# Atlantic States Marine Fisheries Commission

## Northern Shrimp Section

*December 17, 2021*
*9:00 - 11:00 a.m.*

Link to register for webinar:
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## Draft Agenda

The times listed are approximate; the order in which these items will be taken is subject to change; other items may be added as necessary

| | | |
|---|---|---|
| 1. | Welcome/Call to Order *(R. Kane*) | 9:00 a.m. |
| 2. | Section Consent<br>• Approval of Agenda | 9:00 a.m. |
| 3. | Public Comment | 9:05 a.m. |
| 4. | Review 2021 Stock Assessment Update Report (*M. Hunter*) | 9:15 a.m. |
| 5. | Northern Shrimp Management Strategy Work Group Update (*C. Patterson)* | 9:45 a.m. |
| 6. | Set 2022 Fishery Specifications **Final Action**<br>• Review Projections and Technical Committee Recommendations (*K. Drew*)<br>• Review Advisory Panel Recommendations (*G. Libby*)<br>• Set 2022 Fishery Specifications | 10:00 a.m. |
| 7. | Elect Vice-Chair (*R. Kane*) **Final Action** | 10:55 a.m. |
| 8. | Other Business/Adjourn | 11:00 a.m. |

# Atlantic States Marine Fisheries Commission

*Northern Shrimp Stock Assessment Update 2021*

**Vision: Sustainably Managing Atlantic Coastal Fisheries**

**Atlantic States Marine Fisheries Commission**

*Northern Shrimp Stock Assessment Update*


Prepared by the
ASMFC Northern Shrimp Technical Committee

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**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).

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**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 20$^{th}$ percentile of the time series from 1984-2017 indicated an adverse state, and being above the 80$^{th}$ percentile indicated a favorable state. For the environmental indicators, the opposite was true: being below the 20$^{th}$ percentile indicated a favorable state while being above the 80$^{th}$ 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**

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**List of Appendices**

Appendix 1: Diagnostic Plots for the VAST Index Standardization Models
Appendix 2: An evaluation of efficiency differences between alternative trawl door configurations of the Gulf of Maine shrimp survey gear
Appendix 3: Model Input and Diagnostic Plots for the UME Statistical Catch-at-Length Model

**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<br>Trawl fleet: 2000-2013, 2014-2021<br>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**

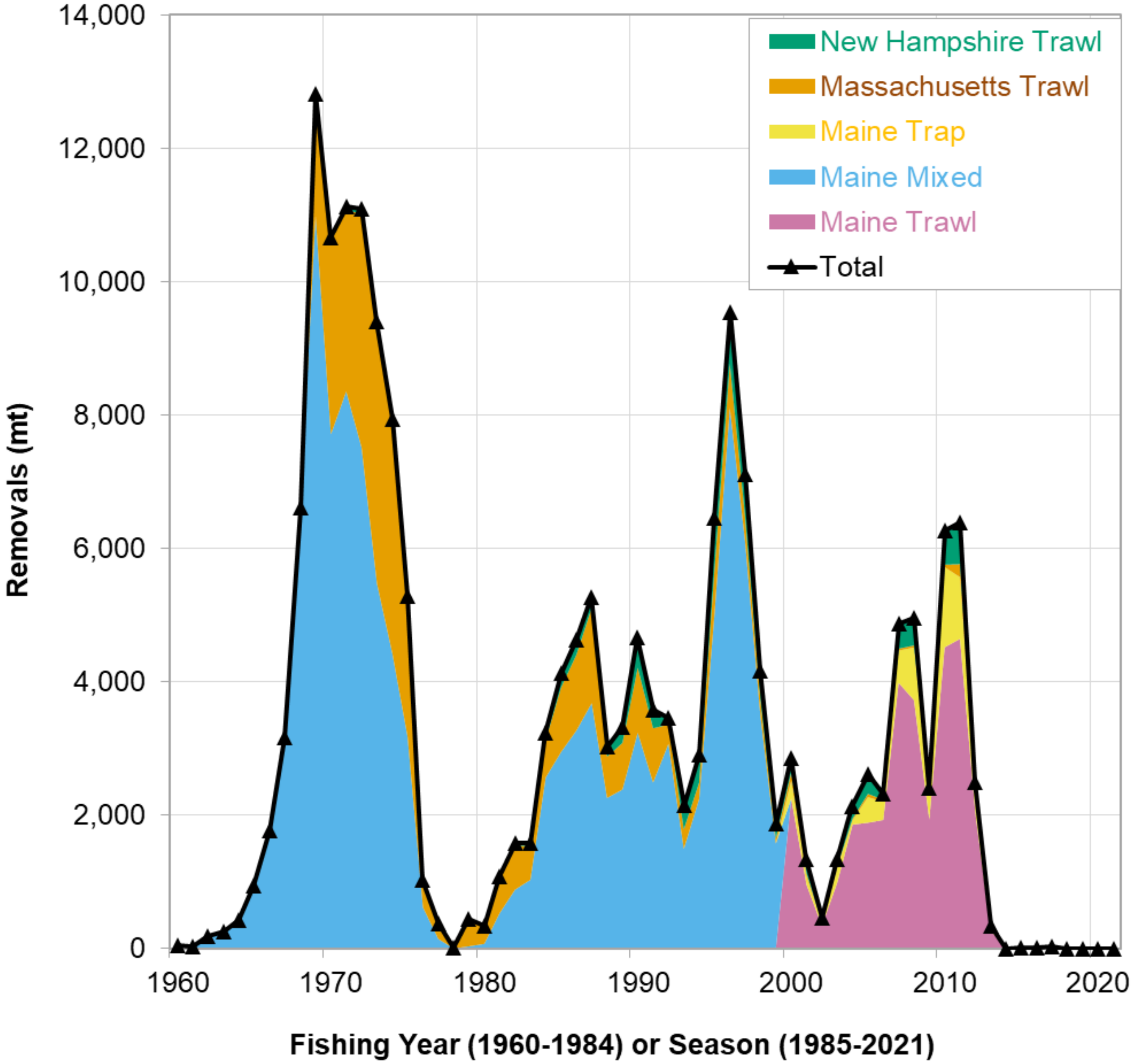



**Figure 1. Northern shrimp landings from the Gulf of Maine by state and gear.**

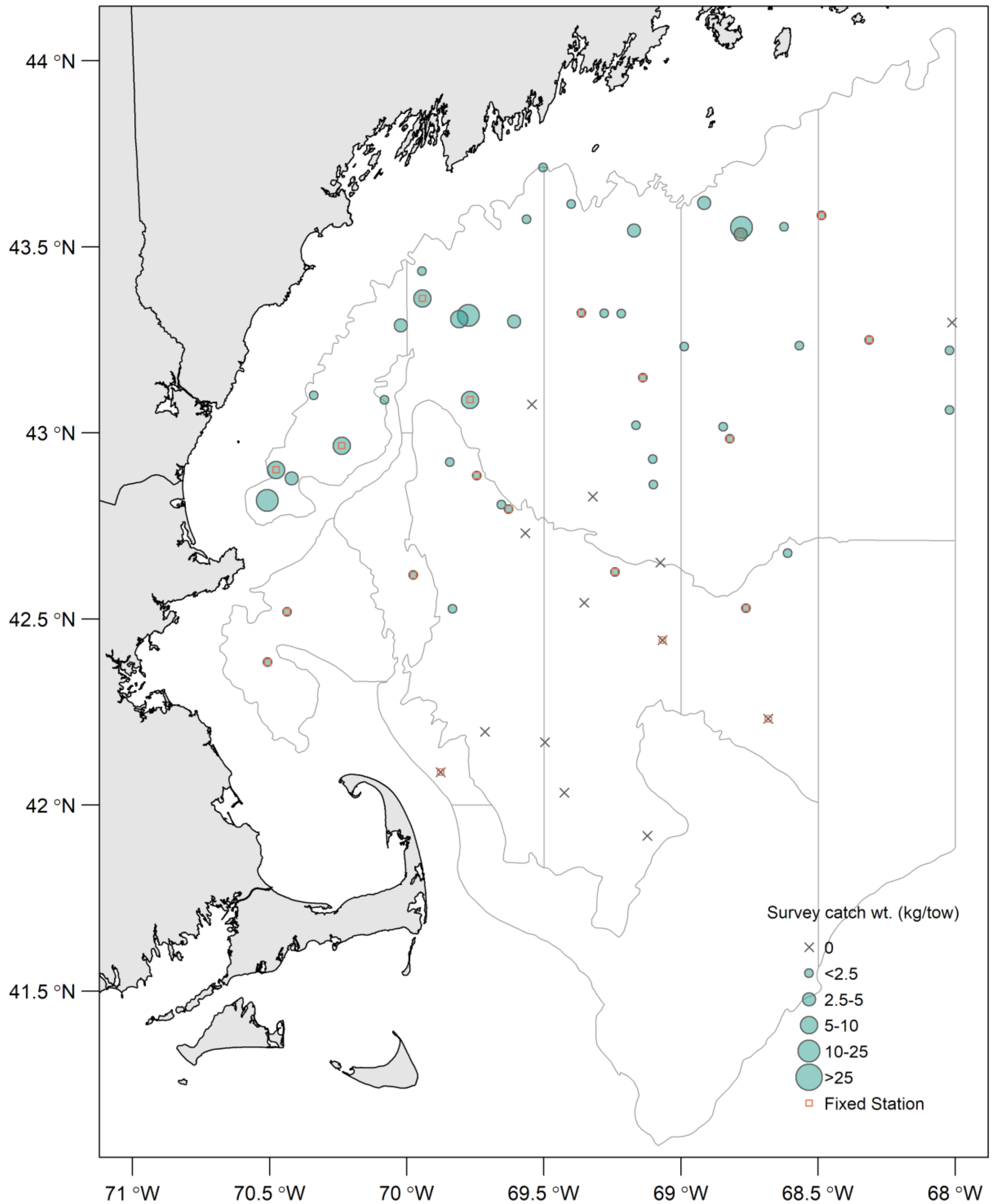



**Figure 2. 2021 ASMFC summer survey catches (kg per tow) by tow location.**

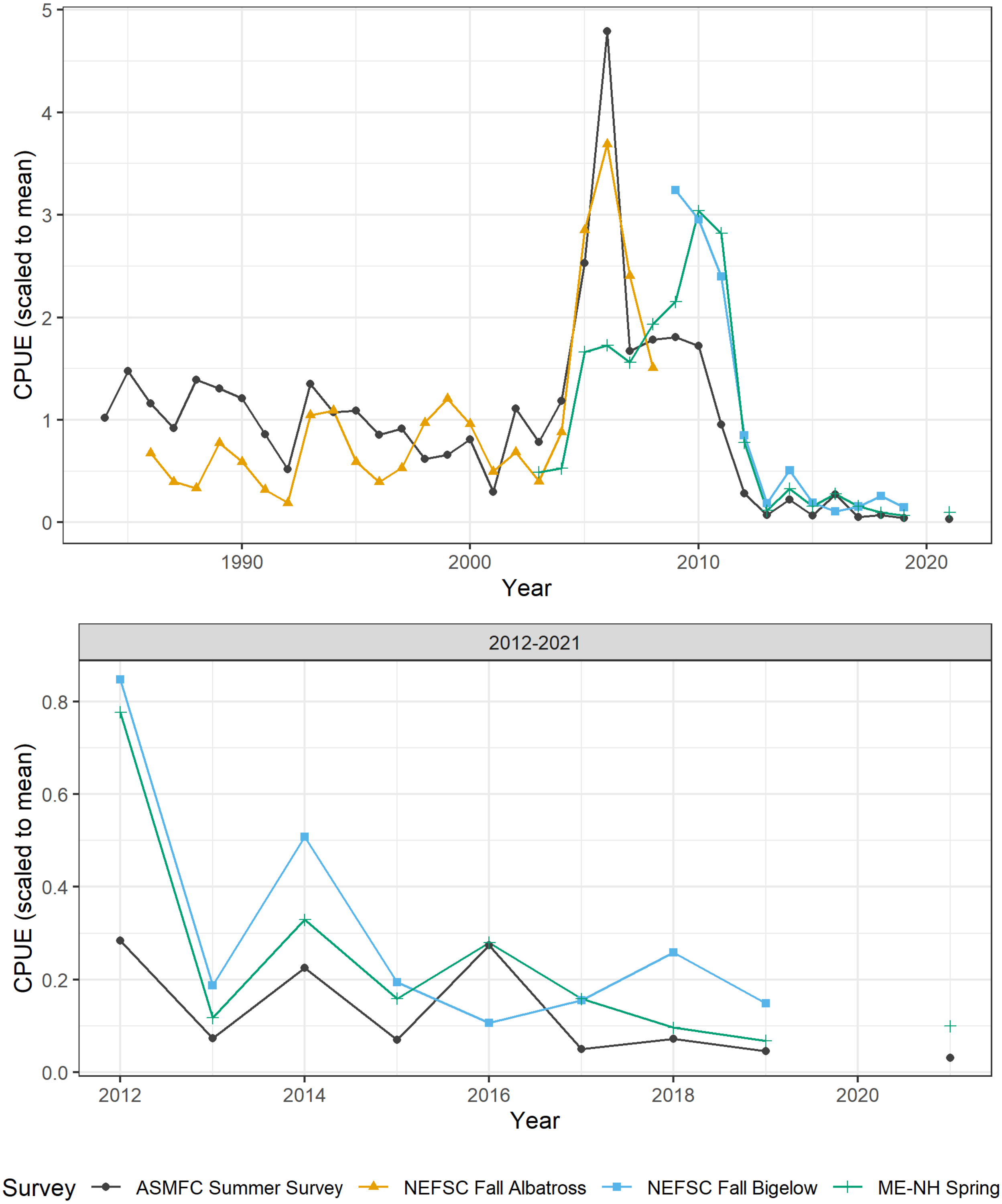



**Figure 3. Standardized indices of abundance for Gulf of Maine northern shrimp for 1984-2021 (top) and truncated to 2012-2021 to show detail in recent years (bottom).**

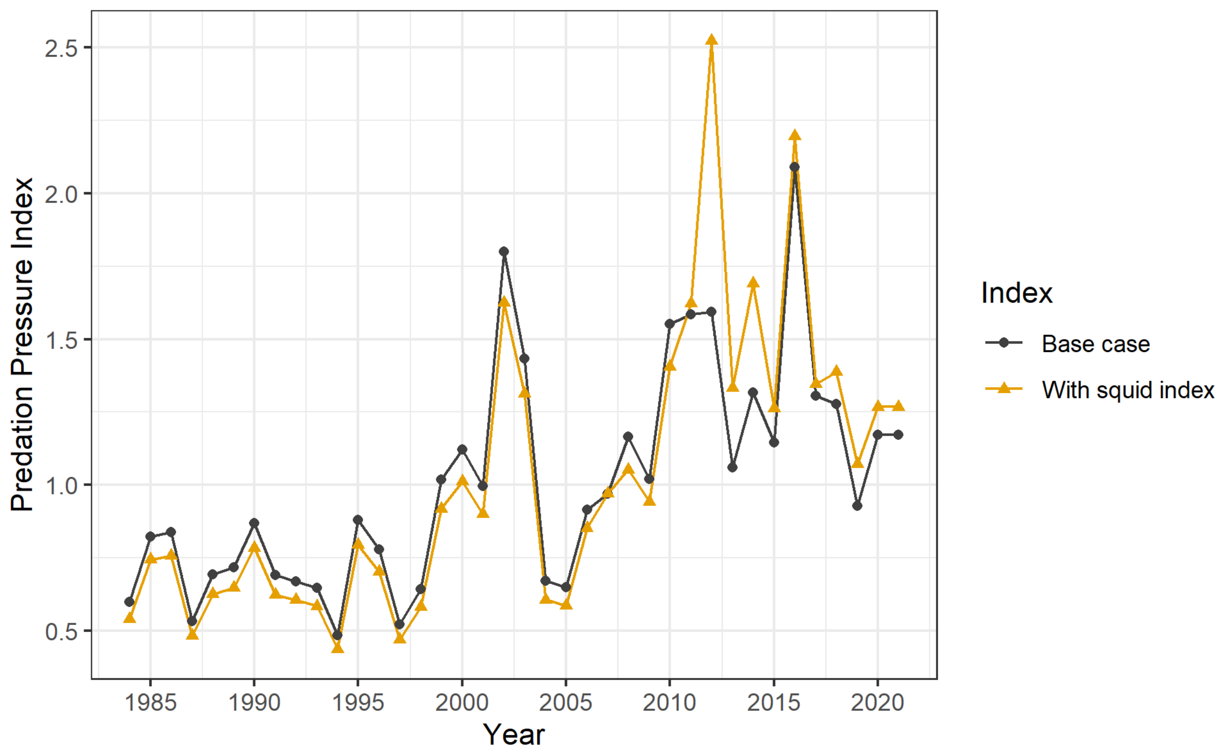



**Figure 4. Predation pressure index used to scale M in the UME model with and without (base case) inclusion of a longfin squid index.**

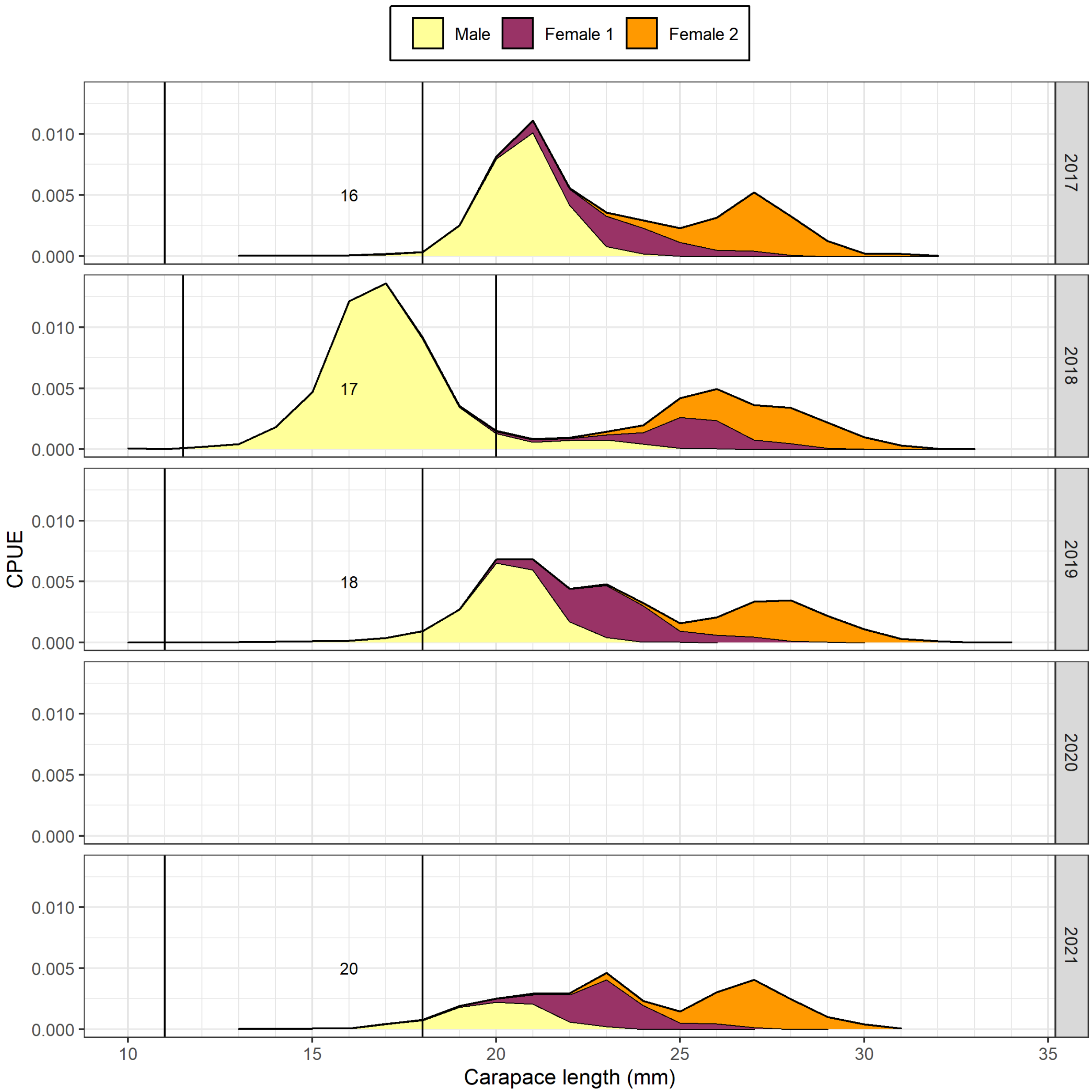



**Figure 5. Gulf of Maine northern shrimp Summer Survey abundance by year, length, and development stage for 2017 – 2021. Vertical black lines indicate length cutoffs that identify recruits (shrimp that are assumed to be age 1.5 at the time of the survey); the two-digit numbers indicate the year class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

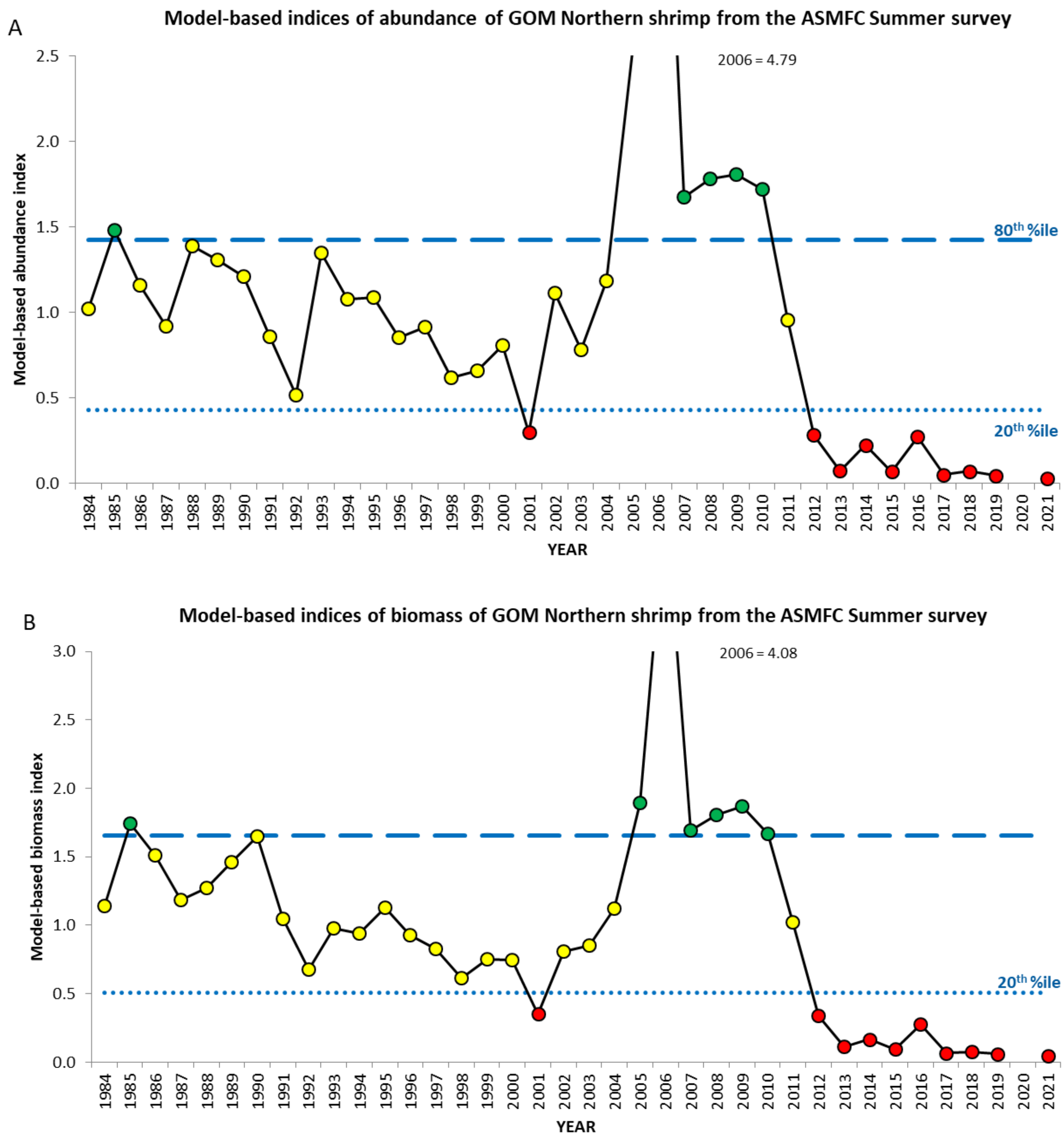
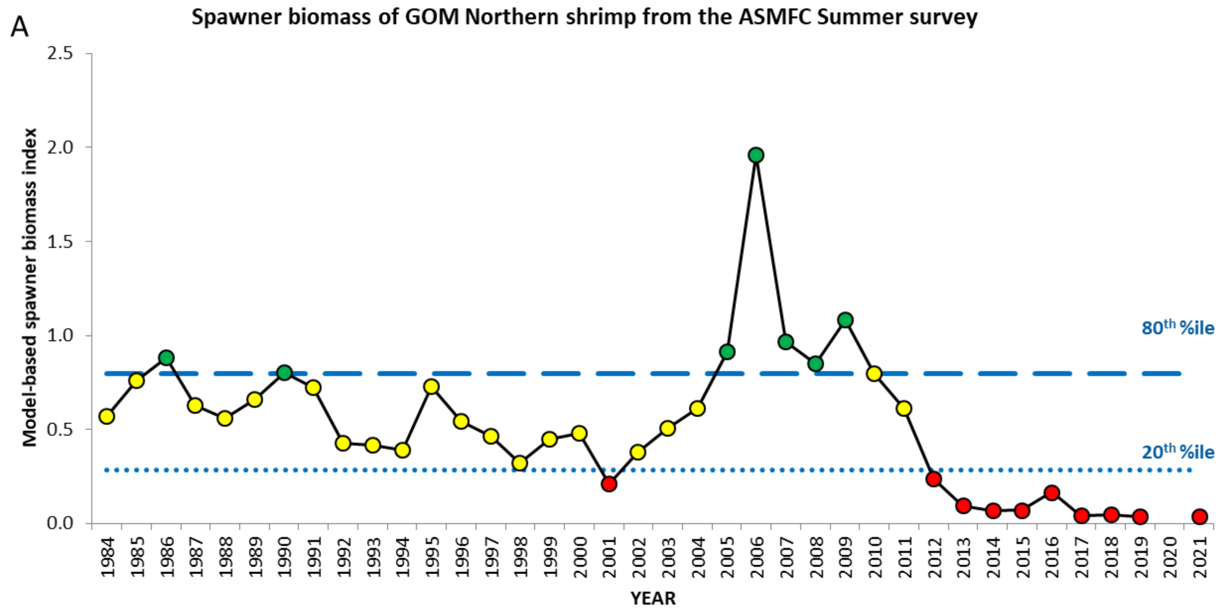



**Figure 6. Traffic light analysis for the model-based index of abundance (A) and biomass (B) of Gulf of Maine northern shrimp from the Summer Shrimp Survey, 1984-2021. The 20th percentile of the time series from 1984-2017 delineated an adverse state, and the 80th percentile of the time series from 1984-2017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



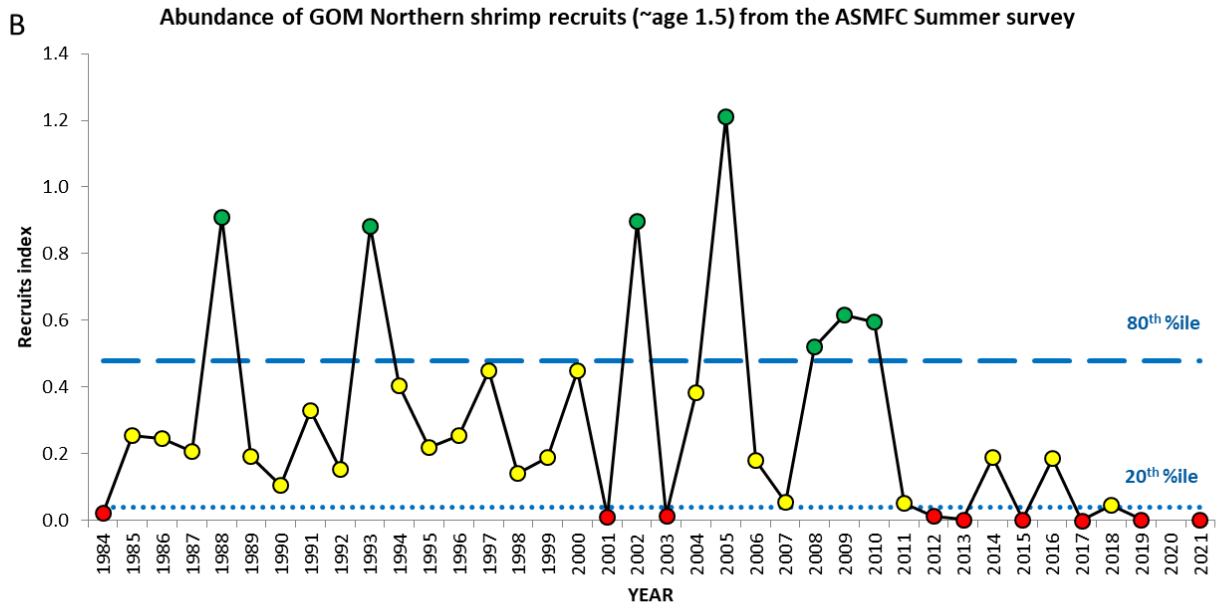




**Figure 7. Traffic light analysis of spawning biomass (top) and recruitment (bottom) of Gulf of Maine northern shrimp from the Summer Shrimp survey, 1984-2021. The 20th percentile of the time series from 1984-2017 delineated an adverse state, and the 80th percentile of the time series from 1984-2017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

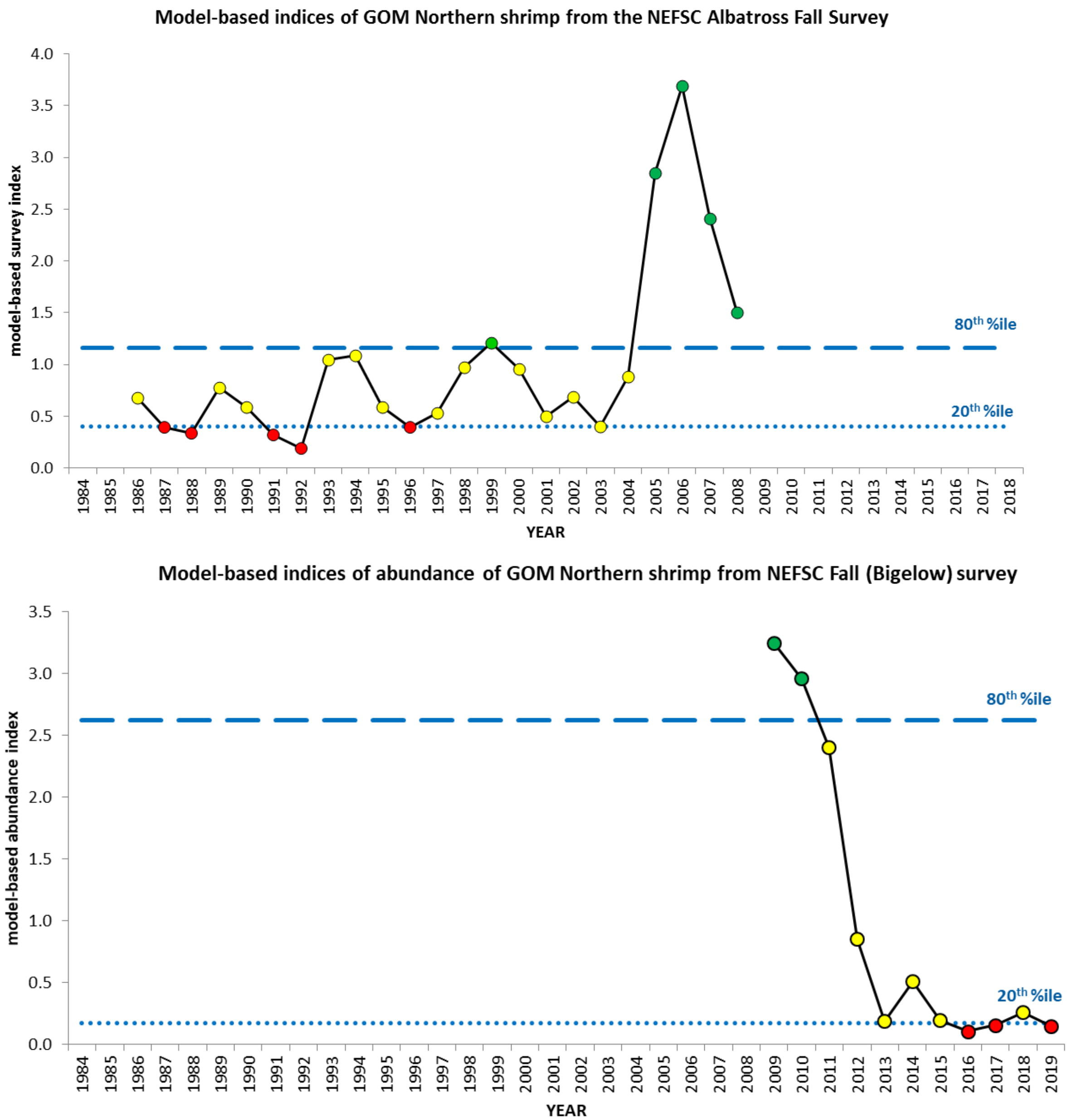



**Figure 8. Traffic light analysis for the model-based index of abundance of Gulf of Maine northern shrimp from the NEFSC Fall Survey (Albatross years top, Bigelow years bottom). The 20th percentile of the time series through 2017 delineated an adverse state, and the 80th percentile of the time series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

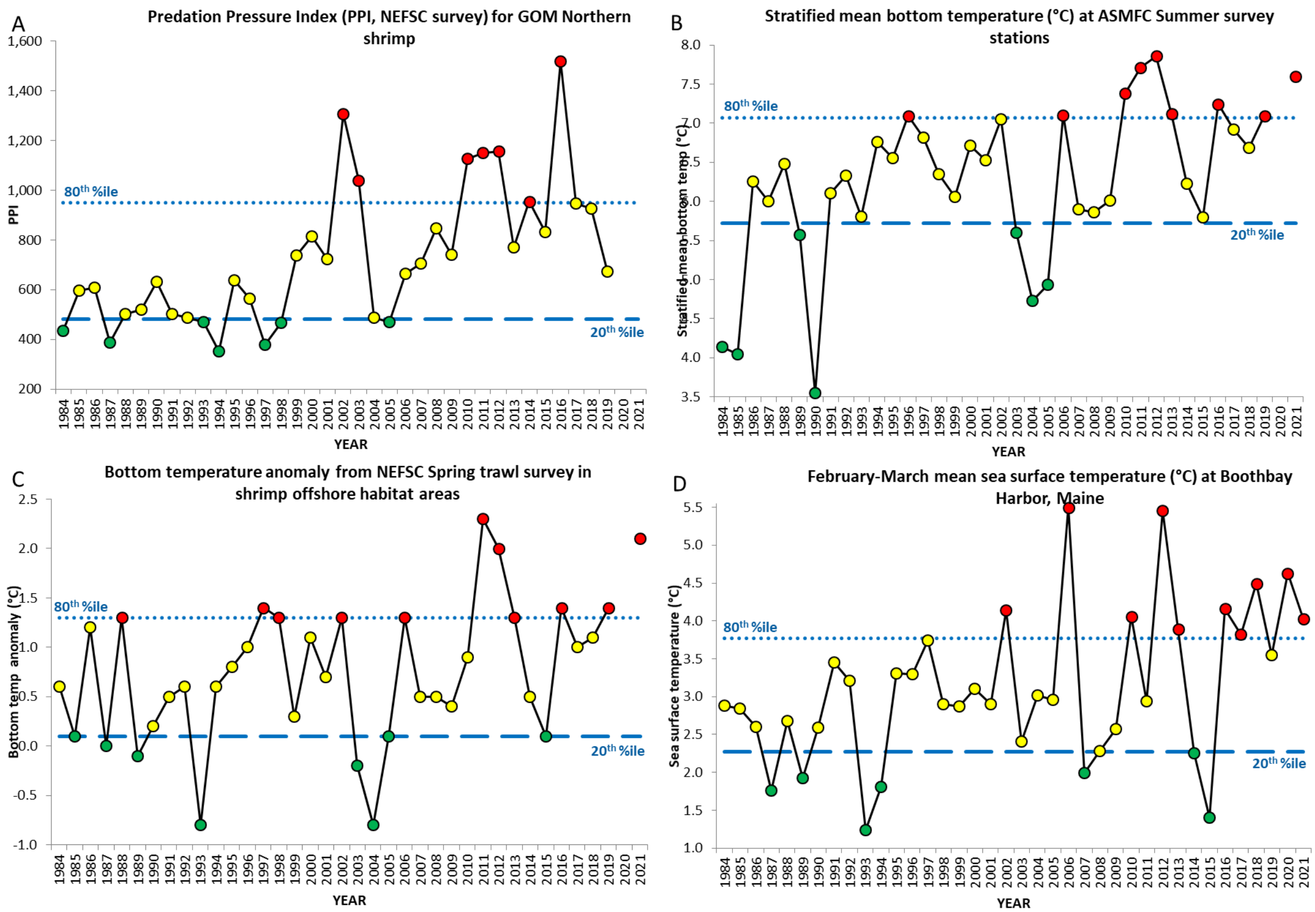



**Figure 9. Traffic light analysis of environmental conditions in the Gulf of Maine 1984-2019, including predation pressure (A), summer bottom temperature (B), spring bottom temperature (C), and winter sea surface temperature (D). The 20th percentile of the time series from 1984-2017 delineated a favorable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

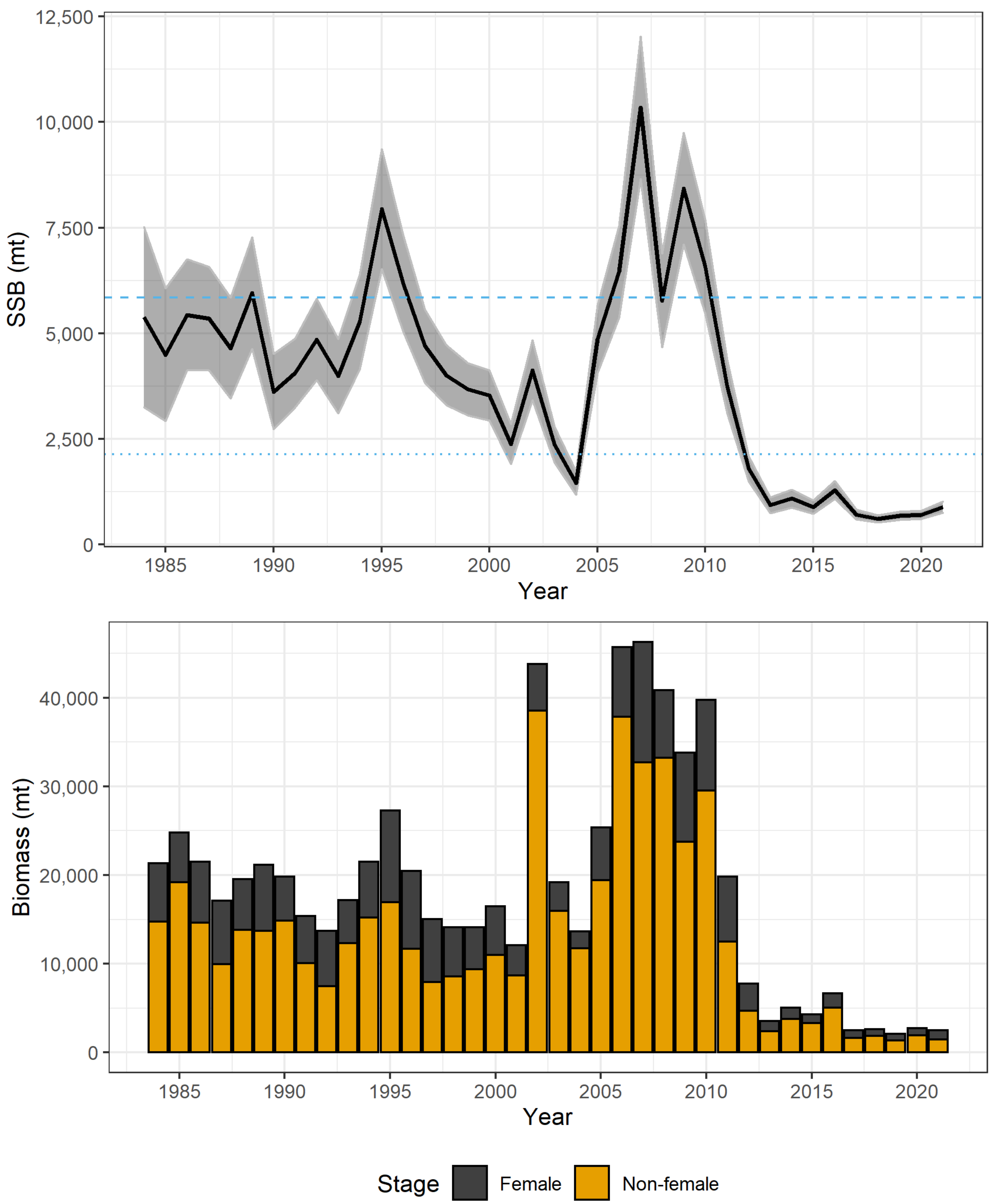



**Figure 10. Estimates of Gulf of Maine northern shrimp spawning stock biomass with 95% confidence intervals (top) and total biomass by stage (bottom) from the UME model. Dashed lines in the top figure indicated the 80th and 20th percentiles of the 1984-2017 SSB estimates.**

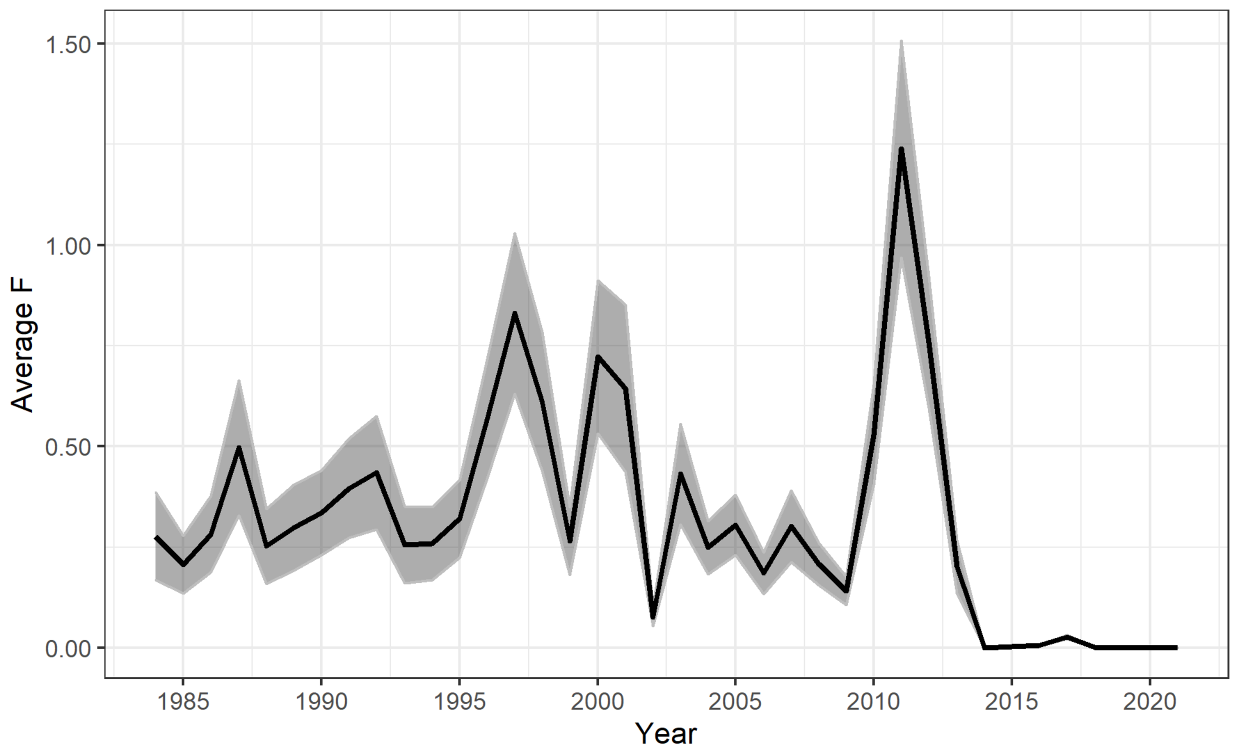



**Figure 11. Average fishing mortality on Gulf of Maine northern shrimp estimated by the UME model with 95% confidence intervals.**

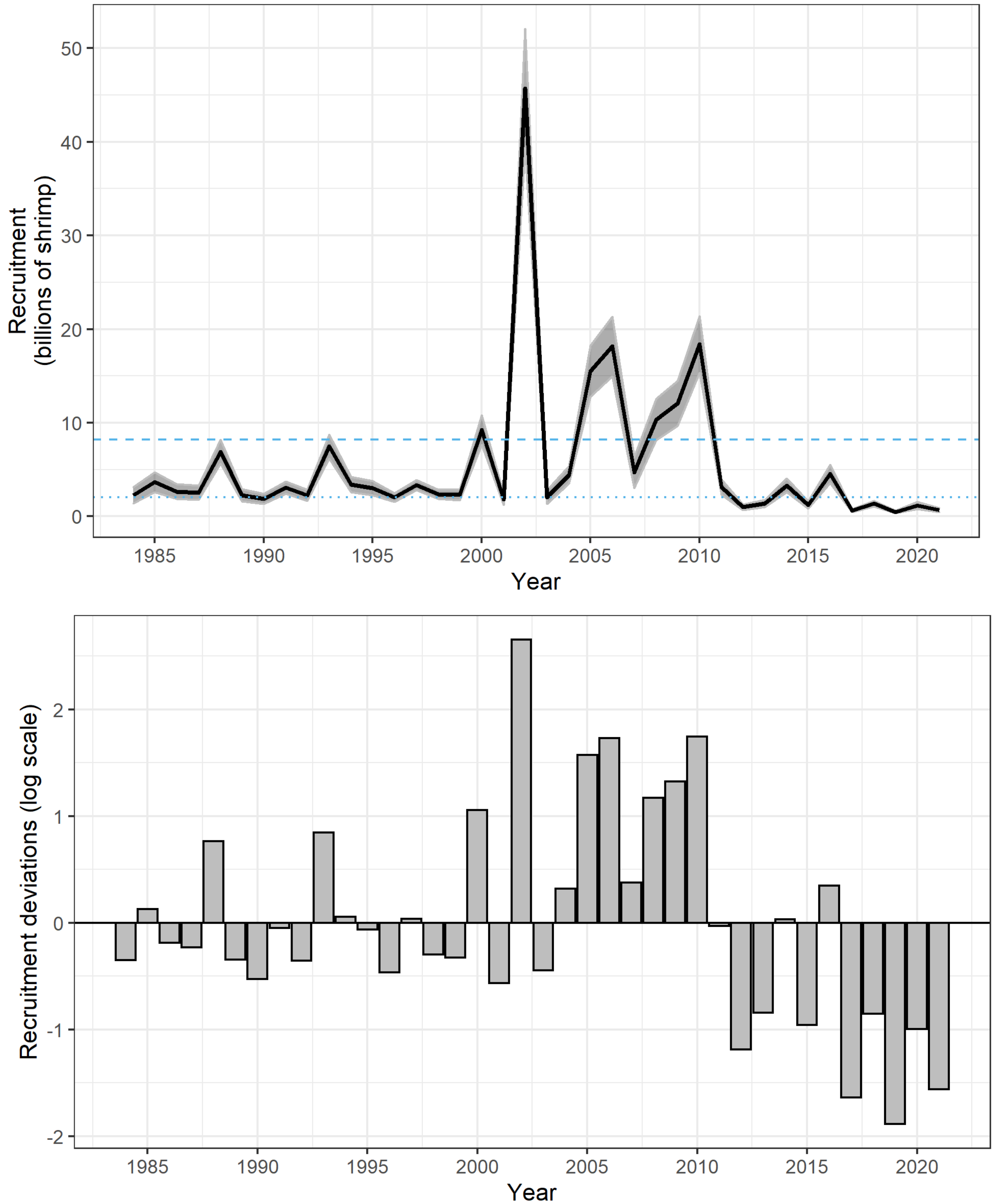



**Figure 12. Estimates of total recruitment with 95% confidence intervals (top) and annual deviations from mean recruitment (bottom) for Gulf of Maine northern shrimp from the UME model. Dashed lines in the top plot indicate the 80th and 20th percentiles of the 1984-2017 estimates.**

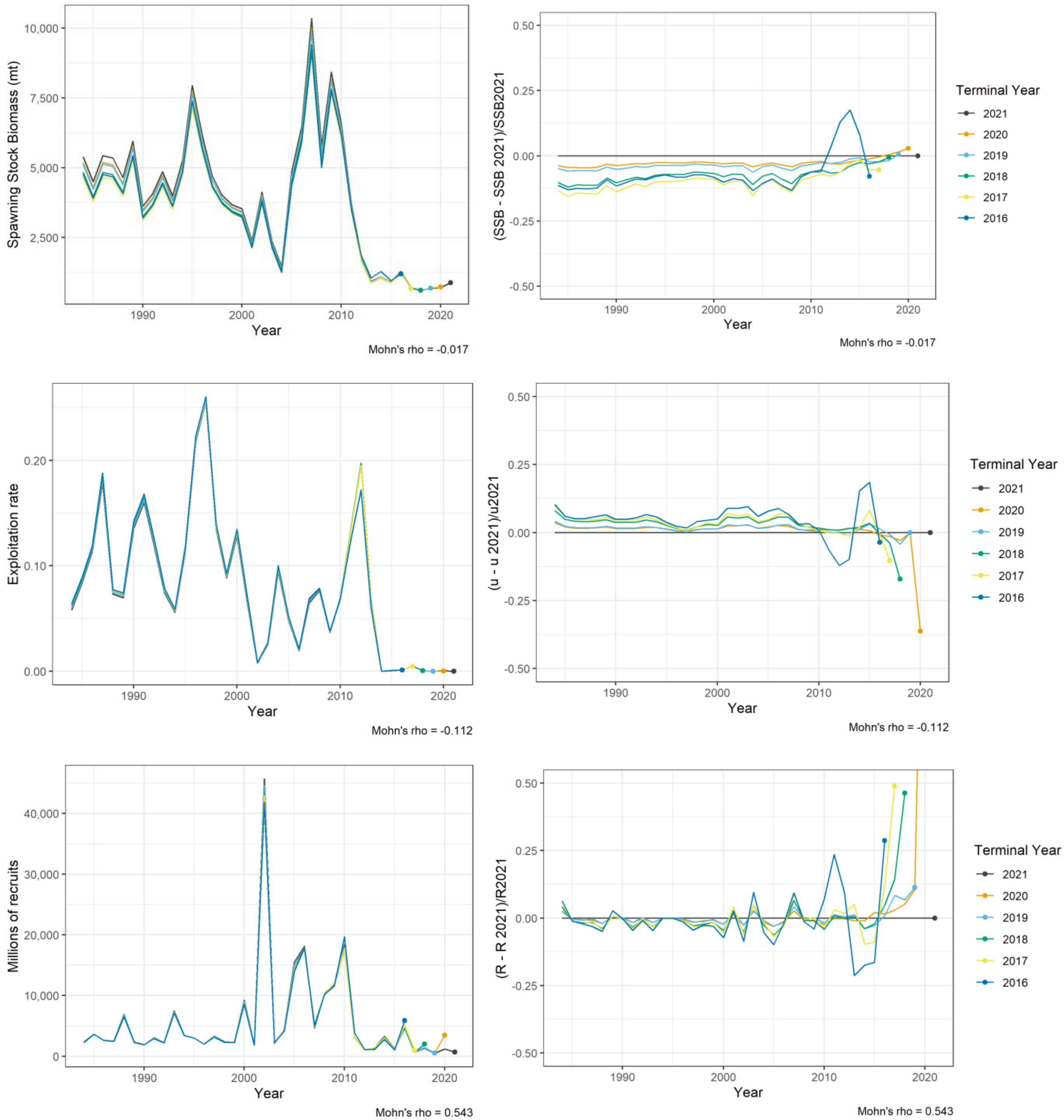



**Figure 13. Retrospective analysis of UME model results for spawning stock biomass (top), exploitation rate (middle), and recruitment (bottom).**

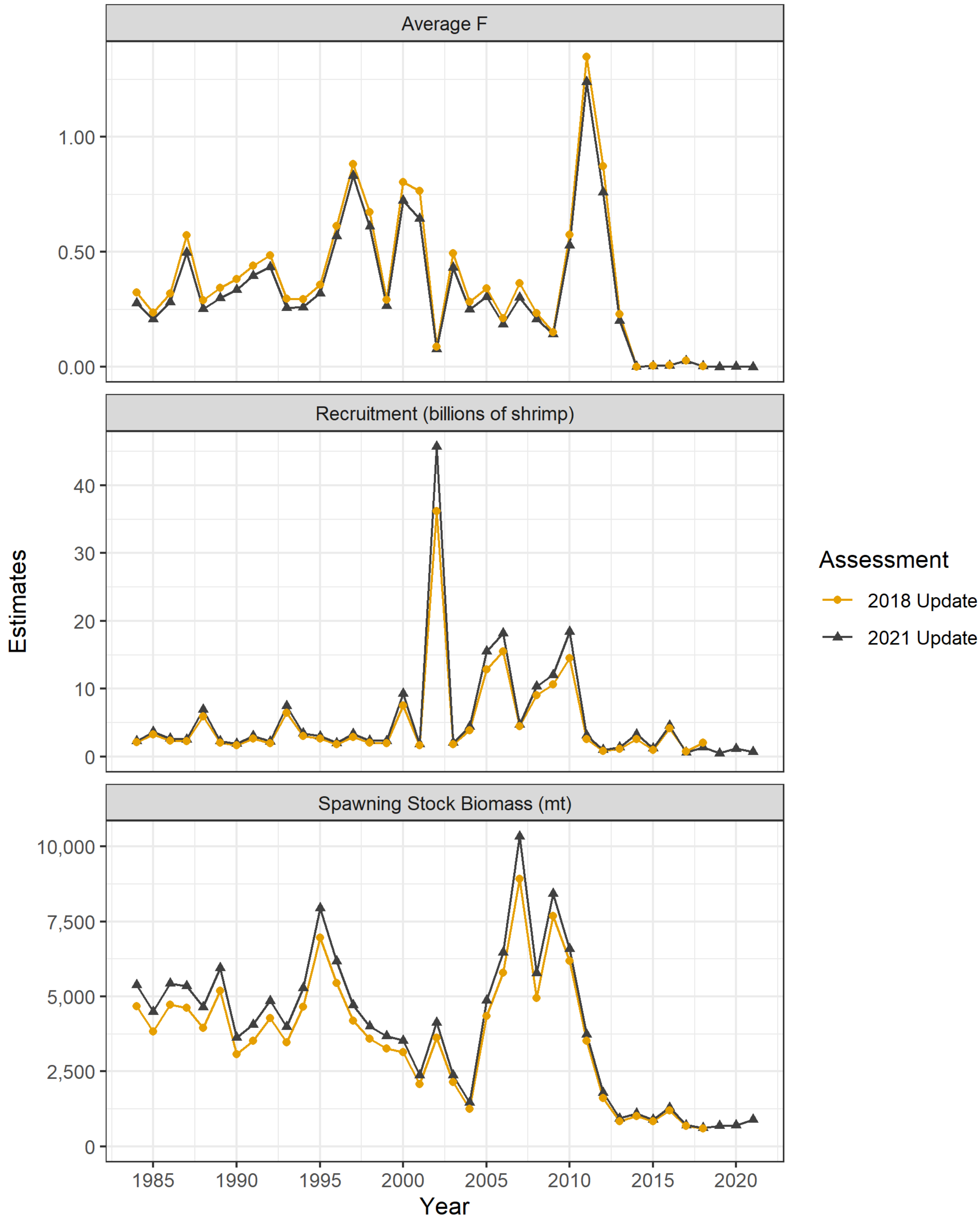



**Figure 14. Comparison of results from the 2018 assessment update and the 2021 assessment update.**

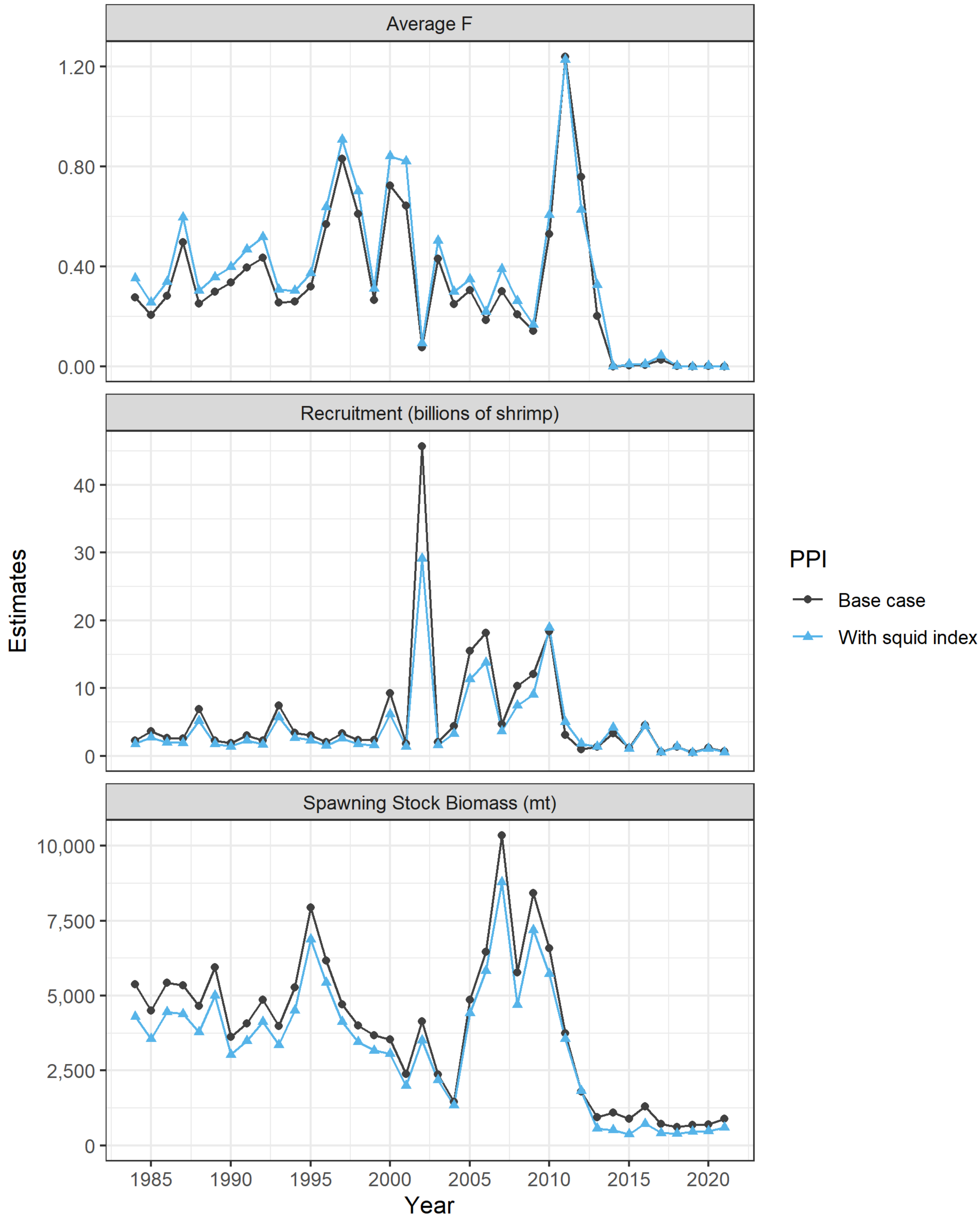



**Figure 15. Comparison of *F*, recruitment, and SSB for the base model and the model with the PPI that included squid.**

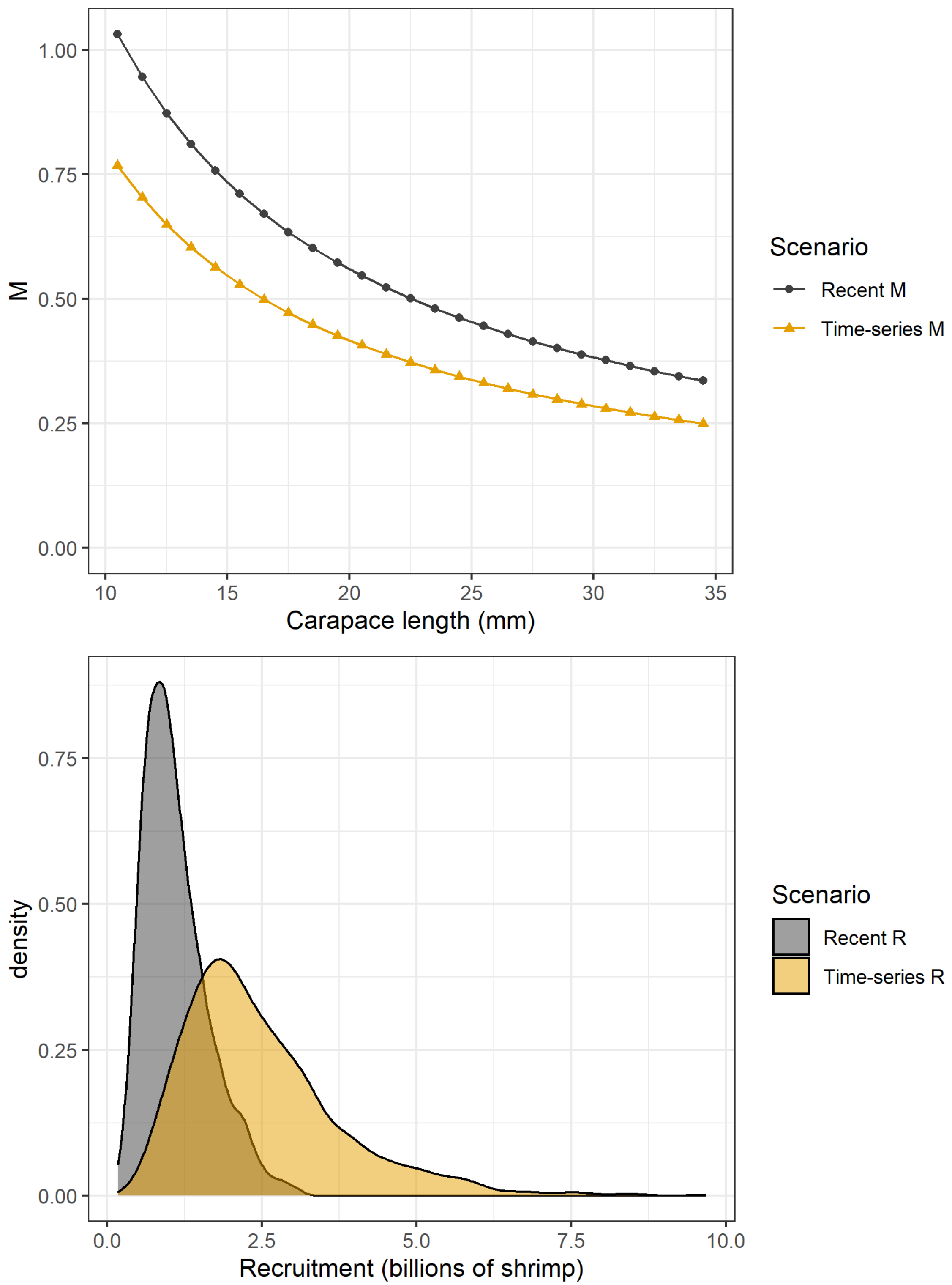



**Figure 16. Estimates of M and recruitment used in the short and long term projections.**

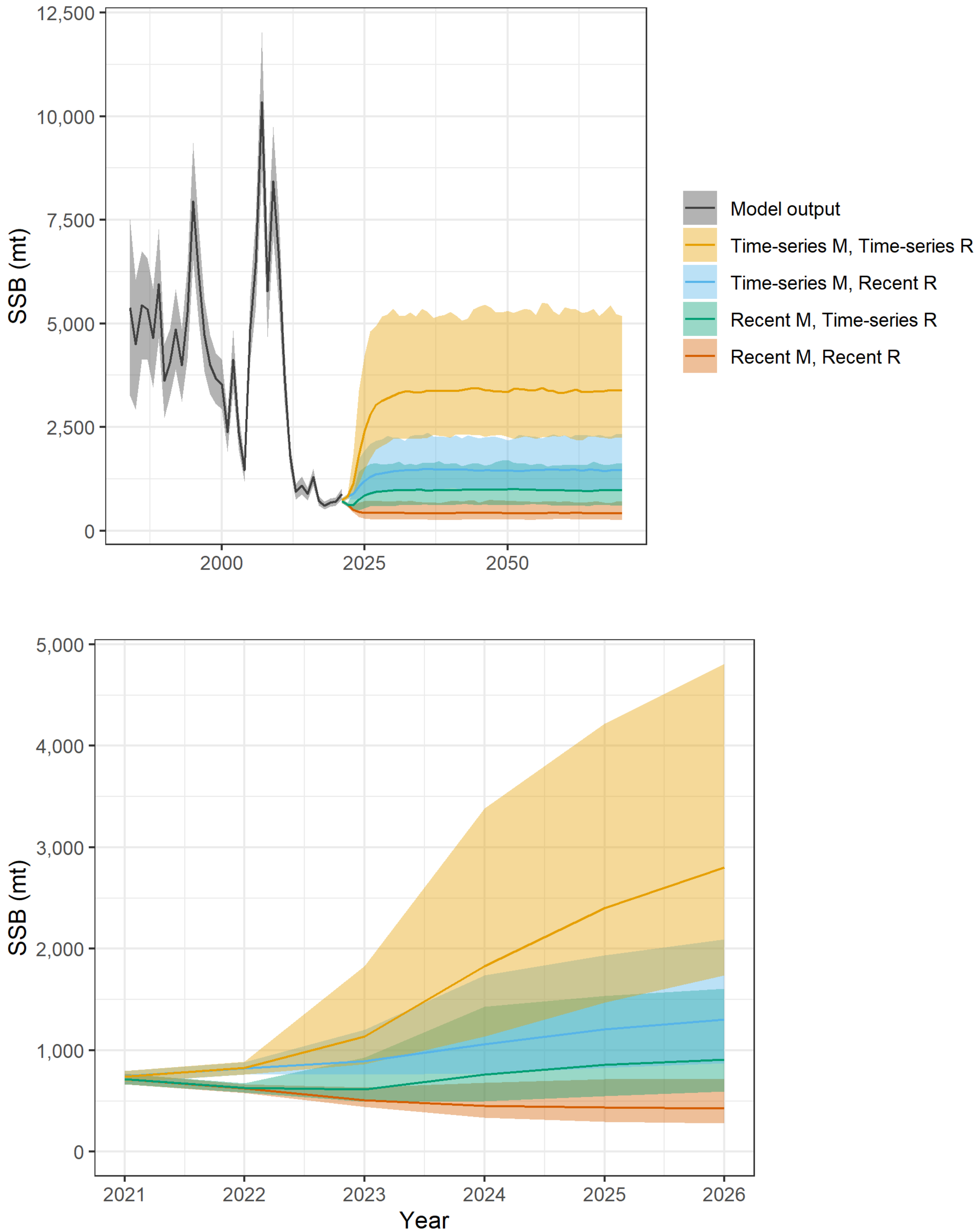



**Figure 17. Trajectory of long term (top) and short term (bottom) median spawning stock biomass estimates for Gulf of Maine northern shrimp under different natural mortality and recruitment scenarios in the absence of fishing. Shaded areas indicate 95% confidence intervals.**

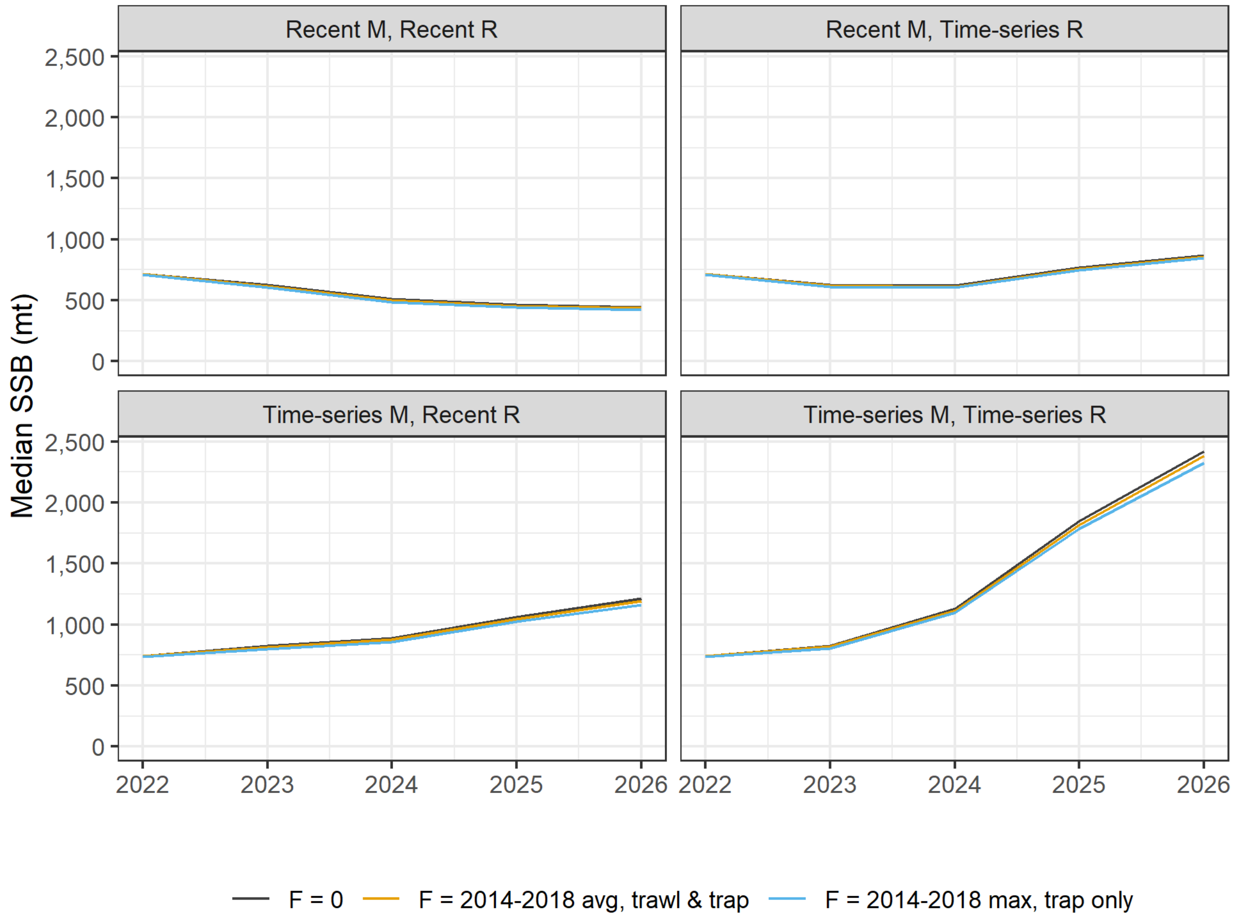



**Figure 18. Median SSB trajectories for short-term projections under different *F*, M, and recruitment scenarios.**

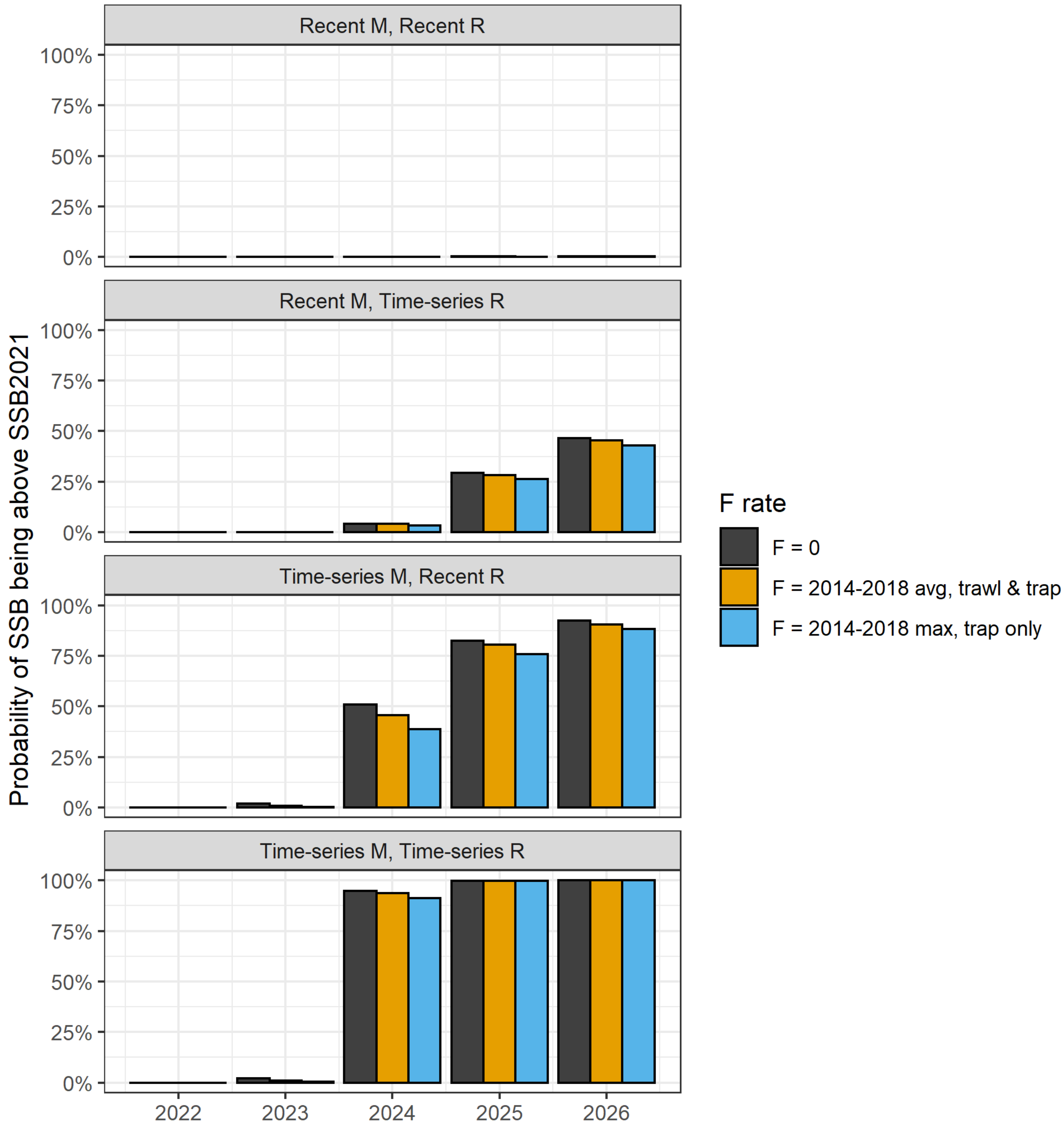



**Figure 19. Probability of SSB being above $SSB_{2021}$ under different combinations of *F*, M, and recruitment.**

**Appendix 1: Diagnostic Plots for the VAST Index Standardization Models**

N. Shrimp 2021 Assessment Update

**Table 1. VAST model configuration for the ASMFC Summer Survey index standardization.**

```
$Version
[1] "VAST_v13_0_0"

$Method
[1] "Mesh"

$grid_size_km
[1] 25

$n_x
[1] 500

$FieldConfig
  Omega1 Epsilon1   Omega2 Epsilon2
       1        1        1        1

$RhoConfig
   Beta1    Beta2 Epsilon1 Epsilon2
       0        0        0        0

$OverdispersionConfig
    Vessel VesselYear
         0          0

$ObsModel
[1] 2 3

$Kmeans_Config
$Kmeans_Config$randomseed
[1] 1

$Kmeans_Config$nstart
[1] 100

$Kmeans_Config$iter.max
[1] 1000
```

**Table 2. VAST model configuration for the NEFSC Fall Survey index standardization.**

```
$Version
[1] "VAST_v13_0_0"

$Method
[1] "Mesh"

$grid_size_km
[1] 25

$n_x
[1] 100

$FieldConfig
  Omega1 Epsilon1   Omega2 Epsilon2
       1        1        1        1

$RhoConfig
   Beta1    Beta2 Epsilon1 Epsilon2
       0        0        0        0

$OverdispersionConfig
    Vessel VesselYear
         0          0

$ObsModel
[1] 2 0

$Kmeans_Config
$Kmeans_Config$randomseed
[1] 1

$Kmeans_Config$nstart
[1] 100

$Kmeans_Config$iter.max
[1] 1000
```

**Table 3. VAST model configuration for the ME-NH Spring Survey index standardization.**

```
$Version
[1] "VAST_v13_0_0"

$Method
[1] "Mesh"

$grid_size_km
[1] 25

$n_x
[1] 500

$FieldConfig
  Omega1 Epsilon1   Omega2 Epsilon2
       1        1        1        1

$RhoConfig
   Beta1    Beta2 Epsilon1 Epsilon2
       0        0        0        0

$OverdispersionConfig
    Vessel VesselYear
         0          0

$ObsModel
[1] 2 3

$Kmeans_Config
$Kmeans_Config$randomseed
[1] 1

$Kmeans_Config$nstart
[1] 100

$Kmeans_Config$iter.max
[1] 1000
```

## Table 4. VAST parameter estimates for the ASMFC Summer Survey

| Parameter | Lower Bound | MLE | Upper Bound | Final Gradient |
|---|---|---|---|---|
| ln_H_input | -5 | -0.07 | 5 | -2.20E-07 |
| ln_H_input | -5 | 0.18 | 5 | 4.52E-08 |
| beta1_ft | -Inf | 15.00 | Inf | -2.75E-08 |
| beta1_ft | -Inf | 15.22 | Inf | -1.97E-07 |
| beta1_ft | -Inf | 13.88 | Inf | -6.45E-10 |
| beta1_ft | -Inf | 14.07 | Inf | 8.38E-09 |
| beta1_ft | -Inf | 15.80 | Inf | 3.63E-08 |
| beta1_ft | -Inf | 16.85 | Inf | 6.95E-09 |
| beta1_ft | -Inf | 16.73 | Inf | -1.11E-08 |
| beta1_ft | -Inf | 17.13 | Inf | -5.19E-08 |
| beta1_ft | -Inf | 15.88 | Inf | -2.39E-07 |
| beta1_ft | -Inf | 20.39 | Inf | -1.07E-07 |
| beta1_ft | -Inf | 16.48 | Inf | -2.61E-09 |
| beta1_ft | -Inf | 16.12 | Inf | -3.86E-07 |
| beta1_ft | -Inf | 15.27 | Inf | -2.36E-07 |
| beta1_ft | -Inf | 16.03 | Inf | 1.81E-09 |
| beta1_ft | -Inf | 16.39 | Inf | -6.21E-08 |
| beta1_ft | -Inf | 15.97 | Inf | -9.99E-08 |
| beta1_ft | -Inf | 16.42 | Inf | -1.75E-07 |
| beta1_ft | -Inf | 16.77 | Inf | -3.43E-07 |
| beta1_ft | -Inf | 16.97 | Inf | -3.85E-07 |
| beta1_ft | -Inf | 17.22 | Inf | -2.17E-07 |
| beta1_ft | -Inf | 16.14 | Inf | -1.54E-07 |
| beta1_ft | -Inf | 14.56 | Inf | 6.29E-08 |
| beta1_ft | -Inf | 16.24 | Inf | -2.69E-07 |
| beta1_ft | -Inf | 16.63 | Inf | -9.82E-09 |
| beta1_ft | -Inf | 13.73 | Inf | 6.34E-08 |
| beta1_ft | -Inf | 14.72 | Inf | -5.02E-08 |
| beta1_ft | -Inf | 13.08 | Inf | 1.16E-07 |
| L_omega1_z | -Inf | 34.82 | Inf | 3.19E-07 |
| L_epsilon1_z | -Inf | 102.87 | Inf | -4.73E-08 |
| logkappa1 | -4.61 | -0.65 | 1.33 | -4.94E-06 |
| beta2_ft | -Inf | 9.88 | Inf | 1.53E-10 |
| beta2_ft | -Inf | 10.57 | Inf | 1.11E-10 |
| beta2_ft | -Inf | 10.07 | Inf | 2.53E-11 |
| beta2_ft | -Inf | 9.74 | Inf | 5.24E-11 |
| beta2_ft | -Inf | 9.94 | Inf | 1.90E-10 |
| beta2_ft | -Inf | 10.16 | Inf | 2.27E-09 |
| beta2_ft | -Inf | 10.13 | Inf | -2.12E-09 |
| beta2_ft | -Inf | 9.75 | Inf | 2.91E-10 |

**Table 4 (cont.)**

| Parameter | Lower Bound | MLE | Upper Bound | Final Gradient |
|---|---|---|---|---|
| beta2_ft | -Inf | 9.27 | Inf | -6.77E-10 |
| beta2_ft | -Inf | 9.95 | Inf | -5.21E-10 |
| beta2_ft | -Inf | 9.84 | Inf | 7.82E-10 |
| beta2_ft | -Inf | 9.94 | Inf | -5.83E-10 |
| beta2_ft | -Inf | 9.36 | Inf | -2.27E-10 |
| beta2_ft | -Inf | 9.53 | Inf | 2.72E-10 |
| beta2_ft | -Inf | 8.98 | Inf | 1.89E-09 |
| beta2_ft | -Inf | 9.36 | Inf | 9.80E-10 |
| beta2_ft | -Inf | 9.62 | Inf | 1.48E-09 |
| beta2_ft | -Inf | 8.68 | Inf | -7.31E-10 |
| beta2_ft | -Inf | 9.87 | Inf | -1.50E-10 |
| beta2_ft | -Inf | 9.60 | Inf | 7.35E-10 |
| beta2_ft | -Inf | 10.07 | Inf | 5.33E-11 |
| beta2_ft | -Inf | 10.85 | Inf | -2.81E-10 |
| beta2_ft | -Inf | 11.46 | Inf | 5.24E-10 |
| beta2_ft | -Inf | 10.15 | Inf | 3.07E-11 |
| beta2_ft | -Inf | 10.34 | Inf | -1.59E-10 |
| beta2_ft | -Inf | 10.26 | Inf | 1.55E-10 |
| beta2_ft | -Inf | 9.87 | Inf | -2.20E-10 |
| beta2_ft | -Inf | 9.31 | Inf | 5.07E-10 |
| beta2_ft | -Inf | 7.92 | Inf | 2.20E-11 |
| beta2_ft | -Inf | 6.46 | Inf | 5.70E-10 |
| beta2_ft | -Inf | 7.72 | Inf | 2.43E-10 |
| beta2_ft | -Inf | 6.70 | Inf | 1.35E-09 |
| beta2_ft | -Inf | 7.94 | Inf | -1.38E-10 |
| beta2_ft | -Inf | 6.25 | Inf | 4.78E-10 |
| beta2_ft | -Inf | 6.47 | Inf | 7.67E-10 |
| beta2_ft | -Inf | 5.89 | Inf | 1.13E-09 |
| beta2_ft | -Inf | 5.76 | Inf | 6.17E-10 |
| L_omega2_z | -Inf | 1.67 | Inf | -3.25E-08 |
| L_epsilon2_z | -Inf | 0.64 | Inf | -2.21E-08 |
| logkappa2 | -4.61 | -3.50 | 1.33 | 4.90E-08 |
| logSigmaM | -Inf | -0.21 | 10 | -3.01E-08 |

**Table 5. VAST parameter estimates for the NEFSC Fall Survey**

| Parameter | Lower Bound | MLE | Upper Bound | Final Gradient |
|---|---|---|---|---|
| ln_H_input | -5 | -0.03 | 5 | -1.50E-09 |
| ln_H_input | -5 | 0.55 | 5 | -2.24E-09 |
| beta1_ft | -Inf | 1.50 | Inf | -1.70E-10 |
| beta1_ft | -Inf | 0.76 | Inf | 3.20E-11 |
| beta1_ft | -Inf | 0.71 | Inf | -4.19E-10 |
| beta1_ft | -Inf | 0.95 | Inf | 6.45E-11 |
| beta1_ft | -Inf | 0.52 | Inf | 7.38E-11 |
| beta1_ft | -Inf | 1.34 | Inf | -4.55E-10 |
| beta1_ft | -Inf | 1.23 | Inf | -3.95E-11 |
| beta1_ft | -Inf | 1.26 | Inf | -4.24E-11 |
| beta1_ft | -Inf | -0.06 | Inf | 3.08E-10 |
| beta1_ft | -Inf | -0.51 | Inf | 4.33E-10 |
| beta1_ft | -Inf | -0.46 | Inf | 2.76E-10 |
| L_omega1_z | -Inf | -2.23 | Inf | 1.08E-09 |
| L_epsilon1_z | -Inf | 0.00 | Inf | 1.23E-09 |
| logkappa1 | -Inf | -3.69 | Inf | -2.07E-09 |
| beta2_ft | -Inf | 9.59 | Inf | -3.97E-12 |
| beta2_ft | -Inf | 9.42 | Inf | 2.05E-10 |
| beta2_ft | -Inf | 9.12 | Inf | 8.71E-11 |
| beta2_ft | -Inf | 8.12 | Inf | -1.30E-10 |
| beta2_ft | -Inf | 6.31 | Inf | -5.19E-11 |
| beta2_ft | -Inf | 7.33 | Inf | -1.29E-10 |
| beta2_ft | -Inf | 6.39 | Inf | 2.95E-11 |
| beta2_ft | -Inf | 6.10 | Inf | 6.58E-11 |
| beta2_ft | -Inf | 6.22 | Inf | 1.37E-11 |
| beta2_ft | -Inf | 6.93 | Inf | 7.39E-11 |
| beta2_ft | -Inf | 6.47 | Inf | 2.72E-11 |
| L_omega2_z | -Inf | -1.51 | Inf | 4.95E-09 |
| L_epsilon2_z | -Inf | 0.64 | Inf | 1.45E-09 |
| logkappa2 | -Inf | -3.25 | Inf | -3.39E-09 |
| logSigmaM | -Inf | 0.00 | 10 | -2.15E-10 |

**Table 6. VAST parameter estimates for the ME-NH Spring Survey**

| Parameter | Lower Bound | MLE | Upper Bound | Final Gradient |
|---|---|---|---|---|
| ln_H_input | -5 | -0.03 | 5 | -1.50E-09 |
| ln_H_input | -5 | 0.55 | 5 | -2.24E-09 |
| beta1_ft | -Inf | 1.50 | Inf | -1.70E-10 |
| beta1_ft | -Inf | 0.76 | Inf | 3.20E-11 |
| beta1_ft | -Inf | 0.71 | Inf | -4.19E-10 |
| beta1_ft | -Inf | 0.95 | Inf | 6.45E-11 |
| beta1_ft | -Inf | 0.52 | Inf | 7.38E-11 |
| beta1_ft | -Inf | 1.34 | Inf | -4.55E-10 |
| beta1_ft | -Inf | 1.23 | Inf | -3.95E-11 |
| beta1_ft | -Inf | 1.26 | Inf | -4.24E-11 |
| beta1_ft | -Inf | -0.06 | Inf | 3.08E-10 |
| beta1_ft | -Inf | -0.51 | Inf | 4.33E-10 |
| beta1_ft | -Inf | -0.46 | Inf | 2.76E-10 |
| L_omega1_z | -Inf | -2.23 | Inf | 1.08E-09 |
| L_epsilon1_z | -Inf | 0.00 | Inf | 1.23E-09 |
| logkappa1 | -Inf | -3.69 | Inf | -2.07E-09 |
| beta2_ft | -Inf | 9.59 | Inf | -3.97E-12 |
| beta2_ft | -Inf | 9.42 | Inf | 2.05E-10 |
| beta2_ft | -Inf | 9.12 | Inf | 8.71E-11 |
| beta2_ft | -Inf | 8.12 | Inf | -1.30E-10 |
| beta2_ft | -Inf | 6.31 | Inf | -5.19E-11 |
| beta2_ft | -Inf | 7.33 | Inf | -1.29E-10 |
| beta2_ft | -Inf | 6.39 | Inf | 2.95E-11 |
| beta2_ft | -Inf | 6.10 | Inf | 6.58E-11 |
| beta2_ft | -Inf | 6.22 | Inf | 1.37E-11 |
| beta2_ft | -Inf | 6.93 | Inf | 7.39E-11 |
| beta2_ft | -Inf | 6.47 | Inf | 2.72E-11 |
| L_omega2_z | -Inf | -1.51 | Inf | 4.95E-09 |
| L_epsilon2_z | -Inf | 0.64 | Inf | 1.45E-09 |
| logkappa2 | -Inf | -3.25 | Inf | -3.39E-09 |
| logSigmaM | -Inf | 0.00 | 10 | -2.15E-10 |

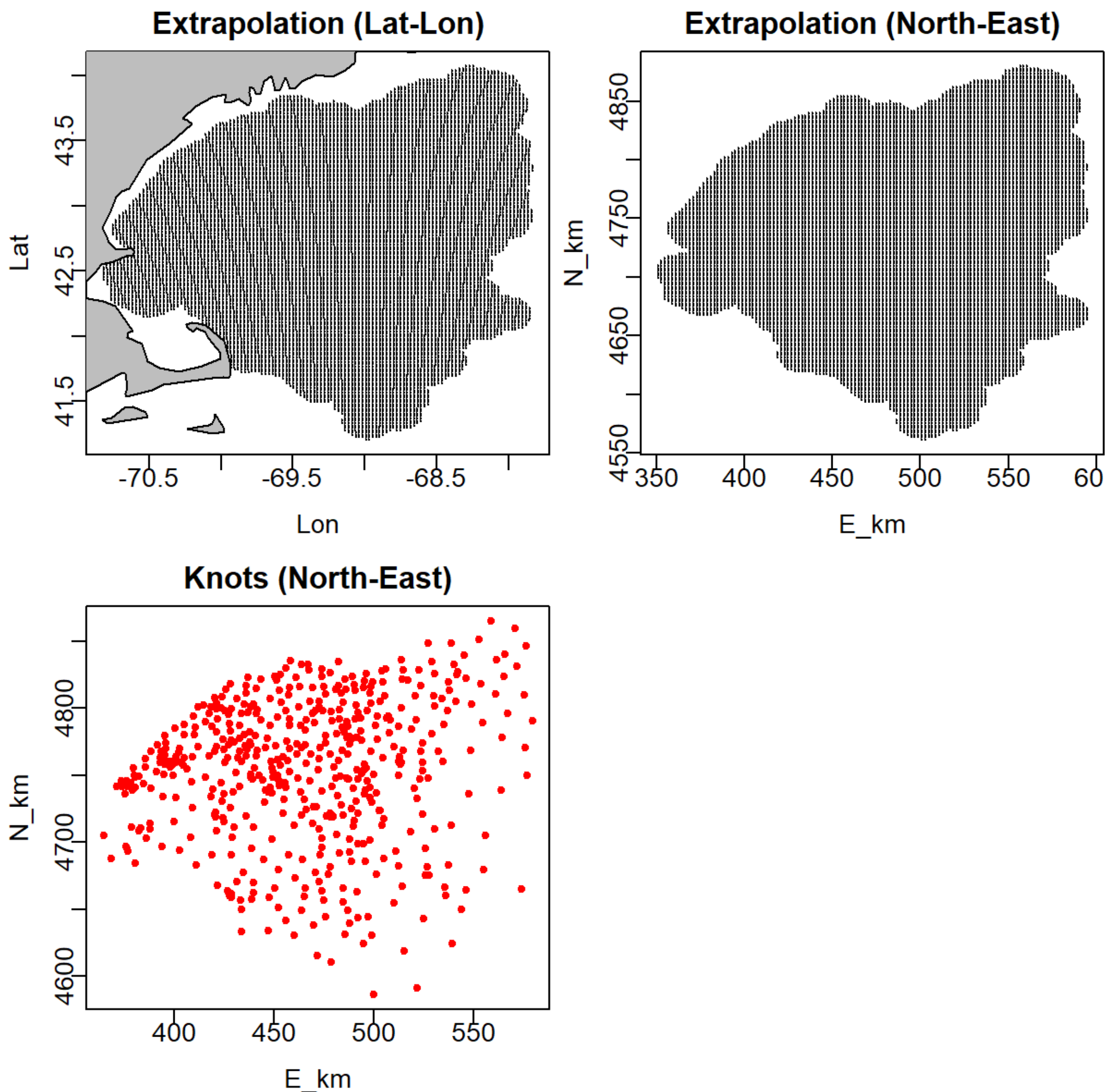



**Figure 1. Extrapolation grid and knots for ASMFC Summer Survey.**


**Figure 2. ASMFC Summer Survey catch locations by year.**

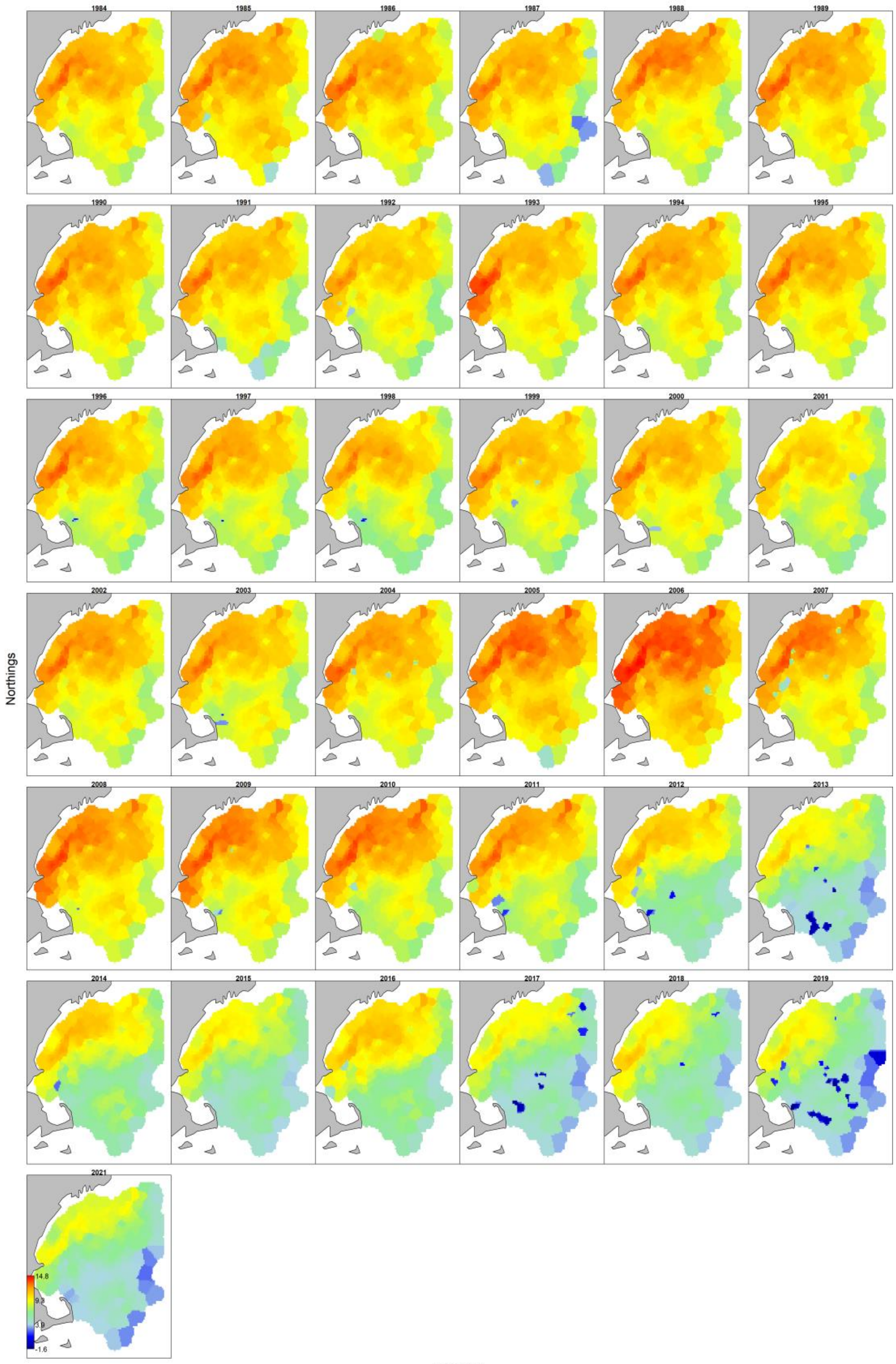



**Figure 3. Annual predicted population density (log-scale) by area for the ASMFC Summer Survey.**


**Figure 4.** Annual proportion positive Pearson residuals by area for the ASMFC Summer Survey.


**Figure 5. Annual total catch Pearson's residuals by area for the ASMFC Summer Survey.**

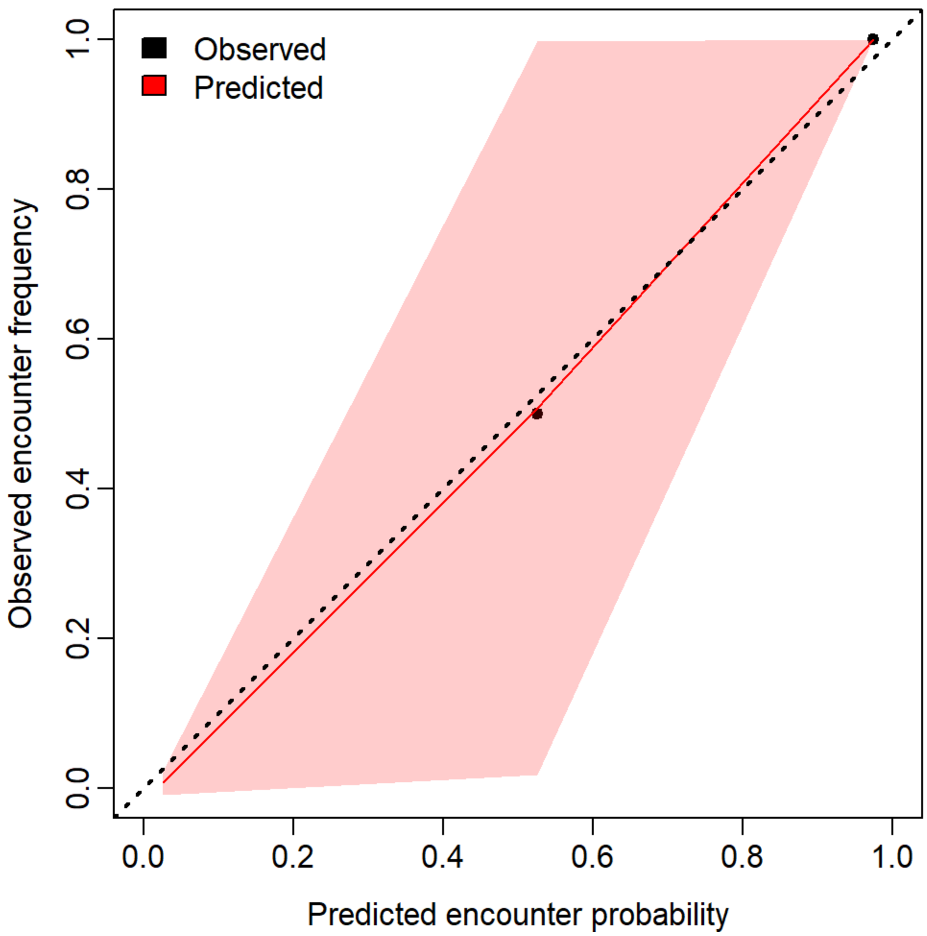



**Figure 6. Observed and predicted encounter probability with confidence intervals (shaded red area) for the ASMFC Summer Survey.**

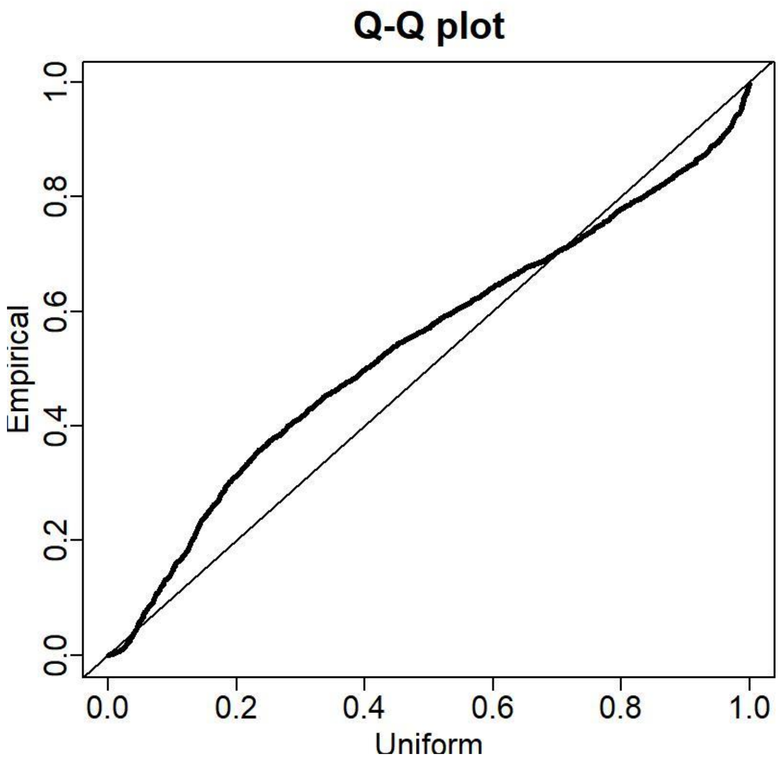



**Figure 7. QQ-plot for ASMFC Summer Survey residuals.**

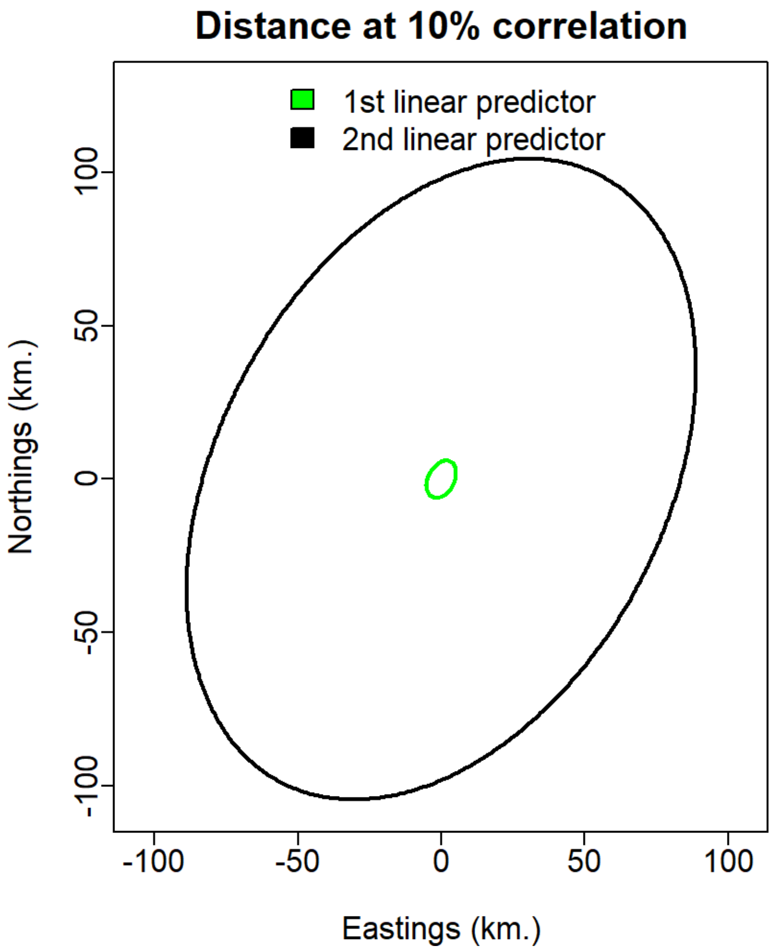


**Figure 8. Direction of geometric anisotropy for the ASMFC Summer Survey.**

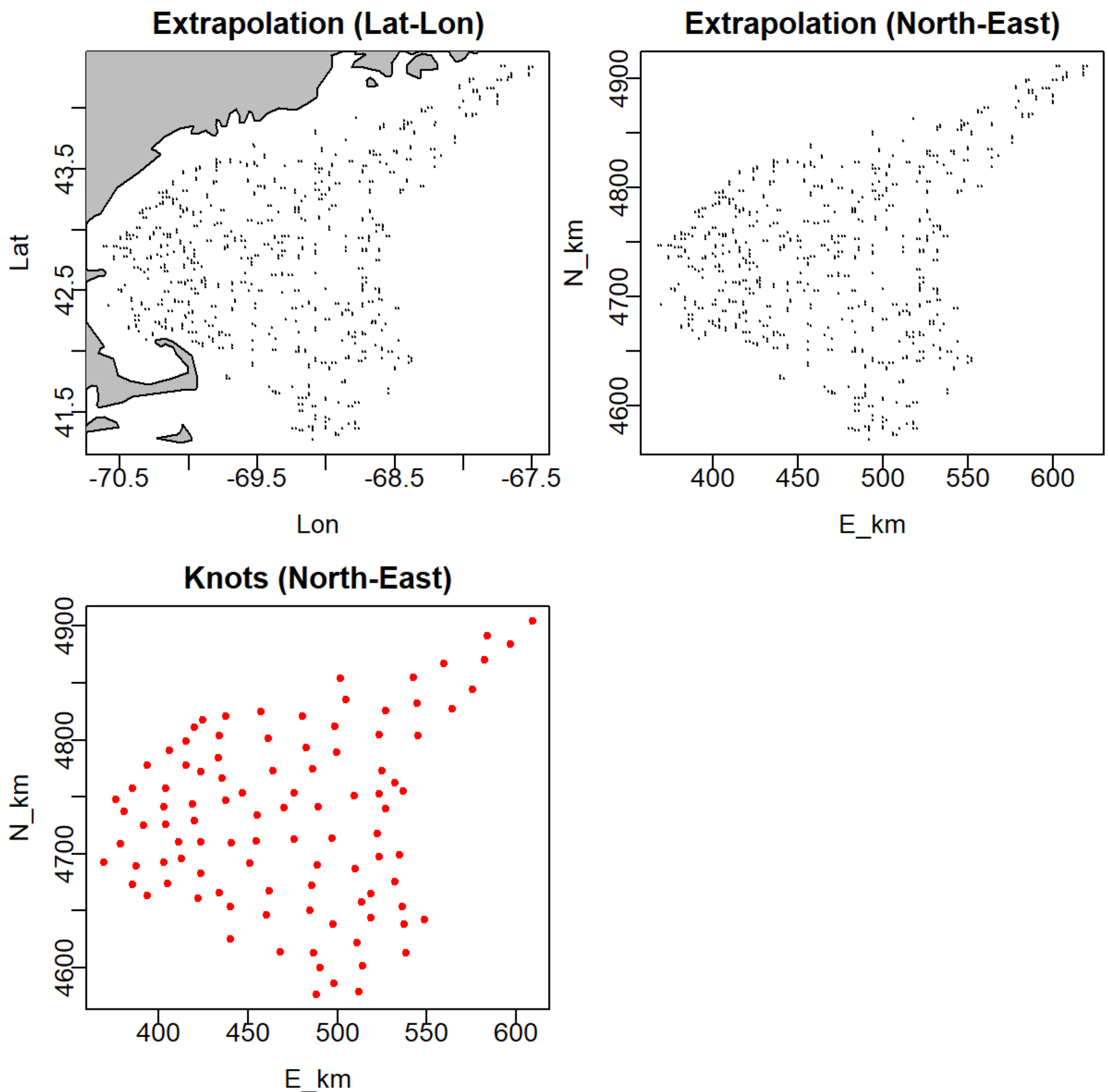



**Figure 9. Extrapolation grid and knots for NEFSC Fall Survey.**

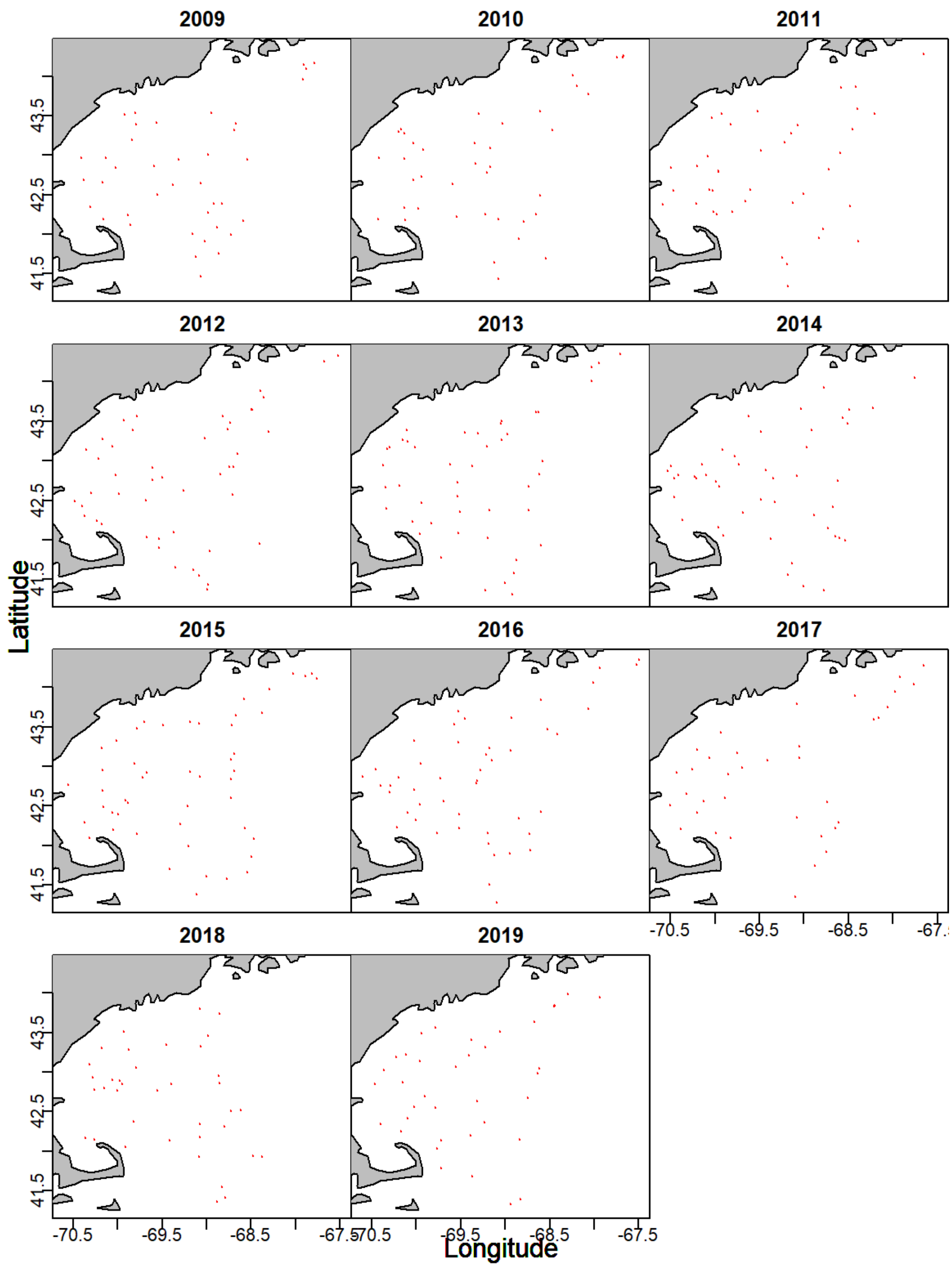



**Figure 10. NEFSC Fall Survey catch locations by year.**

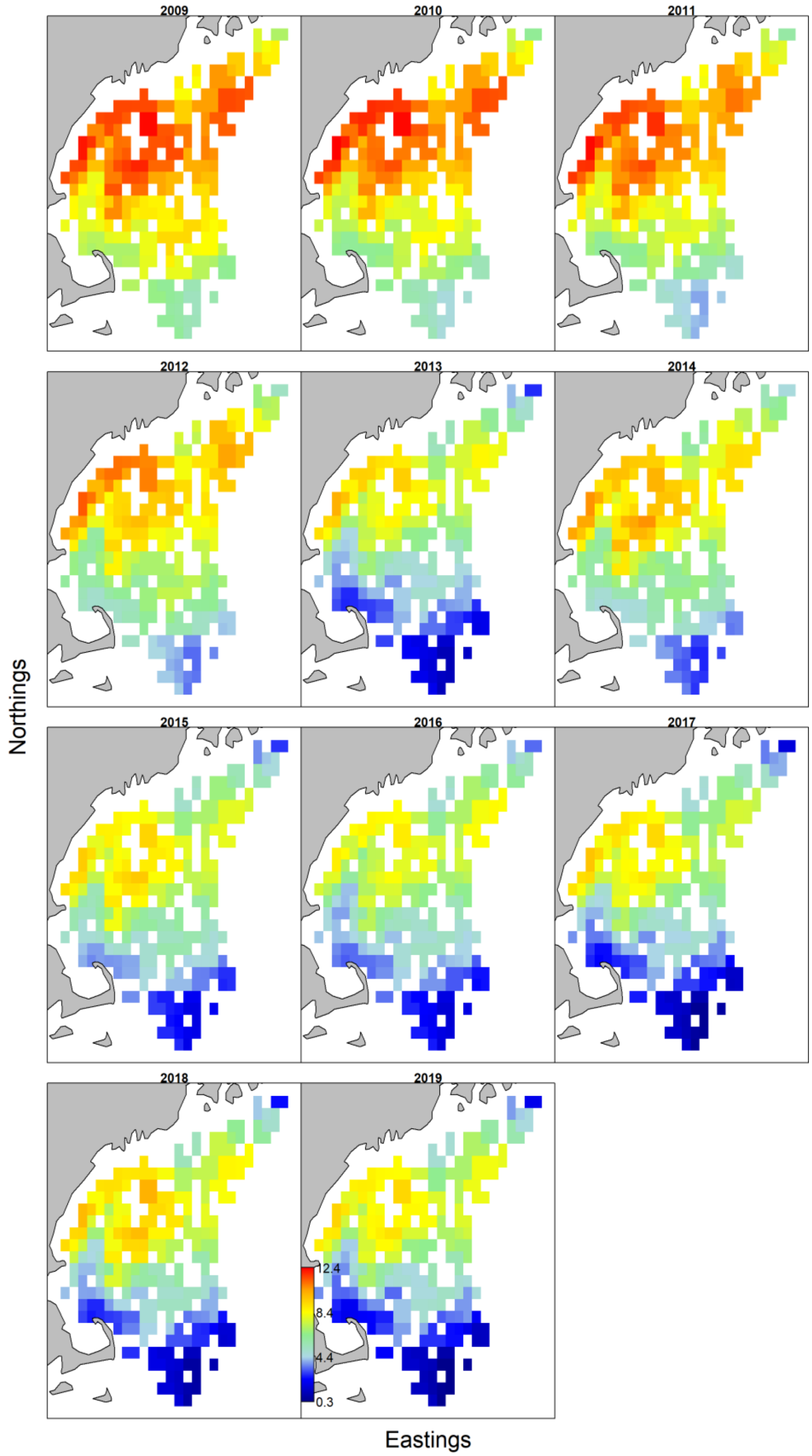



**Figure 11. Annual predicted population density (log-scale) by area for the NEFSC Fall Survey.**

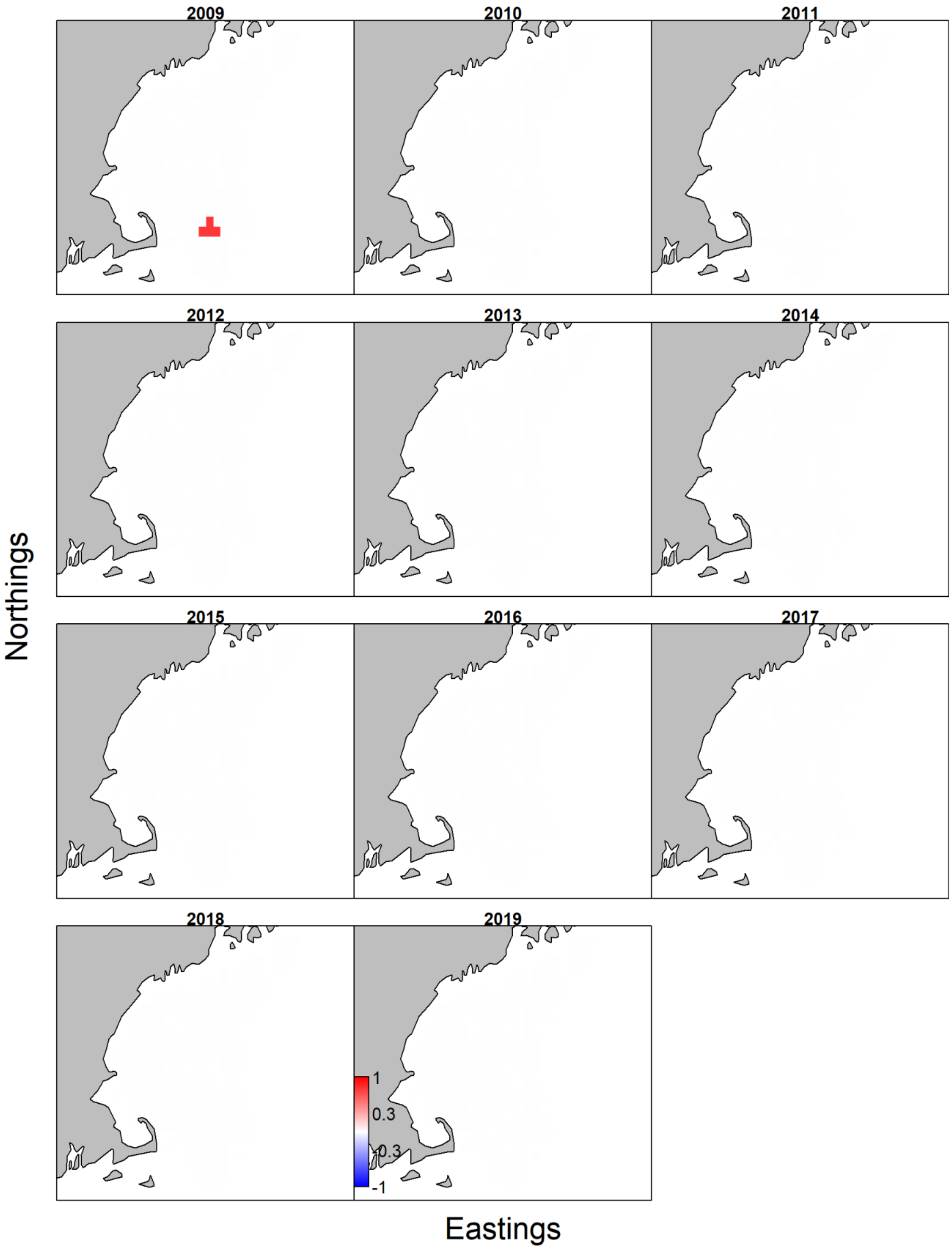



**Figure 12. Annual proportion positive Pearson residuals by area for the NEFSC Fall Survey.**

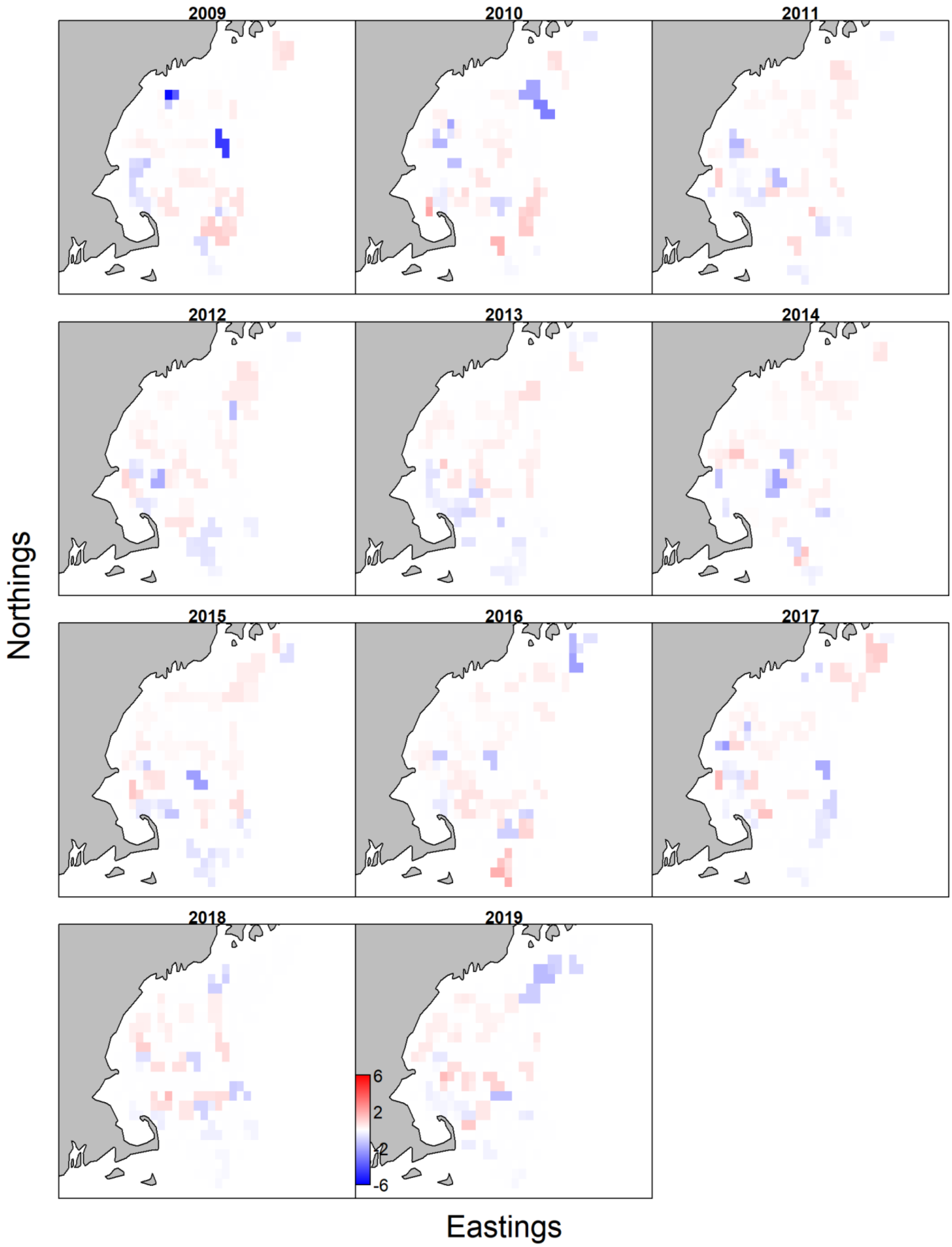



**Figure 13. Annual total catch Pearson residuals by area for the NEFSC Fall Survey.**

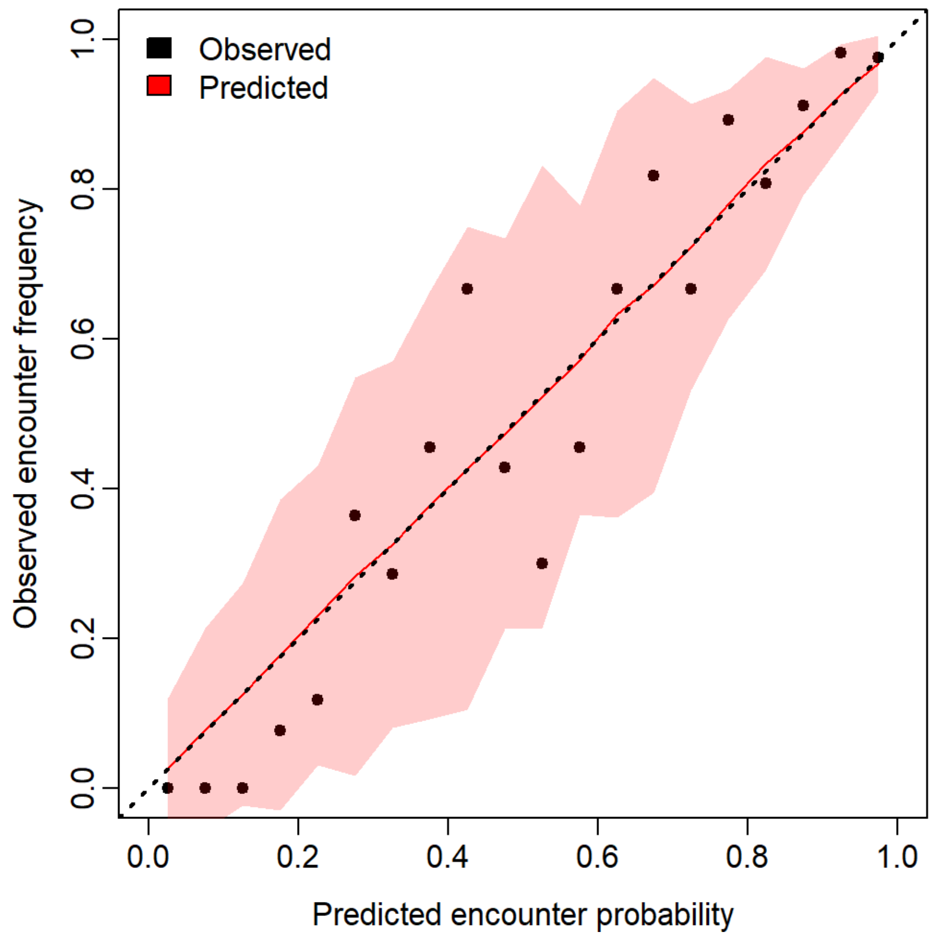



**Figure 14. Observed and predicted encounter probability with confidence intervals (shaded red area) for the NEFSC Fall Survey.**

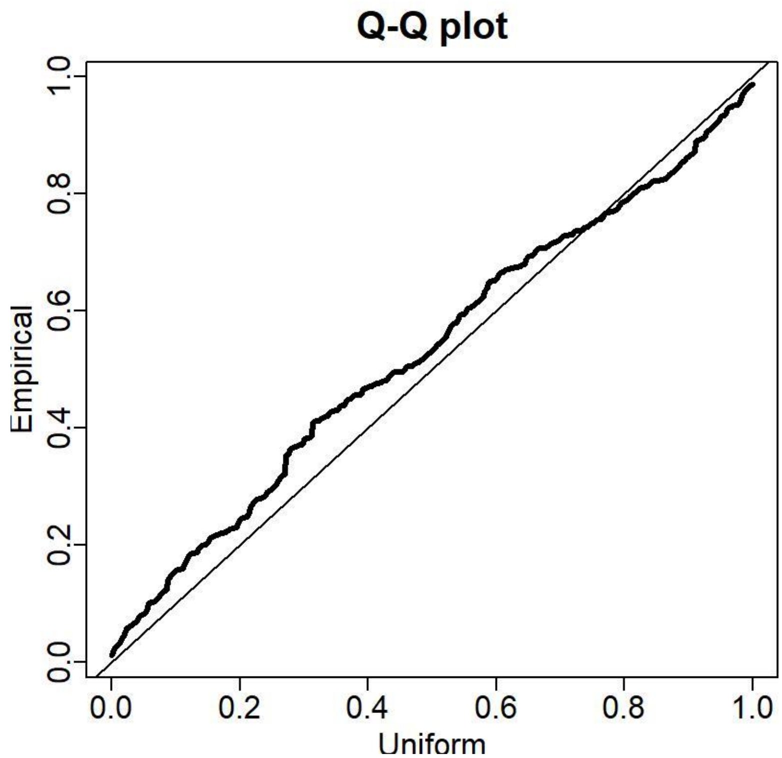



**Figure 15. QQ-plot for NEFSC Fall Survey residuals.**

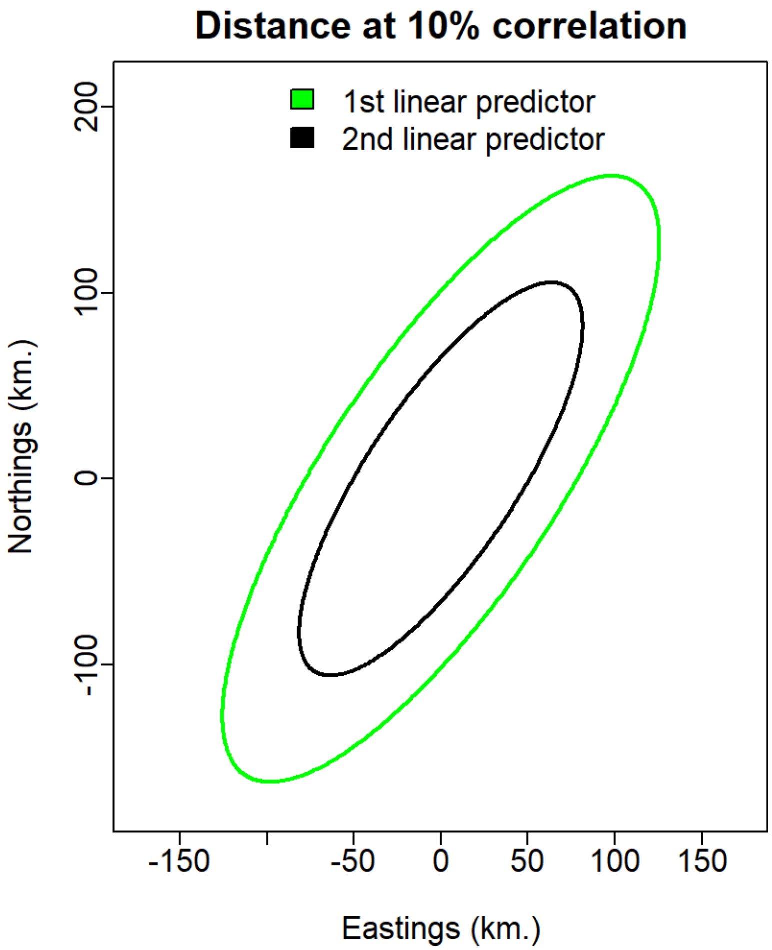


**Figure 16. Direction of geometric anisotropy for the NEFSC Fall Survey.**

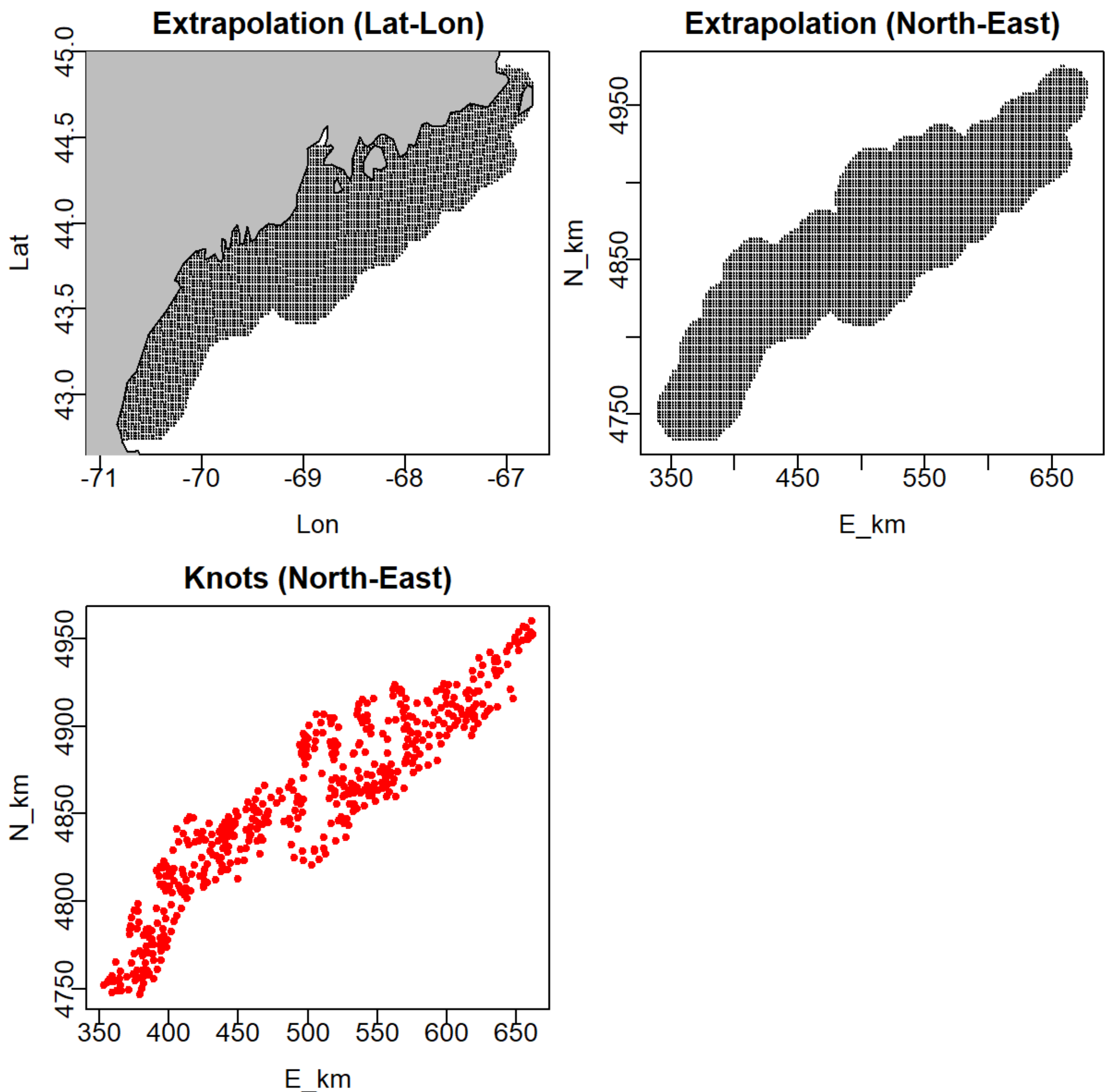



**Figure 17. Extrapolation grid and knots for ME-NH Spring Survey.**

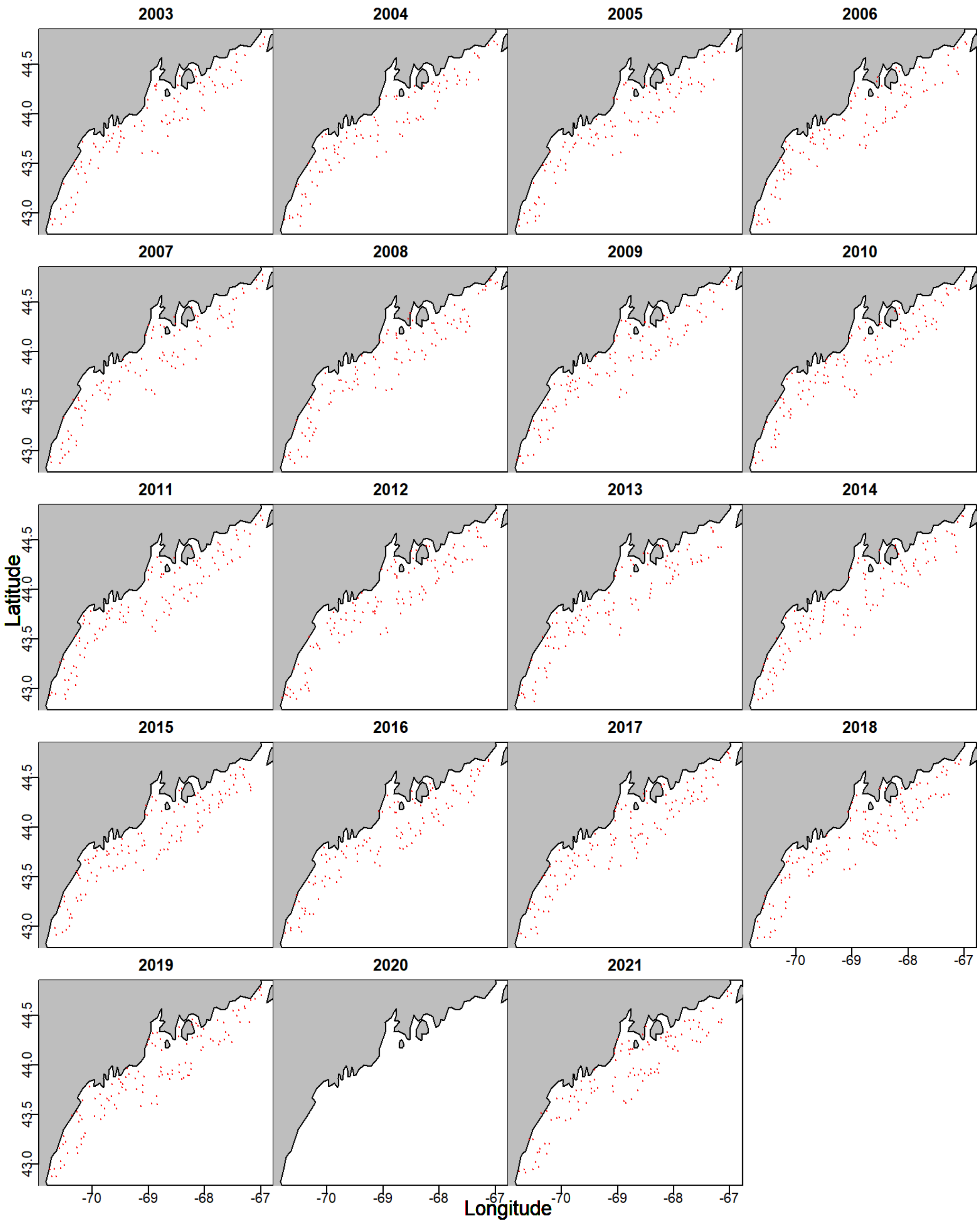



**Figure 18. ME-NH Survey catch locations by year.**

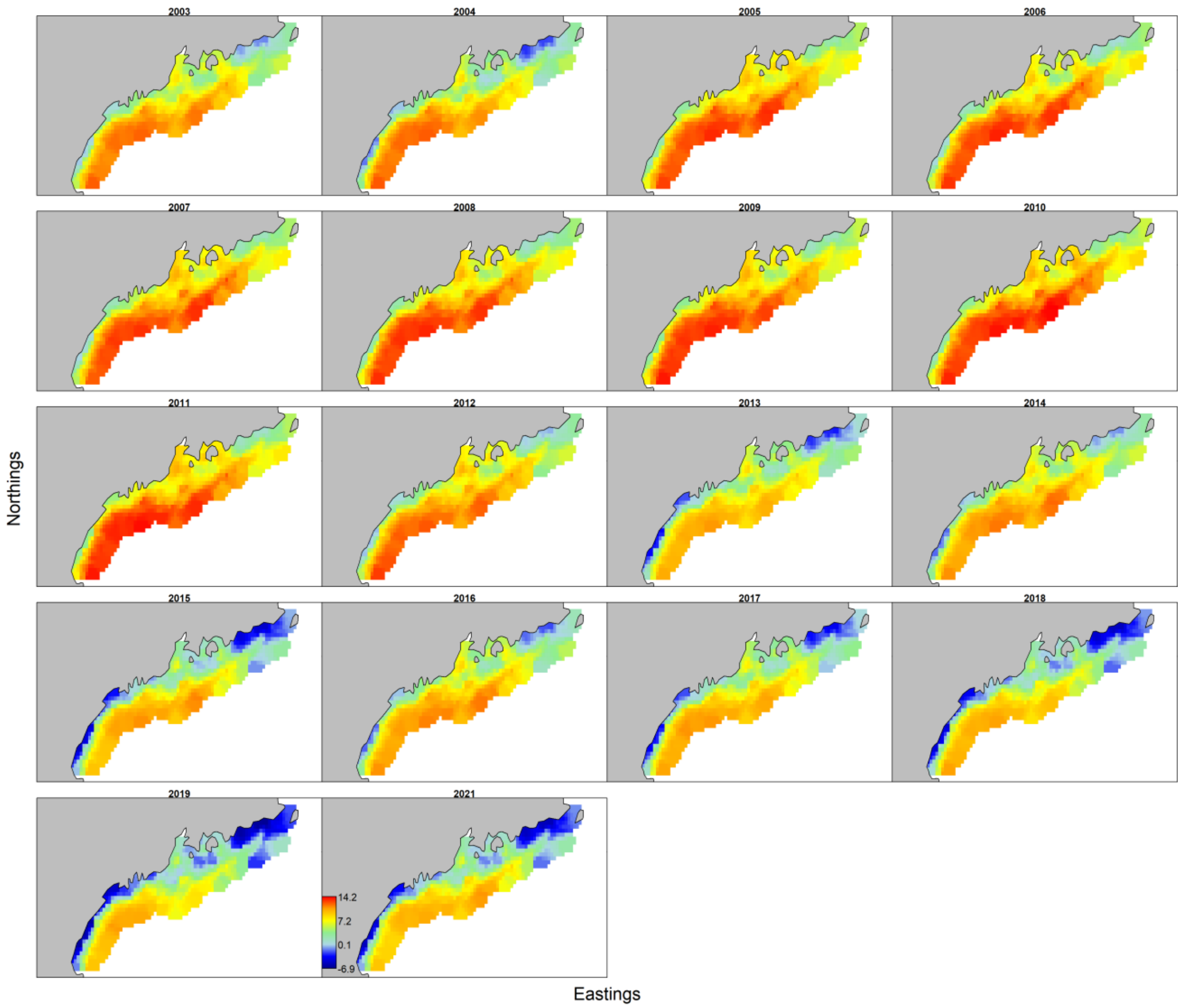



**Figure 19. Annual predicted population density (log-scale) by area for the ME-NH Spring Survey.**

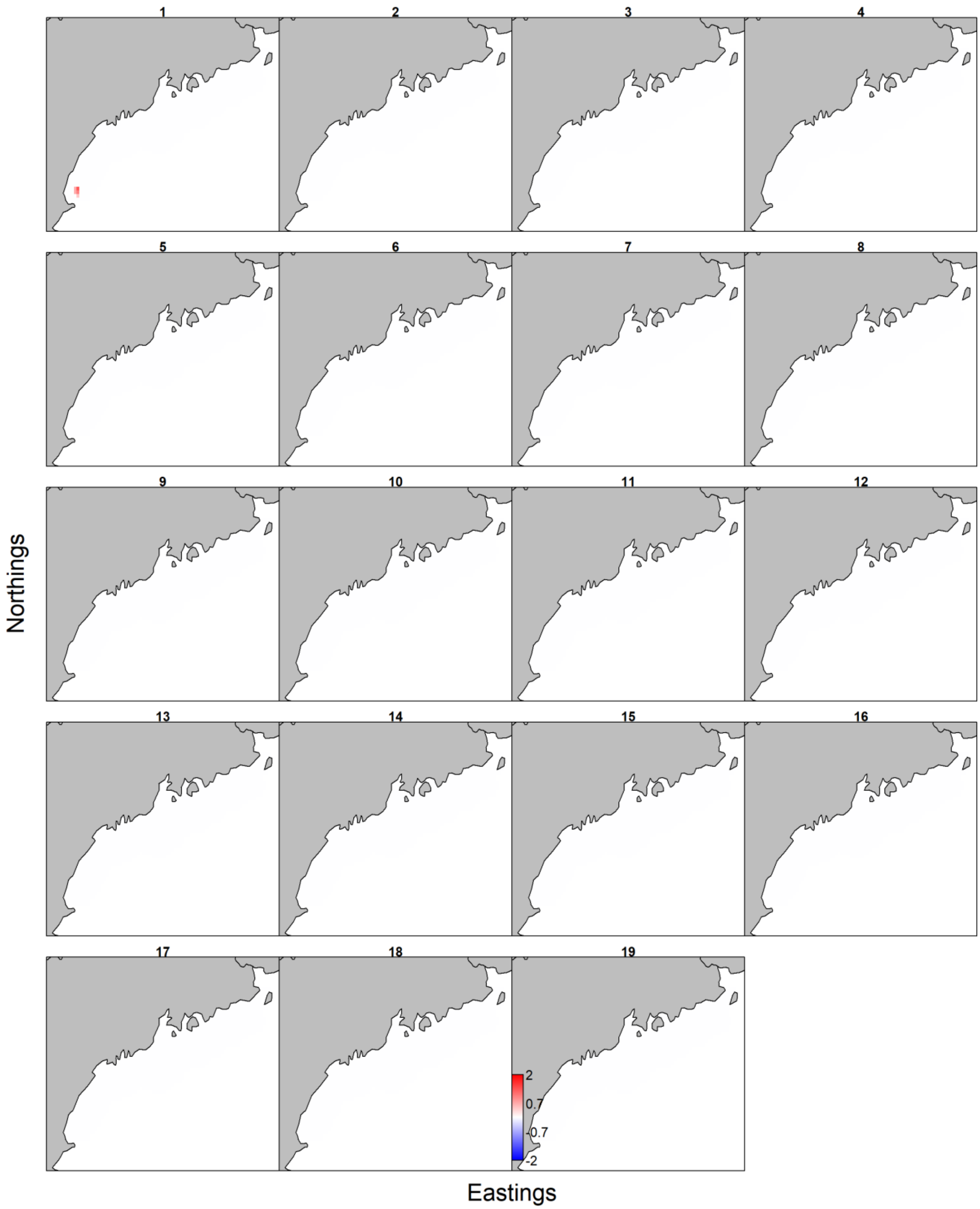



**Figure 20. Annual proportion positive Pearson residuals by area for the ME-NH Spring Survey.**

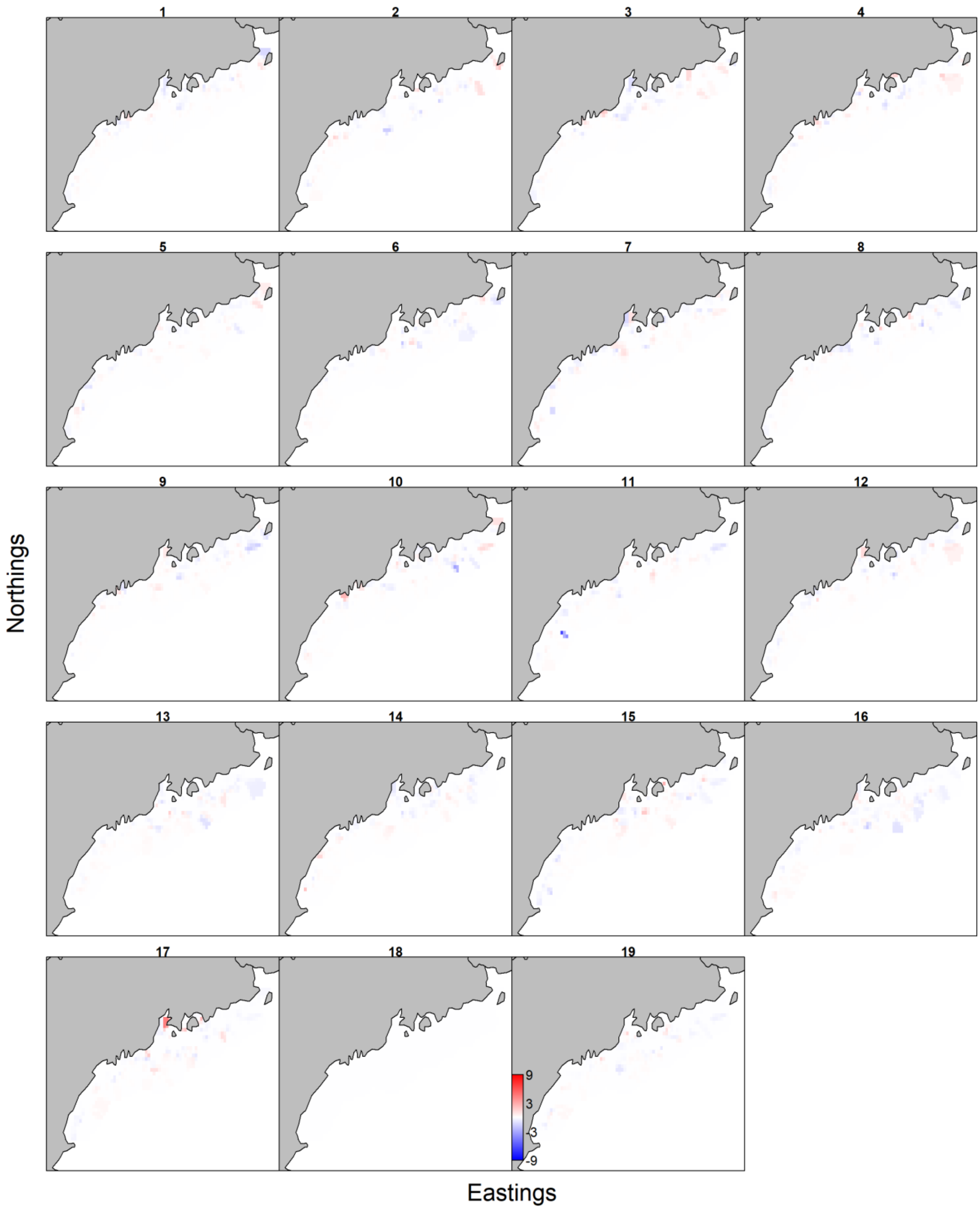



**Figure 21. Annual total catch Pearson residuals by area for the ME-NH Spring Survey.**

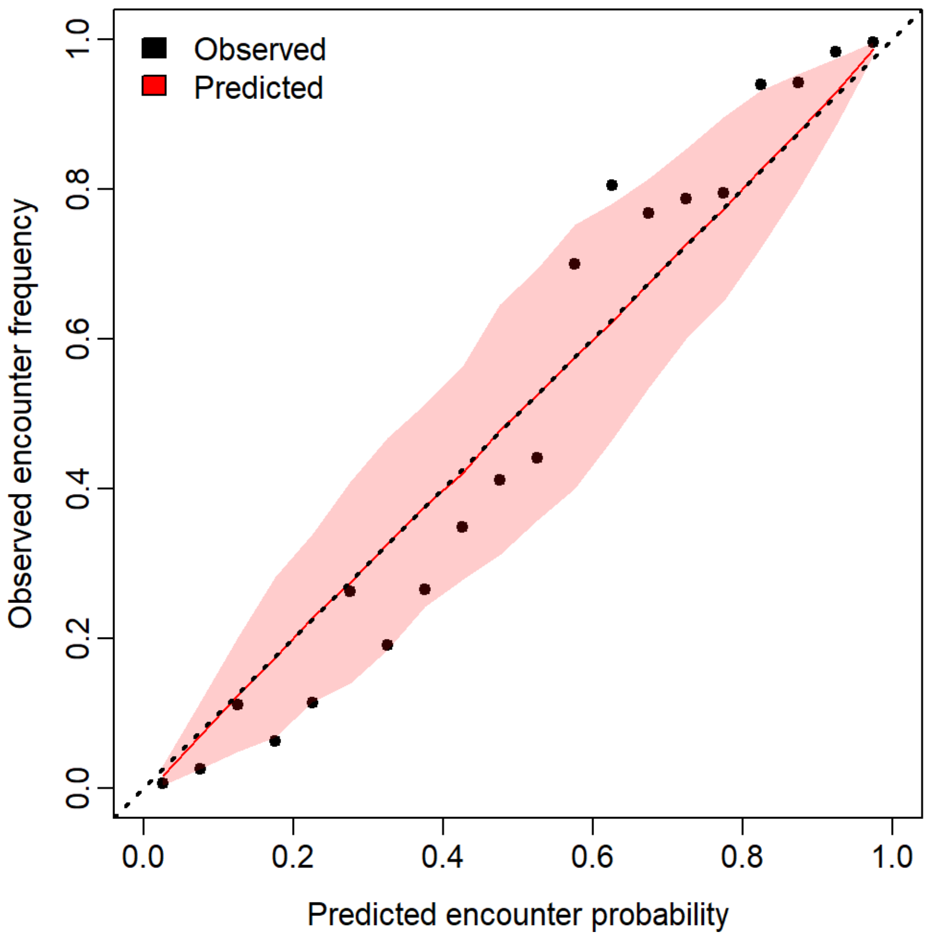


**Figure 22. Observed and predicted encounter probability with confidence intervals (shaded red area) for the ME-NH Spring Survey.**

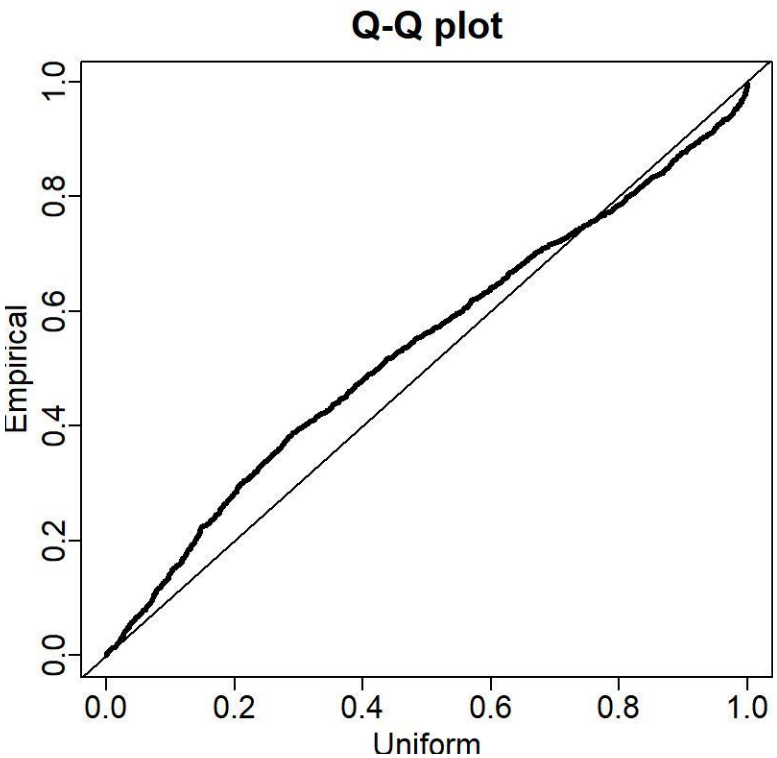



**Figure 23. QQ-plot for ME-NH Spring Survey residuals.**

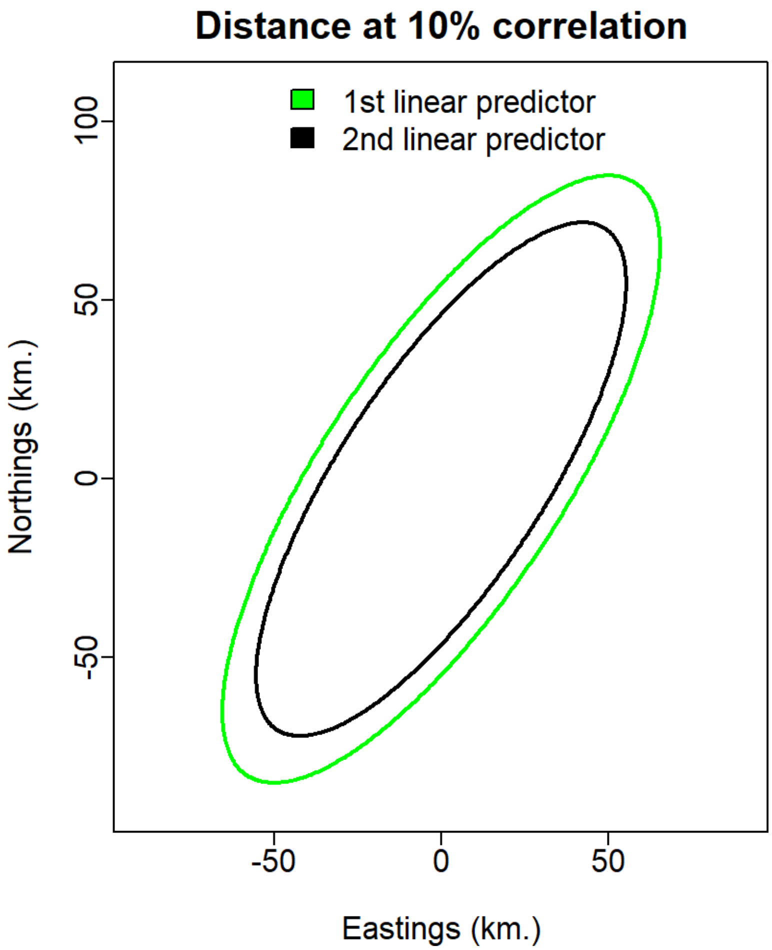


**Figure 24. Direction of geometric anisotropy for the ME-NH Spring Survey.**

**Appendix 2: Report on the ASMFC Summer Survey Trawl Door Calibration Analysis**

N. Shrimp 2021 Assessment Update

# An evaluation of efficiency differences between alternative trawl door configurations of the Gulf of Maine shrimp survey gear

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## Abstract

During operations of the Gulf of Maine shrimp survey betweeen 2017 and 2019, several sequential tows were conducted alternating between gear configurations with the historically used Portuguese doors and lighter Bison doors. Using these paired tow observations, we estimated several models that considered different assumptions about variation of relative efficiency between paired gear tows and size effects on the relative efficiency, and extra-binomial variation of observations within paired gear tows. The best performing model assumed no differences in catch efficiency between the two gear configurations.

# Introduction

In 2017 the shrimp survey adopted new trawl gear that incuded switching from Portuguese doors to lighter weight Bison doors. During the 2017, 2018, and 2019 surveys extra stations were sampled sequentially alternating trawl gear configurations between these two door types. A total of 39 paired tows were conducted during that span.

With these data, we used a previously published modeling approach for estimating relative catch efficiency for the Henry B. Bigelow and Albatross IV that accounts for differences in swept area and individual size effects on the ratio of the catch efficiencies of the two gear types. It also allows variation in this ratio between stations and extra-binomial variation among observations collected for each pair of tows (Miller 2013).

# Methods

## Paired-tow analysis

We use the hierarchical modeling approach from (Miller 2013) to estimate the relative efficiency of alternative Gulf of Maine shrimp survey trawl configurations using Portuguese and Bison doors. We began by fitting and comparing the same 13 models as Miller (2013) with different assumptions about variation of relative efficiency between paired gear tows, size effects on the relative efficiency, and extra-binomial variation of observations within paired gear tows. The binomial ($BI_0$ to $BI_4$) and beta-binomial ($BB_0$ to $BB_7$) models are described in Table 1 including pseudo-formulas comparable to those used for fitting mixed or generalized additive models in R (Wood 2006; R Core Team 2019).

All of the models in Table 1 estimate parameters describing the difference in catch efficiency between the two gears. Here we are particularly interested in whether we have evidence for a different efficiencies of the gears. More specifically, we are interested in whether there are differences in the *average* efficiencies of the gears across pairs. There may be variability in these ratios from station to station, but do we have any evidence of different efficiences at the larger scale across stations? Therefore, given the best performing model in Table 1 we fit an analogous null model where the average efficiencies were equal (by constraining the ratio of efficiencies to equal 1) and kept all other assumptions of the model the same.

We implemented the models using the Template Model Builder package (Kristensen et al. 2016) in R and we used the "nlminb" optimizer to fit the models (R Core Team 2019).

# Results

The best performing model in Table 1 was the most complex conditional beta-binomial model ($BB_7$) which had an AIC more than 90 units lower than the next best model ($BB_5$) and more than 55,500 units lower than the best binomial model ($BI_4$). Allowing extra-binomial variation withing paired-tows (overdispersion via the beta-binomial assumption) provided the primary improvements in model performance. Allowing size-effects on the extra-binomial variation ($\phi$) and station-specific size-effects on relative efficiency were also major factors in AIC reduction. The best-performing model estimated small changes in relative efficiency with size and the hypothesis of equal efficiencies of the Bison and Portuguese doors on average across paired tows ($\rho = 1$) was contained in the 95% confidence intervals (Figure 1). Assuming no size effects on the average relative catch efficiency ($BB_8$) provided similar AIC to $BB_7$ (Figure 2) and the null model (Figure 3) which assumes the average efficiencies are equal ($BB_9$) provided an AIC nearly 2 units lower than $BB_7$. Note that in Figure 3 there is no uncertainty in the average relative catch efficiency because it is not estimated. These results indicate evidence for unequal efficiencies of the two gears is weak.

## References


Kristensen, K., Nielsen, A., Berg, C.W., Skaug, H., and Bell, B.M. 2016. TMB: Automatic differentiation and Laplace approximation. Journal of Statistical Software **70**(5): 1–21.

Miller, T.J. 2013. A comparison of hierarchical models for relative catch efficiency based on paired-gear data for U.S. Northwest Atlantic fish stocks. Canadian Journal of Fisheries and Aquatic Sciences **70**(9): 1306–1316.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from https://www.R-project.org.

Wood, S.N. 2006. Generalized additive models: An introduction with R. Chapman & Hall, Boca Raton, Florida.

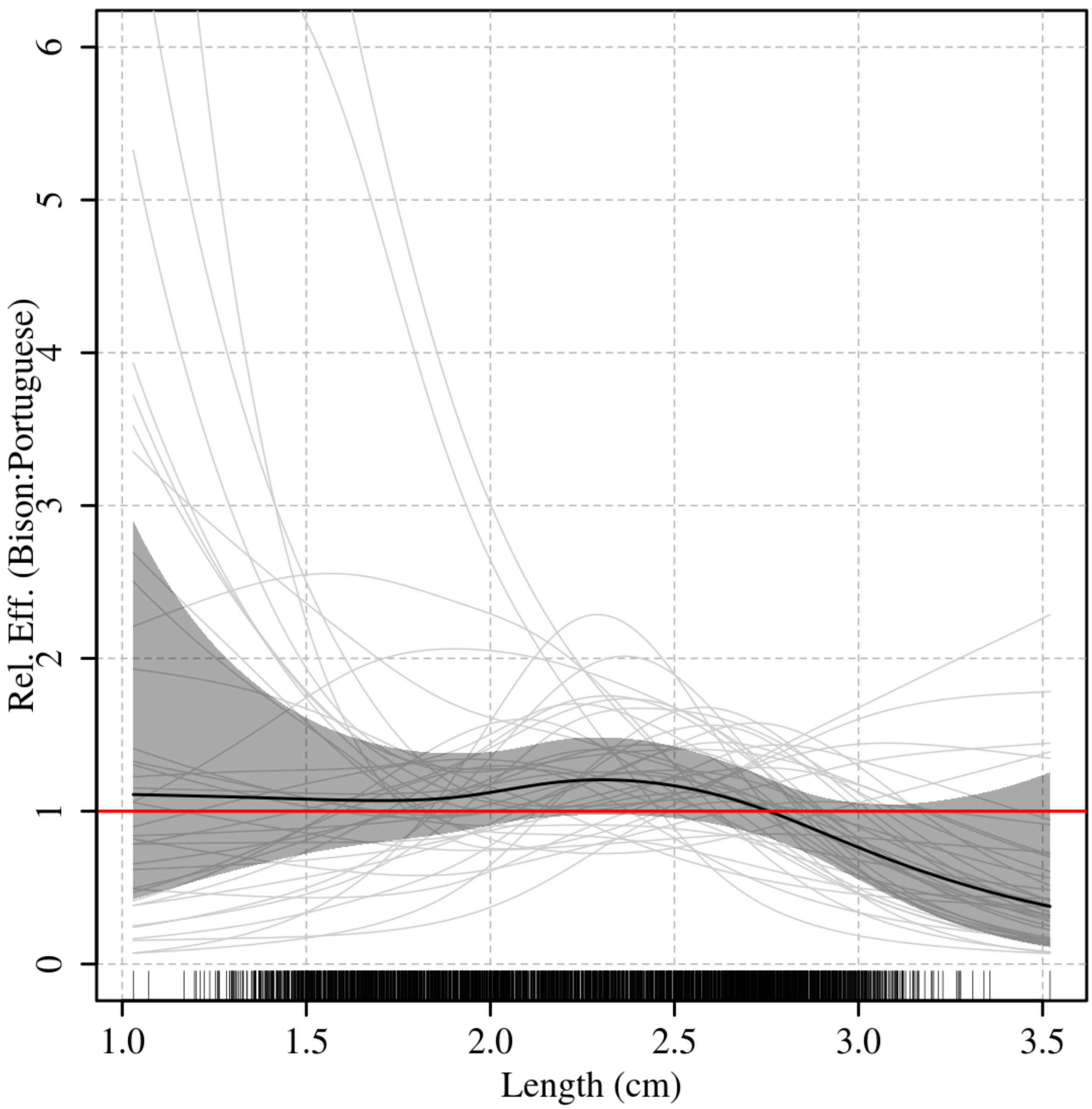



Fig. 1. Relative efficiency of shrimp trawl gears using Bison and Portuguese doors from model $BB_7$ (Table 1). The thick and thin lines represent average and paired-tow specific estimates of relative catch efficiency, respectively, horizontal red line indicates equal efficiencies of the gears, and polygons represent hessian-based 95% confidence intervals.

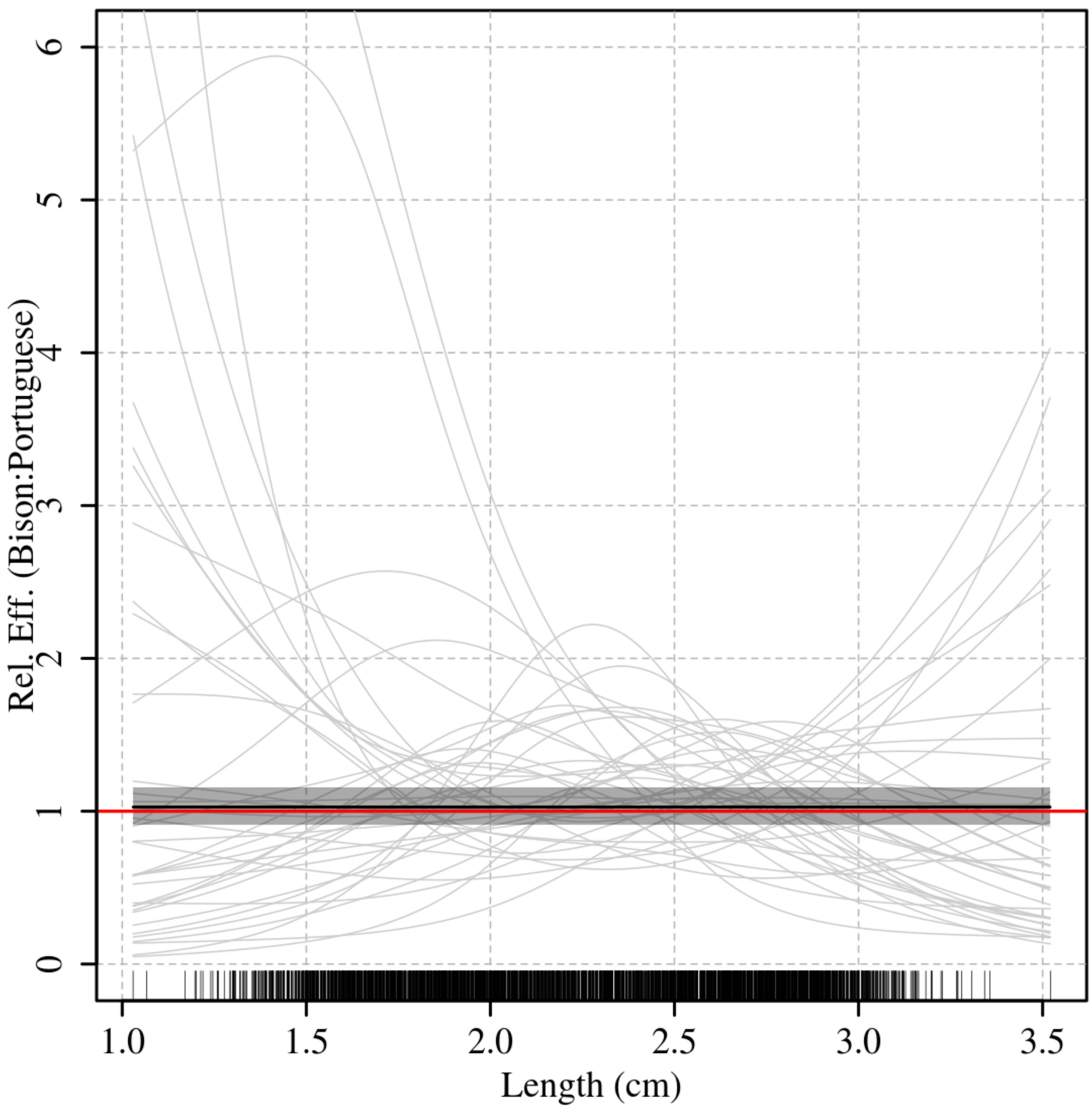



Fig. 2. Relative efficiency of shrimp trawl gears using Bison and Portuguese doors from model $BB_8$ (Table 1). The thick and thin lines represent average and paired-tow specific estimates of relative catch efficiency, respectively, horizontal red line indicates equal efficiencies of the gears, and polygons represent hessian-based 95% confidence intervals.

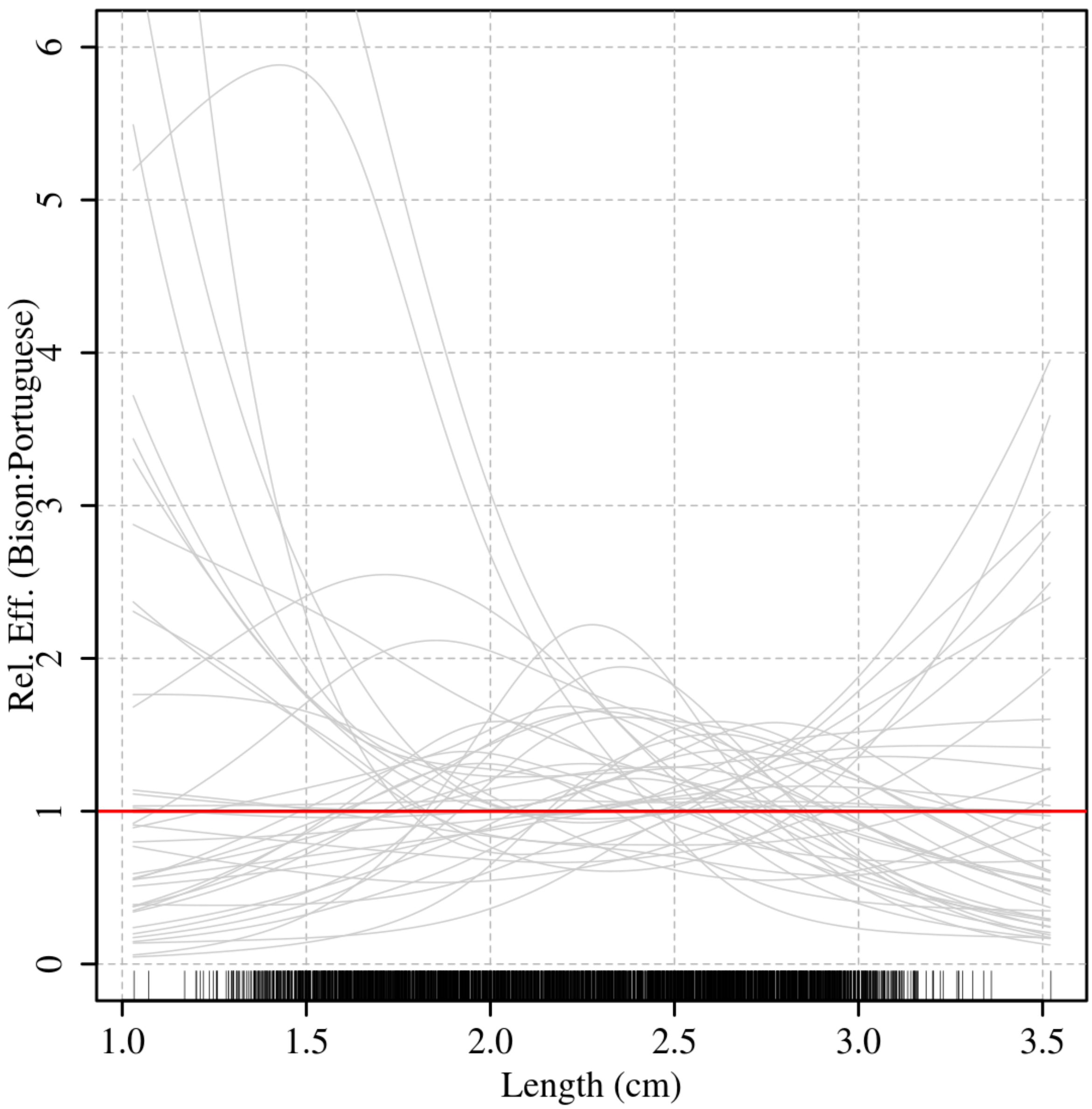



Fig. 3. Relative efficiency of shrimp trawl gears using Bison and Portuguese doors from model $BB_9$ (Table 1). The thin lines represent average and paired-tow specific estimates of relative catch efficiency, respectively, horizontal red line indicates equal efficiencies of the gears, and polygons represent hessian-based 95% confidence intervals.

Table 1. Model descriptions and estimated parameters.

| Model | $\log(\rho)$ | $\log(\phi)$ | log-likelihood | $P$ | $\Delta$AIC | Akaike weights | Description |
|---|---|---|---|---|---|---|---|
| $BI_0$ | $\sim 1$ | – | -42813.00 | 1 | 70164.10 | 0.00 | population-level mean for all observations |
| $BI_1$ | $\sim 1 + 1\|$pair | – | -39959.88 | 2 | 64459.85 | 0.00 | population- and random station-level $\rho$ |
| $BI_2$ | $\sim$ s(length) | – | -42558.00 | 3 | 69658.09 | 0.00 | population-level smooth size effect on $\rho$ |
| $BI_3$ | $\sim$ s(length) + 1\|pair | – | -39732.19 | 4 | 64008.47 | 0.00 | population-level smooth size effect and random station-level intercept for $\rho$ |
| $BI_4$ | $\sim$ s(length) + s(length)\|pair | – | -35487.34 | 7 | 55524.78 | 0.00 | population-level and random station-level smooth size effects for $\rho$ |
| $BB_0$ | $\sim 1$ | $\sim 1$ | -7951.32 | 2 | 442.74 | 0.00 | population-level $\rho$ and $\phi$ |
| $BB_1$ | $\sim 1 + 1\|$pair | $\sim 1$ | -7941.51 | 3 | 425.11 | 0.00 | population-level and random station-level intercept for $\rho$ and population-level $\phi$ |
| $BB_2$ | $\sim$ s(length) | $\sim 1$ | -7940.61 | 4 | 425.31 | 0.00 | population-level smooth size effect on $\rho$ and population-level $\phi$ |
| $BB_3$ | $\sim$ s(length) | $\sim$ s(length) | -7785.77 | 6 | 119.65 | 0.00 | population-level smooth size effect on $\rho$ and $\phi$ |
| $BB_4$ | $\sim$ s(length) + 1\|pair | $\sim 1$ | -7931.19 | 5 | 408.49 | 0.00 | population-level smooth size effect and random station-level intercept for $\rho$ and population-level $\phi$ |
| $BB_5$ | $\sim$ s(length) + 1\|pair | $\sim$ s(length) | -7771.45 | 7 | 93.01 | 0.00 | population-level smooth size effect on $\rho$ and $\phi$ and random station-level intercepts for $\rho$ |
| $BB_6$ | $\sim$ s(length) + s(length)\|pair | $\sim 1$ | -7890.96 | 8 | 334.02 | 0.00 | population-level and random station-level smooth size effects on $\rho$ and population-level $\phi$ |
| $BB_7$ | $\sim$ s(length) + s(length)\|pair | $\sim$ s(length) | -7722.89 | 10 | 1.88 | 0.22 | population-level and random station-level smooth size effects on $\rho$ and population-level smooth size effects on $\phi$ |
| $BB_8$ | $\sim 1$ + s(length)\|pair | $\sim$ s(length) | -7724.86 | 8 | 1.82 | 0.22 | population-level mean and random station-level smooth size effects on $\rho$ and population-level smooth size effects on $\phi$ |
| $BB_9$ | $\sim$ s(length)\|pair | $\sim$ s(length) | -7724.95 | 7 | 0.00 | 0.56 | population-level equal efficiencies and random station-level smooth size effects on $\rho$ and population-level smooth size effects on $\phi$ |

**Appendix 3: Model Input and Diagnostic Plots for the UME Statistical Catch-at-Length Model**

N. Shrimp 2021 Assessment Update

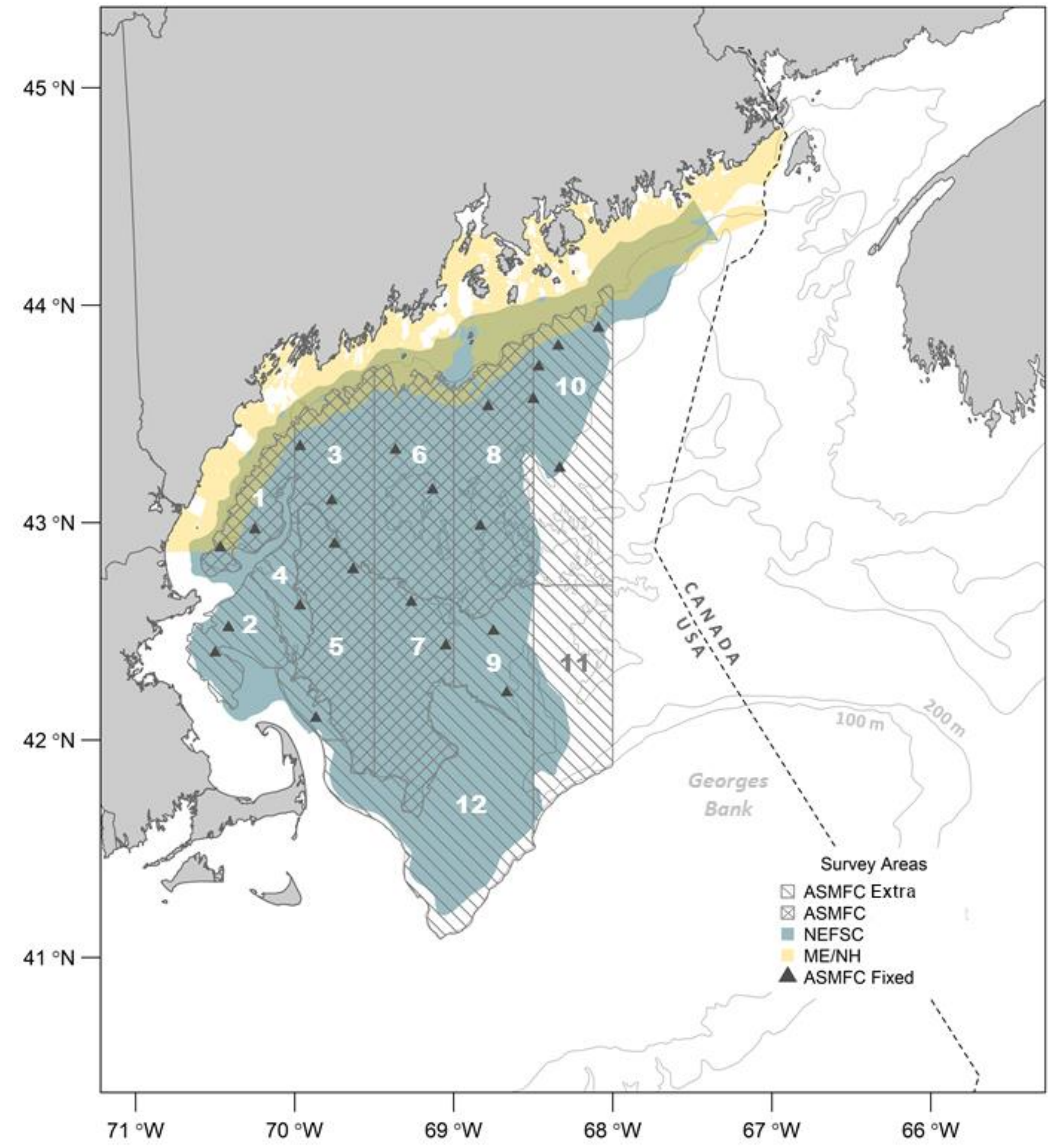



**Figure 1. Area covered by the surveys used in the Gulf of Maine northern shrimp assessment. ASMFC extra strata were historically not used to develop the index of abundance, but the current assessment uses all strata.**

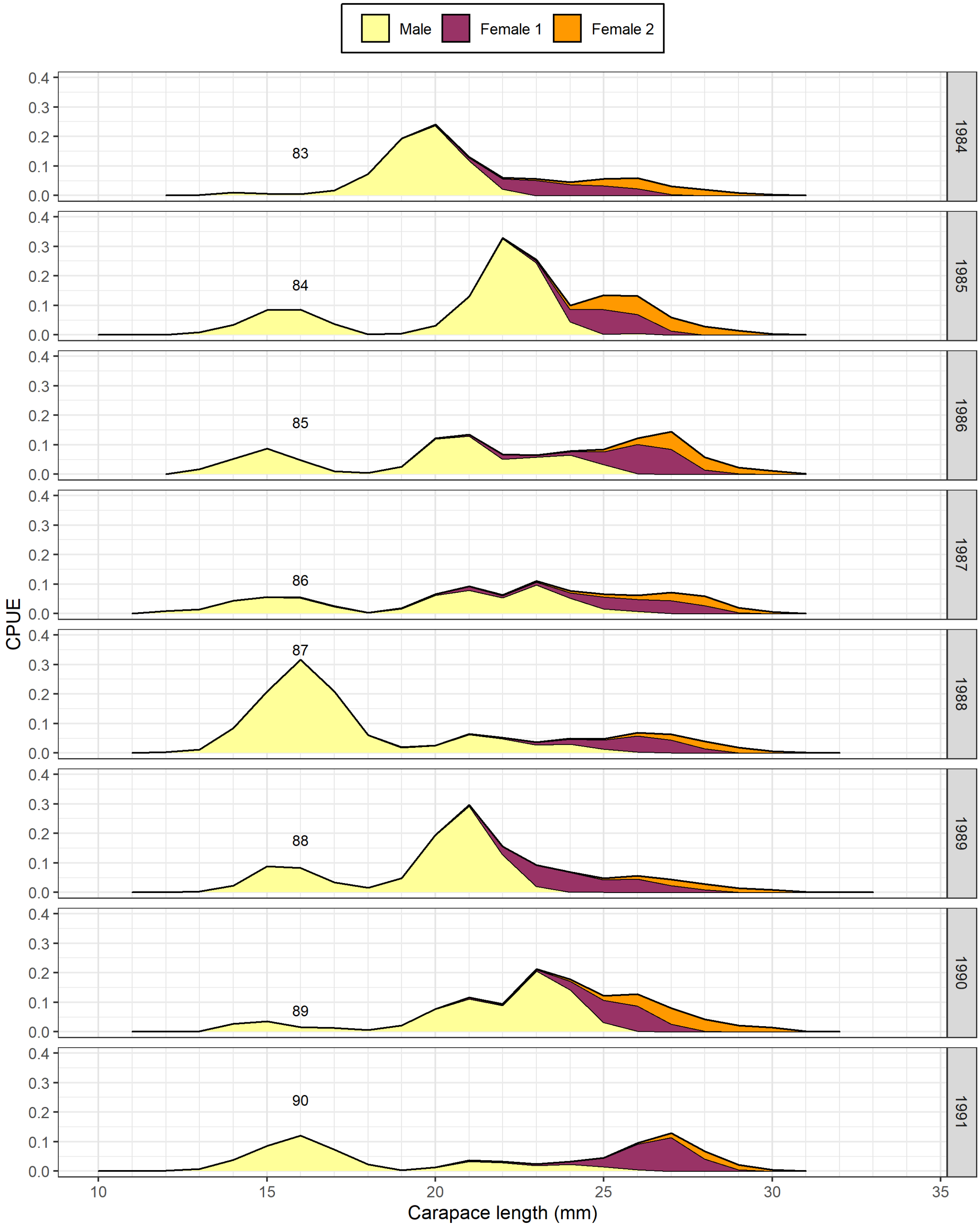



**Figure 2. Gulf of Maine northern shrimp Summer Survey index by year, length, and development stage for 1984-2021. Two-digit years on plot indicates year class at assumed age 1.5.**

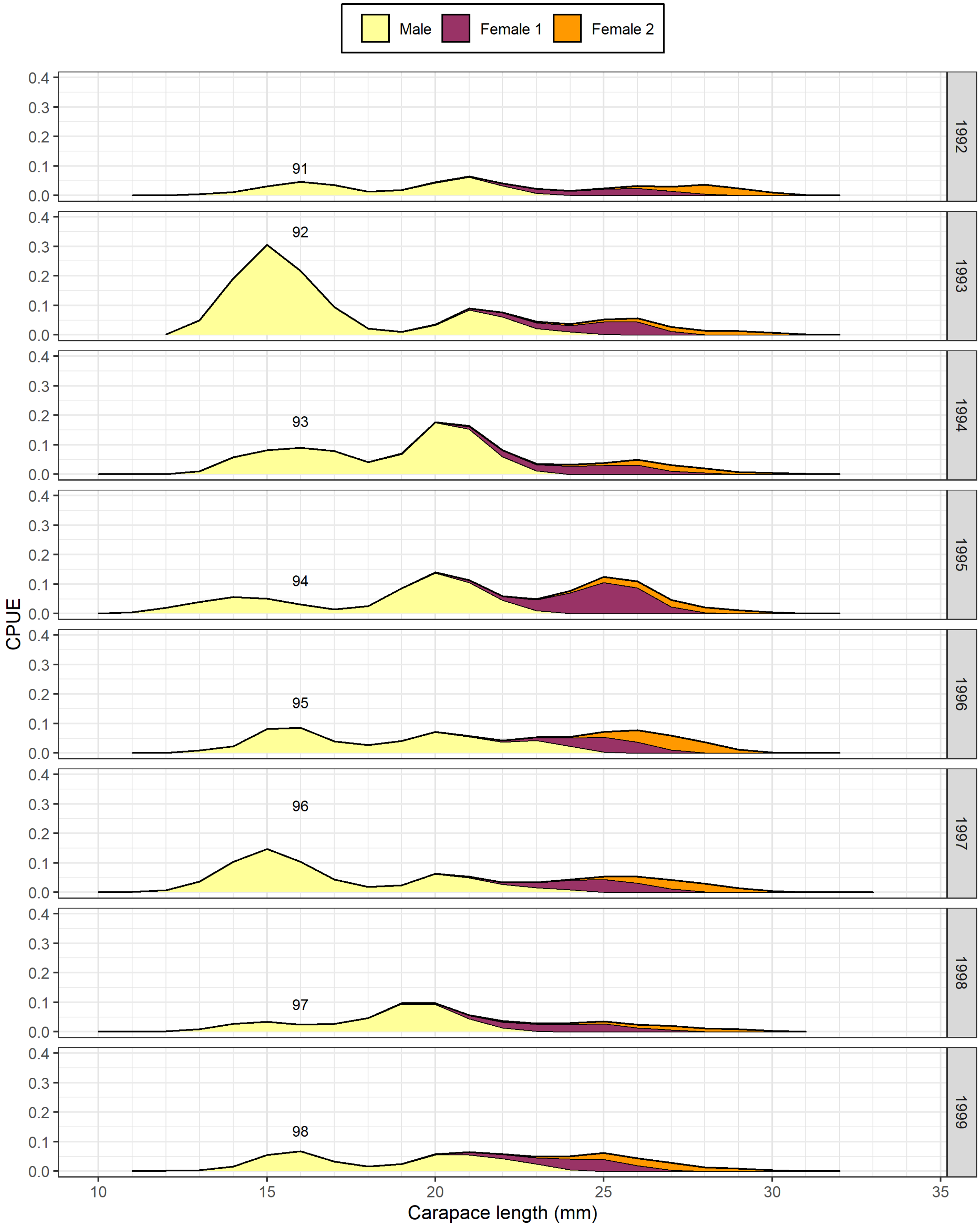



Figure 2 (cont)

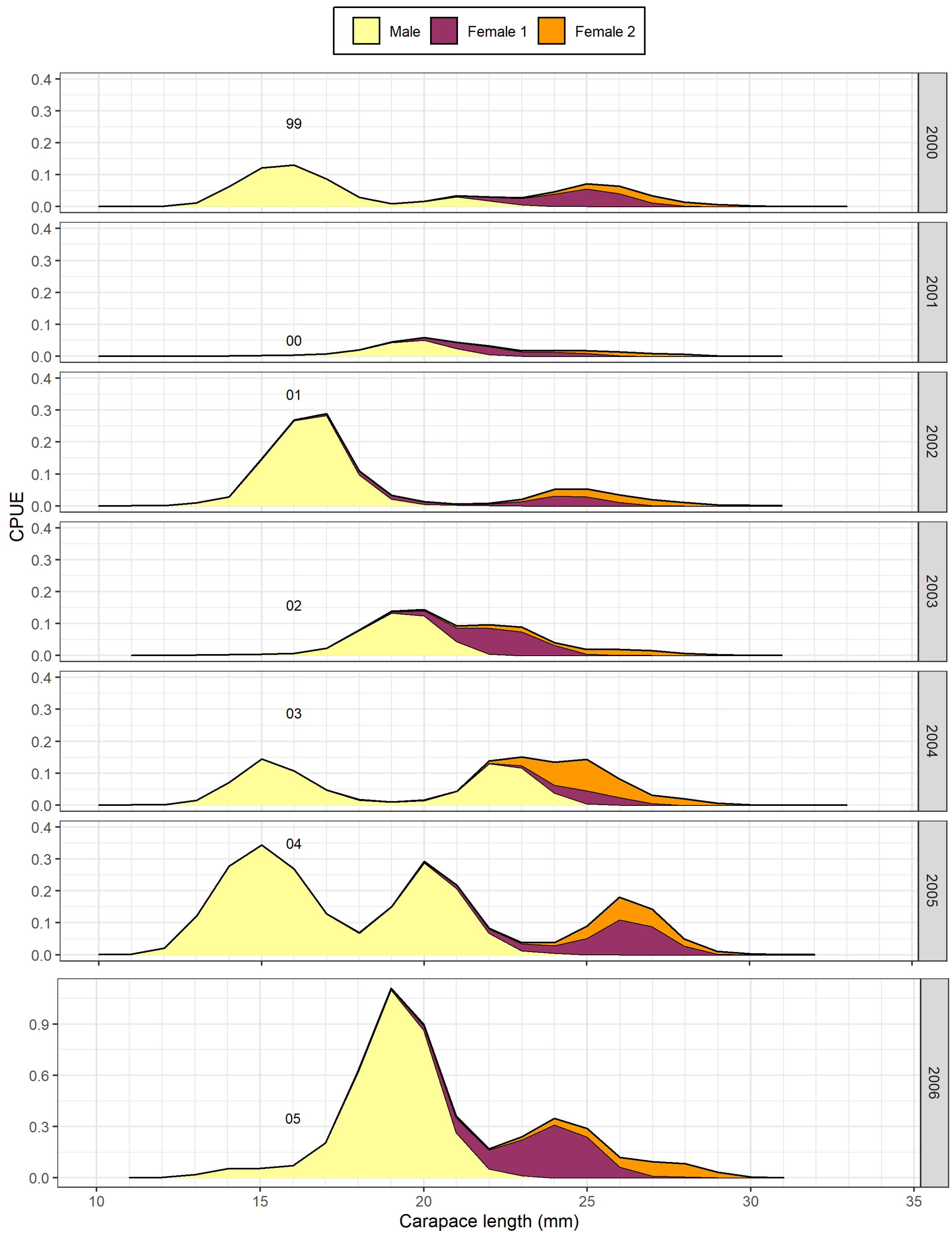



Figure 2 (cont.)

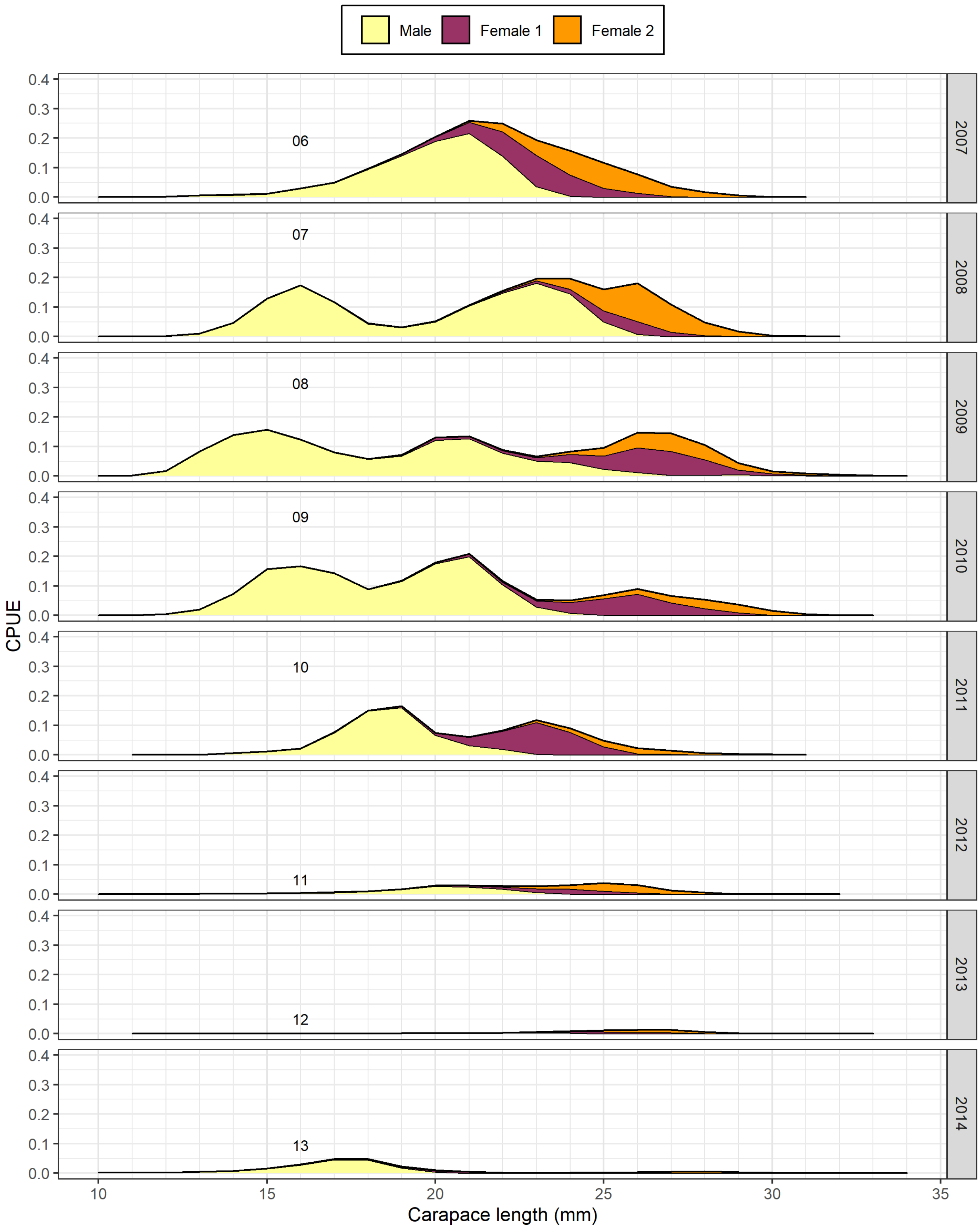



Figure 2 (cont)

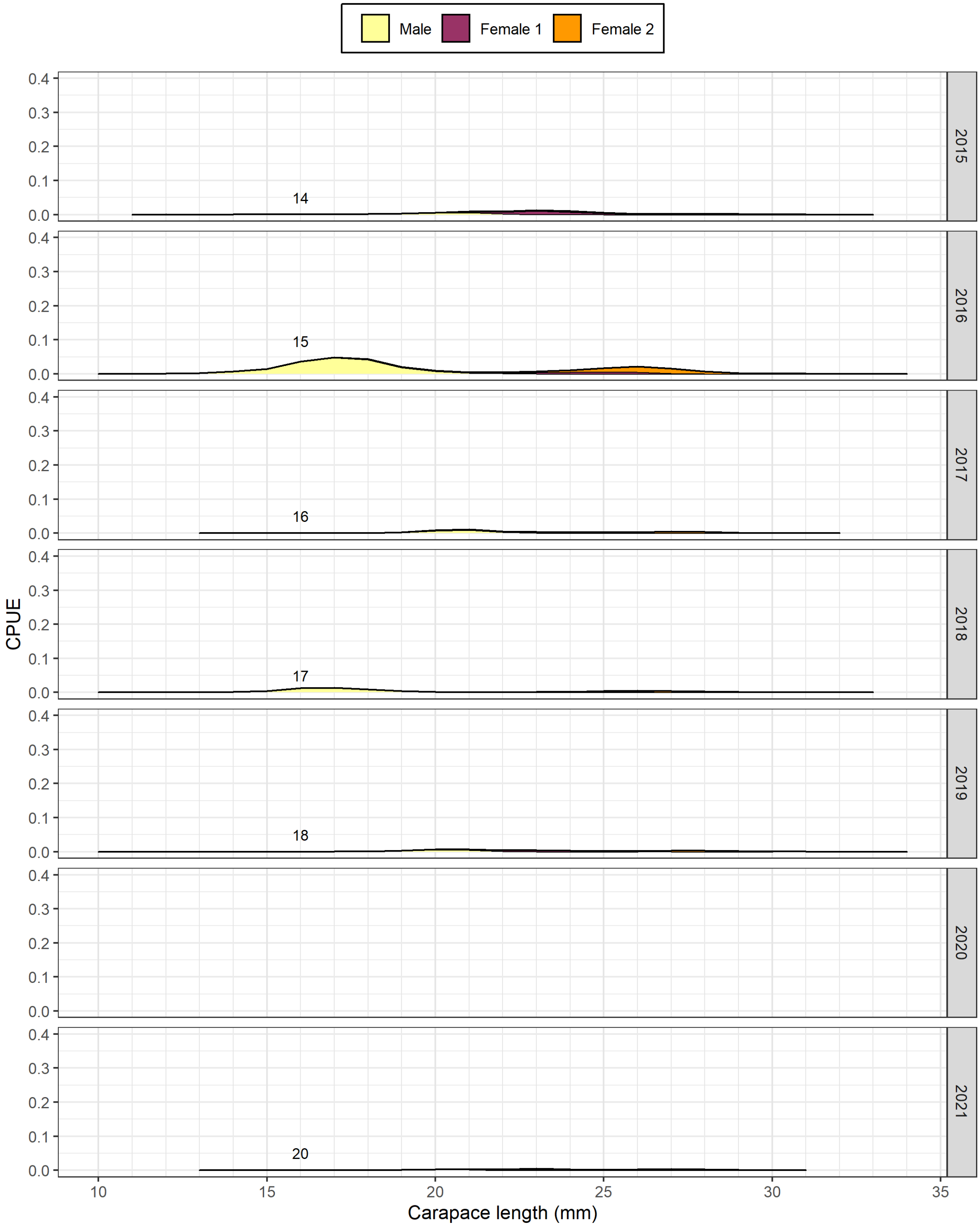



Figure 2 (cont.)

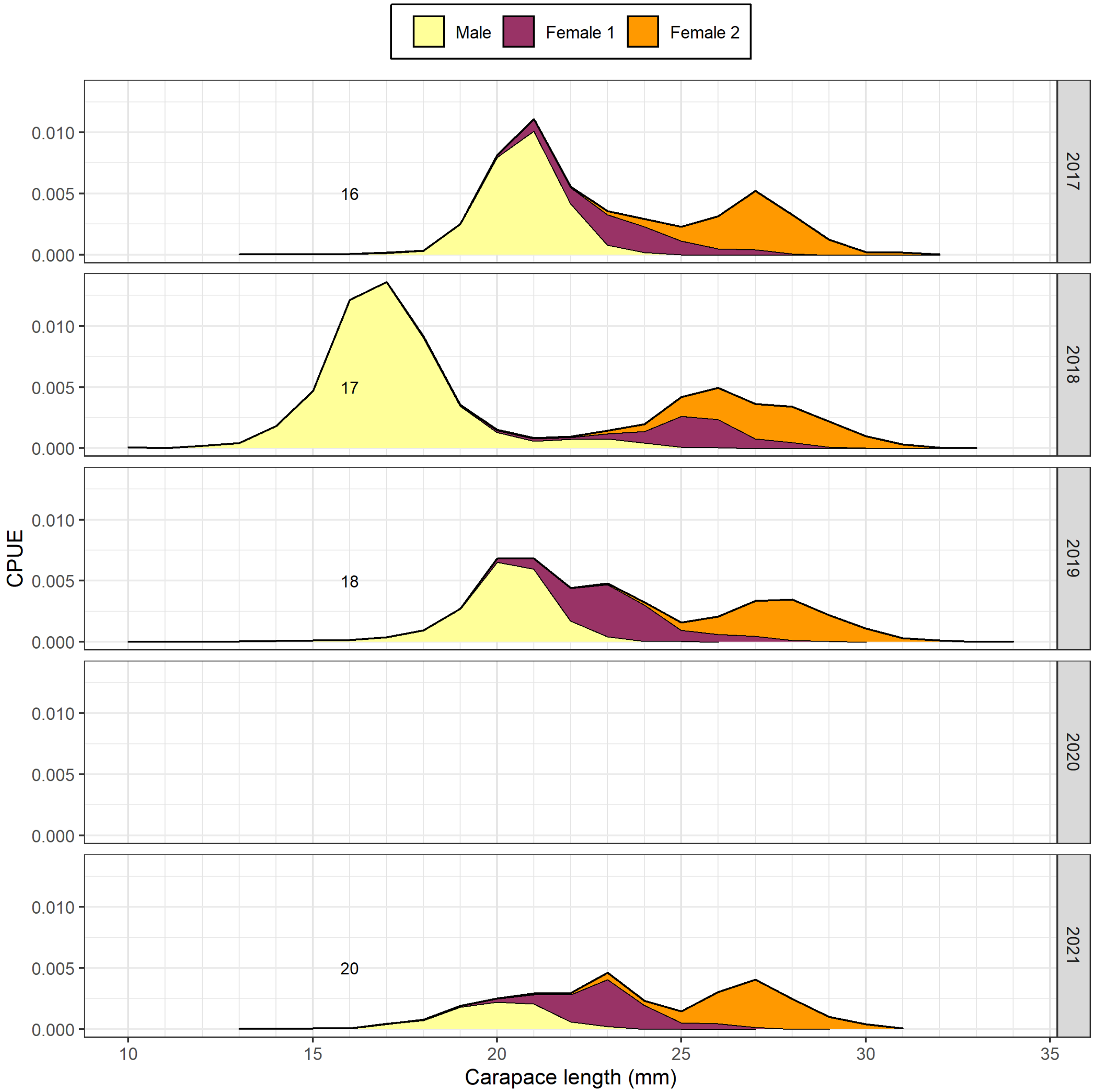



**Figure 3. Gulf of Maine northern shrimp Summer Survey abundance by year, length, and development stage for 2017 – 2021 with an expanded axis to show detail. Two-digit years are year class at assumed age 1.5.**

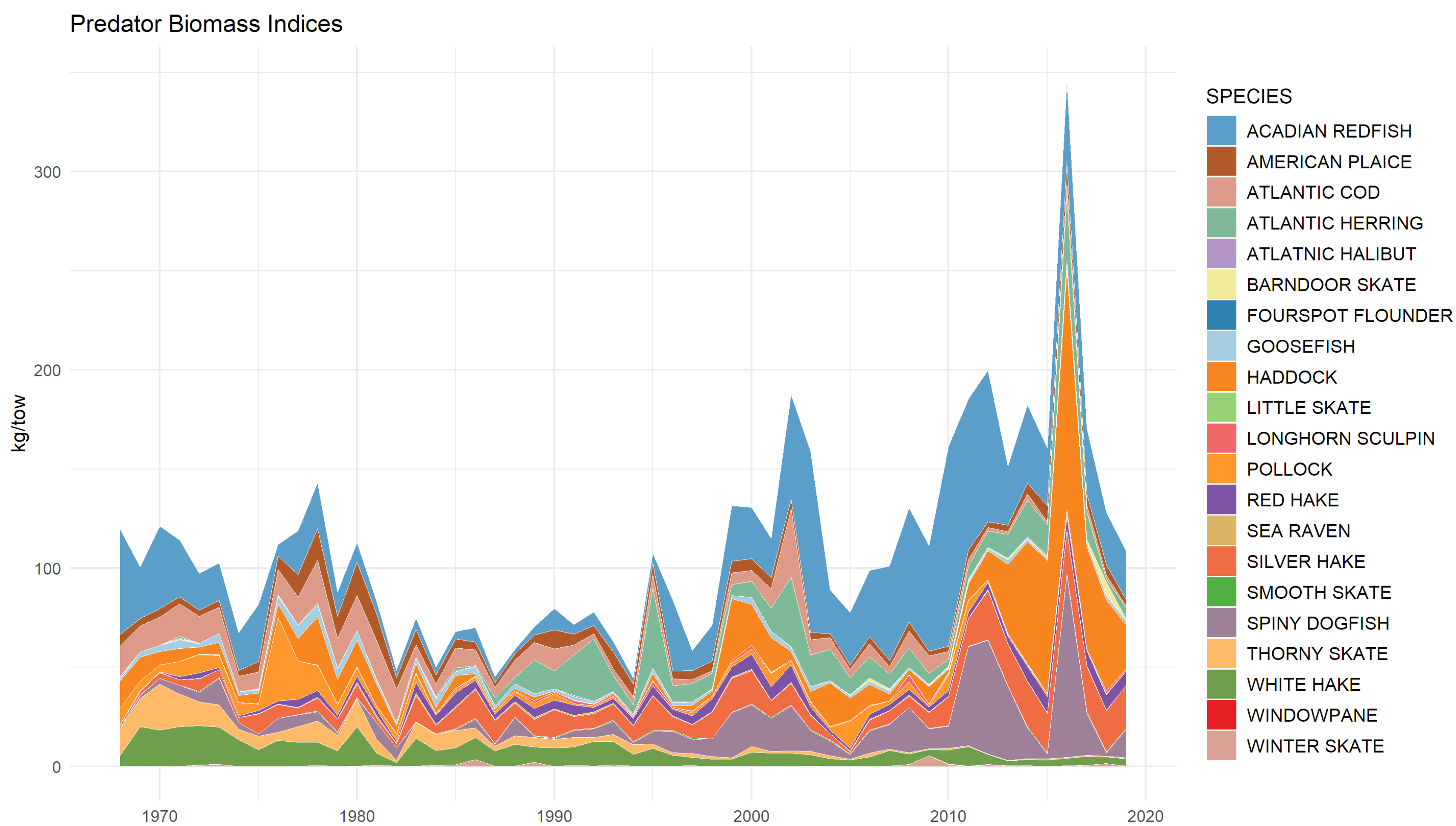
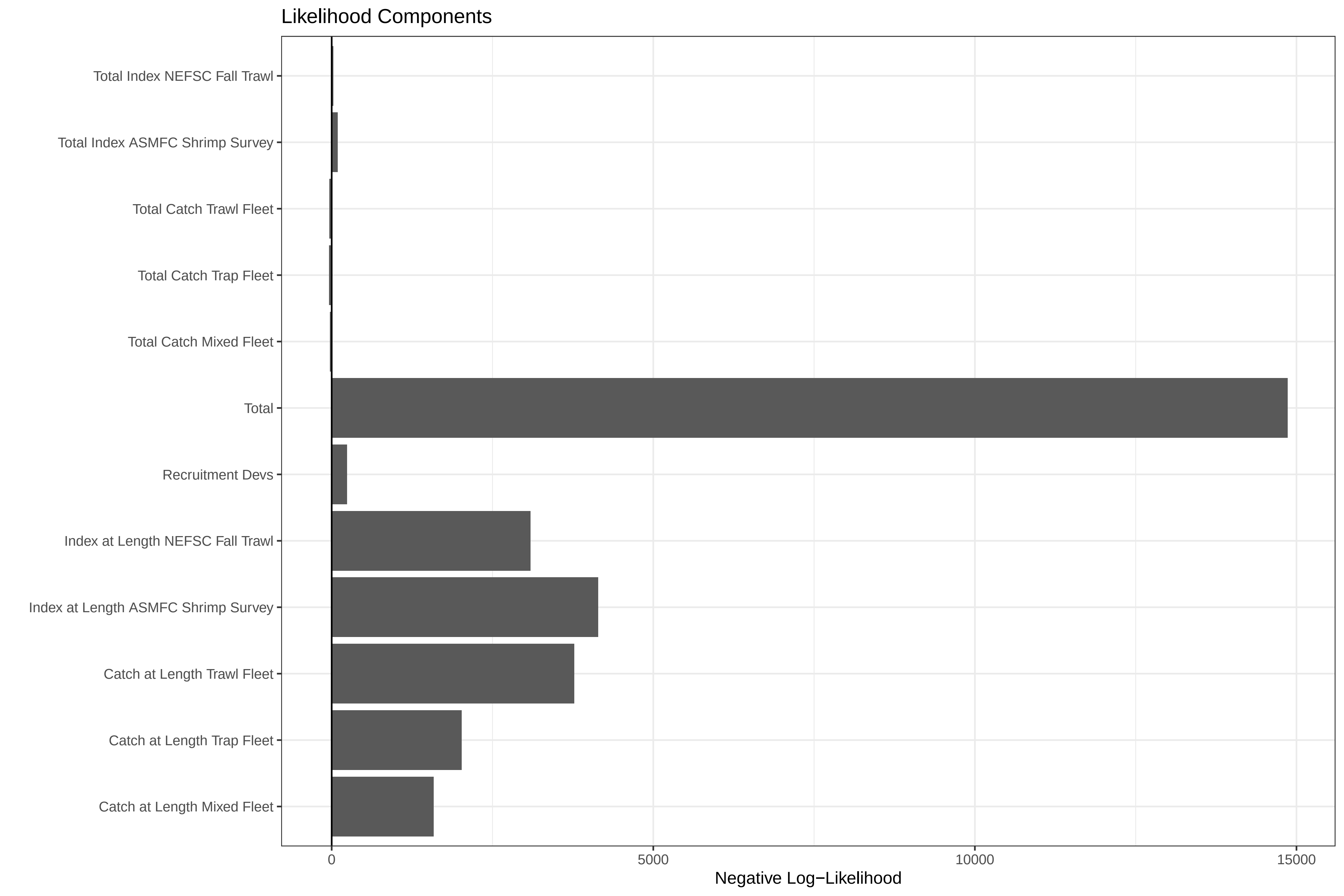
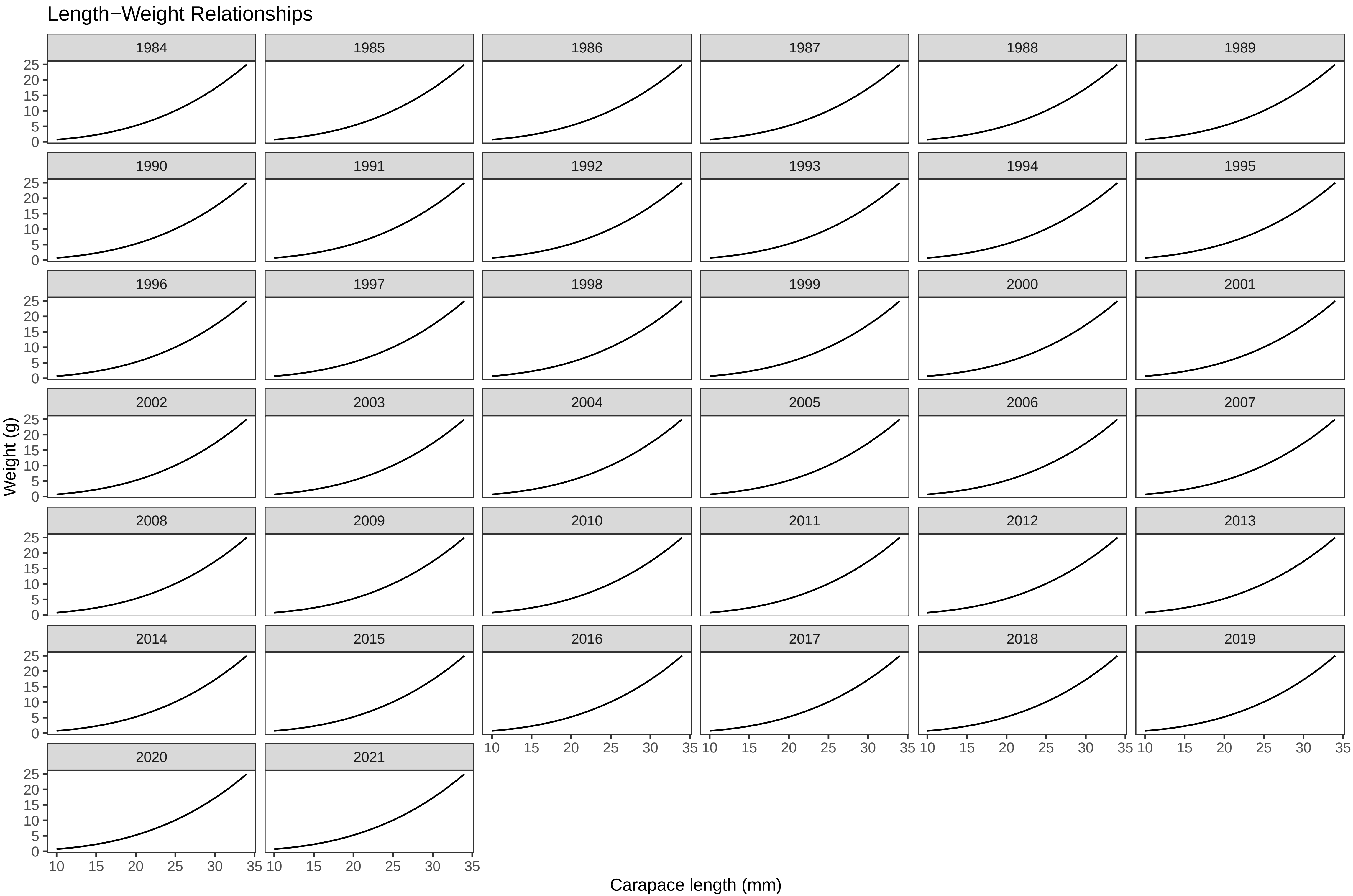
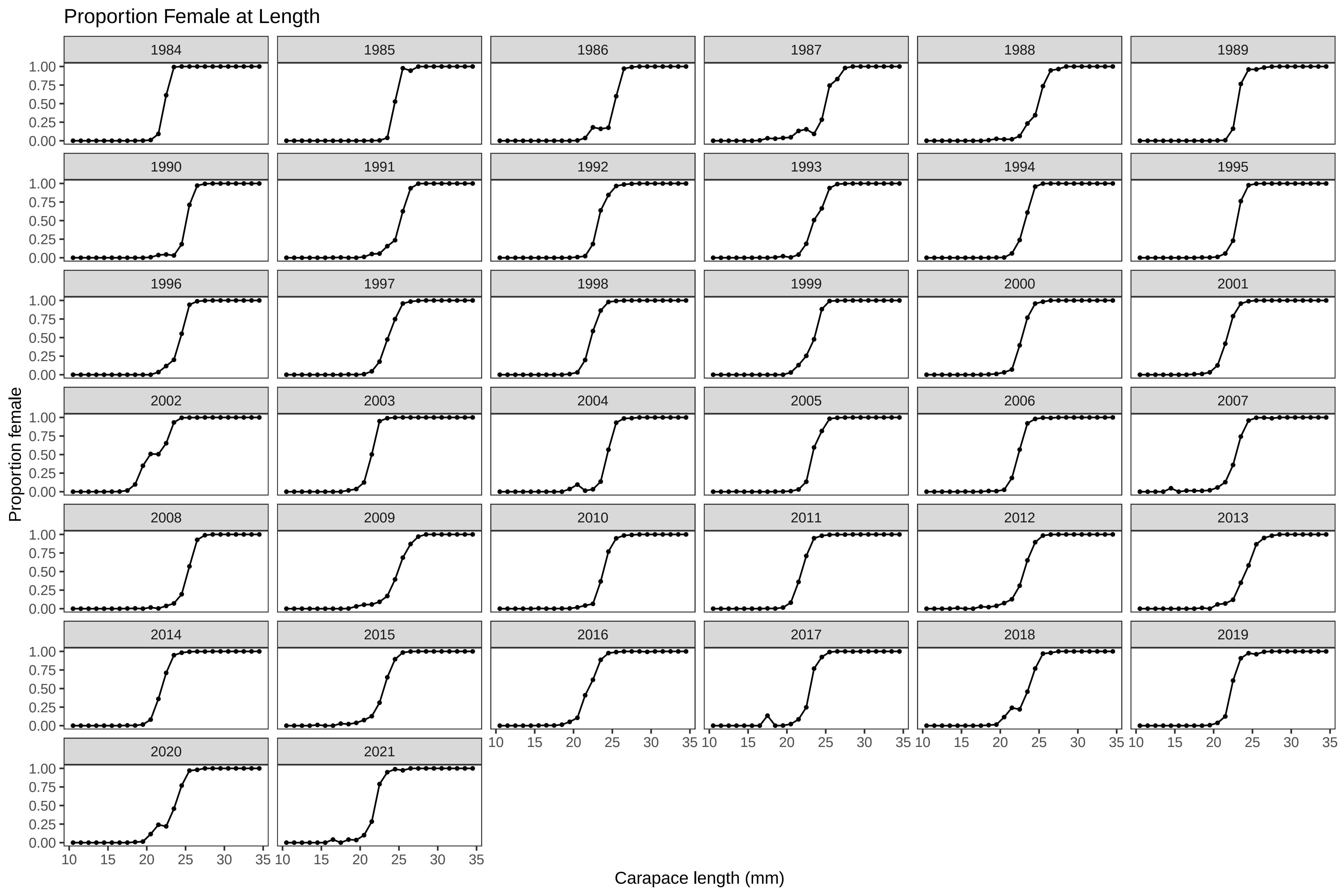
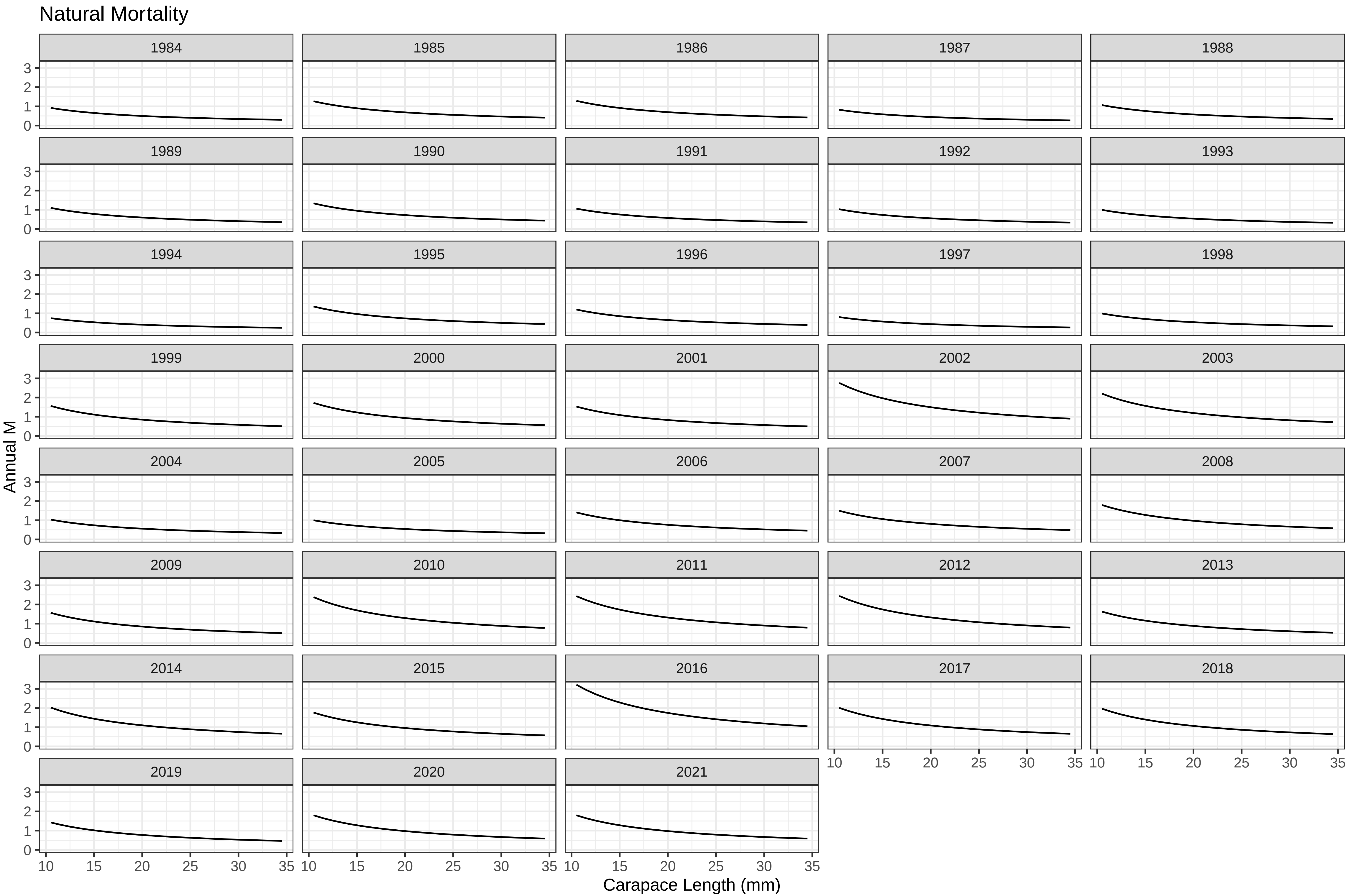



**Figure 4. Biomass indices of the key northern shrimp predators used to develop the predation pressure index (PPI) used in the assessment.**

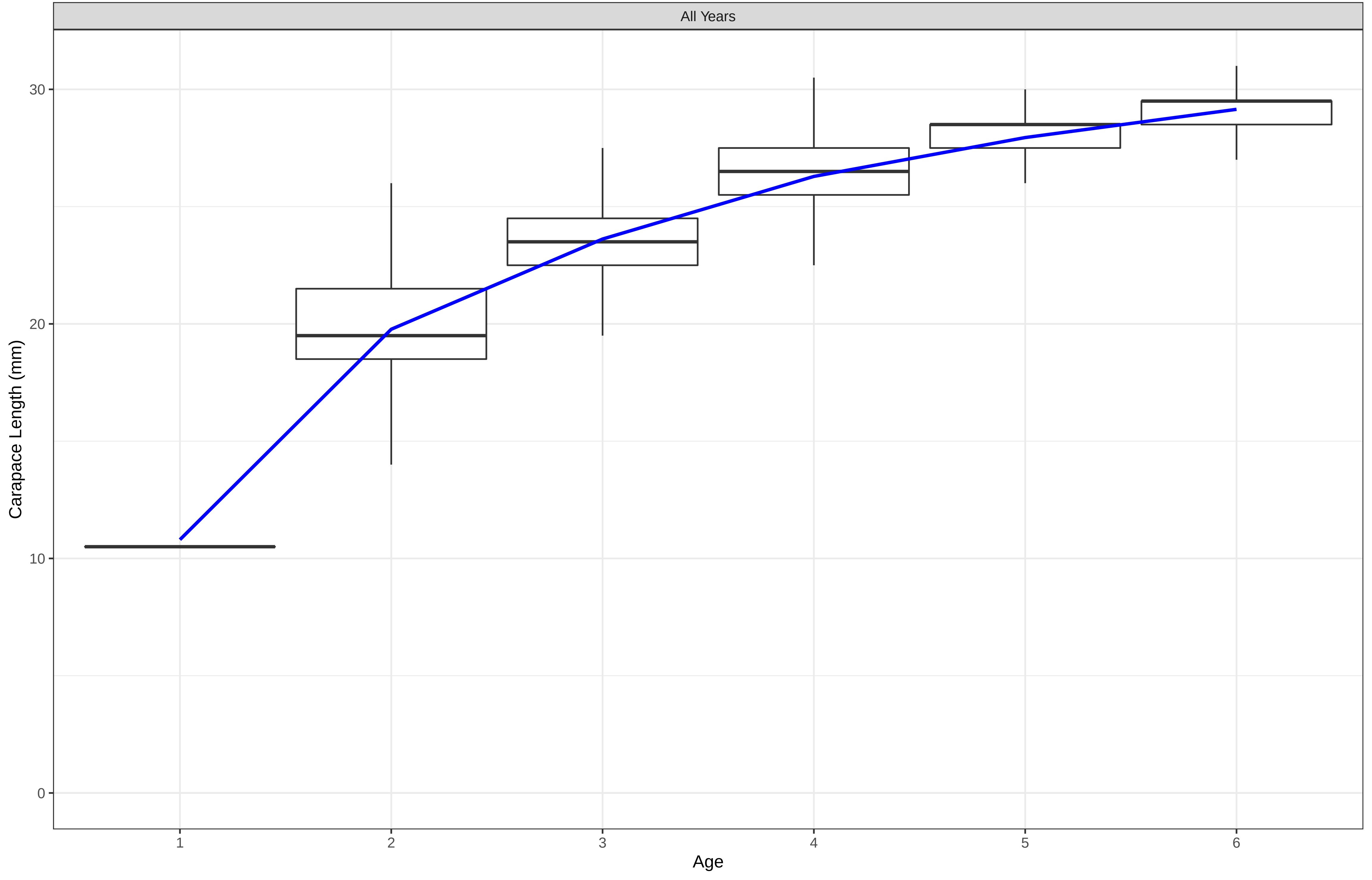

Likelihood Components
Total Index NEFSC Fall Trawl
Total Index ASMFC Shrimp Survey
Total Catch Trawl Fleet
Total Catch Trap Fleet
Total Catch Mixed Fleet
Total
Recruitment Devs
Index at Length NEFSC Fall Trawl
Index at Length ASMFC Shrimp Survey
Catch at Length Trawl Fleet
Catch at Length Trap Fleet
Catch at Length Mixed Fleet
0
5000
10000
15000
Negative Log−Likelihood

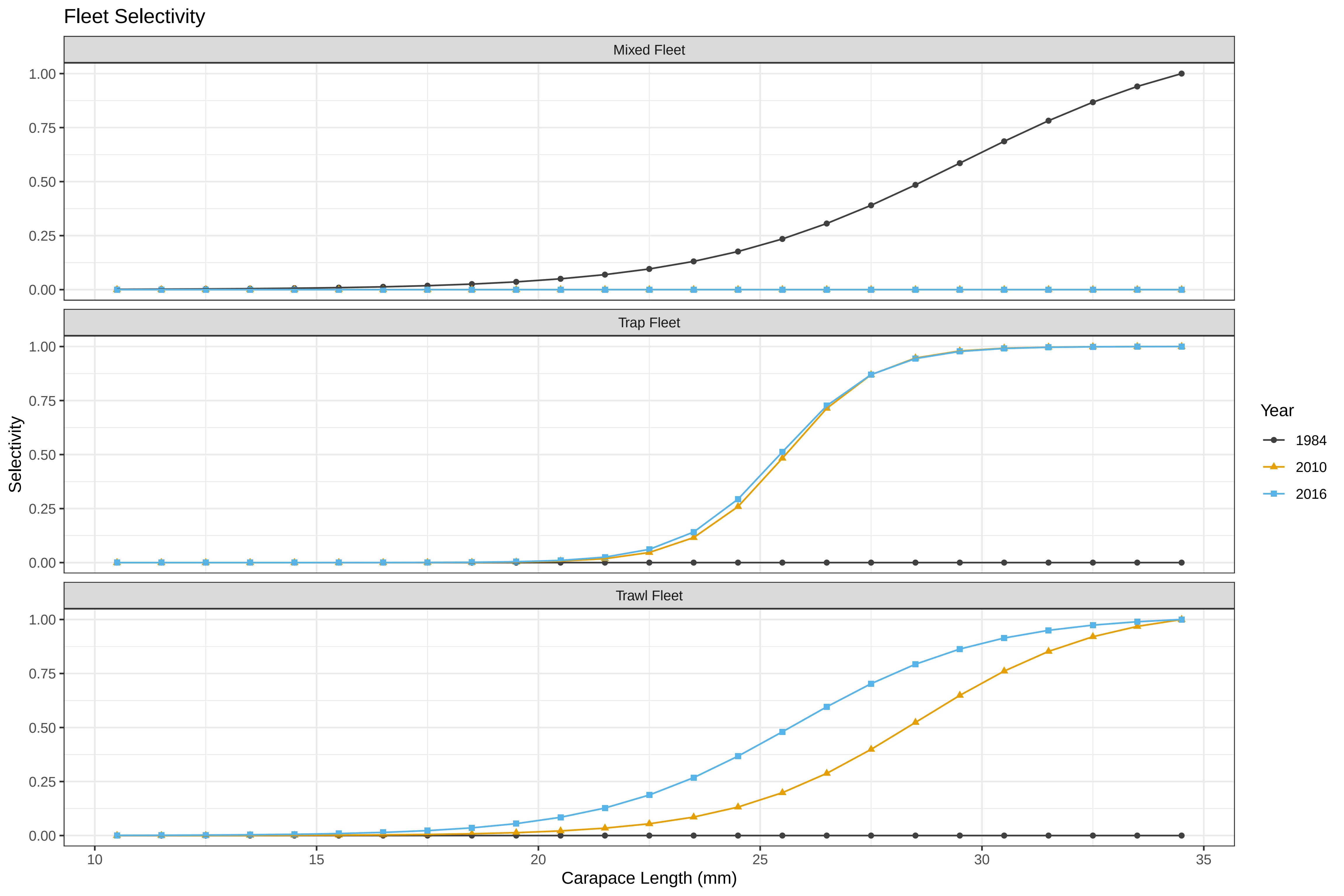

Length−Weight Relationships
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
0 5 10 15 20 25
10 15 20 25 30 35
Weight (g)
Carapace length (mm)


Proportion Female at Length
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
0.00
0.25
0.50
0.75
1.00
10
15
20
25
30
35
Proportion female
Carapace length (mm)

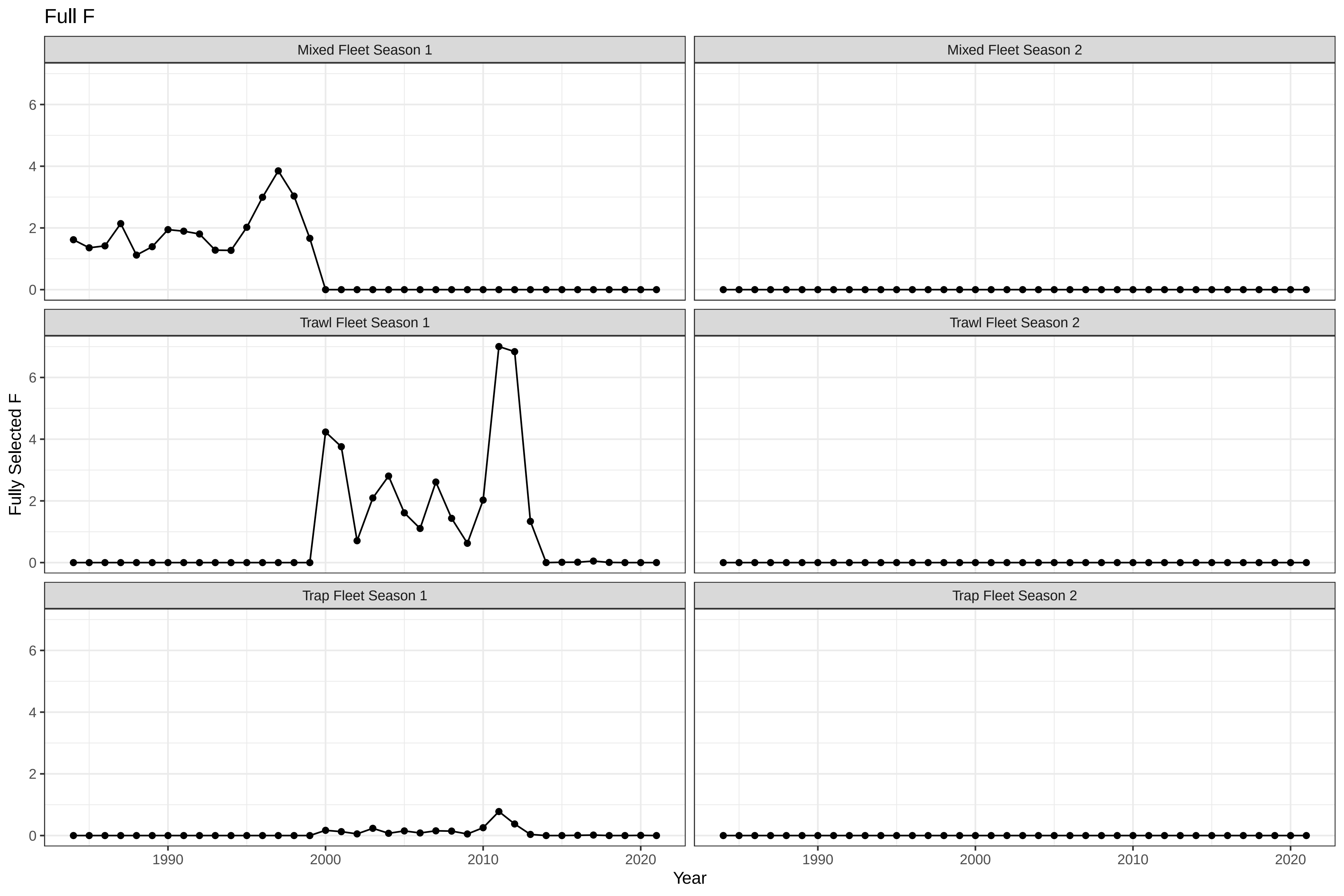

Natural Mortality
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Annual M
0
1
2
3
10
15
20
25
30
35
Carapace Length (mm)

Growth Matrix

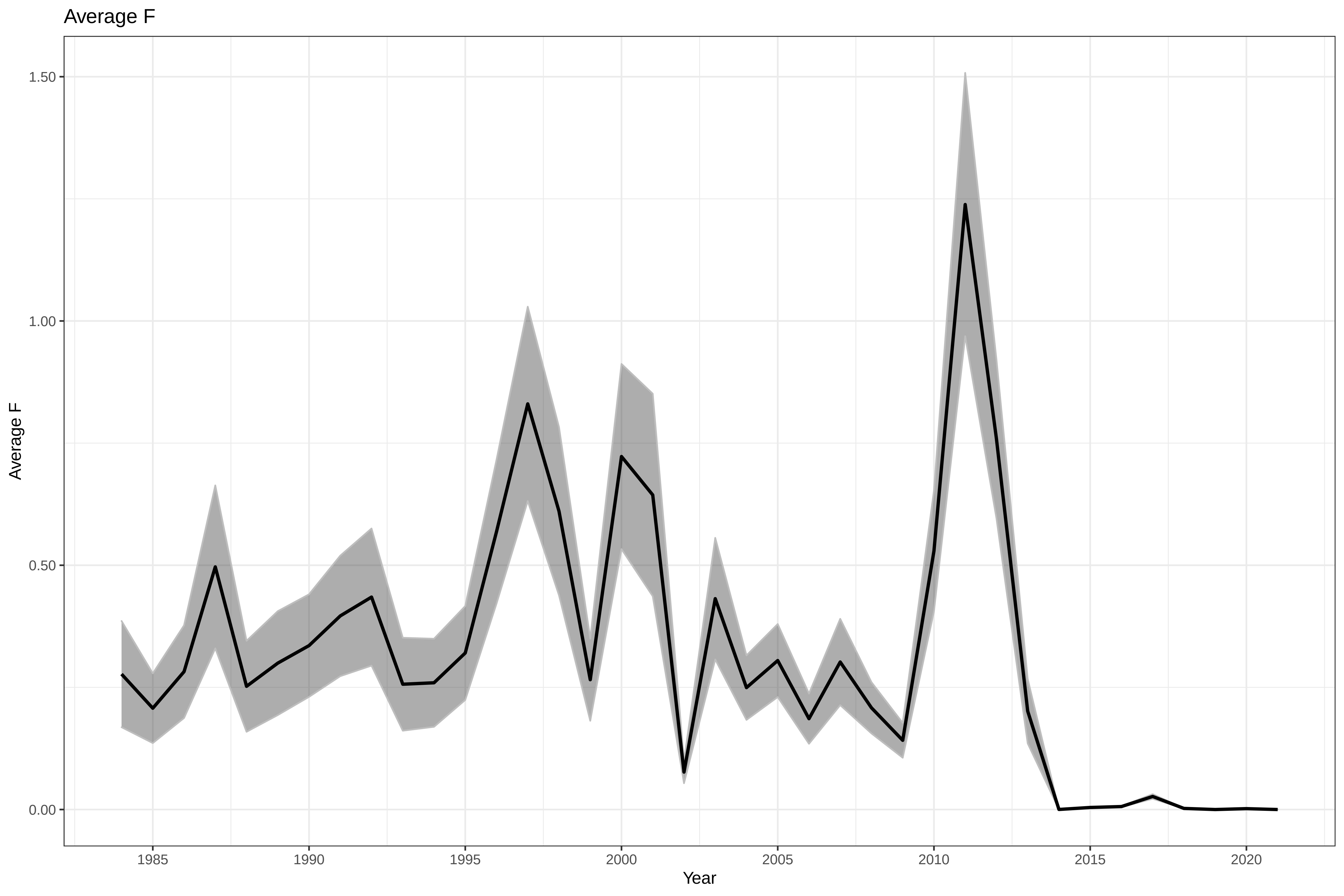




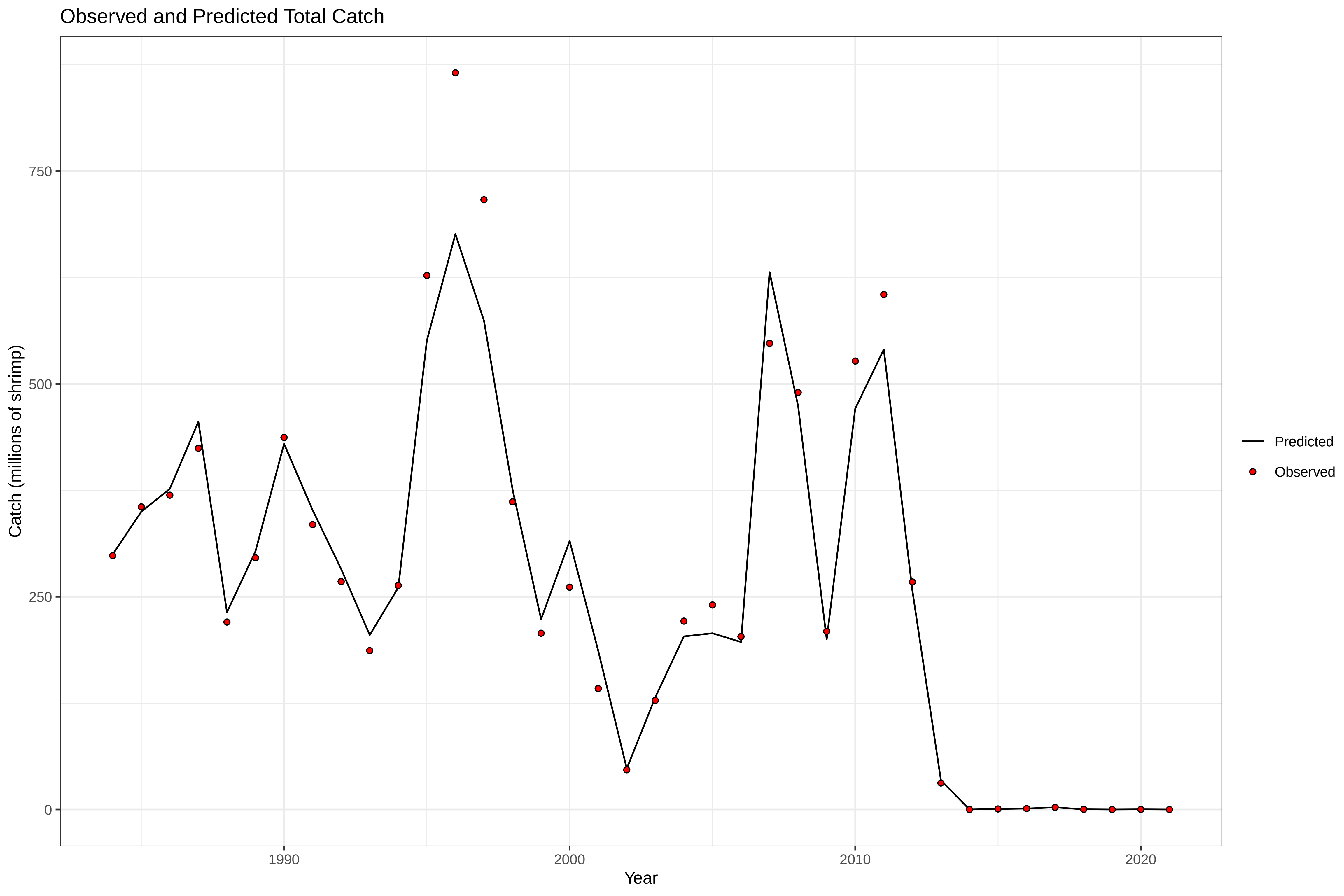
Fleet Selectivity
Mixed Fleet
Trap Fleet
Trawl Fleet
Selectivity
Carapace Length (mm)
0.00
0.25
0.50
0.75
1.00
10
15
20
25
30
35
Year
1984
2010
2016



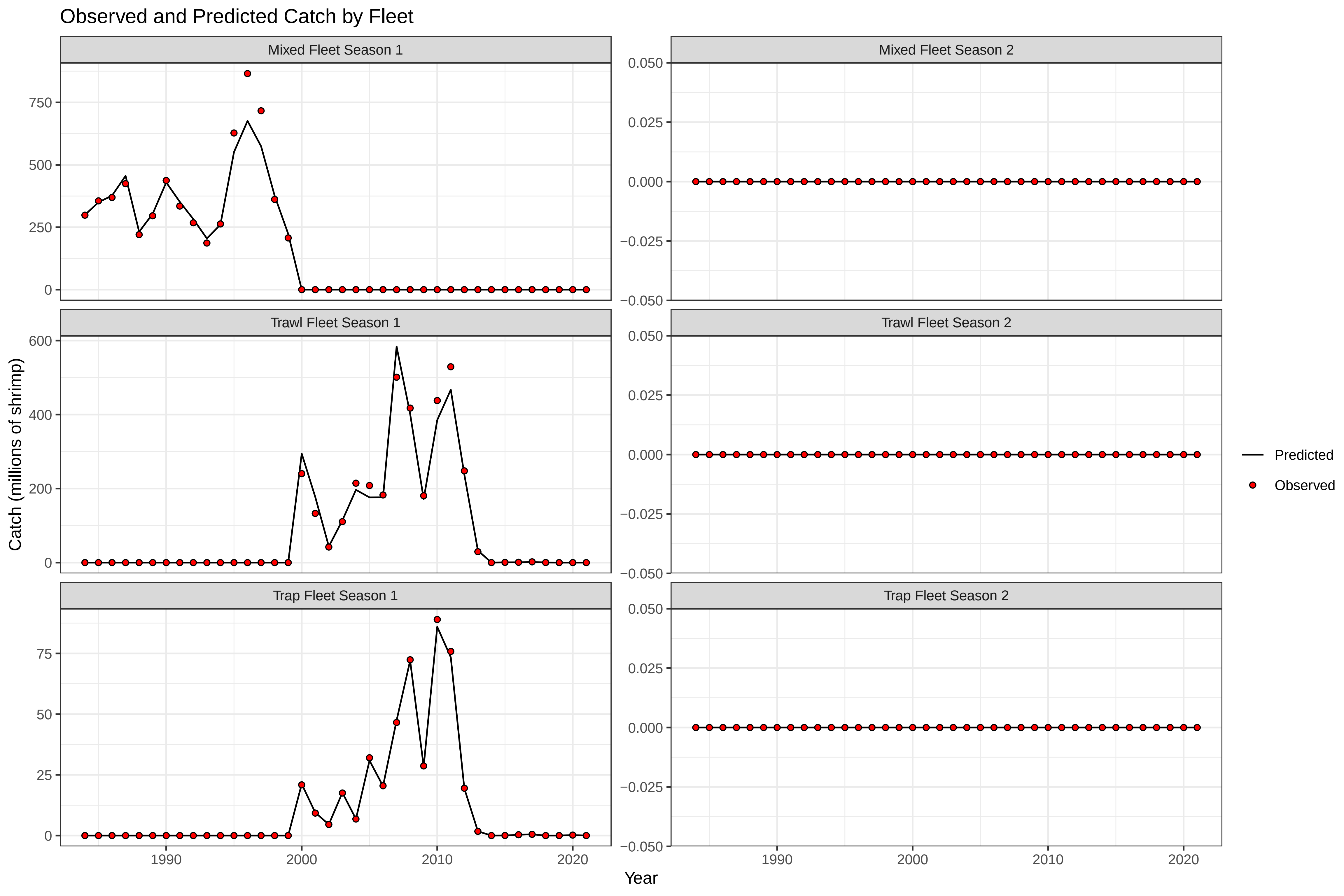
Full F
Mixed Fleet Season 1
Mixed Fleet Season 2
Trawl Fleet Season 1
Trawl Fleet Season 2
Trap Fleet Season 1
Trap Fleet Season 2
Fully Selected F
Year
0
2
4
6
1990
2000
2010
2020

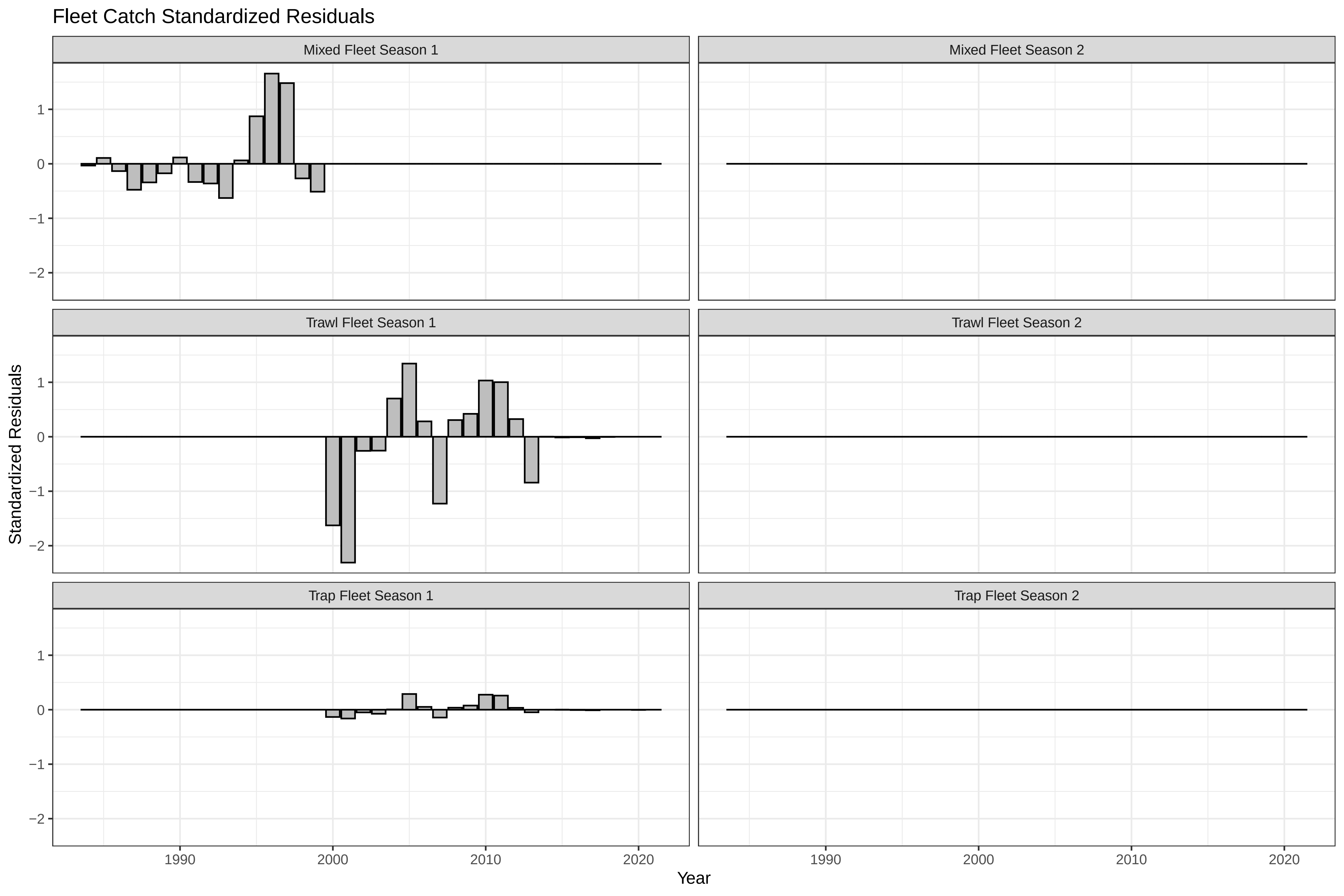


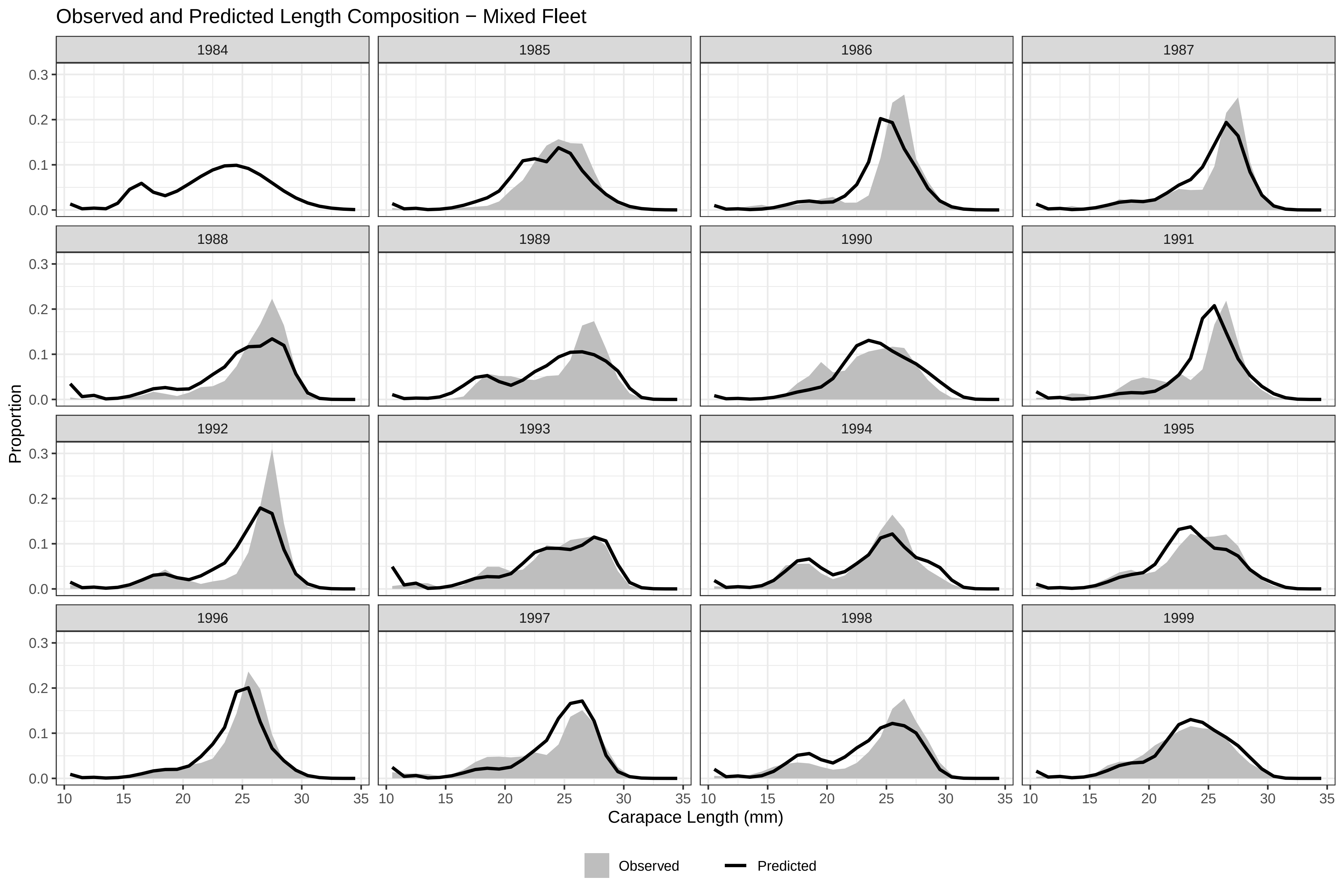
Average F
Average F
1.50
1.00
0.50
0.00
1985
1990
1995
2000
2005
2010
2015
2020
Year

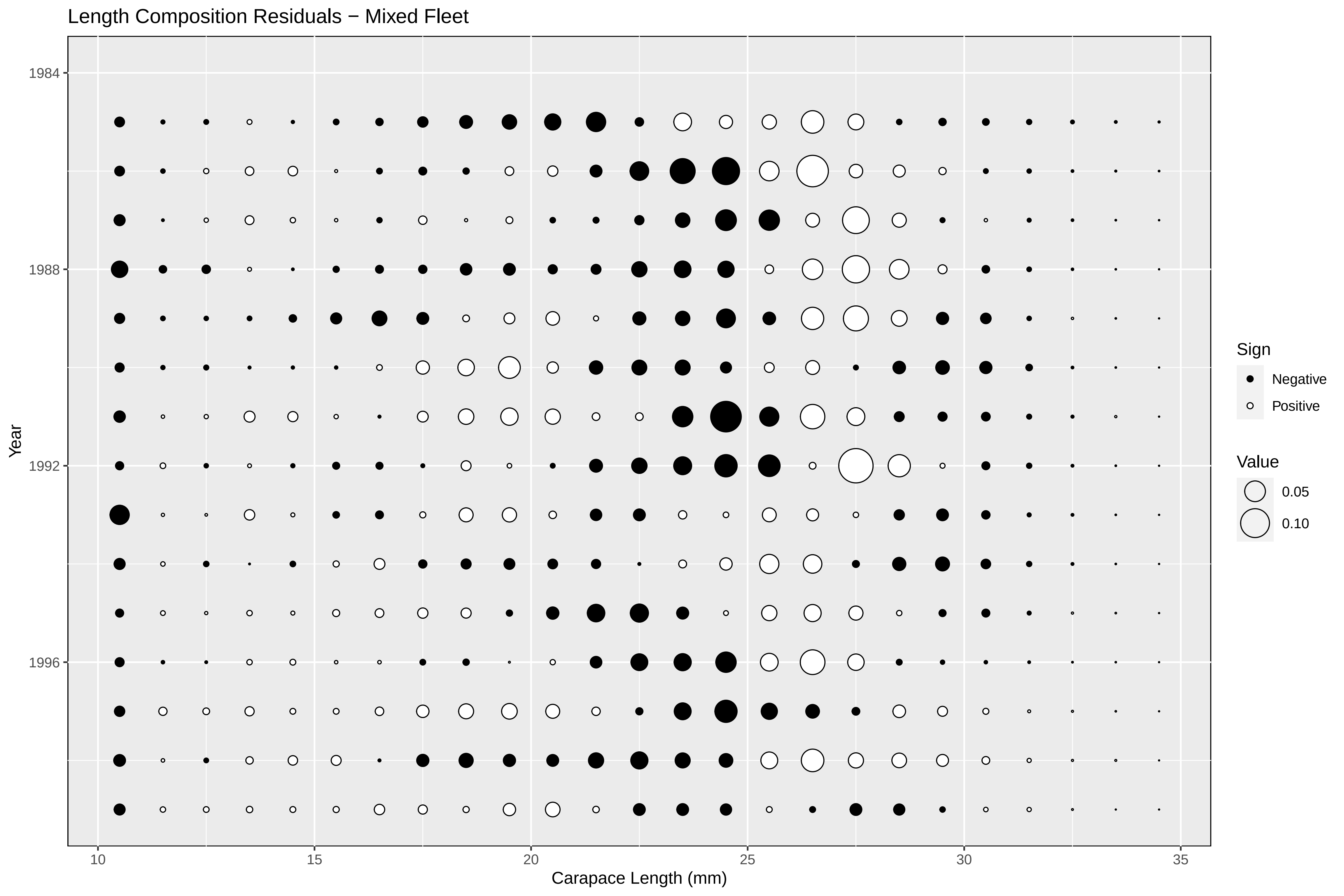


Observed and Predicted Total Catch
Catch (millions of shrimp)
750
500
250
0
1990
2000
2010
2020
Year
Predicted
Observed

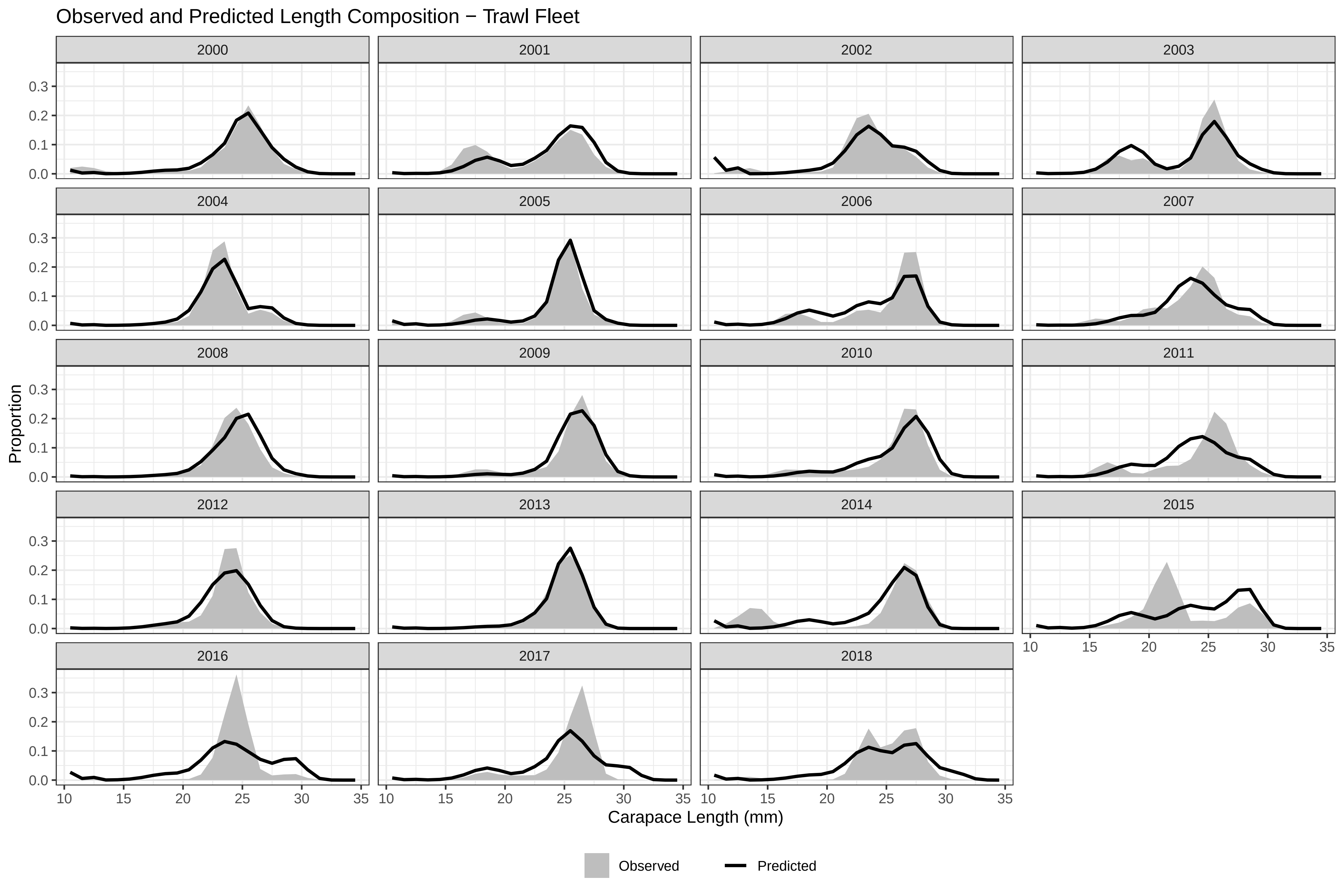

Observed and Predicted Catch by Fleet
Mixed Fleet Season 1
Mixed Fleet Season 2
Trawl Fleet Season 1
Trawl Fleet Season 2
Trap Fleet Season 1
Trap Fleet Season 2
Catch (millions of shrimp)
Year
Predicted
Observed
750
500
250
0
600
400
200
75
50
25
0.050
0.025
0.000
−0.025
−0.050
1990
2000
2010
2020

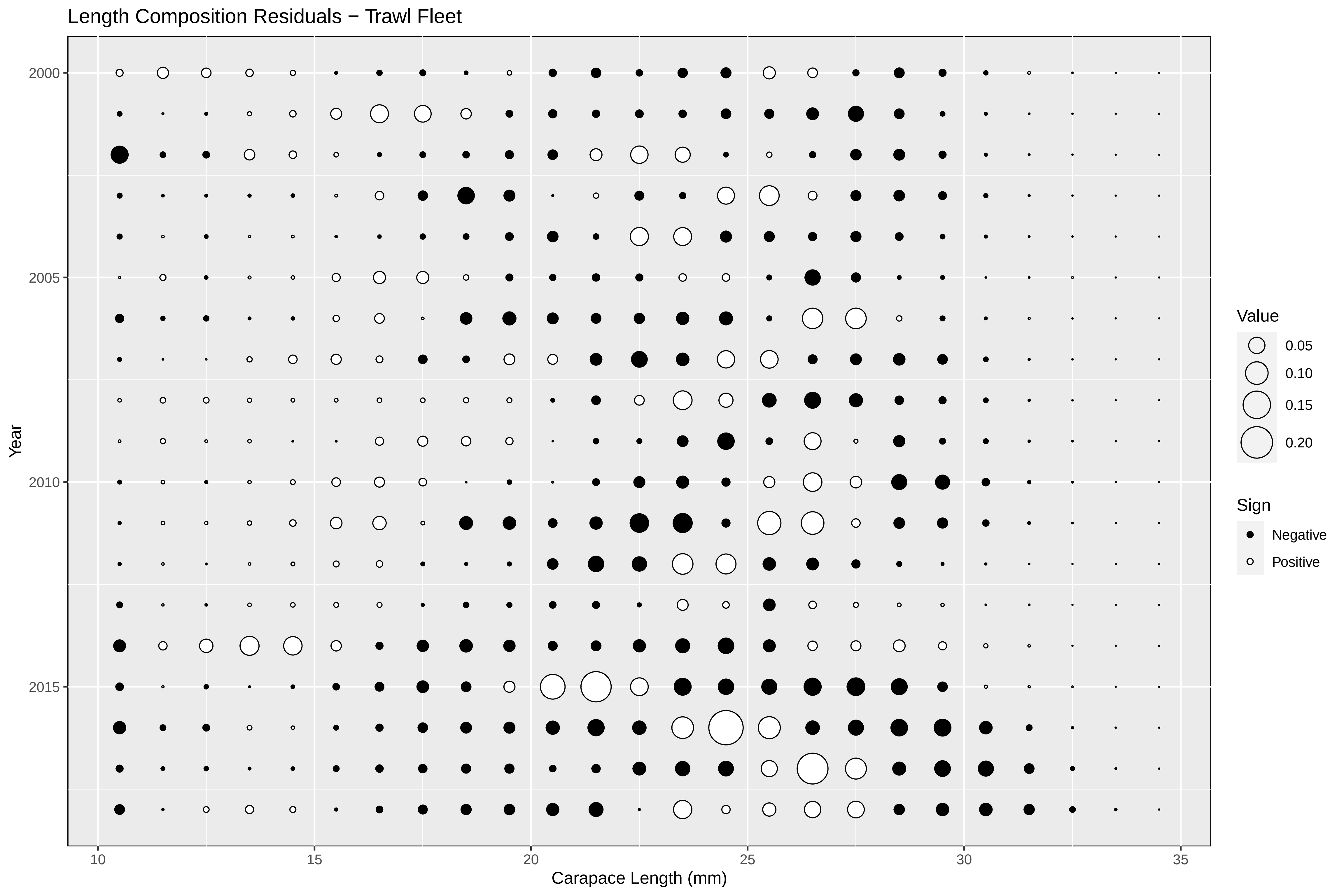

Fleet Catch Standardized Residuals
Mixed Fleet Season 1
Mixed Fleet Season 2
Trawl Fleet Season 1
Trawl Fleet Season 2
Trap Fleet Season 1
Trap Fleet Season 2
Standardized Residuals
1
0
−1
−2
1990
2000
2010
2020
Year


Observed and Predicted Length Composition − Mixed Fleet
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
Proportion
Carapace Length (mm)
Observed
Predicted

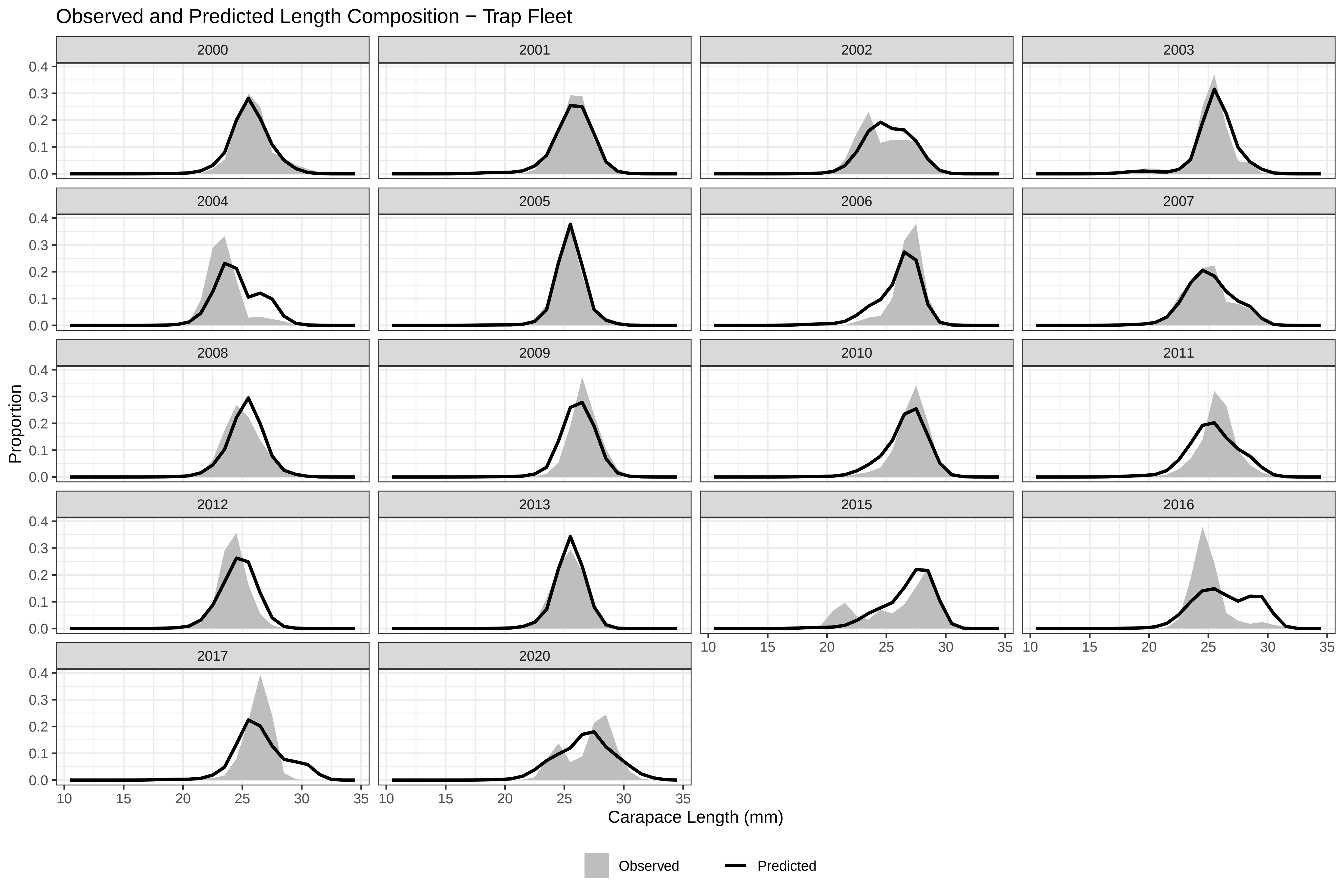


Length Composition Residuals − Mixed Fleet
1984
1988
1992
1996
Year
10
15
20
25
30
35
Carapace Length (mm)
Sign
Negative
Positive
Value
0.05
0.10

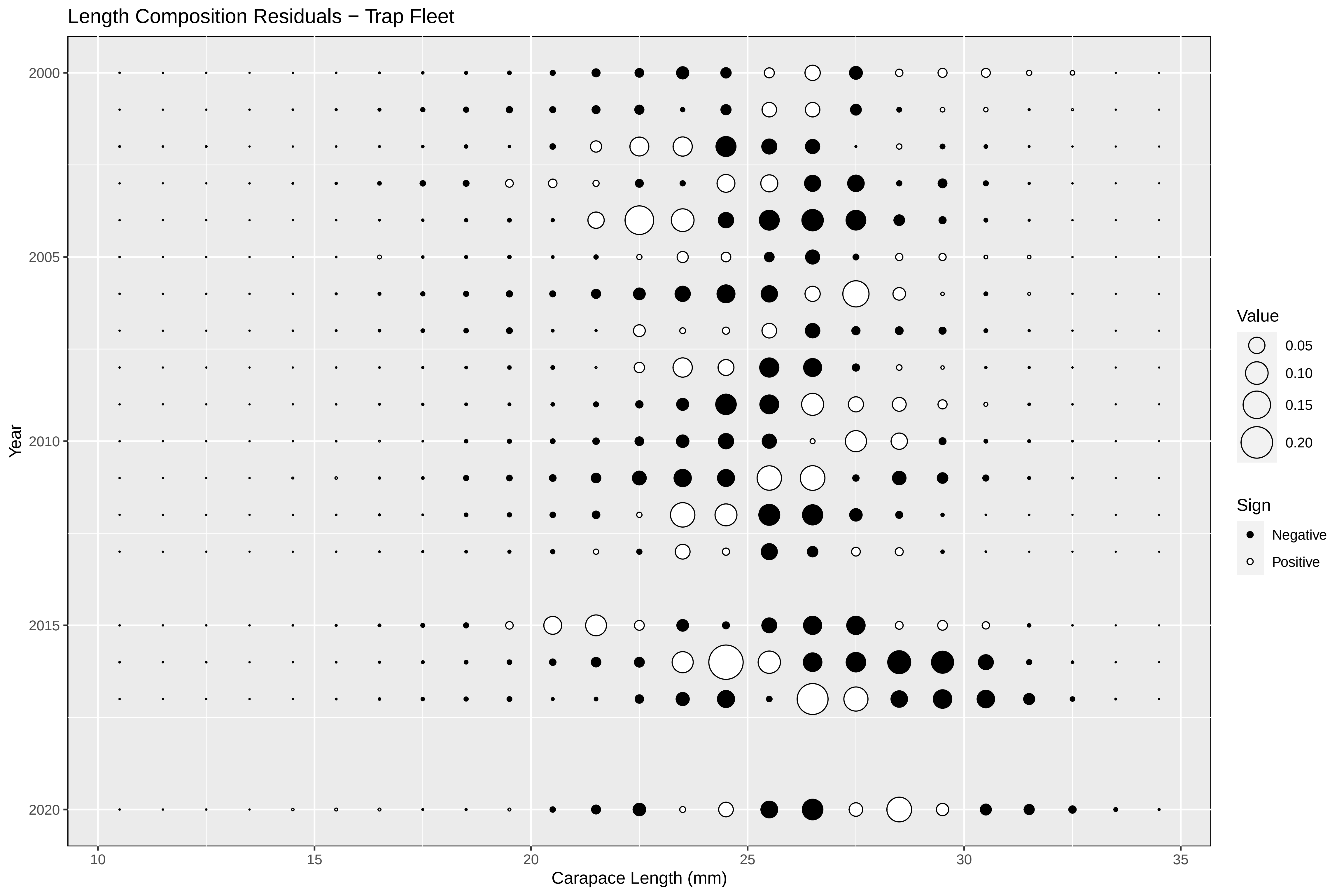

Observed and Predicted Length Composition − Trawl Fleet
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Proportion
0.0
0.1
0.2
0.3
10
15
20
25
30
35
Carapace Length (mm)
Observed
Predicted



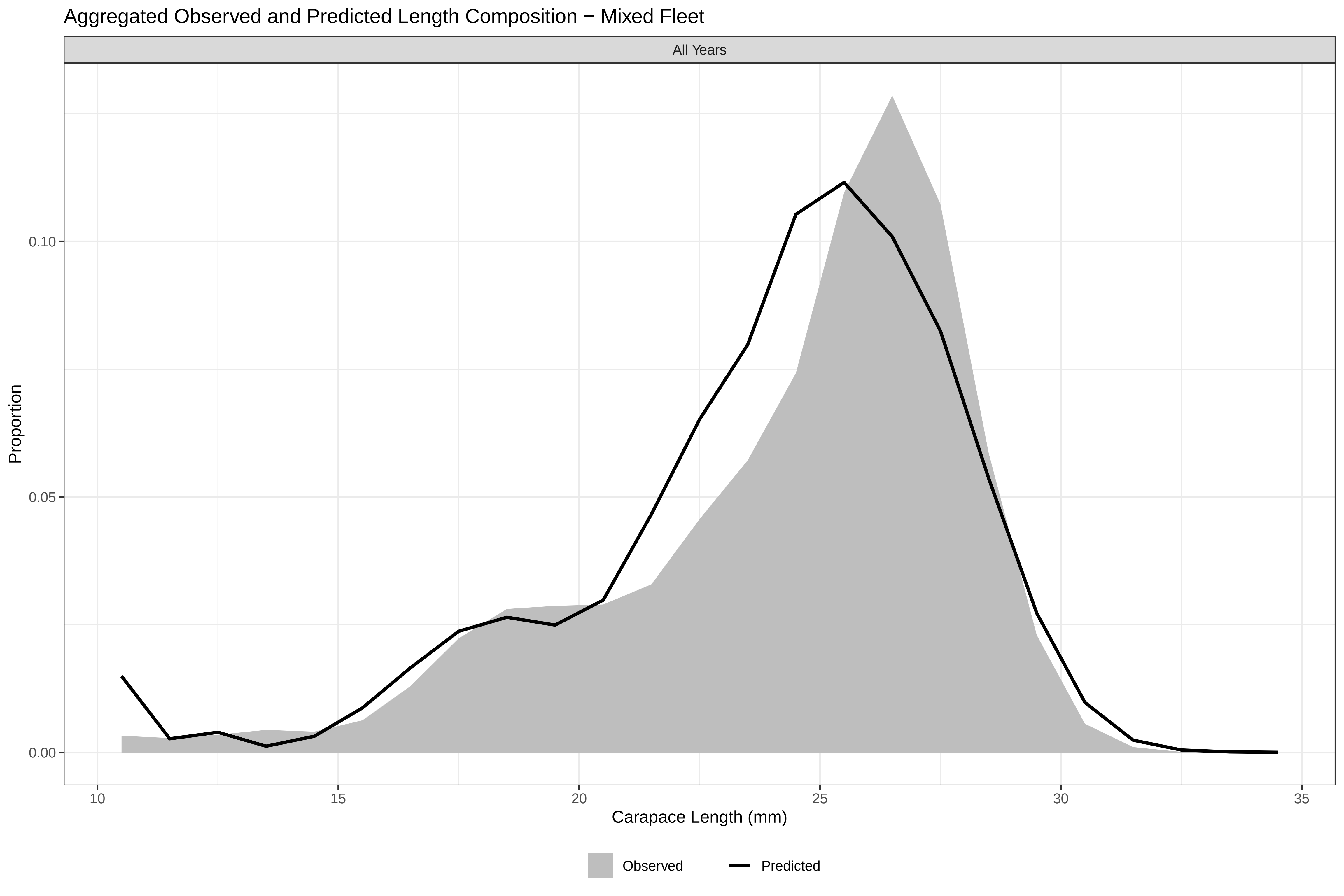
Length Composition Residuals − Trawl Fleet
Year
2000
2005
2010
2015
10
15
20
25
30
35
Carapace Length (mm)
Value
0.05
0.10
0.15
0.20
Sign
Negative
Positive



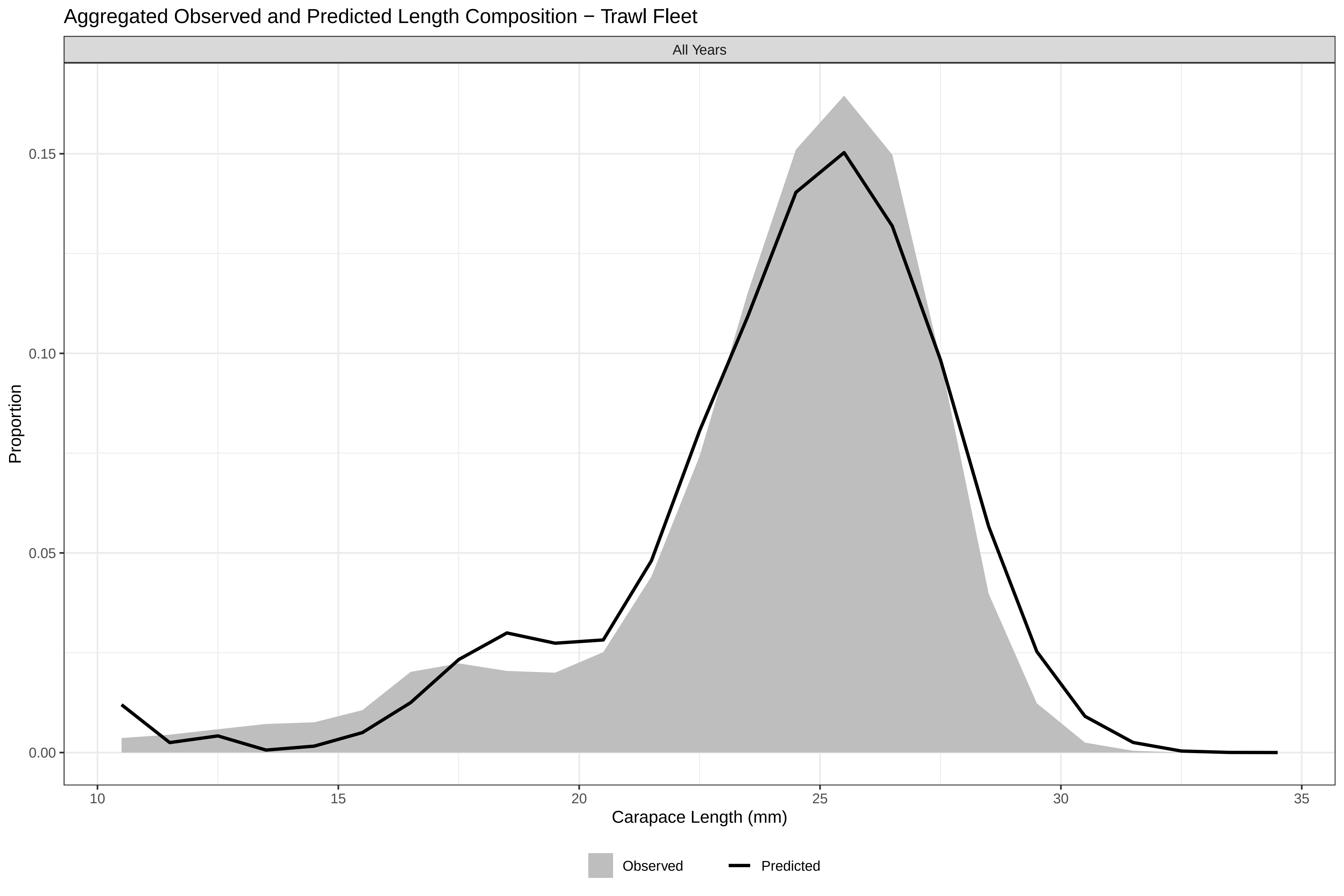
Observed and Predicted Length Composition − Trap Fleet
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2015
2016
2017
2020
Proportion
0.0
0.1
0.2
0.3
0.4
10
15
20
25
30
35
Carapace Length (mm)
Observed
Predicted

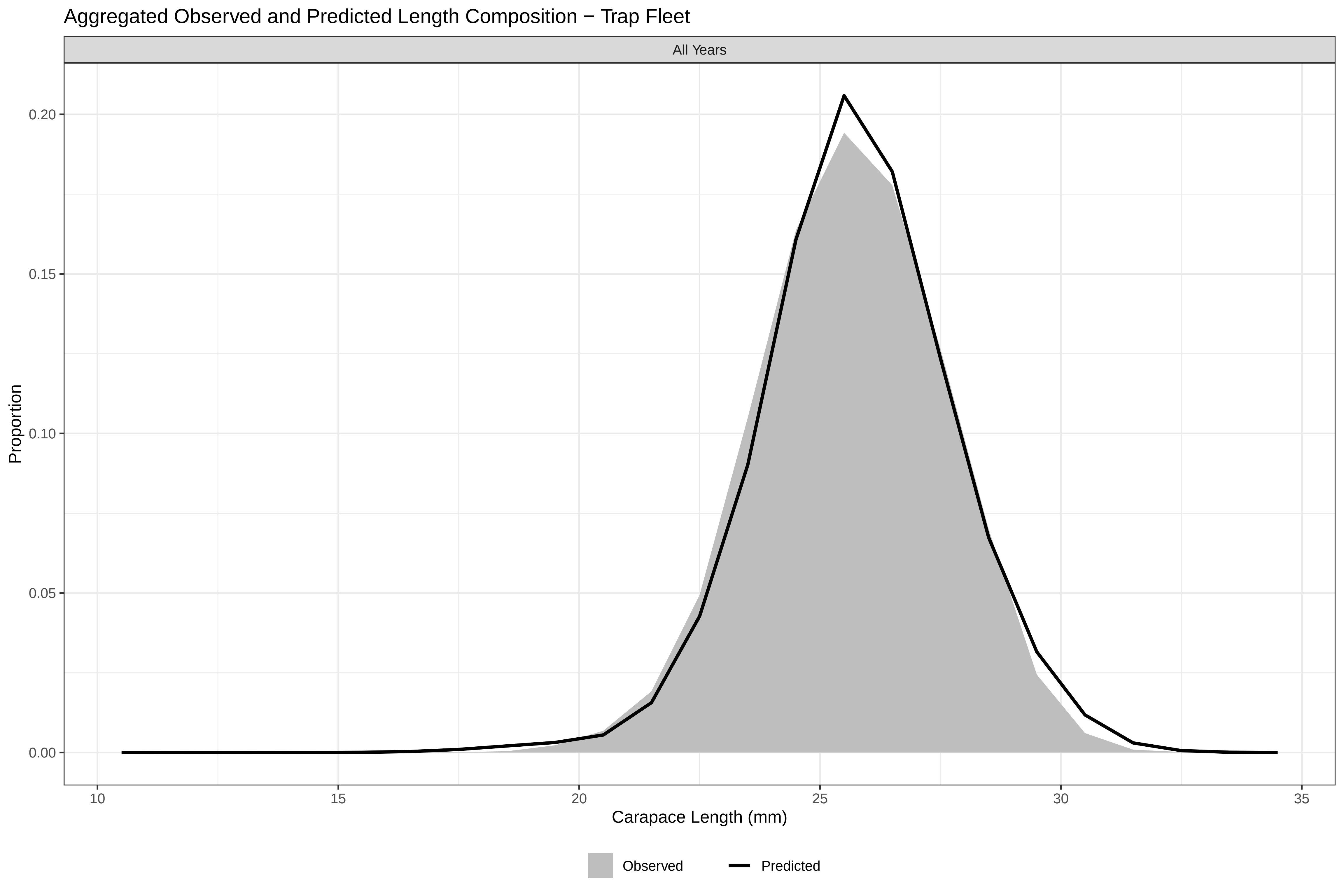


Length Composition Residuals − Trap Fleet
Year
2000
2005
2010
2015
2020
10
15
20
25
30
35
Carapace Length (mm)
Value
0.05
0.10
0.15
0.20
Sign
Negative
Positive

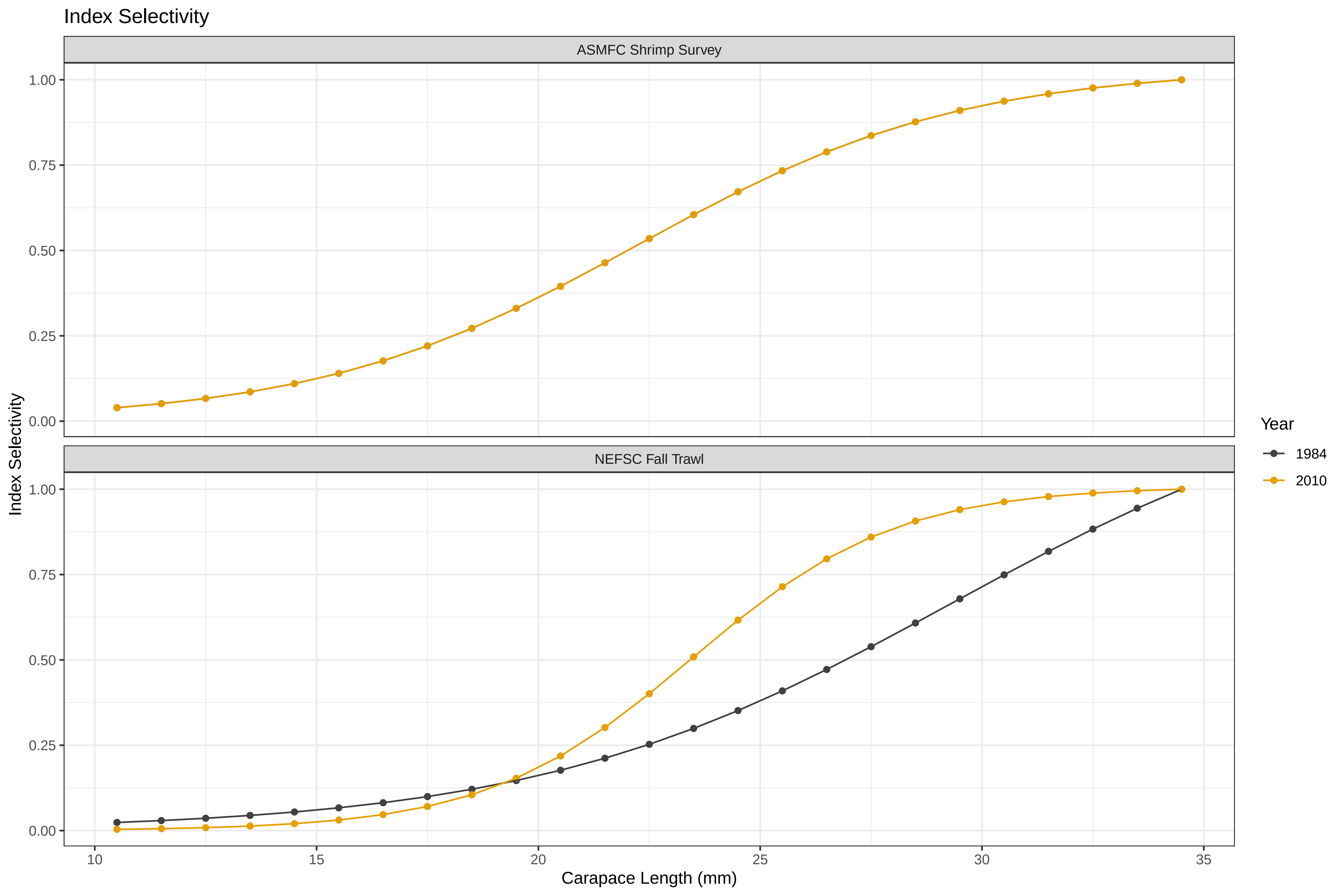


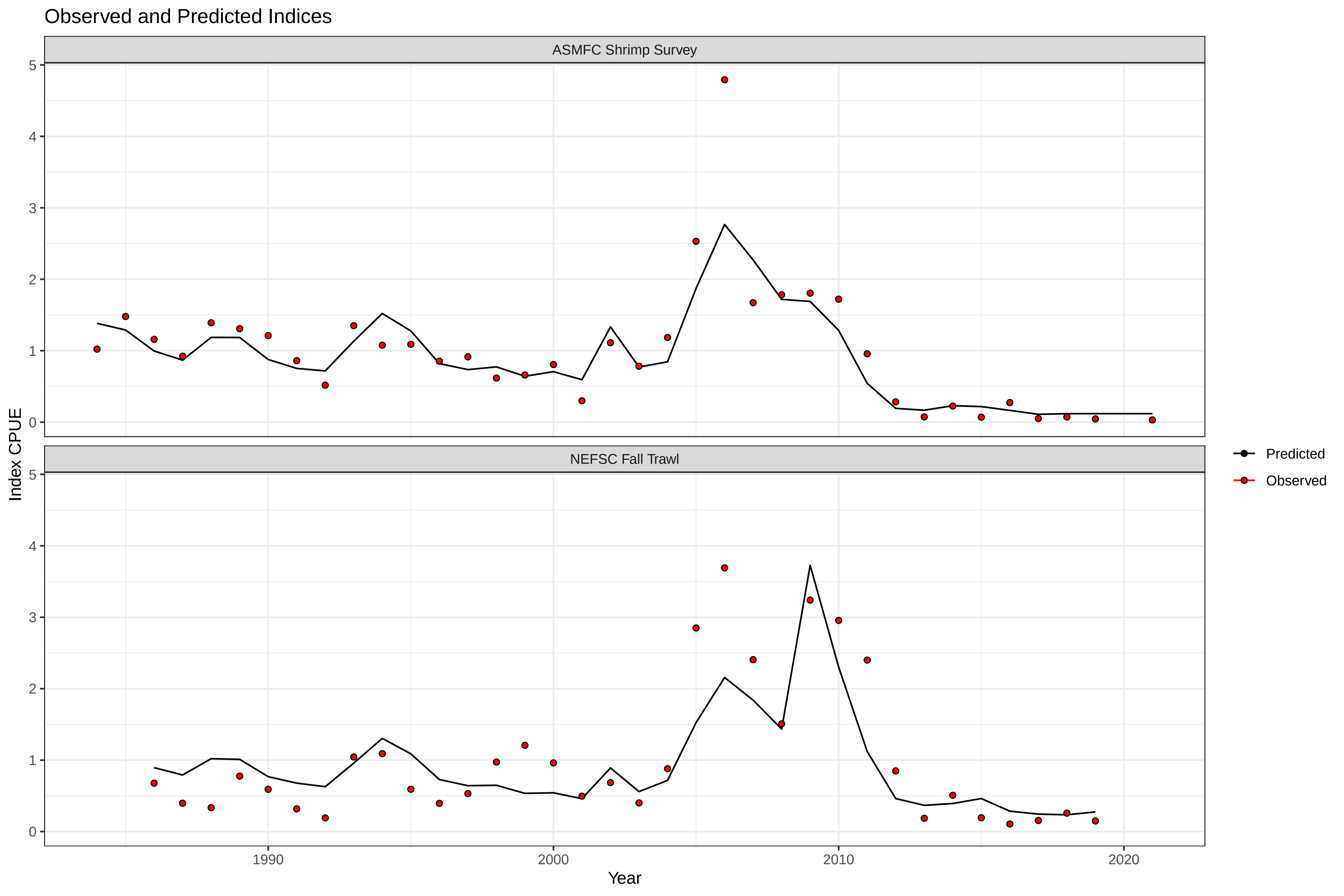
Aggregated Observed and Predicted Length Composition − Mixed Fleet
All Years
Proportion
0.10
0.05
0.00
10
15
20
25
30
35
Carapace Length (mm)
Observed
Predicted


Aggregated Observed and Predicted Length Composition − Trawl Fleet
All Years
Proportion
0.00
0.05
0.10
0.15
10
15
20
25
30
35
Carapace Length (mm)
Observed
Predicted

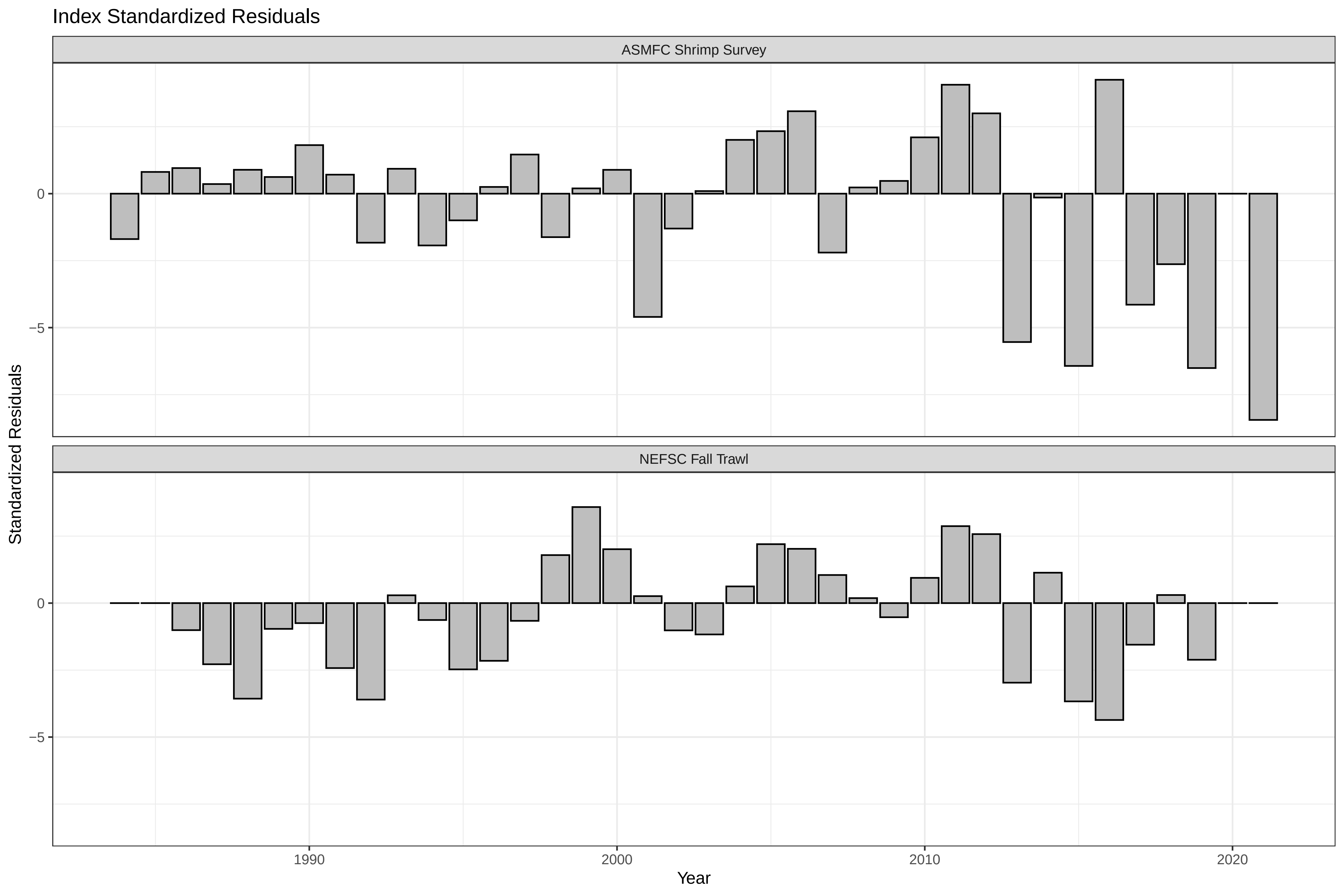


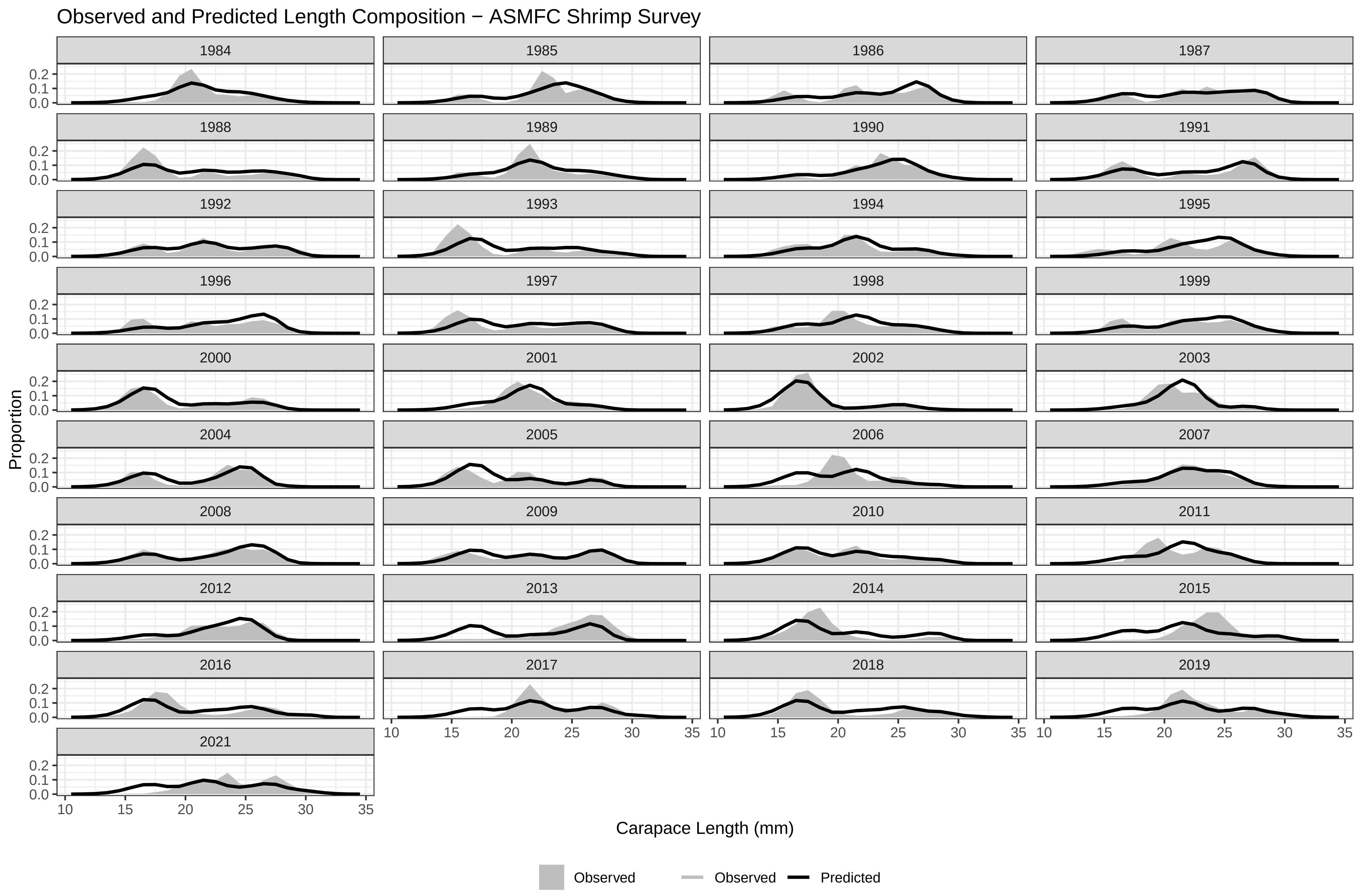
Aggregated Observed and Predicted Length Composition − Trap Fleet
All Years
Proportion
0.00
0.05
0.10
0.15
0.20
10
15
20
25
30
35
Carapace Length (mm)
Observed
Predicted


Index Selectivity
ASMFC Shrimp Survey
NEFSC Fall Trawl
Index Selectivity
1.00
0.75
0.50
0.25
0.00
10
15
20
25
30
35
Carapace Length (mm)
Year
1984
2010

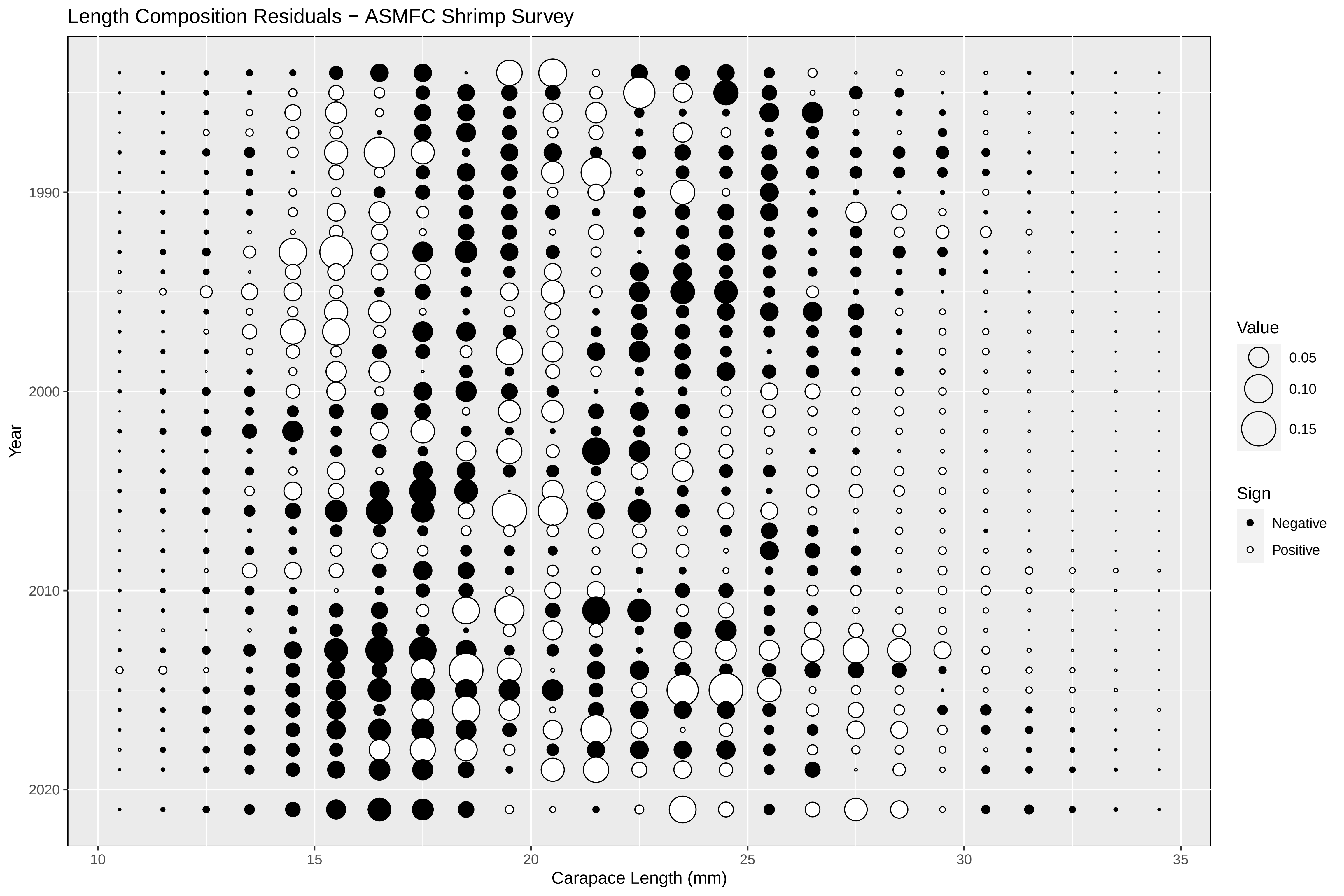


Observed and Predicted Indices
ASMFC Shrimp Survey
NEFSC Fall Trawl
Index CPUE
Year
0
1
2
3
4
5
1990
2000
2010
2020
Predicted
Observed

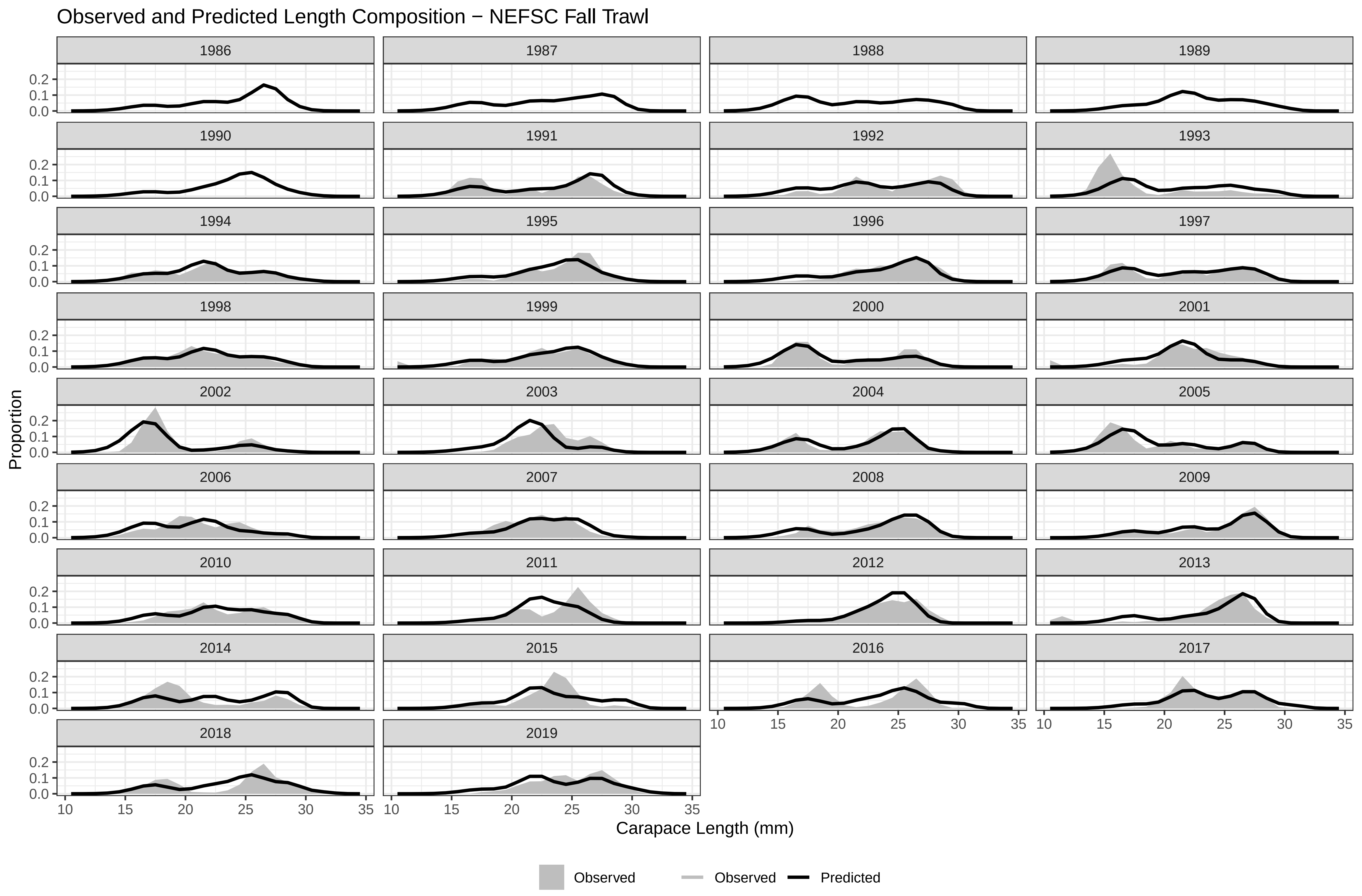

Index Standardized Residuals
ASMFC Shrimp Survey
NEFSC Fall Trawl
Standardized Residuals
0
−5
0
−5
1990
2000
2010
2020
Year

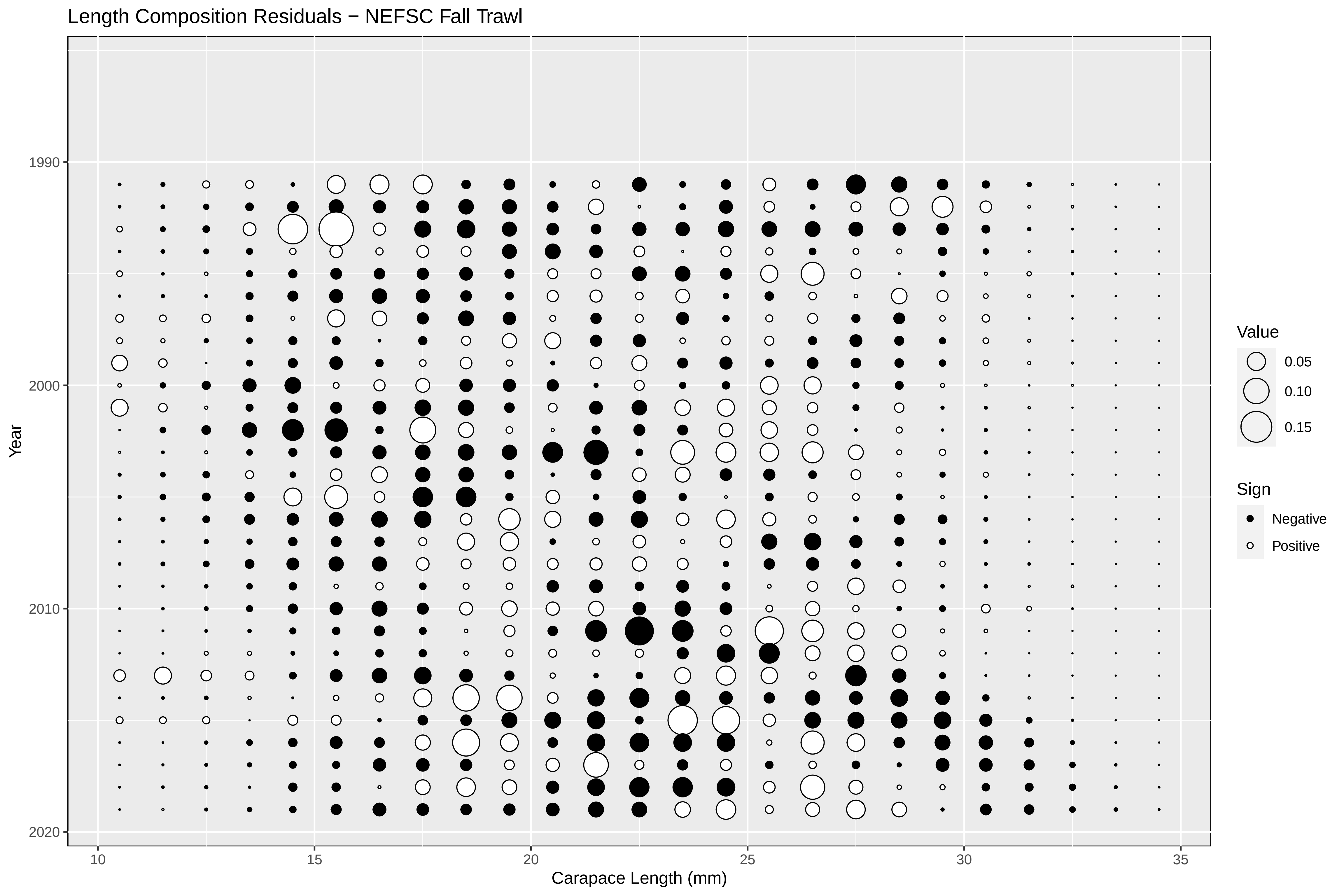


Observed and Predicted Length Composition − ASMFC Shrimp Survey
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2021
Proportion
0.0
0.1
0.2
10
15
20
25
30
35
Carapace Length (mm)
Observed
Observed
Predicted

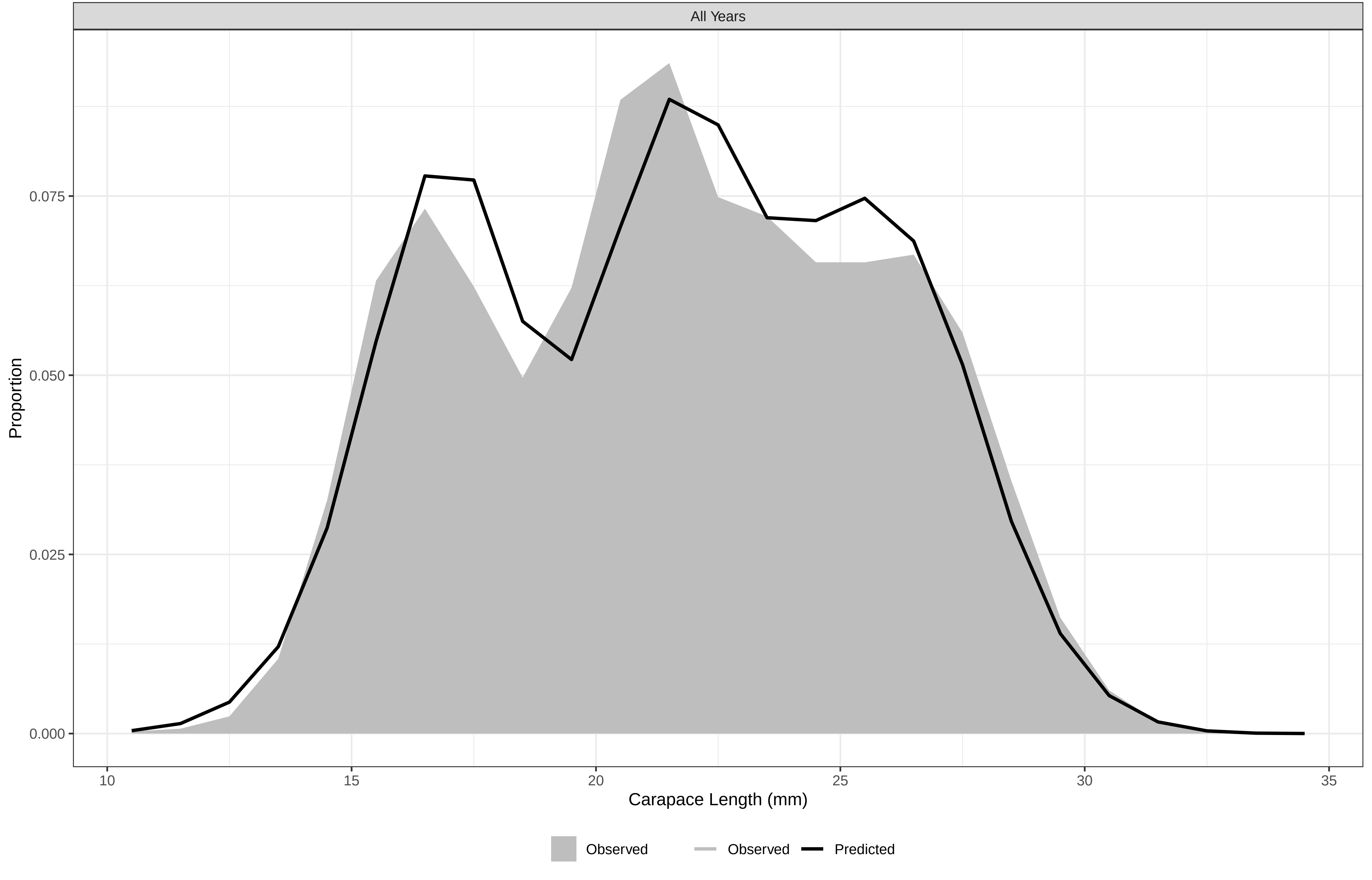


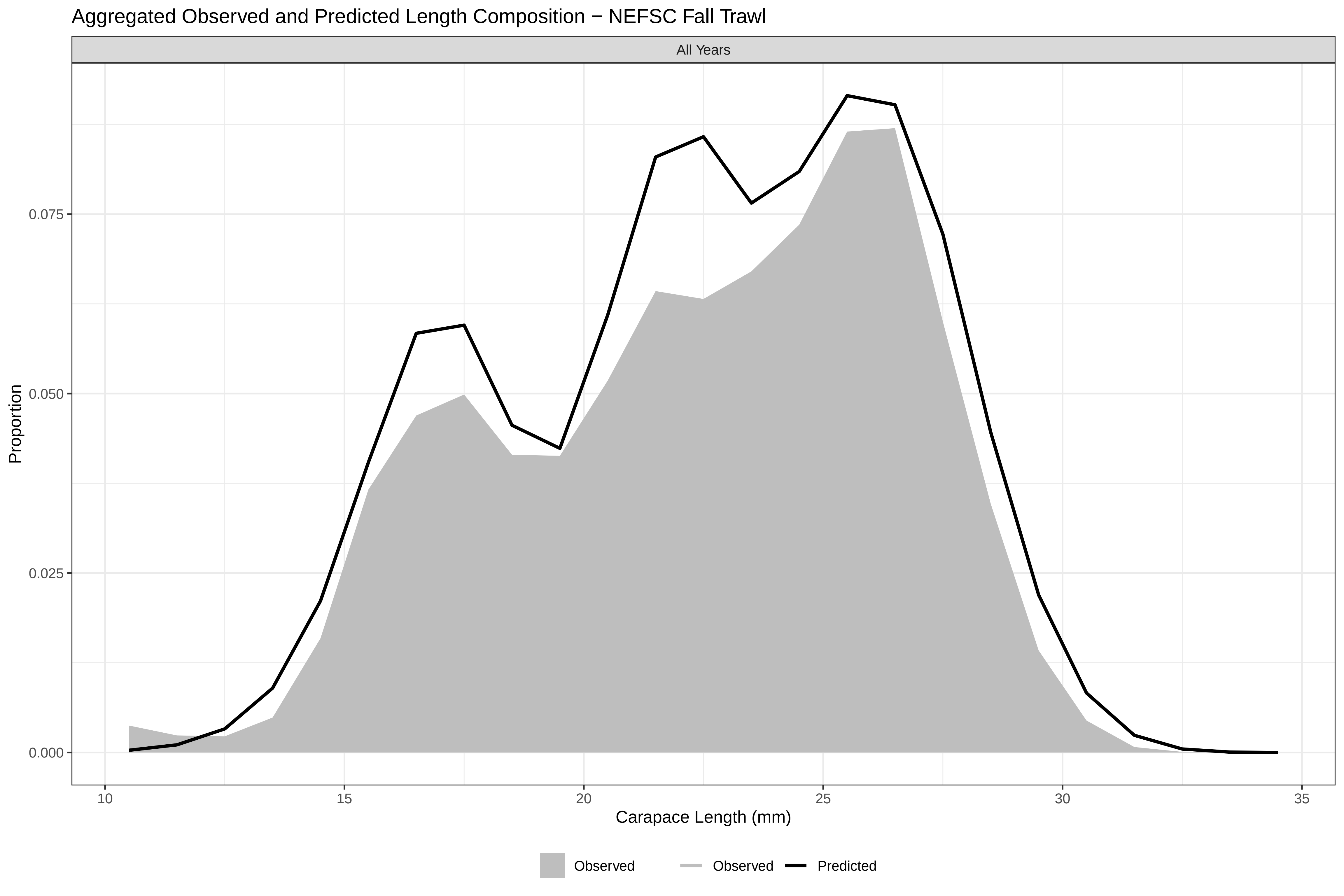
Length Composition Residuals − ASMFC Shrimp Survey
Year
1990
2000
2010
2020
10
15
20
25
30
35
Carapace Length (mm)
Value
0.05
0.10
0.15
Sign
Negative
Positive

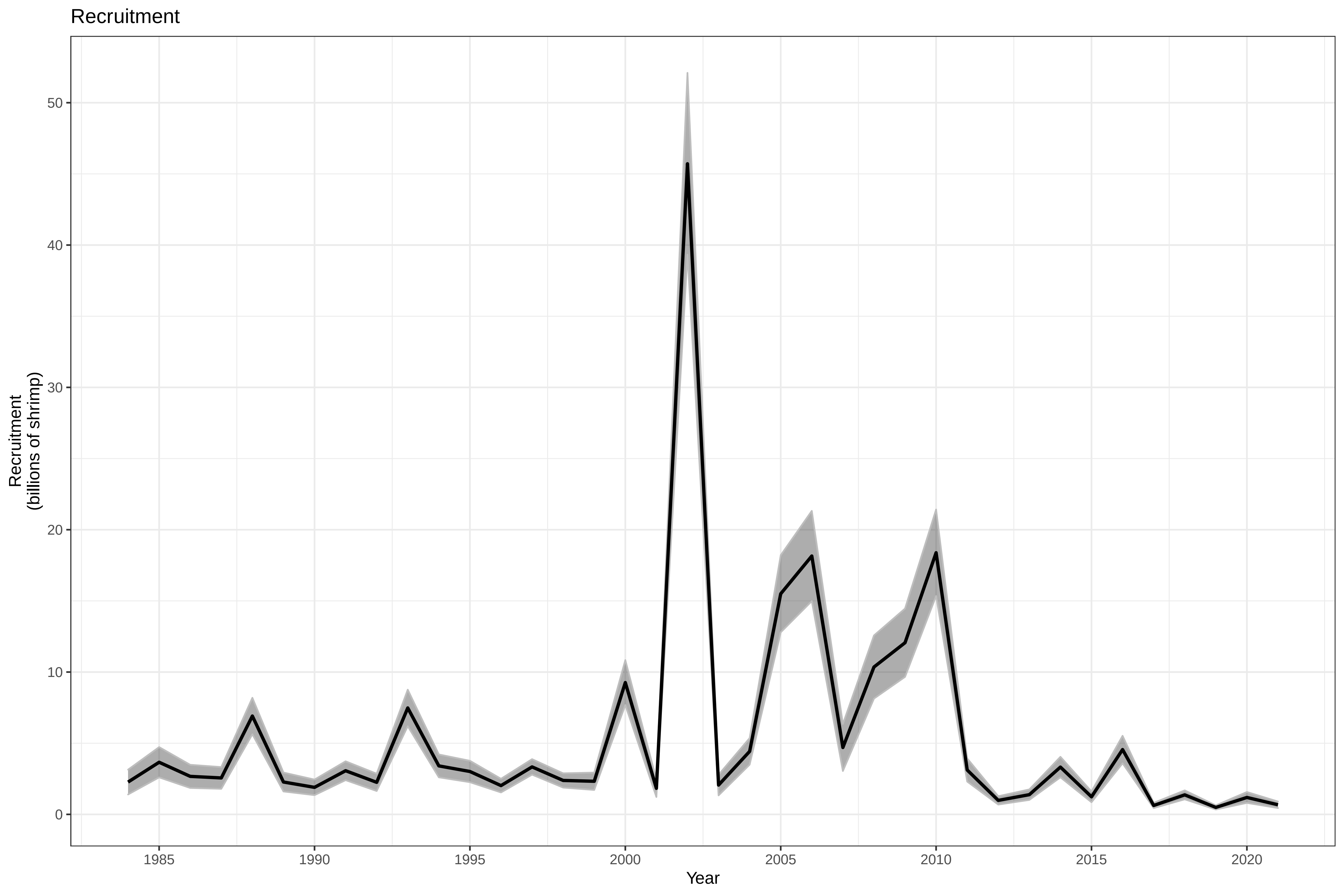

Observed and Predicted Length Composition − NEFSC Fall Trawl
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Proportion
0.0
0.1
0.2
Carapace Length (mm)
10
15
20
25
30
35
Observed
Observed
Predicted


Length Composition Residuals − NEFSC Fall Trawl
Year
1990
2000
2010
2020
10
15
20
25
30
35
Carapace Length (mm)
Value
0.05
0.10
0.15
Sign
Negative
Positive

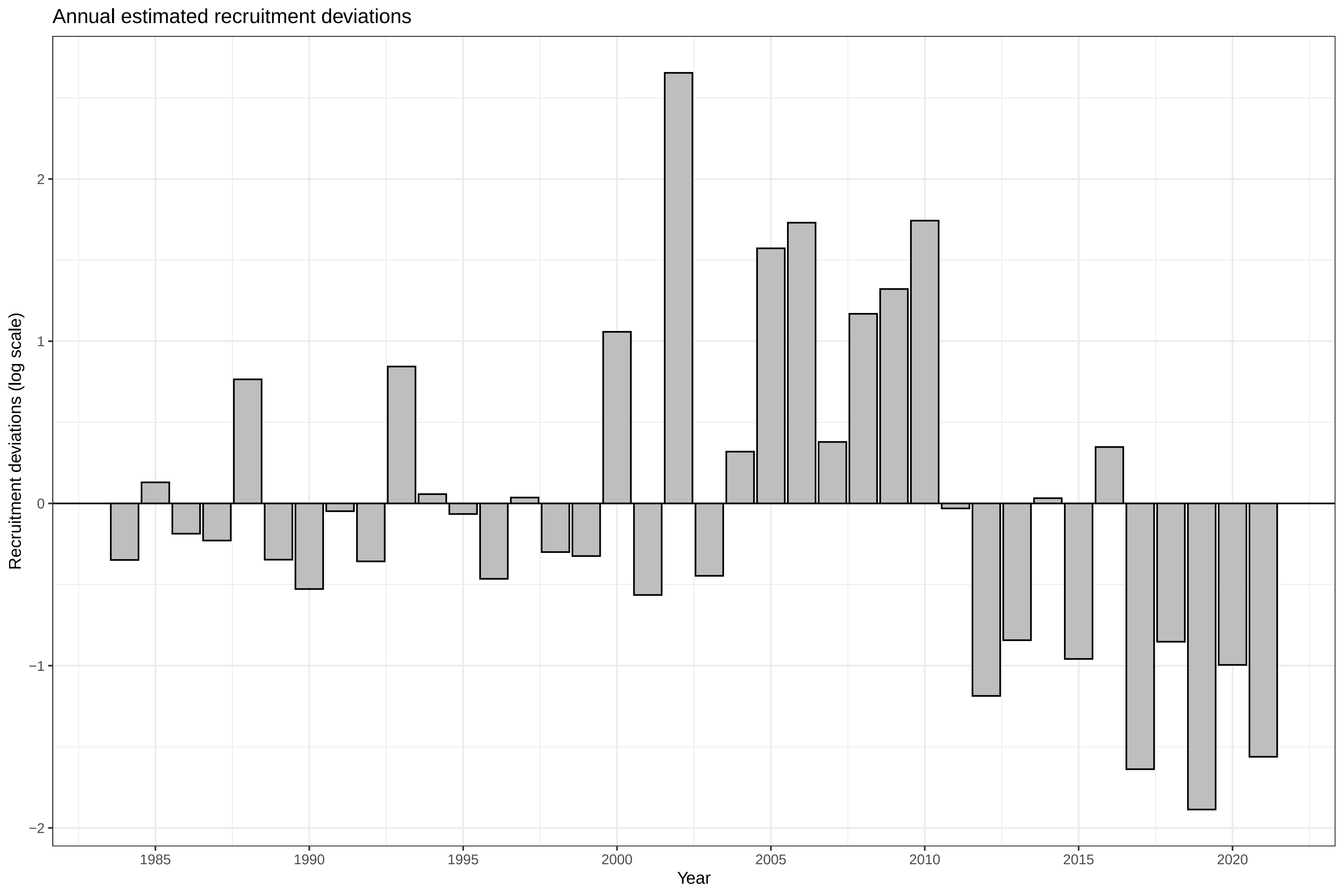
Aggregated Observed and Predicted Length Composition − ASMFC Shrimp Survey

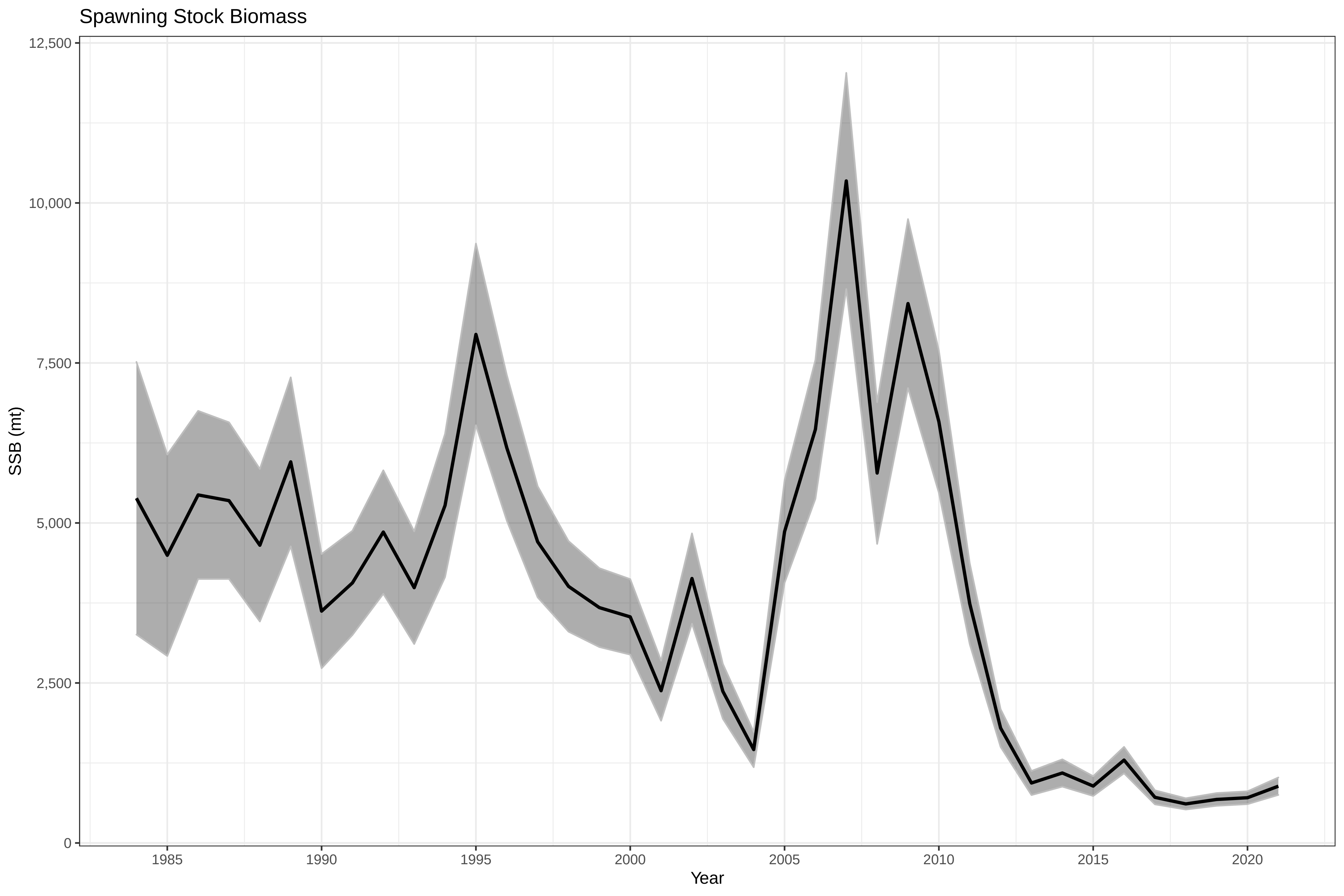


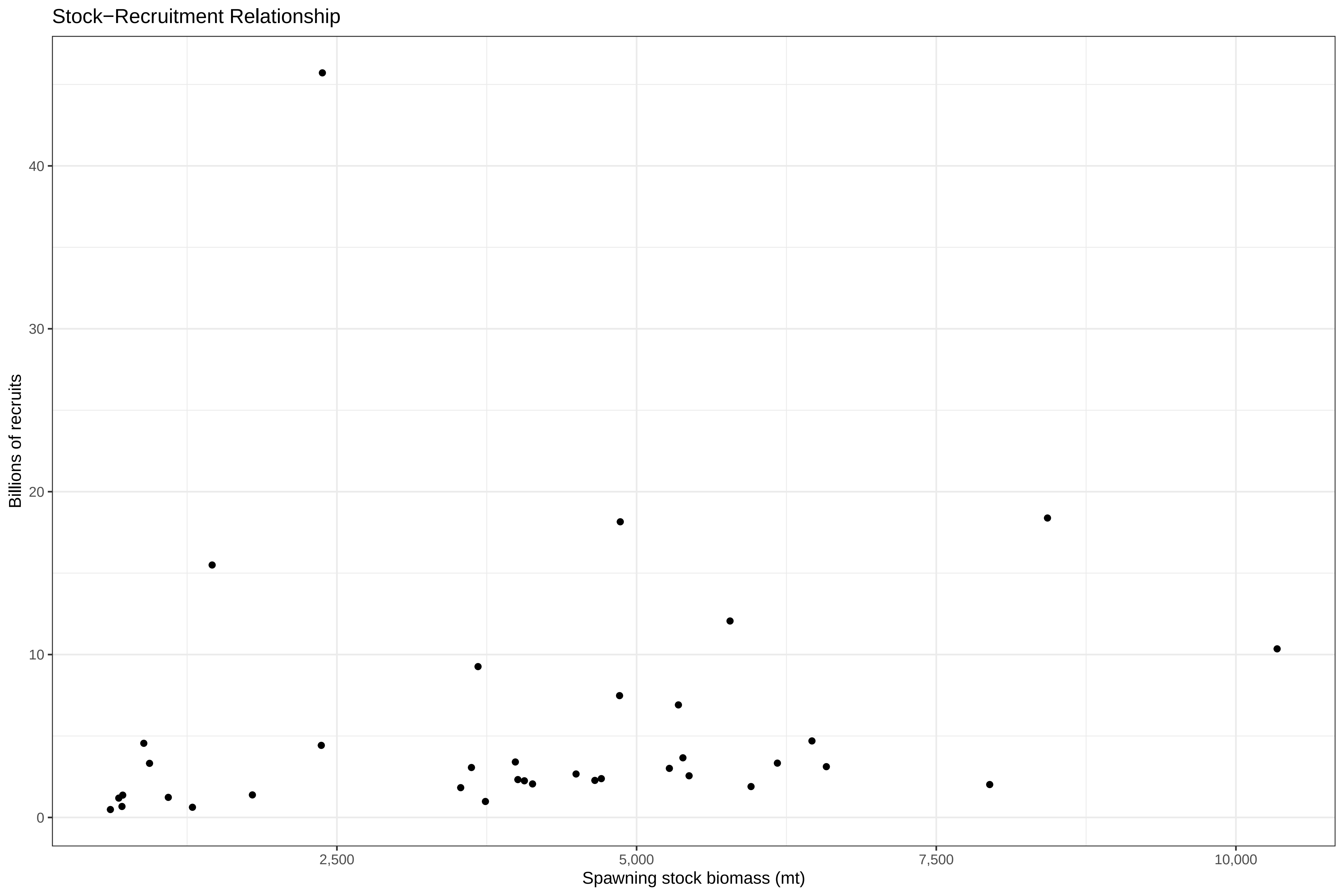

Aggregated Observed and Predicted Length Composition − NEFSC Fall Trawl
All Years
Proportion
0.000
0.025
0.050
0.075
10
15
20
25
30
35
Carapace Length (mm)
Observed
Observed
Predicted



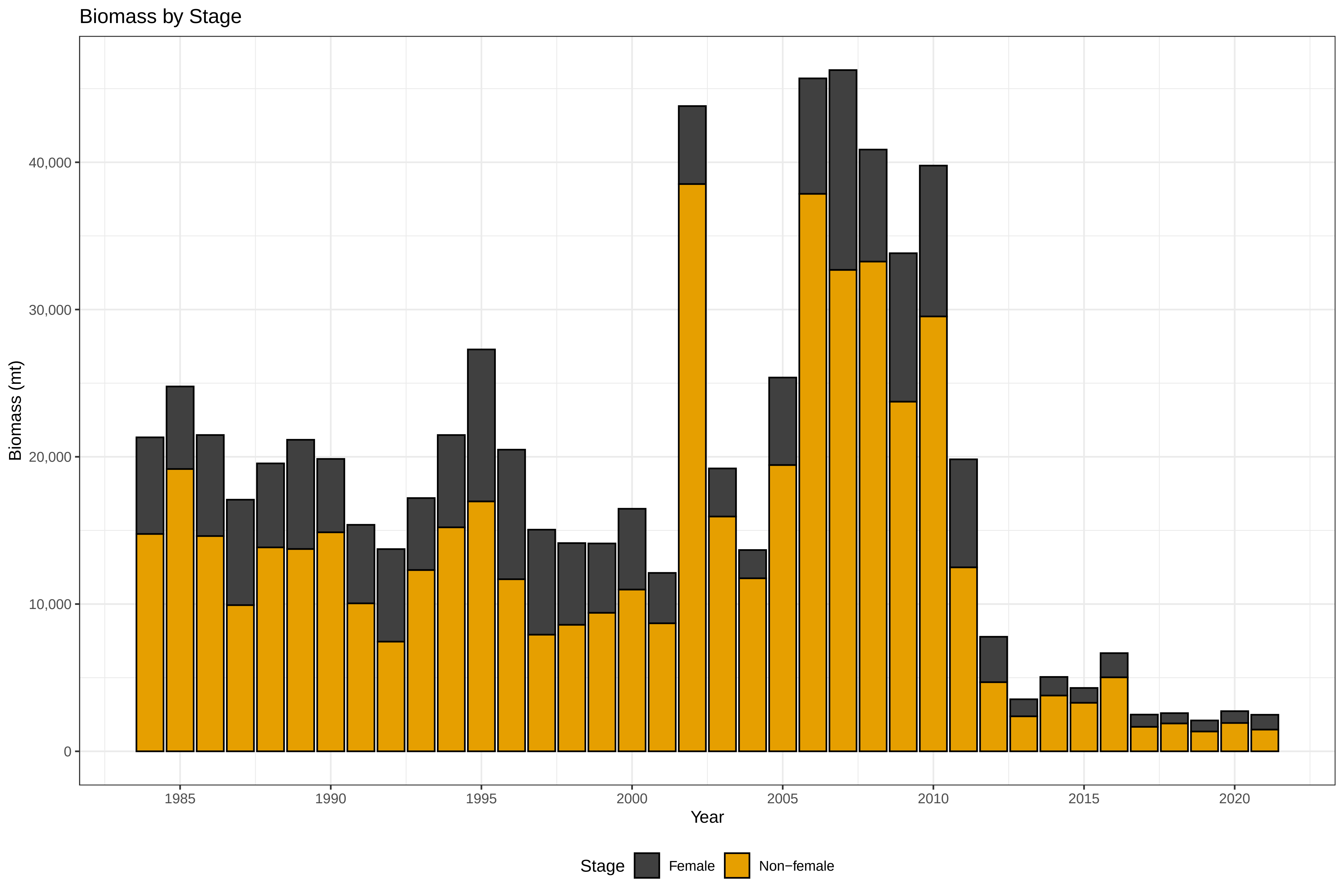
Recruitment
Recruitment
(billions of shrimp)
0
10
20
30
40
50
1985
1990
1995
2000
2005
2010
2015
2020
Year


Annual estimated recruitment deviations
Recruitment deviations (log scale)
Year
2
1
0
−1
−2
1985
1990
1995
2000
2005
2010
2015
2020

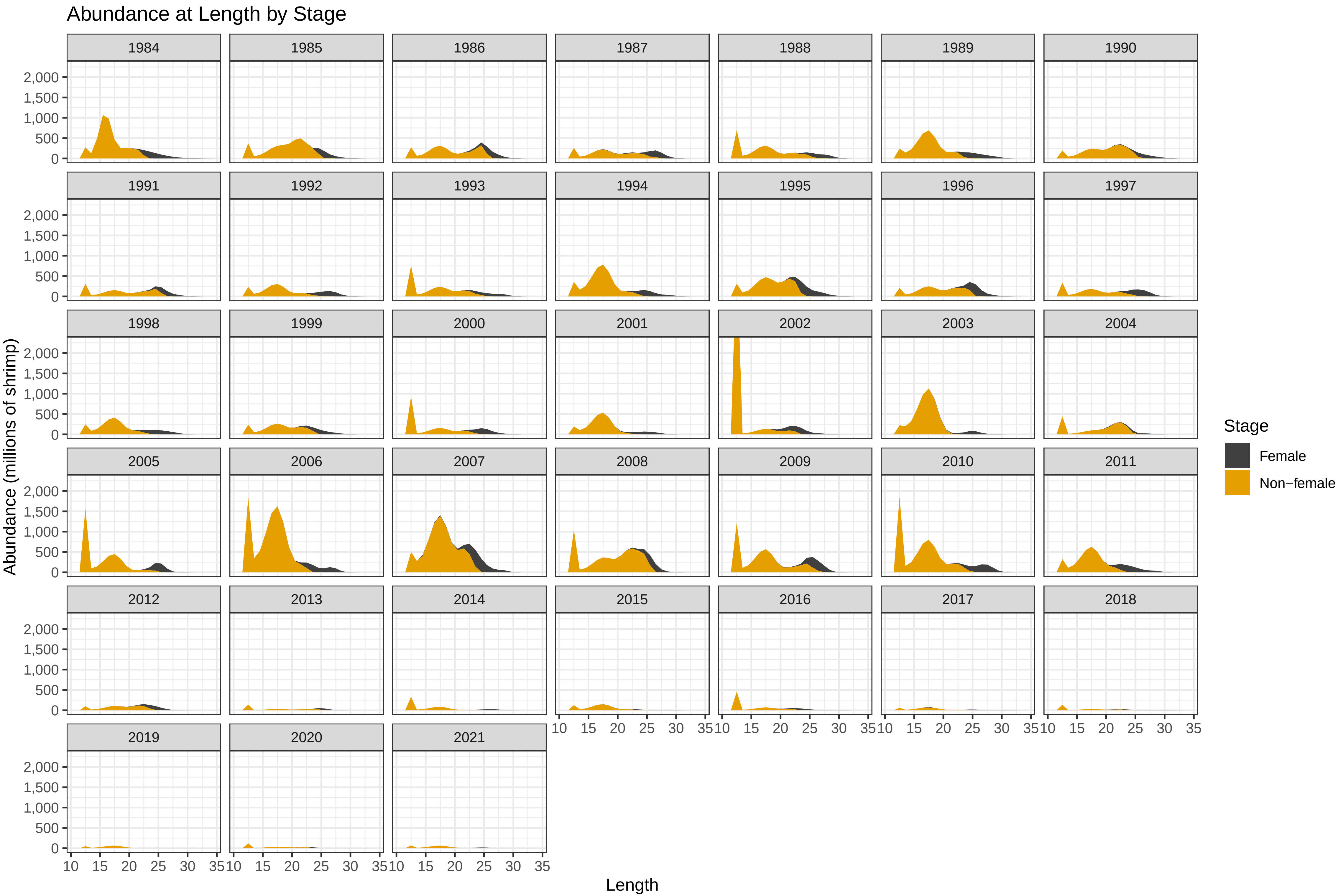

Spawning Stock Biomass
12,500
10,000
7,500
5,000
2,500
0
SSB (mt)
1985
1990
1995
2000
2005
2010
2015
2020
Year



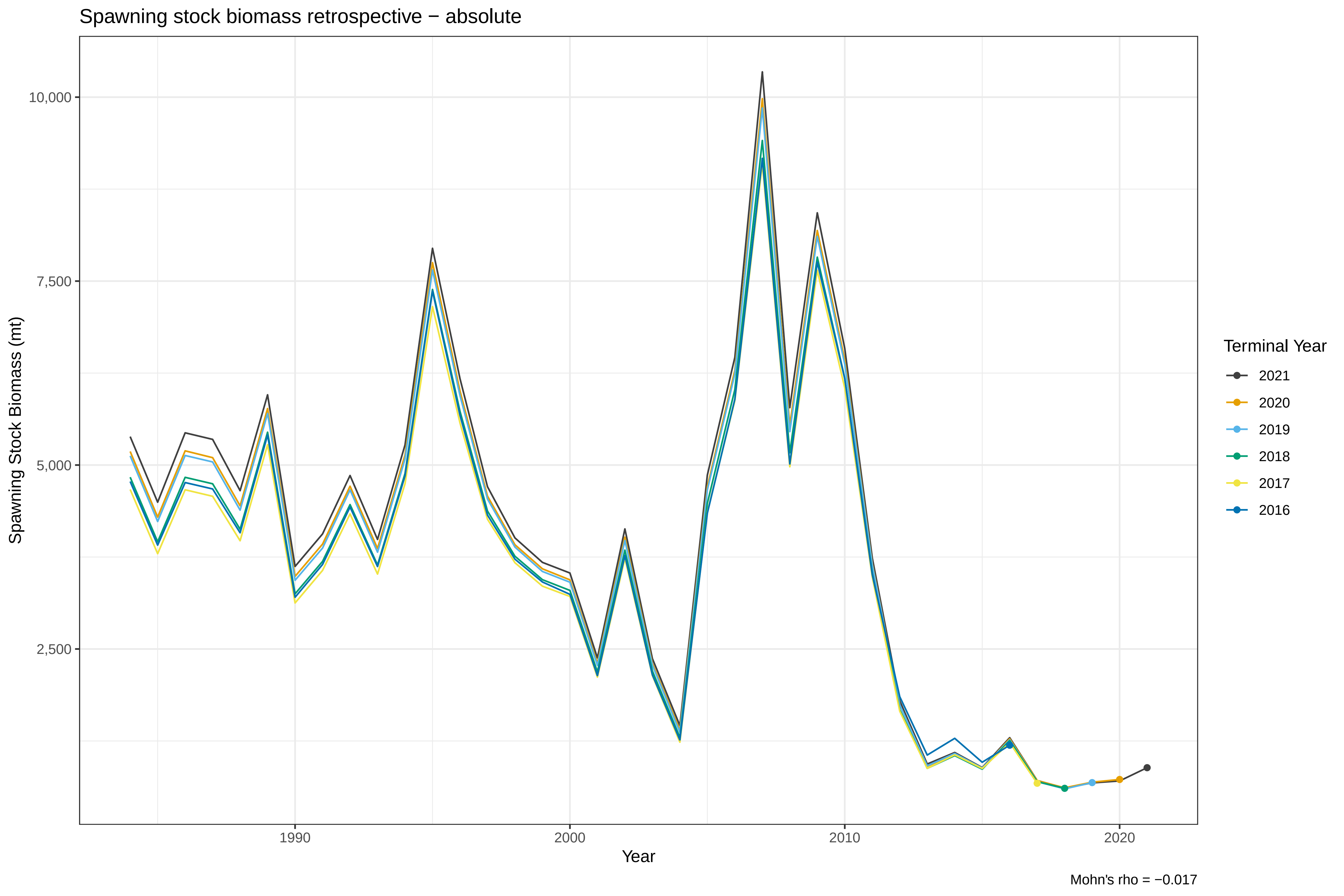
Stock−Recruitment Relationship
Billions of recruits
0
10
20
30
40
2,500
5,000
7,500
10,000
Spawning stock biomass (mt)

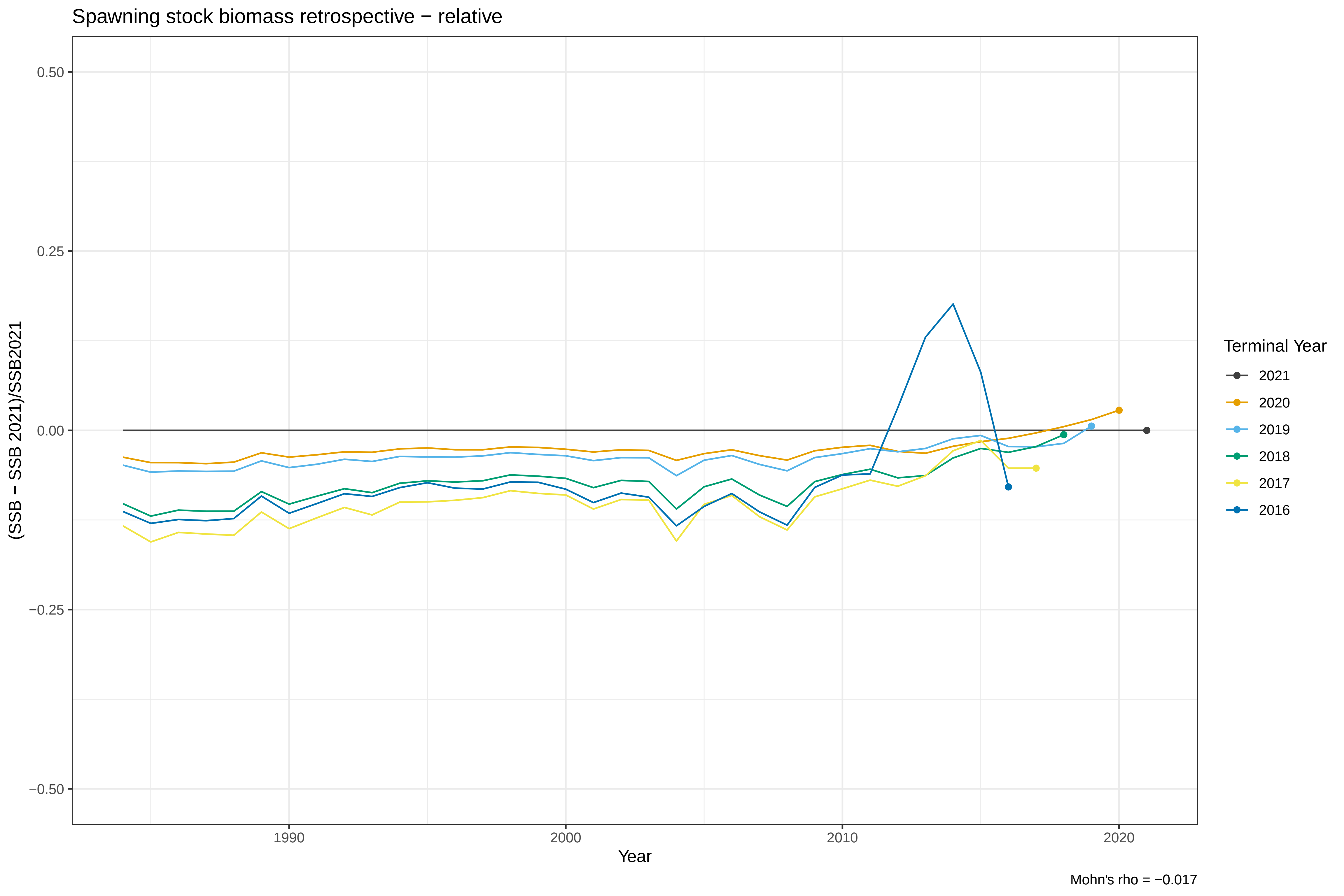


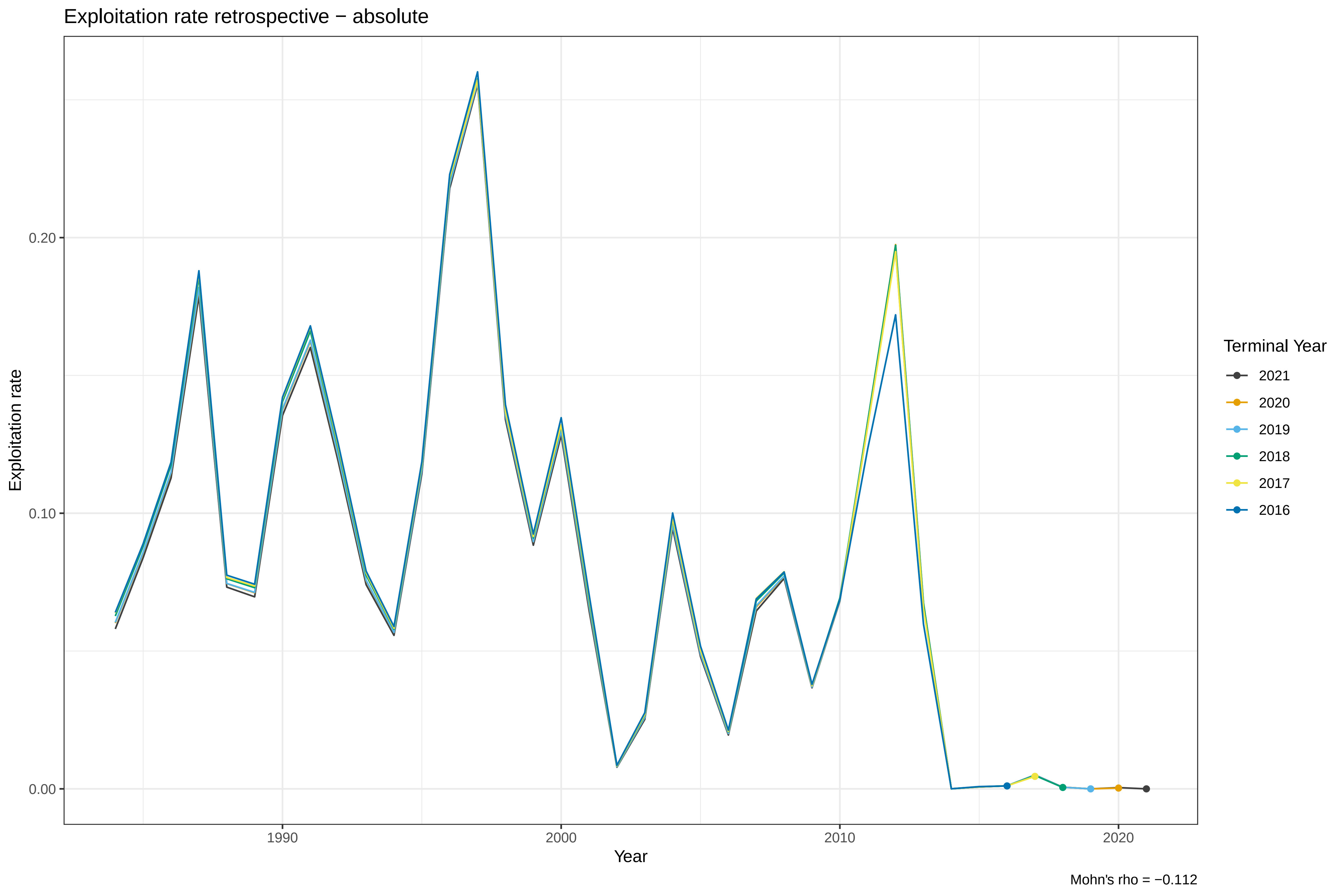
Biomass by Stage
Biomass (mt)
0
10,000
20,000
30,000
40,000
1985
1990
1995
2000
2005
2010
2015
2020
Year
Stage
Female
Non−female



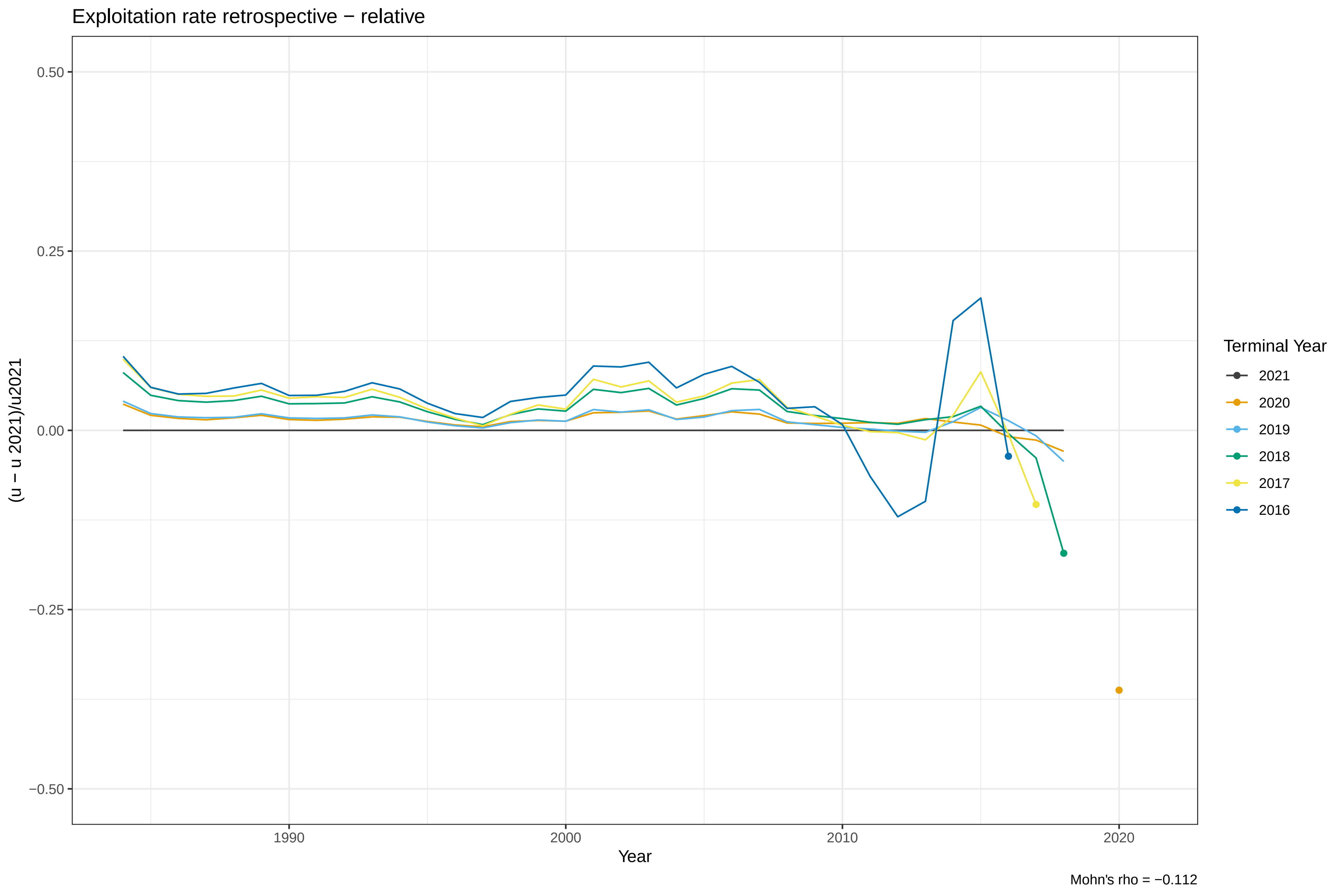
Abundance at Length by Stage
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Abundance (millions of shrimp)
0
500
1,000
1,500
2,000
Length
10
15
20
25
30
35
Stage
Female
Non−female

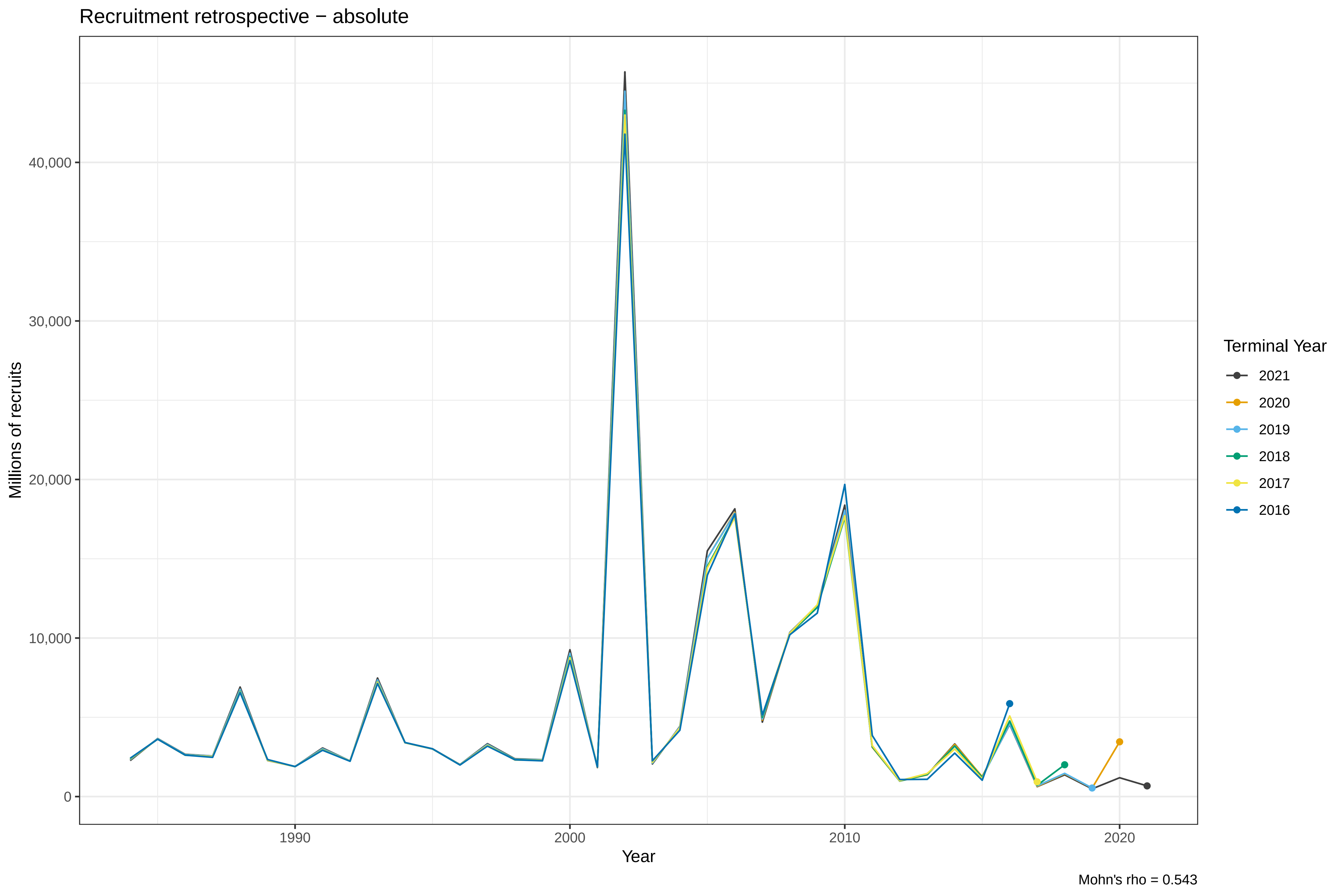

Spawning stock biomass retrospective − absolute
Spawning Stock Biomass (mt)
10,000
7,500
5,000
2,500
1990
2000
2010
2020
Year
Terminal Year
2021
2020
2019
2018
2017
2016
Mohn's rho = −0.017

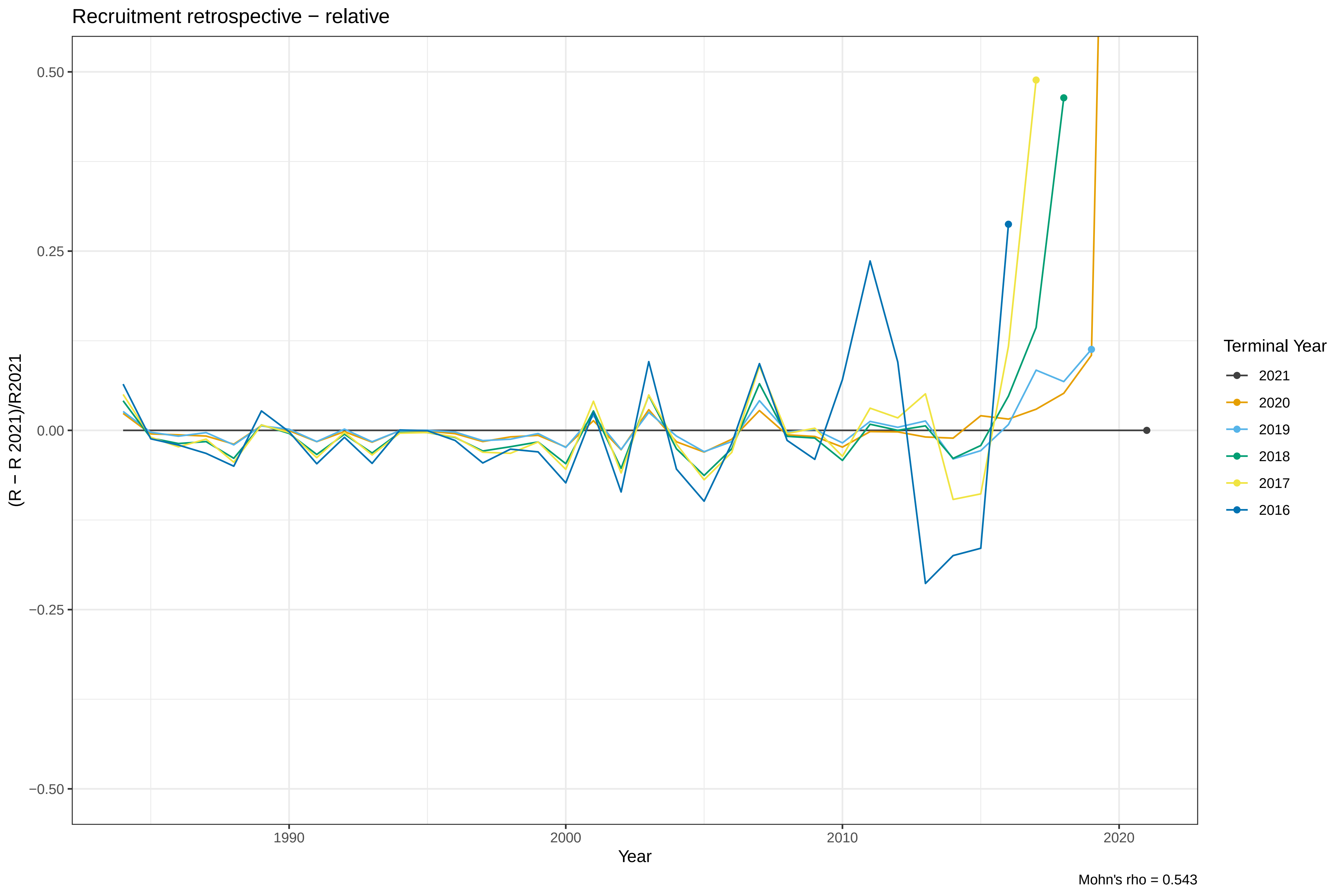

Spawning stock biomass retrospective − relative
(SSB − SSB 2021)/SSB2021
0.50
0.25
0.00
−0.25
−0.50
1990
2000
2010
2020
Year
Terminal Year
2021
2020
2019
2018
2017
2016
Mohn's rho = −0.017



Exploitation rate retrospective − absolute
Exploitation rate
0.20
0.10
0.00
1990
2000
2010
2020
Year
Terminal Year
2021
2020
2019
2018
2017
2016
Mohn's rho = −0.112


Exploitation rate retrospective − relative
0.50
0.25
0.00
−0.25
−0.50
(u − u 2021)/u2021
1990
2000
2010
2020
Year
Terminal Year
2021
2020
2019
2018
2017
2016
Mohn's rho = −0.112


Recruitment retrospective − absolute
Millions of recruits
40,000
30,000
20,000
10,000
0
1990
2000
2010
2020
Year
Terminal Year
2021
2020
2019
2018
2017
2016
Mohn's rho = 0.543


Recruitment retrospective − relative
0.50
0.25
0.00
−0.25
−0.50
(R − R 2021)/R2021
1990
2000
2010
2020
Year
Terminal Year
2021
2020
2019
2018
2017
2016
Mohn's rho = 0.543

# Atlantic States Marine Fisheries Commission

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## MEMORANDUM

**TO: Northern Shrimp Section**

**FROM: Northern Shrimp Work Group**

**DATE: December 1, 2021**

**SUBJECT: Management Scenario Planning for Northern Shrimp**

### Background

At the Northern Shrimp Section's (Section) 2018 meeting in November, the following motion was made: "Move to establish a Work Group made up of Section and Plan Development Team members to adjust management strategies based on ASMFC policy regarding changes in species abundance and distribution resulting from climate change." Since then, the Northern Shrimp Work Group has convened on four occasions to respond to the Section tasking.

### Statement of the Problem

The most recent stock assessment report, the 2019 stock assessment data update, indicated that the northern shrimp stock remains in a depleted condition despite the fishing moratorium that has been in place since 2014. Abundance and biomass indices derived from the summer shrimp survey, spring Maine-New Hampshire (ME-NH) inshore survey, and fall Northeast Fisheries Science Center (NEFSC) survey were all at or near time series lows. Below average recruitment, and even recruitment failure, has continued since the moratorium went into effect. The stock is less likely to rebound due to poor environmental conditions for northern shrimp, such as high predation pressure and high Gulf of Maine ocean temperatures, in effect preventing sustainable recruitment.

The current fishing moratorium is scheduled to expire in 2021. The Section will need to either continue the moratorium, reopen the fishery and set specifications for 2022, or consider a new management strategy which takes into consideration the biological, economic, and cultural importance of this stock. Determining an appropriate management strategy is challenging given stock status remains poor even under a moratorium, one of the most restrictive management tools at the Section's disposal. The 2021 assessment update will be made available for the upcoming Section meeting, scheduled in December 2021. However, the Work Group acknowledges that there is high likelihood that the 2021 stock assessment update will indicate that the stock remains depleted. As such, the Section should consider the most recent stock assessment information and any supplementary guidance the Work Group is able to provide before determining the next steps for managing the northern shrimp stock.

M21-133

## Management Scenarios

In response to the Section's tasking, the Work Group has developed descriptions of four potential management scenarios for consideration along with a table differentiating the pros and cons of each approach, taking into account current stock condition.

1. **Continuation of the fishing moratorium:** The current fishing moratorium remains in place with continued monitoring for signs of improving stock health.
2. **Personal use fishery:** Northern shrimp are landed for personal consumption only, meaning the commercial sale of shrimp would not be permitted. This could be accomplished with a small possession limit, a limited season, and/or potential gear restrictions.
3. **Commercial fishery operates under existing fishery management plan:** While in a fishing moratorium since 2014, Addendum I and Amendment 3 of the Northern Shrimp Fishery Management Plan allow for a limited fishery in accordance with the existing management regime. This includes management tools such as fishing seasons, trip limits, trap limits, and days out of the fishery.
4. **Economically-driven commercial fishery:** Harvesters decide their own level of fishing effort based on a personal calculation of the cost of fishing weighed against the revenue they expect to earn. This could be accomplished with very limited use of traditional management measures.

**Table 1. Northern Shrimp Management Scenario Comparison Table**

| **Management Scenario:** | Benefits | Challenges | Outstanding Considerations and Questions |
|---|---|---|---|
| Continuation of moratorium | - Continue to provide ecosystem benefits (e.g. as forage fish)<br>- If environmental conditions improve, provides best opportunity for rebuilding<br>- Best aligns with MSA NS1[1] by preventing overfishing and increasing chances of rebuilding the stock | - Continued loss of fishery infrastructure, economic welfare, cultural value<br>- Limits diversification of income streams<br>- Continuation of poor environmental conditions may limit potential for rebuilding | - Will the summer survey continue to be funded?<br>- Could a trigger (e.g. minimum stock size) be identified as when to consider reopening fishery? How often to reassess and which data sets to use? (see TC response on Page 4) |
| Personal use fishery | - Allowance of small fishery provides cultural value and maintains heritage aspects of fishery<br>- Potentially smaller impact on stock (than commercial fishery) | - Some concerns about alignment with NS1?<br>- Possible enforcement concerns of peddled product?<br>- Without knowing potential participation level, some risk to further depleting the stock | - Will the summer survey continue to be funded?<br>- Would/should this be (by default or managed as) a trap/pot-only fishery? If so, cultural/heritage aspects may not be as widely realized |

[1] Magnuson-Stevens Fishery Conservation and Management Act, National Standard 1

| | | | |
|---|---|---|---|
| Personal use fishery (continued) | - Potential for fishery-dependent data collection | | - Potential for biological data collection but unclear how informative these data would be (limited sampling, not comparable to long term data series)<br>- What would be the proper permitting structure?<br>- Consideration of vertical lines with trap component of fishery, with regard to protected resources and Take Reduction Plan |
| Commercial fishery operates under existing management | - Maintains one of the remaining open access fisheries in the GOM<br>- Provides commercial access to the fishery (as opposed to personal use)<br>- Supports shoreside infrastructure<br>- Provides the ability for harvesters to diversify catch and secure a secondary income (although potentially small amount)<br>- Potentially increases fishery-dependent data collection, providing winter stage/length-frequency data<br>- Could increase knowledge of the efficacy of dual grate gear (Amendment 3) | - Negative impact on depleted stock and risk to further depletion of stock<br>- Potentially low economic cost/benefit considering resources and staff time involved with managing a very small fishery<br>- Potential for quota overages if quota is set very low<br>- Short-duration sampling event does not allow for data on timing of egg hatch<br>- Substantial concerns about alignment with MSA NS1 if fishery is allowed in conflict with Amendment 3 rebuilding program<br>- Possible enforcement concerns of peddled product? | - Will the summer survey continue to be funded?<br>- Would electronic daily reporting be needed and required?<br>- Are state agency port samplers available or have they been assigned other workload?<br>- Potential for regulatory discarding due to low trip limit and patchy aggregation of northern shrimp<br>- Low TAC may require harvesters to sell directly to consumer instead of distributing through processors.<br>- With depleted stock, consideration of ecosystem benefits vs. short-term gain of small commercial fishery<br>- Consideration of vertical lines with trap component of fishery, with regard to protected resources and Take Reduction Plan |
| Economically-driven commercial fishery | - Simple management scheme<br>- Maintains fishery access and supports shoreside infrastructure (although potentially small harvest levels) | - Substantial concerns about alignment with MSA if the fishery is allowed to conflict with Amendment 3 rebuilding program<br>- Greater risk to further depletion of stock<br>- Possible enforcement concerns of peddled product | - Summer survey may not be as important for a functioning fishery under this management scenario<br>- Consideration of vertical lines with trap component of fishery, with regard to protected resources and Take Reduction Plan |

The Northern Shrimp Technical Committee (TC) assisted the Work Group by responding to some technical questions, which are summarized in the following paragraphs.

The Work Group was interested in determining appropriate environmental and biological triggers to help indicate when a fishery could be reopened. The TC responded that not enough is currently known about the mechanisms driving continued low abundance of shrimp. While sea surface and bottom temperature in the Gulf of Maine have been identified as environmental factors affecting recruitment, causal links are poorly understood. In response to questions concerning appropriate trigger levels and the frequency of reviewing management triggers, the TC indicated that appropriate levels and frequency depend on the overall goals of managing the fishery; the TC added that the traffic light analysis can be repeated annually as long as survey data are collected. When asked about the relative importance of each component of the current monitoring effort, the TC concluded that the dedicated Gulf of Maine Northern shrimp summer survey continues to be the most important source of data. The supplemental ME-NH spring and NEFSC fall surveys sample only a portion of the population during female migration. Moving forward, if data from the summer survey become unavailable, the traffic light analysis would become limited in scope.

The Work Group asked the TC several questions regarding fishery-dependent monitoring under several different management scenarios. The TC did not have any new or different recommendations given that monitoring was set up under the management regime pre-moratorium but also acknowledged that more time and consideration would be needed to determine the appropriate level of fishery-dependent monitoring for a personal use trap fishery or a commercial fishery. While more data can improve scientific understanding, the cost and staff time required to collect fishery dependent data would need to be considered as well.

The Work Group posed several questions regarding differences in selectivity between gear types and determining appropriate controls on effort. The TC replied that differences in selectivity across traps and trawling have previously been analyzed through port samples, but prior analyses did not test for statistical significance nor control for fishing location. The TC also said determining an appropriate commercial season for the purpose of reducing the risk of harvesting juvenile, male, and egg-bearing female shrimp would require the collection of more recent data through weekly sampling.

Lastly, at the Work Group's request, the TC agreed to include a brief discussion of Richards and Hunter's 2021 work on "Northern shrimp *Pandalus borealis* population collapse linked to climate-driven shifts in predator distribution," within the 2021 stock assessment report. Related to this work, the TC intends to conduct a sensitivity analysis by including longfin squid into the predation pressure index to test if this influences the natural mortality model parameters and helps to explain continued declines in biomass during the moratorium.

## Northern Shrimp Work Group Recommendation

The Work Group considered the range of scenarios in the table above and does not recommend the economically-driven commercial fishery option. This option has the greatest potential to lead to further depletion of the stock via uncontrolled levels of catch. As a result, it would likely be detrimental to sustainable management of the stock and to ecosystem services that northern shrimp provide. Further, while ASMFC is not bound by the Magnuson-Stevens Act, this option has the greatest potential to conflict with National Standard 1, given part of the fishery operates within federal waters.