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United States Research Report for 2021

by

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A. Status of the Fisheries (Subareas 3- 6 Inclusive)

Revised sampling and protocols were implemented in the Northeast Region in 1994, in 2004, in 2010 and in 2020. Auditing and allocation procedures have been used to prorate total reported landings by species among areas. However, these procedures are subject to change and the landings, by area, are still considered provisional.

Most spring and autumn survey indices for 2009-2021 were converted from the FSV *Henry B. Bigelow* catches (weights) to RV *Albatross IV* catches (weights) using either a single conversion factor or length-specific conversion factors which have only been estimated for some species. Consequently, 2009-2021 survey data points should be interpreted cautiously, and these values may change in the future as new methodologies are considered. The 2009-2021 data points have been plotted separately in the figures presenting spring and fall survey data. In 2014, the spring survey did not cover a large portion of the Mid-Atlantic region and this impacted the survey indices for summer flounder, southern red hake, Atlantic mackerel, Atlantic herring, spiny dogfish and little skate. The impact differs for each species and this is discussed in those sections. In 2017, the fall survey did not cover the Southern New England to Mid-Atlantic region and this has impacted the survey indices for Southern New England yellowtail flounder, southern windowpane flounder, southern silver hake, butterfish, longfin inshore squid, shortfin squid, winter skate, barndoor skate, thorny skate, smooth skate, clearnose skate, and rosette skate. The impact differs for each species and this is discussed in those sections. Additionally, the survey was conducted on a different vessel the FSV *Pisces*, which is considered a sister ship of the FSV *Henry B. Bigelow*. The impact of this change is unknown but should be minimal. The spring survey in 2020 was only partially conducted covering NAFO Subarea 6 aboard the FSV *Henry B. Bigelow*. Due to COVID-19 only 133 stations out of the normal 350-380 were successfully completed. No fall survey was conducted. Therefore, the survey data for all species sections do not include 2020 surveys.

For the last few years, the United States has been transferred quota for Div. 3LNO yellowtail flounder from Canada and, from 2012-2021 at least one vessel fished in the area. The sections for cod, white hake, yellowtail flounder, other flounders, Atlantic halibut, silver hake, and squids contain the landings and the discards of these species in 2021. In addition, sculpins and cusk were discarded.

1. Atlantic Cod

United States commercial landings of Atlantic cod (*Gadus morhua*) in 2021 were 611 mt, a 18% decrease from the 2020 landings of 744 mt. In addition, <0.6 mt were landed from Div. 3N and 0.2 mt were discarded in 2021.

Northeast Fisheries Science Center (NEFSC) research vessel survey biomass indices of Gulf of Maine cod remain below time series mean levels (Figure 1) and the stock continues to exhibit a truncated age structure and low recruitment. The NEFSC research vessel survey biomass indices for the Georges Bank stock remain low (Figure 2) and the stock continues to exhibit a truncated age structure and exhibit low recruitment.

2. Haddock

United States commercial landings of haddock (*Melanogrammus aeglefinus*) in 2021 were 7,413 mt, a 30% decrease from the 2020 landings of 10,209 mt.

Northeast Fisheries Science Center (NEFSC) research vessel survey biomass indices in the Gulf of Maine have declined from recent historical high levels to below the time series average in both seasons (Figure 3). The NEFSC research vessel survey biomass indices for the Georges Bank stock have declined from recent historic high levels; the fall biomass index is now below the time series average (Figure 4).

3. Redfish

USA landings of Acadian redfish (*Sebastes fasciatus*) decreased by 4% from 5,887 mt in 2020 to 5,658 mt in 2021. Fall research vessel survey biomass indices generally increased from the mid-1990s to a record-high index value of 77.05 kg/tow in 2010 (Figure 5). The survey biomass indices have generally decreased since the peak in 2010. Most recently, the survey biomass indices increased by 21% from 19.56 kg/tow in 2019 to 23.71 kg/tow in 2021.

4. Pollock (USA Waters of Areas 5&6 stock)

USA landings of pollock (*Pollachius virens*) decreased by 5% from 3,527 mt in 2020 to 3,368 mt in 2021. Fall research vessel survey biomass indices generally increased from the mid-1990s through 2005, before decreasing in 2006 (Figure 6). The survey biomass indices have been variable since 2006, reaching a record-low of 0.18 kg/tow in 2009. Most recently, the index decreased by 74% from 1.32 kg/tow in 2019 to 0.34 kg/tow in 2021.

5. White Hake

Nominal USA landings of white hake (*Urophycis tenuis*) from NAFO Subareas 5 and 6 increased by 1% from 1,872 mt in 2020 to 1,891 mt in 2021. There were < 1 mt of discards in NAFO Div. 3N and no landings reported. Research vessel survey indices declined during the 1990s and increased in 2000 due to good recruitment of the 1998 year class. The indices have generally been variable since 2001. The indices have been stable since 2013 (Figure 7).

6. Yellowtail Flounder

USA landings of yellowtail flounder (*Limanda ferruginea*) from NAFO subareas 5 and 6 were 313 mt in 2021, a 140% increase from 2020 landings of 130 mt. In Div. 3N, landings increased by 4% from 398 mt in 2020 to 413 mt in 2021. Additionally, 21 mt of yellowtail flounder was discarded in Div. 3N bringing the total catch of yellowtail flounder in Div. 3N to 434 mt in 2021.

The NEFSC autumn survey biomass index in the Gulf of Maine has generally been variable since 2008. Most recently, the index increased by 17% from 4.0 kg/tow in 2019 to 4.7 kg/tow in 2021 (Figure 8). On Georges

Bank, the NEFSC autumn survey has remained low since 2010. The Southern New England-Mid Atlantic yellowtail NEFSC autumn survey index is also at low levels and decreased further in 2021 compared to 2019 (0.025 kg/tow in 2019 to 0.003 kg/tow in 2021 - Figure 9).

7. Other Flounders

USA commercial landings of flounders (other than yellowtail flounder and Atlantic halibut) from Subareas 3-6 in 2021 totaled 6,643 mt, 7% higher than in 2020. Summer flounder (*Paralichthys dentatus*; 71%), witch flounder (*Glyptocephalus cynoglossus*; 12%), American plaice (*Hippoglossoides platessoides*; 10%), winter flounder (*Pseudopleuronectes americanus*; 7% comprising the Georges Bank, Southern New England, and Gulf of Maine stocks), and windowpane flounder (*Scophthalmus aquosus*; <1% comprising the Northern and Southern stocks) accounted for virtually all of the 'other flounder' landings in 2021. Compared to 2020, commercial landings in 2021 were lower for American plaice (-3%), witch flounder (-6%), winter flounder (-8%), and windowpane flounder (-74%) but higher for summer flounder (14%). The American plaice landings from Div. 3N were 39.1 mt. In addition, 0.3 mt of American plaice were discarded in Div. 3N bringing the total catch of American plaice in Div. 3N in 2021 to 39.4 mt. Witch flounder landings were 0.6 mt while discards were < 0.1 mt.

Research vessel survey indices in 2021 increased for summer flounder, decreased for American plaice and witch flounder, while Georges Bank winter flounder, northern windowpane and southern windowpane remained relatively unchanged (Figures 11-16).

8. Atlantic halibut

USA landings of Atlantic halibut (*Hippoglossus hippoglossus*) in the Gulf of Maine-Georges Bank region decreased 10% from 43.2 mt in 2020 to 39.2.2 mt in 2021. The discards in NAFO Subarea 3 were < 0.1 mt in 2021 and no landings were reported. Research vessel survey indices have little trend and high interannual variability due to the low capture rate of Atlantic halibut (Figure 17). In some years there are no Atlantic halibut caught, indicating that abundance is close to being below the detectability level of the survey. Indices for 2009 – 2019 were converted from FSV *Henry .B. Bigelow* units to RV *Albatross IV* units using the mean calibration coefficient of other flounders.

9. Silver hake

USA landings of silver hake (*Merluccius bilinearis*) from NAFO subareas 5 and 6 decreased compared to 2020. In 2021, US commercial landings of silver hake totaled 4,402 mt, a 14% difference compared to 2020 of 5,103 mt. Discards in NAFO Div. 3N were < 1 mt and no landings were reported.

The NEFSC autumn research vessel survey biomass indices for northern silver hake have generally been increasing over the last ten years. Most recently, the NEFSC autumn survey biomass index increased by 17% from 13.69 kg/tow in 2019 to 16.05 kg/tow in 2021 (Figure 18). In the south, the NEFSC autumn survey index has also been increasing albeit with incomplete coverage in 2017. Most recently, the autumn index decreased by 73% from 2.59 kg/tow in 2019 to 0.71 kg/tow in 2021.

10. Red Hake

USA landings of red hake (*Urophycis chuss*) decreased from 328 mt in 2020 to just 221 mt in 2021, a 33% decline. Research vessel survey biomass indices for the Gulf of Maine - Northern Georges Bank stock declined through 2006, but have increased in recent years and are now at the same level or higher than they were before 2003. In 2021, the NEFSC spring biomass index was 4.3 kg/tow, an increase from 2019 and above the average post-2003 value of 2.76 kg/tow (Figure 20). Indices for the Southern Georges Bank - Mid-Atlantic stock declined in the 1990s and in most years have remained below 1 kg/tow since (Figure 21).

11. Atlantic Herring

Nominal USA catches of Atlantic herring (*Clupea harengus*) declined to a time series low, equaling 8,052 mt in 2020 and 5,187 mt in 2021, which continues a decline that began in 2014. Spring survey indices generally declined during 2012-2021 and averaged 7.06 kg/tow (Figure 22). The 2021 spring survey index was 0.76 kg/tow, which was the lowest observation since 2010. Based on a 2020 update stock assessment, spawning biomass generally increased from 1982 to 1997, declined from 1998 to 2009, increased through 2014, but has steadily declined since. Recruitment during 2012-2019 was below average, with several of the lowest recruitments ever observed occurring in the last five years. The 2020 assessment did not exhibit a retrospective pattern, a problem that has often plagued previous assessments. The lack of a retrospective pattern may have been in part due to a modeled change in catchability to account for the change in survey vessel used for the spring and fall NMFS bottom trawl surveys. Age composition data show that survey and fishery catches in recent years are entirely comprised of fish from below average cohorts, and little or no evidence of strong cohorts can be observed. An update Atlantic herring assessment is scheduled for 2022, when examining the strength of recent cohorts is likely to be of great interest given the recent poor recruitments and subsequent reduced quotas.

12. Atlantic Mackerel

U.S. commercial landings of Atlantic mackerel (*Scomber scombrus*) decreased 32% from 8,039 mt in 2020 to 5,476 mt in 2021. Recreational catches increased 10% from 2,017 mt in 2020 to 2,222 mt in 2021.

Northwest Atlantic mackerel in NAFO subareas 3-6 was last assessed in the U.S. in 2021 through the Northeast and Mid-Atlantic Region Management Track Assessment process. This assessment recommended that Atlantic mackerel be considered overfished with overfishing occurring. A rebuilding plan is currently being updated by the U.S.'s Mid Atlantic Fishery Management Council (MAFMC).

For the 2021 U.S. assessment, a range-wide spawning stock biomass (SSB) index was incorporated that combined estimates from Canada's dedicated Atlantic mackerel egg survey and estimates from the U.S.'s ichthyoplankton surveys. The combined SSB index showed a general decline over the time series from a maximum of 1,846,983 mt in 1986 to a time-series low of 28,786 mt in 2010 (Figure 1). Since 2010, spawning stock biomass increased slightly to approximately 105,410 mt in 2017, but then decreased to 82,692 mt in 2019. The proportion of the total spawning biomass represented by the southern contingent varied over time from a maximum of 43% in 1983 to a minimum of 1% in 2005 and averaged 13.9% since 2010. Accordingly, trends in the combined SSB index closely followed those of the northern contingent.

13. Butterfish

USA landings of butterfish (*Peprilus triacanthus*) decreased 30.9% from 3432 mt in 2019 to 2370 mt in 2020. Fall research vessel survey biomass indices have fluctuated since the 1970s, but were generally highest in the late 1970s to early 1990s. Since 1995, annual values have averaged 4.37 kg/tow. Biomass in 2017 was NA due to limited sampling of butterfish strata (Figure 24).

14. Squids

Longfin inshore squid

The USA small-mesh bottom trawl fishery for longfin inshore squid, *Doryteuthis (Amerigo) pealeii*, began in 1987. During 1987-2018, landings averaged 15,136 mt, with a low of 6,751 in 2010 and a peak of 23,733 mt in 1989. In addition to other factors, landings have been affected by in-season quotas, since 2000, which have been trimester-based since 2007. Landings during 2007-2019 averaged 11,365 mt and declined by 25% in 2020 to 9,405 mt, which was 41% of the annual quota. During 2021, preliminary landings totaled 10,848 mt.

Like most squid species, fall survey relative abundance indices for longfin inshore squid are highly variable. During 2002-2011, relative abundance (derived using only daytime tows) generally declined from the second highest point in the time series (1,960 squid per tow) to 339 squid per tow; below the 1975-2019 median of 625 squid per tow (Figure 25). Following an increase to 1,371 squid per tow in 2012 abundance indices decreased again to 536 squid per tow in 2016. Abundance indices were not computed for 2017 or 2020 due to inadequate sampling of the species fall habitat area and the lack of a survey due to the COVID-19 pandemic. Relative abundance was near the median during 2018 and 2019, but in 2021 was 1,854 squid per tow; the third highest in the time series.

Northern shortfin squid

The USA small-mesh bottom trawl fishery for Northern shortfin squid (*Illex illecebrosus*) began in 1987. During 1987-2020, landings averaged 13,520 mt, with a low of 1,958 mt in 1988 and a high of 30,163 mt in 2021. In recent years, landings declined from 18,797 mt in 2011 to 2,422 mt in 2015. However, during 2017-2021, the US fishery experienced five consecutive years of very high landings (averaging 26,626 mt), resulting in fishery closures during each of these years. This landings trend has occurred previously, but not for the domestic fishery. Landings during this period increased from 26,516 mt in 2017 to the highest since 1963, 30, 886 mt. The 2017-2021 landings increase was in part due to increased fishing effort (e.g., due to increased ex-vessel value and increasing quotas since 2019) but also due to increased relative abundance on the US shelf, at least during two of the three years for which such indices were available (refer to following paragraph). In addition < 0.1 mt of squid were discarded in NAFO Div. 3N.

The NEFSC fall survey relative abundance indices attained a record-high in 2006 (29.5 squid/tow) then steadily declined to below the 1967-2019 median of 8.0 squid per tow in 2013. Thereafter, relative abundance was near the median through 2016 (Figure 26). Abundance indices were not computed for 2017 and 2020 due to inadequate sampling of the primary *Illex* habitat areas and the lack of a survey in 2020 (due to the COVID19 pandemic), respectively. During 2018 and 2021, relative abundance was 15.8 squid per tow (the highest since 2006) and was 11.1 squid per tow in 2021, respectively.

15. Atlantic Sea Scallops

USA Atlantic sea scallop (*Placopecten magellanicus*) landings in 2021 were 19,606 mt (meats), a decline of over 2,500 mt from 2020. However, due to increased prices, the ex-vessel value of the landings in 2021 was a record $670 million, an increase of over $184 million from 2020. Landings are expected to decline further in the next several years due to the depletion of the large 2012 and 2013 year classes and below average recruitment in subsequent years.

Biomass in federally managed waters in 2021, based on dredge and optical surveys, was 87,118 mt (meats) on Georges Bank, 24,400 mt (meats) in the Mid-Atlantic Bight, and 2752 mt (meats) in the Gulf of Maine, for a total of 114,270 mt (meats). This is about a 20% decline from the estimated 2020 biomass, although the stock remains above B_{MSY}. Recruitment was well below average in the Mid-Atlantic Bight, and moderate on Georges Bank. However, there were indications of a good one year old (prerecruit) year class in the Nantucket Lightship area.

16. Northern Shrimp

The USA fishery for northern shrimp has been closed since 2014 due to extremely low abundance of all life stages based on fishery independent surveys of northern shrimp in the Gulf of Maine (Figure 27).

17. Spiny Dogfish

USA landings of spiny dogfish (*Squalus acanthias*) declined by 37% from 7,915 mt in 2020 to 5,788 mt in 2021. Survey indices of males and females combined, which are highly variable, generally declined between the early

1990s and 2005, but increased sharply in 2006 and have since generally remained high (Figure 28). The indices for males and females are also plotted separately and show diverging patterns. The male index has been fairly stable and then increased in the last few years. The female index tends to drive the overall index showing a decline between the early 2990s and 2005 and then increasing.

18. Skates

USA nominal landings of skates declined 44% between 2020 and 2021 from 13,453 mt in 2020 to 9,355 mt in 2021. The landings are sold as wings for human consumption and as bait for the lobster fishery. Landings have increasingly been reported by species, however 390 mt were reported as unclassified in 2021, an increase from 2.2% to 4.0% of the total.

Winter Skate

Winter skate (*Leucoraja ocellata*) reported landings decreased by 82% between 2020 and 2021 from 9,970 mt to 5,485 mt. For the survey, adjustment for the lack of coverage in the Southern New England and the Mid-Atlantic strata for fall 2017 was described in 2019 (SCS 19/15). A similar adjustment was made to account for missing strata in the north in 2018. Survey biomass indices for winter skate peaked in the mid-1980s (Figure 29) but then declined, possibly due to an increase in the directed fishery in the late 1980s and early 1990s. During the mid-1990s, the indices stabilized at an intermediate level, increased and generally remained at a slightly higher level with some peaks in 2009 and 2019.

Little Skate

Reported landings of little skate (*Leucoraja erinacea*) decreased 29.3% between 2019 and 2020 from 2,791 mt to 2,997 mt. For the survey, the adjustment for the lack of coverage in the southern strata described above for spring 2014 was described in 2015 (SCS 15/09). Little skate survey indices have generally fluctuated without trend (Figure 30).

Barndoor Skate

Landings of barndoor skate (*Dipturus laevis*) were allowed starting in 2018. Reported landings increased 15% between 2020 and 2021 from 179 mt to 210 mt. The adjustment for the lack of coverage in the Southern New England strata was described in 2019 (SCS 19/15). In 2018, a similar adjustment was made to account for missing strata in the north. Survey indices declined markedly in the mid-1960s and remained very low through the late-1980s. Biomass indices subsequently increased to levels observed in the mid-1960s and in were the highest in the time series in 2018 (Figure 31).

Thorny Skate

There has been a possession prohibition on landings of thorny skate (*Amblyraja radiata*) in United States waters since 2003. Some landings still occur due to the high volume nature of the fishery. Reported landing increased 83% from 0.004 mt in 2020 to 0.023 mt. in 2021. The adjustment for the lack of coverage in the Southern New England strata was described in 2019 (SCS 19/15). In 2018, a similar adjustment was made to account for missing strata in the north. Thorny skate survey indices have declined over the entire time series, and are currently near record lows (Figure 32).

Smooth Skate

There has been a possession prohibition on landings of smooth skate (*Malacoraja senta*) in the Gulf of Maine (NAFO Div. 5Y) since 2003 although landings are permitted in other parts of the United States. Smooth skate reported landings increased by 31% between 2020 and 2021 from 164.5 mt to 239.3 mt. The adjustment for the lack of coverage in the Southern New England strata was described in 2019 (SCS 19/15). In 2018, a similar adjustment was made to account for missing strata in the north. Survey indices for smooth skate are highly variable, but were been generally stable from the 1980s through 2005 (Figure 33.

Clearnose Skate

Clearnose skate (*Raja eglanteria*) reported landings decreased by 40% between 2019 and 2020 from 47.7 mt to 34.0 mt. There were no indices available for 2017 since the entire strata set was not covered. Indices generally increased between 1995 and 2010 (Figure 34) but have been stable over the last decade.

Rosette Skate

Rosette skate (*Leucoraja garmani*) reported landings were zero in 2020 and 2021. There were no indices available for 2017 since the entire strata set was not covered. Indices generally increased between 1995 and 2010 (Figure 35) but have been stable since.

B. Special Research Studies

1. Environmental Studies

A total of 1201 CTD (conductivity, temperature, depth) profiles were collected and processed by the Northeast Fisheries Science Center (NEFSC) in 2021 over the course of 9 cruises. Of this total, 1,070 CTD profiles were obtained within NAFO Subareas 5 and 6, and 76 profiles were collected in NAFO Subarea 4. These data are archived in an oracle database. Cruise reports, and annual hydrographic summaries are accessible at: https://www.fisheries.noaa.gov/resource/data/2010-2019-hydrographic-conditions-northeast-us-continental-shelf-conductivity. Data are publicly available from the World Ocean Database maintained by NOAA's National Centers for Environmental Information at: http://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.html

Hourly bottom temperature records were obtained by participants of the **Environmental Monitors on Lobster Trap Project** (see emolt.org) at approximately 30 fixed locations/depths around the Gulf of Maine and Southern New England Shelf. The results indicate that 2021 was, in general, an extremely warm year (Fall months especially) relative to the 20+ years the project has been underway. We continue our c ollaboration with similar projects in an attempt to merge bottom temperature datasets from around the region.

Real-time bottom temperatures have now been reported from more than 50 commercial vessels. Approximately 40 00 haul-averaged bottom temperatures were automatically transmitted via satellite from a variety of locations and depths in 2021 bringing the project total to nearly 18 ,000 hauls. Observations from both fixed and mobile gear are compared to three different local ocean models as well as the empirically-derived climatology. The results are displayed in both tabulated and mapped form.

Approximately one dozen **satellite-tracked surface drifters** were deployed off the coast of New England in 2021 (see http://apps-nefsc.fisheries.noaa.gov/drifter). The collective archive helps resolve the transport pathways of coastal currents in shelf waters. The drifter project is promoted as an educational tool where students are involved with both the construction of the instruments and the processing, plotting, and analysis of the data. Sensor packages can now be deployed on the few dozen unmanned sailboats (see http://educationalpassages.org) that are released each year.

Nearly all this NEFSC environmental data is available via our ERDDAP server.

b) Plankton Studies

During 2021, field operations to monitor zooplankton community distribution and abundance started resuming and returning to the levels of normal operation seen in pre-pandemic years. 723 plankton tows were made over the course of eight surveys, using 61 centimeter bongo nets. Each of these surveys covered a portion of the continental shelf region from Cape Hatteras to the Gulf of Maine. These surveys included an Atlantic Marine Assessment Program for Protected Species (AMAPPS) cruise with 184 tows, two Right Whale Surveys totaling 35 tows, a Spring Bottom Trawl Survey with 92 tows, a Fall Bottom Trawl Survey with 109 tows, the Spring Ecosystem Monitoring Survey with 92 tows, a Summer Ecosystem Monitoring Survey with 132 tows and a Fall Ecosystem Monitoring Survey with 79 tows. In addition to these tows made with the large 61 cm diameter bongo nets, additional samples were collected on the Ecosystem Monitoring Surveys with smaller 20 cm diameter bongo nets. These samples were for the Census of Marine Zooplankton being conducted by the University of Connecticut and for larval fish and eggs sample genetics studies being conducted at the Narragansett laboratory of the NEFSC.

After a hiatus in 2020, operations with the Imaging FlowCytoBot unit from the Woods Hole Oceanographic Institute were resumed. Images of phytoplankton from the scientific seawater flow-through system on the ecosystem monitoring cruises were collected during the course of these three surveys. In addition, these three surveys also made a total of 90 water casts to monitor levels of nutrients, oxygen and Dissolved Inorganic Carbon in the euphotic zone.

Environmental DNA research also resumed in 2021 with a collection of environmental DNA samples on 35 water casts conducted during the Summer Ecosystem Monitoring Survey, for research being conducted at the NEFSC Milford Laboratory.

In a first study of its kind conducted aboard an Ecosystem Monitoring Cruise, scientists aboard every 2021 Ecosystem Monitoring Survey also collected pteropods from the plankton samples, while at sea. The pteropods were rinsed with fresh water and dried in a drying oven for analysis of their shell thickness as an indicator of the effects of increased ocean acidity, for a study being conducted by researchers at the Bermuda Institute of Ocean Sciences.

c) Benthic Studies

No field work done for 2021.

2. Biological Studies

a) Fish Species

Flatfishes: During 2015-2020, we implemented work on the plasticity of responses to high and variable thermal regimes and CO_2, and the degree of intraspecific, inter-population differences in resilience to these climate-related environmental changes. We are interpreting these results in the context of differences in thermal and CO_2 regimes between stocks that experience contrasting levels of environmental *in situ*. In 2019, we began a study of responses to elevated thermal and CO_2 regimes for summer flounder (*Paralichthys dentatus*) offspring drawn from parents collected near the northerly (New Jersey) reaches of its geographic range. The effort examined the early life-stage responses to a large number of distinct thermal and CO_2 regimes. Regarding thermal regimes, we used a large number of distinct constant thermal regimes on embryos (N=20 regimes) and larvae / young juveniles (N=11) as well as two seasonally varying regimes for larvae and young juveniles. Responses included effects on viability, growth, and development. Up to 12 different constant CO_2 regimes were also evaluated under three different constant thermal regimes. A similar evaluation of effects of constant and variable thermal and CO_2 regimes on winter flounder (*Psuedopleuronectes americanus*) was conducted in the winter 2019-2020.

Sturgeons: Macro-phenotypic data on effects of thermal regimes and of contaminants that were collected during 2014-2017 are being further analyzed for publication.

Forage fish. A set of studies on Atlantic silverside, *Menidia menidia*, continued through 2019. Those studies focus on effects of climate (thermal and CO_2 variations), hypoxia, and parentage on key traits of the early life-stages (ELS). Those data are being further analyzed. An analogous system with a large number of treatment levels was developed in 2018 for dissolved oxygen and the first test used the fertilization rate of Atlantic silverside as the response variable. A clear, negative trend in fertilization rate occurred with increasing degrees of hypoxia.

Indicator species. A study on the potential effects of contaminated sediments on finfish was initiated in 2020 and continued through 2021. Using white perch, *Morone americana*, as an indicator species but also an ecologically important one in estuaries and source river water in the Mid-Atlantic States, studies focused on evidence of reproductive impairment in fish inhabiting waterways of New Jersey known to have been subjected to contaminants. Adults are being assayed for evidence of impairment at the genetic to organismal levels. Sediments are being used for exposure experiments on the embryos and young larvae. The study includes fish populations and sediments from target (contaminated) and reference locations.

b) Resource Survey Cruises

During 2021, personnel from the Ecosystems Surveys Branch (ESB) staged, staffed, and supported the spring and fall multi-species bottom trawl survey and the northern shrimp trawl survey. Additional staff and gear support was provided for the sea scallop dredge survey and the Atlantic surfclam dredge survey. In aggregate, the survey staff efforts totaled 135 research and charter vessel sea days. NOAA scientific and contract staff involvement in the various cruises totaled of 1,685 person-sea days. ESB cruises occupied 886 stations in an area extending from Cape Hatteras, North Carolina to Nova Scotia. A total of 58,737 length measurements were recorded, representing 110,413 individuals from 285 species during these cruises. Ecosystem survey data are used as fishery independent inputs for 48 single species stock assessments and for several ecosystem dynamics modeling efforts.

Significant effort was also expended in 2021 to fulfill special survey sampling requests from 25 NOAA and university investigators. This sampling included 12,783 feeding ecology observations, collection of 22,560 aging structures, and acquisition of 32,610 samples/specimens to support additional shore-based research. Additionally, the HabCam cruise tracks from the scallop survey completed 708 nm, collecting a total of 2,504,492 image pairs.

c) Fishery Biology Program (https://www.fisheries.noaa.gov/new-england-mid-atlantic/science-data/age-and-growth-studies-northeast):

Fish age determinations by the Fishery Biology Program are used in age-structured single- and multi-species stock assessments for regions from the international (US-Canada) border regions in the Gulf of Maine and Georges Bank, south through the middle US Atlantic seaboard. These stock assessments serve as the basis for scientific advice to two federal fishery management councils (i.e., NEFMC, MAFMC).

In 2021, FBP staff provided ages for over 28,100 otoliths from 18 species. The top species by number aged were silver hake (3,759), haddock (3,495), and tilefish (3,197). Large numbers of white hake, black sea bass, scup, and summer flounder (combined total 9,784) were also aged. These data provide information on age composition, recruitment strength, and growth dynamics, which ultimately inform scientific determinations of stock status, biological reference points, and annual catch limits.

The FBP utilizes a robust set of QA/QC protocols to monitor and maintain 1) accuracy, 2) precision, and 3) inter-agency consistency in age determinations. Results of all these tests are posted publicly at https://fish.nefsc.noaa.gov/fbp/QA-QC/. The coefficient of variation is used to measure precision levels, with values under 5% deemed acceptable. Samples re-aged as part of this testing are not counted in the above totals.

1. Accuracy: Through the use of reference collections, personnel are regularly tested to measure whether there has been any deviation of their age estimates relative to a collection of consensus-aged samples. The Program currently has reference collections for 4 species and is currently working to build reference collections for additional species.

2. Precision: A subsample of recently-aged samples is re-aged blindly by personnel to quantify the random error of the age estimates. In addition, inter-reader precision tests are conducted when there is a change in the person responsible for ageing of a given species, and inter-structure tests are conducted when there is a change in the method for ageing. In 2021, 64 intra-reader precision tests were conducted across 17 species.

3. Inter-agency exchanges: For transboundary stocks, the FBP exchanges age structures with other laboratories. In 2021, 1 inter-agency exchange was conducted for haddock with the St. Andrews Biological Station (Fisheries and Oceans Canada),

Detailed sampling of fish collected from NEFSC Cooperative Research Study Fleet program was not possible in 2021 due to COVID-19 pandemic. Despite the limited laboratory access during the pandemic, analysis of previously collected samples continued. These analyses included histological analysis of gonads (n= 879 yellowtail flounder, 333 haddock) and determination of fecundity (376 yellowtail flounder, 487 winter flounder, 93 haddock).
The NEFSC analysis of forage fish energy content continued in 2021 as monitoring programs (seasonal bottom trawl surveys) resumed. The study focuses on the following species; Atlantic herring, alewife, silver hake, butterfish, northern sandlance, Atlantic mackerel, longfin squid, and northern shortfin squid. Energy density was predicted the percent dry weight using previously determined relationships. Samples have been analyzed for proximate composition and energy density from limited spring 2020 (n=243) and complete spring 2021 (n=801) bottom trawl surveys. Results have been summarized in the annual State of the Ecosystem Report for the Northeast U.S. shelf.

d) Food Web Dynamics

The NEFSC collections of fish diet data as part of a long-term (since 1973) monitoring program continued in 2021 despite the COVID-19 pandemic. Along with these data, modeling and analytical efforts continued to focus on species interactions among small pelagics, flatfish, elasmobranchs, and gadiformes.

Fish diet samples were collected on the northeastern U.S. continental shelf (South-Atlantic Bight to Scotian shelf) during the NEFSC bottom trawl survey. Estimates of prey volume and composition were made primarily at sea for selected species. During 2021, stomachs from 6,915 individuals and 49 species were examined in the spring, and 5,925 individuals and 50 species were examined in the fall. Diet sampling emphasized gadiformes, elasmobranchs, small pelagics, flatfishes, and lesser-known species.

The time series of fish diet spans 49 years (1973-2021). The majority of the time series is available for analysis, including data from over 687,000 stomach samples and over 160 predators. Processing of the 2021 bottom trawl survey diet data is scheduled for completion in 2022.

These diet data undergo two rigorous data quality audits including initial checks at sea during sample collection, and secondary checks in the lab to ensure data quality. These checks consider the various facets of prey taxonomy, predator/prey mass, predator/prey length, and prevent missing information. In 2021, stomachs from juveniles (<=12 cm) routinely examined at sea were preserved for laboratory processing.

Since 2004, training workshops for identifying fish stomach contents and refreshing staff knowledge of marine invertebrate and fish taxonomy are offered once per year in the winter prior to the spring trawl survey. These workshops continued remotely in 2021 and provided class discussions and photos of specimens as aids for prey identification in association with the spring and autumn trawl surveys.

Staff prepared several papers and reports for publication and presentations on a wide range of trophic ecology issues in the Northwest Atlantic ecosystem. Since trophic interactions are central to food web and ecosystem considerations, research continues with respect to making fish diet metadata publically accessible, examining the trophic ecology of lesser-studied fishes such as Gulf Stream flounder (*Citharichthys arctifrons*), quantifying benthic pressures: predation and bottom fishing effort relative to fish stock rebuilding, and incorporating fish consumption into stock assessments.

e) Apex Predators Program

Apex Predators Program (APP) research focused on determining migration patterns, age and growth, feeding ecology, reproductive biology, and relative abundance trends of highly migratory species, particularly Atlantic sharks. Members of the Cooperative Shark Tagging Program (CSTP), involving thousands of volunteer recreational and commercial fishermen, scientists, and fisheries observers, continued to tag coastal and pelagic sharks and provide information to define essential fish habitat for shark species in U.S waters in 2021. Over 300,000 fish including more than 50 shark species have been tagged since this program was initiated in 1962 and recaptures include more than 30 of the shark species tagged. In 2021, CSTP movement and distribution data from great, scalloped, and smooth hammerhead sharks (*Sphyrna mokarran*, *S. lewini*, and *S. zygaena*, respectively) were used to inform stock identification during the Southeast Data Assessment and Review (SEDAR) Stock ID process.

APP staff participated in the SEDAR 77 Stock ID and Data processes in 2021 towards the assessment of Atlantic hammerhead populations, specifically the Carolina (*S. gilberti*), great, scalloped, and smooth hammerhead species. During the Stock ID process, staff contributed samples, data, and analyses to the Life History and Spatial (Co-Lead) Working Groups. During the Data process, staff contributed to the Catches, Ecosystem (Lead), Indices (Co-Lead), and Life History Working Groups. Staff presented working papers on great and scalloped hammerhead age & growth and reproductive parameters. Staff also provided a working paper on length-length and length-weight conversions using data from APP surveys, recreational tournament sampling, and commercial opportunistic sampling, as well as contributions from other domestic (NOAA Fisheries Southeast Fisheries Science Center; South Carolina Department of Natural Resources, SCDNR; Georgia Department of Natural Resources, University of North Florida, UNF; and University of Southern Mississippi) and international (Fisheries and Oceans Canada) partners. During the SEDAR 77 Data Workshop, APP staff presented a working paper on scalloped and smooth hammerhead discard estimates for the northeast sink gillnet fishery using data collected by the Northeast Fisheries Observer Program. Additionally, staff presented six working papers detailing multiple indices of abundance and summarizing length data for scalloped hammerhead sharks using gillnet and longline survey data from the Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) surveys and longline survey data from the NEFSC Coastal Shark Bottom Longline Survey and Southeast Area Monitoring and Assessment Program longline surveys by the South Carolina Department of Natural Resources (SCDNR) and the University of North Carolina.

The NEFSC Coastal Shark Bottom Longline Survey began in 1986 and is conducted every two to three years. This survey is the longest running coast-wide (Florida to the Mid-Atlantic) fishery-independent shark survey in the U.S. Atlantic Ocean. The primary objective is to conduct a standardized, systematic survey of the shark populations off the U.S. Atlantic coast to provide unbiased indices of relative abundance. Additional survey objectives are to investigate the distribution, abundance, and species composition of sharks; tag sharks for migration studies; inject, with tetracycline, tagged sharks whenever feasible for age validation studies; collect biological samples for age and growth, food habits, and reproductive studies; and collect morphometric data. Results from the 2021 survey included 2462 sharks representing 11 species, of which 2,132 (87%) were tagged and released. Sharks represented 99% of the total catch of which sandbar sharks were the most common, followed by dusky, tiger, scalloped hammerhead, blacktip, Atlantic sharpnose, and spinner sharks. Life history samples and morphometric data collected from great and scalloped hammerheads during this survey across years were used in the SEDAR 77 process, and indices of abundance for scalloped hammerhead sharks were also developed for use during this process in 2021.

Since 1961, recreational shark tournament sampling has been conducted annually during the summer from New Jersey to Maine, until 2020 when the majority of tournaments were cancelled. Tournaments are a primary source of biological samples used in NEFSC shark food habits, reproduction, and age/growth studies that provide biological reference points used during the ICCAT pelagic shark assessments and SEDAR process. Several tournaments were cancelled in 2021, but APP staff were able to attend two tournaments. Staff provided tags for sharks released during the tournaments and examined 21 sharks (shortfin mako, common thresher, and a tiger shark). An additional 5 sharks (a basking shark, common thresher, great hammerhead, porbeagle, and a sand tiger) were sampled from commercial incidental mortality and stranding events. The great hammerhead was a large female that contributed to life history analyses for the SEDAR 77 assessment.

The NEFSC Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) Program continued to survey and monitor shark nursery habitat in nearshore waters along the U.S. Atlantic coast using federal, state, university, and commercial platforms. COASTSPAN surveys help determine the relative abundance, distribution, and migrations of sharks using coastal nursery habitat through longline and gillnet sampling and mark-recapture data. In 2021, our COASTSPAN participants were the Virginia Institute of Marine Science, South Carolina Department of Natural Resources (SCDNR), the University of North Florida (UNF), which conducted the survey in both Georgia and northern Florida waters, and Florida Atlantic University. Additionally, NEFSC staff conducted COASTSPAN surveys in Delaware Bay in 2021. Results from 2021 COASTSPAN surveys were provided to NMFS Highly Migratory Species Management Division for use in updating the EFH section of the annual Stock Assessment and Fisheries Evaluation (SAFE) Report. In addition, young-of-the-year catch-per-unit-effort data from COASTSPAN gillnet and longline surveys conducted by the SCDNR and UNF were standardized with respect to fishing gear and environmental variables to create recruitment indices of abundance for scalloped hammerhead sharks during the SEDAR 77 Data process. Additionally, COASTSPAN data contributed to the length-length and length-weight conversion factors used during the SEDAR 77 Data process.

In 2021, APP staff worked in cooperation with staff from the Dauphin Island Sea Lab and NOAA Fisheries Alaska Fisheries Science Center to publish a study in *Fishery Bulletin*. This publication was on the validation of the use of vertebrae and dorsal-fin spines for age determination of spiny dogfish (*Squalus acanthias*) in the western North Atlantic Ocean. Spiny dogfish are traditionally aged by counting band pairs on dorsal-fin spines; however, wear and tear of the spines make obtaining accurate age estimates of older spiny dogfish difficult. Vertebral centra are an alternate structure that can be used to estimate age, but success in their use has been varied. APP staff conducted a tag-recapture study using oxytetracycline injections to validate annual deposition in both dorsal-fin spines and vertebral centra of spiny dogfish. When band pairs in vertebral centra were used, time at liberty was significantly underestimated. Additionally, band-pair counts were found to change along the vertebral column of an individual, further refuting the use of vertebral centra to generate age estimates. Band-pair deposition in dorsal-fin spines was confirmed to be annual in spiny dogfish at liberty for up to 2.6 years. Dorsal-fin spines should continue to be used to age spiny dogfish, and vertebral centra are not a viable alternative.

APP staff contributed to a publication in a proceedings volume on developments in x-ray tomography by the Society of Photo-Optical Instrumentation Engineers in 2021. This work was a collaboration with staff from Northwestern University, Duke University, University of Florida, Stony Brook University, and NOAA Fisheries Southwest Fisheries Science Center. Diffraction tomography can be performed using energy dispersive diffraction and polychromatic synchrotron x-radiation to map crystallographic texture, as found in bioapatite, a mineral component of shark centra. Unlike conventional x-ray diffraction techniques that use x-rays of one energy, energy dispersive diffraction irradiates with x-rays of different wavelengths. Differently oriented nanocrystals diffract different wavelengths, so moving the specimen across the beam allows the varied crystal orientations to be mapped. This study conducted 3D mapping of the integrated intensity of several reflections from the bioapatite in the mineralized cartilage of a blue shark (*Prionace glauca*) centrum. The shark centrum consists of a double cone structure (corpora calcerea) supported by the intermedialia consisting of four wedges. The integrated intensities of the c-axis reflection and of a reflection with no c-axis component reveals the bioapatite within the cone wall is oriented with its c-axes lateral, i.e., perpendicular to the axis of the backbone, whereas the bioapatite within the wedges is oriented with its c-axes axial. Application of energy dispersive diffraction tomography to 3D mapping of large specimens promises to add to the understanding of other mineralized tissue samples which cannot be sectioned.

In 2021, APP staff with coauthors from the Massachusetts Division of Marine Fisheries, University of Massachusetts Dartmouth, State College of Florida, University of Washington, Woods Hole Oceanographic Institution, and NOAA Fisheries Greater Atlantic Regional Fisheries Office published a study in *Frontiers in Marine Science* on horizontal and vertical movement patterns and habitat use of juvenile porbeagles (*Lamna nasus*) in the western North Atlantic. Although much is known of the life history of this species, there is little fisheries-independent information about habitat preferences and ecology. To examine migratory routes, vertical behavior, and environmental associations, pop-up satellite archival transmitting tags were deployed on 20 porbeagles in November 2006 from a commercial longline fishing vessel on the northwestern edge of Georges Bank, about 150 km east of Cape Cod, MA. Tags were programmed to release in March (n = 7), July (n = 7), and November (n = 6) of 2007, and 17 (85%) successfully reported. Based on known and derived geopositions, the porbeagles exhibited broad seasonally-dependent horizontal and vertical movements ranging from minimum linear distances of 937 to 3,310 km and from the surface to 1,300 m, respectively. All of the sharks remained in the western North Atlantic from the Gulf of Maine, the Scotian Shelf, on George's Bank, and in the deep, oceanic waters off the continental shelf along the edge of, and within, the Gulf Stream. In general, the population appears to be shelf-oriented during the summer and early fall with more expansive offshore radiation in the winter and spring. Although sharks moved through temperatures ranging from 2 to 26°C, the bulk of their time (97%) was spent in 6-20°C. In the summer months, most of the sharks were associated with the continental shelf moving between the surface and the bottom and remaining < 200 m deep. In the late fall and winter months, the porbeagles moved into pelagic habitat and exhibited two behavioral patterns linked with the thermal features of the Gulf Stream: "non-divers" (n = 7) largely remained at epipelagic depths and "divers" (n = 10) made frequent dives into and remained at mesopelagic depths (200–1000 m). These data demonstrate that juvenile porbeagles are physiologically capable of exploiting the cool temperate waters of the western North Atlantic as well as the mesopelagic depths of the Gulf Stream, possibly allowing exploitation of prey not available to other predators.

APP staff contributed to a study using compound-specific stable isotope analysis of amino acids in pelagic shark vertebrae to reveal baseline, trophic, and physiological effects on bulk protein isotope records that was published in *Frontiers in Marine Science* in 2021 with international (University of Southampton, Fano Marine Centre, Cefas Laboratory, Universidade do Porto, Consejo Superior de Investigaciones Científicas, Instituto Português do Mar e da Atmosfera, Secretariat of the International Commission for Conservation of Atlantic Tunas) and domestic (Woods Hole Oceanographic Institution) participation. Variations in stable carbon and nitrogen isotope compositions in incremental tissues of pelagic sharks can be used to infer aspects of their spatial and trophic ecology across life-histories. This may not be the case for bulk tissue isotopic compositions, because multiple processes influence these values, including variations in primary producer isotope ratios and consumer diets and physiological processing of metabolites. Stable isotope compositions of individual amino acids can partition the isotopic variance in bulk tissue into components associated with primary production or diet and physiology. The carbon framework of essential amino acids can be synthesized *de novo* only by plants, fungi and bacteria and must be acquired by consumers through the diet. Consequently, the carbon isotopic composition of essential amino acids in consumers reflects that of primary producers in the location of feeding, whereas that of non-essential amino acids is additionally influenced by trophic fractionation and isotope dynamics of metabolic processing. This study determined isotope chronologies from vertebrae of individual blue sharks and porbeagles from the North Atlantic using carbon and nitrogen isotope compositions in bulk collagen and carbon isotope compositions of amino acids. Despite variability among individuals, common ontogenetic patterns in bulk isotope compositions were seen in both species. However, while life-history movement inferences from bulk analyses for blue sharks were supported by carbon isotope data from essential amino acids, inferences for porbeagles were not, implying that the observed trends in bulk protein isotope compositions in porbeagles have a trophic or physiological explanation, or are spurious effects. Variations in carbon isotope compositions of non-essential amino acids were explored in search for systematic variations that might imply ontogenetic changes in physiological processing, but patterns were highly variable and did not explain variance in bulk protein $\delta^{13}C$ values. Isotopic effects associated with metabolite processing may overwhelm spatial influences that are weak or inconsistently developed in bulk tissue isotope values, but interpreting mechanisms underpinning isotopic variation in patterns in non-essential amino acids remains challenging.

In 2021, APP staff worked in cooperation with staff from NOAA Fisheries Southeast Fisheries Science Center and international partners from the Portuguese Institute for Sea and Atmosphere, University of Algarve, Dirección Nacional de Recursos Acuáticos, Universidade Federal Rural de Pernambuco, Instituto Español de Oceanografía, and the Centro de Investigación y Conservación Marina to publish a study in *Frontiers in Marine Science* on the movements, habitat use and diving behavior of shortfin mako (*Isurus oxyrhincus*) in the Atlantic Ocean. Given increasing concerns for the stock status of the species, the present study was designed to fill in knowledge gaps on habitat use and movement patterns of shortfin mako in the Atlantic Ocean. From 2015 to 2019, 53 shortfin makos were tagged with pop-up satellite archival tags within the North, Central, and Southwest Atlantic Ocean, with successful transmissions received from 34 tags. Generally, sharks tagged in the Northwest and Central Atlantic moved away from tagging sites showing low to no apparent residency patterns, whereas sharks tagged in the Northeast and Southwest Atlantic spent large periods of time near the Canary Archipelago and Northwest Africa, and over shelf and oceanic waters off southern Brazil and Uruguay, respectively. These areas showed evidence of site fidelity and were identified as possible key areas for shortfin mako. Sharks spent most of their time in temperate waters (18–22°C) above 90 m; however, data indicated the depth range extended from the surface down to 979 m, in water temperatures ranging between 7.4 and 29.9°C. Vertical behavior of sharks seemed to be influenced by oceanographic features, and ranged from marked diel vertical movements, characterized by shallower mean depths during the night, to yo-yo diving behavior with no clear diel pattern observed. These results may aid in the development of more informed and efficient management measures for this species.

f) Marine Mammals

Cetacean surveys:

Right whale cruises were conducted on the R/V Gloria Michelle to collect photo id, biological and physical oceanographic data in the area wind energy lease areas and near sighted right whales (*Eubalaena glacialis*). This is part of an effort to better understand right whale prey resources in southern New England. Zooplankton samples were collected with bongo nets and were processed at the Poland Sorting Center, returning species ID and abundance for zooplankton species, and as well as life stage information for *Calanus finmarchicus*. We also collected video plankton recorder (VPR) data to quantify zooplankton at particular depths in the water column. Lastly, we collected echosounding data over multiple frequencies to be paired with VPR and bongo net data to examine the preyscape over a larger time and area. Analysis of these data is ongoing and will be compared with similar data collected in 2020 and 2021. We are summarizing species abundance and distribution in southern New England, are collaborating with University of Massachusetts at Dartmouth to assess energy density of collected zooplankton, and have recently hired a contractor to assist in the analysis and processing acoustic data collected.

A right whale survey was also conducted on board the contract research vessel Warren Junior in the Fall of 2021. Tagging, passive acoustics, sUAS photogrammetry, photo-id, and dimethyl sulfide sampling were among the research goals accomplished on this cruise.

During 07 to 15 November 2021, two NEFSC scientists participated in visual survey operations on board the Woods Hole Oceanographic Institution's vessel the R/V Neil Armstrong. The researchers also deployed sonobouys to enhance detection of whales.

During 27 June to 23 August 2021, the NEFSC conducted a shipboard line transect abundance survey targeting marine mammals, sea turtles and seabirds on the NOAA ship Henry B. Bigelow. The survey area was between 36°N and 42°N and 65°W and 74°W, south of Massachusetts to east of Virginia in waters offshore of the 100 m depth contour. We used the 2 independent team's data collection protocol targeting marine mammals and sea turtles using visual line transect sampling techniques. In addition, we had a team targeting seabirds using strip transect sampling techniques; a team monitoring a passive acoustic towed hydrophone array; and a team collecting physical and biological oceanographic data. In Beaufort sea states of 6 and less, we surveyed about 5,354 km of on-effort track lines at about 10 knots.

Also as part of the Atlantic Marine Assessment Program for Protected Species (AMAPPS), the NEFSC conducted aerial abundance surveys during 1 August to 15 September 2021 in the area extending from New Jersey to Nova Scotia, Canada. The main goal of this survey was to assess the distribution and abundance of marine mammals and sea turtles in the US Atlantic waters in conjunction with the shipboard surveys. More information on the AMAPPS program as well as links to reports can be found at https://www.fisheries.noaa.gov/new-england-mid-atlantic/population-assessments/atlantic-marine-assessment-program-protected.

The North Atlantic Right Whale Sighting Survey (NARWSS) is a NOAA Fisheries program that conducts aerial surveys for North Atlantic right whales off the northeastern coast of the United States and Canada. Images of individual whales are collected for mark-recapture models to monitor abundance and residency. In 2021, NARWSS flew 323 hours over 70 surveys in US waters from New Jersey to the Canadian border, and detected 380 right whales (including duplicates of the same individual). In Canada, NARWSS flew 32 hours over 7 surveys in 2021 in the Gulf of St Lawrence, and detected 48 right whales (including duplicates of the same individual).

During April and May 2021, research crews working from the NOAA research vessel Selkie (24' Safeboat) worked in Cape Cod Bay when right whales were in the area. All right whales encountered were photographed for the North Atlantic Right Whale catalog. Biopsy samples and unmanned aerial images for photogrammetry were also collected.

Work continued with the New England Aquarium and University of Rhode Island to update the North Atlantic Right Whale Individual ID catalog and right whale sightings databases.

Cetacean bycatch and other analyses:

Incidental bycatches of cetacean, turtle, and pinniped species were estimated based on observed takes in commercial fisheries from Maine to North Carolina. Fisheries observed during 2021 included gill nets, otter trawls, mid-water otter trawls, mid-water pair trawls, scallop trawls, scallop dredges, purse seines, and some pot traps.

Serious injury determinations were made on non-fatal large whale fishery interactions and vessel strikes, as well as bycaught small cetaceans and pinnipeds to determine causes and extents of injuries.

Passive acoustics:

NEFSC researchers in the Passive Acoustics Group have been working to: (1) elucidate the basic acoustic behavior of various marine mammal and fish species and potential impacts of anthropogenic noise and offshore wind farm development; (2) monitor baleen whale presence using near real-time reporting from fixed and autonomous acoustic platforms; (3) improve the application of passive acoustics as a tool for monitoring and mitigation; and (4) set up a long term database for acoustic data collection and detection information.

Throughout 2021, 8 SoundTraps and FPODs were deployed along the coast of Maine, and 7 in Southern New England, covering Cox's Ledge and Nantucket Shoals to monitor for North Atlantic right whales, Atlantic Cod, Harbor Porpoises. Additional mysticete, odontocete, and fish species are analyzed, as time allows. Recorders were also deployed in three National Marine Sanctuaries (Stellwagen Bank, Gray's Reef, and Florida Keys), as part of a collaborate effort to evaluate sanctuary soundscapes throughout the U.S. Long-term NOAA Noise Reference Station recorders continue to collect data in the Stellwagen Bank National Marine Sanctuary and offshore of Georges Bank. In collaboration with colleagues at the Woods Hole Oceanographic Institution, gliders were deployed in the Gulf of Maine, Stellwagen Bank National Marine Sanctuary, and Cox Ledge; real-time monitoring buoys are also active off Martha's Vineyard, the New York Bight, the New Jersey Coast, and Cape Hatteras, North Carolina. Detections from these real-time platforms are being used to trigger North Atlantic right whale Slow Zones; results can be found at http://dcs.whoi.edu. As part of the AMAPPS program, analyses of the distributions of sperm whales, beaked whales, members of the Kogiidae family, and baleen whales continued for data collected both on the towed array and bottom mounted recorders deployed in previous years. Finer-scale studies include improving classification methods of passive acoustic data, as well as describing acoustic and diving behavior of odontocetes. The NEFSC Passive Acoustics Research Group also works in collaboration on projects in Australia Marine Parks and Hong Kong Harbor to describe soundscapes and assess illegal vessel activity, and to apply these methods in Northeast U.S. waters, working with NOAA Office of Law Enforcement. Lastly, the group launched the Passive Acoustic Cetacean Map (PACM, https://apps-nefsc.fisheries.noaa.gov/pacm/#/), which gives public access to explore all acoustic detection data for all focal species, across different types of recording platforms, and from multiple organizations (displaying both NEFSC's and outside colleagues' analyses in the same portal). This website includes the development of templates for data submission to PACM, as well as our developing database. For more information on our projects and publications, please visit https://www.fisheries.noaa.gov/new-england-mid-atlantic/endangered-species-conservation/passive-acoustic-research-atlantic-ocean.

Pinnipeds:

In January 2021, the NEFSC completed an aerial survey of gray seal (*Halichoerus grypus*) pupping colonies throughout the U.S. to update estimates of abundance and trends for the Northwest Atlantic gray seal stock. A report of the results is currently in preparation. Live captures of gray seals normally conducted in the pupping season were curtailed due to COVID restrictions, but in April the NEFSC, in collaboration with the Navy, Atlantic Marine Conservation Society, and Marine Mammals of Maine captured 7 harbor seals and 1 juvenile gray seal for studies of health, diet, and movements. In late 2021, the NEFSC partnered with Oceans Unmanned and the National Ocean Service to survey Muskeget Island with a Trinity F90 vertical takeoff and landing (VTOL) drone, to test various sensors and to document the early gray seal pupping season.

A manuscript was published in 2021 which used telemetry data collected in 2019 and 2020 to evaluate gray seal susceptibility to fisheries bycatch in sink gillnet gear. Work continued in 2020 to collect data on pinniped diet from fatty acids in blubber (predator) and various fish (prey) samples, in collaboration with researchers at University of Dalhousie and Maritime Canada Department of Fisheries and Oceans, as well as from stomach content hard part remains obtained from bycaught harbor and gray seals. Analysis of hard part remains and prey fatty acid signature data will begin in 2021. In addition, a pilot study that began in 2018 continues to investigate the feasibility of seal diet analysis via DNA analysis of pinniped scat and stomachs. Initial results processed at the University of Guelph were not sufficient to confidently identify seal prey so alternate methods are being explored including DNA extraction using a Qiagen Stool kit designed to maximize DNA yield for fecal samples. Samples are currently at a next generation sequencing facility, and data should be available for interpretation later this year.

Bycatch estimation of harbor (*Phoca vitulina*), gray, harp (*Pagophilus groenlandicus*), and hooded (*Cystophora cristata***)** seals in the Mid-Atlantic Gillnet, Northeast Sink Gillnet, and Northeast and mid-Atlantic bottom trawl fisheries was not conducted in 2021 due to the lapse in observer coverage as a result of COVID19.

g) Turtles

The NEFSC collaborated with academics, industry groups, and researchers from other NMFS science centers to (1) collect and assess data on sea turtles in the Greater Atlantic; and (2) assess and reduce sea turtle bycatch in U.S. commercial fisheries in the Northwest Atlantic Ocean.

During calendar year 2021, the Turtle Ecology team completed several field work trips. In February/March, we collaborated with their Gear Research program to deploy satellite tags on loggerhead sea turtles off North Carolina, gathering valuable information on turtle behavior such as surface duration and dive depth. In May, the SEFSC and NEFSC collaborated on leatherback satellite tagging off North Carolina on the R/Vs Julius and Selkie. The main objectives of this research were to gather data on leatherback surfacing behavior and habitat use. Also in May, a loggerhead research cruise aboard the F/V Kathy Ann was led by Coonamessett Farm Foundation (CFF), funded from an Atlantic Sea Scallop Research Set Aside Cooperative Agreement, with an NEFSC Point of Contact to represent NEFSC Turtle Ecology priorities. During this cruise, satellite tags were deployed on loggerheads off the Mid-Atlantic Bight. In August/September, SEFSC, NEFSC, and others collaborated for leatherback satellite tagging aboard the M/V Warren Jr. in Massachusetts state and federal waters. This cruise allowed us to gain experience in leatherback field operations in an area south of the MA islands. In 2021, our collaborative team made progress on analysis and publication, with one new publication on loggerhead habitat and climate change (Patel et al 2021) and two new manuscripts (leatherback surface behavior, loggerhead surface availability) in review.

In 2021, the NEFSC gear research program continued to focus on testing buoyless systems in the lobster fishery to reduce large whale and sea turtle entanglements. The ropeless system "gear library" that we are maintaining to provide fishermen and researchers ropeless systems to trial and develop has been expanded to over 100 systems. In winter of 2021 we successfully navigated the hurdles of COVID-19 and completed a comparative study of a low-profile gillnet to reduce sea turtle bycatch. Preliminary results show that the large mesh bottom set gillnet with the tie-down height reduced by half, reduced the bycatch of sea turtles in the study by ~68%. The final report is currently undergoing technical review and is expected to be released as a center. As this work was recently completed, robust data analysis and reports have not yet been completed. We also plan to submit a manuscript to the North American Journal of Fisheries Management.

h) Environmental DNA

In 2021, Northeast Fisheries Science Center (NEFSC) continued eDNA research under the NMFS agency-wide genomics strategic initiative (SI). The focus at the NEFSC remained using environmental DNA (eDNA) to characterize fish communities. We also made progress on using eDNA to characterize microbial communities and to study trophic dynamics.

1.) The 2021 Northeast summer ecosystem monitoring survey aboard NOAA Ship Pisces sampled 30 stations along the U.S. East Coast. During the 16-day research cruise (8/4 - 8/19/2021), 322 water samples including 13 negative field controls were filtered for eDNA metabarcoding analysis. A time-series sampling was also conducted at a station where there were North Atlantic right whale sightings. DNA extraction and PCR on these samples are underway. Through the analysis of these samples, the effects of water column stratification on the detected fish community will be explored. Spatial variation in fish communities detected by eDNA from the Delmarva Peninsula to the Canadian Maritimes will be investigated.

2.) A trial study using eDNA metabarcoding on 24 seal fecal samples was conducted, and the prey items identified by eDNA will be compared to those identified from seals' gut content. Fourteen positive samples containing different larval fish eyeballs analyzed alongside showed that eDNA metabarcoding was accurate in capturing the biodiversity with almost no false positives or false negatives.

3. Studies of Fishing Operations

This section will be provided for 2021 and 2022 in 2023.

4. Observer estimation of catch on NAFO Div 3 trips

a. The checker pen is measured and total volume is calculated prior to the catch being dumped onboard (The F/V Titan uses varying size checker pens as they can change the size by adding or removing pen boards).

b. Once the catch is dumped the observer takes the depth of the checker pen (filled with catch) in 10 random locations within it using a measuring stick. The average depth of the fish in the checker pen is then calculated. The total volume of the catch is then calculated by multiplying the length times the width of the checker pen times the depth of the catch.

c. The observer then fills (depending on amount of catch) 1.47 cu. ft. baskets with the catch from random locations throughout the checker pen. The number of baskets varies from 8 to 15 (unless the catch is very low it could be less). The number of baskets used is then multiplied by the volume of one basket to obtain the Total Volume Subsampled. The fish are then separated by species and whether they are kept or discarded. The discard size is determined by the observer according to the legal U.S. fisheries regulations. The kept and discards of each species are weighed and recorded.

d. The kept and discarded catch weights are then calculated by the following formula:

1) A Sample Multiplier is calculated by (Total Volume (see # 2 above / total Subsample Volume (see # 3 above)

2) The weight of each species Subsampled is then multiplied by the Sample Multiplier to calculate the Estimated Total Weight for that species and catch disposition.

3) The percent Subsampled can be calculated by dividing the Total Subsample Volume by the Total Volume of the catch.

5. Population Dynamics Research

a) Stock Assessments

Population dynamics research conducted within the NEFSC supports a number of domestic and international fisheries management authorities. Within the United States Northeast Region, management plans are developed by the New England (states of Maine through Connecticut) and Mid-Atlantic (New York through North Carolina) Fishery Management Councils, and the Atlantic States Marine Fisheries Commission (ASMFC). There are about four dozen managed species; all require periodic stock status updates as a basis for fishery management.

The Northeast Region recently revamped its stock assessment scheduling and review process system to better serve our management partners. The region has transitioned to a new stock assessment process that separates stock assessment development from operational stock assessments used to inform management. The Research Track Assessment Process is designed to develop, review and implement new stock assessment approaches for individual or groups of species. Results of the Research Track are not used directly in management, rather they establish the stock assessment approaches and methods that will be used in the Management Track process. The Management Track process is designed to develop, review and approve updated stock assessments for use in management (e.g. specification setting).

In 2021, Research Track Assessments were continued for haddock (Gulf of Maine and Georges Bank), shortfin inshore squid (Georges Bank/Cape Hatteras), and butterfish (Gulf of Maine/Cape Hatteras). Research Track Assessments were initiated for American plaice (Gulf of Maine/Georges Bank), bluefish (Atlantic Coast), black sea Bass (Gulf of Maine/Cape Hatteras), spiny dogfish (Atlantic Coast) Atlantic cod (stock structure being revised).

In addition, the Management Track produced updated stock assessments in 2021 for Atlantic cod (Gulf of Maine and Georges Bank), summer flounder, scup, black sea bass, Atlantic mackerel, bluefish and Golden Tilefish. The U.S. also coordinated with Canada to develop and review stock assessments conducted and reviewed through the TRAC process included Eastern Georges Bank cod, Eastern Georges Bank haddock, and Georges Bank yellowtail flounder through the U.S./Canada Transboundary Resources Assessment Committee (TRAC).

b) Atlantic Salmon Research

Atlantic salmon populations in eastern Maine are listed as endangered under the United States Endangered Species Act (ESA). Spawning populations have dwindled over the years, and both smolt escapement and ocean survival rates have declined. Research programs conducted by the NEFSC, in conjunction with various agencies, private partners and international collaborators, are designed to better understand the factors contributing to these declines. Research activities include a variety of projects in natal rivers, estuaries, and at sea. The data from these studies are used to provide information for local, national, and international stock assessment activities. These assessments support ESA and North Atlantic Salmon Conservation Organization (NASCO) management efforts.

Research has recently focused on (1) monitoring the importance of diadromous fishes as prey for nearshore Gulf of Maine groundfish species; (2) monitoring of fishery removals on the high seas; (3) describing the marine migration of salmon from Greenland to natal rivers. However, in 2021 these research efforts were significantly hindered due to challenges brought on by the COVID-19 pandemic. Our expectations are that these activities will return to pre-pandemic levels once the go-ahead is given to resume in a safe capacity.

c) Cooperative Research

Industry-Based Gulf of Maine Bottom Longline Survey

During 2021 staff from the NEFSC Cooperative Research Branch completed the Gulf of Maine bottom longline survey (LLS) started in 2014. This survey was started in an effort to provide additional sampling in rocky and hard-bottom habitats and address concerns for some groundfish and data-poor species. The survey covers the western Gulf of Maine across the central Gulf to the US/Canada boundary. This includes all or portions of bottom trawl offshore survey strata 26-29, 36-37, and is further sub-stratified into smooth and rough bottom. The survey uses tub-trawl bottom longline gear similar to that used by commercial fishermen for groundfish. The biannual survey was conducted in 2021 completing 92 stations in total in the spring (April-May) and fall (Oct-Nov) with 35 vessel days at sea on two chartered commercial vessels. A total of 17,539 lengths were measured representing 18,578 individual organisms. Biological sampling of 1,470 organisms for samples such as age and maturity were collected, as well as tagging and other samples to support both NEFSC research studies and external investigators. The data collected on this survey will be used to support stock assessments, ecosystem and habitat studies, and management decisions for a range of fish, skates, and other species in the Gulf of Maine, and particularly beneficial for several data poor species.

Application of fishery data to explore relationships with oceanographic conditions

In 2021, we began initial research to explore the relationships between oceanographic conditions and shortfin squid, *Illex Illecebrosus,* catch using the fine-scale fishery data from the Study Fleet Program hosted by Northeast Fisheries Science Center's Cooperative Research Branch. The precise fishing locations and *Illex* catch rates from the Study Fleet Program were paired with coincident oceanographic data from high resolution satellite products as well as a global ocean reanalysis model. Using multivariate generalized additive models, we identified a suite of oceanographic processes that correlate with catch data throughout the fishery footprint. In particular, we identified relationships between the spatiotemporal distribution of *Illex* catch and specific properties of oceanographic features (e.g.: mesoscale eddies, chlorophyll and sea surface temperature fronts, salinity at depth) with implications for understanding the mechanistic processes influencing the productivity and availability of this species. These results were the product of a collaborative effort across government, industry and academia and further work is needed to assign causative or mechanistic understanding to these relationships to better understand the availability of *Illex* to the fishery. As such, this work is ongoing and will develop further throughout the upcoming *Illex* fishing season.

Development of CPUE indices from fishery data

In 2021 we worked to leverage existing fishery data sets to create standardized catch per unit effort (CPUE) time series to inform a number of stock assessments. In the northeast US the development of electronic logbook technology and a sustained investment in the Northeast Fisheries Science Center's Cooperative Study Fleet Research Program has greatly facilitated the collection of high-resolution catch, effort, and environmental data by fishing captains. Fine-scale data from a number of the region's fisheries has accumulated over the past fifteen years, as the hardware and software associated with the logbooks has evolved. Today this data set is an extensive time series that is utilized by regional scientists and managers. This fine-scale catch and effort information is similar to the data collected by the NEFSC's observer program, and can be used to answer a variety of research questions about catch rates, environmental drivers, and fishery dynamics. In 2021, we worked to develop standardized CPUE time series to inform the stock assessment for American plaice (*Hippoglossoides platessoides*) and provide scientific advice on northern shortfin squid (*Illex illecebrosus*) for the species' research track stock assessment.

In addition to these concrete applications of fishery data, a larger collaborative project aimed at developing standardized CPUE indices for species regulated in the large mesh groundfish fishery was initiated in collaboration with scientists from University of Massachusetts Dartmouth's School for Marine Science &

Technology and the New England Fisheries Management Council. A summary publication of the state of the Study Fleet program was also published in Frontiers in Marine Science (doi: 10.3389/fmars.2022.869560).

Application of fishery data to evaluate operational conflicts with wind developments

The fine-scale fishery data collected from the Northeast Fisheries Science Center's Cooperative Study Fleet Research Program was also used in 2021 to enhance understanding of fishery footprints and the potential spatial conflict with planned offshore wind energy developments. For this work, the time series of fine scale effort information was explored for the longfin squid fishery (*Doryteuthis (Amerigo) pealeii*). Preliminary results suggest that the fine-scale effort information collected by the Northeast Fisheries Science Center's Cooperative Study Fleet Research Program improves our understanding of the impact of offshore wind energy development on fishing operations by better characterizing the true footprint of individual fishing trips and effort events, and by providing higher coverage in fisheries that are likely to be impacted (e.g., the longfin squid (*D. pealeii*) fishery).

Estimates of the previously unaccounted for releases of butterfish

As part of the butterfish research track assessment, we developed a method to estimate the weight of butterfish that were likely released and not accounted for in the current discard estimates. This involved curating the observer records of releases of butterfish from 2014-2019 (the period when releases have been systematically recorded), consulting members of the fishing industry who participate in the butterfish fishery, and developing a method to expand observer-recorded butterfish releases to the larger set of trips. These expanded estimates were then included in a sensitivity run using the 2020 management track assessment model. Results of this run indicated that these releases do not impact the assessment.

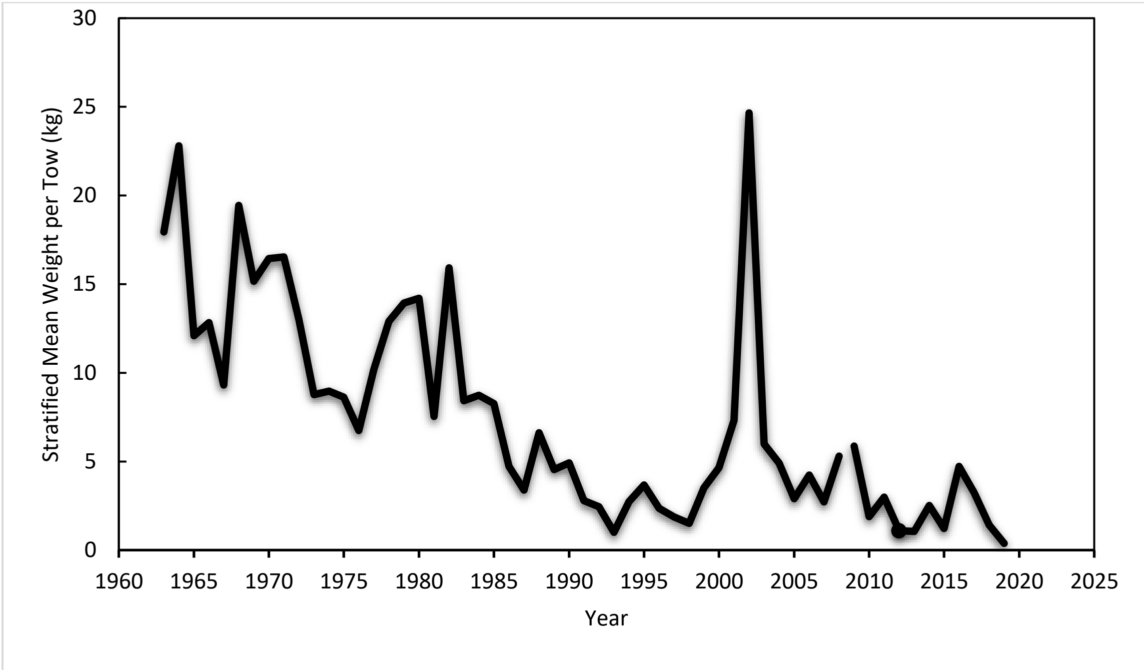

Figure 1. NEFSC autumn bottom trawl survey biomass indices for Gulf of Maine cod.

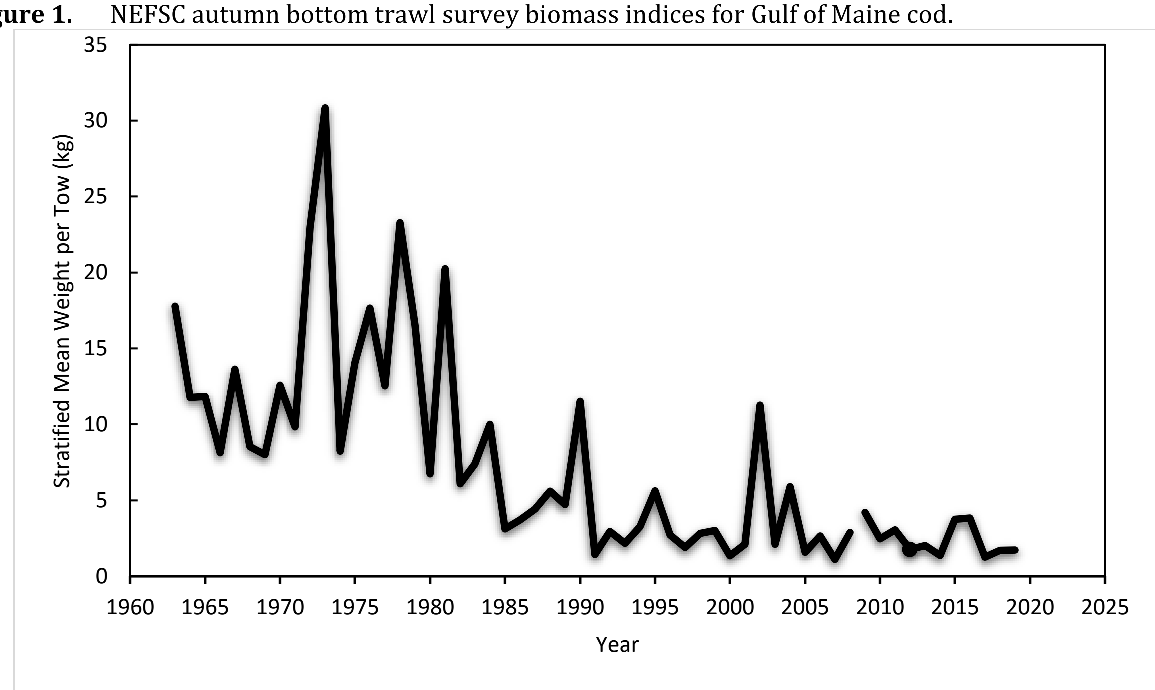

Figure 2. NEFSC autumn bottom trawl survey biomass indices for Georges Bank cod.

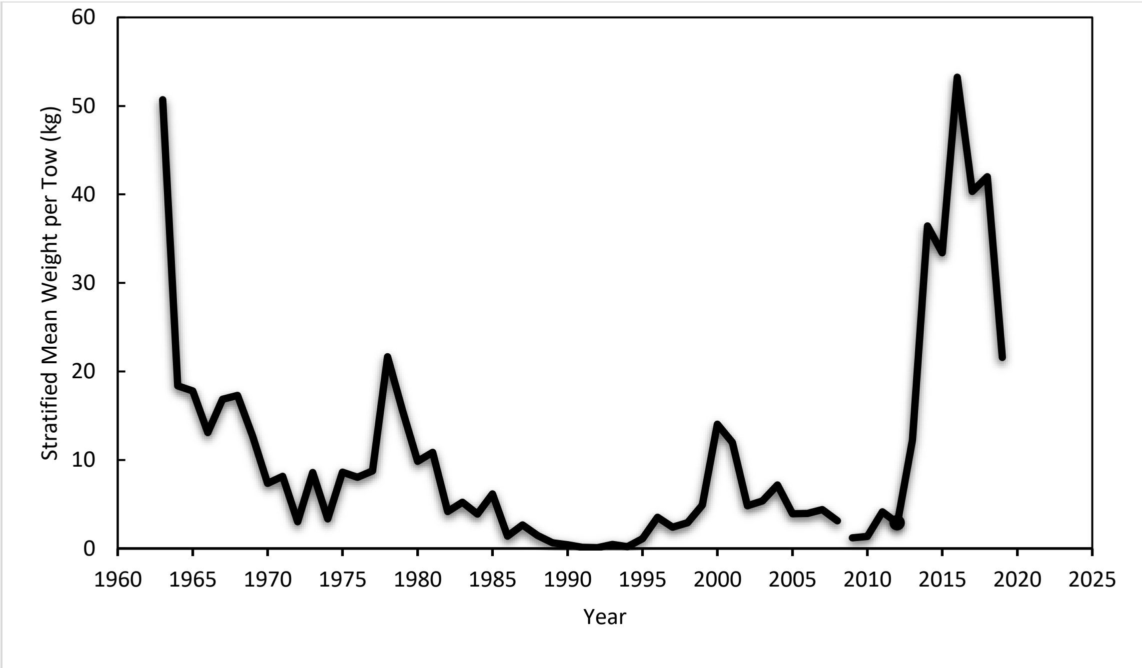

Figure 3. NEFSC autumn bottom trawl survey biomass indices for Gulf of Maine haddock.

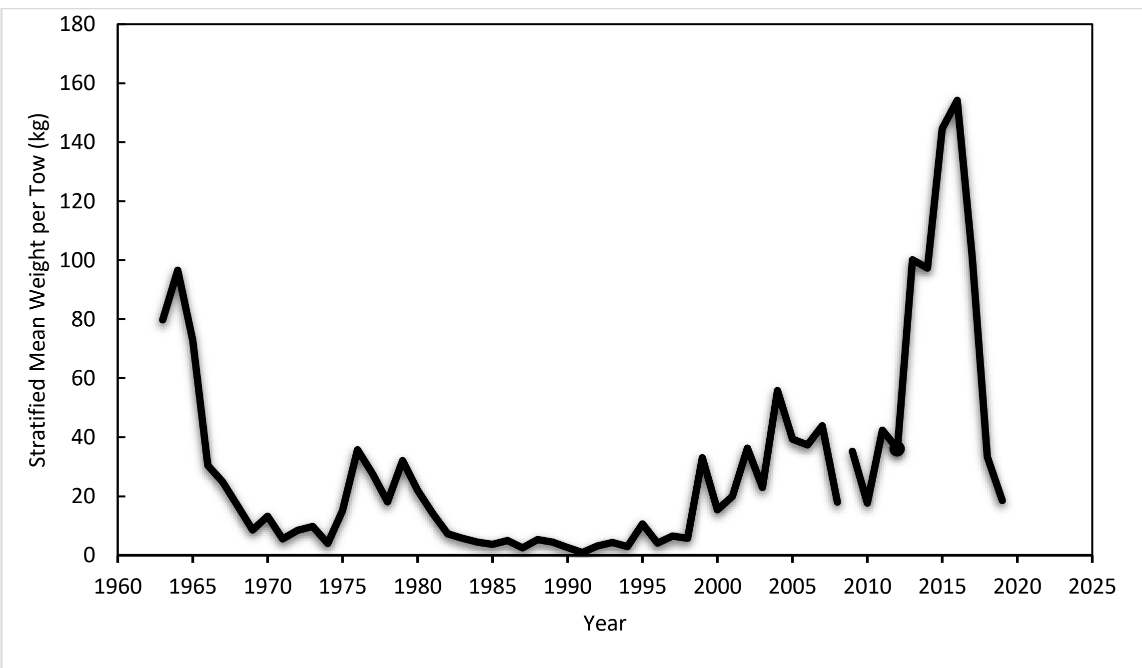

Figure 4. NEFSC autumn bottom trawl survey biomass indices for Georges Bank haddock.

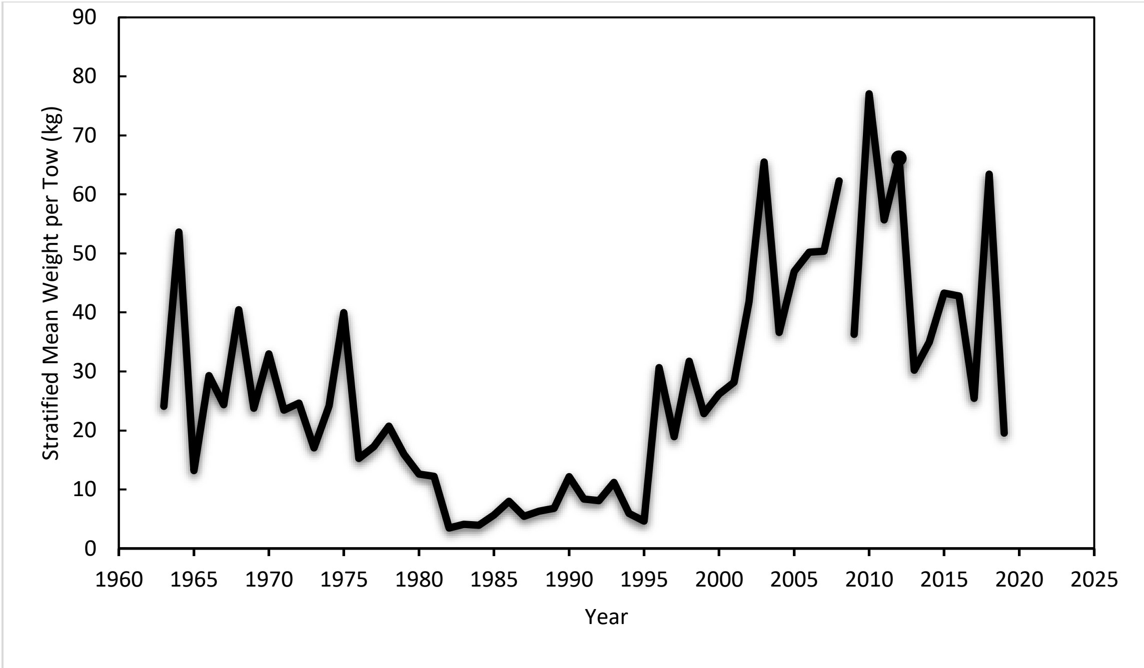

Figure 5. NEFSC autumn bottom trawl survey biomass indices for Acadian redfish.

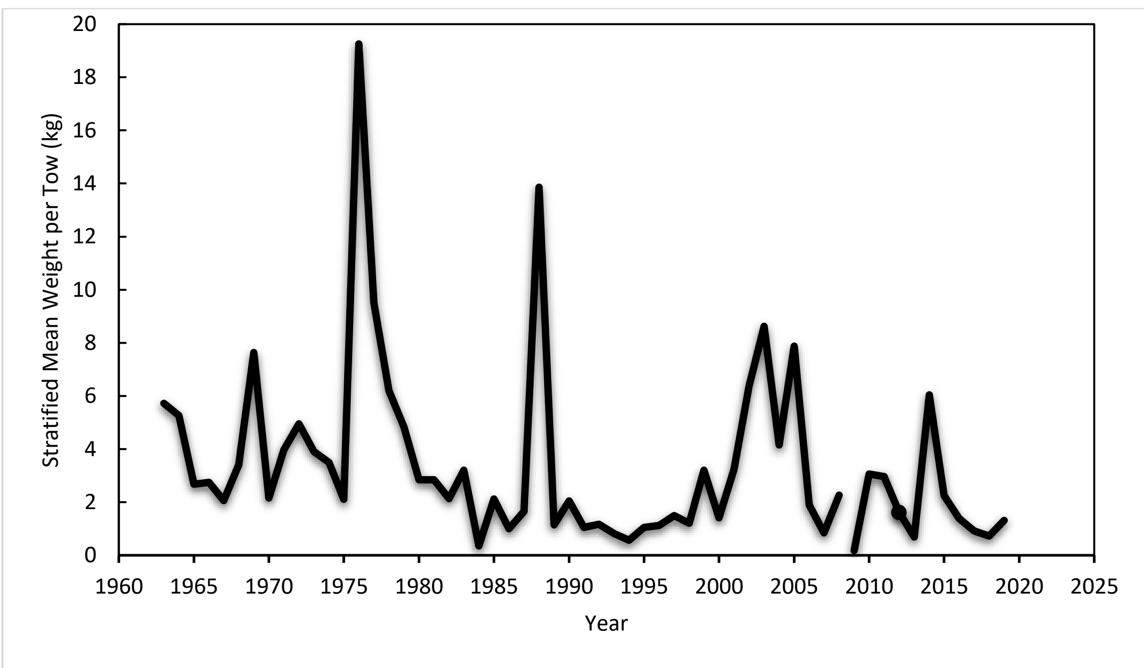

Figure 6. NEFSC autumn bottom trawl survey biomass indices for pollock.

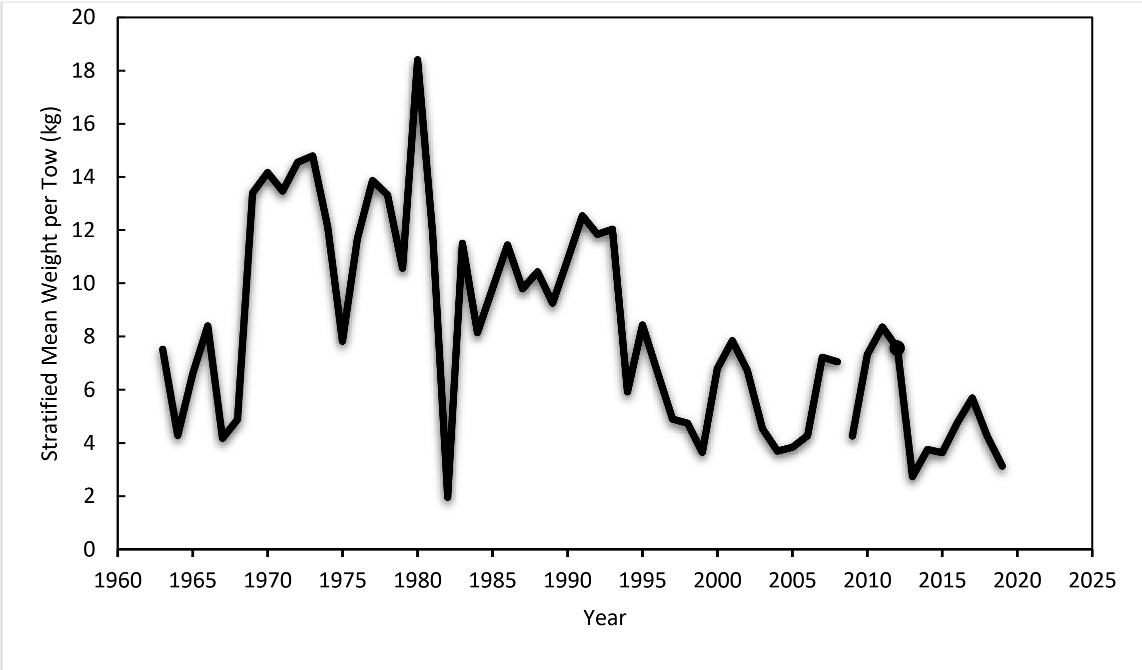

Figure 7. NEFSC autumn bottom trawl survey biomass indices for white hake.

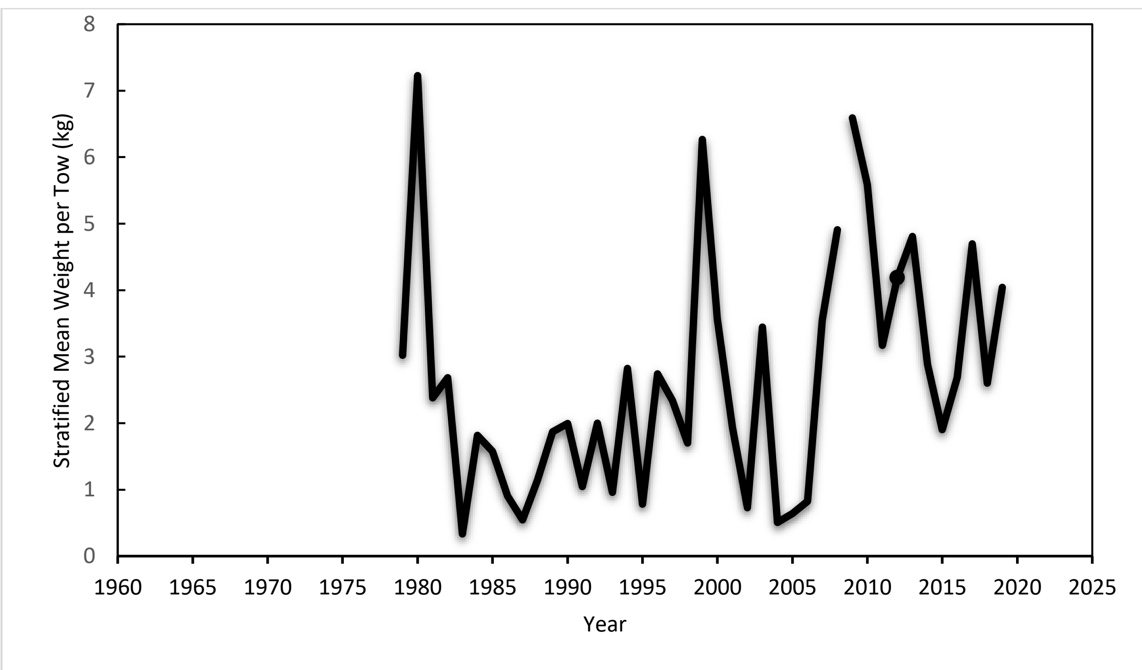

Figure 8. NEFSC autumn bottom trawl survey biomass indices for Cape Cod-Gulf of Maine yellowtail flounder.

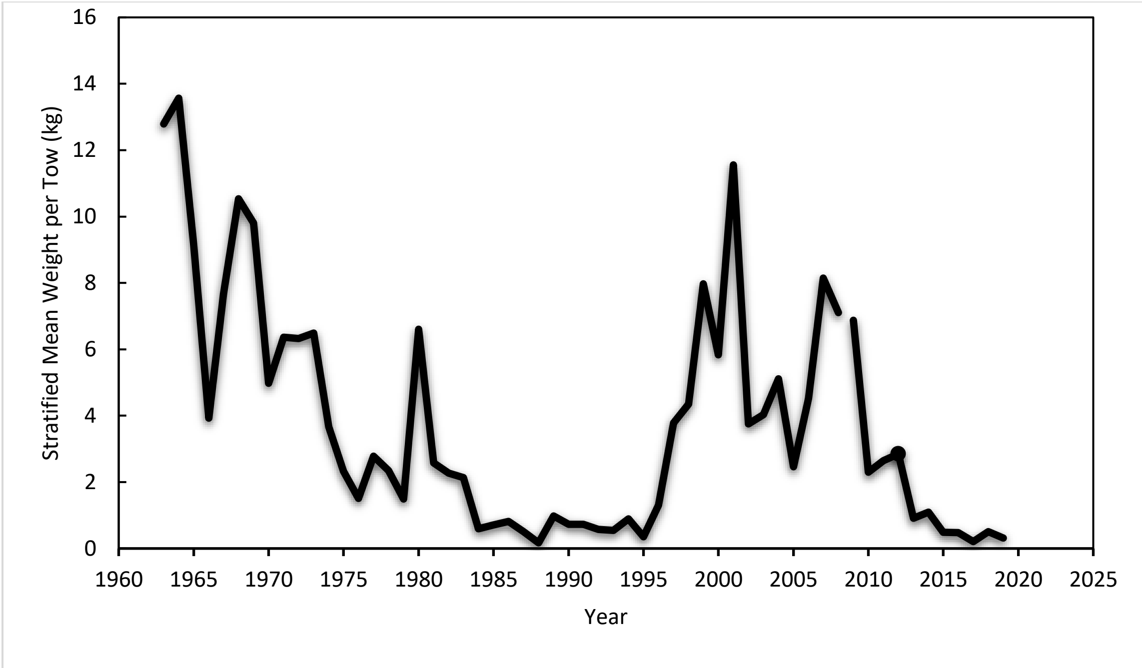

Figure 9. NEFSC autumn bottom trawl survey biomass indices for Georges Bank yellowtail flounder.

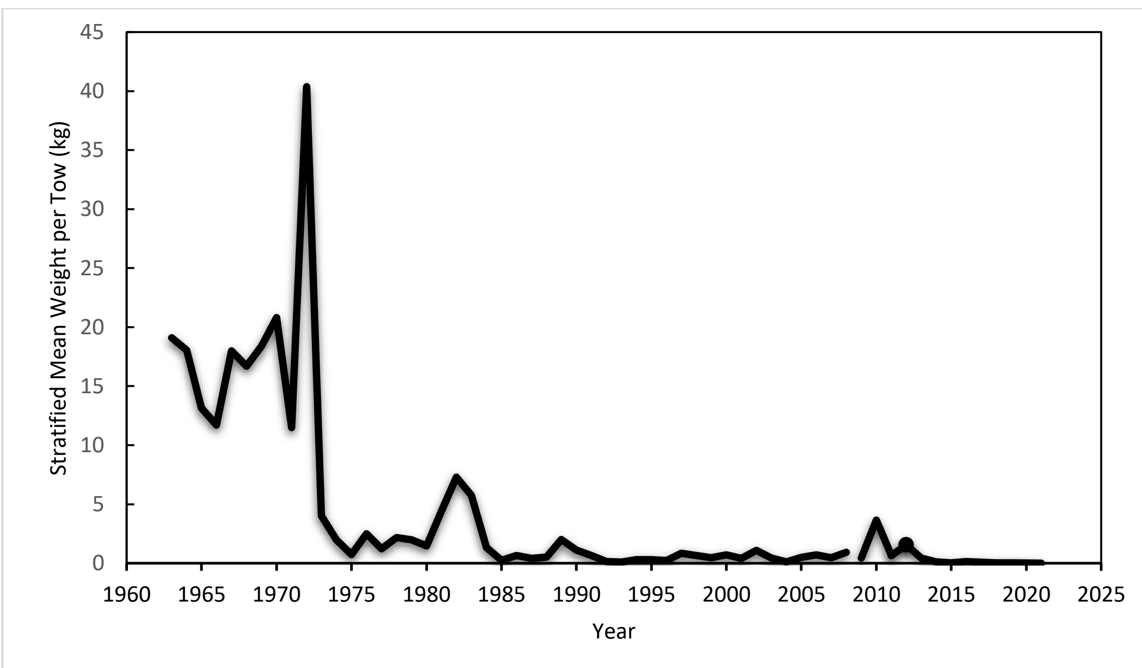

Figure 10. NEFSC autumn bottom trawl survey biomass indices for Southern New England-Mid-Atlantic yellowtail flounder.

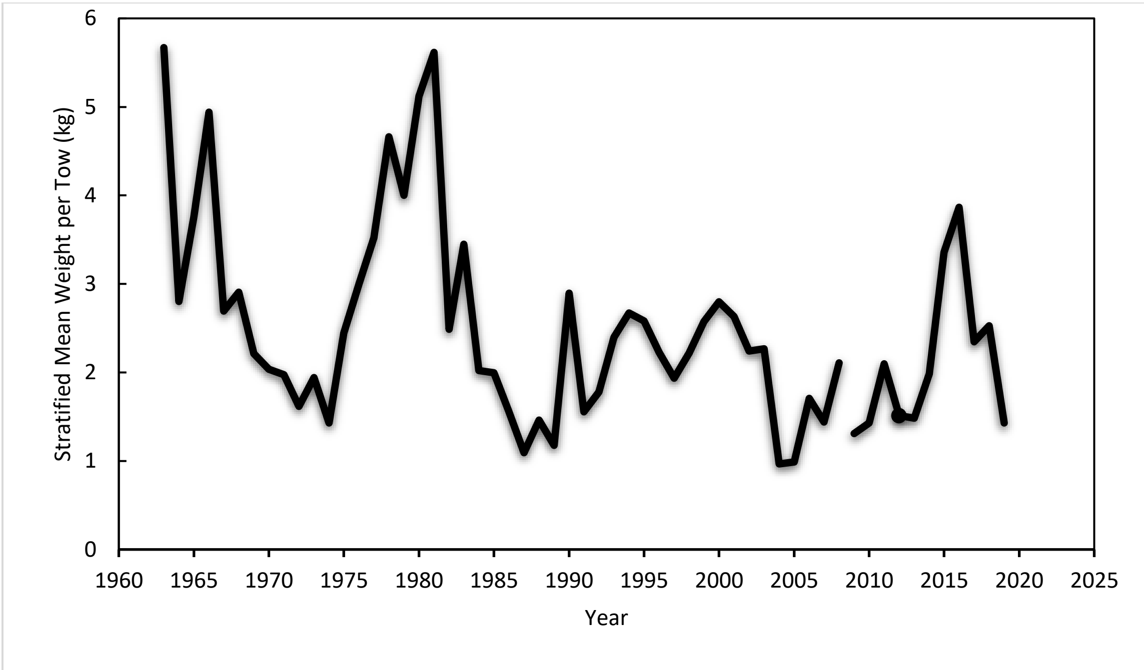

Figure 11. NEFSC autumn bottom trawl survey biomass indices for American plaice.

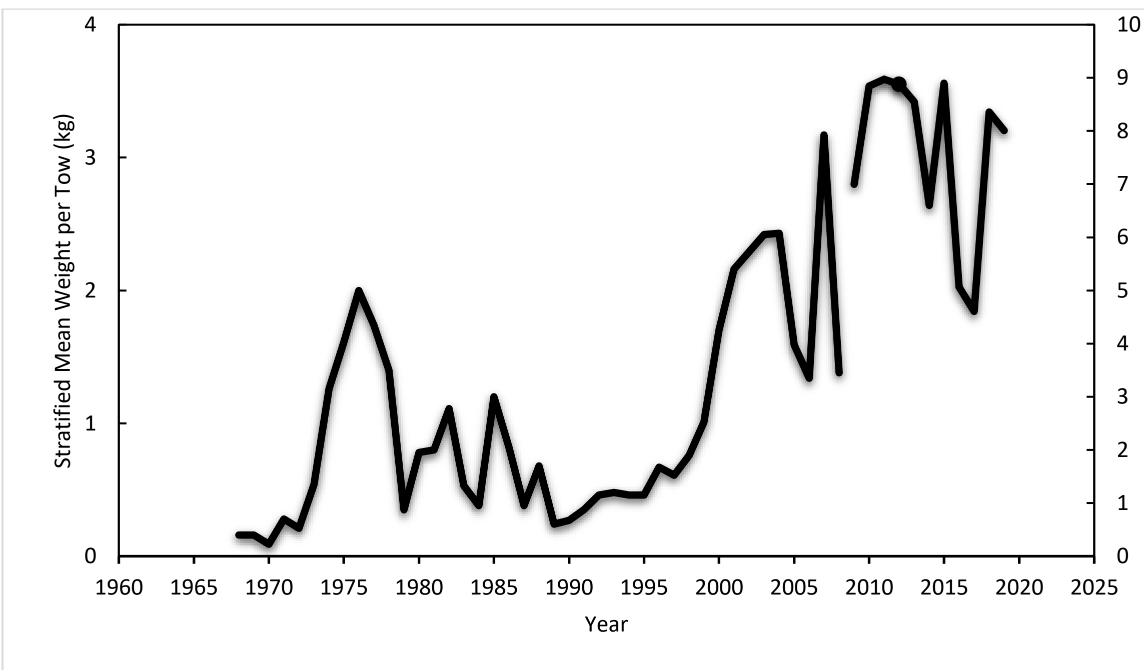

Figure 12. NEFSC spring bottom trawl survey biomass indices for summer flounder Data from 2009-2021 have not been calibrated to the earlier time series and are plotted on the right axis.

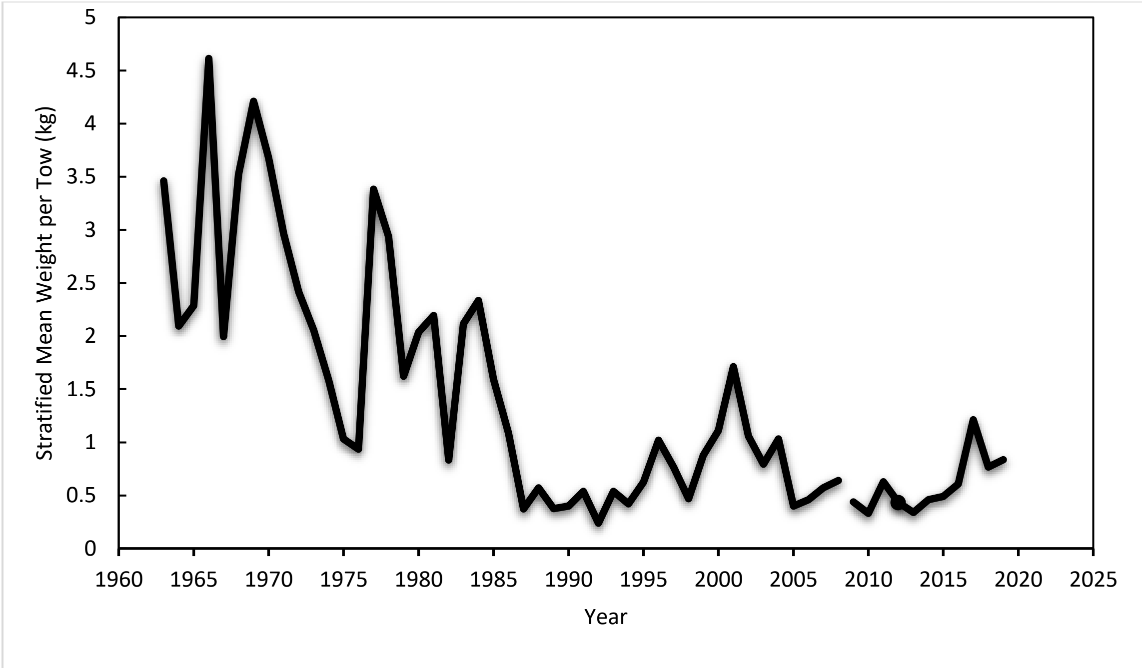

Figure 13. NEFSC autumn bottom trawl survey biomass indices for witch flounder.

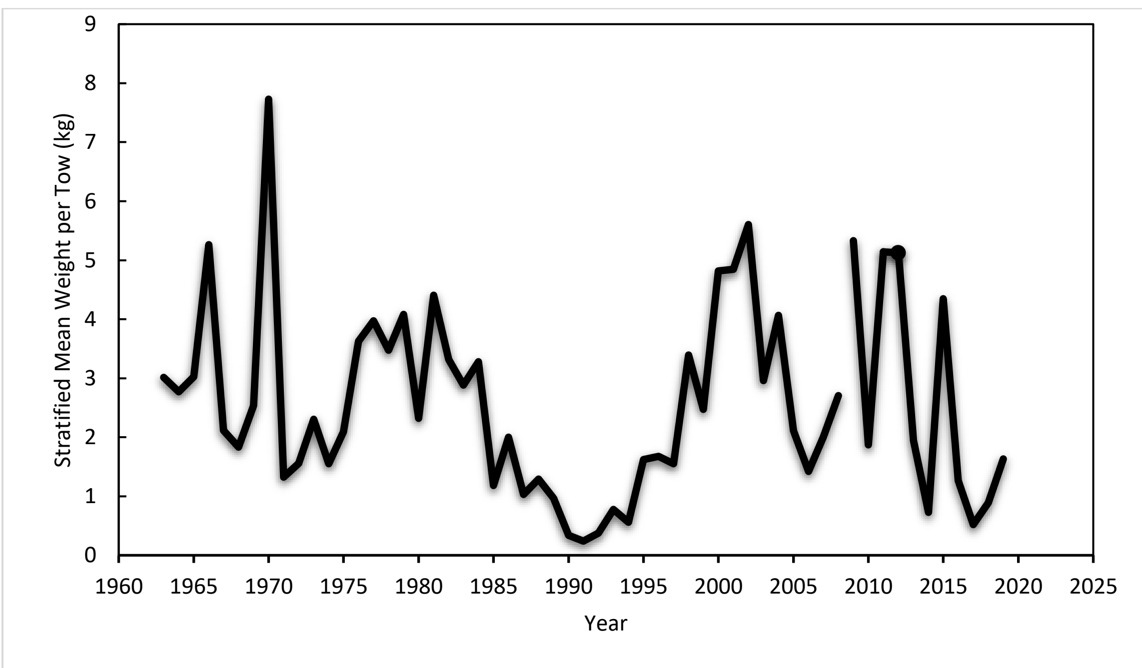

Figure 14. NEFSC autumn bottom trawl survey biomass indices for Georges Bank winter flounder.

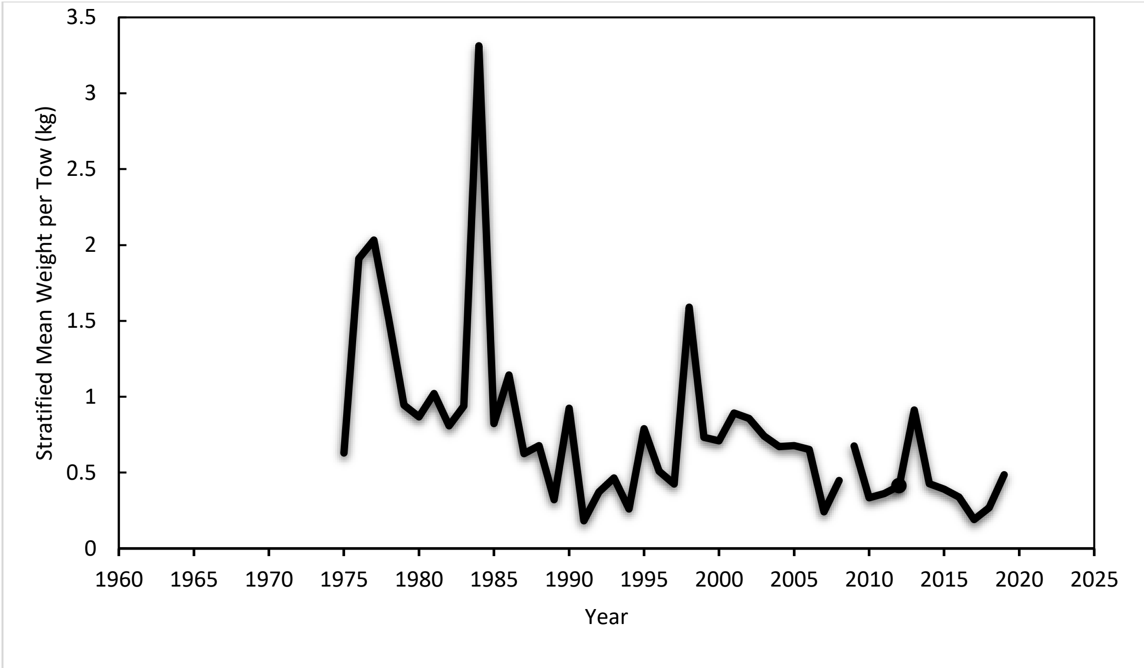

Figure 15. NEFSC autumn bottom trawl survey biomass indices for northern windowpane flounder.

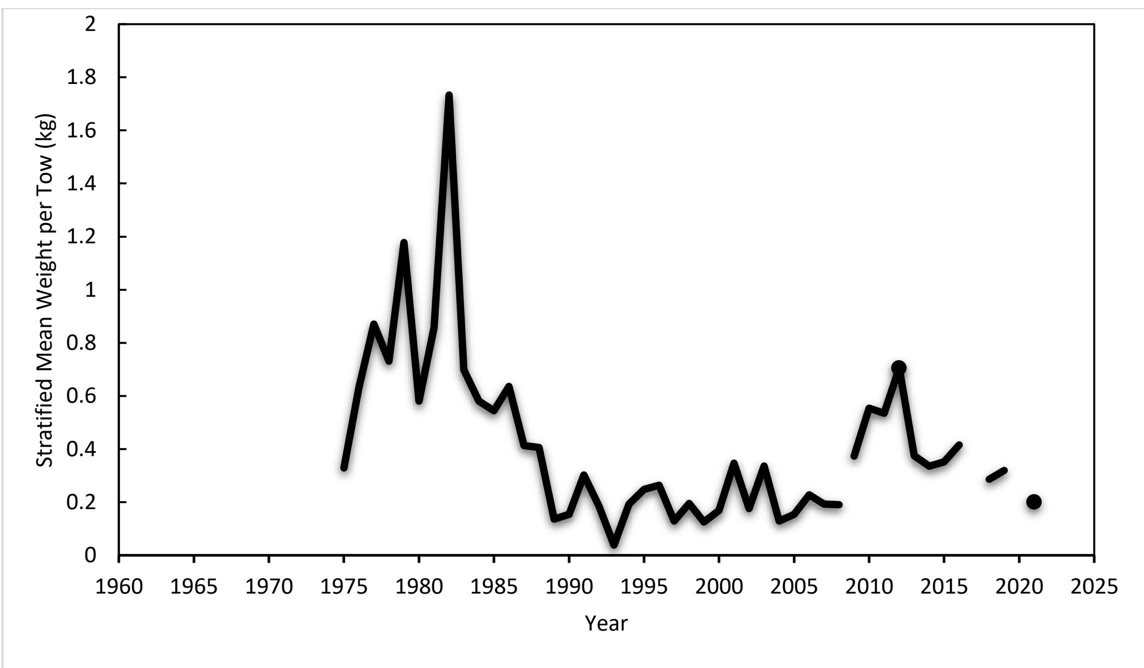

Figure 16. NEFSC autumn bottom trawl survey biomass indices for southern windowpane flounder.

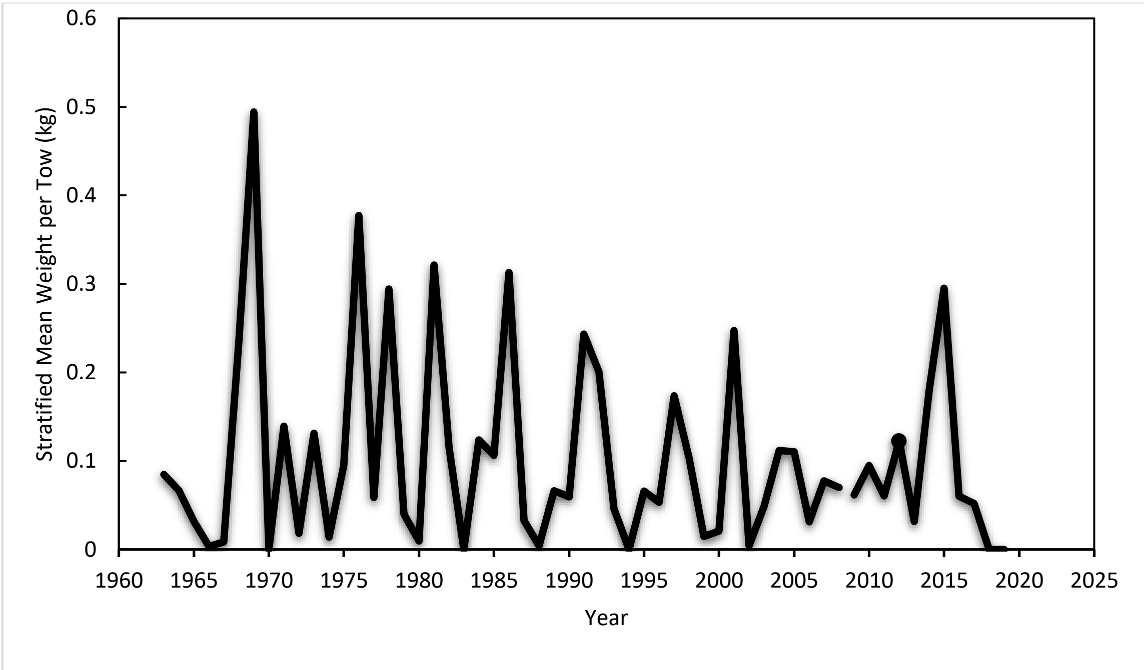

Figure 17. NEFSC autumn bottom trawl survey biomass indices for Atlantic halibut.

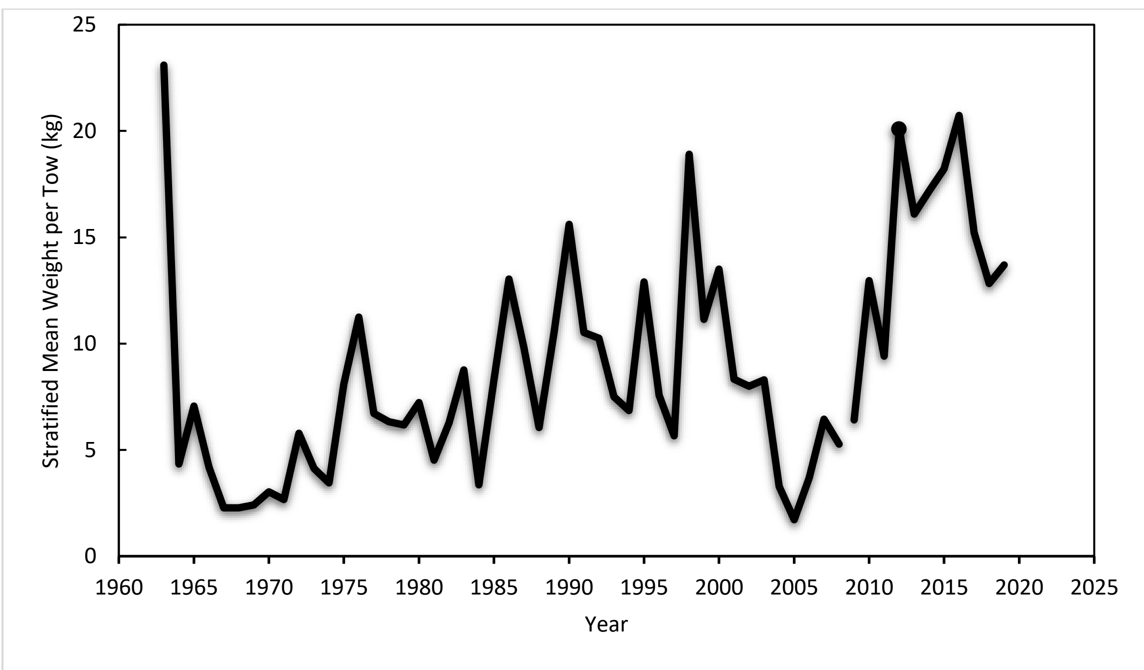

Figure 18. NEFSC autumn bottom trawl survey biomass indices for northern silver hake.

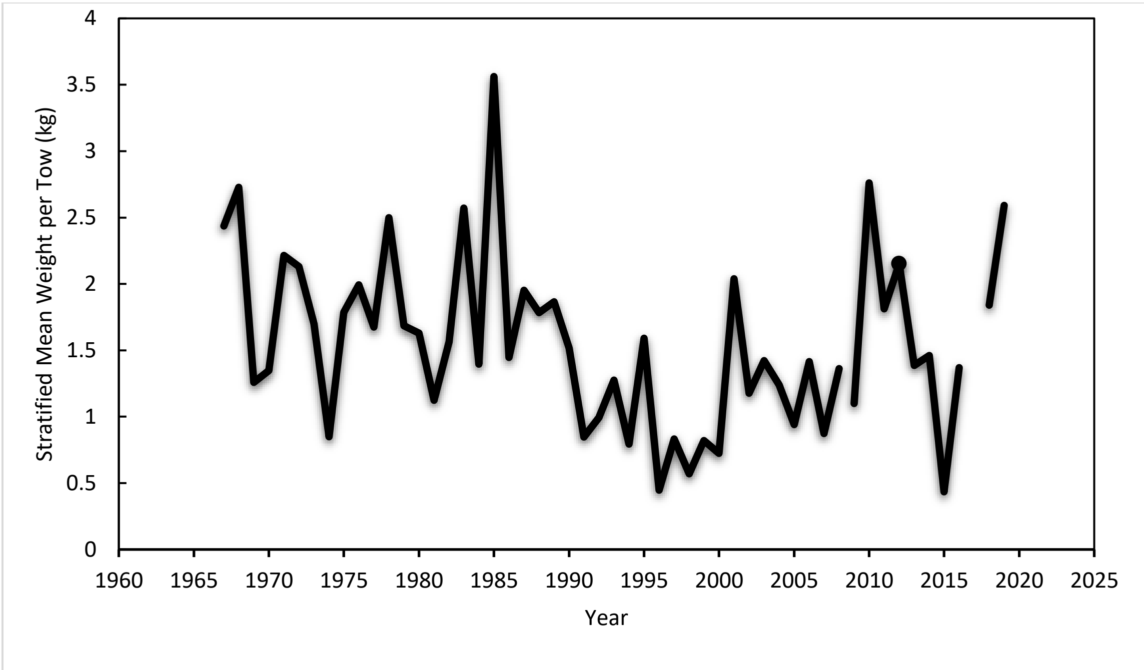

Figure 19. NEFSC autumn bottom trawl survey biomass indices for southern silver hake.

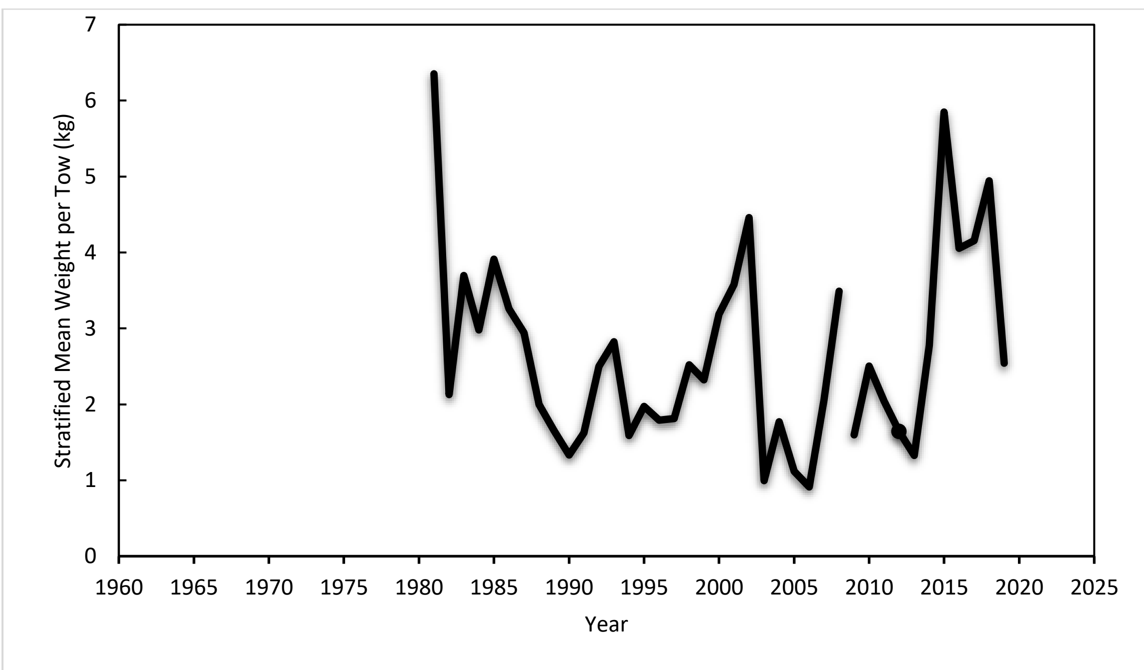

Figure 20. NEFSC spring bottom trawl survey biomass indices for northern red hake.

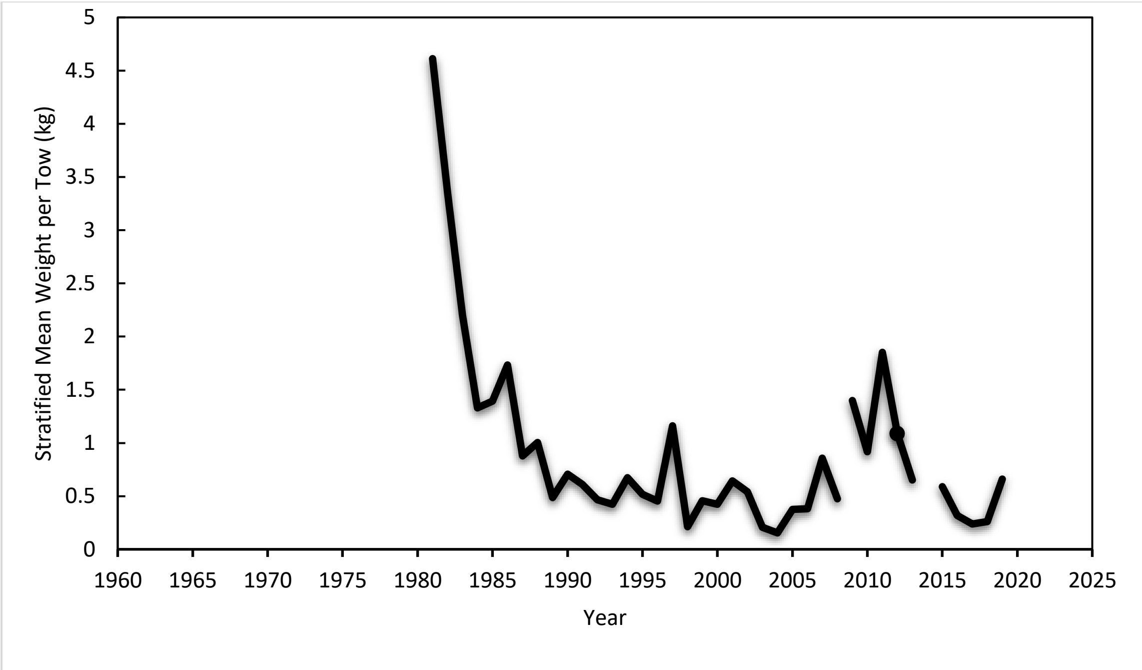

Figure 21. NEFSC spring bottom trawl survey biomass indices for southern red hake.

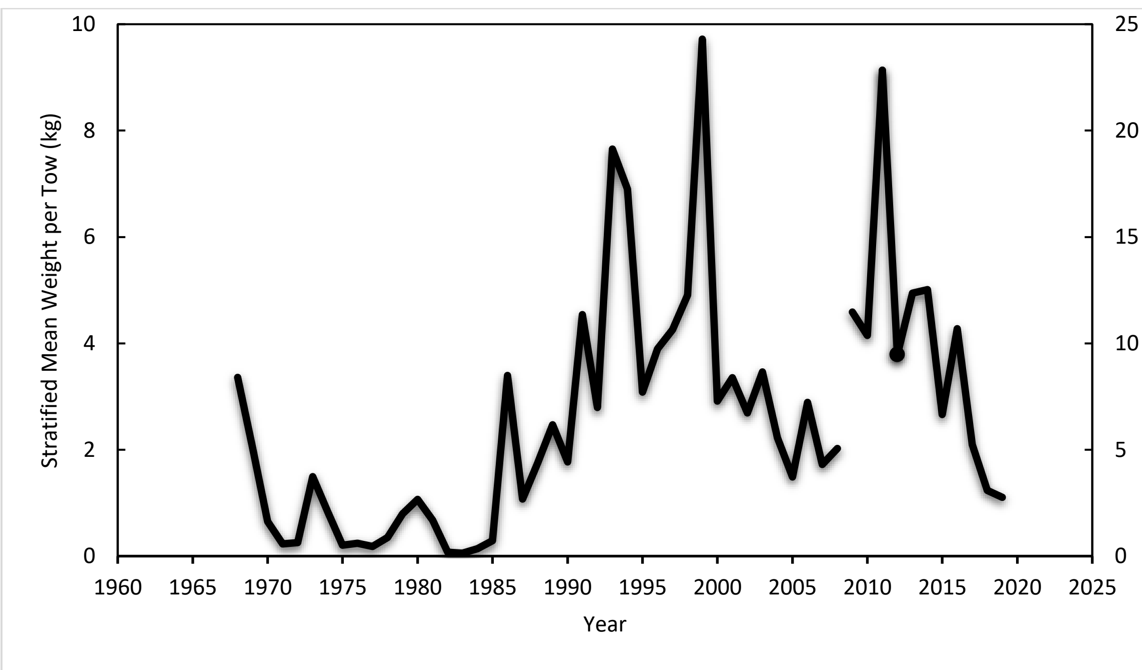

Figure 22. NEFSC spring bottom trawl survey biomass indices for Atlantic herring. Data from 2009-2019 have not been calibrated to the earlier time series and are plotted on the right axis.

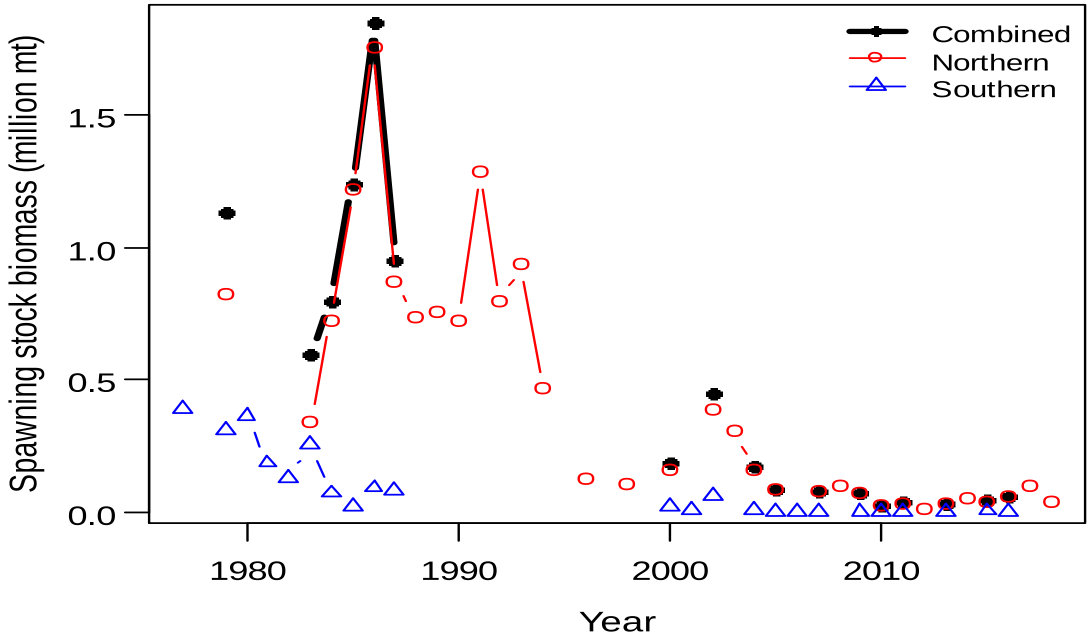

Figure 23. Atlantic mackerel spawning stock biomass index (millions metric tons) calculated using the total egg production method, based on egg densities observed in the southern Gulf of St. Lawrence (northern contingent) and the Northeast U.S. Continental Shelf (southern contingent). The combined SSB index represents the sum of northern and southern contingents and was only calculated in years where indices from both contingents were available. For 2017-2018, only index values from the northern contingent were available. For 2019, values were not available.

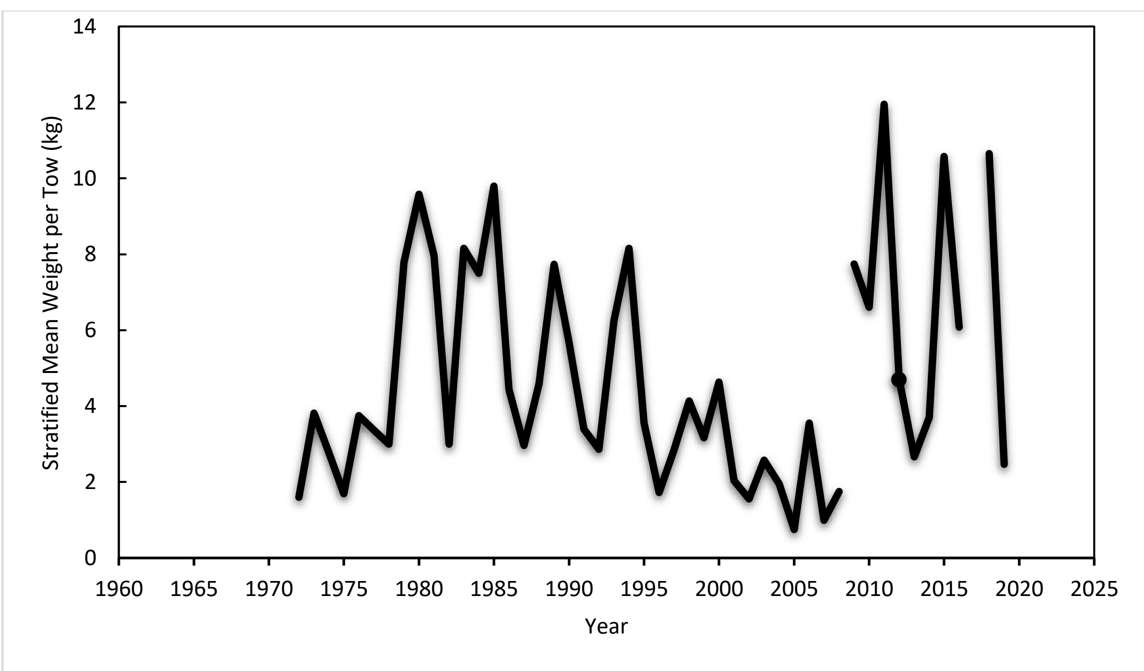

Figure 24. NEFSC autumn bottom trawl survey biomass indices for butterfish.

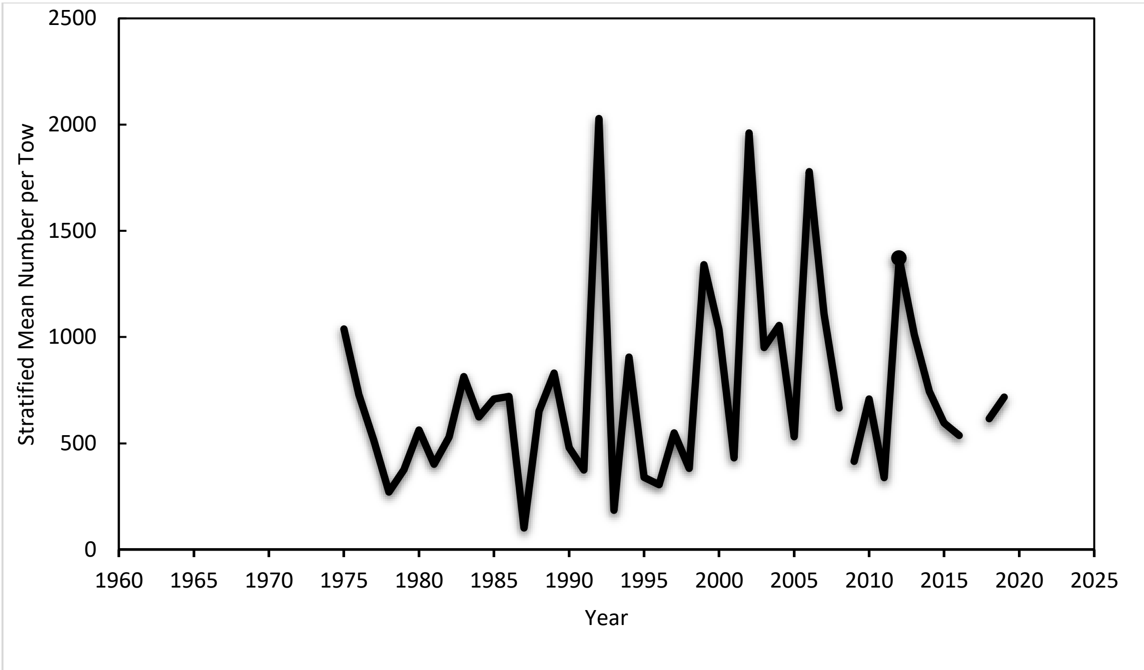

Figure 25. NEFSC autumn bottom trawl survey abundance indices for longfin inshore squid.

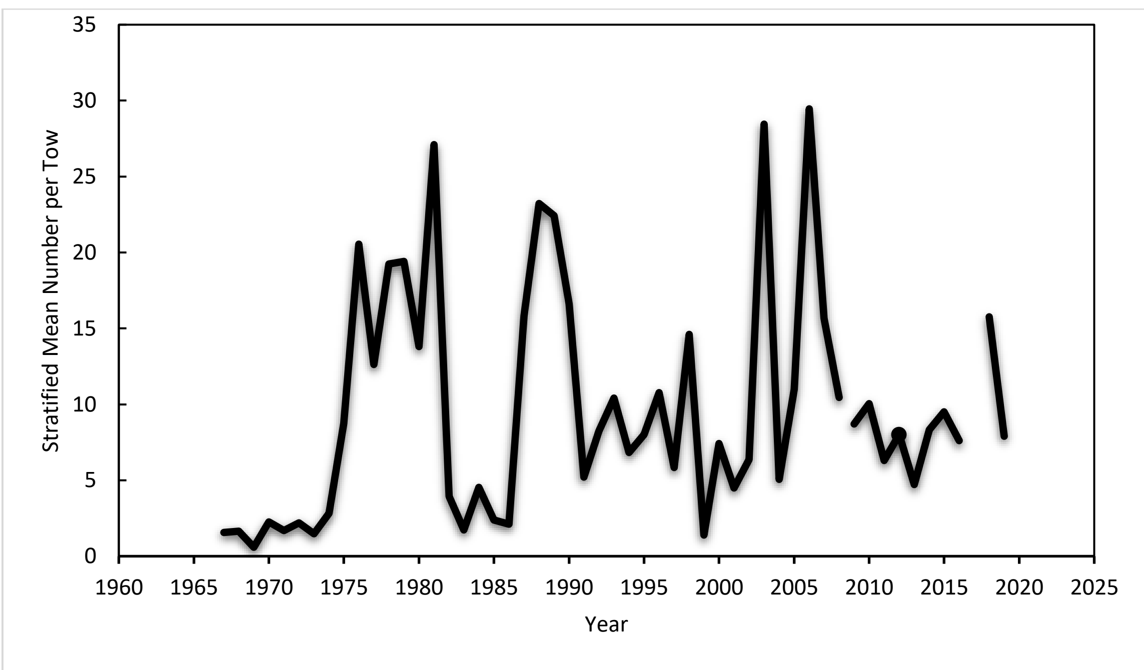

Figure 26. NEFSC autumn bottom trawl survey abundance indices for northern shortfin squid.

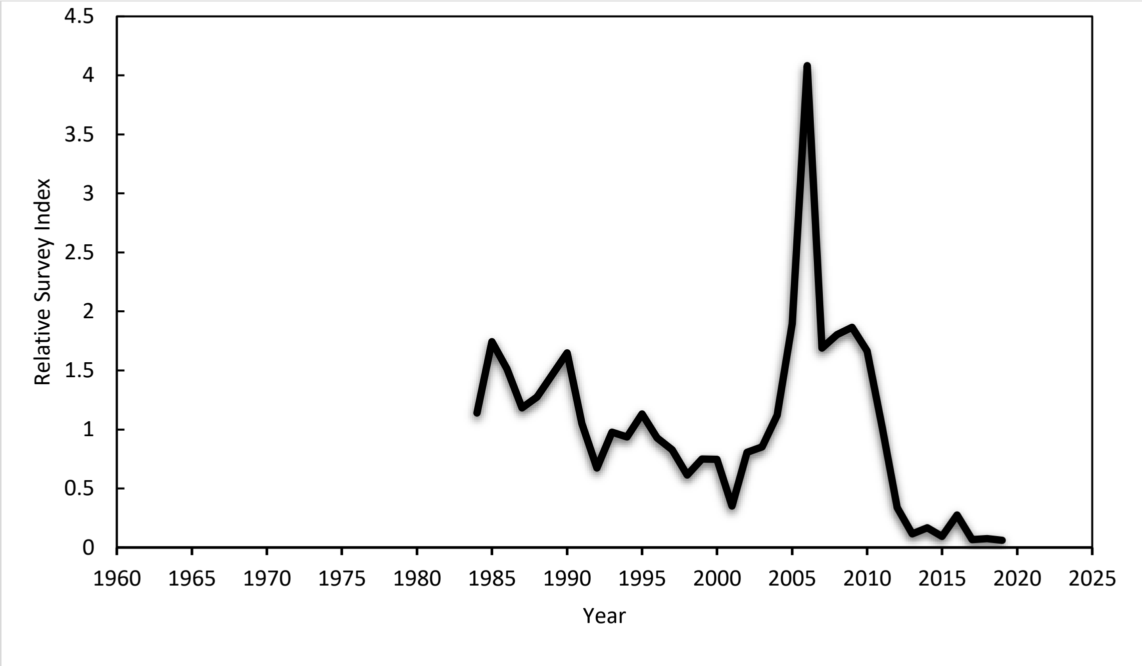

Figure 27. ASMFC summer shrimp survey biomass indices scaled to the mean for northern shrimp.

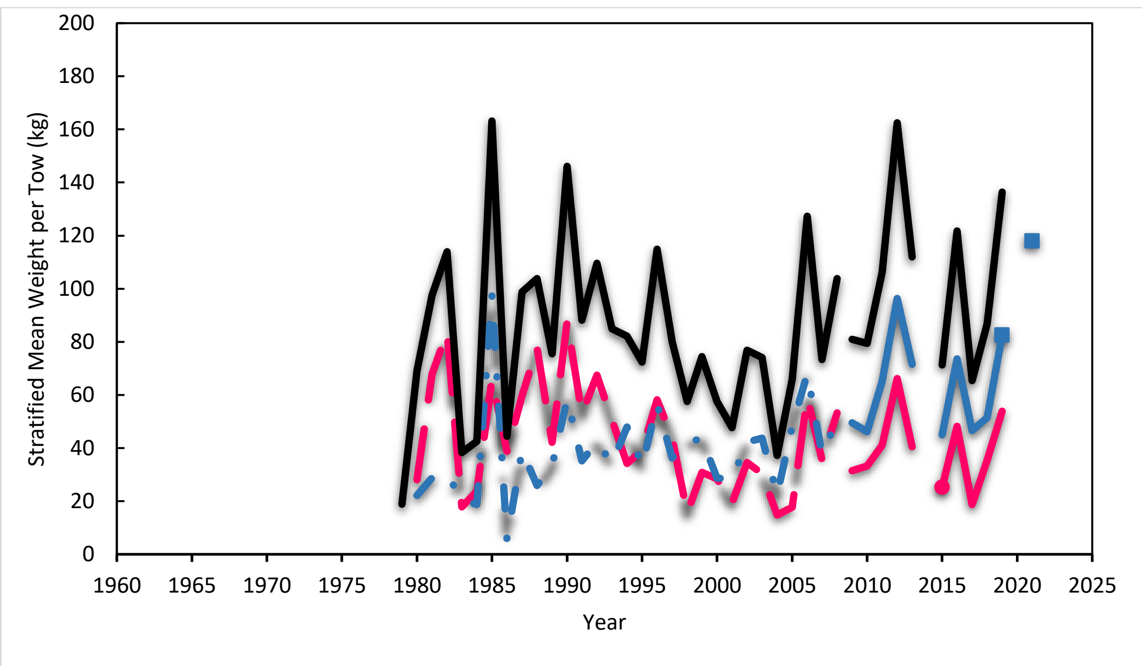

Figure 28. NEFSC spring bottom trawl survey biomass indices for spiny dogfish. The black line with triangles is the total biomass, the blue line with the squares is male biomass and the pink line with circles is female biomass.

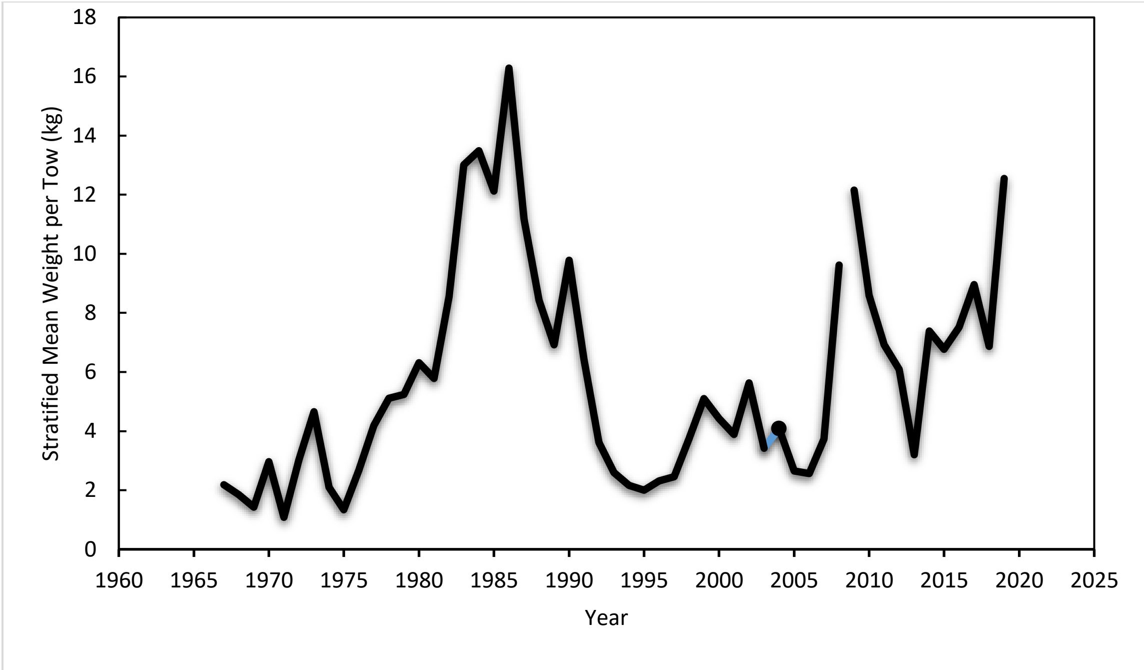

Figure 29. NEFSC autumn bottom trawl survey biomass indices for winter skate.

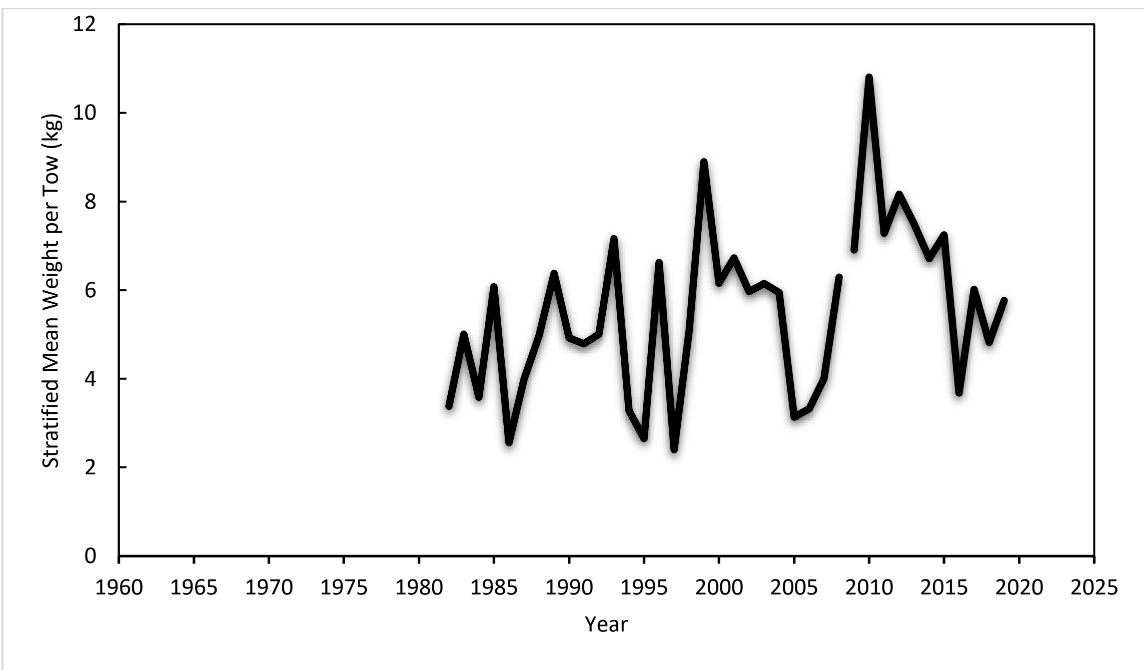

Figure 30. NEFSC spring bottom trawl survey biomass indices for little skate.

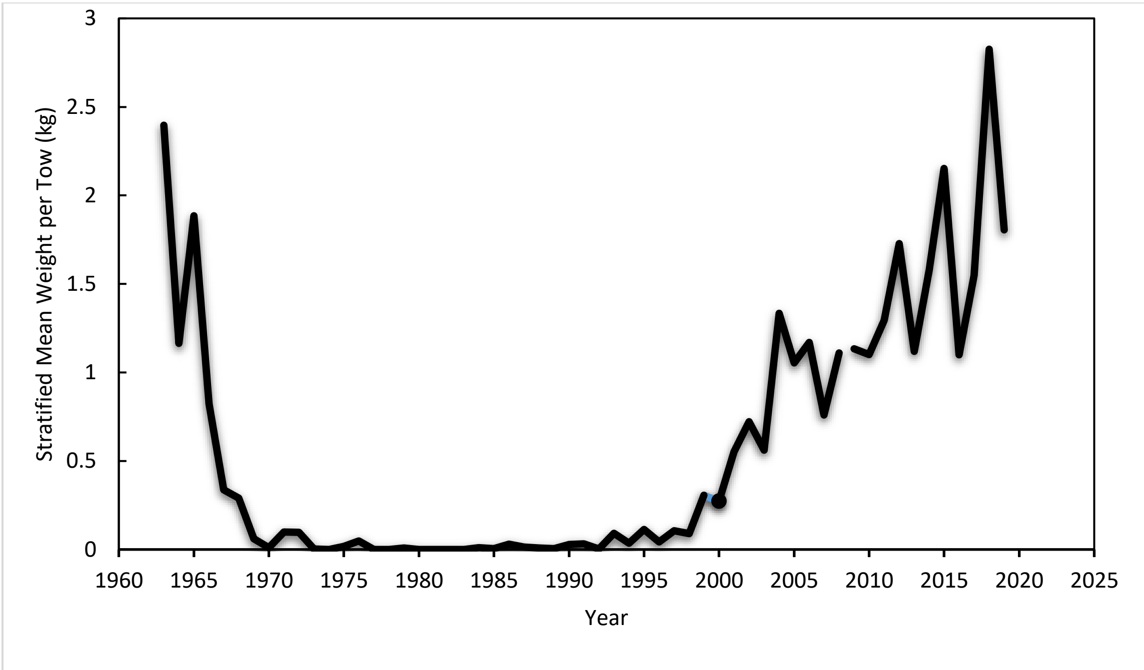

Figure 31. NEFSC autumn bottom trawl survey biomass indices for barndoor skate.

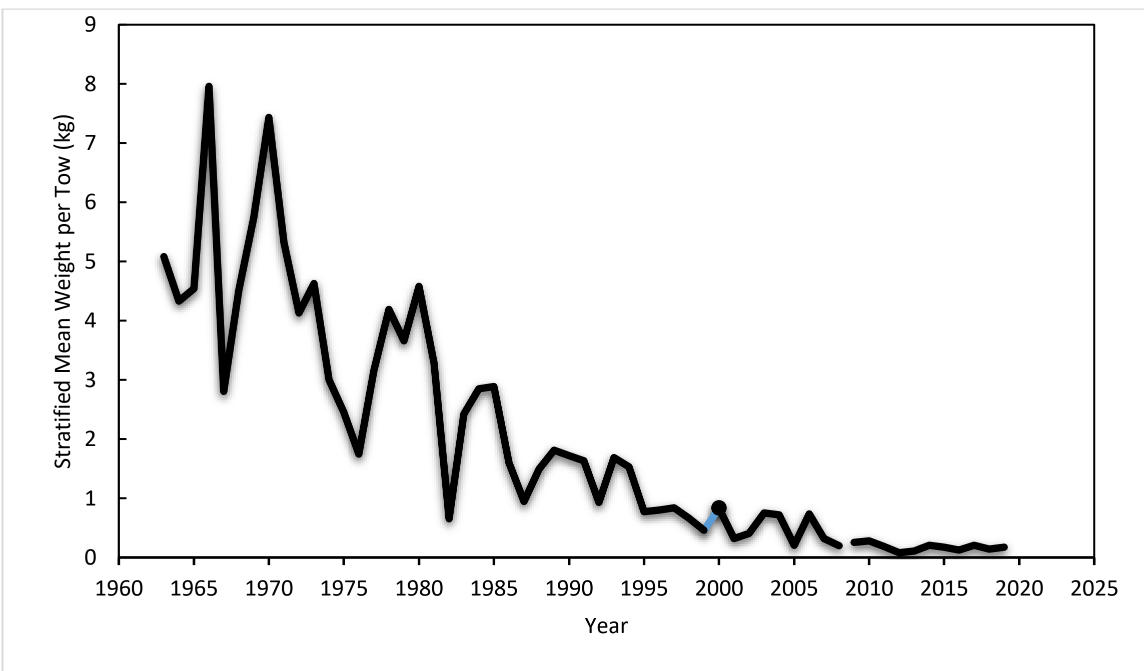

Figure 32. NEFSC autumn bottom trawl survey biomass indices for thorny skate.

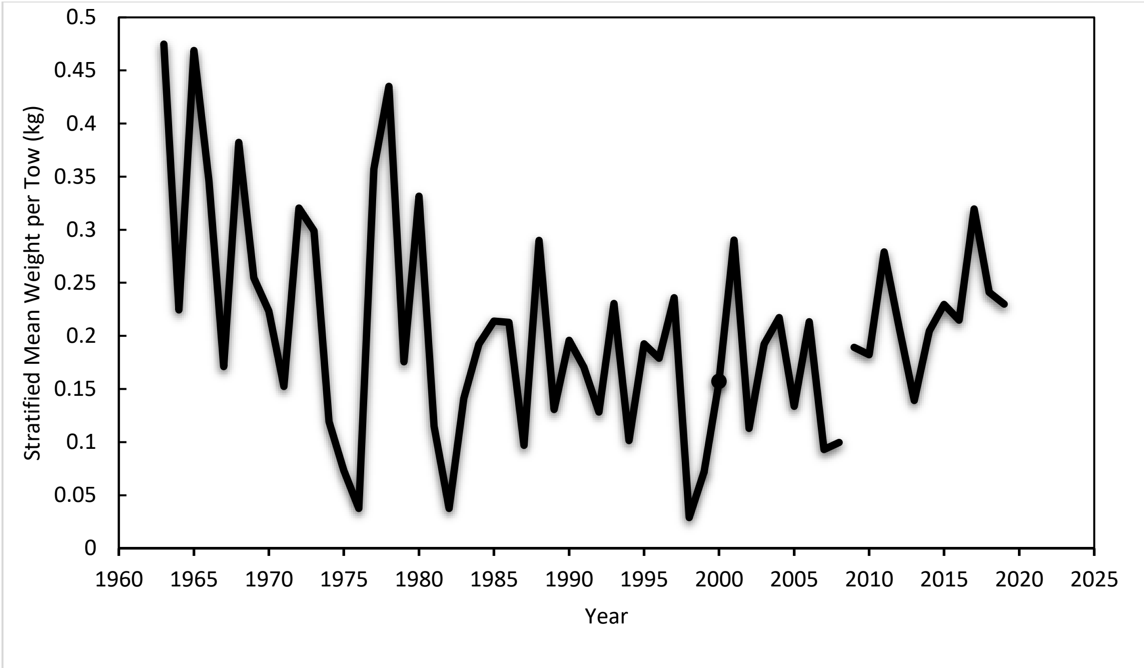

Figure 33. NEFSC autumn bottom trawl survey biomass indices for smooth skate.

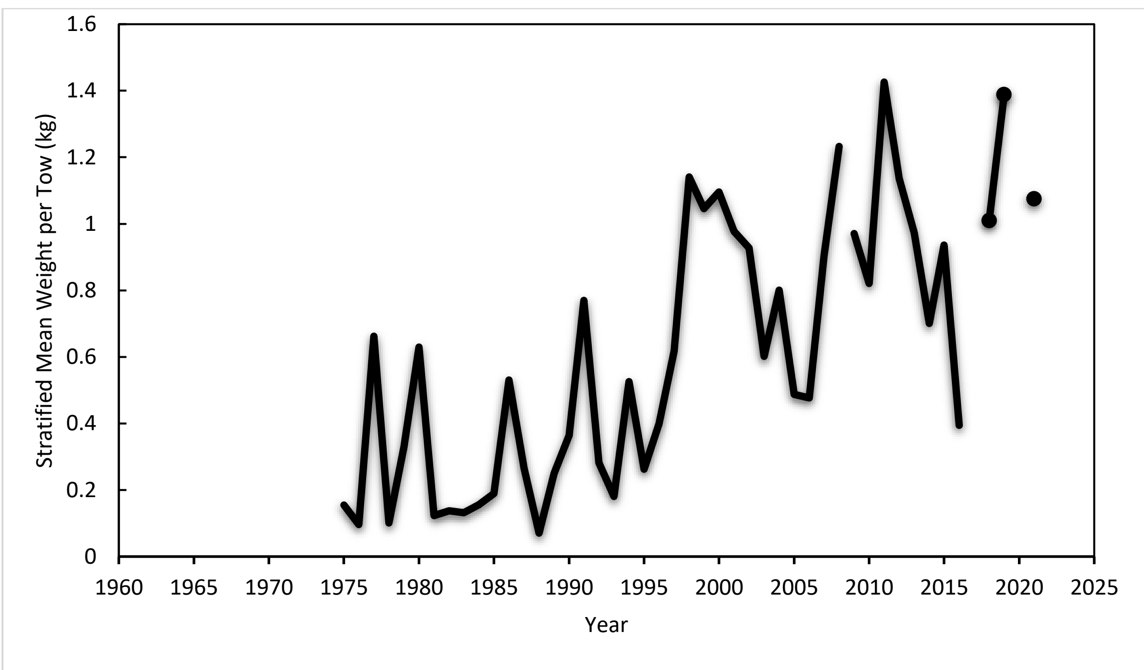

Figure 34. NEFSC autumn bottom trawl survey biomass indices for clearnose skate.

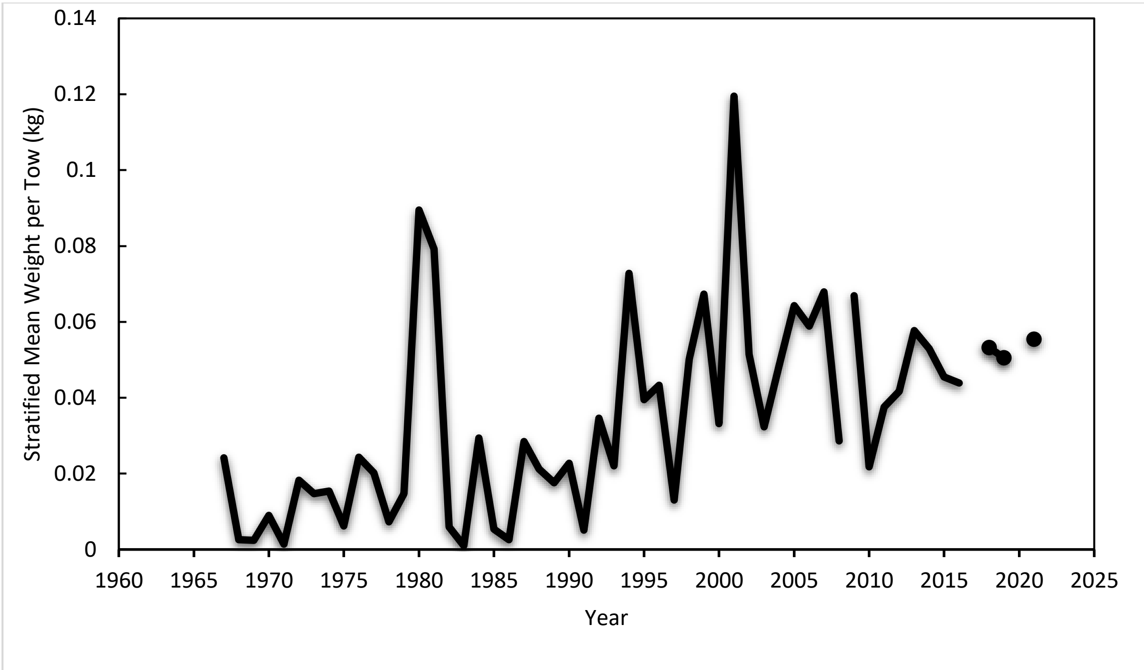

Figure 35. NEFSC autumn bottom trawl survey biomass indices for rosette skate.