Northeast Fisheries Science Center Reference Document 15-06

Butterfish 2014 Stock Assessment

by Charles F. Adams, Timothy J. Miller, John P. Manderson,
Dave E. Richardson, and Brian E. Smith

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

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ABSTRACT/EXECUTIVE SUMMARY

A butterfish (*Peprilus triacanthus*) stock assessment was completed in January 2014. This document provides a summary of the data and results of the final model accepted by the Stock Assessment Review Committee panel. Commercial data used in the assessment consisted of US landings and discard estimates, and commercial mean weights at age, from 1989–2012. Survey data used in the assessment consisted of swept area abundances, and abundance indices (number/tow) by age from 1989–2012 Northeast Fisheries Science Center (NEFSC) fall surveys (inshore and offshore); and swept area abundances from the Northeast Area Monitoring and Assessment Program (NEAMAP) fall (2007–2012) survey. An augmented version of the age-structured assessment program (ASAP) catch at age model of Legault and Restrepo (1999) was used in the assessment. ASAP augmentations included: 1) reparameterization of catchability as the product of availability and efficiency; 2) estimation of natural mortality (*M*) made possible by fixing catchability, and 3) a length-based calibration of bottom trawl survey data in 2009–2012 was performed internal to the model. Catchability for the NEFSC fall offshore survey was reparameterized by using an average measure of availability based on bottom temperature, 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 include an estimate of $M = 1.22$ (CV = 0.05). The current fishing mortality ($F_{2012} = 0.02$, CV = 0.33) is well below the accepted overfishing reference point (F_{MSY} proxy = $2M/3 = 2 \times 1.22/3 = 0.81$). The accepted spawning stock biomass reference point SSB_{MSY} proxy (median SSB based on a 50 year projection at the F_{MSY}) proxy is 45,616 mt (CV = 0.25). SSB_{2012} is estimated to be 79,451 mt, which is well above the accepted SSB_{MSY} proxy. The accepted maximum sustainable yield (MSY) proxy is 36,199 mt (CV = 0.20). $SSB_{threshold}$ is one half the SSB_{MSY} proxy, or 22,808 mt. Overfishing is not occurring, and the stock is not overfished

INTRODUCTION

Butterfish (*Peprilus triacanthus*) are distributed from Florida to Nova Scotia, occasionally straying as far north as Newfoundland, but are primarily found from Cape Hatteras to the Gulf of Maine, where the population is considered to be a unit stock (Collette and Klein-MacPhee 2002). Butterfish begin schooling around 6 cm. They are a fast growing species, overwintering offshore, and then moving inshore and northwards in the summer. Butterfish mature during their second summer (age 1) around 18 cm TL and are fully recruited by their third summer (age 2). Spawning occurs primarily during June–July. The diet consists primarily of tunicates (Larvacea, Ascidacea, Thaliacea), ctenophores and pelagic mollusks (*Clione*). They are preyed upon by a number of commercially important fishes such as bluefish (*Pomatomus saltatrix)*, spiny dogfish (*Squalus acanthias)*, silver hake (*Merluccius bilinearis)*, summer flounder (*Paralichthys dentatus)*, goosefish (*Lophius americanus)*, and swordfish (*Xiphias gladius*). Although it is generally thought that butterfish comprise a large part of the diet of longfin inshore squid (*Doryteuthis* (Amerigo) *pealeii*), recent stable isotope and fatty acid work suggests this is not the case (pers. comm., Olaf Jensen, 2013. Rutgers University, New Brunswick NJ 08901).

The last benchmark assessment for this stock was completed in 2009 (NEFSC 2010). The Stock Assessment Review Committee (SARC) accepted the trends in fishing mortality (F) and spawning stock biomass (SSB) but recommended that point estimates of F and SSB be interpreted with caution. In addition, the panel did not accept the redefined biological reference points (BRPs) or the reference points generated in the previous assessment (NEFSC 2004). Subsequent management advice was based on an "envelope analysis" which provided a bounded estimate of catch from an empirical analysis of commercial catch and Northeast Fisheries Science Center (NEFSC) survey data.

A new butterfish stock assessment was completed in January 2014 and reviewed by the SARC (NEFSC 2014). This document provides a summary of the data and results of the final model accepted by the review panel.

METHODS

Commercial Data

A variety of data sources were used to derive the catch time series. Landings prior to 1965 were obtained from Lyles (1967) as compiled by Murawski et al. (1978). Landings from 1965 to 1989 were obtained from the NEFSC commercial fisheries state canvas data table, while landings from 1990 to 2012 were obtained from the NEFSC commercial fisheries detail species data tables. Butterfish catch data for foreign fleets from 1963 to 1982, and 1983 to 1986, were obtained from Waring and Anderson (1983), and NEFSC (1990), respectively.

Two additional sources of data were used to estimate discards: the Greater Atlantic Regional Office Vessel Trip Report database; and the NEFSC Observer Database System. The observer database begins in 1989 which served as the beginning of the catch time series used in the assessment model.

Commercial landings

During 1963 to 1986 landings of butterfish were reported by foreign fleets targeting longfin inshore squid in offshore areas. In many cases the reported catch included discards; thus, foreign landings are described below in the Total Catch section. Domestic landings of butterfish averaged 1,976 mt from 1965 to 1979 without any trend (Table 1; Figures 1 and 2). A domestic fishery was developed to supply the Japanese market, leading to peak landings of 11,715 mt in 1984, but then declined to 2,298 mt in 1990. From 1991 to 2001 landings ranged between 1,449 mt and 4,608 mt. From 2002 to 2012 there was no directed fishery, and landings, primarily as bycatch in the small mesh (< 10.2 cm) bottom trawl longfin squid fishery, ranged between 428 mt and 872 mt. A directed fishery was reestablished in January 2013, and landings for the year were 1,091 mt.

Commercial size composition

Butterfish are sampled dockside as part of the National Marine Fisheries Service (NMFS) commercial sampling program. Samples, containing approximately 100 fish, are collected per market category, port and gear. Since 1989 an average of 28 butterfish samples per year have been collected, averaging 91 mt of landings per sample (range: 11–345 mt per sample). Sampling has resulted in an average of 2,864 length measurements per year, ranging from 688 in 1995 to 6,431 in 2007 (Table 2). Size composition from commercial samples of butterfish ranged from 7 to 29 cm during 1989 to 2012, with modal lengths from 14 to 17 cm (Figures 3–8).

Discard estimates

Catch data from 1976 to 1986 as presented in historic assessment documents include discards, which were assumed to be 10% of landings (Waring and Anderson 1983; NEFSC 1990). In the previous assessment (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 1. Foreign catch in Table 1 also includes discards, which were estimated by dividing longfin inshore squid catch by survey ratios to account for butterfish discards of countries reporting only longfin (Murawski and Waring 1979; NEFSC 1990).

The standardized bycatch reporting methodology (Wigley et al. 2007) combines landings, vessel trip report and observer sampling data to provide estimates of discard rates and total discards for specified stocks. Butterfish discard estimates from 1989 to 2012 were developed by using the combined ratio estimator (method 2 in Wigley et al. 2007). Strata were defined by quarter, gear type, and region (New England or Mid-Atlantic waters). Total discard estimates varied from just under 239 mt in 2007 to a high of 8,867 mt in 1999, but the precision of these estimates is generally poor (Table 3). In only 5 years is the estimated coefficient of variation ≤ 0.30.

Almost all estimated discards are attributable to bottom trawls; either in a single otter trawl configuration or a twin trawl configuration (Table 4). Details for these 2 gear types, with an additional stratification of small mesh (< 10.2 cm) vs. large mesh (≥ 10.2 cm), are shown in Tables 5 and 6. The number of observed trips for any stratum ranged from a low of 12 in 1994 for small mesh in the Mid-Atlantic (Table 5) to a high of 1,591 in 2011 for large mesh in New England (Table 6). The average number of observed trips was greater in New England (116 for small mesh and 450 for large mesh) relative to the Mid-Atlantic (88 for small mesh and 124 for large mesh size). Discards are roughly an order of magnitude higher with small mesh, averaging

1,151 mt in New England and 1,291 mt in the Mid-Atlantic; while large mesh discards averaged 259 mt and 144 mt in New England and Mid-Atlantic, respectively.

Discard size composition

Data from observed trips in 1989 to 2012 were used to examine the size composition of the discarded and kept fraction of trips where butterfish were caught. The number of butterfish measured averaged 4,600, ranging from 1,176 in 1992 to 18,774 in 2011 (Figures 9–11). The size composition of discarded butterfish ranged from 3 to 34 cm, with modal lengths from 8 to 15 cm. The size composition of kept butterfish also ranged from 3 to 36 cm, with modal lengths from 15 to 19 cm.

Total commercial catch

Total catches of butterfish increased from 15,167 mt in 1965 to a peak of 39,896 mt in 1973 and were dominated by catches from the offshore foreign fleets (Table 1; Figure 1). Total catches 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. Butterfish catches by foreign fleets are likely underestimated because Spain and Italy did not report their butterfish bycatch from the squid fisheries from 1972 to 1976 (Murawski and Waring 1979).

A domestic fishery was developed to supply the Japanese market, leading to a peak catch of 22,401 mt in 1984, but then declined to 2,831 mt in 1990 (Table 1; Figures 1 and 2). From 1991 to 2001 catches ranged between 3,928 mt and 12,185 mt. Catches declined from 2002 to 2012 because of the lack of a directed fishery, ranging between 918 mt and 4,593 mt. Discards comprised a majority of the total butterfish catch, averaging 58% from 1989 to 2001, and 67% from 2002 to 2012. Total catch estimates were highly variable and imprecise, with coefficients of variation ranging from 0.07 – 1.43 (Table 3) because of the uncertain discard estimates.

Almost all of the total catch (not including landings by pound net and unknown gear types) was with single or twin bottom trawls, averaging 99% from 1989 to 2001, and 96% from 2002 to 2012 (Table 4).

Commercial catch at age

Commercial landings were composed primarily of age 1 and age 2 butterfish (Table 7), discards were composed primarily of age 0 and age 1 fish (Table 8), and total catches were composed primarily of age 1, age 0 and age 2 fish (Table 9; Figure 12). Commercial mean weights at age are presented in Table 10.

Recreational catch

Recreational catch was insignificant as measured by the Marine Recreational Information Program (MRIP).

Survey Data

Research survey abundance and biomass indices for assessing the status of the butterfish resource are available from the NEFSC survey, as well as a number of state surveys. The accepted final model for this assessment used fall abundance indices from the NEFSC and

Northeast Area Monitoring and Assessment Program (NEAMAP) surveys. Thus, this section only describes abundance indices; details of biomass indices can be found in (NEFSC 2014).

NEFSC survey indices

In spring 2009 the FSV *Henry B. Bigelow* (HBB) replaced the FRV *Albatross IV* (AIV). Because of the deeper draft of the HBB, the 2 innermost inshore strata have not been surveyed since 2008. Thus, the NEFSC strata were split as follows: the offshore series (Figure 13) consisted of the outermost of the 3 inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44–46, 56, 59–61 and 64–66) plus the offshore strata (1–14, 16, 19, 20, 23, 25 and 61–76); while the inshore series (Figure 14) consisted of the 2 innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58 and 63).

Offshore indices from the HBB for 2009 to 2012 presented below are converted to AIV units with the calibration coefficients in Table 11.

The NEFSC spring offshore abundance indices (stratified mean number per tow) averaged 58.0, ranging from 8.4 in 1990 to 142.6 in 2012 (Table 12; Figure 15). In general this index increased over the course of the time series. The inshore strata were not sampled during the spring in 1994–1996, while the highest abundance was observed in 1991. Although both indices were considered during development of the base model, only the offshore series was included in the base model presented to SARC 58.

The NEFSC fall offshore abundance indices averaged 186.3, ranging from 39.2 in 2005 to 510.4 in 1994 (Table 13; Figure 15). In general this index decreased over the course of the time series. The fall inshore abundance indices averaged 246.8, ranging from 39.5 in 1995 to 632.9 in 1997. Both indices were included in the base model presented to SARC 58.

The estimated precision of the NEFSC survey abundance indices are poorest for the spring series, with the coefficient of variation (CV) averaging 0.44 and 0.54 for the offshore and inshore, respectively (Table 12, Figure 16). The fall offshore CV averages 0.28 (Table 13; Figure 16) while the fall inshore CV is generally the lowest, averaging 0.25.

Aged NEFSC survey indices

The number of stations where butterfish were sampled averaged 217 (or 45.0% of stations), ranging from 132 (or 32.7% of stations) in 1989 to 322 (or 62.3% of stations) in 2012 (Table 14). The number of butterfish aged averaged 1,061, ranging from 543 in 1989 to 1,771 in 2011. The number of butterfish measured averaged 1,105, ranging from 543 in 1989 to 1,861 in 2011.

The NEFSC spring offshore abundance at age indices show that this survey generally catches age groups 1–3 and usually some fish from age group 4 (Table 15; Figure 17). The same pattern holds for the spring inshore series, albeit with fewer butterfish (Table 16; Figure 18). Fall offshore abundance at age indices show that this survey generally catches age groups 0–3, with age 0 dominating the total catch (Table 17; Figure 19). The same pattern holds for the fall inshore series (Table 18; Figure 20).

NEAMAP survey

The NEAMAP survey has covered inshore waters from Cape Cod to Cape Hatteras since fall 2007 and has used strata consistent with the NEFSC inshore strata.

The NEAMAP spring abundance indices (stratified mean number per tow) were higher than the comparable NEFSC spring inshore abundance indices, averaging 407.5, and ranging from 188.5 in 2009 to 525.6 in 2012 (Table 19; Figure 21). The fall abundance indices were generally an order of magnitude higher than the comparable NEFSC fall inshore abundance indices, averaging 1509.2, and ranging from 625.7 in 2012 to 3,600.8 in 2009. The CVs for NEAMAP abundance indices were ≤ 0.21 with the exception of 1 outlier each in the spring and fall series (Table 19; Figure 22). Both indices were included in the base model presented to SARC 58.

Aged NEAMAP survey indices

NEAMAP does not yet have an age-length key for age 3+ butterfish. Thus, the NEFSC age-length keys were used to calculate NEAMAP abundance indices at age. The spring abundance indices at age show that this survey generally catches age groups 1–2 (Table 20; Figure 23); while the fall survey catch is dominated by age 0 butterfish (Table 21; Figure 24).

State Surveys

Multiple surveys that capture butterfish have been conducted by individual states within inshore waters. The decision was made by the working group not to include these data in the base model as each survey only covers a small proportion of the butterfish stock area. However, the data are presented here to highlight the available information.

Maine-New Hampshire survey

The Maine-New Hampshire survey began in fall 2000 (Table 22). There are gaps in the spring series during 2003–2005, and in 2009, while the highest abundance was observed in 2012 (Table 22; Figure 25). The fall abundance indices were higher, averaging 71.3, and ranging from 2.3 in 2000 to 303.6 in 2009. In general the fall index increased over the course of the time series. CVs for the spring and fall abundance indices averaged 0.41 and 0.29, respectively (Figure 25).

Massachusetts Division of Marine Fisheries survey

The Massachusetts Division of Marine Fisheries (MADMF) survey began in spring 1978, although data presented are for 1989–2012 only. The MADMF spring abundance indices (stratified mean number per tow) averaged 9.9, ranging from 0.02 in 1989 to 46.1 in 2007 (Table 22; Figure 25). The fall abundance indices were higher, averaging 426.1, and ranging from 72.0 in 2001 to 979.2 in 2009. CVs for the spring and fall abundance indices averaged 0.62 and 0.25, respectively (Figure 25).

Rhode Island Department of Environmental Management survey

The Rhode Island Department of Environmental Management (RIDEM) survey began in spring 1979, although data presented are for 1989–2012 only. The RIDEM spring abundance indices (stratified mean number per tow) averaged 21.3 and ranged from 0 butterfish in 1989, 1992 and 2005, to a maximum of 405.0 in 2006 (Table 22; Figure 25). The fall abundance indices were higher, averaging 468.1 and ranging from 42.7 in 2000 to 2507.7 in 2009. In general the fall index increased over the course of the time series. CVs for the spring and fall abundance indices averaged 0.71 and 0.38, respectively (Figure 25).

Connecticut Department of Energy and Environmental Protection survey

The Connecticut Department of Energy and Environmental Protection (CTDEEP) survey of Long Island Sound began in 1984, although data presented are for 1989–2012 only. There was no fall survey in 2010. The CTDEEP spring abundance indices (geometric mean number per tow) ranged from 0.5 in 1993 to 18.7 in 2006 (Table 22; Figure 26). The fall abundance indices were higher, ranging from 39.6 in 2011 to 477.9 in 1999.

New York Department of Environmental Conservation survey

The New York State Department of Environmental Conservation (NYSDEC) survey of Peconic Bay began in 1987. Sixteen stations are sampled weekly during May–October. The survey was not conducted in 2005. Data described below are annual means for 1989–2012 only. The NYSDEC abundance indices (mean number per tow) averaged 1.2 and ranged from 0.3 in 2007 to 5.2 in 2010 (Table 22; Figure 26).

New Jersey Department of Environmental Protection survey

The New Jersey Department of Environmental Protection (NJDEP) survey began in August 1988. Surveys are conducted in January, April, June, August and October. Data described below are annual means for 1989–2012 only. The NJDEP abundance indices (stratified mean number per tow) averaged 841.35 and ranged from 97.3 in 2012 to 2018.9 in 1994 (Table 22; Figure 26).

Delaware Department of Natural Resources and Environmental Control surveys

Bottom trawl surveys of Delaware Bay were conducted during 1966–1971 and 1979–1984; the Delaware Department of Natural Resources and Environmental Control (DDNREC) reinstated a 30-foot multispecies bottom trawl survey in 1990 (Table 22). The young-of-the-year seine survey in the estuaries of Delaware Bay began in 1980; in 1986 this was expanded to include Indian River and Rehoboth Bays (Table 22). Data described below are annual means for 1989–2012 only.

The trawl survey abundance indices (mean number per tow) averaged 16.4 and ranged from 3.6 in 1992 to 66.7 in 1993 (Table 22; Figure 26).

The seine survey abundance indices (mean number per tow) for estuaries ranged from 0.05 in 1994 and 2006 to 0.57 in 1999, while abundance indices for the bays ranged from 0 butterfish in 2001 to 2.27 in 2009 (Table 22; Figure 26).

Chesapeake Bay Multispecies Monitoring and Assessment Program survey

The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) survey began in spring 2002. The ChesMMAP annual abundance indices (geometric mean number per tow) ranged from 13.6 in 2010 to 126.7 in 2005 (Table 22; Figure 27).

Virginia Institute of Marine Science juvenile survey

The Virginia Institute of Marine Science (VIMS) juvenile trawl survey began in 1988. Data presented below are annual means for 1989–2012 only. The VIMS juvenile abundance indices (geometric mean number per tow) ranged from 0.2 in 2007 to 2.3 in 1990 (Table 22; Figure 27).

North Carolina Department of Environment and Natural Resources survey

The North Carolina Department of Environment and Natural Resources (NCDENR) of Pamlico Sound began in 1990. The NCDENR annual abundance indices (weighted mean number per tow) ranged from 0.5 in 1997 to 7.8 in 2008 (Table 22; Figure 26).

Correlation coefficients

Correlation coefficients for spring abundance indices considered for inclusion in the final model are shown in Table 23. The NEFSC offshore survey had a correlation coefficient of 0.49 with the MDMF survey. The NEAMAP survey had correlations > 0.4 with the Maine-New Hampshire survey, the MDMF survey, and the RIDEM survey. Standardized spring abundance indices are plotted in Figure 28.

Correlation coefficients for fall abundance indices considered for inclusion in the final model are shown in Table 24. The NEFSC offshore survey had a correlation coefficient of 0.54 with the NEAMAP survey. The NEAMAP survey had correlations > 0.4 with all the state surveys. The Maine-New Hampshire survey also had correlations > 0.4 with the 3 other state surveys. Standardized fall abundance indices are plotted in Figure 29.

NEFSC spring offshore, NEFSC fall offshore, NEFSC fall inshore, NEAMAP spring and fall survey data were included in the base model presented to SARC 58. NEFSC spring inshore data were not included because of the high CVs associated with this series. Other state survey data considered in this correlation analysis were not used as tuning indices in the base model.

Consumptive removals by predators

Consumptive removals of butterfish by its predators were evaluated for possible inclusion in the assessment model to explain annual deviations in natural mortality (*M*). Briefly, fish diet data from NEFSC bottom trawl surveys were examined for a broad suite of butterfish predators. The total amount of food eaten and the type of food eaten were the primary diet data examined. From these basic food habits data, diet composition of butterfish, per capita consumption, total consumption, and the amount of butterfish removed by the fish predators were calculated. Combined with abundance estimates of these predators, butterfish consumption was summed across all predators for total butterfish consumption. Further details of this analysis can be found in (NEFSC 2014). Results are summarized here.

The top 6 finfish predators of butterfish are listed in Table 25. As in the previous assessment (NEFSC 2010), estimates of consumption by these 6 predators of butterfish appear low, generally between 1,000 and 8,000 mt/year (Figure 30). Based on a dynamic factor analysis, a single trend model fit the butterfish consumption data best, implying the trend in butterfish consumption was similar among these 6 predators. Additionally, for each predator, fitted consumption was generally constant relative to the time series mean (Figure 31). Annual CV estimates for total consumption across all fish predators were between 0.27 and 1.06, with a time series mean of 0.45. Although consumptive removals were not directly incorporated into the assessment model, the results of this analysis supported the estimation of a constant *M* in the model.

ASAP Model

The age structured assessment program (ASAP) statistical catch at age model (Legault and Restrepo 1999) was used in this assessment. ASAP uses forward computations assuming the separability of fishing mortality into year and age components to estimate population sizes given

observed catches, indices of abundance, and respective age compositions. The objective function is the sum of the likelihood components for aggregate annual catch, indices, and age composition data, and various penalties may be specified. Observations of proportions at age are modeled assuming a multinomial distribution, while all other model components are assumed to have a lognormal error distribution. Diagnostics include index fits, residuals in catch and catch-at-age, and effective sample size calculations. Weights can be specified for different components of the objective function and allow for relatively simple age-structured production models to fully parameterized statistical catch-at-age models. The standard ASAP (NFT 2013a) was used in the development of the base model; while an augmented version of ASAP (described below) was used both in the development of the base model and for the final model.

ASAP Augmentations

Covariate Effects on Survey Catchability

Survey catchability was reparameterized as a product of gear efficiency E and availability to the gear A. Each of these components are bounded between 0 and 1, and A is allowed to be functions of covariates $\boldsymbol{X}_A$,

$$\log\left(\frac{A}{1-A}\right) = \boldsymbol{X}_A^T \boldsymbol{\beta}_A \tag{1}$$

Normal priors/penalties are allowed on $\log(E/(1-E))$ and average $\log(A/(1-A))$ across years as well.

A time varying estimate of A was developed for possible inclusion in the assessment model. Briefly, this was done in 5 steps: 1) a thermal niche model was developed by using maximum likelihood to estimate parameters of a thermal reaction norm fit to catch and temperature data from federal and state fishery independent bottom trawl surveys conducted throughout the Northwest Atlantic; 2) a hindcast of bottom water temperature for the Northwest Atlantic was constructed by using historical climatology to remove systematic bias in the output from a numerical circulation model; 3) butterfish catch data was used to evaluate patterns of sample occupancy in relation to hindcasts of a thermal habitat suitability index (HSI), which was generated by coupling the thermal niche model to hindcast temperatures, as well as temperatures measured *in situ* with samples; 4) availability of the butterfish stock to surveys was calculated by using daily regional hindcasts of thermal habitat suitability and the locations and times of survey samples, as the proportion of available habitat suitability sampled in the region during the survey period; and 5) model based estimates of availability were compared with empirical estimates developed for simultaneous but nonoverlapping fall surveys and day:night differences in detectability. Further details of the time varying estimate of A can be found in (NEFSC 2014).

For efficiency, an approach similar to that described in (NEFSC 2014) for estimating minimum bounds on biomass was used; the primary difference was that abundance indices were utilized in place of biomass indices. Briefly, the relative efficiency of the survey between day and night was used to scale the maximum efficiency of NEFSC fall offshore survey over the standard 24-hour operations. Night was defined as a solar zenith angle of ≥ 90° 50′ (Jacobson et al 2011). It was assumed daytime tows conducted by the HBB detected all available butterfish (δ_{day} = 1), and that average efficiency for the day and night tows combined was less than 1. The stratified mean day and night catch rates for 1989 to 2008 NEFSC fall offshore survey data from the AIV were calculated to obtain the nighttime efficiency:

$$\frac{\delta_{night,max}}{\delta_{day,max}} = \delta_{night,max} = \frac{Catch_{day}}{Catch_{night}} \tag{2}$$

and in turn a maximum value for the average efficiency for all tows combined:

$$\delta_{max} = \delta_{day,max} * Proportion\ day\ tows + \delta_{night,max} * Proportion\ night\ tows \tag{3}$$

Prior to retiring the AIV there was a large-scale paired gear experiment carried out with the new HBB. This paired-gear study indicated that the HBB was much more efficient than the AIV for most species (Miller et al. 2010). On average, the HBB was estimated to catch 1.935 times the butterfish in numbers per tow as the AIV during the fall survey. Additionally, the ratio of the average HBB and AIV wing swept area per tow is 0.024 km^2/0.038 km^2 = 0.63. Combining these 2 factors indicates that the efficiency per km^2 of the AIV is 0.33 that of the HBB, and combined with the maximum efficiency of the HBB, the maximum efficiency of the AIV is 0.2. This analysis assumes the HBB daytime tows are fully efficient and estimates the maximum efficiency for all HBB tows and a constant calibration factor from Miller et al. (2010) to provide an estimate of maximum efficiency for the AIV for the entire time series. Note that using an estimate of maximum efficiency is conservative since abundance estimates are inversely related to efficiency with all other parameters equal.

Incorporation of Length-based Relative Catch Efficiency of HBB:AIV

There are substantial size effects on this calibration factor for butterfish (Miller 2013). To incorporate uncertainty in size-based estimates of relative catch efficiency in the assessment model, a penalty was added to the likelihood for the estimates of the spline smoother coefficients $\boldsymbol{\beta}$ (p = 10 is the number of coefficients) provided by Miller (2013),

$$f(\hat{\boldsymbol{\beta}}) = (2\pi)^{-\frac{\rho}{2}} \left|\boldsymbol{\Sigma}\right|^{-\frac{1}{2}} e^{-\frac{1}{2}(\boldsymbol{\beta}-\hat{\boldsymbol{\beta}})^T \Sigma^{-1} (\boldsymbol{\beta}-\hat{\boldsymbol{\beta}})} \tag{4}$$

where $\boldsymbol{\Sigma}$ is the estimated variance-covariance matrix from the fitted hierarchical generalized additive model. The data file includes the estimates of $\boldsymbol{\beta}$ and $\boldsymbol{\Sigma}$ as well as the design matrix for calculating the relative catch efficiency at length and, for the HBB surveys (2009–2012), the numbers-at-length indices and age-length keys. The calibrated (AIV scale) survey indices are calculated as

$$\hat{I}_A = \sum_{l=1}^{L} I_{H,l} \rho_l \tag{5}$$

where $I_{H,l}$ is the HBB numbers-at length l,

$$\rho_l = e^{-X_l^T \boldsymbol{\beta}} \tag{6}$$

is the relative catch efficiency (AIV:HBB) at length l and X_l is the row of the design matrix for the spline smoother associated with length l. The AIV proportions at age are calculated from the indices-at-age,

$$\hat{I}_{A,a} = \sum_{l=1}^{L} p(a \mid l) I_{H,l} \rho_l \tag{7}$$

where $p(a \mid l)$ is the proportion at age a given length l from the age length key. The indices $\hat{I}_A$ are used in the normal calculations of the survey likelihood components using the CVs supplied

with the index data. Thus it is implicitly assumed that the CVs of the indices and effective sample sizes for the proportions-at-age are the same as if the AIV were being used in those years to conduct the bottom trawl survey. The calibrated indices and proportions at age also replace the normal index data for the calibrated years in the report file. Note that there will be p more parameters estimated when calibrated indices are used so that deviations from $\boldsymbol{\beta}$ can be allowed. This approach allows the catchability in years when the HBB was used to differ from those years when the AIV was used, but in a way that is informed by the paired-gear experiment.

The final butterfish model included internal length-based calibration for the NEFSC fall offshore survey data from 2009 to 2012 (Table 26). The sizes observed in the data on butterfish from the paired gear study ranged from 2 to 21 cm, but there were some sizes observed in the 2009–2012 data outside of this range. Thus, for sizes > 21cm the same relative efficiency was assumed as that at 21 cm, and the relative efficiency at 2 cm was applied to any observations at 1 cm. Observations outside 2–21 cm are rare and this type of extrapolation has little effect on the calibrated aggregate indices or the age composition.

Estimation of Natural Mortality effects

There was also a change in the parameterization of natural mortality so that annual or age-specific effects of covariates on natural mortality could be specified or estimated. The annual and age-specific effects are linear on the log scale

$$\log M_{y,a} = \boldsymbol{X}_y^T \boldsymbol{\beta}_{M,y} + \boldsymbol{X}_a^T \boldsymbol{\beta}_{M,a}. \tag{8}$$

Estimating effects of covariates on M by subsets of ages or years was accomplished by specifying appropriate design matrices.

Given the parameterization described above which constrains the catchability of the NEFSC fall offshore survey it was possible to estimate a constant M in the final model.

RESULTS

A final model, consisting of the NEFSC fall offshore, NEFSC fall inshore, and NEAMAP fall survey data, was chosen on the basis of better diagnostics and because most of the population is thought to be well distributed within the survey domain at this time. Specifications for the final model and swept area abundance inputs are shown in Tables 27 and 28, respectively.

The time varying HSI indicated that the NEFSC fall offshore survey sampled between 62% to 75% of thermal habitat suitable for butterfish (Figure 32). Preliminary runs with this covariate did not improve the model. Thus, a more parsimonious configuration, without the time varying HSI, was adopted. In this configuration, the median HSI over the time series (A = 0.68) was used to estimate catchability for scaling the final model.

Diagnostics for the Final Model

Objective function components for the final model are shown in Table 29. Root mean square error (MSE) for data components for the final model are generally close to 1 (Table 30).

Although there are more positive residuals in the mid part of the catch time series, the magnitude of these residuals is small in recent years (Figure 33). The NEFSC offshore survey has positive residuals early in the time series (Figure 34), while the NEFSC inshore survey has the reverse trend (Figure 35). No trends are apparent in the shorter NEAMAP time series (Figure 36). There is a predominance of negative residuals at age 2 and of positive residuals at age 3 in

the catch age composition (Figure 37). No trends are apparent in the residuals for NEFSC survey age compositions (Figures 38 and 39), or NEAMAP survey age composition (Figure 40).

Results for the Final Model

The peak in fishing mortality rate on fully selected ages (ages 2+) was F = 0.15, which occurred in 1993 (Tables 31 and 32; Figure 41). Fishing mortality ranged between 0.04 and 0.14 during 1994 to 2001, but has been ≤ 0.07 since 2002. Butterfish are fully selected by age 2 in the fishery (Figure 42). The model also provided a new estimate of M = 1.22.

Spawning stock biomass (Age 1+) averaged 79,410 mt during 1989 to 2012 (Table 31; Figures 43 – 45). Spawning stock biomass peaked in 2000 at 106,590 mt.

Recruitment averaged 8.5 billion fish during 1989 to 2012 (Table 31; Figures 45 – 47). The 1997 year class was the largest, at 14.8 billion fish, while the 2012 year class, estimated to be 2.4 billion fish, was the smallest of the time series. Estimated numbers at age are shown in Table 33 and Figure 48.

CVs for SSB and recruitment were ≤ 0.33 (Table 31; Figure 49), while CVs for F were variable, ranging from 0.22 to 1.00.

Index catchabilities and selectivities are shown in Figures 50 and 51, respectively.

Sensitivities and Simulations

Sensitivities of annual estimates of spawning biomass, recruitment, and fishing mortality to various assumptions and augmentations of the ASAP model were explored during the Stock Assessment Workshop (SAW) 58 prior to the development of the final model. Further details of the HSI can be found in the SAW 58 report (NEFSC 2014). Similarly, a series of simulations were run prior to the development of the final model to evaluate the behavior of the model statistically with respect to the incorporation of the internal length-based calibration and estimation of natural mortality. The simulations showed no evidence of bias (NEFSC 2014).

Retrospective patterns

A retrospective analysis of the final model using a 4 year peel was done for spawning biomass, recruitment and fishing mortality estimates. Four years was chosen as the break point between the AIV and HBB. There was no trend in terminal year estimates of SSB, recruitment and fishing mortality (Figure 52). Furthermore, the scale of the differences is relatively small based on calculated Mohn's rho (Mohn 1999) values.

Biological Reference Points Based on the Final Model

Based on Patterson (1992), the overfishing reference point is $F = 2M/3 = 2 \times 1.22/3 = 0.81$ (CV = 0.05). The current fishing mortality (F_{2012} = 0.02, CV = 0.33) is well below the overfishing reference point (Figure 53). The biomass reference point SSB_{MSY} proxy (median SSB based on a 50 year projection at the F_{MSY} proxy) is 45,616 mt (CV = 0.25). SSB_{2012} is estimated to be 79,451 mt, which is well above the SSB_{MSY} proxy (Figure 54). The MSY proxy is 36,199 mt; CV = 0.20. $SSB_{threshold}$ is one half the SSB_{MSY} proxy, or 22,808 mt.

Stock Status

Fishing mortality was estimated to be 0.02 in 2012, which is well below the overfishing reference point F_{MSY} proxy = 0.81 (Figure 54). There is a < 1% chance the estimated 2012 fishing mortality is above the F_{MSY} proxy (Figure 55), and thus overfishing is not occurring.

SSB_{2012} was estimated to be 79,451 mt, which is well above the accepted biomass reference point SSB_{MSY} proxy = 45,616 mt. There is a < 1% chance the estimated SSB is below $SSB_{threshold}$ (Figure 56), thus the stock is not overfished.

Projections

Stochastic projections were made to provide forecasts of stock size and catches in 2013–2014. The projections assume that recent patterns of fishery selectivity, discarding, maturity at age and mean weight at age will continue over the time span of the projections. One hundred projections were made for each of 1000 Markov Chain Monte Carlo (MCMC) realizations of 2012 stock sizes using AGEPRO (NFT, 2013b). Future recruitment at age 1 was generated randomly from the probability density function of the updated recruitment series for 1989–2012 (average recruitment = 8.1 billion fish).

If preliminary butterfish catch (landings plus discards) for 2013 (2,489 mt) is assumed, the median projection of SSB in 2013 is 51,746 mt, with 5% and 95% confidence limits of 32,489 mt and 81,073 mt, respectively (Figure 57). If the 2014 butterfish catch is assumed equal to the allowable biological catch (ABC) (9,100 mt), the median projection of SSB in 2014 is 53,580 mt, with 5% and 95% confidence limits of 38,365 mt and 73,885 mt, respectively (Figure 57).

DISCUSSION

There were 3 augmentations to the standard ASAP (NFT 2013a) for the final model: 1) catchability was reparameterized as the product of availability and efficiency, with the former specified by using availability estimates based on bottom temperature; 2) length-based calibration of bottom trawl survey data in 2009–2012 was performed internal to the model; and 3) estimation of natural mortality. For the NEFSC fall offshore survey, an average measure of availability based on a bottom temperature was used, and the efficiency was based on the relative efficiency of the FRV *Albatross IV* to the FSV *Henry B. Bigelow* and an assumption that the Bigelow was 100% efficient for daytime tows. Additionally, by fixing catchability it was possible to estimate natural mortality. Ability to estimate parameters within the new model framework was confirmed through simulation.

Conflicting trends were observed between several survey abundance indices: the NEFSC offshore spring series has generally been increasing, while the NEFSC offshore fall series has been decreasing. While the spring series tracked cohorts more clearly through the age structure, butterfish are more widely distributed throughout the survey area during fall, and thus fall survey trends more accurately represent patterns in overall abundance. Research into the age structure and spatiotemporal distribution of butterfish may provide insights into these divergent trends. Two other clear contrasts with the NEFSC offshore fall series are the increasing trend in the Maine-New Hampshire and RIDEM fall surveys. It may be possible to address these discrepancies in future assessments with the inclusions of more state survey data, if methods can

be developed to combine these data sources into a single series such that it is representative of the unit stock.

As in the previous assessment, estimates of consumption by the top 6 finfish predators of butterfish within the NEFSC food habits database appear to be very low and similar in magnitude to historic fishing mortality but well below the estimated natural mortality rate. The ratio of M/F ×1711 mt (2012 catch from Table 1) approximates a loss from natural mortality of 105,591 mt. However, only 2,093 mt were estimated for consumptive removals by the top 6 finfish predators in 2012 (Figure 30). Similarly, average estimates of biomass losses from natural mortality since 1989, based on the standard catch equation and model output, are 220,107 mt, whereas average consumptive removals over the same time period is only 3,056 mt. This discrepancy suggests potentially significant removals by other predators not available to the bottom trawl survey. Evidence was presented during the assessment that longfin inshore squid are not a major predator on butterfish (pers. comm., Olaf Jensen, 2013. Rutgers University, New Brunswick NJ 08901). Food habits of other potential predators, such as sharks, tuna, swordfish, marine mammals and seabirds are not adequately sampled by the NEFSC bottom trawl survey to determine total butterfish consumption. Elucidation of other sources of natural mortality is a priority research topic.

It is unclear why there was little variation in the HSI, given opposing trends in abundance indices between the NEFSC offshore survey and the NEFSC inshore survey to the north and east. One possibility is that changes in thermal habitat dynamics for butterfish during the fall do not completely account for the empirical trends. The other is that changes in thermal habitat dynamics do account for empirical trends, but the Regional Ocean Modeling System (NEFSC 2014) does not capture them well enough. This could occur because of misspecification of the niche model or because bias corrected model based temperatures did not capture real trends. The latter is possible because hindcast bottom temperatures were spatially bias corrected by using monthly bottom temperature from a long term climatology. This approach adjusted the model hindcast to match climatology[1] spatially and may have smoothed temperature variability on the edges of the ecosystem that may have increased over recent years. Research is ongoing to address these issues.

Two issues regarding the geographic extent of the butterfish stock need to be addressed. One is the possibility of spawning south of Cape Hatteras, NC, and the potential contribution to the northern stock. This consideration was put forward as a research recommendation by the working group. The other issue is the off-shelf density of butterfish. The latter could be addressed by a study with comparable HBB trawl gear and sampling protocols to depths of 367–700 m, from the southern Scotian Shelf to Cape Hatteras, concurrent with sampling of the deepest NEFSC strata during the spring and fall bottom trawl surveys. Swept area estimates of stock size for the off-shelf areas could be calculated to determine their effect on the NEFSC survey indices.

Conclusions

In the previous butterfish assessment (NEFSC 2010) it was not possible to determine stock status relative to BRPs because of assessment uncertainties. Nevertheless the population was thought to be declining over time. The current assessment, which used a modified age-

[1] Climatology is commonly known as the study of climate, yet the term encompasses many other important definitions. Climatology is also defined as the long-term average of a given variable, often over time periods of 20-30 years. http://iridl.ldeo.columbia.edu/dochelp/StatTutorial/Climatologies/

structured catch at age model, as well as additional survey data from NEAMAP, yielded different insights into the butterfish stock. Fishing mortality has generally declined since 1989 but has always been low relative to natural mortality, which was estimated to be much higher than previously thought. Research on the estimation of catchability provided an improved basis for understanding the stock history and allowed estimation of BRPs. Although the accepted MSY proxy (36,199 mt) is high relative to recent catch limits, it is comparable to the peak historical catch observed in 1973 (Table 1; Figure 1). This result suggests that continued, judicious development of the recently reestablished directed butterfish fishery is reasonable.

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Table 1. Butterfish (*Peprilus triacanthus*) USA landings (mt), historic USA discards (mt), estimated USA discards (mt), foreign catch (mt), and total catch (mt), 1965–2012.

Year	USA Landings	Historic USA Discards	USA 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	3216		4480		7696
1990	2298		533		2831
1991	2189		4887		7076
1992	2754		5025		7779
1993	4608		7577		12185
1994	3634		6694		10328
1995	2067		6353		8420
1996	3555		1049		4604
1997	2794		1134		3928
1998	1966		6412		8378
1999	2110		8867		10977
2000	1449		7044		8493
2001	4404		4969		9373
2002	872		2350		3222
2003	536		2088		2624
2004	497		1323		1820
2005	428		647		1075
2006	555		856		1411
2007	679		239		918
2008	452		1029		1481
2009	435		1079		1514
2010	576		4017		4593
2011	664		1612		2276
2012	671		1040		1711

Table 2. US commercial butterfish (*Peprilus triacanthus*) samples and lengths collected, 1989–2012.

		Quarter				
		1	2	3	4	Total
1989	Total number of samples taken	11	4	8	5	28
	Total number of fish measured	1115	399	800	504	2818
1990	Total number of samples taken	8	6	11	9	34
	Total number of fish measured	812	589	1103	901	3405
1991	Total number of samples taken	9	4	10	7	30
	Total number of fish measured	901	402	1002	700	3005
1992	Total number of samples taken	8	6	7	5	26
	Total number of fish measured	803	600	710	513	2626
1993	Total number of samples taken	2	6	4	9	21
	Total number of fish measured	206	539	451	969	2165
1994	Total number of samples taken		3	4	7	14
	Total number of fish measured		142	419	724	1285
1995	Total number of samples taken	1	3	2		6
	Total number of fish measured	210	314	164		688
1996	Total number of samples taken	3	1	5	7	16
	Total number of fish measured	400	115	421	791	1727
1997	Total number of samples taken	14	4	2	11	31
	Total number of fish measured	1499	413	199	964	3075
1998	Total number of samples taken	9	7	4	5	25
	Total number of fish measured	893	618	383	467	2361
1999	Total number of samples taken	12	8	5	3	28
	Total number of fish measured	1239	728	521	237	2725
2000	Total number of samples taken	3	3	1	3	10
	Total number of fish measured	345	280	108	295	1028
2001	Total number of samples taken	6	14	7	1	28
	Total number of fish measured	637	1446	714	114	2911
2002	Total number of samples taken	6	1	2	3	12
	Total number of fish measured	617	98	215	313	1243
2003	Total number of samples taken	9	9	7	3	28
	Total number of fish measured	930	931	774	312	2947
2004	Total number of samples taken	5	12	17	7	41
	Total number of fish measured	540	1117	1755	682	4094
2005	Total number of samples taken	11	9	9	10	39
	Total number of fish measured	1124	924	903	975	3926
2006	Total number of samples taken	10	17	7	16	50
	Total number of fish measured	988	1795	731	1638	5152
2007	Total number of samples taken	13	10	23	17	63
	Total number of fish measured	1433	1005	2232	1761	6431
2008	Total number of samples taken	13	10	12	7	42
	Total number of fish measured	1374	1043	980	694	4091
2009	Total number of samples taken	7	7	3	8	25
	Total number of fish measured	694	614	325	818	2451

Table 2, continued. US commercial butterfish (*Peprilus triacanthus*) samples and lengths collected, 1989–2012.

2010	Total number of samples taken	5	11	9	7	32
	Total number of fish measured	563	1109	867	702	3241
2011	Total number of samples taken	13	4	1	6	24
	Total number of fish measured	1307	400	100	557	2364
2012	Total number of samples taken	11	5	2	4	22
	Total number of fish measured	1011	500	200	400	2111

Table 3. Estimated USA butterfish (*Peprilus triacanthus*) discards (mt) and total catch (mt) from Table 1, and respective coefficients of variation (CV), 1989–2012.

Year	USA Discards	CV
1989	4480	0.85
1990	533	0.37
1991	4887	0.99
1992	5025	0.54
1993	7577	0.32
1994	6694	0.41
1995	6353	0.49
1996	1049	0.71
1997	1134	0.84
1998	6412	1.87
1999	8867	0.36
2000	7044	0.23
2001	4969	0.54
2002	2350	1.25
2003	2088	1.38
2004	1323	0.28
2005	647	0.21
2006	856	0.71
2007	239	0.60
2008	1029	0.64
2009	1079	0.30
2010	4017	0.33
2011	1612	0.15
2012	1040	0.35

Year	USA Catch	CV
1989	7696	0.49
1990	2831	0.07
1991	7076	0.68
1992	7779	0.35
1993	12185	0.20
1994	10328	0.26
1995	8420	0.37
1996	4604	0.16
1997	3928	0.24
1998	8378	1.43
1999	10977	0.29
2000	8493	0.19
2001	9373	0.29
2002	3222	0.91
2003	2624	1.10
2004	1820	0.20
2005	1075	0.13
2006	1411	0.43
2007	918	0.16
2008	1481	0.44
2009	1514	0.22
2010	4593	0.29
2011	2276	0.10
2012	1711	0.22

Table 4. Butterfish (*Peprilus triacanthus*) commercial catch (mt) by gear, 1989–2012. Otter trawl/twin trawl and other gear types include discards. Pound net and unknown gear types are landings only.

Year	Otter trawl/twin trawl	Pound net	Other gear types	Unknown gear types	Total
1989	7545	86	52	0	7683
1990	2750	27	52	0	2830
1991	6996	12	66	0	7074
1992	7704	22	49	0	7775
1993	11969	131	84	0	12183
1994	10139	74	56	57	10326
1995	8236	57	52	71	8416
1996	4386	63	151	3	4603
1997	3680	67	172	11	3930
1998	8244	47	80	8	8378
1999	10844	66	66	0	10977
2000	8359	49	84	1	8493
2001	9242	43	87	0	9372
2002	3131	28	53	7	3219
2003	2563	16	41	0	2620
2004	1672	37	49	61	1819
2005	901	25	80	68	1074
2006	1276	0	62	72	1411
2007	742	7	74	94	917
2008	1344	2	45	84	1475
2009	1374	0	52	86	1512
2010	4427	0	76	118	4621
2011	2034	0	79	161	2274
2012	1462	0	108	140	1710

Table 5. Total kept weight of all species, number of observed trips, discard rate (estimated from observed trips), estimated butterfish (*Peprilus triacanthus*) discards, and coefficient of variation (CV) for bottom trawl (Northeast Fisheries Science Center gear code = 050 and 053) and small mesh (< 10.2 cm) in New England and Mid-Atlantic waters, 1989–2012. Note that the kept weight all for trips with unknown mesh size are also included. Discard ratios are shown to 5 decimal places for consistency with Table 6.

	New England					Mid-Atlantic				
Year	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV
1989	50243.8	82	0.03061	1538.2	0.33	41179.1	32	0.02401	988.6	0.52
1990	58802.0	33	0.00544	320.0	1.68	42540.6	32	0.02589	1101.4	0.43
1991	60282.0	96	0.03191	1923.9	0.35	54585.1	70	0.03892	2124.4	0.37
1992	58985.4	61	0.07948	4688.2	0.56	60993.5	42	0.06455	3936.9	0.29
1993	55228.0	24	0.07214	3984.3	0.66	53899.8	31	0.02705	1457.9	0.71
1994	53374.0	37	0.05067	2704.3	0.89	53873.0	12	0.03075	1656.5	0.54
1995	36928.6	91	0.00546	201.8	0.91	39937.8	69	0.03398	1357.1	1.15
1996	43164.7	60	0.01053	454.3	0.72	44140.6	82	0.02427	1071.1	1.06
1997	36975.9	54	0.01564	578.4	0.68	45364.4	46	0.01060	480.7	2.11
1998	43587.3	18	0.01959	854.0	0.54	52020.5	36	0.00283	147.4	0.92
1999	38744.0	54	0.05833	2260.0	0.42	35266.2	45	0.10642	3753.1	0.82
2000	36838.8	62	0.07821	2881.0	0.41	33633.4	42	0.06130	2061.6	0.60
2001	39801.3	39	0.01316	523.7	3.24	22552.0	63	0.01137	256.4	1.68
2002	32708.4	111	0.00407	133.2	0.49	21027.5	33	0.04703	988.9	1.34
2003	33097.4	107	0.00970	320.9	0.59	21102.8	33	0.18842	3976.1	1.20
2004	48966.3	190	0.02269	1111.1	0.41	44612.8	150	0.01500	669.3	0.41
2005	30654.2	193	0.00587	179.8	0.32	28943.6	92	0.02360	683.2	0.32
2006	22857.4	91	0.00960	219.5	0.39	50379.5	117	0.01042	525.0	1.46
2007	24195.8	115	0.00421	101.8	0.43	21247.8	128	0.00243	51.6	3.26
2008	22415.0	92	0.03194	715.9	0.76	25240.4	98	0.01546	390.3	0.80
2009	25453.9	253	0.01980	504.1	0.31	29155.7	206	0.01830	533.5	0.60
2010	21369.0	341	0.04472	955.5	0.29	29775.9	219	0.02462	733.2	0.36
2011	15354.4	324	0.01186	182.1	0.25	30353.0	273	0.04526	1373.8	0.17
2012	16985.1	251	0.01651	280.5	0.24	26585.6	158	0.02547	677.0	0.49

Table 6. Total kept weight of all species, number of observed trips, discard rate (estimated from observed trips), estimated butterfish (*Peprilus triacanthus*) discards, and coefficient of variation (CV) for bottom trawl (Northeast Fisheries Science Center gear code = 050 and 053) and large mesh (≥ 10.2 cm) in New England and Mid-Atlantic waters, 1989–2012. Discard ratios are shown to 5 decimal places to illustrate that all rates are greater than zero.

	New England					Mid-Atlantic				
Year	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV	Kept all (mt)	Obs. trips	Ratio	Discards (mt)	CV
1989	41411.8	68	0.00014	6.0	0.55	1463.4	21	0.00732	10.7	0.28
1990	55075.1	55	0.00214	117.7	0.85	1699.2	18	0.00092	1.6	0.64
1991	49171.0	91	0.00104	51.1	0.53	2161.1	22	0.00538	11.6	0.50
1992	39275.2	69	0.00015	5.8	0.76	2194.5	24	0.00683	15.0	0.87
1993	32234.4	54	0.06094	1964.3	0.48	2170.1	19	0.02464	53.5	0.45
1994	25936.9	40	0.00178	46.1	0.76	2683.8	29	0.00128	3.4	0.66
1995	30538.5	69	0.00535	163.3	1.07	5404.7	58	0.00469	25.4	1.02
1996	36679.1	45	0.00085	31.3	11.58	5838.5	27	0.00271	15.8	1.30
1997	32028.2	32	0.00130	41.6	0.58	5919.3	31	0.01428	84.5	0.78
1998	33224.9	28	0.02903	964.6	1.58	6866.9	17	0.12694	871.7	2.77
1999	32605.6	41	0.05569	1815.8	0.67	7794.3	43	0.12486	973.2	0.61
2000	36877.8	110	0.00354	130.4	0.84	6389.7	38	0.00061	3.9	0.55
2001	44410.8	168	0.01115	495.3	0.63	7285.3	63	0.14814	1079.2	0.81
2002	40569.8	246	0.00628	255.0	1.17	7292.8	111	0.00041	3.0	0.56
2003	42864.3	408	0.00075	32.3	0.93	6940.8	64	0.00006	0.4	0.66
2004	39100.5	605	0.00092	35.9	0.62	9446.1	249	0.00171	16.1	0.77
2005	34591.4	1497	0.00004	1.4	0.42	11538.0	194	0.00204	23.5	0.47
2006	27821.9	651	0.00015	4.1	0.79	9802.6	118	0.01690	165.7	0.20
2007	28541.1	638	0.00081	23.1	0.74	7327.9	273	0.00093	6.8	0.52
2008	30011.9	766	0.00024	7.1	1.07	6747.1	203	0.00335	22.6	0.93
2009	27999.5	893	0.00033	9.2	0.47	9523.5	265	0.00195	18.6	0.89
2010	26152.1	1053	0.00030	7.9	0.42	6300.2	438	0.00173	10.9	0.64
2011	32666.9	1591	0.00008	2.8	0.32	12875.6	385	0.00088	11.3	0.44
2012	35371.0	1573	0.00008	2.7	0.29	9463.0	269	0.00166	15.7	1.11

Table 7. Butterfish (*Peprilus triacanthus*) commercial landings at age (numbers, 000s), 1989–2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	519	14510	18229	7271	131
1990	1766	13052	10781	2953	261
1991	1139	10532	10133	3961	252
1992	298	13459	15746	3563	144
1993	5337	31738	17984	5391	0
1994	1359	11349	21275	8407	786
1995	374	7496	14411	2863	15
1996	2169	7205	21989	10732	956
1997	1139	18582	10847	2193	105
1998	209	6649	13783	2393	19
1999	815	6877	12115	3244	241
2000	539	5697	4469	1294	934
2001	959	9507	39195	3732	5
2002	1222	2714	3399	1998	251
2003	152	1118	1211	1812	743
2004	371	1710	2259	965	310
2005	259	751	1374	1603	802
2006	1569	3234	1822	802	302
2007	312	2670	3676	1211	123
2008	271	1332	2255	961	177
2009	672	1825	2293	877	178
2010	565	2496	2004	1580	180
2011	617	1868	2642	1387	1224
2012	511	3795	2553	1314	410

Table 8. Butterfish (*Peprilus triacanthus*) commercial discards at age (numbers, 000s), 1989–2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	43467	54831	22578	4748	109
1990	4892	6007	1404	241	27
1991	50316	64322	8207	2595	0
1992	38176	40354	24727	977	0
1993	30890	44222	25629	16008	0
1994	37253	74821	20033	4758	2159
1995	76725	78882	27475	3024	0
1996	6675	7890	6319	1572	25
1997	10713	14994	2102	173	0
1998	19040	68852	36428	1089	0
1999	48926	110810	24757	3444	2446
2000	105253	53089	22367	4353	2643
2001	57136	30651	22411	2160	728
2002	22996	21961	9224	1434	628
2003	15944	10468	5516	4899	816
2004	5939	14143	3532	1030	410
2005	1997	5120	4035	959	230
2006	7566	7931	1738	700	290
2007	654	2668	833	119	53
2008	10969	7409	4208	470	59
2009	7559	12156	3180	746	317
2010	23001	33742	16007	4800	326
2011	13229	15125	5905	1492	599
2012	3500	13248	3076	806	233

Table 9. Butterfish (*Peprilus triacanthus*) commercial catch at age (numbers, 000s), 1989–2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	43985	69341	40807	12020	240
1990	6658	19059	12185	3194	288
1991	51455	74854	18339	6557	252
1992	38474	53813	40473	4540	144
1993	36227	75960	43613	21399	0
1994	38612	86170	41308	13165	2945
1995	77100	86378	41886	5886	15
1996	8844	15095	28307	12303	981
1997	11853	11853	11853	11853	11853
1998	19249	75501	50211	3482	19
1999	49741	117687	36872	6688	2687
2000	105792	58786	26836	5647	3577
2001	58095	40158	61606	5892	732
2002	24218	24675	12623	3432	879
2003	16097	11586	6727	6711	1559
2004	6310	15853	5790	1995	720
2005	2256	5871	5409	2562	1032
2006	9135	11165	3560	1501	592
2007	967	5338	4509	1330	176
2008	11240	8741	6463	1431	237
2009	8232	13981	5474	1623	496
2010	23566	36238	18011	6380	506
2011	13846	16993	8548	2879	1822
2012	4011	17043	5629	2120	642

Table 10. Butterfish (*Peprilus triacanthus*) commercial catch mean weight at age (kg), 1989–2012. Italicized values were originally missing; thus they were interpolated as the age 3 value plus the average difference between age 3 and age 4 for the entire time series.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.02	0.04	0.06	0.09	0.21
1990	0.04	0.06	0.09	0.10	0.12
1991	0.03	0.04	0.09	0.10	0.17
1992	0.03	0.05	0.08	0.12	0.16
1993	0.04	0.06	0.09	0.12	*0.16*
1994	0.04	0.04	0.08	0.10	0.18
1995	0.02	0.04	0.07	0.11	*0.15*
1996	0.04	0.06	0.08	0.09	0.10
1997	0.03	0.07	0.09	0.11	*0.16*
1998	0.04	0.05	0.07	0.12	*0.17*
1999	0.03	0.04	0.08	0.09	*0.14*
2000	0.02	0.05	0.08	0.10	0.17
2001	0.03	0.04	0.08	0.13	*0.17*
2002	0.02	0.05	0.07	0.10	*0.14*
2003	0.04	0.05	0.08	0.10	0.13
2004	0.04	0.05	0.08	0.11	0.17
2005	0.05	0.04	0.06	0.10	0.12
2006	0.04	0.05	0.08	0.10	0.16
2007	0.05	0.06	0.08	0.12	0.19
2008	0.03	0.05	0.07	0.12	*0.16*
2009	0.04	0.04	0.07	0.09	0.17
2010	0.03	0.05	0.07	0.09	0.10
2011	0.03	0.05	0.07	0.09	0.11
2012	0.04	0.05	0.08	0.10	0.12

Table 11. FSV *Henry B. Bigelow* to FRV *Albatross IV* mean calibration coefficients for butterfish (*Peprilus triacanthus*) from Miller et al. (2010).

	Number		Weight	
	$\hat{\rho}$	SE($\hat{\rho}$)	$\hat{\rho}$	SE($\hat{\rho}$)
Spring	1.487	0.220	2.356	0.332
Fall	1.935	0.172	1.808	0.184

Table 12. Butterfish (*Peprilus triacanthus*) stratified mean number per tow from Northeast Fisheries Science Center spring surveys, and corresponding coefficients of variation (CV), for data collected in offshore strata 1989–2012 and inshore strata 1989–2008.

	Offshore			Inshore	
Year	Number	CV	Year	Number	CV
1989	29.84	0.80	1989	0.42	0.85
1990	8.39	0.44	1990	0.44	0.57
1991	26.57	0.68	1991	47.19	0.25
1992	16.40	0.21	1992	0.31	0.40
1993	24.66	0.39	1993	0.32	0.08
1994	33.01	0.28	1994	0	0
1995	38.10	0.59	1995	0	0
1996	10.37	0.40	1996	0	0
1997	102.98	0.38	1997	1.98	0.24
1998	37.23	0.61	1998	0.12	0.81
1999	69.31	0.59	1999	0.02	1.00
2000	33.44	0.36	2000	0.05	1.00
2001	55.61	0.37	2001	0.03	1.00
2002	42.64	0.44	2002	2.92	0.60
2003	43.37	0.60	2003	0.03	1.00
2004	115.11	0.32	2004	0.06	0.83
2005	33.97	0.39	2005	0.02	1.00
2006	64.63	0.39	2006	12.41	0.04
2007	128.34	0.54	2007	0.22	0.78
2008	122.83	0.70	2008	2.59	0.30
2009	97.58	0.39			
2010	73.47	0.28			
2011	40.90	0.20			
2012	142.55	0.21			

Table 13. Butterfish (*Peprilus triacanthus*) stratified mean number per tow from Northeast Fisheries Science Center fall surveys, and corresponding coefficients of variation (CV), for data collected in offshore strata 1989–2012 and inshore strata 1989–2008.

	Offshore			Inshore	
Year	Number	CV	Year	Number	CV
1989	377.34	0.38	1989	594.95	0.52
1990	379.94	0.23	1990	63.71	0.32
1991	187.87	0.43	1991	172.60	0.24
1992	246.05	0.27	1992	107.53	0.12
1993	248.98	0.25	1993	292.31	0.25
1994	510.35	0.47	1994	303.32	0.12
1995	116.57	0.26	1995	39.52	0.35
1996	78.85	0.22	1996	157.52	0.32
1997	220.26	0.13	1997	632.94	0.10
1998	214.49	0.33	1998	112.32	0.37
1999	247.81	0.38	1999	185.17	0.30
2000	202.92	0.28	2000	312.86	0.27
2001	63.62	0.31	2001	368.50	0.24
2002	92.61	0.21	2002	225.53	0.34
2003	187.75	0.15	2003	267.15	0.19
2004	75.50	0.29	2004	317.13	0.29
2005	39.19	0.30	2005	228.52	0.07
2006	179.31	0.24	2006	202.04	0.23
2007	41.21	0.23	2007	220.95	0.14
2008	131.93	0.23	2008	131.67	0.14
2009	182.45	0.25			
2010	128.16	0.24			
2011	250.38	0.28			
2012	66.59	0.31			

Table 14. Northeast Fisheries Science Center survey number of stations sampled in offshore and inshore strata, number of stations with butterfish (*Peprilus triacanthus*) sampled, butterfish aged, and lengths collected, 1989–2012.

		Spring	Fall	Total
1989	Total number of stations sampled	195	209	404
	Total number of stations with butterfish	27	105	132
	Total number of fish aged	98	445	543
	Total number of fish measured	98	445	543
1990	Total number of stations sampled	206	223	429
	Total number of stations with butterfish	27	119	146
	Total number of fish aged	128	552	680
	Total number of fish measured	128	552	680
1991	Total number of stations sampled	218	211	429
	Total number of stations with butterfish	49	153	202
	Total number of fish aged	201	771	972
	Total number of fish measured	201	771	972
1992	Total number of stations sampled	230	239	469
	Total number of stations with butterfish	45	197	242
	Total number of fish aged	218	964	1182
	Total number of fish measured	219	971	1190
1993	Total number of stations sampled	234	231	465
	Total number of stations with butterfish	41	161	202
	Total number of fish aged	190	791	981
	Total number of fish measured	190	806	996
1994	Total number of stations sampled	237	239	476
	Total number of stations with butterfish	33	184	217
	Total number of fish aged	187	910	1097
	Total number of fish measured	187	920	1107
1995	Total number of stations sampled	232	250	482
	Total number of stations with butterfish	48	165	213
	Total number of fish aged	253	782	1035
	Total number of fish measured	253	790	1043
1996	Total number of stations sampled	264	255	519
	Total number of stations with butterfish	34	142	176
	Total number of fish aged	146	684	830
	Total number of fish measured	147	688	835
1997	Total number of stations sampled	235	254	489
	Total number of stations with butterfish	77	157	234
	Total number of fish aged	416	742	1158
	Total number of fish measured	423	758	1181
1998	Total number of stations sampled	241	261	502
	Total number of stations with butterfish	48	174	222
	Total number of fish aged	192	846	1038
	Total number of fish measured	196	861	1057
1999	Total number of stations sampled	232	233	465
	Total number of stations with butterfish	39	150	189
	Total number of fish aged	188	729	917
	Total number of fish measured	193	737	930
2000	Total number of stations sampled	232	234	466
	Total number of stations with butterfish	53	123	176
	Total number of fish aged	218	561	779
	Total number of fish measured	228	590	818

Table 14, continued. Northeast Fisheries Science Center survey number of stations sampled in offshore and inshore strata, number of stations with butterfish (*Peprilus triacanthus*) sampled, butterfish aged, and lengths collected, 1989–2012.

2001	Total number of stations sampled	234	232	466
	Total number of stations with butterfish	41	136	177
	Total number of fish aged	254	565	819
	Total number of fish measured	257	590	847
2002	Total number of stations sampled	236	238	474
	Total number of stations with butterfish	69	149	218
	Total number of fish aged	297	697	994
	Total number of fish measured	315	734	1049
2003	Total number of stations sampled	229	232	461
	Total number of stations with butterfish	35	173	208
	Total number of fish aged	167	805	972
	Total number of fish measured	179	851	1030
2004	Total number of stations sampled	234	227	461
	Total number of stations with butterfish	35	153	188
	Total number of fish aged	139	687	826
	Total number of fish measured	142	778	920
2005	Total number of stations sampled	234	239	473
	Total number of stations with butterfish	34	161	195
	Total number of fish aged	170	748	918
	Total number of fish measured	235	797	1032
2006	Total number of stations sampled	239	257	496
	Total number of stations with butterfish	57	206	263
	Total number of fish aged	263	996	1259
	Total number of fish measured	266	1017	1283
2007	Total number of stations sampled	263	249	512
	Total number of stations with butterfish	65	154	219
	Total number of fish aged	316	723	1039
	Total number of fish measured	324	746	1070
2008	Total number of stations sampled	241	247	488
	Total number of stations with butterfish	66	183	249
	Total number of fish aged	300	841	1141
	Total number of fish measured	316	875	1191
2009	Total number of stations sampled	274	252	526
	Total number of stations with butterfish	62	193	255
	Total number of fish aged	376	1042	1418
	Total number of fish measured	384	1070	1454
2010	Total number of stations sampled	270	262	532
	Total number of stations with butterfish	74	209	283
	Total number of fish aged	431	1178	1609
	Total number of fish measured	445	1204	1649
2011	Total number of stations sampled	254	258	512
	Total number of stations with butterfish	70	213	283
	Total number of fish aged	352	1419	1771
	Total number of fish measured	369	1492	1861
2012	Total number of stations sampled	260	257	517
	Total number of stations with butterfish	169	153	322
	Total number of fish aged	864	621	1485
	Total number of fish measured	1050	733	1783

Table 15. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from Northeast Fisheries Science Center spring surveys for data collected 1989–2012 in offshore strata.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0	24.27	4.70	0.87	0.01
1990	0.01	6.84	1.23	0.28	0.03
1991	0.02	24.63	1.35	0.57	0.02
1992	0	14.57	1.61	0.21	0.01
1993	0	21.51	2.67	0.47	0.00
1994	0	26.98	5.05	0.94	0.04
1995	0	24.00	11.74	2.37	0
1996	0	6.98	2.19	1.16	0.04
1997	0	98.19	4.15	0.64	0.00
1998	0	16.55	19.60	1.08	0
1999	0	57.44	10.09	1.78	0
2000	0	31.58	1.55	0.28	0.03
2001	0	44.78	10.12	0.72	0
2002	0	34.92	5.59	1.91	0.22
2003	0	35.80	4.99	2.42	0.16
2004	0	113.98	1.04	0.07	0.02
2005	0	25.60	7.02	0.91	0.44
2006	0	60.31	3.06	0.94	0.32
2007	0	109.78	15.47	2.90	0.19
2008	0	113.91	8.19	0.66	0.07
2009	0	92.76	3.86	0.79	0.17
2010	0	63.04	8.81	1.52	0.10
2011	0	33.68	5.19	1.43	0.60
2012	0	128.94	9.99	3.10	0.53

Table 16. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from Northeast Fisheries Science Center spring surveys for data collected 1989–2008 in inshore strata.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.07	0	0.07	0.29	0
1990	0.19	0.25	0	0	0
1991	0	37.69	6.05	3.44	0.01
1992	0	0.14	0.14	0.02	0.02
1993	0	0.30	0.02	0	0
1994	0	0	0	0	0
1995	0	0	0	0	0
1996	0	0	0	0	0
1997	0	1.75	0.14	0.08	0
1998	0	0	0.09	0.03	0
1999	0	0	0	0.02	0
2000	0	0.03	0.03	0	0
2001	0	0.03	0	0	0
2002	0	0.72	1.76	0.17	0.28
2003	0	0.03	0	0	0
2004	0	0.06	0	0	0
2005	0	0	0	0.02	0
2006	0	2.93	7.68	1.57	0.23
2007	0	0.22	0	0	0
2008	0	2.01	0.46	0.06	0.06

Table 17. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from Northeast Fisheries Science Center fall surveys for data collected 1989–2012 in offshore strata.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	325.84	39.43	11.45	0.62	0
1990	343.42	32.55	3.15	0.82	0
1991	167.26	18.37	2.21	0.02	0
1992	232.64	9.93	3.43	0.05	0
1993	195.92	46.58	6.07	0.42	0
1994	475.76	23.85	9.38	1.33	0.03
1995	41.44	48.16	26.91	0.07	0
1996	59.40	15.01	4.21	0.24	0
1997	204.14	13.81	2.14	0.19	0
1998	164.99	41.97	6.84	0.69	0
1999	241.17	4.92	1.72	0	0
2000	151.05	45.85	5.73	0.29	0
2001	38.53	15.20	9.66	0.22	0
2002	80.45	9.27	2.84	0.05	0
2003	175.45	10.38	1.69	0.11	0.12
2004	57.31	12.75	4.81	0.22	0.41
2005	33.92	3.17	1.52	0.58	0
2006	155.83	17.51	5.17	0.74	0.06
2007	26.03	13.65	1.51	0.02	0
2008	124.81	6.17	0.94	0.02	0
2009	158.32	20.06	3.88	0.17	0.01
2010	84.10	35.90	6.90	1.25	0
2011	218.27	26.86	4.76	0.42	0.06
2012	27.15	28.83	9.91	0.62	0.07

Table 18. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from Northeast Fisheries Science Center fall surveys for data collected 1989–2008 in inshore strata.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	397.24	144.43	49.62	3.65	0
1990	38.02	11.54	11.86	2.29	0
1991	115.28	28.59	21.61	7.12	0
1992	89.42	7.40	10.30	0.40	0
1993	250.77	28.49	11.64	1.41	0
1994	291.99	7.04	3.43	0.85	0.01
1995	24.11	7.99	7.20	0.22	0
1996	130.65	23.71	2.77	0.39	0
1997	589.52	41.98	1.44	0	0
1998	66.98	38.05	6.80	0.48	0
1999	145.37	30.57	8.88	0.34	0
2000	305.24	6.38	0.55	0.67	0
2001	345.76	19.79	2.73	0.23	0
2002	185.27	30.25	9.12	0.88	0
2003	220.99	39.48	3.01	2.90	0.77
2004	184.48	65.98	58.96	4.55	3.16
2005	210.89	10.62	3.60	3.25	0.16
2006	176.14	19.40	4.81	1.45	0.23
2007	194.59	20.58	5.70	0.08	0
2008	119.82	9.76	1.83	0.25	0

Table 19. Butterfish (*Peprilus triacanthus*) arithmetic mean number per tow from Northeast Area Monitoring and Assessment Program spring and fall surveys, and corresponding coefficients of variation (CV), for data collected 2007–2012.

	Spring			Fall	
Year	Number	CV		Number	CV
			2007	1061.01	0.36
2008	343.18	0.21	2008	1032.49	0.17
2009	188.48	0.12	2009	3600.76	0.14
2010	521.88	0.58	2010	1073.33	0.12
2011	458.63	0.15	2011	1661.64	0.17
2012	525.57	0.16	2012	625.73	0.21

Table 20. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from Northeast Area Monitoring and Assessment Program spring surveys for data collected 2008–2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
2008	9.11	316.12	16.03	1.64	0.27
2009	3.28	168.20	15.48	1.31	0.20
2010	9.97	408.85	98.44	4.21	0.41
2011	3.21	390.74	56.46	7.03	1.18
2012	5.45	369.49	146.20	3.83	0.61

Table 21. Butterfish (*Peprilus triacanthus*) stratified mean number per tow at age from Northeast Area Monitoring and Assessment Program fall surveys for data collected 2007–2012.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
2007	991.54	52.62	14.44	2.18	0.23
2008	981.64	45.26	4.57	0.91	0.11
2009	3360.82	199.37	36.05	4.11	0.42
2010	860.64	164.43	40.66	6.90	0.71
2011	1443.41	174.90	37.87	4.91	0.55
2012	442.03	116.20	54.84	11.40	1.26

Table 22. Butterfish (*Peprilus triacanthus*) mean number per tow for state surveys, 1989–2012. Empty cells indicate no survey was conducted. ME-NH = Maine New Hampshire, MADMF = Massachusetts Division of Marine Fisheries, RIDEM = Rhode Island Department of Environmental Management, CTDEEP = Connecticut Department of Energy and Environmental Protection, NYSDEC = New York State Department of Environmental Conservation, NJDFW = New Jersey Division of Fish and Wildlife.

Year	ME-NH Spring	ME-NH Fall	MADMF Spring	MADMF Fall	RIDEM Spring	RIDEM Fall	CTDEEP Spring	CTDEEP Fall	NYSDEC Peconic	NJDFW Annual
1989			0.15	109.82	0	163.95	0.80	174.87	0.89	506.14
1990			8.82	297.93	0.02	497.84	1.60	154.65	1.38	356.26
1991			16.18	248.49	0.83	92.23	2.17	170.59	0.36	609.31
1992			0.64	660.11	0	277.94	2.60	301.72	0.90	2767.81
1993			1.06	731.89	27.35	688.06	0.48	87.73	0.40	214.66
1994			2.84	391.87	0.30	292.24	1.71	93.05	0.34	3220.32
1995			8.23	586.18	1.79	273.93	1.06	320.06	0.52	388.69
1996			2.59	337.35	3.71	281.52	3.22	173.74	0.36	1046.29
1997			5.14	401.52	1.73	1002.19	6.16	186.62	1.86	439.45
1998			3.05	921.22	3.73	399.59	6.51	355.49	0.75	233.08
1999			0.59	448.46	0.29	243.54	1.90	477.91	0.52	698.72
2000		2.26	24.94	148.36	3.24	42.70	3.35	125.97	0.99	247.85
2001	0.03	11.73	11.01	71.97	11.22	165.02	2.94	142.89	0.69	308.36
2002	0.06	37.90	9.55	283.15	10.88	213.23	7.09	165.07	0.66	348.65
2003		19.65	8.04	578.91	0.71	429.69	3.17	112.86	1.46	651.43
2004		37.24	2.49	135.54	24.08	193.71	2.10	175.37	0.65	584.18
2005		36.16	1.27	372.14	0	269.18	2.27	197.24		412.00
2006	0.14	38.91	7.55	147.40	404.98	292.71	18.67	140.23	3.09	1477.43
2007	0.18	24.85	46.06	293.85	1.00	378.59	3.48	154.53	0.25	504.23
2008	0.04	112.10	5.98	531.96	0.10	590.48	4.64	181.71	1.78	2529.77
2009		303.59	13.74	979.18	0.31	2507.67	9.44	409.75	2.33	1607.49
2010	0.39	63.24	26.45	129.26	0.51	437.07	1.99		5.24	319.73
2011	0.34	108.94	2.44	833.27	1.14	920.81	15.64	39.62	1.97	603.91
2012	0.44	130.27	29.08	587.53	13.57	580.16	13.44	132.47	0.49	116.53

Table 22, continued. Butterfish (*Peprilus triacanthus*) mean number per tow for state surveys, 1989–2012. Empty cells indicate no survey was conducted. Delaware Department of Natural Resources and Environmental Control (DDNREC), ChesMMAP = Chesapeake Bay Multispecies Monitoring and Assessment Program, VIMS = Virginia Institute of Marine Science, NCDMF = North Carolina Department of Environment and Natural Resources

Year	DDNREC 30 ft	DDNREC Estuary	DDNREC Bays	ChesMMAP	VIMS Juvenile	NCDMF Annual
1989		0.25	0.78		1.86	
1990	8.02	0.41	0.51		2.27	2.59
1991	6.72	0.13	0.62		1.48	2.57
1992	3.60	0.19	0.32		0.88	1.31
1993	66.67	0.22	0.20		1.44	2.25
1994	5.68	0.05	0.31		0.52	1.91
1995	9.08	0.13	0.15		0.33	1.34
1996	12.64	0.06	0.04		1.14	2.26
1997	23.93	0.41	0.33		0.45	0.53
1998	35.41	0.36	0.07		1.03	1.72
1999	16.23	0.57	0.44		0.74	1.99
2000	9.83	0.46	0.07		0.87	1.8
2001	12.01	0.14	0		0.47	1.57
2002	10.90	0.10	0.25	31.16	0.40	1.49
2003	29.97	0.20	0.22	87.46	1.01	1.46
2004	32.02	0.24	0.33	59.34	0.86	1.38
2005	3.98	0.17	0.08	126.69	0.36	2.73
2006	8.34	0.05	0.77	81.79	1.26	1.96
2007	7.03	0.10	0.18	60.81	0.16	2.01
2008	14.62	0.17	0.44	73.82	0.98	7.79
2009	6.89	0.13	2.27	78.56	1.06	3.91
2010	14.98	0.41	0.42	13.62	1.45	5.18
2011	27.54	0.49	1.17	27.63	0.78	5.95
2012	9.98	0.21	0.13	15.12	0.27	2.54

Table 23. Correlation coefficients between Northeast Fisheries Science Center (NEFSC), Northeast Area Monitoring and Assessment Program (NEAMAP), and state surveys for butterfish (*Peprilus triacanthus*) spring abundance indices (number per tow). Values > 0.4 are in bold. There is no correlation coefficient for NEFSC Inshore and NEAMAP because of the low sample size (*n* = 1 pair).

	NEFSC Offshore	NEFSC Inshore	ME-NH	MDMF	RIDEM	CTDEEP	NEAMAP
NEFSC Offshore	1						
NEFSC Inshore	-0.11	1					
ME-NH	0.23	0.31	1				
MDMF	**0.49**	0.16	0.37	1			
RIDEM	0.05	0.19	-0.16	-0.05	1		
CTDEEP	0.32	0.15	0.29	0.10	**0.60**	1	
NEAMAP	-0.09	NA	**0.98**	**0.47**	**0.49**	0.07	1

Table 24. Correlation coefficients between Northeast Fisheries Science Center (NEFSC), Northeast Area Monitoring and Assessment Program (NEAMAP), and state surveys for butterfish (*Peprilus triacanthus*) fall abundance indices (number per tow). Values > 0.4 are in bold. Note the correlation coefficient for NEFSC Inshore and NEAMAP is due to the low sample size (*n* = 2 pairs).

	NEFSC Offshore	NEFSC Inshore	ME-NH	MDMF	RIDEM	CTDEEP	NEAMAP
NEFSC Offshore	1						
NEFSC Inshore	0.19	1					
ME-NH	0.27	-0.78	1				
MDMF	0.11	-0.40	**0.80**	1			
RIDEM	0.04	0.23	**0.96**	**0.63**	1		
CTDEEP	-0.06	-0.35	**0.71**	0.35	0.27	1	
NEAMAP	**0.54**	**1**	**0.86**	**0.71**	**0.97**	**0.79**	1

Table 25. The top 6 fish predators of butterfish (*Peprilus triacanthus*) identified from Northeast Fisheries Science Center (NEFSC) bottom trawl survey food habits database.

Common Name	Species Name
Bluefish	*Pomatomus saltatrix*
Spiny dogfish	*Squalus acanthias*
Silver hake	*Merluccius bilinearis*
Summer flounder	*Paralichthys dentatus*
Goosefish	*Lophius americanus*
Smooth dogfish	*Mustelus canis*

Table 26. Estimated smoother coefficients and covariance matrix for butterfish (*Peprilus triacanthus*) length-based relative catch efficiency from Miller (2013) used to specify the penalty in the final model.

Coefficient	Covariance matrix									
-1.231	0.018	0.003	-0.006	-0.010	-0.012	-0.012	-0.010	-0.003	0.008	0.020
-0.102	0.003	0.059	0.009	-0.020	-0.034	-0.041	-0.041	-0.031	-0.026	-0.028
-1.047	-0.006	0.009	0.090	0.091	0.100	0.103	0.097	0.057	0.005	-0.018
-0.838	-0.010	-0.020	0.091	0.129	0.145	0.153	0.141	0.085	0.018	-0.015
-0.764	-0.012	-0.034	0.100	0.145	0.183	0.193	0.179	0.110	0.027	-0.012
-0.753	-0.012	-0.041	0.103	0.153	0.193	0.217	0.202	0.126	0.036	-0.007
-0.807	-0.010	-0.041	0.097	0.141	0.179	0.202	0.203	0.132	0.047	0.008
-0.468	-0.003	-0.031	0.057	0.085	0.110	0.126	0.132	0.114	0.073	0.057
0.222	0.008	-0.026	0.005	0.018	0.027	0.036	0.047	0.073	0.180	0.311
0.737	0.020	-0.028	-0.018	-0.015	-0.012	-0.007	0.008	0.057	0.311	0.949

Table 27. Specifications for the final age-structured assessment program (ASAP) model. CV = coefficient of variation, RMSE = Root Mean Squared Error

Catch CVs	based on variance estimation for discards
Aggregate survey index CVs	design-based estimates were rescaled for RMSE diagnostics
Fishery effective sample size (input)	27
Starting value for fishery selectivity, Age 0	1
Starting value for fishery selectivity, Age 1	1
Starting value for fishery selectivity, Age 2	1 (fixed)
Starting value for fishery selectivity, Age 3	1 (fixed
Starting value for fishery selectivity, Age 4+	1 (fixed)
NEFSC fall offshore effective sample size (input)	19
NEFSC fall inshore effective sample size (input)	14
NEAMAP fall effective sample size (input)	41
Starting value for NEFSC fall offshore survey selectivity, Age 0	1 (fixed)
Starting value for NEFSC fall offshore survey selectivity, Age 1	0.58
Starting value for NEFSC fall offshore survey selectivity, Age 2	0.632
Starting value for NEFSC fall offshore survey selectivity, Age 3	0.632 (fixed)
Starting value for NEFSC fall offshore survey selectivity, Age 4+	0.632 (fixed)
Starting value for NEFSC fall inshore survey selectivity, Age 0	1 (fixed)
Starting value for NEFSC fall inshore survey selectivity, Age 1	0.461
Starting value for NEFSC fall inshore survey selectivity, Age 2	0.657
Starting value for NEFSC fall inshore survey selectivity, Age 3	0.349
Starting value for NEFSC fall inshore survey selectivity, Age 4+	0.349 (fixed)
Starting value for NEAMAP fall survey selectivity, Age 0	1 (fixed)
Starting value for NEAMAP fall survey selectivity, Age 1	1
Starting value for NEAMAP fall survey selectivity, Age 2	0.298
Starting value for NEAMAP fall survey selectivity, Age 3	0.298
Starting value for NEAMAP fall survey selectivity, Age 4+	0.298
Fraction of year at NEFSC fall offshore survey	0.75
Fraction of year at NEFSC fall inshore survey	0.75
Fraction of year at NEAMAP fall survey	0.67
Fraction of year at spawning	0.5

Table 28. Swept area abundance (000s) inputs for the final model. Northeast Fisheries Science Center (NEFSC) survey areas used to derive these values were 42,945 nmi^2 (147,297 km^2) and 3,521 nmi^2 (12,077 km^2) for the offshore and inshore series, respectively; while swept area was assumed to be 0.0112 nmi^2 (0.0384 km^2). Northeast Area Monitoring and Assessment Program (NEAMAP) survey area and swept areas were assumed to be 11,868 km^2 and 0.025 km^2, respectively.

Year	NEFSC Fall Offshore	NEFSC Fall Inshore	NEAMAP Fall
1989	1,446,871	187,037	
1990	1,456,820	20,029	
1991	720,360	54,262	
1992	943,447	33,805	
1993	954,693	91,896	
1994	1,956,873	95,355	
1995	446,988	12,423	
1996	302,335	49,521	
1997	844,577	198,979	
1998	822,423	35,309	
1999	950,207	58,213	
2000	778,073	98,354	
2001	243,934	115,849	
2002	355,108	70,900	
2003	719,912	83,986	
2004	289,500	99,699	
2005	150,261	71,842	
2006	687,532	63,517	
2007	158,014	69,462	488,812
2008	505,868	41,393	507,284
2009	699,575		1,758,311
2010	491,395		520,072
2011	960,040		804,646
2012	255,318		307,599

Table 29. Objective function components for the final model.

Component	Objective Function
Aggregate catch	189.851
Aggregate survey indices	659.819
Catch age composition	180.909
Survey age composition	161.395
Relative catch efficiency penalty	-5.73728
Total	1186.24

Table 30. Root Mean Squared Error (RMSE) for data components from the final model. NEFSC = Northeast Fisheries Science Center, NEAMAP = Northeast Area Monitoring and Assessment Program

Component	RMSE
Aggregate catch	0.07
Aggregate survey indices	1.15
NEFSC fall offshore indices	0.98
NEFSC fall inshore indices	1.35
NEAMAP fall indices	1.00

Table 31. Annual estimates of spawning biomass (mt), recruitment (millions), fully selected fishing mortality F (age 2+), and respective coefficient of variation (CV) from the final model.

Year	Spawning Biomass	CV	Recruitment	CV	Full F	CV
1989	62,910	0.31	8,196	0.28	0.13	0.56
1990	89,052	0.27	9,030	0.24	0.03	0.29
1991	76,674	0.23	7,573	0.23	0.11	0.72
1992	77,013	0.21	7,175	0.21	0.10	0.41
1993	78,509	0.19	10,438	0.21	0.15	0.28
1994	69,763	0.19	11,587	0.20	0.14	0.33
1995	78,885	0.18	5,000	0.24	0.11	0.40
1996	75,485	0.19	9,403	0.22	0.06	0.26
1997	94,390	0.19	14,836	0.17	0.04	0.31
1998	103,490	0.16	8,873	0.23	0.08	1.00
1999	90,151	0.18	13,628	0.22	0.12	0.35
2000	106,590	0.18	10,586	0.22	0.09	0.28
2001	100,740	0.19	7,934	0.22	0.09	0.34
2002	85,021	0.19	8,044	0.21	0.04	0.78
2003	80,428	0.19	9,135	0.19	0.03	0.88
2004	85,343	0.17	5,126	0.22	0.02	0.28
2005	56,055	0.18	7,581	0.18	0.02	0.22
2006	67,460	0.17	7,397	0.20	0.02	0.45
2007	79,627	0.17	5,691	0.19	0.01	0.24
2008	62,643	0.18	7,595	0.19	0.02	0.47
2009	57,039	0.18	11,113	0.22	0.02	0.29
2010	77,877	0.20	6,546	0.24	0.07	0.36
2011	71,239	0.23	9,483	0.26	0.03	0.26
2012	79,451	0.25	2,432	0.33	0.02	0.33

Table 32. Estimated fishing mortality at age from the final age-structured assessment program (ASAP) model.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	0.005	0.040	0.132	0.132	0.132
1990	0.001	0.010	0.032	0.032	0.032
1991	0.004	0.032	0.107	0.107	0.107
1992	0.004	0.031	0.102	0.102	0.102
1993	0.005	0.045	0.150	0.150	0.150
1994	0.005	0.043	0.143	0.143	0.143
1995	0.004	0.033	0.109	0.109	0.109
1996	0.002	0.017	0.057	0.057	0.057
1997	0.002	0.013	0.044	0.044	0.044
1998	0.003	0.024	0.078	0.078	0.078
1999	0.004	0.035	0.116	0.116	0.116
2000	0.003	0.026	0.088	0.088	0.088
2001	0.003	0.027	0.091	0.091	0.091
2002	0.001	0.011	0.037	0.037	0.037
2003	0.001	0.009	0.030	0.030	0.030
2004	0.001	0.007	0.022	0.022	0.022
2005	0.001	0.005	0.017	0.017	0.017
2006	0.001	0.006	0.022	0.022	0.022
2007	0.000	0.004	0.012	0.012	0.012
2008	0.001	0.007	0.024	0.024	0.024
2009	0.001	0.007	0.025	0.025	0.025
2010	0.002	0.020	0.067	0.067	0.067
2011	0.001	0.009	0.031	0.031	0.031
2012	0.001	0.007	0.024	0.024	0.024

Table 33. Estimated numbers at age (millions) on January 1 from the final age-structured assessment program (ASAP) model.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1989	8,196	2,784	742	217	15
1990	9,030	2,397	786	191	60
1991	7,573	2,650	698	224	71
1992	7,175	2,217	754	184	78
1993	10,438	2,101	632	200	70
1994	11,587	3,051	590	160	68
1995	5,000	3,387	859	150	58
1996	9,403	1,463	963	226	55
1997	14,836	2,757	423	267	78
1998	8,873	4,352	799	119	97
1999	13,628	2,600	1,249	217	59
2000	10,586	3,988	738	327	72
2001	7,933	3,101	1,141	199	107
2002	8,044	2,324	886	306	82
2003	9,135	2,361	675	251	110
2004	5,126	2,681	687	192	103
2005	7,581	1,505	783	197	85
2006	7,397	2,226	440	226	82
2007	5,691	2,172	650	127	88
2008	7,595	1,672	636	189	62
2009	11,113	2,230	488	182	72
2010	6,546	3,263	650	140	73
2011	9,483	1,919	940	179	58
2012	2,432	2,783	559	268	68

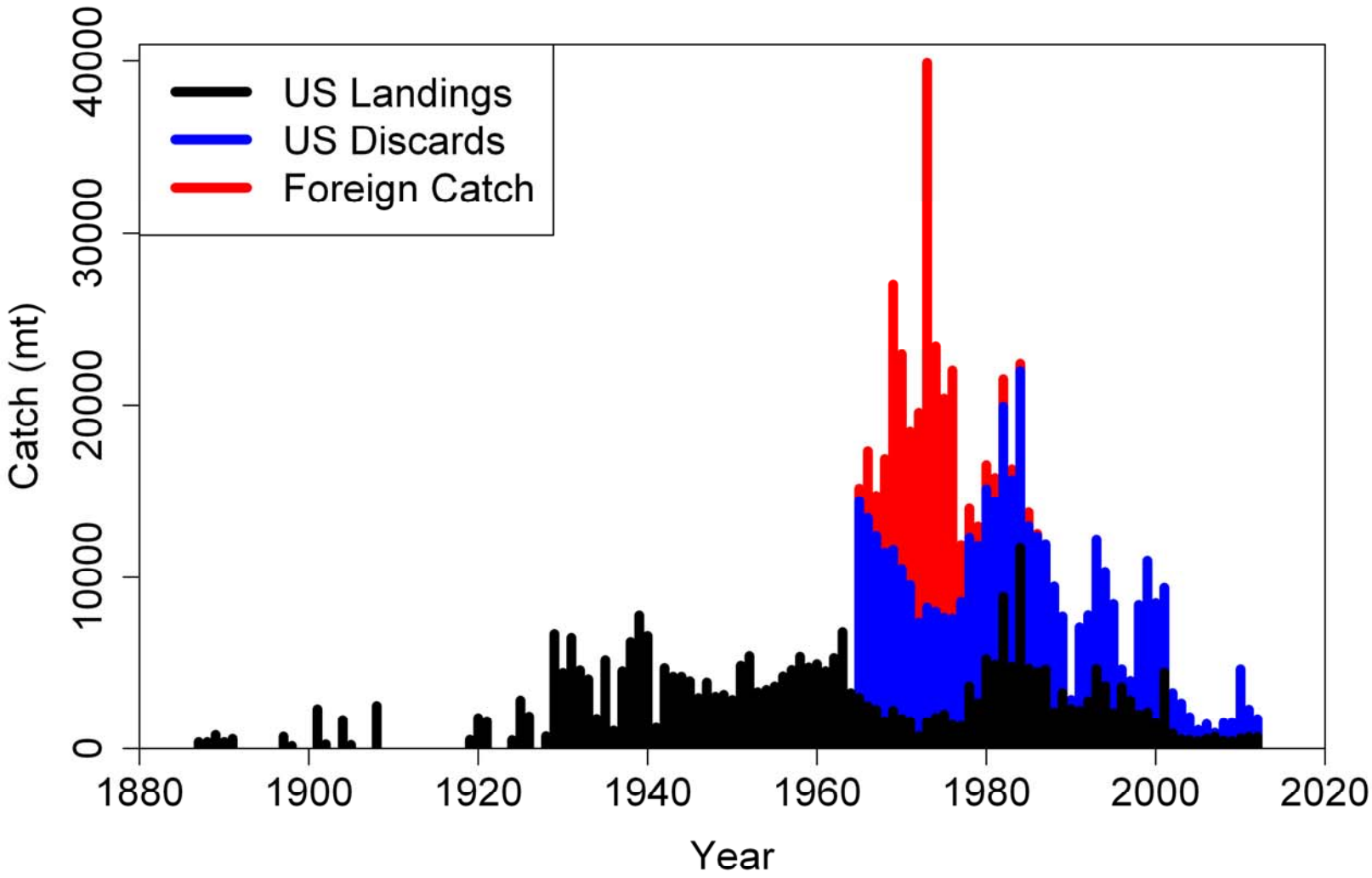

Figure 1. Butterfish (*Peprilus triacanthus*) total catch, 1887–2012. Annual catch data are missing for some years prior to 1930. Discards are unavailable prior to 1965. Total catch 1965–1988 includes discards estimated by applying an average of discard rates for trawl gear 1989–1999 to annual landings of all species 1965–1988 by trawl gear.

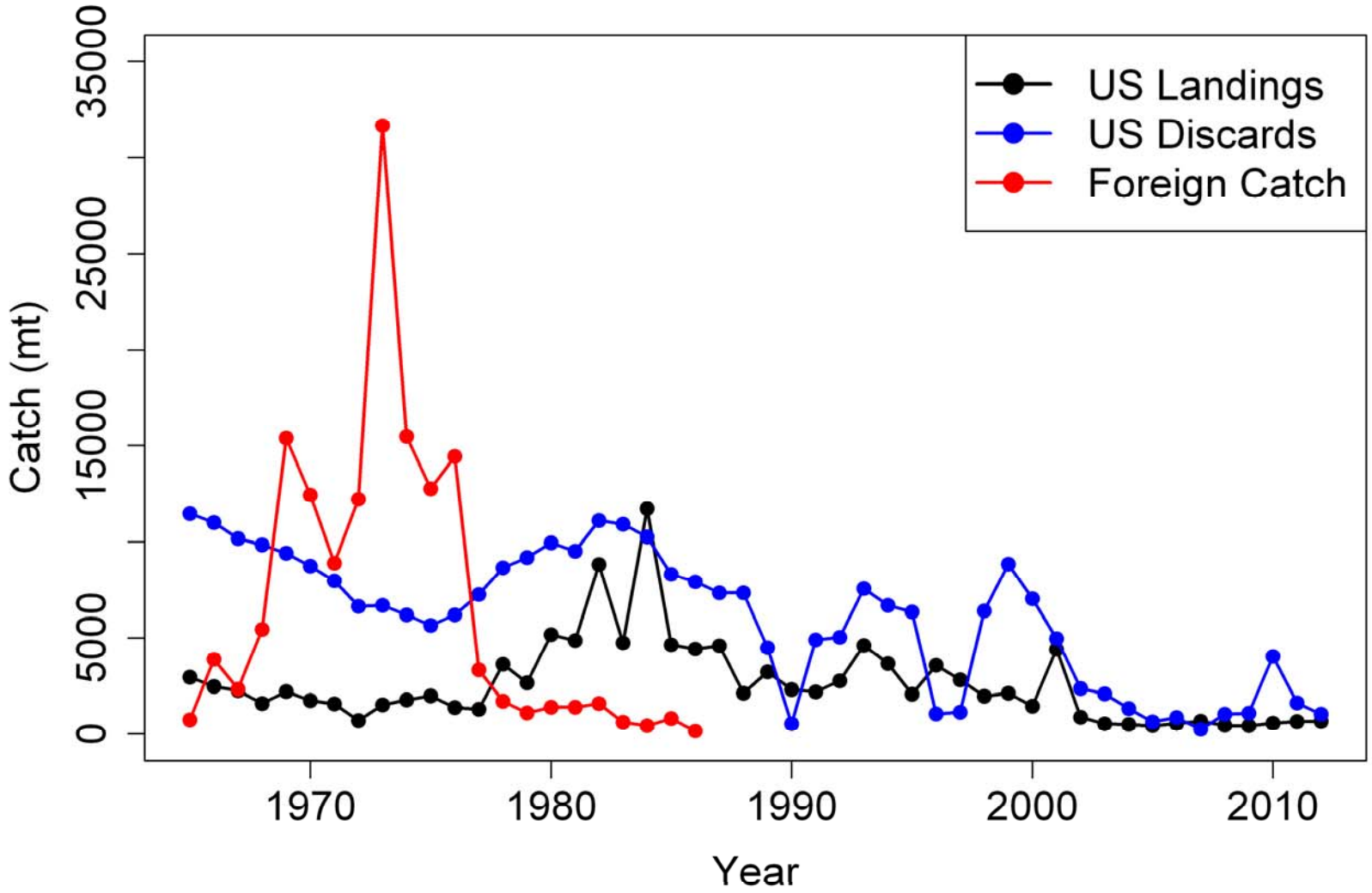

Figure 2. USA landings, USA discards, and foreign catch of butterfish (*Peprilus triacanthus*), 1965–2012.

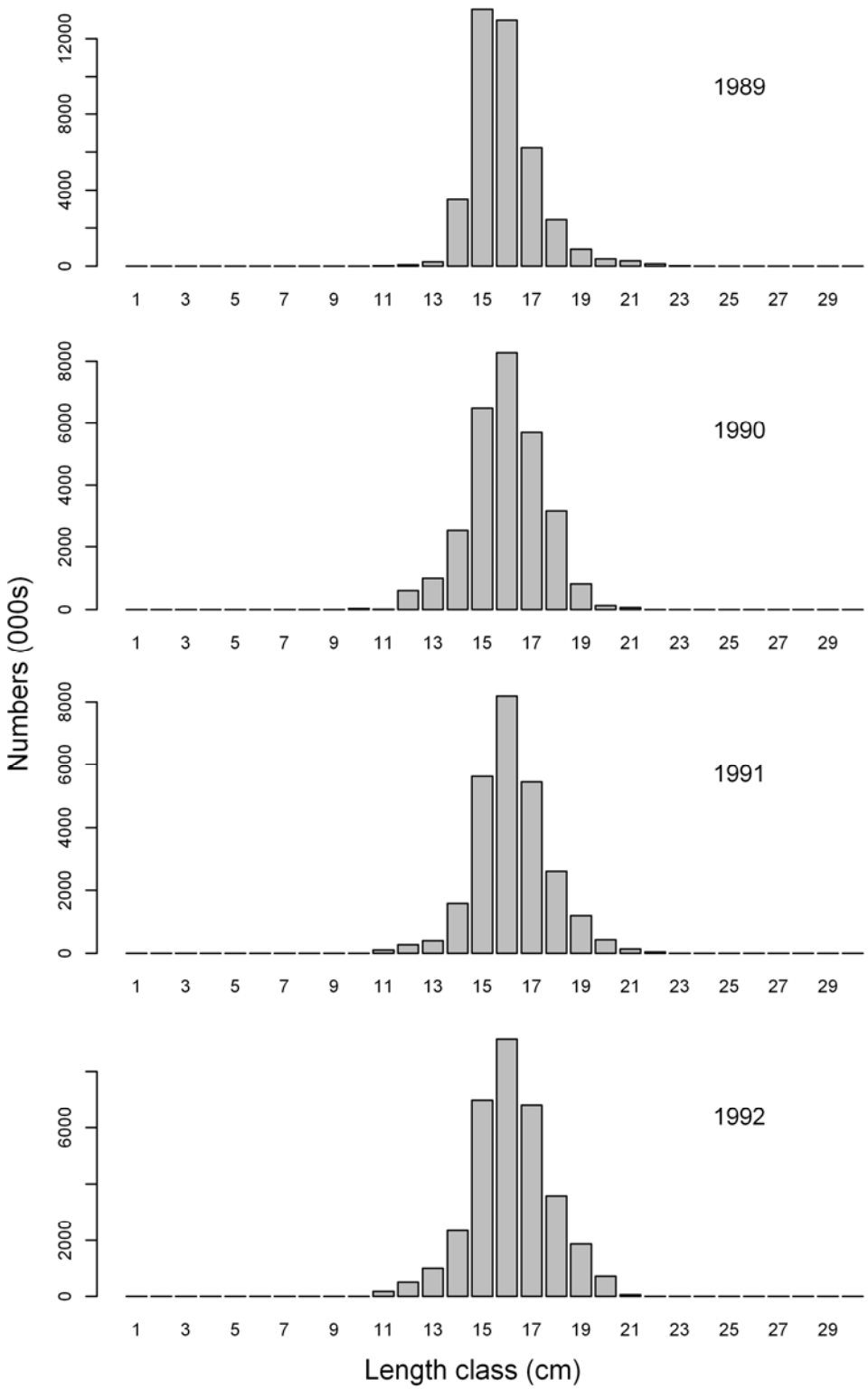

Figure 3. Size composition data from New England and Mid-Atlantic commercial landings of butterfish (*Peprilus triacanthus*), 1989–1992. Note the Y-axis varies by year.

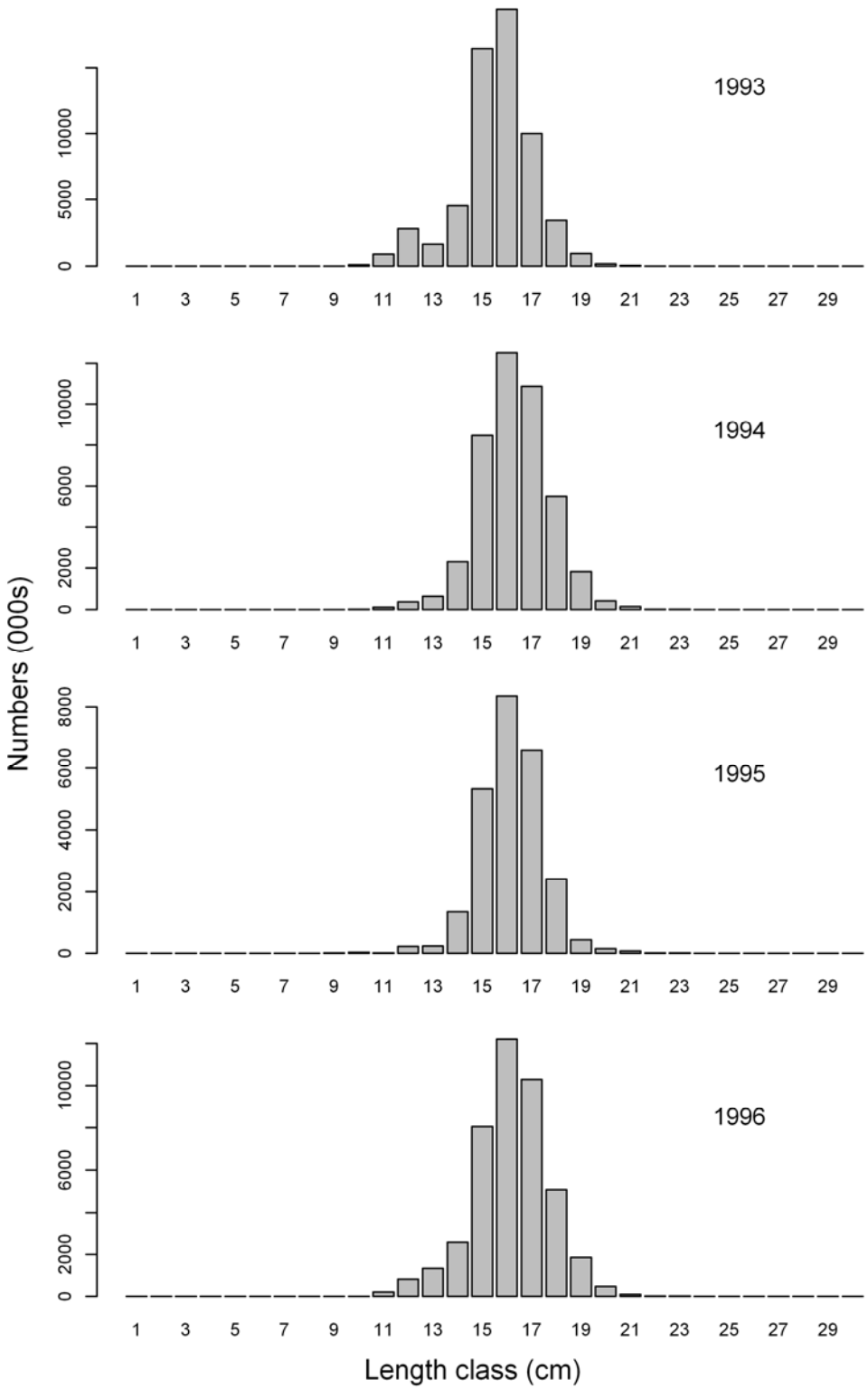

Figure 4. Size composition data from New England and Mid-Atlantic commercial landings of butterfish (*Peprilus triacanthus*), 1993–1996. Note the Y-axis varies by year.

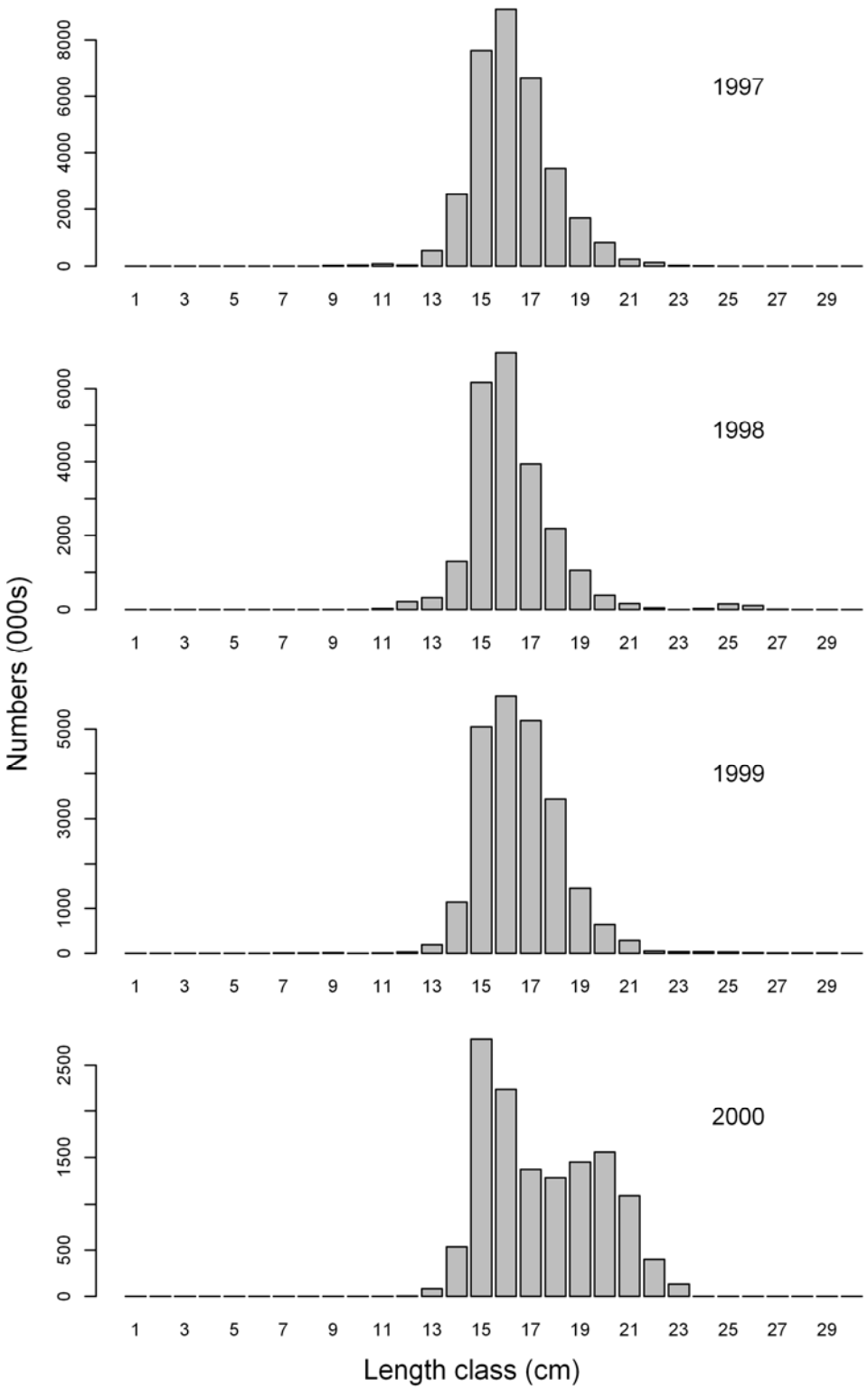

Figure 5. Size composition data from New England and Mid-Atlantic commercial landings of butterfish (*Peprilus triacanthus*), 1997–2000. Note the Y-axis varies by year.

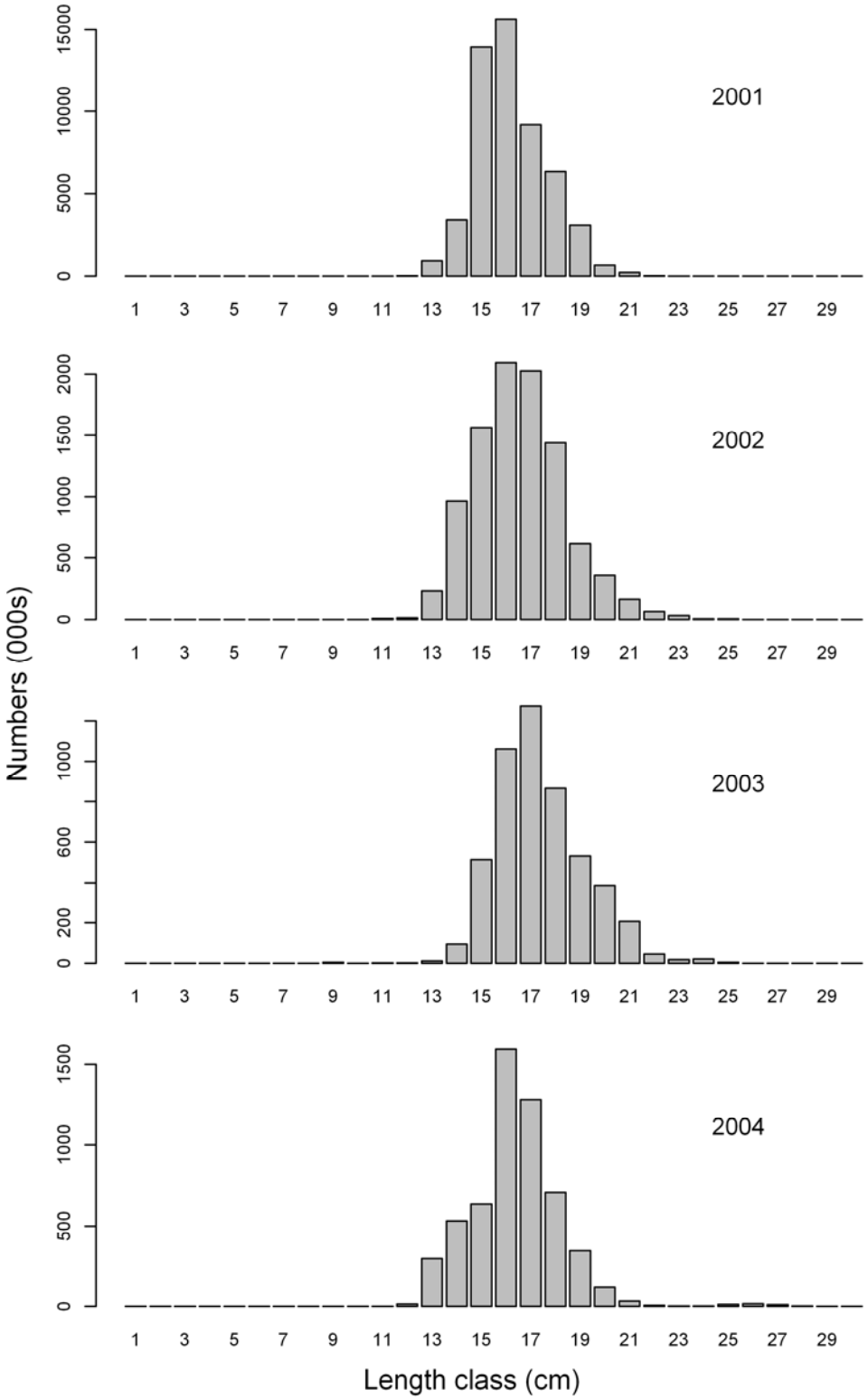

Figure 6. Size composition data from New England and Mid-Atlantic commercial landings of butterfish (*Peprilus triacanthus*), 2001–2004. Note the Y-axis varies by year.

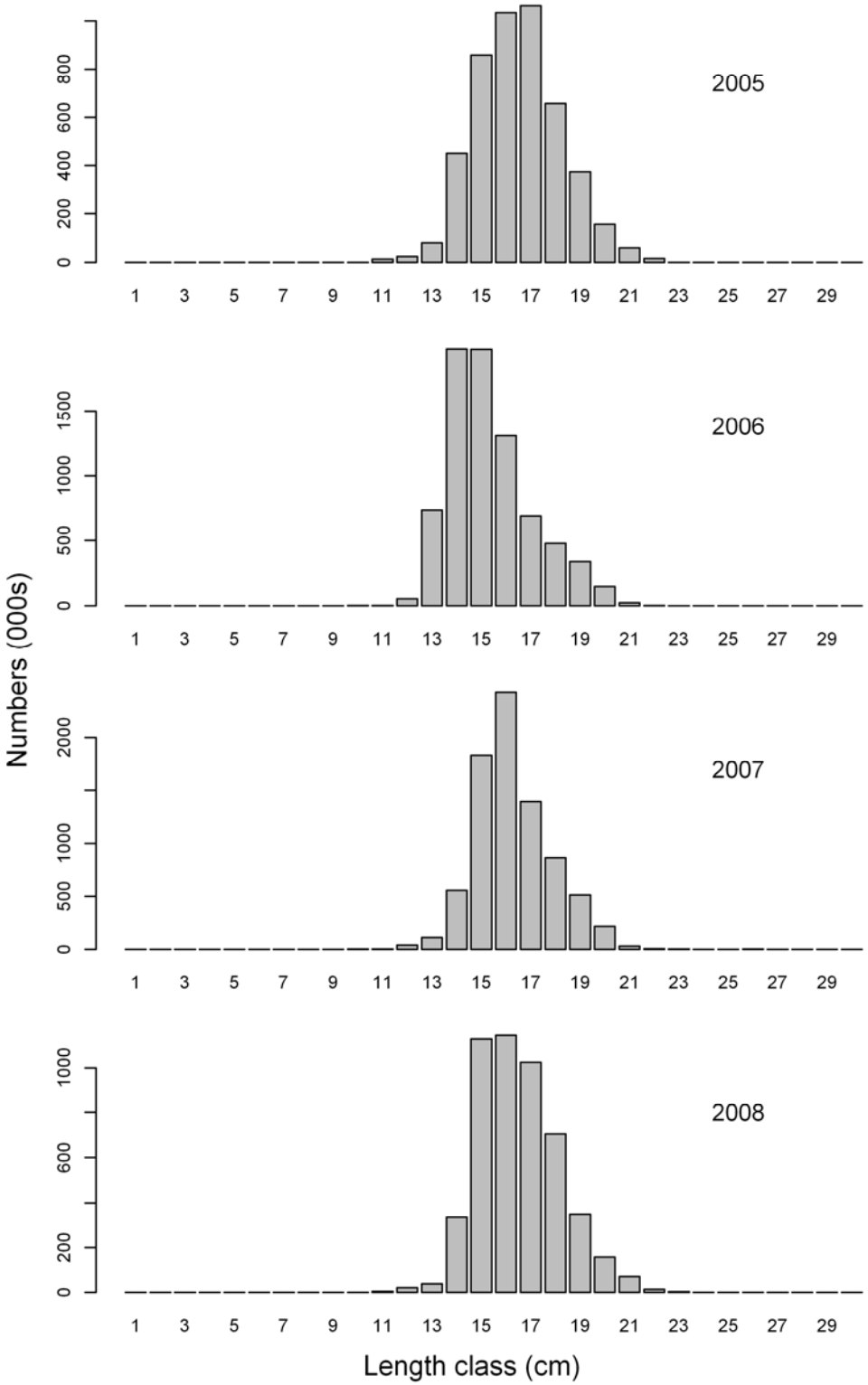

Figure 7. Size composition data from New England and Mid-Atlantic commercial landings of butterfish (*Peprilus triacanthus*), 2005–2008. Note the Y-axis varies by year.

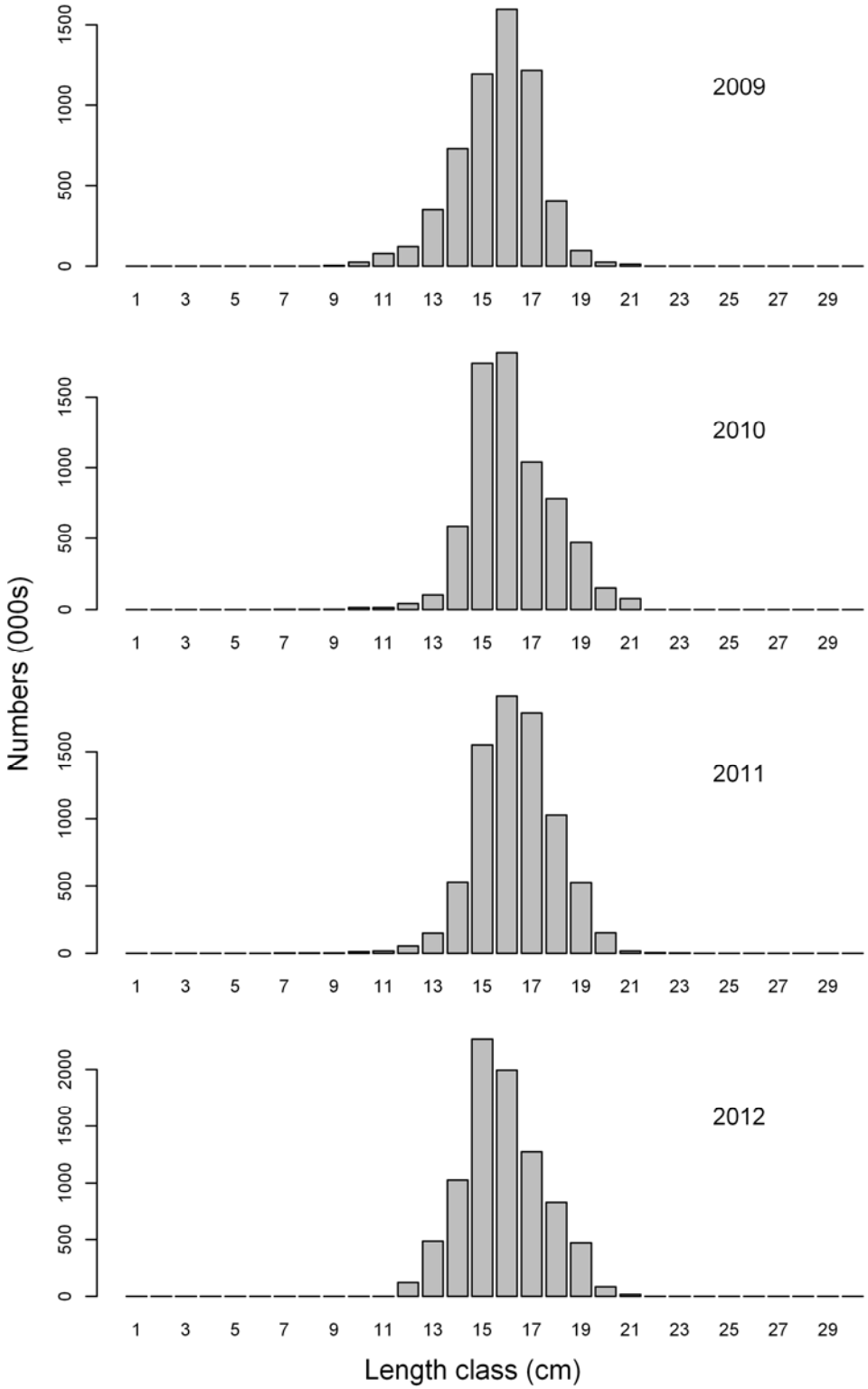

Figure 8. Size composition data from New England and Mid-Atlantic commercial landings of butterfish (*Peprilus triacanthus*), 2009–2012. Note the Y-axis varies by year.

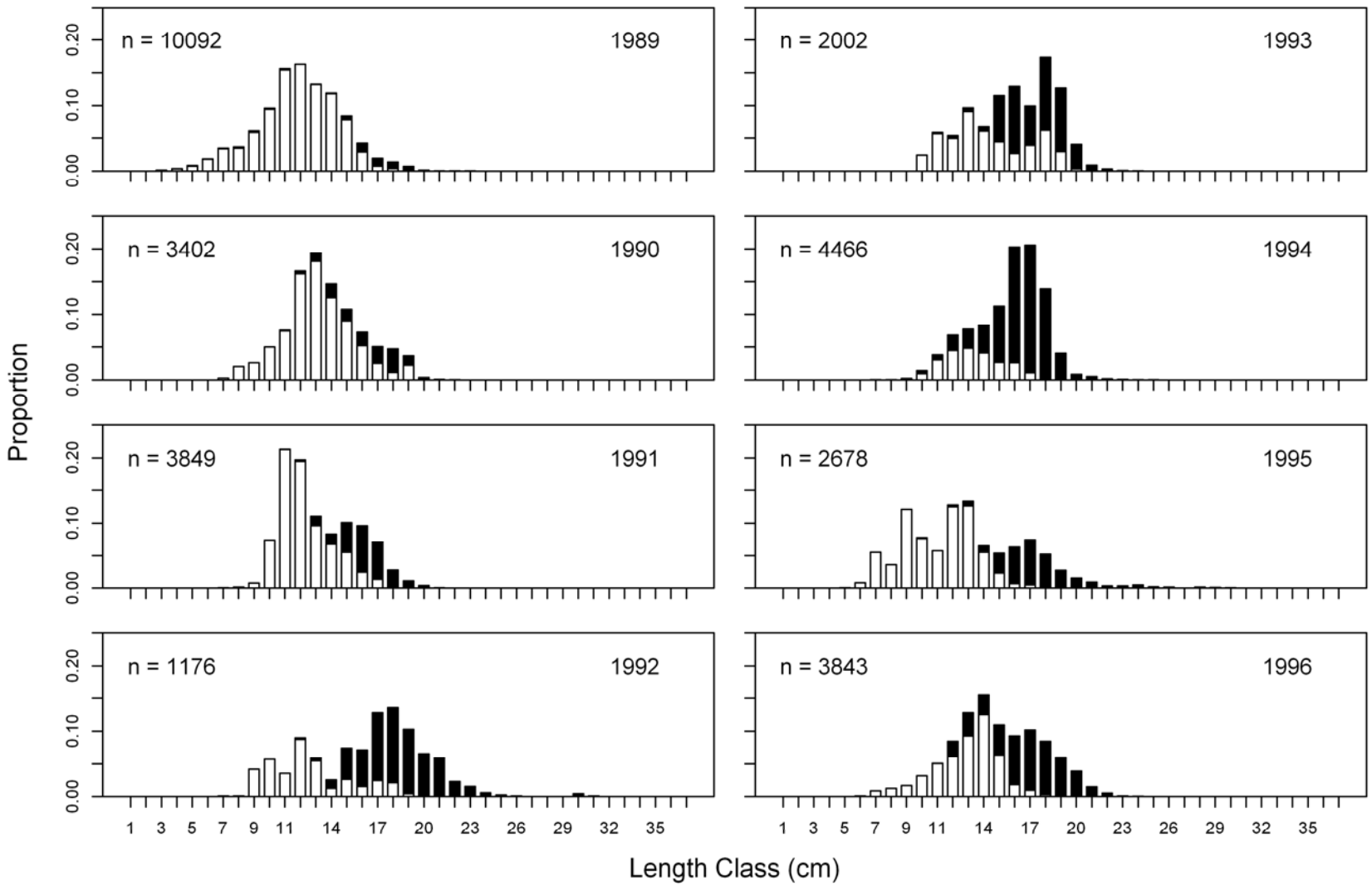

Figure 9. Length composition of butterfish (*Peprilus triacanthus*) from National Marine Fisheries Service Observer Program, 1989–1996, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

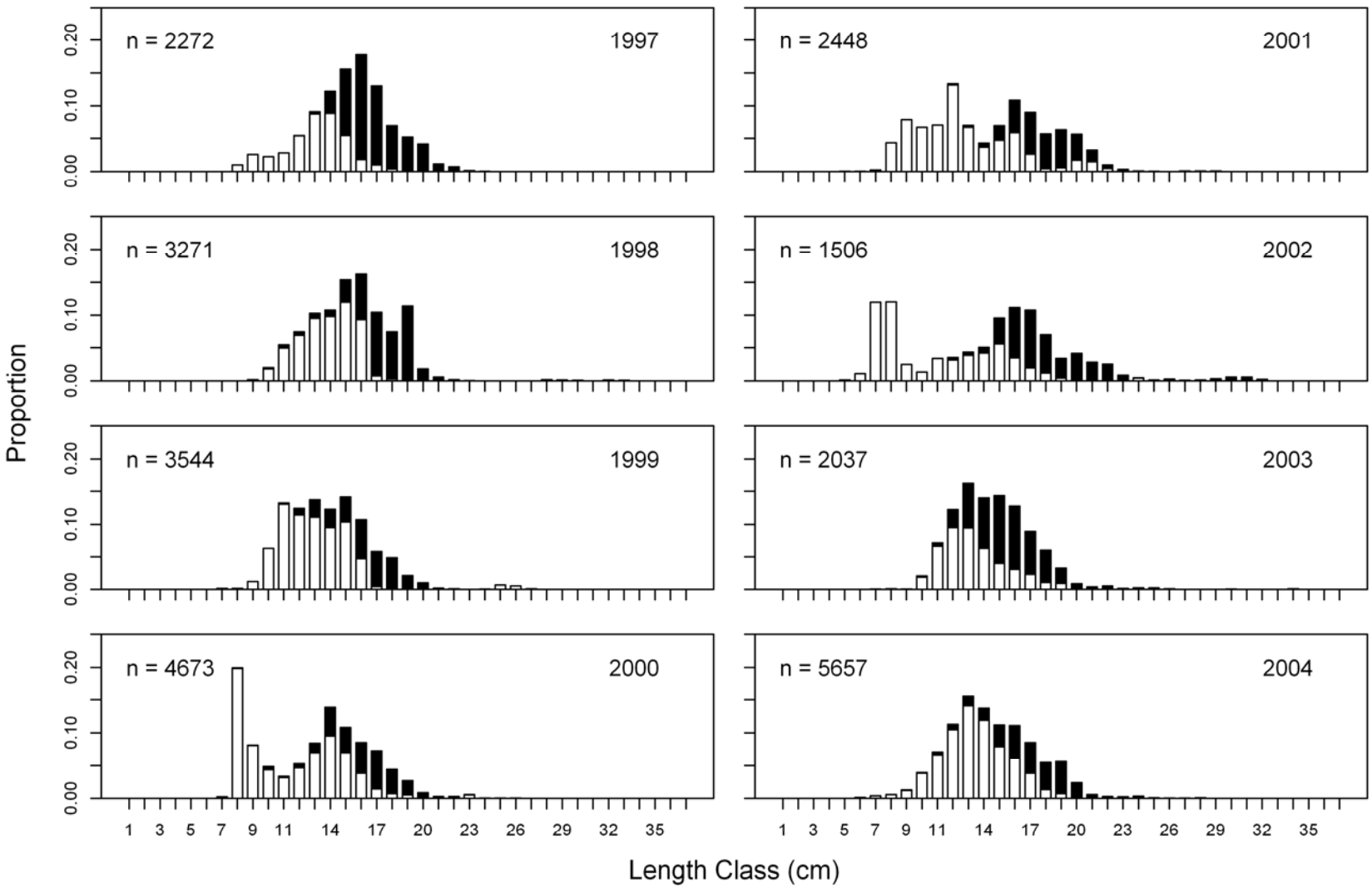

Figure 10. Length composition of butterfish (*Peprilus triacanthus*) from National Marine Fisheries Service Observer Program, 1997–2004, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

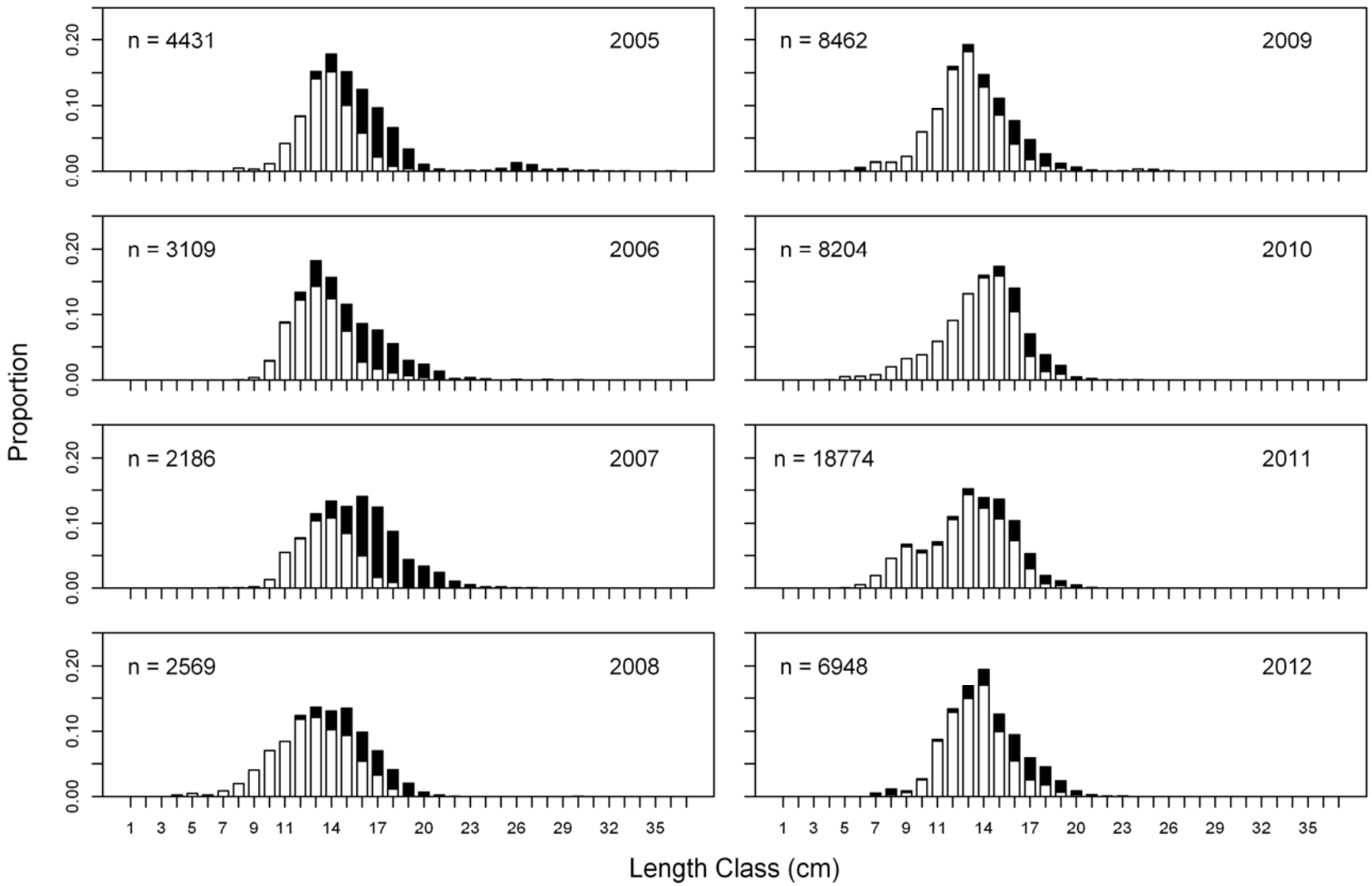

Figure 11. Length composition of butterfish (*Peprilus triacanthus*) from National Marine Fisheries Service Observer Program, 2005–2012, with kept fish in black and discards in white. Bars are stacked. Size of a bar of a given color is the proportion of total length samples in the length interval and corresponding disposition.

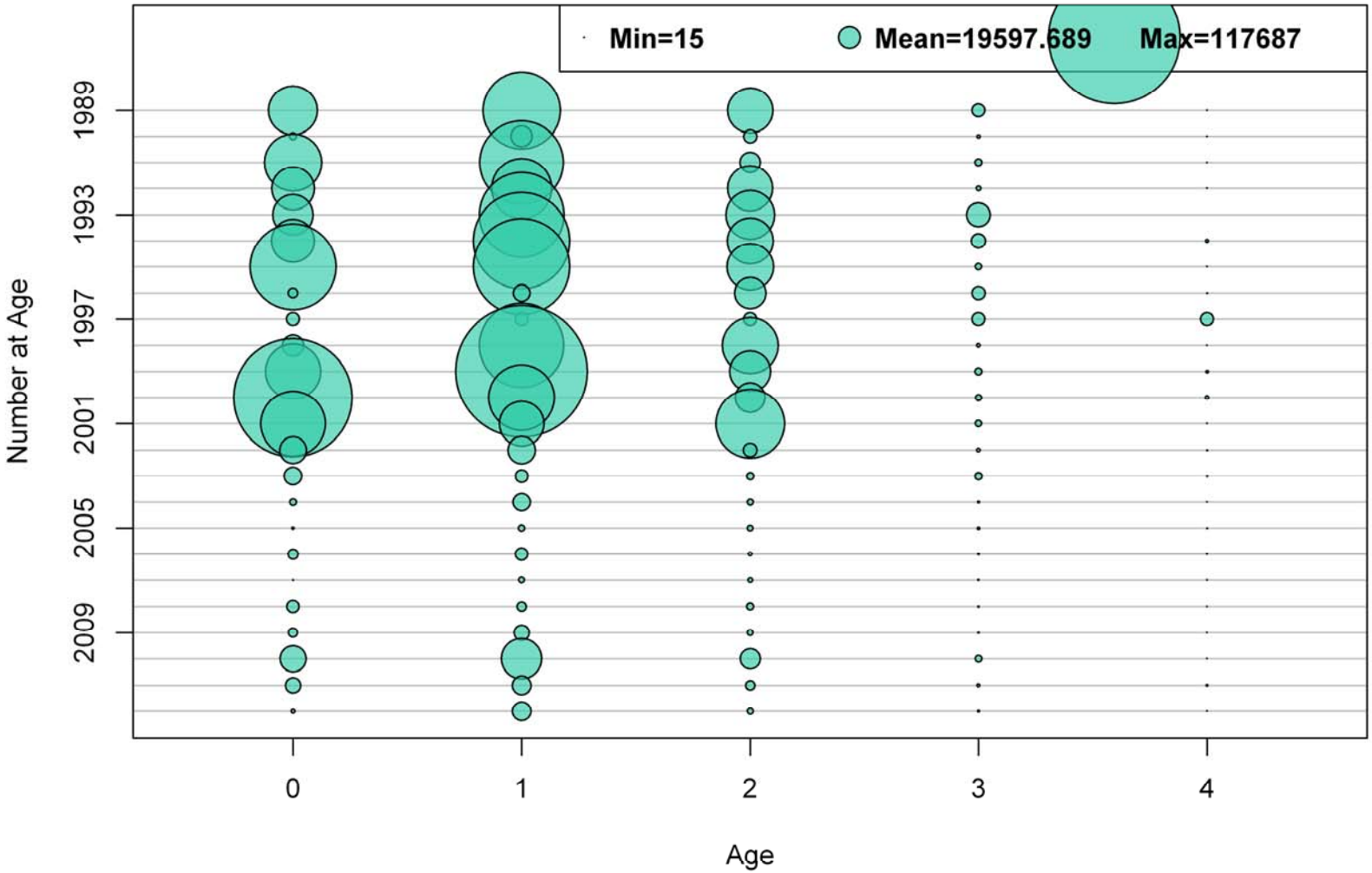

Figure 12. Butterfish (*Peprilus triacanthus*) commercial catch (number) at age, 1989–2012.

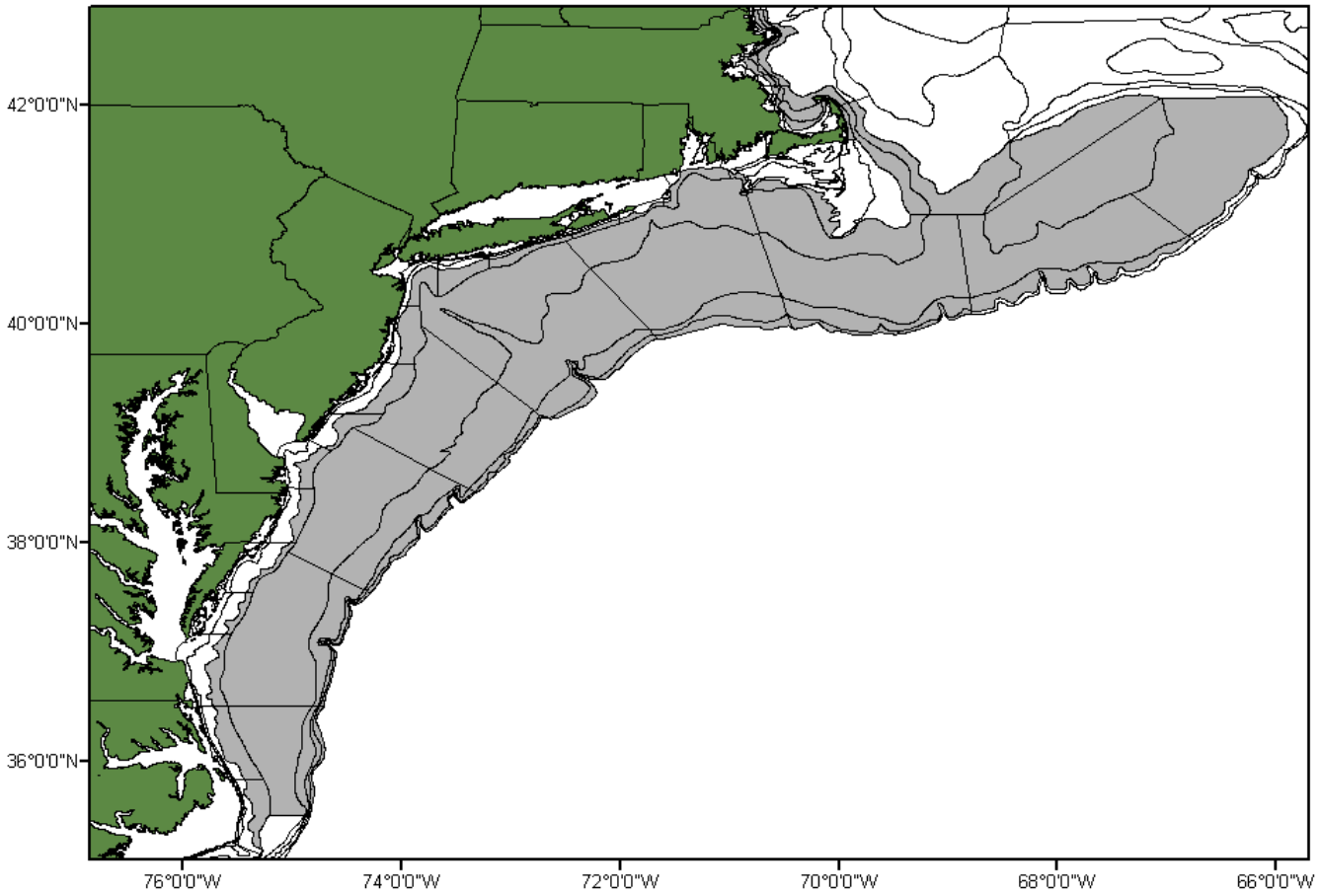

Figure 13. Strata (in gray) used for Northeast Fisheries Science Center offshore indices for butterfish (*Peprilus triacanthus*), 1989–2012. Strata include the outermost inshore strata (2, 5, 8, 11, 14, 17, 20, 23, 26, 29, 32, 35, 38, 41, 44–46, 56, 59–61, and 64–66) and offshore strata (1–14, 16, 19, 20, 23, 25, and 61–76).

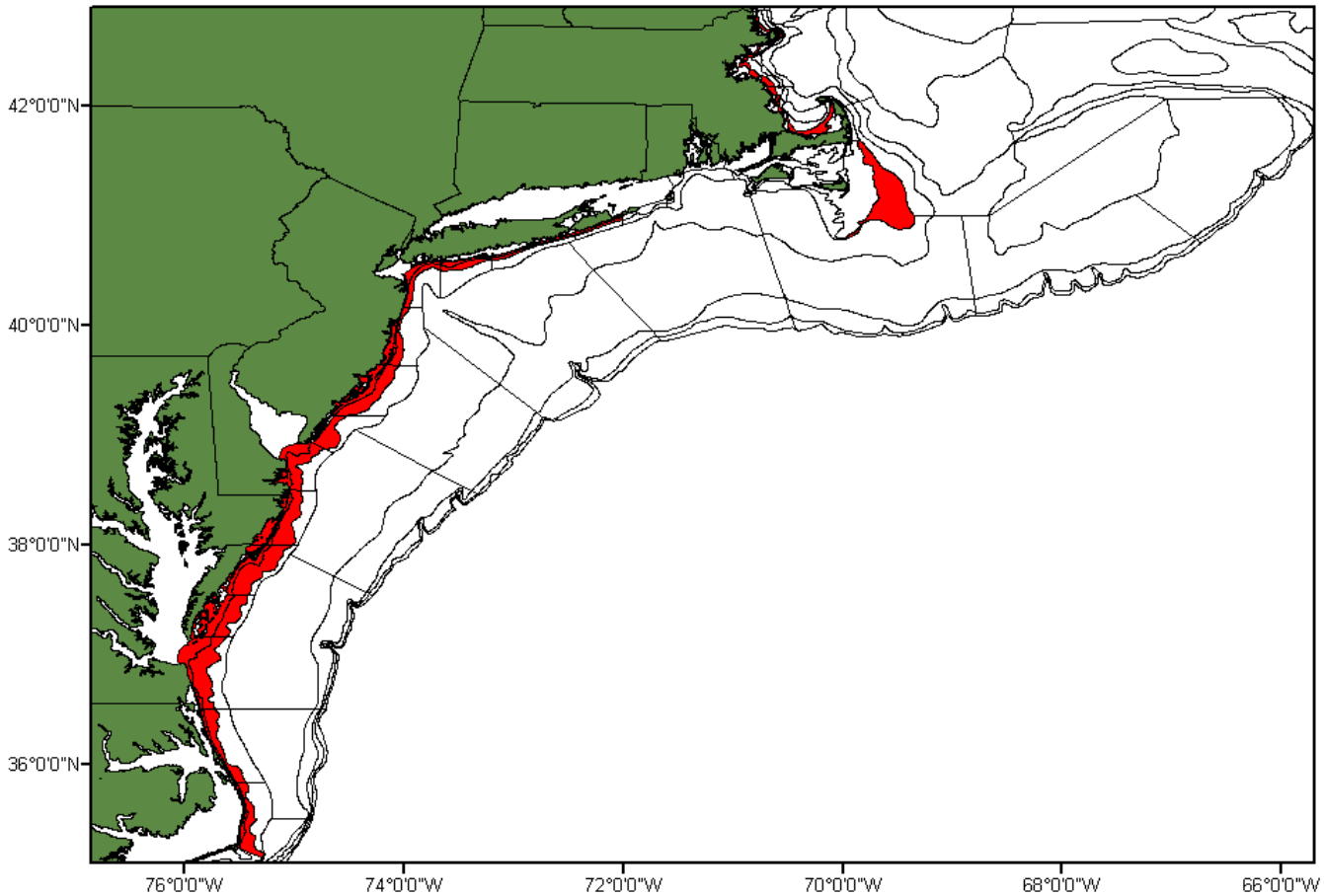

Figure 14. Strata (in red) used for Northeast Fisheries Science Center inshore indices for butterfish (*Peprilus triacanthus*), 1989–2008. Strata include the 2 innermost inshore strata (3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19, 21, 22, 24, 25, 27, 28, 30, 31, 33, 34, 36, 37, 39, 40, 42, 43, 55, 58, and 63).

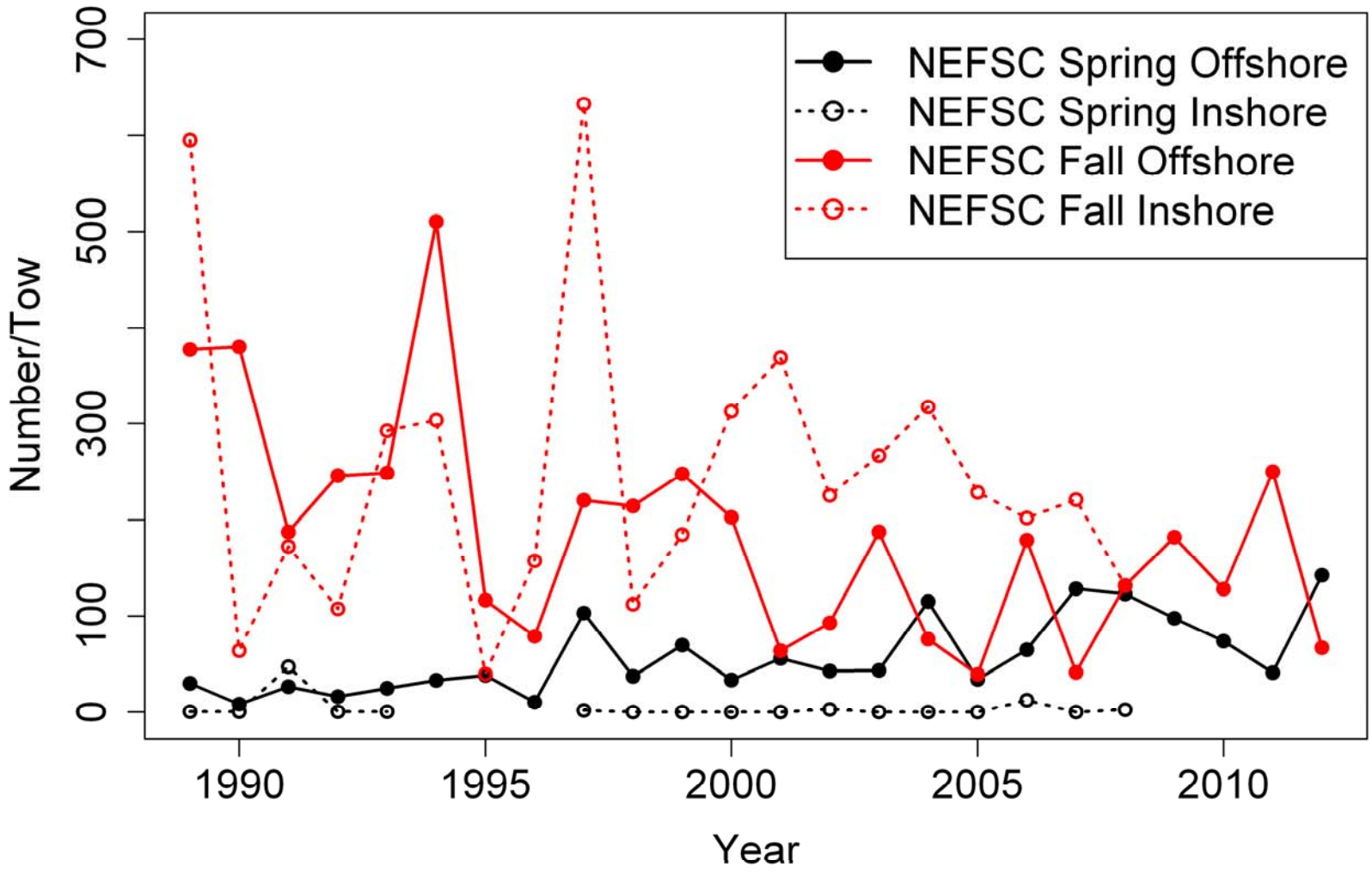

Figure 15. Northeast Fisheries Science Center (NEFSC) spring offshore, spring inshore, fall offshore and fall inshore survey stratified mean number per tow for butterfish (*Peprilus triacanthus*).

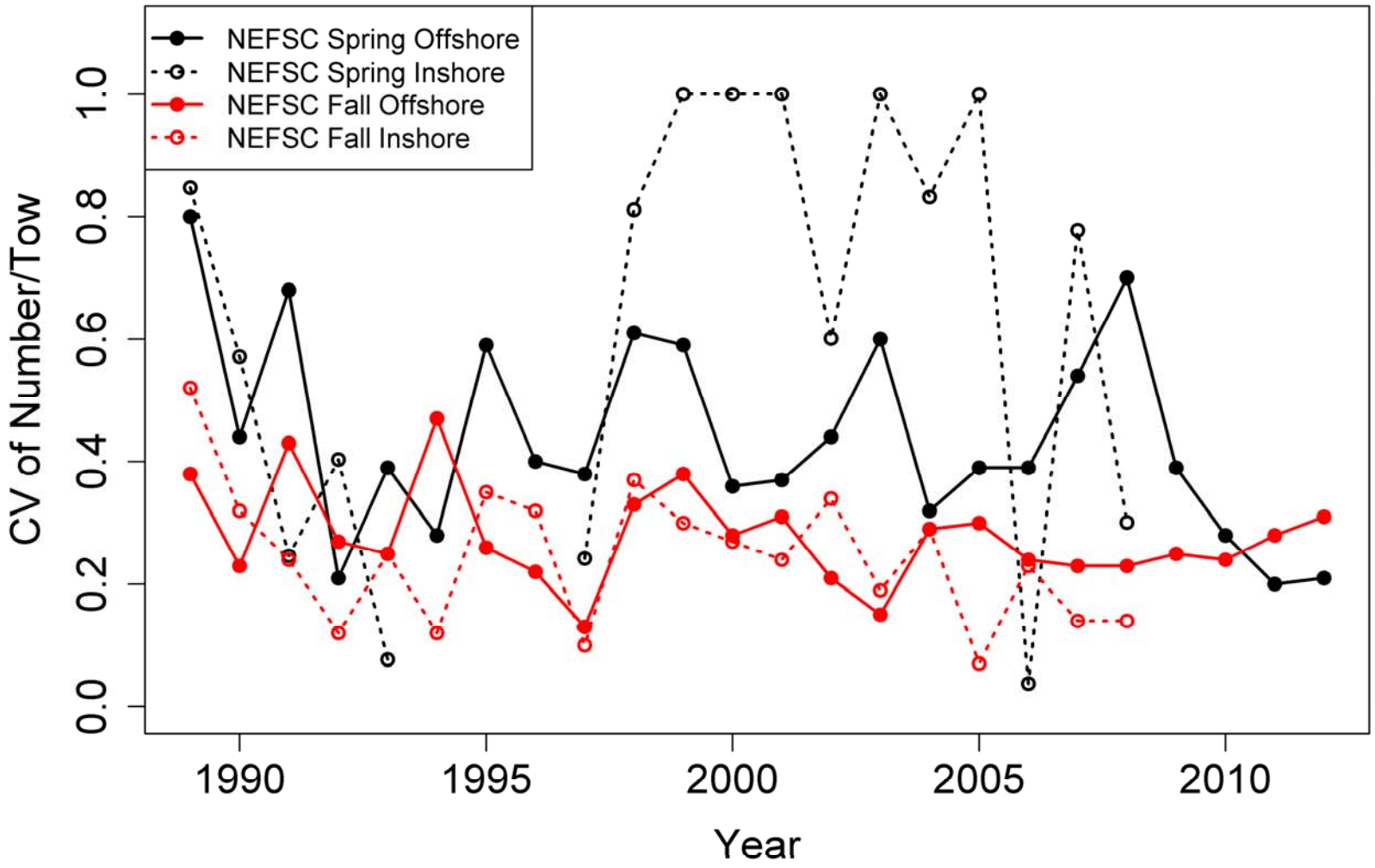

Figure 16. Coefficient of variation (CV) for Northeast Fisheries Science Center (NEFSC) spring offshore, spring inshore, fall offshore, and fall inshore survey stratified mean number per tow for butterfish (*Peprilus triacanthus*).

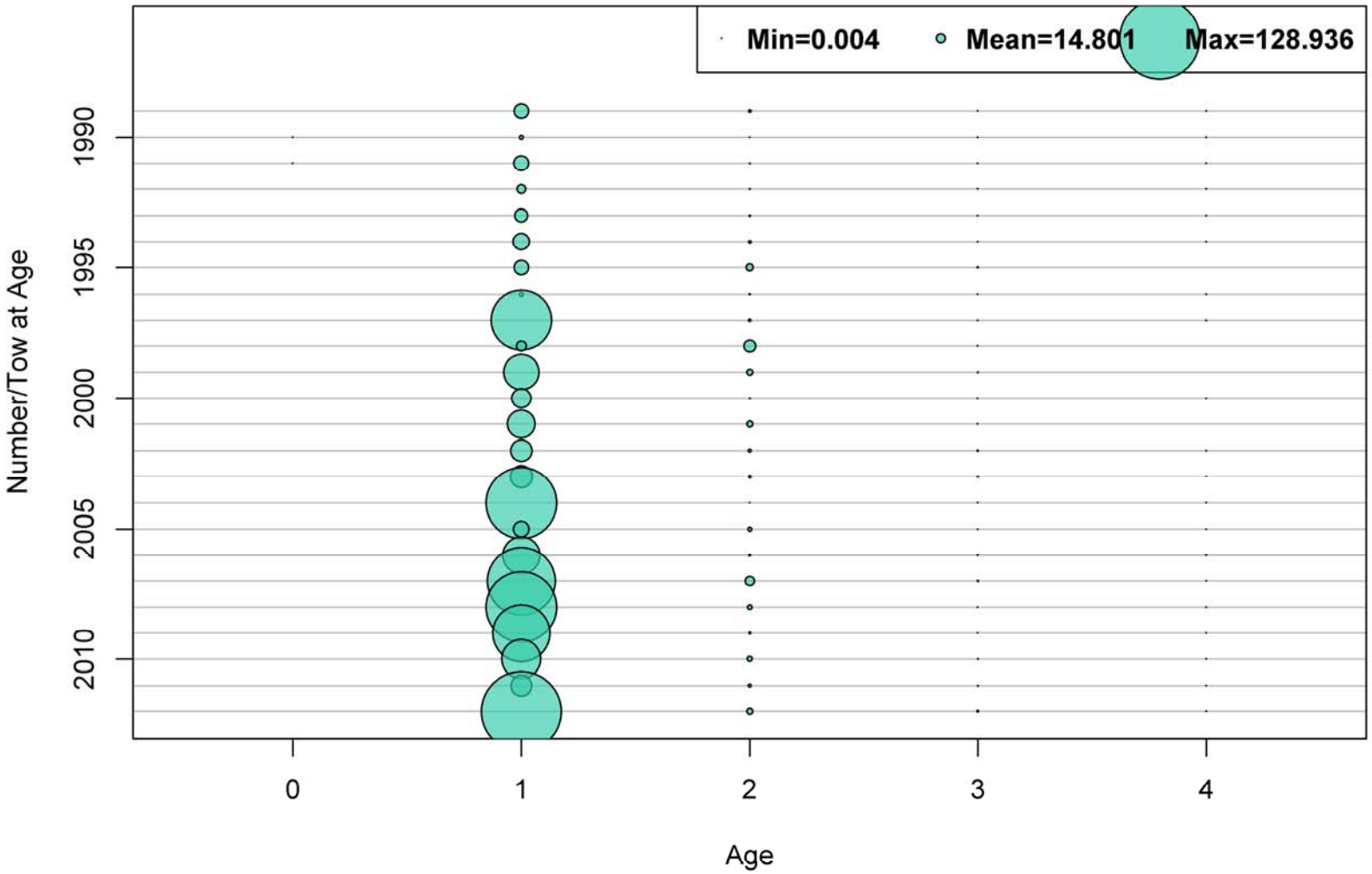

Figure 17. Age composition of butterfish (*Peprilus triacanthus*) in Northeast Fisheries Science Center (NEFSC) spring offshore surveys, 1989–2012. Note: different scaling as compared with the other NEFSC age composition plots.

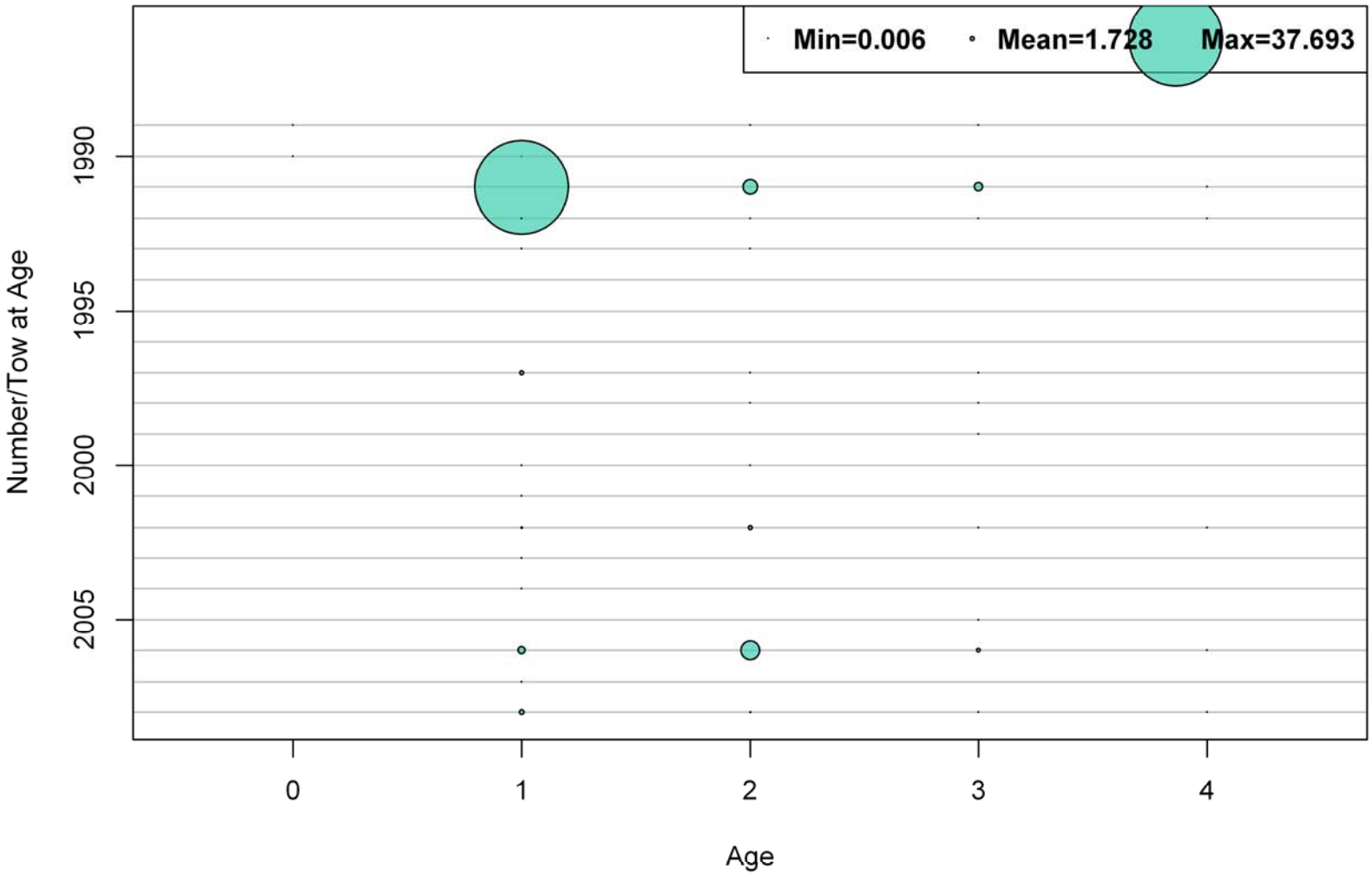

Figure 18. Age composition of butterfish (*Peprilus triacanthus*) in Northeast Fisheries Science Center (NEFSC) spring inshore surveys, 1989–2008. Note: different scaling as compared with the other NEFSC age composition plots.

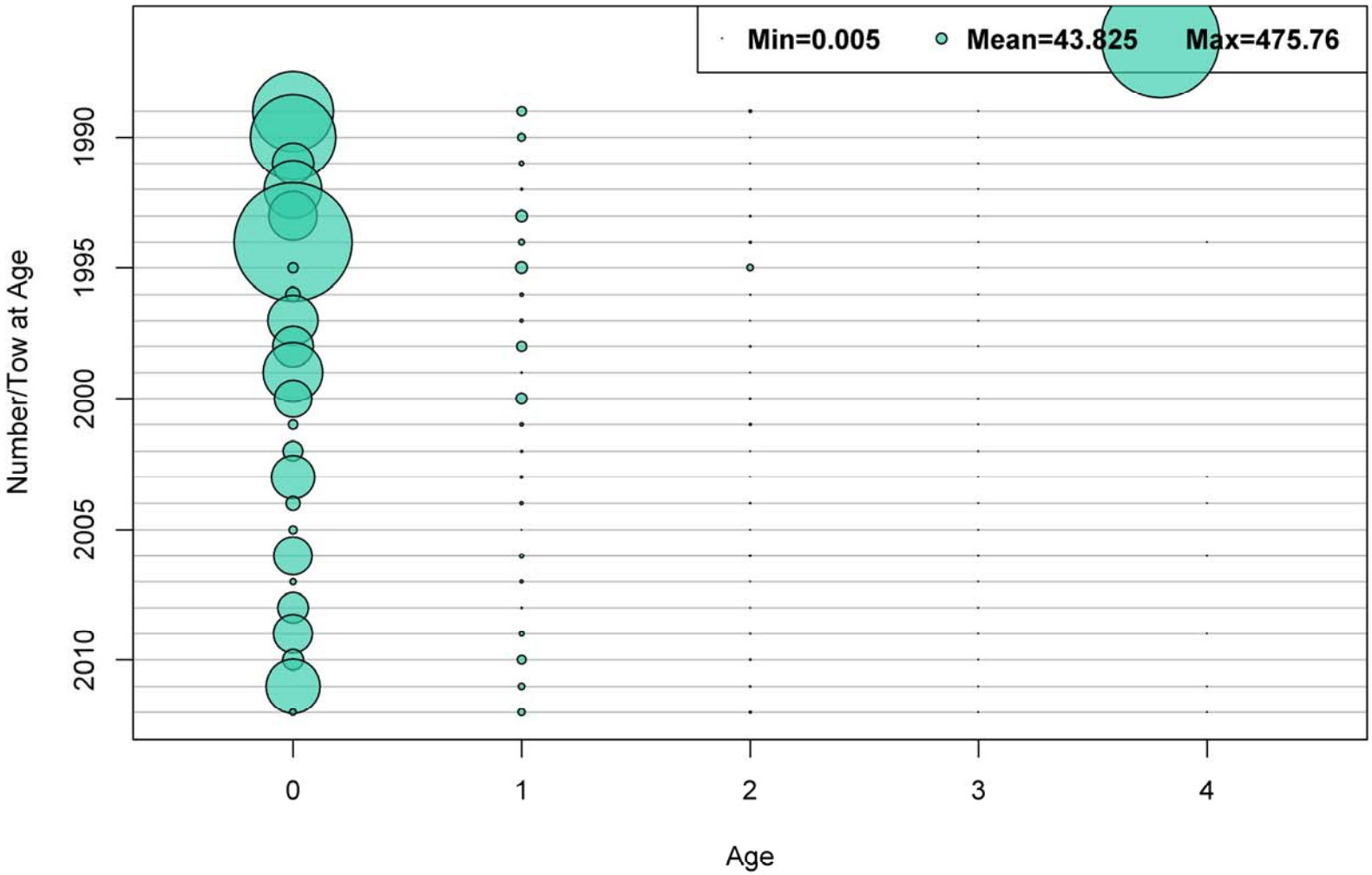

Figure 19. Age composition of butterfish (*Peprilus triacanthus*) in Northeast Fisheries Science Center fall offshore surveys, 1989–2012.

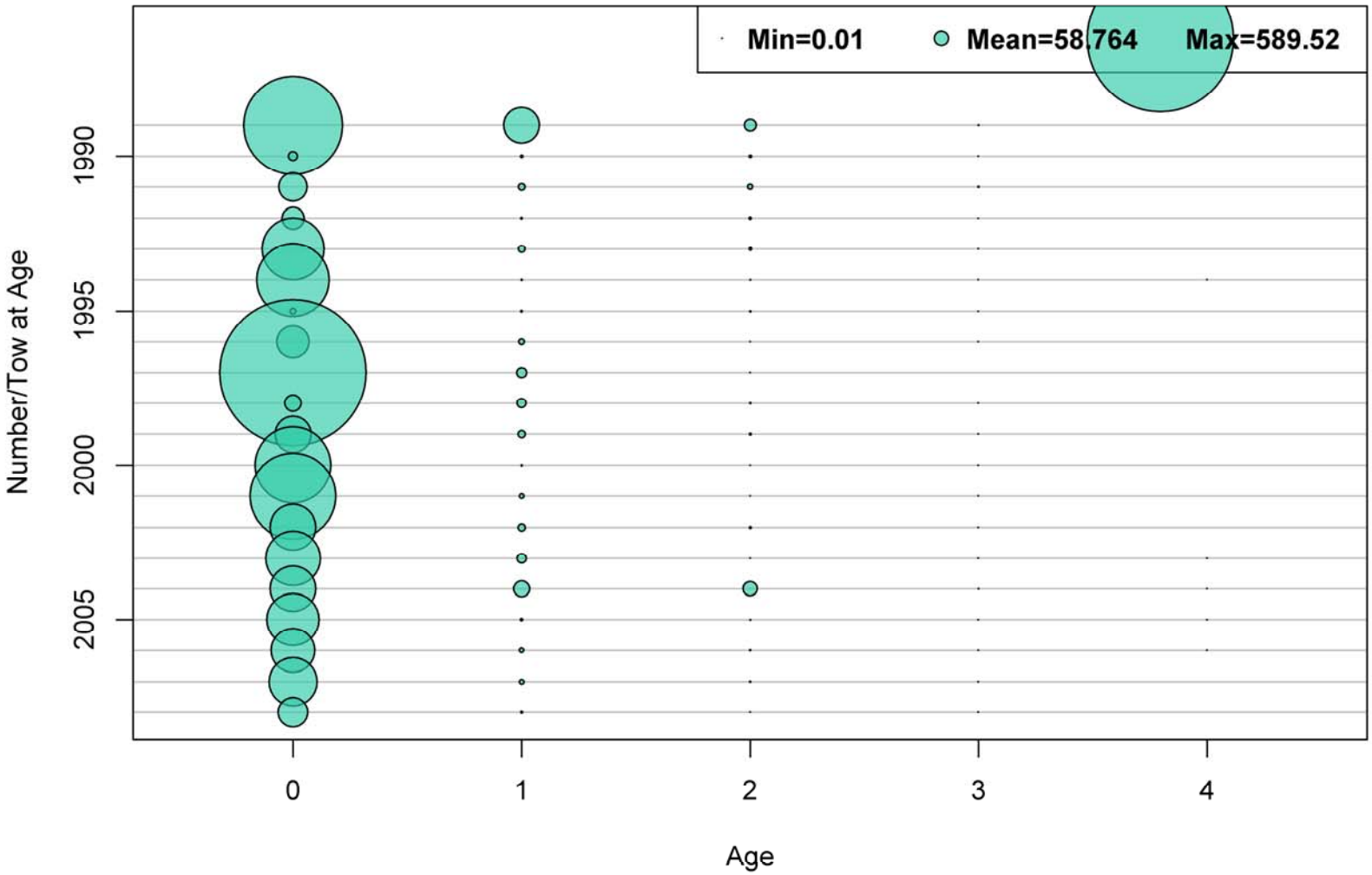

Figure 20. Age composition of butterfish (*Peprilus triacanthus*) in Northeast Fisheries Science Center fall inshore surveys, 1989–2008.

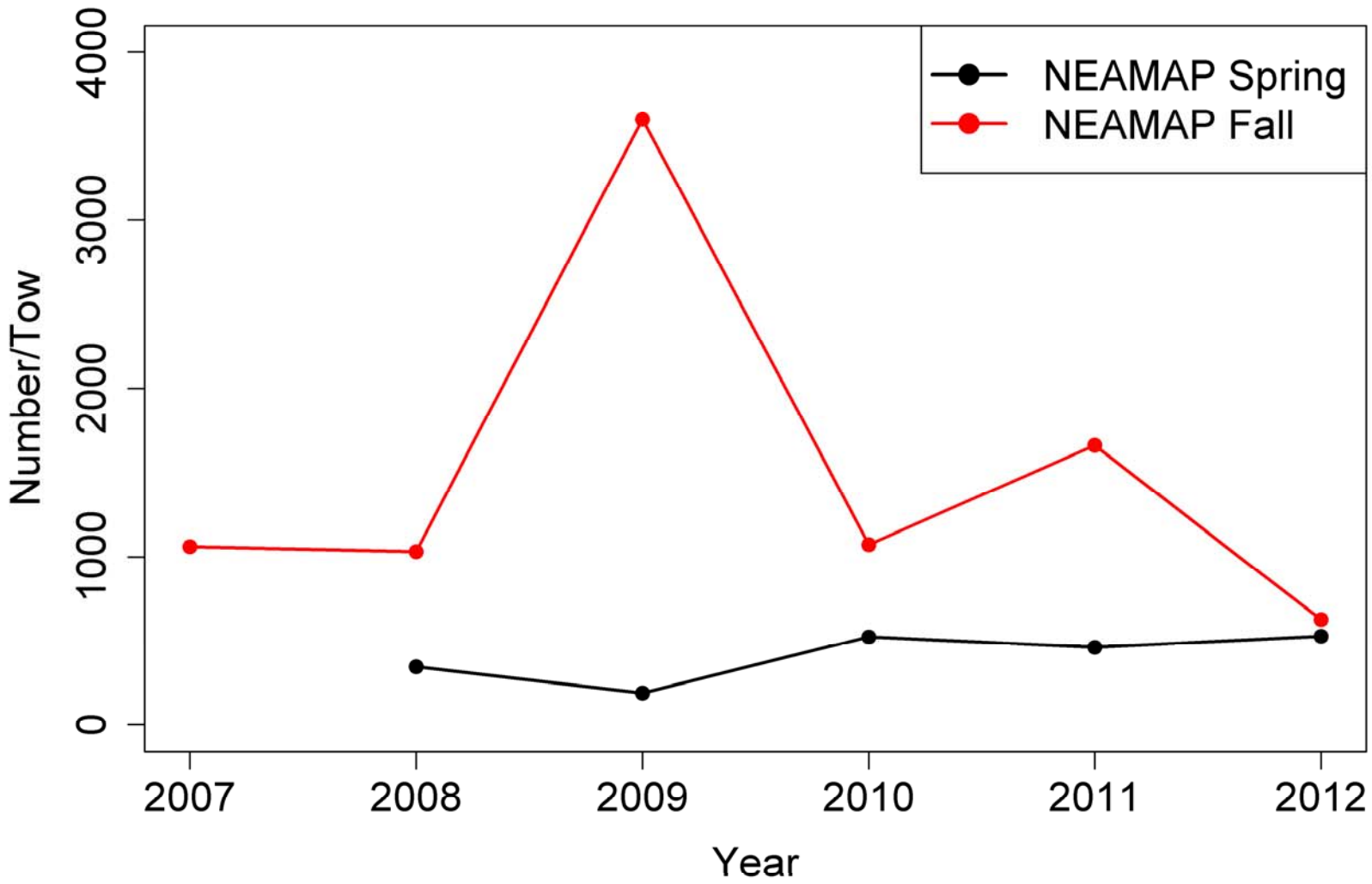

Figure 21. Northeast Area Monitoring and Assessment Program (NEAMAP) spring and fall survey stratified arithmetic mean number per tow for butterfish (*Peprilus triacanthus*).

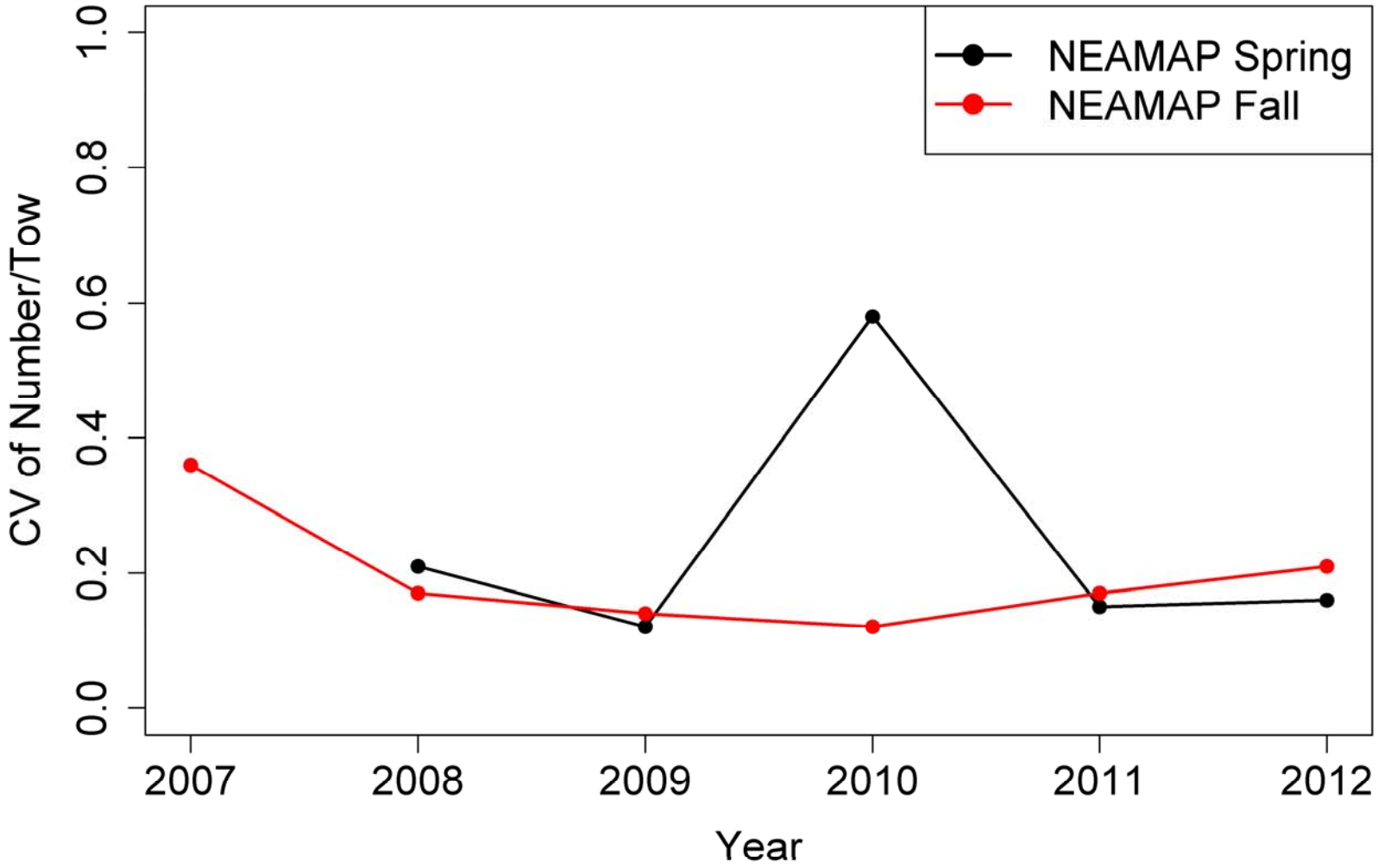

Figure 22. Coefficient of variation (CV) for Northeast Area Monitoring and Assessment Program (NEAMAP) spring and fall survey stratified mean number per tow for butterfish (*Peprilus triacanthus*).

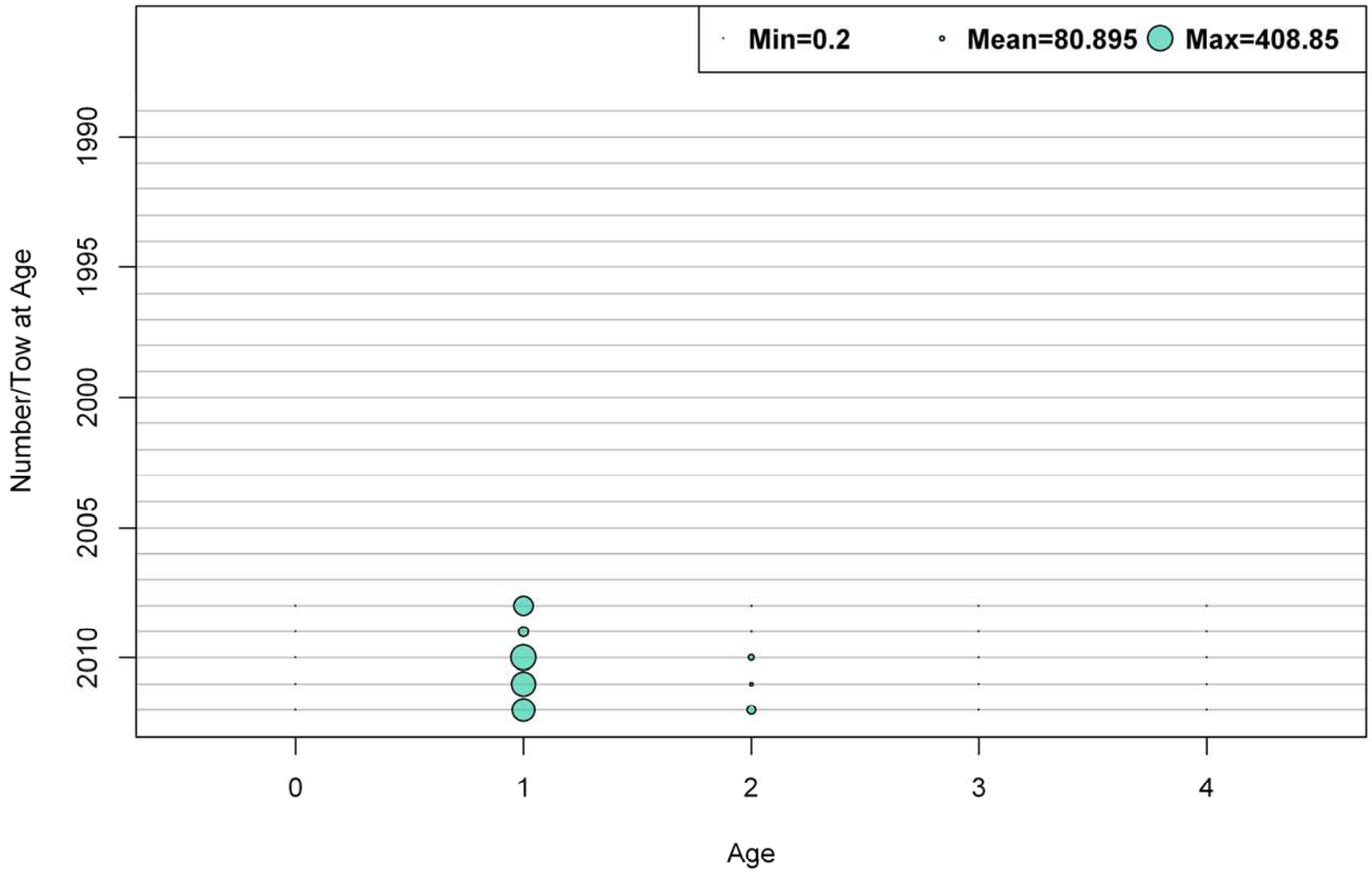

Figure 23. Age composition of butterfish (*Peprilus triacanthus*) in Northeast Area Monitoring and Assessment Program (NEAMAP) spring surveys, 2008–2012.

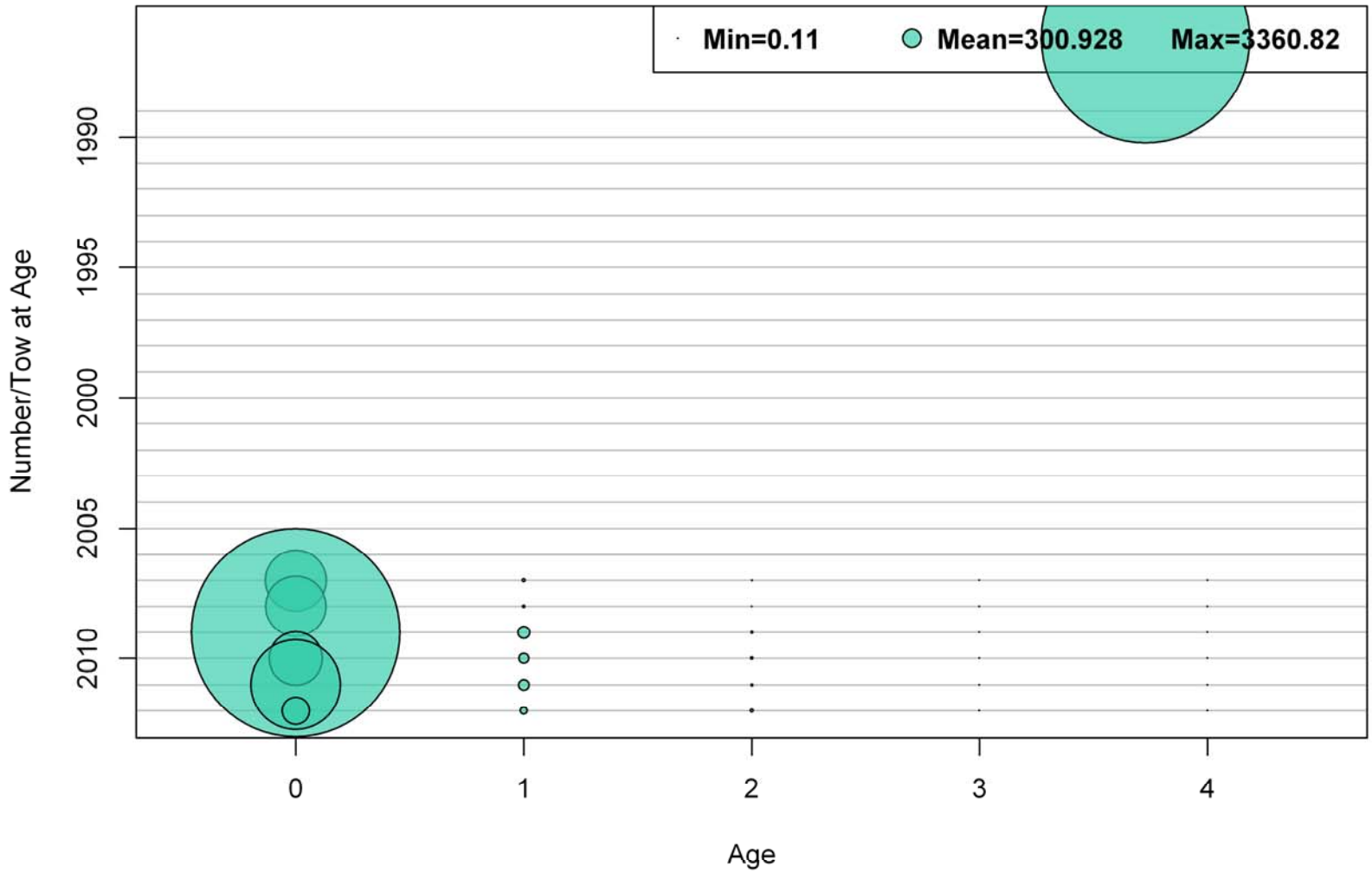

Figure 24. Age composition of butterfish (*Peprilus triacanthus*) in Northeast Area Monitoring and Assessment Program (NEAMAP) fall surveys, 2007–2012.

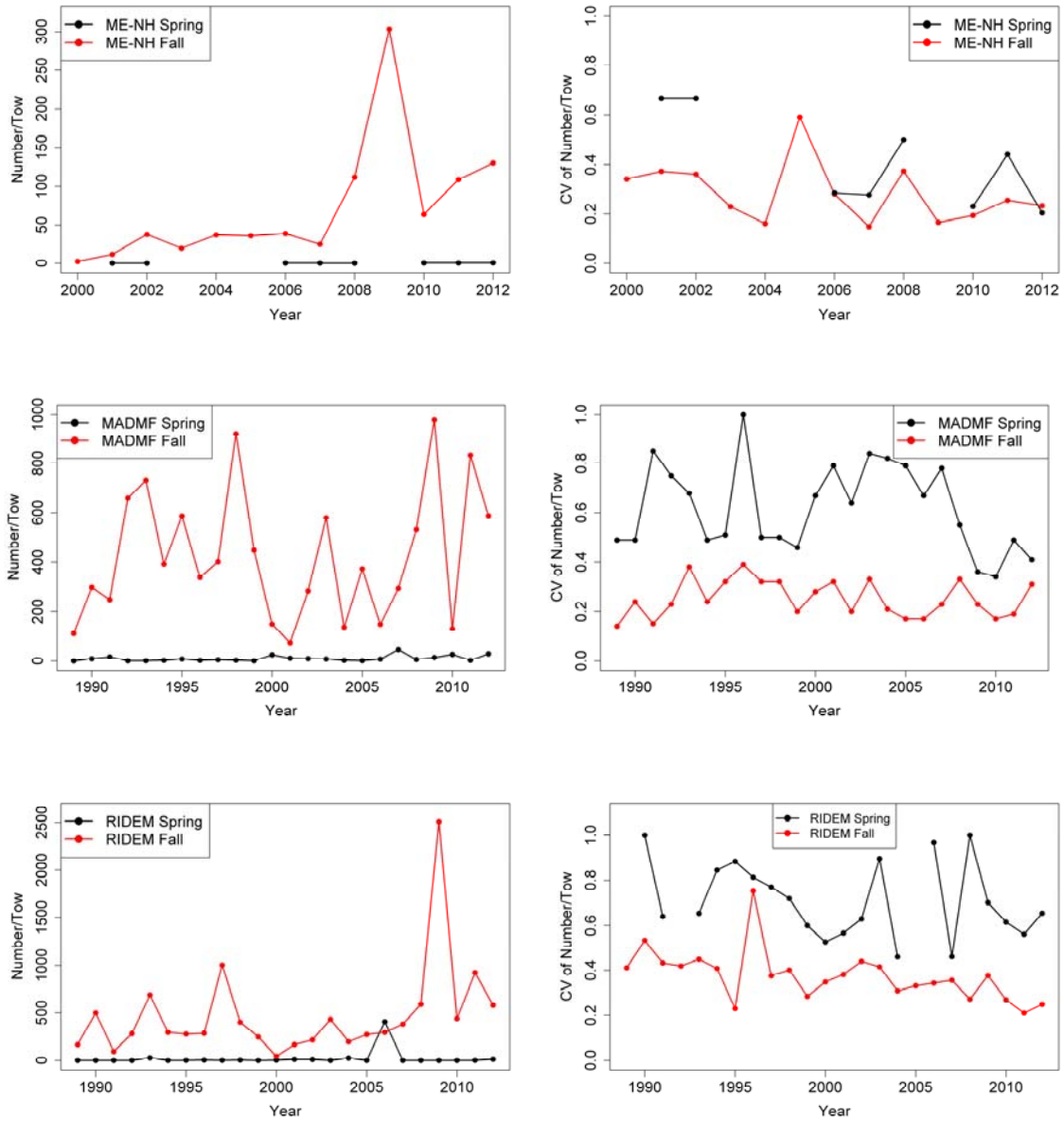

Figure 25. Mean number per tow (left column) for butterfish (*Peprilus triacanthus*) and coefficient of variation (right column) for the Maine-New Hampshire (ME-NH) (top row), Massachusetts Division of Marine Fisheries (MADMF) (middle row), and Rhode Island Department of Environmental Management (RIDEM) (bottom row) surveys.

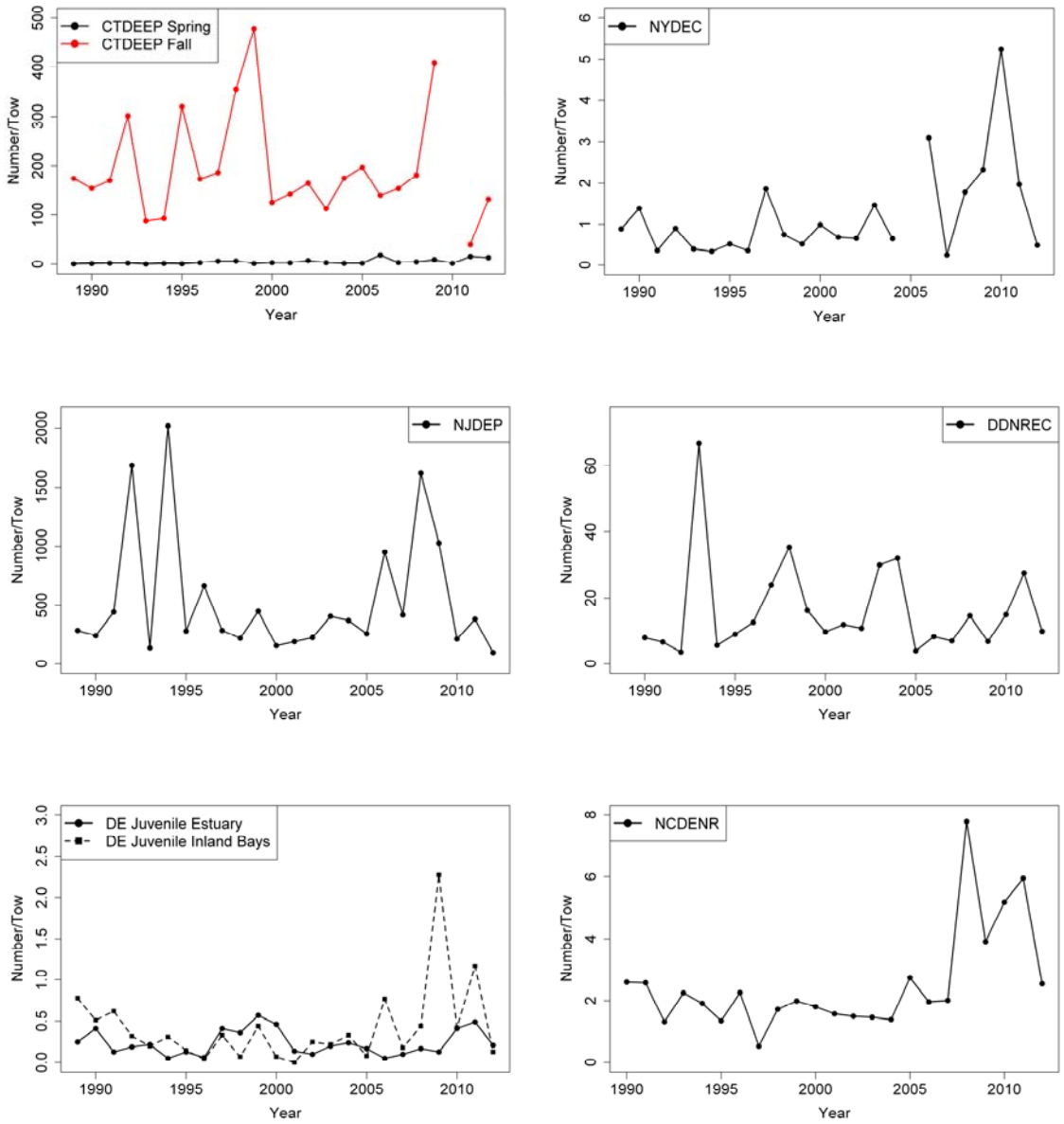

Figure 26. Mean number per tow for butterfish (*Peprilus triacanthus*) the Connecticut Department of Energy and Environmental Protection (CTDEEP) (upper left), New York State Department of Environmental Conservation (NYSDEC) Peconic Bay (upper right), New Jersey Division of Fish and Wildlife (NJDEP) (middle left), Delaware Department of Natural Resources and Environmental Control (DDNREC) (middle right), DDNREC juvenile (bottom left), and North Carolina Department of Environment and Natural Resources (NCDENR) Pamlico Sound (bottom right) surveys. CTDEEP is the geometric mean. All others are annual means.

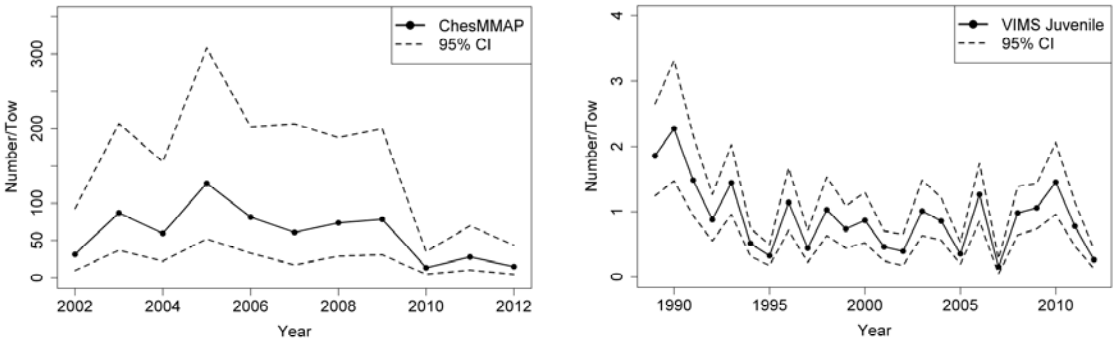

Figure 27. Geometric mean number per tow for butterfish (*Peprilus triacanthus*) and 95% confidence interval for the Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) (right) and Virginia Institute of Marine Science (VIMS) juvenile (left) surveys.

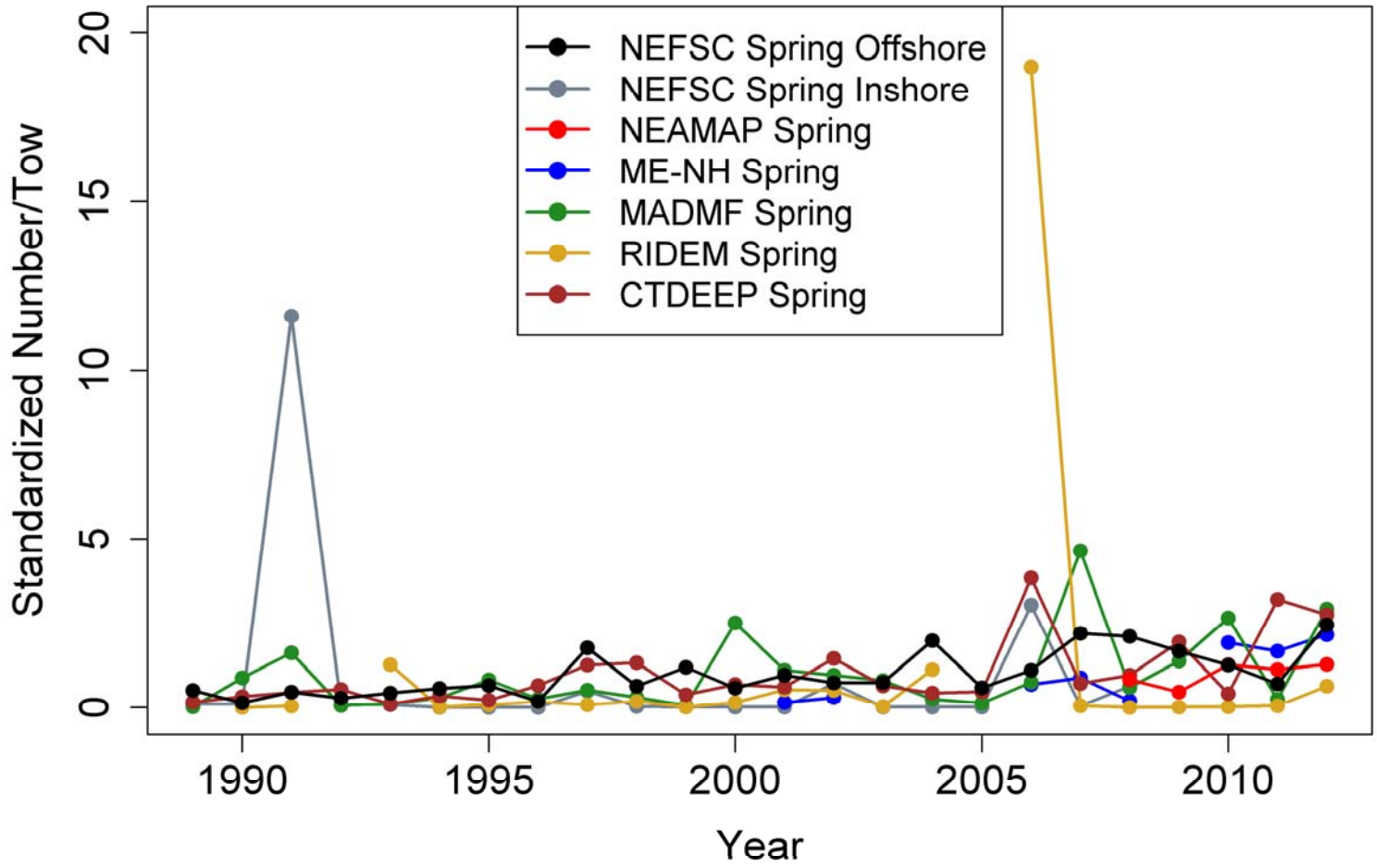

Figure 28. Butterfish (*Peprilus triacanthus*) mean number per tow for Northeast Fisheries Science Center (NEFSC), Northeast Area Monitoring and Assessment Program (NEAMAP), and state surveys in spring, standardized to the mean of the respective time series. ME-NH = Maine New Hampshire, MADMF = Massachusetts Division of Marine Fisheries, RIDEM = Rhode Island Department of Environmental Management, CTDEEP = Connecticut Department of Energy and Environmental Protection.

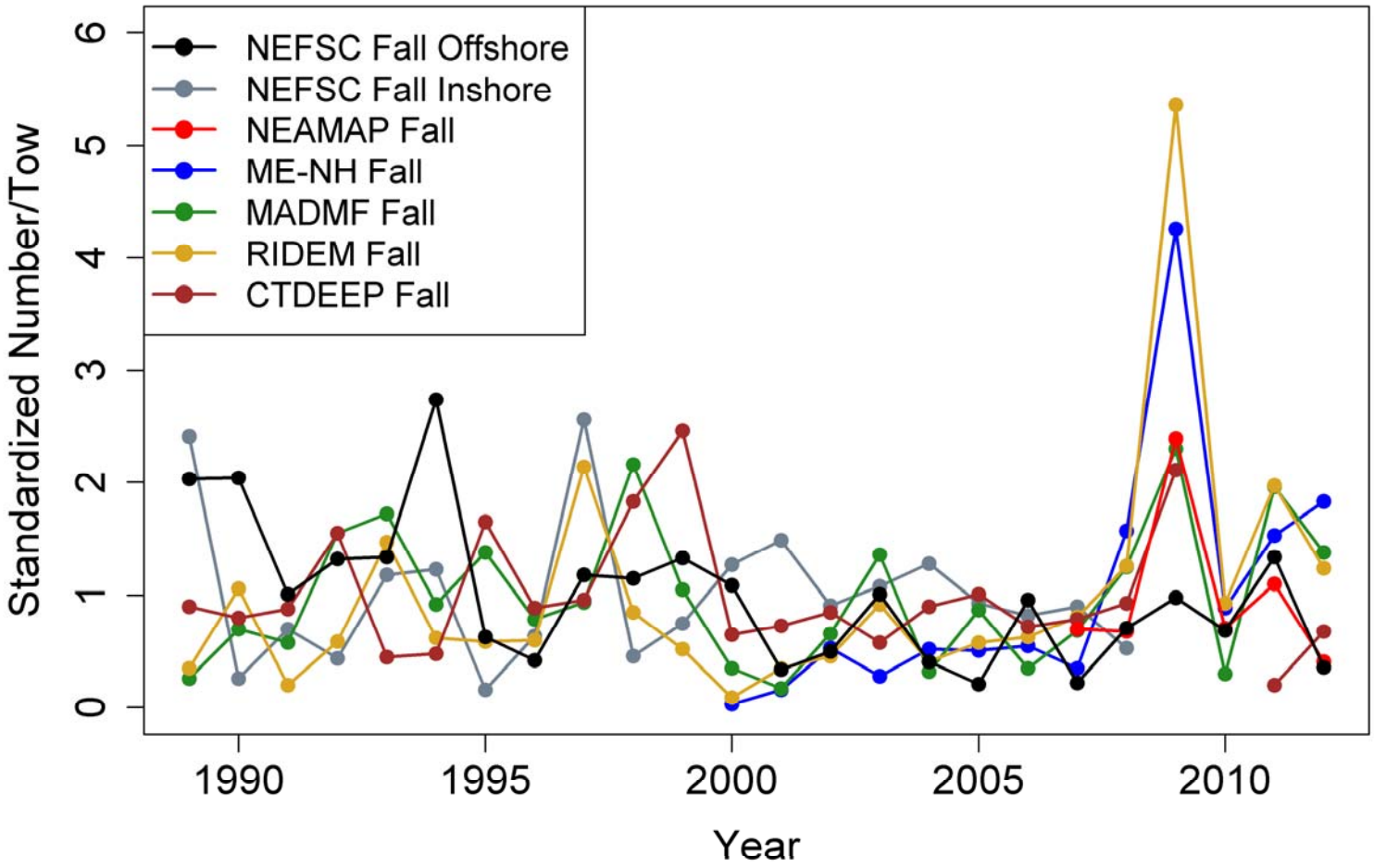

Figure 29. Butterfish (*Peprilus triacanthus*) mean number per tow for Northeast Fisheries Science Center (NEFSC), Northeast Area Monitoring and Assessment Program (NEAMAP), and state surveys in fall, standardized to the mean of the respective time series. ME-NH = Maine New Hampshire, MADMF = Massachusetts Division of Marine Fisheries, RIDEM = Rhode Island Department of Environmental Management, CTDEEP = Connecticut Department of Energy and Environmental Protection.

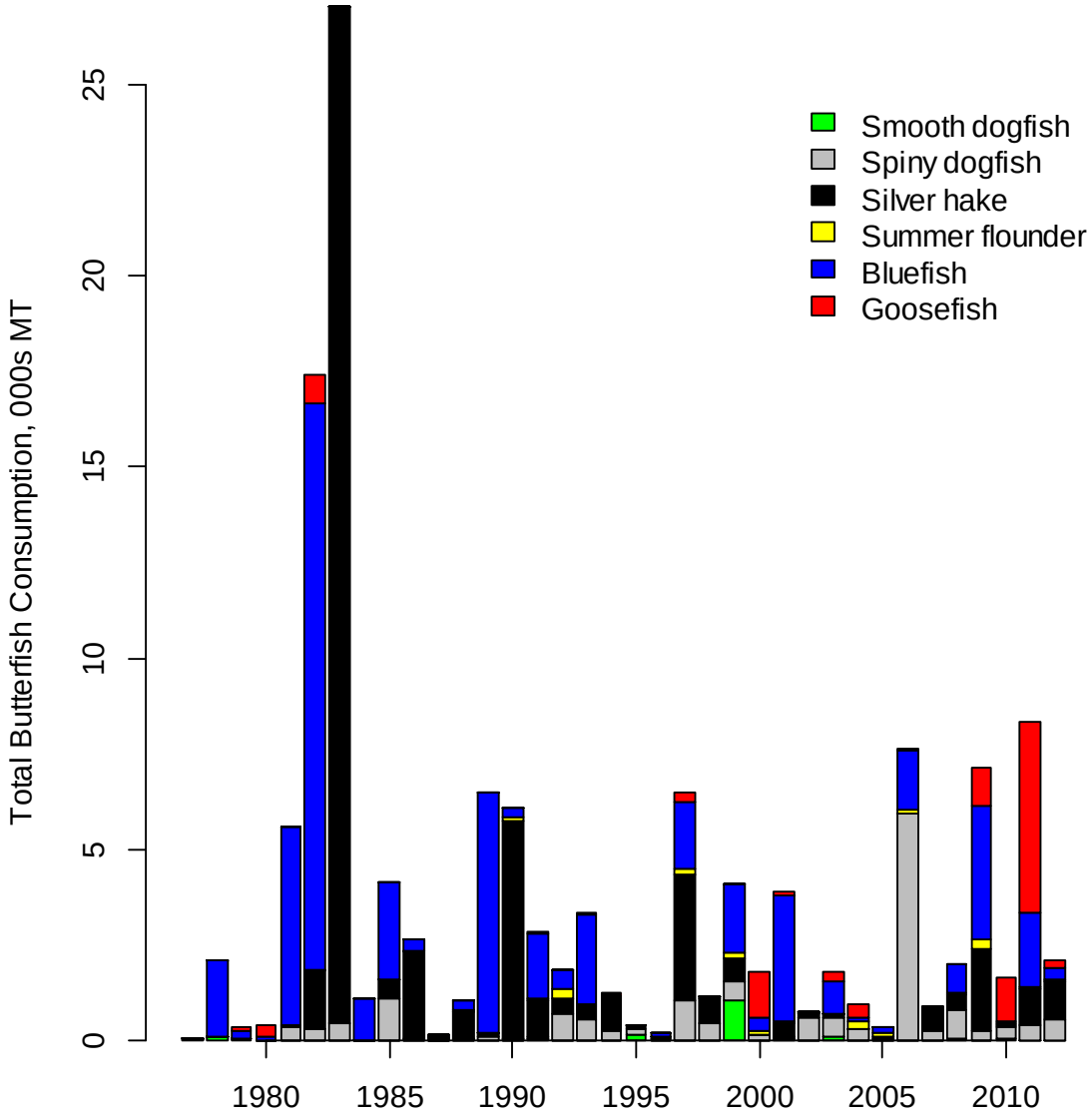

Figure 30. Total consumption by the top 6 finfish predators of butterfish (*Peprilus triacanthus*), 1977–2012: Smooth dogfish (*Mustelus canis*), Spiny dogfish (*Squalus acanthias*), Silver hake (*Merluccius bilinearis*), Summer flounder (*Paralichthys dentatus*), Bluefish (*Pomatomus saltatrix*), Goosefish (*Lophius americanus*).

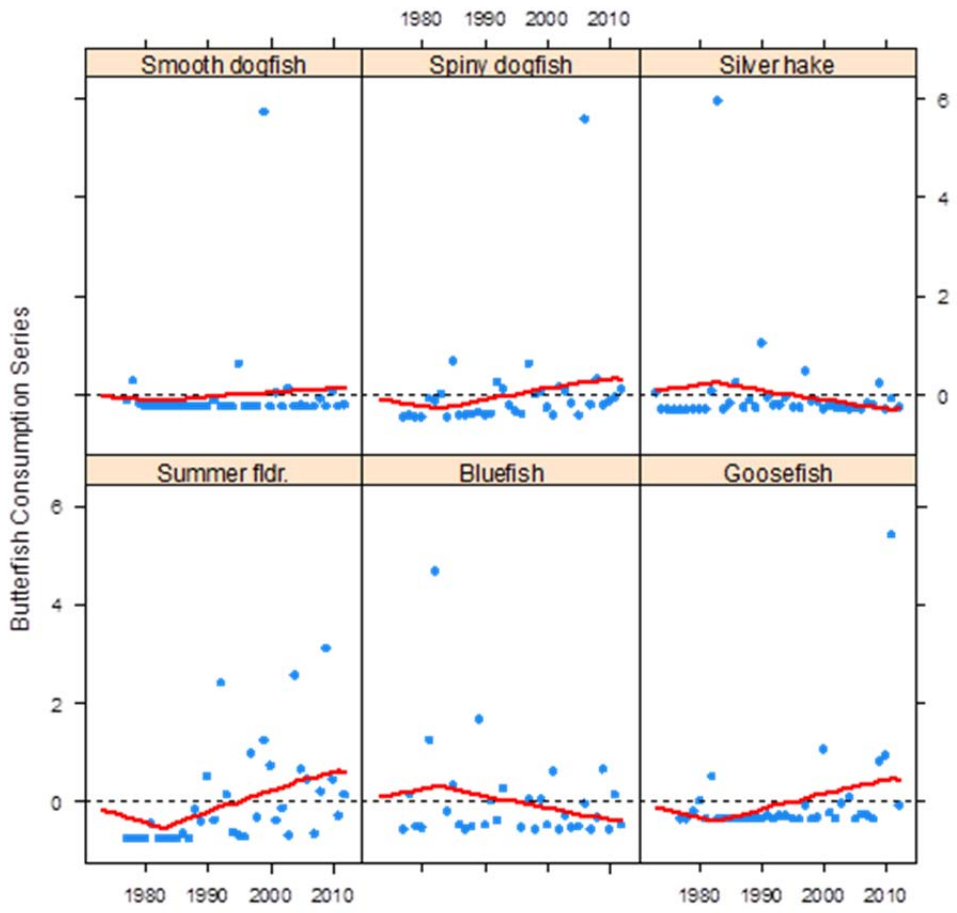

Figure 31. Fitted values (red lines) for annual butterfish (*Peprilus triacanthus*) consumption data by predator (blue dots). Chosen model contains 1 trend and a diagonal and equal covariance matrix. Data were transformed with mean = 0 and standard deviation = 1.

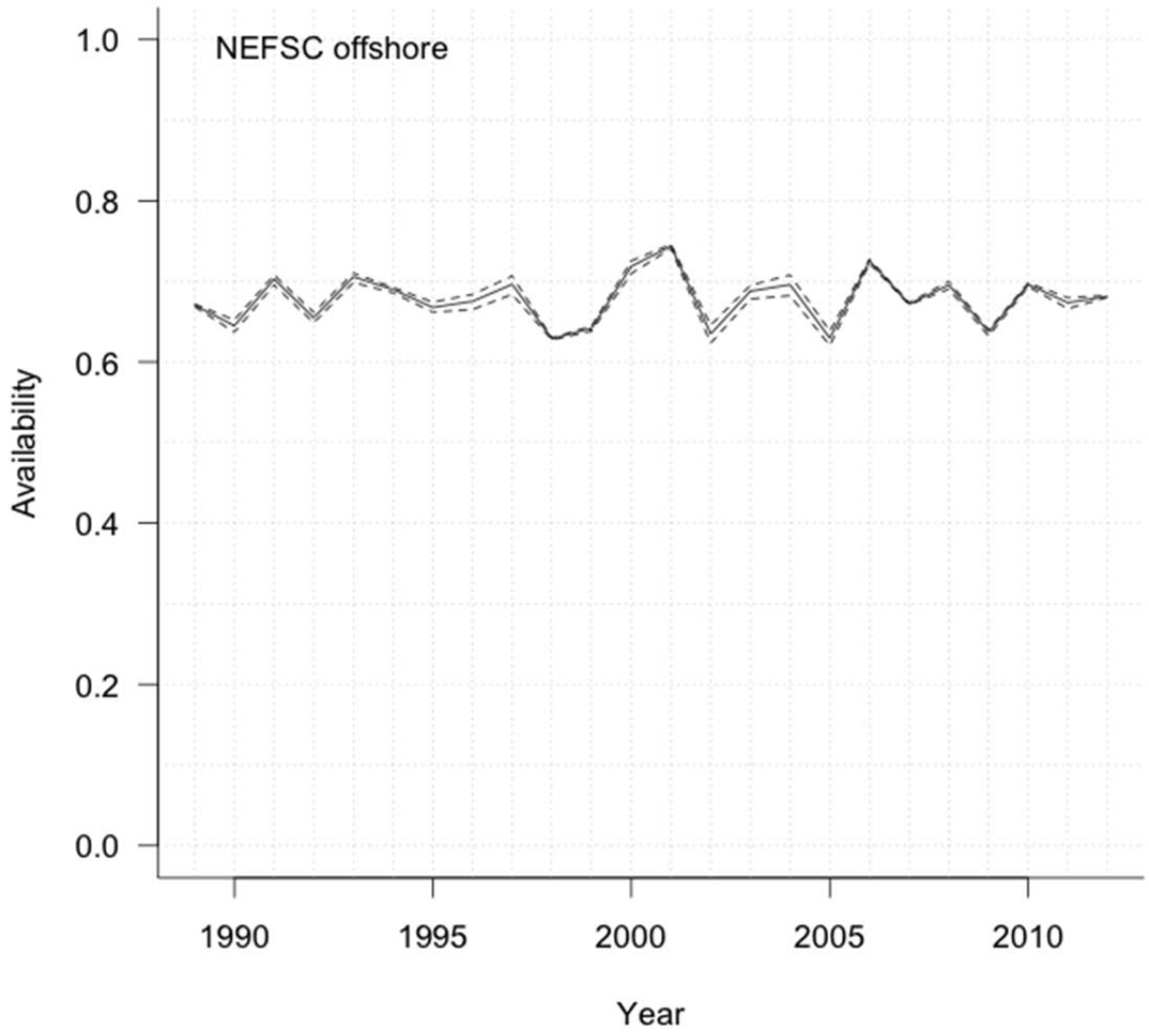

Figure 32. Availability of butterfish (*Peprilus triacanthus*) to the Northeast Fisheries Science Center (NEFSC) offshore survey, 1989–2012. Solid line indicates availability *A*, while dashed lines show the 95% confidence interval. Median *A* = 0.68, with range from 0.62 to 0.75.

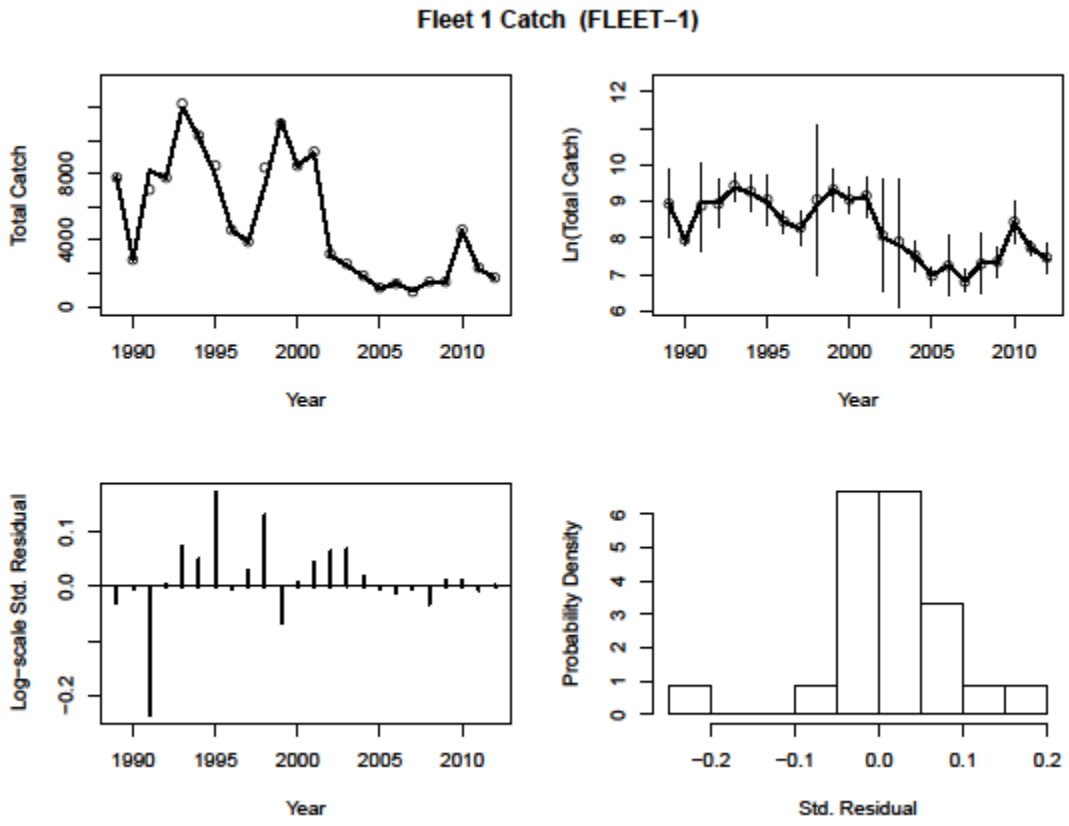

Figure 33. Diagnostics for aggregate catch from the final model.

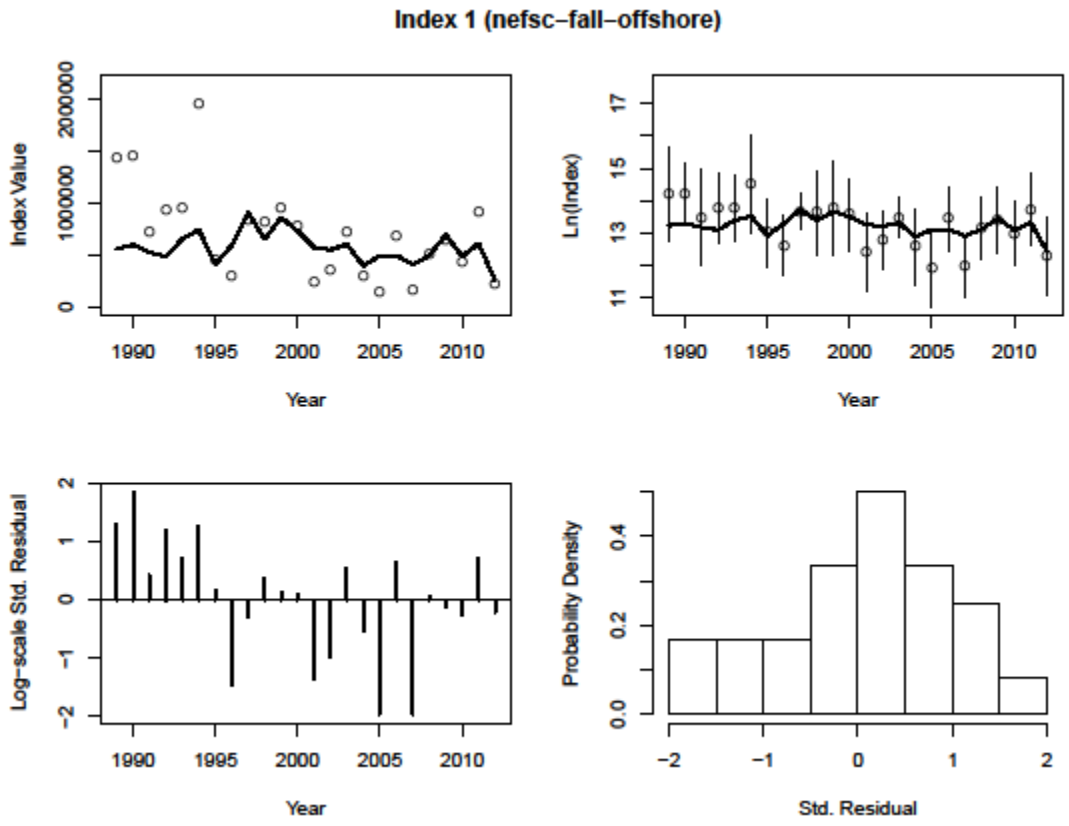

Figure 34. Diagnostics for the Northeast Fisheries Science Center (NEFSC) fall offshore survey from the final model.

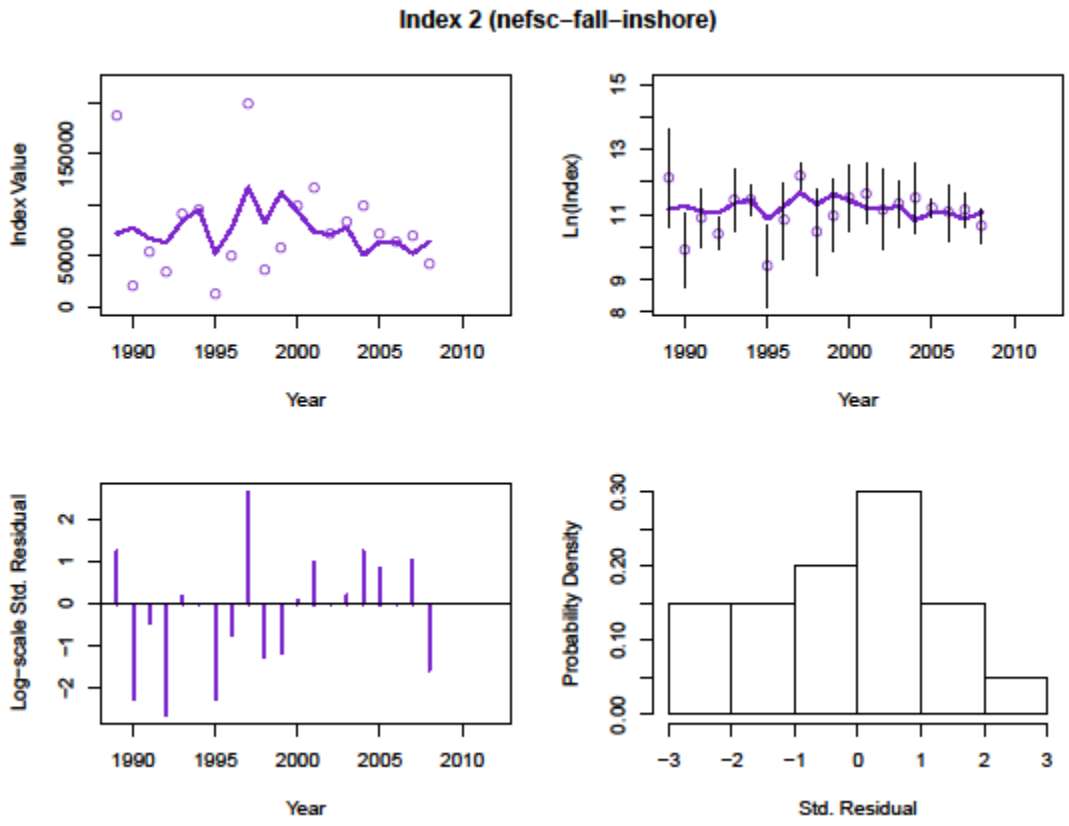

Figure 35. Diagnostics for the Northeast Fisheries Science Center (NEFSC) fall inshore survey from the final model.

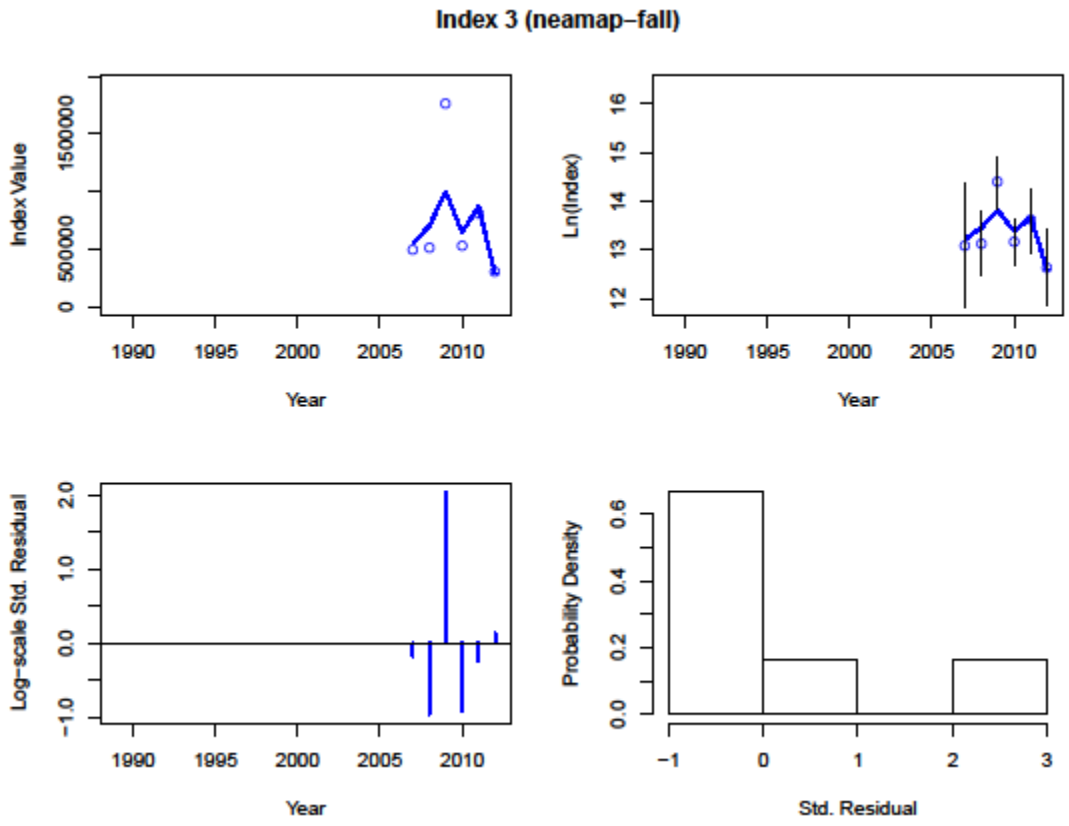

Figure 36. Diagnostics for the Northeast Area Monitoring and Assessment Program (NEAMAP) fall survey from the final model.

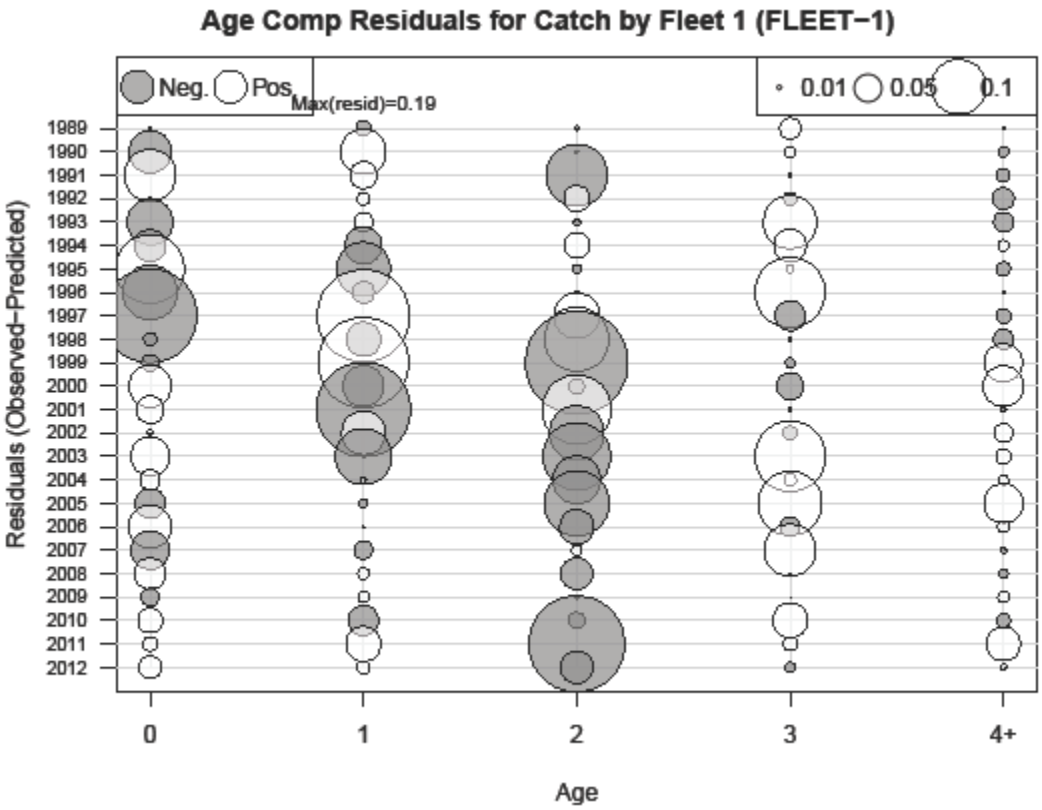

Figure 37. Residuals for catch age composition from the final model.

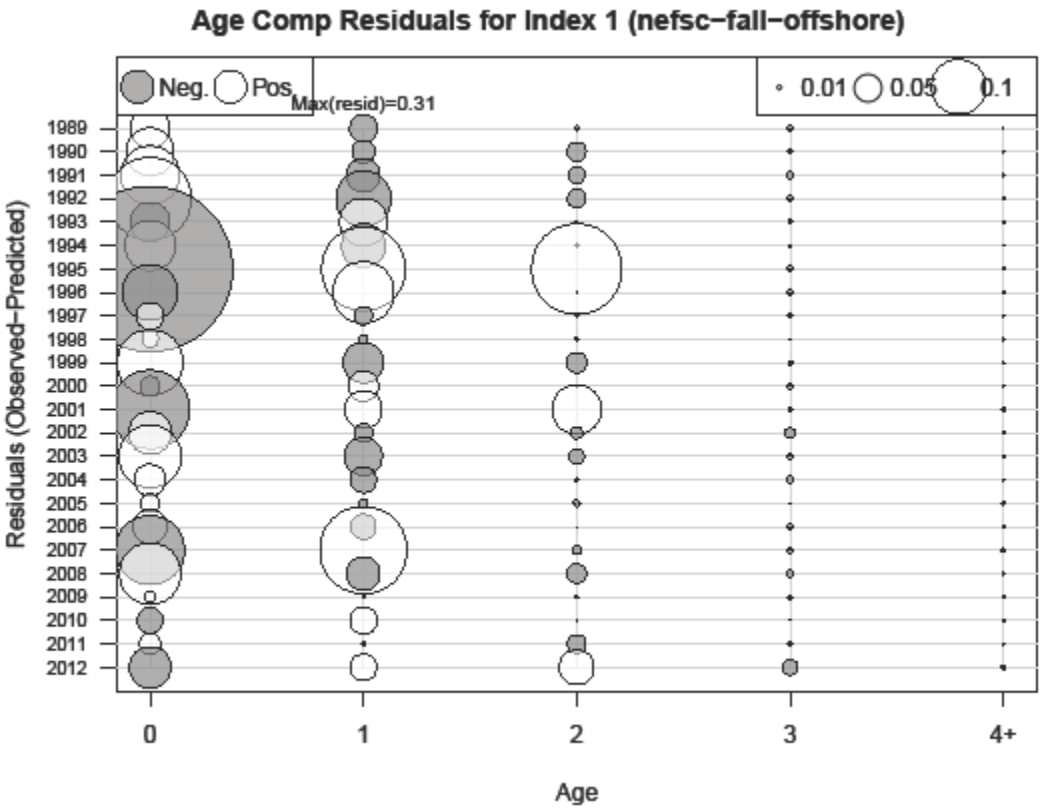

Figure 38. Residuals for Northeast Fisheries Science Center (NEFSC) fall offshore age composition from the final model.

Figure 39. Residuals for Northeast Fisheries Science Center (NEFSC) fall inshore age composition from the final model.

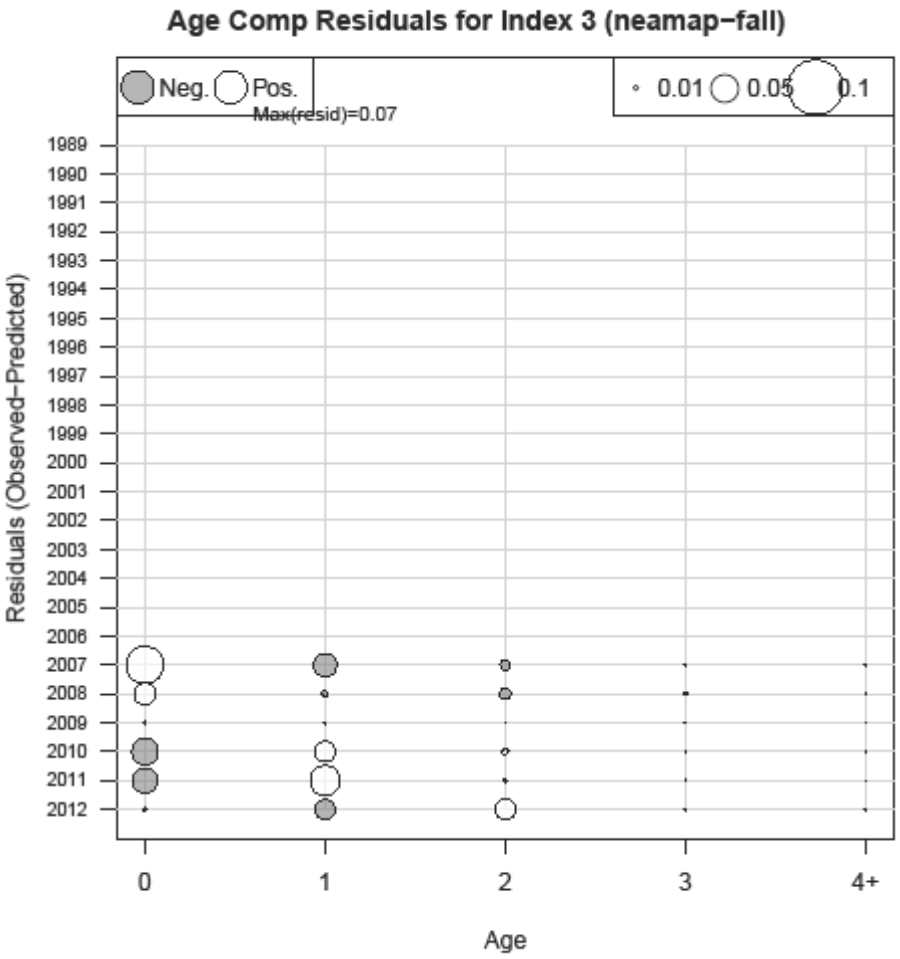

Figure 40. Residuals for Northeast Area Monitoring and Assessment Program (NEAMAP) fall age composition from the final model.

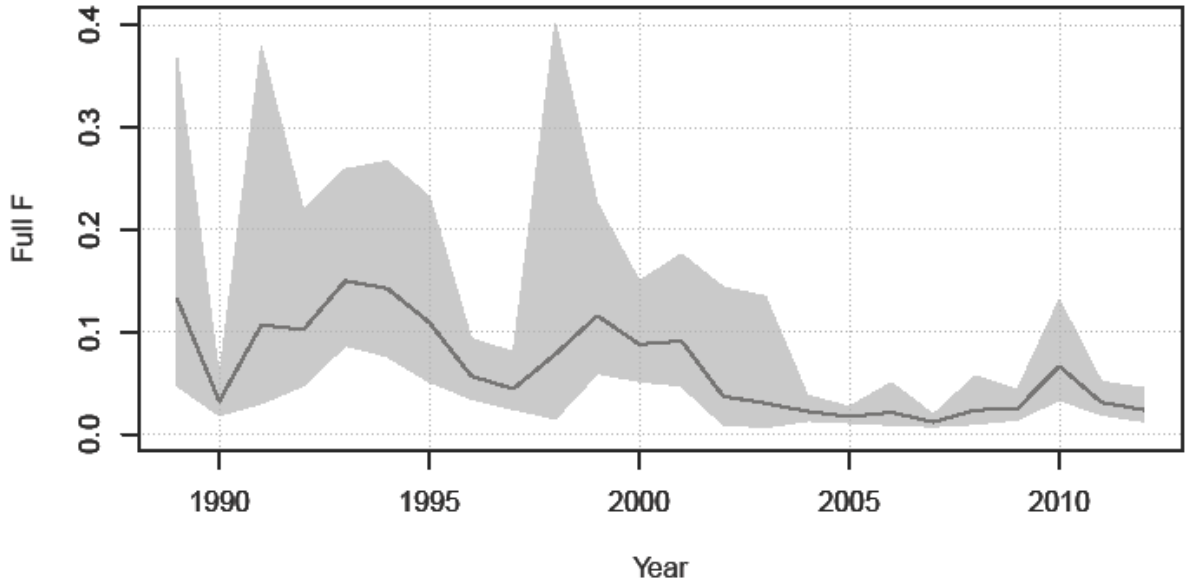

Figure 41. Estimated fully selected fishing mortality (F) rate and 95% confidence interval from the final model.

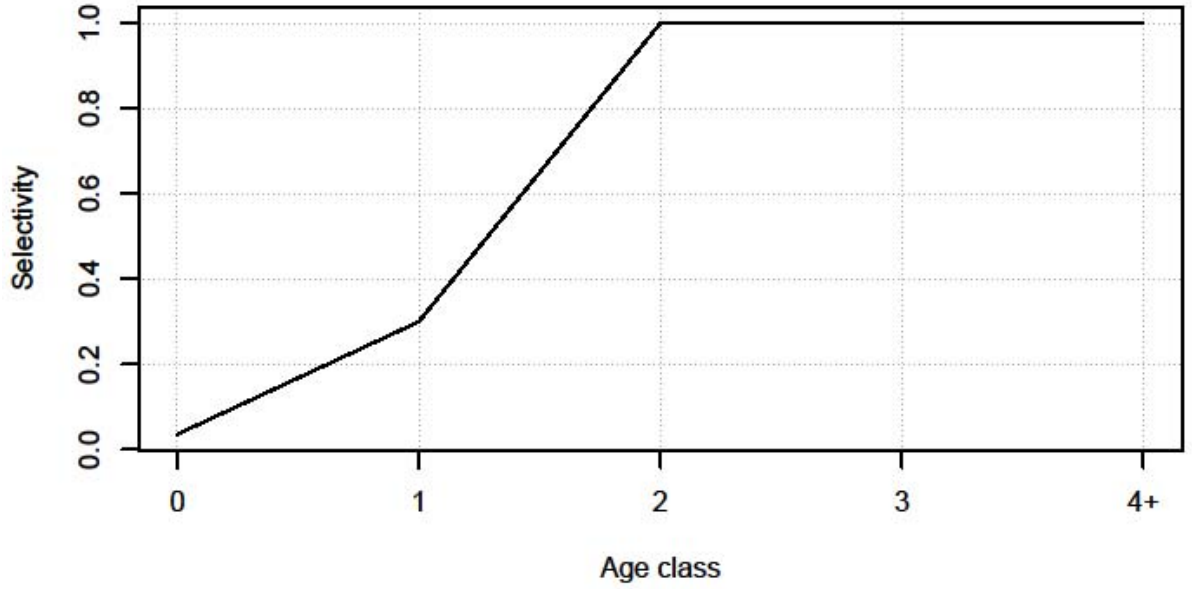

Figure 42. Fleet selectivity at age from the final model.

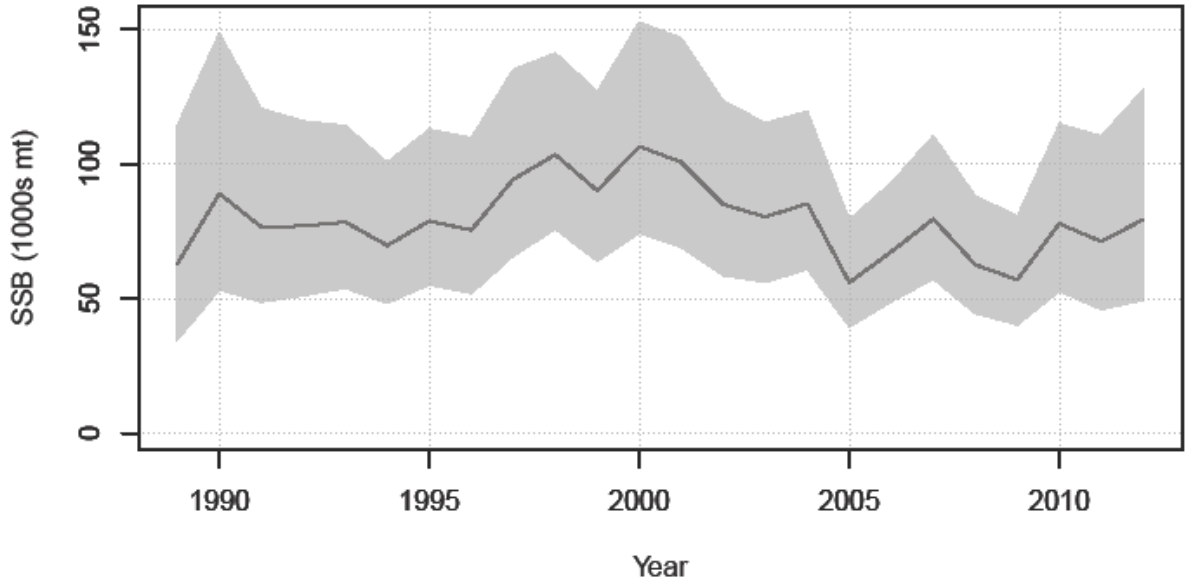

Figure 43. Estimated spawning biomass and 95% confidence interval from the final model.

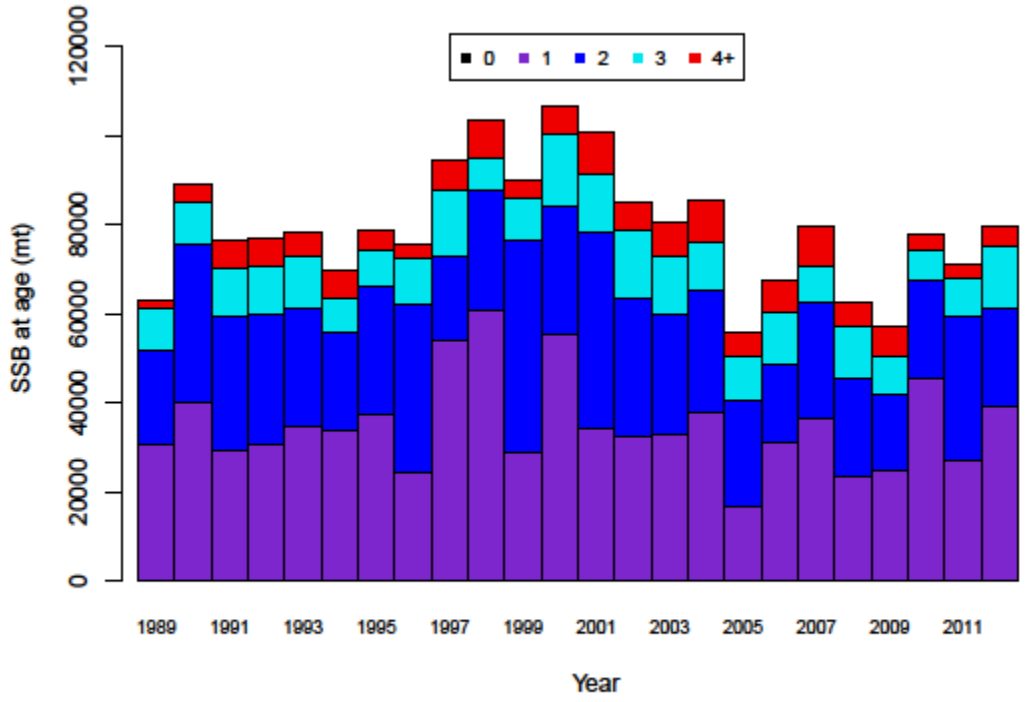

Figure 44. Estimated annual spawning biomass at age (0, 1, 2, 3, 4+) from the final model.

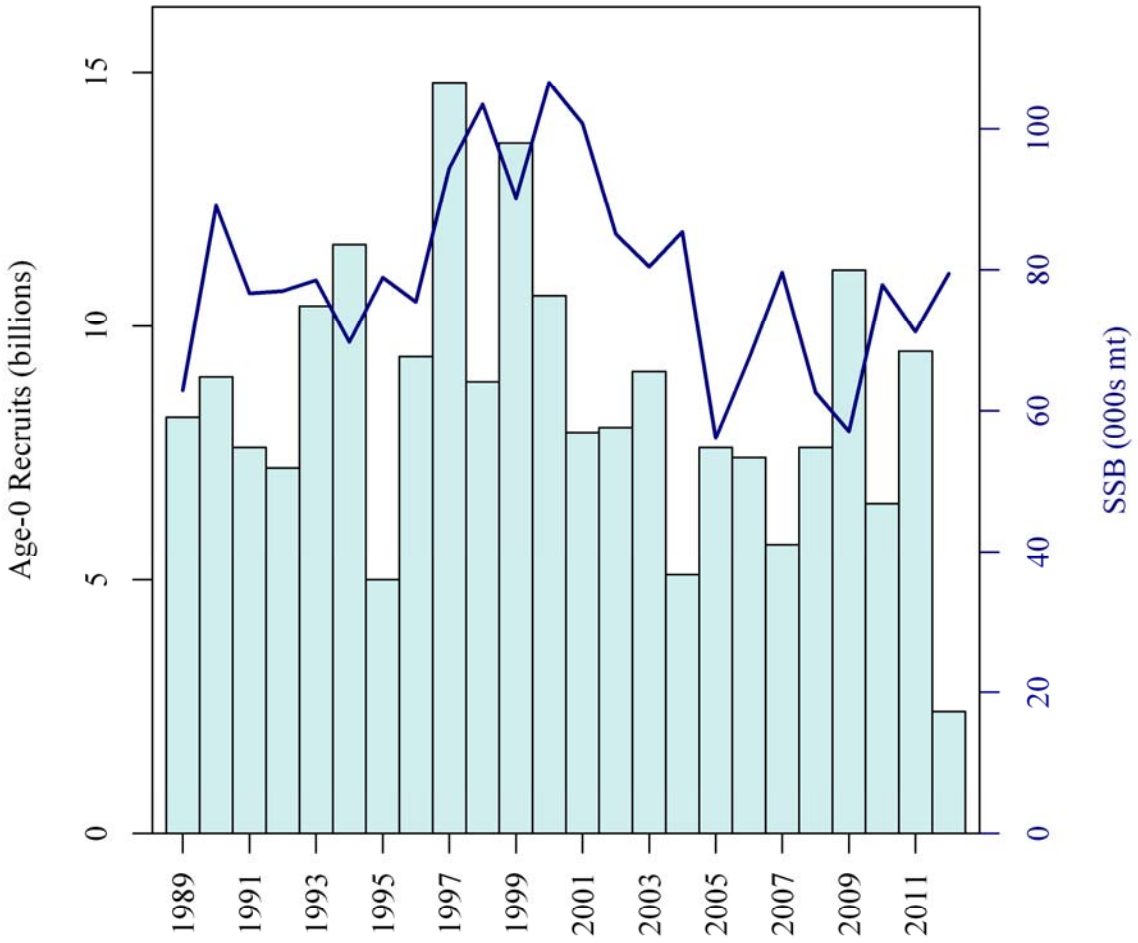

Figure 45. Butterfish (*Peprilus triacanthus*) recruitment (vertical bars), and the spawning stock biomass (SSB) (blue line) that produced the corresponding recruitment. Year refers to spawning year.

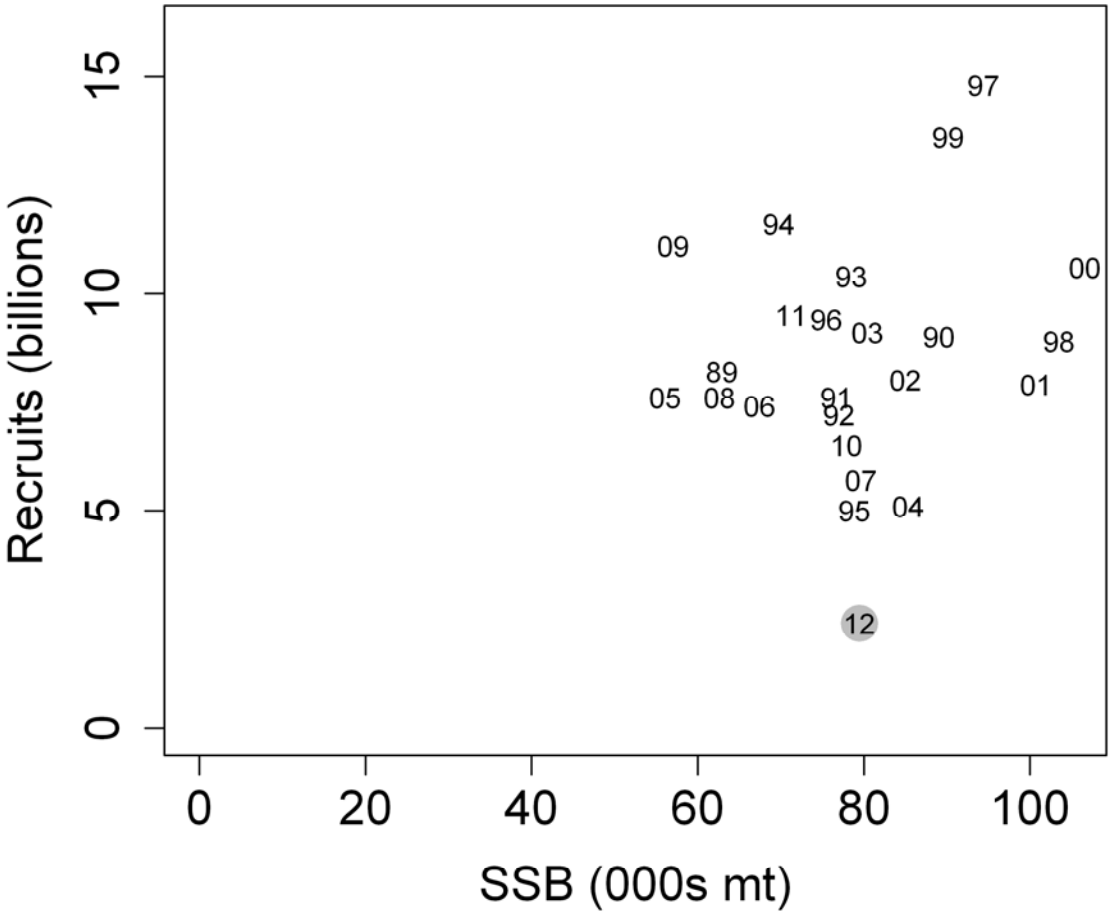

Figure 46. Butterfish (*Peprilus triacanthus*) stock-recruitment scatter plot, with two digit indicator of model year.

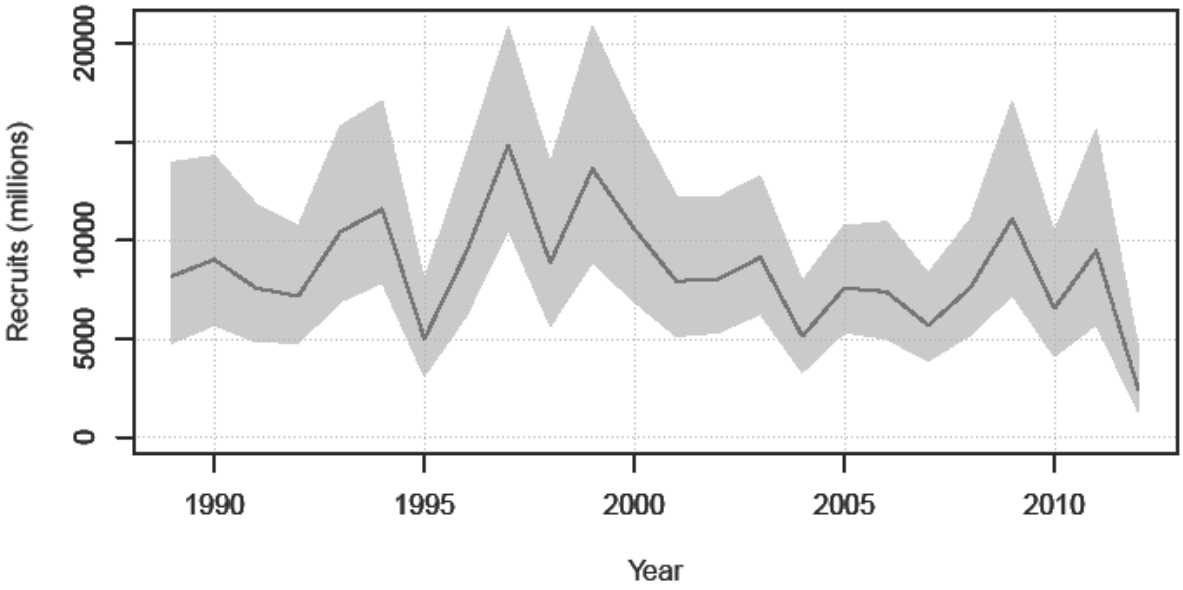

Figure 47. Estimated recruitment and 95% confidence interval from the final age structured assessment program (ASAP) model.

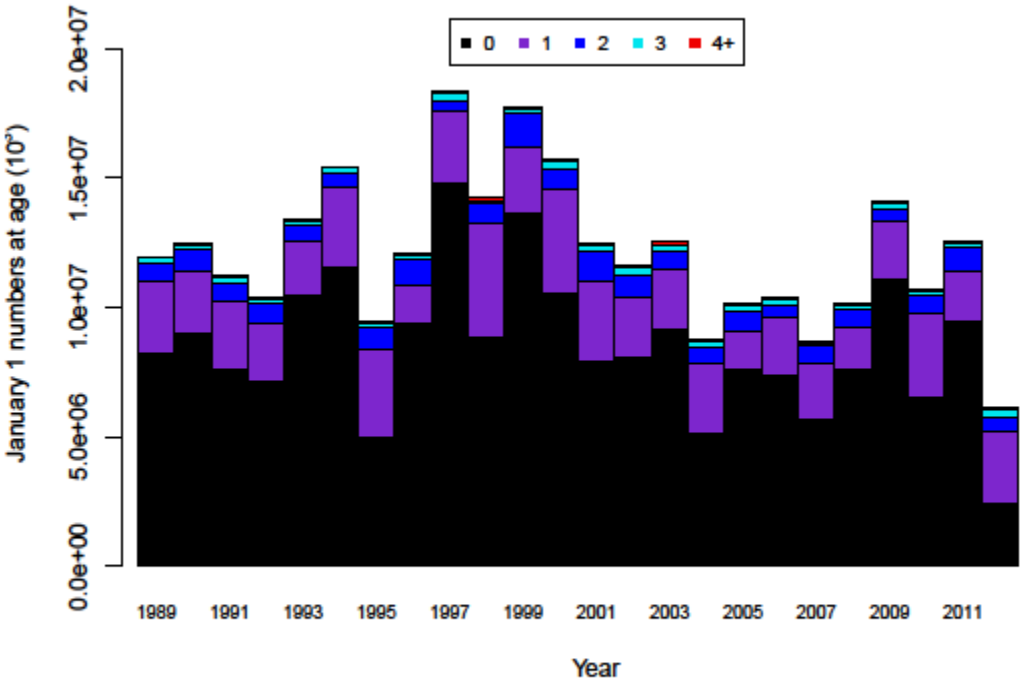

Figure 48. Estimated numbers at age (0, 1, 2, 3, 4+) on January 1 from the final age structured assessment program (ASAP) model.

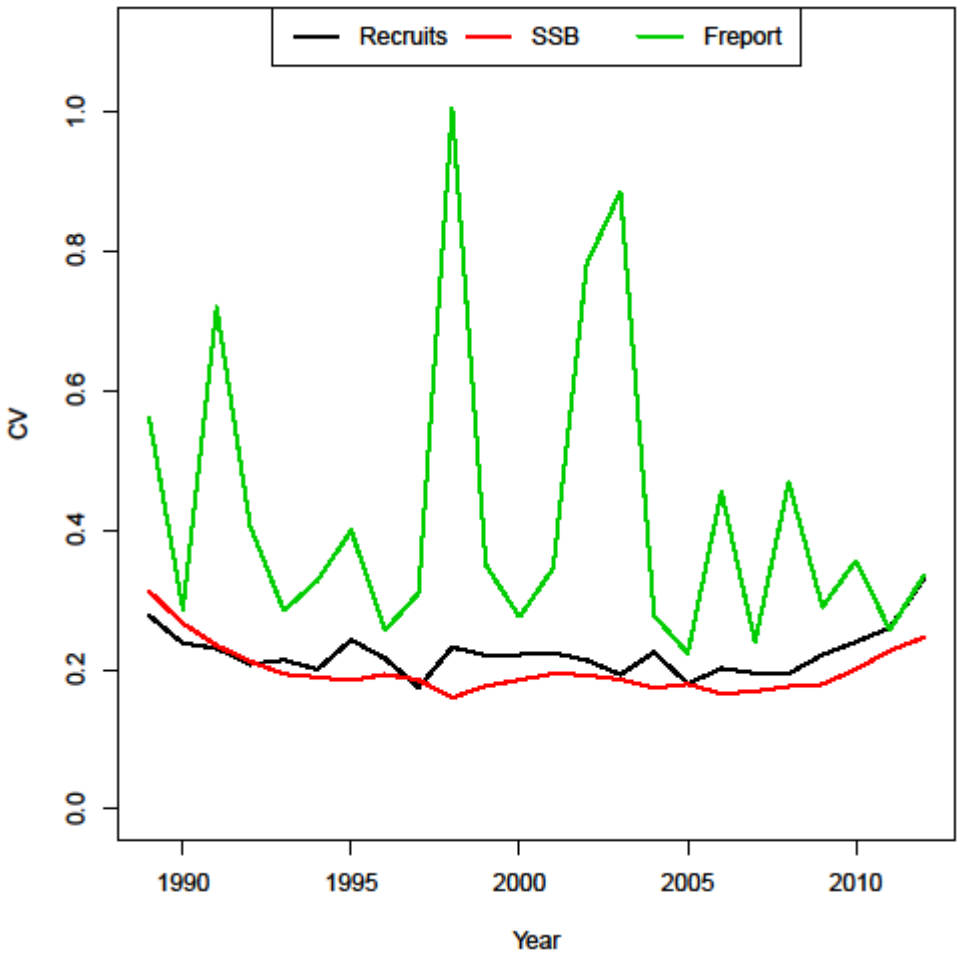

Figure 49. Coefficients of variation for estimates of spawning stock biomass (SSB), recruits and fully selected fishing mortality from the final age structured assessment program (ASAP) model.

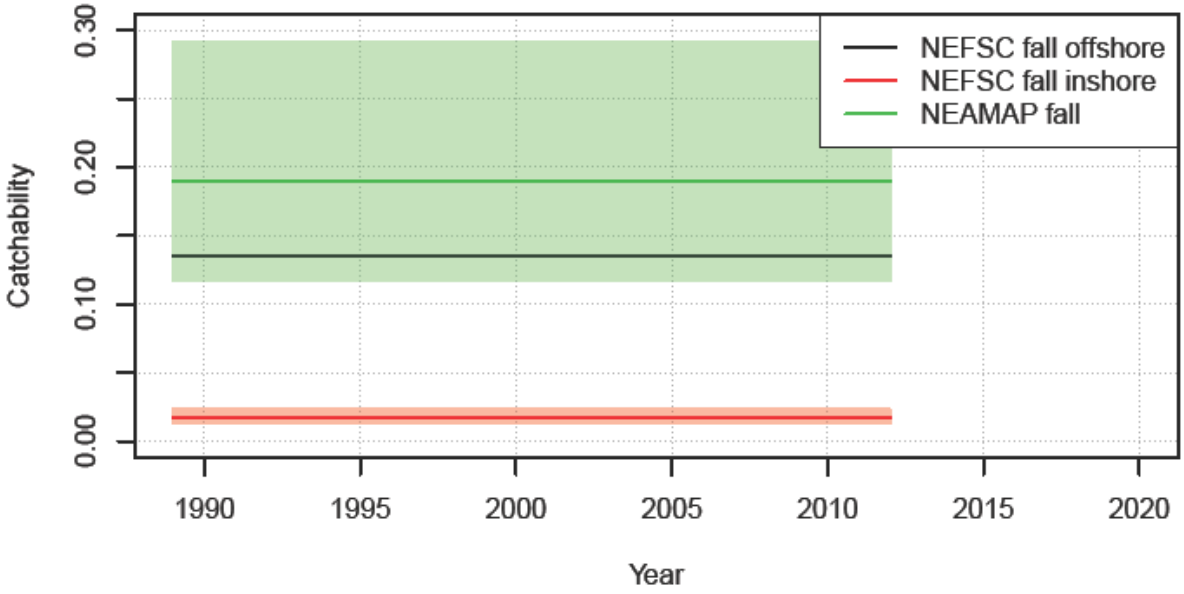

Figure 50. Index catchability and 95% confidence interval from the final age structured assessment program (ASAP) model. NEFSC = Northeast Fisheries Science Center. NEAMAP = Northeast Area Monitoring and Assessment Program.

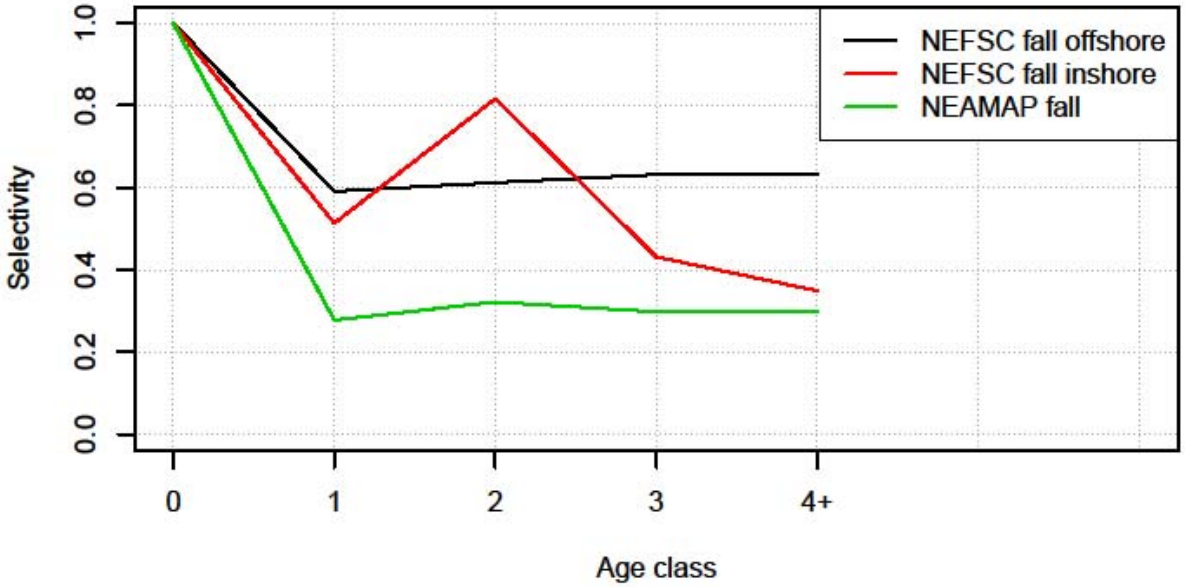

Figure 51. Index selectivity from the final age structured assessment program (ASAP) model. NEFSC = Northeast Fisheries Science Center. NEAMAP = Northeast Area Monitoring and Assessment Program.

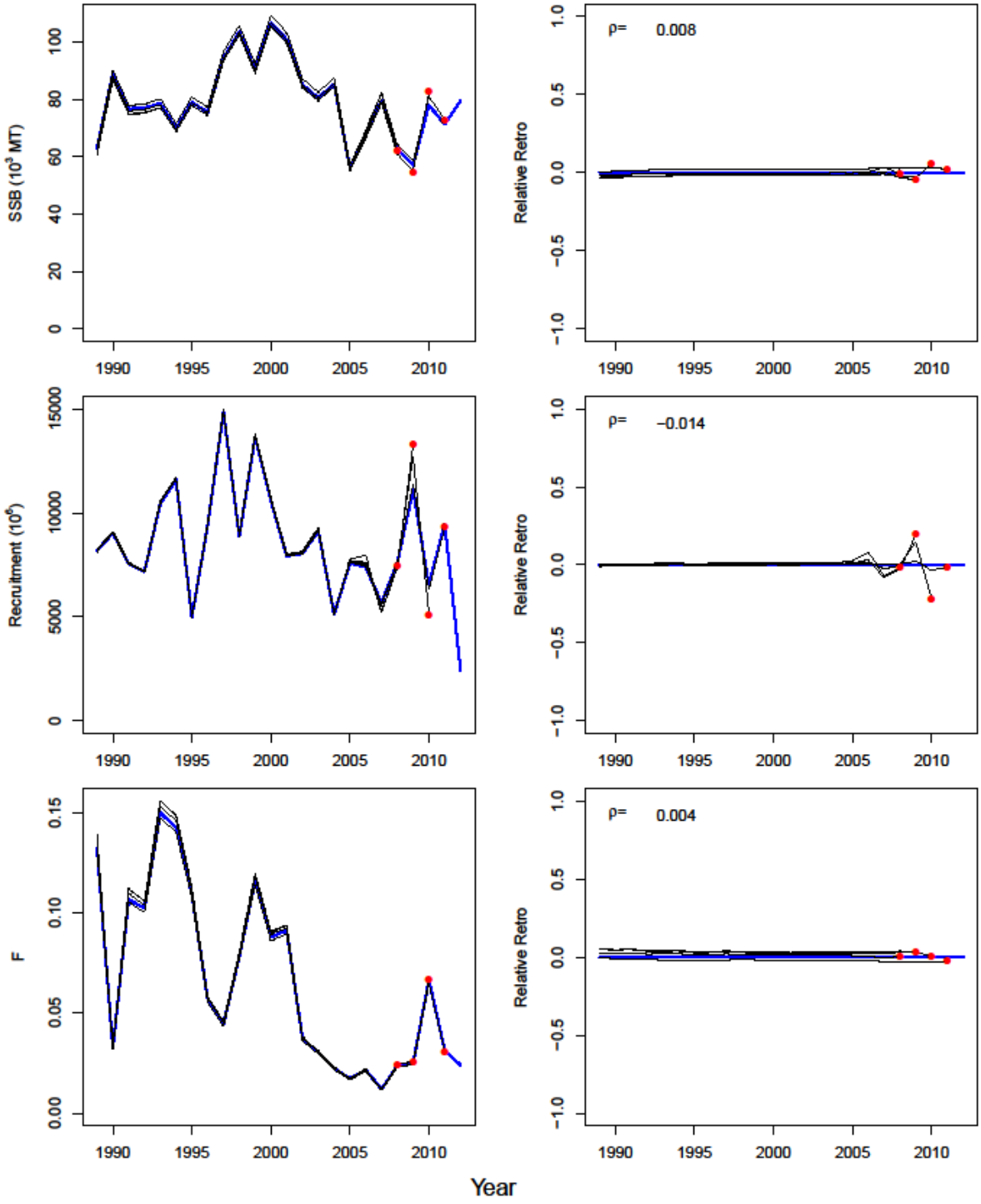

Figure 52. Retrospective patterns for spawning biomass (SSB), recruitment, and fishing mortality (F) in the final age structured assessment program (ASAP) model. SSB = spawning stock biomass

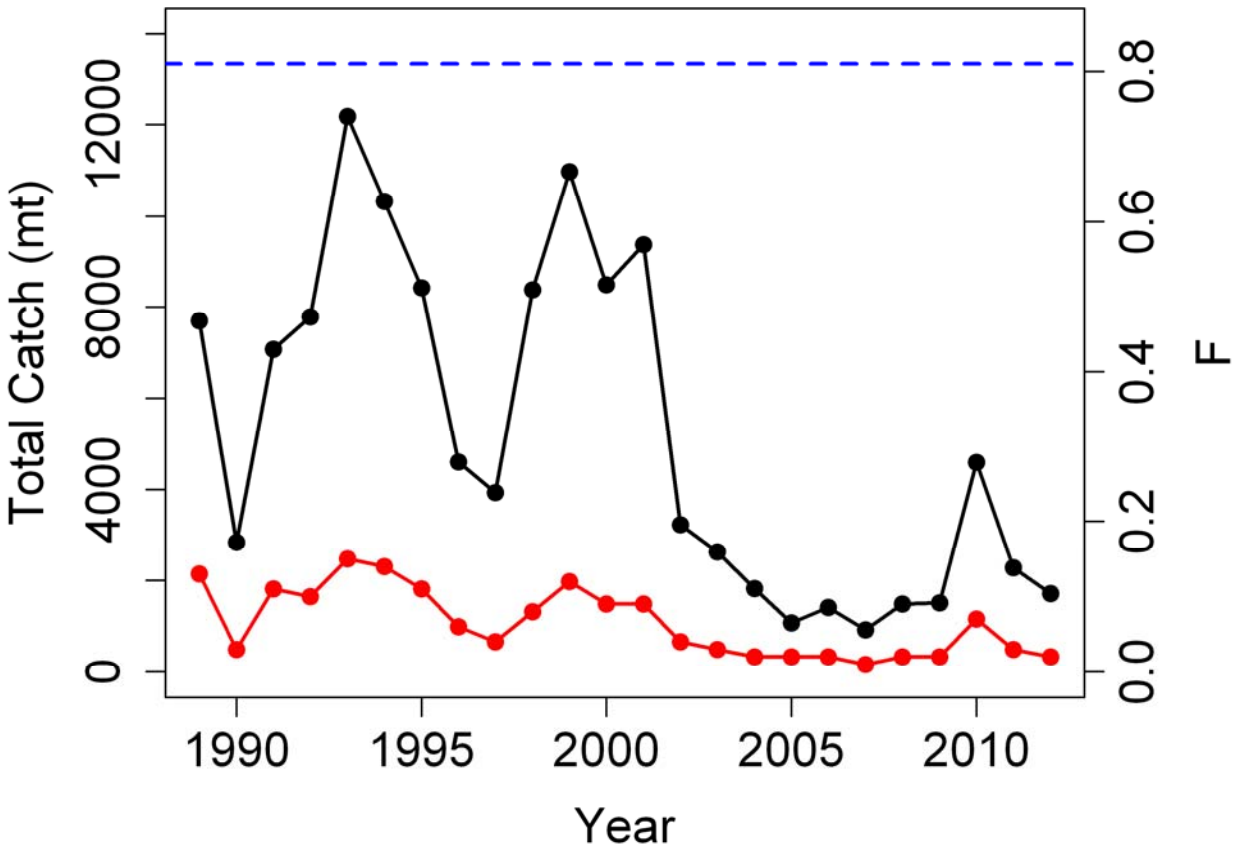

Figure 53. Butterfish (*Peprilus triacanthus*) total catch (black line) and fishing mortality (F) (red line). Dashed blue line is the F_{MSY} proxy = 0.81.

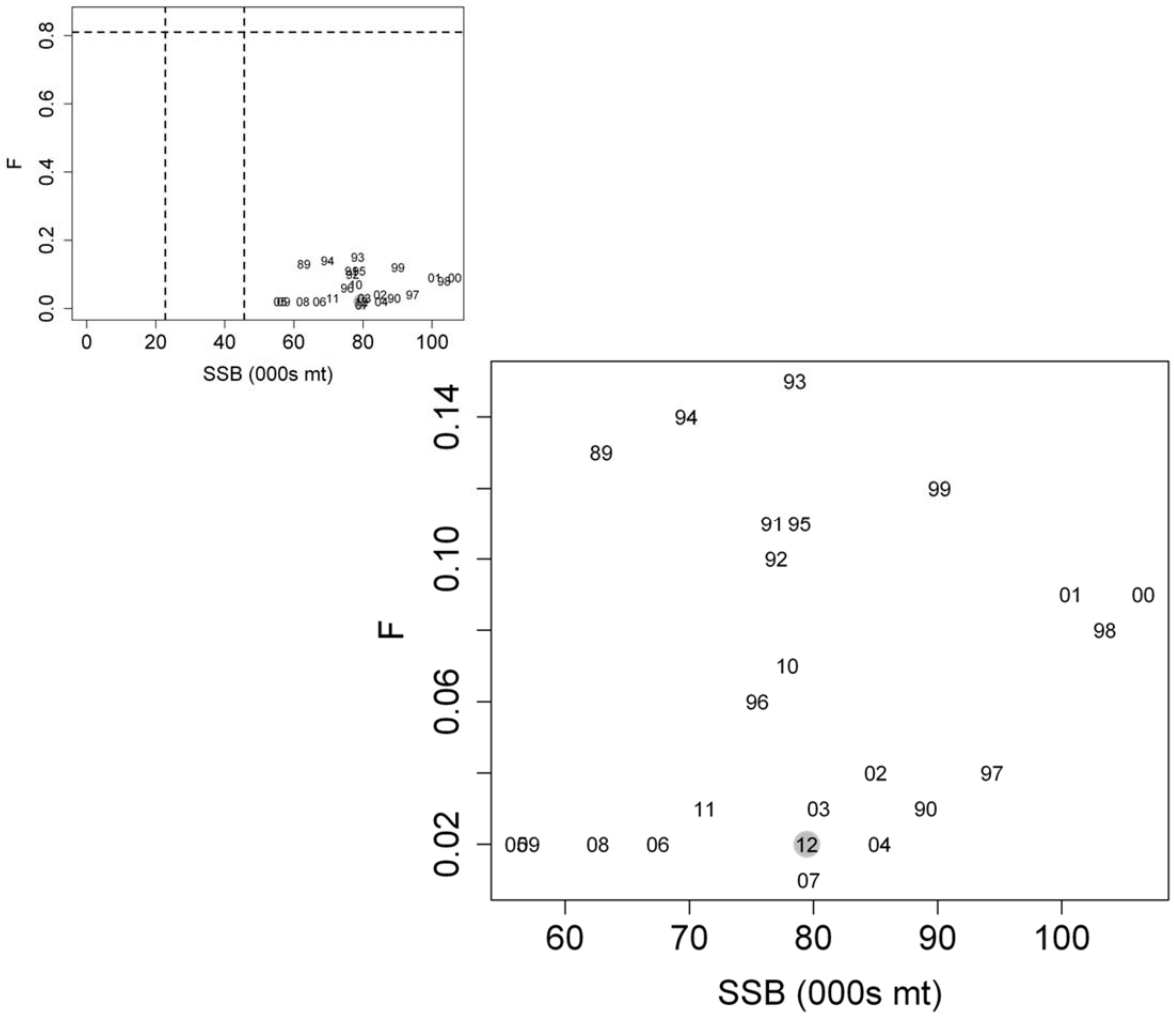

Figure 54. Butterfish (*Peprilus triacanthus*) spawning stock biomass (SSB) and fishing mortality (F) relative to the biological reference points $SSB_{threshold}$ = 22,808 mt, SSB_{MSY} proxy = 45,616 mt, and F_{MSY} proxy = 0.81 (upper left panel). Plot is expanded for clarity in lower right panel.

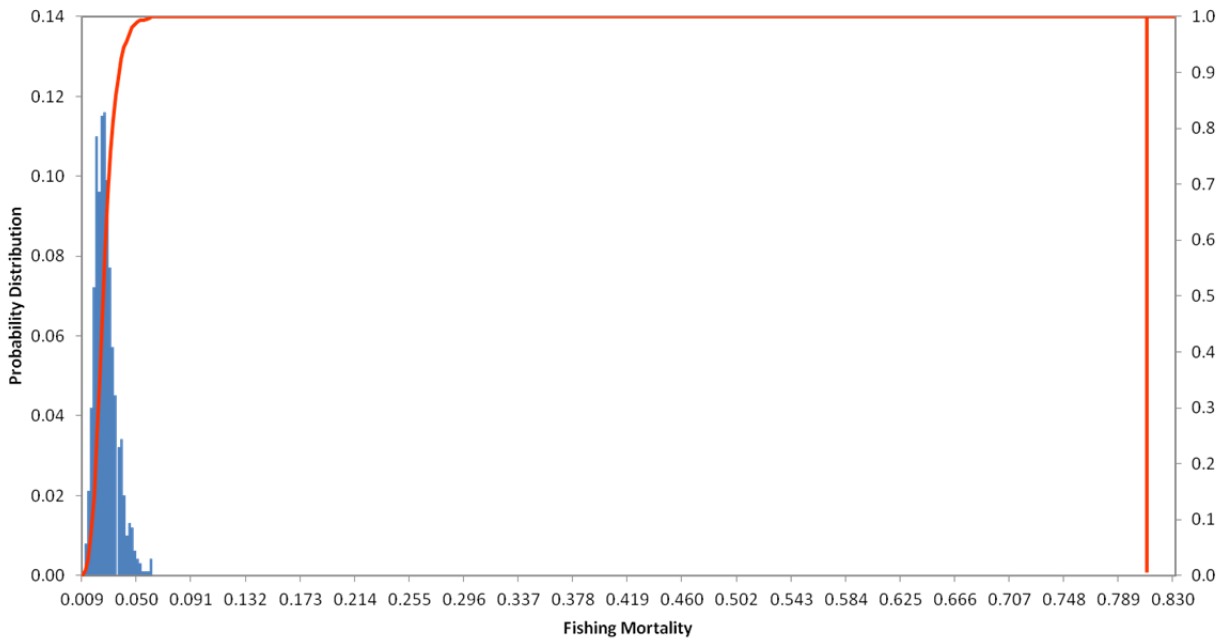

Figure 55. Markov Chain Monte Carlo distribution plots for annual total fishing mortality (F). Vertical line shows F_{MSY} proxy = 0.81.

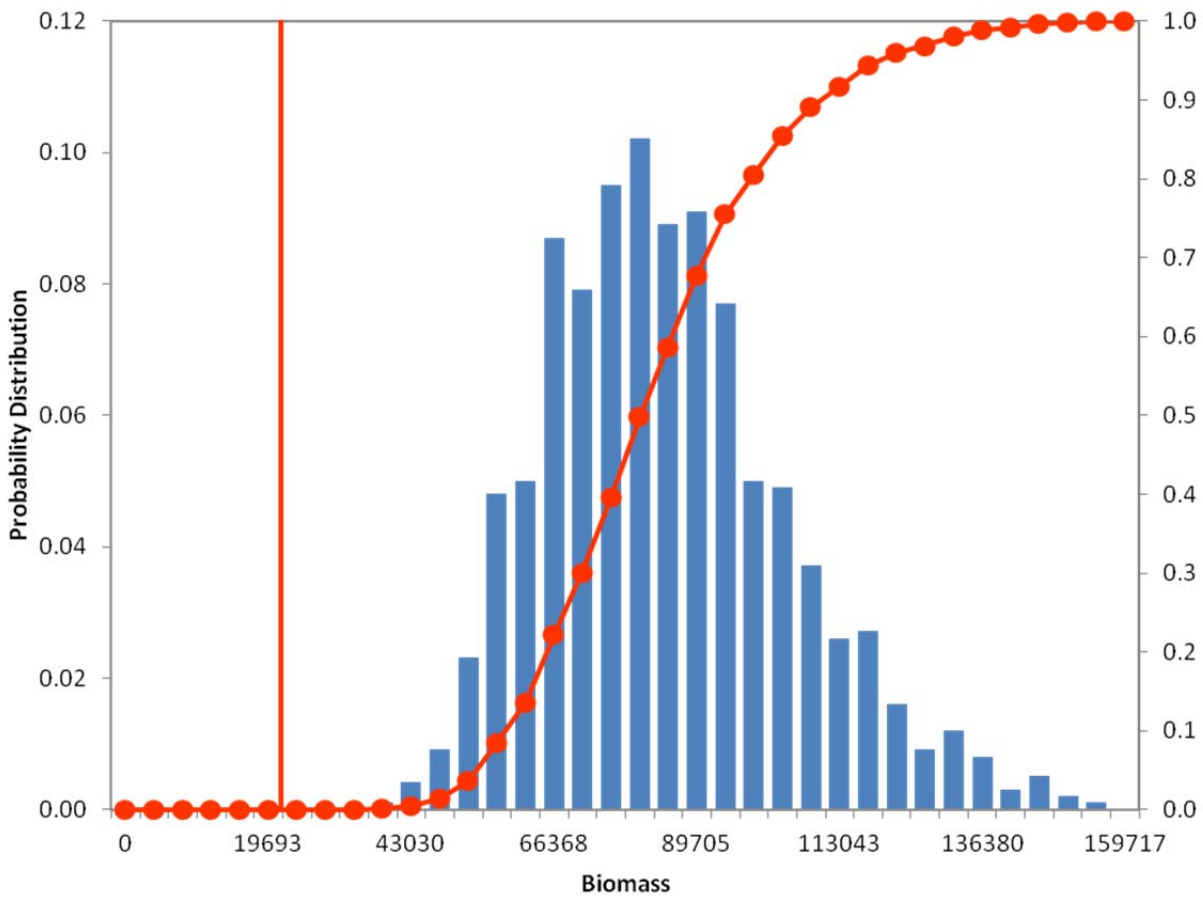

Figure 56. Markov Chain Monte Carlo distribution plots for annual total spawning stock biomass (SSB). Vertical line shows $SSB_{threshold}$ = 22,808 mt.

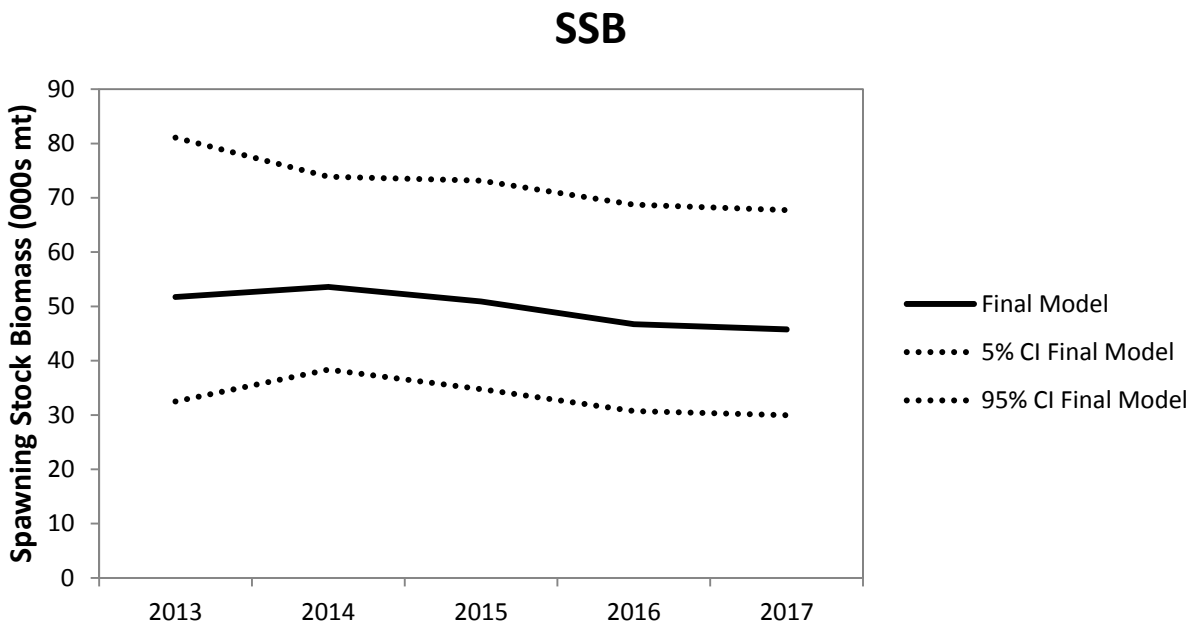

Figure 57. Projection of median butterfish (*Peprilus triacanthus*) spawning stock biomass (SSB) and 95% confidence interval (CI) with preliminary 2013 catch (2,489 mt), 2014 ABC (9,100 mt), and F_{MSY} proxy = 0.81 in 2015 and beyond.

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