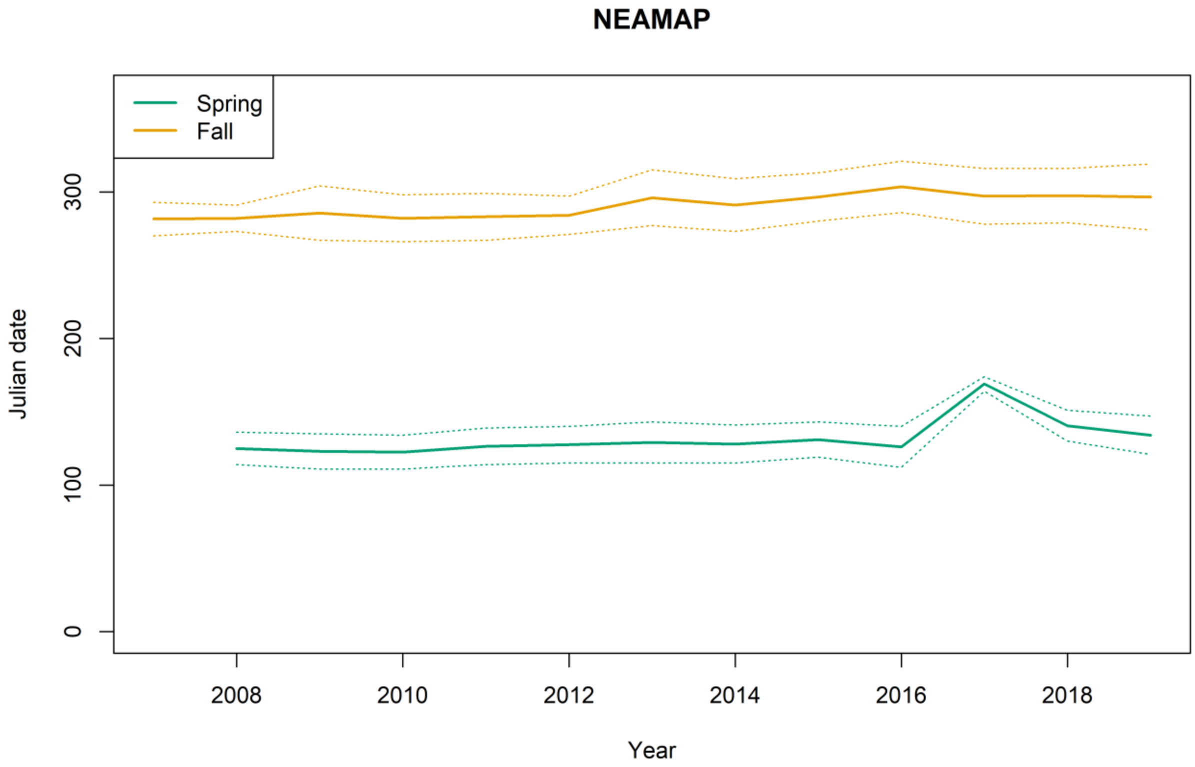

Figure 36. Northeast Area Monitoring and Assessment Program (NEAMAP) bottom trawl survey dates. Solid lines represent the mid-date; lower and upper dotted lines represent the start- and end-dates for the respective survey.

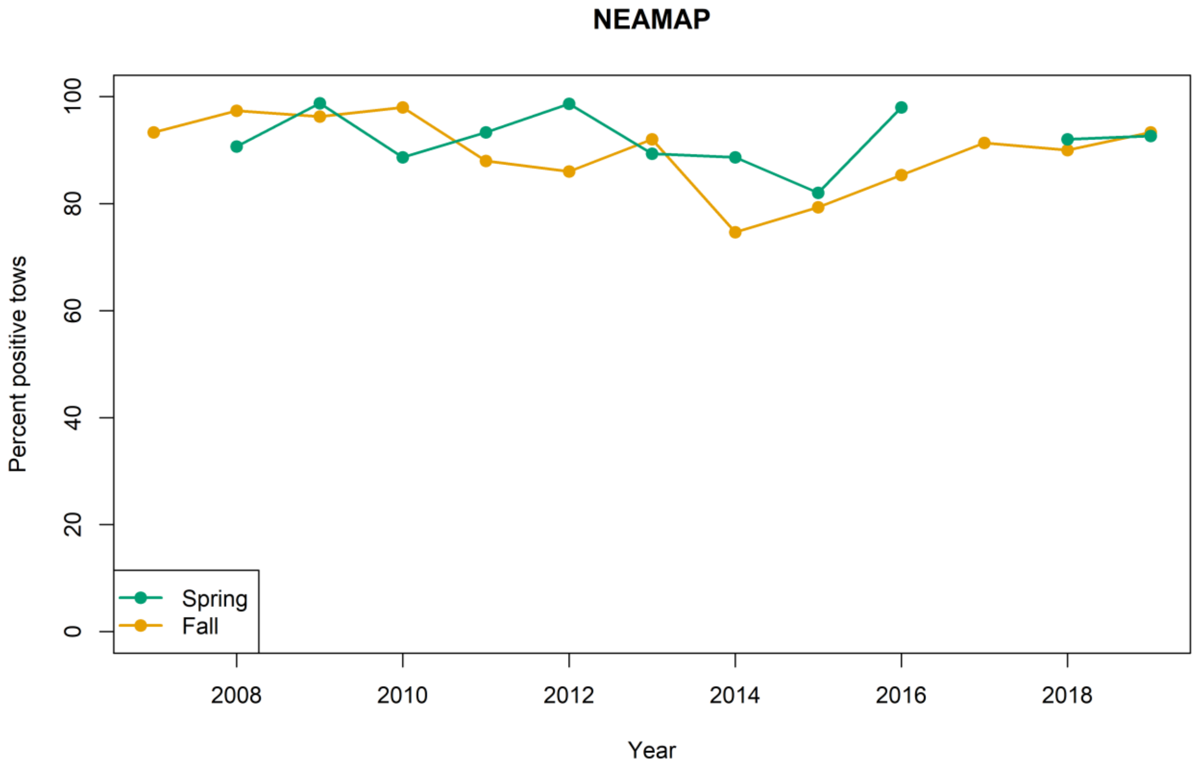

Figure 37. Percent positive tows for the Northeast Area Monitoring and Assessment Program (NEAMAP) bottom trawl survey.

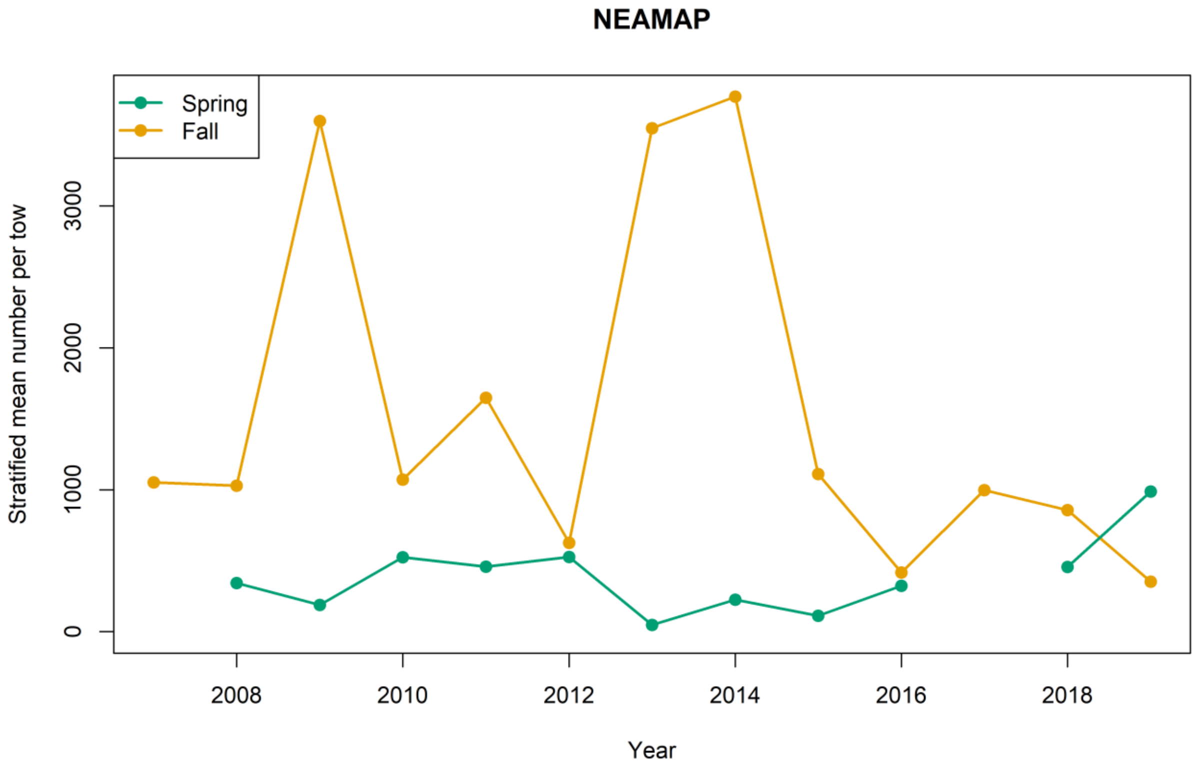

Figure 38. Northeast Area Monitoring and Assessment Program (NEAMAP) bottom trawl survey arithmetic stratified mean number per tow for butterfish (*Peprilus triacanthus*).

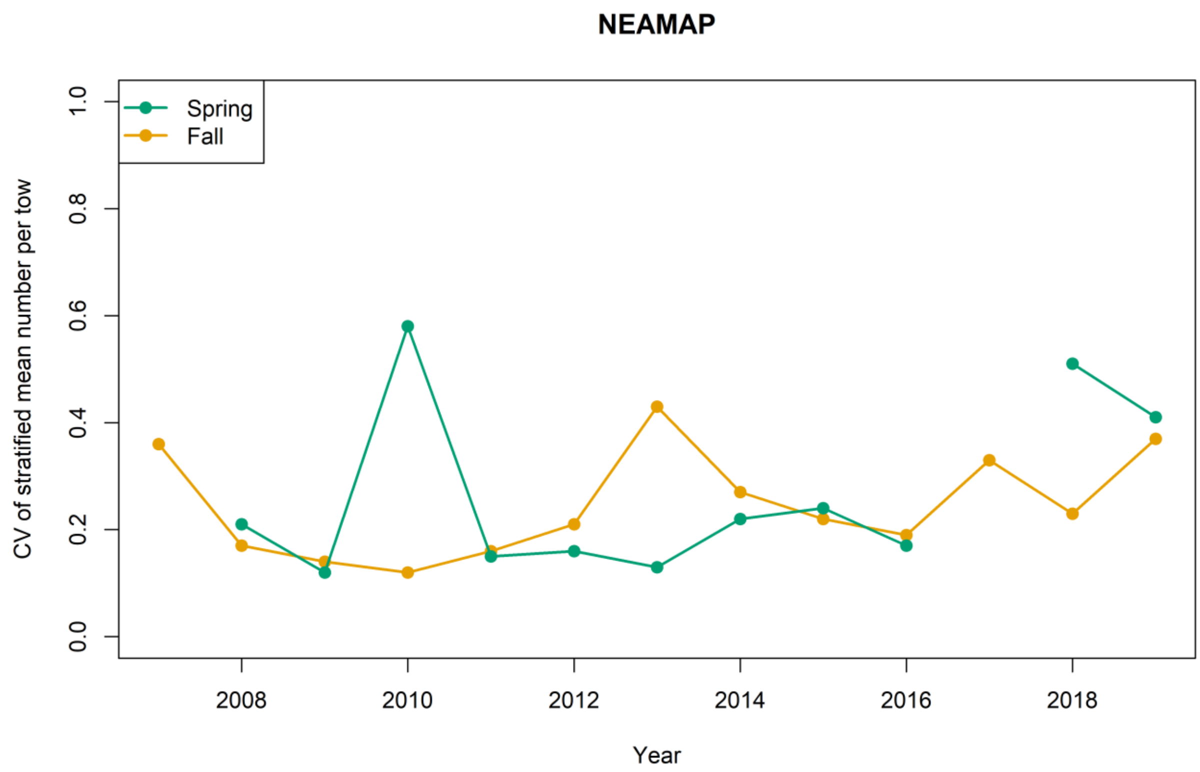

Figure 39. Coefficient of variation (CV) for Northeast Area Monitoring and Assessment Program (NEAMAP) bottom trawl survey stratified mean number per tow for butterfish (*Peprilus triacanthus*).

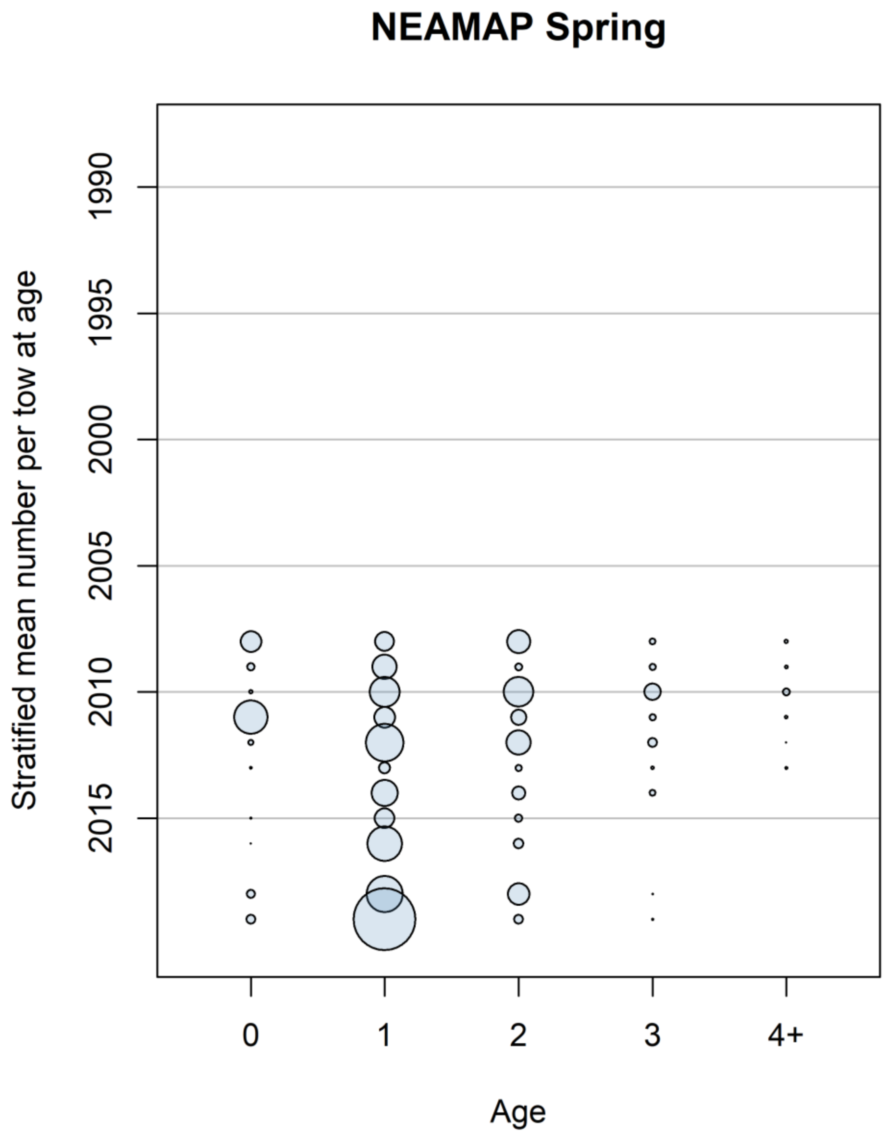

Figure 40. Northeast Area Monitoring and Assessment Program (NEAMAP) spring bottom trawl survey arithmetic stratified mean number per tow at age for butterfish (*Peprilus triacanthus*).

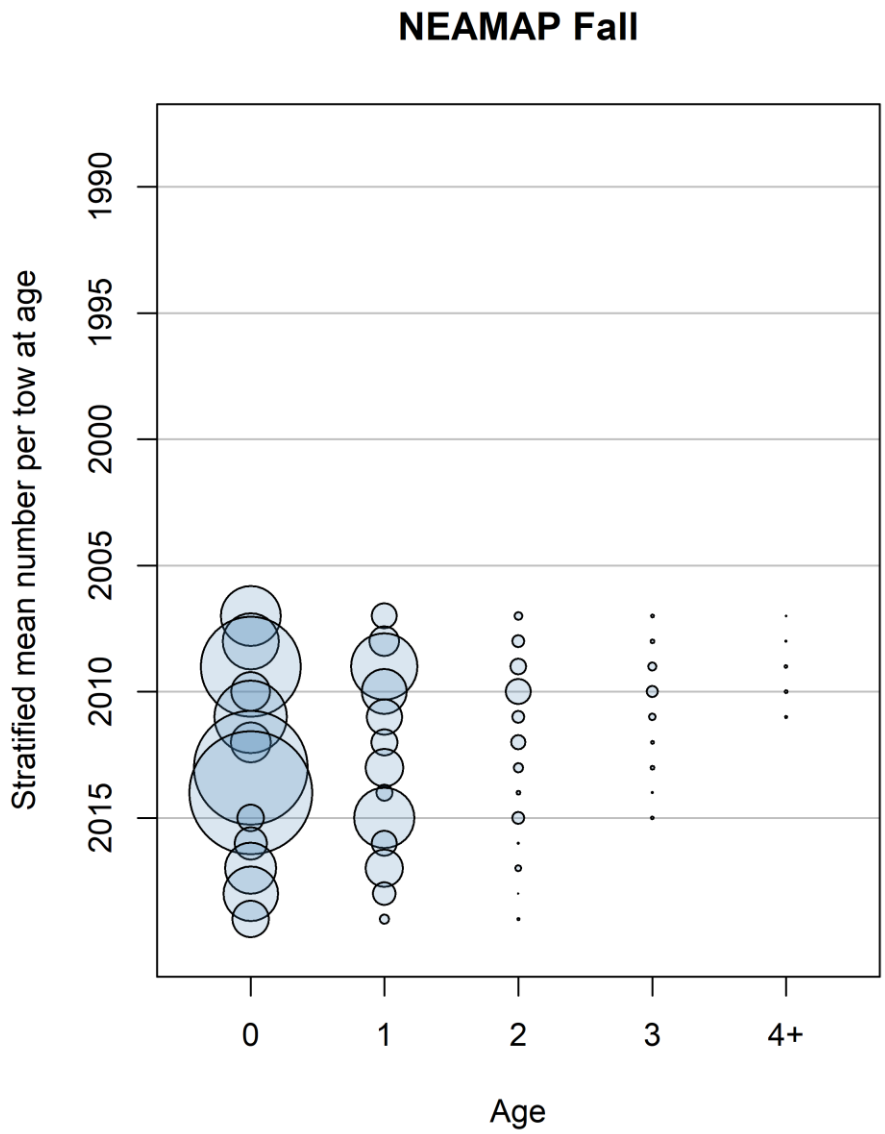

Figure 41. Northeast Area Monitoring and Assessment Program (NEAMAP) fall bottom trawl survey arithmetic stratified mean number per tow at age for butterfish (*Peprilus triacanthus*).

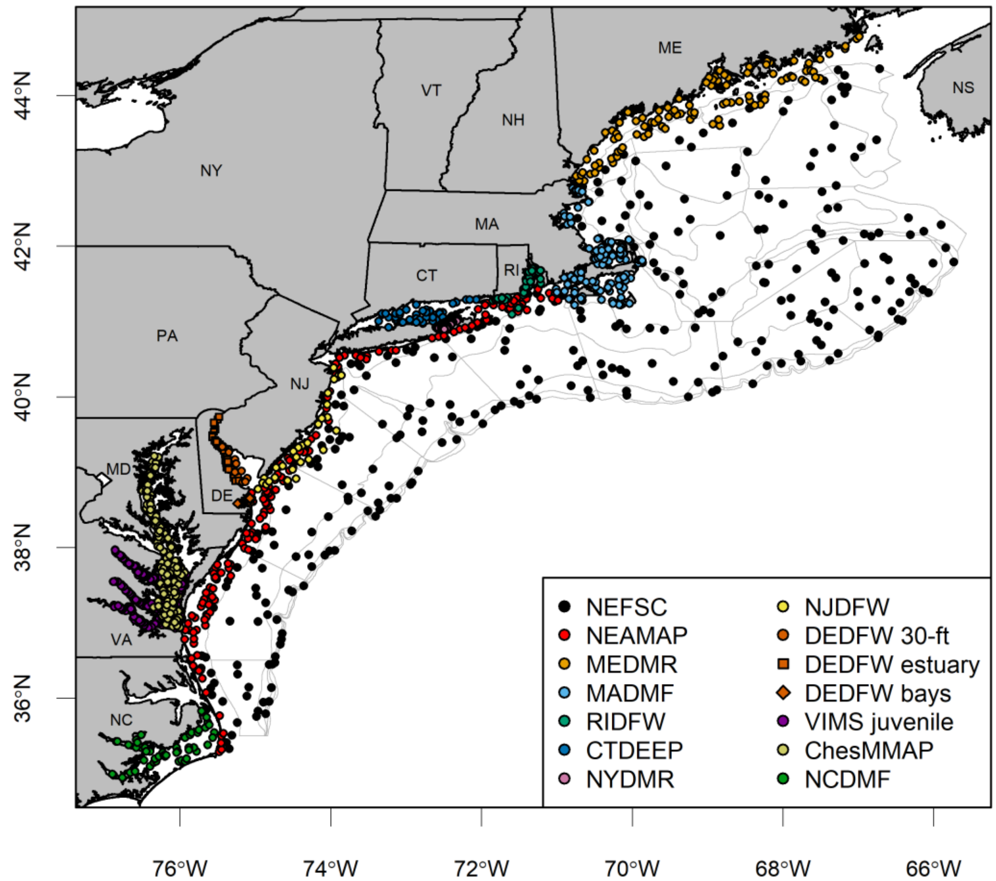

Figure 42. State survey tow locations in fall 2019. Tow locations are shown because some surveys have fixed stations rather than randomly sampled strata. Northeast Fisheries Science Center (NEFSC) and Northeast Area Monitoring and Assessment Program (NEAMAP) tow locations, as well NEFSC offshore (prefix 01) strata, are shown for comparison. State survey acronyms are: Maine Department of Marine Resources (MEDMR); Massachusetts Division of Marine Fisheries (MADMF); Rhode Island Department of Fish and Wildlife (RIDFW); Connecticut Department of Energy and Environmental Protection (CTDEEP); New York Division of Marine Resources (NYDMR); New Jersey Division of Fish and Wildlife (NJDFW); Delaware Division of Fish and Wildlife (DEDFW); Virginia Institute of Marine Science (VIMS); Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP); North Carolina Division of Marine Fisheries (NCDMF).

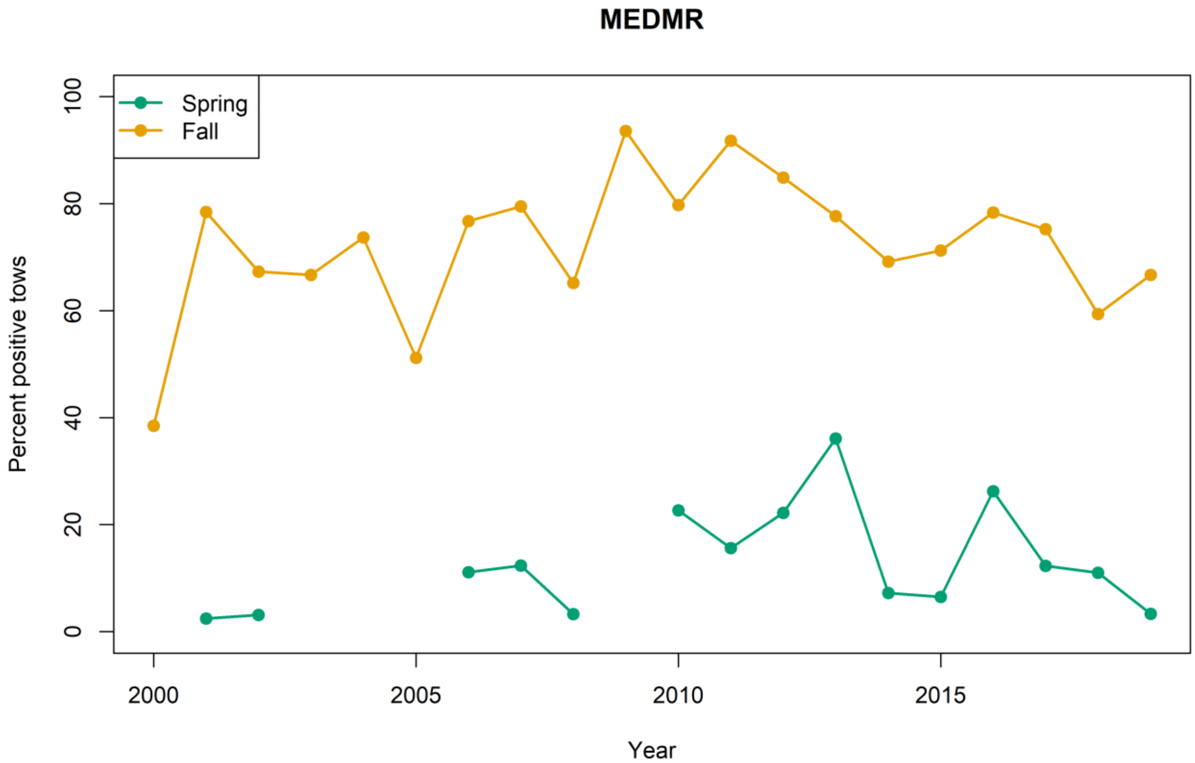

Figure 43. Percent positive tows for the Maine Department of Marine Resources (MEDMR) bottom trawl survey.

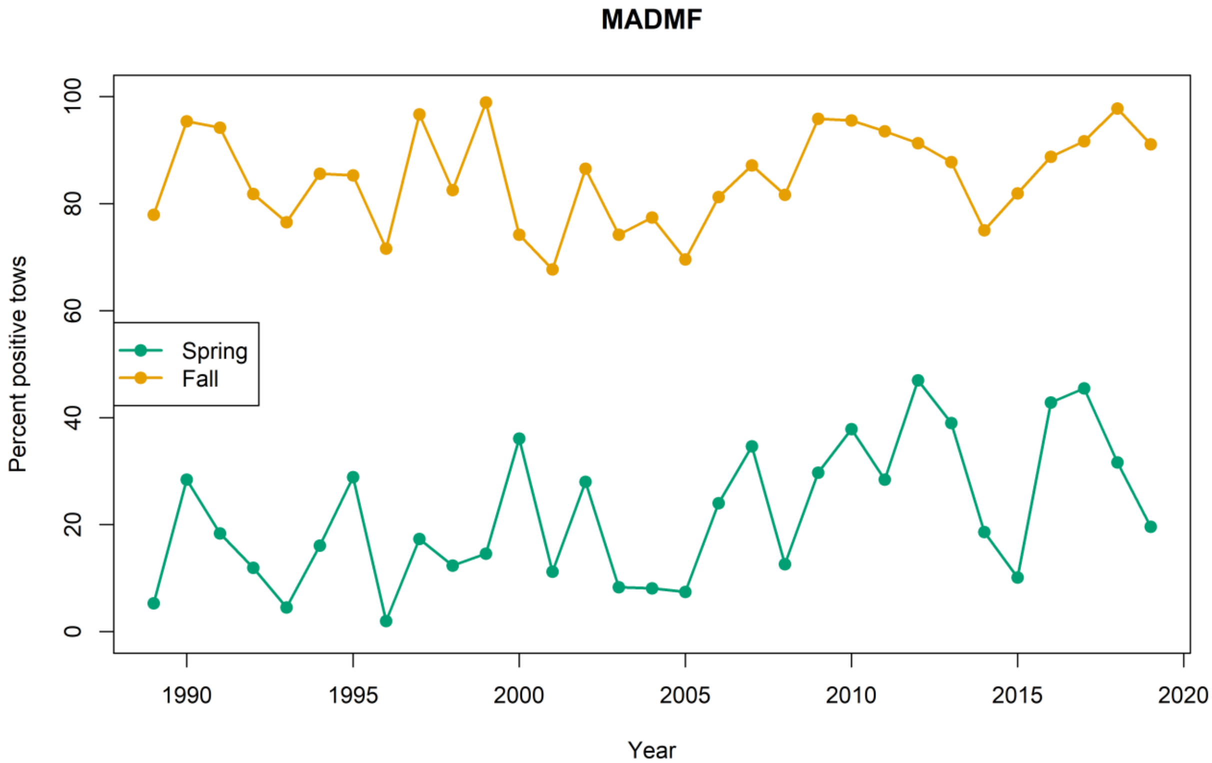

Figure 44. Percent positive tows for the Massachusetts Division of Marine Fisheries (MADMF) bottom trawl survey.

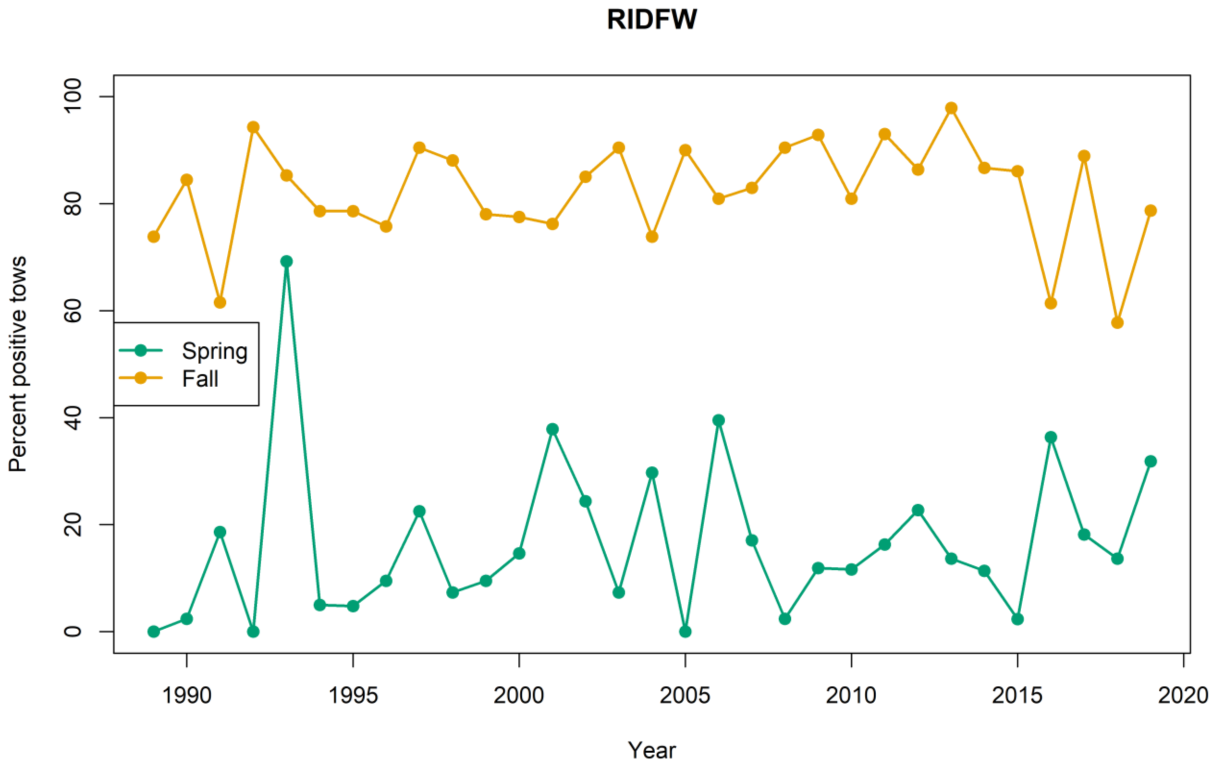

Figure 45. Percent positive tows for the Rhode Island Department of Fish and Wildlife (RIDFW) bottom trawl survey.

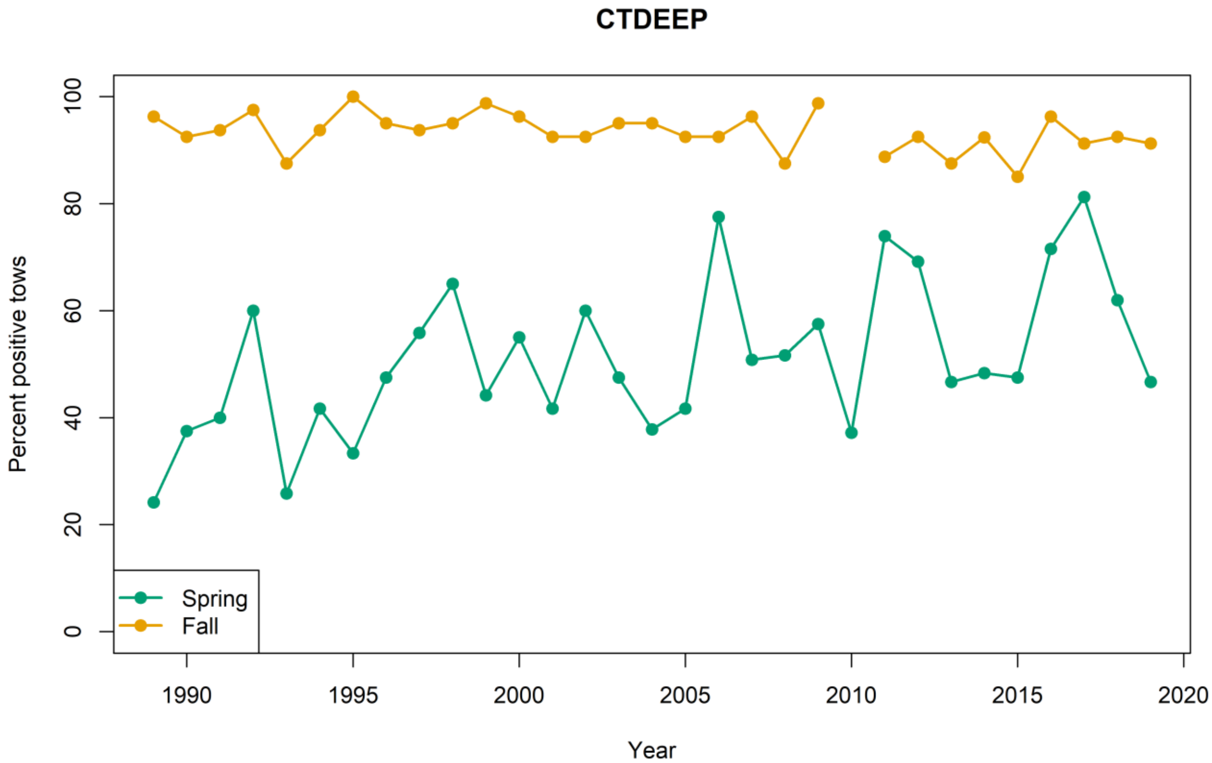

Figure 46. Percent positive tows for the Connecticut Department of Energy and Environmental Protection (CTDEEP) bottom trawl survey.

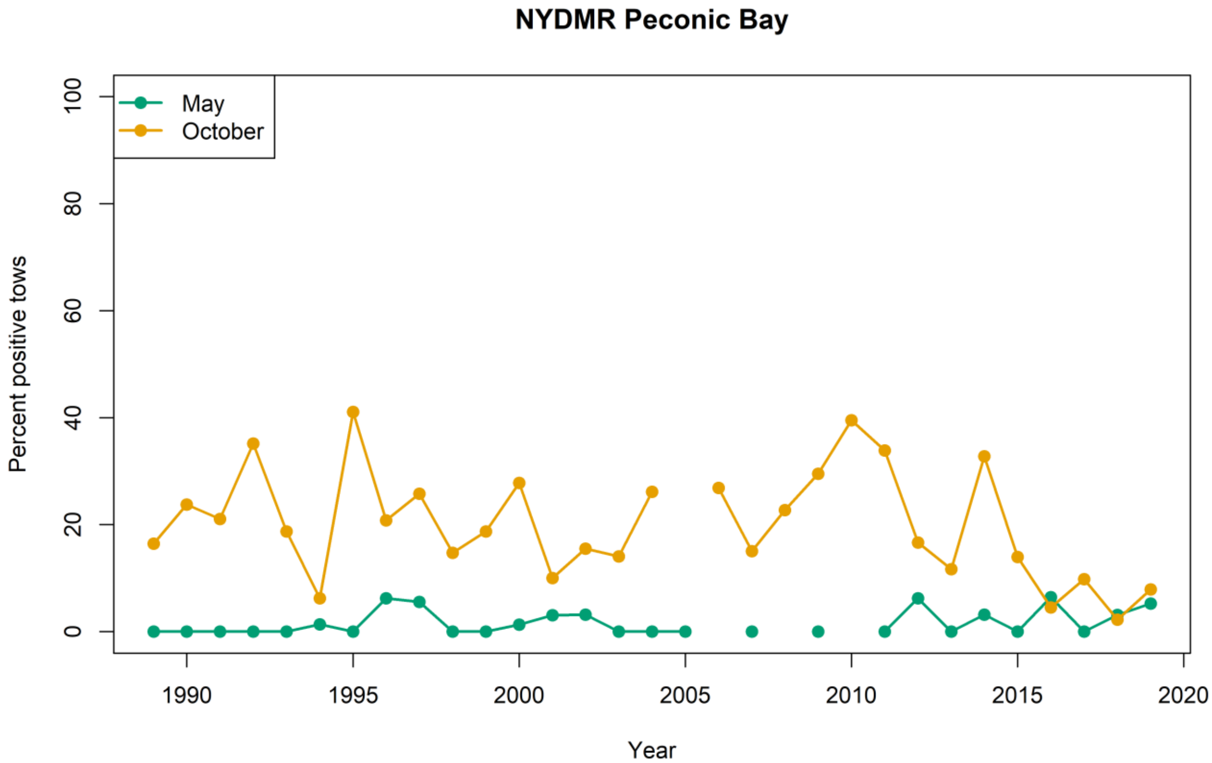

Figure 47. Percent positive tows for the New York Division of Marine Resources (NYDMR) bottom trawl survey of Peconic Bay.

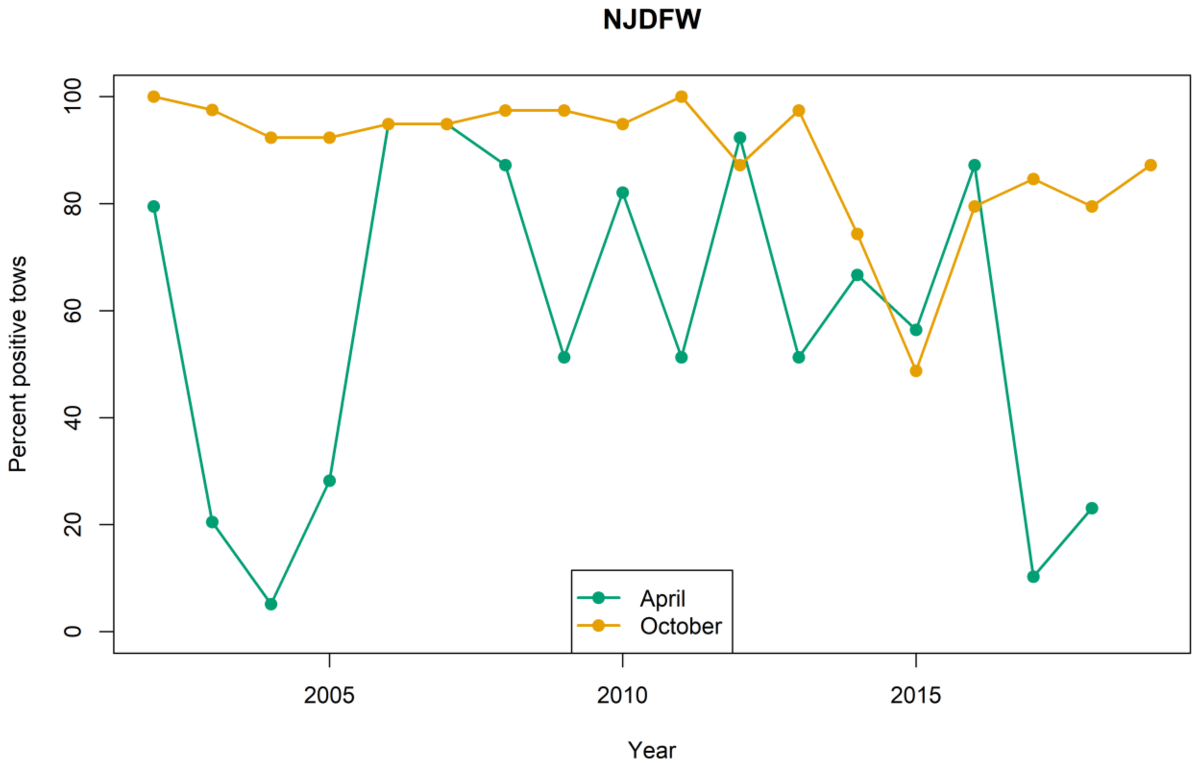

Figure 48. Percent positive tows for the New Jersey Division of Fish and Wildlife (NJDFW) bottom trawl survey.

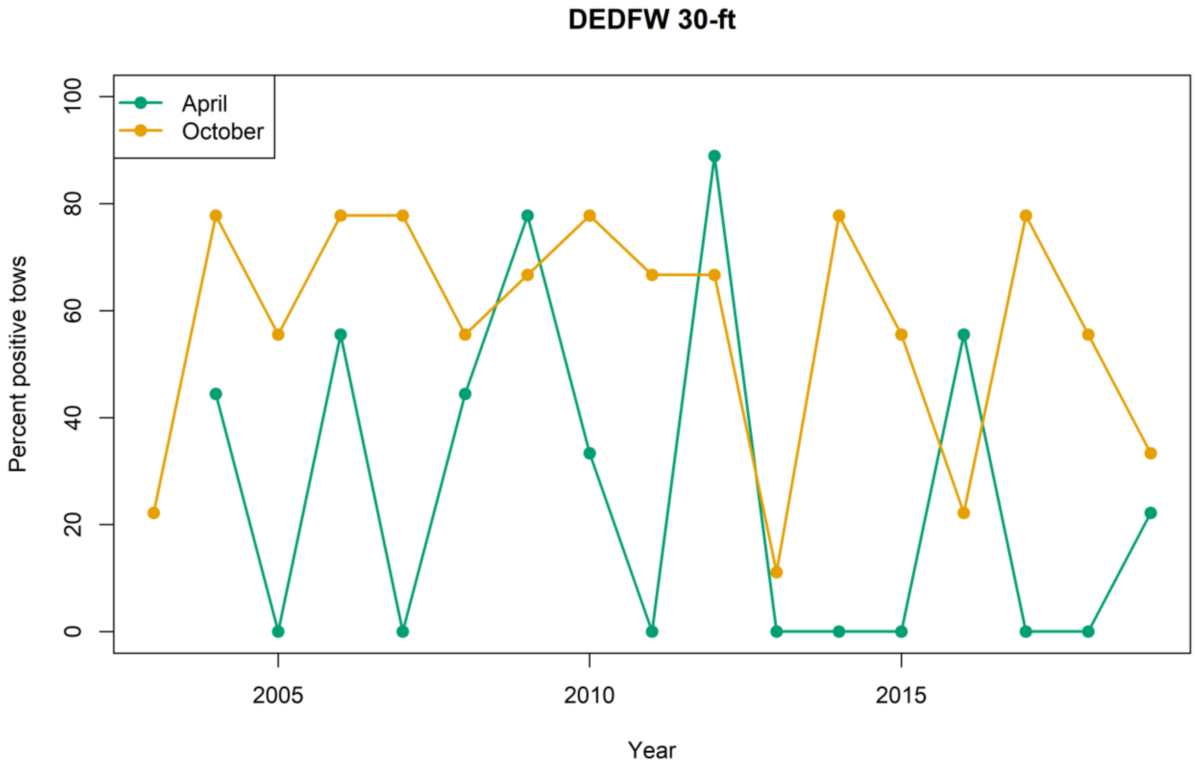

Figure 49. Percent positive tows for the Delaware Division of Fish and Wildlife (DEDFW) 30-foot headrope bottom trawl survey.

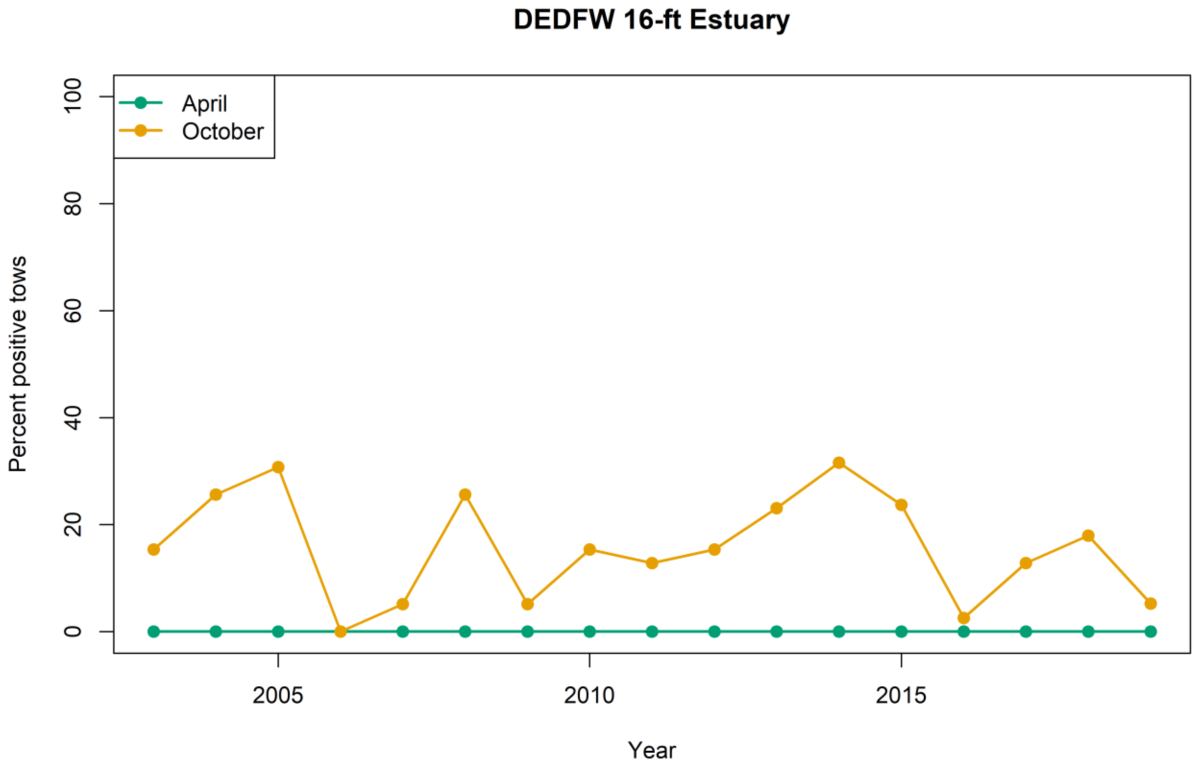

Figure 50. Percent positive tows for the Delaware Division of Fish and Wildlife (DEDFW) 16-foot headrope bottom trawl survey of the Delaware estuary.

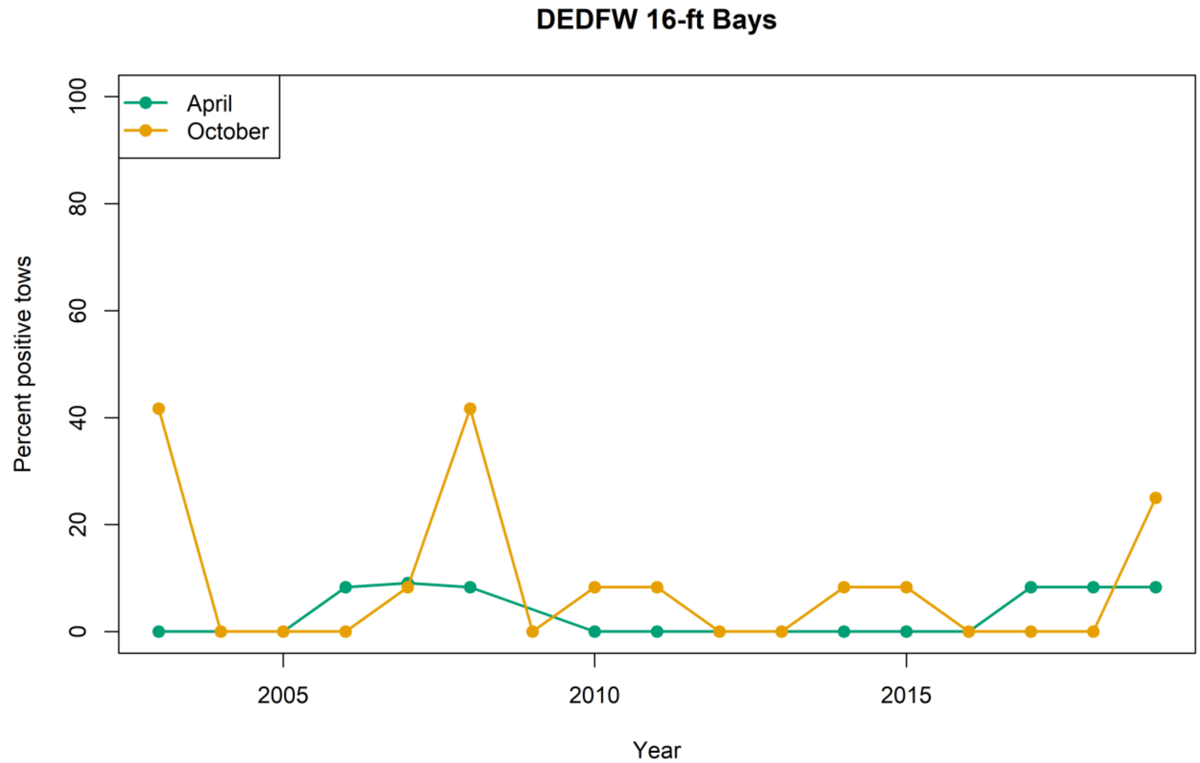

Figure 51. Percent positive tows for the Delaware Division of Fish and Wildlife (DEDFW) 16-foot headrope bottom trawl survey of the inland bays.

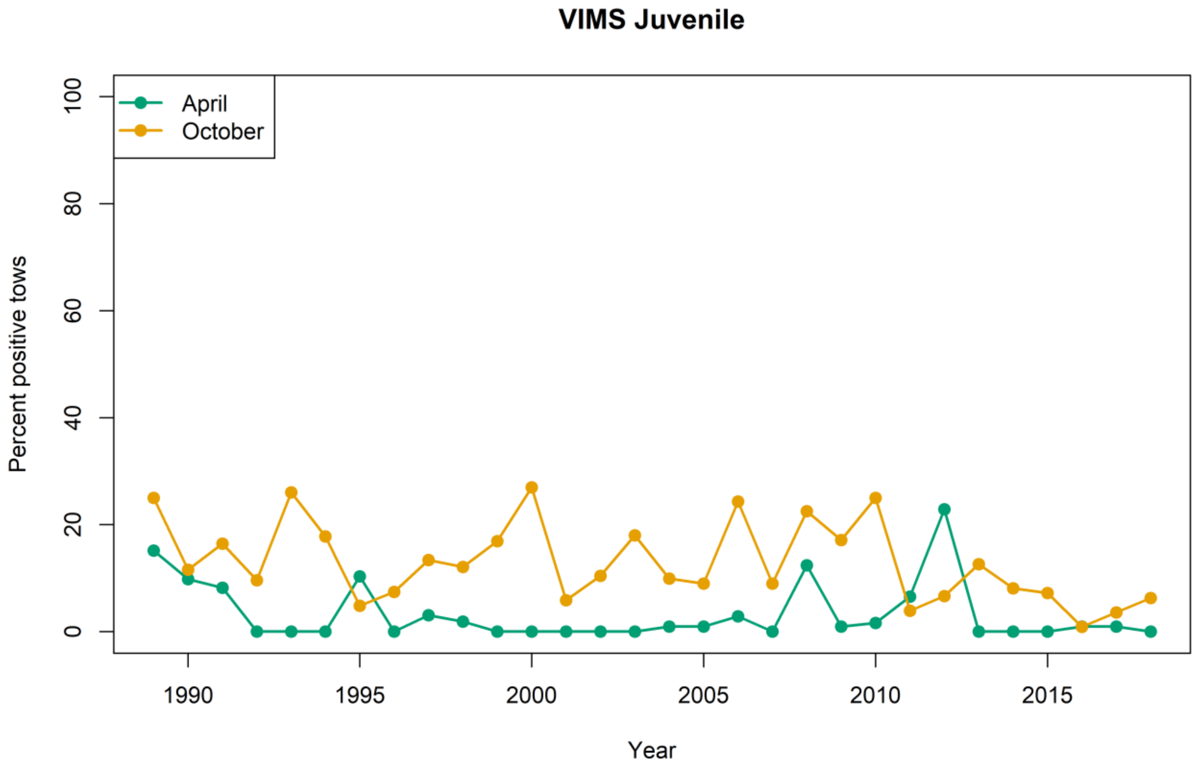

Figure 52. Percent positive tows for the Virginia Institute of Marine Science (VIMS) juvenile fish and blue crab (*Callinectes sapidus)* trawl survey.

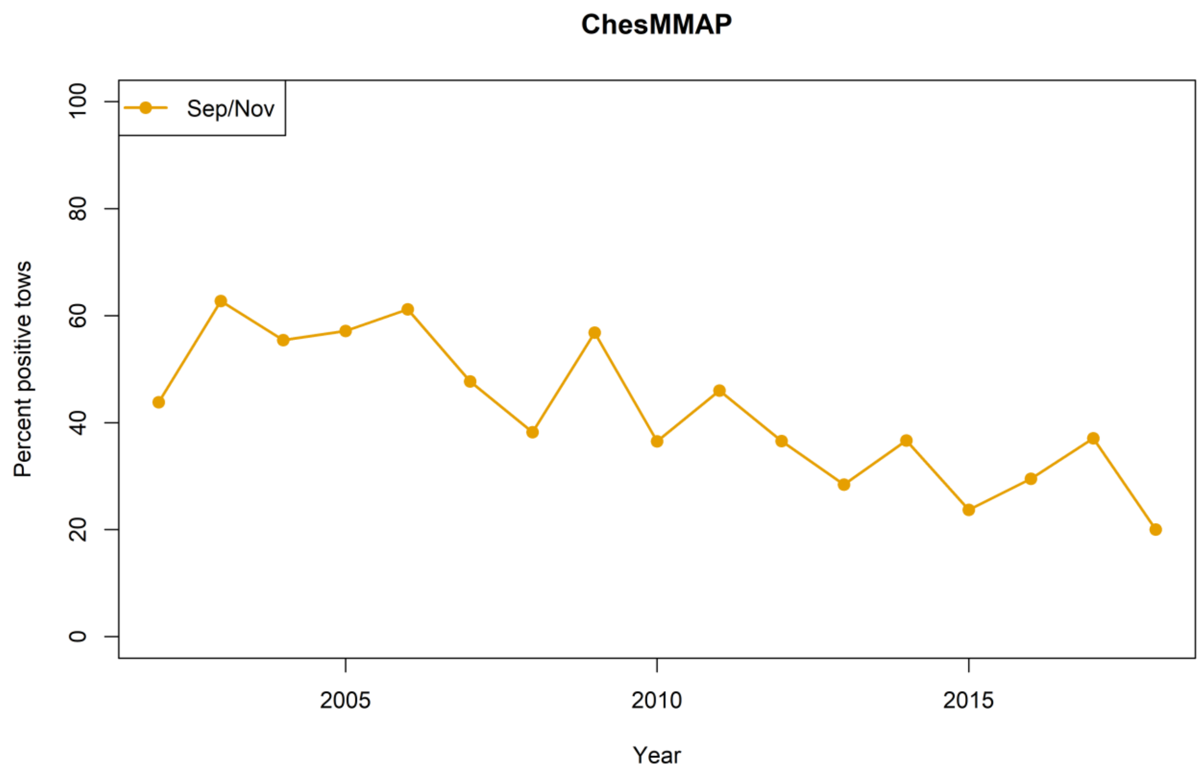

Figure 53. Percent positive tows for the Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) bottom trawl survey for regions 4 and 5.

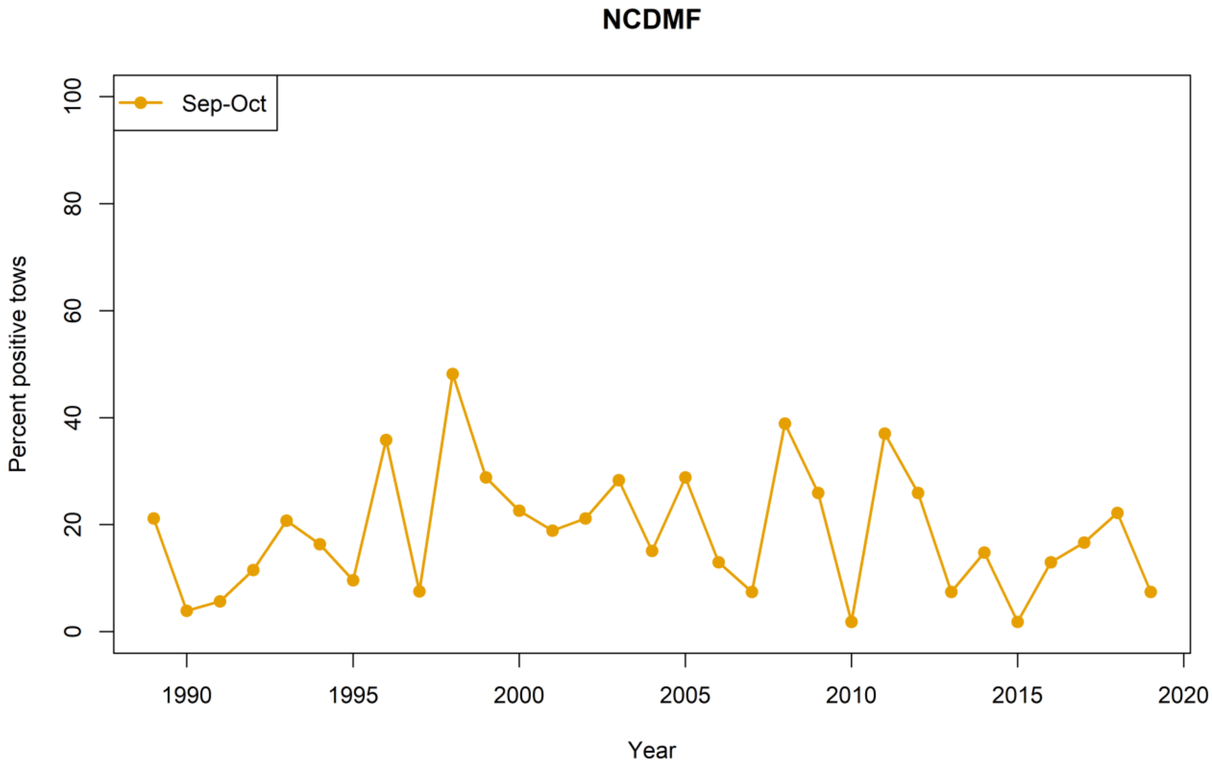

Figure 54. Percent positive tows for the North Carolina Division of Marine Fisheries (NCDMF) bottom trawl survey of Pamlico Sound.

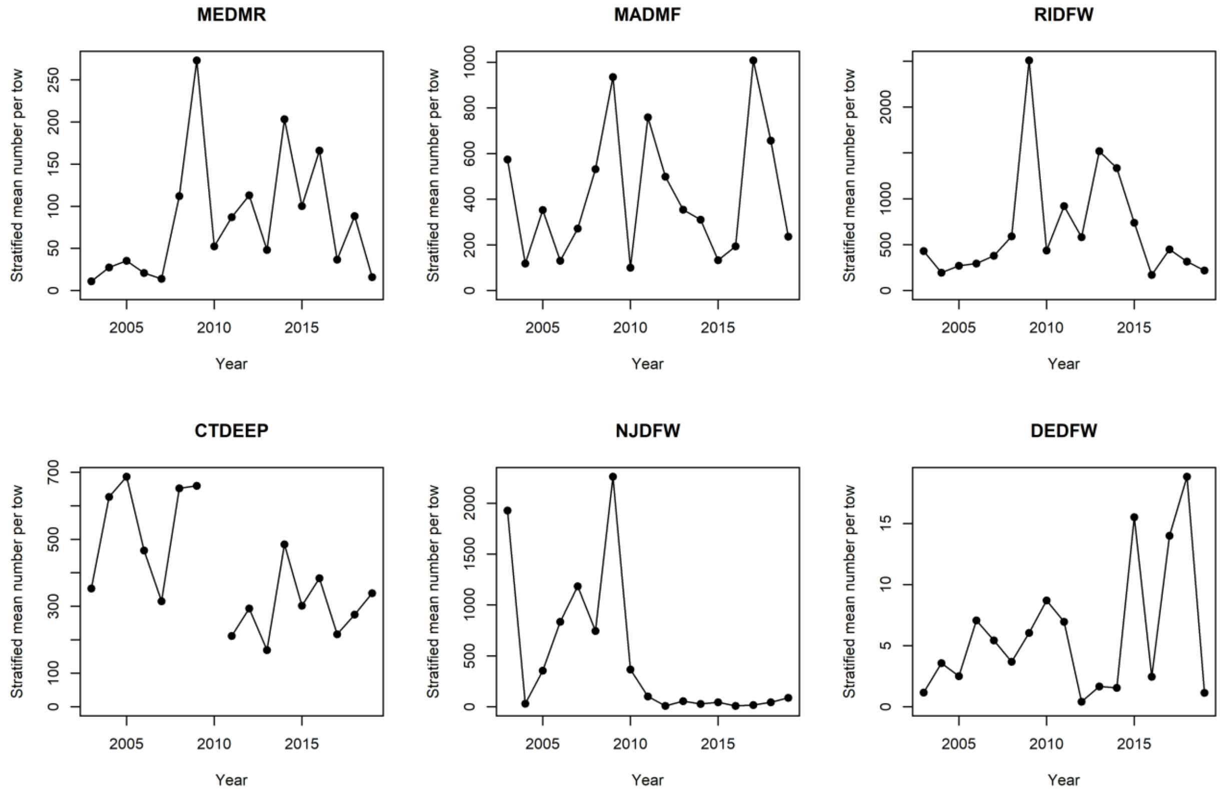

Figure 55. Young-of-the-year indices for the state surveys used in this assessment. Survey acronyms are: Maine Department of Marine Resources (MEDMR); Massachusetts Division of Marine Fisheries (MADMF); Rhode Island Department of Fish and Wildlife (RIDFW); Connecticut Department of Energy and Environmental Protection (CTDEEP); New Jersey Division of Fish and Wildlife (NJDFW); Delaware Division of Fish and Wildlife (DEDFW).

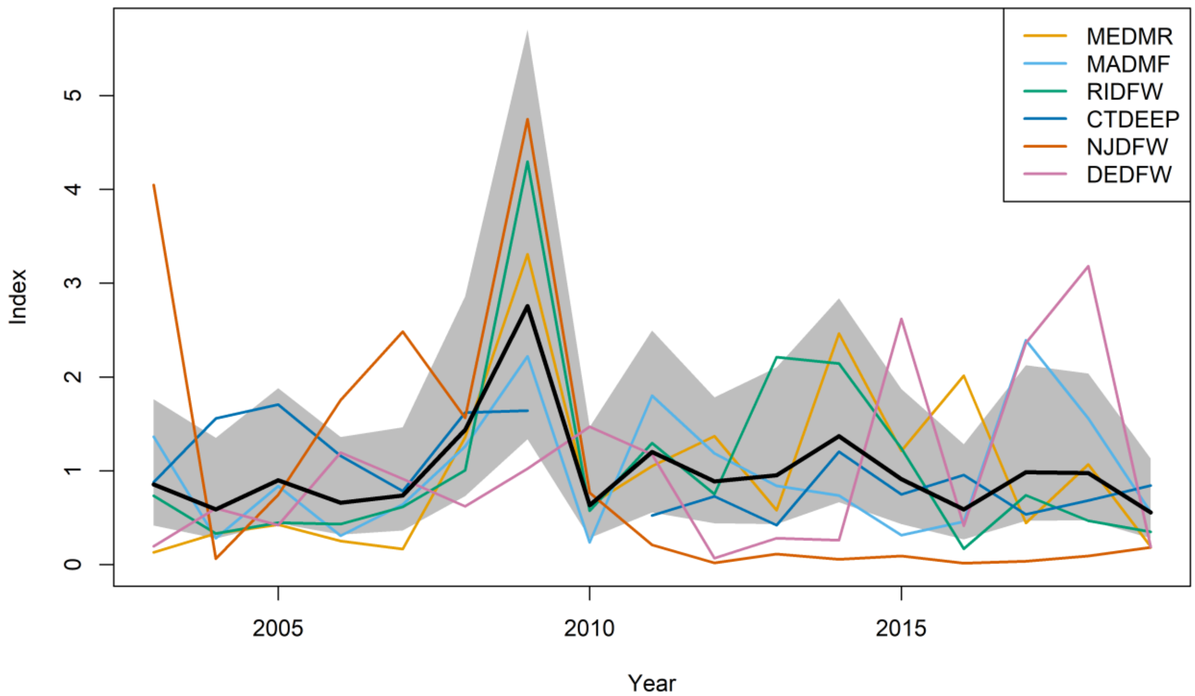

Figure 56. Combined young-of-the-year (YOY) index (black line) and associated 95% credible interval (shaded area). Standardized YOY indices for the state surveys are also shown for comparison. Survey acronyms are: Maine Department of Marine Resources (MEDMR); Massachusetts Division of Marine Fisheries (MADMF); Rhode Island Department of Fish and Wildlife (RIDFW); Connecticut Department of Energy and Environmental Protection (CTDEEP); New Jersey Division of Fish and Wildlife (NJDFW); Delaware Division of Fish and Wildlife (DEDFW).

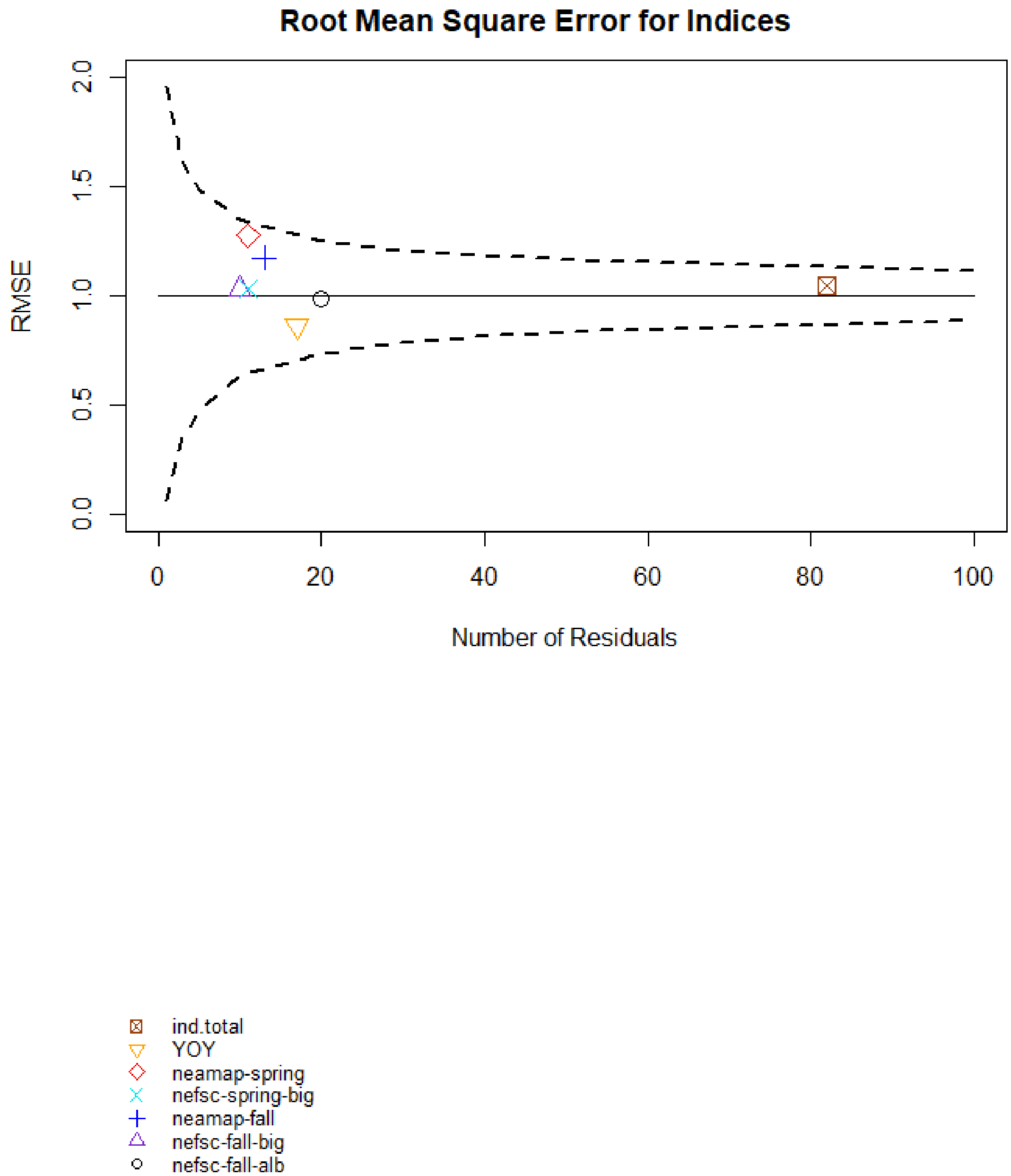

Figure 57. Root mean square error (RMSE) of the survey indices from the final age structured assessment program (ASAP) 3 model (run 036).

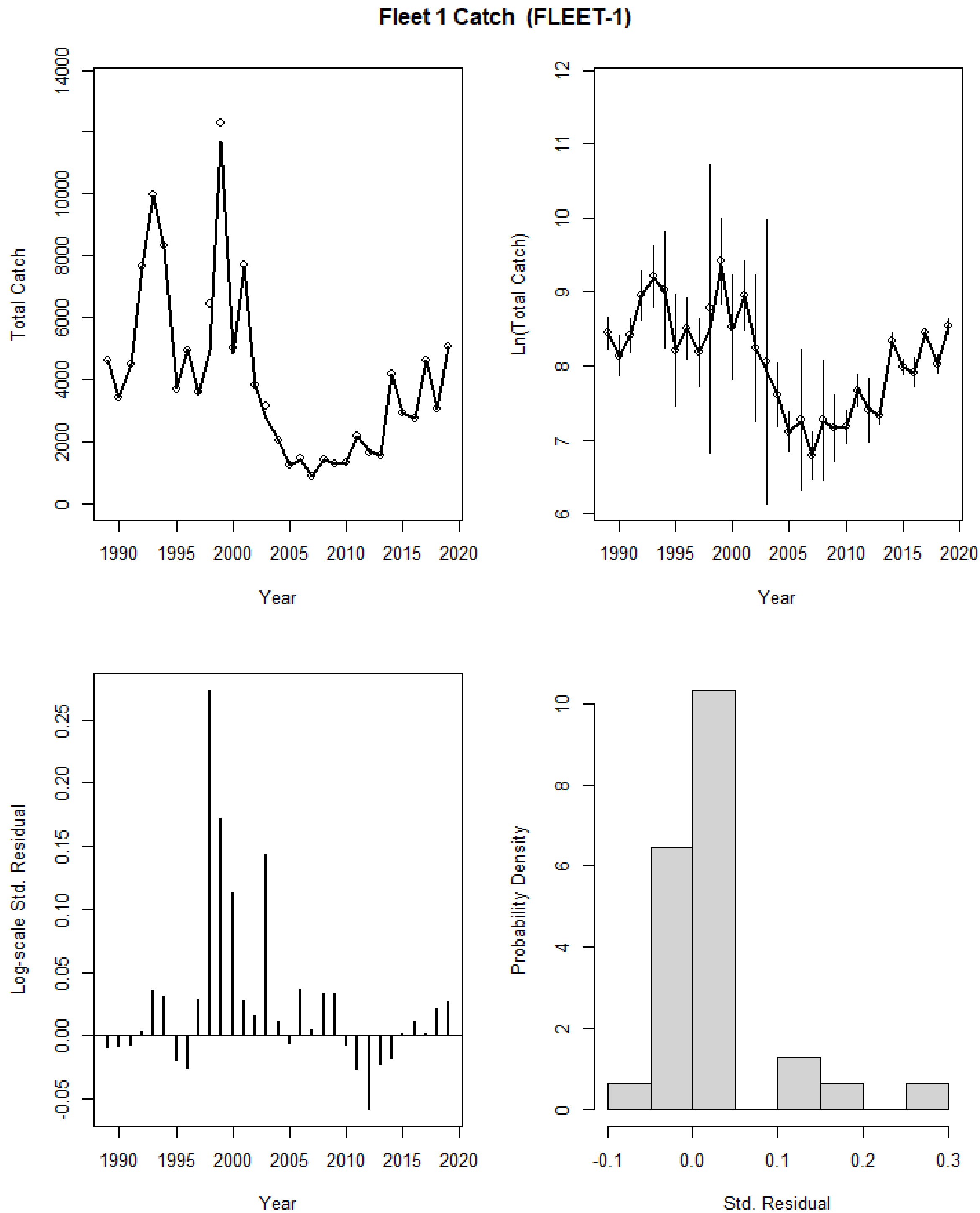

Figure 58. Diagnostics for the aggregate catch for the final age structured assessment program (ASAP) 3 model (run 036).

Figure 59. Residuals for the catch age composition from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

Index 1 (nefsc-fall-alb)

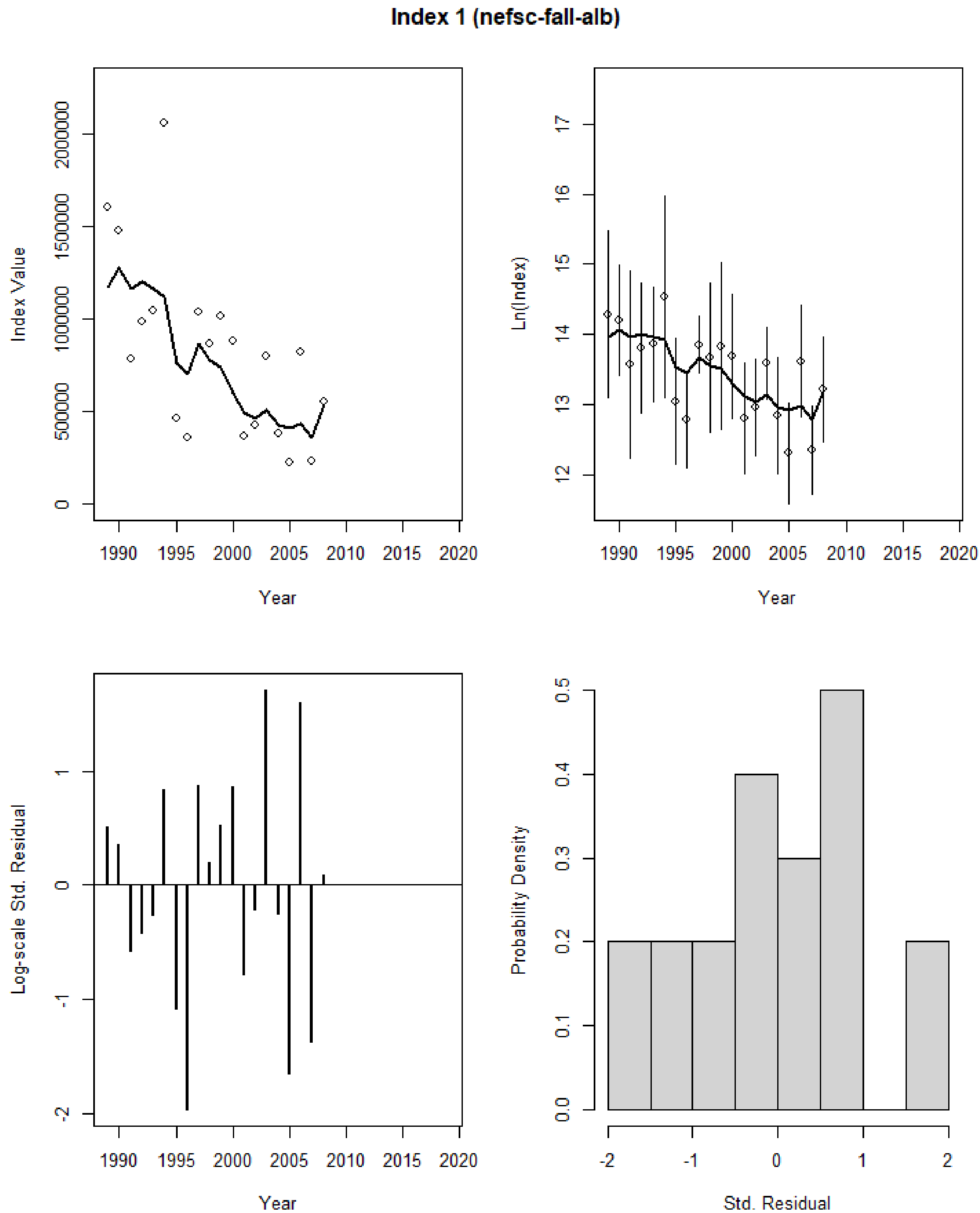

Figure 60. Diagnostics for the Northeast Fisheries Science Center (NEFSC) fall FRV *Albatross IV* survey from the final age structured assessment program (ASAP) 3 model (run 036).

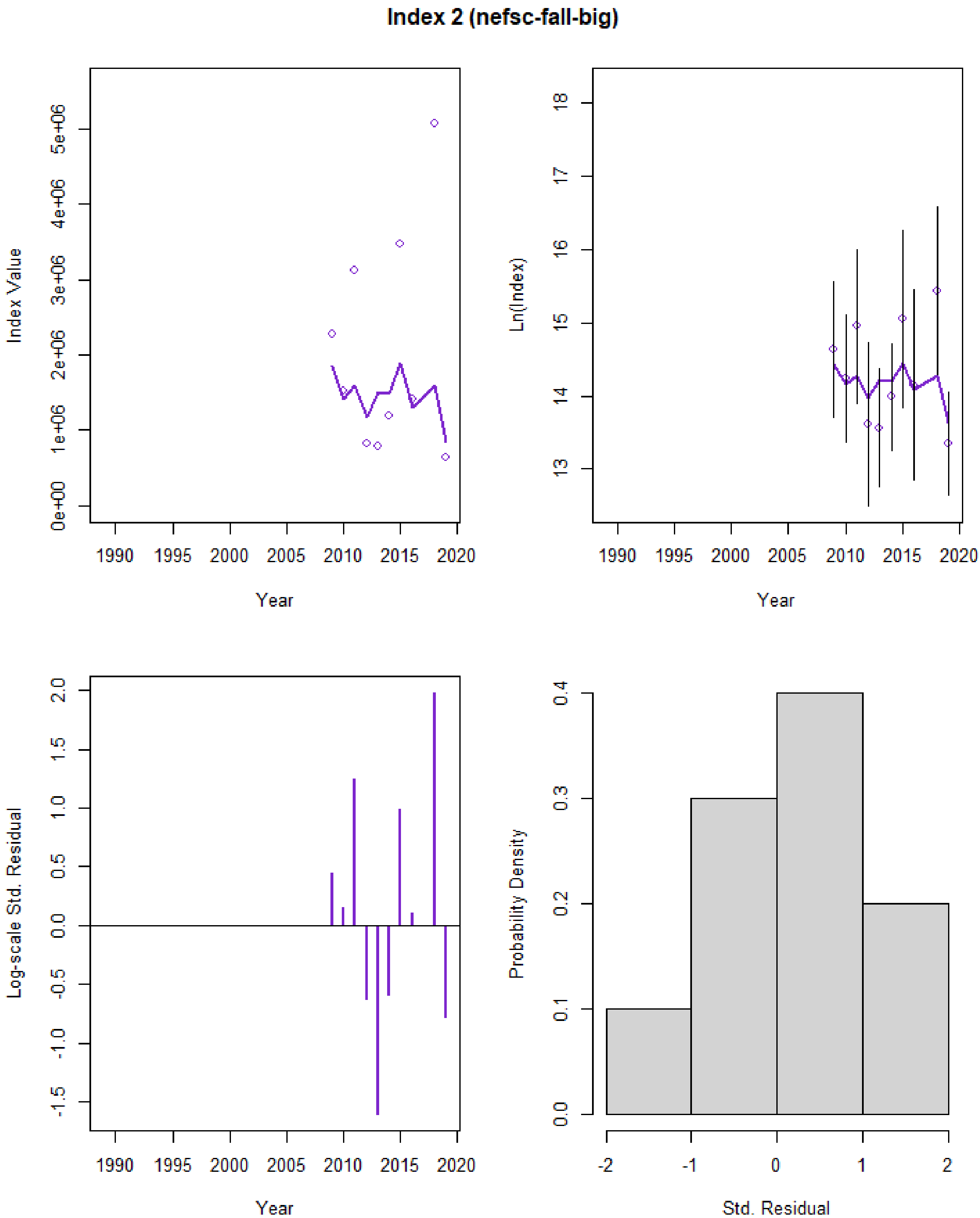

Figure 61. Diagnostics for the Northeast Fisheries Science Center (NEFSC) fall FSV *Henry B. Bigelow* survey from the final age structured assessment program (ASAP) 3 model (run 036).

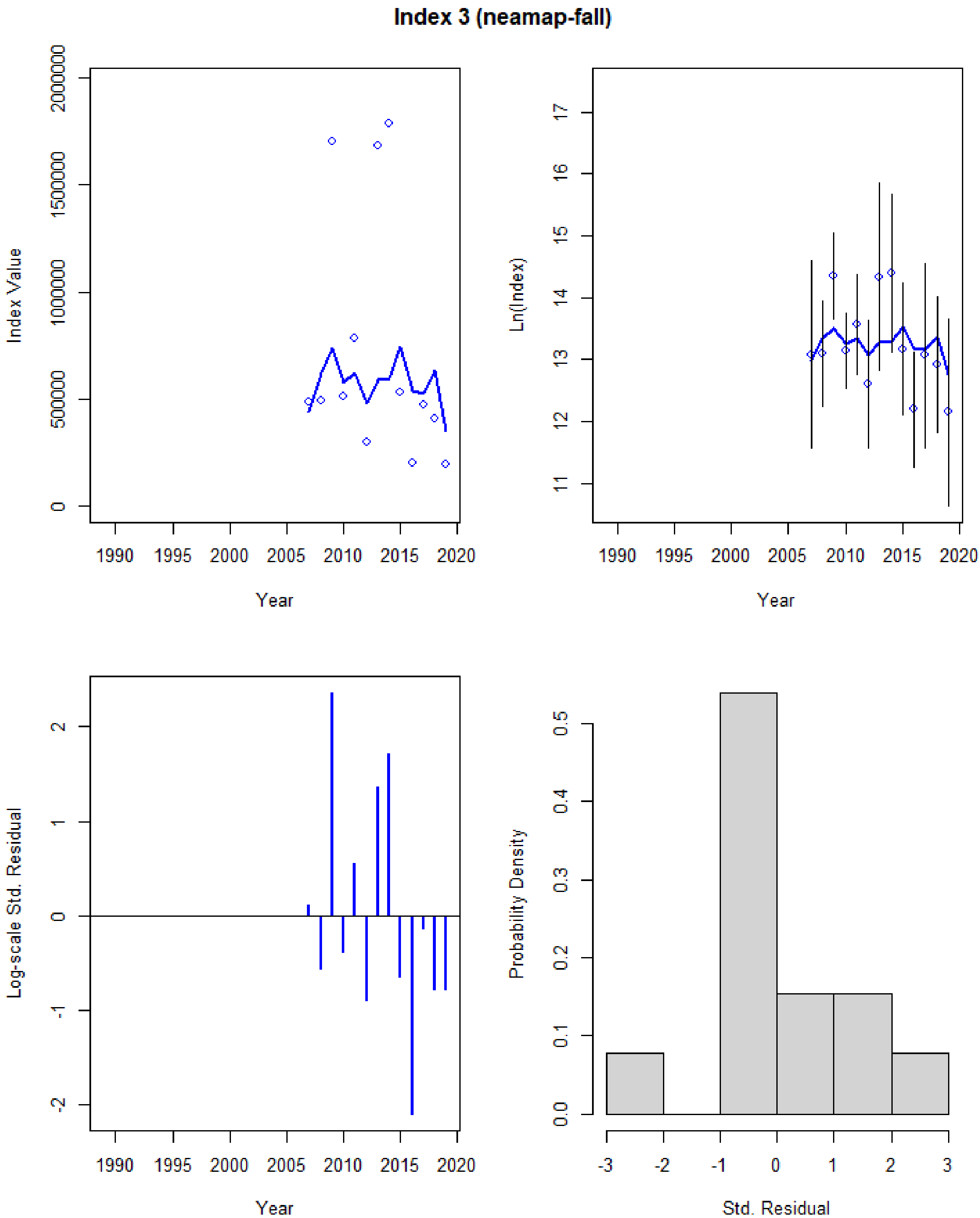

Figure 62. Diagnostics for the Northeast Area Monitoring and Assessment Program (NEAMAP) fall survey from the final age structured assessment program (ASAP) 3 model (run 036).

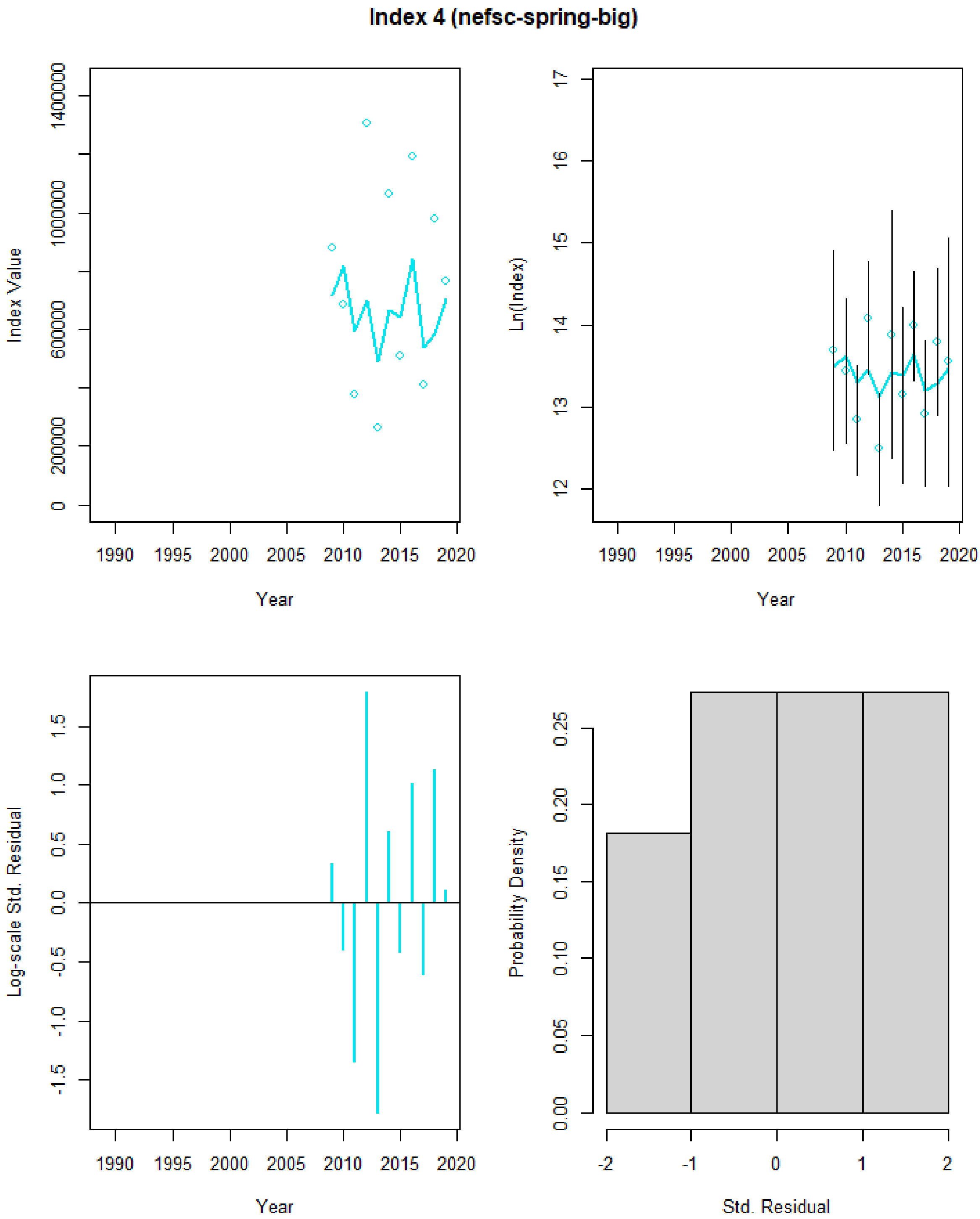

Figure 63. Diagnostics for the Northeast Fisheries Science Center (NEFSC) spring FSV *Henry B. Bigelow* survey from the final age structured assessment program (ASAP) 3 model (run 036).

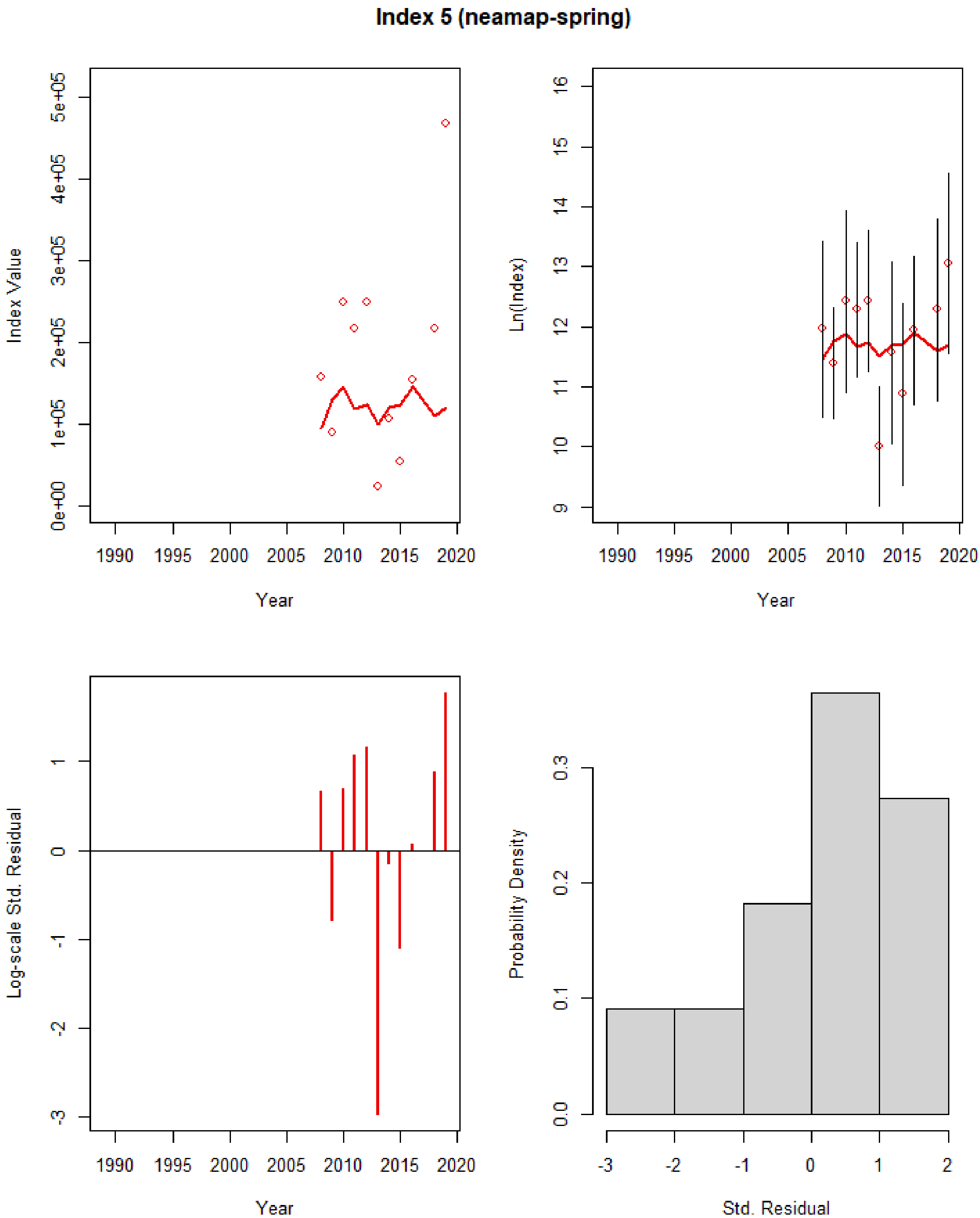

Figure 64. Diagnostics for the Northeast Area Monitoring and Assessment Program (NEAMAP) spring survey from the final age structured assessment program (ASAP) 3 model (run 036).

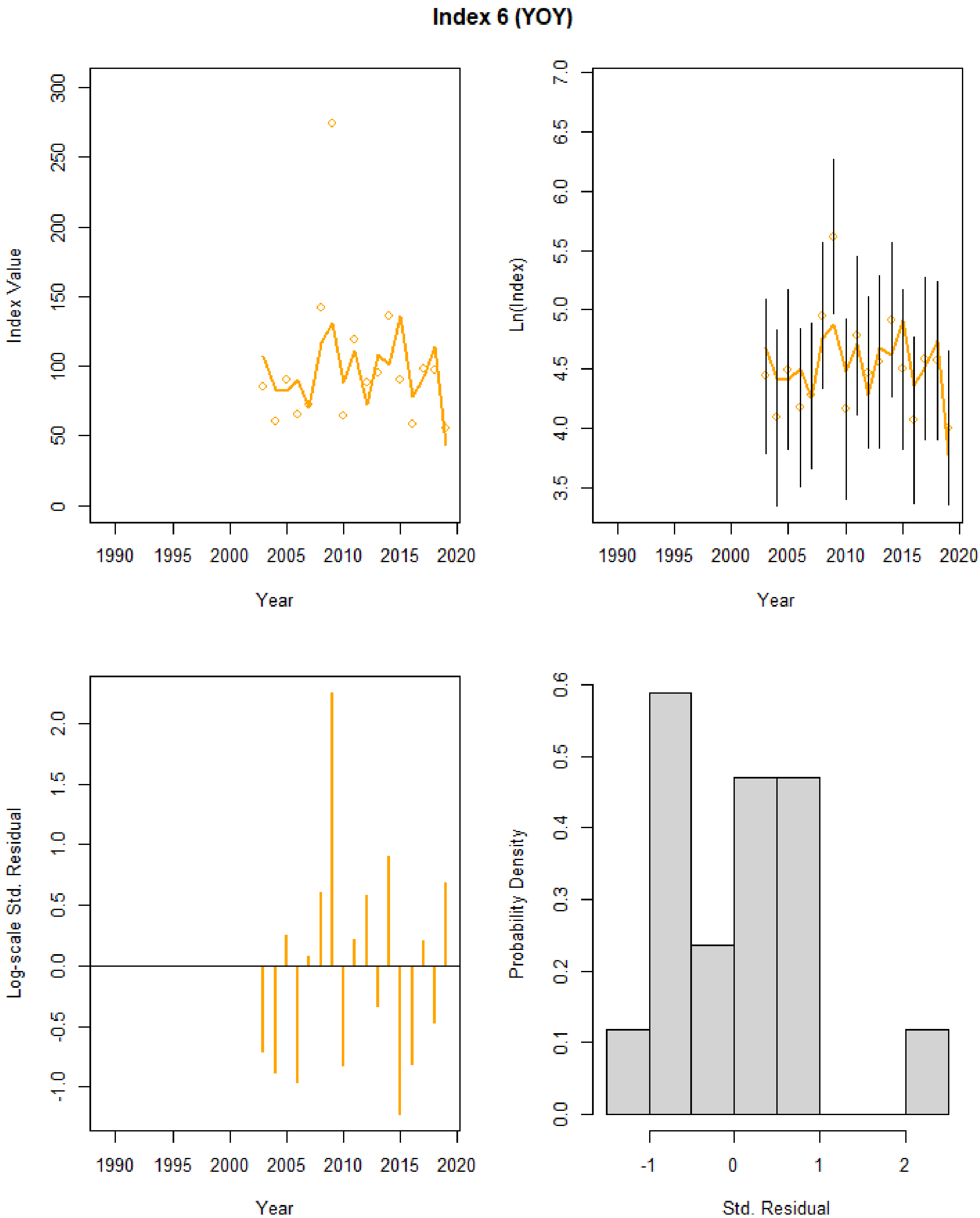

Figure 65. Diagnostics for the combined young-of-the-year (YOY) index from the final age structured assessment program (ASAP) 3 model (run 036).

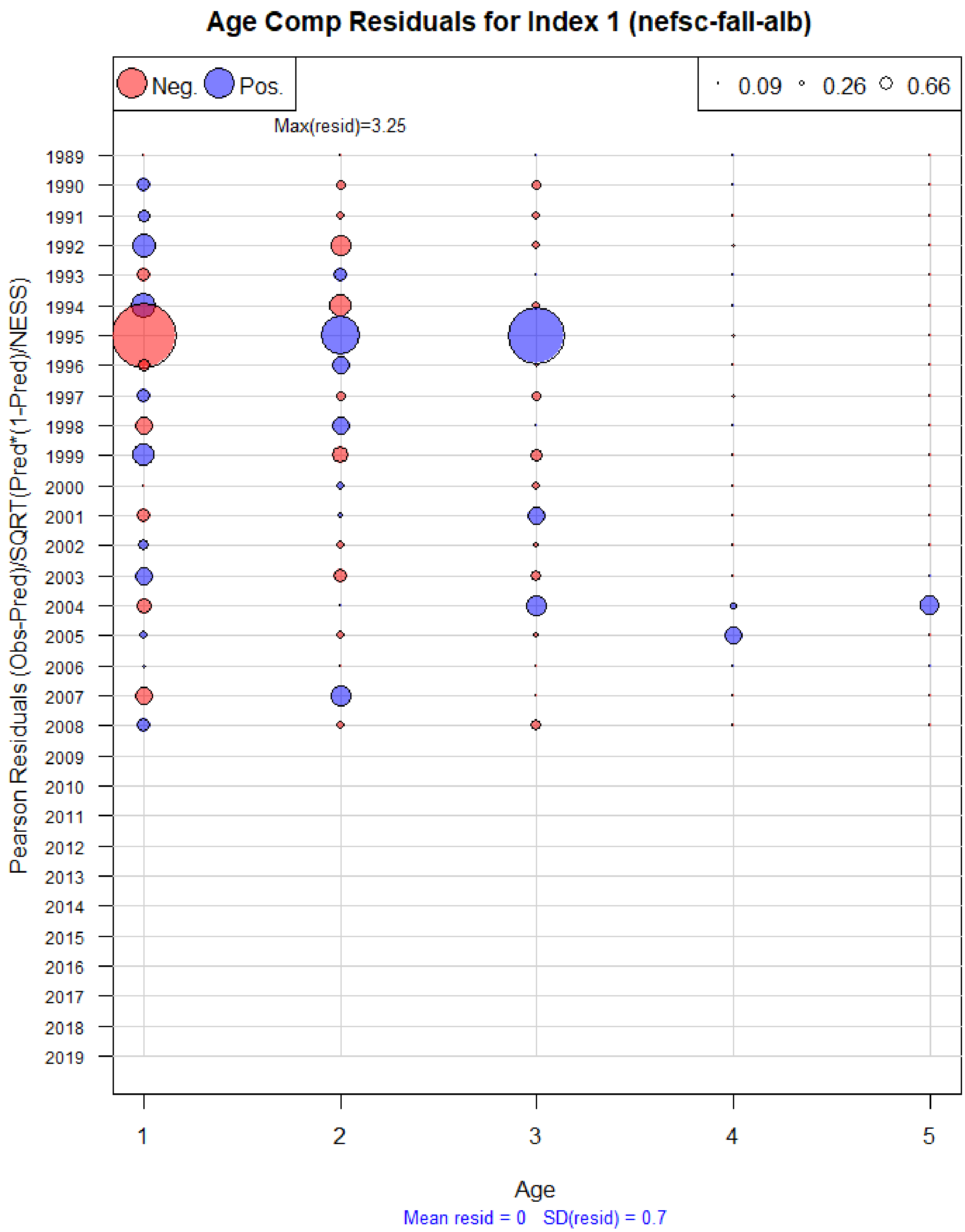

Figure 66. Residuals for the Northeast Fisheries Science Center (NEFSC) fall FRV *Albatross IV* age composition from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

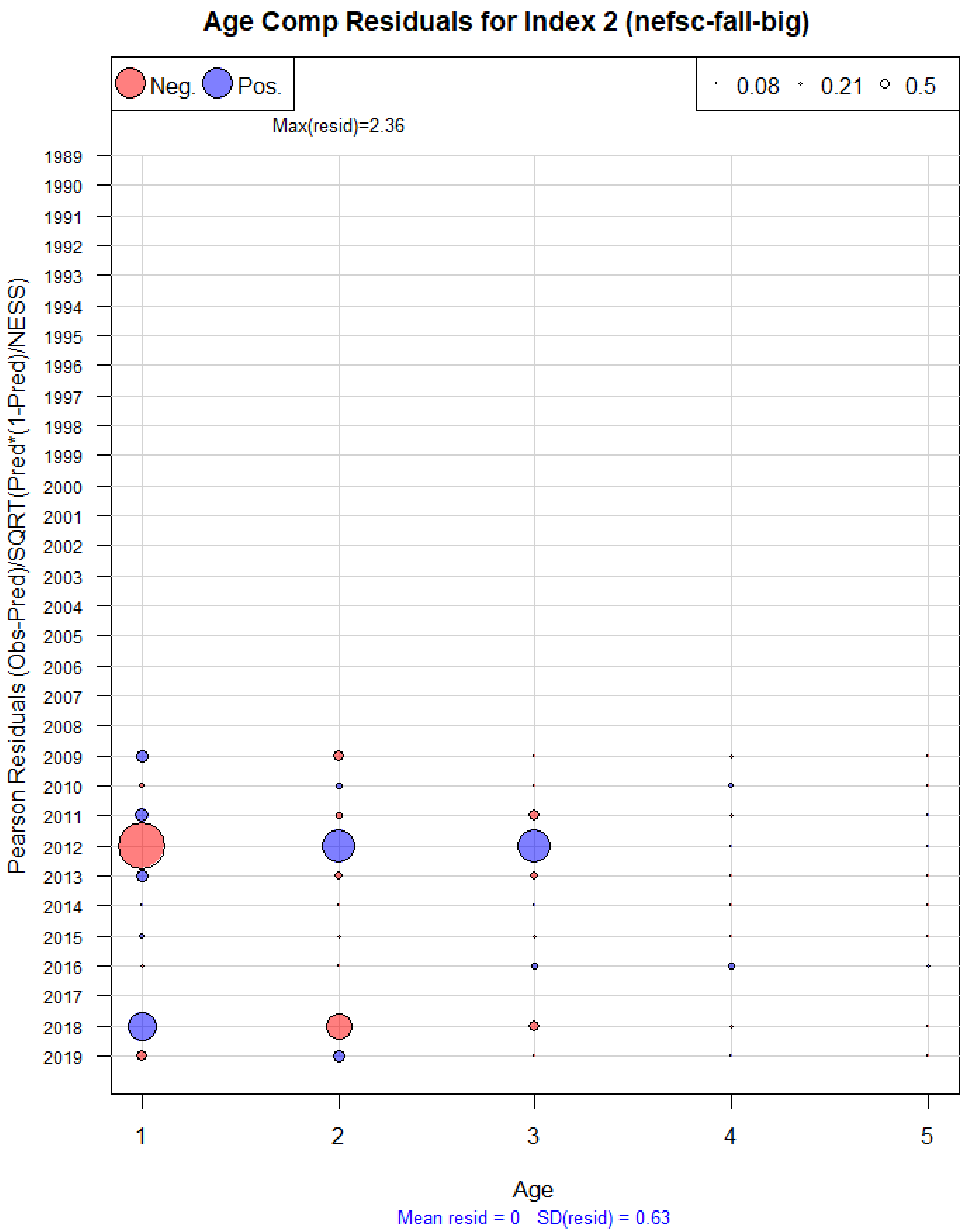

Figure 67. Residuals for the Northeast Fisheries Science Center (NEFSC) fall FSV *Henry B. Bigelow* age composition from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

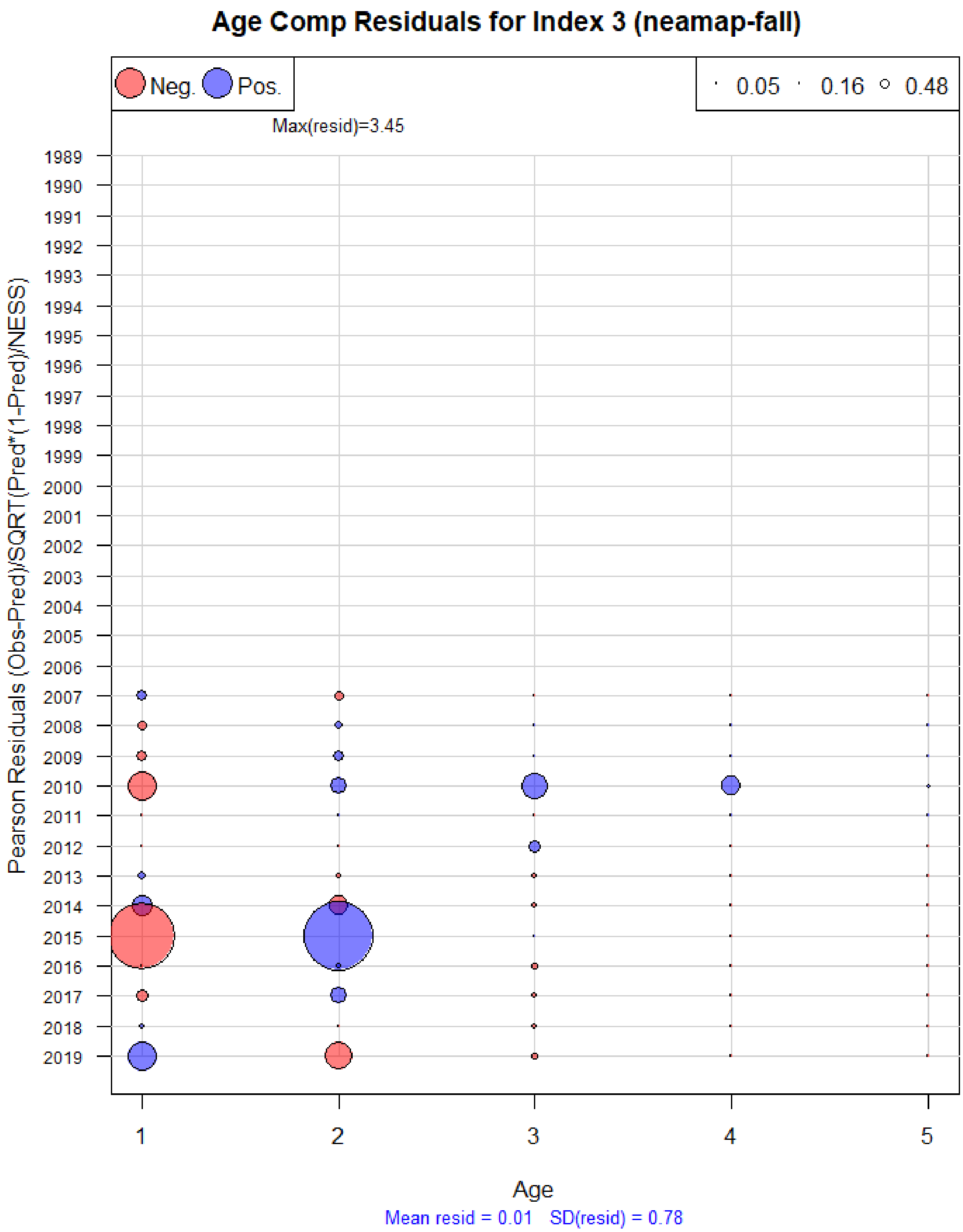

Figure 68. Residuals for the Northeast Area Monitoring and Assessment Program (NEAMAP) fall age composition from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

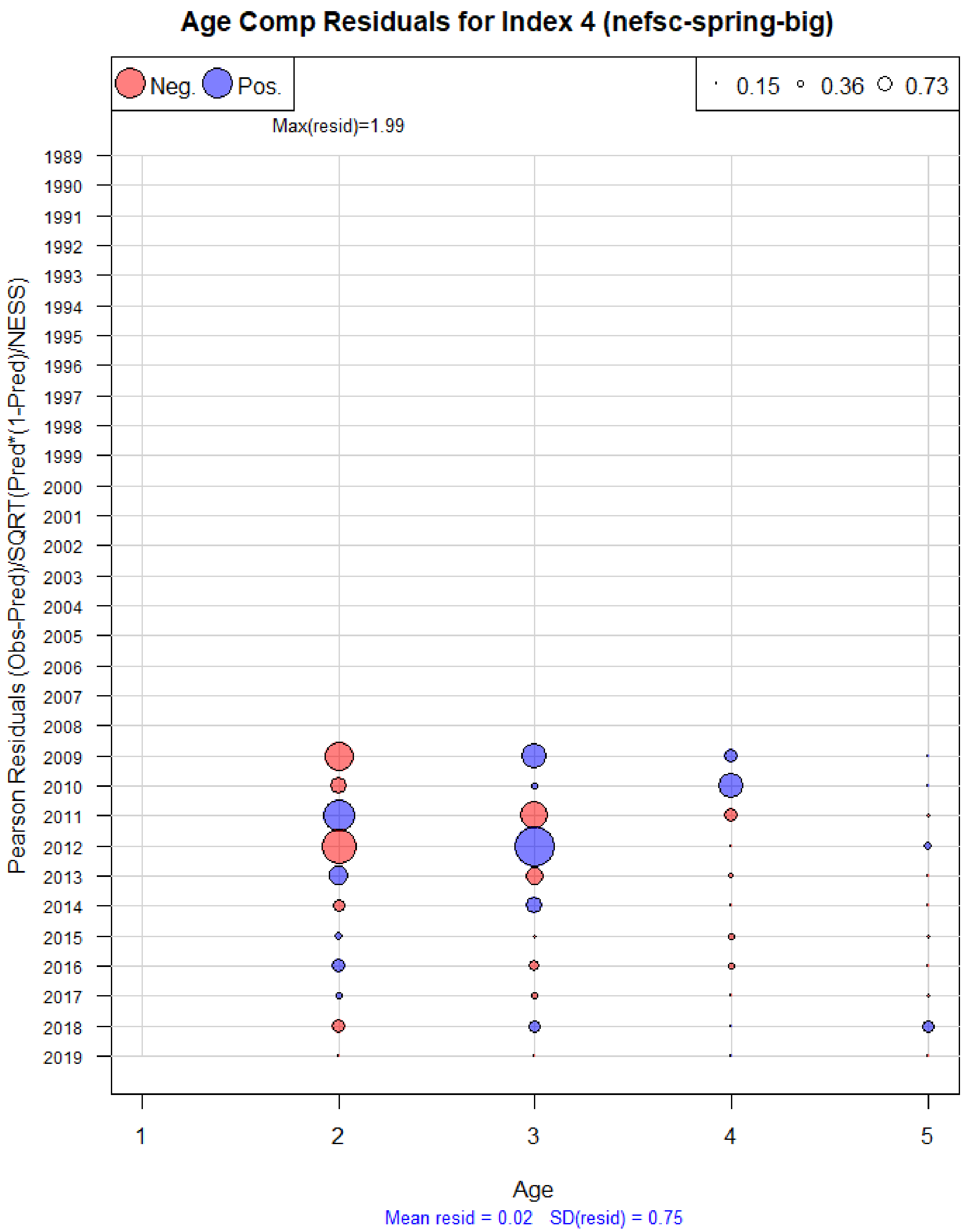

Figure 69. Residuals for the Northeast Fisheries Science Center (NEFSC) spring FSV *Henry B. Bigelow* age composition from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

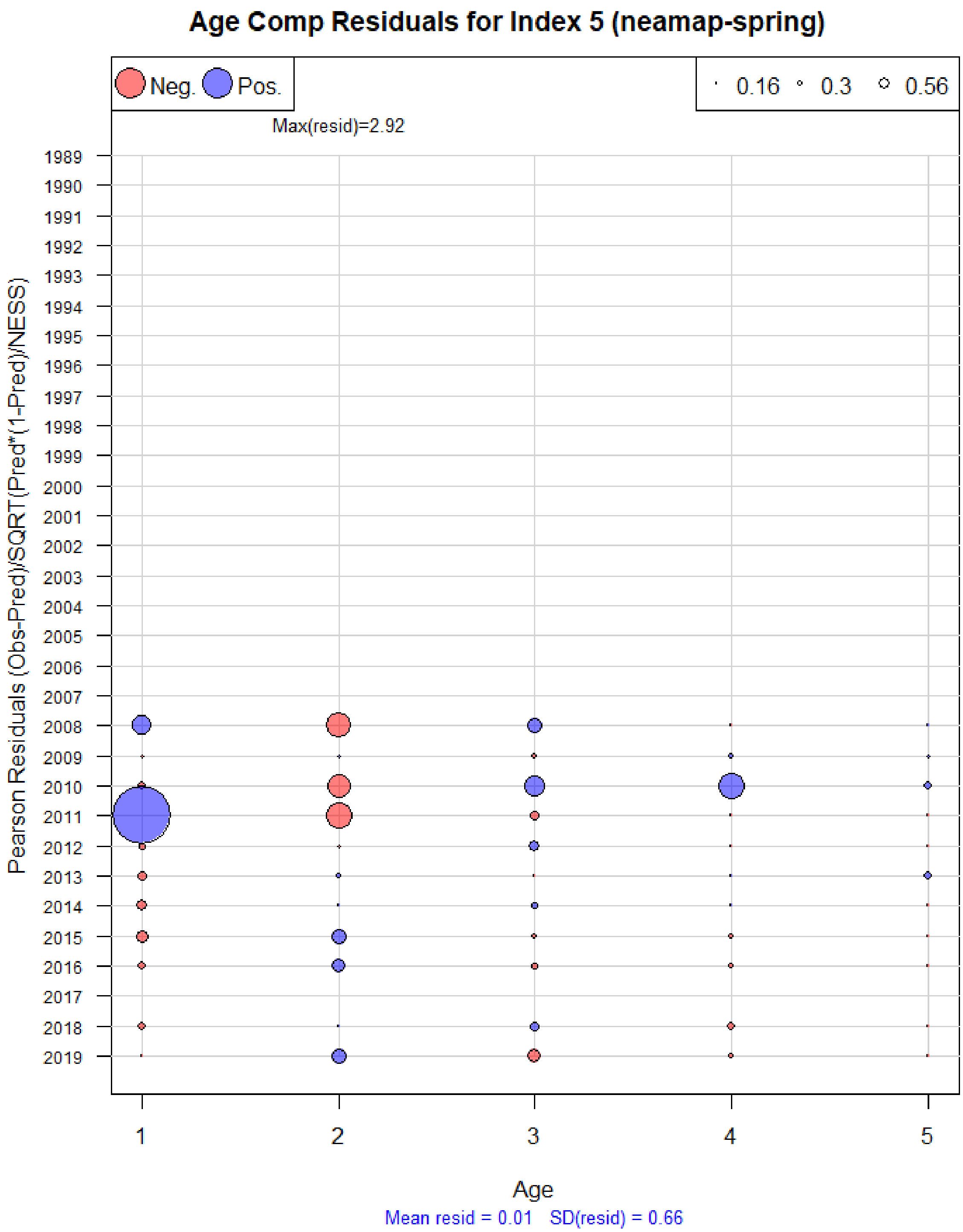

Figure 70. Residuals for the Northeast Area Monitoring and Assessment Program (NEAMAP) fall age composition from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

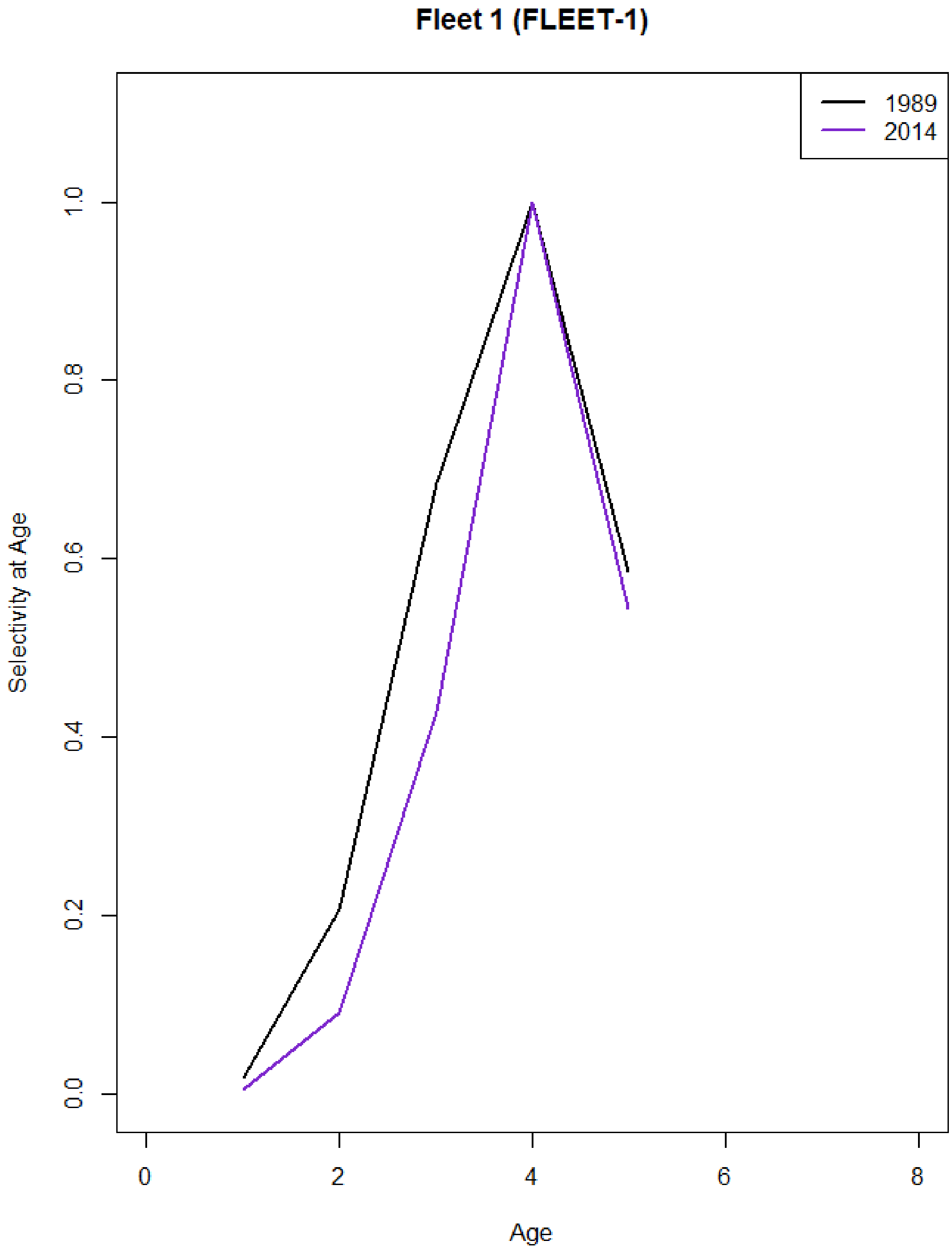

Figure 71. Fishery selectivity at age from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

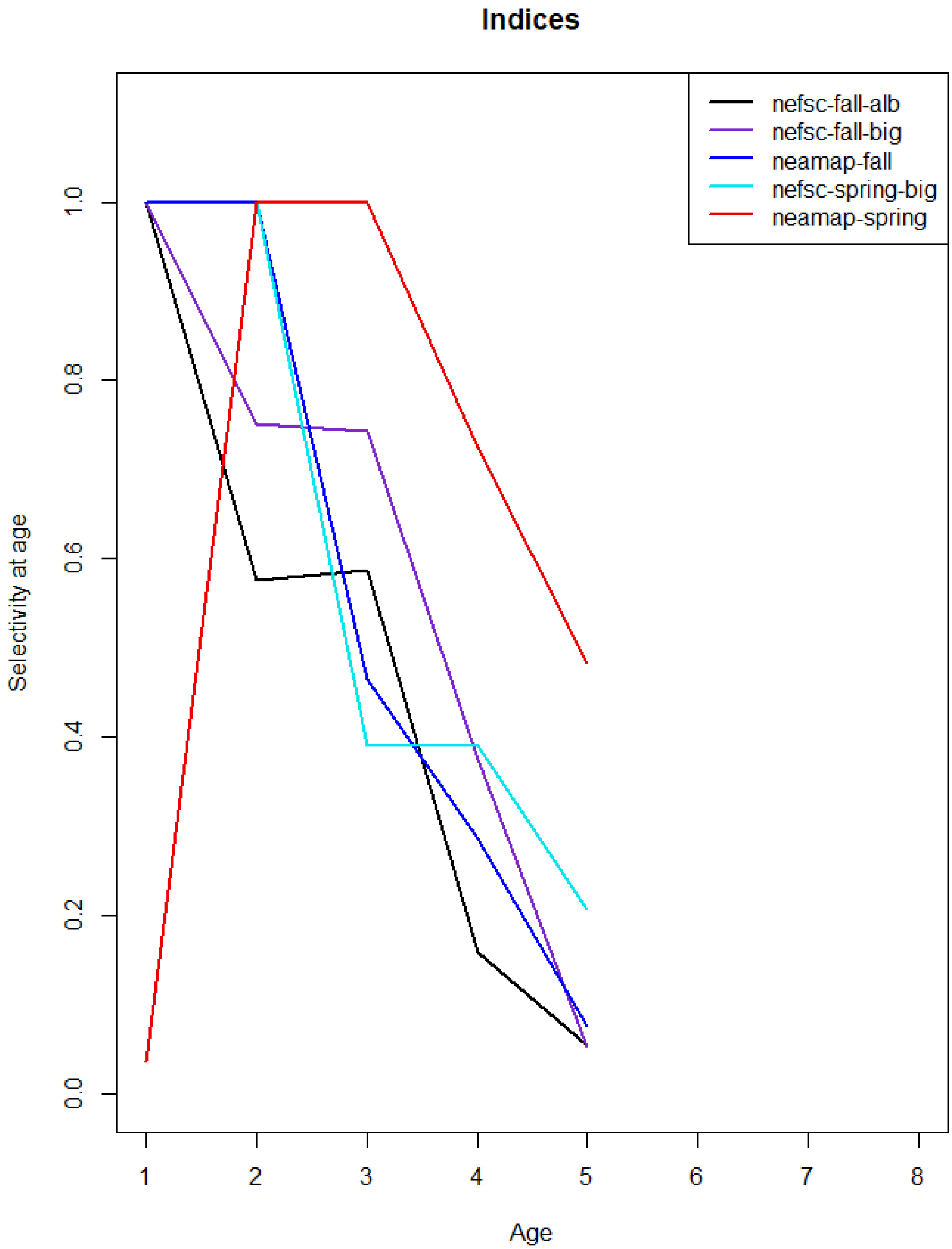

Figure 72. Survey selectivity at age from the final age structured assessment program (ASAP) 3 model (run 036). Note that model ages 1 to 5 correspond to true ages 0 to 4+.

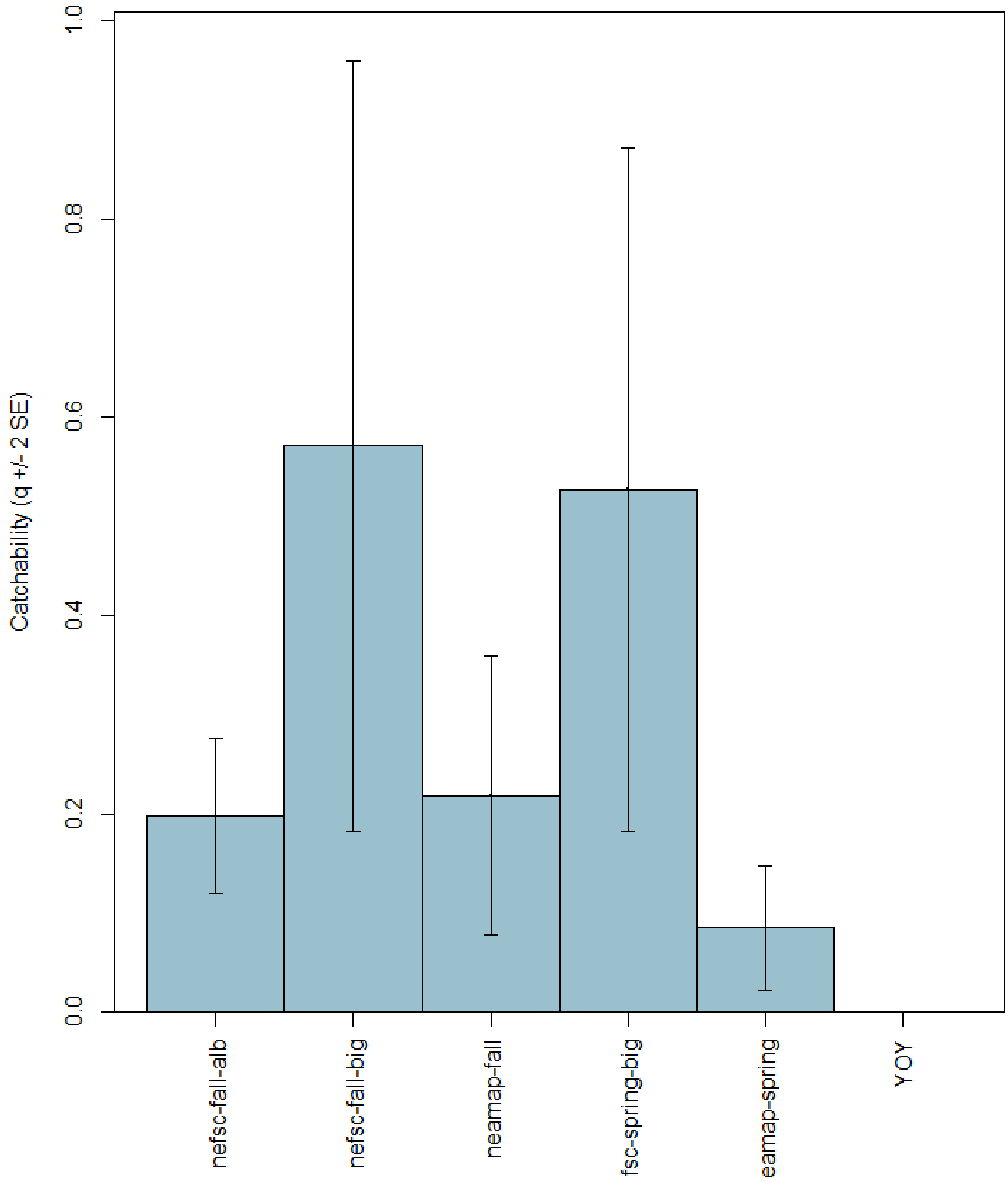

Figure 73. Index catchability and 95% confidence interval from the final age structured assessment program (ASAP) 3 model (run 036).

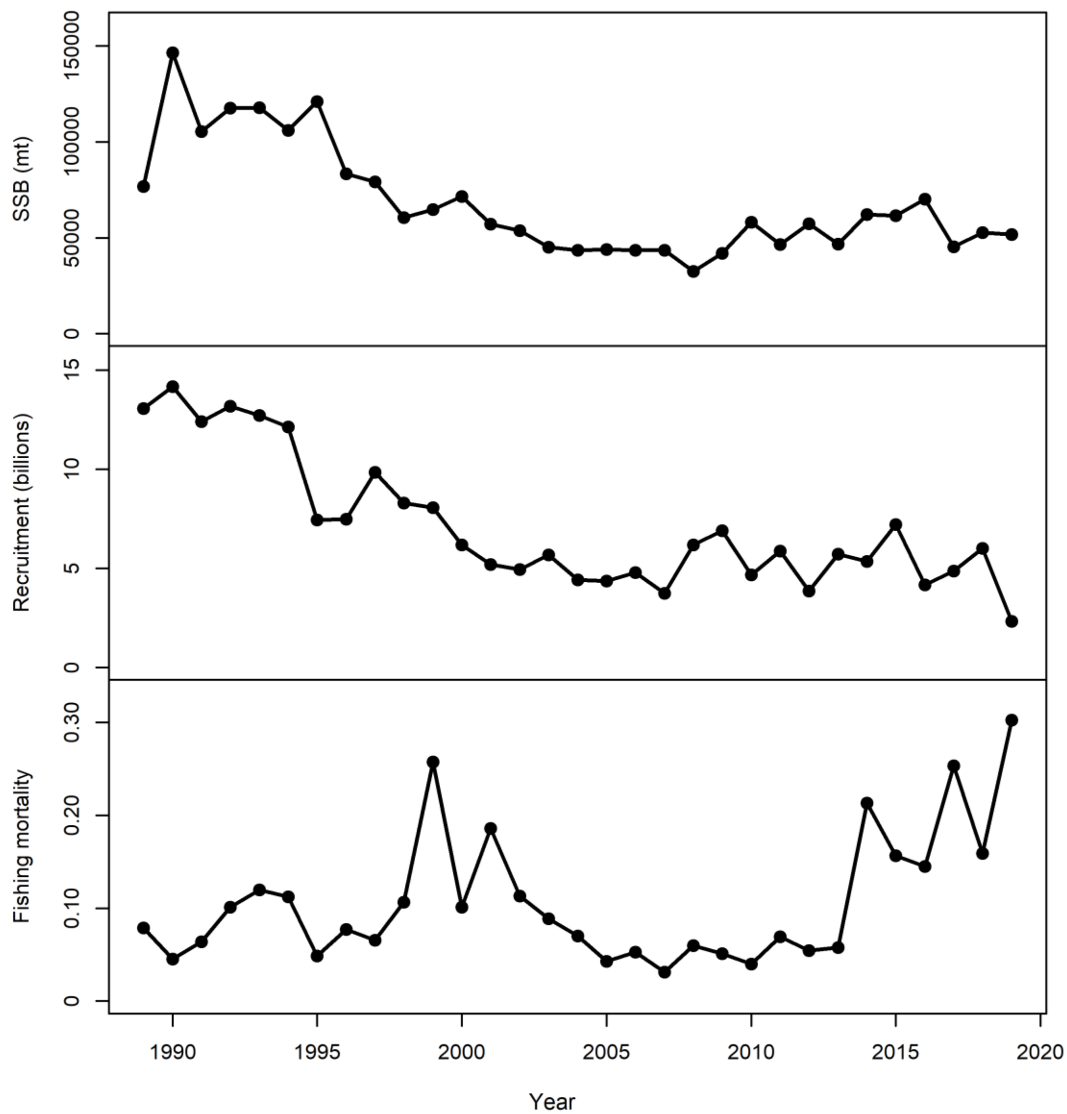

Figure 74. Spawning stock biomass (SSB), recruitment, and fishing mortality from the final age structured assessment program (ASAP) 3 model (run 036).

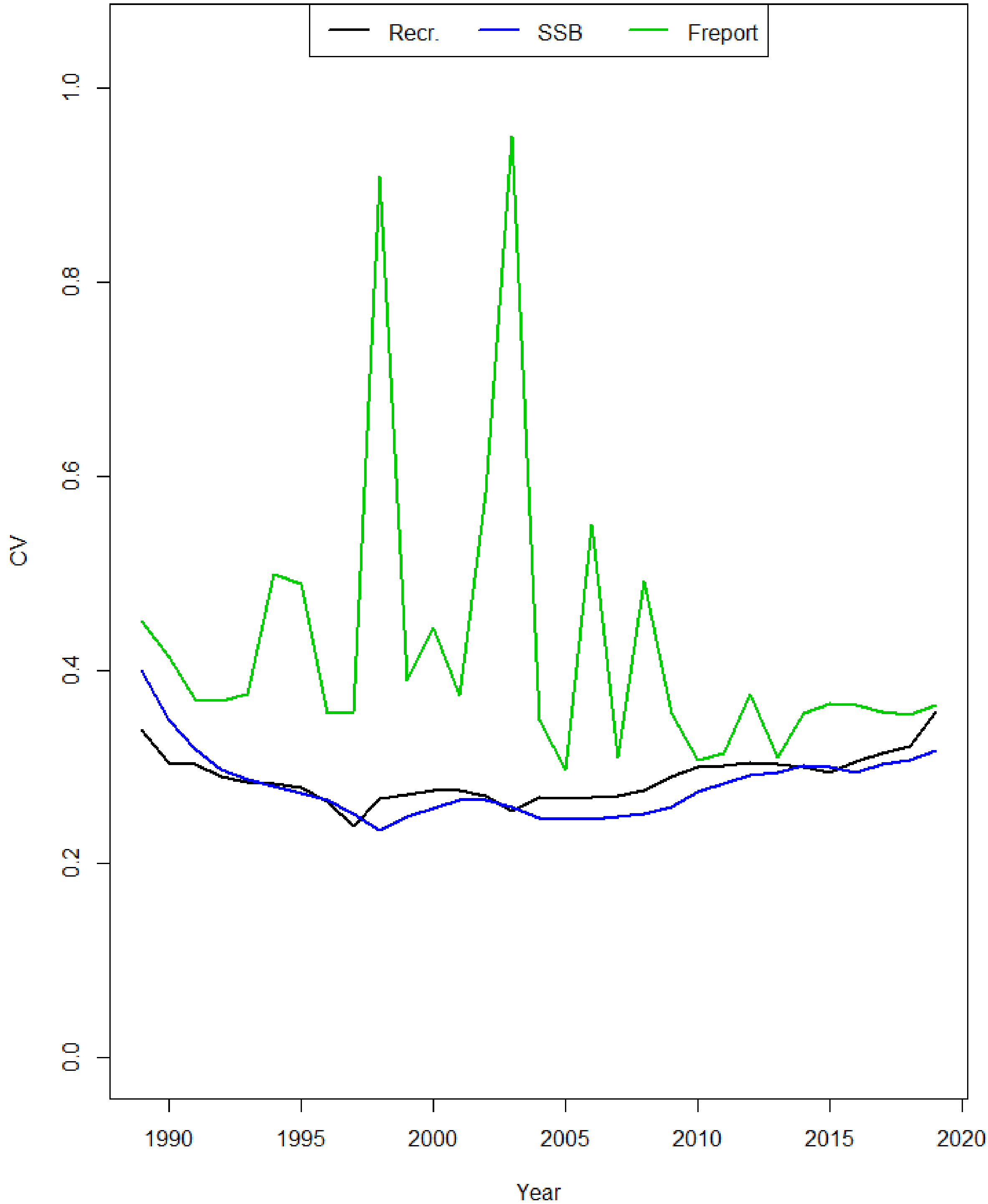

Figure 75. Coefficients of variation for estimates of spawning stock biomass (SSB), recruitment, and fishing mortality from the final age structured assessment program (ASAP) 3 model (run 036).

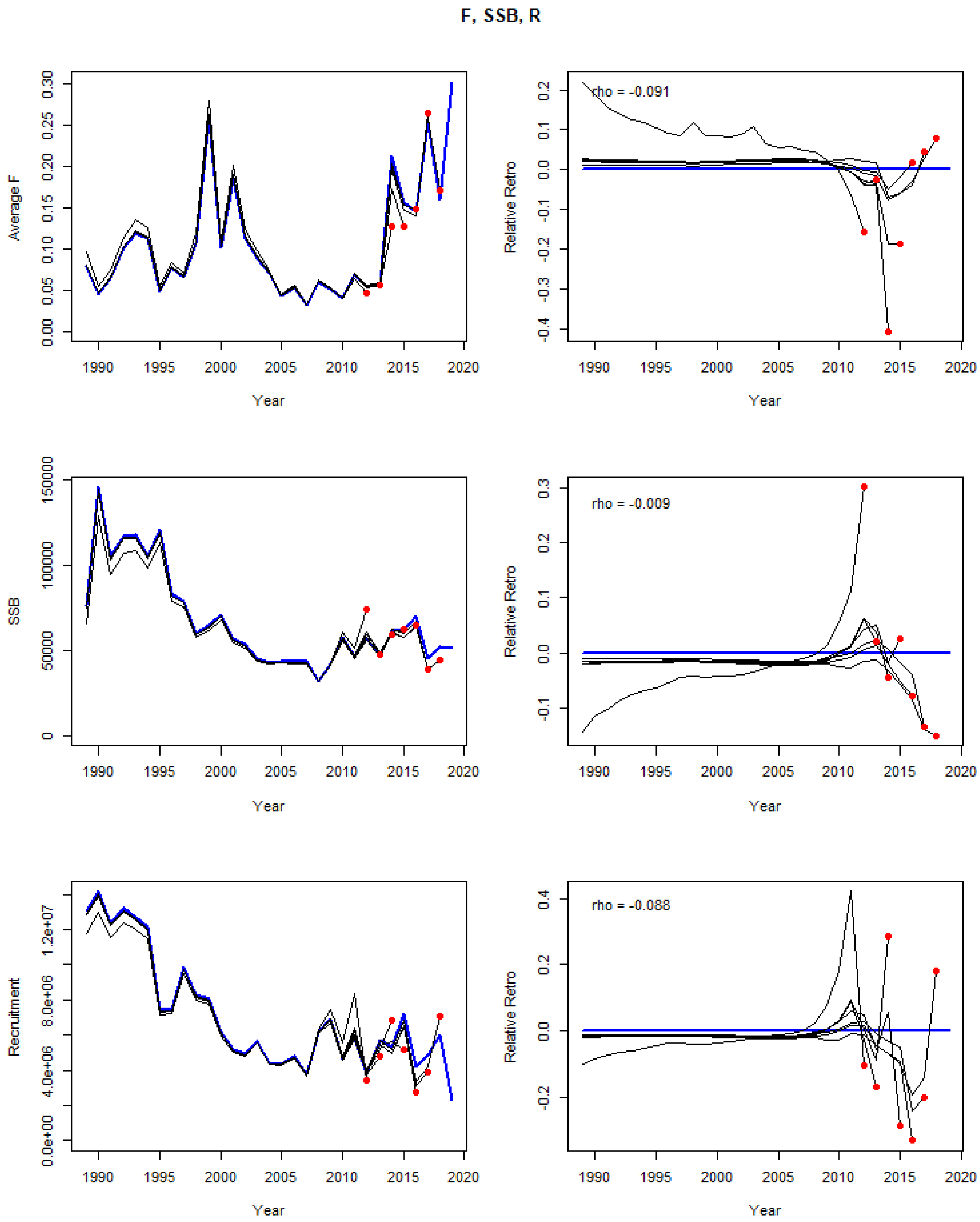

Figure 76. Retrospective patterns for fishing mortality (F), spawning stock biomass (SSB), and recruitment from the final age structured assessment program (ASAP) 3 model (run 036).

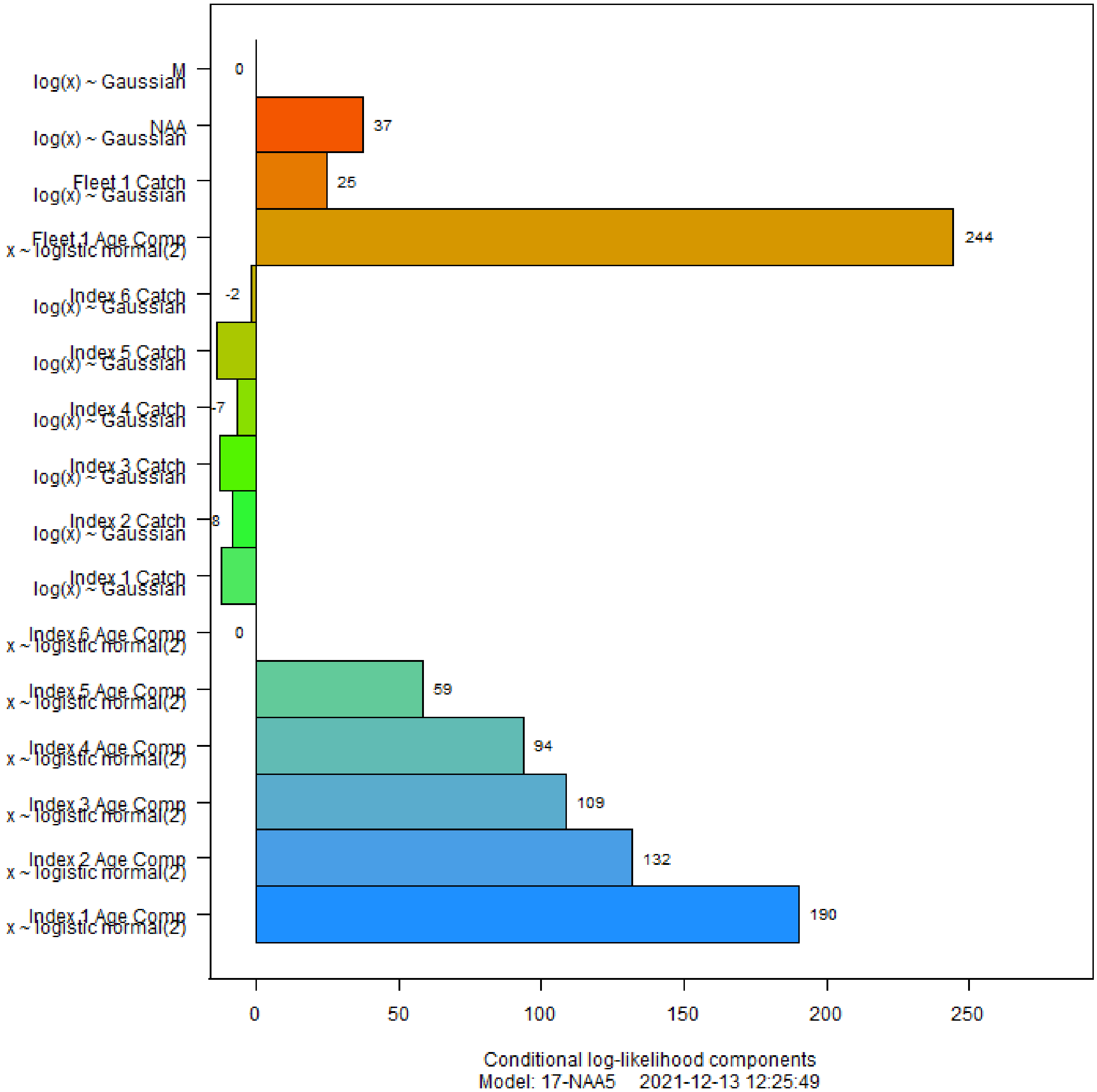

Figure 77. Conditional log-likelihood components for the best Woods Hole Assessment Model (WHAM) 17-NAA5.

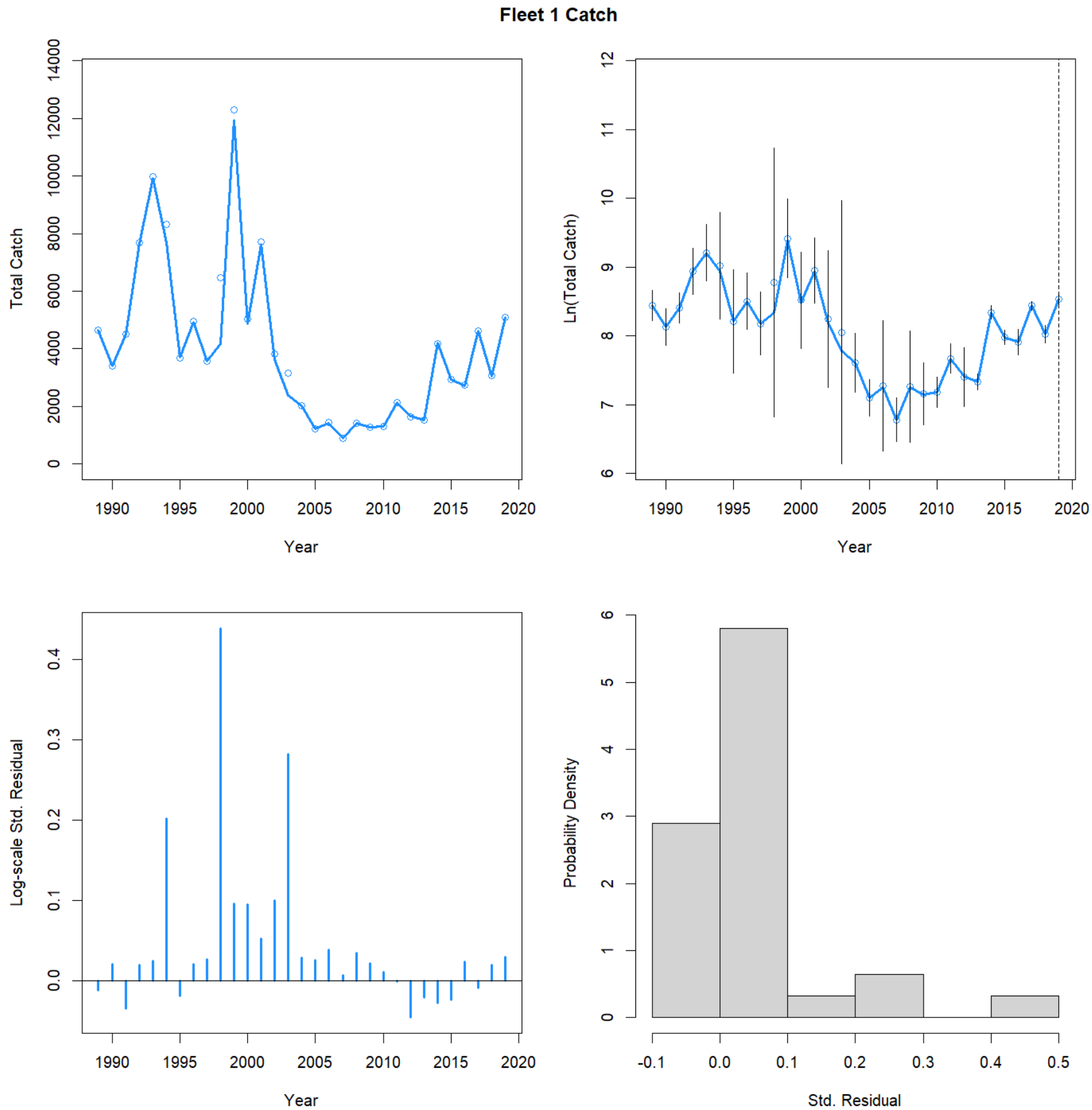

Figure 78. Diagnostics for the aggregate catch for the best Woods Hole Assessment Model (WHAM) 17-NAA5.

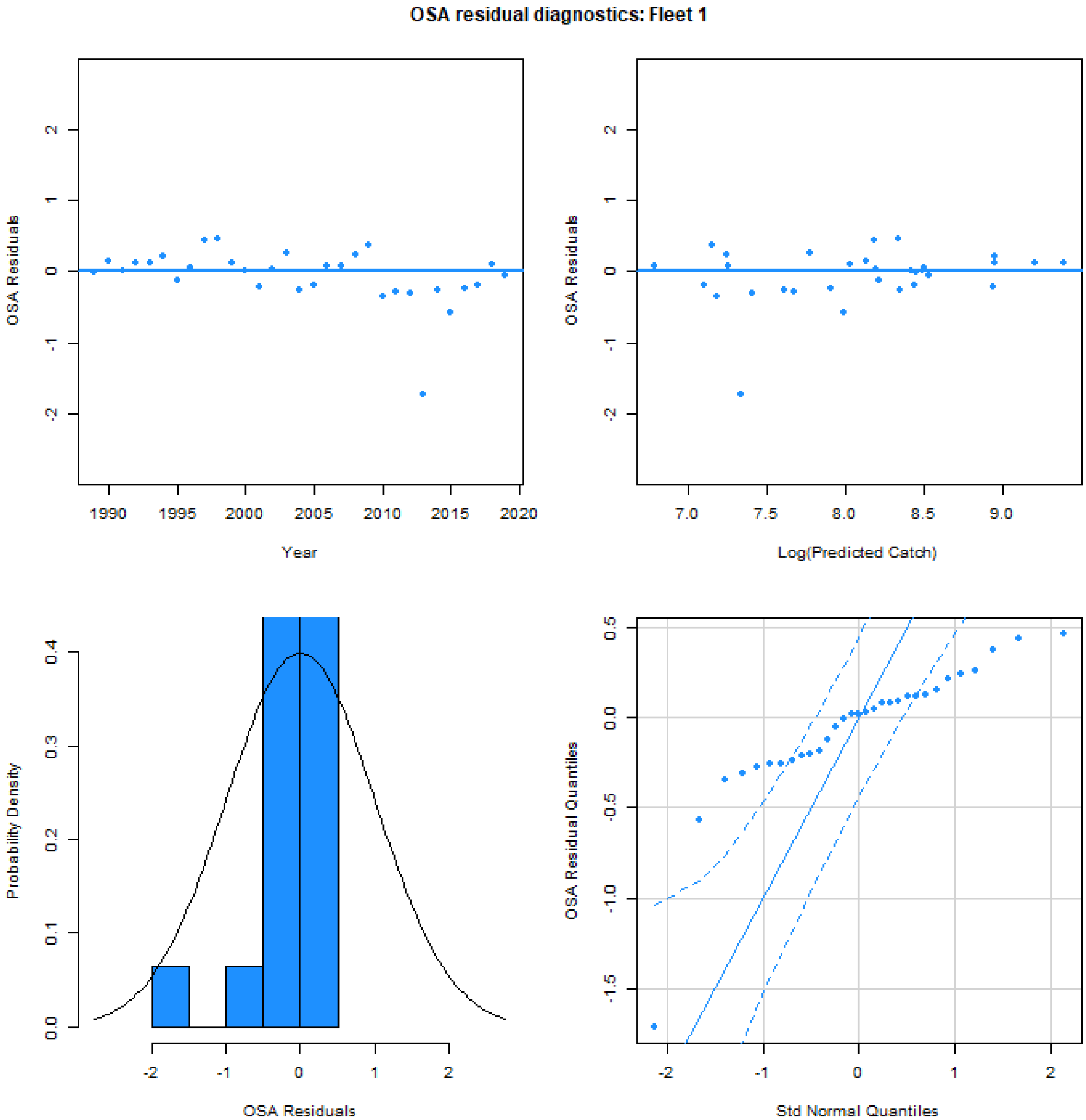

Figure 79. One-step ahead residuals for the aggregate catch for the best Woods Hole Assessment Model (WHAM) 17-NAA5.

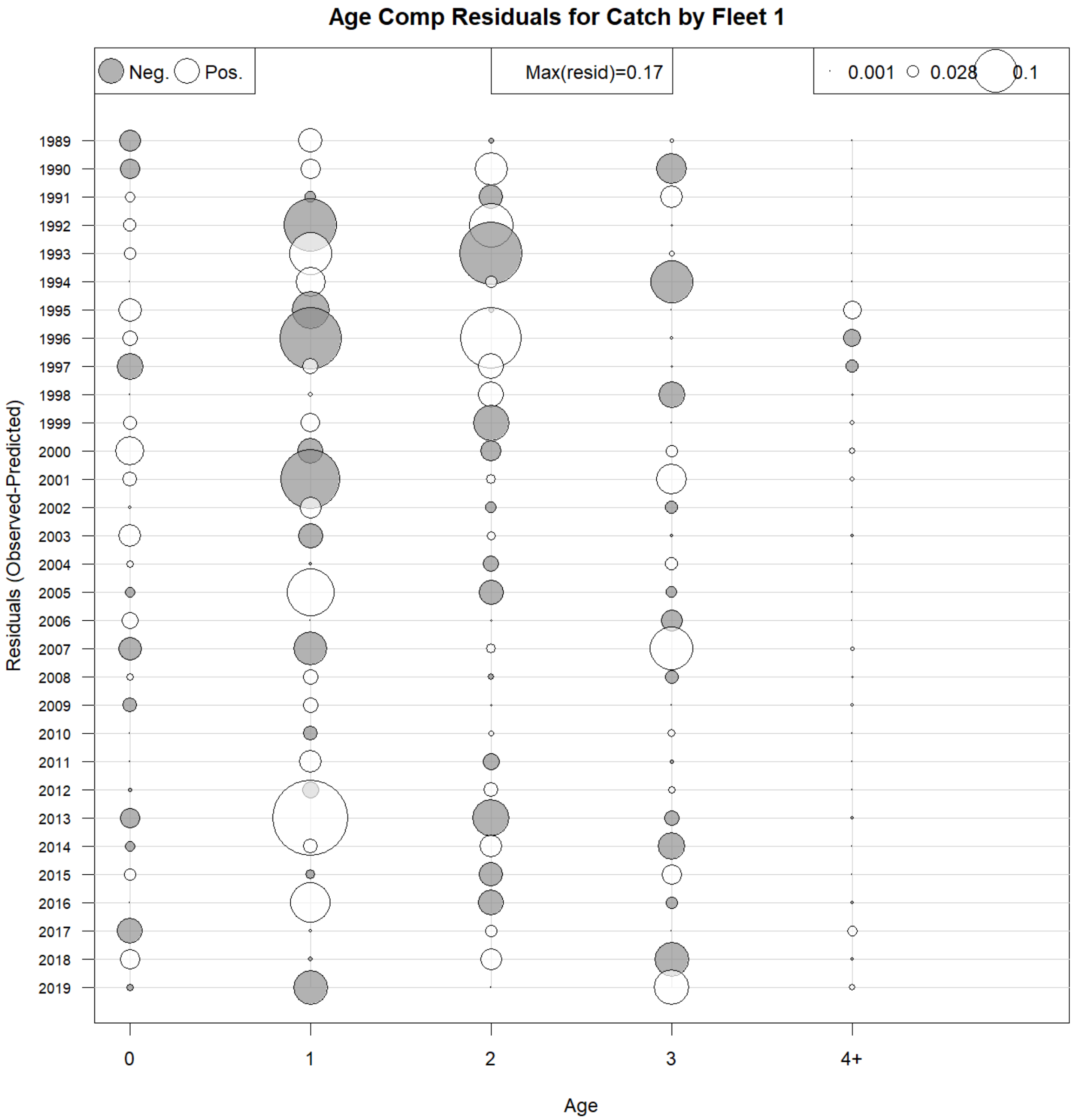

Figure 80. Residuals for the catch age composition from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

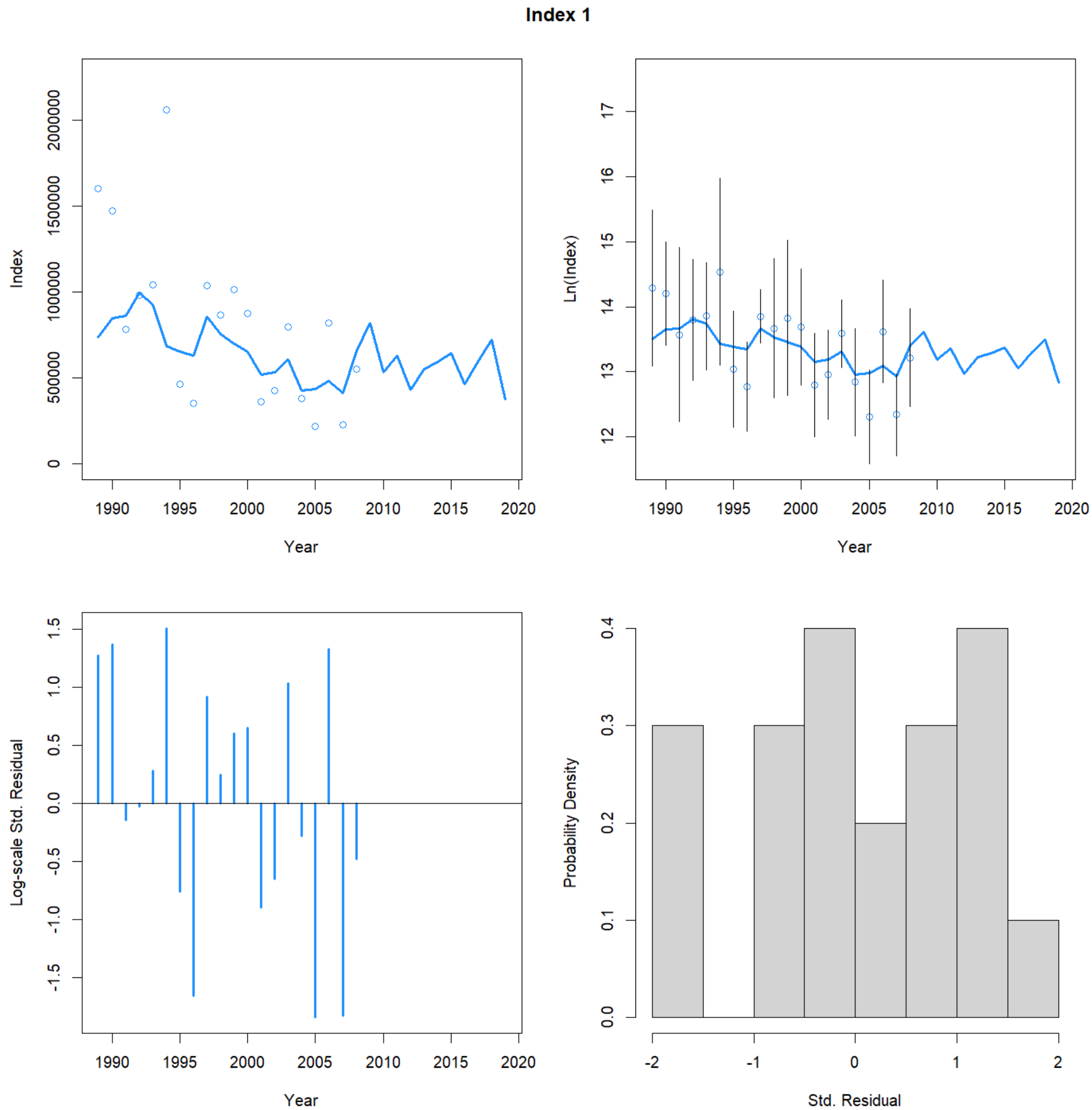

Figure 81. Diagnostics for the Northeast Fisheries Science Center (NEFSC) fall FRV *Albatross IV* survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

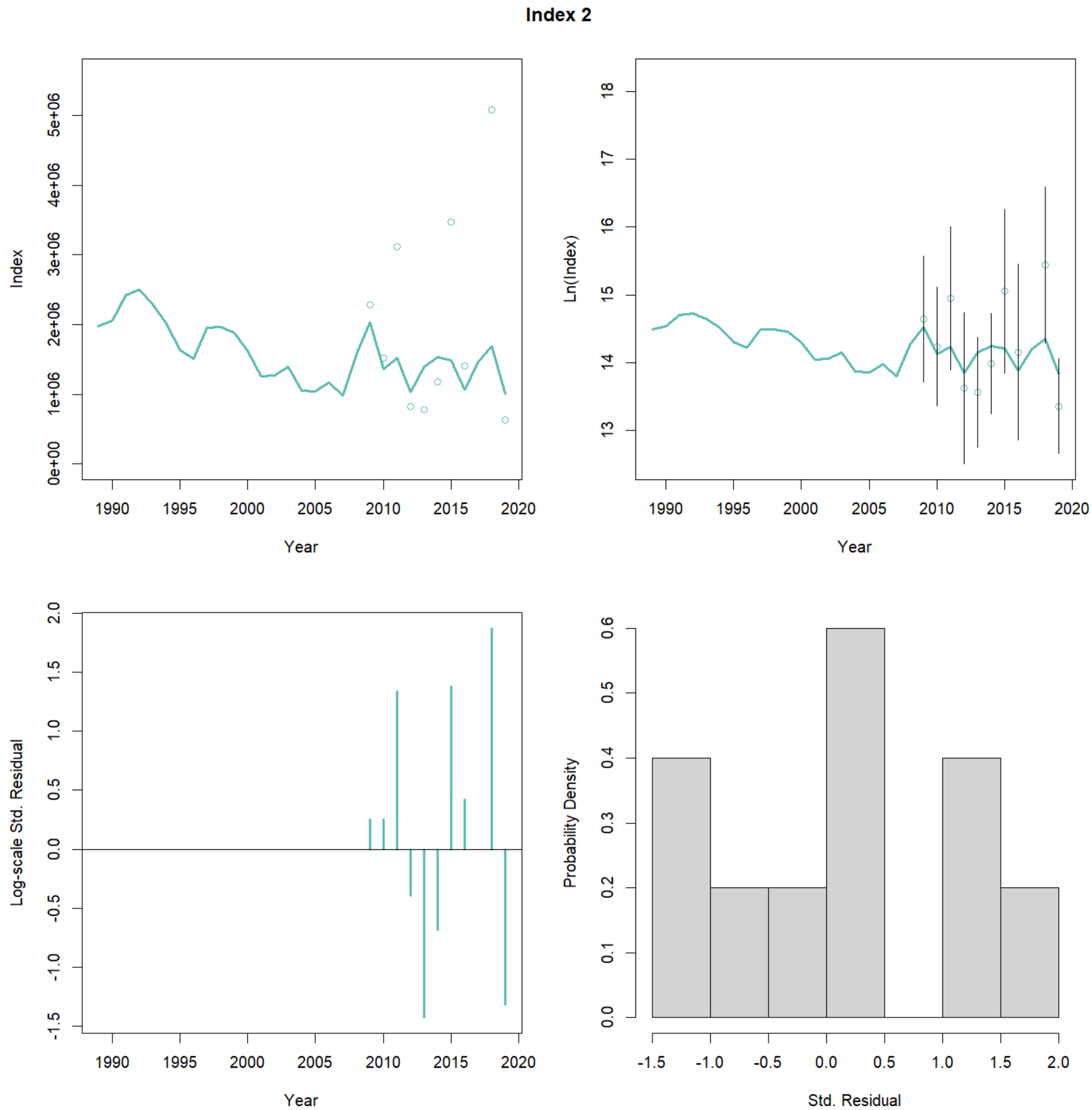

Figure 82. Diagnostics for the Northeast Fisheries Science Center (NEFSC) fall FSV *Henry B. Bigelow* survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

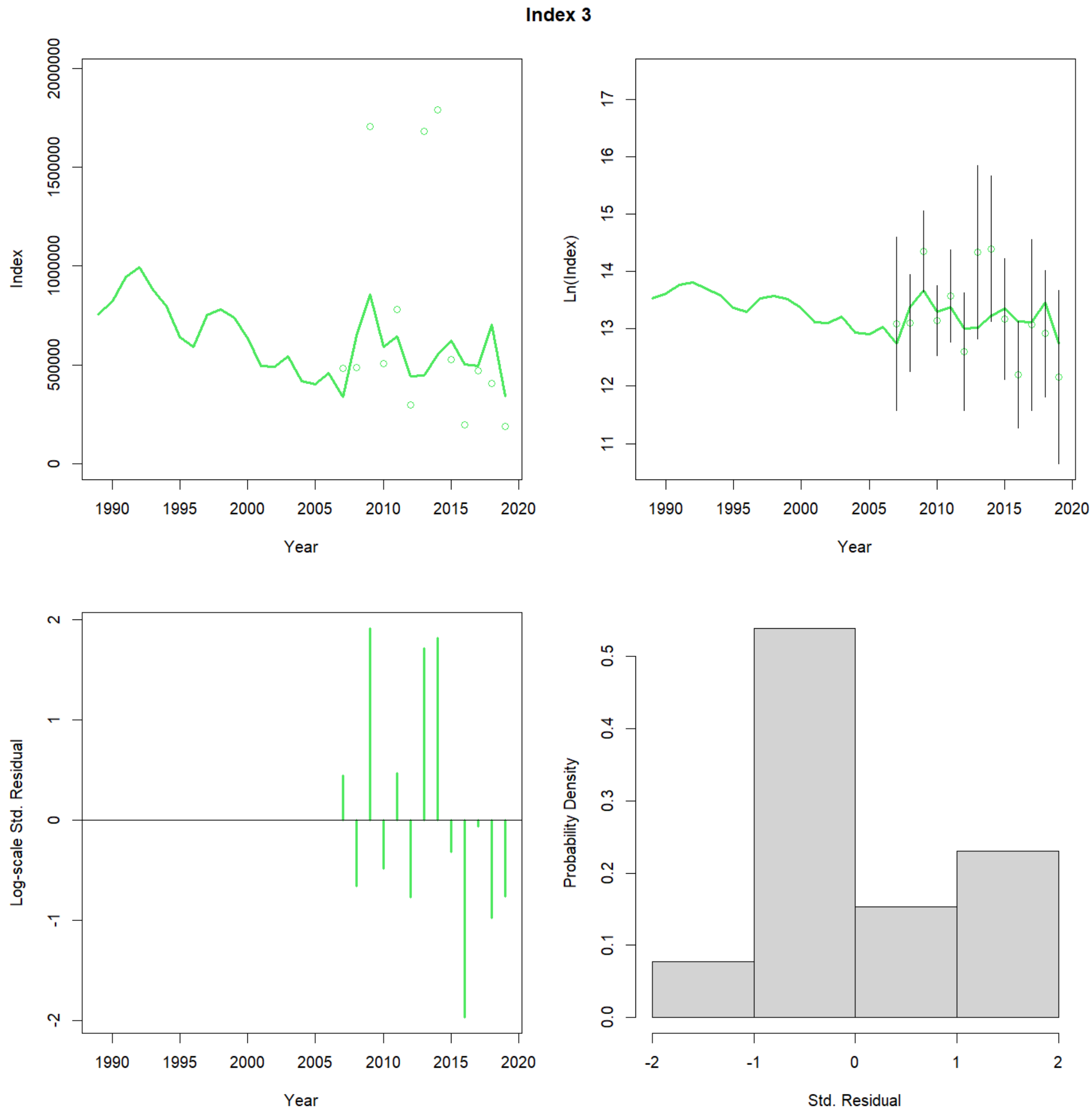

Figure 83. Diagnostics for the Northeast Area Monitoring and Assessment Program (NEAMAP) fall survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

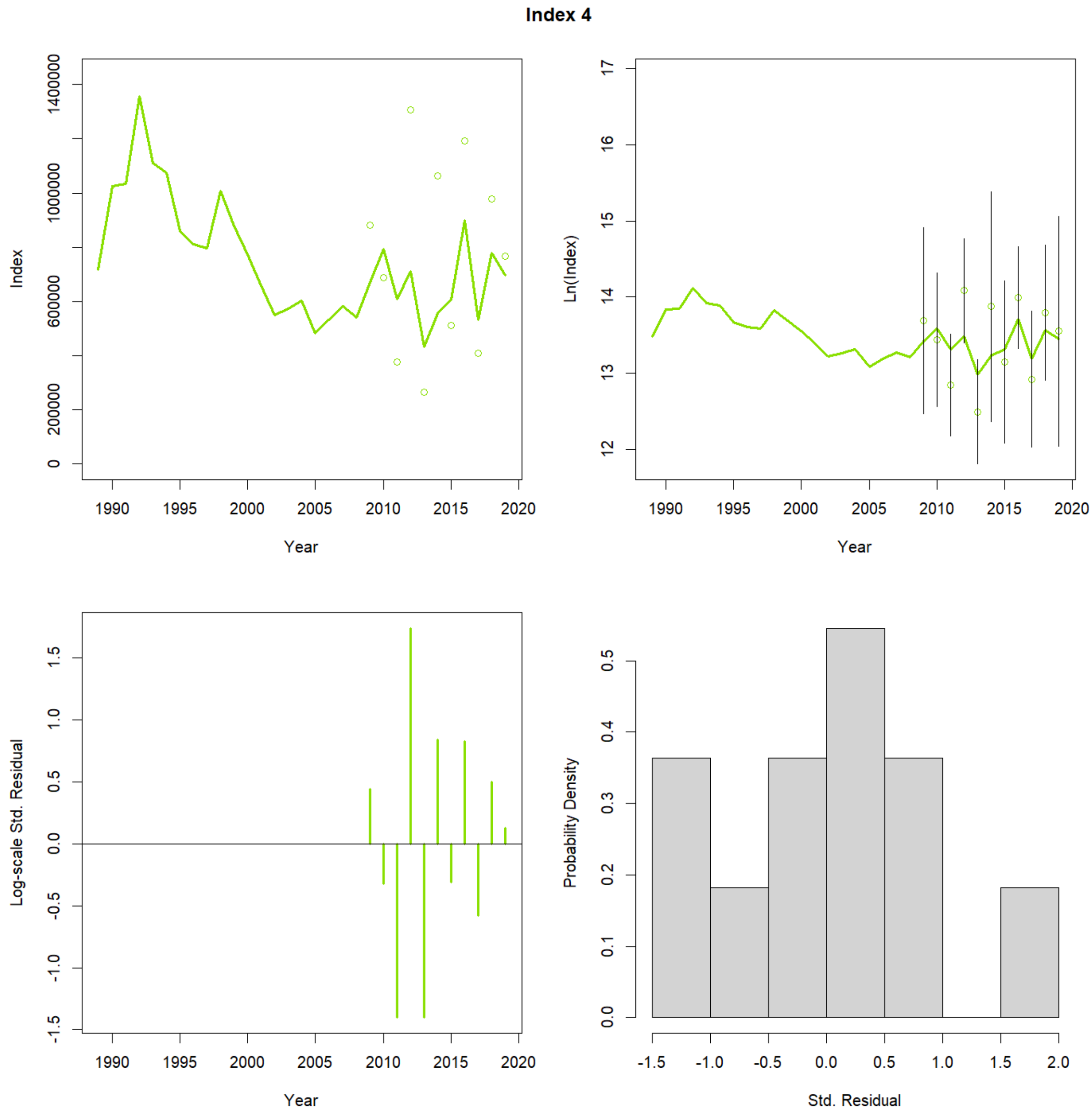

Figure 84. Diagnostics for the Northeast Fisheries Science Center (NEFSC) spring FSV *Henry B. Bigelow* survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

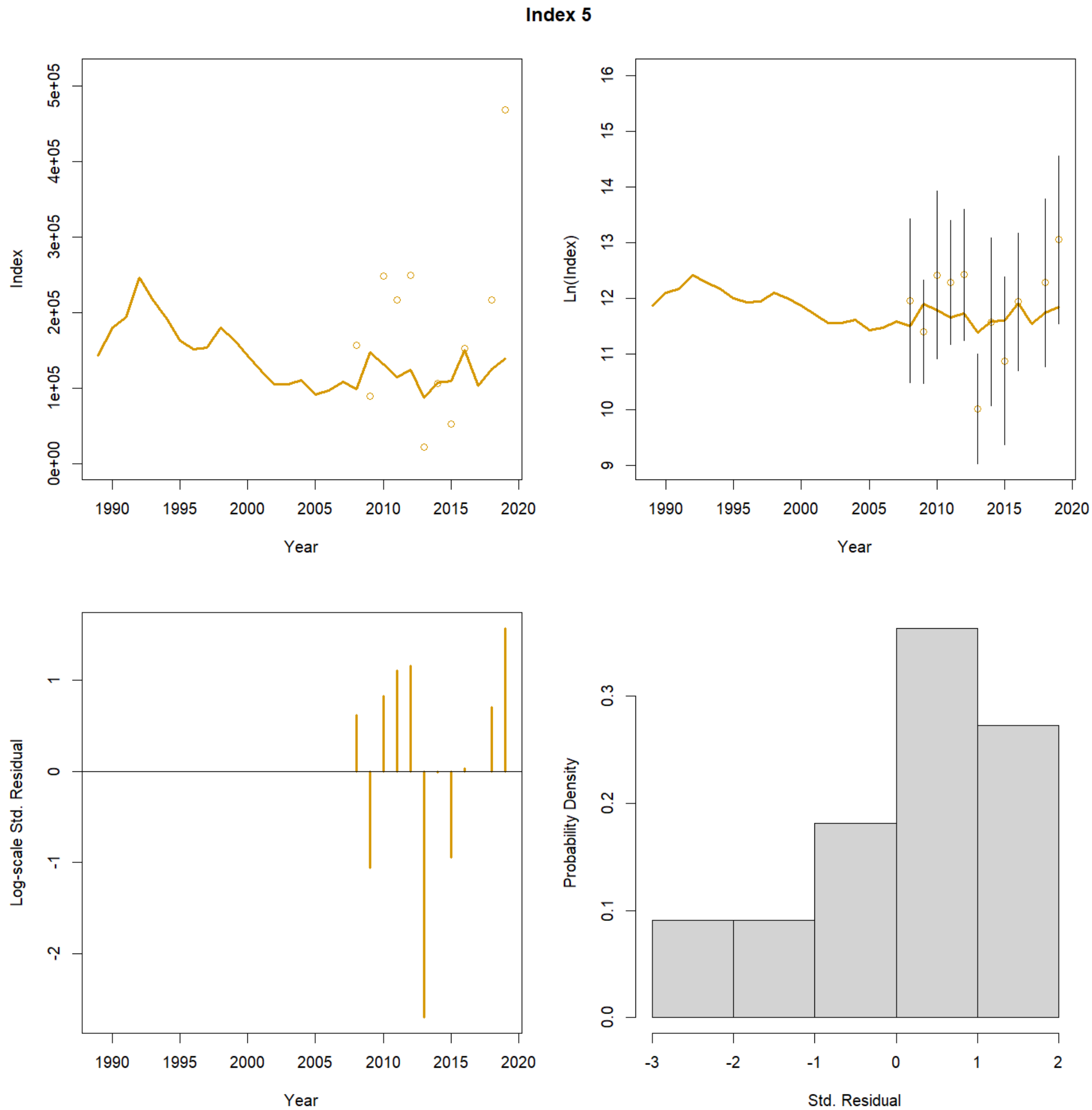

Figure 85. Diagnostics for the Northeast Area Monitoring and Assessment Program (NEAMAP) spring survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

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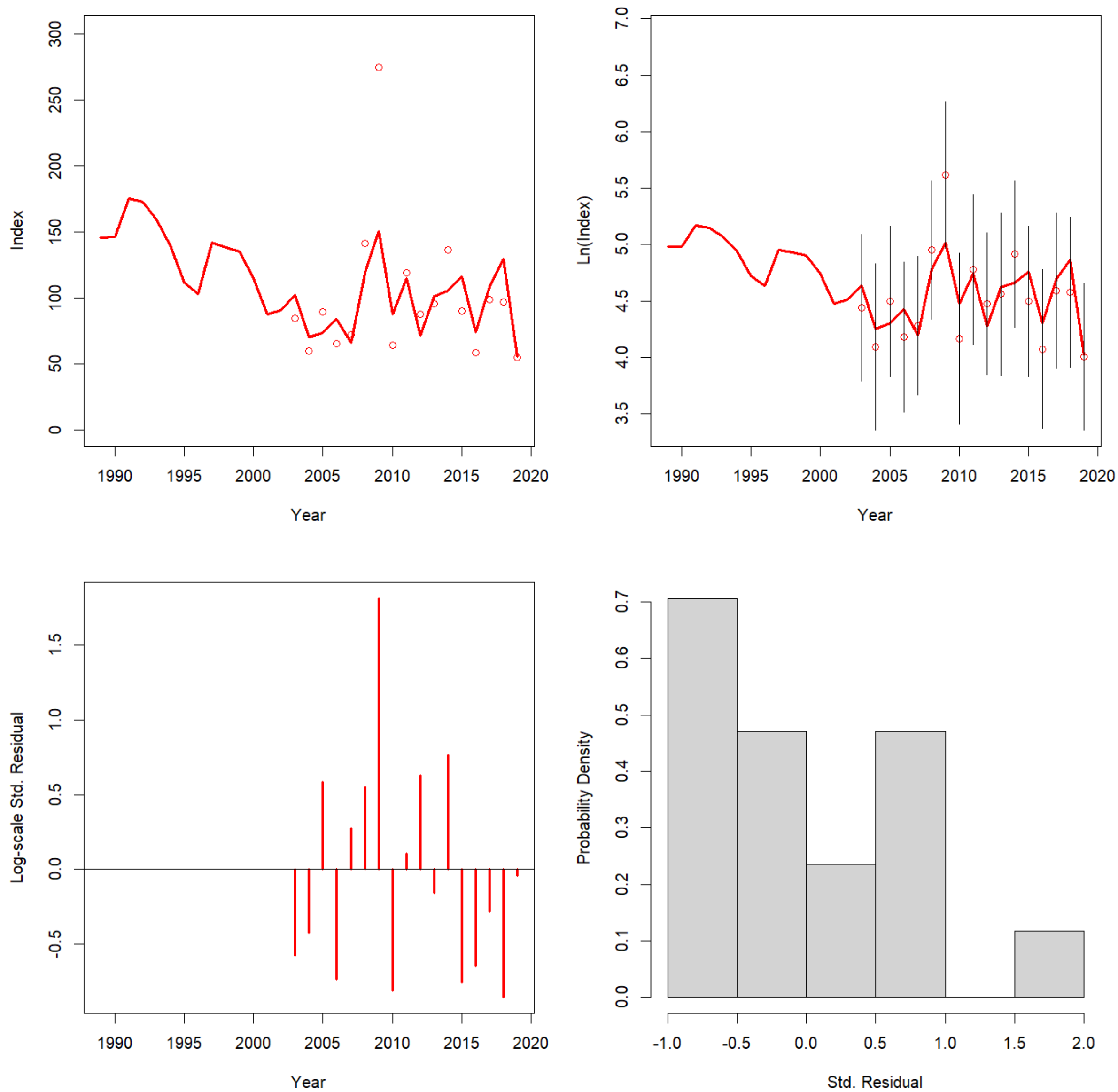

Figure 86. Diagnostics for the combined young-of-the-year (YOY) index from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

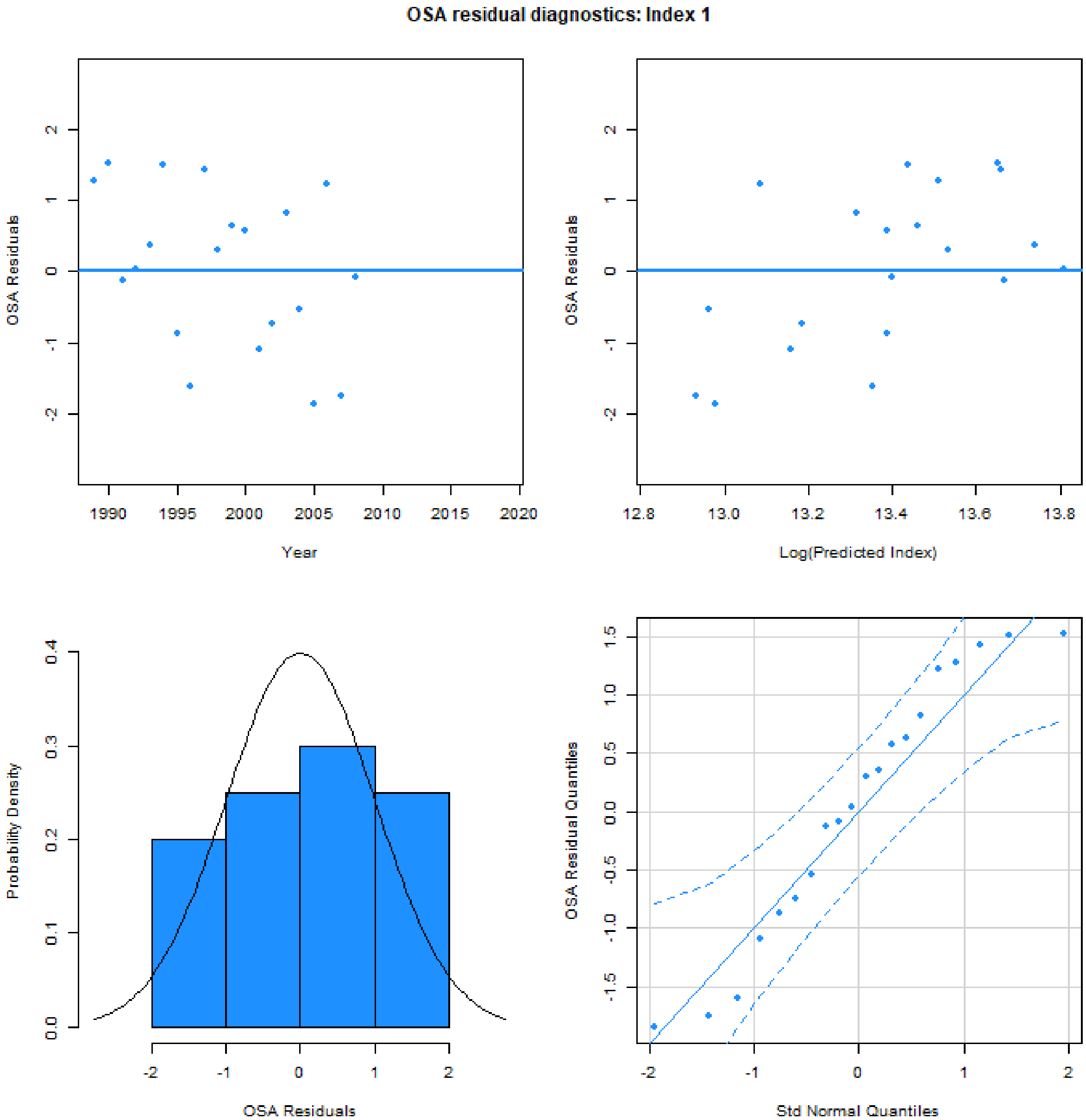

Figure 87. One-step ahead residual diagnostics for the Northeast Fisheries Science Center (NEFSC) fall FRV *Albatross IV* survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

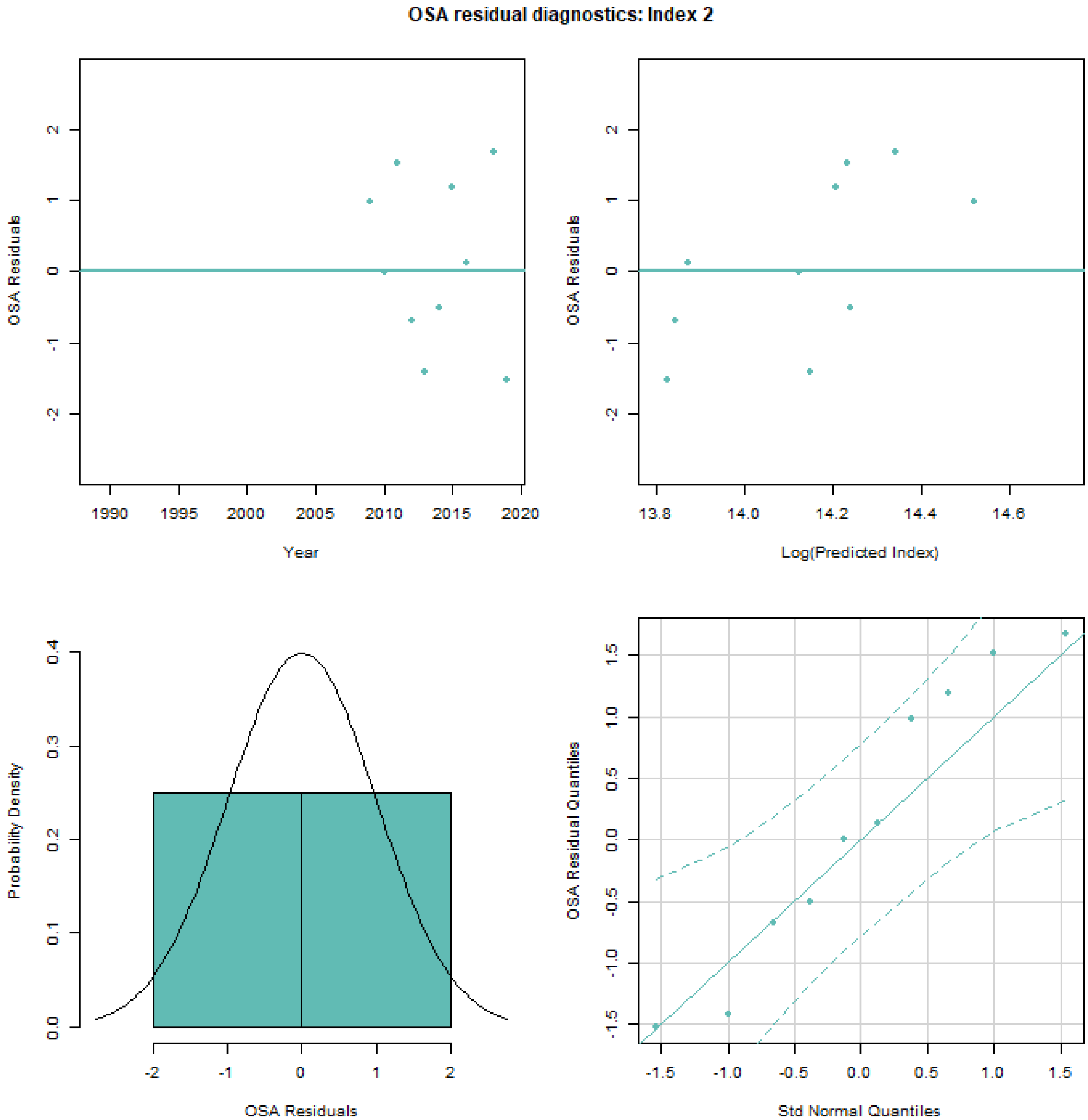

Figure 88. One-step ahead residual diagnostics for the Northeast Fisheries Science Center (NEFSC) fall FSV *Henry B. Bigelow* survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

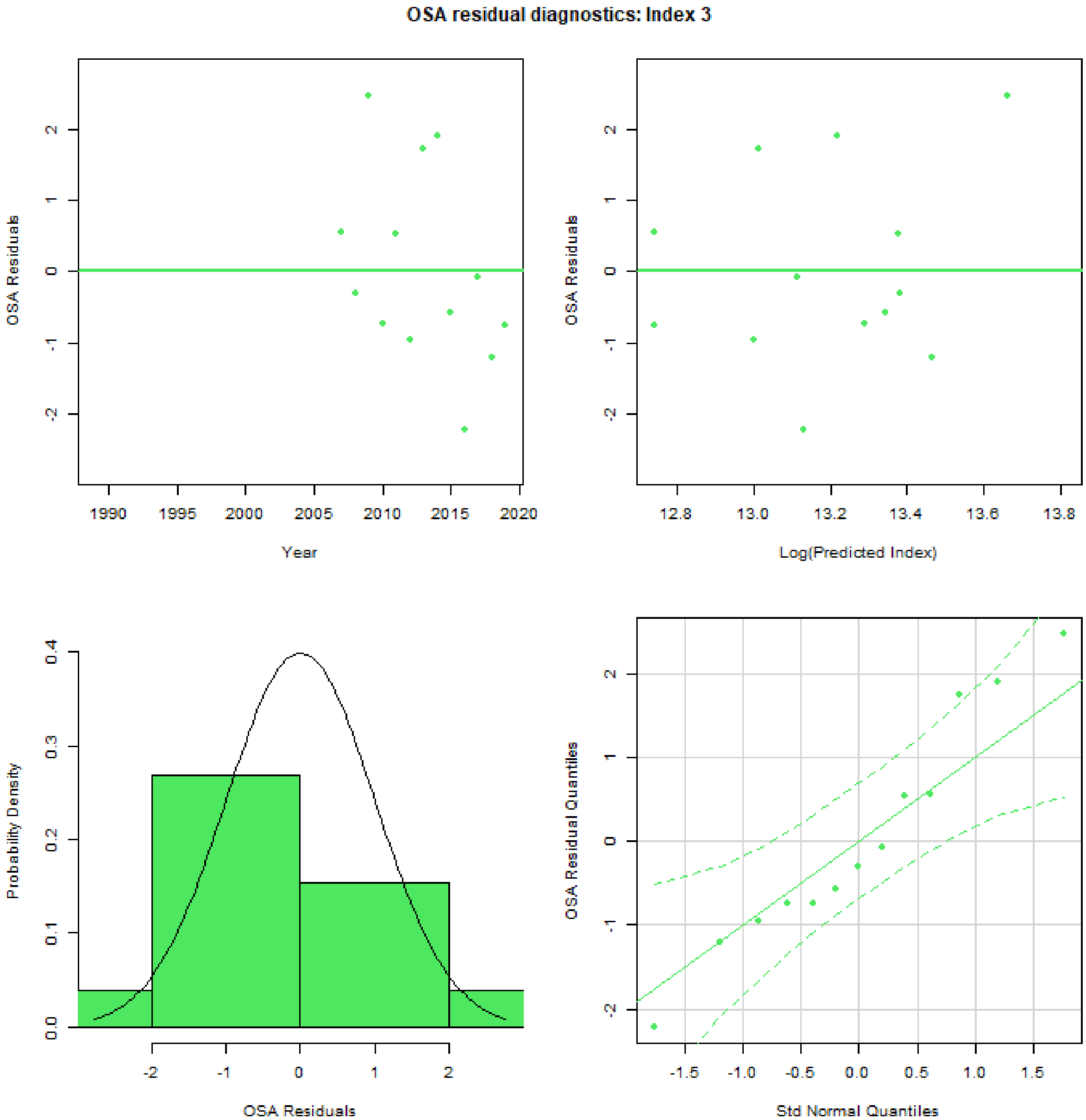

Figure 89. One-step ahead residual diagnostics for the Northeast Area Monitoring and Assessment Program (NEAMAP) fall survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

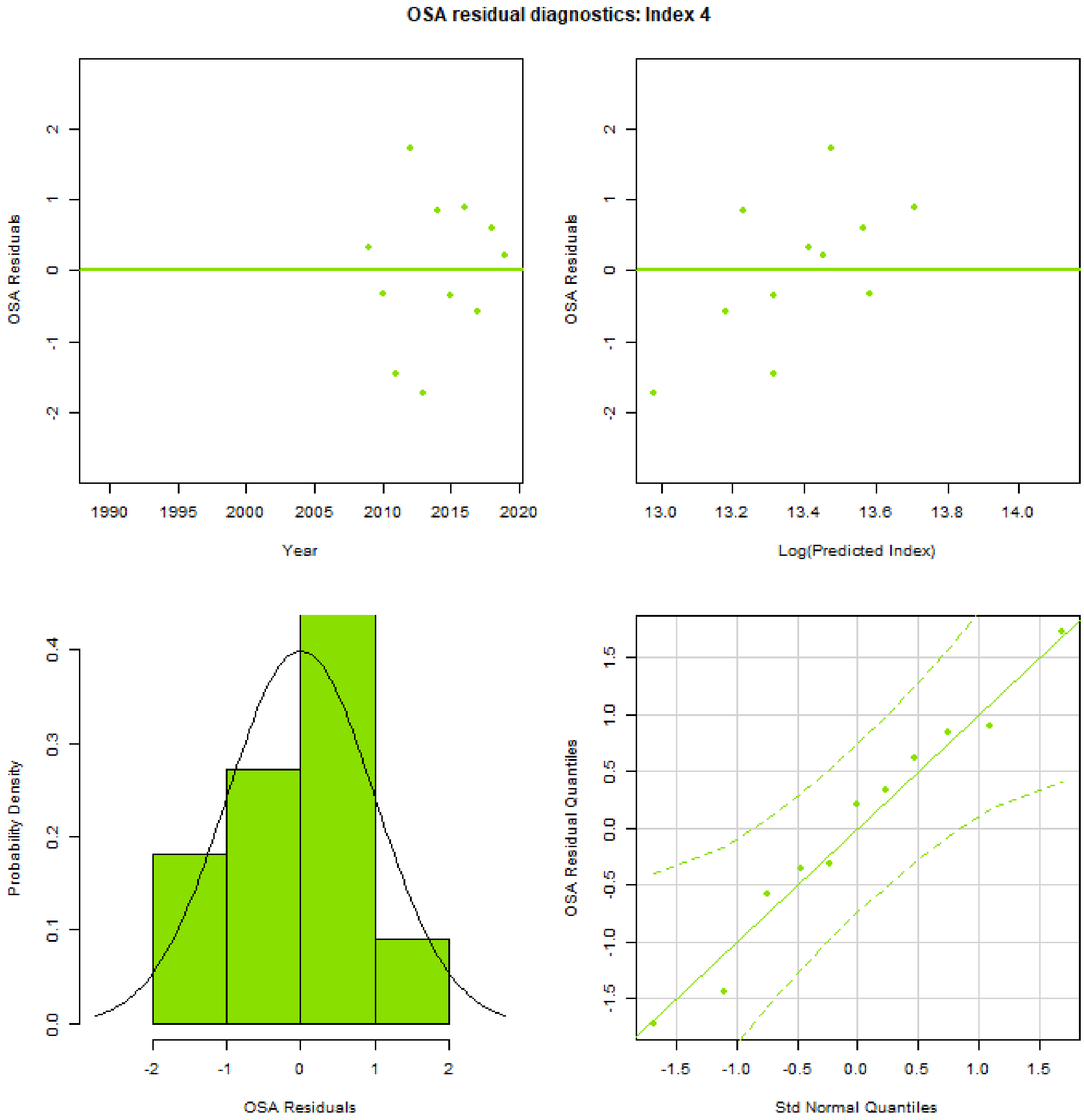

Figure 90. One-step ahead residual diagnostics for the Northeast Fisheries Science Center (NEFSC) spring FSV *Henry B. Bigelow* survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

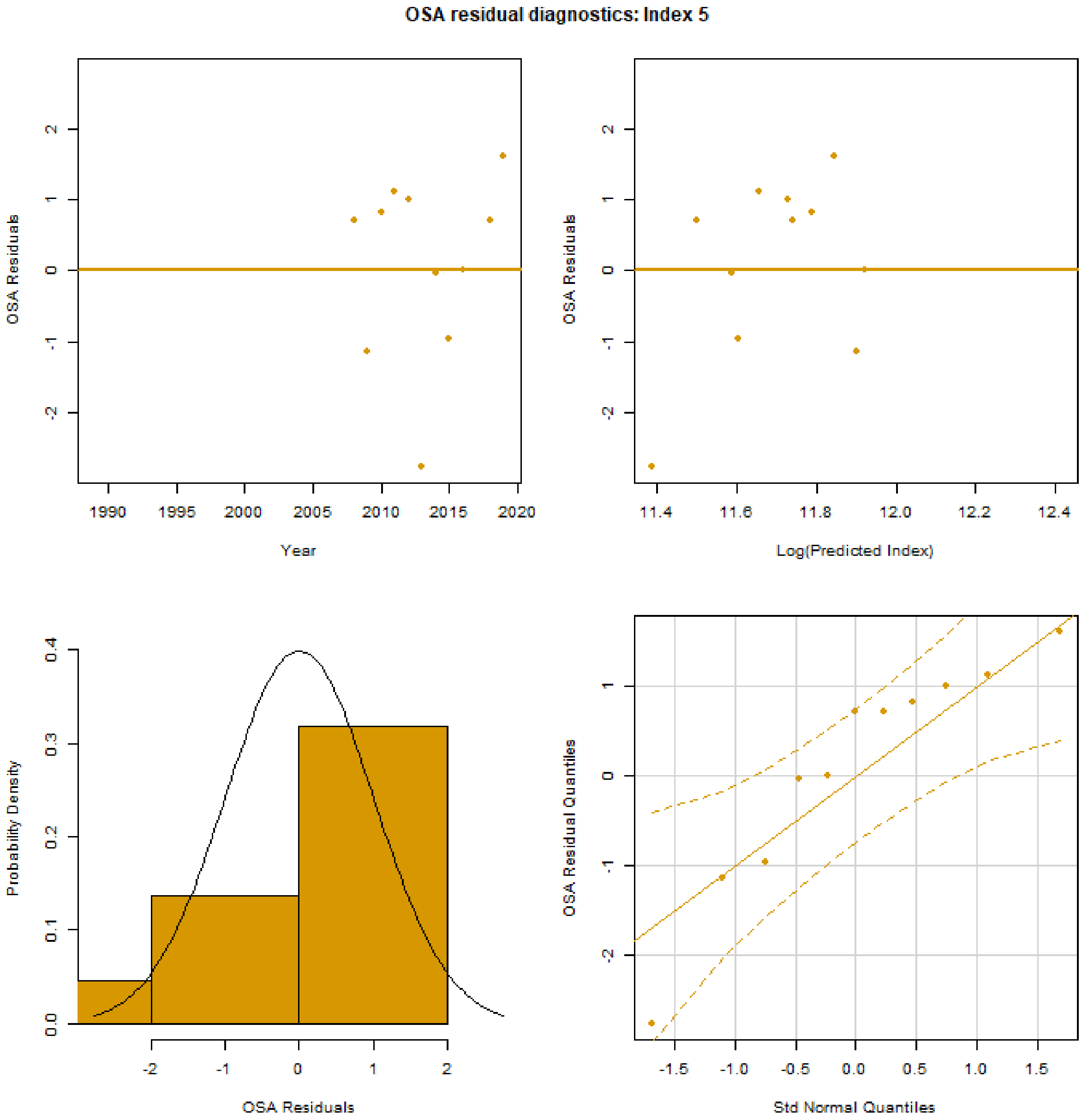

Figure 91. One-step ahead residual diagnostics for the Northeast Area Monitoring and Assessment Program (NEAMAP) spring survey from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

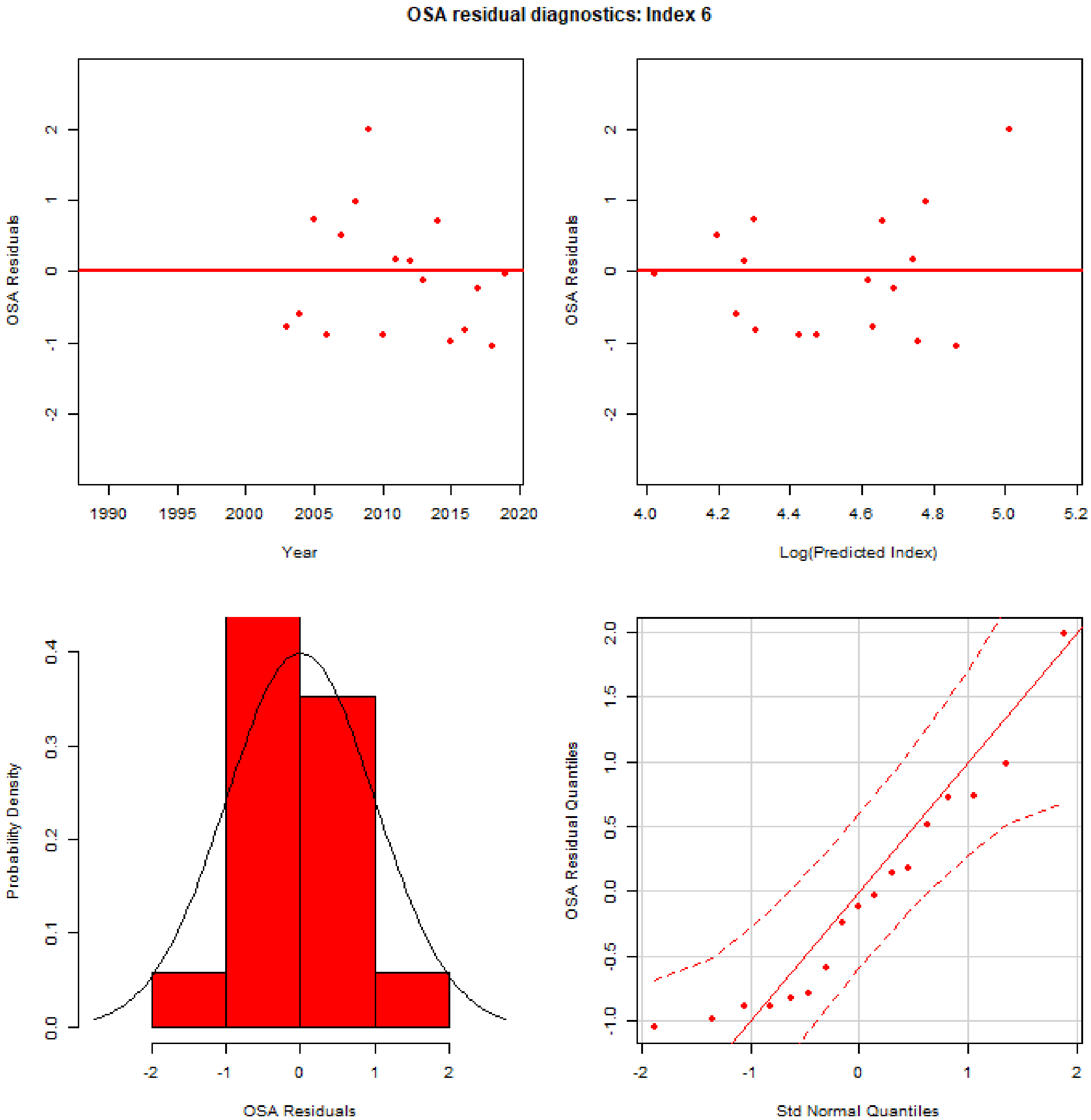

Figure 92. One-step ahead residual diagnostics for the combined young-of-the-year (YOY) index from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

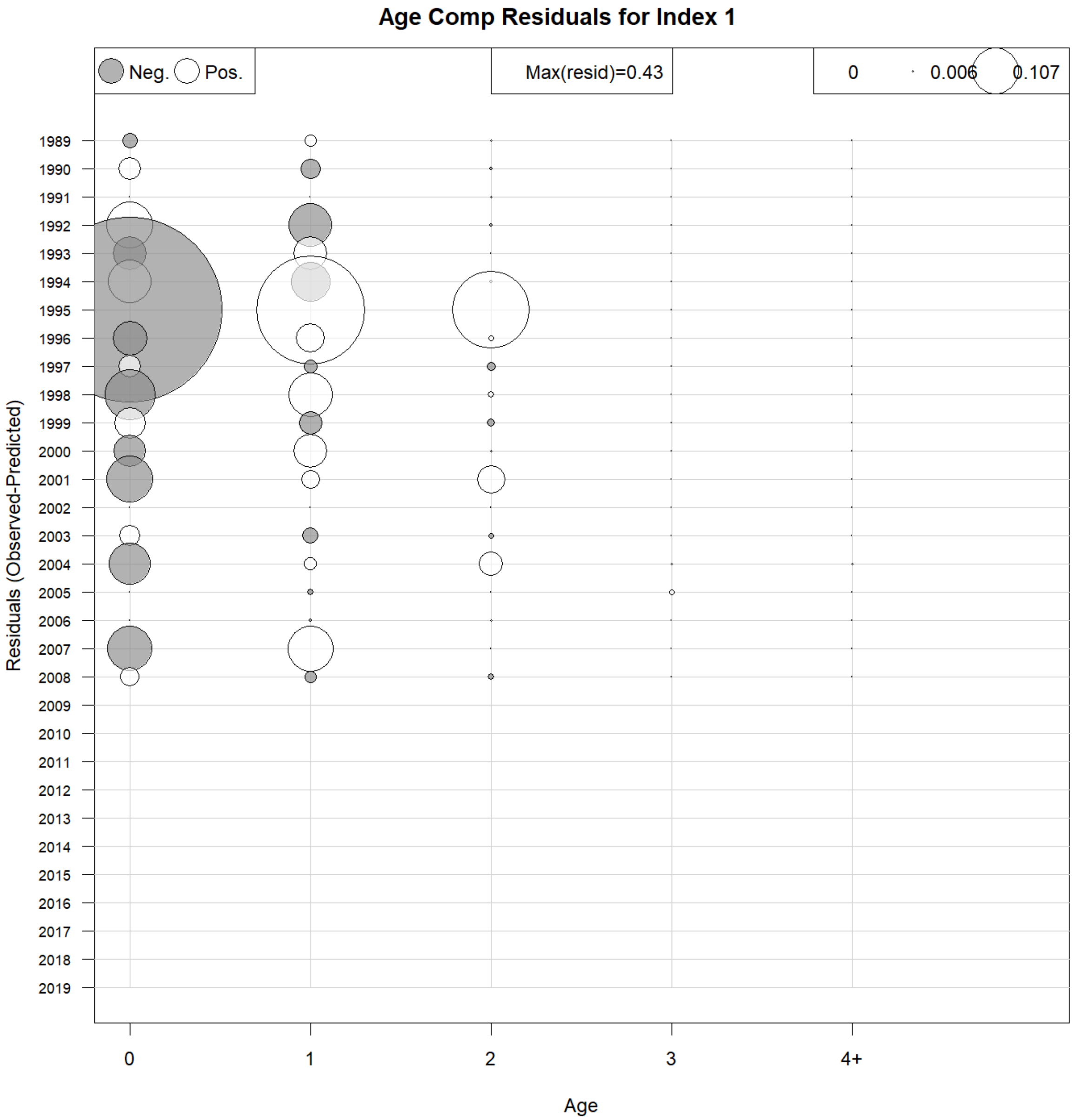

Figure 93. Residuals for the Northeast Fisheries Science Center (NEFSC) fall FRV *Albatross IV* age composition from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

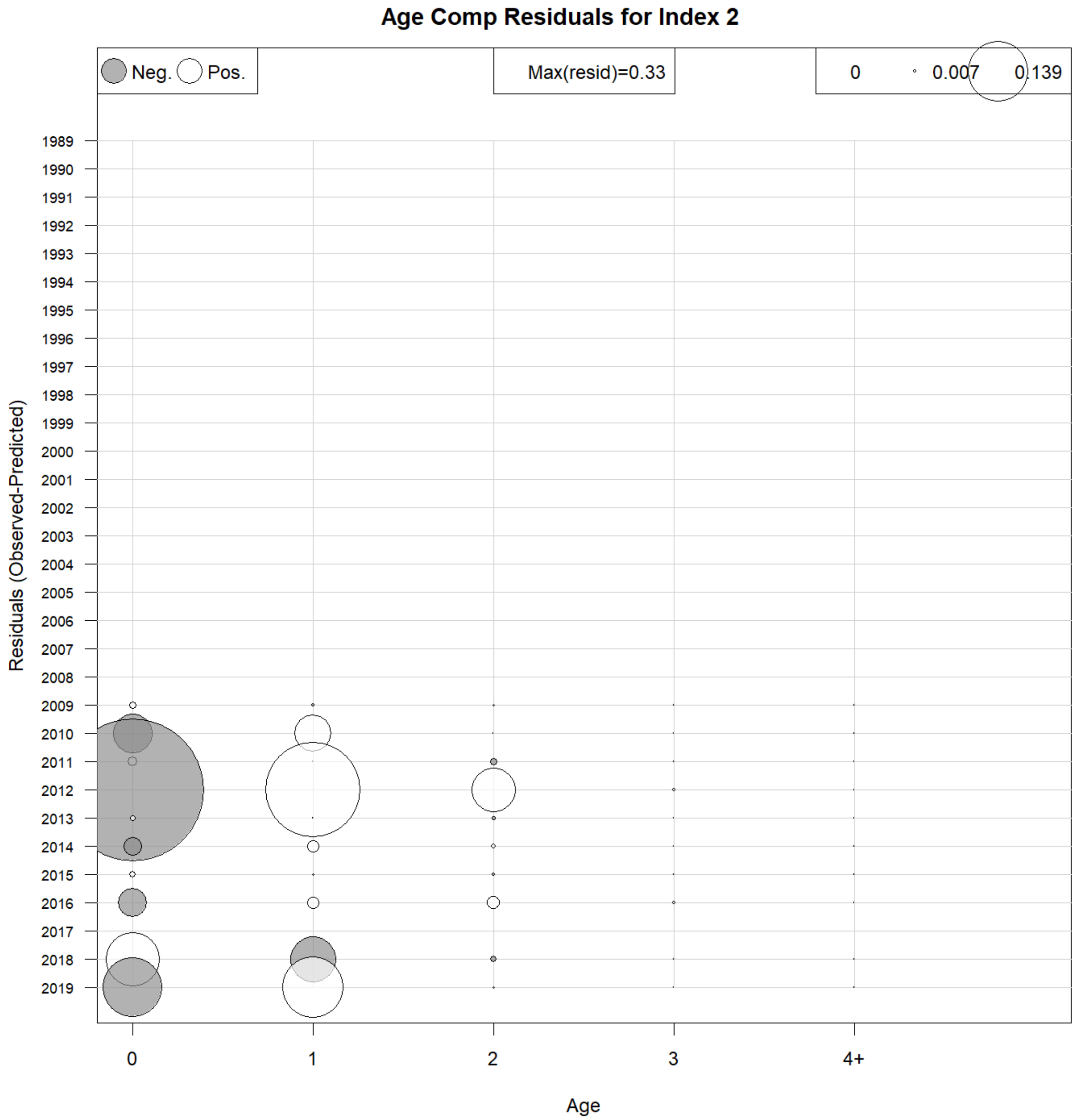

Figure 94. Residuals for the Northeast Fisheries Science Center (NEFSC) fall FSV *Henry B. Bigelow* age composition from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

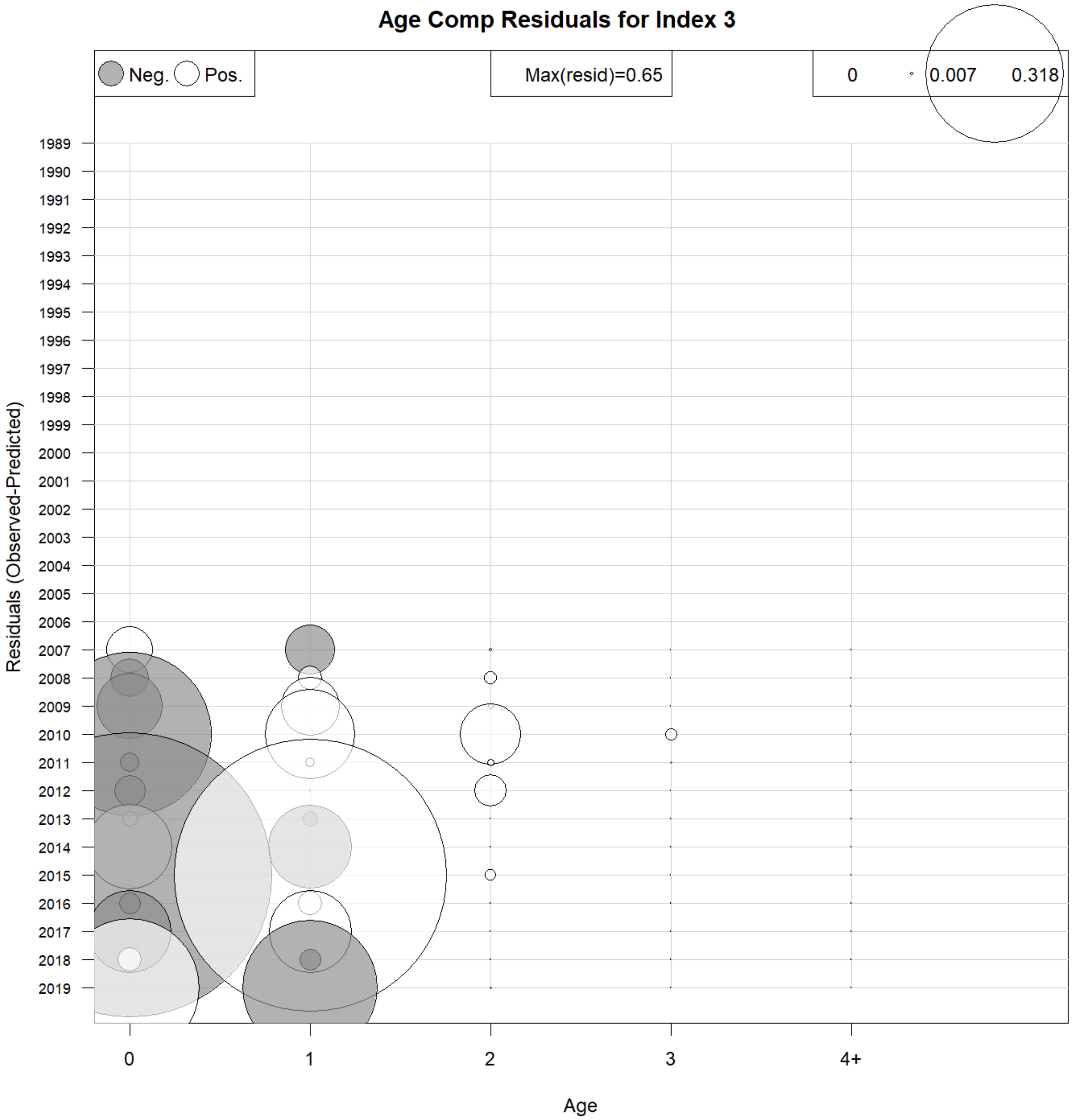

Figure 95. Residuals for the Northeast Area Monitoring and Assessment Program (NEAMAP) fall age composition from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

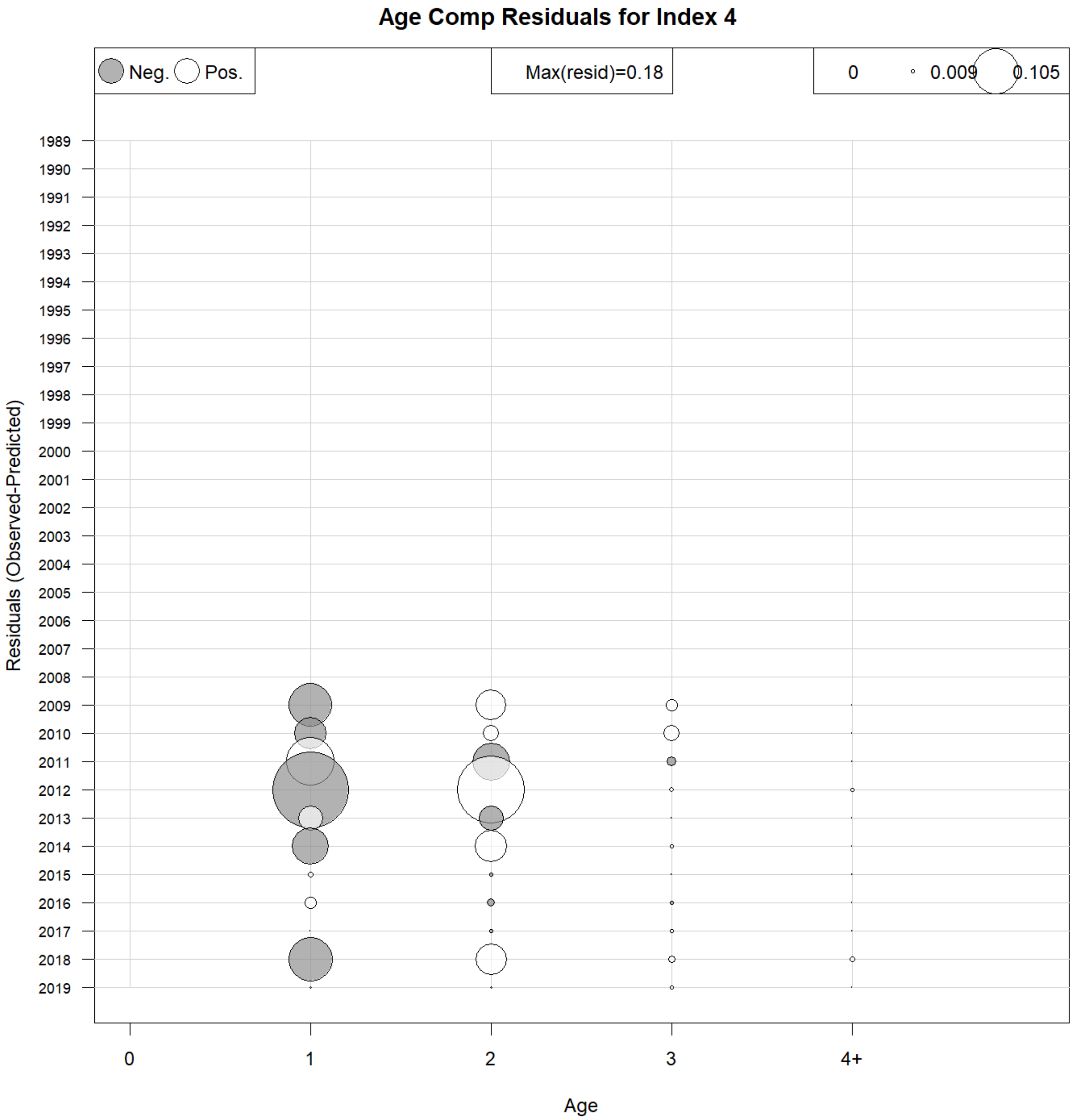

Figure 96. Residuals for the Northeast Fisheries Science Center (NEFSC) spring FSV *Henry B. Bigelow* age composition from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

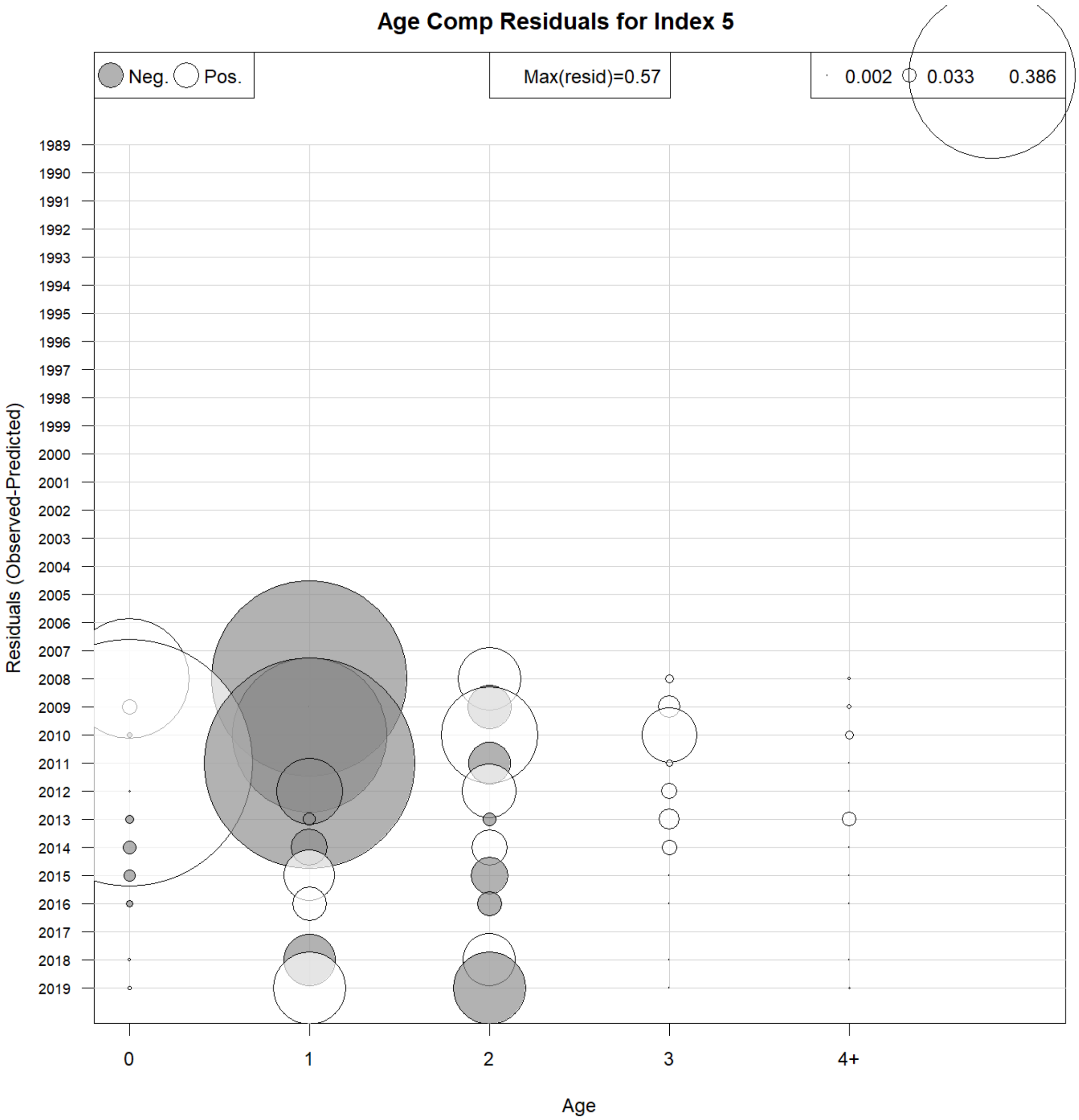

Figure 97. Residuals for the Northeast Area Monitoring and Assessment Program (NEAMAP) spring age composition from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

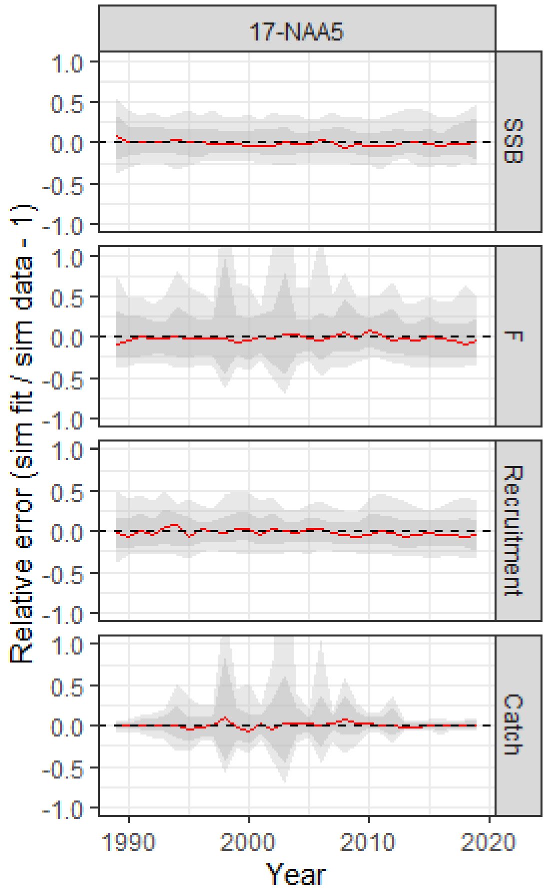

Figure 98. Simulation self-test results for the best Woods Hole Assessment Model (WHAM) 17-NAA5. Light gray shading shows the middle 80%, dark gray shows the middle 50%, and red lines are the medians of 100 simulations.

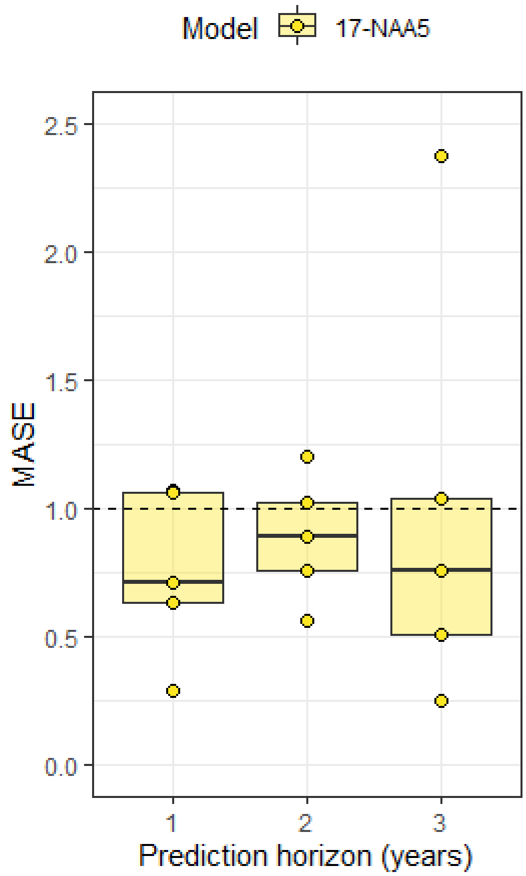

Figure 99. Hindcast performance of the best Woods Hole Assessment Model (WHAM) 17-NAA5, as measured by mean absolute scaled error (MASE). Points are the average MASE predicting each index at the specified time horizon. Median MASE < 1 means that the model is better than the naive/baseline forecast, and MASE = 0.5 means that model forecasts are twice as accurate as naive/baseline. The analysis was only performed for the 5 indices with data in the last 3 years (i.e., fall FRV *Albatross IV* stops in 2008).

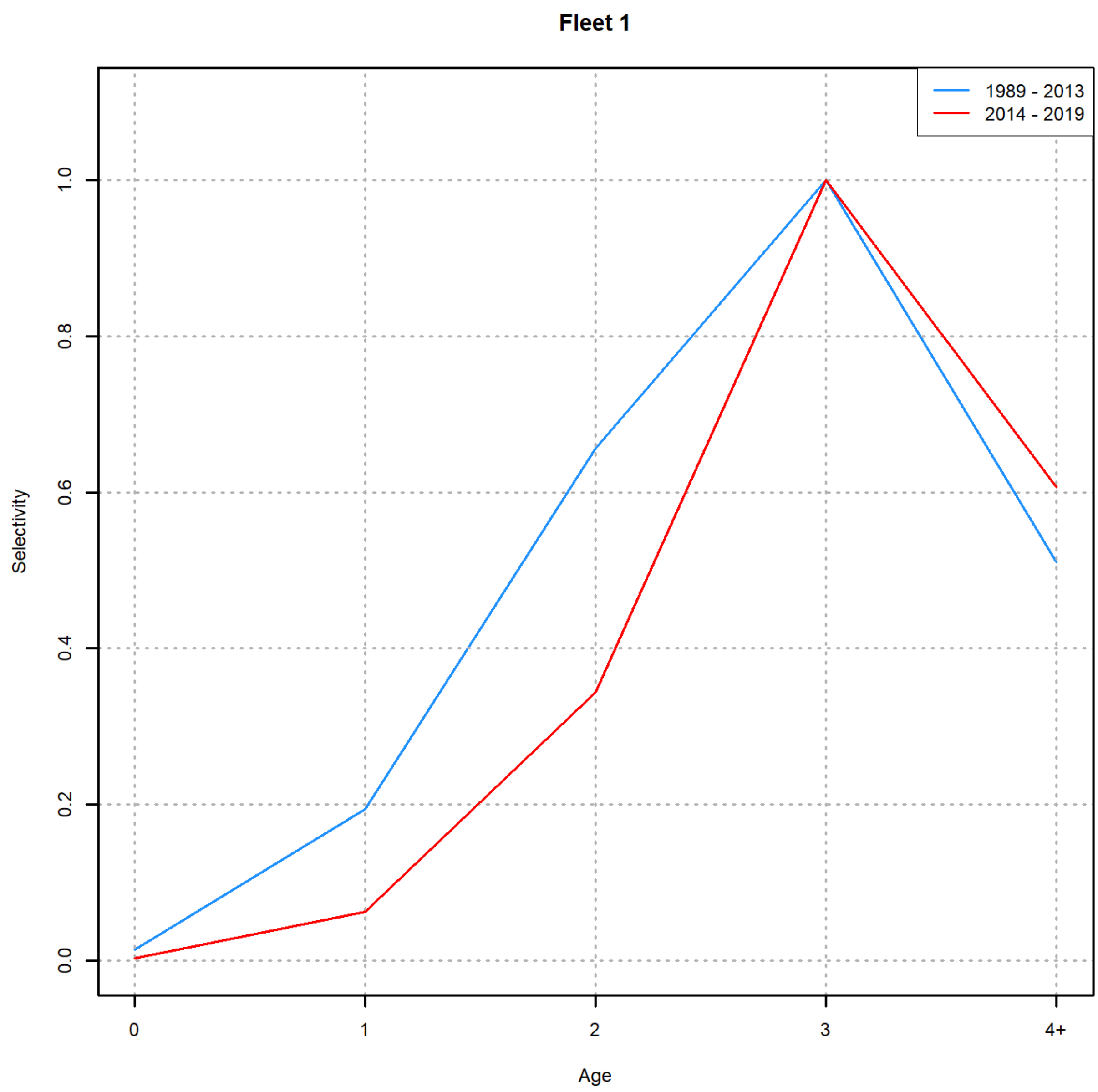

Figure 100. Fishery selectivity at age from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

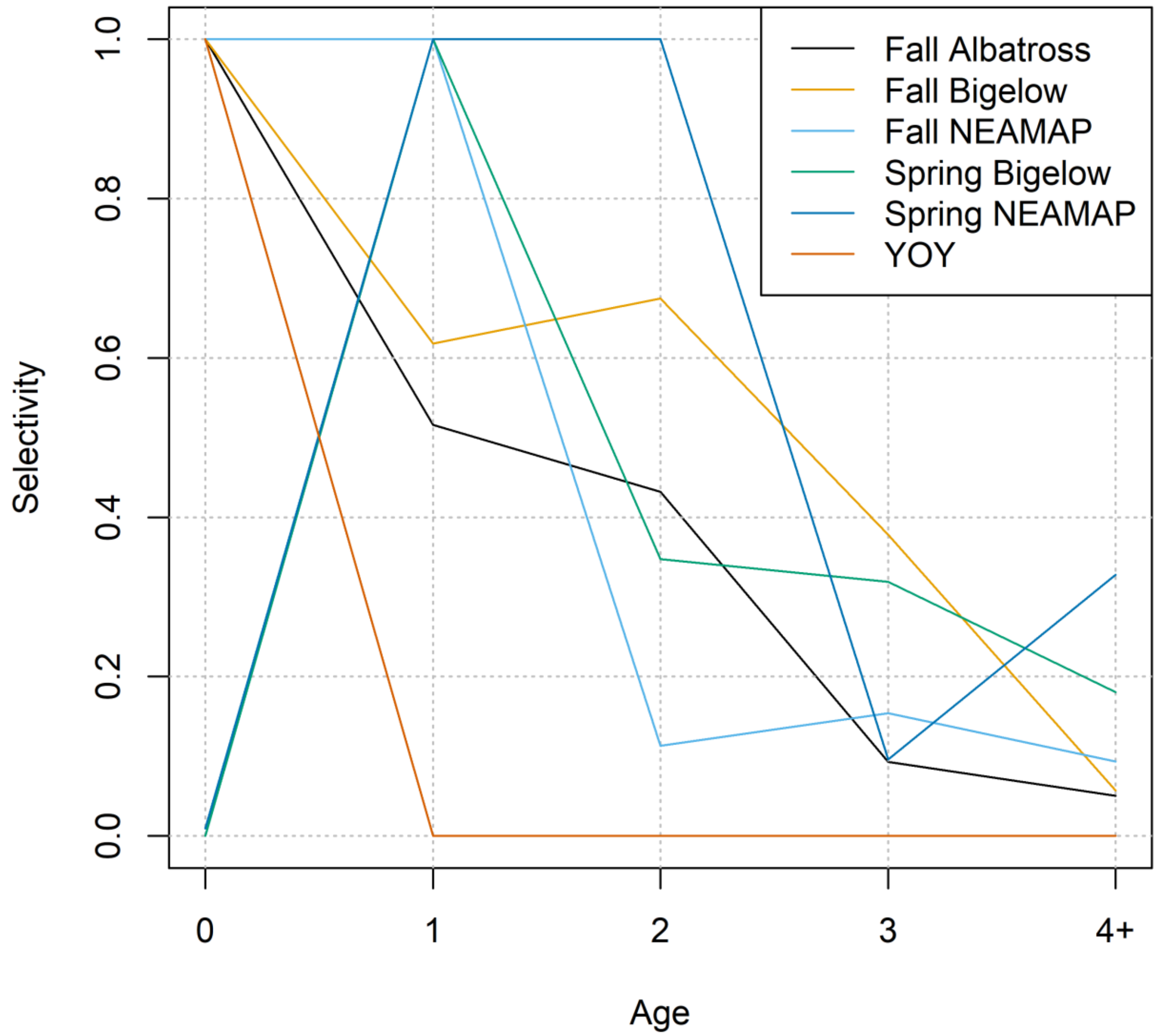

Figure 101. Survey selectivity at age from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

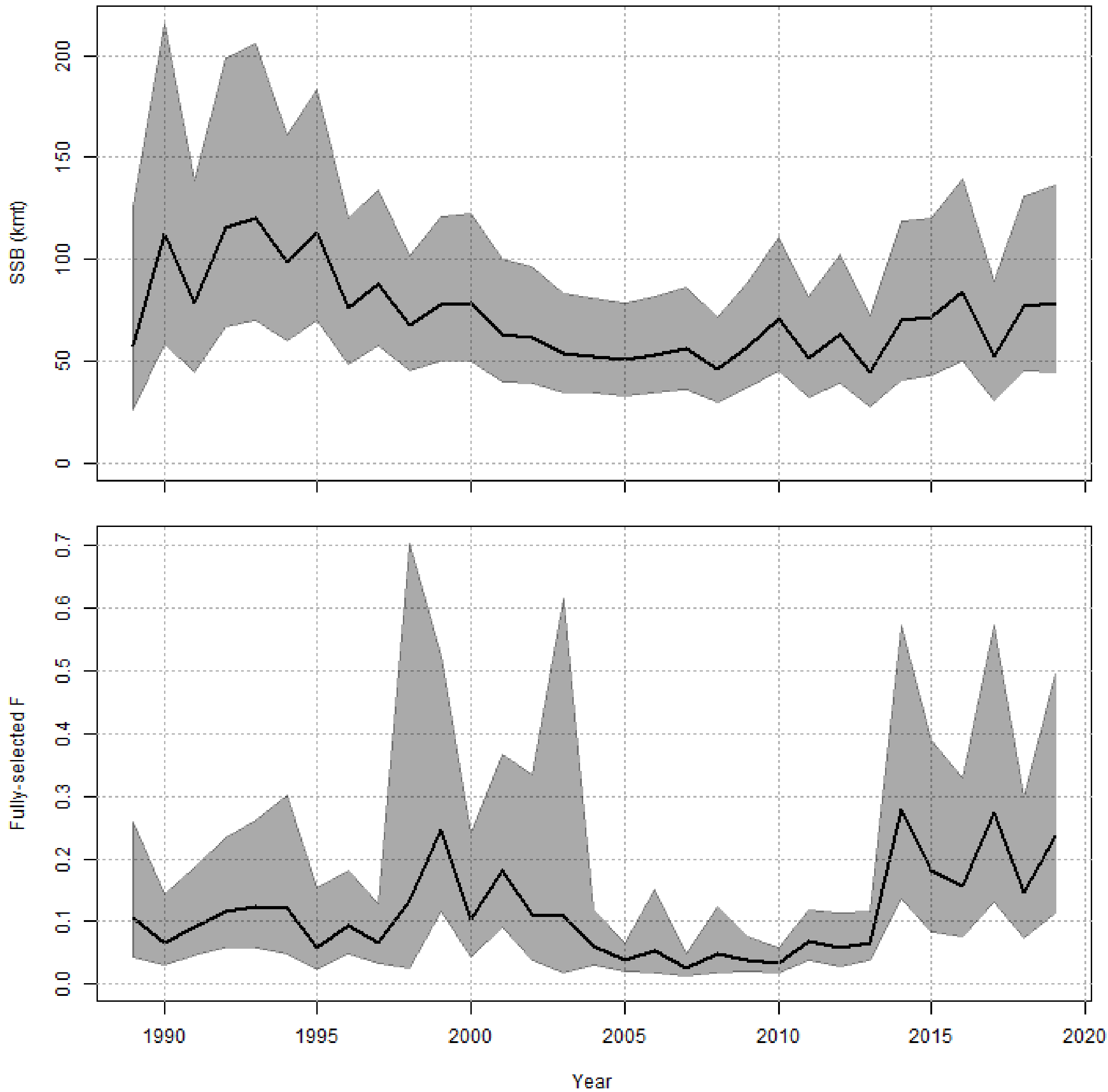

Figure 102. Spawning stock biomass (SSB) and fishing mortality (F) with 95% confidence intervals from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

Figure 103. Results of internal model retrospective analysis for fully selected fishing mortality (F; age 3) from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

Figure 104. Results of internal model retrospective analysis for spawning stock biomass (SSB) from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

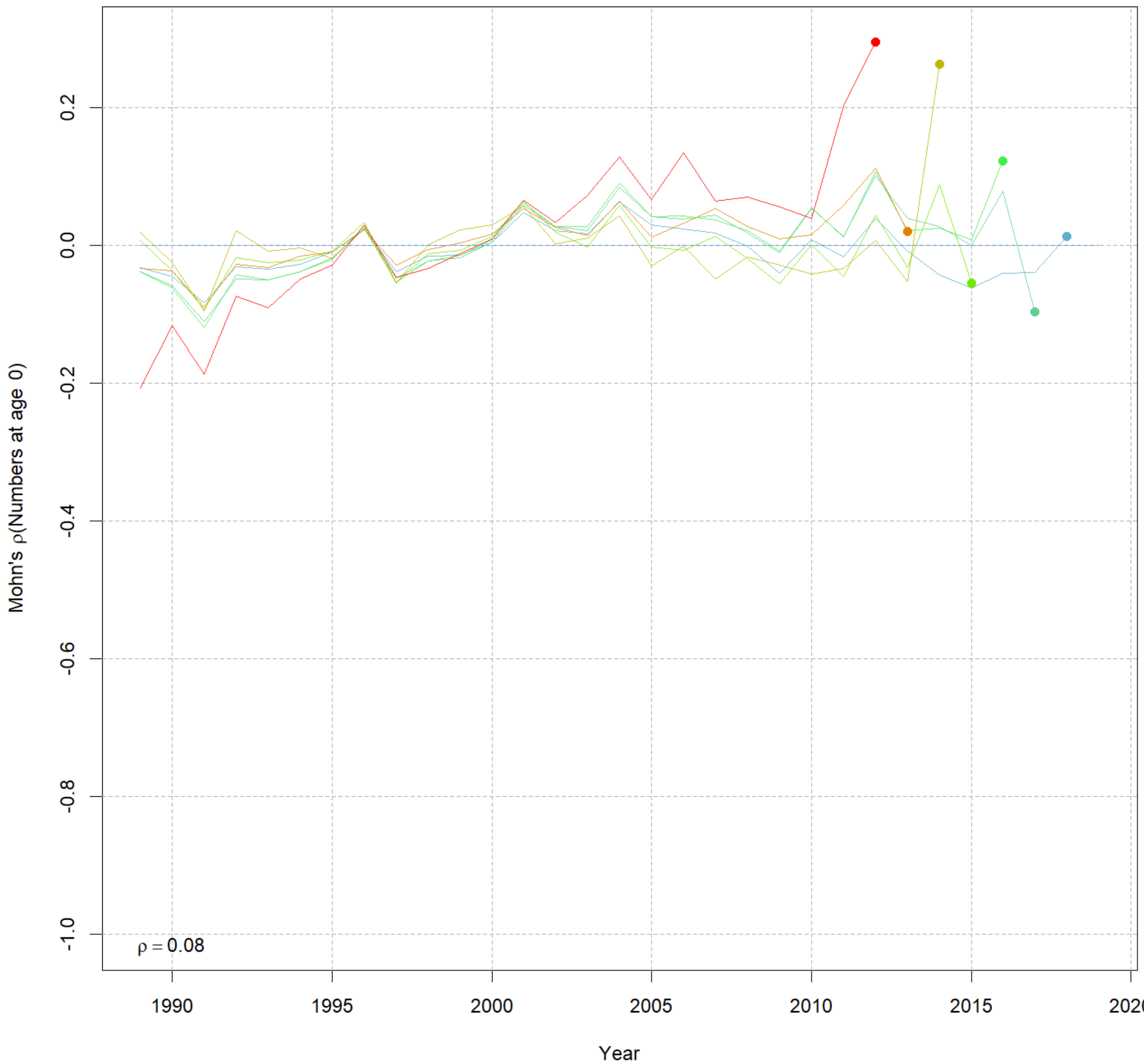

Figure 105. Results of internal model retrospective analysis for recruitment (age 0) from the best Woods Hole Assessment Model (WHAM) 17-NAA5.

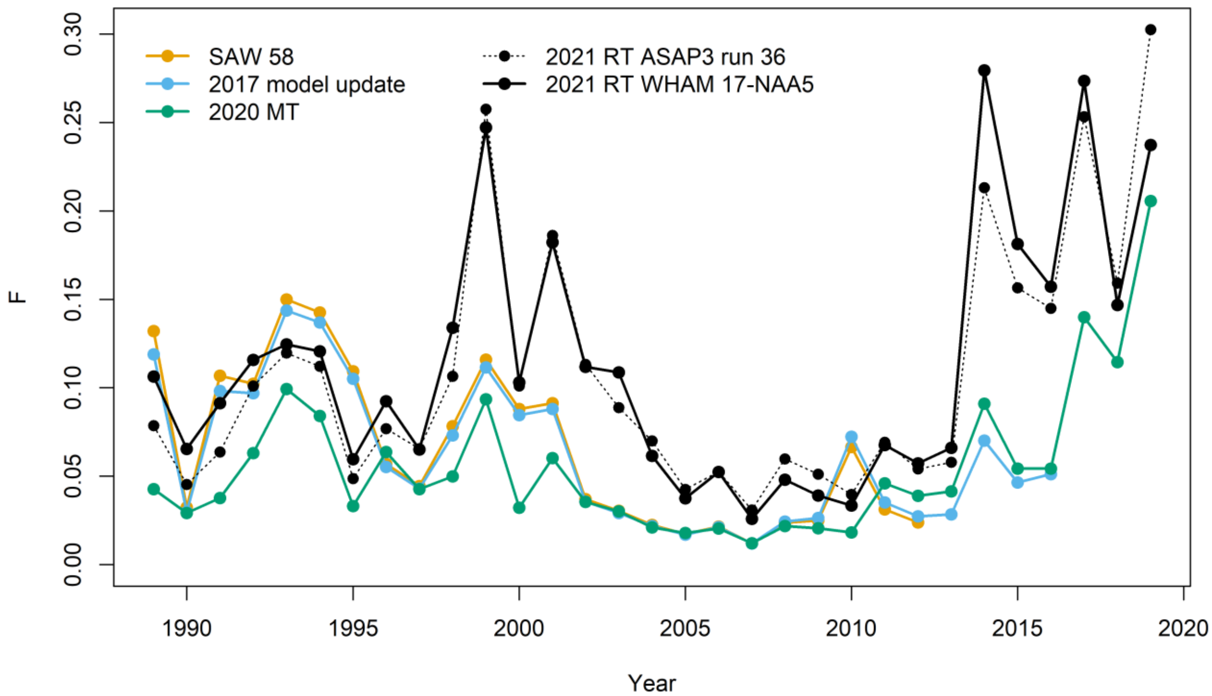

Figure 106. Historical retrospective for fishing mortality (F) from Stock Assessment Workshop (SAW) 58, the 2017 model update, the 2020 management track, and 2 runs from the 2021 research track: age structured assessment program (ASAP) 3 run 036 and Woods Hole Assessment Model (WHAM) 17-NAA5. Note that for WHAM 17-NAA5. F is fully selected for age 3, whereas for ASAP3 run 036 and all earlier models, it is fully selected for ages 2 to 4+.

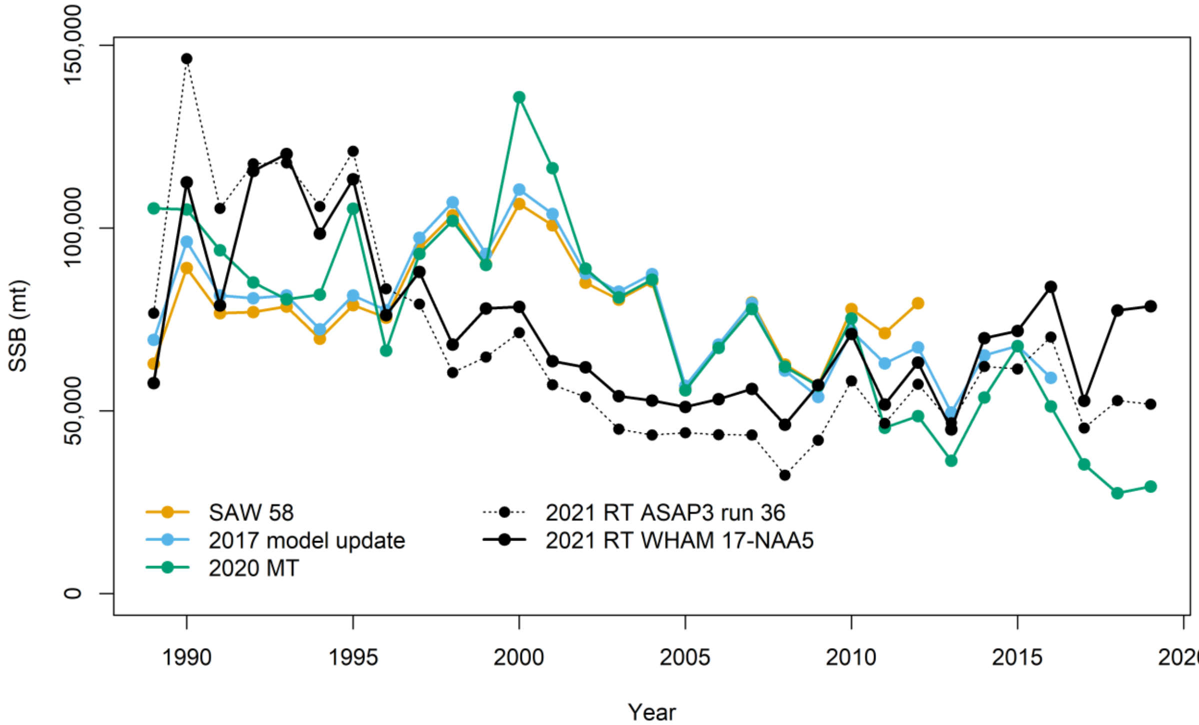

Figure 107. Historical retrospective for spawning stock biomass (SSB) from Stock Assessment Workshop (SAW) 58, the 2017 model update, the 2020 management track, and 2 runs from the 2021 research track: age structured assessment program (ASAP) 3 run 036 and Woods Hole Assessment Model (WHAM) 17-NAA5.

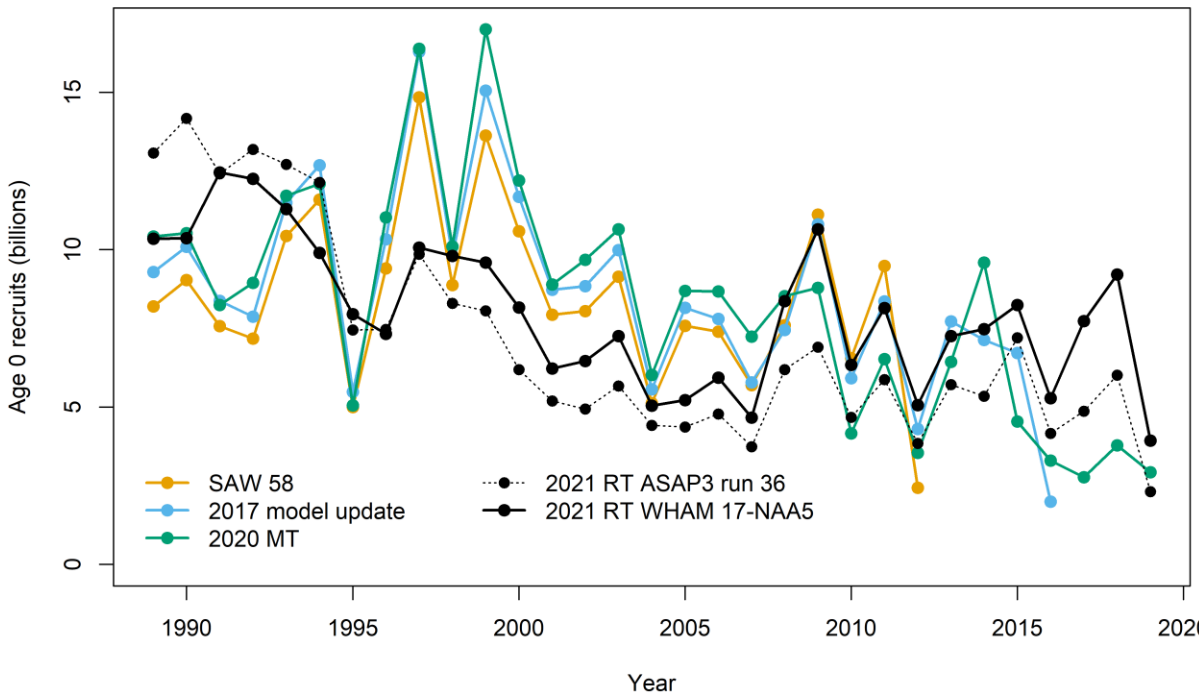

Figure 108. Historical retrospective for recruitment from Stock Assessment Workshop (SAW) 58, the 2017 model update, the 2020 management track, and 2 runs from the 2021 research track: age structured assessment program (ASAP) 3 run 036 and Woods Hole Assessment Model (WHAM) 17-NAA5.

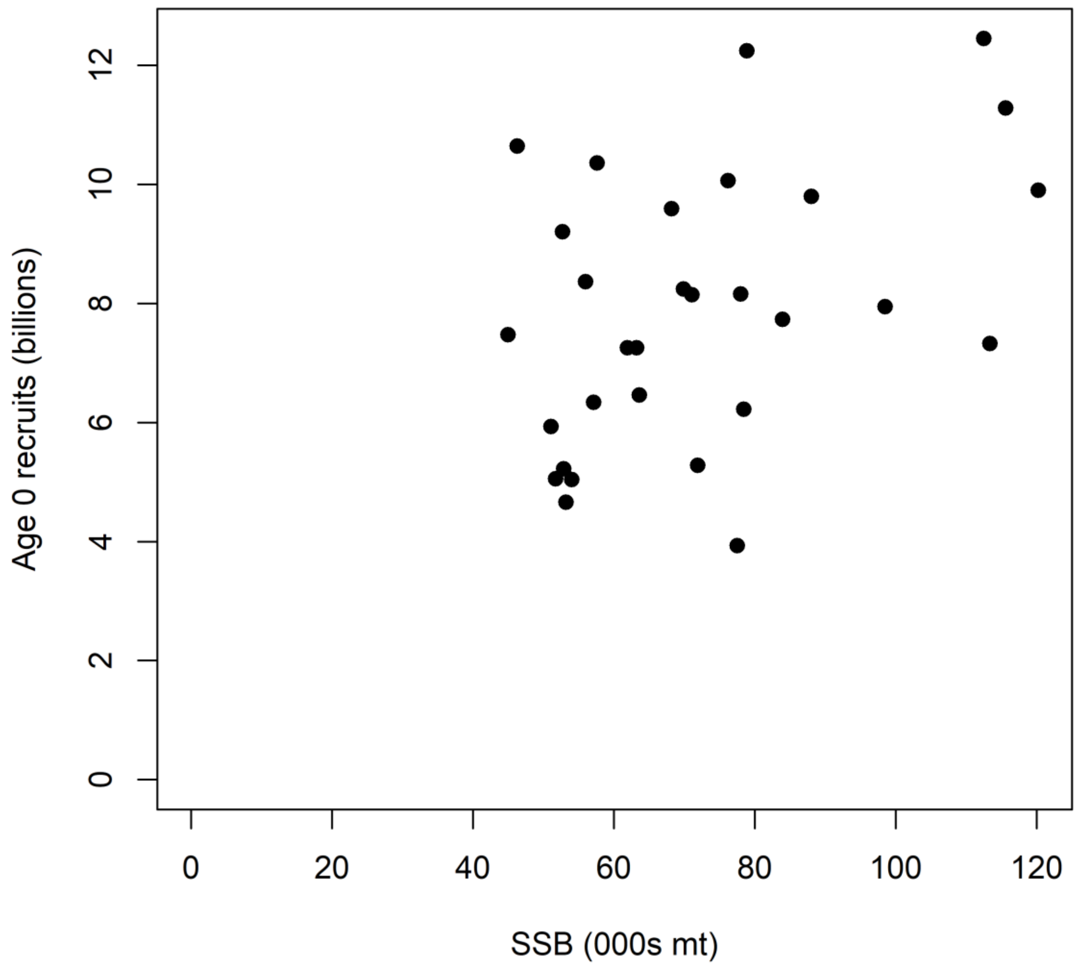

Figure 109. Stock-recruit scatter plot for Woods Hole Assessment Model (WHAM) 17-NAA5.

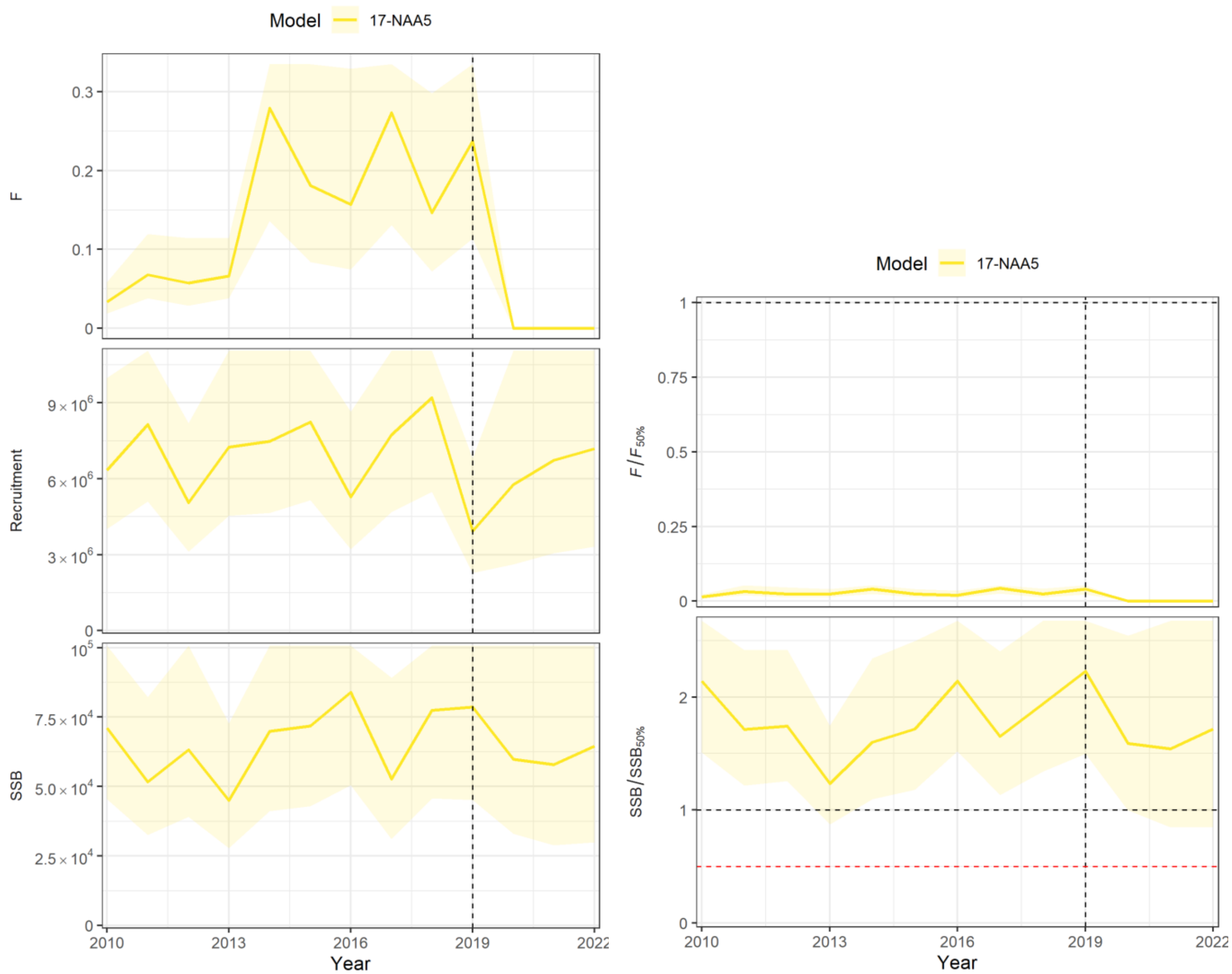

Figure 110. Spawning stock biomass (SSB), fishing mortality (F), and recruitment estimated by Woods Hole Assessment Model (WHAM) in the final 10 assessment years (2010-2019; left of vertical dashed line) and projection period (2020-2022; right of vertical dashed line) under the F = 0 projection scenario. Black horizontal dashed lines indicate $F/F_{50\%}$ = 1 and $B/B_{50\%}$ = 1. Red dashed line indicates $B/B_{50\%}$ = 0.5.

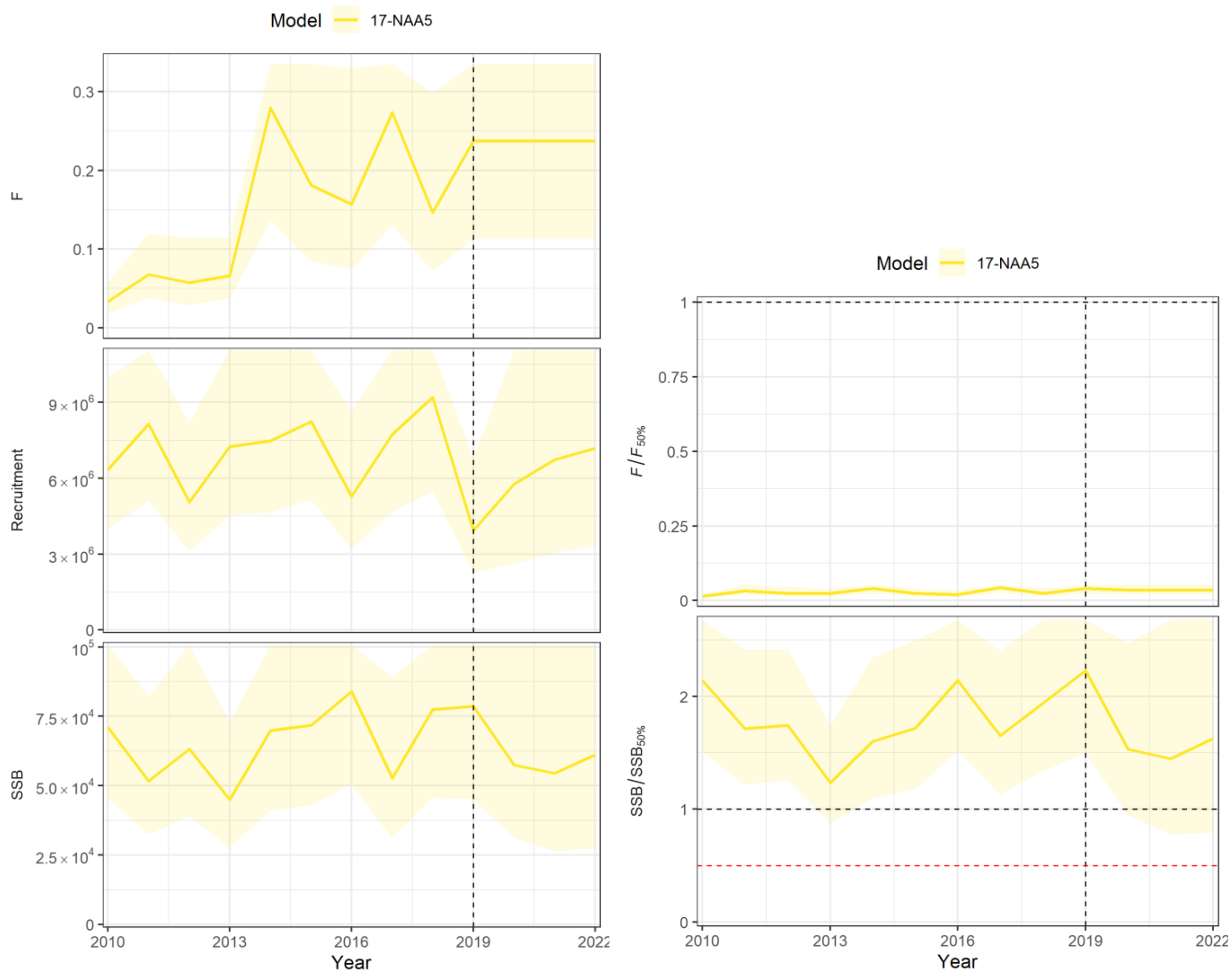

Figure 111. Spawning stock biomass (SSB), fishing mortality (F), and recruitment estimated by Woods Hole Assessment Model (WHAM) in the final 10 assessment years (2010-2019; left of vertical dashed line) and projection period (2020-2022; right of vertical dashed line) under the F = F_{2019} projection scenario. Black horizontal dashed lines indicate $F/F_{50\%}$ = 1 and $B/B_{50\%}$ = 1. Red dashed line indicates $B/B_{50\%}$ = 0.5.

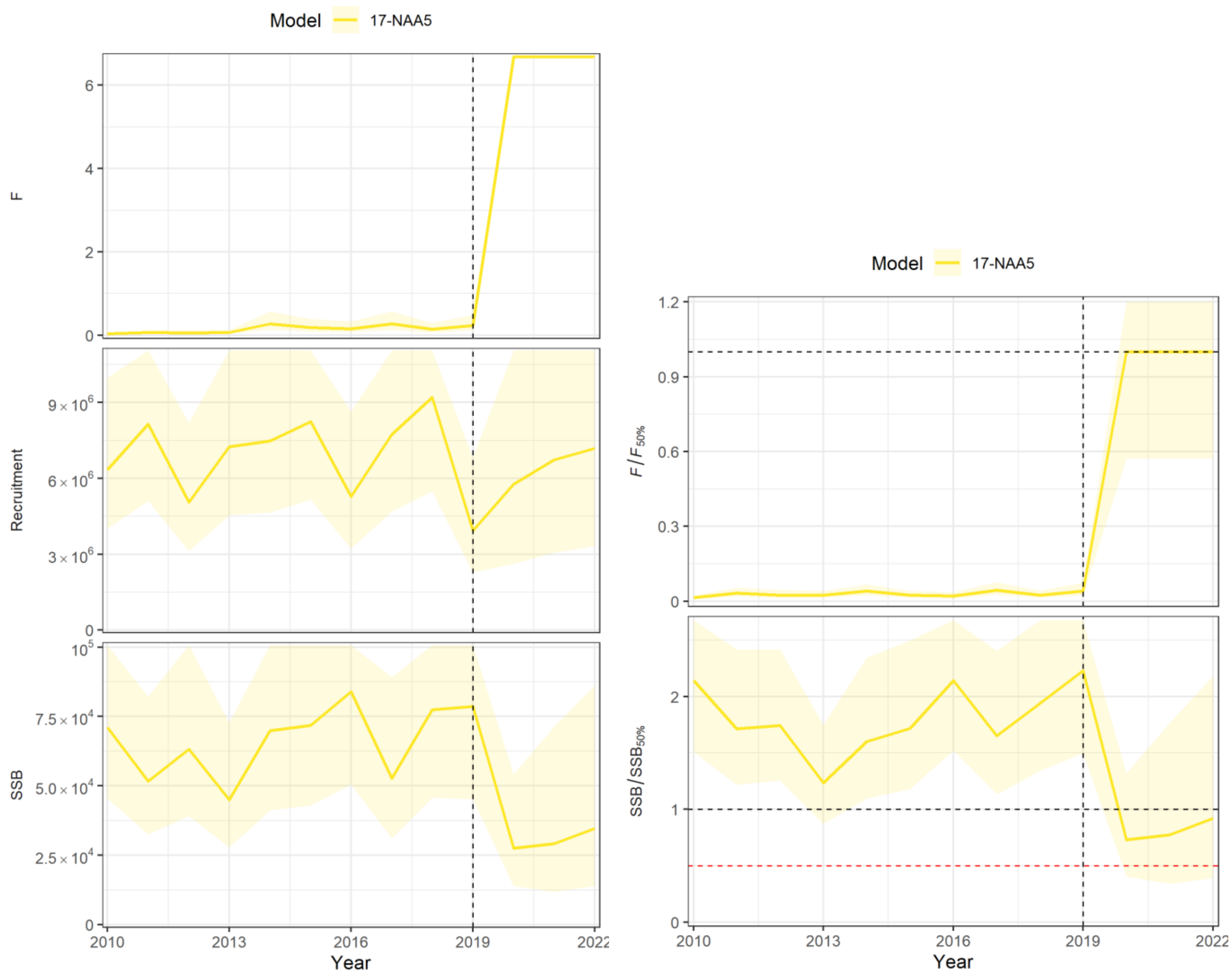

Figure 112. Spawning stock biomass (SSB), fishing mortality (F), and recruitment estimated by Woods Hole Assessment Model (WHAM) in the final 10 assessment years (2010-2019; left of vertical dashed line) and projection period (2020-2022; right of vertical dashed line) under the F = $F_{50\%}$ projection scenario. Black horizontal dashed lines indicate $F/F_{50\%}$ = 1 and $B/B_{50\%}$ = 1. Red dashed line indicates $B/B_{50\%}$ = 0.5.

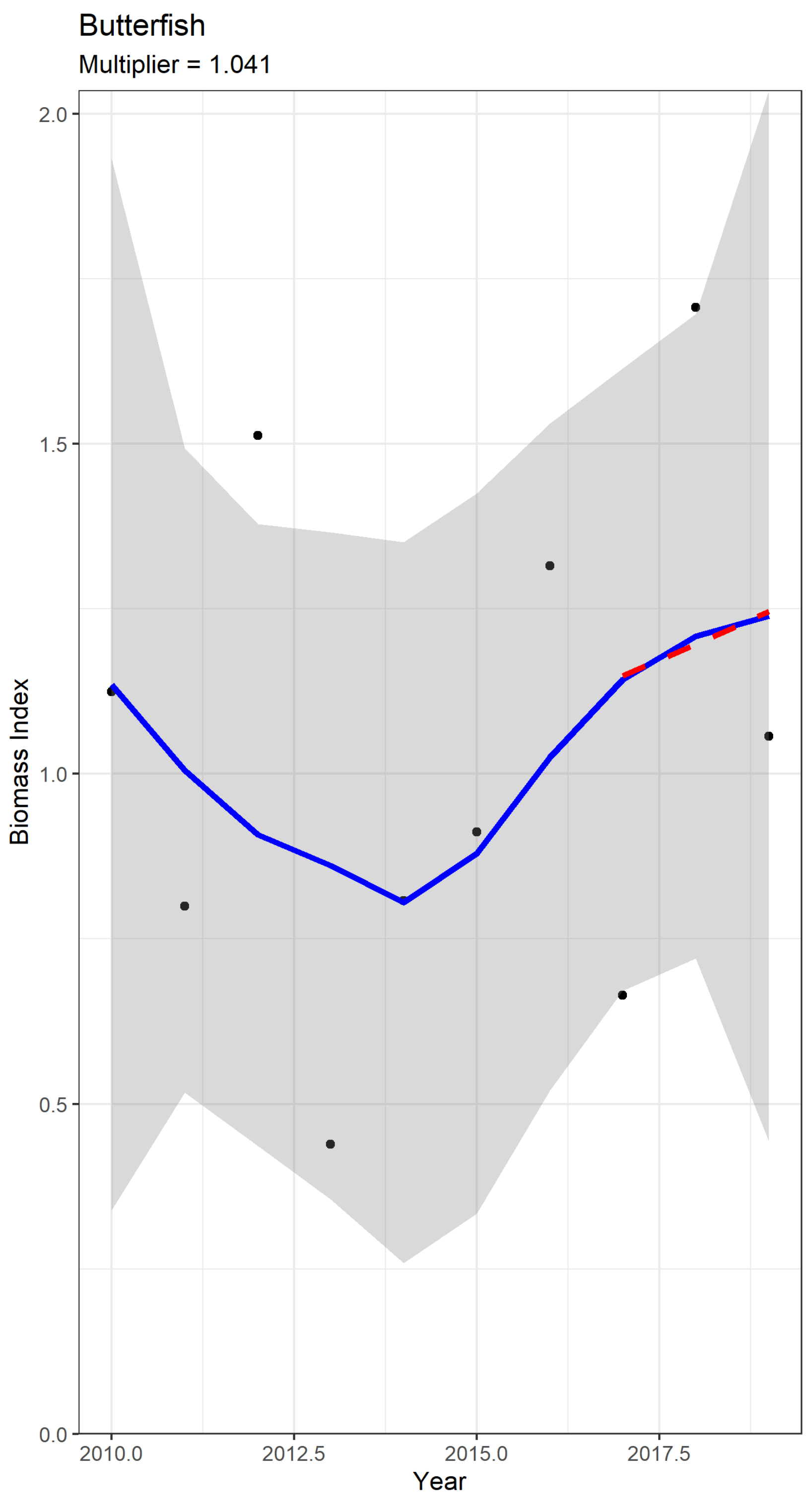

Figure 113. Results of PlanBsmooth for butterfish (*Peprilus triacanthus*). Black dots show the average survey biomass index, the blue line is the loess smooth, the gray area is the 95% confidence interval for the loess smooth, and the red dashed line shows the retransformed log-linear regression of the most recent 3 years of loess smoothed values.

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APPENDIX 1: TERMS OF REFERENCE

1. Estimate catch from all sources including landings and discards. Describe the spatial and temporal distribution of landings, discards, and fishing effort. Characterize the uncertainty in these sources of data.
2. Present the survey data available (e.g., indices of relative or absolute abundance, recruitment, state surveys, age-length data, etc.), and describe the basis for inclusion or exclusion of those data in the assessment. Characterize the uncertainty in these sources of data.
3. Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and estimate their uncertainty. Include retrospective analyses (both historical and within-model) to allow a comparison with previous assessment results and projections, and to examine model fit.
4. Update or redefine status determination criteria (SDC point estimates or proxies for BMSY, BTHRESHOLD, FMSY and MSY) and provide estimates of their uncertainty. If analytic model-based estimates are unavailable, consider recommending alternative measurable proxies for BRPs. Comment on the scientific adequacy of existing BRPs and the "new" (i.e., updated, redefined, or alternative) BRPs.
5. Make a recommended stock status determination (overfishing and overfished) based on new modeling approaches developed for this peer review.
6. Define the methodology for performing short-term projections of catch and biomass under alternative harvest scenarios, including the assumptions of fishery selectivity, weights at age, and maturity.
7. Review, evaluate and report on the status of the Stock Assessment Review Committee (SARC) and Working Group research recommendations listed in most recent SARC reviewed assessment and review panel reports, as well as the most recent management track assessment report. Identify new research recommendations.
8. Develop a "Plan B" for use if the accepted assessment model fails in the future.

Additional Terms of Reference

1. Describe life history characteristics and the stock's spatial distribution, including any changes over time. Describe ecosystem and other factors that may influence the stock's productivity and recruitment. Consider any strong influences and, if possible, integrate the results into the stock assessment.
2. Evaluate consumptive removals of butterfish by its predators, including (if possible) marine mammals, seabirds, tunas, swordfish and sharks. If possible, integrate results into the stock assessment.

APPENDIX 2

Model Selection Procedure for Butterfish Research Track 2022

1. We considered WHAM model variants based on structural aspects of greatest relevance to butterfish. In particular, estimation of M, time varying selectivity, various random effect structures, and different age composition likelihoods.
2. We initially focused on the “traditional” requirement that the model converge to be considered. This convergence criteria eliminated many of the variants considered.
3. AIC was only relevant for comparison of a few model variants, and really only played a role in deciding not to estimate M, which had a worse AIC than the fixed value used in other models.
4. We then focused on another “traditional” diagnostic, comparison of residual patterns. Patterns were generally similar among all model variants, with the exception of residuals for the fit to the NEFSC fall survey in Albatross years. Models with a strong temporal trend in residuals for this survey were eliminated from consideration. Only three models remained after applying these four criteria: 04-base, 04-NAA2, 17-NAA5.
5. We examined retrospective patterns for the remaining 3 models, but these did not differ among the runs in any meaningful way.
6. Self-tests were then conducted. The most useful outcome of this diagnostic was that 04-base and 04-NAA2 converged less than half the time (8% and 40% respectively) while 17-NAA5 converged 95% of the time. Thus lending support to 17-NAA5.
7. We then evaluated prediction skill and 17-NAA5 had marginally better MASE values than the other two models. Thus lending a bit more support to 17-NAA5.
8. With criteria 1-5 generally being similar among the 3 remaining models, it was criteria 6-7 that drove the WG to prefer 17-NAA5. The WG also preferred 17-NAA5 based on first principles; namely that the logistic-normal likelihood is more objective and shown to perform better than the multinomial, and the AR(1) recruitment process of 17-NAA5 is more parsimonious than the 04-base model.

In summary, the WG conducted model selection initially using “traditional” diagnostics that have been conducted for age-based assessments for several decades. With only 3 models remaining after using the “traditional” methods, the results of self-tests and prediction skill consistently supported 17-NAA5, which also had some other attractive features related to objectivity and parsimony.

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