DATA UPDATE

FOR

GULF OF MAINE NORTHERN SHRIMP – 2019

Prepared
by the
Atlantic States Marine Fisheries Commission's
Northern Shrimp Technical Committee

Margaret Hunter, Chair (ME DMR)
Kelly Whitmore (MA DMF)
Robert Atwood (NH FGD)
Dr. Anne Richards (NEFSC)
Alicia Miller (NEFSC)
Dr. Katie Drew (ASMFC)
Dustin Colson Leaning (ASMFC)

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Executive Summary

In 2018, the Northern Shrimp Section extended the existing moratorium on commercial fishing through 2021. The three-year moratorium was set in response to the continued low levels of biomass and recruitment. This report presents updated data from the most recent years of fishery independent surveys and environmental indices to keep managers and stakeholders informed about current stock trends. The stock assessment model was not updated, and no projections were performed.

Based on the results of the most recent stock assessment update, the northern shrimp stock in the Gulf of Maine was depleted in 2018, with spawning stock biomass (SSB) at extremely low levels since 2013 (Hunter *et al.* 2018). The traffic light analysis of 2019 data indicated no improvement in status in 2019, with indices of abundance, biomass, and spawning stock biomass at new time-series lows, and recruitment the third-lowest in the time series, well below the 2018 level. Recent environmental conditions continue to be unfavorable for northern shrimp.

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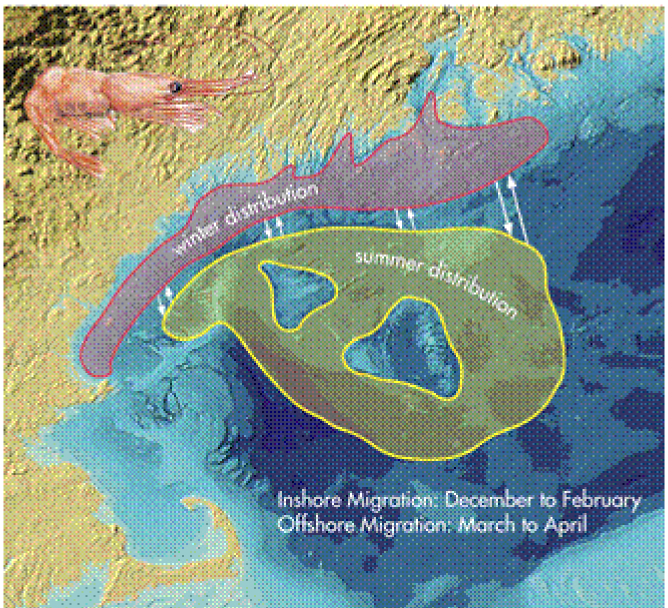
Introduction

Biological Characteristics

Northern shrimp (*Pandalus borealis* Krøyer) inhabit boreal waters of the North Atlantic, ranging from about 42° to 77° N latitude (Shumway et al. 1985). The population in the Gulf of Maine, which is the southern extent of the range, is thought to be a single stock that does not mix with other populations further north (Jorde *et al.* 2015).

Northern shrimp are hermaphroditic, maturing first as males at about 1½–2½ years of age and then transforming to females at roughly 3½ years of age in the Gulf of Maine. Spawning takes place in offshore waters beginning in late July. By early fall, most adult females extrude their eggs onto the abdomen. Egg-bearing females move inshore in late autumn and winter, where the eggs hatch. Juveniles remain in coastal waters for a year or more before migrating to deeper offshore waters, where they mature as males. The exact extent and location of these migrations is variable and unpredictable. The males pass through a series of transitional stages before maturing as females. Some females may survive to repeat the spawning process in succeeding years. Females that have never extruded eggs are referred to here as "female I"; non-ovigerous females that have carried eggs in the past are "female II". The egg-bearing females and female IIs are the individuals targeted in the Gulf of Maine fishery. Natural mortality seems to be most pronounced immediately following egg-hatch, and it is believed that most northern shrimp do not live past age 5 in the Gulf of Maine (Haynes and Wigley 1969; review by Clark *et al*. 2000).



Distribution of adult female northern shrimp (NAMA, 2006)

Fishery Management

The Gulf of Maine northern shrimp fishery is managed by the Atlantic States Marine Fisheries Commission (ASMFC) Northern Shrimp Section (Section). The management framework evolved during 1972–1979 under the auspices of the State/Federal Fisheries Management Program. In 1980, this program was restructured as the Interstate Fisheries Management Program (ISFMP) of ASMFC. The Interstate Fishery Management Plan (FMP) for Northern Shrimp was first approved under the ISFMP in October 1986 (ASMFC 1986). The FMP sought to generate the greatest possible economic and social benefits from the harvest of northern shrimp and implemented measures to optimize yield. Specific regulations included a minimum mesh size, season limitations, and reporting requirements.

In 2004, the Section implemented Amendment 1 which established biological reference points for the first time in the northern shrimp fishery (ASMFC 2004). In addition, the document expanded the tools available to manage the fishery, including gear modifications. Management of northern shrimp under Amendment 1 resulted in a rebuilt stock and increased fishing opportunities. However, due to late reporting and higher than anticipated landings, the 2010 and 2011 fishing seasons exceeded the recommended total allowable catch (TAC) and were closed for the remainder of the season.

In 2011, the Section implemented Amendment 2. The amendment provided management options to slow catch rates throughout the season, including trip limits, trap limits, and days out of the fishery (ASMFC 2011). Subsequently, the Section implemented Addendum I to Amendment 2 in November 2012. The addendum clarified the annual specification process and allocated the annual hard TAC between gear types, with 87% allocated to the trawl fishery and 13% allocated to trap fishery (ASMFC 2012). Addendum I also implemented a season closure provision designed to close the northern shrimp fishery when a pre-determined percentage (between 80–95%) of the annual TAC is projected to be caught. Lastly, the addendum instituted a research set aside (RSA) program which allowed the Section to "set aside" a percentage of the annual TAC to help support research on the northern shrimp stock and fishery.

In 2013, the Northern Shrimp Section imposed a moratorium on the fishery for the 2014 season. The Section considered several factors prior to closing the fishery: (1) northern shrimp abundance in the western Gulf of Maine had declined steadily since 2006; (2) the 2012 and 2013 survey indices of total biomass and spawning stock biomass (SSB) were the lowest on record; (3) the stock experienced failed recruitment for three consecutive years prior to 2014 (2010 – 2012 year classes); and (4) long term trends in environmental indices were not favorable for northern shrimp in the Gulf of Maine. The 2014 through 2017 stock status reports indicated continued poor trends in biomass, recruitment, and environmental indices which prompted the Section to extend the moratorium each year through 2018. Winter sampling via selected commercial shrimp vessels occurred in each year of the moratorium to continue the time series of biological samples that had been obtained from the Gulf of Maine commercial northern shrimp fishery.

Given the low abundance and unfavorable environmental conditions which resulted in a highly uncertain future for the resource, the Section implemented Amendment 3 in August 2017. Amendment 3 is designed to improve management of the northern shrimp resource, in the event the fishery reopens (ASMFC 2017). Specifically, the Amendment refines the FMP objectives and implements a state-specific allocation program to better manage effort in the fishery; 80% of the annual TAC is allocated to Maine, 10% to New Hampshire, and 10% to Massachusetts. The Amendment also implements mandatory use of size sorting grate systems in trawls to reduce the harvest of small shrimp, specifies a maximum fishing season length, and formalizes fishery-dependent monitoring requirements.

Amendment 3 also outlines the specification process for the northern shrimp fishery. The Section meets in-person annually to adjust commercial fishery management measures. The

Section sets a hard TAC for the fishing year based upon the best available science as well as recommendations from the Northern Shrimp Technical Committee (NSTC) and Advisory Panel. In addition, the Section can specify the fishing season, the projected percentage of harvest at which the fishery will close (between 80-95%), trip limits, traps limits, days out of the fishery, and a research set aside. These management tools can be specific to a gear type and the Section can establish harvest triggers to automatically initiate or modify any option.

In 2018, the Section extended the moratorium on commercial fishing through 2021. This three-year moratorium was set in response to the continued low levels of biomass and recruitment and the fact that, should recruitment improve, it would take several years for those shrimp to be commercially harvestable. The Section also approved Addendum I to Amendment 3, which provides states the authority to allocate their state-specific quota between gear types in the event the fishery reopens (ASMFC 2018a). Given the low biomass of the stock, the Section did not establish a Research Set Aside for the winter of 2018-19.

Commercial Fishery Trends

The Gulf of Maine fishery has been seasonal in nature, peaking in late winter when egg-bearing females move inshore and terminating in spring under regulatory closure. Northern shrimp have been an accessible and valuable resource to fishermen working inshore areas in small vessels in the winter. Most northern shrimp fishing in the Gulf of Maine has been conducted by otter trawls, although traps have also been employed, mostly off the central Maine coast, since the 1970s. A fishing moratorium has been in effect since the fishery closed in April 2013.

Commercial Fishery Landings

Annual landings of Gulf of Maine northern shrimp declined from an average of 11,400 metric tons (mt) during 1969–1972 to about 400 mt in 1977, culminating in a closure of the fishery in 1978 (Table 1). The fishery reopened in 1979 and landings increased steadily to over 5,000 mt by 1987. Landings ranged from 2,100 to 6,500 mt during 1988–1995, and then rose dramatically to 9,500 mt in 1996, the highest since 1973. Landings declined to an average of 2,000 mt for 1999–2001, and dropped further in the 25-day 2002 season to 450 mt, the second lowest landings in the time series at that time. Landings then increased steadily, averaging 2,100 mt during the 2003 to 2006 seasons, then jumping to 4,900 mt in 2007 and 5,000 mt in 2008. In 2009, 2,500 mt were landed during a season that was thought to be market-limited.

In 2010, the proposed 180-day season was cut short to 156 days due to landing rates being higher than expected, and concerns about catching small shrimp in the spring. Landings were 6,263 mt, while the TAC was set at 4,900 mt. In 2011, the season was similarly closed early due to landings higher than the TAC. About 6,400 mt of shrimp were landed, exceeding the recommended TAC of 4,000 mt (Table 1 and Figure 1). In 2012, the season was further restricted by having trawlers begin on January 2 with three landings days per week and trappers begin on February 1 with a 1,000 pound (454 kg) limit per vessel per day. Landings for 2012 were 2,485 mt. In 2013, the TAC was set at 625 mt (with 5.44 mt set aside for research tows) and would close when the projected landings reached 85% of the TAC in each fishery (trap and trawl). Trawlers fished for 54 days and trappers fished 62 days culminating in 346 mt landed, which is 279 mt below the TAC.

Winter Sampling Programs (2014–2018)

In the absence of a commercial fishery in 2014, the State of Maine contracted with a commercial shrimp trawler to collect northern shrimp samples during January–March near Pemaquid Point, in MidCoast Maine, chosen as best representing the spatial "center" of a typical winter Maine shrimp fishery. No shrimp were landed during the 2014 cooperative winter sampling program, except the collected samples, but the total catch was estimated at 264 kg (Hunter 2014).

In 2015, four trawlers and five trappers collected northern shrimp during January–March under the RSA program. Each trawler fished about once every two weeks, conducting at least three tows per trip, made no more than five trips, and could keep or sell up to 1,800 lbs (816 kg) per trip. Five trappers were also selected from MidCoast and eastern Maine and each fished ten traps, tended as often as needed, and could keep up to 100 lbs (45 kg) per week, for personal use only. 2015 RSA catches (including discards) were estimated at 6.7 mt (Whitmore *et al*. 2015).

In 2016, four trawlers and two trappers collected northern shrimp during January–April under the RSA program. Each trawler fished about once every two weeks, no more than five trips total, made at least three tows per trip, and could keep or sell up to 1,800 lbs (816 kg) per trip. Two trappers were also selected from MidCoast Maine and each fished forty traps, tended as often as needed, and could keep or sell up to 100 lbs (45 kg) per week. 2016 RSA catches (including discards) were estimated at 13.3 mt (Hunter 2016).

In 2017, the RSA was expanded to ten trawlers and five trappers collecting northern shrimp during January–March: one vessel from Massachusetts, one from New Hampshire, three from western Maine, three from MidCoast Maine, and two from eastern Maine, with a 1,200 pound (544 kg) trip limit. Four trappers were also selected from MidCoast Maine and one from eastern Maine, fishing up to 40 traps with a 500 lbs (227 kg) limit per week. 2017 RSA catches (including discards) were estimated at 32.6 mt (Hunter *et al*. 2017).

For 2018, the Section established an RSA of 7.3 mt; one trawler from Massachusetts and one from New Hampshire, each fishing one trip per week for up to 10 weeks, with an 800 pound (363 kg) landing limit per trip,. Maine contracted with one trawler to make three sampling trips with no landings allowed. The three boats caught a total of 3.1 mt, including discards (Hunter *et al*. 2018). There was no RSA and no winter sampling program during 2019.

Size, Sex, and Maturity Stage Composition of Landings

The northern shrimp commercial fishery has been under a moratorium since April 2013. Previous reports, e.g. Hunter et al. 2018, may be referenced for discussions of the composition of landings.

Discards
Discard rates of northern shrimp in the northern shrimp fishery are thought to be near zero because no size limits are in effect and most fishing effort occurs in areas where only the larger females are present.

Effort, Distribution of Effort, and Catch per Unit Effort
The northern shrimp commercial fishery has been under a moratorium since April 2013. Previous reports, e.g. Hunter *et al.* 2018, may be referenced for discussions of commercial fishery effort and CPUE.

Data Update

Data Sources
The traffic light analysis was updated with the 2019 Summer Survey data, the 2018 NEFSC fall survey data, and the 2019 ME-NH spring inshore data, as well as with 2019 data for temperature indicators and the 2018 data for the predation index. The 2019 NEFSC fall survey data, which inform the index of northern shrimp abundance, the predation pressure index, and the fall bottom temperature index, are not yet available, so those time series only go through 2018.

Traffic Light Analysis
The NSTC utilized an index-based approach to evaluate stock status of Gulf of Maine northern shrimp. The Traffic Light Approach, developed by Caddy (1999a, 1999b, 2004) and extended by McDonough and Rickabaugh (2014) was applied to the northern shrimp stock to characterize indices of abundance, fishery performance, and environmental trends from 1984 to present. The approach categorizes annual values of each index as one of three colors (red, yellow, or green). Red represents unfavorable condition or status, yellow designates intermediate values, and green represents favorable condition or status.

The NSTC applied the Strict Traffic Light Approach (STLA, Caddy 1999a, 1999b and 2004) to a suite of indicators (Tables 2-3, Figures 7-10). Fishery-independent indices included survey indices from the ASMFC summer survey, the NEFSC fall surveys, and the Maine-New Hampshire spring inshore survey. Indices of total biomass and abundance, harvestable biomass, spawner biomass, and recruitment from the Summer Survey were also evaluated. Environmental conditions included a predation pressure index (NEFSC 2014; Richards and Jacobson 2016), and several sources of surface and bottom temperature data for the northern shrimp resource area.

Two qualitative stock status reference levels were developed for the traffic light approach. For the abundance and biomass indices, being below the 20th percentile of the time series from 1984-2017 indicated an adverse state, and being above the 80th percentile of the time series from 1984-2017 indicated a favorable state. For the environmental indicators, the opposite was true: being below the 20th percentile of the time series from 1984-2017 indicated a favorable state while being above the 80th percentile of the time series indicated an adverse state, as higher temperature and predation pressure have negative consequences for northern shrimp.

Resource Conditions

Trends in abundance of Gulf of Maine northern shrimp were monitored between 1968 and 1983 from data collected in the NEFSC fall bottom trawl surveys (Despres-Panajo *et al.* 1988) and summer surveys conducted by the State of Maine DMR (discontinued in 1983). The NEFSC fall survey has continued; however, the survey vessel and gear were replaced in 2009, and this is considered the beginning of a new survey time series for shrimp (Politis *et al.* 2014). A state-federal survey (i.e. the Summer Survey) was initiated by the NSTC in 1984 to specifically assess the shrimp resource in the western Gulf of Maine. This survey is conducted each summer aboard the *RV Gloria Michelle*, employing a stratified random sampling design and shrimp trawl gear designed for Gulf of Maine conditions (Clark 1989). An inshore trawl survey has been conducted by Maine and New Hampshire aboard the *FV Robert Michael* each spring and fall, beginning in the fall of 2000 (Sherman *et al*. 2005).

The NSTC has placed primary importance on the Summer Shrimp Survey (described in more detail below) for fishery-independent data used in stock assessments, although the other survey data are also considered. See Figures 1 and 2 for the areas covered by the different surveys.

For the 2017 Summer Survey, the *RV Gloria Michelle's* winches were replaced, and new Bison trawl doors replaced the old Portuguese trawl doors, which had been in use since the first year of the survey in 1984. Just before the 2017 survey, eight pairs of calibration tows were made to compare the performance of the gear with the old and new doors and winches. The differences were not statistically significant (Eckert *et al.* 2017). Thirty-one additional calibration tows were conducted in 2018–2019, but the results have not been analyzed yet. The data and discussion below assume that there was no significant difference in the performance of the 2017-2019 survey gear compared with the gear in prior years.

The indices of abundance from the surveys were calculated with design-based estimators (stratified arithmetic or geometric means) in assessments conducted before 2018. For the 2018 Benchmark Assessment (ASMFC 2018) and thereafter, a spatio-temporal standardization approach was used to develop the fishery-independent indices. This approach used a spatial delta-generalized linear mixed model (delta-GLMM) to incorporate habitat information and spatial auto-correlation in survey data to develop indices of abundance (Cao *et al.* 2017); as part of the process, the indices were then standardized to their mean, so the scale of the indices is no longer comparable to the design-based numbers or weights per tow.

Abundance and biomass indices (spatio-temporal standardized) for northern shrimp from the Summer Survey from 1984–2019 are given in Table 2 and Figures 7 and 8; length-frequencies by sex-stage and year are provided in Figures 3 and 4. These indices were calculated using data from all successful tows in all years, at both fixed and randomly chosen sites, in all stratum areas surveyed. The standardized index of total biomass closely follows the trends of the total abundance index (Table 2 and Figure 7).

The total abundance index averaged 1.10 from 1984 through 1993, then gradually declined to 0.28 in 2001. The index increased markedly, reaching a time series high in 2006 (4.55). Although 2006 was a high stock year, as corroborated by the NEFSC fall survey index (see below), the 2006 Summer Survey index should be viewed with caution because it was based on 41 survey tows compared with about 57 tows in most years. The index averaged 1.73 during 2007–2010, then declined steeply to 0.07 by 2013 and reached a time series low of 0.04 in 2019. Seven out of eight of the lowest biomass indices, and eight out of eight of the lowest abundance indices have occurred since 2011. The three lowest indices of both abundance and biomass occurred in the most recent three years. The Summer Survey abundance index and biomass index for 2019 were both time series lows, 4% and 6% of their 1984-2019 time series means, respectively.

The standardized catch of assumed 1.5-year-old shrimp (Table 2, Figure 8 (bottom), and graphically represented as the first (left-most) size mode at about 16 mm in Figures 3 and 4), represents a recruitment index. Although these shrimp are not fully recruited to the survey gear, this index appears sufficient as a preliminary estimate of year class strength. The recruitment index indicated strong (greater than 0.800) assumed 1987, 1992, 2001, and 2004 year classes. The assumed 1983, 2000, 2002, and 2006 year classes were weak (less than 0.060), well below the time series mean of 0.281. From 2008 to 2010, the recruitment index varied around 0.57, indicating above average assumed 2007, 2008, and 2009 year classes. The index dropped markedly to 0.050 in 2011. Very low values (less than 0.015) were observed in 2012, 2013, 2015, and 2017, indicating recruitment failure of the assumed 2011, 2012, 2014, and 2016 year classes. In 2014, 2016, and 2018 the indices were somewhat higher but below the time series mean, reflecting below-average recruitment of the 2013, 2015, and 2017 year classes. The recruitment index for 2019 was 0.003, the third lowest. All recruitment indices have been below average since 2011, with time series lows in 2013, 2015, 2017, and 2019.

Mean numbers per tow at size for 2012-2019 are too low to be clearly visible in Figure 3, which uses a constant y-axis scale for the time series (with the exception of 2006). Expanded vertical axes for the 2012-2019 data show that the mean carapace lengths of the assumed age-1.5 shrimp in the 2014, 2016, and 2018 surveys were larger than the time series mean of 16 mm, suggesting a high initial growth rate for the 2013, 2015, and 2017 year classes. The bulk of the 2013 year class appears to have transitioned early, to female I in 2015 and female II in 2016. In 2019, the population comprises second year males and female 1s from the assumed 2017 year class, and female IIs from the assumed 2015 year class (Figure 4).

Individuals larger than 22 mm carapace length (CL) in the summer are expected to be available to a fishery the following winter (as primarily age 3 and older). Thus, survey catches of shrimp in this size category provide indices of harvestable numbers and biomass for the coming winter (Table 2). The harvestable biomass index exhibited peaks in 1985–86, 1990, and 1995–96, reflecting the strong assumed 1982, 1987, and 1992 year classes respectively. The index then trended down through 2001 to a low of 0.19, indicative of small and/or heavily fished assumed 1997–98 year classes. From there the index increased dramatically, reaching a time series high in 2006 (1.81). It remained high through 2010 with above-average recruitment of the 2007–2008 year classes, then declined rapidly, despite above-average recruitment of the 2009 year class. The index has continued to decline steadily, reaching time series lows in 2013–18, and a new time series low in 2019 (0.04), consistent with the below average recruitment of the 2010–2016 year classes.

An index of spawning stock biomass was estimated by applying a length-weight relationship for non-ovigerous shrimp (Haynes and Wigley 1969) to the abundance of females at each length, and summing over lengths. The spawning biomass index shows trends similar to the harvestable biomass indices, with the most recent seven years having the lowest values in both time series (Table 2 and Figure 8 (top)).

The NEFSC fall survey conducted by the NOAA Ship *Albatross IV* provided an index of northern shrimp abundance from 1968 to 2008. The spatio-temporal standardized abundance index is available beginning in 1986 (Table 2 and Figure 9). The index fluctuated with the influences of strong and weak year classes and fishing effort through the 1980s and 1990s, and the survey ended in 2008 with values well above the time series mean during its last four years, including the time series high of 3.69 in 2006. This high value corresponded with the time series high seen in the Summer Survey the same year (Table 2 and Figure 7). In 2009, the NEFSC fall survey changed vessels, gear, and protocols; thus, indices since 2009 are not directly comparable to earlier years. The abundance index from the new (NOAA Ship *Bigelow*) NEFSC fall survey declined rapidly, from a high of 3.60 in 2009 to a time series low of 0.10 in 2017, parallel to trends in the Summer Shrimp Survey and the ME-NH survey (Figure 6). The index for 2018 was 0.20, well below the time series mean (Table 2 and Figure 9). The 2019 survey index is not available yet.

The Maine-New Hampshire inshore trawl survey takes place biannually, during spring and fall, in five regions and three depth strata (1 = 5–20 fa (9–37 m), 2 = 21–35 fa (38–64 m), 3 = 36–55 fa (65–101 m)). A deeper stratum (4 = > 55 fa (101 m) out to about 12 miles) was added in 2003. The survey consistently catches shrimp in regions 1–4 (NH to Mt. Desert Is.) and depths 3–4 (> 35 fa (64 m)), and more are caught, with less variability, in the spring than the fall. The spatio-temporal standardized abundance index for northern shrimp for the spring surveys using all regions and depths for 2003–2019 is presented in Table 2 and Figure 6. The index rose steadily from 0.46 in 2003 to a time series high of 2.90 in spring 2010. It remained high in 2011, and then dropped abruptly, reaching a time series low of 0.06 in 2019 (preliminary). Trends in the spring ME/NH survey may be affected by inter-annual variation in the timing of the offshore migration of post-hatch females. However, the low 2013–2019 biomass indices and size and sex-stage structure observed in the ME-NH survey are consistent with the 2013–2019 Summer Survey results (Figure 6).

Environmental Conditions

Ocean temperature has an important influence on northern shrimp in the Gulf of Maine (Dow 1964; Apollonio *et al.* 1986; Richards *et al.* 1996; Richards *et al.* 2012; Richards *et al.* 2016). Survival during the first year of life has been negatively correlated with ocean temperature during two periods: (1) during the time of the hatch and early larval period, and (2) during the late summer when ocean temperatures and water column stratification are reaching their maximum (Richards *et al.* 2016). Relatively cool temperatures during these sensitive periods are associated with higher recruitment indices in the Summer Survey. Spawner abundance also influences recruitment, with more recruits produced with higher spawner abundance, but environmental influences have increased in importance since around 1999 (Richards *et al.* 2012).

Sea surface temperature (SST) has been measured daily since 1906 at Boothbay Harbor, Maine, near the center of the inshore nursery areas for northern shrimp. Average winter SST (Feb-Mar) at Boothbay has increased fairly steadily from an average of 0.8^{o} C during 1906-1948 to 3.4^{o} C during 2008-2019 (Table 3 and Figure 10). Average winter SST during 2019 was 3.5^{o} C.

Spring bottom temperature anomalies (temperature changes measured relative to a standard time period) in offshore shrimp habitat areas have been above average in recent years with 2016 and 2019 reaching levels in the 80th percentile (Figure 10). Summer bottom temperature in shrimp habitat as measured by the Summer Survey has also shown an increasing trend over time. Average summer bottom temperature was 5.4^{o}C from 1984-1993, but increased to 6.7^{o}C from 2013 – 2019. The stratified mean summer bottom temperature was 7.1^{o}C in 2019, above the long-term average and within the 80th percentile.

Northern shrimp are an important component of the food web in the Gulf of Maine. An index of predation pressure (PPI) was developed from NEFSC survey data by weighting the predator biomass indices by the long-term average percent frequency of shrimp in each predator's diet estimated from food habits sampling (NEFSC 2014; Richards and Jacobson 2016). Predation pressure has generally increased since the late 1990s (Figure 10). In the last decade, the PPI has shown some periods of highs (2010-2012) including a time series high in 2016. This peak was attributable to an increased biomass index of spiny dogfish (*Squalus acanthias*) (unpub. data, NEFSC 2017). Following this spike in 2016, it has fluctuated around the 80th percentile in 2017 and 2018.

Data Update Summary

Fishery-independent model-based Summer Survey indices of abundance and biomass have remained at historic lows for the past eight years (2012–2019) (Table 2, Figure 7). Similarly, spawning biomass and recruitment indices have remained below the 20th percentile during 2012–2019, and are also the lowest estimates on record (Table 2, Figure 8). Shrimp indices from surveys with shorter time series have exhibited a similar trend. The NEFSC fall survey (*Bigelow*, 2009-2018) and ME-NH spring inshore survey (2003-2019) abundance indices were above the 80th percentile in 2009-2010, but have since declined dramatically. The NEFSC fall index was above the 20th percentile in 2018 but still very low compared to the start of the time series (Table 2, Figure 9). The 2019 (ME-NH spring) reached a time series low in 2019, well below the 20th percentile (Table 2).

Recruitment has been low to extremely poor for eight consecutive years. Recruitment was below the 20th percentile in 2012, 2013, 2015, 2017, and 2019 with the lowest recruitment value on record observed in 2017 (Table 2, Figure 8). The recruitment index in 2013 (2012 year class), 2014 (2013 year class), 2017 (2016 year class), and 2019 (2018 year class) were the weakest observed in the 35-year time series (Table 2, Figure 8).

Trends in environmental indicators suggest that conditions have not been favorable for northern shrimp in recent years (Table 3, Figure 10). An overall rise in seawater temperatures since 1984 is evident across the series, with spring anomalies and summer bottom temperatures in offshore shrimp habitat at or exceeding the 80th percentile from 2011 to 2013 and again in 2016; temperature anomalies were near or above the 80th percentile in 2019 (Table 3, Figure 10). Predation levels remain high compared to the stable period, with the predation pressure index just under the 80th percentile threshold in 2018, although down from the time series high in 2016 (Table 3, Figure 10).

Status of the Stock

Based on the results of the 2018 Stock Assessment Update, the northern shrimp stock in the Gulf of Maine remains depleted, with spawning stock biomass (SSB) at extremely low levels since 2013 (ASMFC 2018b). SSB in 2018 was estimated at 600 mt, well below the time series average of 3,710 mt. In addition, recruitment remained low, with values in 2018 estimated at 2.0 billion shrimp, higher than in 2017 but still lower than the time series median of 2.6 billion shrimp. Variability in recruitment has increased since 2000, with higher highs and lower lows in recruitment deviations than in previous years (1984-1999). Fishing mortality has been very low in recent years due to the moratorium.

The traffic light analysis of 2019 data indicated no improvement in status in 2019, with indices of abundance, biomass, and spawning stock biomass at new time-series lows, and recruitment the third-lowest in the time series, well below the 2018 level. Environmental conditions remain unfavorable.

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Table 1. **U.S. Commercial landings (mt) of northern shrimp in the Gulf of Maine, by year (1958–1984, left) or by season (1985–2018, right). Landings by season include the previous December. Landings in 2014–2018 are from RSA and winter sampling programs, and include discards.**

Year	Maine	Mass.	New Hamp.	Total
1958	2.2	0.0	0.0	2.2
1959	5.5	2.3	0.0	7.8
1960	40.4	0.5	0.0	40.9
1961	30.5	0.3	0.0	30.8
1962	159.5	16.2	0.0	175.7
1963	244.3	10.4	0.0	254.7
1964	419.4	3.1	0.0	422.5
1965	941.3	8.0	0.0	949.3
1966	1,737.8	10.5	18.1	1,766.4
1967	3,141.2	10.0	20.0	3,171.2
1968	6,515.2	51.9	43.1	6,610.2
1969	10,993.1	1,773.1	58.1	12,824.3
1970	7,712.8	2,902.3	54.4	10,669.5
1971	8,354.8	2,724.0	50.8	11,129.6
1972	7,515.6	3,504.6	74.8	11,095.0
1973	5,476.6	3,868.2	59.9	9,404.7
1974	4,430.7	3,477.3	36.7	7,944.7
1975	3,177.2	2,080.0	29.4	5,286.6
1976	617.3	397.8	7.3	1,022.4
1977	142.1	236.9	2.2	381.2
1978	0.0	3.3	0.0	3.3
1979	32.8	405.9	0.0	438.7
1980	69.6	256.9	6.3	332.8
1981	530.0	539.4	4.5	1,073.9
1982	883.0	658.5	32.8	1,574.3
1983	1,029.2	508.2	36.5	1,573.9
1984	2,564.7	565.4	96.8	3,226.9

Season	Maine	Mass.	New Hamp.	Total
1985	2,946.4	968.8	216.7	4,131.9
1986	3,268.2	1,136.3	230.5	4,635.0
1987	3,680.2	1,427.9	157.9	5,266.0
1988	2,258.4	619.6	157.6	3,035.6
1989	2,384.0	699.9	231.5	3,315.4
1990	3,236.3	974.9	451.3	4,662.5
1991	2,488.6	814.6	282.1	3,585.3
1992	3,070.6	289.3	100.1	3,460.0
1993	1,492.5	292.8	357.6	2,142.9
1994	2,239.7	247.5	428.0	2,915.2
1995	5,013.7	670.1	772.8	6,456.6
1996	8,107.1	660.6	771.7	9,539.4
1997	6,086.9	366.4	666.2	7,119.5
1998	3,481.3	240.3	445.2	4,166.8
1999	1,573.2	75.7	217.0	1,865.9
2000	2,516.2	124.1	214.7	2,855.0
2001	1,075.2	49.4	206.4	1,331.0
2002	391.6	8.1	53.0	452.7
2003	1,203.7	27.7	113.0	1,344.4
2004	1,926.9	21.3	183.2	2,131.4
2005	2,270.2	49.6	290.3	2,610.1
2006	2,201.6	30.0	91.1	2,322.7
2007	4,469.3	27.5	382.9	4,879.7
2008	4,515.8	29.9	416.8	4,962.4
2009	2,315.7	MA & NH: 185.6		2,501.2
2010	5,721.4	35.1	506.8	6,263.3
2011	5,569.7	196.4	631.5	6,397.5
2012	2,219.9	77.8	187.8	2,485.4
2013	289.7	18.9	36.9	345.5
2014	0.3	0.0	0.0	0.3
2015	6.1	0.6	0.0	6.7
2016	11.5	0.0	1.8	13.3
2017	31.2	0.9	0.5	32.6
2018	0.1	1.9	1.1	3.1

Table 2. **Fishery independent indicators for GOM northern shrimp traffic light analysis. Colors indicate status relative to reference levels, where: RED = at or below the 20th percentile; YELLOW = between the 20th and 80th percentiles; and GREEN = at or above the 80th percentile of the time series from 1984-2017. Stipples indicate no data.**

Fishery Independent Indices

Survey	Model-based Survey Indices: ASMFC Summer	Model-based Survey Indices: NEFSC Fall Albatross	Model-based Survey Indices: NEFSC Fall Bigelow	Model-based Survey Indices: ME-NH Spring	ASMFC Summer				
Indicator	**Total Abundance**	**Total Abundance**	**Total Abundance**	**Total Abundance**	**Num Tows**	**Total Biomass**	**Harvestable Biomass (>22 mm CL)**	**Spawner Biomass**	**Recruitment (age ~1.5)**
1984	0.98				39	1.05	0.54	0.53	0.02
1985	1.41				55	1.73	1.49	0.75	0.24
1986	1.24	0.68			54	1.55	1.21	0.91	0.26
1987	0.92	0.40			57	1.17	0.93	0.62	0.20
1988	1.34	0.34			43	1.18	0.69	0.52	0.88
1989	1.28	0.78			49	1.42	0.82	0.64	0.19
1990	1.14	0.59			47	1.56	1.34	0.76	0.10
1991	0.82	0.32			55	0.97	0.79	0.67	0.32
1992	0.50	0.19			55	0.68	0.49	0.43	0.15
1993	1.35	1.04			53	0.98	0.53	0.41	0.88
1994	1.04	1.09			45	0.88	0.43	0.37	0.39
1995	1.04	0.59			49	1.09	0.76	0.70	0.21
1996	0.83	0.40			49	0.93	0.68	0.55	0.25
1997	0.90	0.53			55	0.80	0.52	0.45	0.44
1998	0.59	0.97			59	0.60	0.32	0.31	0.14
1999	0.66	1.21			59	0.73	0.51	0.43	0.19
2000	0.80	0.96			54	0.76	0.52	0.49	0.45
2001	0.28	0.50			54	0.34	0.19	0.20	0.01
2002	1.08	0.69			54	0.77	0.34	0.36	0.87
2003	0.76	0.40		0.46	60	0.81	0.42	0.48	0.01
2004	1.19	0.88		0.52	51	1.13	0.93	0.62	0.38
2005	2.38	2.85		1.62	67	1.84	0.97	0.89	1.14
2006	4.55	3.69		1.77	41	3.84	1.81	1.85	0.17
2007	1.66	2.41		1.45	73	1.67	1.10	0.96	0.05
2008	1.80	1.51		1.73	59	1.84	1.49	0.87	0.52
2009	1.79		3.60	1.97	75	1.89	1.39	1.10	0.61
2010	1.66		2.45	2.90	72	1.58	0.91	0.75	0.57
2011	0.95		2.25	2.67	76	1.02	0.60	0.61	0.05
2012	0.28		0.59	0.78	80	0.34	0.26	0.24	0.01
2013	0.07		0.18	0.11	74	0.11	0.10	0.09	0.00
2014	0.22		0.38	0.32	68	0.17	0.06	0.07	0.18
2015	0.07		0.15	0.15	40	0.09	0.07	0.07	0.00
2016	0.27		0.11	0.26	70	0.27	0.16	0.16	0.19
2017	0.05		0.10	0.14	56	0.06	0.05	0.04	0.00
2018	0.07		0.20	0.09	41	0.08	0.05	0.05	0.04
2019	0.04			0.06	83	0.06	0.04	0.04	0.00
1984-2013 mean	**1.18**	**1.00**	**1.81**	**1.45**	**57**	**1.18**	**0.77**	**0.62**	**0.32**
2014-2019 mean	**0.12**	**NA**	**0.19**	**0.17**	**60**	**0.12**	**0.07**	**0.07**	**0.07**
80th percentile (1984-2017)	**1.37**	**1.16**	**2.33**	**1.81**	**69**	**1.57**	**1.02**	**0.76**	**0.48**
20th percentile (1984-2017)	**0.41**	**0.40**	**0.13**	**0.24**	**49**	**0.49**	**0.30**	**0.28**	**0.04**

Table 3. **Environmental condition indicators for GOM northern shrimp traffic light analysis. Colors indicate status relative to reference levels, where: RED = at or above the 80th percentile; YELLOW = between the 80th and 20th percentiles; and GREEN = at or below the 20th percentile of the time series from 1984-2017. Stipples indicate no data.**

Environmental Condition Indices

Survey	NEFSC	ASMFC	NEFSC	NEFSC	Boothbay Harbor, ME	NEFSC
Indicator	Predation Pressure Index	Summer Bottom temp.	Spring Bottom temp. anomaly	Fall Bottom temp. anomaly	Feb-Mar Surface temp.	Spring Surface temp. anomaly
1984	434.3	4.1	0.6	0.8	2.9	-0.1
1985	597.8	4.0	0.1	0.6	2.8	0.1
1986	608.1	6.3	1.2	0.7	2.6	0.8
1987	387.8	6.0	0.0	0.0	1.8	-0.6
1988	503.1	6.5	1.3	-0.1	2.7	-0.2
1989	520.4	5.6	-0.1	-0.3	1.9	-0.6
1990	631.3	3.6	0.2	0.1	2.6	0.0
1991	501.8	6.1	0.5	0.1	3.4	0.6
1992	486.7	6.3	0.6	-0.2	3.2	-0.9
1993	470.1	5.8	-0.8	-0.3	1.2	-0.7
1994	351.9	6.8	0.6	1.3	1.8	0.2
1995	638.5	6.6	0.8	0.5	3.3	0.1
1996	564.8	7.1	1.0	1.1	3.3	-0.2
1997	378.1	6.8	1.4	0.5	3.7	0.0
1998	466.6	6.3	1.3	-0.4	2.9	0.5
1999	738.7	6.1	0.3	0.6	2.9	0.9
2000	813.7	6.7	1.1	0.7	3.1	0.9
2001	723.3	6.5	0.7	0.1	2.9	0.4
2002	1,305.8	7.1	1.3	1.3	4.1	1.2
2003	1,040.8	5.6	-0.2	-0.1	2.4	-0.6
2004	487.8	4.7	-0.8	-1.1	3.0	-0.9
2005	471.3	4.9	0.1	0.5	3.0	0.2
2006	663.5	7.1	1.3	1.2	5.5	0.9
2007	704.7	5.9	0.5	-0.3	2.0	0.0
2008	846.3	5.9	0.5	0.4	2.3	1.2
2009	740.6	6.0	0.4	0.7	2.6	0.4
2010	1,126.5	7.4	0.9	1.7	4.1	1.7
2011	1,150.4	7.7	2.3	1.4	2.9	0.9
2012	1,156.6	7.9	2.0	2.0	5.5	1.9
2013	769.3	7.1	1.3	1.2	3.9	1.8
2014	955.1	6.2	0.5	1.4	2.2	0.5
2015	832.2	5.8	0.1	0.3	1.4	0.1
2016	1,518.4	7.2	1.4	2.0	4.1	1.7
2017	948.2	6.9	1.0	1.3	3.8	0.9
2018	927.2	6.7	1.1	1.3	4.5	0.5
2019		7.1	1.4		3.5	0.7
1984-2013 mean	**676.0**	**6.1**	**0.7**	**0.5**	**3.0**	**0.3**
2014-2019 mean	**1,036.2**	**6.7**	**0.9**	**1.3**	**3.3**	**0.7**
20th percentile (1984-2017)	**480.5**	**5.7**	**0.1**	**-0.1**	**2.3**	**-0.2**
80th percentile (1984-2017)	**950.9**	**7.1**	**1.3**	**1.3**	**3.8**	**0.9**

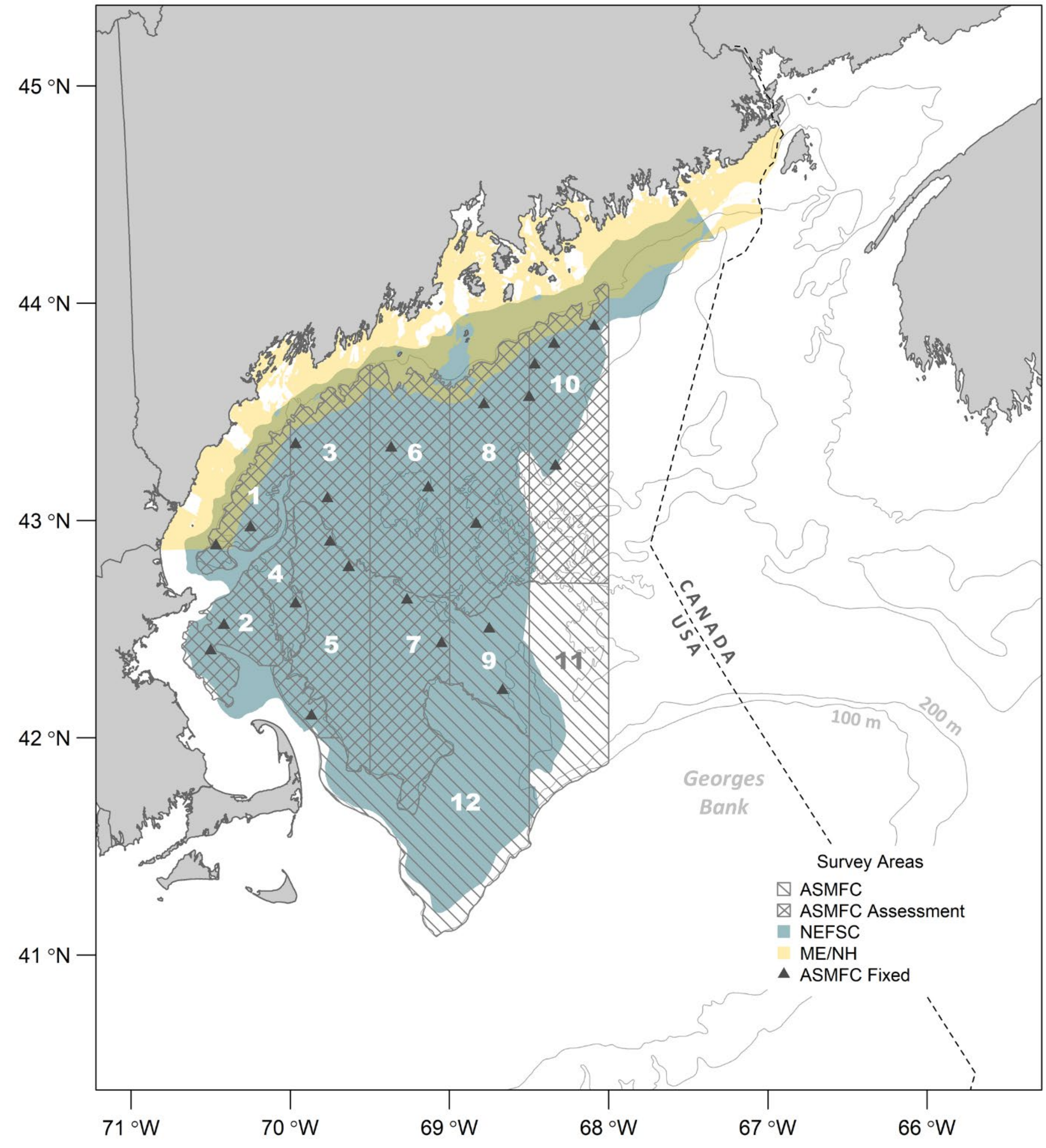


Figure 1. Gulf of Maine survey areas and station locations.

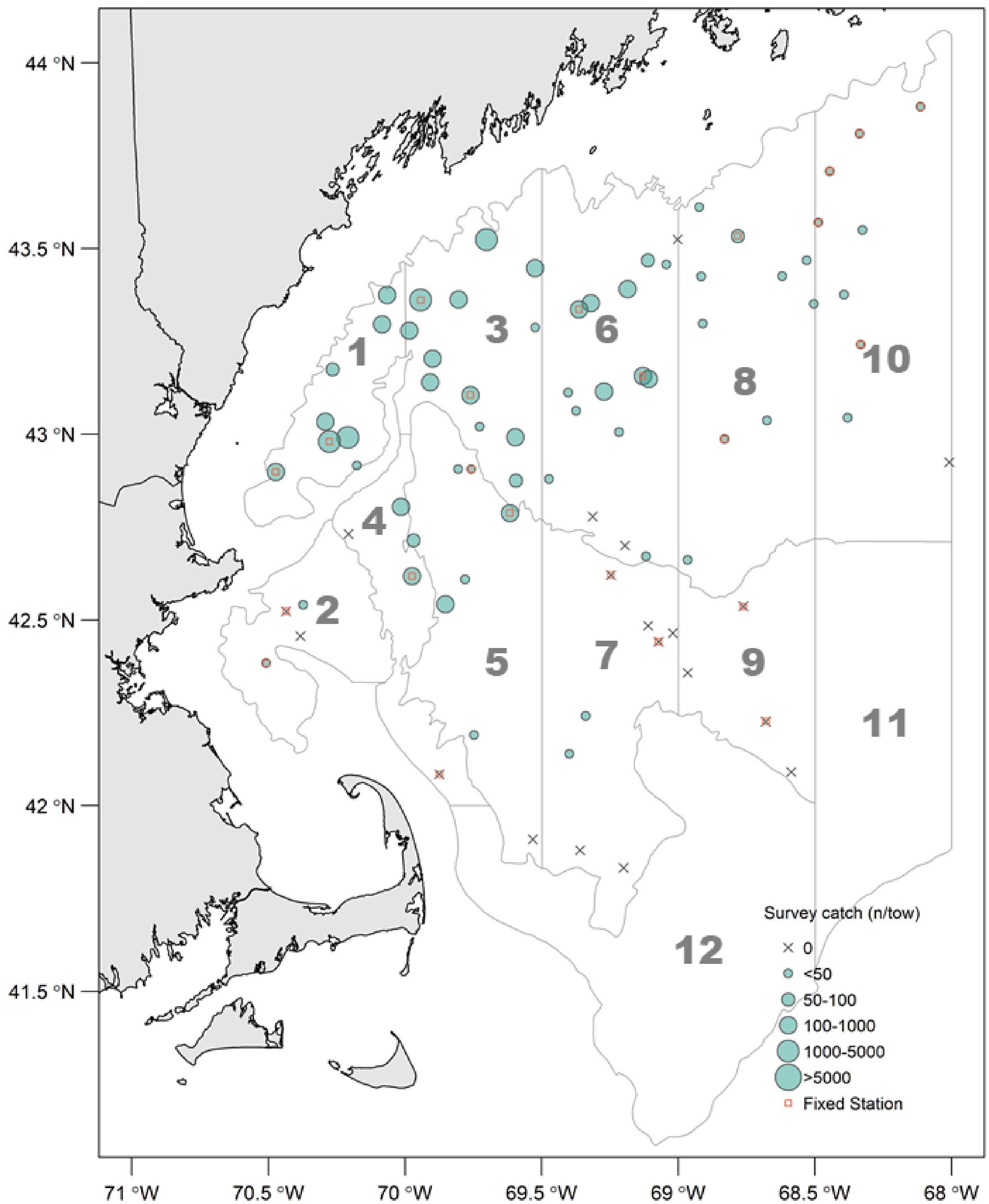


Figure 2. **2019 Summer Survey sampling sites and shrimp catches in number/tow.**

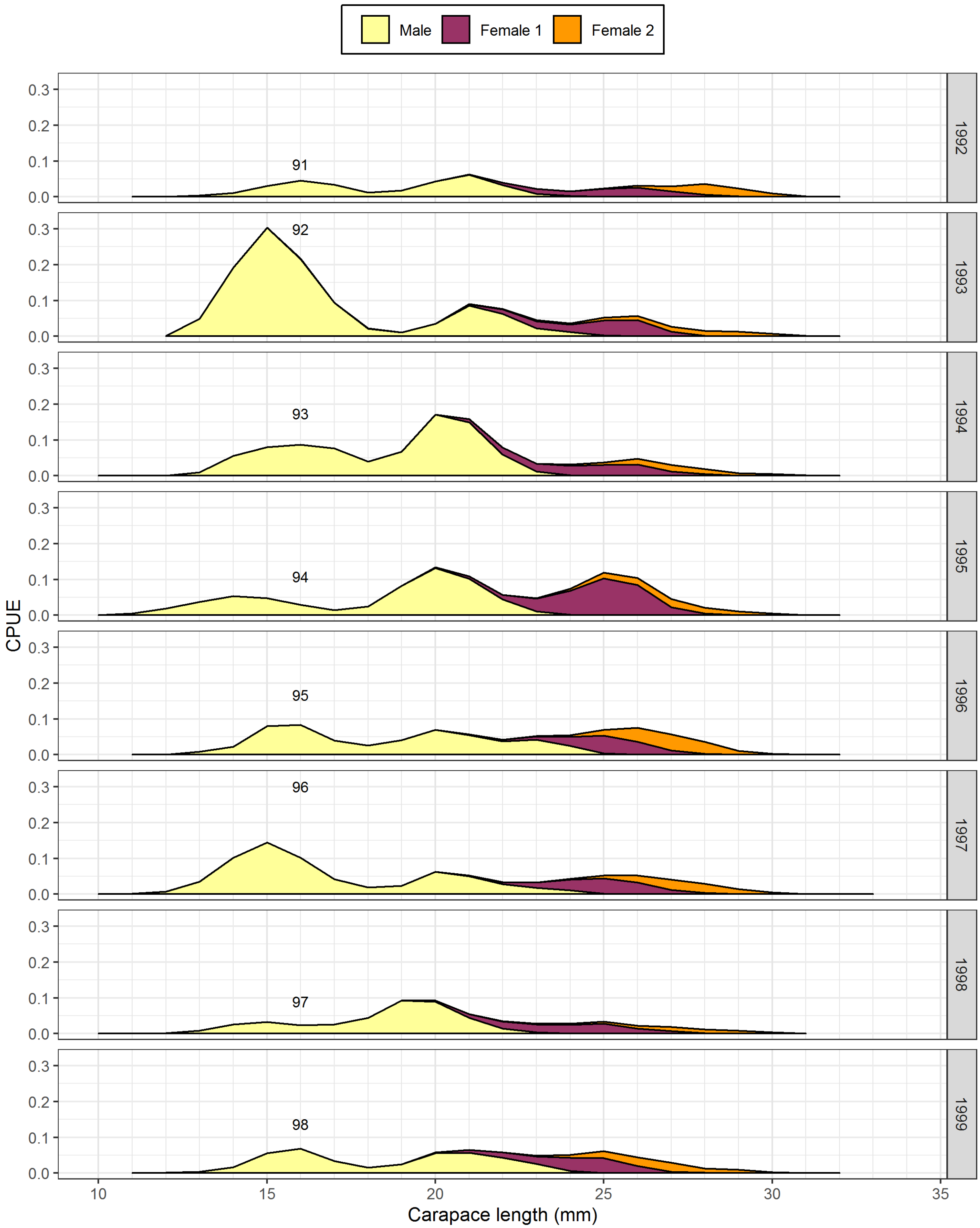


Figure 3. **Gulf of Maine northern shrimp Summer Survey abundance by year, length, and development stage. Two-digit years are year class at assumed age 1.5.**

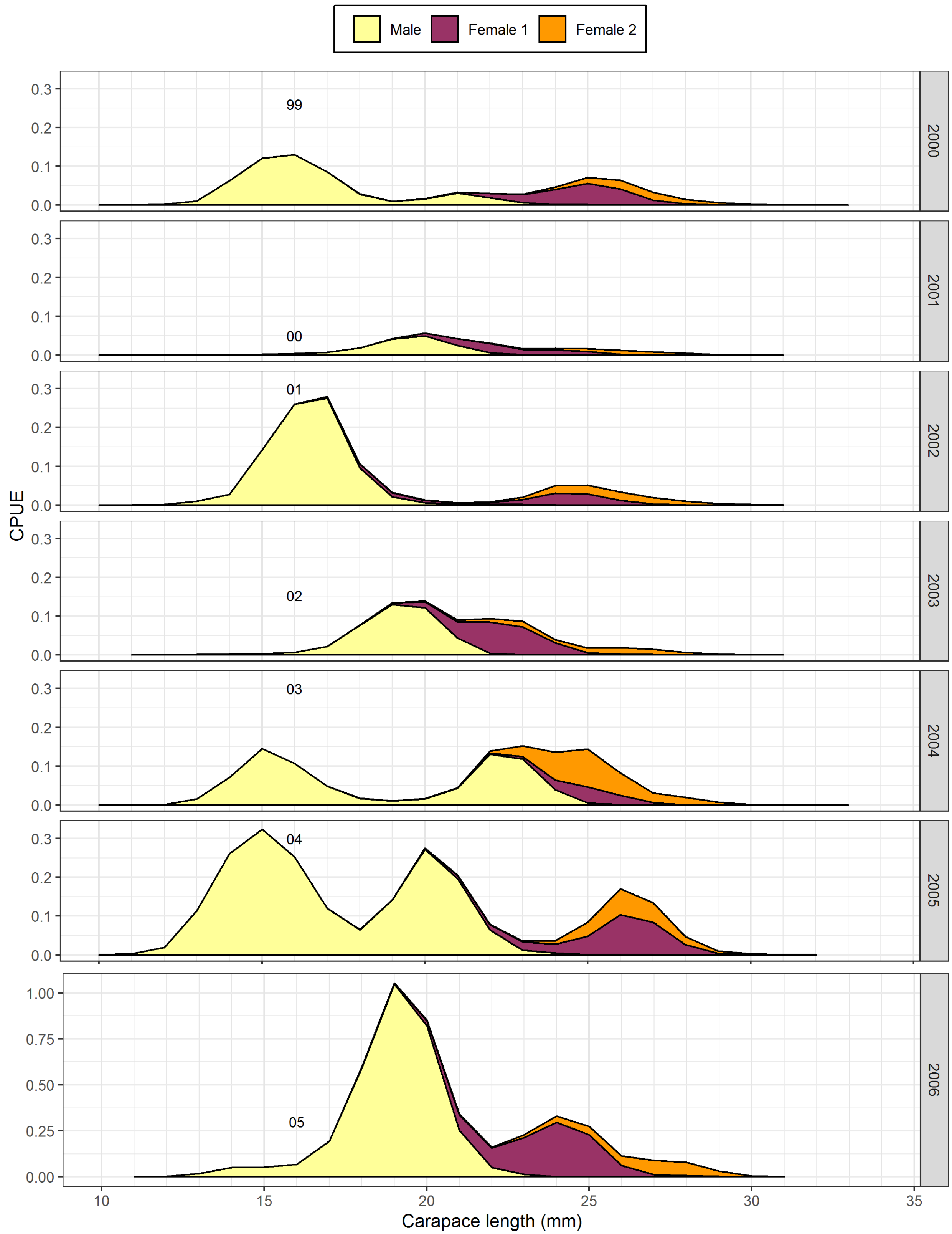


Figure 3 (continued) – Summer Survey. Note difference in y-axis scale for 2006.

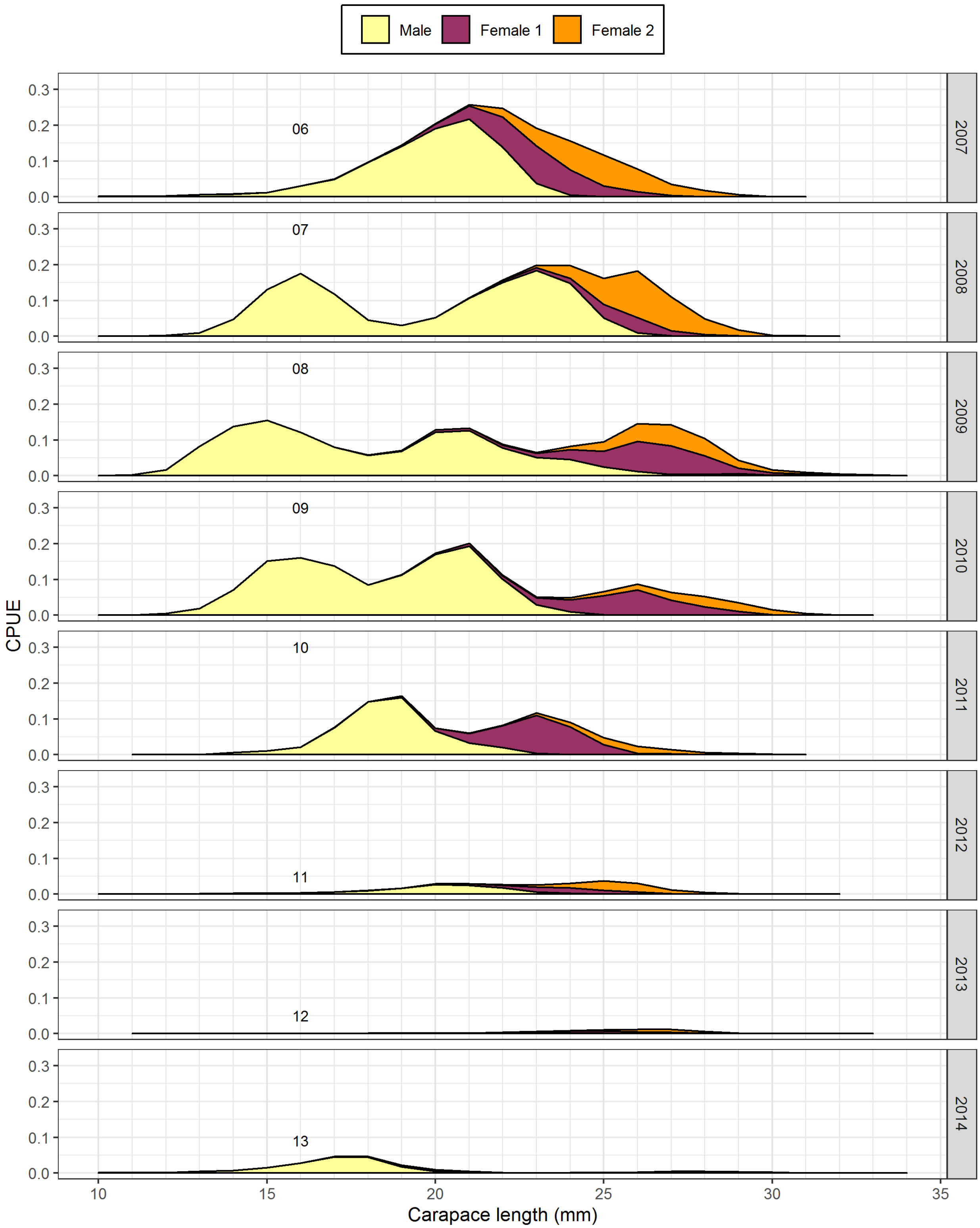


Figure 3 (continued) – Summer Survey.

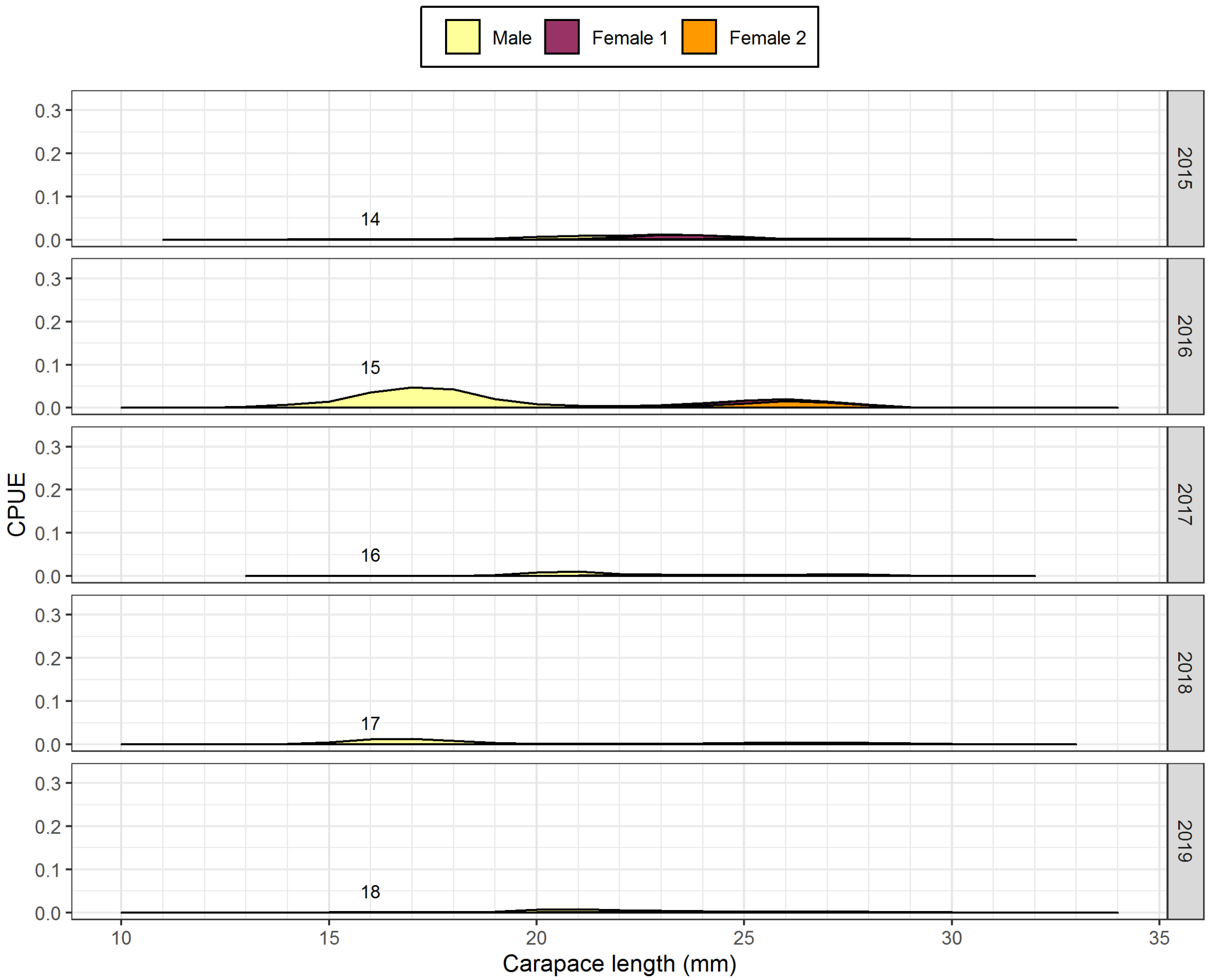


Figure 3 (continued) – Summer Survey.

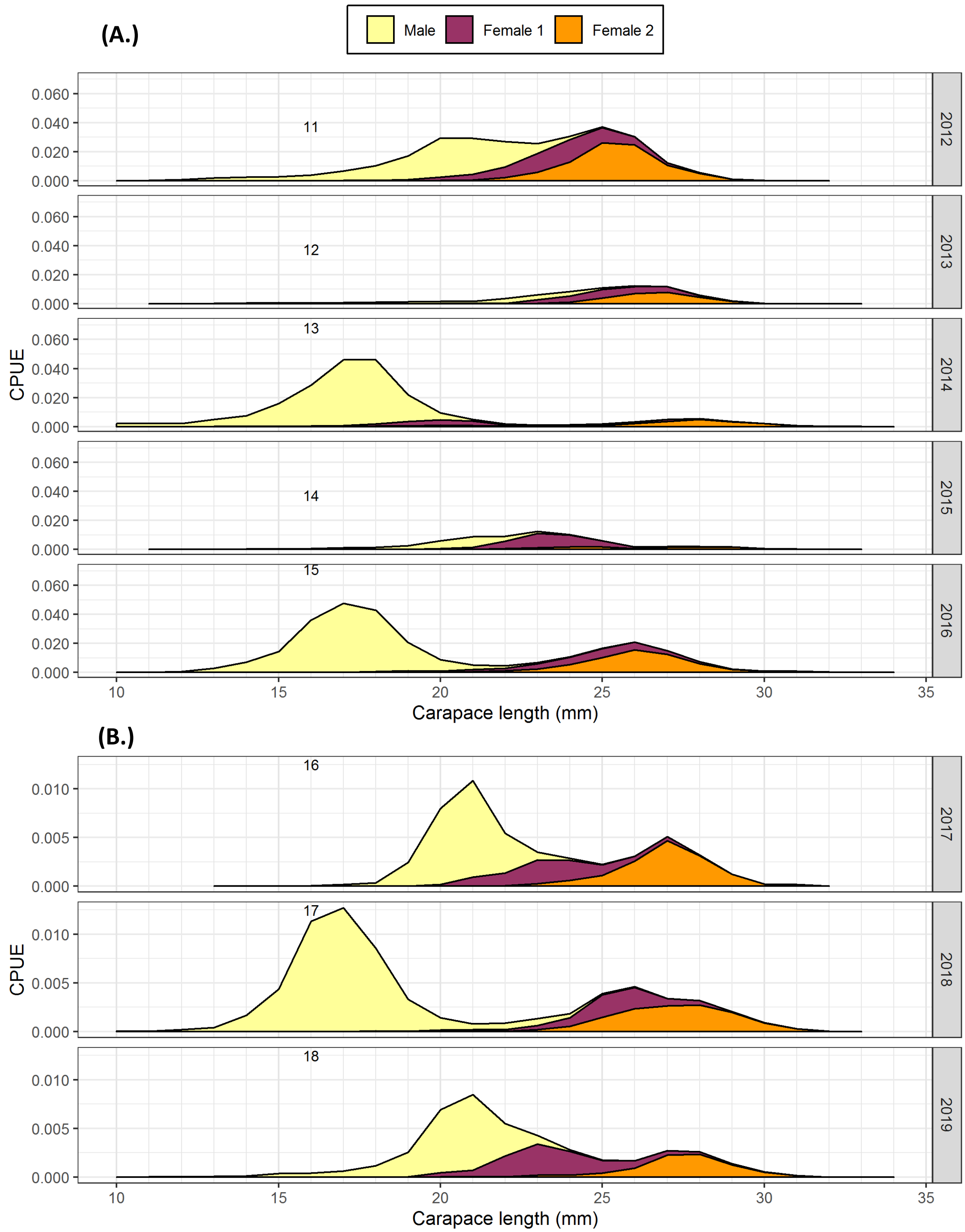


Figure 4. **Gulf of Maine northern shrimp Summer Survey abundance by year, length, and development stage for 2012 – 2016 (A) and 2017 – 2019 (B) with expanded axes to show detail. Two-digit years are year class at assumed age 1.5 Note difference in y-axis scale between (A) & (B).**

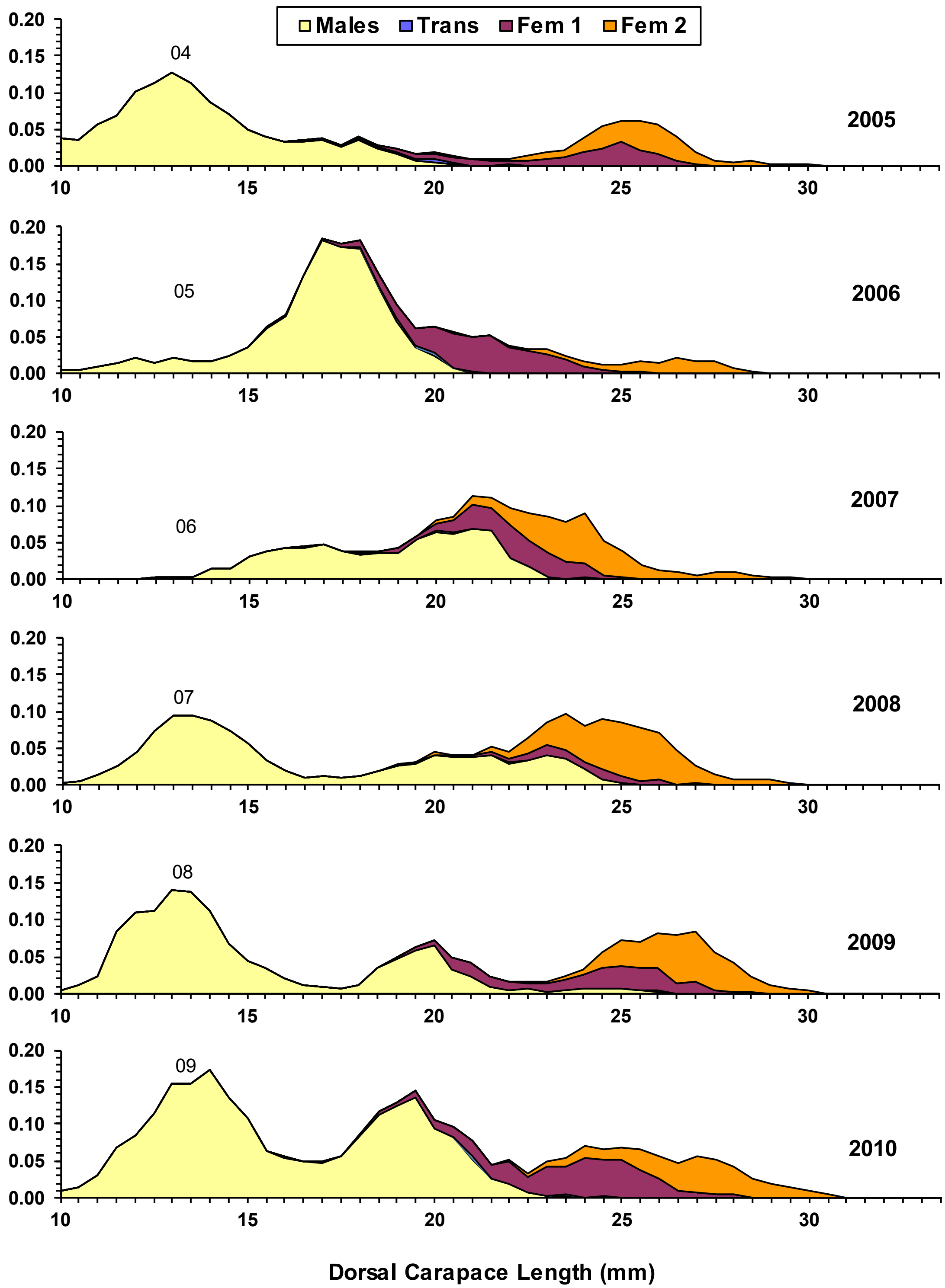


Figure 5. **Maine-New Hampshire spring inshore survey northern shrimp standardized abundance indices by year, length, and development stage. Two-digit years are the year class at assumed age 1.**

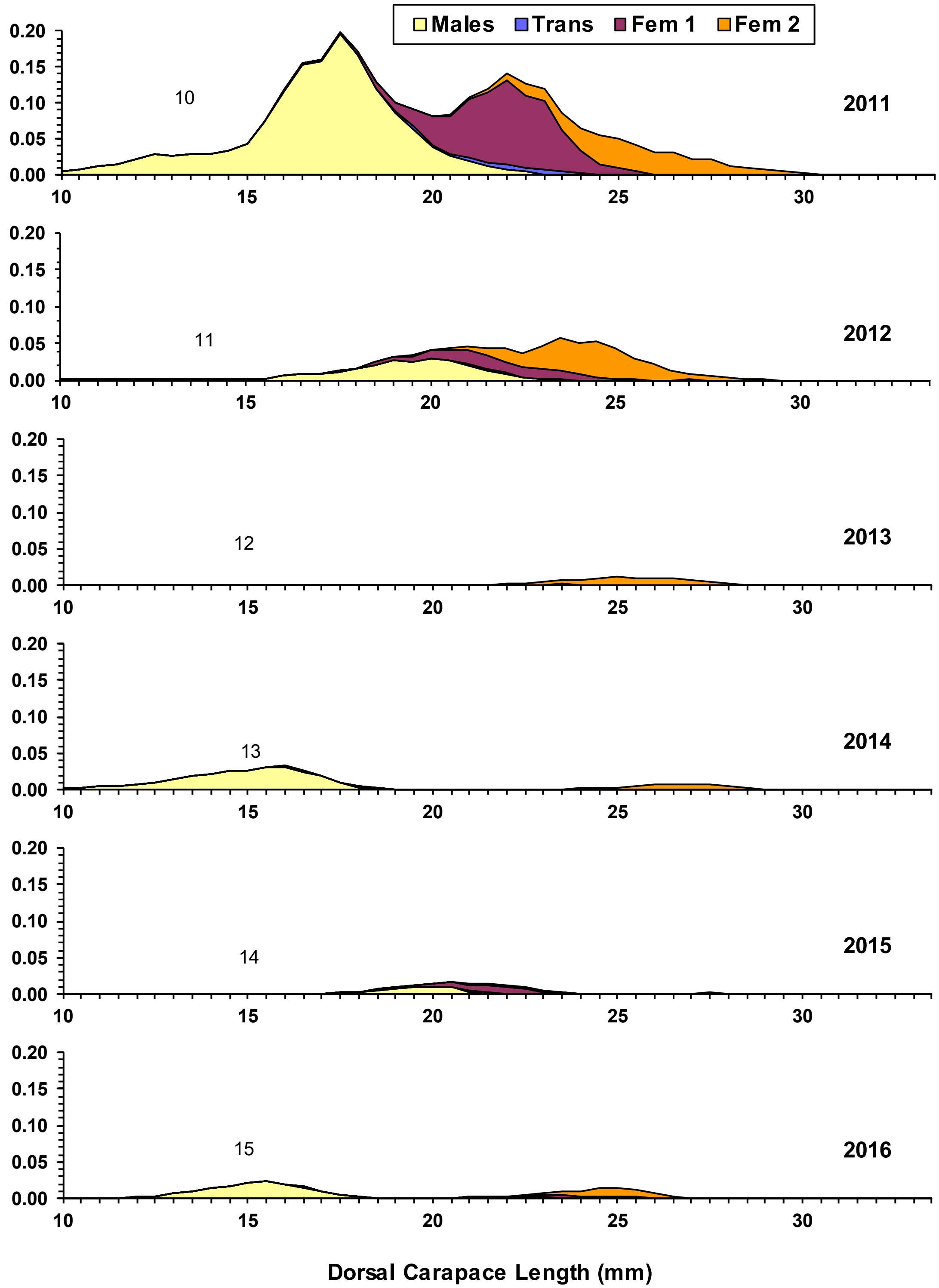


Figure 5 (continued) – Maine-New Hampshire spring inshore survey.

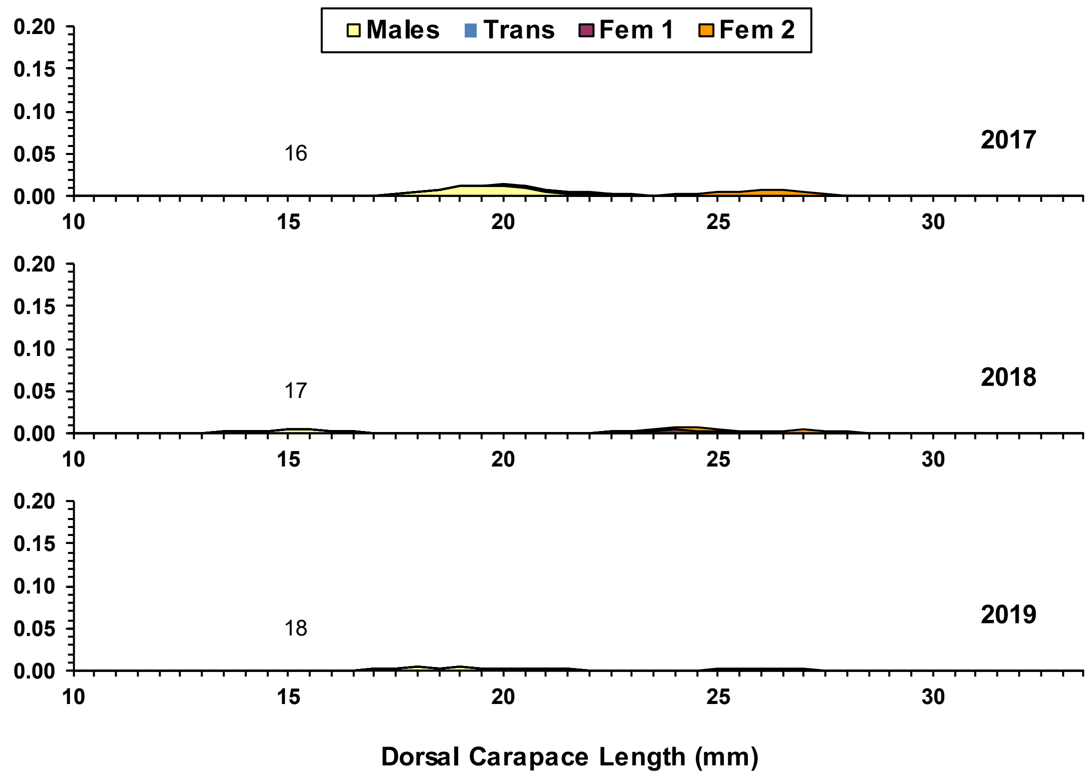


Figure 5 (continued) – Maine-New Hampshire spring inshore survey.

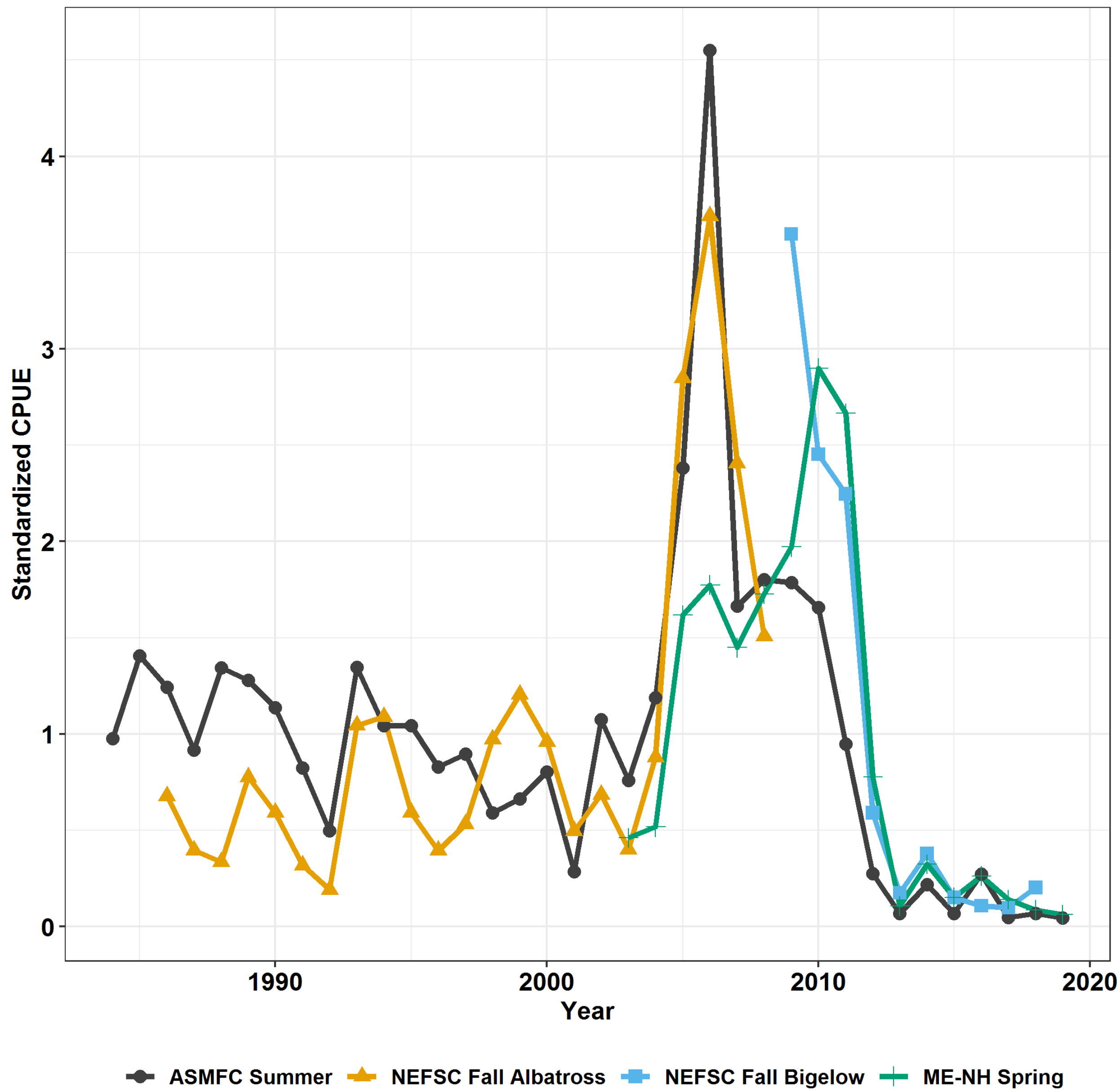
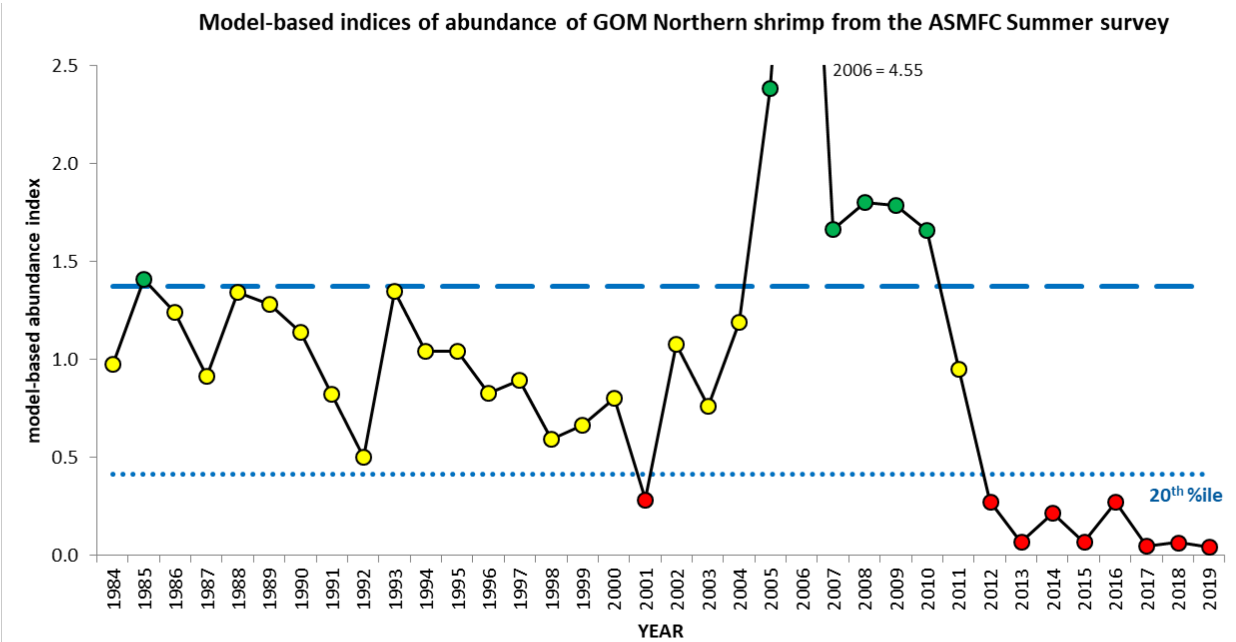


Figure 6. **Model-based indices of abundance from the Summer Survey, the NEFSC fall survey, and the ME-NH inshore spring survey plotted together.**



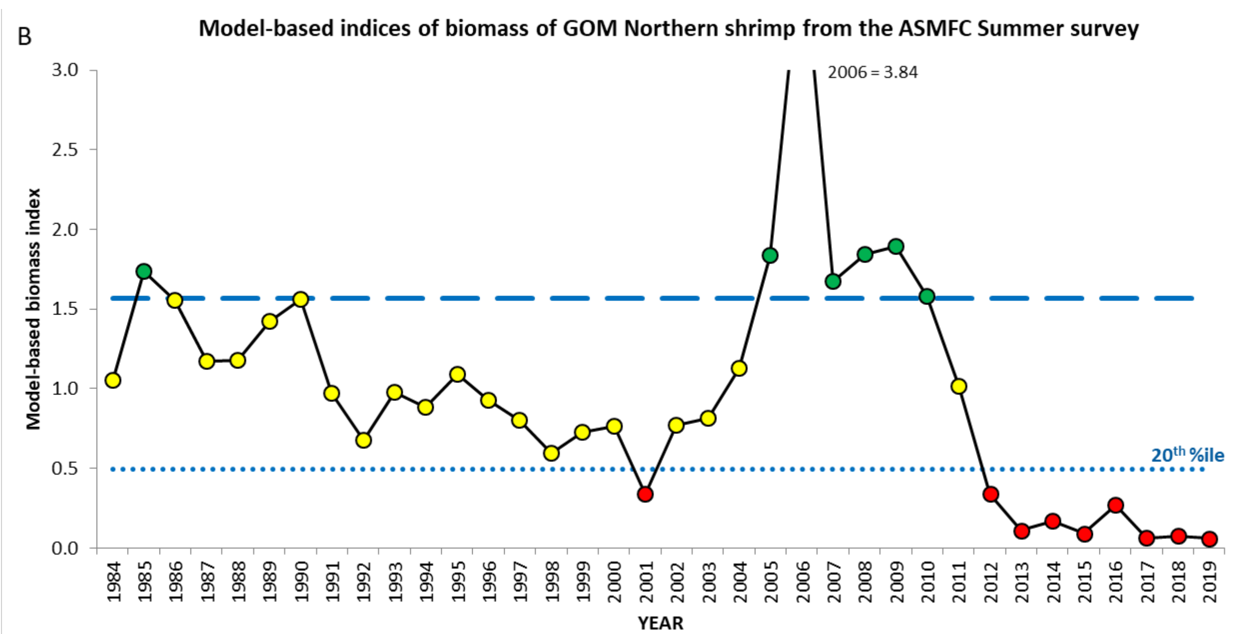
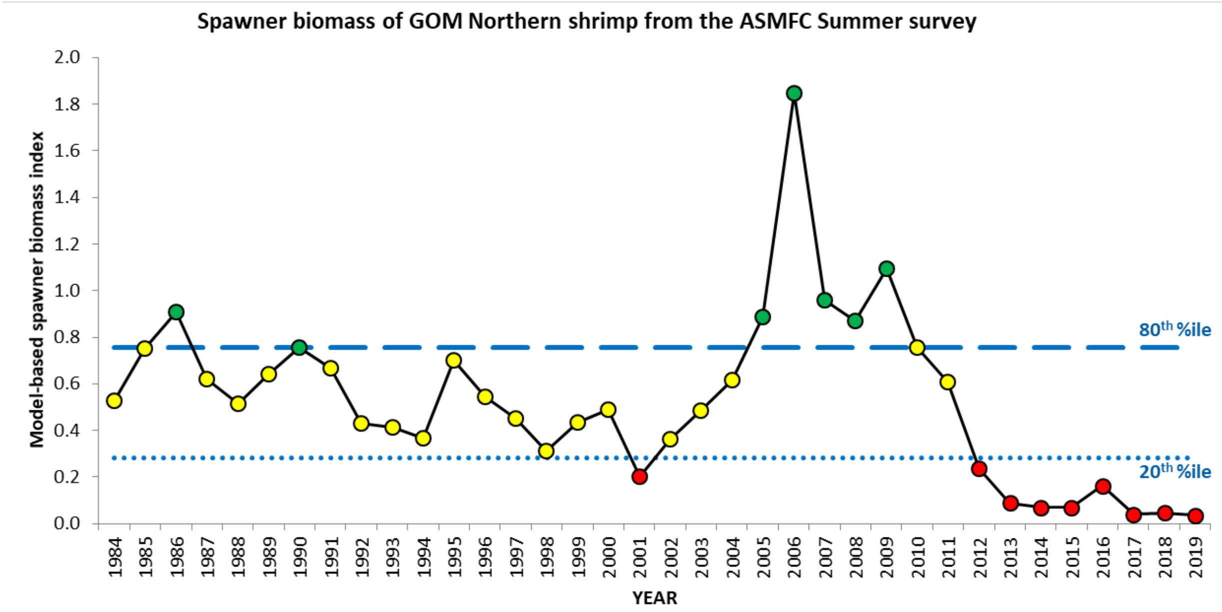


Figure 7. **Traffic light analysis for the model-based index of Gulf of Maine northern shrimp from the Summer Shrimp Survey 1984-2019 for total abundance (top) and total biomass (bottom). The 20th percentile of the time series from 1984-2017 delineated an adverse state, and the 80th percentile of the time series from 1984-2017 delineated a favorable state.**



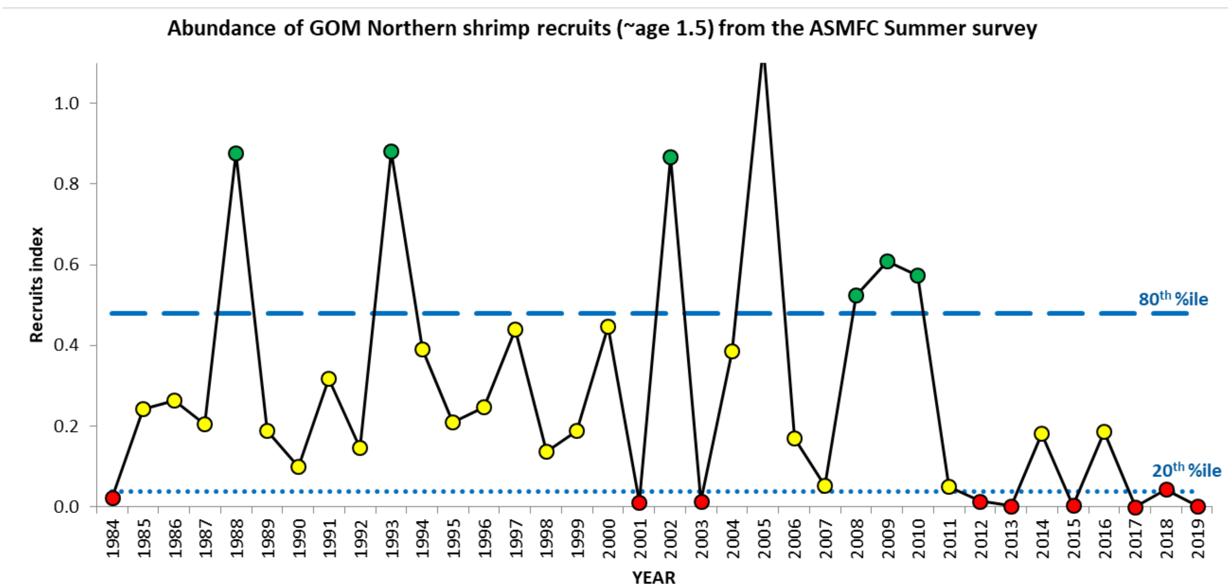
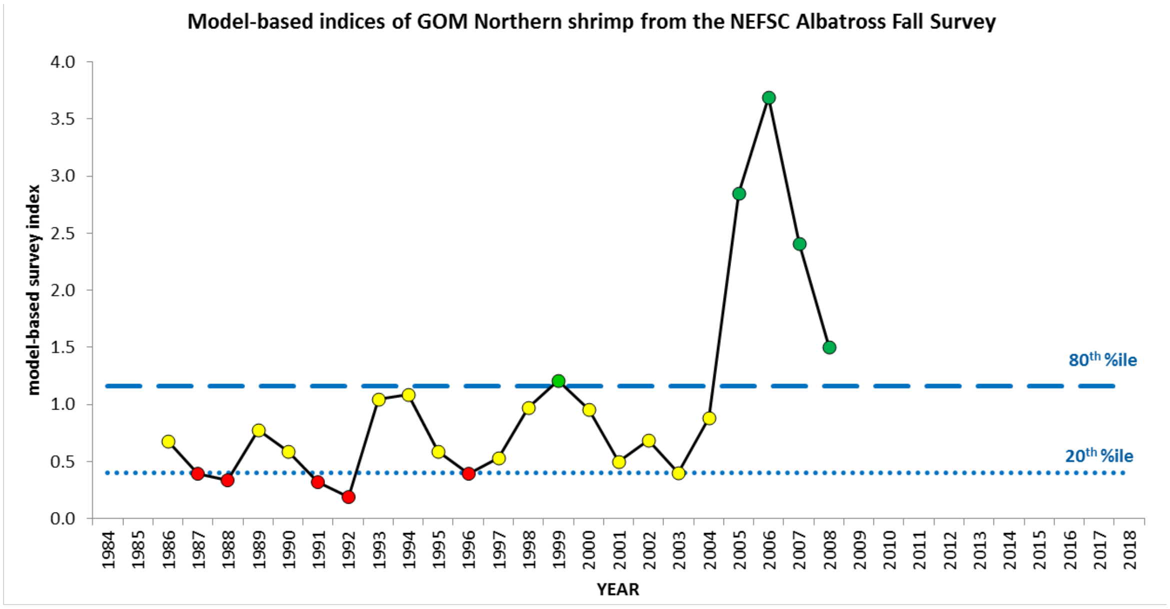


Figure 8. **Traffic light analysis of spawning biomass (top) and recruitment (bottom) of Gulf of Maine northern shrimp from the Summer Shrimp survey 1984-2019. The 20th percentile of the time series from 1984-2017 delineated an adverse state, and the 80th percentile of the time series from 1984-2017 delineated a favorable state.**



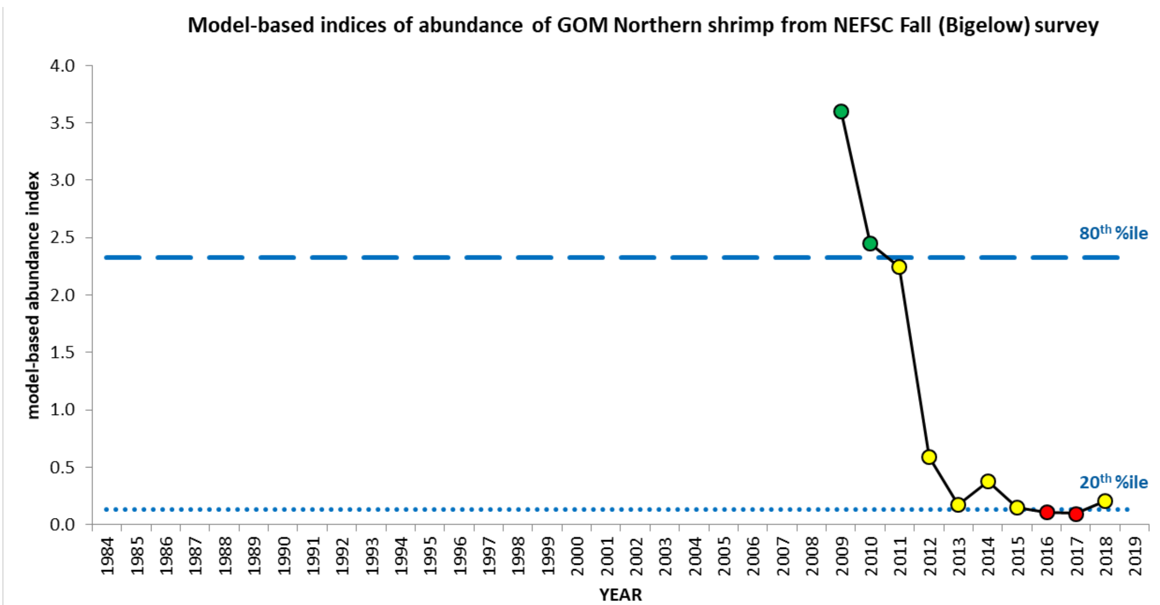


Figure 9. **Traffic light analysis of abundance of Gulf of Maine northern shrimp from the NEFSC Fall Survey for the Albatross (top) and Bigelow (bottom) years. The 20th percentile of the time series from 1984-2017 delineated an adverse state, and the 80th percentile of the time series from 1984-2017 delineated a favorable state.**

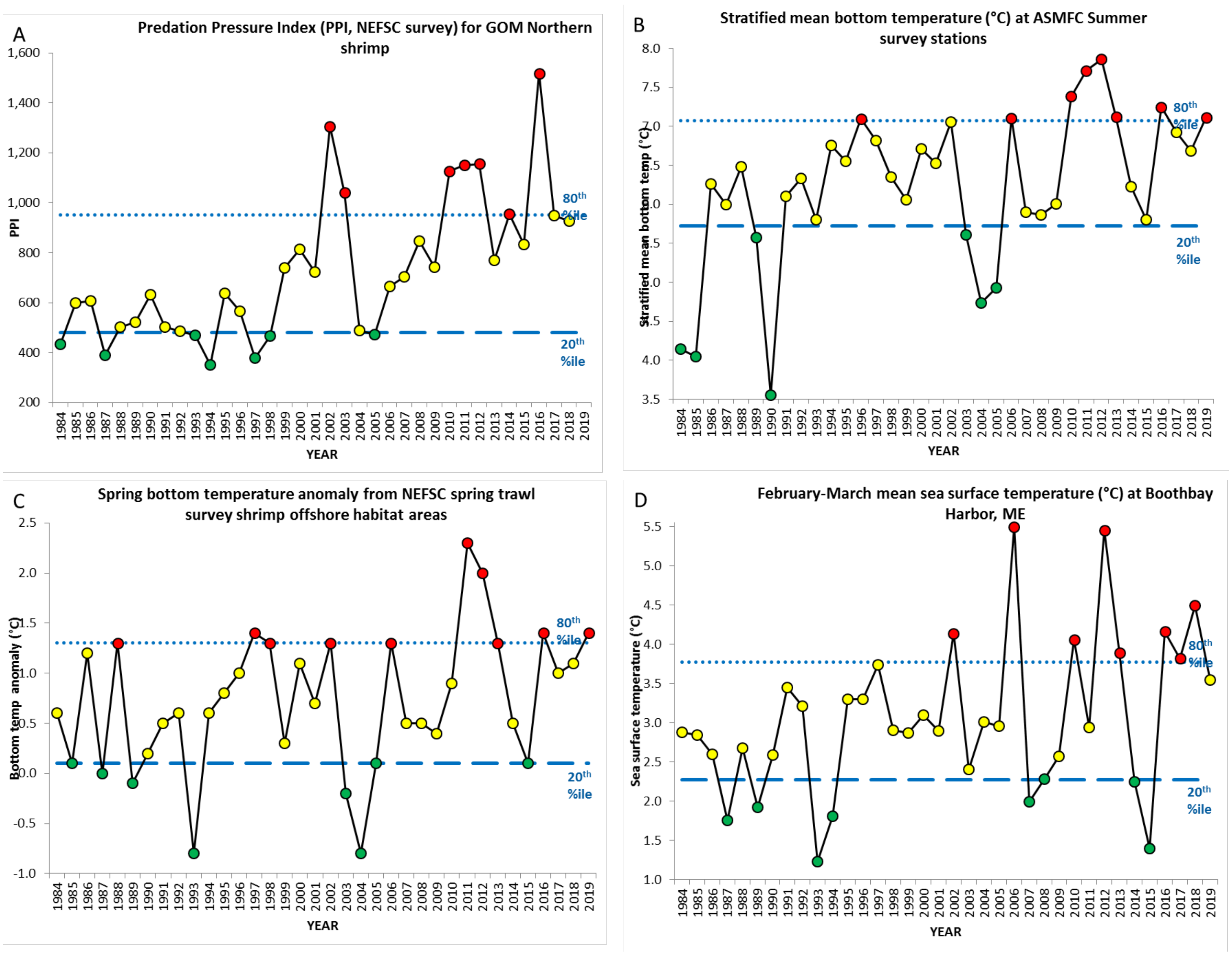


Figure 10. **Traffic light analysis of environmental conditions in the Gulf of Maine, including predation pressure (A), summer bottom temperature (B), spring bottom temperature (C), and winter sea surface temperature (D). The 20th percentile of the time series from 1984-2017 delineated a favorable state, and the 80th percentile of the time series from 1984-2017 delineated an adverse state.**