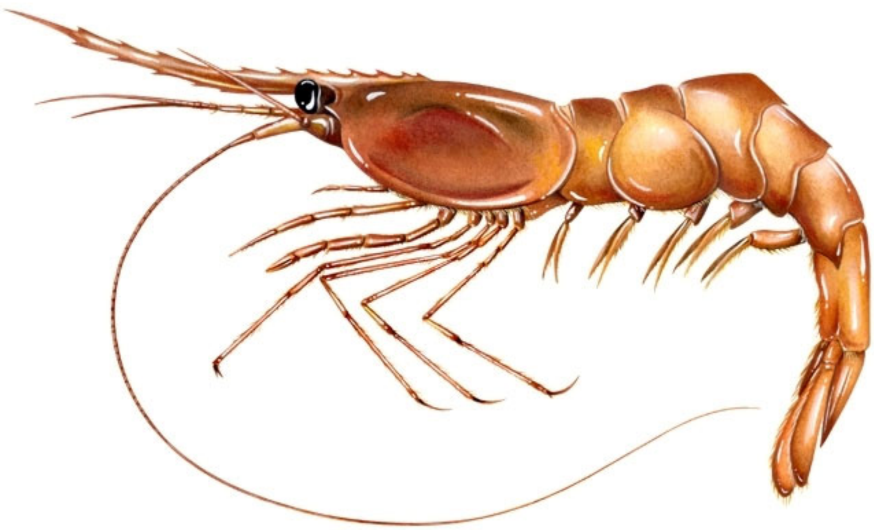
Atlantic States Marine Fisheries Commission

Northern Shrimp Stock Assessment Update 2021



Sustainable and Cooperative Management of Atlantic Coastal Fisheries

Atlantic States Marine Fisheries Commission

Northern Shrimp Stock Assessment Update

Prepared by the
ASMFC Northern Shrimp Technical Committee

Margaret Hunter, Chair, Maine Department of Marine Resources
Robert Atwood, New Hampshire Fish and Game Department
Alicia Miller, National Marine Fisheries Service, Northeast Fisheries Science Center
Steve Wilcox, Massachusetts Division of Marine Fisheries
and
Katie Drew, Atlantic States Marine Fisheries Commission
Dustin Colson Leaning, Atlantic States Marine Fisheries Commission

A publication of the Atlantic States Marine Fisheries Commission pursuant to National Oceanic and Atmospheric Administration Award No. NA20NMF4740012.

Executive Summary
The most recent benchmark assessment for Gulf of Maine northern shrimp (*Pandalus borealis)* was conducted in 2018 (ASMFC 2018a). An assessment update was completed later in 2018 (ASMFC 2018b), and a data update report was made in 2019. This stock assessment update presents new data compiled since 2018, and results from the accepted statistical catch-at-length model and traffic light analyses. Data sources include industry research catch data, indices of abundance and biomass from fishery-independent data sources, and environmental data, through 2021, with some exceptions: no surveys that provide data for this assessment (the spring inshore survey, the summer survey, and the fall offshore survey) were conducted in 2020, and fall survey data for 2021 are not available yet.

Stock status for northern shrimp continues to be poor, as illustrated by both the traffic light analyses and the catch-at-length model. The 2021 summer survey indices of abundance, biomass, and recruitment were at time-series lows, and spawning stock biomass was the second-lowest in the 1984-2021 time series. The predation pressure index declined recently from a time-series high in 2016, but has been above the time-series median in every year since 2006. Other environmental conditions continue to be unfavorable.

A commercial fishing moratorium has been in place since 2014, and fishing mortality since then, attributed to several small industry sampling and research projects, has been extremely low. Spawning stock biomass in 2021 was estimated to be 887 mt, higher than in 2018, but well below the time series median of 4,037 mt. Recruitment also remained low for 2019-2021, a continuation of the series of below-average year classes for the last ten years.

Model bias, illustrated by retrospective patterns, was small. After 2015, SSB was overestimated in some years and the exploitation rate was underestimated. Recruitment was consistently overestimated in the terminal year.

Long- and short-term stock projection results varied depending on assumptions about future natural mortality and recruitment levels, as well as fishing mortality. Under the recent unfavorable levels of natural mortality and recruitment, spawning stock biomass was projected to decline from 2021 levels to about 444 mt in 2026, and there was less than a 1% chance that it would be greater in 2026 than in 2021, even under the scenario of zero fishing mortality. In long-term projections, it would stabilize at about 418 mt under that scenario. If fishing mortality were maintained at 0.05 (landings of about 21 mt in 2022) in a trap-only fishery, with recent levels of natural mortality and recruitment, spawning stock biomass would decline to about 423 mt in 2026 and landings would have to decline to about 12 mt in 2026 to maintain a constant fishing mortality rate.

Given the continued poor condition of the resource, the extremely low likelihood of being able to fish sustainably, and the value of maximizing spawning potential to rebuild the stock if environmental conditions improve, the Northern Shrimp Technical Committee (NSTC) does not see any biological justification for harvest and recommends that the Section extend the

moratorium on all fishing. The NSTC based its recommendation on its assessment of current stock status, the biology of the species, and the stated management objectives to protect and maintain the northern shrimp stock at sustainable levels that will support a viable fishery, and minimize the adverse impacts the shrimp fishery may have on other natural resources (Amendment 3 to the FMP, ASMFC 2017).

Table of Contents

TOR 1. Update fishery-dependent data (landings, discards, catch-at-age, etc.) that were used in the previous peer-reviewed and accepted benchmark stock assessment.

The time series for commercial and research removals was extended from the previous assessment update (ASMFC 2018b) through 2021. Fisheries for northern shrimp occur in Maine, New Hampshire and Massachusetts, with landings from Maine dominating the modern era (1960-present, Table 1 and Table 4, Figure 1). Fishery-dependent data were derived from a combination of dealer reports, harvester reports, port sampling, sea sampling, and licensing data. Landings were equated with removals because discarding is uncommon in this fishery.

A commercial fishery moratorium has been in place since 2014. Landings since then have been limited to industry research trips for sample collection. Removals since 2014 have included discards. No industry research trips were made in 2019. An industry trapping project was conducted in Maine in 2020 (Hunter 2021).

TOR 2. Update fishery-independent data (abundance indices, age-length data, etc.) that were used in the previous peer-reviewed and accepted benchmark stock assessment.

The time series for fishery-independent data were extended from the previous assessment update (ASMFC 2018b) through 2021, with some exceptions noted below.

Fishery-independent data include abundance and biomass indices from the ASMFC summer shrimp offshore trawl survey (1984–2021), the Northeast Fisheries Science Center (NEFSC) fall bottom trawl survey (1986–2008 and 2009–2019), and the Maine-New Hampshire spring inshore trawl survey (2003–2021) (Table 2, Figure 2 and Figure 3). Length and sex-stage compositions were also developed from the summer and fall surveys. All surveys used a random stratified design. Model-based indices of abundance were developed using a spatio-temporal standardization approach and calculated using the VAST package in R. (standardization results, and diagnostics are shown Appendix 1). None of these surveys were conducted during 2020 due to COVID-19 restrictions, and data from the NEFSC fall 2021 survey are not yet available.

A recruitment index was calculated from the summer survey standardized catch of assumed 1.5-year-old shrimp which are typically 11–18 mm dorsal carapace length (Figure 5). An index of spawning stock biomass (SSB) was estimated by applying a length-weight relationship for non-ovigerous shrimp to the abundance of females at each length, and summing over lengths. The observed proportion female-at-length from the summer survey is used to calculate SSB in the UME model. As a proxy for the missing 2020 value, the proportion female-at-length from 2018 was used because a visual comparison of the 2017 and 2019 sex-at-length data (Figure 5) suggested the population in 2018 had similar size and sex compositions to those expected in 2020.

The NEFSC fall survey vessel and gear were replaced in 2009, and this is considered the beginning of a new survey time series for shrimp; the NEFSC trawl survey is split into an Albatross index (1986-2008) and a Bigelow index (2009-2019).

In 2017 the ASMFC summer shrimp survey adopted new trawl gear, switching from Portuguese doors to lighter-weight Bison doors. Using data from alternating gear research tows, Miller and Chase (2021, Appendix 2) found little evidence for unequal efficiencies of the two gears for shrimp. Therefore, no calibration of the summer survey data to account for the gear change was performed.

Other fishery-independent data include time series of February–March sea surface temperatures (SST) at Boothbay Harbor, Maine, spring bottom temperature anomalies from NEFSC spring bottom trawl survey strata in offshore shrimp habitat areas (also without 2020), and summer bottom temperature measured by the ASMFC summer shrimp survey.

An index of predation pressure (PPI) was developed from NEFSC survey data by weighting predator biomass indices by the long-term average percent frequency of shrimp in each predator's diet estimated from food habits sampling (Appendix 3). The three-year average of 2017-2019 PPIs was used for the missing 2020 and 2021 values in the UME model. A version of the PPI with an index of longfin squid included was used as a sensitivity run (Figure 4); the alternate index was generally similar to the base model PPI, but had a higher peak in 2011-2014, when longfin squid predation may have contributed to the northern shrimp stock collapse (Richards and Hunter, 2021).

TOR 3. Tabulate or list the life history information used in the assessment and/or model parameterization (M, age plus group, start year, maturity, sex ratio, etc.) and note any differences (e.g., new selectivity block, revised M value) from benchmark.

The University of Maine statistical catch-at-length model (UME model) used the same parameterization as the 2018 benchmark assessment (ASMFC 2018a), including time-varying M and maturity at length. Model structure is summarized in Table 3; see Appendix 3 for annual M-at-length and proportion female-at-length plots.

TOR 4. Update accepted model(s) or trend analyses and estimate uncertainty. Include sensitivity runs and retrospective analysis if possible and compare with the benchmark assessment results.

For this assessment, the Northern Shrimp Technical Committee (NSTC) updated the Traffic Light Analysis (TLA) and the UME model for northern shrimp.

Traffic Light Approach

The TLA is an index-based approach to evaluate stock status and resource conditions and was applied to indices of abundance, fishery performance, and environmental trends from 1984 to present. 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 indicated a favorable state. For the environmental indicators, the opposite was true: being below the 20th percentile indicated a favorable state while being above the 80th percentile indicated an adverse state, as higher temperature and predation pressure have negative consequences for northern shrimp.

The traffic light analysis was updated with the 2019 and 2021 ASMFC summer survey data, the 2018 and 2019 NEFSC fall survey data, and the 2019 and 2021 ME-NH spring inshore data, as well as with 2019–2021 data for temperature indicators and the 2018–2019 data for the predation index. The 2021 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 extend through 2019. In addition, fishery-independent surveys were not conducted in 2020 due to COVID-19 restrictions.

The traffic light analysis of 2021 data indicated continued decline in stock status with all indices below the 20^{th} percentile. The indices of abundance, biomass, and recruitment from the summer survey were at new time-series lows, and spawning stock biomass was the second-lowest in the time series (Table 5, Figure 6 and Figure 7). The NEFSC Bigelow fall survey abundance was below the 20^{th} percentile in its terminal year of 2019 and the second lowest in its time series as well (Table 5, Figure 8). The predation pressure index declined from a time-series high in 2016 to slightly above the time series median in 2019, the last year of available data (Table 6, Figure 9). All other environmental conditions remain unfavorable, with temperatures above the 80^{th} percentile (Table 6, Figure 9).

UME Statistical Catch-at-Length Model

The UME model indicated total abundance and spawning stock biomass for northern shrimp remained at low levels for 2019-2021 (Table 7 and Figure 10). SSB did trend up slightly from 2018 to 2021 as *F* remained low and the 2017 year class matured. The 2017 year class was stronger than other recent year classes and just above the 20^{th} percentile threshold as age 1.5 recruits in the 2018 summer survey (Figure 7 and Figure 12). SSB in 2021 was estimated to be 887 mt, higher than in 2018, but well below the time series median of 4,037 mt and the 1984-2017 20^{th} percentile of 2,140 mt.

An average fishing mortality (*F*) for the time series (i.e., abundance-weighted average F on shrimp ≥22 mm carapace length) was calculated to account for differences in selectivity patterns across years and between fleets. Average fishing mortality has been extremely low since the implementation of the moratorium in 2014 (Table 7 and Figure 11). The average *F* peaked shortly before that in 2011 and 2012. Fishing mortality was extremely low in 2020 (F=0.002) and zero in 2019 and 2021.

Recruitment also remained low from 2019-2021 (Table 7, Figure 12), a continuation of the series of below average year classes in recent years. Eight of the last ten years of recruitment have been less than the 20^{th} percentile of the 1984-2017 estimates (equal to 2.0 billion shrimp). Recruitment in 2021 was estimated to be 0.67 billion shrimp; recruitment in 2020 was estimated to be stronger at 1.2 billion shrimp, but 2019 was the lowest recruitment in the time series at 0.49 billion shrimp. Variability in recruitment has increased since 2000, with higher highs and lower lows in recruitment deviations than 1984-1999 (Figure 12).

The retrospective pattern in the assessment was small, with SSB being slightly underestimated and exploitation rate being slightly overestimated for most of the time series; however, the pattern changed around 2015, with SSB being overestimated in some years and exploitation rate being underestimated (Figure 13). The retrospective pattern in recruitment was more variable over the time series, but was consistently overestimated in the terminal year (Figure 13). Overall, the magnitude of the bias remained small.

Consistent with the retrospective pattern, estimates of average *F* from the 2021 assessment were slightly lower than estimates from the 2018 assessment for the earliest part of the time series, and estimates of SSB from the 2021 assessment were slightly higher. However, in recent years, estimates of *F*, SSB, and recruitment were very similar between the two assessments (Figure 14).

A sensitivity run with the PPI that included longfin squid showed very similar results to the base model, with the squid PPI run resulting in a slightly lower SSB and higher *F* over the time series, with very little effect of the increased peak in M from 2011-2014 (Figure 15).

Long-term projections were carried out under different assumptions about M and recruitment. The population was projected forward for 50 years with no fishing mortality under different combinations of recent recruitment (the median of recruitment estimates from 2011-2021), long term median recruitment, recent natural mortality (the mean of natural mortality from 2015-2019), and long term mean natural mortality (Figure 16). Under recent M and recent recruitment, the population continued to decline from 2021 levels and stabilized at an SSB level of 418 mt (Figure 17). If recruitment returned to time-series median levels, but M remained at recent levels, SSB would stabilize just above the 2021 values, at approximately 983 mt. If natural mortality returned to time-series average levels, but recruitment remained low, the population would increase more, with SSB stabilizing around 1,456 mt (Figure 17). If both recruitment and natural mortality returned to their long-term values, the population would recover to close to the long-term median population size, at 3,358 mt (Figure 17).

TOR 5. Update the biological reference points or trend-based indicators/metrics for the stock. Determine stock status.

There are currently no biological reference points for northern shrimp. Based on the results of the 2021 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. SSB in 2021 was estimated at 887 mt, higher than in 2018, but well below the time series median of 4,037 mt and the 1984-2017 20^{th} percentile of 2,140 mt. In addition, recruitment continues to be low, with the 2016, 2018, and 2020 year classes being the lowest in the time series (Table 7). Fishing mortality has been very low in recent years due to the moratorium, but high levels of natural mortality and low recruitment have hindered rebuilding.

Given the continued poor condition of the resource, the extremely low likelihood of being able to fish sustainably, and the value of maximizing spawning potential to rebuild the stock if environmental conditions improve, the NSTC does not see any biological justification for harvest and recommends that the Section extend the moratorium on all fishing. The NSTC bases its recommendation on its assessment of current stock status, the biology of the species, and the stated management objectives to protect and maintain the northern shrimp stock at sustainable levels that will support a viable fishery, and minimize the adverse impacts the shrimp fishery may have on other natural resources (Amendment 3 to the FMP, ASMFC 2017).

TOR 6. Conduct short term projections when appropriate. Discuss assumptions if different from the benchmark and describe alternate runs.

Short-term projections were conducted using the same set of assumptions about M and recruitment that were used in the long-term projections (see TOR 4 above, and Figure 16), and 3 levels of *F*: *F*=0, *F*=the mean of the research period (2014-2018) for the trawl fishery with the trap fishery equal to 12% of the trawl fishery (the proportion from the last 3 years of the active fishery, 2011-2013), and *F*=the maximum of the research period (2014-2018) with only the trap fleet active.

Under recent levels of M and recruitment, median SSB was projected to decline from 2021 levels and there was less than a 1% chance that SSB in 2026 would be greater than SSB in 2021, even under the *F*=0 scenario (Table 8, Figure 18 and Figure 19). In this scenario, removals ranged from 4.8 mt to 21.2 mt, declining in each year of the projection as a constant *F* was applied to a decreasing population (Table 8). The probability of being above SSB_{2021} in 2026 increased in scenarios with lower M and higher recruitment levels.

TOR 7. Comment on research recommendations from the benchmark stock assessment and note which have been addressed or initiated. Indicate which improvements should be made before the stock undergoes a benchmark assessment.

A number of research recommendations were identified from the benchmark stock assessment in 2018. Some of the highest priority focused on efforts to improve the sampling, modeling, and biological understanding of the northern shrimp species. Due to the continued moratorium of the fishery and the COVID-19 pandemic, many of these recommendations, particularly the fishery-dependent priorities, were not addressed.

Fishery-dependent priorities included an evaluation of shrimp selectivity from the two gear types (traps and trawls), continued port, sea, and RSA sampling to confirm and potentially update length-frequency of the species, and identify by-catch in the fishery. In order to continue sample collection during the fishing moratorium, winter sampling efforts were conducted through an RSA program, however this ended in 2018. Should a fishery reopen, these recommendations could be considered.

It was recommended under fisheries-independent research priorities that the ASMFC summer survey continue sampling. Due to the COVID-19 pandemic, this survey was cancelled in 2020, but resumed in 2021. The suggestion for re-stratification of the survey due to changes in shrimp distribution may be less relevant given that Richards and Hunter (2021) showed no significant shift in distribution from historical habitat areas, however a significant overall contraction in the population was evident. An analysis by Miller and Chase (2021, Appendix 2) found little evidence that replacing the trawl doors in 2017 caused a change in trawling efficiency for shrimp. The potential for using acoustic survey methods for shrimp was explored by the Gulf of

Maine Research Institute (Sherwood and Whitman, 2020) working with the Maine DMR (Hunter 2021).

Many life-history related recommendations were made during the benchmark including a re-evaluation of size-based relationships for maturity and fecundity, an investigation of newly developed direct ageing methods, and understanding oceanic and climate variation on survival, growth, and the stock-recruitment relationship. Chang and Chen (2020) addressed sampling strategies for fecundity estimation using samples from the NEFSC fall bottom trawl surveys and Chang et. al (2021) carried out a fecundity study that included temperature effects and maternal size. Chang (2021) also summarized how changes in the GOM may be linked to habitat suitability for northern shrimp. These studies combined can help our understanding of environmental effects on distribution and reproduction potential, a good start in addressing some of these life-history research recommendations.

The TC supports the modeling research recommendations from the benchmark assessment, and has adopted the recommendation to include model diagnostics for the index standardization as an appendix to this report. No progress has been made on other model recommendations to date.

References

Atlantic States Marine Fisheries Commission. 2017. Amendment 3 to the interstate fishery management plan for northern shrimp. 102pp. https://www.asmfc.org/uploads/file/59f0f084NShrimpAmendment3_Oct2017.pdf

Atlantic States Marine Fisheries Commission. 2018a. Northern Shrimp Benchmark Stock Assessment and Peer Review Report. 356pp. https://www.asmfc.org/uploads/file/5bc798aaNShrimpBenchmarkAssessment_PeerReviewReport_2018_web.pdf

Atlantic States Marine Fisheries Commission. 2018b. Assessment report for Gulf of Maine northern shrimp – 2018. 78 pp. https://www.asmfc.org/uploads/file/5c000eb2NShrimpAssessmentUpdateReport_2018.pdf

Chang, H.-Y., "The impacts of climate change on the Gulf of Maine northern shrimp (*Pandalus borealis*) distribution, reproduction, and life" 2021. University of Maine. *Electronic Theses and Dissertations*. 3411. https://digitalcommons.library.umaine.edu/etd/3411

Chang, H.-Y. and Chen, Y. 2020. Evaluating sampling strategies for collecting size-based fish fecundity data: an example of Gulf of Maine northern shrimp (*Pandalus borealis*). *J. Northw. Atl. Fish. Sci.* 51**:** 33–43. https://doi.org/10.2960/J.v51.m730

Chang, H.-Y., Richards, R.A., and Chen, Y. 2021. Effects of environmental factors on reproductive potential of the Gulf of Maine northern shrimp (*Pandalus borealis)*. *Glob. Ecol. Conserv.*30**:** e01774. https://doi.org/10.1016/j.gecco.2021.e01774

Hunter, M. 2021. 2020 winter acoustic survey and trapping for Gulf of Maine northern shrimp. Maine Department of Marine Resources. https://www.maine.gov/dmr/science-research/species/shrimp/

Sherwood, G., and A. Whitman. 2020. Acoustic survey of northern shrimp (*Pandalus borealis*) distribution/abundance in relation to trap catches in midcoast Maine. Gulf of Maine Research Institute report to the Maine Department of Marine Resources. 15 pp. https://www.maine.gov/dmr/science-research/species/shrimp/documents/GMRI2020acoustics.pdf

Richards, R. A. and M. Hunter. 2021. Northern shrimp *Pandalus borealis* population collapse linked to climate-driven shifts in predator distribution. PLoS ONE 16(7): e0253914. https://doi.org/10.1371/journal.pone.0253914

List of Appendices

Tables

Table 1. Total removals in metric tons by season, state, and gear type. Seasons include the previous December. The Maine fishery was "Mixed" until Trawl and Trap landings could be distinguished beginning in 2000. Removals in 2014–2020 are from RSA and winter sampling programs, and include discards. 2009 data for Massachusetts and New Hampshire are combined here to preserve reporting confidentiality.

Season	Maine Trawl	Maine Mixed	Maine Trap	Massachusetts Trawl	New Hampshire Trawl	Total Trawl	Total Mixed	Total Trap	Total
1985		2,946.4		968.8	216.7	1,185.5	2,946.4	0.0	**4,131.9**
1986		3,268.2		1,136.3	230.5	1,366.8	3,268.2	0.0	**4,635.0**
1987		3,680.2		1,427.9	157.9	1,585.8	3,680.2	0.0	**5,266.0**
1988		2,258.4		619.6	157.6	777.2	2,258.4	0.0	**3,035.6**
1989		2,384.0		699.9	231.5	931.4	2,384.0	0.0	**3,315.4**
1990		3,236.3		974.9	451.3	1,426.2	3,236.3	0.0	**4,662.5**
1991		2,488.6		814.6	282.1	1,096.7	2,488.6	0.0	**3,585.3**
1992		3,070.6		289.3	100.1	389.4	3,070.6	0.0	**3,460.0**
1993		1,492.5		292.8	357.6	650.4	1,492.5	0.0	**2,142.9**
1994		2,239.7		247.5	428.0	675.5	2,239.7	0.0	**2,915.2**
1995		5,013.7		670.1	772.8	1,442.9	5,013.7	0.0	**6,456.6**
1996		8,107.1		660.6	771.7	1,432.3	8,107.1	0.0	**9,539.4**
1997		6,086.9		366.4	666.2	1,032.6	6,086.9	0.0	**7,119.5**
1998		3,481.3		240.3	445.2	685.5	3,481.3	0.0	**4,166.8**
1999		1,573.2		75.7	217.0	292.7	1,573.2	0.0	**1,865.9**
2000	2,249.5		266.7	124.1	214.7	2,588.3	0.0	266.7	**2,855.0**
2001	954.0		121.2	49.4	206.4	1,209.8	0.0	121.2	**1,331.0**
2002	340.8		50.8	8.1	53.0	401.8	0.0	50.8	**452.7**
2003	987.0		216.7	27.7	113.0	1,127.7	0.0	216.7	**1,344.4**
2004	1,858.7		68.1	21.3	183.2	2,063.2	0.0	68.1	**2,131.4**
2005	1,887.1		383.1	49.6	290.3	2,227.1	0.0	383.1	**2,610.1**
2006	1,928.0		273.6	30.0	91.1	2,049.1	0.0	273.6	**2,322.7**
2007	3,986.9		482.4	27.5	382.9	4,397.3	0.0	482.4	**4,879.7**
2008	3,725.0		790.7	29.9	416.8	4,171.7	0.0	790.7	**4,962.4**
2009	1,936.3		379.4	MA & NH:	185.6	2,121.8	0.0	379.4	**2,501.2**
2010	4,517.9		1,203.5	35.1	506.8	5,059.9	0.0	1,203.5	**6,263.3**
2011	4,644.4		925.3	196.4	631.5	5,472.2	0.0	925.3	**6,397.5**
2012	2,026.8		193.1	77.8	187.8	2,292.4	0.0	193.1	**2,485.4**
2013	269.5		20.2	18.9	36.9	325.3	0.0	20.2	**345.5**
2014	0.3		0.0	0.0	0.0	0.3	0.0	0.0	**0.3**
2015	5.6		0.5	0.6	0.0	6.2	0.0	0.5	**6.7**
2016	7.4		4.1	0.0	1.8	9.2	0.0	4.1	**13.3**
2017	24.1		7.1	0.9	0.5	25.5	0.0	7.1	**32.6**
2018	0.1		0.0	1.9	1.1	3.1	0.0	0.0	**3.1**
2019	0.0		0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
2020	0.0		3.1	0.0	0.0	0.0	0.0	3.1	**3.1**
2021	0.0		0.0	0.0	0.0	0.0	0.0	0.0	**0.0**

Table 2. Summary of indices used in the northern shrimp assessment update.

	ASMFC Summer Survey	NEFSC Fall Survey (Albatross)	NEFSC Fall Survey (Bigelow)	ME-NH Inshore Trawl Survey
Index Metric	Number per tow	Number per tow	Number per tow	Number per tow
Design	Stratified Random	Stratified Random	Stratified Random	Stratified Random
Standardization	VAST	VAST	VAST	VAST
Time of Year	Jul-Aug	Sep-Nov	Sep-Nov	Apr-Jun
Years	1984-2021	1986-2008	2009-2019	2003-2021
Size caught	10+mm	10+mm	10+mm	10+mm
Missing data	2020	--	2020-2021	2020
Included in	UME, TLA	UME, TLA	UME, TLA	TLA

Table 3. Model structure and life history information used in the UME model.

Years in Model	1984-2021
Time step	Seasonal (Jan-Jun, Aug-Dec)
Size Classes	10-34mm (carapace length)
Fleets	3 (Mixed trap & trawl, trawl only, trap only)
Selectivity blocks	Mixed fleet: 1984-1999 Trawl fleet: 2000-2013, 2014-2021 Trap fleet: 2000-2013, 2014-2021
Natural mortality	Time- and length-varying
Proportion mature at length	Time-varying

Table 4. Fishery performance 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 the 80th percentiles; and GREEN = at or above the 80th percentile of the commercial fishery time series from 1984-2013. Values from 2014-2021 represent RSA/winter sampling. Slashes indicate no data.

Fishing Season	Number of trips	Commercial CPUE (mt/trip)	Price per lb landed (2018 dollars)	Total landings value (2018 dollars)
1984	6,912	0.43	///////////	///////////
1985	6,857	0.60	$1.05	$9,564,744
1986	7,902	0.59	$1.45	$14,816,717
1987	12,497	0.42	$2.50	$29,023,857
1988	9,240	0.33	$2.40	$16,061,646
1989	9,561	0.35	$2.04	$14,910,780
1990	9,758	0.48	$1.43	$14,699,046
1991	7,968	0.45	$1.71	$13,516,239
1992	7,798	0.44	$1.81	$13,806,670
1993	6,158	0.35	$1.89	$8,928,900
1994	5,990	0.49	$1.30	$8,354,991
1995	10,465	0.62	$1.51	$21,493,893
1996	11,791	0.81	$1.19	$25,026,625
1997	10,734	0.66	$1.25	$19,619,763
1998	6,606	0.63	$1.50	$13,779,332
1999	3,811	0.49	$1.40	$5,759,047
2000	4,554	0.63	$1.18	$7,427,163
2001	4,133	0.32	$1.24	$3,638,596
2002	1,304	0.35	$1.54	$1,536,852
2003	3,022	0.44	$1.21	$3,586,328
2004	2,681	0.79	$0.60	$2,819,337
2005	3,866	0.68	$0.75	$4,315,765
2006	2,478	0.94	$0.47	$2,406,687
2007	4,163	1.17	$0.47	$5,056,211
2008	5,587	0.89	$0.59	$6,454,695
2009	3,002	0.83	$0.48	$2,646,864
2010	5,979	1.03	$0.61	$8,423,072
2011	7,095	0.90	$0.86	$12,129,566
2012	3,648	0.68	$1.06	$5,808,201
2013	1,322	0.23	$1.98	$1,508,183
2014	5	-	No landings	No landings
2015	50	-	$3.77	$55,446
2016	68	-	$7.11	$208,767
2017	153	-	$6.55	$470,579
2018	18	-	Confidential	Confidential
2019	0	///////////	///////////	///////////
2020	160	-	No landings	No landings
2021	0	///////////	///////////	///////////
1984-2013 mean	**6,229**	**0.60**	**$1.29**	**$10,245,509**
2014-2021 mean	**76**	**NA**	**$5.81**	**$244,931**
80th percentile (1984-2013)	**9,304**	**0.81**	**$1.75**	**$14,854,342**
20th percentile (1984-2013)	**3,523**	**0.41**	**$0.69**	**$3,617,689**

Table 5. Fishery independent indicators (model-based survey indices) 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. Slashes indicate no data.

Survey	ASMFC Summer	NEFSC Fall Albatross	NEFSC Fall Bigelow	ME-NH Spring	ASMFC Summer			
Indicator	Total Abundance	Total Abundance	Total Abundance	Total Abundance	Total Biomass	Harvestable Biomass (>22 mm CL)	Spawner Biomass	Recruitment (age ~1.5)
1984	1.02	///////////	///////////	///////////	1.14	0.58	0.57	0.02
1985	1.48	///////////	///////////	///////////	1.74	1.50	0.76	0.25
1986	1.16	0.68	///////////	///////////	1.51	1.18	0.88	0.24
1987	0.92	0.40	///////////	///////////	1.18	0.94	0.63	0.21
1988	1.39	0.34	///////////	///////////	1.27	0.75	0.56	0.91
1989	1.31	0.78	///////////	///////////	1.46	0.85	0.66	0.19
1990	1.21	0.59	///////////	///////////	1.65	1.42	0.80	0.11
1991	0.86	0.32	///////////	///////////	1.05	0.85	0.72	0.33
1992	0.52	0.19	///////////	///////////	0.67	0.48	0.43	0.15
1993	1.35	1.04	///////////	///////////	0.98	0.53	0.41	0.88
1994	1.08	1.09	///////////	///////////	0.94	0.46	0.39	0.40
1995	1.09	0.59	///////////	///////////	1.13	0.78	0.73	0.22
1996	0.85	0.40	///////////	///////////	0.93	0.68	0.54	0.25
1997	0.91	0.53	///////////	///////////	0.83	0.54	0.46	0.45
1998	0.62	0.97	///////////	///////////	0.61	0.33	0.32	0.14
1999	0.66	1.21	///////////	///////////	0.75	0.53	0.45	0.19
2000	0.81	0.96	///////////	///////////	0.75	0.51	0.48	0.45
2001	0.30	0.50	///////////	///////////	0.35	0.19	0.21	0.01
2002	1.11	0.69	///////////	///////////	0.81	0.36	0.38	0.90
2003	0.78	0.40	///////////	0.49	0.85	0.44	0.51	0.01
2004	1.18	0.88	///////////	0.53	1.12	0.93	0.61	0.38
2005	2.53	2.85	///////////	1.66	1.89	1.00	0.92	1.21
2006	4.79	3.69	///////////	1.73	4.08	1.92	1.96	0.18
2007	1.67	2.41	///////////	1.56	1.69	1.11	0.97	0.05
2008	1.78	1.51	///////////	1.93	1.80	1.46	0.85	0.52
2009	1.81	///////////	3.24	2.15	1.87	1.37	1.08	0.62
2010	1.72	///////////	2.96	3.04	1.67	0.96	0.80	0.60
2011	0.96	///////////	2.40	2.82	1.02	0.60	0.61	0.05
2012	0.28	///////////	0.85	0.78	0.34	0.26	0.24	0.01
2013	0.07	///////////	0.19	0.12	0.11	0.11	0.09	0.00
2014	0.23	///////////	0.51	0.33	0.17	0.06	0.07	0.19
2015	0.07	///////////	0.19	0.16	0.09	0.08	0.07	0.00
2016	0.27	///////////	0.11	0.28	0.28	0.17	0.17	0.19
2017	0.05	///////////	0.15	0.16	0.07	0.05	0.04	0.00
2018	0.07	///////////	0.26	0.10	0.08	0.05	0.05	0.05
2019	0.04	///////////	0.15	0.07	0.06	0.04	0.04	0.00
2020	////////////	///////////	///////////	///////////	/////////	///////////	/////////	/////////////
2021	0.03	///////////	///////////	0.10	0.05	0.04	0.04	0.00
1984-2013 mean	**1.21**	**1.00**	**1.93**	**1.53**	**1.21**	**0.79**	**0.63**	**0.33**
2014-2021 mean	**0.11**	**NA**	**0.23**	**0.17**	**0.11**	**0.07**	**0.07**	**0.06**
1984-2017 median	**0.99**	**0.69**	**0.51**	**0.78**	**1.00**	**0.59**	**0.55**	**0.20**
80th percentile (1984-2017)	**1.43**	**1.16**	**2.62**	**1.98**	**1.66**	**1.04**	**0.80**	**0.48**
20th percentile (1984-2017)	**0.43**	**0.40**	**0.17**	**0.26**	**0.51**	**0.30**	**0.29**	**0.04**

Table 6. 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. Slashes indicate no data.

Survey	NEFSC	ASMFC	NEFSC	NEFSC	NEFSC	Boothbay Harbor, ME
Indicator	Predation Pressure Index	Summer Bottom Temp.	Spring Bottom temp. anomaly	Fall Bottom temp. anomaly	Spring Surface temp. anomaly	Feb-Mar Surface temp.
1984	434.3	4.1	0.6	0.8	-0.1	2.9
1985	597.8	4.0	0.1	0.6	0.1	2.8
1986	608.1	6.3	1.2	0.7	0.8	2.6
1987	387.8	6.0	0.0	0.0	-0.6	1.8
1988	503.1	6.5	1.3	-0.1	-0.2	2.7
1989	520.4	5.6	-0.1	-0.3	-0.6	1.9
1990	631.3	3.6	0.2	0.1	0.0	2.6
1991	501.8	6.1	0.5	0.1	0.6	3.4
1992	486.7	6.3	0.6	-0.2	-0.9	3.2
1993	470.1	5.8	-0.8	-0.3	-0.7	1.2
1994	351.9	6.8	0.6	1.3	0.2	1.8
1995	638.5	6.6	0.8	0.5	0.1	3.3
1996	564.8	7.1	1.0	1.1	-0.2	3.3
1997	378.1	6.8	1.4	0.5	0.0	3.7
1998	466.6	6.3	1.3	-0.4	0.5	2.9
1999	738.7	6.1	0.3	0.6	0.9	2.9
2000	813.7	6.7	1.1	0.7	0.9	3.1
2001	723.3	6.5	0.7	0.1	0.4	2.9
2002	1,305.8	7.1	1.3	1.3	1.2	4.1
2003	1,040.8	5.6	-0.2	-0.1	-0.6	2.4
2004	487.8	4.7	-0.8	-1.1	-0.9	3.0
2005	471.3	4.9	0.1	0.5	0.2	3.0
2006	663.5	7.1	1.3	1.2	0.9	5.5
2007	704.7	5.9	0.5	-0.3	0.0	2.0
2008	846.3	5.9	0.5	0.4	1.2	2.3
2009	740.6	6.0	0.4	0.7	0.4	2.6
2010	1,126.5	7.4	0.9	1.7	1.7	4.1
2011	1,150.4	7.7	2.3	1.4	0.9	2.9
2012	1,156.6	7.9	2.0	2.0	1.9	5.5
2013	769.3	7.1	1.3	1.2	1.8	3.9
2014	955.1	6.2	0.5	1.4	0.5	2.2
2015	832.2	5.8	0.1	0.3	0.1	1.4
2016	1,518.4	7.2	1.4	2.0	1.7	4.2
2017	948.2	6.9	1.0	1.3	0.9	3.8
2018	927.2	6.7	1.1	1.3	1.5	4.5
2019	674.4	7.1	1.4	1.4	0.7	3.5
2020	////////////	////////////	////////////	////////////	////////////	4.6
2021	////////////	7.6	2.1	////////////	1.9	4.0
1984-2013 mean	**676.0**	**6.1**	**0.7**	**0.5**	**0.3**	**3.0**
2014-2021 mean	**975.9**	**6.8**	**1.1**	**1.3**	**1.0**	**3.5**
1984-2017 median	**651.0**	**6.3**	**0.6**	**0.6**	**0.3**	**2.9**
20th percentile (1984-2017)	**480.5**	**5.7**	**0.1**	**-0.1**	**-0.2**	**2.3**
80th percentile (1984-2017)	**950.9**	**7.1**	**1.3**	**1.3**	**0.9**	**3.8**

Table 7. Summary of results from the UME model.

Year	Average *F* (N-weighted)	Recruitment (billions of shrimp)	Total Abundance (billions of shrimp)	Spawning Stock Biomass (metric tons)	Total Biomass (metric tons)
1984	0.28	2.3	7.2	5,386.4	21,320.2
1985	0.21	3.7	7.5	4,495.0	24,775.2
1986	0.28	2.7	5.7	5,438.0	21,479.5
1987	0.50	2.6	4.9	5,348.8	17,087.1
1988	0.25	6.9	9.4	4,651.8	19,551.5
1989	0.30	2.3	6.4	5,954.8	21,155.9
1990	0.34	1.9	4.9	3,622.3	19,856.0
1991	0.40	3.1	5.0	4,063.9	15,381.3
1992	0.43	2.3	4.4	4,857.9	13,732.8
1993	0.26	7.5	9.5	3,988.6	17,198.4
1994	0.26	3.4	7.7	5,273.5	21,478.0
1995	0.32	3.0	7.5	7,945.9	27,288.8
1996	0.57	2.0	4.9	6,174.6	20,484.6
1997	0.83	3.3	5.2	4,705.8	15,052.5
1998	0.61	2.4	5.0	4,009.5	14,139.8
1999	0.27	2.3	4.6	3,677.3	14,114.6
2000	0.72	9.3	10.8	3,532.6	16,471.7
2001	0.64	1.8	4.5	2,378.7	12,115.3
2002	0.08	45.7	47.3	4,132.0	43,817.2
2003	0.43	2.1	7.1	2,369.7	19,209.0
2004	0.25	4.4	6.1	1,459.1	13,670.0
2005	0.30	15.5	18.3	4,864.0	25,380.6
2006	0.19	18.2	26.4	6,463.0	45,697.5
2007	0.30	4.7	14.0	10,343.7	46,260.2
2008	0.21	10.4	15.5	5,779.6	40,863.2
2009	0.14	12.1	16.3	8,427.9	33,823.6
2010	0.53	18.4	23.5	6,583.0	39,774.6
2011	1.24	3.1	6.9	3,738.9	19,827.9
2012	0.76	1.0	2.2	1,794.9	7,778.9
2013	0.20	1.4	1.8	936.8	3,534.8
2014	0.0002	3.3	3.8	1,093.3	5,050.4
2015	0.00	1.2	2.0	888.9	4,302.6
2016	0.01	4.6	5.1	1,294.8	6,668.0
2017	0.03	0.6	1.1	713.1	2,494.5
2018	0.002	1.4	1.6	610.3	2,592.1
2019	0.00	0.5	0.9	680.1	2,096.3
2020	0.002	1.2	1.5	706.9	2,727.6
2021	0.00	0.7	1.1	887.0	2,482.8

Table 8. Projection results from the UME model under different *F* scenarios using recent M and recent recruitment.

Year	Trawl F	Trap F	Trawl Catch	Trap Catch	Total Catch	Probability of SSB being above SSB_{2021}	SSB (mt)
2022	F = 0	F = 0	0 mt (0 lbs)	0 mt (0 lbs)	0 mt (0 lbs)	0%	716
2023			0 mt (0 lbs)	0 mt (0 lbs)	0 mt (0 lbs)	0%	624
2024			0 mt (0 lbs)	0 mt (0 lbs)	0 mt (0 lbs)	0.08%	507
2025			0 mt (0 lbs)	0 mt (0 lbs)	0 mt (0 lbs)	0.42%	460
2026			0 mt (0 lbs)	0 mt (0 lbs)	0 mt (0 lbs)	0.35%	444
2022	F = 0.02	F = 0.0024	7.1 mt (15,622 lbs)	0.8 mt (1,815 lbs)	7.9 mt (17,437 lbs)	0%	713
2023			6.1 mt (13,343 lbs)	0.7 mt (1,588 lbs)	6.8 mt (14,931 lbs)	0%	618
2024			5.1 mt (11,315 lbs)	0.6 mt (1,323 lbs)	5.7 mt (12,639 lbs)	0.06%	500
2025			4.6 mt (10,103 lbs)	0.5 mt (1,134 lbs)	5.1 mt (11,237 lbs)	0.32%	452
2026			4.3 mt (9,515 lbs)	0.5 mt (1,055 lbs)	4.8 mt (10,570 lbs)	0.27%	436
2022	F = 0	F = 0.05	0 mt (0 lbs)	21.2 mt (46,729 lbs)	21.2 mt (46,729 lbs)	0%	708
2023			0 mt (0 lbs)	18.2 mt (40,162 lbs)	18.2 mt (40,162 lbs)	0%	606
2024			0 mt (0 lbs)	15 mt (33,170 lbs)	15 mt (33,170 lbs)	0.03%	486
2025			0 mt (0 lbs)	12.7 mt (28,094 lbs)	12.7 mt (28,094 lbs)	0.20%	440
2026			0 mt (0 lbs)	11.9 mt (26,188 lbs)	11.9 mt (26,188 lbs)	0.24%	423

Figures

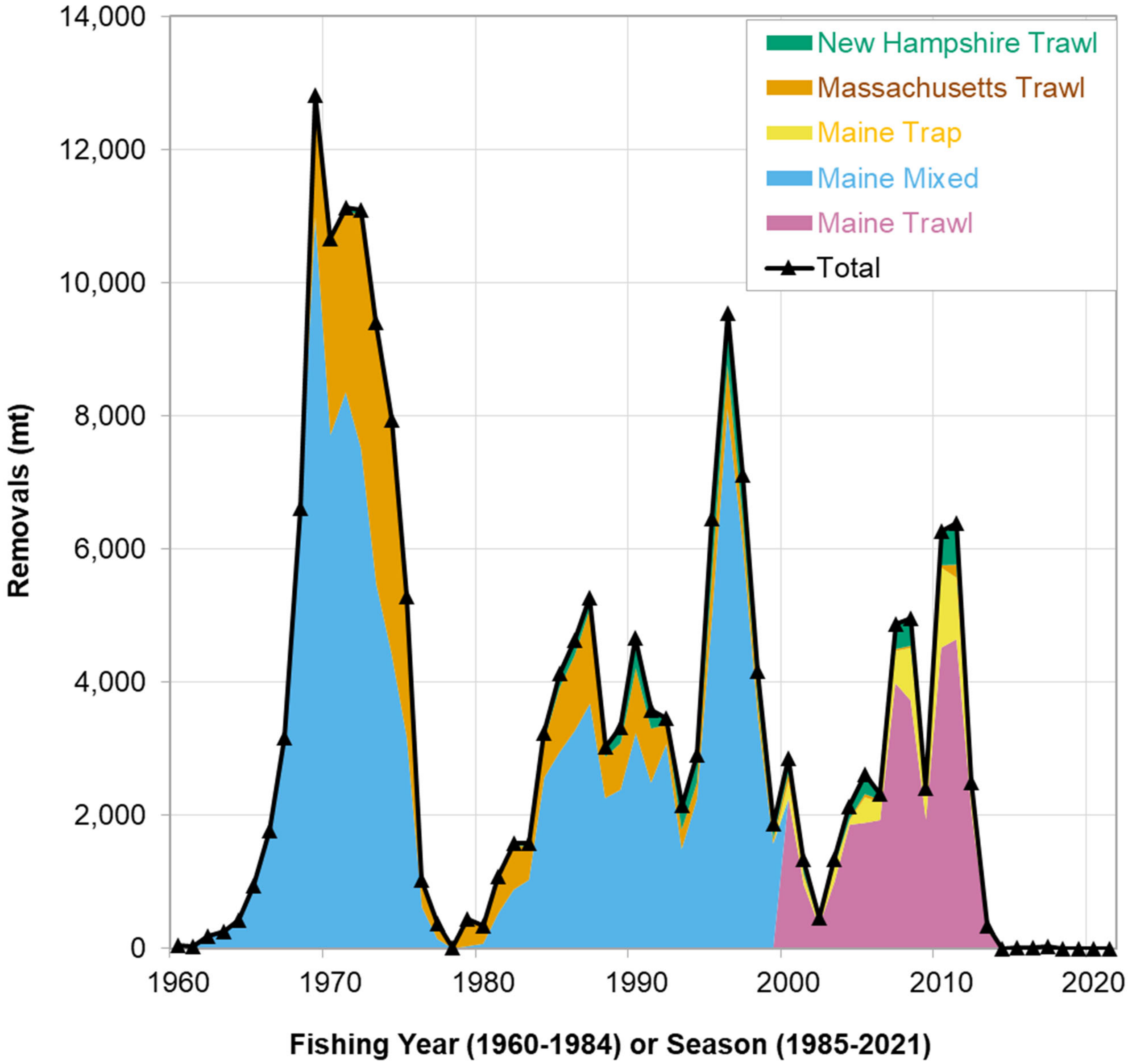


Figure 1. Northern shrimp landings from the Gulf of Maine by state and gear.

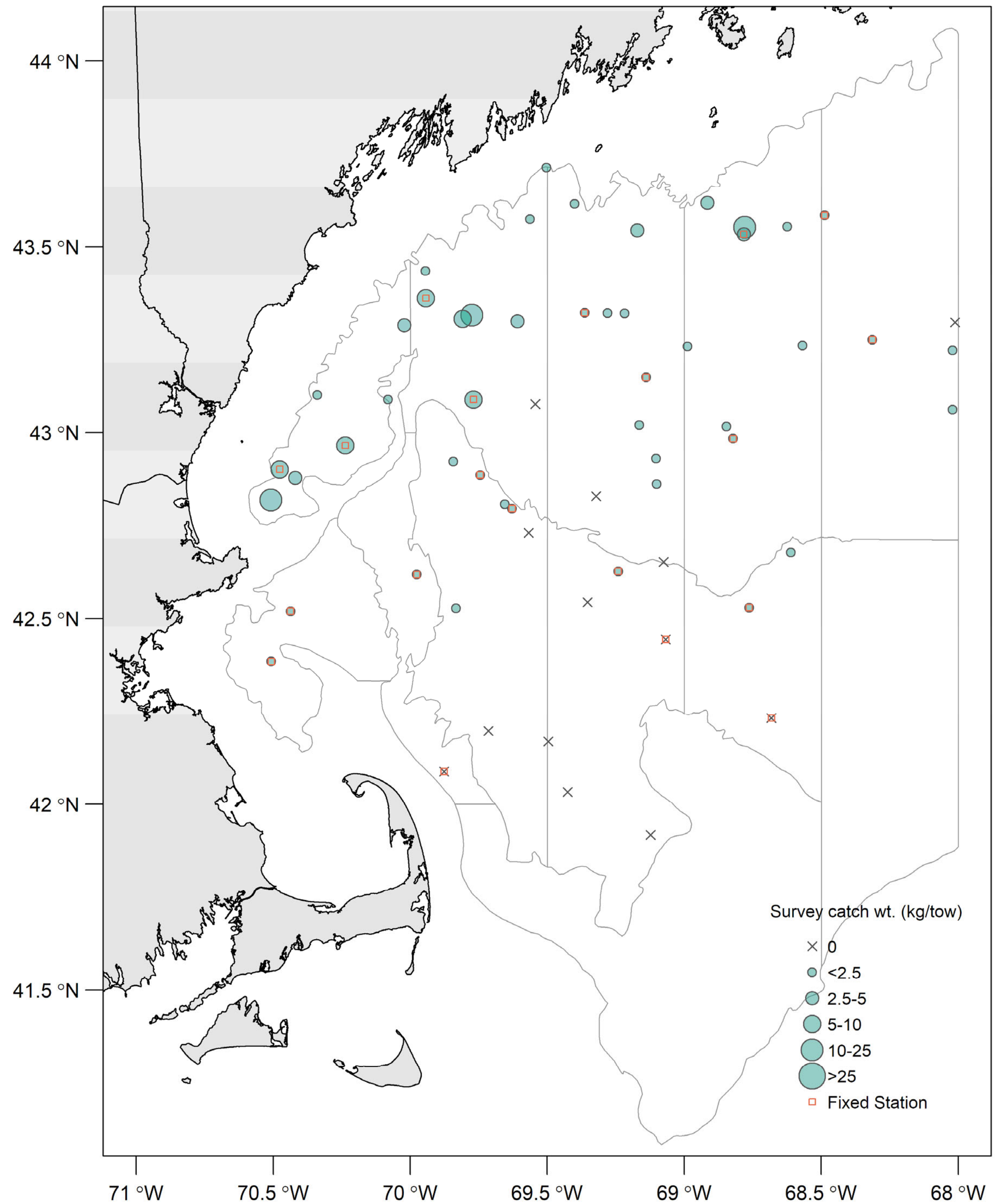


Figure 2. 2021 ASMFC summer survey catches (kg per tow) by tow location.

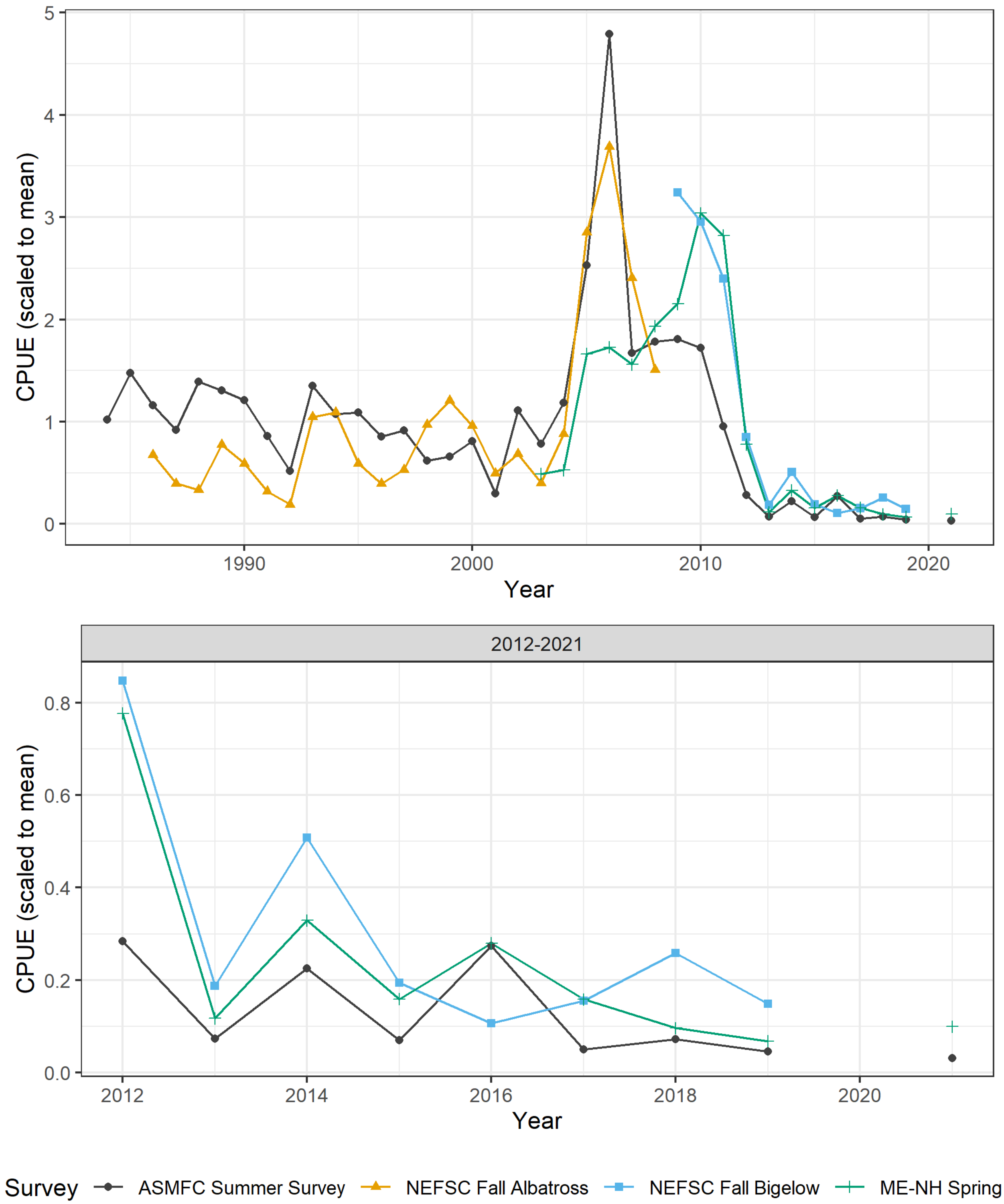


Figure 3. Standardized indices of abundance for Gulf of Maine northern shrimp for 1984-2021 (top) and truncated to 2012-2021 to show detail in recent years (bottom).

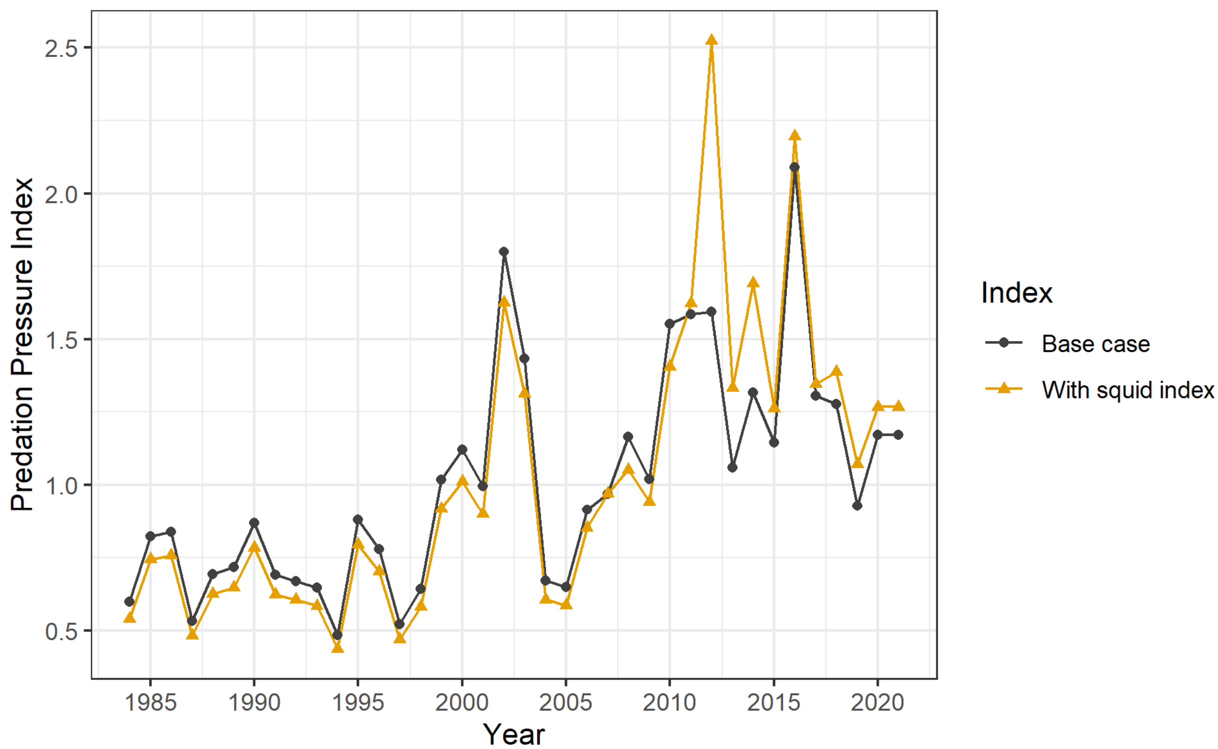


Figure 4. Predation pressure index used to scale M in the UME model with and without (base case) inclusion of a longfin squid index.

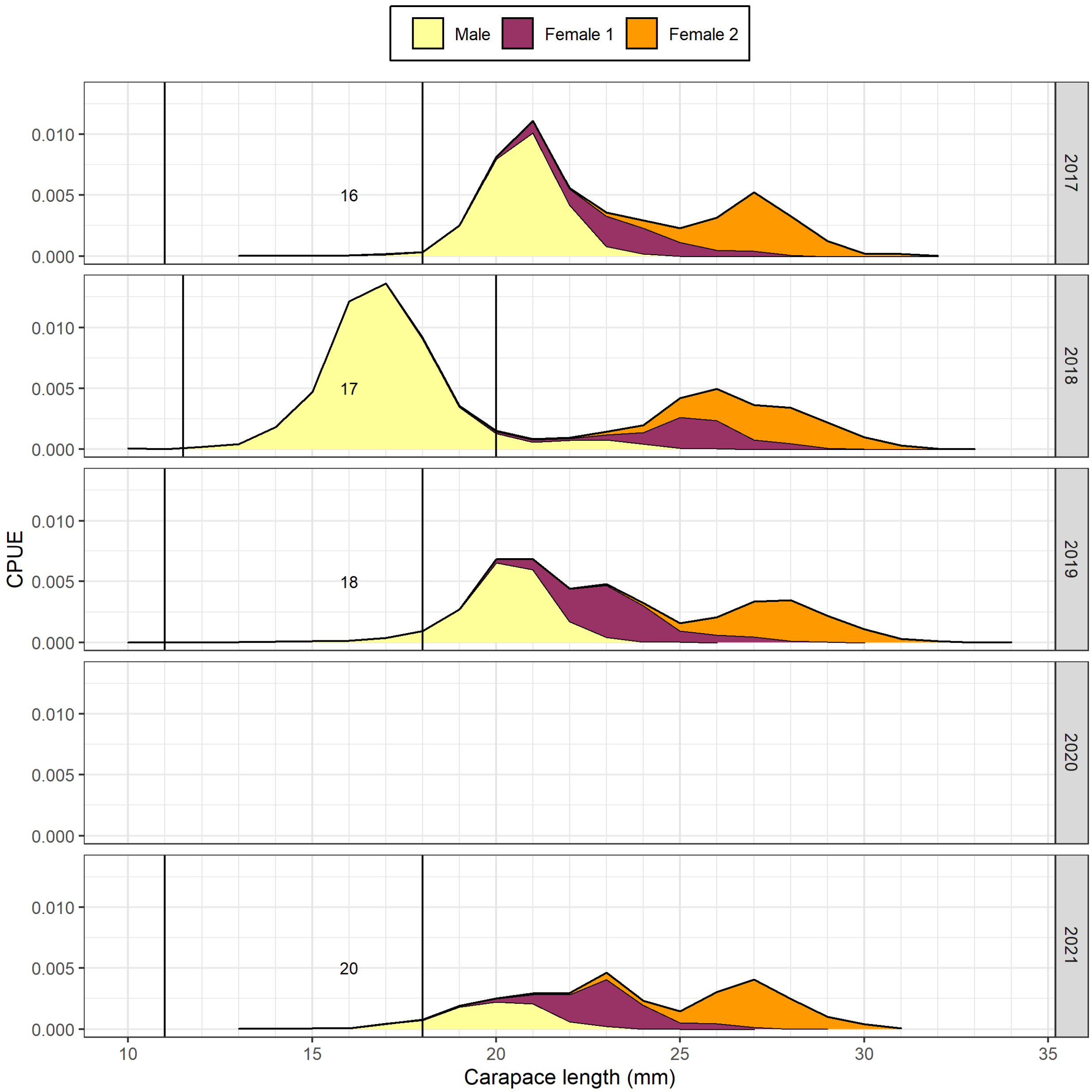
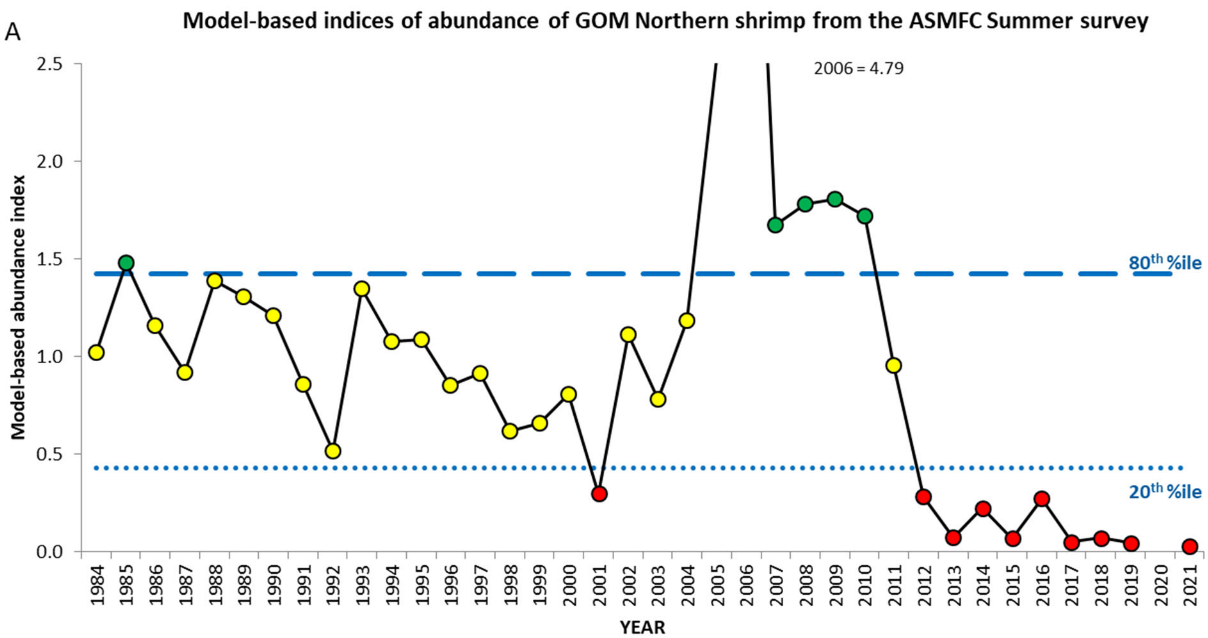


Figure 5. Gulf of Maine northern shrimp Summer Survey abundance by year, length, and development stage for 2017 – 2021. Vertical black lines indicate length cutoffs that identify recruits (shrimp that are assumed to be age 1.5 at the time of the survey); the two-digit numbers indicate the year class of the recruits. See Appendix 3 for the version of this plot with all years of data.

A



B

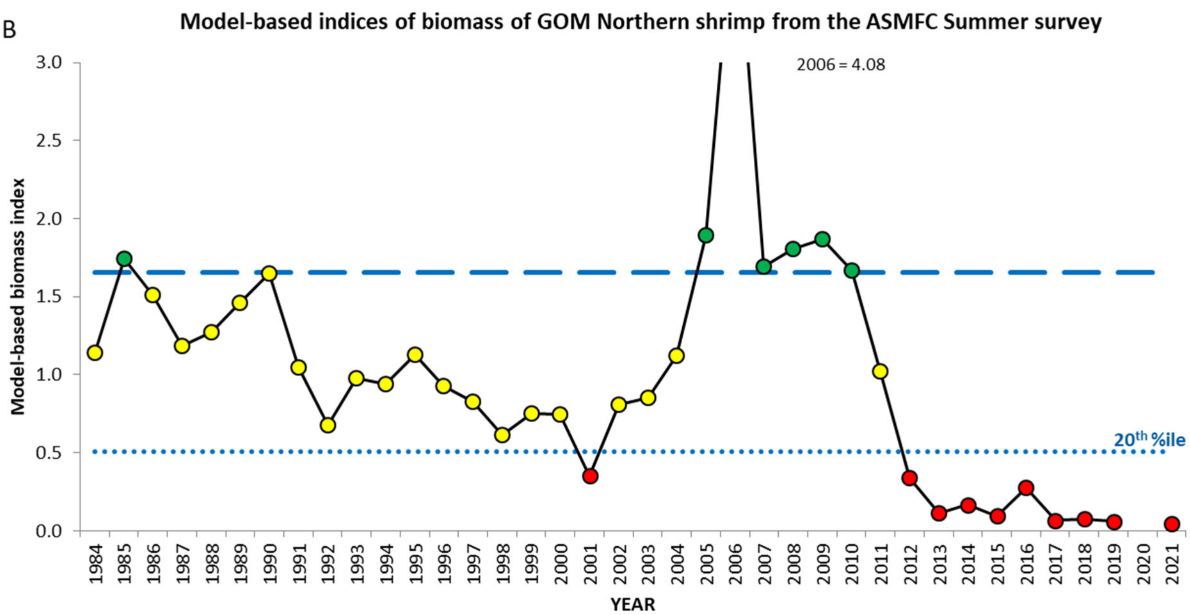
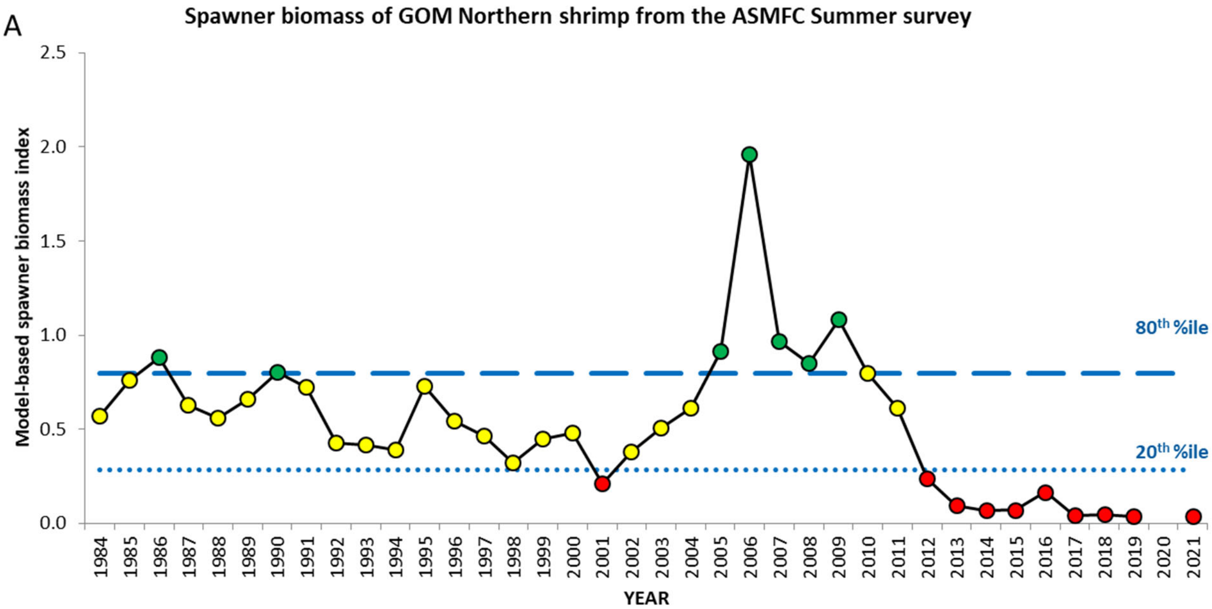


Figure 6. Traffic light analysis for the model-based index of abundance (A) and biomass (B) of Gulf of Maine northern shrimp from the Summer Shrimp Survey, 1984-2021. The 20th percentile of the time series from 1984-2017 delineated an adverse state, and the 80th percentile of the time series from 1984-2017 delineated a favorable state.

A



B

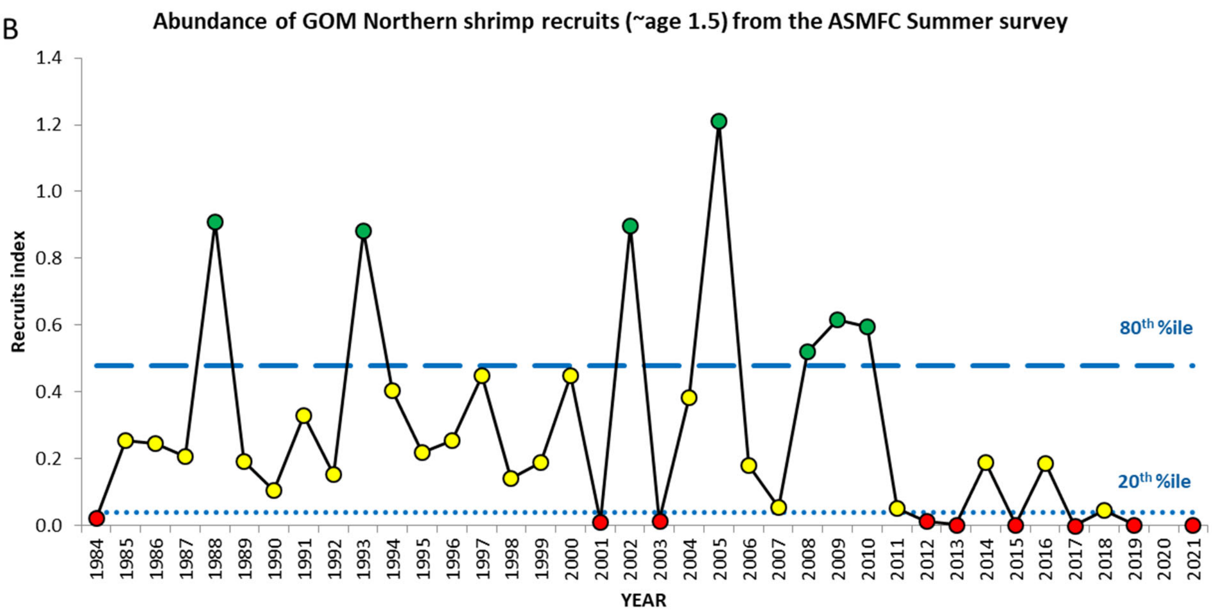
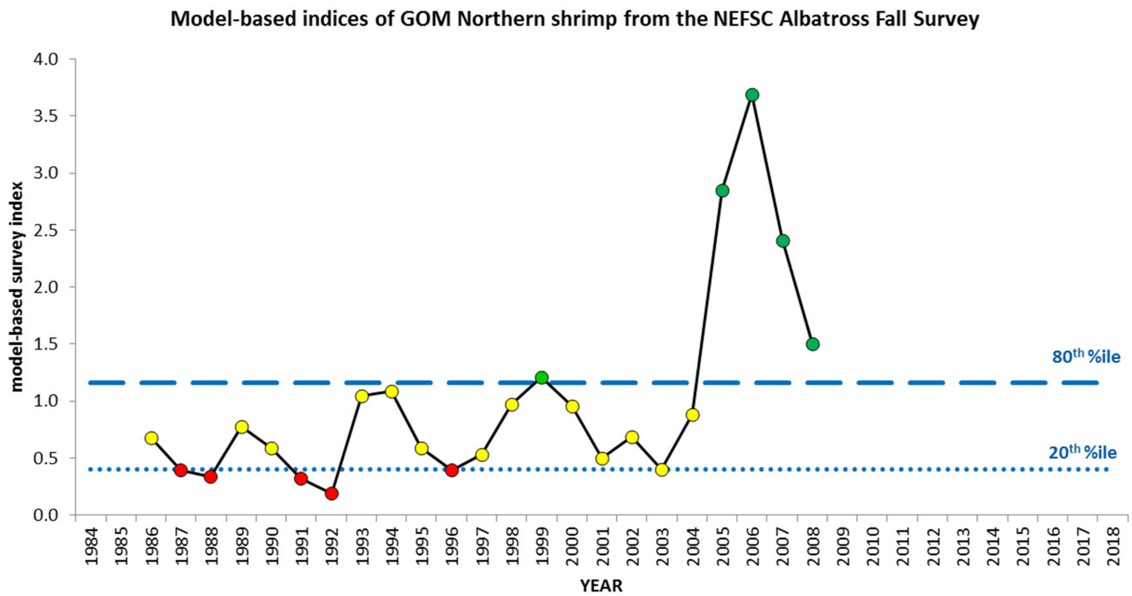


Figure 7. Traffic light analysis of spawning biomass (top) and recruitment (bottom) of Gulf of Maine northern shrimp from the Summer Shrimp survey, 1984-2021. The 20th percentile of the time series from 1984-2017 delineated an adverse state, and the 80th percentile of the time series from 1984-2017 delineated a favorable state.



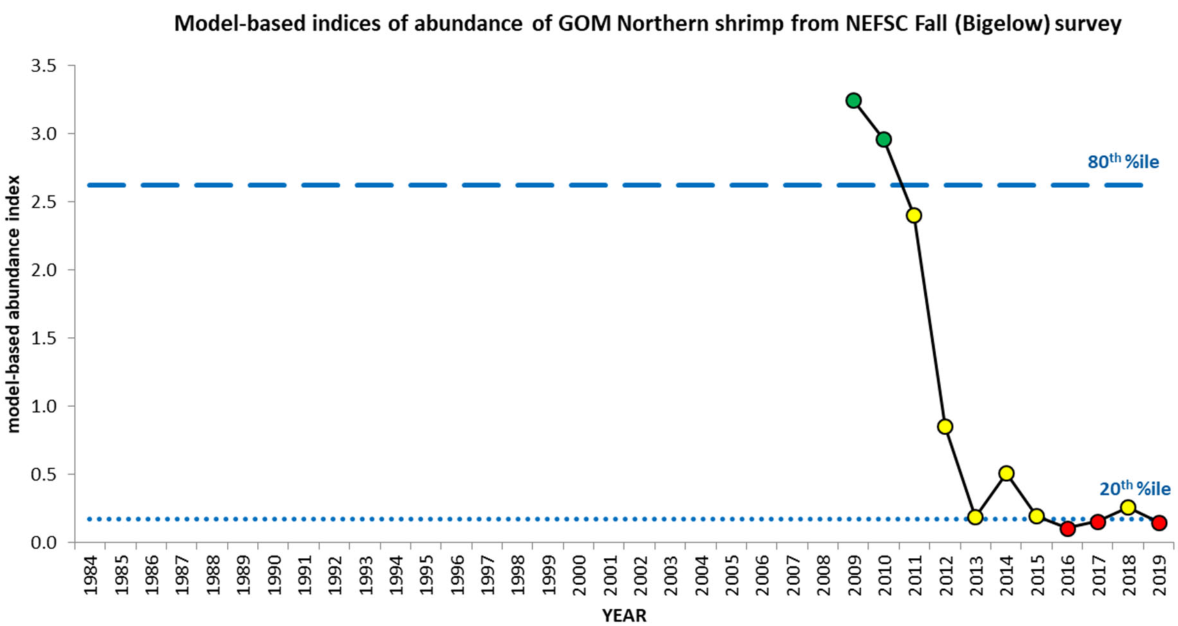


Figure 8. Traffic light analysis for the model-based index of abundance of Gulf of Maine northern shrimp from the NEFSC Fall Survey (Albatross years top, Bigelow years bottom). The 20th percentile of the time series through 2017 delineated an adverse state, and the 80th percentile of the time series through 2017 delineated a favorable state.

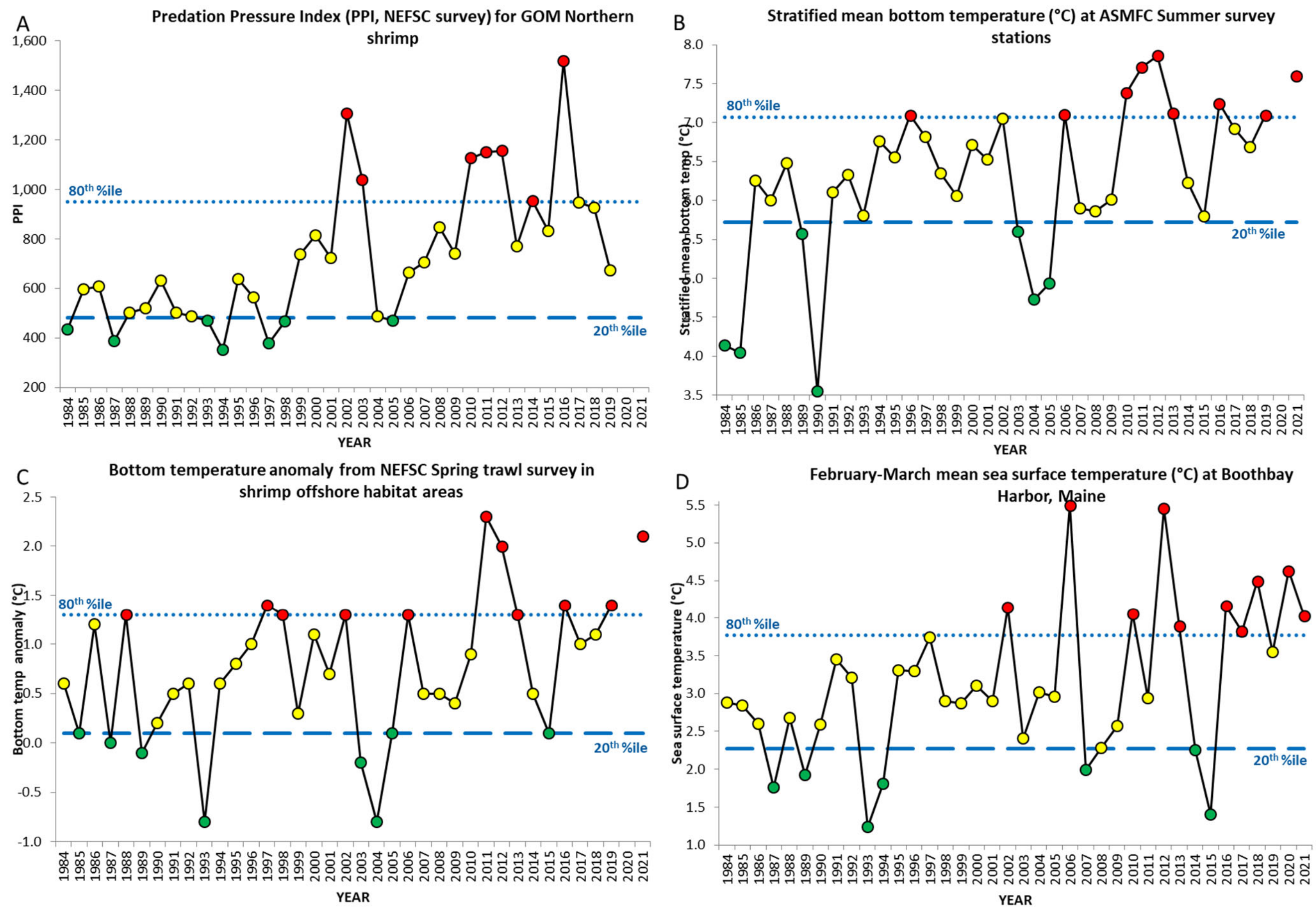


Figure 9. Traffic light analysis of environmental conditions in the Gulf of Maine 1984-2019, including predation pressure (A), summer bottom temperature (B), spring bottom temperature (C), and winter sea surface temperature (D). The 20th percentile of the time series from 1984-2017 delineated a favorable state, and the 80th percentile of the time series from 1984-2017 delineated an adverse state.

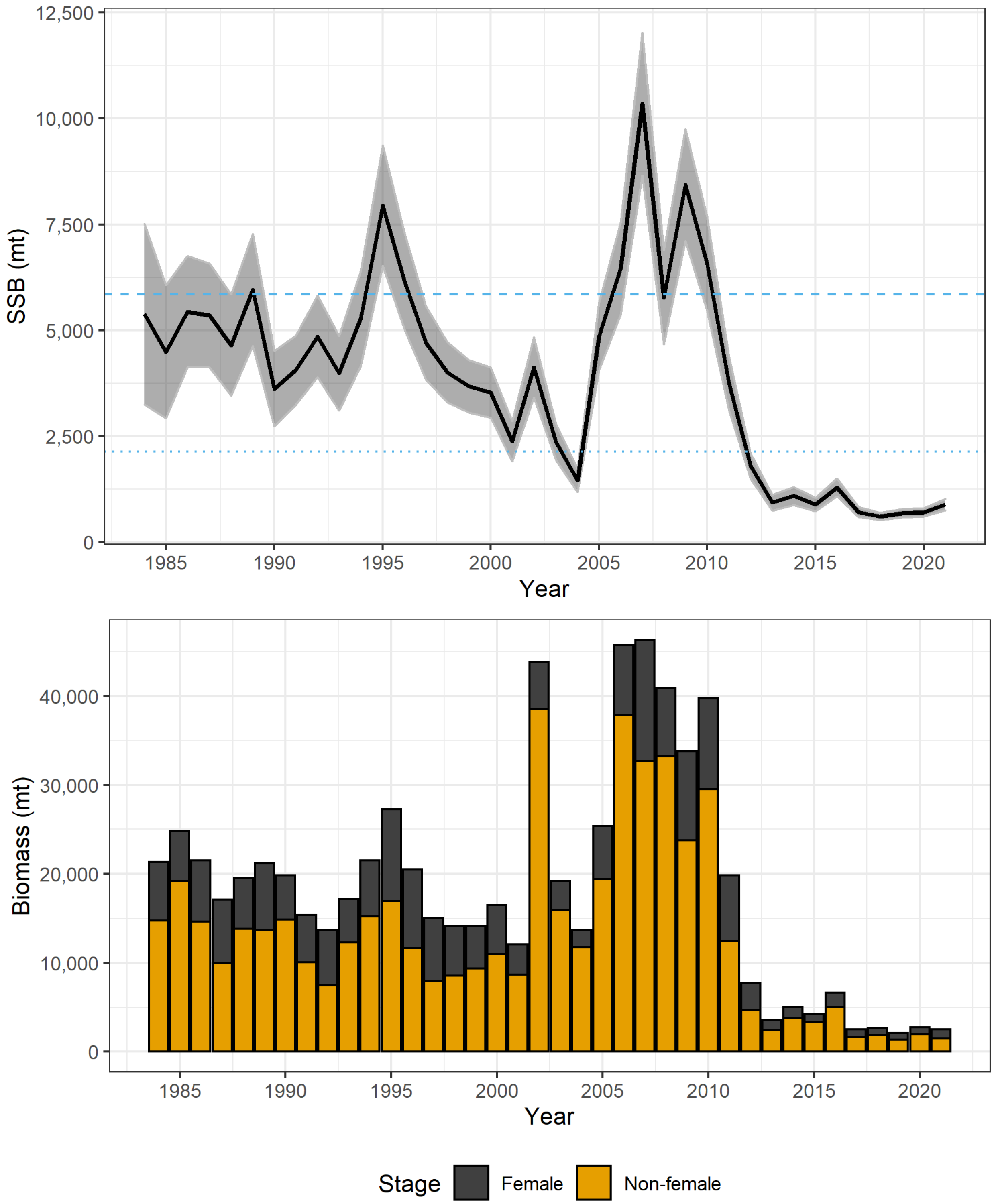


Figure 10. Estimates of Gulf of Maine northern shrimp spawning stock biomass with 95% confidence intervals (top) and total biomass by stage (bottom) from the UME model. Dashed lines in the top figure indicated the 80th and 20th percentiles of the 1984-2017 SSB estimates.

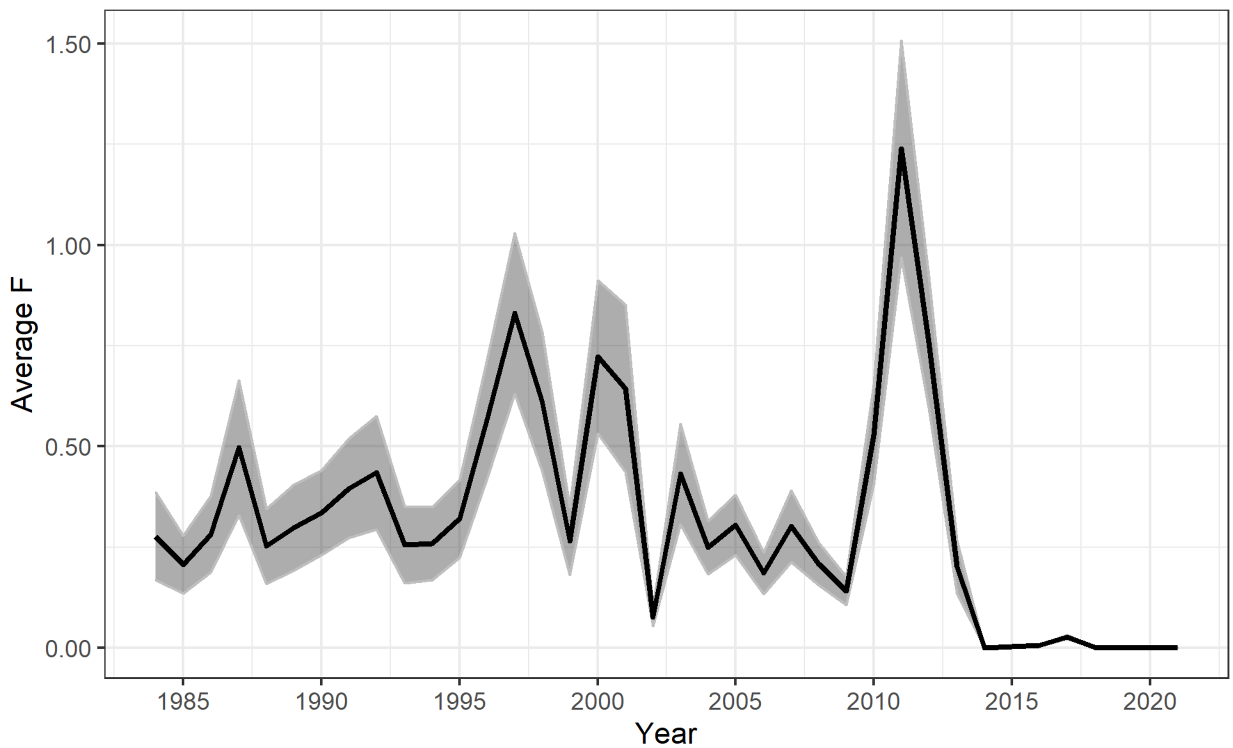


Figure 11. Average fishing mortality on Gulf of Maine northern shrimp estimated by the UME model with 95% confidence intervals.

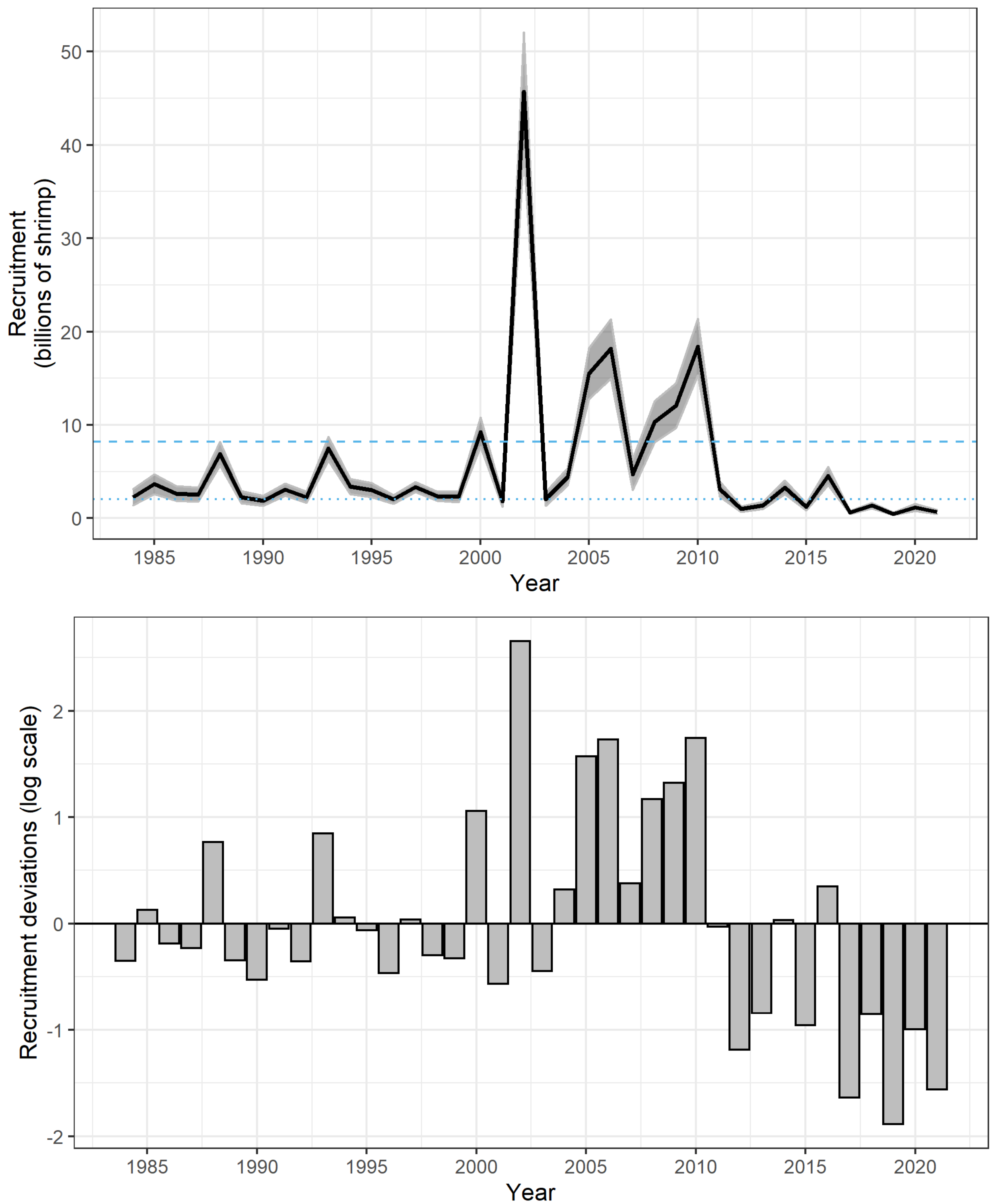


Figure 12. Estimates of total recruitment with 95% confidence intervals (top) and annual deviations from mean recruitment (bottom) for Gulf of Maine northern shrimp from the UME model. Dashed lines in the top plot indicate the 80th and 20th percentiles of the 1984-2017 estimates.

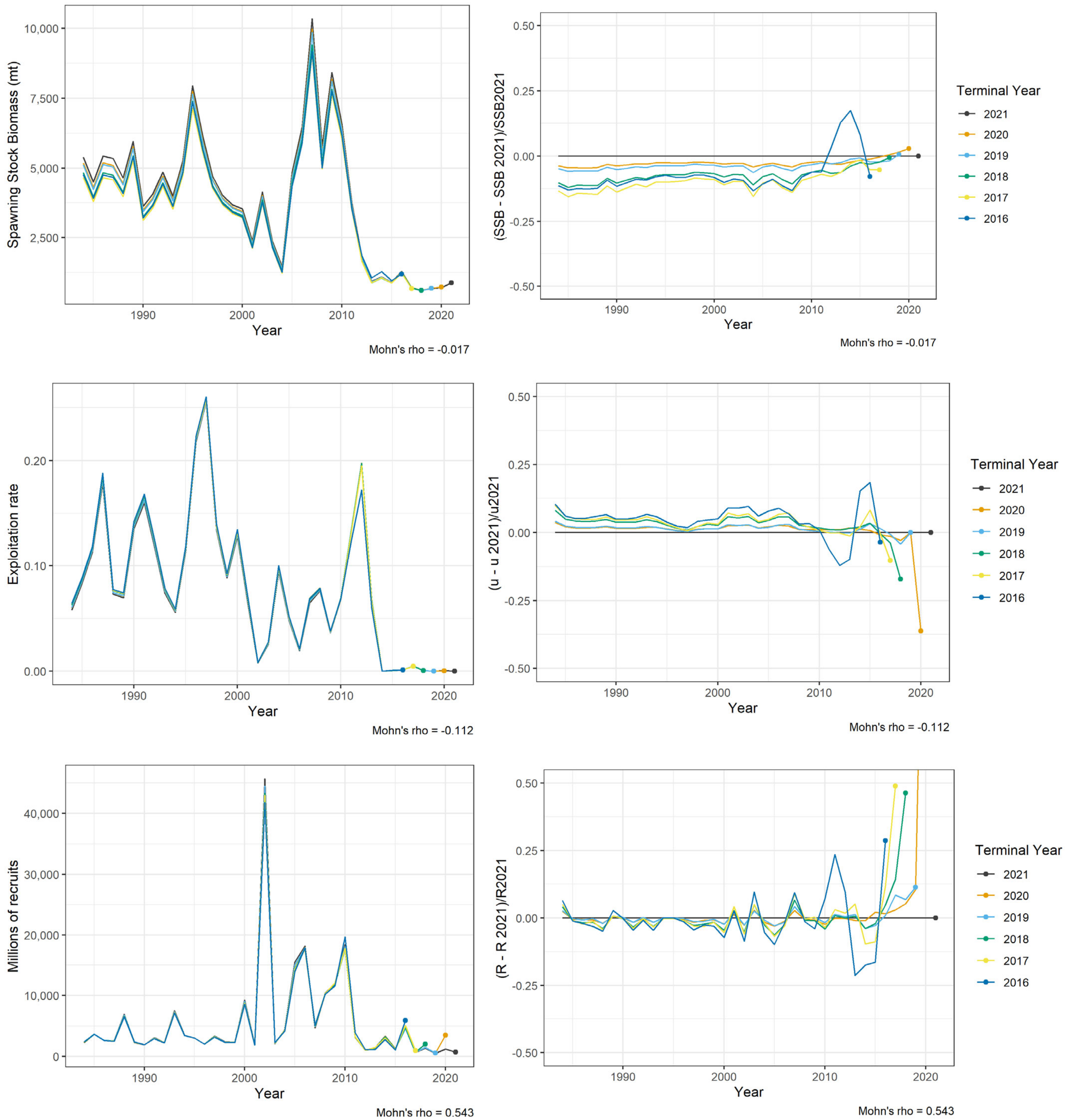


Figure 13. Retrospective analysis of UME model results for spawning stock biomass (top), exploitation rate (middle), and recruitment (bottom).

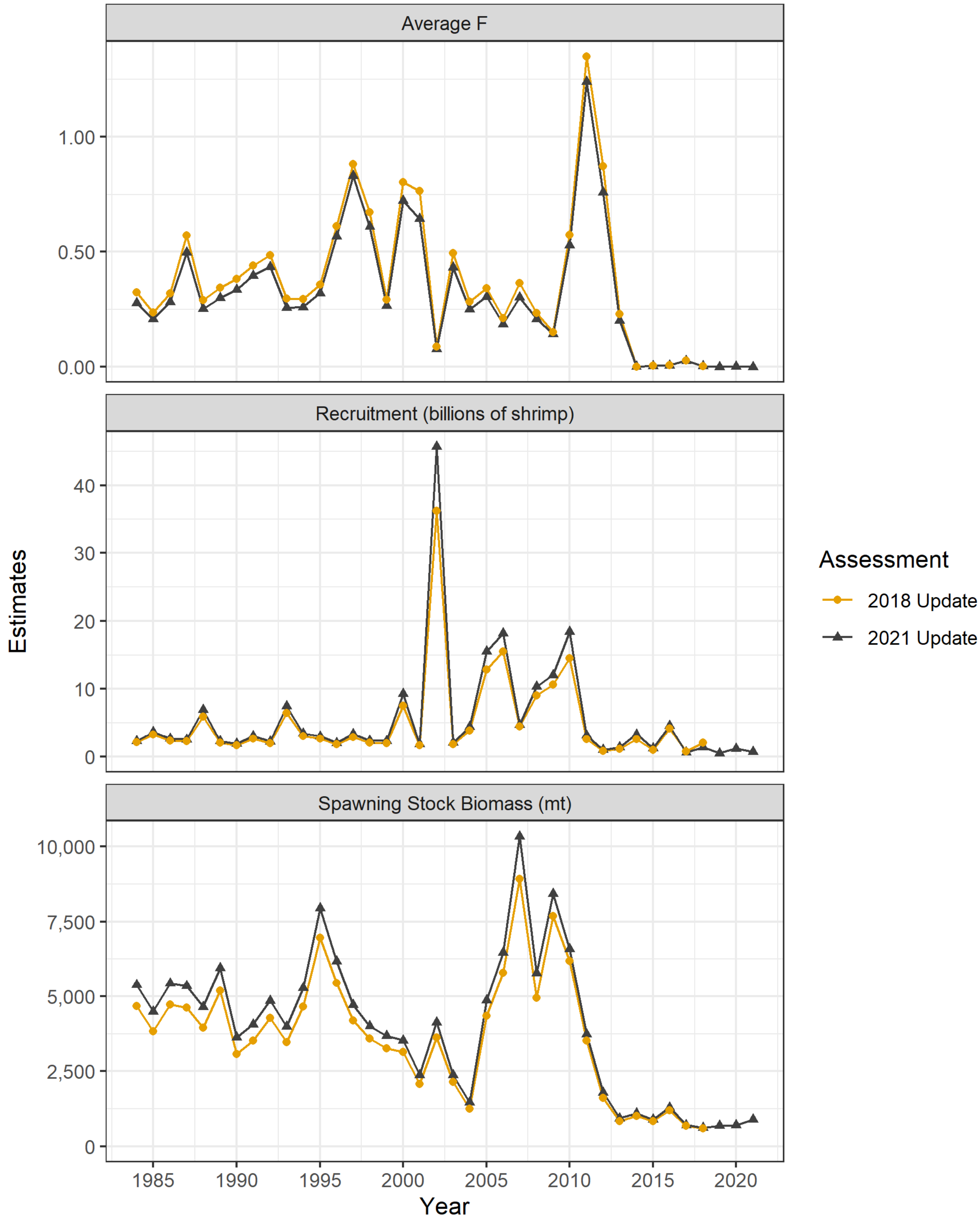


Figure 14. Comparison of results from the 2018 assessment update and the 2021 assessment update.

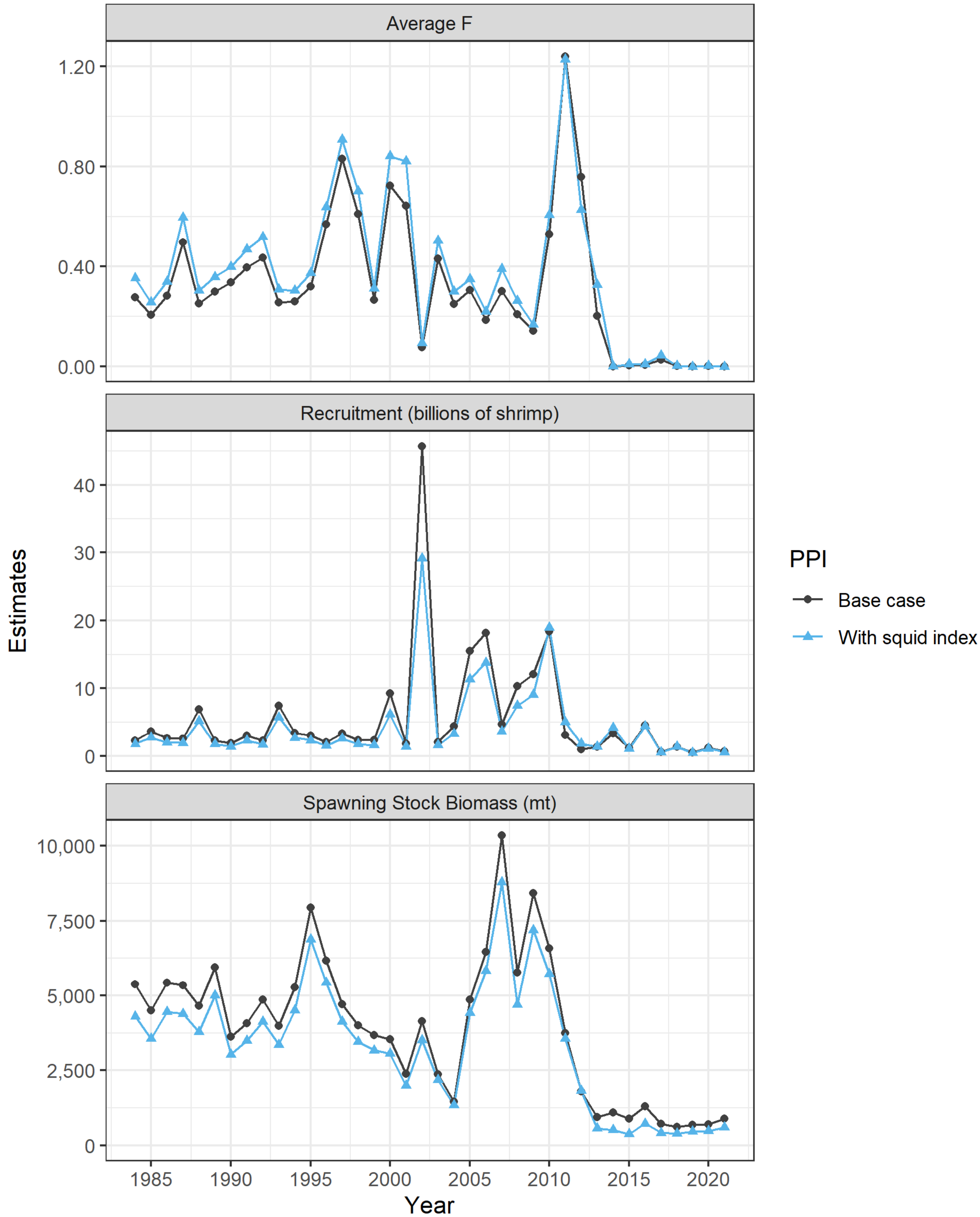


Figure 15. Comparison of *F*, recruitment, and SSB for the base model and the model with the PPI that included squid.

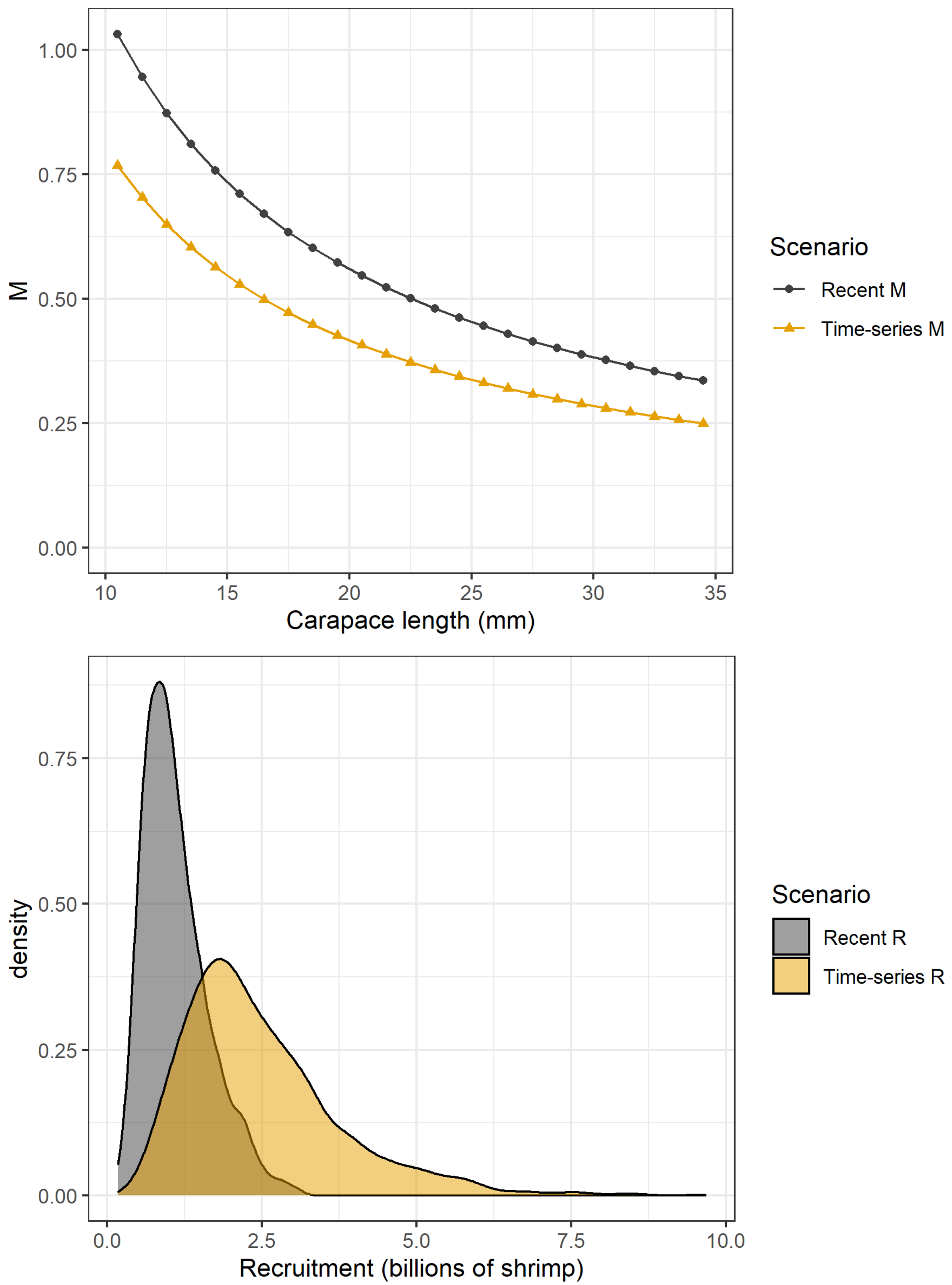


Figure 16. Estimates of M and recruitment used in the short and long term projections.

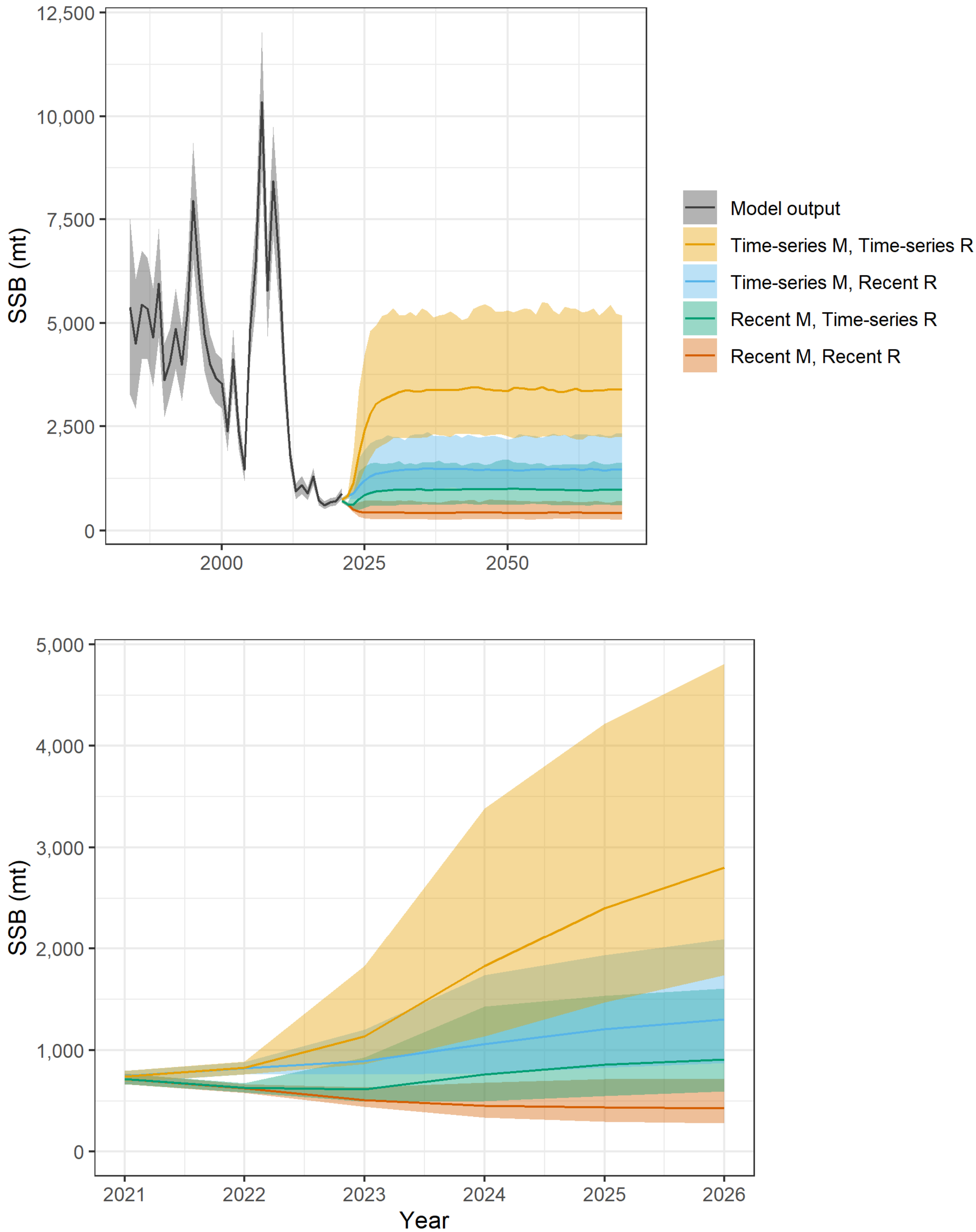


Figure 17. Trajectory of long term (top) and short term (bottom) median spawning stock biomass estimates for Gulf of Maine northern shrimp under different natural mortality and recruitment scenarios in the absence of fishing. Shaded areas indicate 95% confidence intervals.

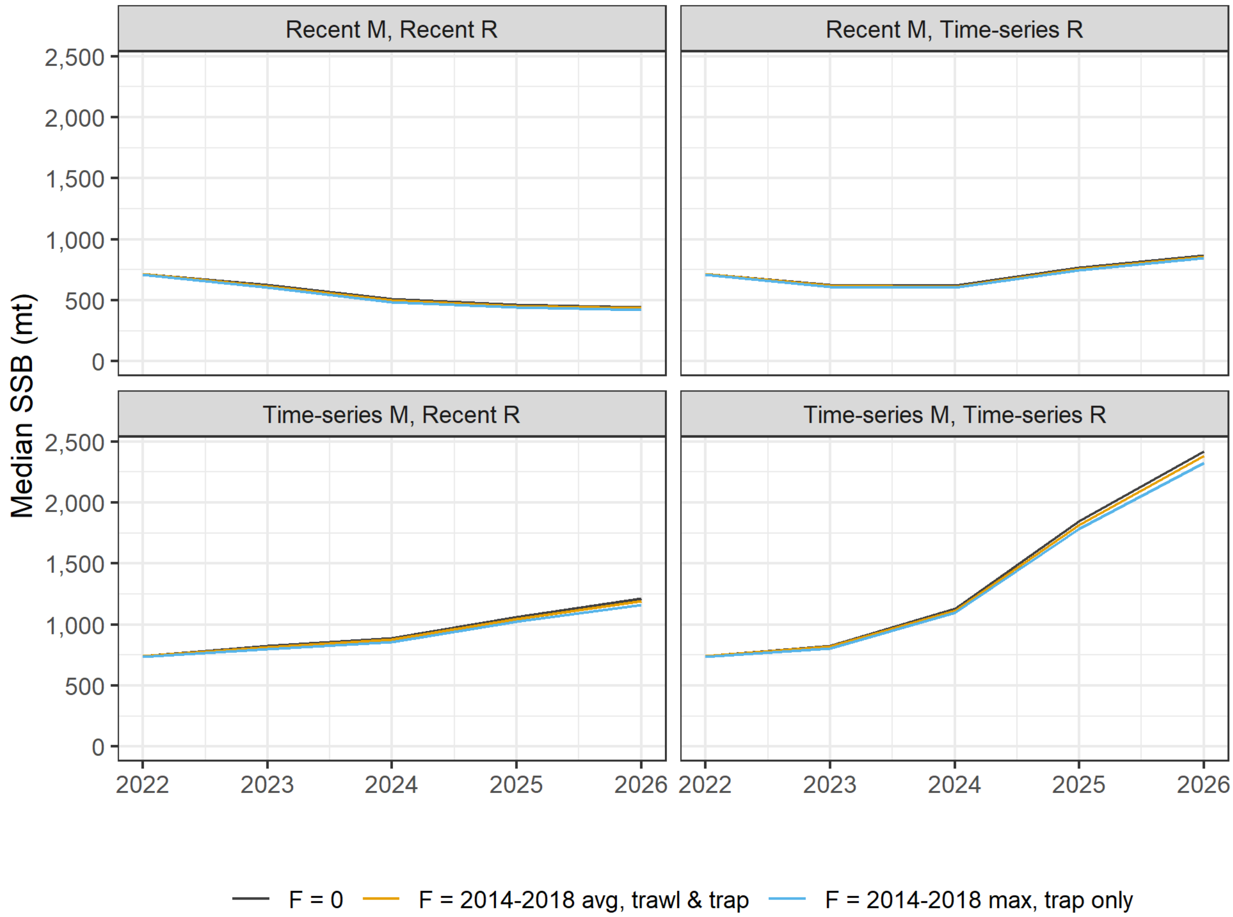


Figure 18. Median SSB trajectories for short-term projections under different *F*, M, and recruitment scenarios.

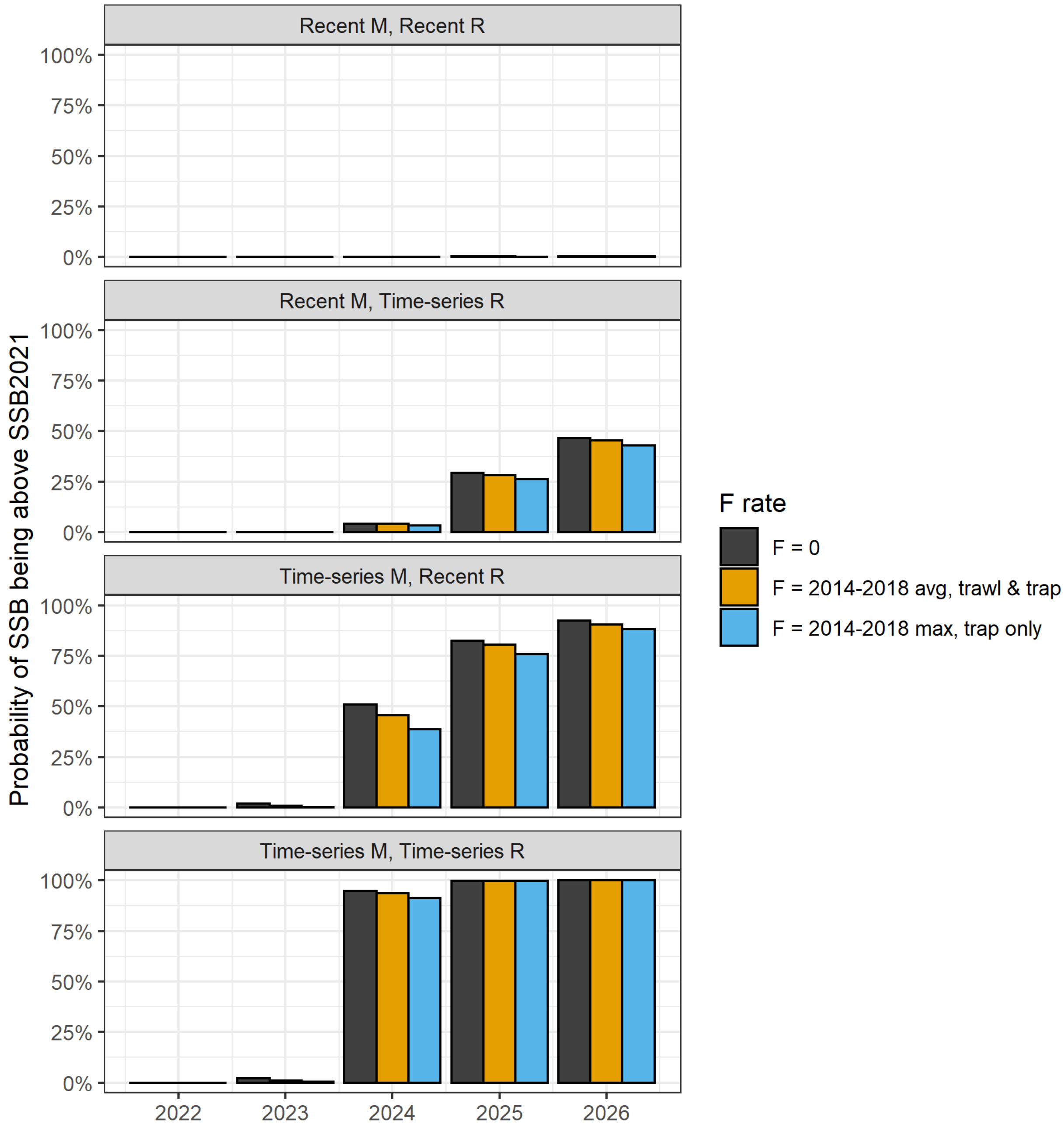


Figure 19. Probability of SSB being above SSB_{2021} under different combinations of *F*, M, and recruitment.