

C. NORTHERN SHRIMP STOCK ASSESSMENT FOR 2014

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

C1.0 CONTRIBUTORS

ASMFC Northern Shrimp Technical Committee

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C2.0 TERMS OF REFERENCE (TOR) FOR NORTHERN SHRIMP

1. Present the Gulf of Maine northern shrimp landings, discards, effort, and fishery-independent data used in the assessment. Characterize the precision and accuracy of the data and justify inclusion or elimination of data sources.
2. Estimate population parameters (fishing mortality, biomass, and abundance) using assessment models. Evaluate model performance and stability through sensitivity analyses and retrospective analysis, including alternative natural mortality (M) scenarios. Include consideration of environmental effects where possible. Discuss the effects of data strengths and weaknesses on model results and performance.
3. Update or redefine biological reference points (BRPs; point estimates or proxies for BMSY, SSBMSY, FMSY, MSY). Evaluate stock status based on BRPs.
4. Characterize uncertainty of model estimates of fishing mortality, biomass and recruitment, and biological reference points.
5. Review the methods used to calculate the annual target catch and characterize uncertainty of target catch estimates.
6. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made before the next benchmark assessment.
7. Based on the biology of species, and potential scientific advances, comment on the appropriate timing of the next benchmark assessment and intermediate updates.

C3.0 EXECUTIVE SUMMARY

C3.1 Major findings for TOR #1 - Gulf of Maine Northern shrimp landings, discards, effort, and fishery independent surveys.

Landings in the Gulf of Maine northern shrimp fishery since the mid-1980s have fluctuated between 306-9,500 mt, reflecting variations in year class strength as well as regulatory measures, participation, and market conditions in the fishery. A peak of 9,500 mt was reached in 1996, after which landings declined steadily to a low in 2002 (450 mt). After 2002, landings generally increased, reaching another peak of around 6,000 mt in 2010 and 2011. Preliminary landings (not accounting for late reporting) in 2013 declined to 306 mt, which was 48% of the TAC set by ASMFC for 2013 (625 mt) despite the 2013 TAC being the lowest set since 1984. Observer sampling indicates discards in the shrimp fishery and in other Gulf of Maine fisheries is negligible. There is no recreational fishery for northern shrimp.

The number of fishing vessels participating in the northern shrimp fishery dropped from a high in 1996 (347 vessels) to an average below 200 vessels during 2002-2007. In 2013, an estimated 198 vessels participated (152 trawl, 46 trap). Trap catches accounted for about 12% of Maine's landings during 2001 to 2007, 18% during 2008 to 2011, and 8% since then. Catch-per-unit-effort (pounds per trap and trawl pounds per trip) was the lowest on record since 1991.

Trends in biomass of Gulf of Maine northern shrimp were monitored during 1968-1983 using data collected in Northeast Fisheries Science Center (NEFSC) autumn bottom trawl surveys and in summer surveys by the State of Maine. Since 1984, two surveys have been used to monitor population trends: the NEFSC fall survey and a summer shrimp survey conducted by the Atlantic States Marine Fisheries Commission (ASMFC). The summer survey was designed specifically for monitoring northern shrimp in the western Gulf of Maine and is considered to provide the highest quality data for this population. The NEFSC fall survey is split into two time periods due to a change in survey protocol in 2009. A Maine-New Hampshire inshore trawl survey conducted each spring since 2001 catches northern shrimp (Sherman et al. 2005), but is not used in the assessment because its results may be influenced by inter-annual variation in the timing of the offshore migration of post-hatch females. The average coefficients of variation for abundance (biomass) for the surveys were: fall survey before 2009 27% (25%), fall survey 2009-2013 36% (36%), summer shrimp survey 21% (14%). Abundance and biomass indices from the ASMFC summer shrimp survey fluctuate widely, reflecting the highly variable recruitment of northern shrimp. The 2013 indices were the lowest on record at 27 shrimp/tow and 1.0 kg/tow. The stratified mean catch per tow in numbers of 1.5-year old shrimp represents a recruitment index. The 2012 index for age 1.5 was the lowest in the time series (until 2013), with only 7 individuals per tow, signifying a very weak 2011 year class. The 2013 age 1.5 index dropped even further to 1 individual per tow, signifying a very weak 2012 year class and an unprecedented three consecutive years of poor recruitment. The indices from the new NEFSC fall survey (2009-2012,

2013 not yet available) have declined since 2009, parallel to recent trends in the summer shrimp survey and the ME-NH survey.

C3.2 Major findings for TOR #2 - Estimate population parameters using assessment models.

The proposed model for Northern shrimp was a forward-projecting size-structured model (UME model) developed by the University of Maine in conjunction with the Northern Shrimp Technical Committee. As complements, a Collie-Sissenwine Analysis (CSA) and a surplus production model (ASPIC) were also developed to estimate biomass and fishing mortality.

None of the proposed models were accepted for management use. The UME size structured model did not fit catch and survey length composition and survey indices sufficiently well. The CSA was sensitive to the data weighting schemes, but the model diagnostics did not clearly indicate the optimal weightings. This resulted in inconsistent determination of overfishing status depending on the weighting scheme. The ASPIC model was unable to respond to the highly variable recruitment of northern shrimp, resulting in an extreme retrospective pattern and making estimates of F and B in the terminal year unreliable.

C3.3 Major findings for TOR #3 - Update or redefine biological reference points and evaluate stock status.

Biological reference points for northern shrimp have been defined using historical proxies of average model-estimated F and exploitable biomass during a stable period in the fishery (1985-1994).

Because none of the models used to estimate F and B during the stable period were accepted, the updated estimates of the reference points were not approved for management use, and stock status could not be determined according to these definitions. However, all fishery-independent and fishery-dependent indices were at or near time-series lows in 2013, suggesting that the Northern shrimp stock is currently at a very low level of abundance.

C3.4 Major findings for TOR #4 - Characterize the uncertainty of model estimates.

Uncertainty in model parameters was estimated through several different methods. For the UME model, asymptotic standard errors were estimated internally by the model. For the CSA model, an MCMC approach was used to estimate error (see Appendix C3 for more details). For the ASPIC model, residuals were bootstrapped to estimate error around the estimated and calculated

parameters. In addition, uncertainty was assessed qualitatively through retrospective and sensitivity analyses.

Sensitivity analyses showed that the UME model is most sensitive to assumptions about the growth model used to develop the growth transition matrix. Choice of M scaled the population and fishing mortality estimates as expected for both the UME and the CSA model. Including a time-varying M , scaled to predation, improved the retrospective pattern for the CSA but not the UME. The ASPIC model was not very sensitive to the surveys included, but had a strong retrospective pattern of underestimating F and overestimating biomass, indicating that the terminal year estimates are highly uncertain.

In addition, both the UME and the CSA model were sensitive to the weighting of data input sources. When the catch data were weighted more heavily than the survey data, the CSA model estimated that F was low in 2013 and overfishing was not occurring. When the survey data were weighted more heavily than the catch data, the model estimated a high terminal F and indicated overfishing was occurring in 2013. See Appendix C6 for the details of additional sensitivity runs that were conducted at the review workshop.

C3.5 Major findings for TOR #5 - Review methods to calculate the annual target catch.

To determine the TAC options for each fishing season, the NSTC uses Pope's approximation (Pope 1972) to the Baranov catch equation (Baranov 1918) to estimate the yield in numbers of shrimp for a given value of F (F_{target} or a proportion of it). The number of shrimp is then converted to weight using the predicted mean weight of an individual northern shrimp based on survey size composition.

Sources of uncertainty of the target catch estimates include uncertainty around (1) model estimates of the numbers of exploitable shrimp, (2) the selected value of M , (3) timing of the upcoming fishing season, and (4) the estimate of mean weight of shrimp in the upcoming season's landings.

Because the model estimates of abundance required for the quota calculations were not accepted, the estimates of total allowable catch were not approved for management use.

C3.6 Major findings for TOR #6 - Research recommendations.

The NSTC identified a number of high priority research needs: (1) improve monitoring and estimates of discards, (2) evaluate the effectiveness of the summer shrimp survey statistical design and its geographic coverage, (3) explore direct ageing methods to evaluate assumptions about the timing of growth and transition, (4) incorporate predation and temperature effects in the size-structured model, (5) develop BRPs appropriate to changing environmental and ecological conditions.

In addition, the NSTC emphasized the primary importance of continuing the summer shrimp survey despite the current low abundance of northern shrimp.

C3.7 Major findings for TOR #7 - Timing of next benchmark assessment and assessment updates.

The NSTC recommended that the Northern shrimp stock assessment be updated annually to incorporate the most recent information on recruitment, size composition, and landings into the quota/specification setting process. Annual specifications are important for a short-lived species with environmentally-driven recruitment like Northern shrimp.

In addition, the NSTC recommends that a full benchmark assessment be conducted sooner than the standard five year interval, ideally in the next two to three years. This will give the NSTC time to evaluate the performance of the new size-structured model through simulation work and resolve the data-weighting and fit issues identified by the Panel. This will also give the NSTC time to incorporate additional information on the Gulf of Maine's changing environmental conditions.

C4.0 INTRODUCTION

C4.1 Management History

The Gulf of Maine fishery for northern shrimp (*Pandalus borealis* Krøyer) is managed through interstate agreement between the states of Maine, New Hampshire and Massachusetts. The management framework evolved during 1972-1979 under the auspices of the State/Federal Fisheries Management Program. In 1980, this program was restructured as the Interstate Fisheries Management Program (ISFMP) of the Atlantic States Marine Fisheries Commission (ASMFC). The Fishery Management Plan (FMP) for Northern Shrimp was approved under the ISFMP in October 1986 (McInnes 1986). Amendment 2, which entirely replaced the original FMP and Amendment 1 in 2011, provides flexible management options including a clarification of fishing mortality reference points, a timely and comprehensive reporting system, trip limits, trap limits, and days out of the fishery.

Addendum I to Amendment 2 (2012) includes provisions to set an annual TAC that may range between the fishing mortality target and threshold values, inclusive; allocate 87% of the TAC to the trawl fishery and 13% to the trap fishery; and close each fishery when a certain percentage of the TAC is projected to be reached. The percentage, ranging between 80 and 95%, will be established by the Section during the annual specification process. The Addendum also provides flexibility to transfer unused TAC between gear types; set aside a portion of the TAC for

research purposes; and allow for the optional use of a size sorting grate system (compound grate or double Nordmore) to minimize the retention of small shrimp.

Within the ISFMP structure, the Northern Shrimp Technical Committee (NSTC) provides annual stock assessments and related information to the ASMFC Northern Shrimp Section. Annually, the Section decides on management regimes after thorough consideration of the NSTC stock assessment, input from the Northern Shrimp Advisory Panel, and comment from others knowledgeable about the shrimp fishing industry. In the first five years (1987 – 1991) after the passage of the 1986 FMP, the NSTC generally recommended full fishing seasons (182 days) and the Section followed the committee's recommendations (Table A.4.1). Nearly every year from 1992 to 1999, the NSTC recommended restricted seasons. The managers set seasons that were less than the full 182 days but more than the seasons recommended by its scientific advisors. With the exception of 2001, the NSTC recommended no fishery from 2000 to 2004. The managers set limited fishing seasons during that time, with the shortest (25 days) in 2002. The NSTC has taken a new approach to its recommendation to the Section since 2005. It recommends a maximum landings amount for the fishing season. The Section used that number and recommendations from the Advisory Panel to establish seasons. In the past two years, the NSTC has recommended a moratorium on northern shrimp. For the 2014 fishing season, a moratorium was implemented by the Section.

C4.2 Assessment History

C4.2.1 Past Assessments

Stock assessments initially consisted of total landings estimates, indices of abundance from Northeast Fisheries Science Center (NEFSC) groundfish surveys, fishing mortality estimates from the application of cohort slicing of length frequencies from the State of Maine survey, and yield per recruit modeling (Clark and Anthony 1980; Clark 1981, 1982).

The NSTC unified individual state port sampling programs in the early 1980s to better characterize catch at length and developmental stage (sex and maturity), and established a dedicated research trawl survey for the species in the summer of 1983 to monitor relative abundance, biomass, size structure and demographics of the stock annually. Subsequent stock assessments provided more detailed description of landings, size composition of catch, patterns in fishing effort, catch per unit effort, relative year class strength and survey indices of total abundance and biomass. Length distributions from the summer shrimp survey have been used for size composition analysis to estimate mortality rates, but the early length-based models did not fit well because of variable recruitment and growth (Terceiro and Idoine 1990, Fournier et al. 1991).

Beginning in 1997, the northern shrimp stock in the Gulf of Maine has been evaluated more quantitatively using three analytical models that incorporate much of the available data (Cadrin et al. 1999):

- Preferred: Collie-Sissenwine analysis (CSA) that tracks removals of shrimp using summer survey indices of recruits and fully-recruited shrimp scaled to total catch in numbers, and provides estimates of F (instantaneous fishing mortality rate) and B (exploitable biomass);
- Supportive: A surplus production analysis (ASPIC) that models the biomass dynamics of the stock with a longer times series of total landings and three survey indices of stock abundance;
- A yield-per-recruit (YPR) model and an eggs-per-recruit (EPR) model that simulate the life history of northern shrimp (including growth rates, transition rates, natural mortality, and fecundity) and fishing mortality on recruited shrimp. It uses estimates of trawl selectivity to estimate yield and egg production at various levels of fishing mortality, providing guidance on the selection of biological reference points (Cadrin et al. 1999).

In 2004, Amendment 1 to the ASMFC Interstate Fishery Management Plan for Northern Shrimp was adopted. This was the first time formal biological reference points were defined for this fishery. The assessment model configuration reviewed by SARC 45 (2007) is updated annually in October to provide a recommended quota for the winter season.

C4.2.2 Current Assessment and Changes from Past Assessments

For this assessment, a statistical catch-at-length model was developed by Yong Chen and Jie Cao of the University of Maine in conjunction with the NSTC. This model uses catch-at-length data, total catch, and fishery independent indices of abundance to estimate fishing mortality, total abundance, spawning female abundance and biomass, and recruitment. It also provides biological reference points in the form of yield-per-recruit and spawning stock biomass-per-recruit reference points.

As complements to the length-structured model, the CSA model and the ASPIC model were also used. The CSA model (NMFS Toolbox v. 4.2.2) was updated to use a formal likelihood framework and to allow the use of multiple indices of abundance.

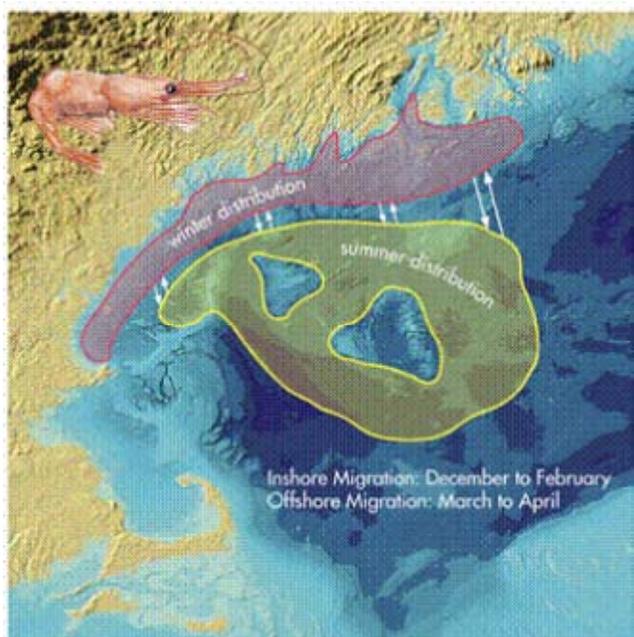
The new length-structured model and the changes to the CSA allow us to make better use of the available data and improve our understanding of stock dynamics.

C4.3 BIOLOGY

C4.3.1 Life History

Northern shrimp (*Pandalus borealis*) inhabit boreal waters of the North Atlantic, North Pacific and Arctic Oceans (Figure C4.1). In the Gulf of Maine, they are at the southern extent of their range. Northern shrimp are protandric hermaphrodites, usually maturing first as males at approximately 2.5 years of age and then transforming to females at

approximately 3.5 years of age in the Gulf of Maine (Figure C4.2). Spawning takes place in offshore waters beginning in late July. By early fall, most adult females extrude their eggs onto the abdomen. Egg-bearing females move inshore in late autumn and winter, where the eggs hatch. The planktonic larvae pass through six larval stages and settle to the bottom in inshore waters after metamorphosing to a juvenile state (Berkeley 1930; Haynes and Wigley, 1969; Apollonio and Dunton 1969; Stickney and Perkins 1977; Stickney 1980). Juveniles remain in coastal waters



Distribution of adult female northern shrimp, from *Ecosystem Relationships in the Gulf of Maine—Combined Expert Knowledge of Fishermen and Scientists*. NAMA collaborative report 1:1-16, 2006.

for a year or more before migrating to deeper offshore waters, where they mature as males. The males pass through a series of transitional stages before maturing as females. Some females may survive their first egg hatch to repeat the spawning process. Females that have never extruded eggs are referred to here as “female I”. Non-ovigerous females that have carried eggs in the past are “female II”. Female I’s and II’s can be distinguished by the presence or absence of sternal spines (McCrary 1971). The females are the individuals targeted in the Gulf of Maine fishery. It is believed that most *P. borealis* in the Gulf of Maine do not live past age 5 (Haynes and Wigley 1969; Apollonio and Dunton 1969).

Several factors may influence the size and age at sex transition (Bergström 2000). Several year classes in recent decades show some percentage of 2.5-year old shrimp maturing first as females instead of males (early-maturing females) (Figure C4.3). This presents both sexes in the same year class and may be a reaction to stress in the population as predicted by sex allocation theory (Charnov et al. 1978), or temperature (Apollonio et al. 1986; Hansen and Aschan 2000) or density dependent growth (Koeller et al. 2000), or could be the result of fishery removals of larger females selecting for smaller females (Marliave et al. 1993; Bergström 2000). Other year classes have exhibited some late sex transition. In the 2001 year class, there was evidence of both very early- and late-maturing females, with early-maturing females appearing at assumed age 1.5, but also males remaining as males at assumed age 3.5 (Figure C4.3).

The extent, location, and timing of the transitions and migrations are variable.

Growth, as in other crustaceans, is a discontinuous process associated with molting of the exoskeleton (Hartnoll 1982). Information on growth of Gulf of Maine northern shrimp has been reported by Haynes and Wigley 1969; Apollonio et al. 1986; Terceiro and Idoine 1990; and

Fournier et al. 1991. Differences in size at age by area and season can be ascribed in part to temperature effects, with more rapid growth rates at higher temperatures (Apollonio et al. 1986).

C4.3.2 Habitat

In the Gulf of Maine, northern shrimp populations comprise a single stock (Clark and Anthony 1981), which is concentrated in the southwestern region of the Gulf (Haynes and Wigley 1969; Clark et al. 1999). Water temperature, salinity, depth, and substrate type have all been cited as important factors governing shrimp distribution in the Gulf of Maine (Haynes and Wigley 1969; Apollonio et al. 1986; Shumway et al. 1985). In the Gulf of Maine, northern shrimp are most frequently found in depths ranging from 10 m to over 300 m (30-1000 ft) (Haynes and Wigley 1969), with juveniles and immature males occupying shallower, inshore waters and mature males and females occupying cooler, deeper offshore waters for most of the year (Apollonio and Dunton 1969, Haynes and Wigley 1969, Apollonio et al. 1986). During the summer months, adult shrimp inhabit water from 93-183 m (300-600 ft) (Clark et al. 1999); ovigerous female shrimp are found in shallower near-shore waters during the late winter and spring (Apollonio and Dunton 1969, Clark et al. 1999) when their eggs are hatching.

Northern shrimp most commonly inhabit organic-rich, mud bottoms or near-bottom waters (Hjort and Ruud 1938; Bigelow and Schroeder 1939; Wigley 1960; Haynes and Wigley 1969), where they prey on benthic invertebrates; however, shrimp are not limited to this habitat and have been observed on rocky substrates (Schick 1991). Shrimp distribution in relation to substrate type determined by trawl surveys clearly show northern shrimp primarily occupy areas with fine sediments (sand, silt, and clay) (ASMFC 2004). Shrimp are often associated with biotic or abiotic structures such as cerianthid anemone (Langton and Uzmann 1989) and occasional boulders in these fine sediment habitats (Daniel Schick, Maine Department of Marine Resources, pers. comm.).

Male and non-ovigerous female shrimp exhibit diurnal vertical migration, from bottom and near-bottom during the day, up into the water column to feed at night. Egg-bearing females are less likely to exhibit vertical diurnal migration, and are more likely to stay on the bottom (Apollonio and Dunton 1969; Apollonio et al. 1986).

C4.3.3 Temperature

The most common temperature range for this species is 0-5 °C (Shumway et al. 1985). The Gulf of Maine marks the southern-most extent of this species' range in the Atlantic Ocean, and it is thought that seasonal water temperatures in many areas regularly exceed the upper physiological limit for northern shrimp. This environmental limitation restricts the amount of available habitat occupied by this species to the western region of the Gulf (west of 68° W) where bottom topography and oceanographic conditions create submarine basins protected from seasonal warming by thermal stratification. The deep basins act as cold water refuges for adult shrimp populations

(Apollonio et al. 1986). In the northeastern region of the Gulf, it is hypothesized that large shrimp populations do not persist because bottom waters are not protected from seasonal warming, due to continual mixing from intense tidal currents nearer to the Bay of Fundy (Apollonio et al. 1986).

Ocean temperature has an important influence on northern shrimp in the Gulf of Maine (Apollonio et al. 1986; Richards et al. 1996; Richards et al. 2012). During the warm period of the 1950s, northern shrimp catches declined to zero despite continued fishing effort (Dow 1964), suggesting a population collapse. Several studies have found a significant negative correlation between annual mean temperatures and recruitment of northern shrimp (Dow, 1977; Richards et al. 1996). Spring ocean temperatures during the larval period are particularly important for recruitment, with cooler temperatures favoring higher recruitment (Richards et al. 2012). Spawner abundance also influences recruitment strength, with more recruits resulting from higher spawner abundance (Richards et al. 2012 and Figure C4.3). Timing of the larval hatch is influenced by temperature during late spring through early winter (Richards 2012).

Sea surface temperature (SST) has been measured since 1905 at Boothbay Harbor, Maine, near the center of the inshore nursery areas for northern shrimp. Annual average SST at Boothbay has increased (Figure C5.9) from an average of 7.9° C during 1906-1948 to an average of 10.4° C during 2000-2012. SST has exceeded the 1953 high point three times in the past decade, and 2012 was the warmest year in the 108 years of record. Similar trends have been seen during March-April, a critical time for determining recruitment strength (Figure C5.9). During 2013, the March-April average SST (5.0° C) was cooler than in 2012 (6.9° C), but still well above the 20th century average (3.4° C) (Figure C5.9).

Spring temperature anomalies (deviations measured relative to a standard time period) in offshore shrimp habitat areas were the highest on record during 2012 (surface temperature) and 2011-2012 (bottom temperature) (NEFSC trawl survey data, 1968-2012; Figure C5.9). Spring surface temperature in 2013 was only slightly below the record high 2012 anomaly, while bottom temperatures declined but were still relatively high. The start of the hatch period has become earlier as temperatures have increased, with the hatch now beginning more than a month earlier than before 2000 (10% line in Figure C5.9). The midpoint of the hatch period has changed less than the hatch start, but has trended earlier since 2008 (50% line in Figure C5.9).

C4.3.4 Predators and Prey

Northern shrimp are an important component of marine food chains, preying on both plankton and benthic invertebrates, and being consumed by many commercially important fish species, such as cod, redfish, silver and white hake, and pollock (Shumway et al. 1985, ASMFC 2004, Link and Iodoin 2009; Appendix C2, this document). *P. borealis* diet was documented by Wienberg (1981) and Apollonio and Dunton (1969).

C4.3.5 Natural Mortality

The natural mortality rate (M) used in US Gulf of Maine northern shrimp assessments ($M=0.25$) is one of the lowest assumed for northern shrimp in the North Atlantic (NEFSC 2007). The assumption of $M=0.25$ is based on direct estimates from the Gulf of Maine northern shrimp population and fishery data, as approximated from the intercept of a regression of total mortality by year class in 1968-1972 on effort (Rinaldo 1973, Rinaldo 1976, Shumway et al. 1985) and from catch curve analysis of survey data for age 2+ shrimp during a fishery closure in 1978 (Clark 1981, 1982). In other *Pandalus* stocks, the assumed M ranges from 0.2 to 1.0 (ICES 1977, Abramson 1980, Frechette and Labonte 1980, Shumway et al. 1985). During SAW 45, estimated consumption of *P. borealis* in the Gulf of Maine was compared to model estimates of population size (NEFSC 2007, Link and Idoine 2009). The review panel concluded that M must be higher than 0.25 because the model estimates of abundance were lower than estimated consumption. The panel suggested that a higher M , around $M=0.6$, was likely more realistic for this population.

The NSTC examined alternative M values to better integrate life history knowledge, survey data, and predation information. Several approaches underlying natural mortality assumptions were explored including ratios of assumed age class abundance, age-constant (Table C4.2), age-varying using Lorenzen's (1996) mortality-weight model (Table C4.3), and age-varying using Gislason et al.'s (2010) mortality-growth model (Table C4.4). Ratios from assumed age-class abundance from survey data suggest an average annual total mortality (Z) of 0.43 for assumed ages 2.5 to 3.5, and Z of 0.53 for assumed ages 3.5 to 4.5 (1984-2011 summer survey data). The age-constant and age-varying methods produced a range of instantaneous M values from 0.38 to 5.36. The Lorenzen calculation results in an exponentially declining M -at-age, where $M = 0.71$ in the first year, 0.34 in middle years, and 0.30 for later ages, when scaled so that 1.5% of the population remains at the oldest age class.

These explorations provide support for an assumed M higher than 0.25 for this stock. Several alternative values for natural mortality were considered for the CSA and UME assessment models. Constant values of M included 0.25, 0.5 based on the $3/M$ rule (where M is equal to $3/\text{max age of the species}$ (6) $=0.5$), and 0.6 as suggested by SARC 45. Length- and time-varying estimates of M were also considered, where M is U-shaped M over the life span of the shrimp (UME model) or where M changes annually. To determine values for the U-shape over the life span of the shrimp, M was calculated by weight for the smallest size/weight bins (Lorenzen 1996), then reduced to 0.25 for the mid-weight classes as measured for age 2+ shrimp (Rinaldo 1973), and for the largest size classes, M was increased so that only 1.5% of the population would remain at age six (Hoenig 1983) (Table C4.5). Time-varying (but not length-varying) M was also tested in the UME and CSA models. A baseline $M=0.5$ was scaled by an annual predation pressure index (PPI, Appendix C2), which incorporated the occurrence of Pandalids in fish stomachs and predator biomass to derive an annual estimate of M .

C4.3.6 Other Pandalid Species

The striped shrimp, *Pandalus montagui*, and the bristled long-beak shrimp, *Dichelopandalus leptocerus*, both smaller and less frequently-caught than *Pandalus borealis*, are also common in Gulf of Maine commercial and survey catches, but are not targeted by the fishery.

C4.4 Fishery Description

Northern shrimp support important commercial fisheries in boreal and sub-arctic waters throughout the North Atlantic and North Pacific. In the western North Atlantic, commercial concentrations occur off Greenland, Labrador, and Newfoundland, in the Gulf of St. Lawrence, and on the Scotian Shelf. The Gulf of Maine marks the southernmost extent of its Atlantic range (Parsons and Fréchet, 1989). In the Gulf of Maine, primary concentrations occur in the western Gulf where bottom temperatures are coldest. In summer, adults are most common at depths of 90-180 meters (Clark *et al.* 2000).

The fishery formally began as a large-scale fishery in 1938; during the 1940s there were a few landings in Massachusetts, but most of the landings were by Maine vessels from Portland and smaller Maine ports further east. This was an inshore winter trawl fishery, directed towards egg-bearing females in inshore waters (Scattergood 1952). Landings declined from the late 1940's until the fishery stopped altogether from 1954 through 1957. Reports from fishers at the time indicate that this decline was associated with low shrimp abundance. The fishery resumed in 1958 (McInnes 1986).

New Hampshire vessels entered the fishery in 1966, but throughout the 1960s and 1970s New Hampshire landings were minor. New Hampshire currently accounts for about 8% of the total catch for the Gulf of Maine (Table C5.1).

Landings by Massachusetts vessels were insignificant until 1969, but in the early 1970s the fishery developed rapidly, with Massachusetts landings increasing from 14% of the Gulf of Maine total in 1969 to over 40% in 1974-1975. Massachusetts landings have declined to about 2% of total during the past 10 years, while Maine vessels have accounted for about 90% (Table C5.1)

The Gulf of Maine fishery has been seasonal in nature, peaking in late winter when egg-bearing females move into inshore waters and terminating in spring under regulatory closure (ASMFC 2011 and Table C4.1). Northern shrimp have been an accessible and important resource to fishermen working inshore areas in smaller vessels who otherwise have few winter options due to seasonal changes in availability of groundfish, lobsters and other species (Clark *et al.* 2000).

A summer fishery, which existed in the 1970s, caught shrimp of all ages, including age 1 and 2. These immature and male shrimp made up 40-50% of the catch by numbers in April-June, increasing to 70-80% for July-September, during 1973-1974 (Clark *et al.* 2000). Since 1976, fishing has been restricted to months within a December to May timeframe. (Throughout this document, references to a particular fishing year will include the previous December unless otherwise indicated – *e.g.* the 2006 season includes December 2005 but not December 2006, which will belong to the 2007 season.) Since 2000, the months of January and February have accounted for about 80% of landings, and there has not been a significant spring fishery (April-May) since 1999 (Table C5.2) due to management or market constraints.

Maps of the areas fished in 2010 and 2013 are shown in Figure C5.4 (preliminary data).

A wide variety of vessels have been used in the fishery (Bruce 1971; Wigley 1973). The predominant type during the 1960s and 1970s appears to have been side-rigged trawlers in the 14-23 m (45-75 ft) range. During the 1980s and 1990s, side trawlers either re-rigged to stern trawling, or retired from the fleet. Currently, the shrimp fleet is comprised of lobster vessels in the 9-14 m (30-45 ft) range that re-rig for shrimping, small to mid-sized stern trawlers in the 12-17 m (40-55 ft) range, and larger trawlers primarily in the 17-24 m (55-80 ft) range (ASMFC 2011). The number of vessels participating in the fishery in recent years varied from a high of about 347 in 1997 to a low of about 144 in 2006 (Table C5.6).

The otter trawl remains the primary gear employed and is typically roller rigged. There has been a trend in recent years towards the use of heavier, larger roller and/or rock hopper gear. These innovations, in concert with substantial improvements in electronic equipment, have allowed for much more accurate positioning and towing in formerly unfishable grounds, thus greatly increasing the fishing power of the Gulf of Maine fleet. Legal restrictions on trawl gear require a minimum 44.5 mm (1.75 inch) stretch mesh net and the use of a finfish separator device known as the “Nordmore grate” with a maximum grate spacing of 25.4 mm (1 inch) (ASMFC 2011). Some trawlers are voluntarily using a combination grate, which includes a section that performs as a finfish separator and a second section that selects for larger shrimp. Additional restrictions on trawlers include the closure of Maine territorial waters from April 1 through December 31, a limit on the length of the bottom legs of the trawl bridle (Maine DMR Regulations, Chapter 45), and limitations on chafing gear and liners (ASMFC 2011).

Inshore trawl trips during the winter months are usually of only one day’s duration. A typical fishing day consists of about four tows of about two hours each (from port interviews). In April and May, two- and three-day offshore trips are common for Maine boats.

A small pot fishery has also existed in mid-coastal Maine since the 1970s, where in many areas bottom topography provides favorable shrimp habitat that is too rough or restricted for trawling. The trapped product is of good quality, as the traps target only female shrimp once they have

migrated inshore (ASMFC 2011; and see Figure C5.6). Trappers use baited rectangular wire mesh traps with a V-shaped trough opening on top, set in single, double, or triple trap strings (Moffett *et al* 2012). In 2010, trappers hauled an average of 114 traps on an average of three-day sets (from port interviews). Most shrimp trappers also trap lobsters at other times of the year. Trappers accounted for about 13% of Maine's landings in 2000-2013 (Table C5.3).

Since the trap fishery is dependent on the inshore availability of shrimp in a specific area, the fishing season is naturally shorter for trappers than for draggers (e.g. see 2010 in Table C5.3, and ASMFC 2011). There is some indication that trap fishing for shrimp has grown in a few areas such as South Bristol and Boothbay Harbor (mid-coast Maine) and might continue to grow if stock conditions were favorable.

C5.0 - TOR #1: PRESENT THE GULF OF MAINE NORTHERN SHRIMP LANDINGS, DISCARDS, EFFORT, AND FISHERY-INDEPENDENT DATA USED IN THE ASSESSMENT. CHARACTERIZE THE PRECISION AND ACCURACY OF THE DATA AND JUSTIFY INCLUSION OR ELIMINATION OF DATA SOURCES.

C5.1 Landings

C5.1.1 Commercial Data Sources

Commercial landings by state, month, and gear (trawl vs. trap) were compiled by NMFS port agents from dealer reports until the mid-late 1990's, and are available electronically back to 1964. A dealer reporting system became mandatory in 1982 but was repealed in 1991, and NMFS began collecting the data again. In 2004, shrimp reporting for federally permitted dealers buying from federally permitted harvesters became mandatory, but "state-only" dealers, mostly in Maine, continued to report voluntarily. Trip level reporting became mandatory for all licensed Maine shrimp dealers in 2008, although "peddlers" selling directly to the public only were not required to have a license, so catches sold in the peddler market were mostly unreported on the dealer side. This was remedied in 2013, and during the next shrimp season, anyone buying shrimp for resale will need to be licensed in Maine and report landings.

In 1994, a Vessel Trip Report (VTR) system was implemented for many federally permitted harvesters and in 1999 (but not implemented until the 2000 season), reporting became mandatory for all shrimp harvesters landing in Maine. Harvesters report "hail" weights, which are estimates of the caught weight.

The time series used in the current Gulf of Maine northern shrimp stock assessment begins with 1968, when survey data became available. For the period 1968 through 1999, the assessment uses landings data from the NMFS commercial fisheries database, based on dealer reports. For the period 2000-2012, the assessment uses the more complete mandatory harvester report data. When the 2013 data were compiled in September 2013, the dealer report data for 2013 seemed to be more complete (higher total shrimp landings) than the harvester report data, likely due to late reporting on the part of harvesters, so dealer data were used to characterize landings for the 2013 season. Late reporting has been a chronic problem with the terminal year of the annual assessment, and each year the landings from the previous two seasons are re-calculated. However, an effort in Maine to improve dealer reporting compliance in 2012 resulted in only a 2% increase in 2012 landings when they were recalculated in 2013 based on 2012 harvester reports.

It is likely that landings are most completely reported in the 2001-2012 period and are less complete in the 1968-2000 period, but there is no way to be certain of this or of the extent of the problem. Model sensitivity runs described in section C.6.2 address this issue. It is also difficult to separate trawl and trap landings before 2000. For this reason, the length-based model

discussed in section C6.1 uses a mixed fleet before 2000, and separate trawl and trap fleets for 2000-2013.

C5.1.2 Commercial Landings

Landings data for the Gulf of Maine northern shrimp fishery are presented in Tables C5.1-C5.3 and Figures C5.1, C5.2, and C5.4.

Annual landings declined from an average of 11,400 metric tons (mt) (25.2 million lbs) during 1969-1972 to about 400 mt (0.84 million lbs) in 1977, culminating in a closure of the fishery in 1978 (Table C5.1). The fishery reopened in 1979 and landings increased steadily to over 5,000 mt (11.1 million lbs) by 1987. Landings ranged from 2,100 to 6,500 mt (5.1 to 14.2 million lbs) during 1988-1995, and then rose dramatically to 9,500 mt (21.0 million lbs) in 1996, the highest since 1973. Landings declined to an average of 2,000 mt (4.4 million lbs) for 1999 to 2001, and dropped further in the 25-day 2002 season to 450 mt (1.0 million lbs), the lowest northern shrimp landings since the fishery was closed in 1978. Landings then increased steadily, averaging 2,100 mt (4.6 million lbs) during the 2003 to 2006 seasons, then jumping to 4,900 mt (10.8 million lbs) in 2007 and 5,000 mt (10.9 million lbs) in 2008. In 2009, 2,500 mt (5.5 million lbs) were landed during a season that was market-limited. The proposed 180-day season for 2010 was closed after 156 days with 6,100 mt (13.5 million lbs) landed, due to the industry exceeding the NSTC recommended upper limit of 4,900 mt (10.8 million lbs), and concerns about small shrimp. As in 2010, the 2011 season was closed early due to landings in excess of the NSTC recommended limit, of 4,000 mt (8.8 million lbs). A total of 6,400 mt (14.1 million lbs) of shrimp were landed. In 2012, the season was further restricted by having trawlers begin on January 2 with 3 landings days per week and trappers begin on February 1 with a 1,000 pound (0.45 mt) limit per vessel per day. The season was closed on February 17 and trawlers had a 21-day season and trappers had a 17-day season. Preliminary landings for 2012 were 2,500 mt (5.5 million lbs), exceeding the total allowed catch (TAC) of 2,211 mt (4.9 million lbs). In 2013, the TAC was set at 625 mt (1.38 million lbs); the trawl fishery was allocated 539.02 mt (1.19 million lbs) and the trap fishery was allocated 80.54 mt (0.18 million lbs). Trawlers fished for 54 days and trappers fished 62 days culminating with 307.1 mt (0.68 million lbs) landed (preliminary), which is 312.5 mt (0.69 million lbs) below the TAC. The average price per pound was \$1.81 (\$3.98/kg) (USD) and is the highest observed in the Gulf of Maine northern shrimp fishery (Table C5.1).

Maine landed 83% of the 2013 season total, New Hampshire followed with 10% and Massachusetts landed 7% of the season total (preliminary data, Table C5.1). The proportional distribution of landings among the states was similar to 2000-2013, but has shifted gradually since the 1980's when Massachusetts accounted for about 30% of the catch (Table C5.1 and Figure C5.1).

The relative proportion of landings by month in 2013 (Table C5.2 and Figure C5.2b), preliminary data) remained generally similar to past years (compare with 2010 in Figure C5.2a), except for the absence of landings in December and May since the fishery did not begin until January 23 and ended April 12. The month of February yielded the highest proportion of the catch (62%) followed by January (23%) and March (14%) and April (1%).

Most northern shrimp fishing in the Gulf of Maine is conducted by otter trawls, although traps are also employed off the central Maine coast. According to federal and state of Maine VTRs, trappers averaged 12% of Maine's landings during 2001 to 2007, 18% during 2008 to 2011 (preliminary data), and 9% (preliminary data) in 2012 (Table C5.3). Trapping effort has been increasing in recent years, accounting for 22% of Maine's landings in 2010. After 2010, the trapping season was cut short by management actions in 2011 and 2012 that curtailed the season before the month of March, which can be an important month for the trap fishery (e.g. 2005 and 2008 in Table C5.3). In 2013, trap catch rates were very low (from port interviews), possibly because the season started when egg hatch was already well underway (see Figures C5.5-C5.6) and stock conditions were poor. Preliminary dealer reports indicate that trappers accounted for about 6% of Maine's landings in 2013 (Table C5.3).

C5.2 Discards

Discard rates of northern shrimp in the northern shrimp fishery are thought to be near zero because no size limits are in effect and most fishing effort occurs in areas where only the larger females are present. Data from a study which sampled the northern shrimp trap fishery indicated overall discard/kept ratios (kg) for northern shrimp of 0.2% in 2010 and 0.1% in 2011 (Moffett et al. 2012). Sea sampling data from Gulf of Maine shrimp trawlers in the 1990s indicated no discarding of northern shrimp (Richards and Hendrickson 2006). The Northeast Pelagic Observer Program sampled 89 trips targeting Pandalid shrimp from 2001-2012; over that time period, 0.03% of the observed catch was discarded. On an anecdotal level, port samplers in Maine reported seeing manual shakers (used to separate the small shrimp) on a few trawl vessels during April 2010, but made no similar observations in 2011 through 2013. Discarding of northern shrimp in other Gulf of Maine fisheries is also low (Table C5.4). For these reasons and because detailed data for estimating potential discards are lacking, shrimp discards from the shrimp and other fisheries are assumed zero in this assessment.

C5.3 Effort and Catch per Unit Effort

C5.3.1 Vessel Data

The approximate number of vessels participating in the fishery is listed in Table C5.5. Data for fishing seasons before 2000 were gleaned from NSTC annual assessment documents, were probably derived from the NMFS dealer weightout database, and must be considered

approximations. Data from 2000 forward are from harvester VTRs, except 2013, which is from dealer reports as described in C5.1.1. Since 2000, the number has varied from a low of 144 in 2006 to a high of 342 in 2011. In the 2013 fishery, there were 16 vessels from Massachusetts (the most since 2001), 168 from Maine (122 trawling, 46 trapping), and 14 from New Hampshire for a total of 198 (preliminary data).

C5.3.2 Trip Data

Prior to 1994, effort (numbers of trips by state and month) was estimated from landings data collected from dealers, and landings per trip information (LPUE) from dockside interviews of vessel captains:

$$Effort = \frac{Landings}{LPUE}$$

Beginning in the spring of 1994, a vessel trip reporting system (VTR) supplemented the collection of effort information from interviews. From 1995 to 1999, landings per trip (LPUE) from these logbooks were expanded to total landings from the dealer weighouts to estimate the total trips:

$$Total.Trips = VTR.Trips \frac{Total.Landings}{VTR.Landings}$$

Since 2000, VTR landings have exceeded dealer weighout landings, and the above expansion is no longer necessary. The 1996 NSTC assessment report (Schick *et al.* 1996) provides a comparison of 1995 shrimp catch and effort data from both the interview and logbook systems and addresses the differences between the systems at that time. It showed a slightly larger estimate from the logbook system than from the interview system. Thus trip estimates reported through 1994 are not directly comparable to those collected after 1994. However, patterns in effort can be examined if the difference between the systems is taken into account. An additional complication of the logbook system is that one portion of the shrimp fishery may not be adequately represented by the logbook system during 1994-1999. Smaller vessels fishing exclusively in Maine coastal waters are not required to have federal groundfish permits and were not required to submit shrimp vessel trip reports until 2000. In the 1994-1999 time series, effort from unpermitted vessels is characterized by catch per unit effort of permitted vessels.

Beginning in 2000, landings, vessels, and trips are calculated from vessel trip reports (VTRs) only, except for 2013, which used dealer trip-level report data as discussed in C5.1.1 above.

C5.3.3 Hours Towing from Port Interviews, Port Sampling Program

A port sampling program was established in the early 1980s to characterize catch at length and developmental stage, as well as to collect effort (hours towing or numbers of traps hauled and

numbers of set-over-days) and fishing depth and location data. Samplers strive to achieve representative sampling (but see Moffett *et al* 2011) by maintaining up-to-date lists of active buyers and visiting ports in proportion to their estimated landings activity. Sampling consists of interviewing boat captains and collecting a 1 kg (2.2 lbs) sample of shrimp from each catch. The samples are separated and weighed in the lab by species, sex (male, transitional, or female) and development stage, where females are described as: ovigerous, female I (have not carried eggs yet), or female II (have carried eggs). Female stage I or II are determined by the presence (stage I) or absence (stage II) of pronounced sternal spines (McCrary 1971). Measurements are made of all shrimp dorsal carapace lengths, to the nearest 0.5 mm prior to 1994, and to the nearest 0.01 mm since 1994. The numbers of interviews conducted, shrimp measured, and the total weight of samples collected each season since 1985 are summarized in Table C5.6.

C5.3.4. Effort and Catch per Unit Effort Results

Estimated numbers of trips for 1985-2013 are reported in Tables C5.7-C5.8 and Figure C5.3. Locations of 2010 and 2013 fishing trips from federal and state VTRs (preliminary) are plotted by 10-minute square in Figure C5.4. Note that landings and effort in 2010 were relatively high, with some offshore trips in the spring, while 2013 was characterized by low landings and low effort with very few offshore trips.

Catch per unit effort for the shrimp fishery is typically measured in catch per hour (from Maine interview data) or catch per trip. A trip is a less precise measure of effort, because: 1) trips (as presented in Figure C5.3) from interviews and logbooks include both trawl and trap trips (difficult to separate before 2000 as discussed above); 2) there are single day trawl trips and multiple day trawl trips (in the spring), and the proportion of such trips can vary from season to season; 3) in some years, buyers imposed trip limits on their boats; and 4) in 2012 and 2013, Maine DMR imposed day-length limits.

Average pounds landed per trip (lbs/trip; 1 lb = 2.2 kg) was calculated by dividing each season's landings (Table C5.1) by the total number of trips (Table C5.7) and is presented in Table C5.9 and Figure C5.3. It averaged 1,410 pounds during 1995-2000, dropped to 752 pounds in 2001, the lowest since 1994, and remained low in 2002. During 2003-2005 it averaged 1,407 lbs/trip. The increasing trend continued in 2006 and in 2007 the highest pounds per trip of the time series was observed with 2,584 pounds. During 2008-2011, pounds per trip averaged 2,012, with a value of 2,264 in 2010, which is the second highest in the time series. There was a large decrease in 2012 to 1,497 lbs/trip (preliminary). In 2013, the average pounds landed per trip was 512, with 579 lbs per trawl trip (preliminary), both the lowest of their time series.

More precise CPUE estimates from port interviews (pounds landed per hour trawling) were calculated by dividing the pooled landings from interviewed Maine catches by the pooled hours

towing for those catches, and agree well with the (less precise) catch per trip data (see Table C5.9 and Figure C5.3). Maine's season average for 2013 was 110 lbs/hr, less than half the time series average of 250 lbs/hr (Table C5.9 and Figure C5.3).

Because catch rates for this fishery can be affected by many factors in addition to stock abundance, such as possible increasing trawler efficiency (discussed in C.4.4 above), the timing of the season (catch rates are generally highest in January and February), attrition of less successful harvesters, and, most importantly, the inshore/offshore migrating and aggregating behavior of northern shrimp in the Gulf of Maine, catch rates have not historically been reliable indices of shrimp abundance or biomass, and are not used as such in this assessment. See Figure C5.3, in which annual Maine trawler catch rates are plotted against the summer survey biomass index from the previous summer. Note that, in particular, catch rates were very stable during the 2008-2012 seasons, before plummeting in 2013, while the summer survey index dropped steadily after the summer of 2008.

C5.4 Size, Sex, and Stage Composition of Landings

Size and sex-stage composition data were collected from port samples of commercial catches from each of the three states. One-kilogram samples were collected from randomly selected catches, and all northern shrimp in each sample were measured, sexed, and staged as described in C5.3.3 above. Sampled northern shrimp counts were grouped in 0.5 mm carapace length intervals by sex-stage, expanded from the sample to the catch, and then from all sampled catches to landings, for each gear type, state, and month. These expanded counts were then summed for the fishing season to give an estimate of the total number of shrimp landed, and the total number landed in each length bin and sex-stage.

Size composition data (Figures C5.5-C5.8) collected from catches since the early 1980s indicate that trends in landings have been influenced by recruitment of strong (dominant) year classes.

Landings more than tripled with recruitment to the fishery of a strong assumed 1982 year class in 1985 – 1987 and then declined sharply in 1988. A strong 1987 year class was a major contributor to the 1990-1992 fisheries. A strong 1992 year class, supplemented by a moderate 1993 year class, partially supported large annual landings in 1995 – 1998 (Figure C5.8). Low landings in 1999 – 2003 were due in part to poor 1994, 1995, 1997, 1998, and 2000 year classes with only moderate 1996 and 1999 year classes. A very strong 2001 year class supported higher landings in 2004 – 2006. In the 2007 fishery, landings mostly comprised assumed 4 year-old females from the moderate to strong 2003 year class, and possibly 6 year-olds from the 2001 year class. Landings in 2008 were mostly composed of the assumed 4 year-old females from the strong 2004 year class, and the 2003 year class (assumed 5 year-old females, which first appeared as a moderate year class in the 2004 survey).

In the 2009 fishery, catches were comprised mainly of assumed 5-year old females from the strong 2004 year class. Catches in the 2010 fishery consisted of assumed 5 year-old females from the 2005 year class and possibly some 4-year-old females from the weak 2006 year class. The 2011 fishery consisted mainly of 4-year-old females from the assumed 2007 year class. Numbers of 5-year-old shrimp were limited likely due to the weak 2006 year class. The 2011 catch included transitionals and newly-transformed females from the assumed 2008 year class, and some males and juveniles from the assumed 2009 year class, especially in the Massachusetts and New Hampshire catches and Maine's December and January trawl catches. Trawl catches in the 2012 fishery were likely 4-year-olds from the moderate 2008 year class, but they were small for their age (compare with 2011 in Figure C5.8). Low percentages of males and juveniles were caught in 2012 likely due to the later start date of January 2 and early closure on February 17. In the 2013 fishery, catches were limited but likely comprised 4- and 5-year-olds from the moderate 2009 and 2008 year classes, however, these shrimp were small for their assumed age (Figure C5.8). Limited numbers of males and transitionals were observed in catches, in Massachusetts and New Hampshire in samples from January through March (Figure C5.7), and in Maine in April (Figure C5.6).

Maine trappers generally were more likely to catch females after egg hatch, than trawlers, as in previous years, and, as in past years, there were fewer small (male) shrimp in Maine trap catches than in trawl catches (Figure C5.6).

Historically, landings from January to March have consisted primarily of mature female shrimp (presumably age 3 and older) and December, April, and May landings have included higher proportions of males (assumed ages 1 and 2). These patterns reflect shifts in distribution of fishing effort in response to seasonal movements of mature females: inshore in mid-winter and offshore after egg-hatch. Spatial and temporal differences in the timing of egg-hatch can be estimated by noting the relative abundance of ovigerous females to females that have borne eggs in the past but are no longer carrying them (female stage II) (Figures C5.5-C.7).

Pre-season research tows were conducted in winter 2013, to obtain information on catch rates and egg hatch. Three shrimp trawlers from Maine (from Stonington, South Bristol, and Sebasco, east to west, Figure C5.10) and one from Portsmouth, New Hampshire conducted short experimental tows for one day during the week of January 13, 2013. They provided samples of the shrimp from each tow for analysis by Maine DMR and New Hampshire Fish & Game. Catch rates were much lower than the 1991-2013 Maine commercial trawl fishery average of 250 lbs/hr (Table C5.9). Counts per pound (1 pound=2.2 kg) varied greatly, generally from east to west, with 34 for the Stonington boat (downeast Maine), 38 for the South Bristol boat (midcoast Maine), 51 for the Sebasco boat (Casco Bay, mid to southern Maine area), and 48 for the Portsmouth boat (New Hampshire). Egg hatch also varied from east to west, with almost no

hatch in Stonington, 7% hatched near South Bristol, to 26% hatched near Sebasco, to 88% hatched near Portsmouth, NH (Figure C5.5).

Pre-season research traps were also set. Five shrimp trappers from midcoast Maine (from Boothbay to Vinalhaven, Figure C5.10) set experimental pre-season shrimp traps between January 24 and February 2, 2013. Each trapper was allowed to set and haul up to 6 traps. Catch rates were poor, less than 1 pound per trap (1 lb=2.2kg). One sample was collected from the Boothbay Harbor area (Figure C5.10), with 16% of shrimp carrying eggs and 84% hatched off (Figure C5.5).

According to port samples collected from the 2013 season's commercial catches, in January, in Maine, 22.5% of the trawled catch was female stage II; in February this increased to 45% (Figure C5.6). These percentages are higher in 2010 through 2013 than in past seasons, suggesting that egg hatch is occurring somewhat earlier than in 2008 and 2009 (2008: 5.4% in January, 13.5% in February and 2009: 5.8% in January, 17.8% in February).

In New Hampshire trawl catches, the percentage of female stage II shrimp for the 2013 season was 95.6% in January, and 88% in February (Figure C5.7). In Massachusetts trawl catch samples, the percentage of female stage II shrimp was 75.6% in January, and 81.2% in February. Egg hatch was well underway when compared to 2012 (NH: 60.2% in January, 94.6% in February, MA: 17.9% in January, 49.2% in February). New Hampshire and Massachusetts percentage of stage II shrimp in the catch were higher than Maine for the same months (compare Figure C5.6 with C.7), probably reflecting the eastern Gulf lagging the west in the timing of egg hatch.

C5.4.1 Estimated Number and Mean Weight of Northern Shrimp in Landings

Size composition data were collected from port samples of commercial catches from each of the three states as described in C5.3.3 above and Table C5.6. Sampled northern shrimp counts were grouped in 0.5 mm carapace length intervals for each sample, expanded from the sample to the catch, and then from all sampled catches to landings, for each gear type, state, and month, which were then summed for the fishing season by gear to give an estimate of the total number of shrimp landed, and the total number landed in each length bin. If there were landings (usually small amounts) but no samples for a given gear, state, and month, the size composition from samples from an adjacent state or month were used. The results are reported in Tables C5.10-C5.12 for 1985-2013. Total numbers of shrimp landed by season are shown in Figure C5.8 and are used in the CSA model below in Section C6.1. Total numbers of shrimp landed by season, gear (fleet), and length interval are used in the length-based model below at C6.11

General patterns in size composition of landings are reflected in the mean weight of individual shrimp landed by season, state, month, and gear: the mean weight of a landed shrimp generally increases from December to January as fewer small males are caught, peaks in February, and

decreases through the spring as the fleet fishes further offshore on mixed sizes. Mean shrimp size is often larger in Maine landings than in those of the other states, and larger in Maine trap catches than trawl catches. The mean weights of individual shrimp (*P. borealis*) from the 2010 fishery are given below, as an example to illustrate these trends. Note that these weights are calculated by dividing the landed weight by the estimated number of shrimp in the landed weight. Since the landings may also contain water, detritus, and other species of shrimp and other bycatch, these “mean weights” are actually estimates of the amount of catch that contains exactly one *P. borealis*. There is further discussion of these estimates in section C9.

Mean weights (grams, g) of individuals (and numbers of samples) of *P. borealis* in 2010 landings. 1 g = 0.0022 lb

Month	Maine		Massachusetts	New Hampshire
	Trawls	Traps	Trawls	Trawls
December	10.96g (28)	No samples; use January	No samples; use NH Dec.	10.94g (3)
January	11.76g (52)	14.01g (17)	8.77g (3)	9.69g (3)
February	12.70g (63)	13.52g (33)	9.03g (3)	10.15g (3)
March	11.59g (15)	13.38g (16)	No samples; use ME March	No samples; use ME March
April	7.94g (24)	No samples; use March	No samples; use NH April	8.91g (2)
May	8.54g (1)	No landings	No landings	No samples; use ME May

C.5.4.2 Estimated Time of Egg Hatch

Probit analysis of the proportion of reproductive females (ovigerous or female stage II) whose eggs had hatched, from Maine port samples, was used to define metrics of hatch timing. The start of the hatch period has become earlier as temperatures have increased (Figure C4.3). See Richards (2012) and Section C4.3.3 for methods and further discussion.

C5.5 Fishery Independent Surveys

Trends in abundance of Gulf of Maine northern shrimp have been monitored since 1968 from data collected in Northeast Fisheries Science Center (NEFSC) autumn bottom trawl surveys and in summer shrimp surveys by the State of Maine (discontinued in 1983). A dedicated shrimp survey has been conducted annually since 1983 by the ASMFC in the resource area in the

western Gulf of Maine. An inshore trawl survey has been conducted each spring and fall since fall 2000 by the states of Maine and New Hampshire (Sherman *et al.* 2005). The NSTC has placed primary dependence on the ASMFC summer shrimp survey for fishery-independent data used in stock assessments, although the other survey data are also considered (see survey locations in Figure C5.10).

C5.5. 1 State-Federal (ASMFC) Summer Survey

The ASMFC NSTC shrimp survey, or “summer survey”, has been conducted offshore (depths > 50 m or 164 ft) each summer since 1983 aboard the *R/V Gloria Michelle* employing a stratified random sampling design and gear specifically designed for Gulf of Maine conditions (Blott *et al.* 1983, Clark 1989). The summer survey is considered to provide the most reliable information available on abundance, distribution, age and size structure and other biological parameters of the Gulf of Maine northern shrimp resource because all adult life history stages are aggregated during the summer and because the gear is designed specifically for capturing northern shrimp. Indices of abundance and biomass are based on catches in the strata that have been sampled most intensively and consistently over time (strata 1, 3, 5, 6, 7, and 8; Figure C5.10). Survey catches have been highest in strata 1, 3, 6, and 8 – the region from Jeffreys Ledge and Scantum Basin eastward to Penobscot Bay. The 1983 survey did not sample strata 6-8 and is not used in the assessment. Survey sites for 2013 are shown in Figure C5.11.

The statistical distribution of the summer survey catch per tow (in numbers) was investigated to determine the best estimator of relative abundance (Cadrin *et al.* 1999). Catches within strata were distributed with significant positive skew, and arithmetic stratum means were correlated to stratum variances. Log-transformed catches ($\ln[n+1]$) were more normally distributed, therefore, stratified geometric mean catch per tow was used to estimate relative abundance (Cadrin *et al.* 1999).

The CV of geometric mean indices from the summer survey during 1984-2013 averaged 21% for abundance (range 11-46%) and 14% for weight (range 7-13%). Indices with 95% confidence intervals are shown in Figure C5.12. Bias is thought to be relatively low in this survey because year classes can generally be tracked over time (Figure C5.13), and the survey has performed well in predicting availability of harvestable shrimp to the upcoming fishery (Figure C5.3c)). The smallest size mode, assumed to be age 1.5 recruits, may not be fully selected to the survey gear.

Shrimp summer survey catches by length and developmental stage (Figure C5.13) reflect the predominance of strong cohorts in the stock. Although size at age-1.5 varies from year to year, discrete length modes indicate the relative abundance of assumed age-1.5 shrimp (generally around 12-18 mm carapace length (CL)) and assumed age-2.5 shrimp (generally 18.5-23 mm CL). Length modes for older cohorts overlap extensively, but female shrimp that have carried eggs in the past (female stage II) can be separated from those that have not (female stage I). Age

1.5 shrimp are not fully recruited to the survey, probably because of variation in the timing of their migration from inshore to offshore, and also because they are not fully retained by the survey net.

Abundance and biomass indices for 2013 were the lowest on record in this series, with a \log_e transformed mean weight per tow of 1.0 kg/tow (Table C5.14, Figure C5.12). The series averaged 15.8 kg/tow from 1984 through 1990. Beginning in 1991, this index began to decline and averaged 10.2 kg/tow from 1991 through 1996. The survey mean weight per tow then declined further, averaging 6.5 kg/tow from 1997 through 2003, and reaching a low of 4.3 kg/tow in 2001. Between 2003 and 2006 the index increased markedly, reaching a new time series high in 2006 (66.0 kg/tow). Although 2006 was a high abundance year, as corroborated by the fall survey index, the 2006 summer survey index should be viewed with caution because it was based on 29 survey tows compared with about 40 tows in most years (Table C5.13). The summer survey index was 16.8 kg/tow in 2008, and has dropped steadily since then to 8.6 kg/tow in 2011, 2.5 kg/tow in 2012, and 1.0 kg/tow in 2013. These most recent values are well below the time series average of 12.9 kg/tow (Table C5.13). The total mean number of shrimp per tow demonstrated the same general trends over the time series (Table C5.13 and Figure C5.13).

The stratified mean catch per tow in numbers of 1.5-year old shrimp (Table C5.13, Figure C5.13, and graphically represented as the total number in the first (left-most) size modes in Figure C5.13) represents a recruitment index. Although these shrimp are not fully recruited to the survey gear, this index appears sufficient as a preliminary estimate of year class strength. This survey index indicated strong (more than 700 per tow) assumed 1987, 1992, 2001, and 2004 year classes. The assumed 1983, 2000, 2002, and 2006 age classes were weak (less than 100 per tow), well below the time series mean of 367 individuals per tow. From 2008 to 2010, the age 1.5 index varied around 500 individuals per tow (506, 555, and 475 individuals per tow, respectively), indicating moderate but above average assumed 2007, 2008, and 2009 year classes. The age 1.5 index dropped markedly to 44 individuals per tow in 2011, signifying a weak 2010 year class. The 2012 index for age 1.5 was the lowest in the time series (until 2013), with only 7 individuals per tow, signifying an extremely weak 2011 year class. The 2013 age 1.5 index dropped even further with only 1 individual per tow, signifying a very weak 2012 year class and an unprecedented three consecutive years of poor recruitment.

Individuals >22 mm will be fully recruited to the upcoming winter fishery (primarily age 3 and older) and thus survey catches of shrimp in this size category provide indices of harvestable numbers and biomass for the coming season (Table C5.13 and Figure C5.13). The harvestable biomass index exhibited large peaks in 1985 and 1990, reflecting the very strong assumed 1982 and 1987 year classes respectively. This index has varied from year to year but generally trended down until 2004. The 2001 index of 1.5 kg/tow represented a time series low, and is indicative of poor assumed 1997 and 1998 year classes. In 2002 the index increased slightly to 2.9 kg/tow, reflecting recruitment of the moderate 1999 year class to the index. The index subsequently dropped to the second lowest value in the time series (1.7 kg/tow) in 2003. From 2003 to 2006,

the fully recruited index increased dramatically, reaching a time series high in 2006 (29.9 kg/tow). This increase may have been related to the continued dominance of the record 2001 year class, some of which may have survived into the summer of 2006, and to an unexplained increase in the number of female stage 1 shrimp (Figure C5.13), probably the 2003 year class. Note that the 2006 summer survey indices (Table C5.13), which are almost all well above historical norms for this survey, are based on 29 tows, compared with about 40 tows in other years. However, the NEFSC fall survey also recorded very high indices in 2006.

In 2007 the index declined to 4.1 kg/tow with the passing of the 2001 year class and the diminishing of the 2003 year class. The 2008 index increased to 10.8 kg/tow, reflecting the strong 2004 and moderate 2005 year classes. The >22 mm weight index declined slightly in 2009 to 8.5 kg/tow, still above the time series mean of 6.0 kg/tow. The moderate 2005 and 2007 year classes and perhaps a remnant of the strong 2004 year class contributed to the composition of the 2009 summer survey >22 mm index. Since 2009, the index has been below the time-series mean and has declined steadily to new time-series lows of 0.9 kg/tow in 2012 and 0.3 kg/tow in 2013 (Table C5.13 and Figure C5.12). The low values in 2012 and 2013 are most likely due to weak recruitment of the 2010 and 2011 year classes, poor survival of the moderate 2008 and 2009 year classes, and overall small size (carapace length) of female shrimp from those year classes.

The low values in the state-federal summer survey in the most recent years have raised concerns that the survey is no longer adequately tracking abundance. The NSTC examined some of the potential hypotheses to explain the changes. One hypothesis is that the bulk of the northern shrimp population has moved northeast, outside of the area covered by the summer survey. The NEFSC bottom trawl survey samples the entire US Gulf of Maine, and although 2013 fall survey data are not yet available, the 2009-2012 survey data do not suggest a significant shift in distribution of shrimp that would explain the recent decline in abundance indices in the summer survey. Patchiness in the distribution of shrimp in the summer survey appears to have increased slightly since 2008 (Figure C5.15) and shrimp are more concentrated in slightly cooler temperatures relative to the temperature at all stations in the past several years (Figure C5.16). Indices based on randomly selected stations show the same trends in abundance as indices based on fixed stations (Figure C5.17). Three additional fixed stations were added to the 2013 summer survey in Stratum 10 (stations 28-30 in Figure C5.11), based on harvester recommended sites. These stations caught an average of 3.7 kg/tow (32 lbs/hr, untransformed). This does not provide support for the theory that the shrimp have moved northeastward.

C.5.5.2 NEFSC Fall Trawl Survey

The NEFSC autumn survey has been conducted in the northern shrimp resource area since 1963; however, shrimp were not identified to species until 1977 and detailed data on northern shrimp (length, sex, life history stage) were not consistently collected until 1994. The survey is based on a stratified random design. During 1963-2008, the survey was conducted using the *FRV Albatross IV*. In 2009 the *Albatross IV* was replaced by the *FRV Henry Bigelow* and the

sampling gear was re-designed. No conversion coefficients were developed for northern shrimp because none of the experimental tows were conducted in the shrimp resource area. Thus the NEFSC fall survey was treated as two time series in the assessment (1984-2008, 2009-2012). Figure C5.18).

The NEFSC fall survey indices during Albatross years 1994-2008 had CVs averaging 25% for biomass and 27% for abundance. For the first 3 years of the Bigelow survey (2009-2011), CVs averaged 25% (biomass) and 27% (abundance). However in 2012, the indices showed a steep decline and CVs increased to 68% (biomass) and 64% (abundance). NEFSC fall survey data for 2013 are not yet available. Biomass trends in the NEFSC fall survey have generally corresponded to biomass trends in the summer shrimp surveys (Clark et al. 2000).

The fall survey biomass index fluctuated around all-time highs in the late 1960's and early 1970's (Clark et al. 2000). In the mid 1970's the index declined precipitously and the fishery collapsed; this was followed by a substantial increase in the middle 1980's to early 1990's, with peaks in 1986, 1990 and 1994 (Figure C5.18). This reflects recruitment and growth of the strong presumed 1982, 1987 and 1992 year classes and the above average 1993 year class. After declining to 0.90 kg/tow in 1996, the index rose sharply in 1999 to 2.32 kg per tow, well above the time series mean of 1.77 kg/tow. This was likely due to recruitment of the 1996 year class to the survey gear. Beginning in 2000, the fall survey index declined precipitously for two consecutive years reaching a low of 0.63 kg/tow in 2001, indicating very poor 1997 and 1998 year classes. From 2002 to 2006, the index generally increased, reaching unprecedented time series highs in 2006 and 2007 of 6.64 kg/tow and 4.13 kg/tow, respectively. From 2005 to 2008, the fall survey index was well above the time series mean of 1.77 kg/tow.

The NEFSC fall survey indices since 2009 are not directly comparable to earlier years because of the change of survey platform. However, the indices from the new NEFSC fall survey aboard the *FRV Bigelow* have declined since 2009 (Figure C5.18) similar to recent trends in the summer shrimp survey and the ME-NH survey.

C5.5.3 Maine-New Hampshire Inshore Trawl Survey

The Maine-New Hampshire inshore trawl survey (Sherman *et al.* 2005) takes place semi-annually, during spring and fall, in five regions and three depth strata (1 = 5-20 fa, 2 = 21-35 fa, 3 = 36-55 fa) (1 fa = 1 fathom = 6 feet = 1.9 meters). A deeper stratum (4 = > 55 fa out to about 12 miles) was added in 2003. The survey consistently catches shrimp in regions 1-4 (NH to Mt. Desert) and depths 3-4 (> 35 fa), and more are caught in the spring than the fall (Table C5.14). The log_e-transformed stratified mean weights per tow for *P. borealis* for the spring and fall surveys using regions 1-4 and depths 3-4 only are presented in Table C5.14 and Figure C5.19, with 80% confidence intervals. Because the fall indices for northern shrimp are lower and more variable than spring, only the spring survey was considered for inclusion in the assessment.

The Maine-New Hampshire spring index rose from 4.16 kg/tow (1 kg = 2.2 lbs) during 2003 to 15.42 kg/tow during 2008. In 2009, the index dipped to 9.65 kg/tow. This was followed by an increase to 15.95 kg/tow in 2010 and to 17.86 kg/tow in 2011. However, this upward trend dropped abruptly in 2012 to 7.50 kg/tow and then declined further in 2013 to only 1.69 kg/tow. The 2013 index is well below the time-series average of 9.60 kg/tow (Table C5.14 and Figure C5.15).

In 2007-2011, the spring ME-NH inshore trawl survey data did not match the declining trend in the summer survey data. However, the low 2012 and 2013 values in the ME-NH survey are consistent with the 2012 and 2013 summer survey results in showing a severe drop in abundance. This survey also has not provided any evidence of a shift in shrimp populations to the northeast.

Because trends in the spring ME/NH survey may be affected by inter-annual variation in the timing of the offshore migration of post-hatch females, the NSTC did not use this survey as model input below, but included it as a sensitivity run in the length-based model (Section C.6). However, the spring ME/NH size-frequency distributions (Figure C5.16) generally confirm the characterization of strong and weak year classes from the summer survey.

C5.5.4 State of Maine Shrimp Survey

The State of Maine conducted summer shrimp surveys in the Gulf of Maine from 1967 to 1983. Fixed stations were sampled with an otter trawl during daylight at locations where shrimp abundance was historically high (Schick *et al.* 1981; Figure C5.10). The Maine survey biomass index began declining in about 1970, and remained low for the rest of the time series (Clark 1981, 1982; Schick *et al.* 1981). Survey biomass indices with 95% confidence intervals are shown in Figure C5.21. The average CV for biomass indices was 92.0%. The benchmark assessment models did not include this survey because of its high variability and because accurate catch data were not available for this earlier time period.

C6.0 - TOR #2: Estimate population parameters (fishing mortality, biomass, and abundance) using assessment models. Evaluate model performance and stability through sensitivity analyses and retrospective analysis, including alternative natural mortality (M) scenarios. Include consideration of environmental effects where possible. Discuss the effects of data strengths and weaknesses on model results and performance.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

C6.1 University of Maine Size-Structured Assessment Model (UME Model)

Life history and fisheries processes are more likely size-dependent than age dependent, and as such size-structured models may be more appropriate than age-structured models in quantifying the dynamic processes of a fish population (Chen et al. 2005; Kanaiwa et al. 2005). Another benefit of using a size-structured model for a species that is difficult to age (e.g., northern shrimp), is that it avoids the need for age composition data (e.g., catch at age) required by age-structured models.

A size-structured population dynamic model was developed for the assessment of northern shrimp in the Gulf of Maine. This model has the capacity to account for (1) the unique biology and life history of the shrimp including changes in sex, natural mortality varying with environmental variables (e.g., temperature and predator abundances), variability in growth among individuals, uncertainty in stock-recruitment relationship which may be greatly influenced by environmental variables; (2) the uniqueness of the fishery including strong seasonality of the fishery (winter only), multiple gears targeting different fishing grounds and catching different sizes of shrimp; (3) multiple data sources (multiple surveys and multiple CPUEs); (4) temporal changes in management regulations which could result in changes in catchability and selectivity; (5) different sources of uncertainty; (6) the estimation of biological reference points inside the model to make the estimated stock and fishery indicators comparable with the reference points; and (7) the capacity to project how the population may respond to alternative management regulations (e.g., changes in TAC and fishing seasons).

C6.1.1 Model Structure and Configuration

The size-structured model consists of the following five components: (1) size-structured population models to quantify the dynamics of the northern shrimp population in GOM; (2) observational models linking state-space variables in the population models with observations made in the fishery and fishery-independent survey programs; (3) statistical estimators (maximum likelihood and Bayesian) for parameter estimation; (4) models for estimating biological reference points using the parameters estimated in the above; and (5) projection models for risk analysis to evaluate alternative management strategies. The Bayesian estimators and projection model were not used in this stock assessment.

The detailed description of the model and relevant computer program can be found in the technical documentation and user manual included in Appendix C1.

The following input data are required in the UME model for the GOM northern shrimp:

- Survey indices, survey catch length compositions;
- Proportion female at size for each year;
- Weight-at-size matrix (by year if possible, can be calculated from length-weight relationship if not);
- Maturity-at-size matrix (by year if possible);
- Annual (seasonal) commercial catch and CV for catch;
- Commercial catch length composition and associated effective sample size (ESS);
- Survey catch CV; and

- Effective sample sizes related to survey size compositions.

In addition to the above input data, we also need to specify and/or estimate growth parameters for development of a growth transition matrix which describes the probability of shrimp of a given size staying in the same size class or growing into other size classes in a given time step. An algorithm based on the von Bertalanffy growth function (VBGF) (Chen et al. 2003) is used to develop the growth transition matrix. This approach requires information on the VBGF parameters (i.e., L_{∞} and K) and their variances. These parameters can be all or partially estimated in modeling and/or entered as part of the inputs.

The ASMFC Northern Shrimp Technical Committee (NSTC) developed a base case for the UMaine size-structured model (Table C6.1). The time period covered was from 1984 to 2013 with year as the model time step. Two sexes were defined: females and non-females. The range of carapace length (CL) was defined from 10 to 35 mm with the width of the size bin being 1 mm.

Based on an evaluation of temporal variability in fishing gear, three commercial fishing fleets were defined in the model: mixed gear from 1984 to 1999, trawl from 2000 to 2013, and trap from 2000 to 2013. Accordingly, three logistic functions were used to quantify fishing selectivity curves with the model parameters being estimated in by the model. Three sets of survey data were considered in the assessment: NEFSC fall survey (Albatross) with abundance index from 1984 to 2008 and CL composition data from 1991 to 2008; ASMFC summer survey with both abundance index and length frequency data from 1984 to 2013; and NEFSC fall survey (Bigelow); and three separate selectivity logistic functions were used to quantify the selectivity of the three sets of survey data with the parameters being estimated in the assessment.

Natural mortality was assumed to vary with CL with small (young) and large (old) shrimp subject to higher natural mortality than medium sizes of shrimp (Fig. C6.1). The proportion of females at CL was defined by a logistic model with the parameters being estimated in modeling. Recruitments are estimated without a functional relationship being assumed for the spawner-recruit relationship. Annual recruitment is defined as the total number of shrimp growing into the CL range of 10 to 18 mm in a given year. Two sets of growth transition matrices were developed for two time periods when the climate conditions were considered different: cold period from 1984 to 1999 and warm period from 2000 to 2013. One set of K and L_{∞} values from McInnes (1986) were used for both the periods, but the variances for K and L_{∞} were assumed to be different between the two time periods, and were estimated by the model.

The initial size composition (i.e., in 1984) was assumed to be the same as the size composition data from the ASMFC summer survey length composition data. For the base case, likelihood functions for all the data (i.e., catch, catch size compositions, survey abundance indices, survey catch compositions, and sex ratio) were assumed to be the same in their importance.

In addition to the base case run, we ran 12 alternative scenarios to evaluate the sensitivity of the assessment results with respect to various settings hypothesized in the base case (Table C6.2). These scenarios evaluated if the assessment results are sensitive to the hypothesized settings of natural mortality (Scenarios 1, 2, and 3), misreporting of landings (Scenarios 4, 5, and 6), importance of survey data in modeling (Scenarios 7 and 8), number of time periods for the growth transition matrix (Scenario 9 for which the shrimp growth was assumed to be the same from 1984 to 2013 in comparison of two time periods of different growth for the base case), growth parameters (Scenario 10), number of fishing fleets (Scenario 11 for which four fishing fleets were defined), and time step (Scenario 12 for which season was used as time step in modeling). Detailed differences between the base case and alternative scenarios were outlined in Table C6.2.

C6.1.2 Results and Discussion for the Base Case Run

The plots of mean weight versus dorsal carapace length (CL) and the proportion of maturity versus CL were derived from the input parameters (Fig. C6.2). Two growth curves were plotted for the two time periods defined in the base case (Fig. C6.3). These plots describe the two growth transition matrices with K and L_{∞} values from McInnes (1986) and their variances estimated in the model. The difference in growth between the two time periods was small (Fig. C6.3). The UME-estimated fisheries selectivity curves for the three fishing fleets defined showed some differences with traps more likely selective for larger shrimps (Fig. C6.4). The UME-estimated survey selectivity also differed among the three survey programs with the ASMFC summer survey program more likely capturing small individuals and the NEFSC Bigelow survey being more likely to catch larger individuals (Fig. C6.5).

The UME-estimated fishing mortality varied greatly over time (Table C6.3), and traps resulted in much lower fishing mortality than trawl (Fig. C6.6). The UME-estimated recruitment also varied greatly over time (Table C6.3), and recruits had the lowest values in years 2000, 2012 and 2013 (Fig. C6.7). Recruitment showed continued decline from 2009 to 2012 (Table C6.3). Although the recruitment estimated for 2013 increased compared to that for 2012 (Table C6.3), it is still one of the lowest recruitment values in the history (3rd lowest from 1984 to 2013; Fig. C6.7, Table C6.3). The SSB estimates varied more than six-fold from 1984 to 2013 (Table C6.3, Fig. C6.8). The SSB had the highest value in 1995 (8652 mt; (Table C6.3) and lowest value in 2013 (1334 mt; Table C6.3). After reaching a high level in 2007 (2nd highest level of SSB at 8148 mt; Table C6.3; Fig. C6.8), SSB started to decline and had a continuous and substantial decrease over the last three years (Fig. C6.8, Table C6.3), probably resulting from declining recruitment (Fig. C6.7). The downward trends over the last three years occurred across all size classes (Fig. C6.9).

The base-case model fit trends in the NEFSC fall survey but did not capture the exceptionally high value in 2006 (Fig C6.10). Similar to NEFSC, fits to the ASMFC summer survey also failed to capture the exceptionally large value in 2006. The increasing trends from 2009 to 2011 shown in the ME-NH inshore spring survey was not captured by the model which predicted a downturn trend (Fig. C6.10).

Overall, the model fit the average size composition data well for the three survey programs, but the model predictions tended to be lower than observed values for large size classes and higher than observed data for medium size classes (Fig. C6.11). For the NEFSC fall survey, the model fit observed size compositions well for most of the years, but tended to under-estimate the first peak in small size classes in some years (e.g., 1993, 2000, 2002, and 2005; Fig. C6.12). The estimated effective sample sizes differed from input effective sample sizes in many years (Fig. C6.13), suggesting that the model considered the importance of size composition data differently. For those years with under-estimated first peaks (i.e., 1993, 2000, 2002, and 2005), the model predicted effective sample sizes were much smaller than the input value of 40 (Fig. C6.12). For the ASMFC summer survey, the model predictions captured the observed size compositions well for most of the years, but under-estimated or missed peaks for some years (Fig. C6.14). For those years with relatively poor fit, the model-estimated effective sample sizes were much smaller than the input values, suggesting that the model considered these data less reliable (Fig. C6.14). For the NEFSC Bigelow survey, the observed peaks in 2011 and 2012 were not fit well, with model-estimated effective sample sizes smaller than the input effective sample sizes (Fig. C6.15).

Temporal trends in total landings (in numbers) were fit well by the model (Fig. C6.16), and so were landings of individual fisheries (Fig. C6.17). For the mixed-gear fishery defined from 1984 to 1999, the peaks were under-estimated by the model for most years (Fig. C6.18), suggesting the fishery selectivity curve might not be well defined. The same results could be seen for the trawl fishery (Fig. C6.19) and trap fishery (Fig. C6.20). Commercial size composition data averaged over all the years could be captured well by the model for all the three fisheries, although the peaks of observed distribution were still under-estimated (Fig. C6.21).

The model could predict observed proportion of females well (Fig. C6.22). The predicted abundance of females and non-females for each size class at the beginning of each year was shown in Fig. C6.23) For almost all the years from 1984 to 2013, non-females tended to have two peaks, most likely representing two age groups (Fig. C6.23). This suggests that most northern shrimp became females at age 3. The estimated size at which 50% of individuals become females ($L_{50\%}$) varied over time with the highest and lowest $L_{50\%}$ occurring in 2008 and 2002, respectively (Fig. C6.24). The estimated size at which 50% of individuals were female had a significant positive correlation with the estimated non-female biomass ($p=0.035$).

Temporal variability in biomass of females and non-females was shown in Table C6.3 and Figure C6.25. The biomass of both females and non-females was fairly stable from 1984 to

1993, reached the highest level in 1995 and then decreased continuously from 1995 to 2001 (Table C6.3). The biomass bounced back to a high level from 2001 to 2007, followed by a large decline after 2010. The biomass in 2013 was the lowest (Fig. C6.25). The model-predicted exploitation rates, calculated as the ratio of predicted landings (in number/weight) and total abundance/biomass, were shown in Table C6.3 and Figure C6.26. The highest exploitation rates occurred in 2011 and 2012 (Table C6.3; Fig. C6.26). During the time period from 1984 to 2013, more than 50% of females were removed in the fishery for 15 out of 30 years. Of these 15 years, 11 years occurred after 1996 (Table C6.3). More than 50% of the females were caught in the fishery in every year from 2007 to 2012 except for 2009 (Table C6.3). In 2010, 2011 and 2012, 64%, 77% and 74% of females were removed by the fishery, respectively (Table C6.3).

The annual estimates of recruitment, SSB, female biomass, non-female biomass, female abundance, non-female abundance, abundance-based exploitation rate (i.e., ratio of landings in number versus stock abundance), biomass-based exploitation rate (i.e., ratio of landings in weight versus stock biomass), and biomass-based exploitation rate for females (i.e., ratio of female landings in weight versus female biomass) are shown in Table 3.

The retrospective analysis suggests that estimated SSB tended to have a low retrospective error with SSB being likely to have a slight overestimation (Fig. C6.27, C6.28). The recruitment and exploitation rates also had small retrospective errors with the recruitment being under-estimated (Fig. C6.29, C6.30) and exploitation rate being over-estimated (Fig. C6.31, 6.32).

A phase plot for the fishing mortality of fully-recruited shrimp and spawning stock biomass is presented in Figure C6.33.

C6.1.3 Sensitivity Analyses

The total negative log-likelihood (NLL) value and NLL values of each component are shown in Table C6.4. We could not get scenario 12 (using season as time step) converged. The only scenario that had a smaller NLL value than the base case is scenario 10, which used different growth parameters for the derivation of the growth transition matrices. The other alternative scenarios had larger NLL values, suggesting that the configuration of these models is less optimal than the base case. The NLL for the proportion of females had the same NLL value for all the scenarios, suggesting it is not sensitive to the model configuration. Size composition data of both surveys and fisheries had the largest NLL values, resulting from a large number of observations in these data sets. Overall, differences in the NLL values and compositions among the scenarios were not surprising (Table C6.4).

The key population and management parameter estimates for the base case and other alternative scenarios were shown in Table C6.5. Scenario 7 (survey indices were weighted five times in modeling; Table C6.2) yielded least optimistic conclusions about the status of the fishery in 2013 with low SSB and low recruitment, and scenario 10 (alternative growth parameters; Table C6.2) was most optimistic. Most alternative scenarios yielded the results similar to those for the base

case (Table C6.5). The base case and most alternative scenarios suggested that the SSB was less than 30% of B_{MSY} in 2013, which may suggest that the shrimp stock is overfished. However, the exploitation rates, calculated in three different ways (i.e., ratio of catch in number versus the total stock abundance, ratio of catch in weight versus total stock biomass, and ratio of female catch in weight versus female biomass; Table C6.5; Fig. C6.26), were low for most scenarios including the base case, suggesting that overfishing might not occur in 2013. The retrospective errors existed in the estimation of SSB, recruitments and exploitation rates, but were not serious for most scenarios (see Mohn's rho values in Table C6.5).

C6.1.4 Summary

The UME assessment fit the GOM northern shrimp data reasonably well. Retrospective errors were not serious in the assessment (Table C6.5). Sensitivity analysis suggests that the assessment results were most sensitive to alternative hypotheses on growth parameters used in quantifying growth transition matrix (Tables C6.4 and C6.5).

The UME assessment suggests that the GOM northern shrimp stock biomass and recruitment fluctuated greatly from 1984 to 2013 (Table C6.3). The shrimp SSB and recruitment decreased greatly from 2010 to 2013, in parallel with substantially high rates of removal of females during 2010 to 2012 (i.e., 64%, 77%, and 74%, respectively; Table C6.3). The SSB in 2013 was the lowest for the time period from 1984 to 2013, and the recruitment in 2013 was one of the lowest (Table C6.3).

C6.2 Collie-Sissenwine Analysis (CSA)

C6.2.1 Model Structure and Configuration

Collie-Sissenwine Analysis (CSA) is a two-stage stock assessment model that estimates abundance, fishing mortality and recruitment to the fishery using total catch numbers and survey data (Collie and Sissenwine 1983; Conser 1995). The “recruit” stage group consists of animals that will recruit during the current time step. The “post-recruit” animals are those that were fully recruited before the start of the time step. The two stages may correspond to age groups, length groups or any other natural division (e.g. genders in hermaphroditic species). The initial application of CSA to Gulf of Maine northern shrimp is described in Cadrin et al. (1999).

The software for CSA was updated in 2013; the 2013 benchmark assessment used CSA version 4.2.2 from the NOAA Fisheries Toolbox (<http://nft.nefsc.noaa.gov/>). Technical documentation is provided in Appendix C3 of this report. Changes to the software are summarized in Table C1. The most significant improvements are the use of maximum likelihood methods rather than weighted sums of squares to estimate parameters, and the capability to incorporate more than one survey index in fitting the model.

The surveys in CSA ver. 4.2.2 can be of two types. “Recruit/post-recruit” surveys consist of two indices (one for recruits and the other for post-recruits) usually derived from the same survey; aggregate surveys are not divided into recruits and post-recruits. For recruit/post-recruit surveys, the user must specify annual selectivity parameters (sometimes called q-ratios) which cannot be estimated and which measure catchability of recruits relative to post-recruits in each year. It is inadvisable to include multiple recruit/post-recruit surveys because fixed selectivity parameters for the two surveys are likely to conflict.

The model may include any number of “aggregate” surveys. The aggregate surveys involve a single selectivity parameter for recruits that may be fixed or estimated. The selectivity of post-recruits is assumed to be one; the parameter for recruits measures selectivity relative to the selectivity of post-recruits. In the current application to northern shrimp, selectivity of the aggregate surveys was estimated within the model rather than fixed.

The user must specify the time of year (as a fraction) that each survey observation was collected. The model uses this information in comparing the observed survey observation to predicted abundance at the time the observation was collected. This facilitates use of multiple surveys collected at different times of the year and surveys with variable start dates, particularly when mortality rates are high. In the benchmark application, the summer survey was considered the start of the year, the fall survey occurred 0.25 year later, and the ME-NH survey 0.625 year later.

The effects of the new software and model configuration were tested using the final CSA run (ver 3.1.1) from the 2013 annual assessment for northern shrimp (Whitmore et al. 2013) as a base. Subsequent runs were done to include additional surveys (aggregated) and to explore different values of natural mortality (M). Aggregate surveys considered were the NEFSC autumn surveys (Albatross years (1984-2008), Bigelow years (2009-2012)) and the ME-NH spring inshore survey. The ME-NH survey was not included in the base run because of concerns about inter-annual variability in availability of shrimp to this survey (due to timing of migration). The model time period was survey years 1984-2013; however, fall survey data were only available through 2012.

Annual survey CVs were adjusted prior to performing the benchmark model runs to bring the assumed CV values close to that implied based on the model residuals (see Appendix C3 Table 2 and Figure 1). Catch CV for the final runs was assumed equal to 0.05 to match the CV assumed in the UME model. Confidence limits for final model estimates were generated using Markov chain Monte Carlo (MCMC) calculations using 1000 iterations with a thinning rate of 10.

C.6.2.2 Results

Estimates of fishing mortality from the CSA peaked at 1.12 in 1997, with the second and third highest values in the time-series occurring in 2011 and 2012 (0.48 and 0.55, respectively). F subsequently dropped in 2013, to 0.13.

Estimates of 2013 recruit abundance (82 million shrimp), post-recruit abundance (238 million shrimp), and exploitable biomass (3,000 mt) were the lowest values in the time-series. Recruit abundance and exploitable biomass peaked in 2007 (5,790 million shrimp and 62,000 mt, respectively), while post-recruit abundance peaked the following year.

C6.2.4 Sensitivity Runs

Sensitivity runs were done to examine the influence of assumed natural mortality, estimated recruit selectivity, the assumed CV on catch, and possible catch under-reporting.

Three scenarios for M were examined (Figure C2). The first scenario was constant M=0.25 with an ad hoc adjustment in 2006 of M=1.0 to account for the sudden disappearance of an unusually strong year class. Previous assessments assumed a constant M=0.25, but this was considered too low by SARC 45 because consumption estimates were higher than model estimates of shrimp abundance (NEFSC 2007). However empirical estimates of M for Gulf of Maine northern shrimp in the exploitable size range have been relatively low (Rinaldo 1976, regression of Z on effort, M=0.25; Clark 1982, catch curve Z during fishery closure, M=0.17), suggesting there may be some merit in assuming a relatively low M for CSA.

The other two M scenarios incorporated estimates of interannual variation in predation pressure on shrimp using as a baseline either the Rinaldo (1976) empirical estimates (M=0.25) or M=0.5 based on the 3/M rule of thumb (maximum age of shrimp=6 years). In these runs, the baseline M values were adjusted annually according to an index of predation pressure (PPI, Figure C3) developed from food habits sampling and predator biomass data from NEFSC surveys (Appendix C2). The adjustment to M was proportional to the long term average of the PPI, so that M was scaled up in years with above average PPI and down in years with below average PPI:

$$M_i = M_b * \frac{PPI_i}{\overline{PPI}}$$

where i=year and M_b=baseline M. In the ‘Rinaldo’ scenario (M=0.25), M was scaled relative to the average PPI during 1968-1972, the time period when M was estimated. This resulted in an average M during the assessment time period (1984-2013) of M=0.20 under the Rinaldo scenario.

Figure C4 shows the estimates that resulted from incremental changes made to extend the CSA ver 3.1.1 model. The software change had no observable effect on the population estimates (Figure C4, A-D). Adding the fall surveys had some effect in the early part of the time series, but little effect since around 2000 (Figure C4, E-H). Using the adjusted survey CVs smoothed out some of the spikes in the estimates (Figure C4, I-L). Using a constant M=0.5 (vs. constant M=0.25) decreased the estimates of F and increased the estimates of abundance and biomass, as would be expected (Figure C4, M-P). Applying the PPI-adjusted M (base M=0.5) reduced recruit

abundance since 2001 (fishing year) and increased F during the same time period. This reflects the generally higher PPI (and thus higher M) since about 2000 (Figure C3). In the CSA, 6 months of natural mortality is applied to the starting population before the catch is removed, thus years with higher PPI have fewer shrimp at the start of the fishery than would be predicted from models with constant M . A comparison of the cumulative difference between the original CSA ver. 3.1.1 model vs. the ver. 4.2.2 model using PPI-adjusted M ($M=0.5$ base) is shown in Figure C4, U-X.

Goodness of fit was evaluated for 3 assumptions regarding M as described above (Table C3). The PPI-adjusted 3/ M scenario had the lowest overall objective function, although the ad hoc M fit the post-recruits more closely than the other options. The fit to the 3/ M -PPI model improved as catch CV was decreased (Table C3). The 3/ M model was selected as the base model for further development.

The value of including additional surveys (as aggregate indices) was evaluated by examining likelihood components and AIC scores for each model (Table C4). The models that included the ME-NH inshore spring survey performed most poorly. The models that excluded the ME-NH survey had equivalent objective functions but the model that included both shrimp and fall surveys had a higher AIC because it had more parameters. Based on these results and concerns discussed above, the ME-NH survey was dropped from further consideration. The fall surveys were retained despite the somewhat higher AIC.

The final model used the 3/ M PPI-scaled M and included the summer shrimp survey (recruits and post-recruits) and the NEFSC fall surveys (Albatross and Bigelow, aggregate indices). Results and comparison to the 2013 annual assessment model are shown in Figures C5-C8 and Table C5. The strong retrospective patterns seen in the 2013 model are improved when annual M is scaled by the predation pressure index (Figure C6). Mohn's ρ is given in Table C6. The improvement in the retrospective pattern compared to the 2013 annual assessment is due primarily to scaling M by the PPI (Figure C7). The PPI model also better accommodates the large spike in abundance observed in the 2006 surveys (Figure C5). Confidence limits (90%) based on MCMC are shown in Figure C7.

We examined sensitivity of the final model to the annual estimates of recruit selectivity, to hypotheses re. catch under-reporting, and to variation in the assumed baseline M . Recruit selectivity estimated from survey data during 1984-2013 averaged 0.91 (range 0.63-1.0). We varied selectivity by multiplying the annual estimated selectivity by a constant ranging from 0.25 to 0.9, or set selectivity in all years equal to 1 (100% selected, Table C7). The base model (=estimated selectivity) and models with $0.75 \times$ base or $0.9 \times$ base had similar overall fits based on the objective function and likelihood components. Setting selectivity below $0.75 \times$ base resulted in poorer fits, and setting it equal to 1 also resulted in a poorer fit than using the base (estimated) selectivity.

Increasing catch numbers to account for possible under-reporting particularly prior to 2001 did not significantly affect the model fit (Table C8), but had some effect on the resulting estimates (Figure C9). The final model used the catch data as reported and did not adjust for suspected under-reporting.

Using baseline M lower than 0.5 (as multiplier for PPI) resulted in poorer fits of the model; using higher baseline M did not significantly improve the model fit (Table C9).

A final set of runs was done using an alternative formulation of the PPI (PPI2) based on the annual percent of the diet that comprised Pandalids (vs. average frequency over time in the diet of each predator) (Appendix C2). This formulation had slightly poorer goodness of fit and a slightly worse retrospective pattern than the final 3/M-PPI model, and was not considered further.

C6.3 Surplus Production Model (ASPIC)

C6.3.1 Model Structure and Configuration

An alternative method of estimating stock size and F was compared to results from the CSA analysis. A nonequilibrium surplus production model (ASPIC ver. 5.34.9 NOAA/NMFS, Prager 1994, 1995, 2004) was fit to seasonal catch and survey biomass indices from 1968 to 2013 (summarized in Table C6-3; Figure C6-10). The model assumes logistic population growth, in which the change in stock biomass over time (dB_t/dt) is a quadratic function of biomass (B_t):

$$dB_t/dt = rB_t - (r/K)B_t^2$$

where r is the intrinsic rate of population growth, and K is carrying capacity. For a fished stock, the rate of change is also a function of F :

$$dB_t/dt = (r-F_t)B_t - (r/K)B_t^2$$

For discrete time increments, such as annual fishing seasons, the difference equation is:

$$B_{t+1} = B_t + (r-F_t)B_t - (r/K)B_t^2$$

Initial biomass (B_1), r , and K were estimated using nonlinear least squares. The NEFSC R/V Albatross fall groundfish survey catch per unit effort (CPUE) contributed to the total sum of squares as a series of observed effort ($E=CPUE/C$); the Maine summer survey, the ASMFC summer shrimp survey, and the NEFSC R/V Bigelow fall groundfish survey contributed as independent indices of biomass at the start of the fishing season.

C6.3.2 Results

Estimates of F and B from the biomass dynamics model generally confirm the pattern and magnitude of estimates from the size-structured models (Figure C6-10). Biomass estimates have been rapidly declining since 2007 (Tables C6-2 and C6-3; Figure C6-10). Recruitment of the strong 1982, 1987, 1992, 2001, and 2004 cohorts is not as pronounced in the biomass trajectory from the production model. Estimates of biomass from the base model run of ASPIC, which includes four available fishery independent indices, were below B_{MSY} in 2013 indicating the stock is overfished (Table C6-3; Figure C6-11). Estimates of F from the production model were below F_{MSY} in 2013, but above it in 2011 and 2012, indicating the stock has experienced overfishing for two of the last three years (Table C6-3). The biomass dynamics model suggests that a maximum sustainable yield (MSY) of 4,430 mt can be produced when stock biomass is approximately 22,800 mt (B_{MSY}) and F is approximately 0.19 (F_{MSY}). However, estimated biomass was only above B_{MSY} during the first five years in the analysis, which are not reliable (Prager 1994, 1995).

The model struggled to fit two observations from the NEFSC fall groundfish survey conducted on the R/V Albatross (2006 and 2007) and one observation from the ASMFC summer shrimp surveys. The pattern of residuals from the Maine and ASMFC Summer surveys suggest autocorrelation (Figure C6-12). The model did not account for peaks in biomass from 2005 to 2008 that resulted from strong recruitment.

Survey residuals were randomly resampled 1000 times to estimate precision and model bias. Bootstrap results suggest that B_1/B_{MSY} , K , MSY , B_{MSY} and F_{MSY} were relatively well estimated (relative interquartile ranges were <7%, and bias was $\leq 1\%$). Estimates of the survey q 's were moderately precise (relative IQs were 5-18%, bias was $\leq 1\%$). The ratio of F/F_{MSY} in 2013 was estimated with moderate precision (relative IQ = 15%, bias was -10%). B/B_{MSY} in 2013 was estimated with lower precision (relative IQ = 74%, bias 23%).

C6.3.3 Sensitivity Runs and Retrospective Analysis

Estimates of fishing mortality and biomass derived from the biomass dynamics model (ASPIC) were examined for sensitivity to potential uncertainty and biases by excluding and including certain survey indices (NEFSC R/V Bigelow fall survey and Maine-New Hampshire shrimp inshore survey). Two continuity runs were completed. For the first run (Cont. 1), the NEFSC R/V Albatross fall survey catch per unit effort (CPUE) contributed to the total sum of squares as a series of observed effort ($E=CPUE/C$); while the Maine summer survey, and the ASMFC summer shrimp survey contributed as independent indices of biomass at the start of the fishing season. This represented the ASPIC input used in the 2007 SAW Assessment update. The second run (Cont. 2) represented indices used in more recent assessment updates. For this run, the NEFSC R/V Albatross fall survey catch per unit effort (CPUE) contributed to the total sum of squares as a series of observed effort ($E=CPUE/C$); while the Maine summer survey, the

ASMFC summer shrimp survey, and the Maine-New Hampshire spring inshore survey contributed as independent indices of biomass at the start of the fishing season.

Estimates of fishing mortality and starting biomass from ASPIC were slightly sensitive to the exclusion of the NEFSC R/V Bigelow fall groundfish survey. For Cont. 1, the average annual starting biomass was 10% higher than the base run estimate, and the average annual F was 10% lower than the base run (Figure C9-2.1). Fishing mortality and biomass estimates were less sensitive to the inclusion of the Maine-New Hampshire spring inshore survey (with the exclusion of the NEFSC R/V Bigelow fall survey). For Cont. 2, the average annual starting biomass was 0.05% higher than the base run estimate, while the average annual F was 1.8% higher than the base run F (Figure C9-2.2).

A total of five retrospective ASPIC runs were completed and examined to assess the stability of model estimates of biomass and fishing mortality in the terminal year, and to assess the sensitivity of time series trends of biomass and fishing mortality to terminal values of survey and catch time series. The analysis was performed by sequentially removing the last year of survey and catch data (for five years) to create retrospective time series of surplus production fishing mortality and biomass estimates.

Retrospective analyses of results indicate that stock size has been considerably overestimated and the fishing mortality rate has been underestimated by the ASPIC model in recent years (Figure C6-14). F values have been underestimated and B values overestimated since the late 1990's, and the degree of retrospective bias for F and B has increased in recent years. The optimistic bias in estimated biomass is notable since 2007, where the trajectory of the stock has changed from increasing to declining (Figure C6-14).

C6.4 Model Comparisons

All three models show similar trends, with fishing mortality spiking in 2010-2012 and then declining in 2013 (Figure C6.50). Biomass and abundance peak earlier, in 2007/2008 and have declined since then, with 2013 being the lowest value in the time-series for all models (Figure C6.51).

The UME model predicts a much higher full F than the ASPIC and CSA models do; however, the UME model assumes F is separable, and uses a model-estimated selectivity pattern to apply that full F to each size class in the population. When the full F is averaged across all size classes, weighted by the abundance at size, the N-weighted F is similar in magnitude to the F estimated by the CSA and ASPIC.

C7.0 - TOR #3: UPDATE OR REDEFINE BIOLOGICAL REFERENCE POINTS (BRPs; POINT ESTIMATES OR PROXIES FOR B_{MSY} , SSB_{MSY} , F_{MSY} , MSY). EVALUATE STOCK STATUS BASED ON BRPs.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

The current fishing mortality reference points as established by Amendment 2 and re-estimated during the 2013 assessment update by the NSTC are $F_{target}=0.38$ and $F_{threshold}=0.48$. The F_{target} is defined as the average F estimated by the CSA model during a period in the fishery when biomass and landings were considered stable (1985-1994). The $F_{threshold}$ is the maximum F estimated during this time period. Amendment 2 also specifies an $F_{limit} = F_{20\%SSPR} = 0.6$, which was exceeded in the early 1970s when the stock collapsed.

The stock biomass threshold of $B_{Threshold} = 9,000$ mt (19.8 million lbs) and limit of $B_{Limit} = 6,000$ mt (13.2 million lbs) are based on historical abundance estimates and response to fishing pressure. The limit was set 2,000 metric tons higher than the lowest observed biomass – 4,000 mt in 1976 from ASPIC analysis (ASMFC 2001).

C7.1 Historical Proxies

Current management of Northern shrimp relies on historical proxies to establish fishing mortality targets and thresholds. Earlier efforts to develop model-based reference points resulted in values that were not consistent with estimates of F derived from the CSA model and suggested the stock could sustain levels of F and harvest much higher than had been estimated by the CSA model. In addition, uncertainty about natural mortality and the spawner-recruit relationship made model-based reference points and quota calculations less reliable. The historical proxy was chosen in part because the allowable catch and stock status determinations were not sensitive to assumptions about M.

C7.1.1 UME model

Because the selectivity of the fleet during the stable time period is different than the current fishery, the F_{target} and $F_{\text{threshold}}$ are based on the numbers-weighted value of F. The numbers-weighted value of F in the terminal year is calculated to compare to those reference points. The N-weighted F is calculated as the average partial F experienced by each length class, weighted by the numbers of shrimp in that length class:

$$\bar{F}_y = \frac{\sum_1^{L_{\text{max}}} F_y \cdot \text{selectivity}_L \cdot N_{L,y}}{N_{\text{total},y}}$$

The annual N-weighted Fs for 1985-1994 were averaged to produce the $F_{\text{target}} = 0.22$. The maximum N-weighted F for this time period was $F_{\text{threshold}} = 0.39$.

The N-weighted F in 2013 was 0.04, below both the threshold and the target, indicating overfishing was not occurring (Figure C7.1).

The biomass threshold defined in Amendment 2 was used as the historical proxy for the UME model. One-half of the average SSB during the stable period (1985-1994) was defined as the SSB threshold, resulting in $\text{SSB}_{\text{threshold}} = 2,335$ mt.

SSB_{2013} was estimated as 1,334 mt, below the $\text{SSB}_{\text{threshold}}$, indicating the stock is overfished.

The historical biomass limit for Northern shrimp was derived from the ASPIC model and thus cannot be used to compare to the estimates from the size-structured UME model. Thus, a biomass limit reference point was not defined for this assessment.

Amendment 2 to the Northern shrimp FMP does not employ a biomass target because the Section did not want to set unlikely goals for a species whose biomass can easily be affected by environmental conditions. Shrimp management is focused on achieving the target F while

keeping the biomass above the threshold level. Because historical proxy reference points were used, the NSTC did not estimate MSY. Shrimp recruitment is driven in part by temperature, and since environmental conditions in the Gulf of Maine are currently in a state of flux, model-based estimates of MSY would not be biologically meaningful or useful for management purposes.

C7.1.2 CSA model

The average F for the stable period from the updated CSA model was $F_{\text{target}} = 0.20$, with a maximum of $F_{\text{threshold}} = 0.27$. The estimate of F_{2013} was 0.13, below both the threshold and the target, indicating overfishing was not occurring (Figure C7.2).

The average exploitable biomass for the stable period from the updated CSA model was 16,600 mt, resulting in a $B_{\text{threshold}} = 8,300$ mt. The estimate of B_{2013} was 300 mt, well below the B threshold, indicating the stock is overfished.

C7.1.3 ASPIC model

The average F for the stable period from the updated ASPIC model was $F_{\text{target}} = 0.23$, with a maximum of $F_{\text{threshold}} = 0.35$. The estimate of F_{2013} was 0.16, below both the threshold and the target, indicating overfishing was not occurring (Figure C7.3).

The average biomass for the stable period from the updated ASPIC model was 16,230 mt, resulting in a $B_{\text{threshold}} = 8,115$ mt. The estimate of B_{2013} was 1,270 mt, below the B threshold, indicating the stock is overfished.

C7.2 Model-Based Reference Points

C7.2.1 Spawner-per-recruit Reference Points

Spawner-per-recruit reference points ($F_{30\%SPR}$ and $F_{40\%SPR}$) were calculated from the selectivity and growth parameters estimated by the UME model. Setting $F_{40\%SPR} = 0.78$ as the target and $F_{30\%SPR} = 1.17$ as the threshold results in a similar assessment of stock status. The total full F from the trawl and trap fisheries in 2013 was 0.26, indicating overfishing was not occurring (Figure C7.4).

Because of the strong environmental effects on recruitment, and the fact that the environmental conditions in the Gulf of Maine are in a state of flux, the NSTC did not feel any SSB reference points based on a stock-recruitment relationship would be reliable.

C7.2.2 MSY Reference Points

MSY-based reference points were calculated from the ASPIC surplus production model. F_{MSY} was estimated as 0.19, and B_{MSY} was estimated as 22,800 mt. F_{2013} was 0.16, less than F_{MSY} , indicating overfishing was not occurring (Figure C7.5). B_{2013} was estimated to be 1,270 mt, well below B_{MSY} and $0.5B_{\text{MSY}}$, indicating the stock is overfished.

C7.3 Stock Status

Regardless of whether model based or historical reference points are chosen, all three models agree that overfishing was not occurring in 2013, but did occur in 2010-2012. In addition, stock biomass and abundance are at time-series lows and the stock is overfished when compared to historical proxy reference points .

BRP	F reference points	Biomass reference points
UME historical proxy	$F_{\text{target}} = 0.22$ $F_{\text{threshold}} = 0.39$	$SSB_{\text{threshold}} = 2,335 \text{ mt}$
UME SPR	$F_{40\%SPR} = 0.78$ $F_{30\%SPR} = 1.17$	n.a.
CSA historical proxy	$F_{\text{target}} = 0.20$ $F_{\text{threshold}} = 0.27$	$B_{\text{threshold}} = 8,300 \text{ mt}$
ASPIC MSY	$F_{\text{MSY}} = 0.19$	$B_{\text{MSY}} = 22,800 \text{ mt}$

C7.4 BRPs and Changing Environmental Conditions

There is strong evidence that recruitment strength is driven by both spawning stock size and environmental conditions, particularly temperature (Richards *et al.* 2012). Unfortunately, environmental conditions in the Gulf of Maine are currently in flux. Model-based reference points that assume equilibrium conditions and historical reference points calculated from a different temperature regime may not be appropriate for the future dynamics of this stock. As

temperatures in the Gulf of Maine continue to rise, levels of fishing mortality and biomass that were sustainable in the past may become unsustainable as the productivity of the stock declines.

C8.0 - TOR #4: CHARACTERIZE UNCERTAINTY OF MODEL ESTIMATES OF FISHING MORTALITY, BIOMASS AND RECRUITMENT, AND BIOLOGICAL REFERENCE POINTS.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

Uncertainty in model parameters was estimated through several different methods. For the UME model, asymptotic standard errors were estimated internally by the model. For the CSA model, an MCMC approach was used to estimate error (see Appendix C3 for more details). For the ASPIC model, residuals were bootstrapped to estimate error around the estimated and calculated parameters.

In addition, uncertainty was assessed qualitatively through retrospective and sensitivity analyses.

The coefficient of variation and Mohn's rho for fishing mortality, biomass, and recruitment for each model are presented in Table C8.1. Because all three models use different methods to

calculate the CVs, they are not directly comparable. In particular, the asymptotic standard error calculated internally for the UME model is most likely an underestimate of what would be calculated from a bootstrap or Monte Carlo method.

Sensitivity analyses showed that the UME model is most sensitive to assumptions about the growth model used to develop the growth transition matrix (Figure C6.34). Changes in M did not strongly affect the model estimates in recent years, although they had a stronger effect on estimates of F and SSB in the early time period, which would affect the historical proxy reference points. Underestimating catch by 10% or 25% in the early years, before mandatory reporting, and underreported catch in the terminal year did not have a large effect on estimates of SSB and F . Increasing the likelihood weight on the survey did have an effect on estimates of F and SSB in the most recent years, predicting a higher F and lower SSB . The model showed a slight retrospective pattern in overestimating SSB and underestimating F in the terminal year.

Results from the CSA sensitivity analyses were similar (Figures C6.39-C6.41). Choice of M scales the population and fishing mortality estimates as expected. Including a time-varying M , scaled to predation, improved the retrospective pattern for the CSA but not the UME. The ASPIC model was not very sensitive to the surveys included, but had a strong retrospective pattern of underestimating F and overestimating biomass, indicating that the terminal year estimates are highly uncertain.

Absolute values of biological reference points were sensitive to choices of M as well as choice of model, but regardless of BRP calculation or model choice, stock status remained the same.

See Appendix C6 for additional sensitivity runs that were conducted at the review workshop.

C9.0 - TOR #5: REVIEW THE METHODS USED TO CALCULATE THE ANNUAL TARGET CATCH AND CHARACTERIZE UNCERTAINTY OF TARGET CATCH ESTIMATES.

[SAW58 Editor's Note: The SARC58 peer review panel concluded that the northern shrimp stock assessment models presented to them were not acceptable to serve as a basis for fishery management advice. Specifically, the SARC58 concluded that shrimp assessment Terms of Reference #2, #3, #4, and #5 were not met. These particular sections are included in this report to document the analyses that were done for the peer review, but they are not recommended by SARC58 as a basis for management.]

C.9.1 Background

In recent years, as part of the annual stock assessment update each autumn, the NSTC has been recommending a target catch level (TAC) for the upcoming GOM shrimp fishing season. In the past, this was done informally, and the NSTC's recommendation took the form of recommending the length of the fishing season, since season length was the most important, or most relied-upon, management tool to limit fishing effort. In 2005, the committee began recommending an annual TAC and leaving it up to the Section, with advice from industry and the NSTC, to craft a season that might achieve the TAC. From 2006 to 2009, the recommended TAC was not reached, probably because of low effort and poor market conditions. 2010 was the first season in which the Section took emergency action to close the season early when it became apparent that the recommended TAC had been exceeded. Since then, the Section has relied more heavily on the TAC as a management tool, requiring more careful monitoring of landings. For 2012,

mandatory landings reporting by dealers became weekly instead of monthly, and the timely enforcement of a TAC became more attainable.

C.9.2 Annual target catch specification, as described in the FMP

Amendment 2 to the northern shrimp FMP, implemented in 2011 (ASMFC 2011), specifically requires the NSTC to recommend a target TAC annually. The Section can manage to the TAC by adjusting the fishing season length, as well as trip limits, trap limits, and days out, at any time during the season through emergency action. Other management tools are available, but must be implemented through the ASMFC addendum process.

Addendum 1 to Amendment 2 (ASMFC 2012) further specifies the methodology to be used to establish a “hard” TAC, and also addresses allocation by gear type, transferability, projecting the season closure, and research set asides. Addendum 1 also allows the ASMFC to close the fishery automatically (without a Section meeting or public input) when the NSTC projects that the TAC (or a percentage chosen beforehand by the Section at its annual season specifications meeting) will be reached. This process has not been utilized yet, because the 2013 TAC (625 mt) was never reached.

Addendum 1 describes the TAC calculation and specification process thusly:

“Total Allowable Catch (TAC) Specification

“The Section has the flexibility to set a hard TAC annually, that is associated with managing the Northern shrimp fishery,

- At the F_{target} [$F_{\text{target}} = F_{1985-94}$ from Amendment 2]
- At the $F_{\text{threshold}}$ [$F_{\text{threshold}} = F_{1987}$ from Amendment 2]
- Between the F_{target} and $F_{\text{threshold}}$

“The NSTC will estimate a TAC associated with the above management flexibility using results from the most recent stock assessment.

“The methodology used to establish the TAC is described below.

...”Catch in numbers (C) is a function of abundance (N) and exploitation rate (μ , which is a function of fishing mortality F and natural mortality M).

“Using this relationship, it is possible to estimate projected landings (in numbers) for a given year at various levels of F, using population estimates and an assumption of M.

“To convert landings in numbers to landings in weight, an assumption must be made about the mean weight of the shrimp caught in the upcoming fishery. The NSTC uses the relationship between the mean carapace length (mm) of female shrimp during the summer survey, and the mean weight (g) of an individual shrimp in the next fishing season, to predict the fishery mean weight.” (ASMFC 2012)

Note that the committee estimates yield for various levels of F and reports these to the Section as possible TAC options; it is the Section which chooses and sets the TAC. For the 2014 season, the Section selected a TAC of 0 mt (fishery moratorium).

C9.3 Determining the target catch – estimating catch in numbers

To determine the TAC options for the 2014 season, the NSTC used the following relationship, based on Pope's approximation (Pope 1972) to the Baranov catch equation (Baranov 1918), which estimates the yield in numbers of shrimp for a given value of F, and then converts numbers to weight:

$$\text{Yield}_{2014} = F * (\text{exploitable abundance}) * e^{-p*M}$$

Where F = fishing mortality rate

p = proportion of year before start of fisheries (e.g., 52/365 for a fishery with a mid-point of Feb. 14.

M=natural mortality

For the CSA, which starts the year when the summer survey occurs, instead of on January 1:

N = CSA-estimated abundance of new and fully-recruited shrimp at time of survey

p =proportion of year between mean survey date and mean fishery date

For the UME model, exploitable abundance was calculated as the sum of the numbers in each size class in 2013 multiplied by a catch-weighted selectivity-at-length function. For the CSA model, exploitable abundance was calculated as the sum of new recruits and post-recruits in 2014.

This required making some assumptions about the timing of the potential 2014 season. Based on the poor stock conditions, the NSTC assumed a 2014 fishing season would be short and relatively late, to limit catch and allow maximum egg hatch. The results of calculations using these parameters and the formula above are in Table C.9.1.

C.9.4 Converting the catch in numbers to weight (metric tons)

Since specifying a TAC in numbers of shrimp caught is not particularly useful for the managers or for the administration of the TAC, the estimated yield from the process described above must be converted from numbers to weight. For this, the NSTC predicts the mean weight of one individual northern shrimp ("w" in the formula above) in the upcoming fishery, and multiplies the catch in numbers by this weight to estimate the catch in weight. Note that since the catch contains other species of shrimp, water, detritus, and other bycatch, this conversion factor is not actually the mean weight of one northern shrimp, but rather, the amount of catch that contains exactly one northern shrimp. However, it will be referred to here as the mean weight of one shrimp.

The mean weight of one shrimp for past seasons can be easily estimated by dividing each season's landings by the estimated number of northern shrimp in each of those landings. The estimated number of shrimp is obtained from port samples; the number of northern shrimp in a sample is expanded to that sample's catch, summed over samples by month, state, and gear, and expanded to that month-state-gear's landings as described in section C5.4.1 above. The mean weights of shrimp for the 1985-2013 fishing seasons are shown in Table C.9.2. Note that they have varied from 8.9g in 2006 to 13.78g in 1988.

The NSTC has struggled with predicting the size of shrimp in an upcoming fishing season. The previous summer survey provides useful information on stock size structure, but there are a number of complicating factors:

1. Shrimp will grow between the summer survey (late July to August) and the next fishery.
 - a. The timing of the start, middle, and end of that fishery may vary and may be unknown to the NSTC ahead of time.
 - b. The female shrimp will grow very little. Once they have extruded eggs (generally by late September (Clark et al 2000)) they stop molting and growing, as shown in Figure C.9.
2. Fishery gear selectivity is different from the survey gear selectivity. However, the selectivity of the fishing gear is not as important as the natural size selection that occurs when the female shrimp migrate inshore, leaving most of the smaller shrimp offshore.
3. The proportions of males (small) and females (large) in the catch, and the sizes of the males and females, vary from year to year, based on:
 - a. The relative strength of the male and female year classes
 - b. Whether there is good separation of males and females during the female migration.
 - c. Whether the fishery is conducted before (December) and after (April and May) the female inshore migration.
 - d. Fishers' choices of where (inshore vs. offshore) and when (early, middle, or late) to fish, and what gear to use (trawl vs. trap).

The NSTC has found that there is a strong relationship between the mean size (carapace length) of female shrimp from the summer survey (from data displayed in Figure C5.15 [the summer survey lfs]) and the mean size (weight) of a shrimp in the following fishery. This can be seen by eye when viewing Figure C.9.1. There is also a linear correlation when the fishery mean weights are plotted against the previous summer survey mean female lengths, for 1985 through 2013 ($r^2=0.43$, Table C.9.2 and Figure C.9.2). When the mean fishery weights were smaller than predicted (see turquoise outliers in Figure C.9.2), it was often because there was a relatively strong year class of small, 3-year-old shrimp that the fishery was unable to avoid. For instance, in the 2005 survey, the assumed age 1.5 shrimp (2004 year class) were very abundant, and were caught as age 3 in the 2007 fishery (2006 survey year outlier in Figure C.9.2). The fit of the

linear regression was improved ($r^2 = 0.52$) if each year's mean survey female length was corrected downward by subtracting $0.001 \times$ the age 1.5 index (no. per tow) from the previous survey (see method in Table C.9.3 and fit in Figure C.9.3). The fit was further improved ($r^2 = 0.82$) if only recent years were used (survey years 2001 through 2012, Table C.9.3 and Figure C.9.4). Note that an exponential relationship, which might be expected to provide a better fit when correlating weight with length, did not improve the fit ($r^2 = 0.80$, Figure C.9.4).

The mean length of the females in the 2013 summer survey was 26.45 mm. Inserting this value into the linear formula in Table C.9.3 and Figure C.9.4 gives an estimate of 11.64 g for the mean weight of shrimp in a 2014 fishery. This was the value used for “w” in the yield calculation in section C.9.3 above.

For the UME model, exploitable biomass can also be calculated from the numbers-at-length multiplied by the predicted weight-at-length from the length-weight relationship. The TAC from this method is also shown in Table C.9.1. Results are similar. However, it should be noted that the length-weight relationship is for non-ovigerous females, and as a result will underestimate the mean size of a shrimp in the catch when egg-bearing females make up a non-trivial component of the catch. The proportion of egged females in the catch varies annually, and the NSTC favors using the predicted mean weight of the shrimp based on historical data over the L-W relationship.

C.9.5 Uncertainty of target catch estimates

Sources of uncertainty of the target catch estimates include:

1. Uncertainty around the model estimates of the exploitable abundance and biomass. Uncertainty around p , based on guessing the timing of the upcoming fishing season.
2. Uncertainty around the estimate of w , the mean weight of one shrimp in the upcoming season's landings. The difference between observed and predicted weights for 2001-2012 are given in Table C.9.3.

C10.0 - TOR #6: DEVELOP DETAILED SHORT AND LONG-TERM PRIORITIZED LISTS OF RECOMMENDATIONS FOR FUTURE RESEARCH, DATA COLLECTION, AND ASSESSMENT METHODOLOGY. HIGHLIGHT IMPROVEMENTS TO BE MADE BEFORE THE NEXT BENCHMARK ASSESSMENT.

Improvements to be made before the next benchmark assessment are underlined.

In addition to the recommendations listed below, the NSTC emphasized the importance of continuing the summer shrimp survey despite the current low abundance of shrimp and the closure of the shrimp fishery in 2013.

C10.1 Fishery-Dependent Priorities

C10.1.1 Short-term

High

- Improve separator and excluder devices to reduce bycatch and discard of non-targeted species and small shrimp in the shrimp fishery and fisheries targeting other species.
- Evaluate selectivity of shrimp by traps and trawls.

Moderate

- Evaluate commercial fishery sampling design. Increase and/or redistribute sampling of commercial catches as necessary, ensuring good allocation of samples among ports and months, to provide better estimates of size composition.

C10.1.2 Long-term

High

- Continue to quantify the magnitude of bycatch of other species in the shrimp fishery by area and season and take steps necessary to limit negative impacts.

Moderate

- Continue sea sampling efforts.
-

C10.2 Fishery-Independent Priorities

C10.2.1 Short-term

High

- Evaluate effectiveness of summer shrimp survey statistical design, including geographic coverage.

Moderate

- Explore ways to sample age 1 and younger shrimp.

C10.2.2 Long-term

Low

- Verify that summer shrimp survey tow bottom tending times have been consistent.

C10.3 Modeling / Quantitative Priorities

C10.3.1 Short-term

High

- Continue research to refine annual estimates of consumption by predators, and include in models as appropriate.

Moderate

- Explore explicit inclusion of temperature effects in stock assessment models.
- Expand the time series of stock and recruitment data using catchability estimates from the production model.

C10.3.2 Long-term

Moderate

- Continue examination of methods for age determination to develop the possibility of using age based assessment methods.
- Develop a bio-economic model to study the interactions between four variables: movements of shrimp, catchability of shrimp, days fished, and market price.

C10.4 Life History, Biological, and Habitat Priorities

C10.4.1 Long-term

High

- Investigate application of newly developed direct ageing methods to ground truth assumed ages based on size and stage compositions.
- Evaluate larval and adult survival and growth, including frequency of molting and variation in growth rates, as a function of environmental factors and population density.
- Study the effects of oceanographic and climatic variation (i.e., North Atlantic Oscillation) on the cold water refuges for shrimp in the Gulf of Maine.
- Explore the mechanisms behind the stock-recruitment and temperature relationship for Gulf of Maine northern shrimp.

Moderate

- Determine the short and long-term effects of mobile fishing gear on shrimp habitat.
- Study specific habitat requirements and develop habitat maps for early life history stages.
- Evaluate effects of potential habitat loss/degradation on northern shrimp.
- Identify migration routes of immature males offshore and ovigerous females inshore.
- Evaluate maturation, fecundity, and lifetime spawning potential. Estimates of fecundity at length should be updated and the potential for annual variability should be explored. Examine variability of egg quality with female size and stage over time.

- Investigate changes in transition and maturation as a function of stock size and individual size and temperature.
 - Investigate diet of northern shrimp for different life history stages.

C10.5 Management, Law Enforcement, and Socioeconomic Priorities

C10.5.1 Short-term

High

- Explore new markets for Gulf of Maine shrimp, including community supported fisheries.
- Develop a framework to aid evaluation of the impact of limited entry proposals on the Maine fishing industry.

10.5.2 Long-term

High

- Characterize demographics of the fishing fleet by area and season. Perform comparative analysis of fishing practices between areas.
- Develop an understanding of product flow and utilization through the marketplace. Identify performance indicators for various sectors of the shrimp industry. Identify significant variables driving market prices and how their dynamic interactions result in the observed intra-annual and inter-annual fluctuations in market price for northern shrimp.
- Develop a socioeconomic analysis assessing the importance of the northern shrimp fishery in annual activities of commercial fishing.
- Determine the relative power relationships between the harvesting and processing sector and the larger markets for shrimp and shrimp products.
- Develop an economic-management model to determine the most profitable times to fish, how harvest timing affects markets, and how the market affects the timing of harvesting.

Moderate

- Perform cost-benefit analyses to evaluate management measures.

C11.0 - TOR #7: BASED ON THE BIOLOGY OF SPECIES, AND POTENTIAL SCIENTIFIC ADVANCES, COMMENT ON THE APPROPRIATE TIMING OF THE NEXT BENCHMARK ASSESSMENT AND INTERMEDIATE UPDATES.

The NSTC recommends that the Northern shrimp stock assessment be updated annually to incorporate the most recent information on recruitment, size composition, and landings into the quota/specification setting process. Annual specifications are important for a short-live species with highly environmentally-driven recruitment like Northern shrimp.

Initially, the NSTC recommended that a full benchmark assessment be conducted in five years.

In light of the peer review outcome, the NSTC recommends a benchmark assessment be carried out sooner, ideally in the next two to three years. This will give the NSTC time to evaluate the performance of the new size-structured model through simulation work and resolve the data-weighting and fit issues identified by the Panel, as well as incorporate additional information on the Gulf of Maine's changing environmental conditions.

C12.0 REFERENCES

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Table C4.1. Shrimp Section for management of the Gulf of Maine northern shrimp fishery, 1987 – 2014 (adapted from Clark et al. 2000)

Fishing Season	Recommendations	Actions Taken
1987	<ul style="list-style-type: none"> • Extension of season to maximum allowed • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (182 days) • Continuation of mesh regulations
1988	<ul style="list-style-type: none"> • Restriction of season to winter and spring • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (183 days) • Continuation of mesh regulations, except 0.25 inch tolerance in codend eliminated
1989	<ul style="list-style-type: none"> • Extension of season to maximum allowed • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required in April and May
1990	<ul style="list-style-type: none"> • Extension of season to maximum allowed • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required in December, April, and May
1991	<ul style="list-style-type: none"> • Extension of season to maximum allowed • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required throughout season
1992	<ul style="list-style-type: none"> • Restriction of season from January – March • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (153 days). December 16, 1991 – May 15, 1992. • No fishing on Sundays • Continuation of mesh regulations • Shrimp separator trawls required throughout season • Finfish excluder devices required April 1 – May 15
1993	<ul style="list-style-type: none"> • Restriction of season from January – March • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (138 days). December 14, 1992 – April 30, 1993 • No fishing on Sundays • Continuation of mesh regulations • Finfish excluder devices and separator panels required
1994	<ul style="list-style-type: none"> • Restriction of season from January – March • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (122 days) December 15, 1993 – April 15, 1994. • Continuation of mesh regulations • Finfish excluder devices
1995	<ul style="list-style-type: none"> • Restriction of season from January – March • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (128 days). December 1, 1994 – April 30, 1995. • No fishing Fridays or Sundays (state choice) • Continuation of mesh regulations • Finfish excluder devices required
1996	<ul style="list-style-type: none"> • Extension of season to maximum allowed • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (152 days). December 1, 1995 – May 31, 1996 for mobile gear; no fishing one day per week. • Open season (121 days). January 1 – May 31, 1996 for fixed gear (traps) • Continuation of mesh regulations • Finfish excluder devices required
1997	<ul style="list-style-type: none"> • Restriction of effort in December, April, and May • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (156 days). December 1, 1996 – May 31. Two 5-day and four 4-day blocks of no fishing. Trap gear may be left untended. • Continuation of mesh regulations

		<ul style="list-style-type: none"> • Finfish excluder devices required
1998	<ul style="list-style-type: none"> • Restriction of effort in February – March • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (105 days). December 1, 1997 – May 22, 1998 for mobile gear; no fishing weekends except March 14 – 15 and December 25-31 and March 16 – 31. • Open season (65 days). January 1 – March 15 for trap gear. No fishing on Sundays except March 15. • Continuation of mesh regulations • Finfish excluder devices required
1999	<ul style="list-style-type: none"> • Restriction of season to 40 days during February – March • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (90 days). December 15, 1998 – May 25, 1999 for mobile gear. No fishing on weekends plus December 24-25, December 28 – January 1, January 27-29, February 24-26, March 17-31, and April 29-30. • Open season (61 days). January 10 – March 10 for trap gear. • Continuation of mesh regulations • Finfish excluder devices required
2000	<ul style="list-style-type: none"> • No fishing; closed season 	<ul style="list-style-type: none"> • Open season (51 days). January 15 – March 15. No fishing on Sundays. • Continuation of mesh regulations • Finfish excluder devices required
2001	<ul style="list-style-type: none"> • Restriction of season to 61 days • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (83 days). January 9 – April 30. March 18- April 15 no fishing. Experimental offshore fishery in May. • Continuation of mesh regulations • Finfish excluder devices required
2002	<ul style="list-style-type: none"> • No fishing; closed season 	<ul style="list-style-type: none"> • Open season (25 days). February 15 – March 11. • Continuation of mesh regulations • Finfish excluder devices required
2003	<ul style="list-style-type: none"> • No fishing; closed season 	<ul style="list-style-type: none"> • Open season (38 days). January 15 – February 27. No fishing on Fridays. • Continuation of mesh regulations • Finfish excluder devices required
2004	<ul style="list-style-type: none"> • No fishing; closed season 	<ul style="list-style-type: none"> • Open season (40 days). January 19 – March 12. No fishing on weekends. • Continuation of mesh regulations • Finfish excluder devices required • No mechanical shaking of net on vessel
2005	<ul style="list-style-type: none"> • Landings should not exceed 2,500 metric tons • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (70 days). December 19 – 30, no fishing on Friday and Saturday; January 3 – March 25, no fishing on weekends. • Continuation of mesh regulations • Finfish excluder devices required • No mechanical shaking of net on vessel
2006	<ul style="list-style-type: none"> • Landings should not exceed 5,200 metric tons • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (140 days). December 12 – April 30. • 2007 fishing season tentatively set at 140 days. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2007	<ul style="list-style-type: none"> • No recommendation against 140-day season • Continuation of mesh regulations 	<ul style="list-style-type: none"> • Open season (151 days). December 1 – April 30. • 2008 fishing season tentatively set at 151 days. • Continuation of mesh regulations • No mechanical shakers allowed on vessel

2008	<ul style="list-style-type: none"> • No recommendation against 152-day season • Maintain fishing mortality at or below the target/threshold 	<ul style="list-style-type: none"> • Open season (152 days). December 1 – April 30. • 2009 fishing season tentatively set from December to April • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2009	<ul style="list-style-type: none"> • Landings should not exceed 5,103 metric tons • Maintain fishing mortality at or below the target/threshold 	<ul style="list-style-type: none"> • Open season (180 days). December 1 – May 29. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2010	<ul style="list-style-type: none"> • Landings should not exceed 4,400 to 4,900 metric tons • Maintain fishing mortality at or below the target/threshold 	<ul style="list-style-type: none"> • Open season (180 days). December 1 – May 29. Closed early on May 5, 2010. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2011	<ul style="list-style-type: none"> • Based on favored fishing mortality rate, landings should not exceed 3,200 metric tons ($F = 0.22$) or 4,000 metric tons ($F = 0.29$) 	<ul style="list-style-type: none"> • Open season (136 days). December 1 – April 15. Closed early on February 28, 2011. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2012	<ul style="list-style-type: none"> • Maintain fishing mortality at or below the target value ($F = 0.32$) • Landings should not exceed 1,834 metric tons 	<ul style="list-style-type: none"> • Total allowable catch (TAC) of 2,000 metric tons; increased to 2,211 metric tons on January 20, 2012 • Trap season start on February 1 with a 1,000 pound landing limit per vessel per day • Trawl season start on January 2, 2012 with three landing days a week
2013	<ul style="list-style-type: none"> • Moratorium on fishing • If fishing is allowed, start season after 50% of shrimp have hatched their brood 	<ul style="list-style-type: none"> • TAC of 625 metric tons; divided 17% to trap fishery and 83% to trawl fishery • Trawl fishery start on January 22, 2013 with two landings days • Trap fishery start on February 5, 2013 with 6 landings days and an 800 lb limit • Landings days modified throughout season
2014	<ul style="list-style-type: none"> • Moratorium on fishing; the stock has collapsed 	<ul style="list-style-type: none"> • Moratorium on fishing

Table C4.2. Age-constant estimates of natural mortality for Northern shrimp.

ESTIMATORS OF AGE-CONSTANT NATURAL MORTALITY											
INPUT		Type	von B age-length		longevity		maturity		environ.		
Parameter		L_inf	K	t_max	P	a_50	GI	Temp			
Units		mm	year ⁻¹	years		years		° C			
Value		35.2	0.360	6	0.015	1.5	NA	3			
ESTIMATES											
Method	Note	Equation	Required Parameters						M		
			L_inf	K	t_max	P	a_50	GI	temp	instantaneous	annual
Alverson and Carney 1975		$M = 3K/(\exp[0.38 \cdot K \cdot t_{max}] - 1)$		X	X					0.85	0.57
Rikhter and Efanov 1977		$M = [1.521/(a_{50} \cdot 0.720)] - 0.155$					X			0.98	0.63
Gunderson 1980		$M = -0.370 + 4.64GI$						X		NA	NA
Pauly 1980	1	$M = \exp[-0.0152 + 0.6543 \cdot \ln(K) - 0.279 \cdot \ln(L_{inf}/10) + 0.4634 \cdot \ln(Temp)]$	X	X					X	0.59	0.45
Hoinig 1983 (regression)	2	$M = \exp[1.44 - 0.982 \cdot \ln(t_{max})]$			X					0.73	0.52
Hoinig 1983 (rule-of-thumb)	3	$M = -\ln(P)/t_{max}$			X	X				0.70	0.50
Ralston 1987 (linear regression)	4	$M = 0.0189 + 2.06 \cdot K$		X						0.76	0.53
Gunderson and Dygert 1988		$M = 0.03 + 1.68 \cdot GI$						X		NA	NA
Jensen 1996 (theoretical)		$M = 1.50 \cdot K$		X						0.54	0.42
Jensen 1996 (derived from Pauly 1980)		$M = 1.60 \cdot K$		X						0.58	0.44
Gunderson 1997		$M = 1.79 \cdot GI$						X		NA	NA
Hewitt and Hoinig 2005		$M = 4.22/t_{max}$			X					0.70	0.51
Beverton	5	$M = 3 \cdot K / [\exp(a_{50} \cdot K) - 1]$		X			X			1.51	0.78
Notes											
1 Pauly's (1980) equation converted from base 10 to natural logarithms by Quinn and Deriso (1999); L_inf divided by 10 to adjust for mm											
2 Values 1.44 (intercept) and -0.982 (slope) were those recommended by Hoinig (1983)											
3 Equation $\approx 3/t_{max}$ when $P = 0.05$											
4 Ralston's (1987) relationship was developed for snappers and groupers											
5 Was not able to verify this equation or identify reference											

Table C4.3. Age-varying estimates of natural mortality for Northern shrimp using Lorenzen's (1996) method, unscaled and scaled to the maximum observed age in the population.

ESTIMATOR OF AGE-VARYING NATURAL MORTALITY USING LORENZEN'S (1996) MORTALITY-WEIGHT MODEL												
INPUT		Type	age range			von B age-length			len(mm)-wt(g)		mortality-weight *	
Parameter		t_min	t_max	P	L_inf	K	t_0	alpha	beta	M_u	b	
Units		years	years		mm	year ⁻¹	years					
Value		0	6	0.015	35.2	0.360	NA	5.93E-04	3.01	3.69	-0.305	
ESTIMATES												
Method	Equation	Age years	Length mm	Weight g	M(W) - unscaled		M(W) - scaled**					
					instantaneous	annual	instantaneous	annual				
Lorenzen 1996	$M(W) = M_u \cdot W^b$	0	8	0.3	5.224	0.99	1.33	0.74				
Scaled estimate	$-M(a) \cdot \ln(\% \text{ at-max-age}) / \Sigma M(a)$	1	16	2.6	2.752	0.94	0.70	0.50				
		2	22	6.5	2.089	0.88	0.53	0.41				
		3	26	10.7	1.793	0.83	0.46	0.37				
		4	29	14.5	1.633	0.80	0.42	0.34				
		5	31	17.6	1.538	0.79	0.39	0.32				
		6	32	20.1	1.479	0.77	0.38	0.31				

Table C4.4. Age-varying estimates of natural mortality for Northern shrimp using Gislason *et al.*'s (2010) method.

ESTIMATOR OF AGE-VARYING NATURAL MORTALITY USING GISLASON ET AL'S (2010) MORTALITY-GROWTH MODEL						
INPUT	Type	age range		von B age-length		
	Parameter	t min	t max	L inf	K	t 0
	Units	years	years	mm	year ⁻¹	years
	Value	0	6	35.2	0.360	NA
ESTIMATES						
Method	Equation	Age years	Length mm	M(L)		
Gislason et al. (2010)	$M(L)=\exp[0.55 - 1.61*\ln(L/10) + 1.44*\ln(L_inf/10)+\ln(K)]$			instantaneous	annual	
		0	8.1	5.36	1.00	
		1	16	1.74	0.82	
		2	22	1.07	0.66	
		3	26	0.82	0.56	
		4	29	0.70	0.50	
		5	31	0.63	0.47	
		6	32	0.59	0.44	

Table C4.5. Length-varying U-shaped M for Northern shrimp.

Length (mm)	M	Source
10	1.10	Scaled Lorenzen (1996) estimate of M-at-length
11	1.00	
12	0.93	
13	0.86	
14	0.80	
15	0.76	
16	0.71	
17	0.67	
18	0.64	
19	0.61	
20	0.58	Rinaldo (1976)
21	0.25	
22	0.25	
23	0.25	
24	0.25	
25	0.25	
26	0.25	
27	0.25	
28	0.25	Estimated to align with maximum observed age
29	0.75	
30	0.75	
31	0.75	
32	0.75	
33	0.75	
34	0.75	

Table C5.1. U.S. Commercial landings (mt) of northern shrimp in the Gulf of Maine.
 1 mt = 2,205 lbs

Year	Maine	Massachusetts	New Hampshire	Total	Price \$/Lb	Value \$
1958	2.2	0.0	0.0	2.2	0.32	1,532
1959	5.5	2.3	0.0	7.8	0.29	5,002
1960	40.4	0.5	0.0	40.9	0.23	20,714
1961	30.5	0.3	0.0	30.8	0.20	13,754
1962	159.5	16.2	0.0	175.7	0.15	57,382
1963	244.3	10.4	0.0	254.7	0.12	66,840
1964	419.4	3.1	0.0	422.5	0.12	112,528
1965	941.3	8.0	0.0	949.3	0.12	245,469
1966	1,737.8	10.5	18.1	1,766.4	0.14	549,466
1967	3,141.2	10.0	20.0	3,171.2	0.12	871,924
1968	6,515.2	51.9	43.1	6,610.2	0.11	1,611,425
1969	10,993.1	1,773.1	58.1	12,824.3	0.12	3,478,910
1970	7,712.8	2,902.3	54.4	10,669.5	0.20	4,697,418
1971	8,354.8	2,724.0	50.8	11,129.6	0.19	4,653,202
1972	7,515.6	3,504.6	74.8	11,095.0	0.19	4,586,484
1973	5,476.6	3,868.2	59.9	9,404.7	0.27	5,657,347
1974	4,430.7	3,477.3	36.7	7,944.7	0.32	5,577,465
1975	3,177.2	2,080.0	29.4	5,286.6	0.26	3,062,721
1976	617.3	397.8	7.3	1,022.4	0.34	764,094
1977	142.1	236.9	2.2	381.2	0.55	458,198
1978	0.0	3.3	0.0	3.3	0.24	1,758
1979	32.8	405.9	0.0	438.7	0.33	320,361
1980	69.6	256.9	6.3	332.8	0.65	478,883
1981	530.0	539.4	4.5	1,073.9	0.64	1,516,521
1982	883.0	658.5	32.8	1,574.3	0.60	2,079,109
1983	1,029.2	508.2	36.5	1,573.9	0.67	2,312,073
1984	2,564.7	565.4	96.8	3,226.9	0.49	3,474,351

Table C5.1 continued – U.S. commercial landings (metric tons, mt) of northern shrimp in the Gulf of Maine. 1 mt = 2,205 lbs
 (*2012 and 2013 data are preliminary)

Season	Maine	Massachusetts	New Hampshire	Total	Price \$/Lb	Value \$
1985	2,946.4	968.8	216.7	4,131.9	0.44	3,984,562
1986	3,268.2	1,136.3	230.5	4,635.0	0.63	6,451,206
1987	3,680.2	1,427.9	157.9	5,266.0	1.10	12,740,581
1988	2,258.4	619.6	157.6	3,035.6	1.10	7,391,777
1989	2,384.0	699.9	231.5	3,315.4	0.98	7,177,659
1990	3,236.3	974.9	451.3	4,662.5	0.72	7,351,420
1991	2,488.6	814.6	282.1	3,585.3	0.91	7,208,838
1992	3,070.6	289.3	100.1	3,460.0	0.99	7,547,941
1993	1,492.5	292.8	357.6	2,142.9	1.07	5,038,053
1994	2,239.7	247.5	428.0	2,915.2	0.75	4,829,106
1995	5,013.7	670.1	772.8	6,456.6	0.90	12,828,030
1996	8,107.1	660.6	771.7	9,539.4	0.73	15,341,504
1997	6,086.9	366.4	666.2	7,119.5	0.79	12,355,871
1998	3,481.3	240.3	445.2	4,166.8	0.96	8,811,938
1999	1,573.2	75.7	217.0	1,865.9	0.91	3,762,043
2000	2,516.2	124.1	214.7	2,855.0	0.79	4,968,655
2001	1,075.2	49.4	206.4	1,331.0	0.86	2,534,095
2002	391.6	8.1	53.0	452.7	1.08	1,077,534
2003	1,203.7	27.7	113.0	1,344.4	0.87	2,590,916
2004	1,926.9	21.3	183.2	2,131.4	0.44	2,089,636
2005	2,270.2	49.6	290.3	2,610.1	0.57	3,261,648
2006	2,201.6	30.0	91.1	2,322.7	0.37	1,885,978
2007	4,469.3	27.5	382.9	4,879.7	0.38	4,087,120
2008	4,515.8	29.9	416.8	4,962.4	0.49	5,407,373
2009	2,315.7	MA-NH combined 185.6		2,315.7	0.40	2,051,987
2010	5,604.3	35.1	501.4	6,140.8	0.52	6,994,106
2011	5,569.7	196.4	631.5	6,397.5	0.75	10,625,533
*2012	2,211.4	77.8	187.8	2,476.9	0.95	5,212,137
*2013	255.5	20.3	31.3	307.1	1.81	1,223,045

Table C5.2. Distribution of landings (metric tons, mt) in the Gulf of Maine northern shrimp fishery by state and month.

1 mt = 2,205 lbs

	Season							Season Total	Season							Season Total
	Dec	Jan	Feb	Mar	Apr	May	Other		Dec	Jan	Feb	Mar	Apr	May	Other	
1985 Season, 166 days, Dec 1- May 15																
Maine	335.7	851.8	1,095.5	525.1	116.8	215	0.0	2,946.4								
Mass.	91.7	283.9	238.3	239.3	57.8	57.0	0.8	968.8								
N.H.	67.0	86.2	50.4	116	13		0.2	216.7								
Total	494.4	1,221.9	1,384.2	776.0	175.9	78.5	10	4,131.9								
1986 Season, 196 days, Dec 1- May 31, June 8-21																
Maine	346.9	747.8	1,405.3	415.4	104.2	149.2	99.4	3,268.2								
Mass.	154.3	213.4	221.2	200.7	111.2	84.8	150.7	1,136.3								
N.H.	57.7	75.9	70.8	14.2	13	0.0	10.6	230.5								
Total	558.9	1,037.1	1,697.3	630.3	216.7	234.0	260.7	4,635.0								
1987 Season, 182 days, Dec 1- May 31																
Maine	485.9	906.2	1,192.7	672.9	287.6	127.9	7.0	3,680.2								
Mass.	103.5	260.0	384.9	310.2	180.8	182.8	5.7	1,427.9								
N.H.	18.4	53.6	62.8	15.7	7.3	0.0	0.1	157.9								
Total	607.8	1,219.8	1,640.4	998.8	475.7	310.7	12.8	5,266.0								
1988 Season, 183 days, Dec 1- May 31																
Maine	339.7	793.9	788.1	243.6	24.6	67.3	12	2,258.4								
Mass.	14.4	225.8	255.0	104.9	8.6	10.9	0.0	619.6								
N.H.	13.0	72.6	53.7	14.9	0.3	0.0	3.1	157.6								
Total	367.1	1,092.3	1,096.8	363.4	33.5	78.2	4.3	3,035.6								
1989 Season, 182 days, Dec 1- May 31																
Maine	353.6	770.5	700.6	246.4	218.7	94.2		2,384.0								
Mass.	26.2	197.5	154.9	104.8	160.9	55.6		699.9								
N.H.	28.5	106.9	77.0	15.4	3.7	0.0		231.5								
Total	408.3	1,074.9	932.5	366.6	383.3	149.8	0.0	3,315.4								
1990 Season, 182 days, Dec 1- May 31																
Maine	512.4	778.4	509.8	638.7	514.1	282.8	0.1	3,236.3								
Mass.	75.6	344.5	184.8	100.2	159.0	110.0	0.8	974.9								
N.H.	111.3	191.7	116.2	30.7	14			451.3								
Total	699.3	1,314.6	810.8	769.6	674.5	392.8	0.9	4,662.5								
1991 Season, 182 days, Dec 1- May 31																
Maine	238.3	509.2	884.1	455.0	251.8	148.2	2.0	2,488.6								
Mass.	90.6	174.7	176.0	131.2	93.3	133.8	15.0	814.6								
N.H.	107.3	104.4	33.8	27.8	7.8	10		282.1								
Total	436.2	788.3	1,093.9	614.0	352.9	283.0	17.0	3,585.3								
1992 Season, 153 days, Dec 15 - May 15																
Maine	181.2	881.0	1,295.0	462.6	163.6	87.2		3,070.6								
Mass.	17.1	148.3	73.3	47.6	2.9		0.1	289.3								
N.H.	33.4	47.0	11.9	6.8	10			100.1								
Total	231.7	1,076.3	1,380.2	517.0	167.5	87.2	0.1	3,460.0								
1993 Season, 138 days, Dec 14 - April 30																
Maine	101.0	369.1	597.1	297.5	127.8			1,492.5								
Mass.	19.6	82.0	81.9	62.3	42.0	5.0		292.8								
N.H.	33.5	85.4	101.8	77.0	59.9			357.6								
Total	154.1	536.5	780.8	436.8	229.7	5.0	0.0	2,142.9								
1994 Season, 122 days, Dec 15 - Apr 15																
Maine	171.5	647.8	972.1	399.6	48.7			2,239.7								
Mass.	27.1	68.0	100.8	38.8	12.8			247.5								
N.H.	117.2	124.3	128.7	49.6	8.2			428.0								
Total	315.8	840.1	1,201.6	488.0	69.7	0.0	0.0	2,915.2								
1995 Season, 128 days, Dec 1- Apr 30, 1 day per week off																
Maine	747.3	1,392.9	1,336.0	912.1	625.4			5,013.7								
Mass.	160.6	154.0	104.1	111.0	139.5		0.9	670.1								
N.H.	210.2	186.8	18.3	158.5	99.0			772.8								
Total	1,118.1	1,733.7	1,558.4	1,181.6	863.9	0.0	0.9	6,456.6								
1996 Season, 152 days, Dec 1- May 31, 1 day per week off																
Maine	1,122.0	1,693.1	3,236.9	795.6	361.5	897.6	0.4	8,107.1								
Mass.	167.9	106.7	190.7	67.2	66.5	60.3	1.3	660.6								
N.H.	189.8	169.5	234.0	81.9	78.8	17.1	0.6	771.7								
Total	1,479.7	1,969.3	3,661.6	944.7	506.8	975.0	2.3	9,539.4								
1997 Season, 156 days, Dec 1- May 27, two 5-day and four 4-day blocks off																
Maine	1,178.0	1,095.8	1,749.3	758.4	766.8	538.2	0.4	6,086.9								
Mass.	90.2	110.4	111.4	49.0	12	0.5	3.7	366.4								
N.H.	185.6	104.1	140.1	108.4	85.8	42.2	0.0	666.2								
Total	1,453.8	1,310.3	2,000.8	915.8	853.8	580.9	4.1	7,119.5								
1998 Season, 105 days, Dec 8- May 22, weekends off except Mar 14-15, Dec 25-31 and Mar 16-31 off.																
Maine	511.1	926.8	1,211.1	401.0	228.7	202.6		3,481.3								
Mass.	49.1	73.3	88.6	14.0	15.3			240.3								
N.H.	89.4	106.9	143.5	54.3	49.0	2.1		445.2								
Total	649.6	1,107.0	1,443.2	469.3	293.0	204.7	0.0	4,166.8								
1999 Season, 90 days, Dec 15 - May 25, weekends, Dec 24 - Jan 3, Jan 27-31, Feb 24-28, Mar 16-31, and Apr 29 - May 2 off.																
Maine	79.9	192.7	599.3	247.9	205.3	248.1		1,573.2								
Mass.	25.0	23.8	16.0	2.5	8.4			75.7								
N.H.	46.5	63.2	52.2	10.0	36.5	8.6		217.0								
Total	151.4	279.7	667.5	260.4	250.2	256.7	0.0	1,865.9								
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off																
Maine		759.9	1,534.4	221.9				2,516.2								
Mass.		25.9	86.0	12.2				124.1								
N.H.		40.6	133.7	40.4				214.7								
Total	0.0	826.4	1,754.0	274.6	0.0	0.0	0.0	2,855.0								

Table C5.2 continued – Landings by season, state, and month.

	Season							
	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Other</u>	<u>Total</u>
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May								
Maine		575.8	432.8	36.6	29.8	0.3		1075.2
Mass.		38.5	9.0	19		0.002		49.4
N.H.		127.9	78.6	conf	conf			206.4
Total	0.0	742.2	520.3	38.4	29.8	0.3	0.0	1331.0
2002 Season, 25 days, Feb 15 - Mar 11								
Maine			306.8	84.8				391.6
Mass.			8.1	conf				8.1
N.H.			38.6	14.4				53.0
Total	0.0	0.0	353.5	99.1	0.0	0.0	0.0	452.7
2003 Season, 38 days, Jan 15 - Feb 27, Fridays off								
Maine		534.7	668.0	0.4			0.6	1203.7
Mass.		12.0	15.7					27.7
N.H.		30.9	82.1					113.0
Total	0.0	577.6	765.8	0.4	0.0	0.0	0.6	1344.4
2004 Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off								
Maine	18	526.2	945.1	446.4	4.7	2.7	0.04	1926.9
Mass.		conf	213	conf				213
N.H.		27.3	94.8	611				732.2
Total	18	553.5	1061.1	507.5	4.7	2.7	0.04	2,131.4
2005 Season, 70 days, Dec 19 - 30, Fri-Sat off, Jan 3 - Mar 25, Sat-Sun off								
Maine	75.0	369.4	903.2	922.6			0.01	2,270.2
Mass.	7.2	8.1	24.9	9.4				49.6
N.H.	17.3	53.5	175.4	44.1				290.3
Total	99.5	431.0	1,103.6	976.0	0.0	0.0	0.01	2,610.1
2006 Season, 140 days, Dec 12 - Apr 30								
Maine	144.1	691.7	896.9	350.8	118.0			2,201.6
Mass.	conf	conf	30.0	conf	conf			30.0
N.H.	3.4	27.9	9.6	50.3	conf			91.1
Total	147.5	719.6	936.5	401.1	118.0	0.0	0.0	2,322.7
2007 Season, 151 days, Dec 1 - Apr 30								
Maine	761.9	1,480.5	1,590.4	481.9	154.2	0.4	0.03	4,469.3
Mass.	conf	conf	conf	conf				27.5
N.H.	52.5	222.6	81.6	26.1	conf			382.9
Total	814.4	1,730.6	1,672.0	508.1	154.2	0.4	0.0	4,879.7
2008 Season, 152 days, Dec 1 - Apr 30								
Maine	408.5	1,053.7	2,020.4	983.8	49.3		0.1	4,515.8
Mass.	conf	conf	15.4	14.5				29.9
N.H.	94.2	123.7	161.6	37.4	conf			416.8
Total	502.6	1,177.4	2,197.3	1,035.7	49.3	0.0	0.1	4,962.4

	Season							
	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Other</u>	<u>Total</u>
2009 Season, 130 days, Dec 1 - May 29								
Maine	134.6	595.9	988.2	560.1	34.9	18	0.2	2,315.7
Mass.& NH	conf	112.9	72.6	conf	conf			185.6
Total	134.6	708.8	1,060.8	560.1	34.9	18	0.2	2,501.2
2010 Season, 156 days, Dec 1 - May 5								
Maine	263.4	1,683.1	2,914.5	515.6	194.3	33.0	0.4	5,604.3
Mass.	conf	16.9	18.2	conf	conf			35.1
N.H.	107.3	152.4	200.0	14.2	27.4	conf		501.4
Total	370.7	1,852.5	3,132.7	529.8	221.7	33.0	0.4	6,440.8
2011 Season, 90 days, Dec 1 - Feb 28								
Maine	722.7	2,572.2	2,274.3	0.5				5,569.7
Mass.	20.8	100.9	74.7					196.4
N.H.	93.1	304.0	234.4					631.46
Total	836.6	2,977.0	2,583.4	0.5	0.0	0.0	0.0	6,397.5
*2012 Season, Trawling Mon,Wed,Fri, Jan 2- Feb 17 (21days); Trapping Feb 1-17 (17 days)								
Maine	0.5	1,130.1	1,080.2	0.5				2,211.4
Mass.		58.4	19.4					77.8
N.H.		119.2	68.6					187.8
Total	0.5	1,307.7	1,168.2	0.5	0.0	0.0	0.0	2,476.9
*2013 Season, Trawling 3 to 7 days/wk, Jan 23 - Apr 12 (54 days); Trapping 6 or 7 days/wk, Feb 5 - Apr 12 (62 days)								
Maine		54.2	167.2	33.6	0.5			255.5
Mass.		4.3	8.9	7.2	conf			20.3
N.H.		14.5	13.5	3.3	conf			31.3
Total	0.0	72.9	189.5	44.1	0.5	0.0	0.0	307.1

conf = Confidential data were included in an adjacent month.
 * Preliminary data

Table C5.3. Distribution of landings (metric tons, mt) in the Maine northern shrimp fishery by season, gear type, and month.
1 mt = 2,205 lbs

	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Other</u>	<u>Season Total</u>	<u>% of total</u>		<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Other</u>	<u>Season Total</u>	<u>% of total</u>	
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off										2008 Season, 152 days, Dec 1- Apr 30										
Trawl		731.1	1,354.8	163.6				2,249.47	89%	Trawl	408.5	989.6	1,680.8	603.4	42.6		0.1	3,724.9	82%	
Trap		28.9	179.6	58.3				266.7	11%	Trap	conf	64.1	339.6	380.4	6.7			790.8	18%	
Total	0.0	759.9	1,534.4	221.9	0.0	0.0	0.0	2,516.2		Total	408.5	1,053.7	2,020.4	983.8	49.3	0.0	0.1	4,515.8		
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May										2009 Season, 180 days, Dec 1- May 29										
Trawl		533.0	360.1	30.9	29.8	0.3		954.0	89%	Trawl	134.3	579.7	780.9	405.4	33.6	18	0.2	1,935.9	84%	
Trap		42.9	72.6	5.7				121.2	11%	Trap	0.4	16.2	207.3	154.7	13			379.8	16%	
Total	0.0	575.8	432.8	36.6	29.8	0.3	0.0	1,075.2		Total	134.6	595.9	988.2	560.1	34.9	18	0.2	2,315.7		
2002 Season, 25 days, Feb 15 - Mar 11										2010 Season, 156 days, Dec 1- May 5										
Trawl			263.6	77.2				340.8	87%	Trawl	263.4	1,488.3	2,091.1	326.3	194.3	33.0	0.4	4,396.7	78%	
Trap			43.2	7.6				50.8	13%	Trap	conf	194.8	823.4	189.3	conf			1,207.6	22%	
Total	0.0	0.0	306.8	84.8	0.0	0.0	0.0	391.6		Total	263.4	1,683.1	2,914.5	515.6	194.3	33.0	0.4	5,604.3		
2003 Season, 38 days, Jan 15 - Feb 27, Fridays off										2011 Season, 90 days, Dec 1- Feb 28										
Trawl		467.2	518.8	0.4			0.6	987.0	82%	Trawl	720.8	2,194.5	1,728.5	0.5				4,644.4	83%	
Trap		67.5	149.2					216.7	18%	Trap	19	377.7	545.8					925.3	17%	
Total	0.0	534.7	668.0	0.4	0.0	0.0	0.6	1,203.7		Total	722.7	2,572.2	2,274.3	0.5	0.0	0.0	0.0	5,569.7		
2004 Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off										*2012 Season, Trawling Mon, Wed, Fri, Jan 2- Feb 17 (21 days); Trapping Feb 1-17 (17 days)										
Trawl	18	514.0	905.5	430.0	4.7	2.7	0.04	1,858.7	96%	Trawl	0.5	1,130.1	887.1	0.5				2,018.3	91%	
Trap		12.2	39.5	16.5				68.1	4%	Trap			193.1					193.1	9%	
Total	18	526.2	945.1	446.4	4.7	2.7	0.04	1,926.9		Total	0.5	1,130.1	1,080.2	0.5	0.0	0.0	0.0	2,211.4		
2005 Season, 70 days, Dec 19 - 30, Fri-Sat off, Jan 3 - Mar 25, Sat-Sun off										*2013 Season, Trawl 2-7 days/wk, Jan 23-Apr 12 (54 days); Trap 6-7 days/wk, Feb 5-Apr 12 (62 days)										
Trawl	75.0	369.4	770.6	663.6			0.01	1,878.5	83%	Trawl		54.2	154.6	314	0.5			240.7	94%	
Trap		conf	132.6	259.0				391.6	17%	Trap			12.5	2.2	conf			14.8	6%	
Total	75.0	369.4	903.2	922.6	0.0	0.0	0.01	2,270.2		Total	0.0	54.2	167.2	33.6	0.5	0.0	0.0	255.5		
2006 Season, 140 days, Dec 12 - Apr 30																				
Trawl	144.1	675.0	733.8	256.9	117.1			1,927.0	88%											
Trap	conf	16.7	163.1	93.9	0.9			274.6	12%											
Total	144.1	691.7	896.9	350.8	118.0	0.0	0.0	2,201.6												
2007 Season, 151 days, Dec 1- Apr 30																				
Trawl	758.2	1,443.3	1,275.6	362.1	143.6	0.4	0.0	3,983.2	89%											
Trap	3.7	37.2	314.7	119.8	10.6			486.1	11%											
Total	761.9	1,480.5	1,590.4	481.9	154.2	0.4	0.0	4,469.3												

conf = Confidential data were included in an adjacent month.
* Preliminary data

Table C5.4. Discards of shrimp in pounds from NEFOP-observed trips by target species and year. Totals include both Northern shrimp and “unknown” shrimp that could not be identified to species by the observer.

Target Species	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
HERRING, ATLANTIC					1.6	200.5	16	54				5.4	90
GROUND FISH, NK	1	15	20	13.7	28.4	18.8	12.7	15	10		25		4.3
HAKE, SILVER	3			1	0.2	1.5	31.5	18		0.1	2.4		2
SHRIMP, PANDALID					0.6		50		0.1		1		
COD				1	4.2	6.3	3.3	0.9		2.2	2	10.7	3
SHRIMP, NK								30					
HADDOCK						1.2	12			0.2			
FLOUNDER, NK		1		0.1	0.1	10			2.1				
FLOUNDER, YELLOWTAIL						2		5.6	3.1				
FLOUNDER, WINTER						8		1.4	0.5				
MONKFISH				2						6	0.7		
FLOUNDER, WITCH				0.5	2.5	2		0.1		2.2		0.1	0.5
POLLOCK					0.2	0.1		0.2	0.1	0.8		5.4	
FLOUNDER, AM. PLAICE				0.1						2	0.2		
FISH, NK													1
HERRING, NK					0.5								
LOBSTER, AMERICAN					0.2								
QUAHOG, OCEAN						0.1							
HAKE, WHITE										0.1			
HAGFISH, ATLANTIC									0.1				
Grand Total	4	16	20	18.4	38.5	250.5	125.5	125.2	16	13.6	31.3	21.6	100.8

Table C5.5. Estimated numbers of vessels in the Gulf of Maine northern shrimp fishery by fishing season and state.

<u>Season</u>	<u>Maine</u>		<u>Total</u>	<u>Massachusetts</u>	<u>New Hampshire</u>	<u>Total</u>
	<u>Trawl</u>	<u>Trap</u>				
1980			15-20	15-20		30-40
1981			~75	~20-25		~100
1982			>75	~20-25		>100
1983			~164	~25	~5-8	~197
1984			239	43	6	288
1985			~231	~40	~17	~300
1986						~300
1987			289	39	17	345
1988			~290	~70	~30	~390
1989			~230	~50	~30	~310
1990			~220			~250
1991			~200	~30	~20	~250
1992			~259	~50	16	~325
1993			192	52	29	273
1994			178	40	29	247
1995						
1996			275	43	29	347
1997			238	32	41	311
1998			195	33	32	260
1999			181	27	30	238
2000	207	68	265	17	27	304
2001	174	60	234	19	27	275
2002	117	52	168	7	23	198
2003	142	49	191	12	22	222
2004	114	56	170	7	15	192
2005	102	64	166	9	22	197
2006	68	62	129	4	11	144
2007	97	84	179	3	15	196
2008	121	94	215	4	15	234
2009	80	78	158	12 (MA and NH combined)		170
2010	124	112	236	6	14	256
2011	172	143	311	12	19	342
*2012	163	131	293	14	17	324
*2013	122	46	168	16	14	198

note that some boats reported both trapping and trawling

* preliminary

Table C5.6. The total weight of the northern shrimp catches that were sampled (mt), the number of samples and interviews collected, the total weight of the samples (kg), and the numbers of northern shrimp (*P. borealis*) measured, by fishing season, for the Gulf of Maine northern shrimp port sampling project. 1kg=2.205 lbs. 1 mt = 2,205 lbs.

<u>Fishing Season</u>	<u>Catches sampled (mt)</u>	<u>Number of samples</u>	<u>Sample wts (kg)</u>	<u>Numbers measured</u>
1985	42.09	66	65.3	6,032
1986	37.52	72	76.3	6,415
1987	33.83	81	67.2	5,699
1988	41.33	94	79.4	6,393
1989	60.47	106	102.6	8,885
1990	56.24	98	86.5	8,132
1991	120.93	215	174.7	15,058
1992	73.58	162	128.5	10,225
1993	61.42	160	147.1	12,852
1994	78.17	165	132.1	12,221
1995	98.66	131	143.8	14,270
1996	243.70	243	293.8	28,320
1997	251.69	323	351.2	35,033
1998	150.73	227	249.5	23,916
1999	130.60	222	196.1	22,529
2000	112.82	130	121.2	11,458
2001	53.54	146	140.5	14,714
2002	31.28	58	49.4	5,243
2003	63.57	128	121.5	11,805
2004	114.99	113	107.1	10,972
2005	166.22	214	209.9	19,539
2006	171.49	162	176.5	16,218
2007	301.78	207	222.4	25,409
2008	237.43	243	258.6	26,181
2009	130.49	152	152.2	12,804
2010	324.59	266	296.9	25,393
2011	272.52	286	328.1	30,590
2012	278.10	311	370.0	39,748
2013	39.01	115	124.2	11,370

Table C5.7. Distribution of fishing effort (number of trips) in the Gulf of Maine northern shrimp fishery by season, state, and month.

	Season								Total	Season								Total
	Dec	Jan	Feb	Mar	Apr	May	Other	Dec		Jan	Feb	Mar	Apr	May	Other			
1985 Season, 166 days, Dec 1- May 15																		
Maine	552	1438	1979	1,198	260	35		5,462	Maine	249	1,102	1,777	1,032	227		4,387		
Mass.	127	269	224	231	92	73		1,016	Mass.	60	200	250	185	72		767		
N.H.	18	135	78	26	22			379	N.H.	76	246	275	256	151		1,004		
Total	797	1,842	2,281	1,455	374	108	0	6,857	Total	385	1,548	2,302	1,473	450	0	0	6,158	
1986 Season, 183 days, Dec 1- May 31																		
Maine	590	1,309	2,798	831	224	133	68	5,953	Maine	265	1,340	1,889	1,065	122		4,681		
Mass.	128	235	225	320	194	133	159	1,394	Mass.	58	152	147	83	15		455		
N.H.	156	163	165	51	3		17	555	N.H.	169	228	266	173	18		854		
Total	874	1,707	3,188	1,202	421	266	244	7,902	Total	492	1,720	2,302	1,321	155	0	0	5,990	
1987 Season, 182 days, Dec 1- May 31																		
Maine	993	2,373	3,073	2,241	617	340	16	9,653	Maine	879	2,341	2,641	1,337	694		7,892		
Mass.	325	354	414	426	283	317	164	2,283	Mass.	145	385	275	157	109		1,071		
N.H.	67	164	175	95	28		32	561	N.H.	189	331	279	359	344		1,502		
Total	1,385	2,891	3,662	2,762	928	657	212	12,497	Total	1,213	3,057	3,195	1,853	1,147	0	0	10,465	
1988 Season, 183 days, Dec 1- May 31																		
Maine	972	2,183	2,720	1,231	193	122		7,421	Maine	1,341	2,030	3,190	1,461	444	457		8,923	
Mass.	28	326	426	315	26	57		1,178	Mass.	299	248	325	269	106	126		1,373	
N.H.	72	231	236	99	3			641	N.H.	331	311	389	248	155	61		1,495	
Total	1,072	2,740	3,382	1,645	222	179	0	9,240	Total	1,971	2,589	3,904	1,978	705	644	0	11,791	
1989 Season, 182 days, Dec 1- May 31																		
Maine	958	2,479	2,332	936	249	84		7,038	Maine	1,674	1,753	2,737	1,178	793	530		8,665	
Mass.	103	479	402	254	297	102		1,637	Mass.	184	226	245	114	7	1		777	
N.H.	120	369	312	69	16			886	N.H.	277	245	301	218	189	62		1,292	
Total	1,181	3,327	3,046	1,259	562	186	0	9,561	Total	2,135	2,224	3,283	1,510	989	593	0	10,734	
1990 Season, 182 days, Dec 1- May 31																		
Maine	1,036	1,710	1,529	1,986	897	238		7,396	Maine	852	1,548	1,653	725	346	189		5,313	
Mass.	147	459	273	202	175	118		1,374	Mass.	94	200	148	70	3	1		515	
N.H.	178	363	284	157	6			988	N.H.	141	216	182	134	83	22		778	
Total	1,361	2,532	2,086	2,345	1,078	356	0	9,758	Total	1,087	1,964	1,983	929	432	212	0	6,606	
1991 Season, 182 days, Dec 1- May 31																		
Maine	568	1,286	2,070	1,050	438	139		5,551	Maine	190	556	1,125	553	324	172		2,920	
Mass.	264	416	401	231	154	147		1,613	Mass.	39	57	71	9	40			216	
N.H.	279	285	135	82	22	1		804	N.H.	82	192	213	44	123	21		675	
Total	1,111	1,987	2,606	1,363	614	287	0	7,968	Total	311	805	1,409	606	487	193	0	3,811	
1992 Season, 153 days, Dec 15- May 15																		
Maine	411	1,966	2,700	1,222	318	141		6,758	Maine		897	2,494	647				4,038	
Mass.	59	337	145	101	41			683	Mass.		33	117	32	1			183	
N.H.	96	153	76	29	3			357	N.H.		45	201	87				333	
Total	566	2,456	2,921	1,352	362	141	0	7,798	Total	0	975	2,812	766	1	0	0	4,554	
1993 Season, 138 days, Dec 14- April 30																		
Maine	249	1,102	1,777	1,032	227			4,387	Maine	249	1,102	1,777	1,032	227			4,387	
Mass.	60	200	250	185	72			767	Mass.	60	200	250	185	72			767	
N.H.	76	246	275	256	151			1,004	N.H.	76	246	275	256	151			1,004	
Total	385	1,548	2,302	1,473	450	0	0	6,158	Total	385	1,548	2,302	1,473	450	0	0	6,158	
1994 Season, 122 days, Dec 15- Apr 15																		
Maine	265	1,340	1,889	1,065	122			4,681	Maine	265	1,340	1,889	1,065	122			4,681	
Mass.	58	152	147	83	15			455	Mass.	58	152	147	83	15			455	
N.H.	169	228	266	173	18			854	N.H.	169	228	266	173	18			854	
Total	492	1,720	2,302	1,321	155	0	0	5,990	Total	492	1,720	2,302	1,321	155	0	0	5,990	
1995 Season, 128 days, Dec 1- Apr 30, 1 day per week off																		
Maine	879	2,341	2,641	1,337	694			7,892	Maine	879	2,341	2,641	1,337	694			7,892	
Mass.	145	385	275	157	109			1,071	Mass.	145	385	275	157	109			1,071	
N.H.	189	331	279	359	344			1,502	N.H.	189	331	279	359	344			1,502	
Total	1,213	3,057	3,195	1,853	1,147	0	0	10,465	Total	1,213	3,057	3,195	1,853	1,147	0	0	10,465	
1996 Season, 152 days, Dec 1- May 31, 1 day per week off																		
Maine	1,341	2,030	3,190	1,461	444	457		8,923	Maine	1,341	2,030	3,190	1,461	444	457		8,923	
Mass.	299	248	325	269	106	126		1,373	Mass.	299	248	325	269	106	126		1,373	
N.H.	331	311	389	248	155	61		1,495	N.H.	331	311	389	248	155	61		1,495	
Total	1,971	2,589	3,904	1,978	705	644	0	11,791	Total	1,971	2,589	3,904	1,978	705	644	0	11,791	
1997 Season, 156 days, Dec 1- May 31, two 5-day and four 4-day blocks off																		
Maine	1,674	1,753	2,737	1,178	793	530		8,665	Maine	1,674	1,753	2,737	1,178	793	530		8,665	
Mass.	184	226	245	114	7	1		777	Mass.	184	226	245	114	7	1		777	
N.H.	277	245	301	218	189	62		1,292	N.H.	277	245	301	218	189	62		1,292	
Total	2,135	2,224	3,283	1,510	989	593	0	10,734	Total	2,135	2,224	3,283	1,510	989	593	0	10,734	
1998 Season, 152 days, Dec 1- May 31, 1 day per week off																		
Maine	852	1,548	1,653	725	346	189		5,313	Maine	852	1,548	1,653	725	346	189		5,313	
Mass.	94	200	148	70	3	1		515	Mass.	94	200	148	70	3	1		515	
N.H.	141	216	182	134	83	22		778	N.H.	141	216	182	134	83	22		778	
Total	1,087	1,964	1,983	929	432	212	0	6,606	Total	1,087	1,964	1,983	929	432	212	0	6,606	
1999 Season, 152 days, Dec 1- May 31, 1 day per week off																		
Maine	190	556	1,125	553	324	172		2,920	Maine	190	556	1,125	553	324	172		2,920	
Mass.	39	57	71	9	40			216	Mass.	39	57	71	9	40			216	
N.H.	82	192	213	44	123	21		675	N.H.	82	192	213	44	123	21		675	
Total	311	805	1,409	606	487	193	0	3,811	Total	311	805	1,409	606	487	193	0	3,811	
2000 Season, 51 days, Jan 17- Mar 15, Sundays off																		
Maine		897	2,494	647				4,038	Maine		897	2,494	647				4,038	
Mass.		33	117	32	1			183	Mass.		33	117	32	1			183	
N.H.		45	201	87				333	N.H.		45	201	87				333	
Total	0	975	2,812	766	1	0	0	4,554	Total	0	975	2,812	766	1	0	0	4,554	

Table C5.7 continued – Trips by season, state, and month.

	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Other</u>	<u>Season Total</u>
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 15 off, experimental offshore fishery in May								
Maine		1,683	1,551	177	43	6		3,460
Mass.		111	48	10		1		170
N.H.		303	200	conf	conf			503
Total	0	2,097	1,799	187	43	7	0	4,133
2002 Season, 25 days, Feb 15 - Mar 11								
Maine			799	299				1,098
Mass.			31	conf				31
N.H.			119	56				175
Total	0	0	949	355	0	0	0	1,304
2003 Season, 38 days, Jan 15 - Feb 27, Fridays off								
Maine		114	1,582	1			2	2,699
Mass.		41	50					91
N.H.		81	151					232
Total	0	1,236	1,783	1	0	0	2	3,022
2004 Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off								
Maine	7	647	1,197	482	13	14	6	2,366
Mass.		conf	56	conf				56
N.H.		46	147	66				259
Total	7	693	1,400	548	13	14	6	2,681
2005 Season, 70 days, Dec 19 - 30, Fri-Sat off, Jan 3 - Mar 25, Sat-Sun off								
Maine	140	667	1,305	1,255	0	0	1	3,368
Mass.	15	18	49	23				105
N.H.	24	76	216	77				393
Total	179	761	1,570	1,355	0	0	1	3,866
2006 Season, 140 days, Dec 12 - Apr 30								
Maine	148	585	947	530	101			2,311
Mass.	conf	conf	58	conf	conf			58
N.H.	5	23	19	62	conf			109
Total	153	608	1,024	592	101	0	0	2,478
2007 Season, 151 days, Dec 1 - Apr 30								
Maine	437	1,102	1,514	669	136	1	3	3,862
Mass.	conf	45	conf	conf				45
N.H.	26	115	71	44	conf			256
Total	463	1,262	1,585	713	136	1	3	4,163
2008 Season, 152 days, Dec 1 - Apr 30								
Maine	418	1,291	2,076	1,286	102	0	9	5,182
Mass.	conf	conf	25	13				38
N.H.	63	141	125	38	conf			367
Total	481	1,432	2,226	1,337	102	0	9	5,587

	<u>Dec</u>	<u>Jan</u>	<u>Feb</u>	<u>Mar</u>	<u>Apr</u>	<u>May</u>	<u>Other</u>	<u>Season Total</u>
2009 Season, 180 days, Dec 1 - May 29								
Maine	134	785	1,122	739	47	5	1	2,833
Mass. & NH	conf	107	62	conf	conf			169
Total	134	892	1,184	739	47	5	1	3,002
2010 Season, 156 days, Dec 1 - May 5								
Maine	241	1,561	2,593	911	185	29	1	5,521
Mass.	conf	26	23	conf	conf			49
N.H.	54	127	151	21	56	conf		409
Total	295	1,714	2,767	932	241	29	1	5,979
2011 Season, 90 days, Dec 1 - Feb 28								
Maine	599	2,880	2,875	1				6,355
Mass.	28	92	73	0	0			193
N.H.	108	241	198					547
Total	735	3,213	3,146	1	0	0	0	7,095
*2012 Season, Trawling Mon, Wed, Fri, Jan 2 - Feb 17 (21 days); Trapping Feb 1-17 (17 days)								
Maine	1	1,302	2,000	1				3,304
Mass.		74	42					116
N.H.		129	99					228
Total	1	1,505	2,141	1	0	0	0	3,648
*2013 Season, Trawl 2-7 days/wk, Jan 23-Apr 12 (54 days); Trap 6-7 days/wk, Feb 5-Apr 12 (62 days)								
Maine		166	790	196	7			1,159
Mass.		8	30	30	conf			68
N.H.		21	59	15	conf			95
Total	0	195	879	241	7	0	0	1,322

conf = Confidential data were included in an adjacent month.
 * Preliminary data

Table C5.8. Distribution of fishing trips in the Maine northern shrimp fishery by season, gear type, and month.

	Season										Season									
	Dec	Jan	Feb	Mar	Apr	May	Other	Total	%		Dec	Jan	Feb	Mar	Apr	May	Other	Total	%	
2000																				
Trawl		818	2,073	462				3,353	97%		Trawl	414	1,062	1,393	661	51	0	9	3,590	69%
Trap		79	421	185				685	20%		Trap	conf	233	683	625	51			1,592	31%
Total	0	897	2,494	647	0	0	0	4,038			Total	414	1,295	2,076	1,286	102	0	9	5,182	
2001																				
Trawl		1,500	1,214	112	43	6		2,875	83%		Trawl	130	705	673	381	32	5	1	1,927	68%
Trap		183	337	65				585	17%		Trap	4	80	449	358	15			906	32%
Total	0	1,683	1,551	177	43	6	0	3,460			Total	134	785	1,122	739	47	5	1	2,833	
2002																				
Trawl			595	236				831	76%		Trawl	238	1,230	1,512	447	157	29	1	3,614	65%
Trap			204	63				267	24%		Trap	conf	334	1,081	492	conf			1,907	35%
Total	0	0	799	299	0	0	0	1,098			Total	238	1,564	2,593	939	157	29	1	5,521	
2003																				
Trawl		850	1,081	1			2	1,934	72%		Trawl	577	2,068	1,692	1				4,338	68%
Trap		264	501					765	28%		Trap	22	812	1,183					2,017	32%
Total	0	1,114	1,582	1	0	0	2	2,699			Total	599	2,880	2,875	1	0	0	0	6,355	
2004																				
Trawl	7	566	965	382	13	14	6	1,953	83%		Trawl	1	1,302	1,032	1				2,336	71%
Trap		81	232	100				413	17%		Trap			968					968	29%
Total	7	647	1,197	482	13	14	6	2,366			Total	1	1,302	2,000	1	0	0	0	3,304	
2005																				
Trawl	140	647	953	778			1	2,519	75%		Trawl		166	621	164	conf			951	82%
Trap		conf	372	477				849	25%		Trap			169	39	conf			208	18%
Total	140	647	1,325	1,255	0	0	1	3,368			Total	0	166	790	203	0	0	0	1,159	
2006																				
Trawl	145	490	563	273	88			1,559	67%											
Trap	conf	98	384	257	13			752	33%											
Total	145	588	947	530	101	0	0	2,311												
2007																				
Trawl	425	977	921	349	119	1	3	2,795	72%											
Trap	12	125	593	320	17			1,067	28%											
Total	437	1,102	1,514	669	136	1	3	3,862												

conf = Confidential data were included in an adjacent month.
 * Preliminary data

Table C5.9. Gulf of Maine northern shrimp trawl catch rates by season. Mean CPUE in lbs/hour towed is from Maine trawler port sampling. Mean catch in lbs/trip is from NMFS weighout and logbook data for all catches for all states. Trawl lbs/trip is trawler only catches per trawl trip for all states. 1 lb=0.45 kg.

Season	Maine pounds per hour towing			Pounds/trip	Trawl lbs/trip
	<u>Inshore</u> (<55F)	<u>Offshore</u> (>55F)	<u>Combined</u>		
1991	94	152	140	992	
1992	132	93	117	978	
1993	82	129	92	767	
1994	139	149	141	1,073	
1995	172	205	193	1,360	
1996	340	203	251	1,784	
1997	206	192	194	1,462	
1998	158	151	154	1,391	
1999	148	147	147	1,079	
2000	279	224	272	1,382	1,475
2001	100	135	109	710	752
2002	223	91	194	765	854
2003	174	215	182	981	1,102
2004	361	310	351	1,753	2,006
2005	235	212	228	1,488	1,621
2006	572	345	499	2,066	2,616
2007	531	477	507	2,584	3,129
2008	350	327	343	1,958	2,302
2009	400	315	370	1,837	2,231
2010	424	354	401	2,264	2,671
2011	334	435	347	1,988	2,376
*2012	407	313	399	1,497	1,879
*2013	118	78	110	512	579

Table C5.10 Estimated numbers of northern shrimp in Gulf of Maine landings, by season and carapace length (mm).
Mixed fleet (all gears), 1985-1999.

Fishing Season	Total Catch (Millions)	Catch (Millions) at Size (mm)																								
		<=10.0	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22
1985	355.57	1.06	0.50	0.31	0.19	0.33	0.35	0.81	0.16	0.31	0.11	0.19	0.49	0.80	1.09	1.33	1.19	1.26	1.96	2.11	4.60	8.22	7.47	8.21	15.28	19.44
1986	369.32	0.06	0.07	0.01	0.12	1.20	0.60	1.41	1.64	3.07	1.09	0.89	1.19	1.17	1.88	2.45	1.92	3.16	2.90	3.88	5.10	5.69	4.97	3.30	2.63	3.17
1987	424.41	0.17	0.05	0.68	0.17	1.08	0.96	2.70	0.98	1.23	0.56	1.35	1.04	1.33	2.21	3.51	6.71	3.67	4.95	4.35	5.36	4.04	4.49	6.42	8.22	8.94
1988	220.30	0.85	0.12	0.18	0.02	0.24	0.22	0.41	0.10	0.23	0.29	0.57	0.24	0.73	1.24	2.36	1.39	1.53	1.22	0.81	0.86	1.42	1.88	2.81	3.17	3.92
1989	295.73	0.06	0.01	0.05	0.04	0.28	0.18	0.04	0.20	0.05	0.04	0.14	0.37	0.73	1.20	3.20	6.75	7.94	8.89	7.83	7.56	7.36	7.88	7.49	5.78	6.46
1990	437.17	0.07	0.02	0.05	0.06	0.10	0.00	0.09	0.05	0.30	0.18	0.49	1.18	2.75	2.70	6.65	8.92	12.49	10.40	17.34	18.84	15.90	10.30	14.85	13.00	18.95
1991	334.78	0.62	0.55	0.76	0.51	0.85	1.08	2.68	1.79	2.32	1.69	1.18	0.52	1.14	1.39	3.75	4.70	6.59	7.50	7.49	8.79	8.11	6.73	5.88	6.85	9.84
1992	267.74	1.21	1.10	0.70	0.74	0.20	0.50	0.52	0.16	0.09	0.51	0.45	0.77	1.07	2.86	3.35	4.49	6.19	5.34	3.24	3.85	3.17	1.83	1.74	1.21	2.06
1993	186.69	0.75	0.44	0.70	1.05	1.32	1.11	1.16	1.19	0.45	0.23	0.26	0.29	0.66	0.94	2.12	2.85	5.02	4.12	5.46	3.67	4.20	3.11	3.83	4.15	5.19
1994	263.22	1.12	0.40	0.57	0.69	0.37	0.29	0.38	0.47	0.32	0.88	2.63	3.17	6.27	7.40	7.27	7.34	7.93	6.77	4.84	4.23	3.23	2.46	2.66	5.20	5.91
1995	627.47	2.16	0.67	0.90	1.40	1.20	0.98	1.13	1.22	1.13	1.30	3.11	4.34	7.53	7.06	12.42	10.57	14.04	12.43	10.46	10.01	12.24	11.78	20.04	17.03	23.95
1996	865.44	0.31	0.48	0.46	0.32	0.78	0.97	1.47	1.32	1.77	2.31	2.63	2.06	5.37	4.05	5.79	6.08	6.90	7.03	7.65	9.72	12.45	13.27	14.31	15.22	17.21
1997	716.34	6.02	3.76	3.83	4.07	3.73	3.76	3.61	3.22	1.65	1.98	2.62	3.55	5.92	8.01	10.51	15.46	17.14	16.84	16.89	17.62	17.91	15.40	16.87	17.93	21.97
1998	361.46	1.42	0.60	0.93	0.66	0.73	0.61	1.13	1.75	2.46	2.99	4.35	4.95	6.22	5.42	6.78	5.97	5.77	6.19	5.03	4.20	3.58	3.38	3.96	3.91	5.72
1999	207.17	0.30	0.41	0.47	0.64	0.70	0.77	0.58	0.48	0.48	0.77	1.02	1.34	2.74	3.20	3.49	4.14	4.03	3.75	4.90	5.90	7.49	7.71	9.06	9.14	10.81
		<u>22.5</u>	<u>23</u>	<u>23.5</u>	<u>24</u>	<u>24.5</u>	<u>25</u>	<u>25.5</u>	<u>26</u>	<u>26.5</u>	<u>27</u>	<u>27.5</u>	<u>28</u>	<u>28.5</u>	<u>29</u>	<u>29.5</u>	<u>30</u>	<u>30.5</u>	<u>31</u>	<u>31.5</u>	<u>32</u>	<u>32.5</u>	<u>33</u>	<u>33.5</u>	<u>34</u>	
1985		18.39	24.55	26.15	30.63	25.06	25.46	27.16	28.40	23.82	19.35	11.27	5.73	5.70	2.53	1.98	1.05	0.25	0.25	0.02	0.04	0.00	0.00	0.00	0.00	0.00
1986		2.87	4.42	7.45	14.28	28.10	36.89	50.83	54.70	39.62	29.37	12.49	13.97	9.34	5.88	3.37	1.72	0.19	0.15	0.06	0.05	0.01	0.00	0.00	0.00	0.00
1987		10.77	8.56	10.15	9.06	9.98	19.40	21.60	41.88	49.36	59.53	46.37	30.99	14.11	8.35	4.76	3.61	0.44	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1988		2.52	4.86	4.16	6.33	9.83	15.24	12.08	18.57	18.23	27.83	21.32	20.50	15.63	9.44	4.82	1.47	0.51	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1989		6.24	8.13	7.20	8.15	7.66	11.60	14.26	24.58	23.86	27.81	23.42	20.62	12.70	7.87	6.10	2.85	1.08	0.56	0.29	0.16	0.02	0.00	0.00	0.00	0.00
1990		22.41	24.84	21.56	21.79	26.93	24.80	26.30	26.15	23.65	19.59	14.00	11.63	7.11	5.50	2.85	0.94	0.82	0.47	0.07	0.10	0.00	0.00	0.00	0.00	0.00
1991		10.11	6.76	7.55	9.07	13.23	22.91	32.55	38.71	34.47	27.32	14.93	9.03	5.46	4.42	2.57	1.33	0.41	0.37	0.23	0.01	0.00	0.07	0.00	0.00	0.00
1992		2.37	2.79	2.72	3.73	5.20	8.93	12.65	15.28	33.83	42.86	40.24	27.24	11.59	7.33	2.08	1.01	0.35	0.14	0.02	0.02	0.00	0.00	0.00	0.00	0.00
1993		7.12	9.16	8.93	8.54	8.71	9.67	10.57	11.12	9.85	11.94	9.96	9.95	7.85	4.71	2.67	1.06	0.32	0.12	0.17	0.00	0.00	0.00	0.00	0.00	0.00
1994		8.75	10.94	10.50	14.89	19.10	22.41	20.85	19.82	15.02	9.78	7.34	6.12	4.95	4.14	2.75	1.82	0.91	0.29	0.06	0.00	0.00	0.00	0.00	0.00	0.00
1995		35.07	35.80	40.87	33.68	38.11	36.39	36.51	39.01	36.65	34.80	24.73	18.38	9.95	8.31	4.03	2.56	1.65	1.00	0.49	0.33	0.01	0.04	0.00	0.00	0.00
1996		20.75	32.62	36.10	50.97	73.33	98.40	106.27	92.96	77.93	54.61	29.52	19.86	11.46	8.30	6.26	3.21	1.54	0.46	0.75	0.16	0.01	0.00	0.03	0.00	0.00
1997		19.26	20.26	16.88	20.60	33.13	43.73	54.08	52.89	55.27	47.60	39.38	30.86	18.19	12.35	5.65	2.99	1.99	0.53	0.27	0.13	0.01	0.01	0.01	0.01	0.00
1998		6.66	8.65	12.48	15.19	17.79	25.57	30.10	32.41	31.39	23.50	22.08	18.82	11.66	8.29	4.34	2.27	0.92	0.37	0.19	0.03	0.03	0.04	0.00	0.00	0.00
1999		10.81	11.66	12.29	11.71	11.23	11.50	11.12	10.32	7.86	7.01	4.89	3.95	2.96	2.20	1.65	0.92	0.39	0.26	0.10	0.01	0.01	0.00	0.00	0.00	0.00

Table C5.11 Estimated numbers of northern shrimp in Gulf of Maine landings, by season and carapace length (mm).
Trawl fleet, 2000-2013.

Fishing Season	Total Catch (Millions)	Catch (Millions) at Size (mm)																								
		<u><=10.0</u>	<u>10.5</u>	<u>11</u>	<u>11.5</u>	<u>12</u>	<u>12.5</u>	<u>13</u>	<u>13.5</u>	<u>14</u>	<u>14.5</u>	<u>15</u>	<u>15.5</u>	<u>16</u>	<u>16.5</u>	<u>17</u>	<u>17.5</u>	<u>18</u>	<u>18.5</u>	<u>19</u>	<u>19.5</u>	<u>20</u>	<u>20.5</u>	<u>21</u>	<u>21.5</u>	<u>22</u>
2000	240.38	2.81	2.01	3.05	2.91	2.52	2.23	1.36	0.78	0.79	0.26	0.13	0.15	0.09	0.30	0.67	0.95	1.61	2.01	1.79	1.35	1.20	1.96	3.39	5.69	
2001	132.90	0.13	0.01	0.05	0.08	0.04	0.03	0.14	0.29	0.31	0.94	1.23	2.92	5.08	6.40	6.85	6.25	6.05	4.02	3.08	1.96	1.41	0.92	1.32	1.91	2.69
2002	42.12	0.02	0.06	0.16	0.16	0.31	0.26	0.50	0.32	0.22	0.17	0.13	0.04	0.06	0.03	0.05	0.09	0.09	0.15	0.15	0.19	0.27	0.64	1.49	2.90	3.33
2003	110.66	0.01	0.00	0.01	0.01	0.05	0.01	0.04	0.06	0.24	0.17	0.73	1.08	2.70	3.11	3.81	3.06	2.83	2.29	3.12	2.76	1.90	1.76	1.36	0.95	0.72
2004	214.58	0.38	0.39	0.25	0.16	0.18	0.01	0.04	0.03	0.08	0.11	0.04	0.12	0.14	0.25	0.17	0.37	0.58	0.84	1.10	1.53	2.68	4.29	8.14	15.58	23.62
2005	208.30	2.52	0.79	0.98	0.82	0.53	0.34	0.14	0.13	0.10	0.43	1.07	2.00	3.32	4.25	4.39	4.81	3.34	2.08	1.29	0.73	0.62	0.55	0.64	0.80	1.91
2006	182.76	0.15	0.01	0.02	0.02	0.02	0.03	0.06	0.05	0.11	0.27	1.01	1.82	3.23	3.97	4.06	3.75	3.20	2.08	1.22	0.91	0.81	1.26	1.94	3.04	4.22
2007	501.10	0.08	0.08	0.02	0.17	0.17	0.23	0.51	1.69	2.32	4.53	6.27	5.40	6.19	4.28	3.06	3.79	5.66	7.98	11.94	15.62	16.56	14.22	13.63	15.52	19.59
2008	417.54	1.11	0.87	0.94	1.20	1.39	0.98	0.58	0.38	0.34	0.42	0.28	0.76	0.94	1.31	1.51	1.76	2.26	2.62	2.95	3.46	4.36	5.11	6.49	10.27	16.80
2009	192.33	0.62	0.30	0.42	0.45	0.15	0.26	0.12	0.18	0.06	0.03	0.06	0.27	0.84	2.13	2.02	2.94	2.77	2.20	1.81	1.53	0.95	0.58	0.67	1.12	1.76
2010	425.34	2.10	0.57	0.70	0.58	0.40	0.44	0.29	0.35	0.44	1.24	2.34	4.26	5.85	4.98	6.08	4.37	4.51	3.78	3.52	2.94	3.57	3.76	4.01	5.12	5.78
2011	529.15	0.90	0.69	0.55	0.54	0.64	0.63	0.86	0.76	1.38	3.09	6.72	9.51	12.19	14.38	10.84	7.71	4.81	2.38	2.28	3.95	5.95	8.39	10.65	9.37	9.77
2012	246.98	0.26	0.09	0.12	0.11	0.07	0.10	0.06	0.11	0.23	0.32	0.79	1.00	1.38	1.59	1.19	1.17	1.51	2.37	2.61	2.58	2.68	3.15	4.78	6.35	10.08
2013	26.41	0.01	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.05	0.05	0.06	0.08	0.08	0.07	0.05	0.05	0.04	0.05	0.08	0.09	0.07	0.18	0.34	0.56
		<u>22.5</u>	<u>23</u>	<u>23.5</u>	<u>24</u>	<u>24.5</u>	<u>25</u>	<u>25.5</u>	<u>26</u>	<u>26.5</u>	<u>27</u>	<u>27.5</u>	<u>28</u>	<u>28.5</u>	<u>29</u>	<u>29.5</u>	<u>30</u>	<u>31</u>	<u>31</u>	<u>31.5</u>	<u>32</u>	<u>32.5</u>	<u>33</u>	<u>33.5</u>	<u>34</u>	
2000		8.63	10.19	11.48	16.77	23.25	27.96	28.39	25.33	14.47	11.80	8.49	4.86	3.27	2.13	1.64	0.72	0.41	0.27	0.12	0.01	0.00	0.00	0.00	0.00	
2001		3.18	4.30	5.23	6.54	8.75	9.18	10.83	9.61	8.28	5.57	3.19	2.04	1.08	0.50	0.36	0.07	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.00	
2002		4.71	4.50	4.16	2.93	2.66	2.28	1.91	1.91	1.70	1.41	1.05	0.54	0.37	0.13	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2003		0.69	1.53	3.85	8.05	12.83	14.89	13.27	10.20	5.10	2.98	2.03	1.13	0.54	0.46	0.16	0.10	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	
2004		31.54	34.67	27.14	17.13	9.12	4.40	4.24	5.33	6.23	5.69	3.44	2.06	1.44	0.59	0.25	0.17	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	
2005		3.20	6.19	12.34	20.36	28.19	32.97	27.18	17.20	9.00	4.77	2.92	2.20	1.65	1.05	0.22	0.15	0.09	0.00	0.01	0.03	0.00	0.00	0.00	0.00	
2006		4.83	5.28	4.54	4.18	3.91	5.91	10.79	18.63	26.92	27.06	18.94	9.06	3.62	1.09	0.42	0.23	0.02	0.05	0.04	0.00	0.00	0.00	0.00	0.00	
2007		24.40	29.52	37.34	47.12	53.97	48.23	33.58	17.24	11.40	9.32	9.28	9.59	5.96	3.07	1.14	0.23	0.12	0.00	0.03	0.00	0.00	0.00	0.00	0.00	
2008		28.29	37.28	47.32	52.45	46.52	39.51	36.24	23.62	16.23	8.95	4.88	3.39	2.04	1.00	0.44	0.22	0.06	0.01	0.01	0.00	0.00	0.00	0.00	0.00	
2009		2.60	3.19	3.44	6.77	10.08	17.19	23.00	27.21	26.83	20.85	13.39	6.92	3.60	1.87	0.85	0.17	0.06	0.02	0.07	0.00	0.00	0.00	0.00	0.00	
2010		5.35	7.12	7.78	10.86	14.66	21.29	30.26	45.42	54.14	53.07	45.38	29.49	17.01	7.57	2.81	0.77	0.27	0.06	0.05	0.00	0.00	0.00	0.00	0.00	
2011		10.91	14.12	18.17	27.81	39.88	55.13	63.16	56.32	40.73	25.28	16.73	13.03	8.63	5.21	3.34	1.18	0.37	0.16	0.06	0.00	0.01	0.00	0.00	0.00	
2012		17.76	29.45	37.86	39.43	28.63	18.56	12.00	8.36	5.20	2.89	1.24	0.49	0.24	0.12	0.03	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2013		0.81	1.38	1.87	2.71	3.32	3.42	3.22	2.91	2.17	1.30	0.71	0.31	0.12	0.04	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table C5.12 Estimated numbers of northern shrimp in Gulf of Maine landings, by season and carapace length (mm).
Trap fleet, 2000-2013.

Fishing Season	Total Catch (Millions)	Catch (Millions) at Size (mm)																								
		<u><=10.0</u>	<u>10.5</u>	<u>11</u>	<u>11.5</u>	<u>12</u>	<u>12.5</u>	<u>13</u>	<u>13.5</u>	<u>14</u>	<u>14.5</u>	<u>15</u>	<u>15.5</u>	<u>16</u>	<u>16.5</u>	<u>17</u>	<u>17.5</u>	<u>18</u>	<u>18.5</u>	<u>19</u>	<u>19.5</u>	<u>20</u>	<u>20.5</u>	<u>21</u>	<u>21.5</u>	<u>22</u>
2000	20.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
2001	9.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.06
2002	4.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.08	0.16	0.28	
2003	17.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.15	0.20	0.19	0.15	0.14	0.07	0.05	
2004	6.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.16	0.49	0.62		
2005	32.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.00	0.02	0.00	0.02	0.00	0.01	0.03	0.02	0.05	0.10	
2006	20.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.04	0.00	0.03	0.09		
2007	46.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.11	0.35	0.45	1.00	2.06	
2008	72.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.10	0.12	0.31	0.82	1.62		
2009	28.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03		
2010	88.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.06	0.01	0.00	0.00	0.02	0.02	0.03	0.18	0.36		
2011	75.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.02	0.04	0.05	0.02	0.01	0.06	0.03	0.06	0.12	0.17	0.50	0.72	
2012	19.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.09	0.16	0.28	0.65	
2013	1.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00		
		<u>22.5</u>	<u>23</u>	<u>24</u>	<u>24</u>	<u>24.5</u>	<u>25</u>	<u>25.5</u>	<u>26</u>	<u>26.5</u>	<u>27</u>	<u>27.5</u>	<u>28</u>	<u>29</u>	<u>29</u>	<u>30</u>	<u>30</u>	<u>31</u>	<u>31</u>	<u>32</u>	<u>32</u>	<u>33</u>	<u>33</u>	<u>34</u>	<u>34</u>	
2000		0.37	0.39	0.70	1.49	2.32	3.02	3.22	2.72	2.50	0.76	0.90	0.61	0.62	0.31	0.38	0.36	0.02	0.03	0.06	0.00	0.05	0.00	0.00	0.00	
2001		0.08	0.23	0.39	0.54	0.81	1.14	1.58	1.35	1.33	0.71	0.48	0.31	0.08	0.05	0.05	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2002		0.41	0.62	0.43	0.32	0.21	0.30	0.28	0.23	0.35	0.26	0.30	0.16	0.11	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2003		0.07	0.19	0.68	1.61	2.78	3.22	3.27	1.97	1.12	0.57	0.25	0.34	0.38	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2004		1.35	1.44	0.82	0.74	0.41	0.09	0.11	0.12	0.10	0.10	0.06	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2005		0.49	0.85	1.69	3.12	4.86	5.92	5.67	4.06	1.90	0.90	0.82	0.59	0.29	0.28	0.17	0.03	0.04	0.02	0.03	0.00	0.00	0.00	0.00	0.00	
2006		0.19	0.20	0.39	0.32	0.40	0.71	1.38	2.72	3.77	4.43	3.34	1.59	0.58	0.15	0.10	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	
2007		2.97	3.58	4.02	4.35	5.60	6.13	4.27	2.49	1.62	1.66	2.07	1.61	1.26	0.69	0.17	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2008		2.93	4.96	7.66	9.01	10.46	9.12	7.13	5.70	4.28	3.13	1.98	1.27	0.85	0.53	0.23	0.15	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2009		0.05	0.14	0.18	0.52	1.01	2.05	3.44	5.09	5.59	3.93	2.73	2.03	0.94	0.53	0.27	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2010		0.58	0.68	0.96	1.03	2.07	3.25	5.59	8.30	12.79	15.47	14.92	11.16	6.94	2.94	0.96	0.30	0.30	0.02	0.00	0.00	0.00	0.00	0.00	0.00	
2011		1.48	2.30	2.92	4.00	6.49	11.18	13.09	12.25	7.93	4.69	2.79	2.19	1.16	0.89	0.38	0.11	0.11	0.01	0.00	0.00	0.01	0.00	0.00	0.00	
2012		1.11	2.37	3.31	3.76	3.19	2.06	1.14	0.60	0.45	0.12	0.13	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
2013		0.02	0.06	0.08	0.14	0.16	0.20	0.16	0.16	0.10	0.07	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table C13. Stratified* retransformed mean numbers and weights per tow of northern shrimp collected during *R/V Gloria Michelle* state/federal summer surveys.
1 kg=2.2 lbs.

Year	N Tows	Log _e retransformed				
		Age-1.5 Number	>22 mm** Number	>22 mm Weight (kg)	Total Number	Total Weight (kg)
1984	37	18	316	3.4	1,152	10.5
1985	44	332	1,169	11.5	1,825	17.7
1986	40	358	860	10.0	1,695	19.6
1987	41	342	854	9.5	1,533	15.4
1988	41	828	298	3.4	1,269	12.8
1989	43	276	564	6.1	1,884	17.0
1990	43	142	1,127	12.0	1,623	18.1
1991	43	482	657	8.0	1,256	11.7
1992	45	282	397	4.8	955	9.4
1993	46	757	250	2.8	1,157	9.1
1994	43	368	243	2.7	984	8.7
1995	35	292	628	7.0	1,449	13.3
1996	32	232	358	4.0	776	8.8
1997	40	374	245	2.8	762	7.7
1998	35	134	170	1.9	583	6.3
1999	42	114	174	1.9	398	5.8
2000	35	450	283	3.2	808	6.4
2001	36	18	146	1.5	451	4.3
2002	38	1,164	261	2.9	1,445	9.2
2003	37	11	173	1.7	564	5.5
2004	35	286	519	5.3	887	10.3
2005	46	1,752	871	10.3	3,661	23.4
2006	29	374	2,773	29.9	9,998	66.0
2007	43	28	412	4.1	887	11.5
2008	38	506	995	10.8	1,737	16.8
2009	49	555	702	8.5	1,627	15.4
2010	49	475	413	4.8	1,373	13.9
2011	47	44	316	3.2	830	8.6
2012	49	7	81	0.9	138	2.5
2013	40	1	24	0.3	27	1.0
Mean	41	367	543	6.0	1,458	12.9
Median	41	312	377	4	1154	10
1984-93 Mean	42	382	649	7.1	1,435	14.1
Median	43	337	611	7.0	1,401	14.1

*Based on strata 1, 3, 5, 6, 7 and 8.

**Will be fully recruited to the winter fishery.

Table C5.14. Stratified retransformed mean weights (kg) per tow of northern shrimp collected during the Maine - New Hampshire inshore trawl surveys by year, regions 1-4 (NH to Mt. Desert) and depths 3-4 (> 35 fa or 117 m) only, with number of tows (n) and 80% confidence intervals. 1 kg=2.2 lbs.

	Spring				Fall			
	<u>kg/tow</u>	<u>n</u>	<u>80% CI</u>		<u>kg/tow</u>	<u>n</u>	<u>80% CI</u>	
2003	4.16	40	3.40	5.05	1.91	33	1.35	2.60
2004	3.87	42	3.31	4.51	1.53	38	1.04	2.14
2005	7.81	40	6.60	9.21	3.59	25	2.46	5.10
2006	10.99	46	8.50	14.13	2.06	38	1.43	2.84
2007	10.70	43	7.93	14.33	4.04	45	3.15	5.13
2008	15.42	45	12.72	18.64	3.59	37	2.32	5.36
2009	9.65	45	7.67	12.09	2.73	41	2.27	3.27
2010	15.95	48	12.60	20.12			(samples lost)	
2011	17.86	50	14.88	21.40	4.20	32	3.24	5.38
2012	7.50	50	6.07	9.23	1.89	42	1.53	2.30
*2013	1.69	46	1.09	2.46				

*2013 data are preliminary.

Table C5.15. Stratified mean number and weight (kg) per tow from NEFSC fall surveys. New survey methods began in 2009.

Year	Arithmetic				Re-transformed geometric			
	Mean Weight	CV	Mean number	CV	Mean Weight	CV	Mean number	CV
1984					1.7	18.2	710.1	12.7
1985					1.6	19.1	853.0	12.5
1986	2.5		252.65		2.5	13.6	1318.8	7.8
1987	1.7		149.49		1.4	21.8	370.9	12.6
1988	1.2		197.07		1.1	24.6	603.3	16.6
1989	2.1		259.82		2.0	16.9	1763.2	10.8
1990	1.8		164.36		1.7	16.6	788.9	13.3
1991	1.0		103.84		0.9	15.9	323.7	13.4
1992	0.6		56.33		0.6	22.5	157.2	14.3
1993	1.9		361.99		1.7	19.2	2009.4	13.8
1994	2.3	29.3	297.06	28.8	2.2	21.0	2213.9	12.9
1995	1.6	21.2	162.60	22.2	1.7	14.2	755.1	8.4
1996	1.2	16.5	114.92	16.2	1.1	11.7	257.6	5.7
1997	1.4	32.6	181.71	41.2	1.3	19.7	495.0	11.3
1998	2.3	14.6	330.23	15.3	2.3	9.4	2561.4	6.4
1999	2.4	20.4	334.10	21.8	2.3	13.3	1984.0	8.4
2000	1.4	27.5	235.96	27.3	1.4	19.2	1398.6	12.2
2001	0.6	27.2	96.77	24.6	0.6	22.0	268.0	11.0
2002	1.7	26.4	323.66	28.2	1.7	18.9	1976.8	10.9
2003	1.1	32.6	128.12	30.5	1.0	24.8	345.1	12.0
2004	1.6	41.6	262.27	47.9	1.4	23.5	1062.4	14.1
2005	2.8	24.6	585.03	32.4	2.6	12.4	4253.2	8.9
2006	6.6	20.2	1191.32	20.5	7.5	13.2	45950.6	10.9
2007	4.1	25.3	650.40	29.7	4.1	12.6	4228.2	7.4
2008	3.1	17.5	404.75	22.0	3.4	13.8	3807.6	10.5
2009	7.8	25.8	804.0	26.8	8.0	12.3	8054.1	7.8
2010	5.0	28.4	660.3	29.7	4.6	16.1	8561.0	10.9
2011	5.6	21.6	685.8	22.9	5.8	11	11814.9	8.0
2012	1.2	67.6	118.8	63.9	0.8	32.7	124.5	18.4

Table C6.1. Comparison of various aspects of all the UMaine model runs. Model run B is the base case run, and greyed texts are settings different from those hypothesized in the base run scenario.

TI=Terminal year incomplete; PPI=Predation-scaled time-varying, B = base case

#	Time step	Years covered	# of fishery selectivity	Catch	# of survey	Natural mortality	Growth time blocks	Growth parameters	Weights	Initial values
B	Year	1984-2013	3	Standard	3	U-shaped	2	McInnes	Equal	Guess
1	Year	1984-2013	3	Standard	3	0.25	2	McInnes	Equal	Guess
2	Year	1984-2013	3	Standard	3	0.5	2	McInnes	Equal	Guess
3	Year	1984-2013	3	Standard	3	PPI	2	McInnes	Equal	Guess
4	Year	1984-2013	3	Under 10%	3	U-shaped	2	McInnes	Equal	Guess
5	Year	1984-2013	3	Under 25%	3	U-shaped	2	McInnes	Equal	Guess
6	Year	1984-2013	3	TI	3	U-shaped	2	McInnes	Equal	Guess
7	Year	1984-2013	3	Standard	3	U-shaped	2	McInnes	Survey*5	Guess
8	Year	1984-2013	3	Standard	3	U-shaped	2	McInnes	Survey*0.5	Guess
9	Year	1984-2013	3	Standard	3	U-shaped	1	McInnes	Equal	Guess
10	Year	1984-2013	3	Standard	3	U-shaped	2	Fournier	Equal	Guess
11	Year	1984-2013	4	Standard	3	U-shaped	2	McInnes	Equal	Guess
12	Season	1984-2013	3	Standard	3	U-shaped	2	McInnes	Equal	Guess

Table C6.2. Summary of UMaine model base run configuration for Northern shrimp.

Item	Descriptor	Note
Years covered	1984-2013	All years with survey data
Seasons	1	
Number sexes	2	Female/Non-female
Lengths	10-35 mm	
Length bins	1 mm	
Commercial fleets	3	Mixed gear (1984-1999), Trawl (2000-2013), Trap (2000-2013)
Commercial selectivity at length	Mixed fleet inshore (1984-1999)	Logistic
	Trawl fleet (2000-2013)	Logistic
	Trap fleet (2000-2013)	Logistic
Fishing mortality	Instantaneous rates	
Survey data	NEFSC fall	1984-2008 (length composition data 1991-2008)
	ASMFC summer	1984-2013 with length frequency data for all years
	NEFSC Bigelow	2009-2012 (length composition data 2009-2012)
Survey selectivity at length	NEFSC fall	Logistic
	ASMFC summer	Logistic
	NEFSC Bigelow	Logistic
Natural mortality	Natural mortality rate at length used in the model	U-shaped
Maturity at length	Proportion of female at length	Data from ASMFC summer survey, incorporate a likelihood function to estimated the proportion of female
Spawner-recruit relationship	No functional relationship	Recruitments freely estimated
Recruitment lengths	10-18 mm	
Growth	Growth transition matrix used in the model	K and L_{inf} from McInnes 1986; sd of K and L_{inf} were estimated; Two time blocks were used according to climate condition (cold period: 1984-1999; warm period: 2000-2013)
Initial condition	First-year length composition assumed in the model	ASMFC summer survey length composition
Likelihood weights	All one (1.0)	Used to weight each term in the negative log likelihood

Table C6.3. Population estimates from the UMaine model base run
R=Recruitment; SSB=Spawning stock biomass; Abundance in millions and the unit for biomass is metric ton.

Year	R	SSB	Female biomass	Non-female biomass	Female abundance	Non-female abundance	Exploitation of numbers	Exploitation of biomass	Exploitation of female biomass
1984	1162.66	4573.30	4904.62	6657.34	515.53	2101.60	0.12	0.15	0.36
1985	1323.60	5399.92	5857.45	6593.19	509.59	2014.78	0.14	0.19	0.41
1986	1075.40	5444.76	6011.84	5760.44	468.03	1736.35	0.16	0.24	0.46
1987	929.56	4470.17	5144.31	4832.92	399.38	1477.49	0.21	0.31	0.60
1988	2167.14	3001.92	3283.76	6414.14	265.10	2622.16	0.08	0.14	0.42
1989	1374.76	4442.63	4819.41	6487.84	445.60	2180.44	0.11	0.16	0.39
1990	765.87	4410.49	4929.54	6153.24	405.25	1549.99	0.21	0.24	0.53
1991	980.21	4088.51	4575.85	4499.44	362.47	1428.48	0.18	0.27	0.53
1992	867.41	3624.77	4053.21	3540.76	340.91	1255.42	0.16	0.27	0.51
1993	2930.36	3055.79	3304.41	7115.95	285.09	3302.89	0.05	0.11	0.36
1994	2175.08	4784.64	5097.04	9193.93	489.14	3247.10	0.07	0.10	0.28
1995	1501.03	8652.18	9436.02	7178.61	885.16	2377.56	0.16	0.25	0.44
1996	1041.55	7117.38	8203.73	6094.29	677.92	1785.38	0.27	0.36	0.63
1997	1335.54	4275.42	5184.54	4805.94	440.87	1789.97	0.24	0.39	0.74
1998	947.12	2859.55	3263.28	3700.44	335.72	1370.91	0.20	0.29	0.61
1999	560.07	2543.97	2799.27	2962.13	270.52	937.64	0.18	0.24	0.50
2000	439.79	2696.34	3159.94	1895.06	290.35	658.39	0.26	0.43	0.69
2001	581.25	1713.32	1988.35	1676.45	203.74	717.78	0.17	0.35	0.65
2002	945.04	1734.67	1822.41	2289.89	215.62	1085.59	0.04	0.09	0.21
2003	1389.47	2926.90	3144.54	3667.24	344.70	1653.37	0.07	0.16	0.36
2004	1101.87	2645.16	2917.25	5504.20	259.30	1742.79	0.12	0.17	0.49
2005	2178.10	4002.42	4356.33	6493.55	401.77	2669.08	0.08	0.17	0.43
2006	2468.09	5714.91	6070.82	8065.55	605.42	3221.13	0.05	0.12	0.28
2007	1353.13	8148.37	9076.44	7214.25	867.57	2292.29	0.18	0.29	0.52
2008	1146.42	5126.37	5776.52	7571.39	475.79	2008.13	0.20	0.25	0.57
2009	2011.51	4740.12	5111.07	7147.10	414.93	2619.76	0.07	0.15	0.35
2010	1256.81	5324.56	6191.20	6955.74	515.15	2132.55	0.19	0.30	0.64
2011	711.86	5146.51	6330.91	3311.32	645.38	1128.24	0.34	0.51	0.77
2012	306.91	2240.65	2666.08	2077.99	268.89	596.72	0.32	0.42	0.74
2013	542.15	1334.27	1388.38	1915.08	128.32	705.96	0.03	0.06	0.15

Table C6.4. Likelihood components for all the UMaine model runs (Run number is identical to Table C6.1)

Run #	Total	C1	C2	C3	CC1	CC2	CC3	I1	I2	I3	I4	IC1	IC2	IC3	IC4	R-penalty	F-prop
B	12951.5	-27.2	-36.7	-41.9	934.3	1362.6	1784.9	55.2	43.7	37.7	-	2012.0	3387.9	421.1	-	51.8	2966
1	12984.5	-25.9	-31.6	-41.9	933.7	1361.8	1786.4	56.7	46.6	36.6	-	2018.0	3396.8	423.7	-	57.6	2966
2	12981.5	-28.1	-37.2	-41.9	934.4	1362.4	1788.6	52.1	44.6	39.6	-	2015.7	3413.1	421.9	-	50.2	2966
3	12979.1	-32.0	-39.4	-41.8	930.6	1356.8	1780.0	47.8	31.9	36.4	-	2017.3	3429.0	419.8	-	76.6	2966
4	12962.1	-25.5	-36.5	-41.9	935.3	1363.5	1786.0	57.5	44.5	38.3	-	2012.3	3387.8	421.3	-	53.6	2966
5	12978.5	-23.0	-36.1	-41.9	936.9	1364.9	1787.5	60.4	45.9	39.1	-	2012.8	3387.7	421.6	-	56.8	2966
6	12951.6	-27.2	-36.7	-41.9	934.3	1362.6	1785.0	55.2	43.7	37.8	-	2012.0	3388.0	421.1	-	51.7	2966
7	13078.0*	-16.6	-28.3	-41.8	947.9	1374.3	1803.5	144.7	26.7	51.2	-	2027.1	3425.3	427.9	-	148.2	2966
8	13223.5*	-30.1	-37.3	-41.9	933.2	1360.1	1782.1	31.5	31.4	24.3	-	2011.0	3386.5	419.4	-	38.5	2966
9	12955.5	-27.1	-36.5	-41.9	934.7	1362.3	1786.1	56.9	43.4	37.8	-	2012.6	3389.0	421.4	-	51.0	2966
10	12690.4	-34.6	-41.7	-41.9	914.7	1304.3	1701.2	42.7	50.0	43.9	-	1979.1	3348.2	419.4	-	39.1	2966
11	12957.8*	-26.6	-35.9	-41.9	934.4	1361.1	1785.1	56.5	45.5	41.7	5.7	2010.1	3378.9	420.3	1163.1	62.6	2966
12	NOT CONVERGED																

* Adjusted likelihood values for weighting factors used in order to make them comparable

Notes: C1, C2, C3: total catch of fishery 1, 2, and 3;

CC1, CC2, CC3: catch size composition of fishery 1, 2, and 3;

I1, I2, I3, I4: index of survey 1, 2, 3, and 4;

IC1, IC2, IC3, IC4: survey size composition of survey 1, 2, 3, and 4;

R-penalty: recruitment penalty term;

F-prop: proportion of females

Table C6.5. Key estimates for all UMaine model runs (Run number is identical to Table C6.1). *Model exhibited problems converging in one or some retrospective runs.

Run #	Terminal SSB (mt)	Terminal Recruitment (millions)	Mean recruitment (millions)	Terminal exploitation rates	Mohn's rho for SSB/recruitment/exploitation rate	F _{max}	F _{MSY}	MSY (mt)	B _{MSY} (mt)	Terminal SSB/B _{MSY}
				(numbers/biomass/female biomass)						
B	1334.27	542.15	1104.00	0.03/0.06/0.15	0.22/0.93/-0.47	1.77	1.77	2556.1	5643.4	0.236
1	1226.87	257.12	494.36	0.05/0.08/0.16	0.20/1.07/-0.48	0.97	0.97	2541.0	7017.7	0.175
2	1578.72	508.17	965.99	0.03/0.05/0.13	0.25/0.83/-0.53	6.02	6.02	2736.7	4634.9	0.341
3	1330.91	508.64	1029.00	0.03/0.06/0.14	1.27/2.10/-2.11	-	-	-	-	-
4	1388.60	567.20	1151.84	0.03/0.06/0.15	0.00/0.78/-0.26	1.78	1.78	2667.5	5880.6	0.236
5	1464.94	603.38	1219.58	0.03/0.06/0.14	-0.95/0.52/0.37	1.78	1.78	2825.2	6233.7	0.235
6	1342.16	541.75	1104.34	0.04/0.07/0.17	0.22/0.93/-0.47	1.77	1.77	2557.0	5646.2	0.238
7	290.82	194.79	966.74	0.11/0.19/0.56	0.17/1.01/-0.51	1.77	1.77	2233.6	4905.1	0.059
8	2176.42	701.02	1145.67	0.03/0.05/0.11	0.52/1.01/-0.78	1.75	1.75	2650.7	5834.5	0.373
9	1341.11	536.62	1104.72	0.03/0.06/0.15	0.18/0.96/-0.43	1.78	1.78	2563.7	5623.2	0.239
10	3438.66	843.68	1541.13	0.02/0.03/0.06	*	2.78	2.78	2575.5	5951.5	0.578
11	1566.19	411.75	1080.17	0.04/0.07/0.14	0.26/0.91/-0.20	1.78	1.78	2501.4	5526.3	0.283
12	NOT CONVERGED									

Table C6.6. Summary of major changes to CSA software. Version 3 was used for 2013 annual assessment update, version 4 was used for 2014 benchmark assessment.

	CSA Version 3	CSA Version 4.2.2
Fitting method	Nonlinear least squares	Maximum likelihood
Survey inputs	1 series only	multiple surveys can be used
Catch	assumed known, no error	cv can be varied (but not time dependent)
Survey cv	assumed 1 for recruits and post-recruits	time-varying
Catch model	option for Pope's approximation	Baranov's catch equation

Table C6.7. Average CV for each series before and after adjusting CV based on preliminary runs. Catch CV assumed=0.20.

	Initial	After adjustment		
		Ad hoc	3/M rule	Rinaldo
Shrimp survey recruits	0.15	0.40	0.34	0.44
Shrimp survey post-recruits	0.15	0.42	0.55	0.55
ME-NH spring survey	0.03	1.64	1.34	1.51
NEFSC fall Albatross	0.26	0.55	0.53	0.48
NEFSC fall Bigelow	0.36	0.34	0.37	0.31

Table C6.8. Comparison of goodness of fit for 3 scenarios for M. Runs used adjusted cv's for each scenario.

Assumed catch cv		0.2	0.2	0.2	0.1	0.05
		Rinaldo				
		Ad hoc	(M=0.25)	3/M rule, PPI	3/M rule, PPI	3/M rule, PPI
Objective function		-69.7	-62.2	-75.2	-95.3	-115.9
Component	Shrimp survey recruits	-15.7	-10.1	-23.3	-23.1	-23.0
	Shrimp survey post-recruits	-10.4	-2.3	-2.9	-2.4	-2.3
	ME-NH spring	7.0	6.1	5.5	5.4	5.4
	Fall Albatross	-3.2	-8.0	-4.3	-4.1	-4.0
	Fall_Bigelow	-2.1	-3.1	-2.3	-2.2	-2.1
	Catch	-45.3	-44.7	-47.8	-69.0	-89.8

Table C6.9. Comparison of goodness of fit for models which included different surveys. All models estimated under 3/M –PPI scenario for M. Catch CV=0.20.

		All surveys	Drop ME_NH (keep shrimp, fall)	Drop Fall (keep shrimp, ME-NH)	Shrimp only
Objective function		-75.24	-81.11	-74.23	-81.46
Component	Shrimp survey recruits	-23.33	-23.04	-28.08	-27.54
	Shrimp survey post-recruits	-2.90	-4.14	-4.17	-5.81
	ME-NH spring	5.48		6.31	
	Fall Albatross	-4.34	-4.47		
	Fall_Bigelow	-2.31	-1.73		
	Catch	-47.84	-47.74	-48.29	-48.11
	# parameters	68	66	64	62
	AIC	-14.47	-30.22	-20.46	-38.93

Table C6.10. Estimates of fishing mortality, recruit abundance, post-recruit abundance and total biomass from final CSA run.

Fishing Year	Fishing mortality			Recruit Abundance (millions)			Post-recruit Abundance (millions)			Exploitable Biomass (kt)		
	Median	Lower 5%	Upper 5%	Median	Lower 5%	Upper 5%	Median	Lower 5%	Upper 5%	Median	Lower 5%	Upper 5%
1985	0.23	0.15	0.38	1,001	606	1,663	963	531	1,694	15	9	22
1986	0.21	0.14	0.31	1,167	733	1,742	1,211	656	1,877	20	14	29
1987	0.27	0.18	0.40	836	527	1,359	1,289	837	2,009	20	14	29
1988	0.15	0.10	0.22	703	474	1,117	1,121	697	1,793	17	12	25
1989	0.18	0.12	0.25	835	564	1,225	1,223	816	1,942	15	11	21
1990	0.24	0.18	0.34	1,162	817	1,584	1,245	878	1,849	18	14	25
1991	0.22	0.15	0.31	765	525	1,110	1,335	908	1,853	20	15	27
1992	0.20	0.13	0.29	572	348	1,000	1,128	776	1,611	16	12	23
1993	0.15	0.10	0.22	512	352	736	1,004	672	1,542	14	10	20
1994	0.19	0.13	0.27	816	520	1,308	965	655	1,462	12	9	17
1995	0.41	0.30	0.57	1,004	682	1,505	1,078	725	1,668	15	12	20
1996	0.73	0.51	0.97	1,028	716	1,410	1,019	673	1,489	17	13	22
1997	1.12	0.76	1.68	615	412	869	600	389	946	10	8	13
1998	0.47	0.30	0.73	822	554	1,329	285	133	518	7	5	10
1999	0.20	0.14	0.30	812	452	1,290	491	278	850	9	7	13
2000	0.35	0.24	0.53	294	195	482	802	514	1,166	9	7	13
2001	0.20	0.13	0.33	562	304	963	475	288	738	8	5	11
2002	0.07	0.05	0.10	388	227	695	440	245	687	6	4	9
2003	0.13	0.07	0.19	1,196	762	2,341	475	326	745	9	6	16
2004	0.26	0.16	0.40	759	406	1,326	527	340	1,009	9	6	14
2005	0.14	0.09	0.19	1,768	1,197	2,575	512	303	836	17	13	24
2006	0.05	0.03	0.06	4,176	3,033	5,688	1,325	958	2,001	34	26	46
2007	0.09	0.06	0.12	5,790	4,299	8,201	3,156	2,354	4,275	62	49	84
2008	0.16	0.12	0.21	635	327	1,092	3,948	3,033	5,496	39	31	55
2009	0.11	0.08	0.15	903	520	1,483	1,898	1,442	2,791	26	19	35
2010	0.32	0.22	0.45	1,098	740	1,768	1,440	1,045	2,026	22	17	30
2011	0.48	0.34	0.69	1,287	843	1,808	897	596	1,367	16	12	21
2012	0.55	0.35	0.81	292	148	449	617	387	938	7	5	10
2013	0.13	0.08	0.20	82	51	146	238	135	404	3	2	5
2014				16	8	30	144	87	231			

Table C6.11. Mohn's rho for estimates from final CSA model.

Relative Change in Estimate				
Terminal Year	F	Recruit	Post-Recruit	Total B
2013	-0.56	0.26	1.60	1.26
2012	-0.74	4.58	0.59	1.65
2011	-0.25	0.15	0.43	0.27
2010	-0.21	0.03	0.40	0.27
2009	-0.29	0.39	0.37	0.38
Mohn's Rho	-0.41	1.08	0.68	0.77

Table C6.12. Likelihood profile on selectivity of recruits. Base is annual selectivity estimated from shrimp survey data.

		Base	All sel=1.0	0.25*base	0.50*base	0.75*base	0.9*base
Objective function		-121.6	-117.5	-109.6	-118.6	-121.3	-121.7
Component	Shrimp sv recruits	-22.7	-21.5	-7.5	-16.4	-20.5	-22.1
	Shrimp sv post-rcrt	-3.4	-0.7	-2.1	-4.5	-4.3	-3.8
	Fall Albatross	-4.1	-3.8	-7.3	-5.7	-4.9	-4.4
	Fall_Bigelow	-1.5	-1.6	-3.4	-2.3	-1.7	-1.6
	Catch	-89.84	-89.85	-89.34	-89.6	-89.8	-89.8

Table C6.13. Likelihood profile on catch under-reporting. Base assumes no under-reporting.

		Base	10% before 2001	25% before 2001	50% before 2001	25% before 2001, 10% after
Objective function		-121.6	-121.4	-121.1	-120.6	-121.3
Component	Shrimp sv recruits	-22.7	-22.8	-23.0	-23.3	-22.9
	Shrimp sv post-rcrt	-3.4	-3.1	-2.6	-1.8	-2.9
	Fall Albatross	-4.1	-4.2	-4.2	-4.2	-4.2
	Fall_Bigelow	-1.5	-1.5	-1.5	-1.5	-1.5
	Catch	-89.8	-89.8	-89.8	-89.8	-89.8

Table C6.14. Likelihood profile on baseline M for PPI run. Base assumes average M=0.5.

		Base				
		M=0.3	M=0.4	M=0.5	M=0.6	M=0.7
Objective function		-111.5	-117.7	-121.6	-123.4	-123.4
Component	Shrimp sv recruits	-16.4	-20.4	-22.7	-23.7	-24.1
	Shrimp sv post-rcrt	-0.8	-2.3	-3.4	-3.9	-3.5
	Fall Albatross	-4.8	-4.5	-4.1	-3.8	-3.4
	Fall_Bigelow	0.1	-0.8	-1.5	-2.1	-2.6
	Catch	-89.6	-89.8	-89.8	-89.9	-89.9

Table C6.15. ASPIC model inputs.

Fishing Season	ASPIC Model Input					ASPIC Model Results			
	NEFSC Fall R/V	ME	ASMFC Summer	NEFSC Fall R/V	Catch (mt)	Biomass	ASPIC F	B/Bmsy	F/Fmsy
1968	3.20	45.80			6,610	62.58	0.12	2.75	0.61
1969	2.70	31.20			12,824	50.88	0.29	2.23	1.50
1970	3.70	40.80			10,670	38.53	0.31	1.69	1.59
1971	3.00	9.40			11,130	31.09	0.41	1.36	2.09
1972	3.30	7.00			11,095	24.17	0.54	1.06	2.78
1973	1.90	7.80			9,405	17.43	0.65	0.76	3.36
1974	0.80	4.90			7,945	11.83	0.89	0.52	4.56
1975	0.90	6.70			5,287	6.67	1.16	0.29	5.97
1976	0.60	4.80			1,022	2.96	0.34	0.13	1.76
1977	0.20	1.60			381	3.03	0.11	0.13	0.57
1978	0.40	3.20			3	3.88	0.00	0.17	0.00
1979	0.50	4.40			439	5.50	0.07	0.24	0.36
1980	0.50	2.70			333	7.17	0.04	0.31	0.21
1981	1.50	3.00			1,074	9.46	0.10	0.42	0.53
1982	0.30	2.00			1,574	11.52	0.13	0.51	0.65
1983	1.00	4.20			1,574	13.46	0.11	0.59	0.56
1984	1.90		10.47		3,227	15.74	0.20	0.69	1.03
1985	1.60		17.69		4,132	16.57	0.25	0.73	1.29
1986	2.50		19.61		4,635	16.53	0.29	0.73	1.47
1987	1.70		15.40		5,266	15.95	0.35	0.70	1.78
1988	1.20		12.76		3,036	14.63	0.20	0.64	1.04
1989	1.81		16.95		3,315	15.52	0.21	0.68	1.08
1990	2.04		18.12		4,663	16.22	0.29	0.71	1.51
1991	0.44		11.68		3,585	15.58	0.23	0.68	1.17
1992	0.41		9.43		3,460	16.01	0.21	0.70	1.09
1993	1.85		9.14		2,143	16.61	0.12	0.73	0.63
1994	2.24		8.69		2,915	18.67	0.15	0.82	0.77
1995	1.22		13.29		6,457	20.08	0.34	0.88	1.75
1996	0.90		8.77		9,539	17.93	0.64	0.79	3.31
1997	1.12		7.73		7,120	12.25	0.71	0.54	3.65
1998	1.99		6.33		4,167	8.17	0.58	0.36	2.97
1999	2.32		5.78		1,866	6.35	0.29	0.28	1.48
2000	1.28		6.39		2,855	6.65	0.46	0.29	2.35
2001	0.63		4.33		1,331	5.90	0.21	0.26	1.09
2002	1.70		9.16		453	6.67	0.06	0.29	0.30
2003	1.08		5.45		1,344	8.69	0.14	0.38	0.73
2004	1.58		10.27		2,131	10.25	0.20	0.45	1.02
2005	2.77		23.38		2,610	11.32	0.22	0.50	1.15
2006	6.64		65.99		2,323	12.09	0.18	0.53	0.94
2007	4.13		11.51		4,880	13.33	0.39	0.58	1.99
2008	3.05		16.77		4,962	11.99	0.45	0.53	2.30
2009			15.44	7.96	2,501	10.29	0.24	0.45	1.21
2010			13.94	4.65	6,141	10.96	0.67	0.48	3.44
2011			8.47	5.79	6,398	7.66	1.30	0.34	6.70
2012			2.50	0.76	2,477 *	2.95	1.22	0.13	6.25
2013			1.00	N/A	307 *	1.27	0.16	0.06	0.82
2014						1.58		0.07	
Average:	1.77	11.22	12.88	4.79	4,165	14.14	0.35		

*Catch data are preliminary

1971-74 ave: 21.13 0.62

1985-94 ave: 16.23 0.23

2011-2013 (3-yr) ave: 3.96 0.89

Table C7.1. Biological reference points and terminal year estimates for Northern shrimp models.

Fishing Mortality					
	Historical Proxy		F_{2013}^*	Model Based	
	F_{target}	$F_{threshold}$			
UME	0.22	0.39	0.04 (N-weighted), 0.26 (full F)	$F_{40\%SPR} = 0.78$	$F_{30\%SPR} = 1.17$
CSA	0.20	0.27	0.13	n.a.	n.a.
ASPIC	0.23	0.35	0.16	$F_{MSY}=0.19$	

*For the UME model, the N-weighted F_{2013} should be compared to the historical proxies, and the full F should be compared to the model-based reference points.

Biomass*			
	Historical Proxy		Model Based
	$B_{threshold}/SSB_{threshold}$		B_{2013} SSB_{2013}
UME	2,335 mt		1,334 mt n.a.
CSA	16,600 mt		3,000 mt n.a.
ASPIC	16,200 mt		1,270 mt $B_{MSY}=22,800$ mt

*UME biomass reference points and terminal year estimates are for spawning stock biomass; CSA and ASPIC estimates are for exploitable biomass.

Table C7.2 Comparison of current management reference points (approved through SARC 45) and proposed new reference points.

Reference Point	SARC 45		SARC 58	
	Definition	Value	Definition	Value
$F_{Threshold}$	Maximum F during stable period (1985-94)	0.48 ³	Maximum F during stable period (1985-94)	0.39
F_{Target}	Average F during stable period (1985-94)	0.38 ³	Average F during stable period (1985-94)	0.22
$B_{Threshold}$	0.5*Average B during stable period (1985-1994)	9,000 mt	0.5*Average SSB during stable period (1985-1994)	2,335 mt
B_{Limit}	2,000 mt less than lowest value estimated by ASPIC model	6,000 mt	Not defined in this assessment	n.a.

³: The F reference points are updated at each annual assessment update; these values are from the 2013 update.

Table C8.1. Uncertainty of model estimates and Mohn's rho.

Model	Average CV (%)	Mohn's Rho %
UME		
Recruitment	19.0	93.0
Spawning stock biomass	8.4	22.0
Fishing Mortality	11.4	-47.0
CSA		
Recruit Numbers	27.5	108.0
Post-recruit Numbers	27.0	68.0
Biomass	21.5	77.0
Fishing Mortality	26.9	-41.0
ASPIC		
Biomass	11.6	760.0
Fishing Mortality	9.2	220.0

Table C9.1 Yield calculation and input values for determining target catch levels for several values of fishing mortality, for 2014.

CSA	F	Yield (mt)				Yield (mt) avg. weight of shrimp	Yield (mt) calc. weight of shrimp
25% F_{target}	0.05	64					
50% F_{target}	0.1	127					
F_{target}	0.2	255					
		Yield (mt) avg. weight of shrimp	Yield (mt) calc. weight of shrimp			Yield (mt) avg. weight of shrimp	Yield (mt) calc. weight of shrimp
UME	$F_{target} = F_{40\%SPR}$					$F_{target} = \text{avg } F$	
25% F_{target}	0.195	286	244	25% F_{target}	0.055	78	67
50% F_{target}	0.39	572	488	50% F_{target}	0.11	157	134
F_{target}	0.78	1144	976	F_{target}	0.22	314	267

Table C9.2 Mean size (carapace length in mm) of shrimp in summer surveys and mean weights (g) of a shrimp in the GOM northern shrimp fishery landings the following season.

Survey year	Mean survey female length (mm)	Fishing season	Observed mean wt of shrimp in fishery (g)
1984	24.78	1985	11.62
1985	26.06	1986	12.55
1986	26.71	1987	12.41
1987	26.30	1988	13.78
1988	26.65	1989	11.21
1989	25.34	1990	10.67
1990	26.42	1991	10.71
1991	26.98	1992	12.92
1992	26.71	1993	11.48
1993	25.80	1994	11.07
1994	25.49	1995	10.29
1995	25.49	1996	11.02
1996	26.21	1997	9.94
1997	26.11	1998	11.53
1998	24.95	1999	9.01
1999	25.33	2000	10.93
2000	25.54	2001	9.36
2001	23.82	2002	9.70
2002	24.37	2003	10.49
2003	23.20	2004	9.63
2004	25.34	2005	10.86
2005	26.33	2006	11.43
2006	24.72	2007	8.91
2007	24.31	2008	10.13
2008	26.42	2009	11.945
2009	26.91	2010	11.940
2010	26.52	2011	10.57
2011	23.99	2012	9.30
2012	25.09	2013	11.10
2013	26.45		

Table C9.3 Mean size (carapace length in mm) of shrimp in summer surveys and mean weights (g) of shrimp in the GOM northern shrimp fishery landings the following season, with the 3-year-old weighting factor X, and the linear regression coefficients used to predict the mean weight (g) of a shrimp in the 2014 fishery.

MS Excel Solver was used to find the best 3yo weighting factor "X" and the linear regression coefficients a and b by minimizing the sum of the Difference² between Observed and Predicted.

$$X = 0.0016 \quad a = 0.5445$$

$$b = -2.7376$$

Survey year	Mean survey female length (mm)	3yo index (age 1.5 no. per tow in previous survey year)	Mean survey female length - X*3yo	Fishing season	Observed mean wt of shrimp in fishery (g)	Predicted =a(survey len-X*3yo)+b	Difference ²
2001	23.82	450.33	23.08	2002	9.70	9.83	0.018
2002	24.37	17.62	24.34	2003	10.49	10.52	0.001
2003	23.20	1164.45	21.30	2004	9.63	8.86	0.587
2004	25.34	10.72	25.32	2005	10.86	11.05	0.035
2005	26.33	286.39	25.86	2006	11.43	11.34	0.007
2006	24.72	1752.49	21.87	2007	8.91	9.17	0.066
2007	24.31	374.31	23.70	2008	10.13	10.16	0.001
2008	26.42	28.27	26.38	2009	11.95	11.62	0.104
2009	26.91	505.74	26.09	2010	11.94	11.47	0.222
2010	26.52	582.42	25.58	2011	10.57	11.19	0.377
2011	23.99	474.75	23.22	2012	9.30	9.90	0.371
2012	25.09	43.68	25.01	2013	11.10	10.88	0.050
2013	26.45	6.67	26.44	2014	??	11.66	
							1.838

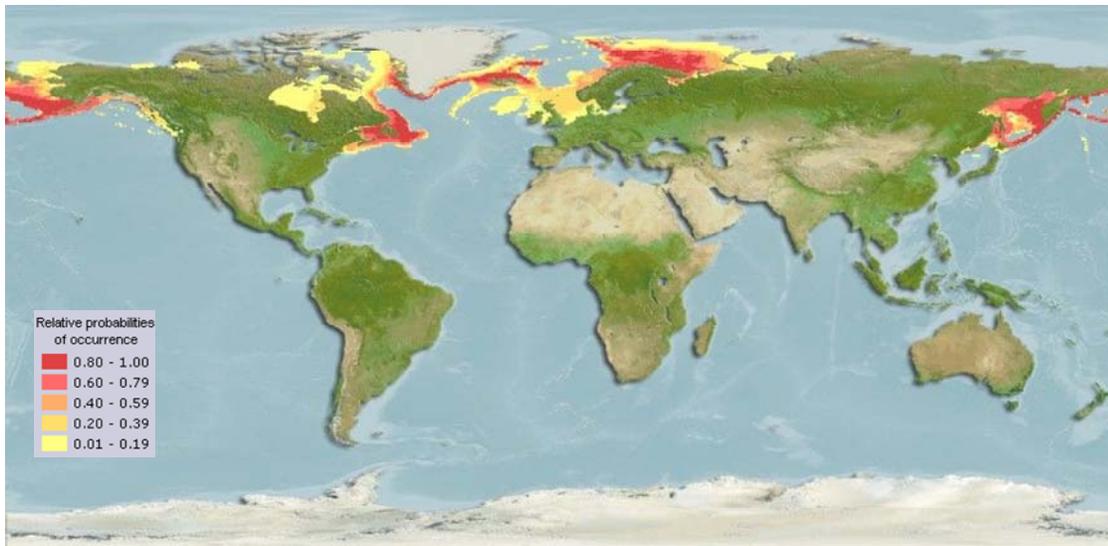


Figure C4.1. Range distribution of northern shrimp with relative probabilities of occurrence (www.aquamaps.org).

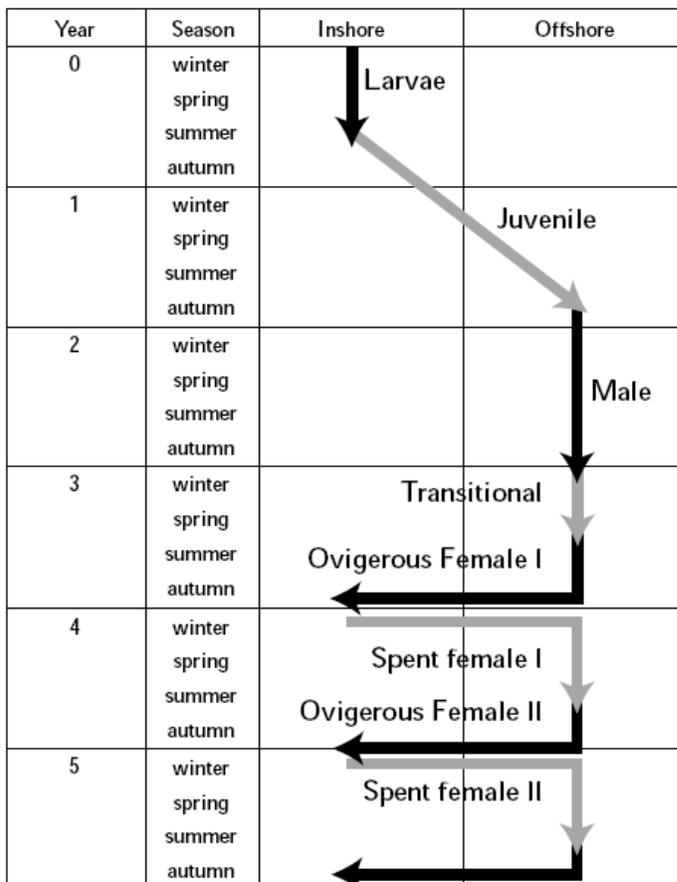


Figure C4.2. Life cycle of northern shrimp in the Gulf of Maine (Clark et al. 2000).

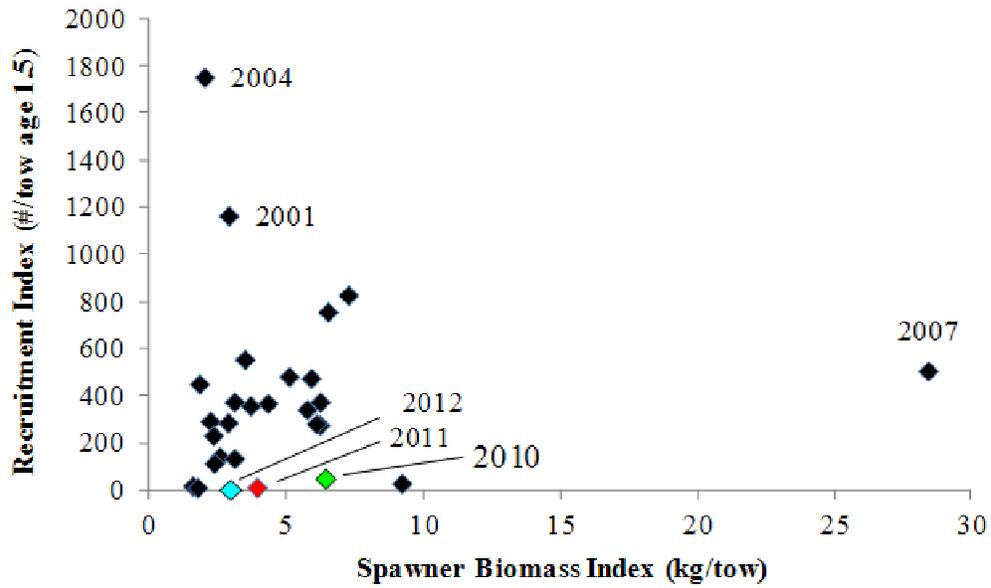


Figure C4.3. Relationship between summer survey index of Gulf of Maine female northern shrimp biomass the summer before spawning to age 1.5 abundance two years later. Year labels indicate the assumed age 1.5 year class.

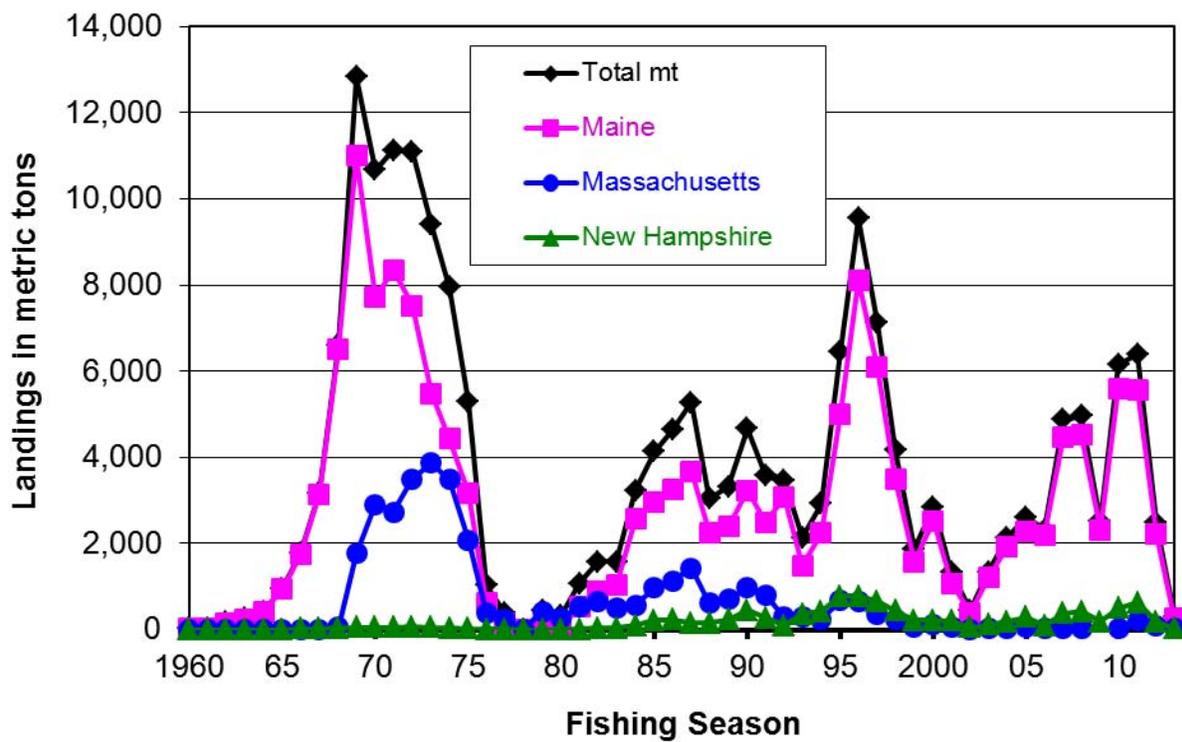


Figure C5.1. Gulf of Maine northern shrimp landings (metric tons, mt) by season and state. MA landings are combined with NH landings in 2009 to preserve confidentiality. 1 mt = 2,205 pounds.

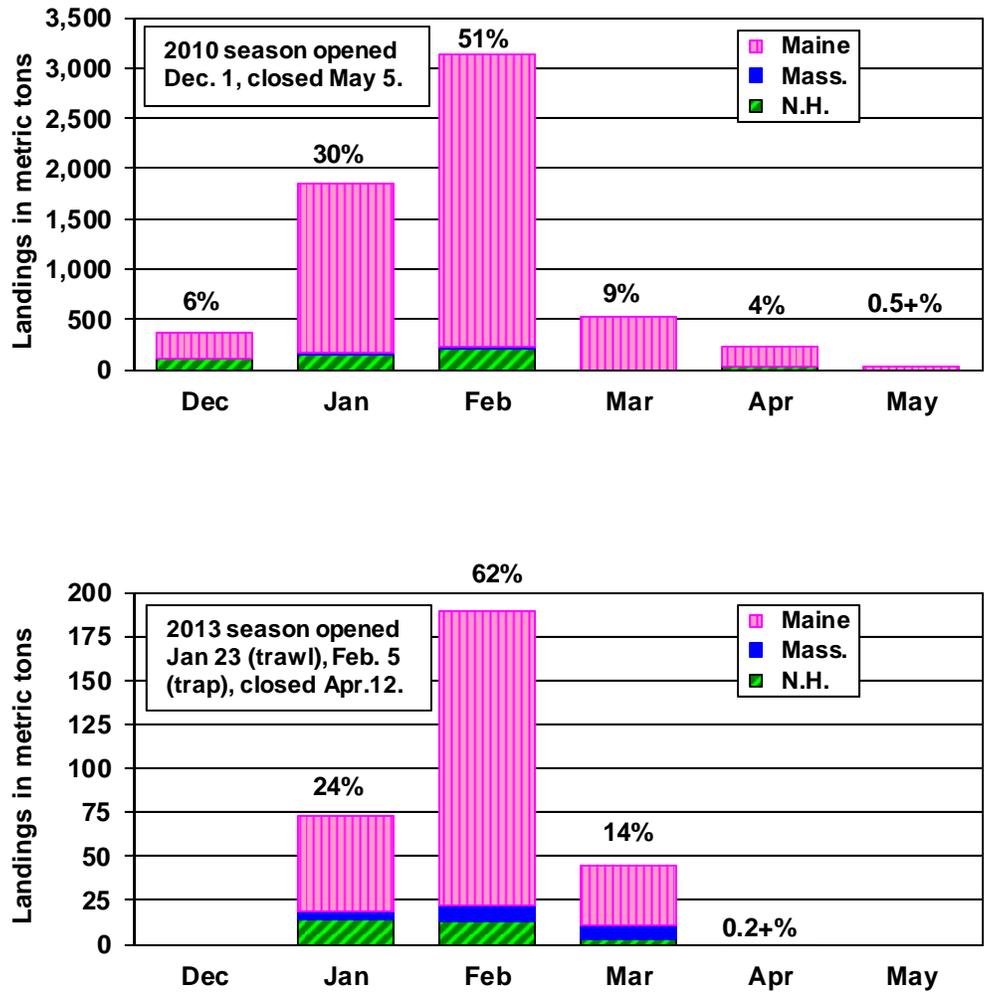


Figure C5.2. Gulf of Maine northern shrimp landings by state and month in the 2010 season (above) and the 2013 season (below) (preliminary data). Landings are in metric tons. 1 mt = 2,205 lbs.

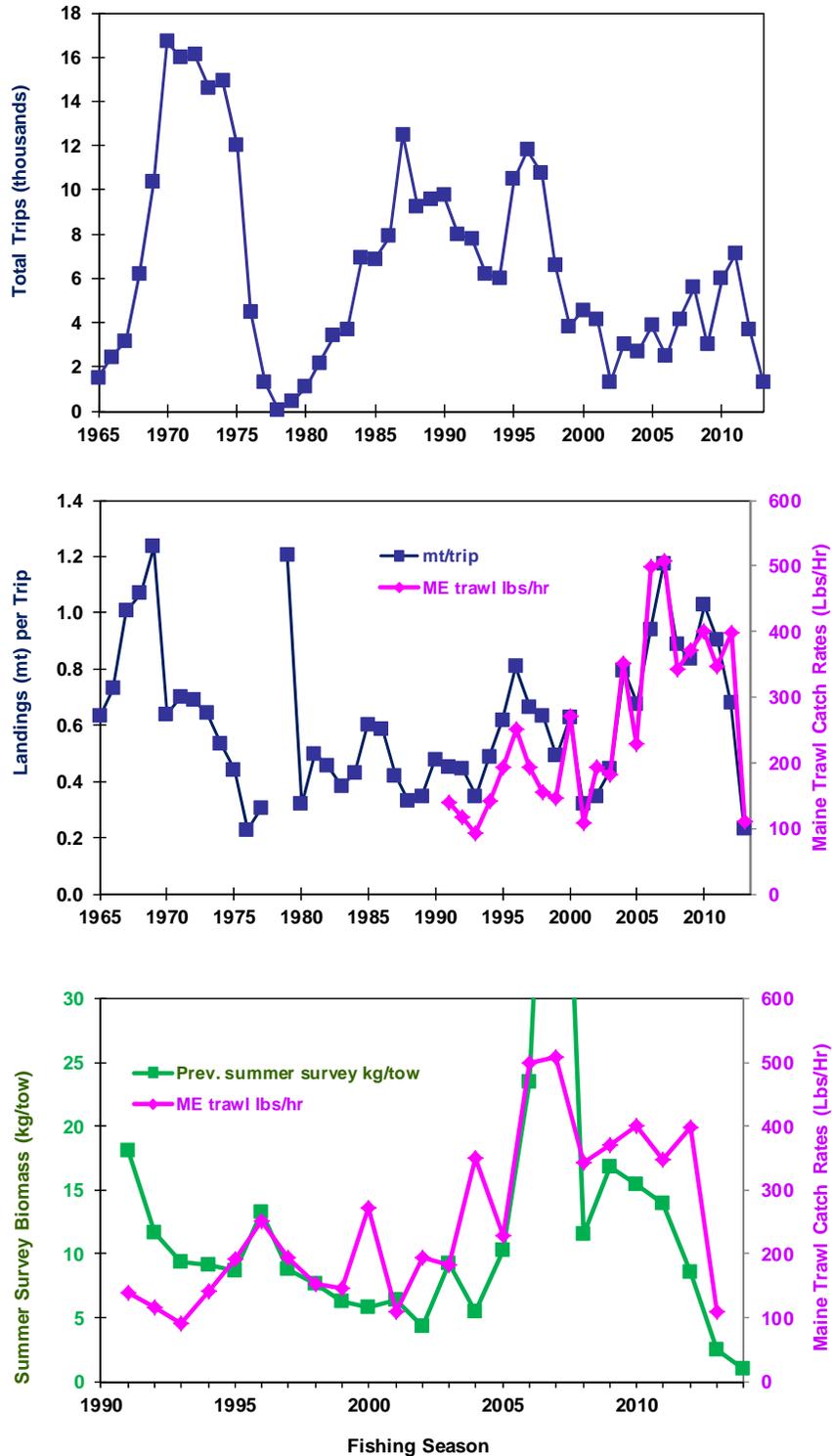


Figure C5.3. Nominal fishing effort (trips) in the Gulf of Maine northern shrimp fishery by season above, catch per unit effort in mt/trip and Maine trawl lbs/hr (middle), and Maine trawl lbs/hr and the previous summer survey index (kg/tow) (below). 2012 and 2013 trip data are preliminary.

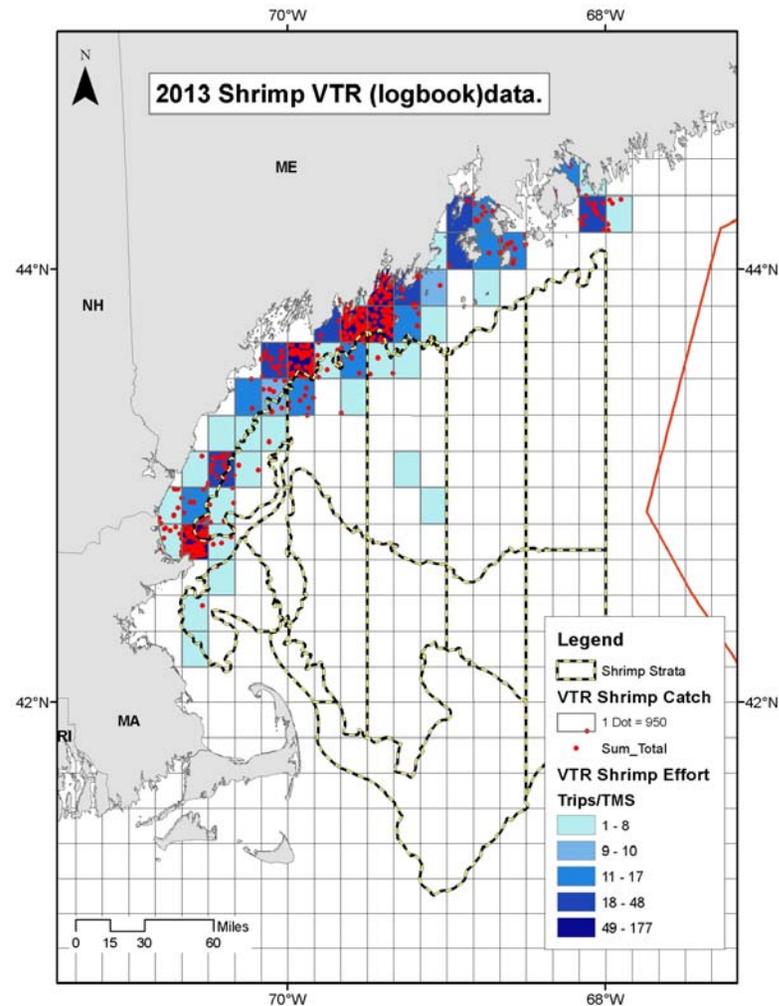
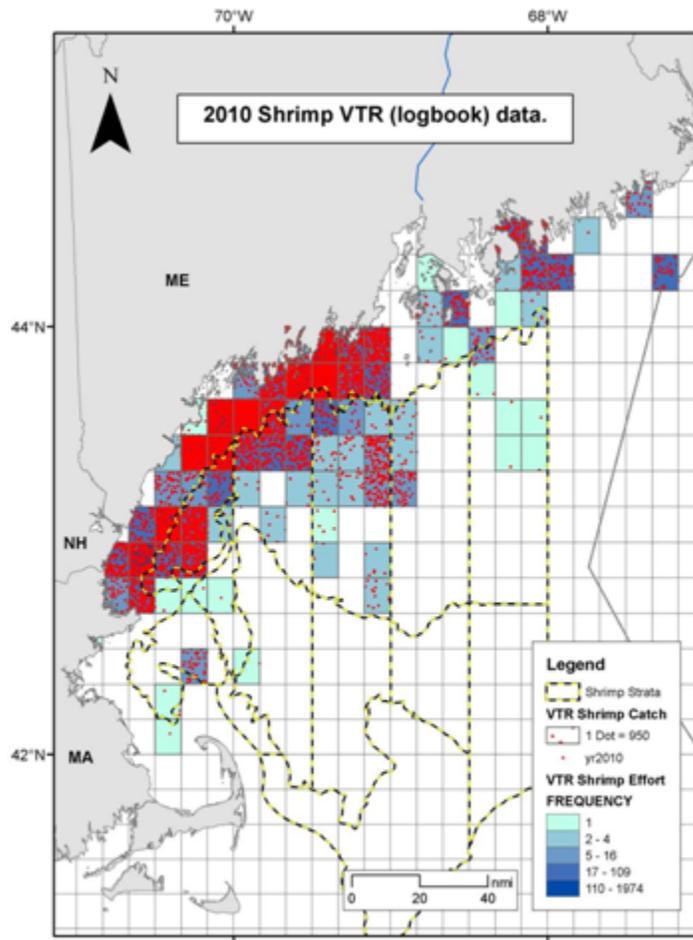


Figure C5.4. Pounds caught and numbers of trips during the 2010 (left) and 2013 (right) northern shrimp fishing seasons by 10-minute-square. Each red dot represents 950 lbs caught; locations of dots within squares are random and do not reflect the actual location of the catch. Number of trips is indicated by the blue palette for the squares. From preliminary state and federal harvester logbook (VTR) data.

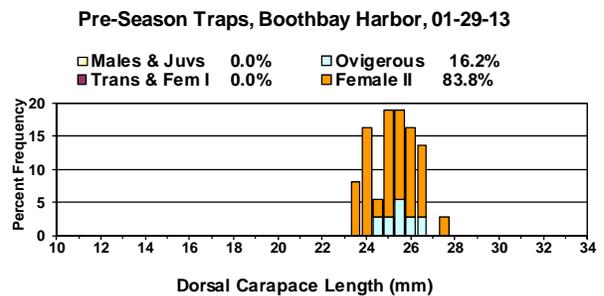
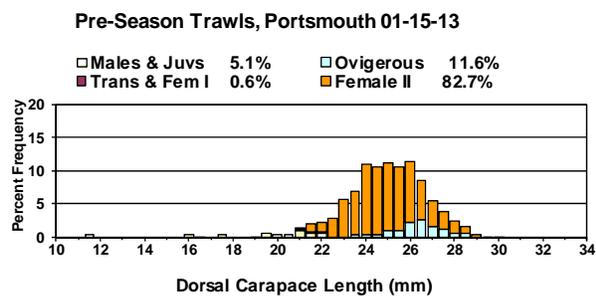
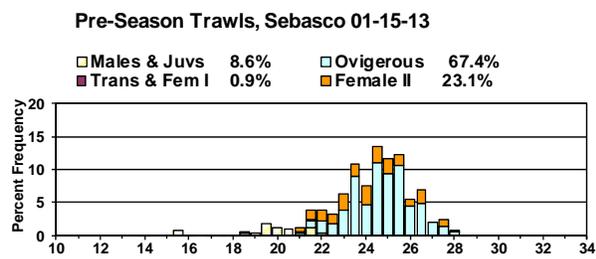
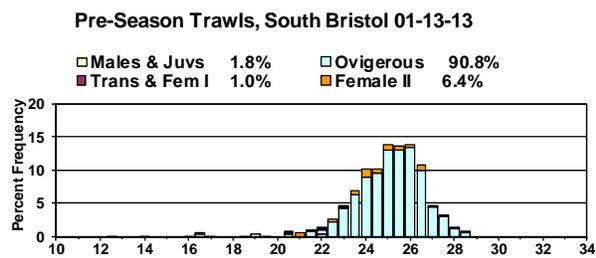
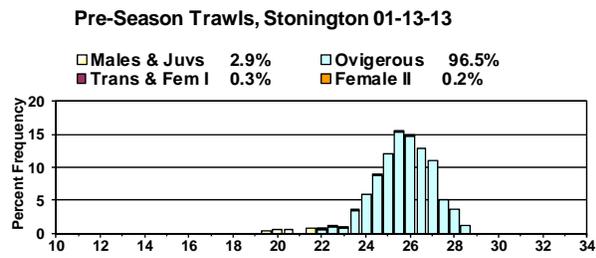


Figure C5.5. Relative length-frequency distributions from samples of northern shrimp from pre-season tows (left) and traps (right), from north (top) to south (bottom).

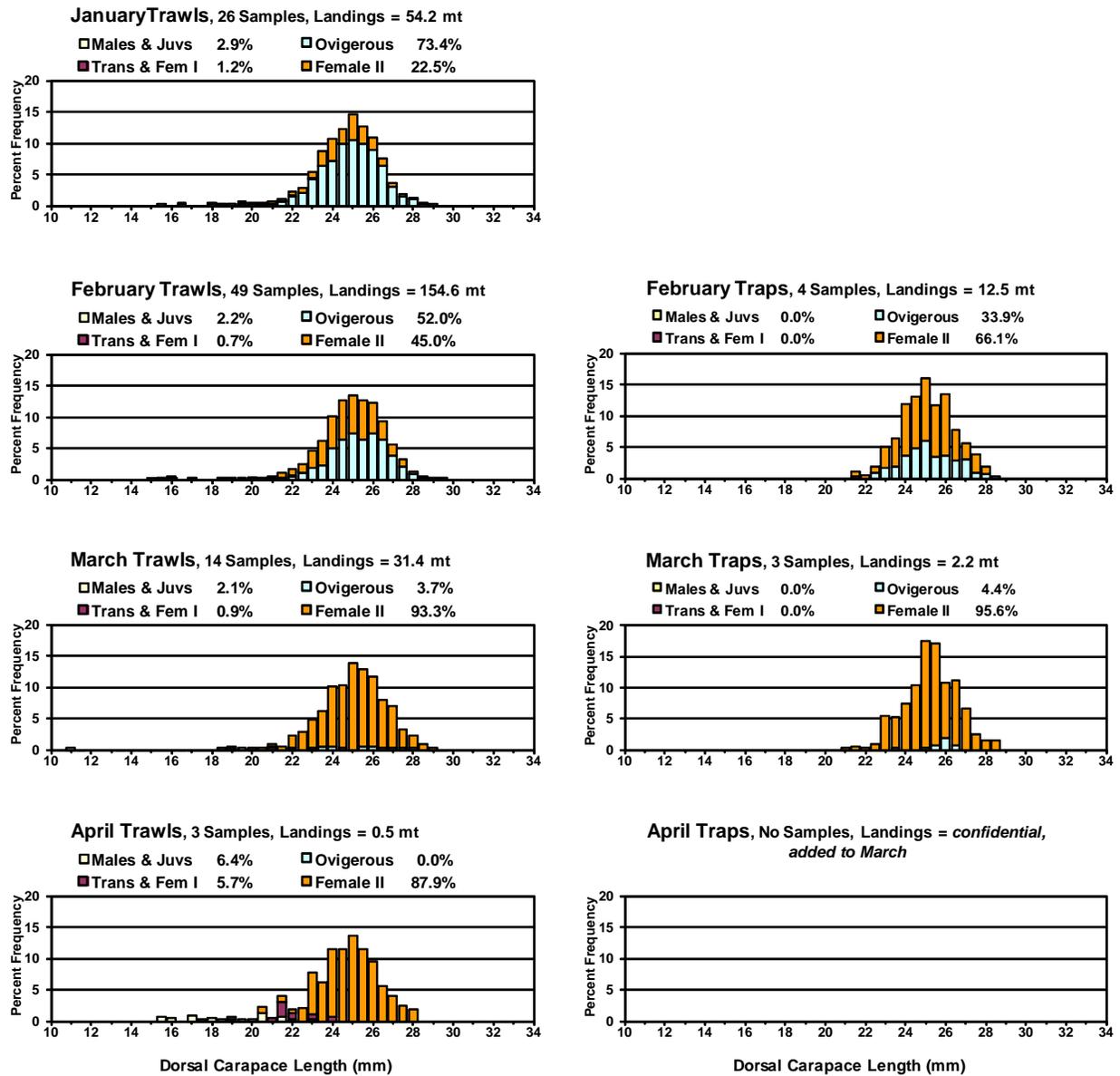


Figure C5.6. Relative length-frequency distributions from samples of Maine northern shrimp catches during the 2013 season by month (top to bottom) and gear, trawls (left) and traps (right). Landings are preliminary. 1 mt = 2,205 lbs.

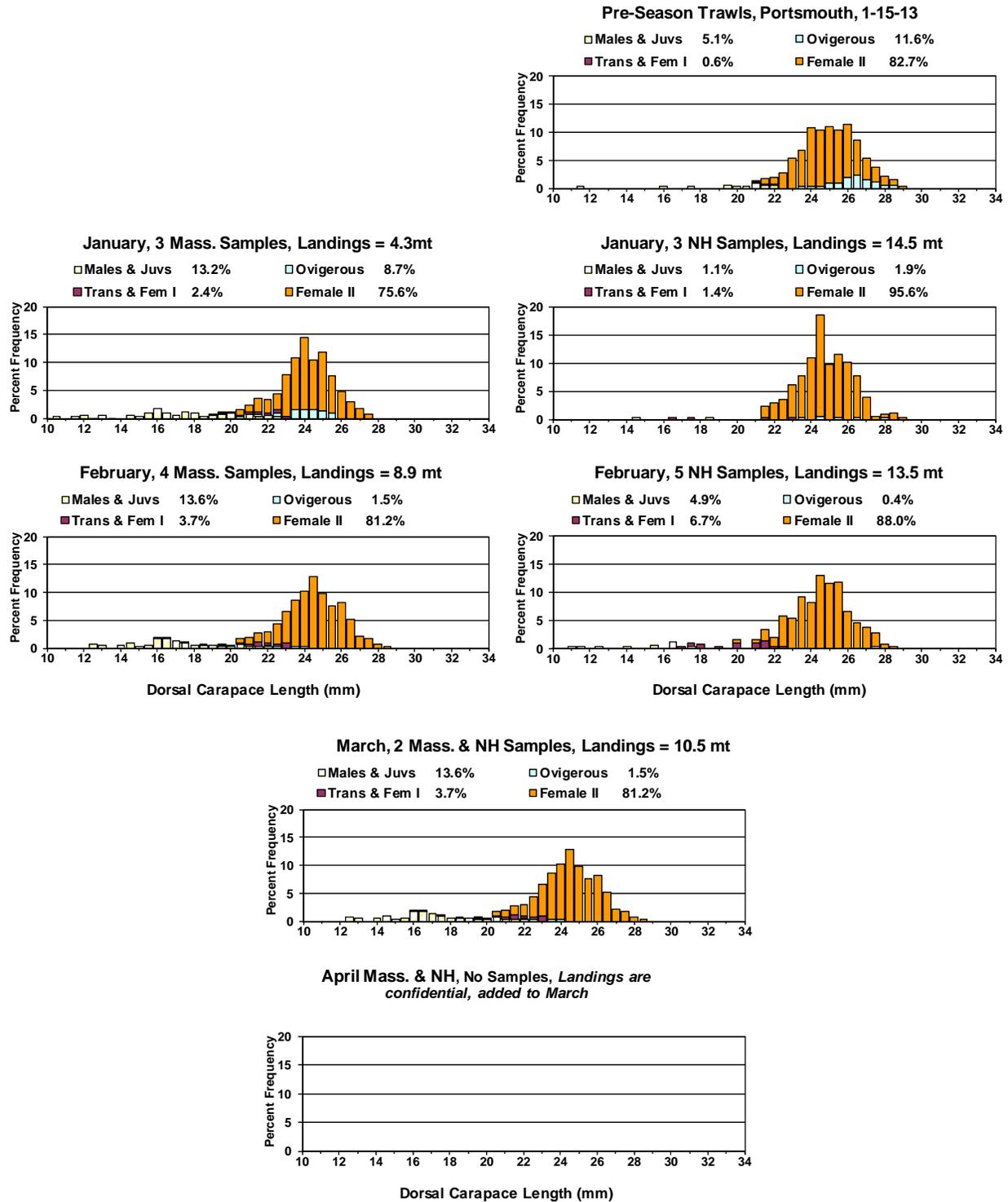


Figure C5.7. Relative length-frequency distributions from samples of Massachusetts (left) and New Hampshire (right) northern shrimp catches during the 2013 season by month (top to bottom). Landings are preliminary. 1 mt = 2,205 lbs.

Landings (millions of shrimp)

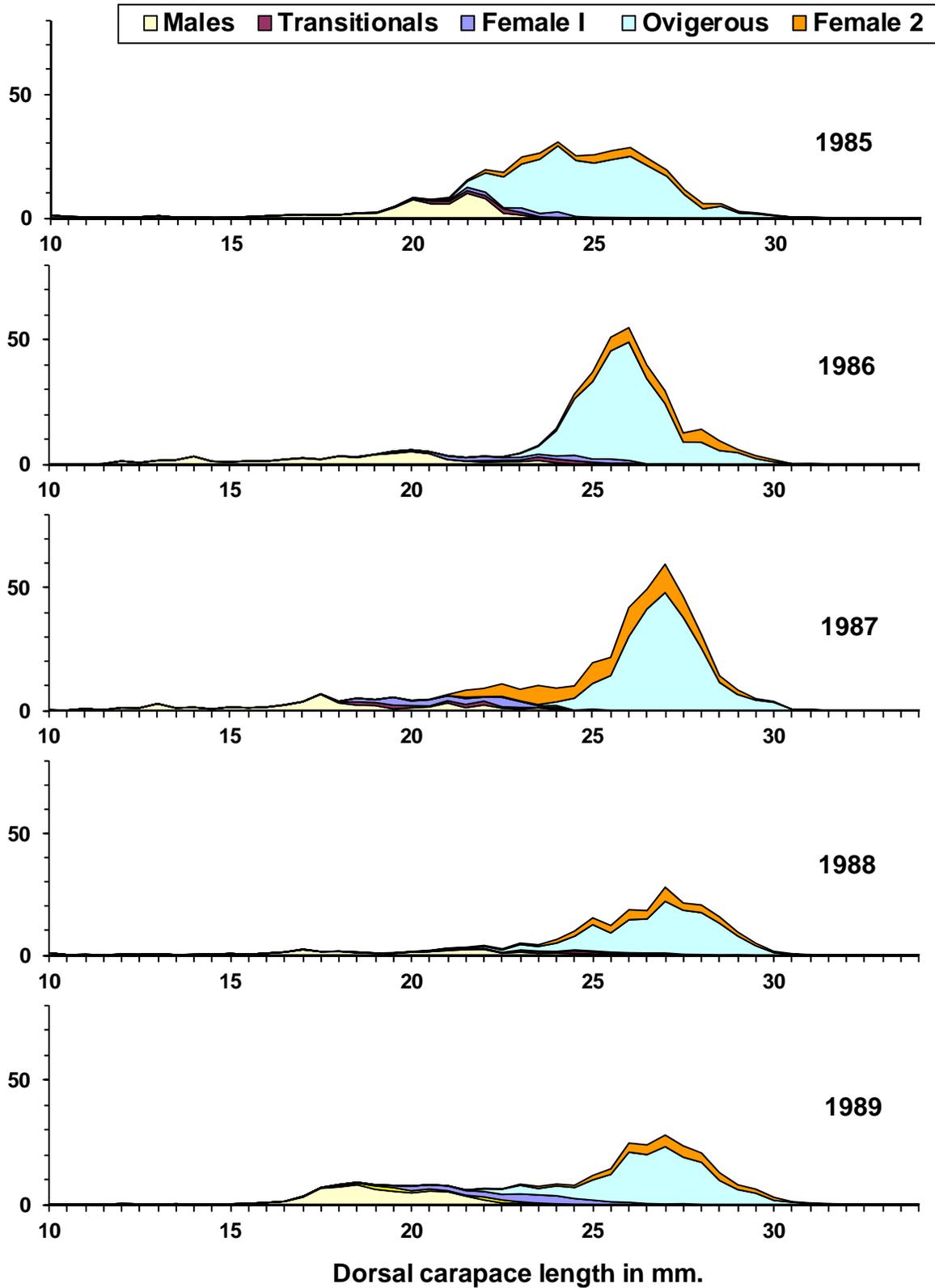


Figure C5.8. Gulf of Maine northern shrimp landings in estimated numbers of shrimp (millions), by length, development stage, and fishing season.

Landings (millions of shrimp)

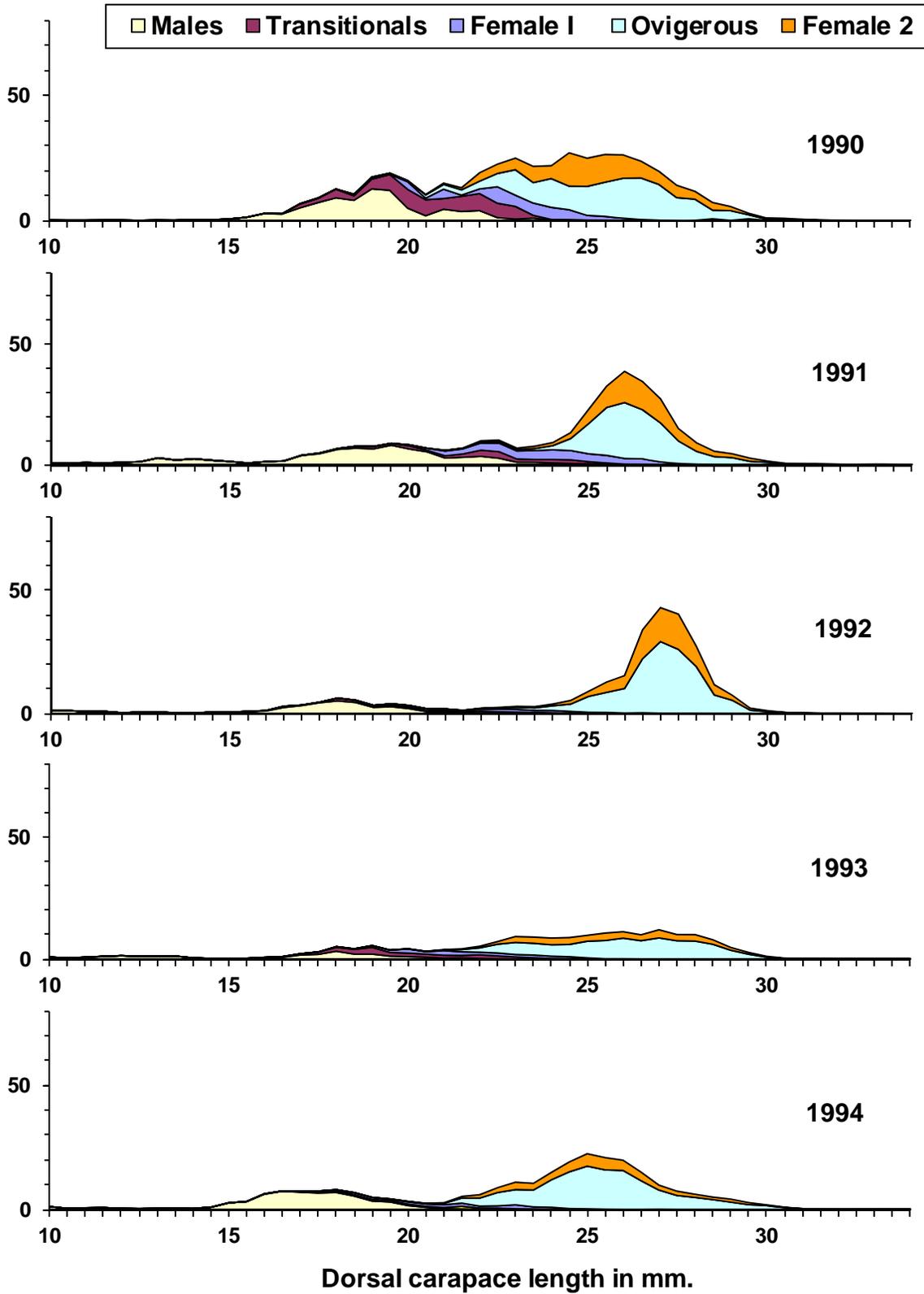


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

Landings (millions of shrimp)

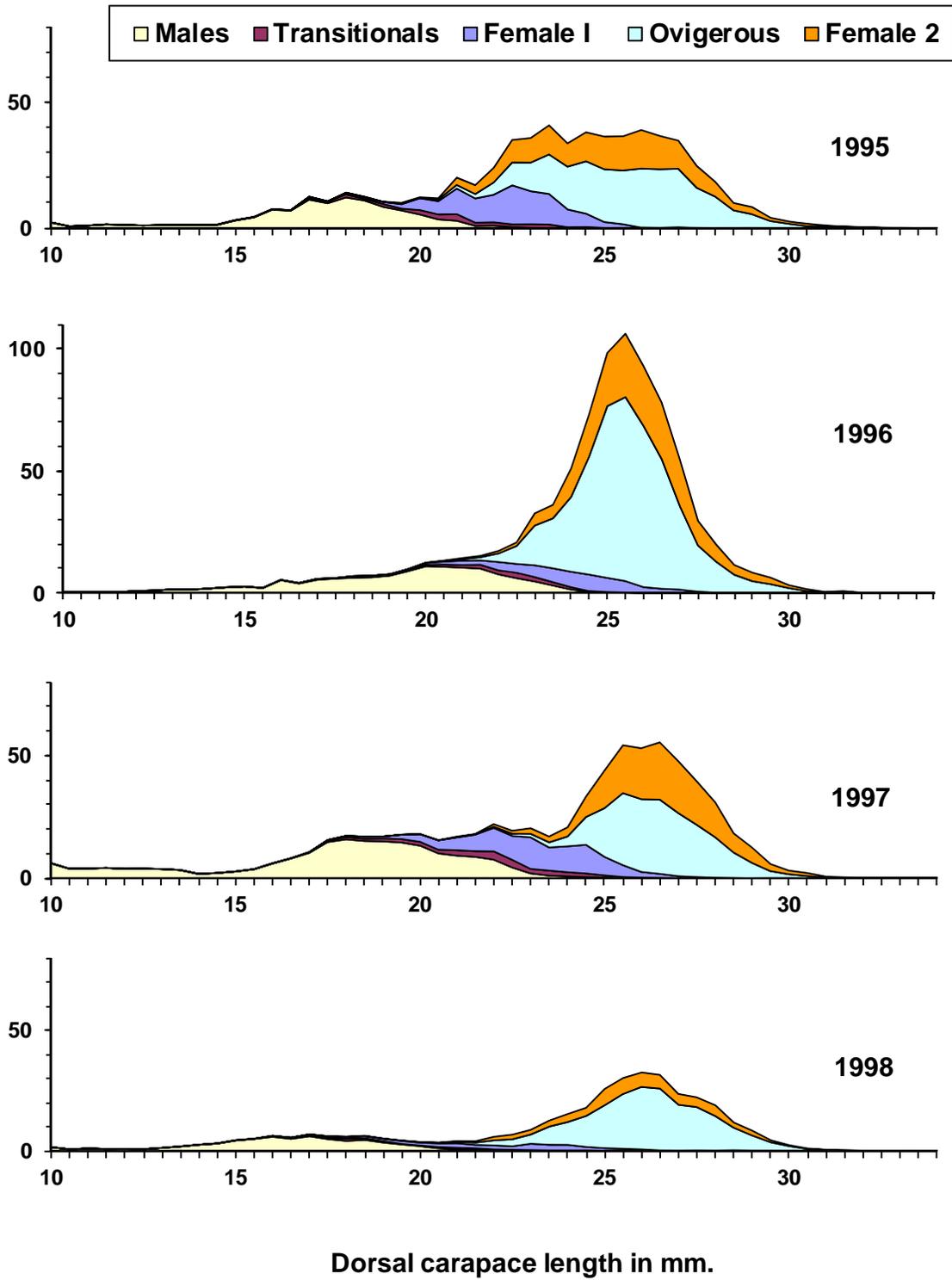


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

Landings (millions of shrimp)

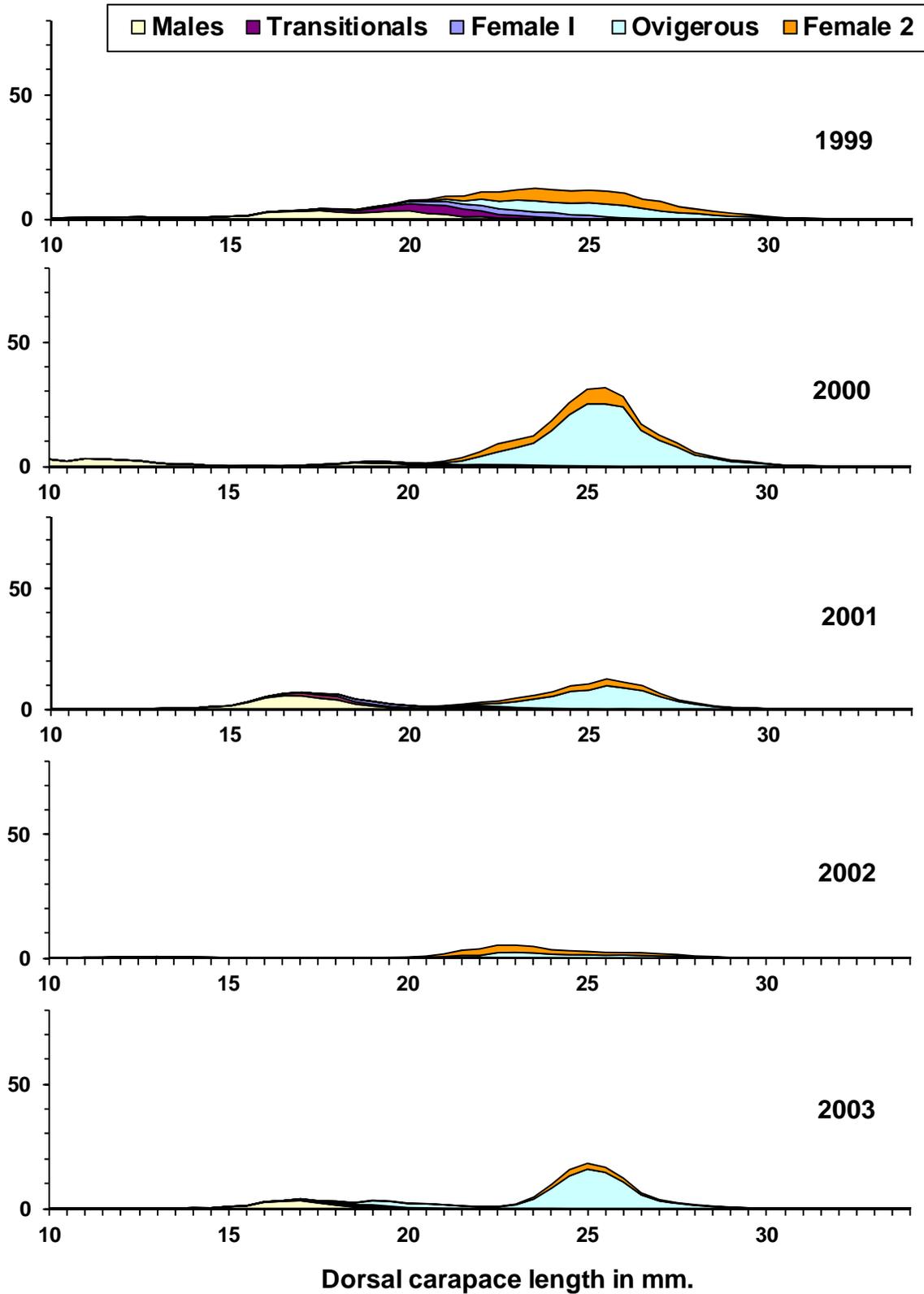


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

Landings (millions of shrimp)

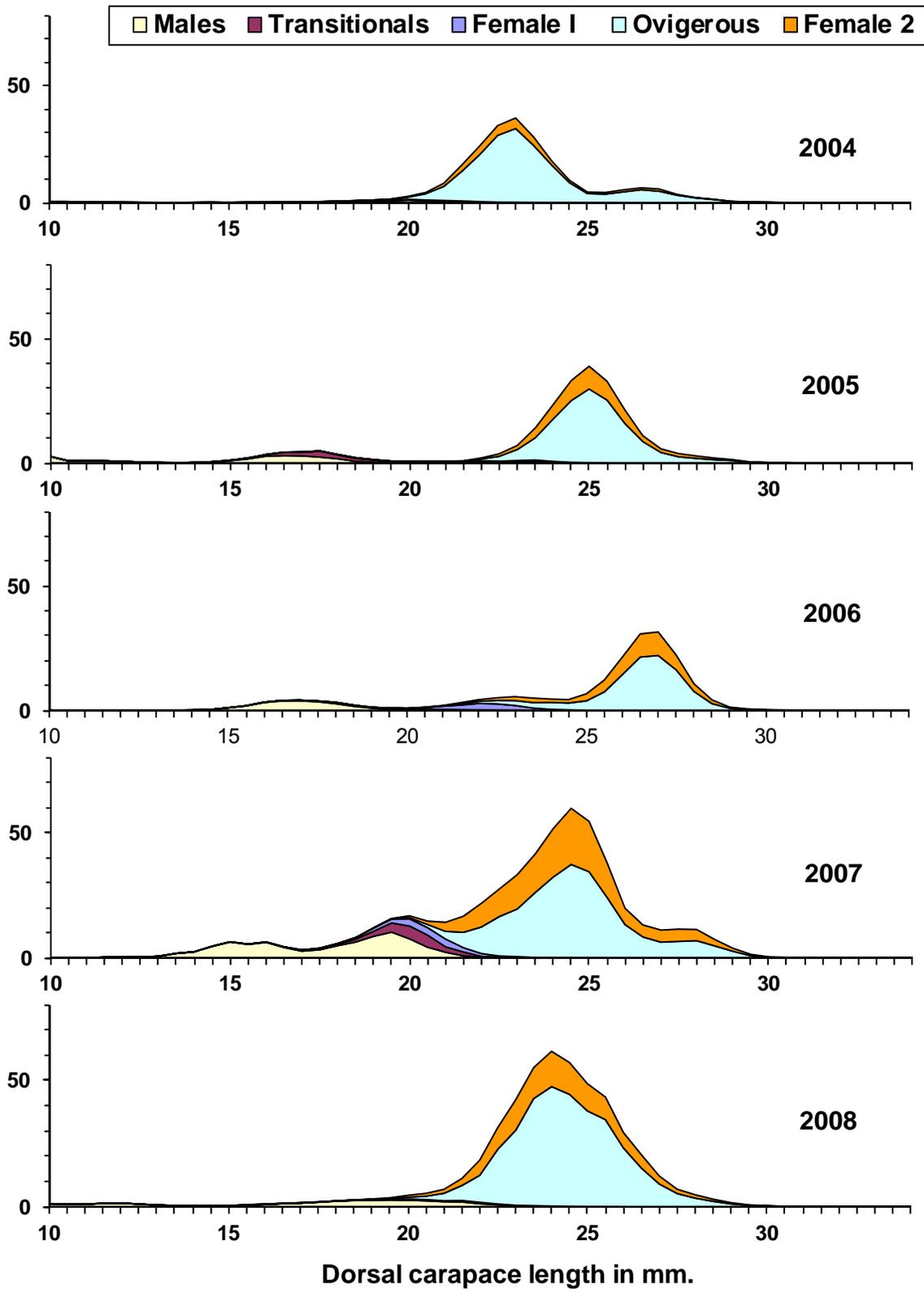


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

Landings (millions of shrimp)

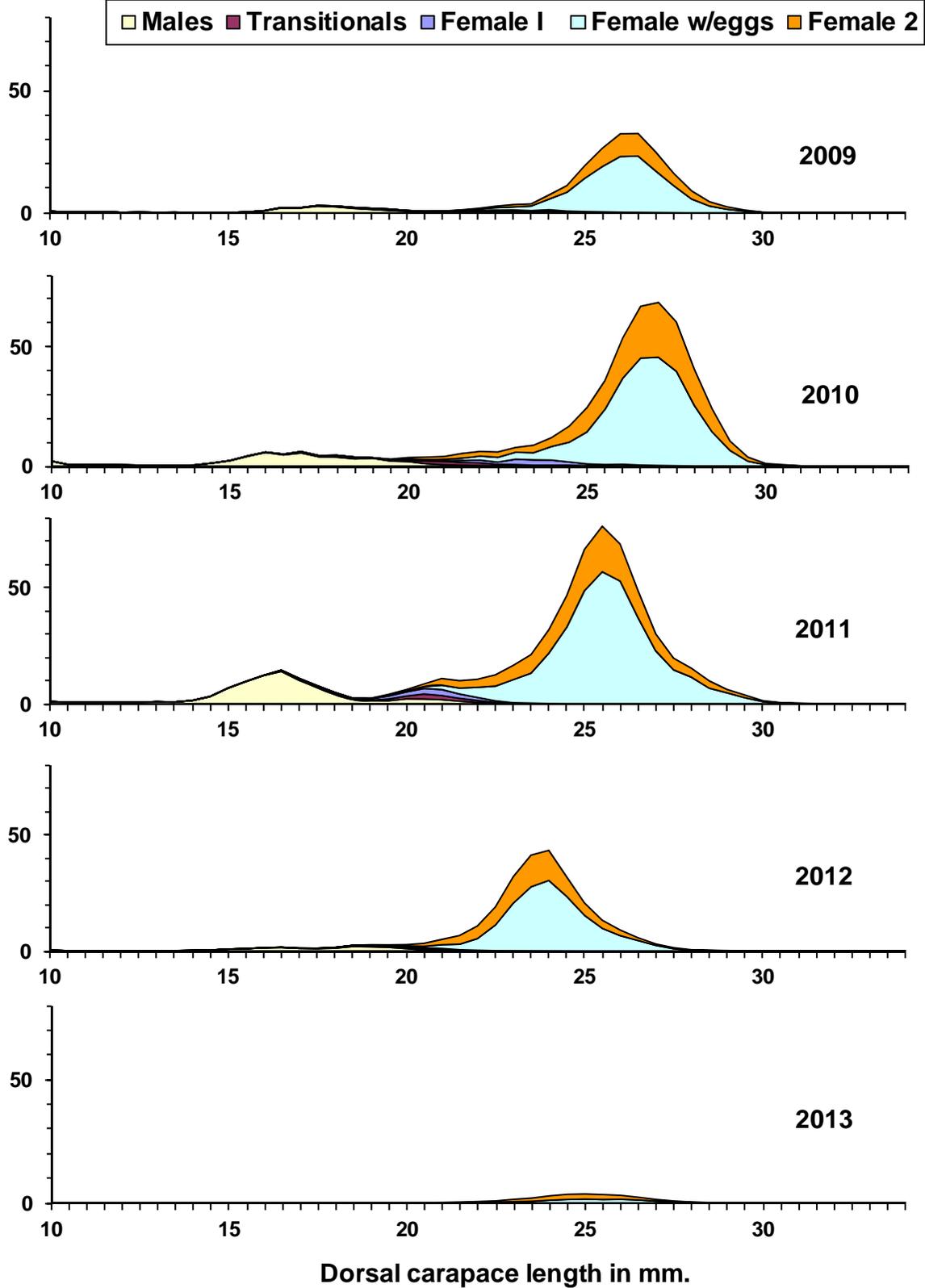


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

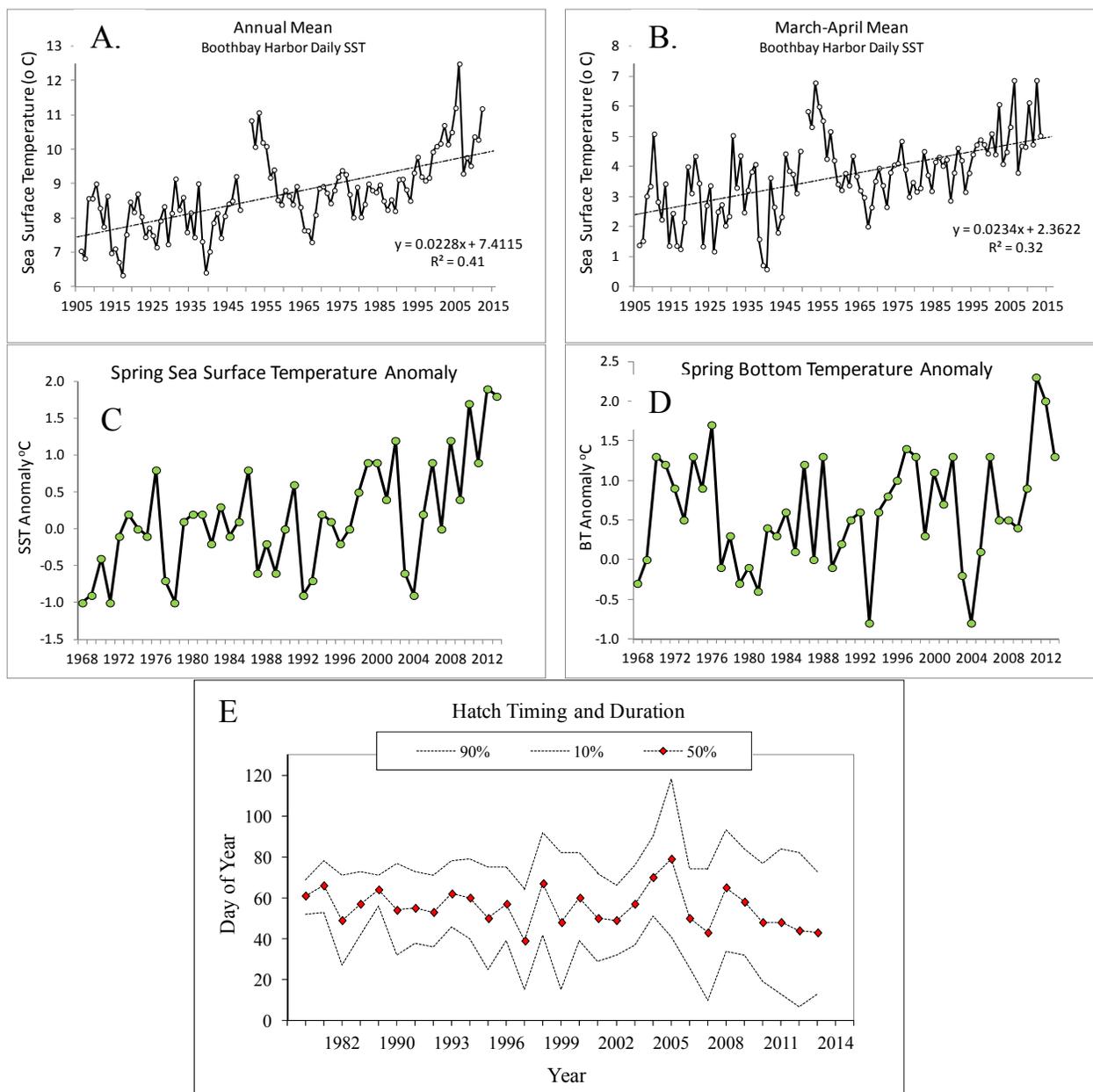


Figure C5.9(A) Average annual sea surface temperature (SST) at Boothbay Harbor, Maine, during 1906-2013 and (B) average SST during March-April, 1906-2013. (C) Spring sea surface temperature anomaly in shrimp offshore habitat areas from NEFSC trawl surveys, 1968-2013. (D) Spring bottom temperature anomaly in shrimp offshore habitat areas from NEFSC trawl surveys, 1968-2013. (E) Estimated hatch timing (10%=start, 50%=midpoint, 90%=completion) for northern shrimp in the Gulf of Maine, 1980-1983 and 1989-2013 (no data 1984-1988).

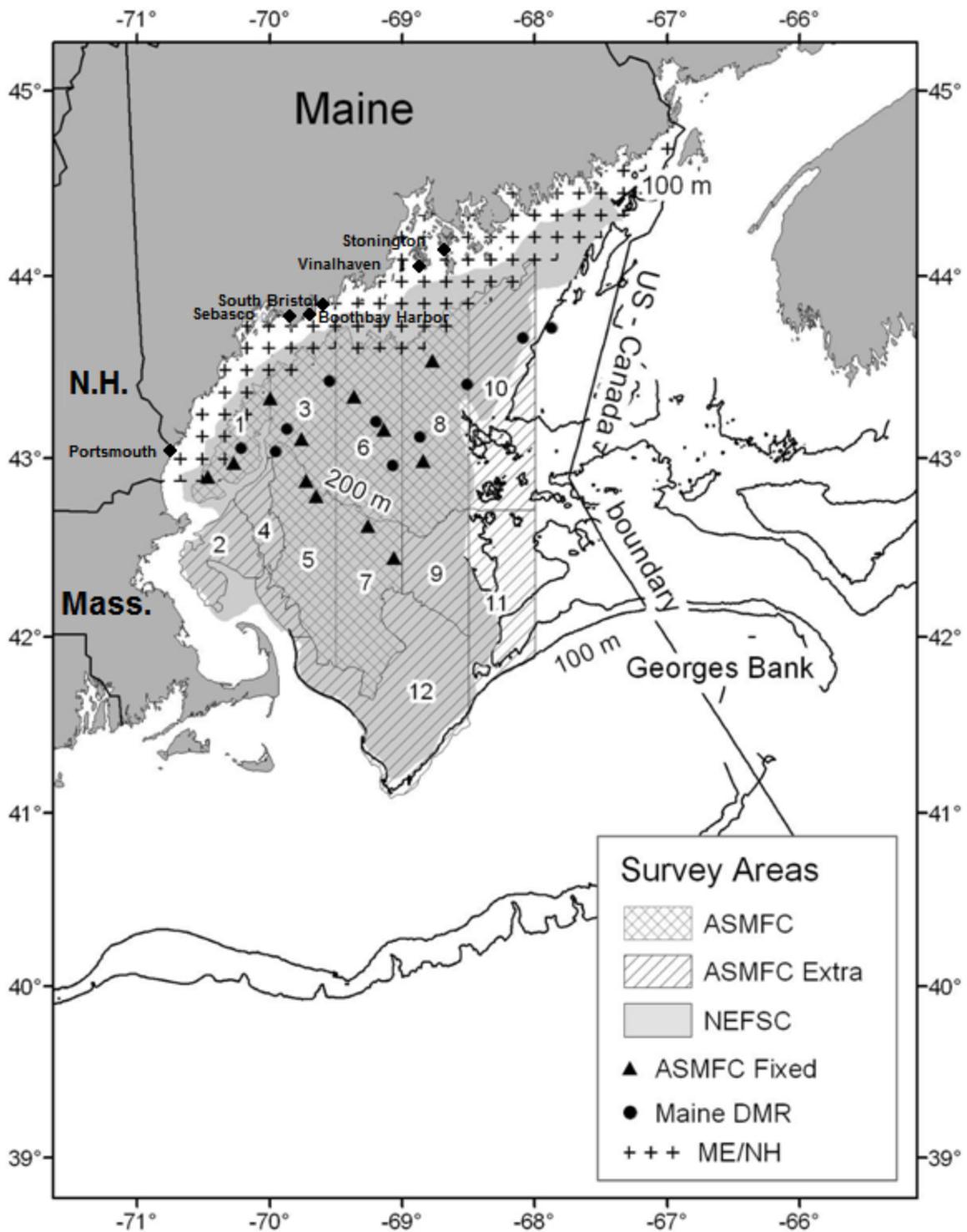


Figure C5.10. Gulf of Maine survey areas and station locations, and harbors mentioned in the text.

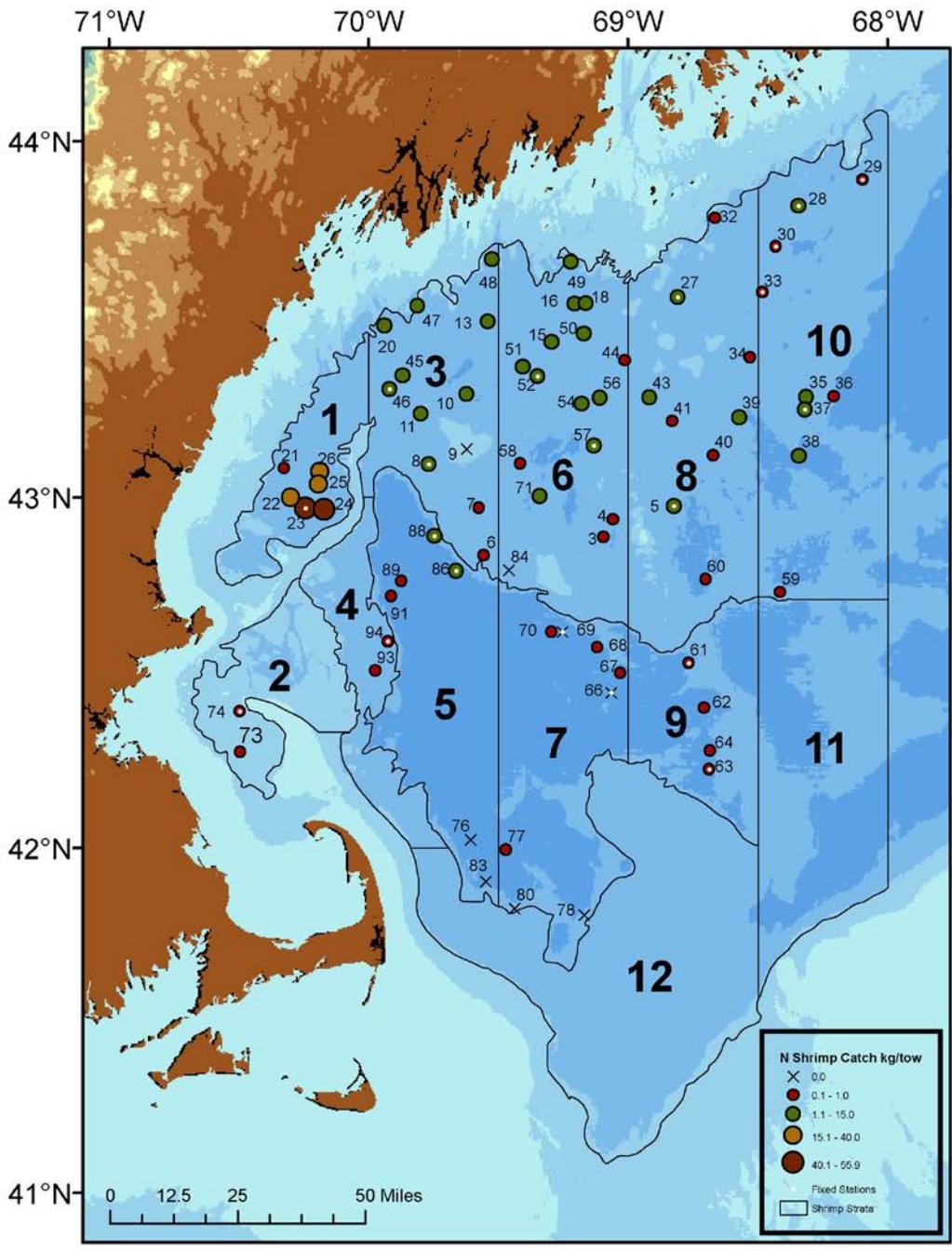


Figure C5.11. State/federal summer northern shrimp survey aboard the *R/V Gloria Michelle*, July 22 – August 14, 2013, fixed and random survey sites and shrimp catches in kg/tow.

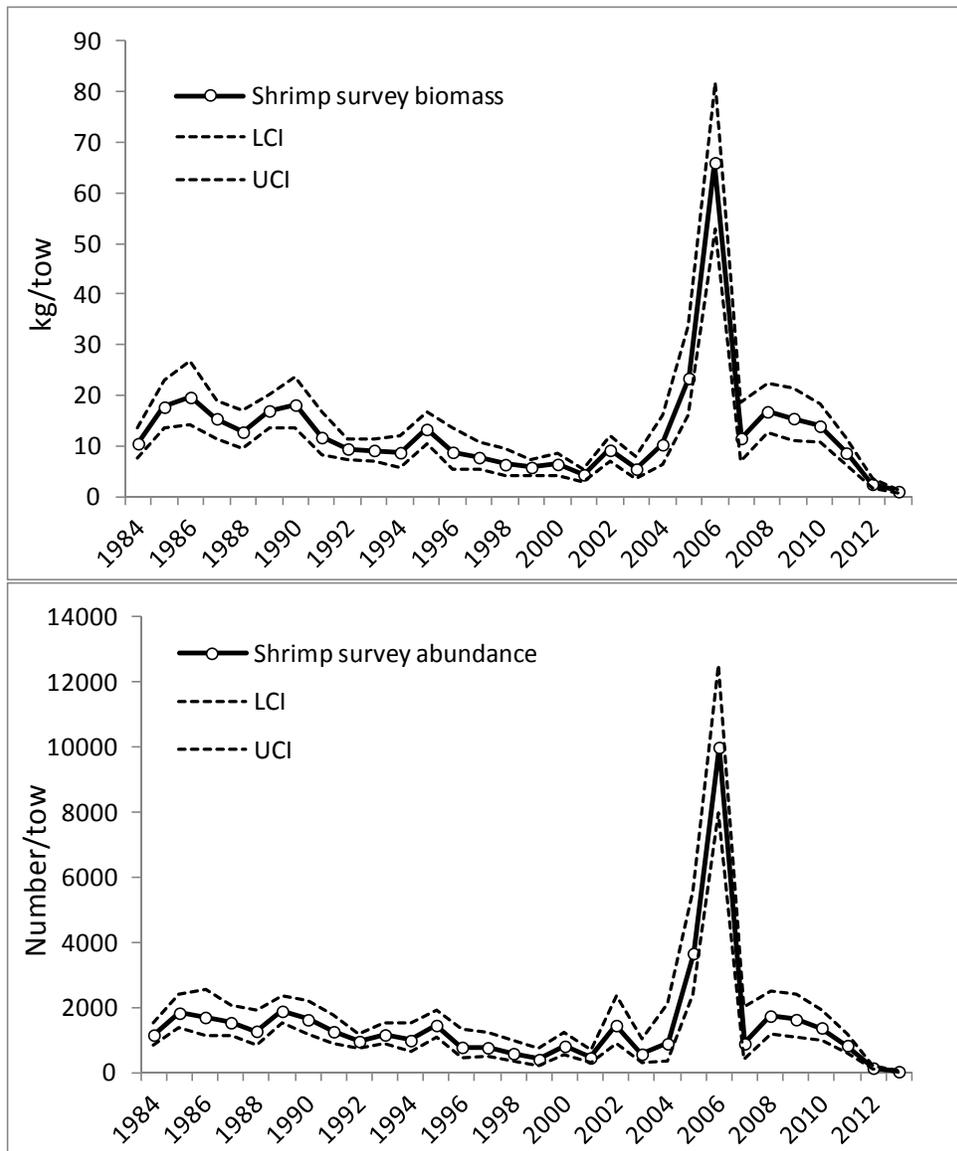


Figure C5.12. Northern shrimp survey indices with 95% confidence intervals from ASMFC summer shrimp survey. LCI lower confidence interval, UCI upper confidence interval.

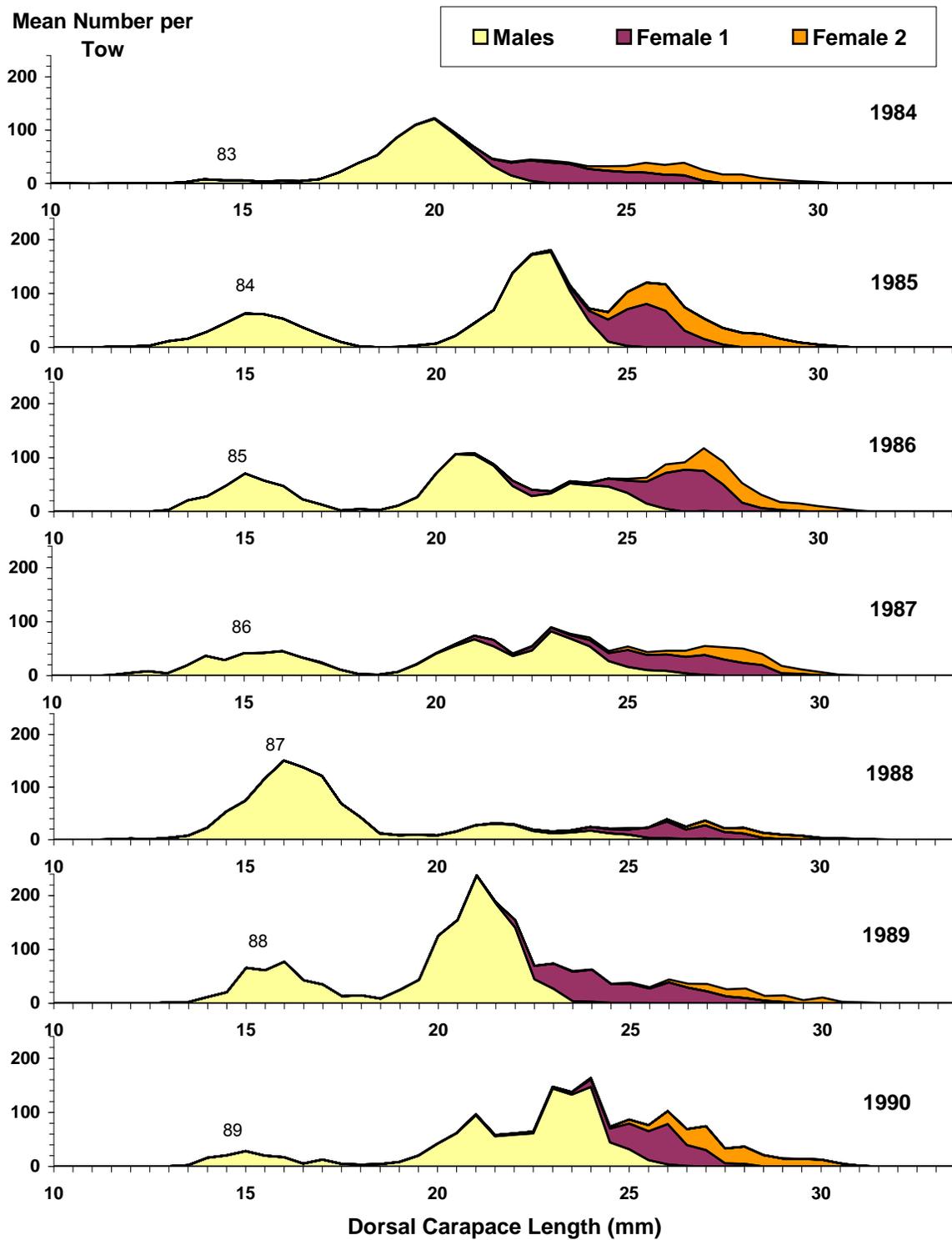


Figure C5.13. Gulf of Maine northern shrimp summer survey mean catch per tow by year, length, and development stage. Two-digit years are year class at assumed age 1.5.

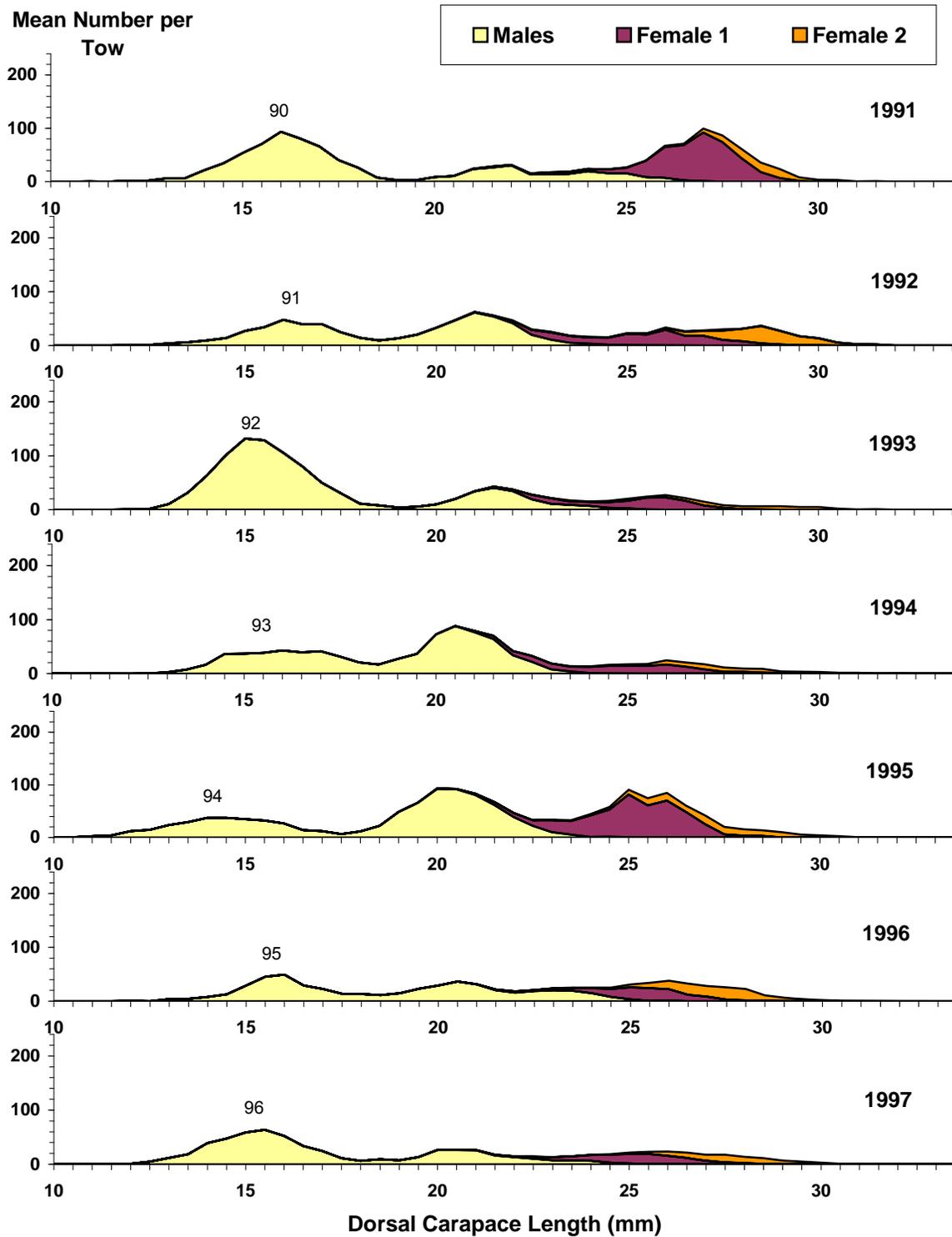


Figure C5.13 continued – summer survey.

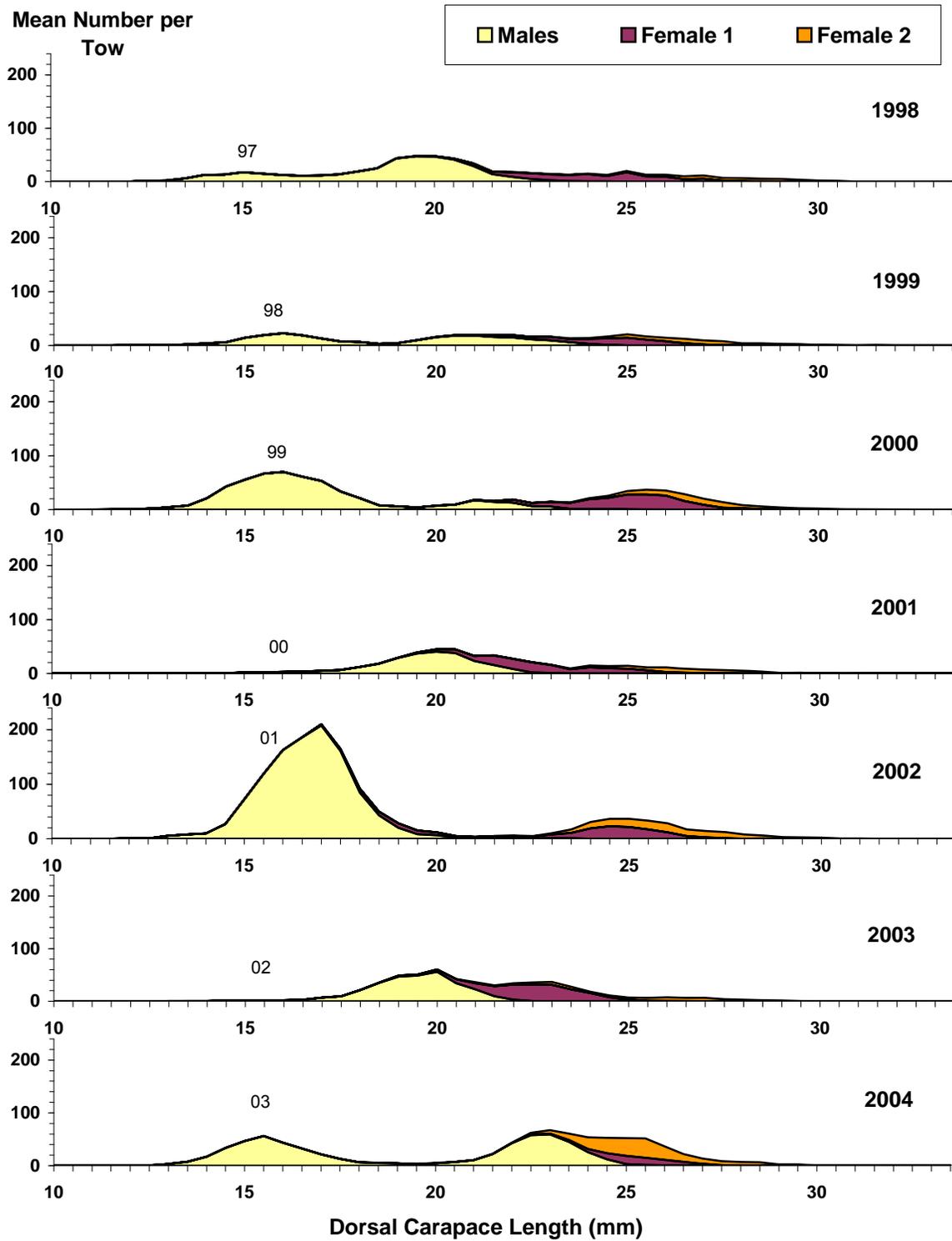


Figure C5.13 continued – summer survey.

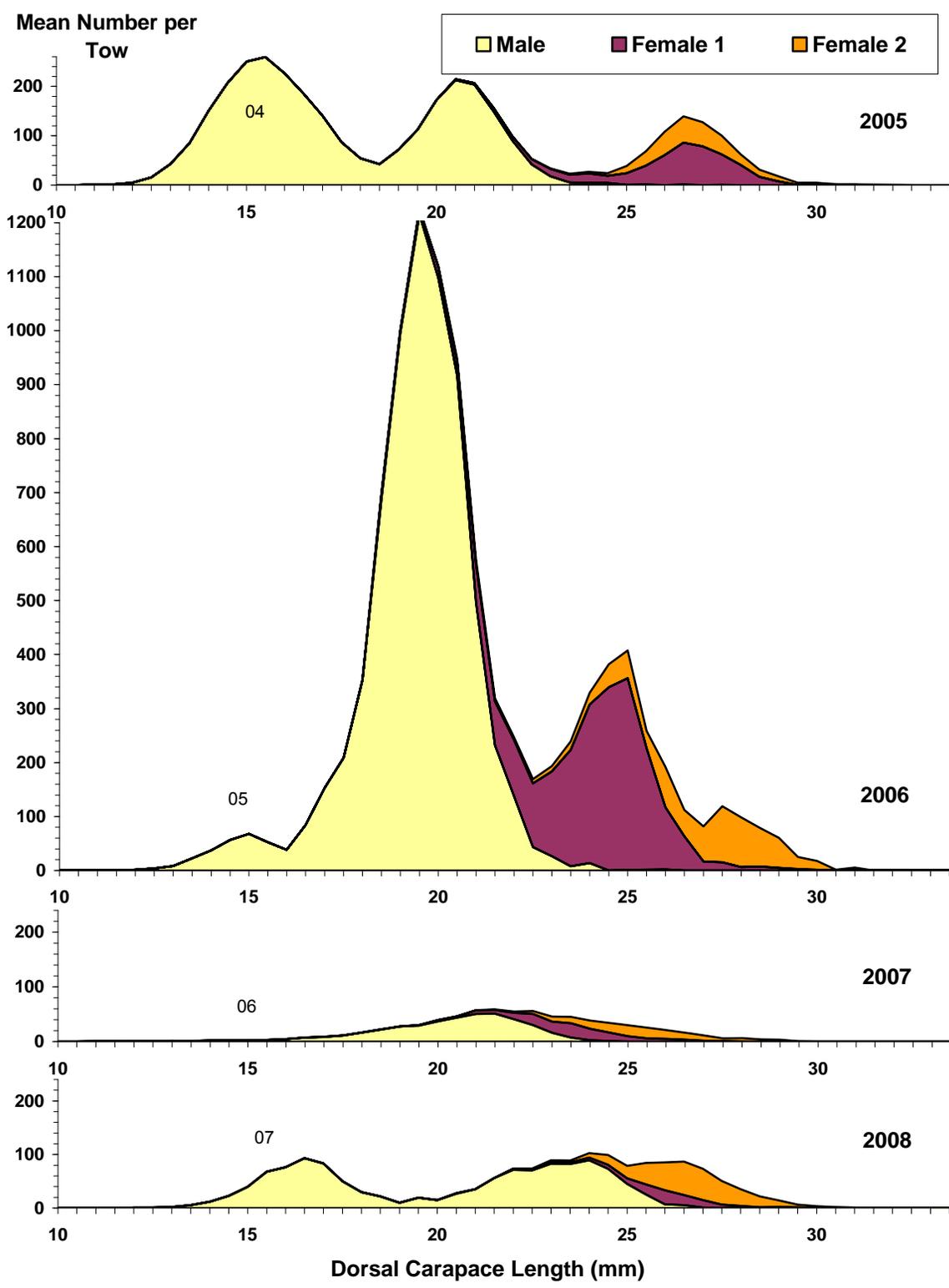


Figure C5.13 continued – summer survey.

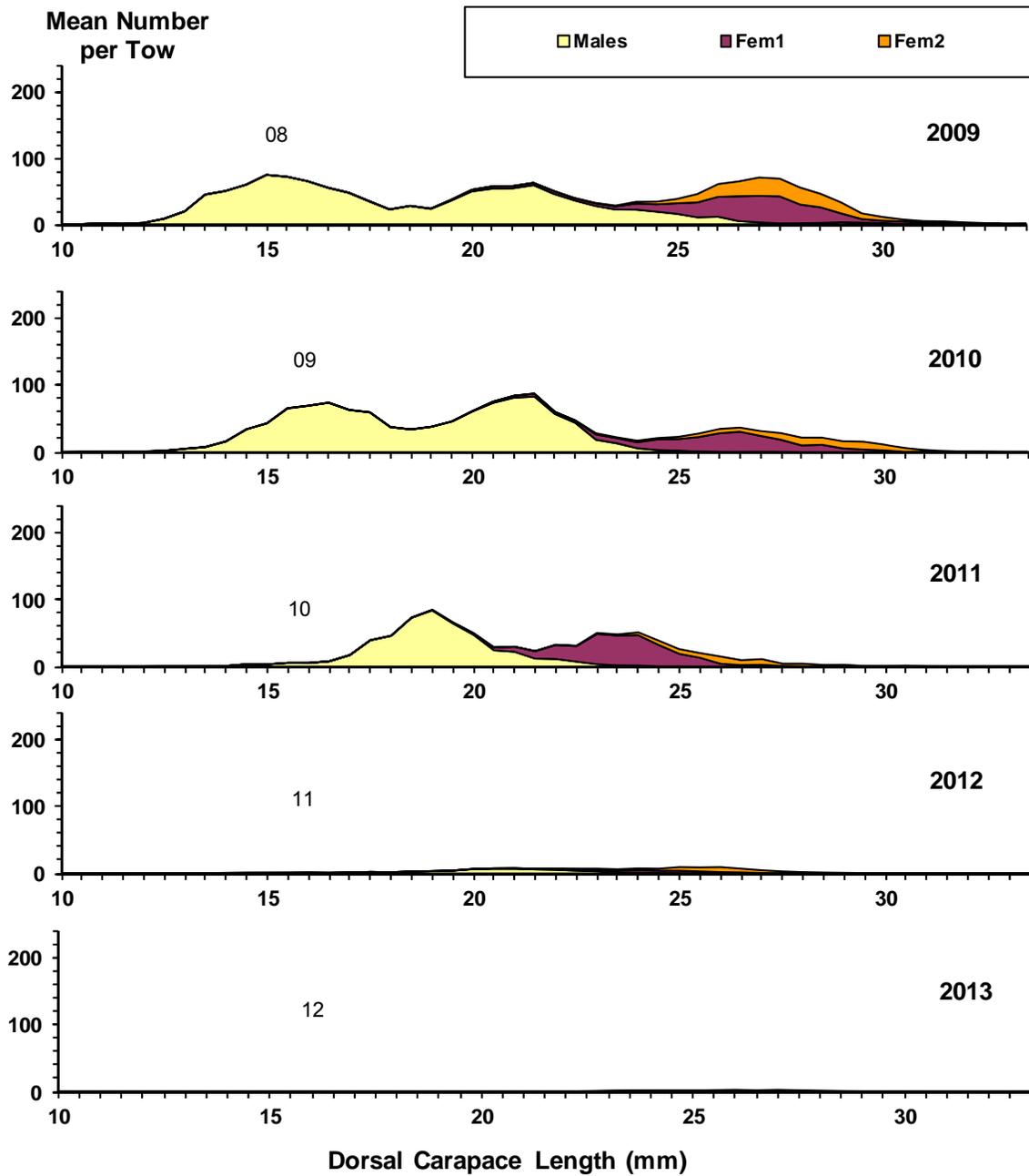


Figure C5.13 continued – summer survey.

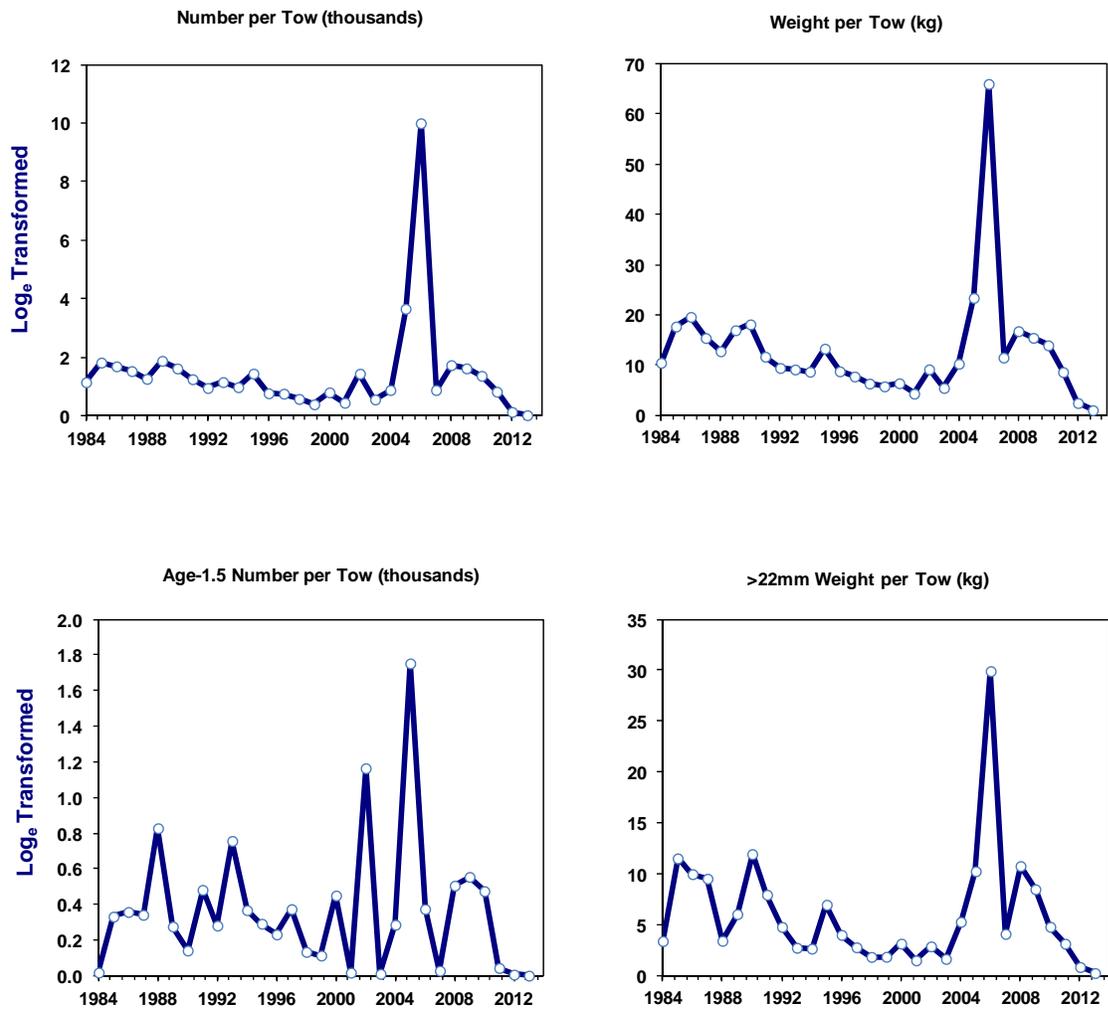


Figure C5.14. Summer survey standardized indices in number and weight for all shrimp (top), age 1.5 (bottom left), and fully-recruited shrimp (bottom right).

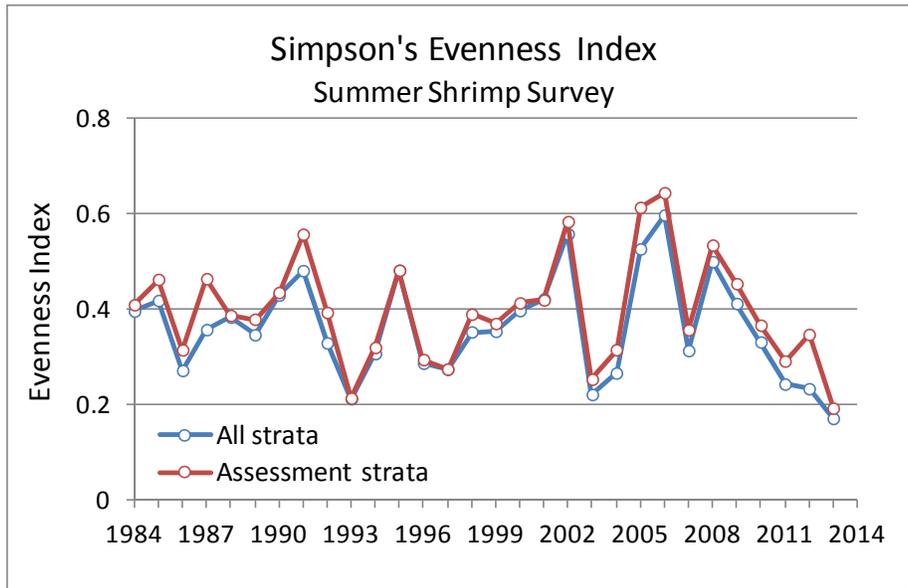


Figure C5.15. Simpson's evenness index (Payne et al. 2005) for northern shrimp in the Gulf of Maine based on summer shrimp survey catches

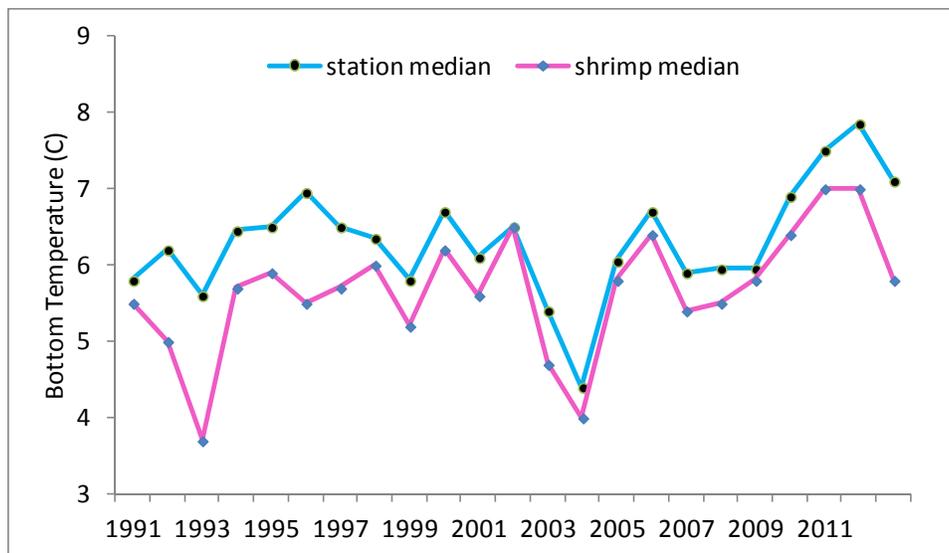


Figure C5.16. Median temperature at sampling stations in summer shrimp survey vs. catch-weighted-median temperature.

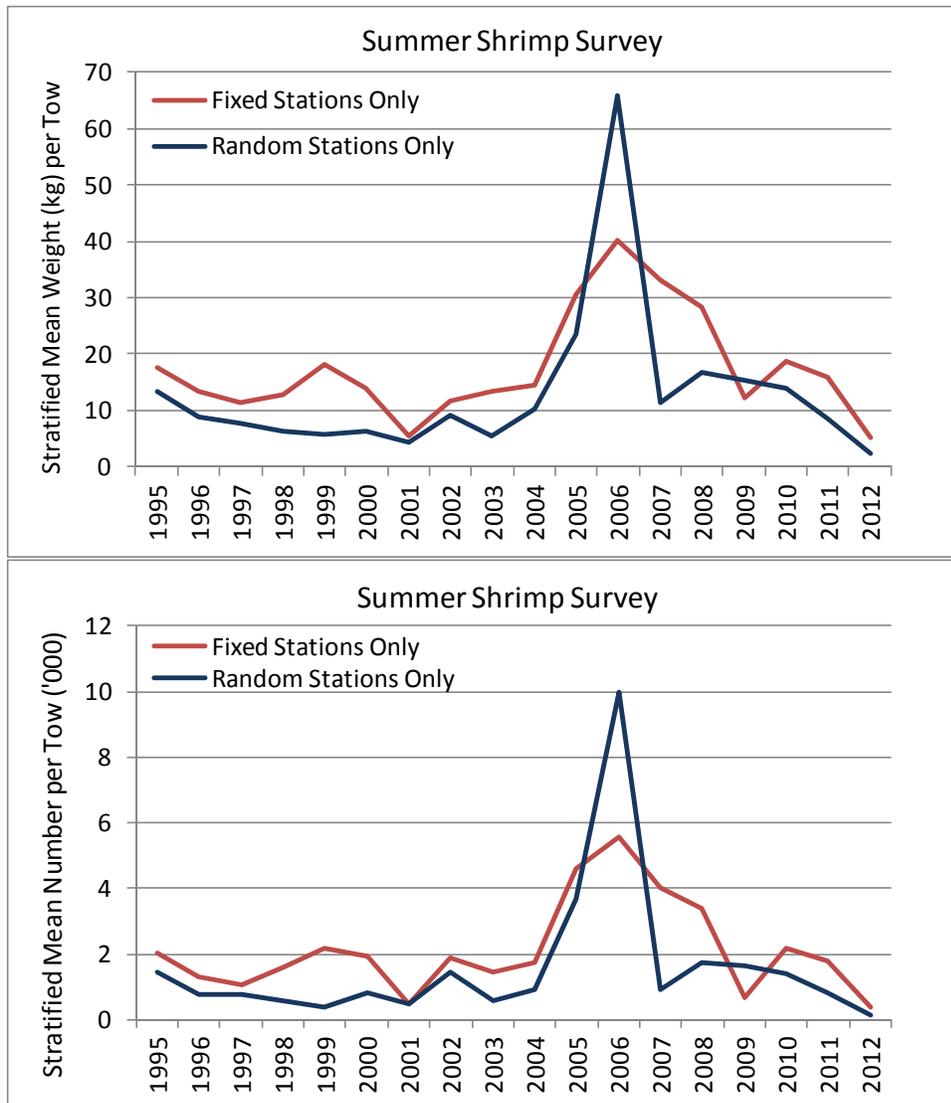


Figure C5.17. Comparison of survey indices from summer shrimp survey based on random stations or fixed stations. All indices \log_e transformed.

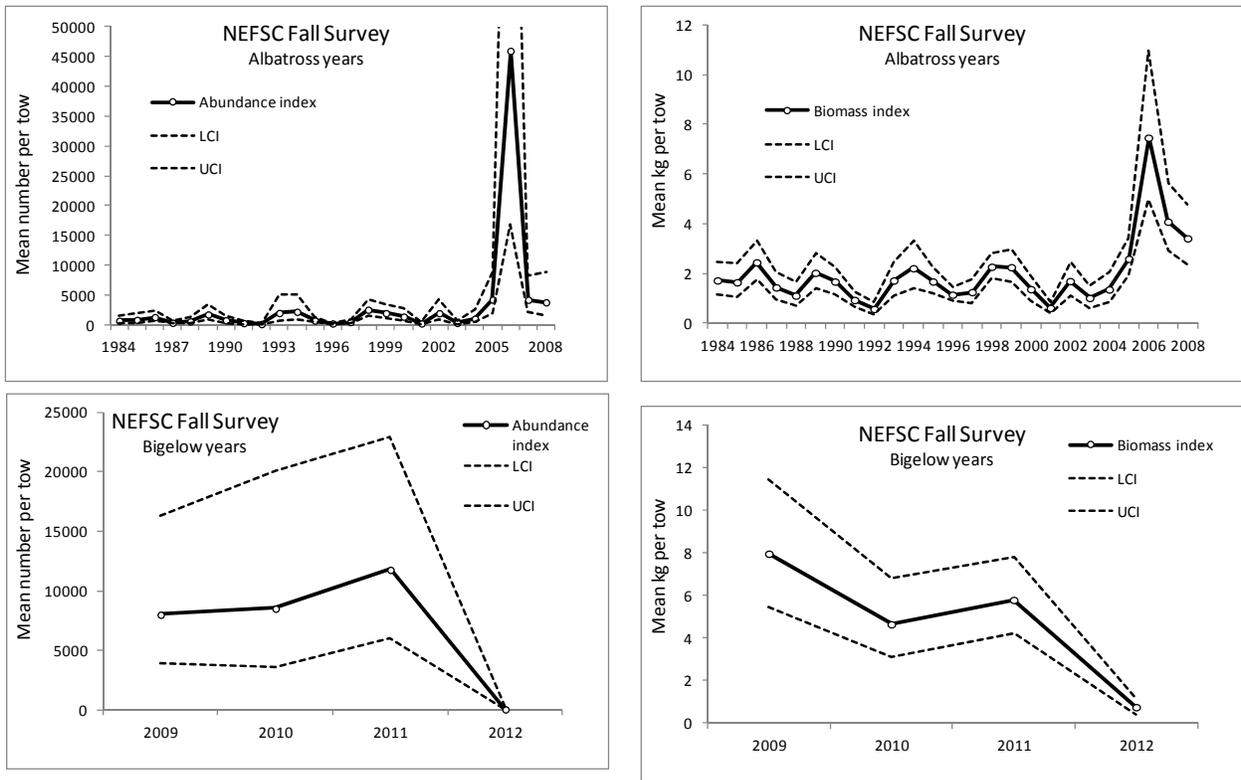


Figure C5.18. Survey indices with 95% confidence intervals for northern shrimp from the NEFSC fall survey, Albatross years (1984-2008) and Bigelow years (2009-2012).

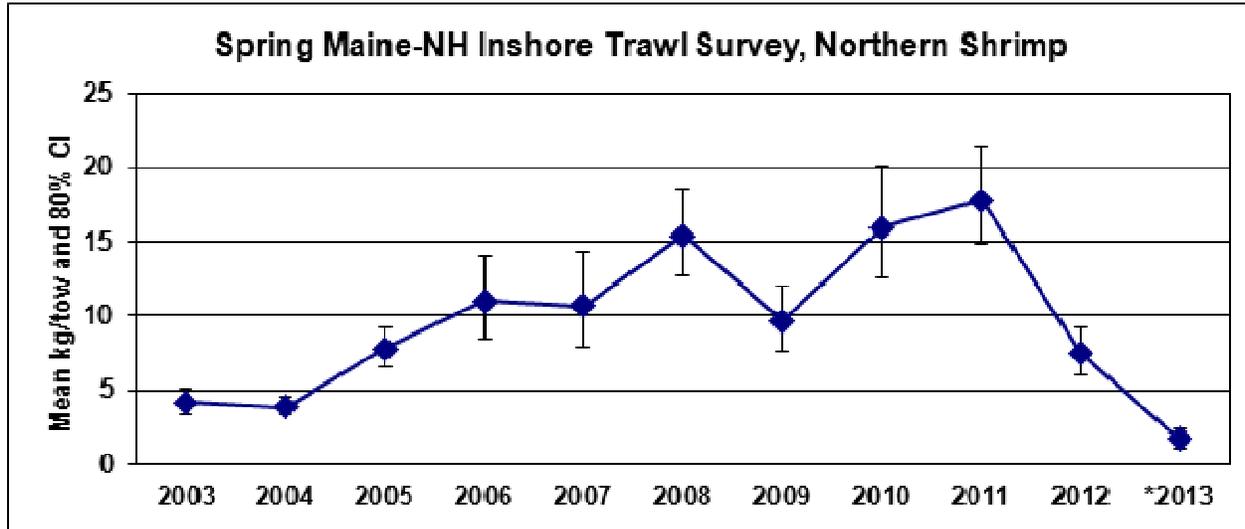


Figure C5.19. Spring Maine-New Hampshire inshore trawl survey northern shrimp biomass indices, with 80% confidence intervals. *2013 data are preliminary.

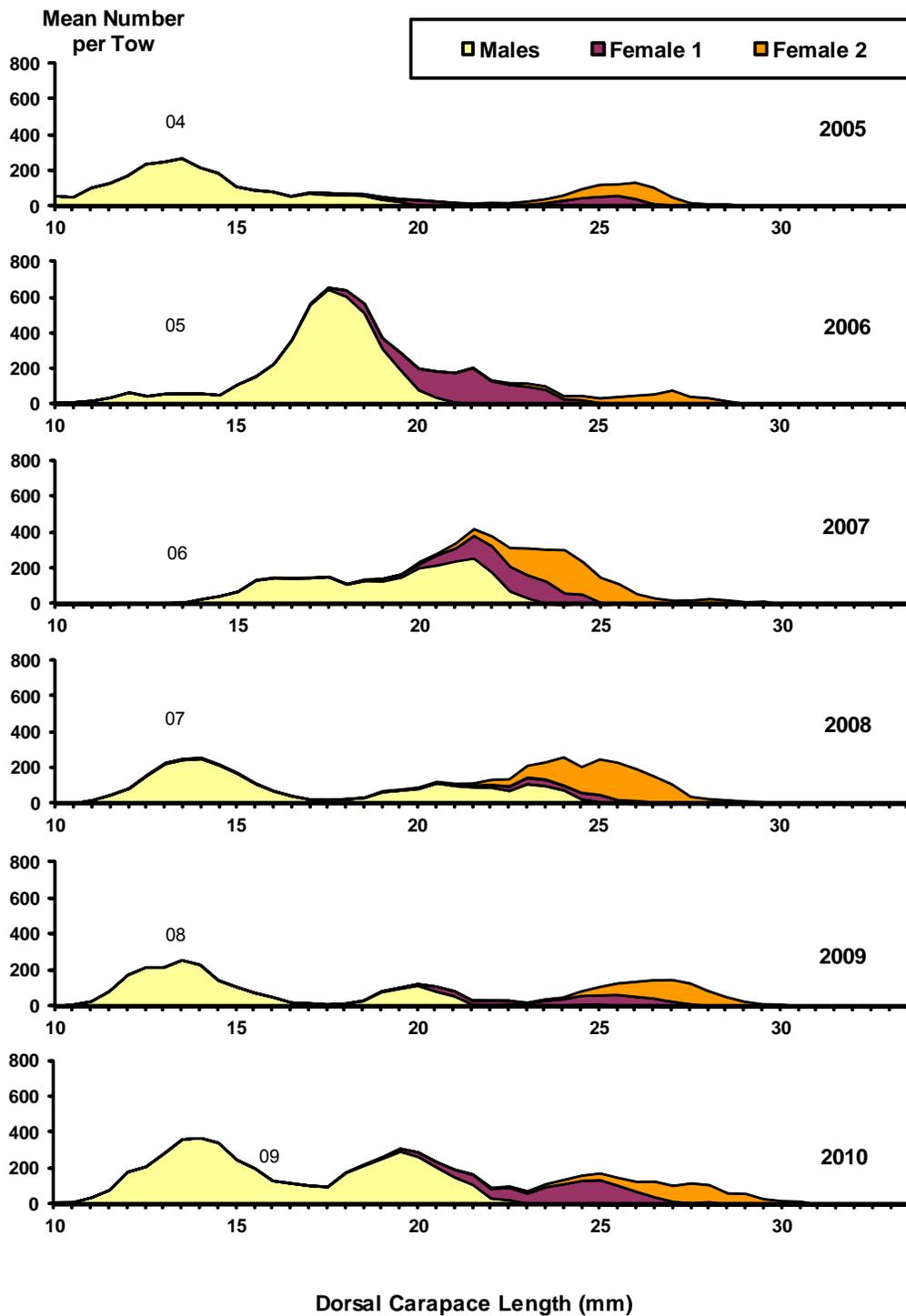


Figure C5.20. Maine-New Hampshire spring inshore survey; northern shrimp untransformed mean catch per tow by year, length, and development stage. Two-digit years are the year class at assumed age 1.

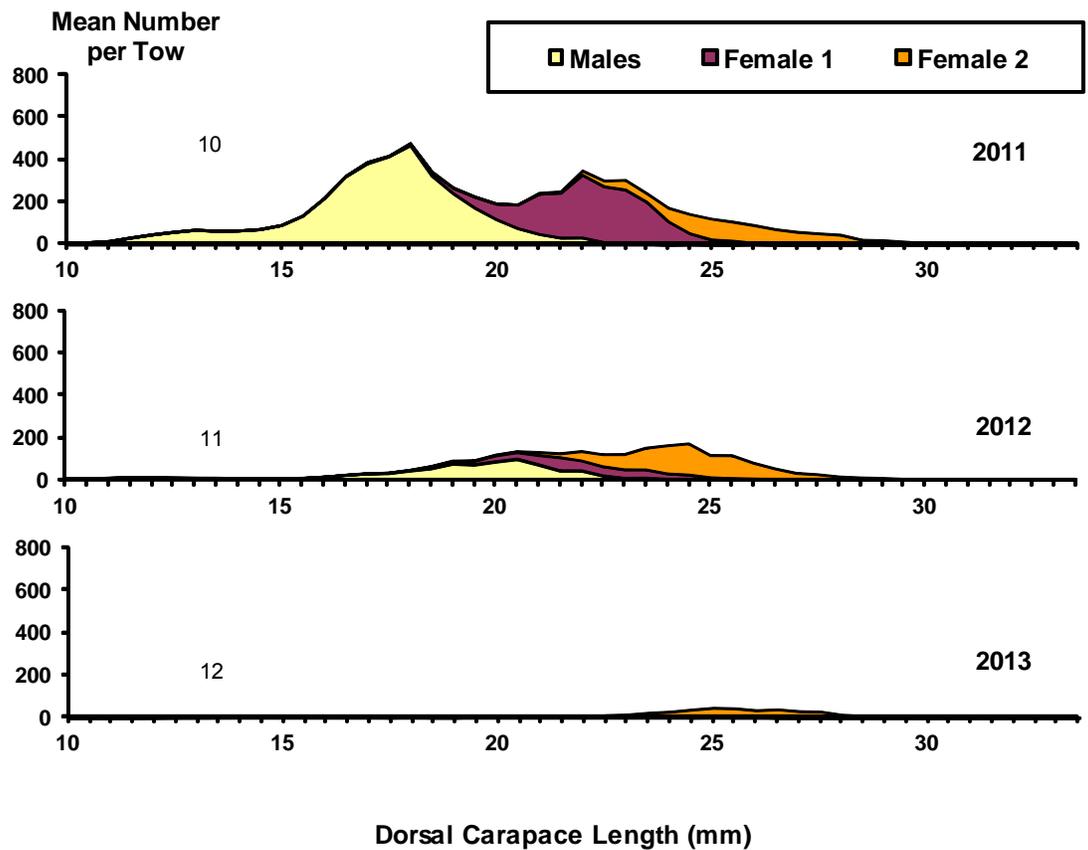


Figure C5.20 continued - ME/NH spring inshore survey.

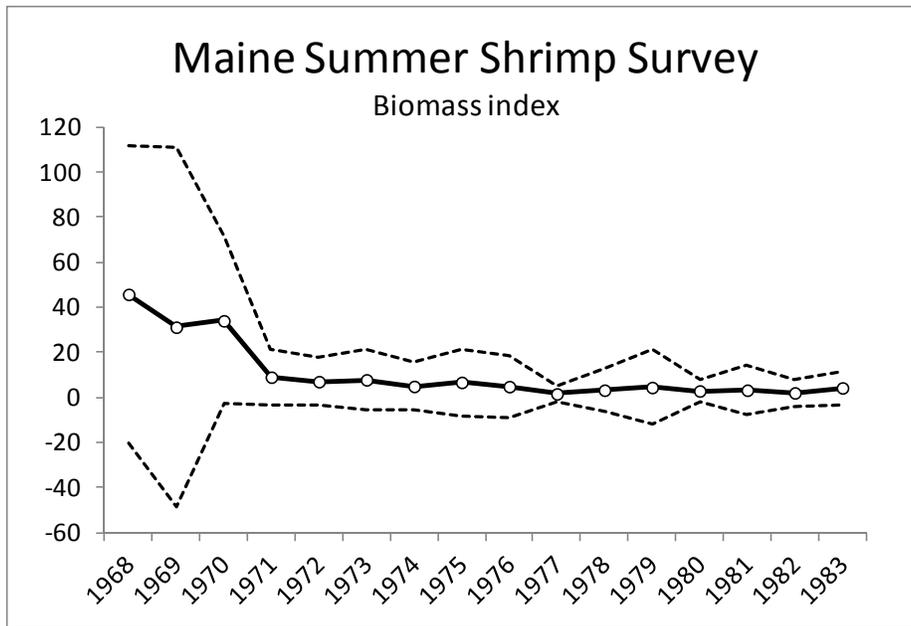


Figure C5.21. Biomass indices and 95% confidence intervals for State of Maine summer shrimp survey conducted during 1968-1983.

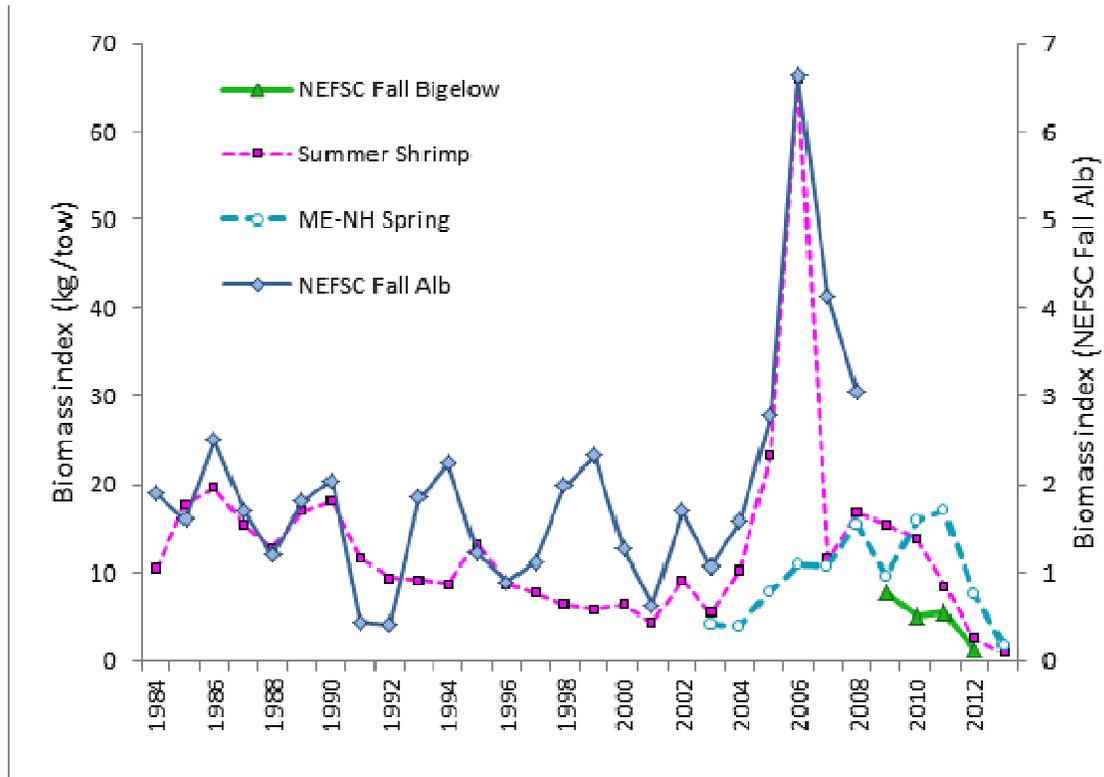


Figure C5.22. Biomass indices (kg/tow) from various northern shrimp surveys in the Gulf of Maine.

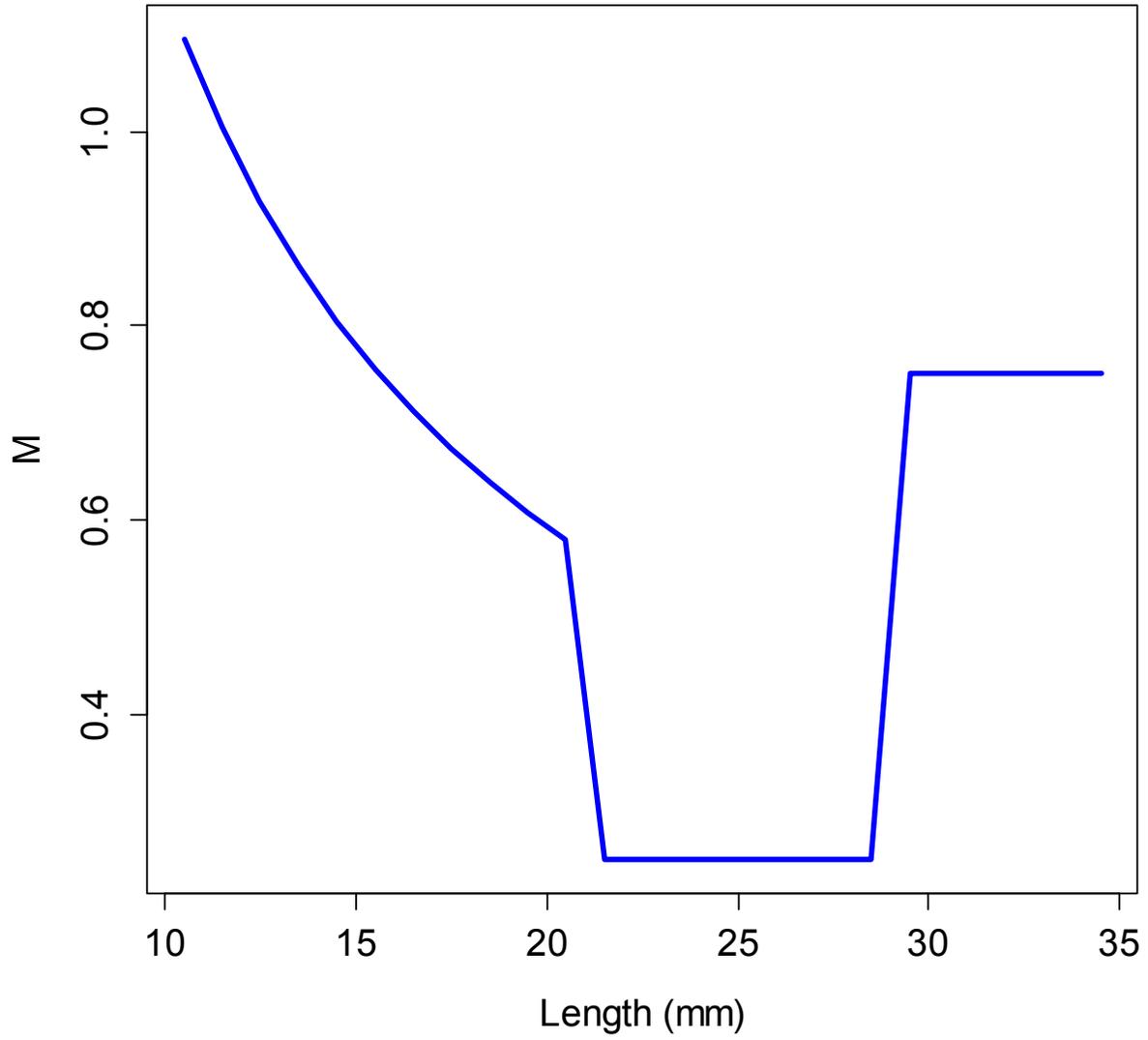


Figure C6.1. Natural mortality (U-shaped) used in the UMaine base run (see table 1).

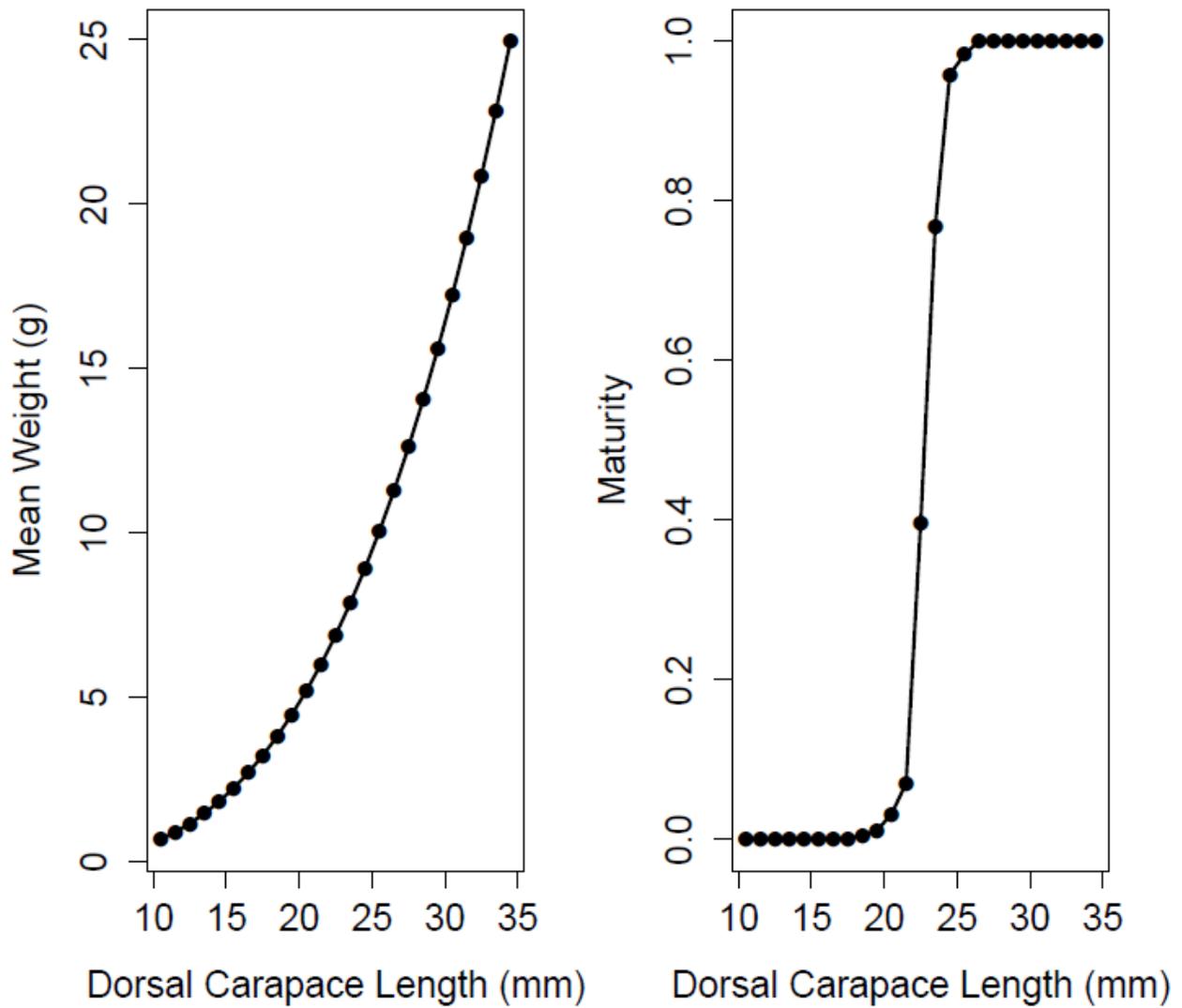


Figure C6.2. Weight-at-length (data were obtained from Haynes and Wigley 1969) and maturity-at-length in 2000 (data were obtained from ASMFC summer survey) of Northern shrimp in the Gulf of Maine.

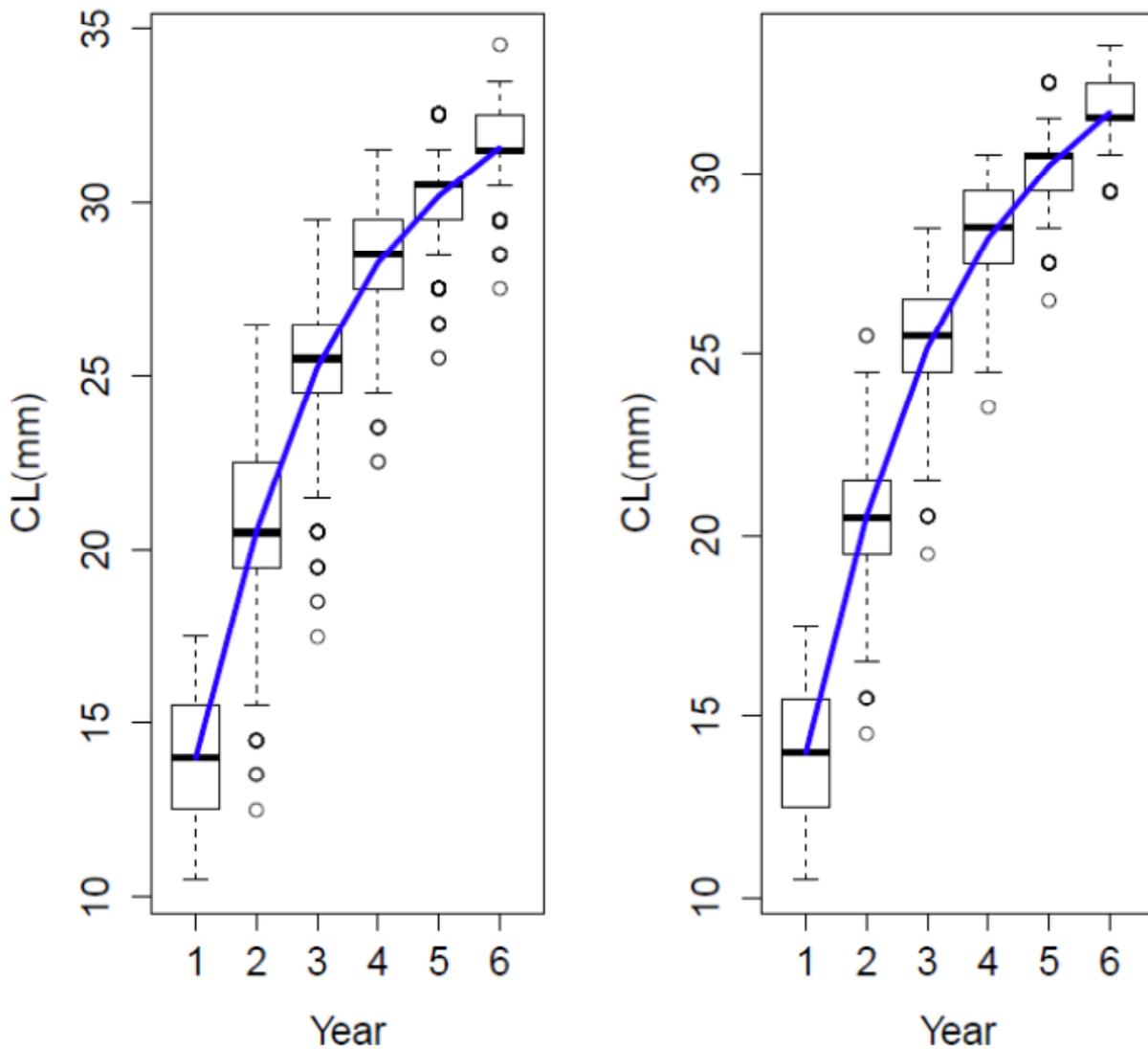


Figure C6.3. Apparent growth of a cohort with no fishing mortality estimated in the UMaine model base run (Left graph is for growth time block 1 and right graph is for growth time block 2 defined in the study to reflect potential impacts of different environment on growth; Table 2). Age values in the X-axis are relative ages. The curves were calculated using the growth transition matrices incorporated in the UMaine model.

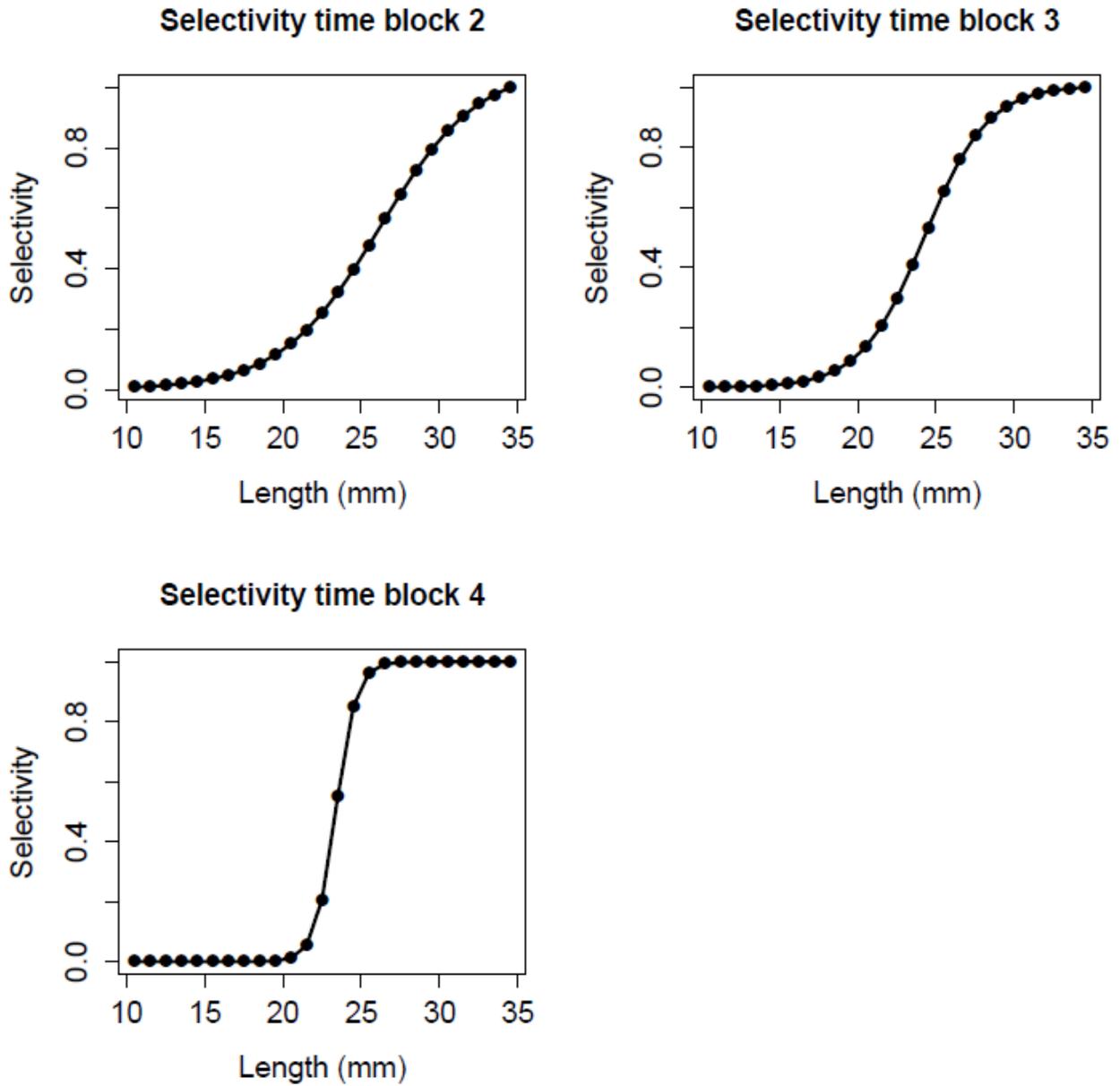


Figure C6.4. Selectivity patterns from the UMaine model base run for each of the fisheries (block 2=mixed fleet; block 3=trawl fleet; block 4=trap fleet).

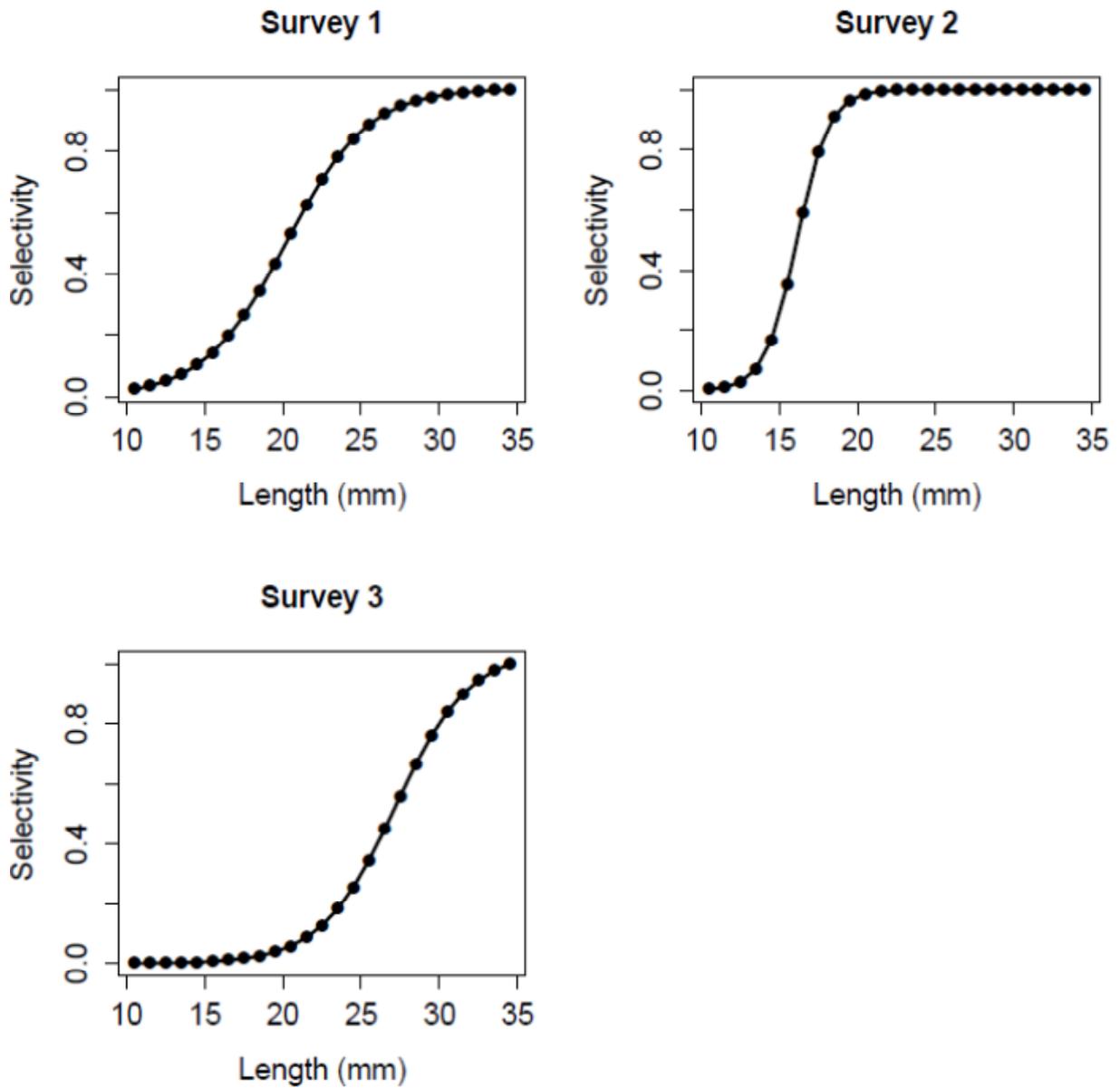


Figure C6.5. Selectivity patterns from the UMaine model base run for each of the surveys (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey)

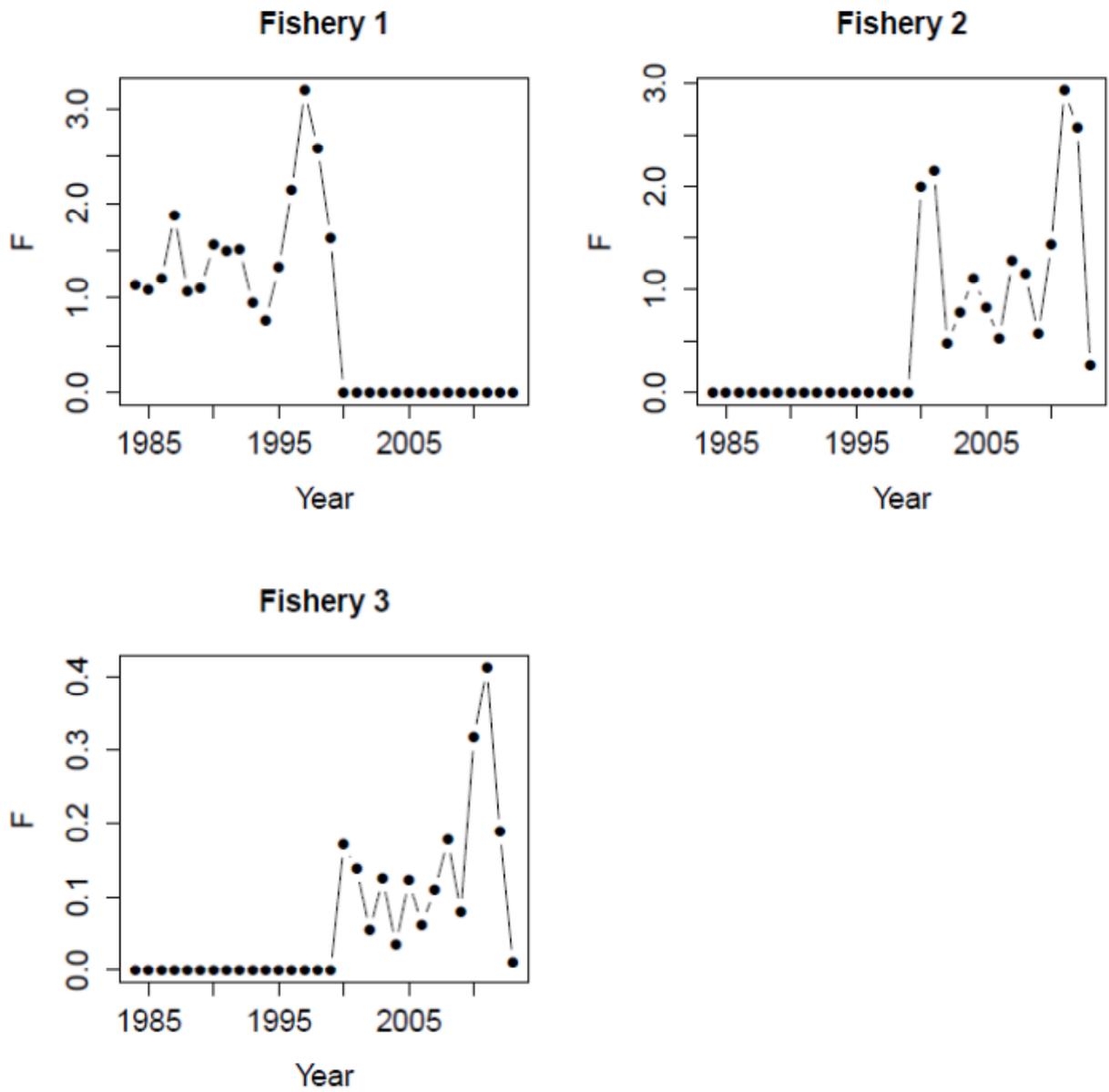


Figure C6.6. Fishing mortality from the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

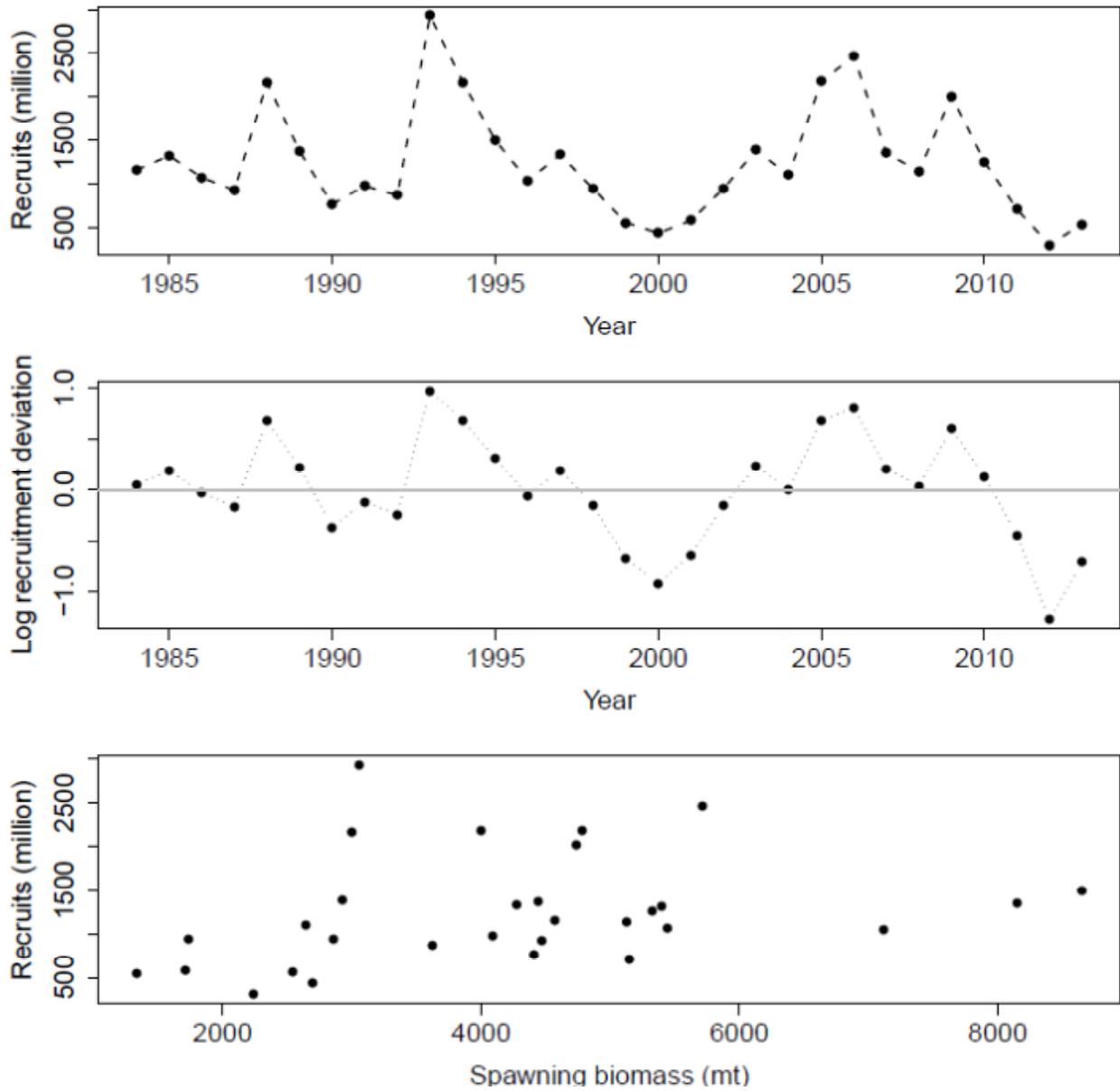


Figure C6.7. Recruitment pattern from UMaine model base run.

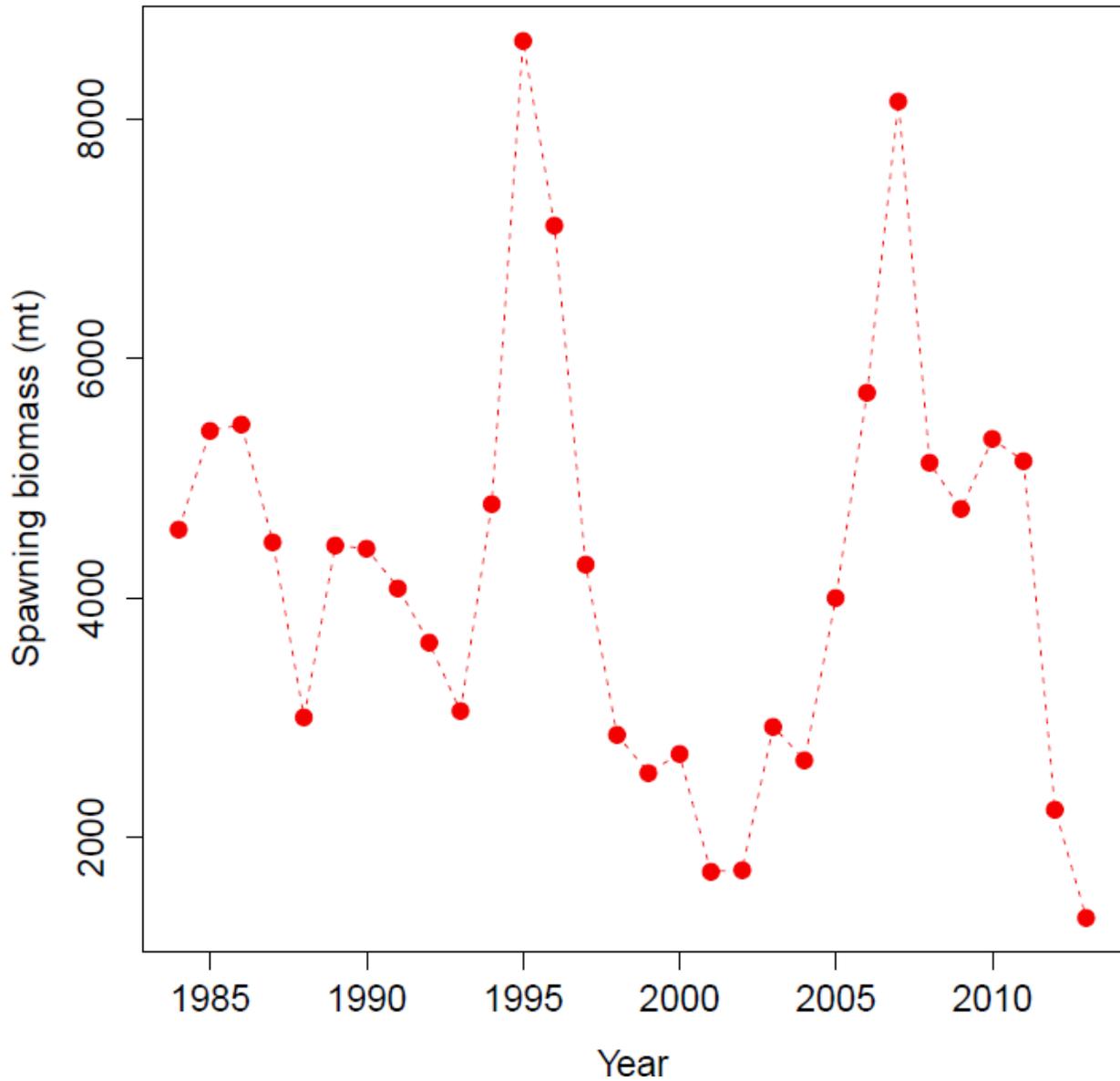


Figure C6.8. Estimates of spawning stock biomass for the UMaine model base run. The spawning stock biomass is measured as the total biomass of females on March 1.

Beginning of year expected numbers at length

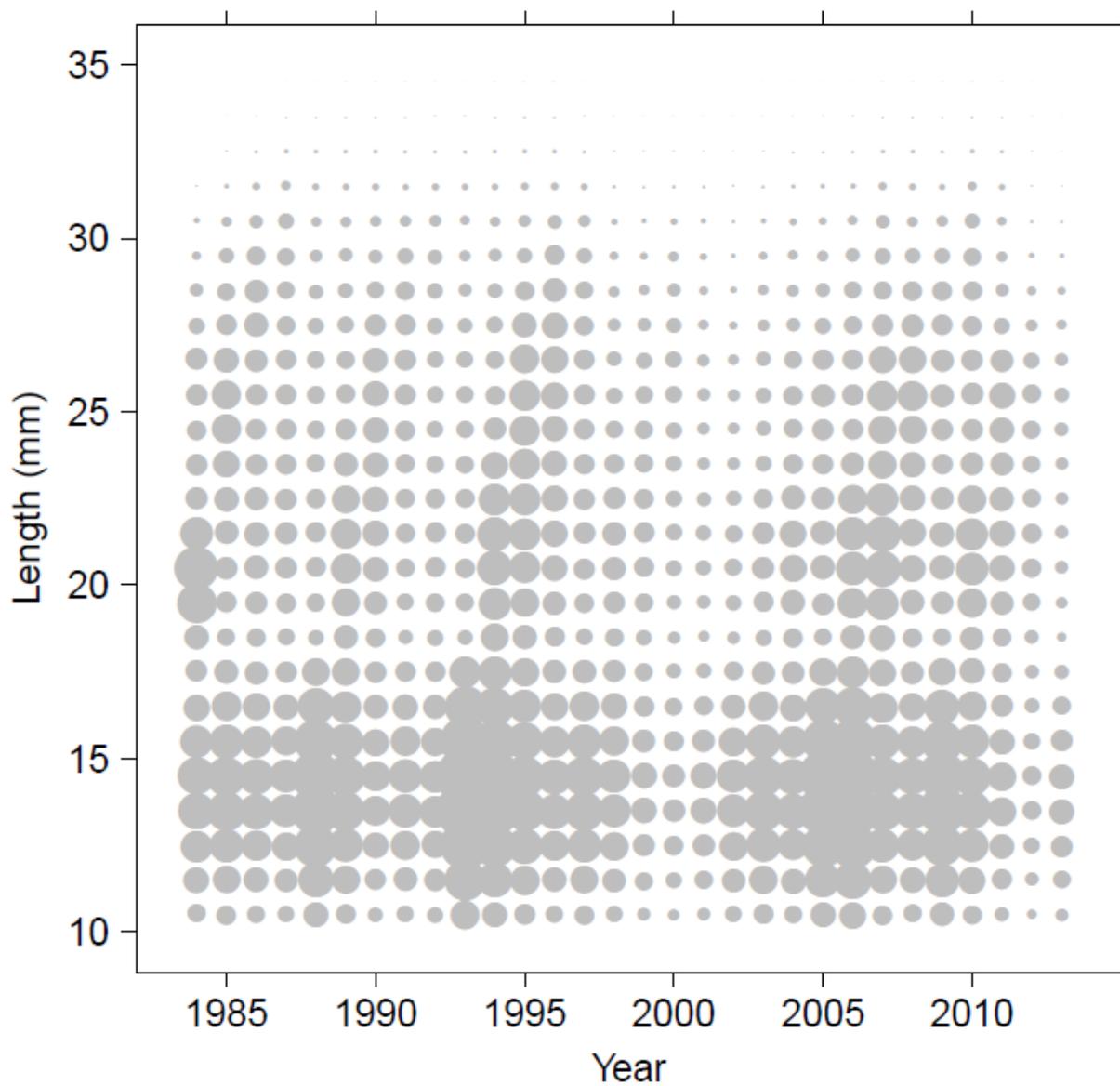


Figure C6.9. "Bubble plot" of the proportion of the estimated abundance at the beginning of each year. Sizes of the bubbles are proportional to the values of abundance.

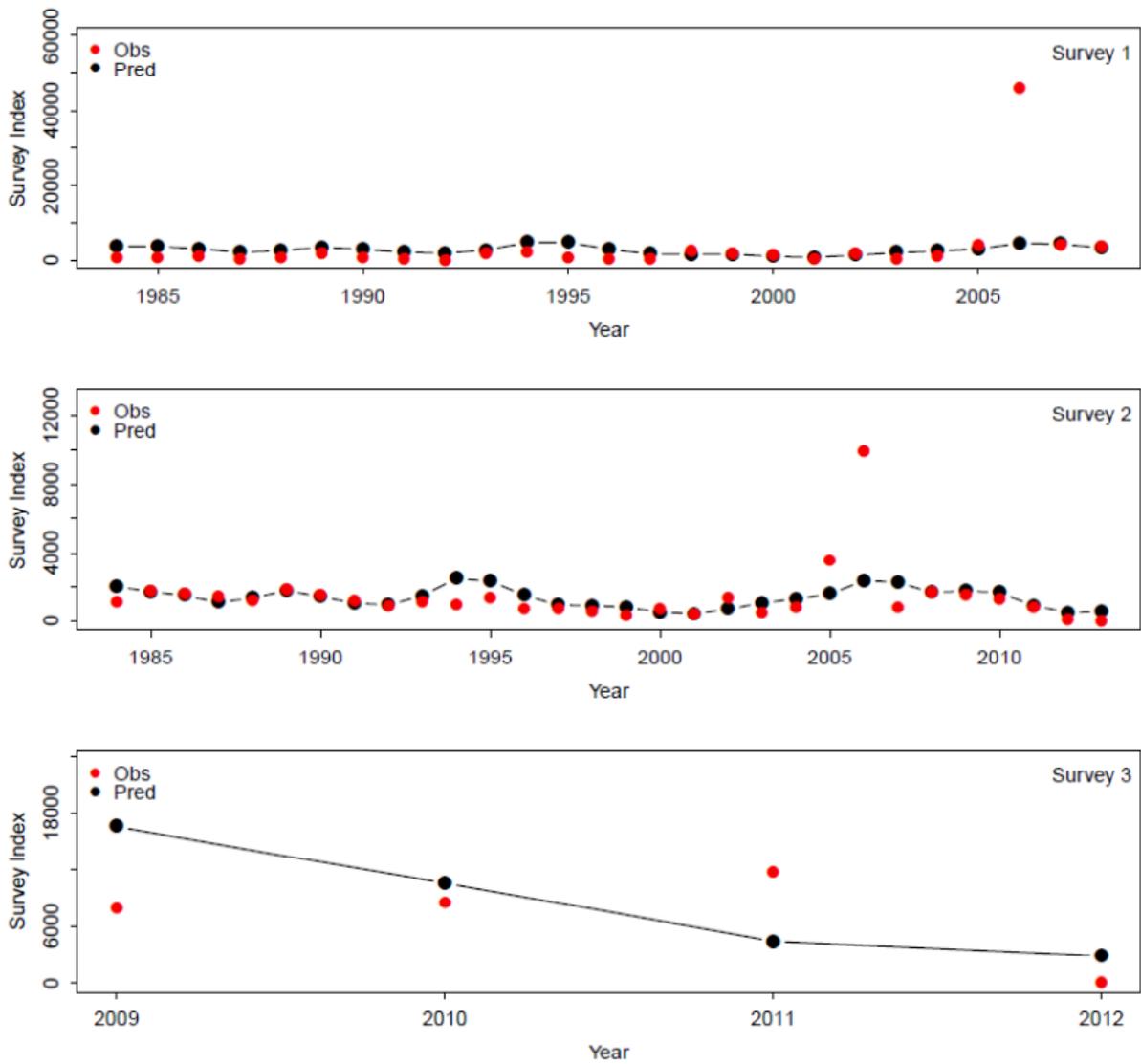


Figure C6.10. Observed (dot) and predicted (line) survey indices for northern shrimp in the UMaine model base run (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey).

Length Comp, aggregated across time by survey ,red line=Obs

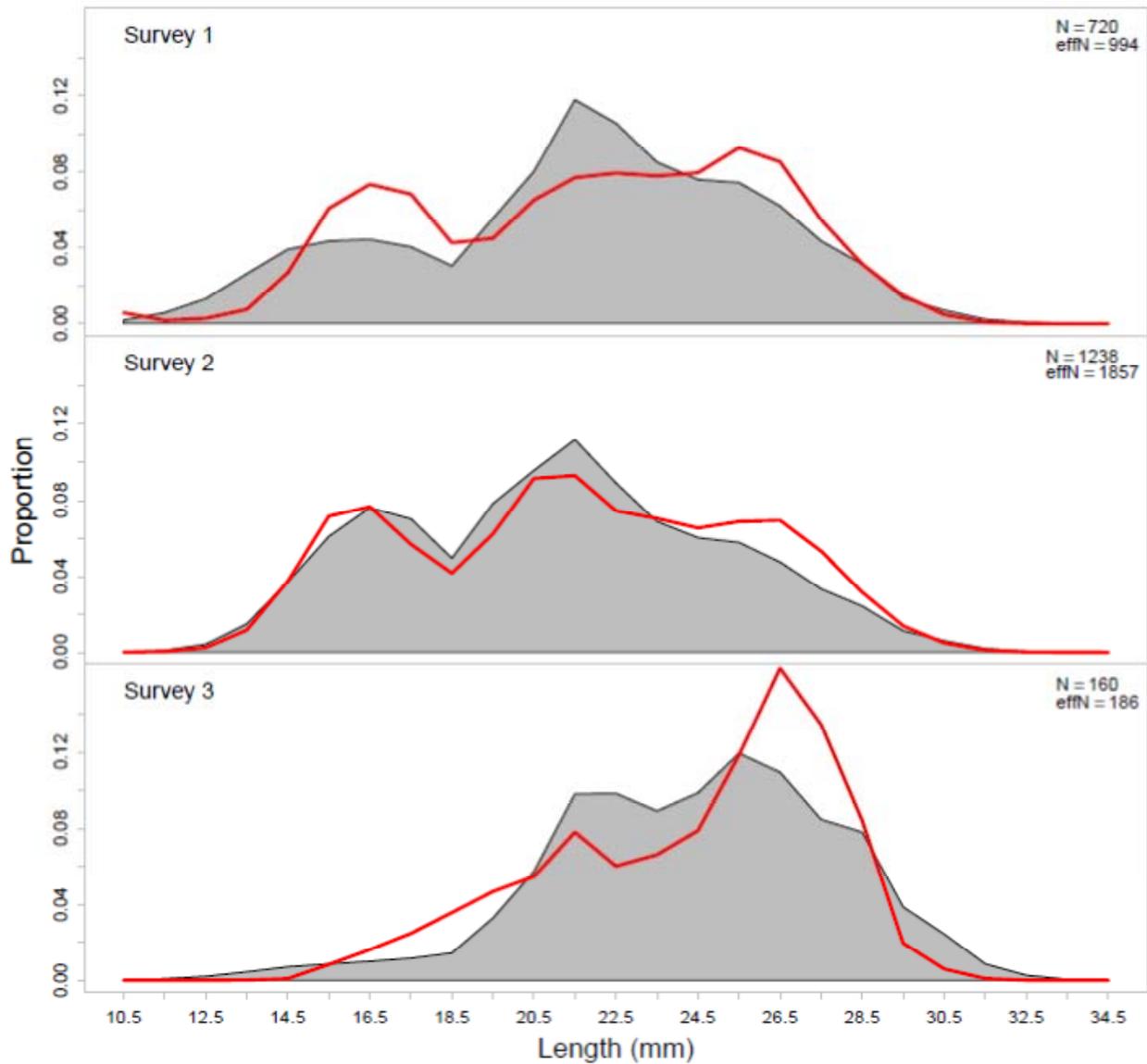


Figure C6.11. Observed (red line) and predicted (in grey) average survey length composition data for northern shrimp in the UMaine model base run (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey).

Survey Length Comp, Survey 1 ,red line=Obs

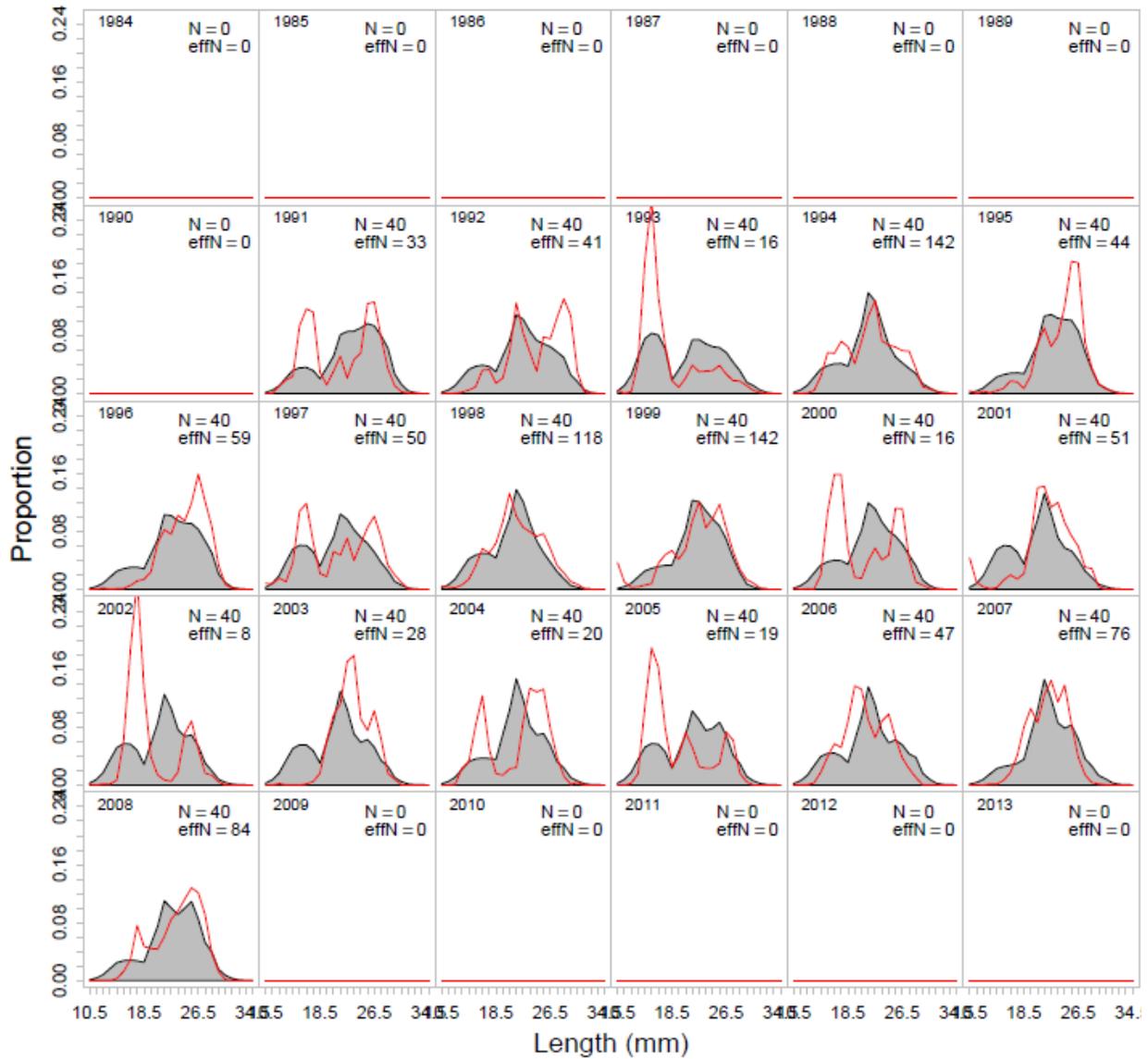


Figure C6.12. Observed (red line) and predicted (in grey) NEFSC fall survey length composition for each year for northern shrimp in the UMaine model base run.

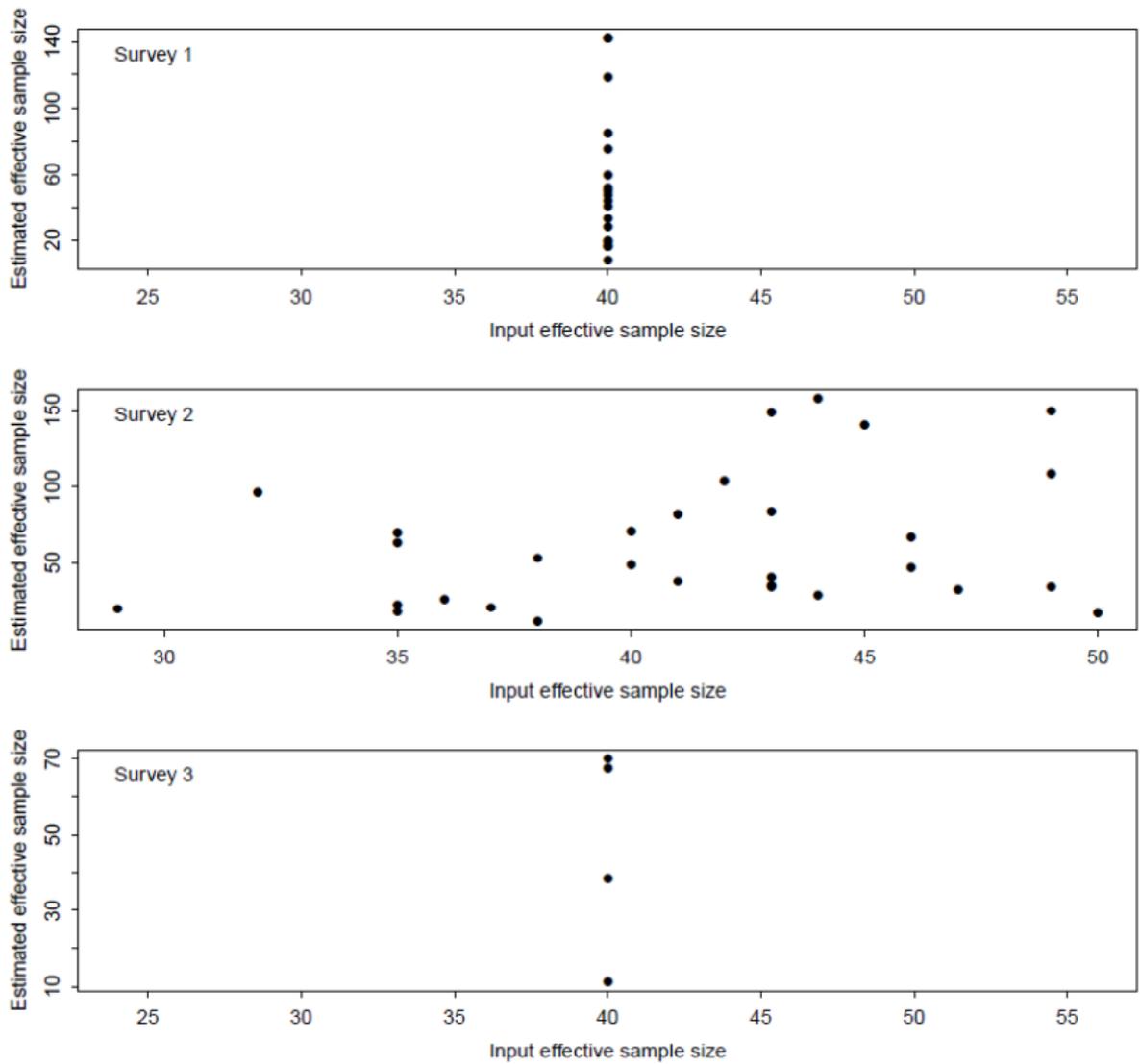


Figure C6.13. Comparison of input effective sample size versus the model estimated effective sample size for the survey indices used in the based run model (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey)

Survey Length Comp, Survey 2 ,red line=Obs

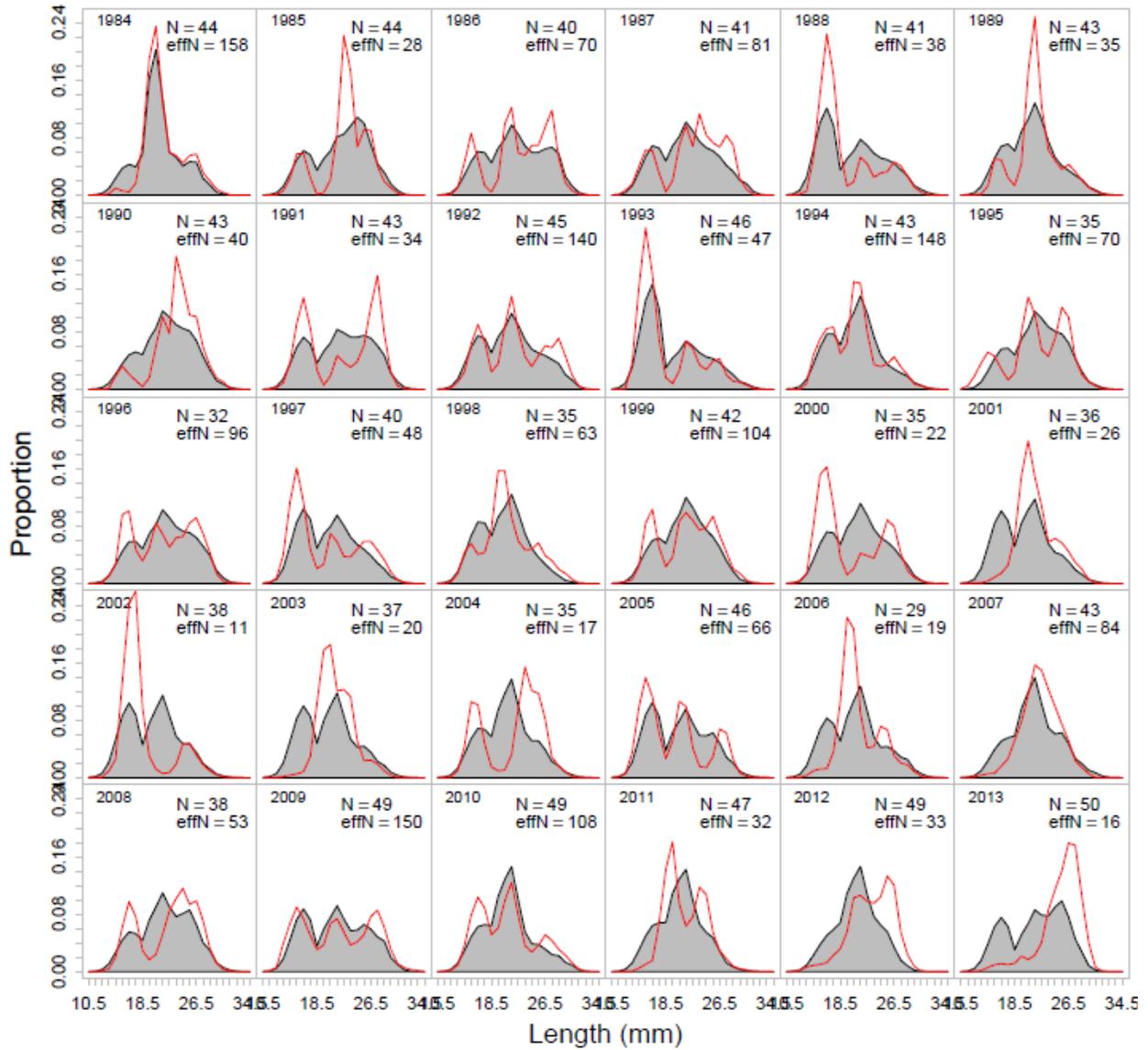


Figure C6.14. Observed (red line) and predicted (in grey) ASMFC summer survey length composition data for each year for northern shrimp in the UMaine model base run.

Survey Length Comp, Survey 3 ,red line=Obs

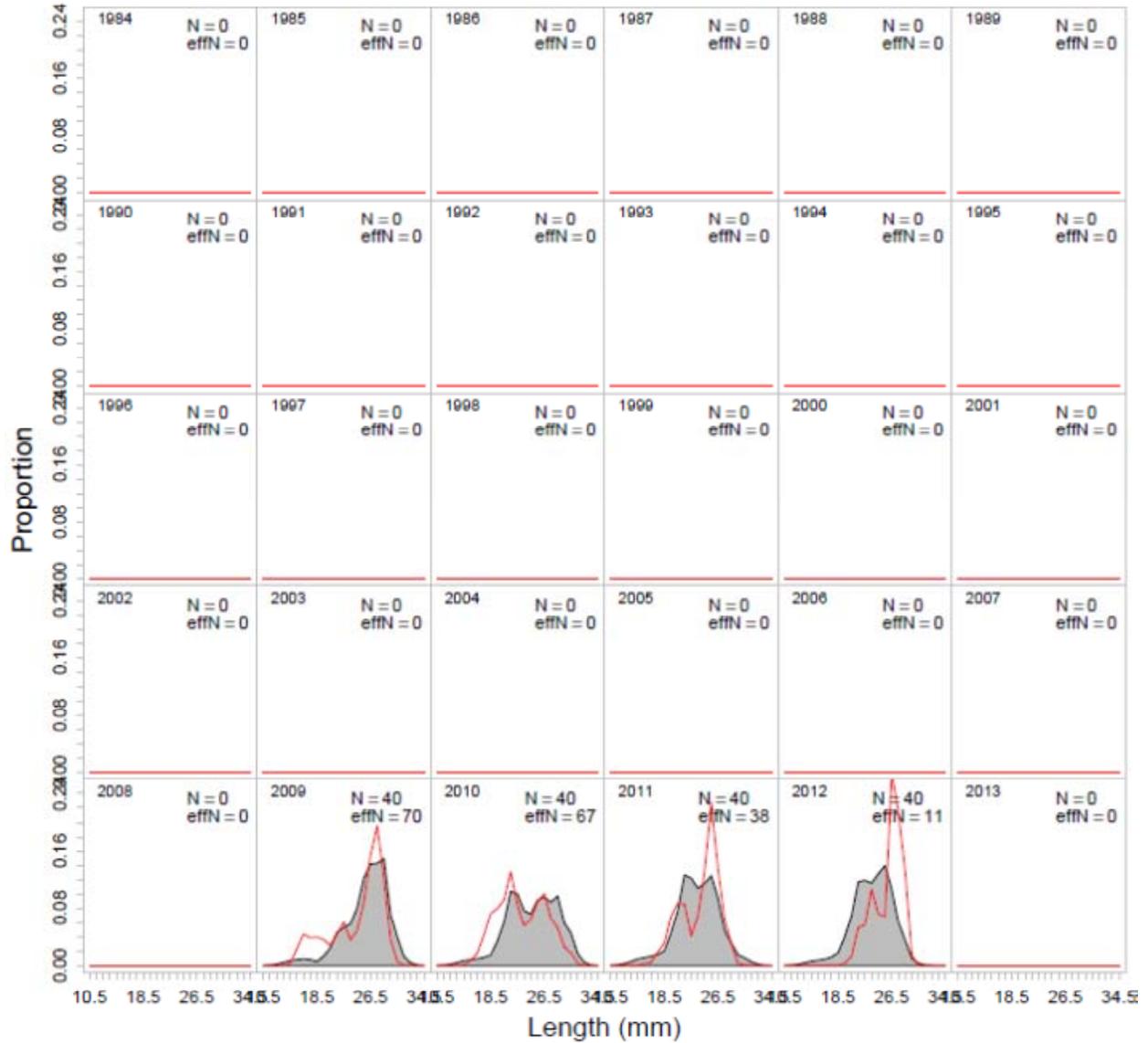


Figure C6.15. Observed (red line) and predicted (in grey) NEFSC Bigelow survey length composition data for each year for northern shrimp in the UMaine model base run.

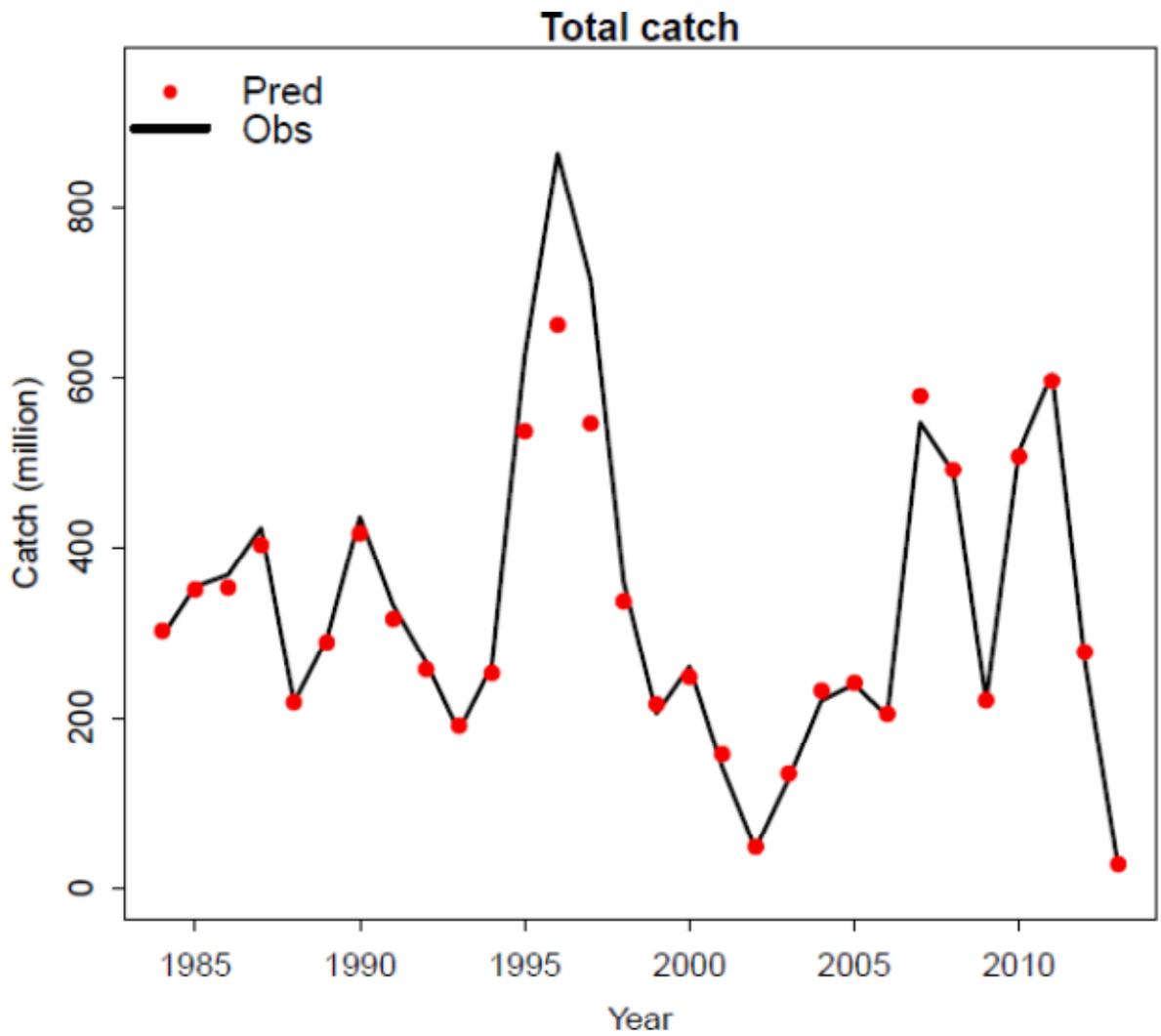


Figure C6.16. Commercial total catch (black line) and predicted values (red dots) for northern shrimp in the UMaine model base run.



Figure C6.17. Commercial total catch by fishery (black line) and predicted values (red dots) for northern shrimp in the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

Length Comp, fishery 1 ,red line=Obs

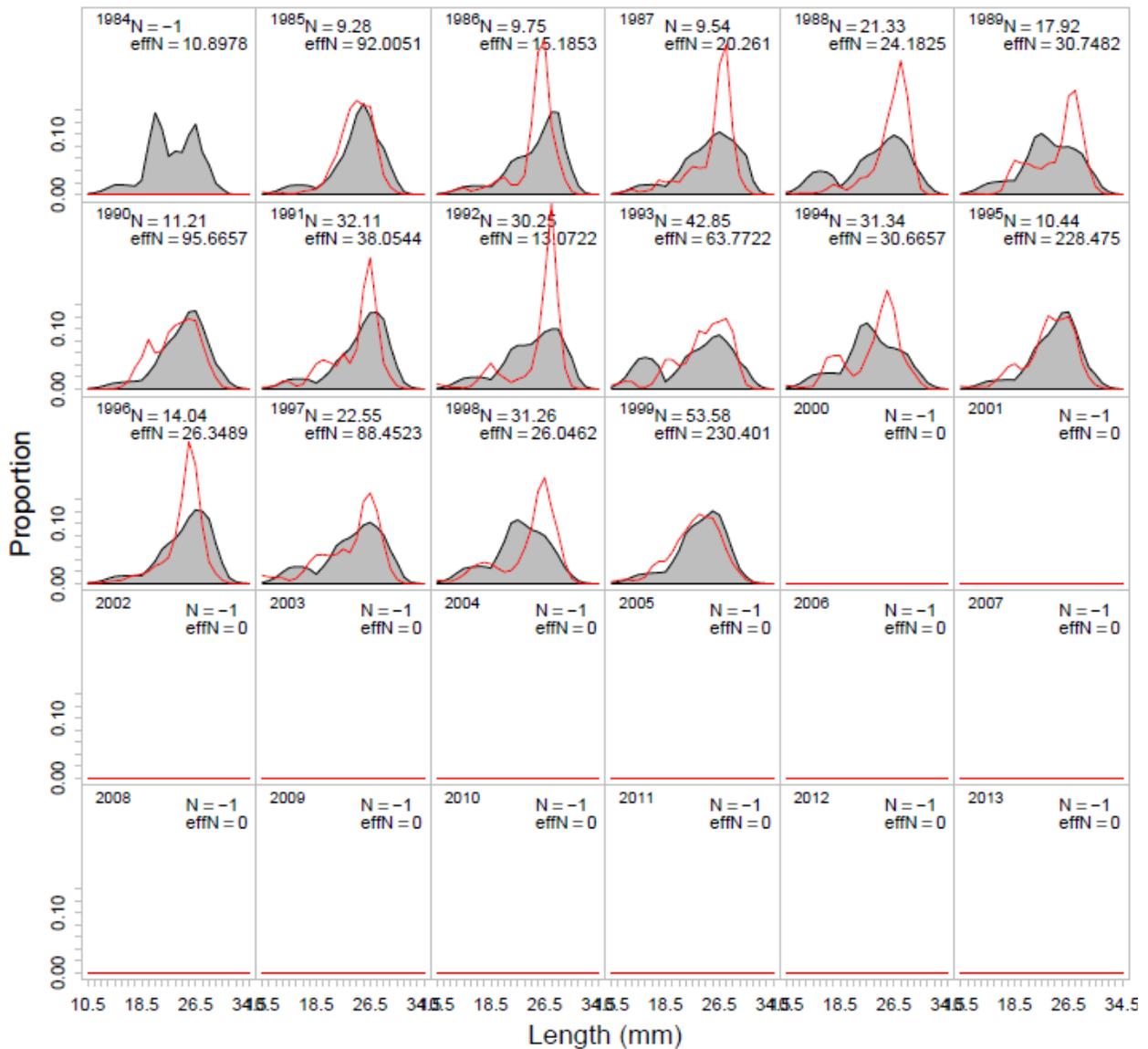


Figure C6.18. Mixed fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

Length Comp, fishery 2 ,red line=Obs

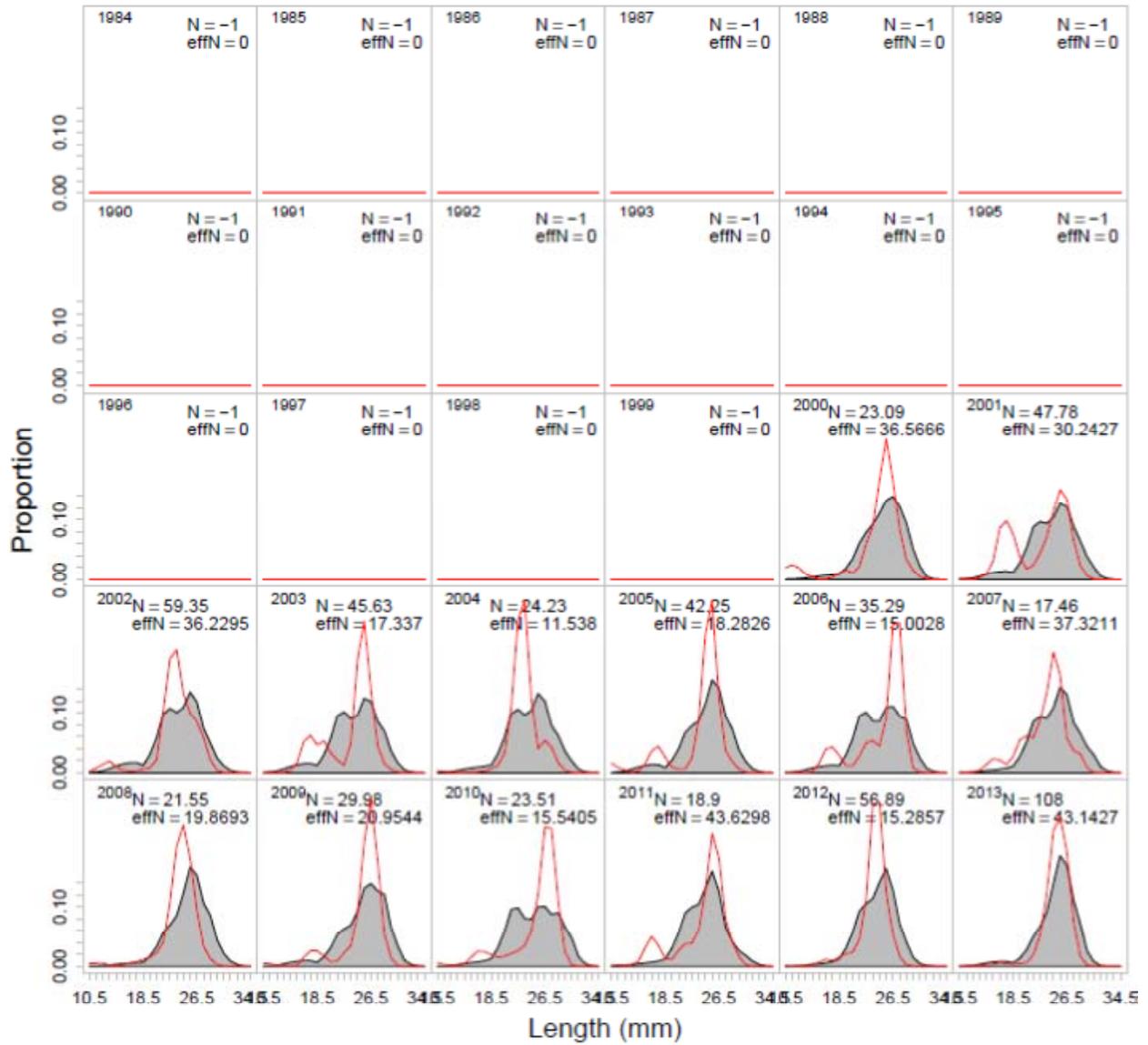


Figure C6.19. Trawl fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

Length Comp, fishery 3 ,red line=Obs

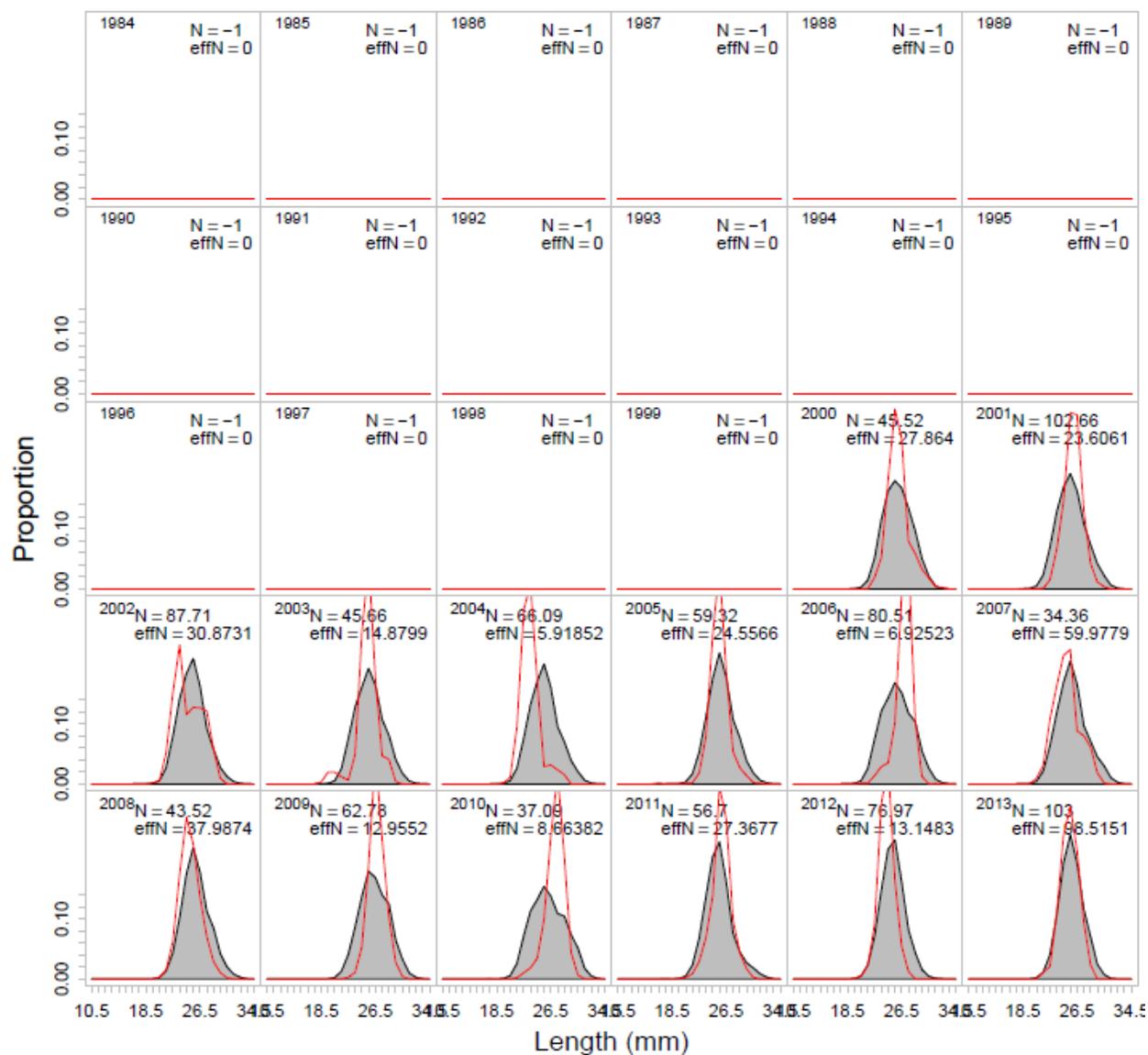


Figure C6.20. Trap fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

Catch Length Comp, aggregated cross time by fleet ,red line=Obs

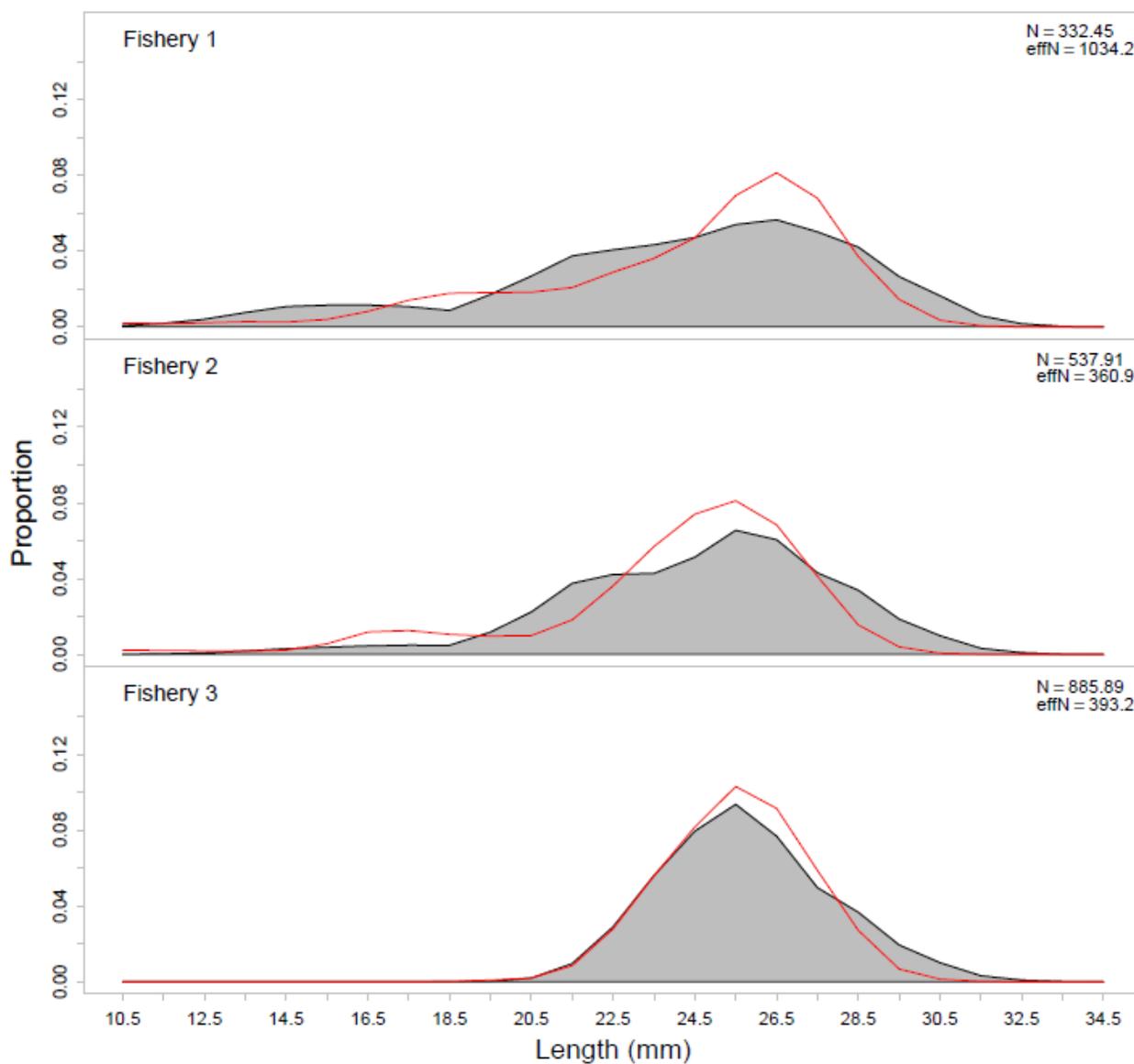


Figure C6.21. Average commercial length composition data (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

Proportion of change sex for a give size, red line=Obs

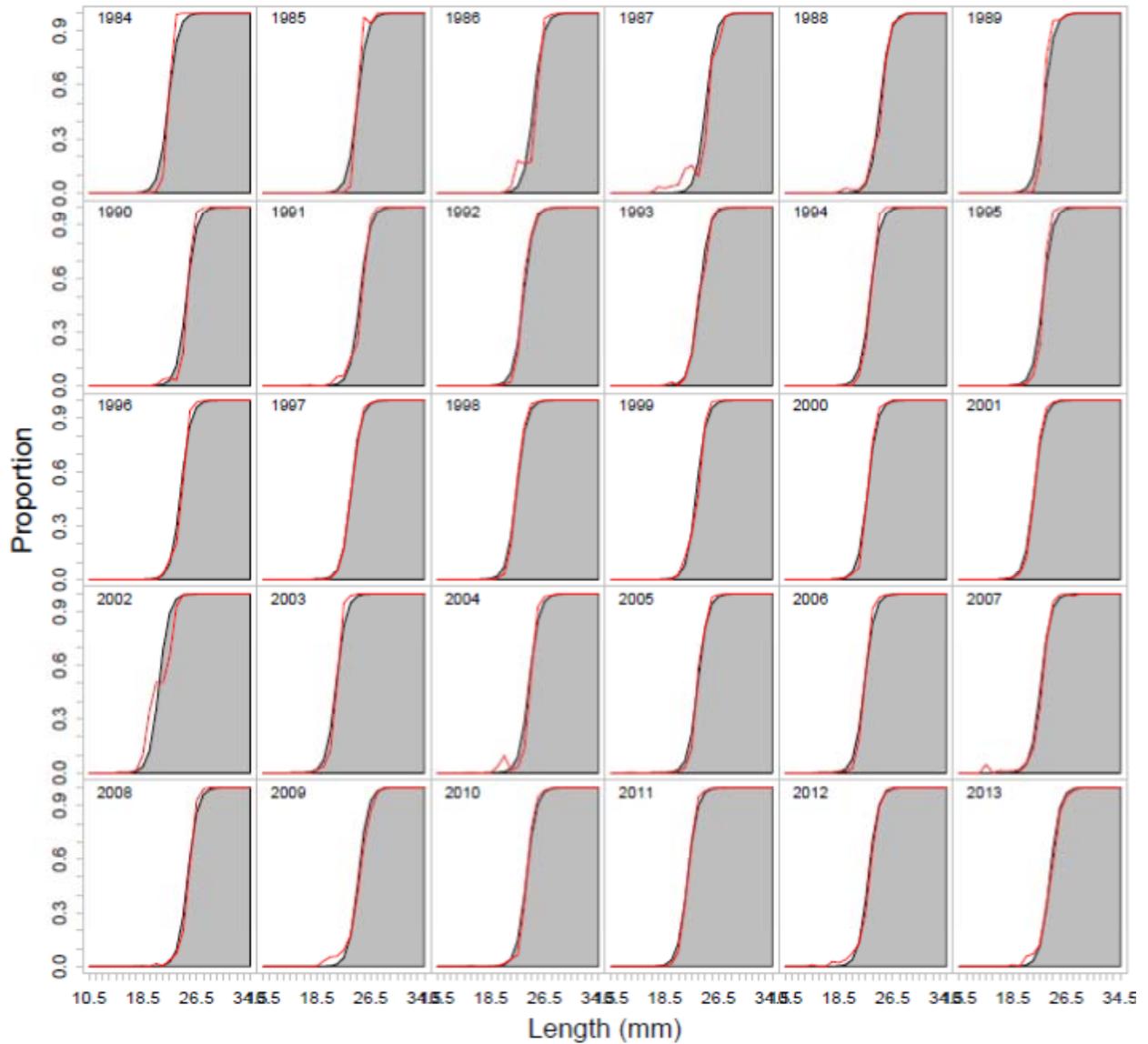


Figure C6.22. Proportion of female data (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

Numbers at stage and size

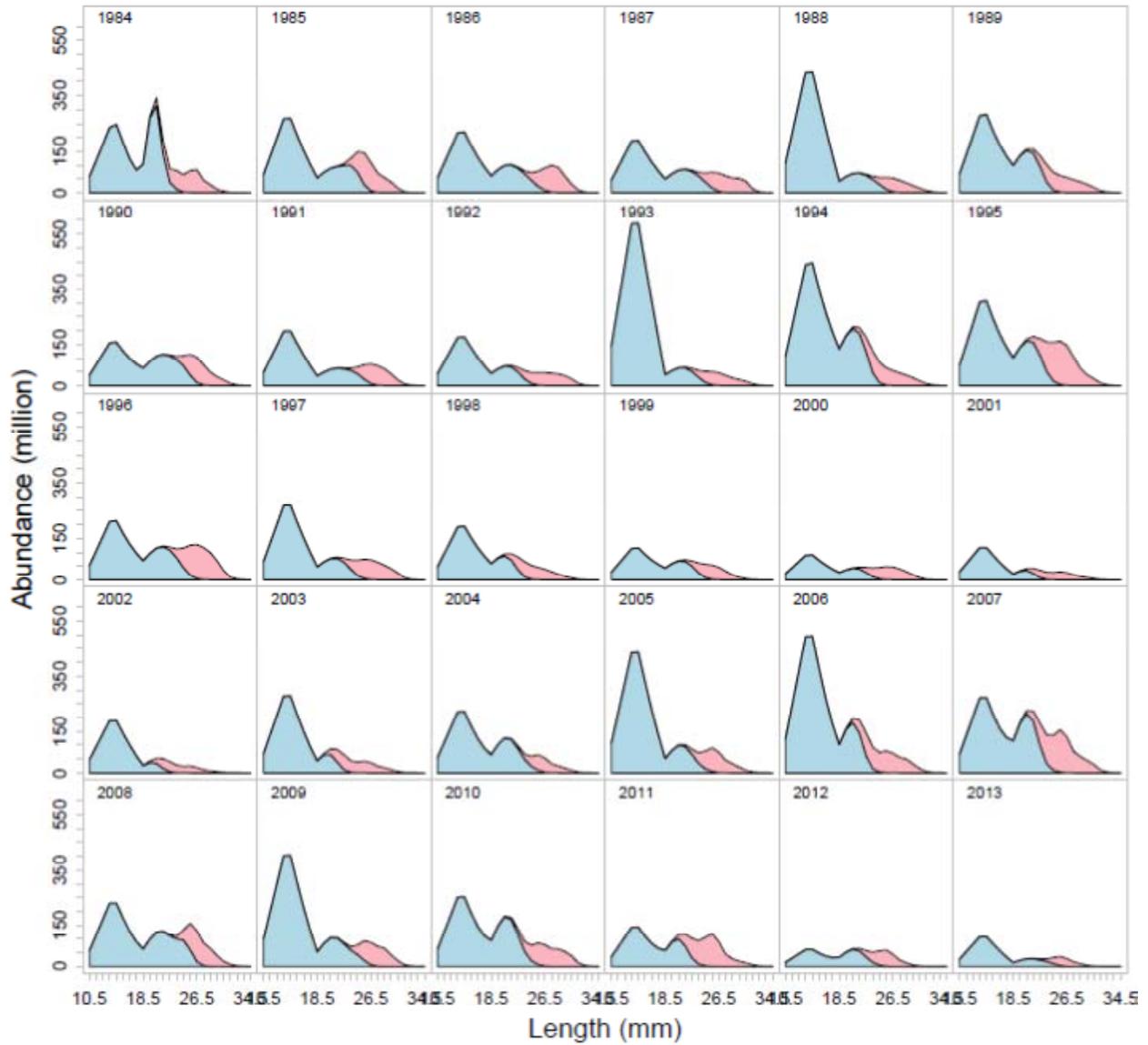


Figure C6.23. Estimated abundance of female (in pink) and non-female (in blue) for each size class at the beginning of each year.

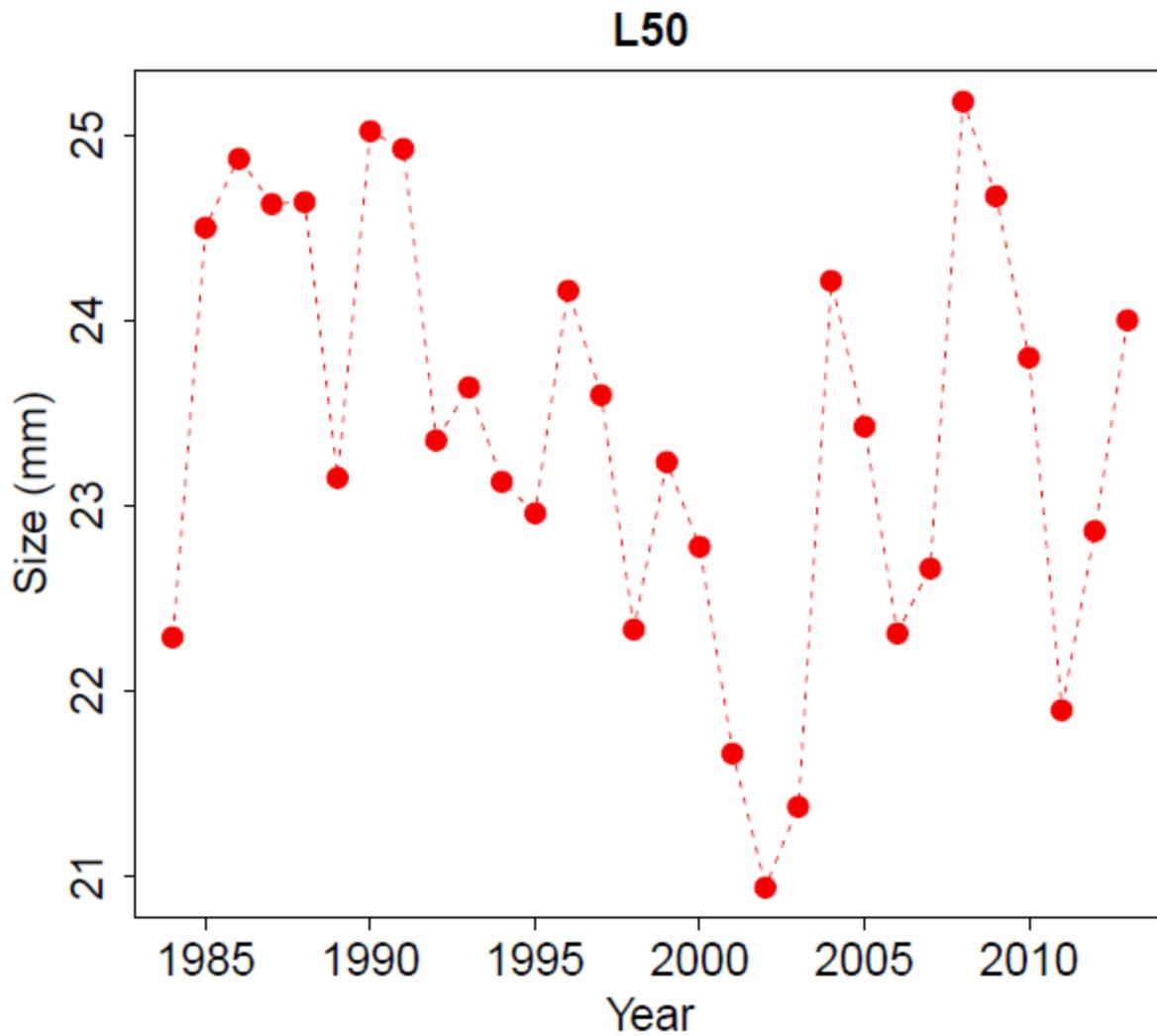


Figure C6.24. Estimated L_{50} (the size at which fifty percents of shrimp change sex to female) for each year from the UMaine model base run.

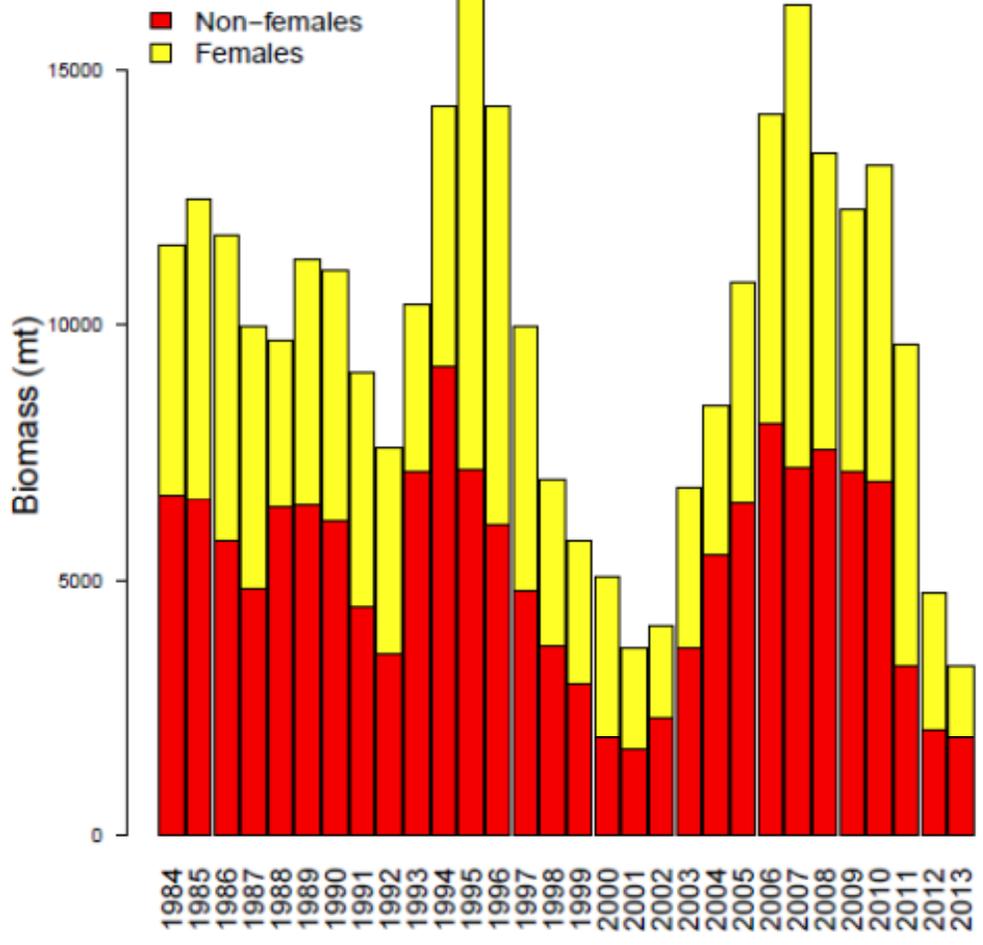


Figure C6.25. Estimates of female biomass (in yellow) and non-female biomass (in red) from the UMaine model base run.

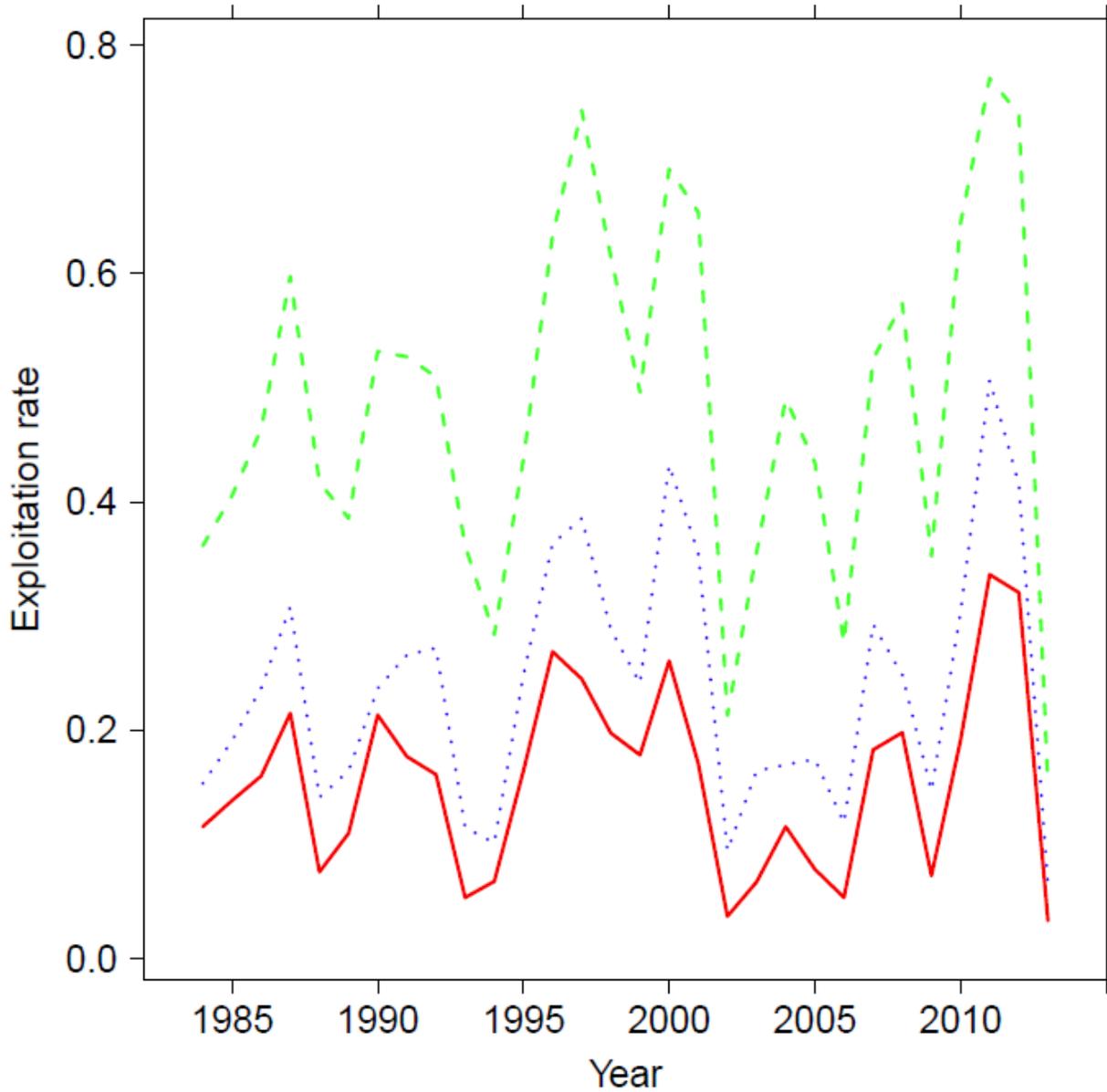


Figure C6.26. Exploitation rates for each year from the UMaine model base run (red line=predicted total catch in numbers/estimates of total numbers; blue line=predicted total catch biomass/estimates of total biomass; green line= predicted total female catch biomass/estimates of female biomass).

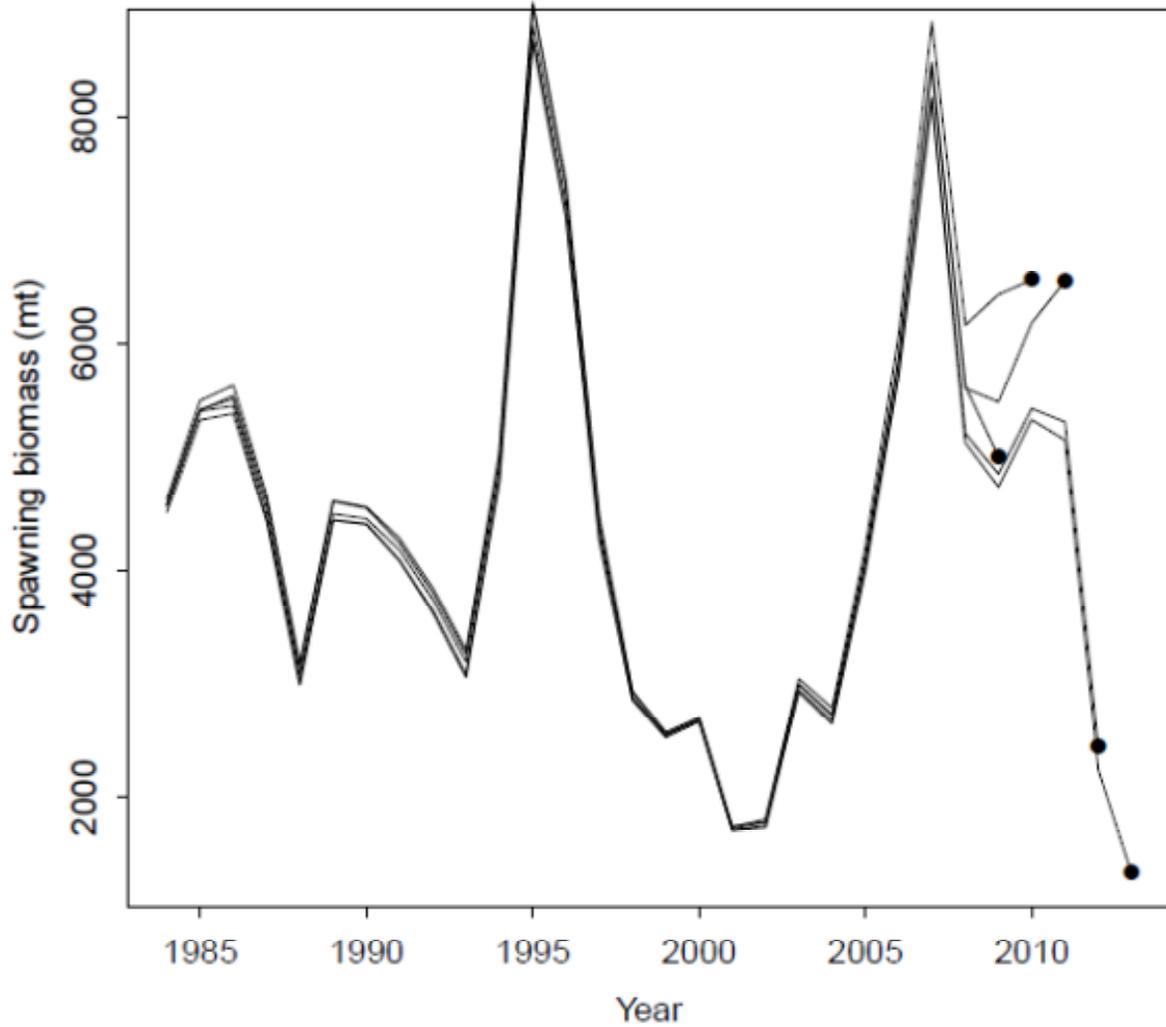


Figure C6.27. Retrospective pattern for spawning stock biomass for the UMaine model base run (Mohn rho=0.22 for 2009 as reference year)

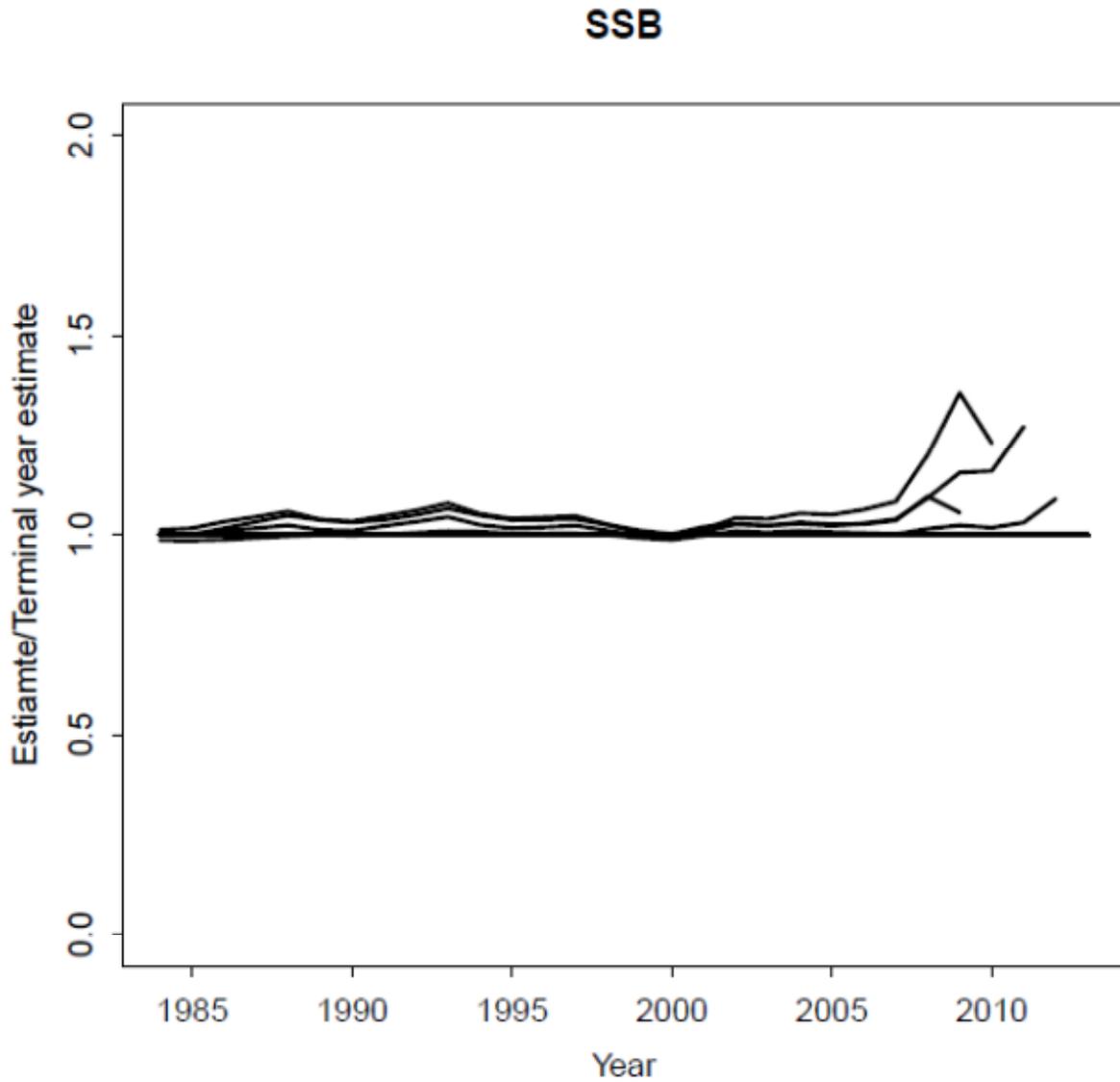


Figure C6.28. Retrospective pattern for spawning stock biomass for the UMaine model base run (Mohn rho=0.22 for 2009 as reference year).

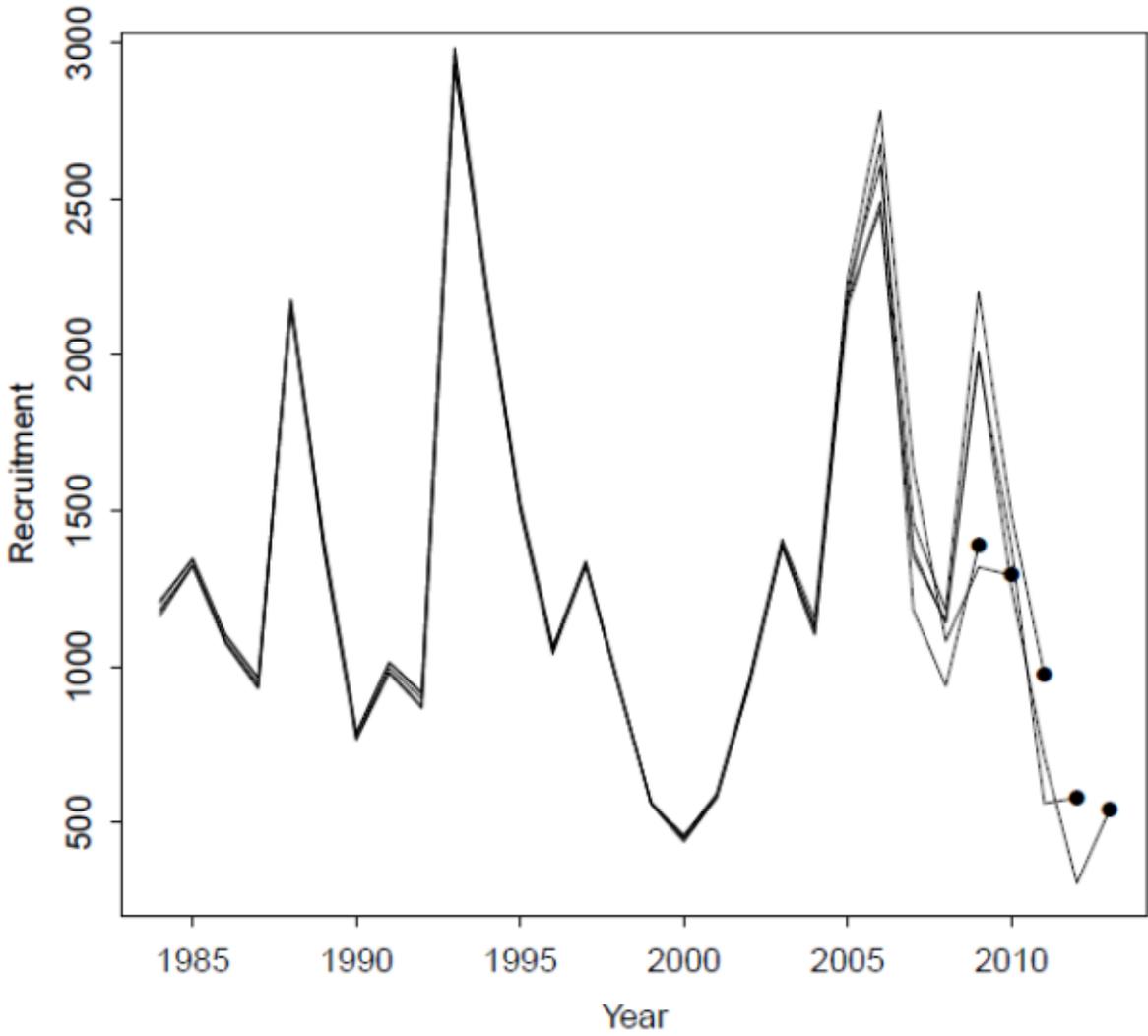


Figure C6.29. Retrospective pattern for recruitment for the UMaine model base run (Mohn rho=0.93 for 2009 as reference year)

Recruitment

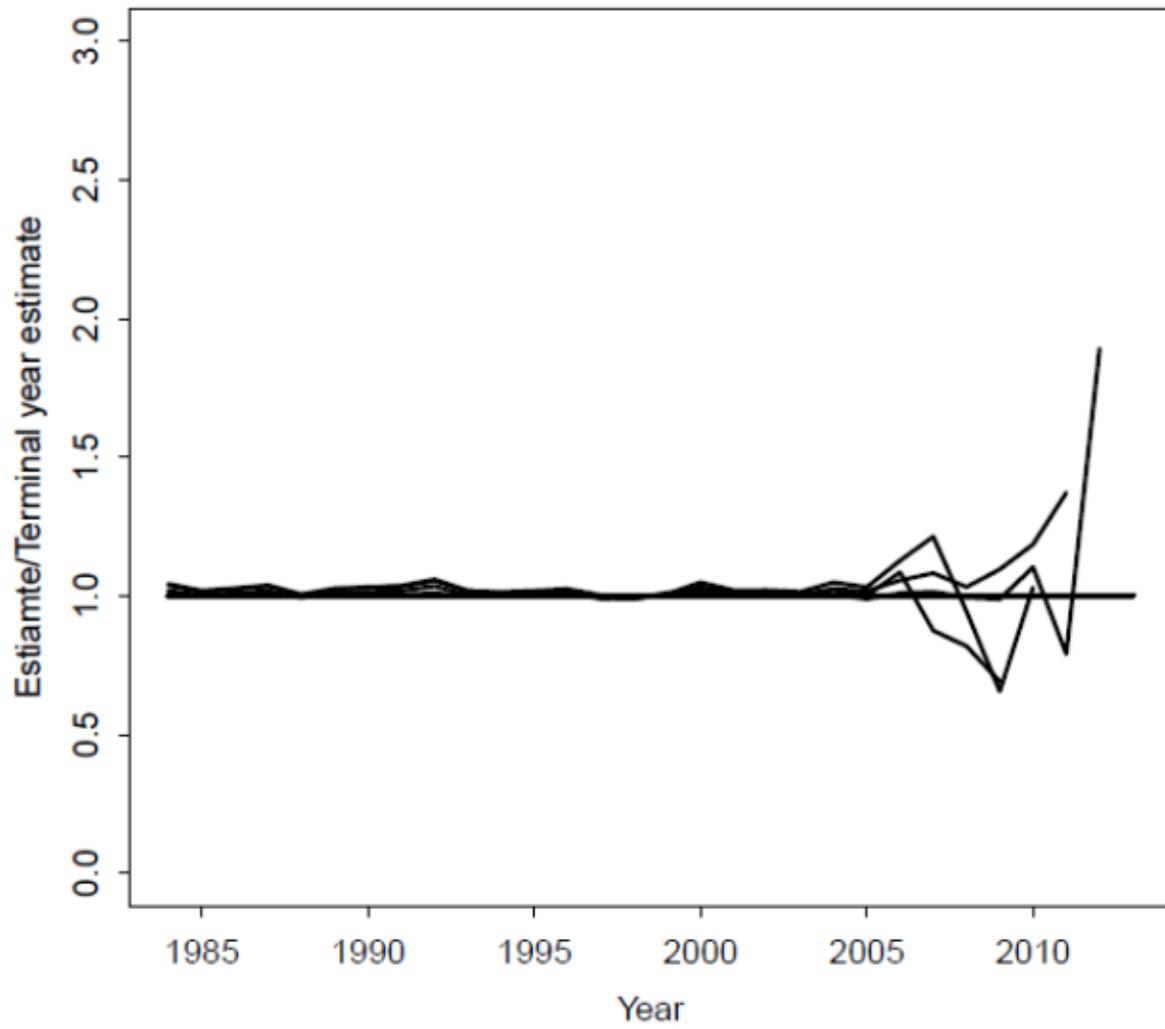


Figure C6.30. Retrospective pattern for recruitment for the UMaine model base run (Mohn $\rho=0.93$ for 2009 as reference year).

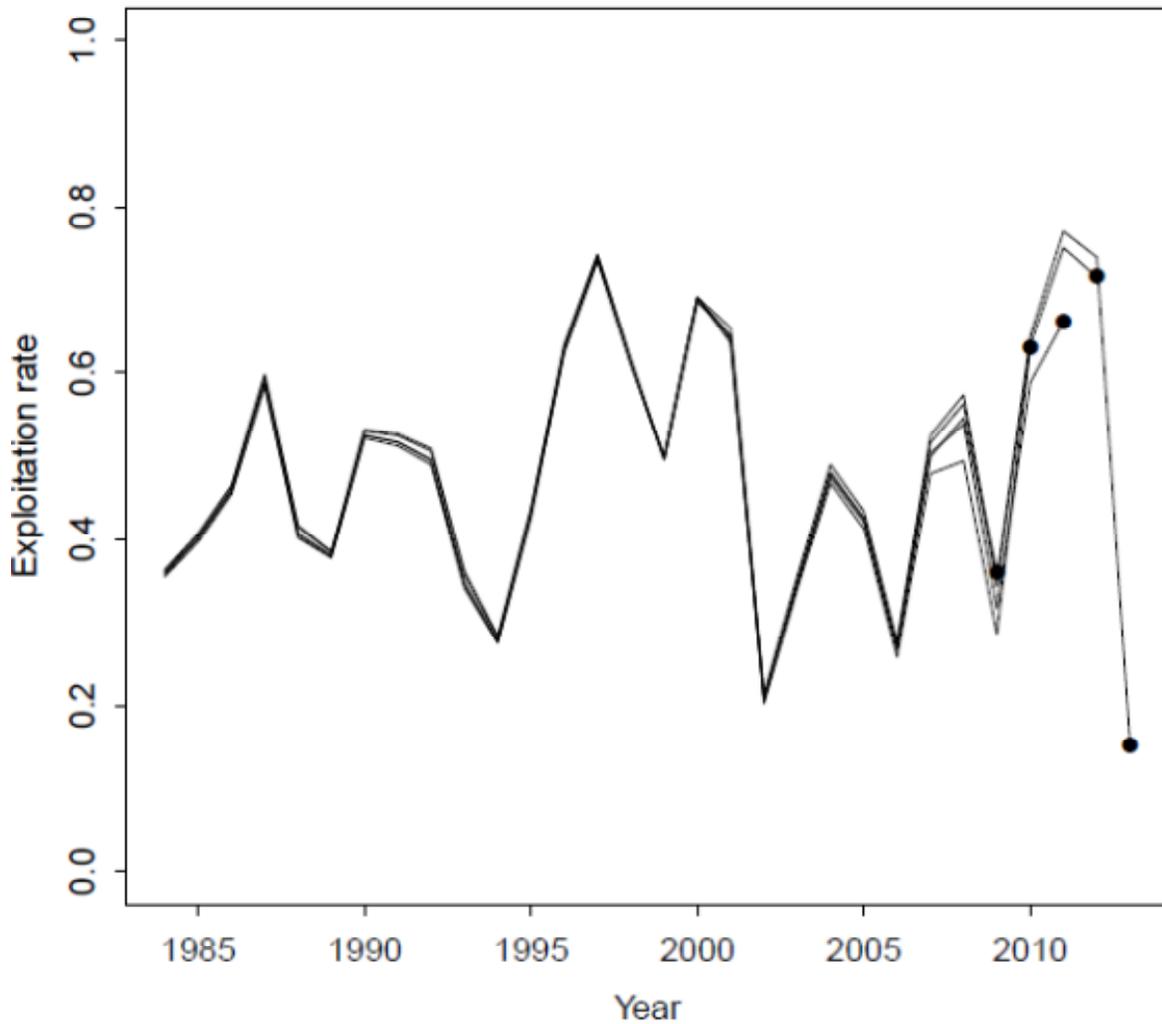


Figure C6.31. Retrospective pattern for exploitation rate (predicted total female catch biomass/estimates of female biomass) for the UMaine model base run (Mohn rho=-0.47 for 2009 as reference year)

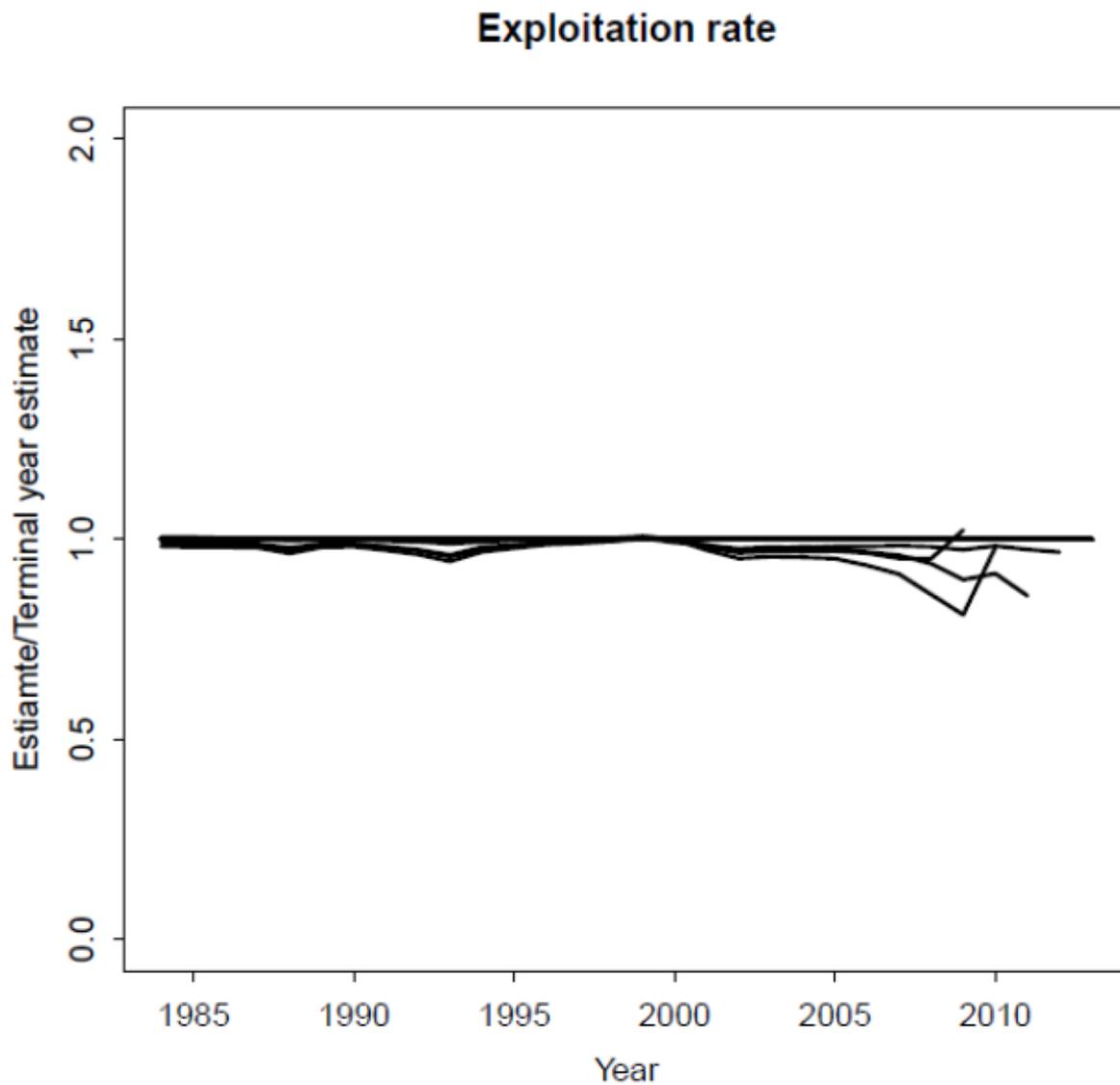


Figure C6.32. Retrospective pattern for exploitation rate (total catch in number/total abundance) for the UMaine model base run (Mohn rho=-0.47 for 2009 as reference year).

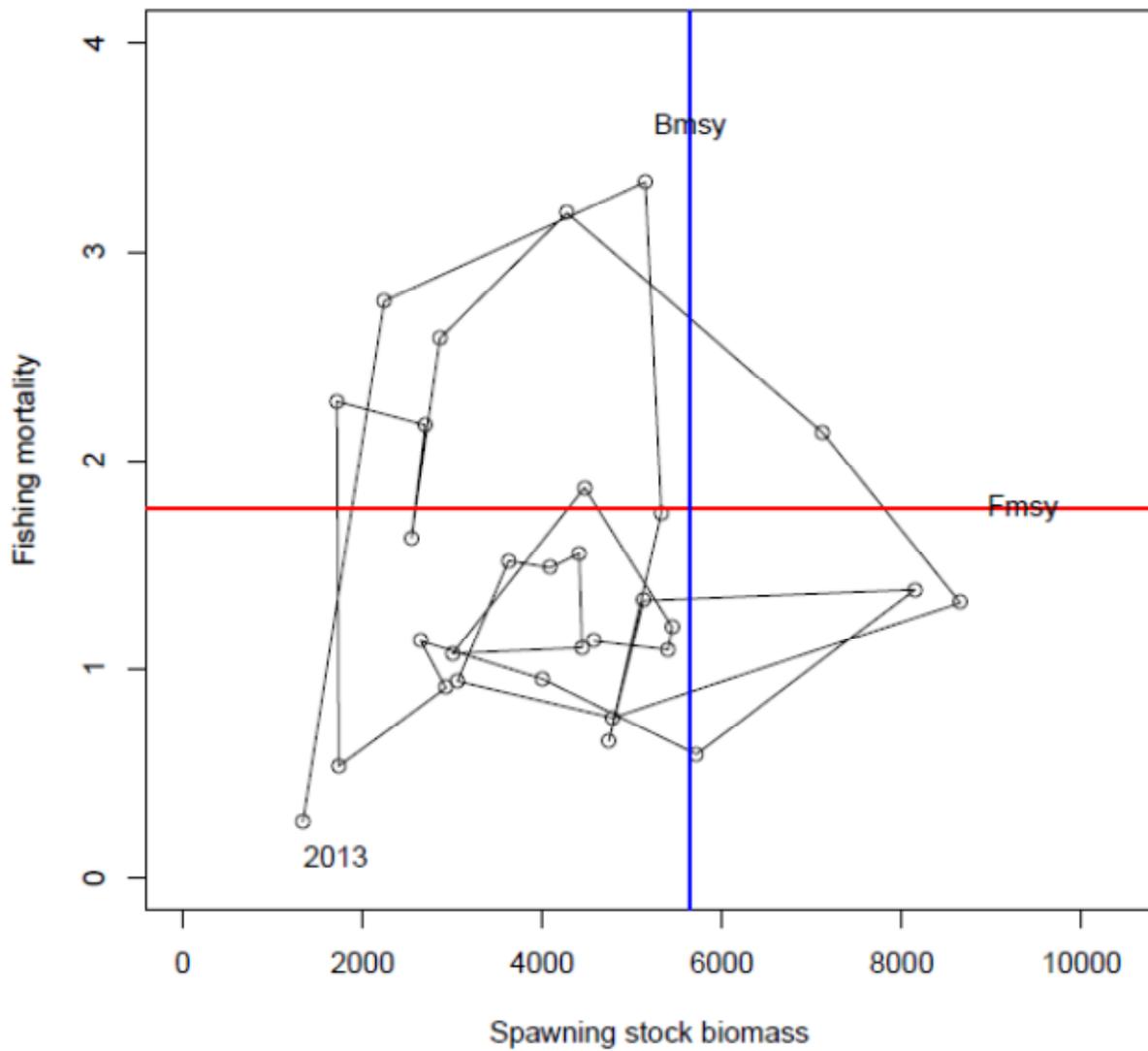


Figure C6.33. Phase plot for the base case. Fishing mortality is the total fishing mortality for fully recruited shrimp. Spawning stock biomass is measured in metric tons. F_{msy} and B_{MSY} for the base case are listed in Table 5.

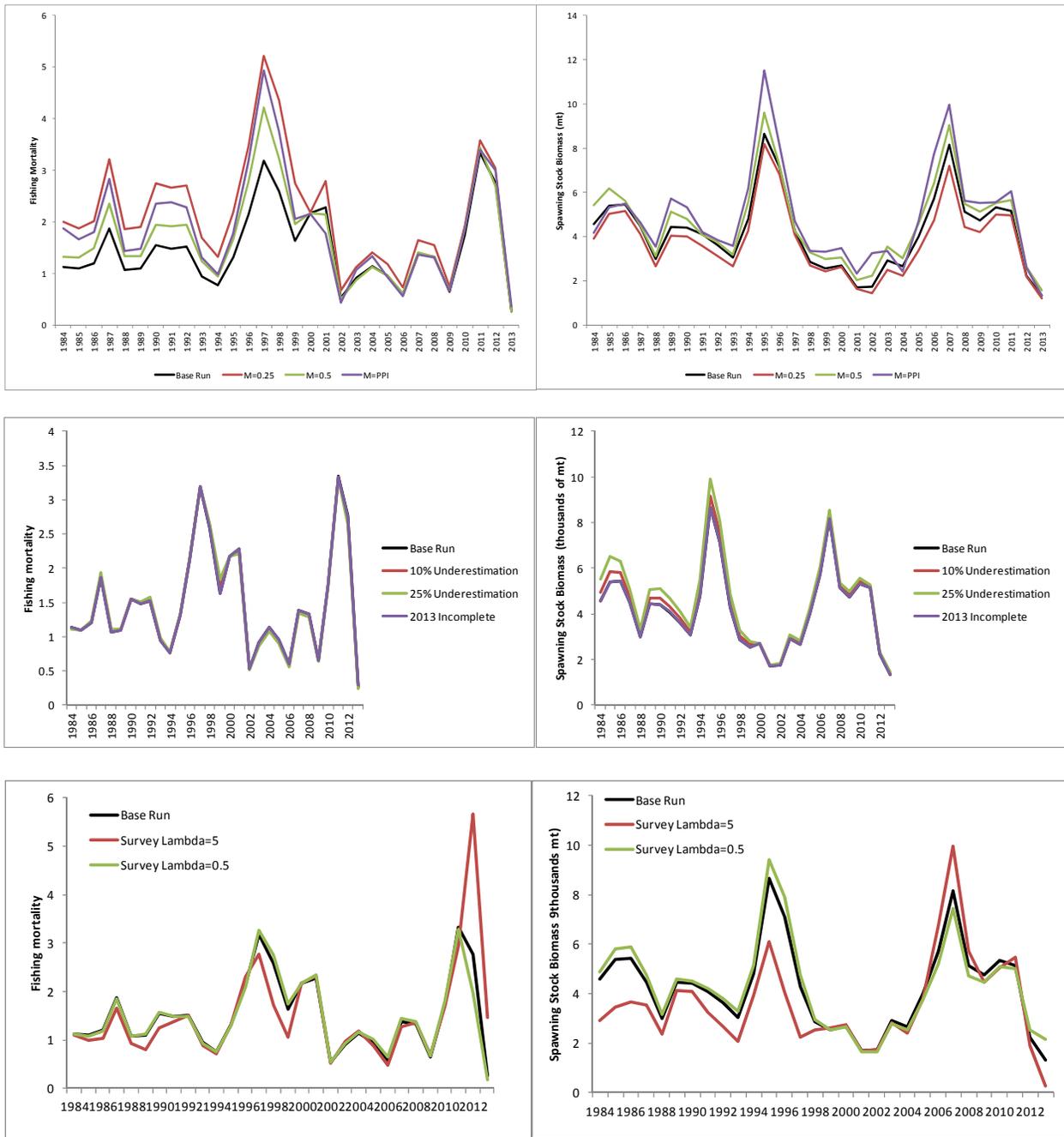


Figure C6.34. Sensitivity runs for UME model examining the effects of assumptions about natural mortality (top), underreporting of catch in the early time period or terminal year (middle), upweighting or downweighting of survey likelihood components relative to total catch (bottom), and choice of growth matrix (next page).

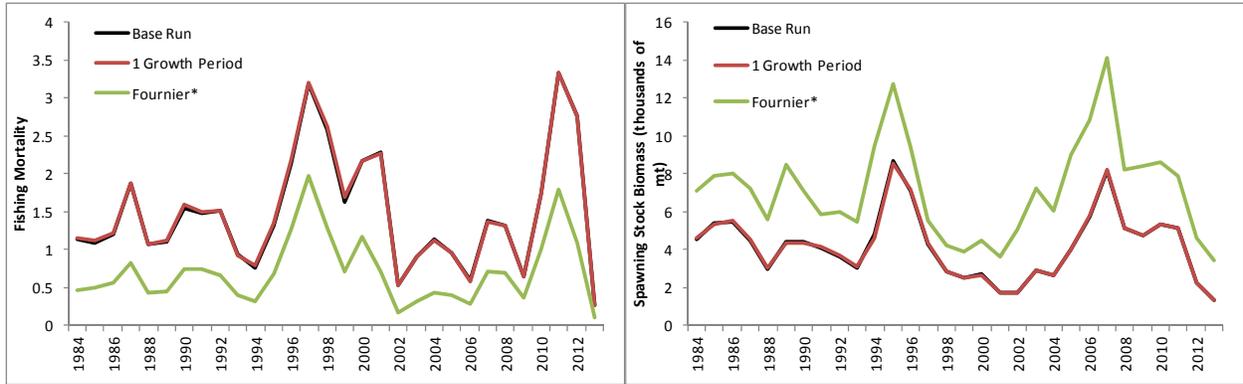


Figure C6.34 cont.

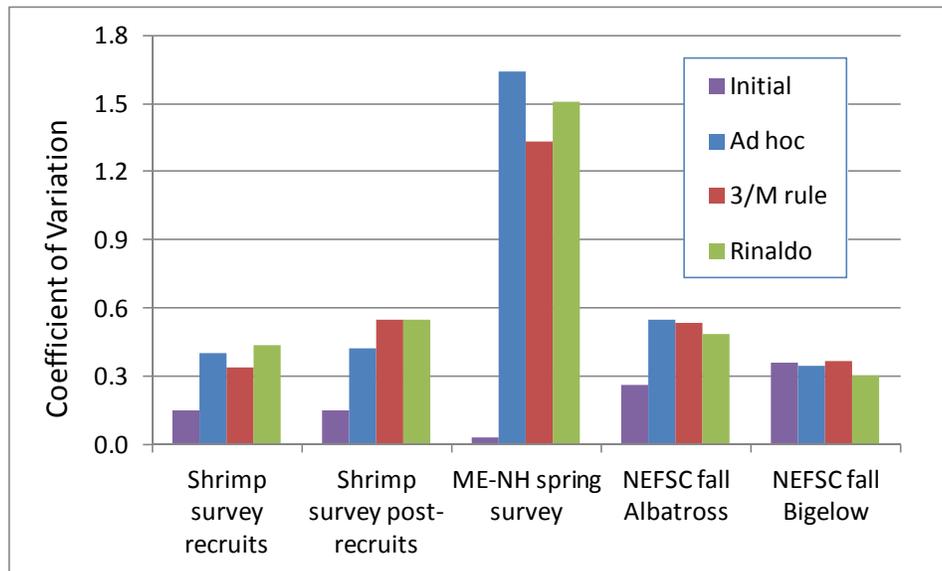


Figure C6.35. Adjustments to observed CV for each survey under different model scenarios for M. ‘Initial’ is CV estimated from survey data, ‘3/M rule’ and ‘Rinaldo’ are PPI-scaled values.

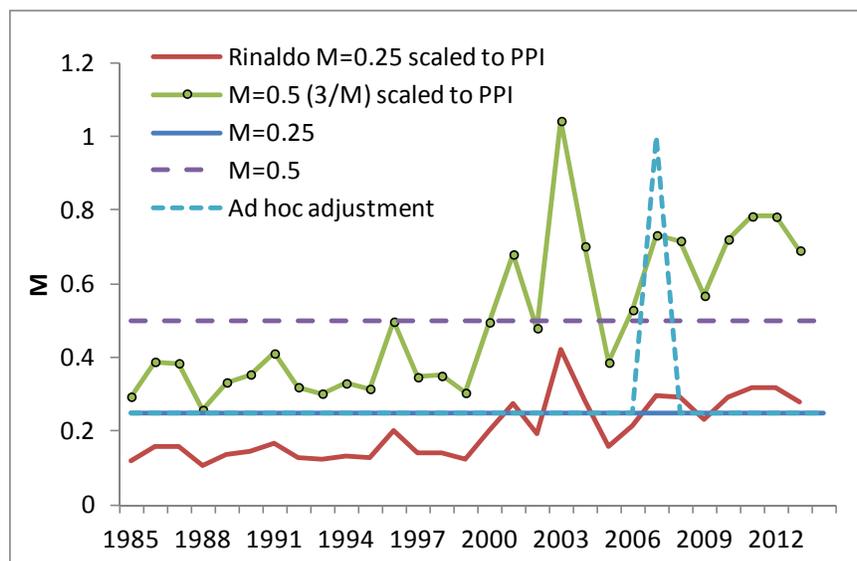


Figure C6.36. Values of natural mortality (M) explored in the CSA modeling framework.

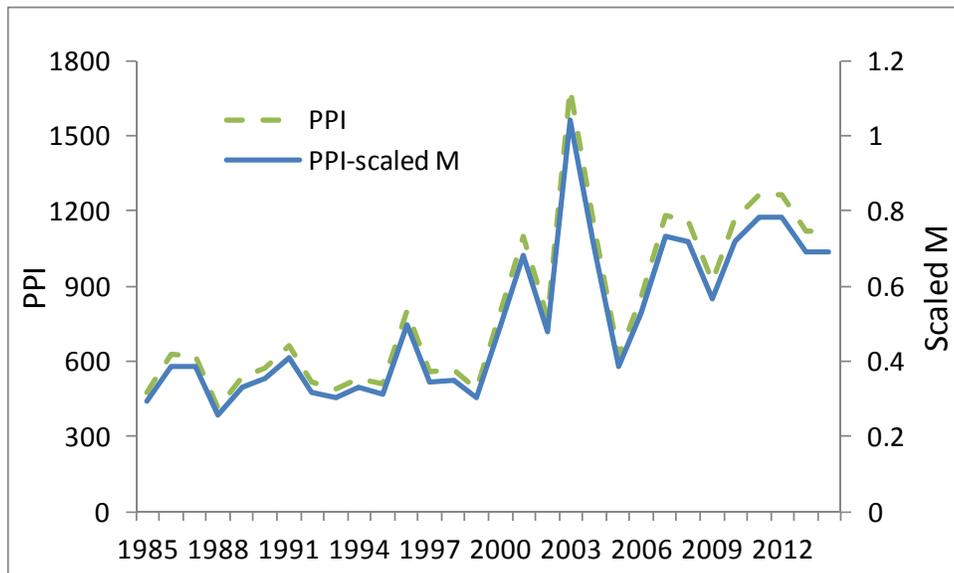


Figure C6.37. Predation pressure index (PPI) and scaled M using baseline M=0.5. For further detail, see Appendix C2.

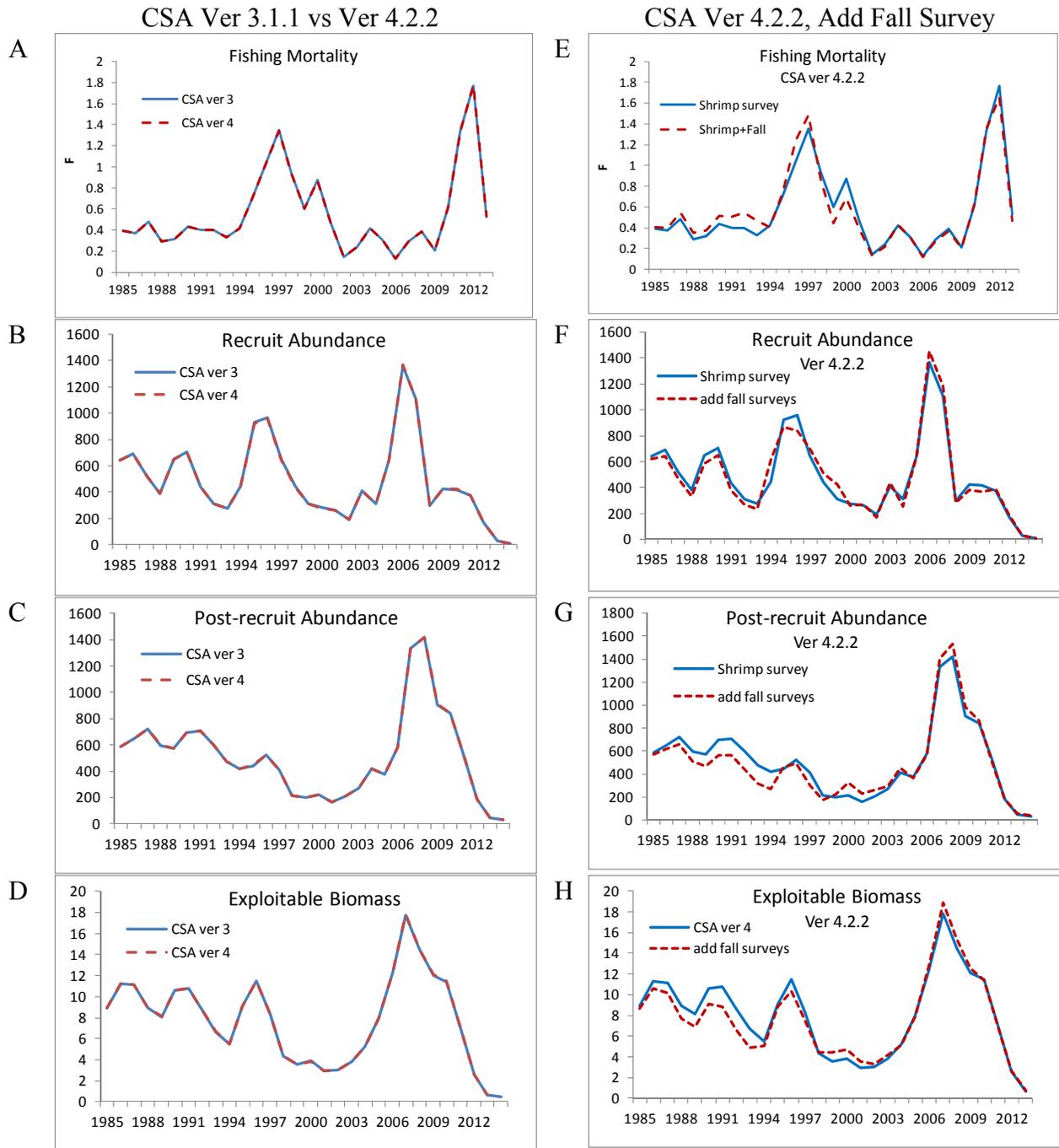


Figure C6.38. A-D: comparison of estimates from CSA version 3.1.1 (run 1) and CSA version 4.2.2 (run 2) using 2013 annual assessment update final CSA run ($M=0.25$) as basis; E-H: run 2 vs run 3 (additional surveys). Catch $CV=0.01$ in version 4.2.2. runs (version 3 assumed catch $CV=0$).

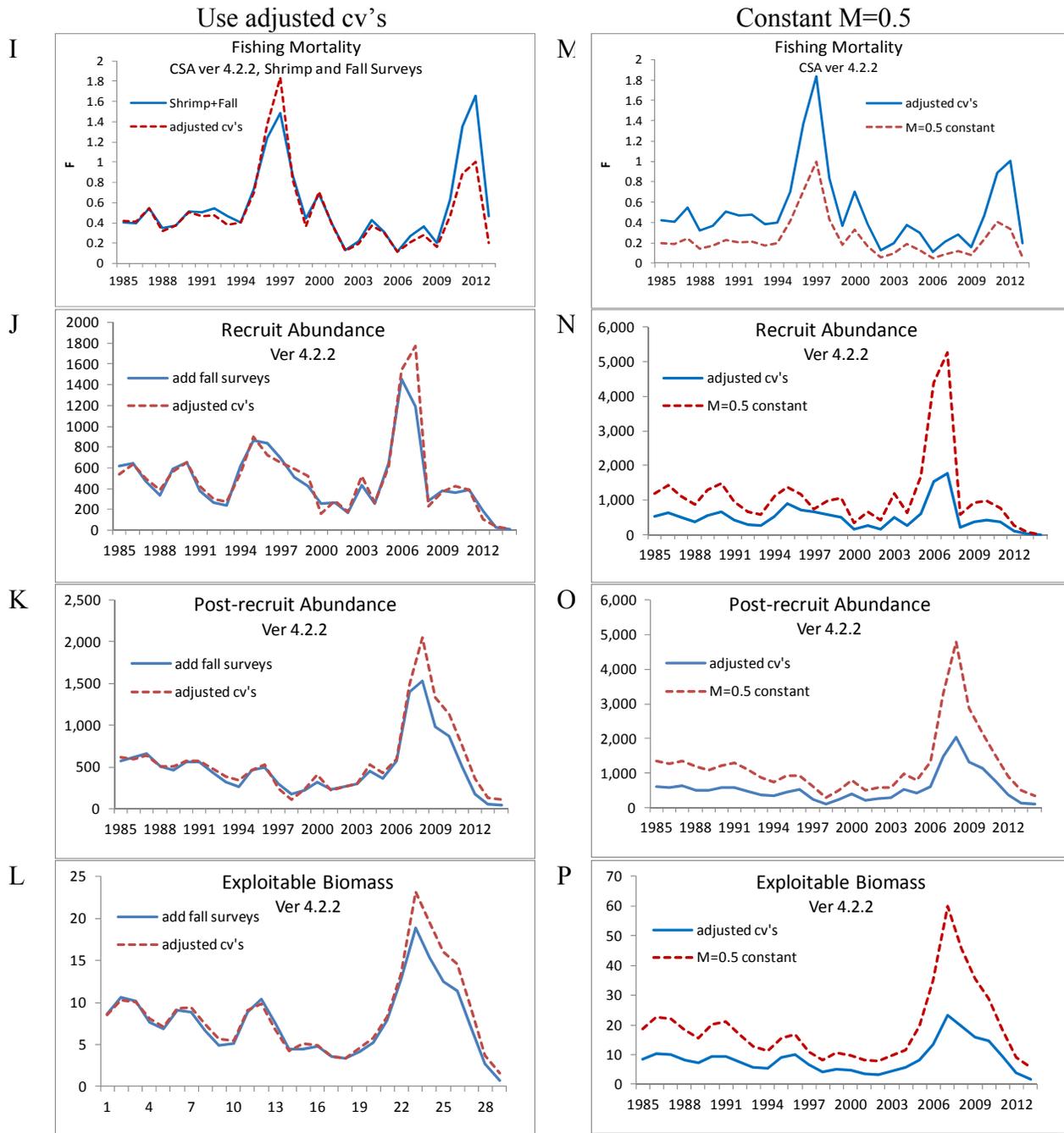


Figure C6.38, continued. I-L: run 3 (includes fall surveys) vs. run 4 (uses adjusted cv's for surveys and catch $CV=0.05$); M-P: run 4 vs run 5 (constant $M=0.5$). Catch $CV=0.05$ in I-P.

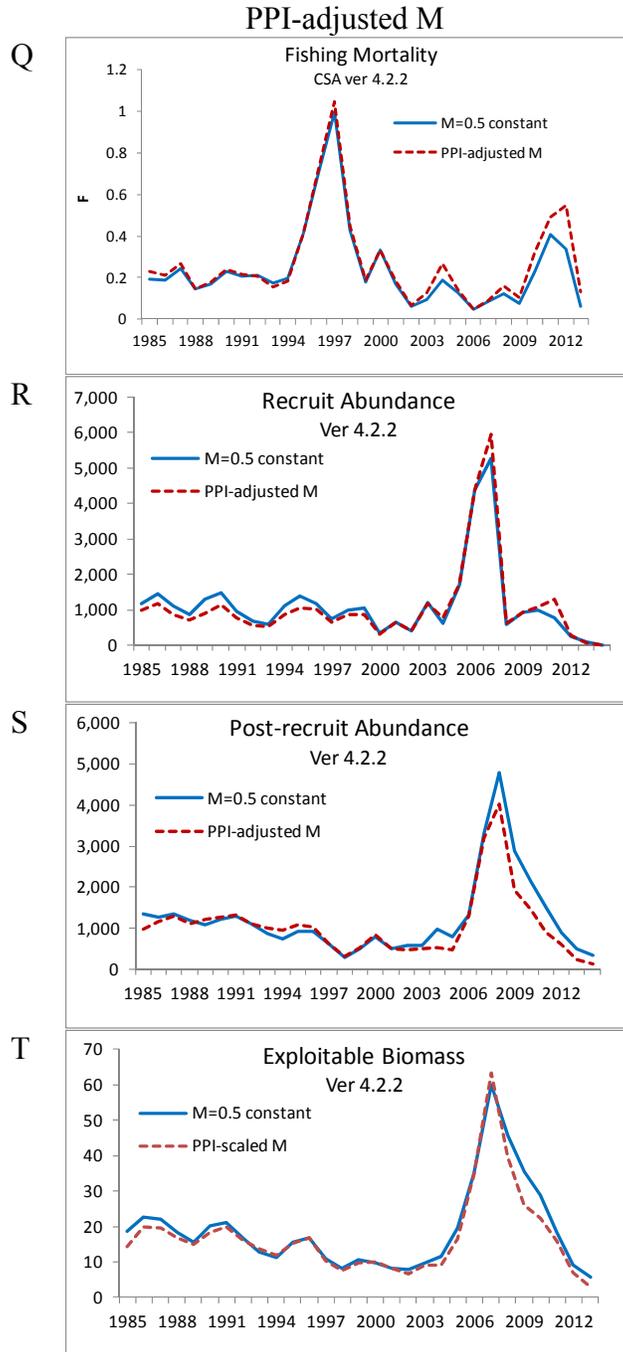


Figure C6.38, continued. Q-T: run 5 (M=0.5, constant) vs. run 6 (PPI-adjusted M using M=0.5 as baseline for adjustments). Catch CV=0.05.

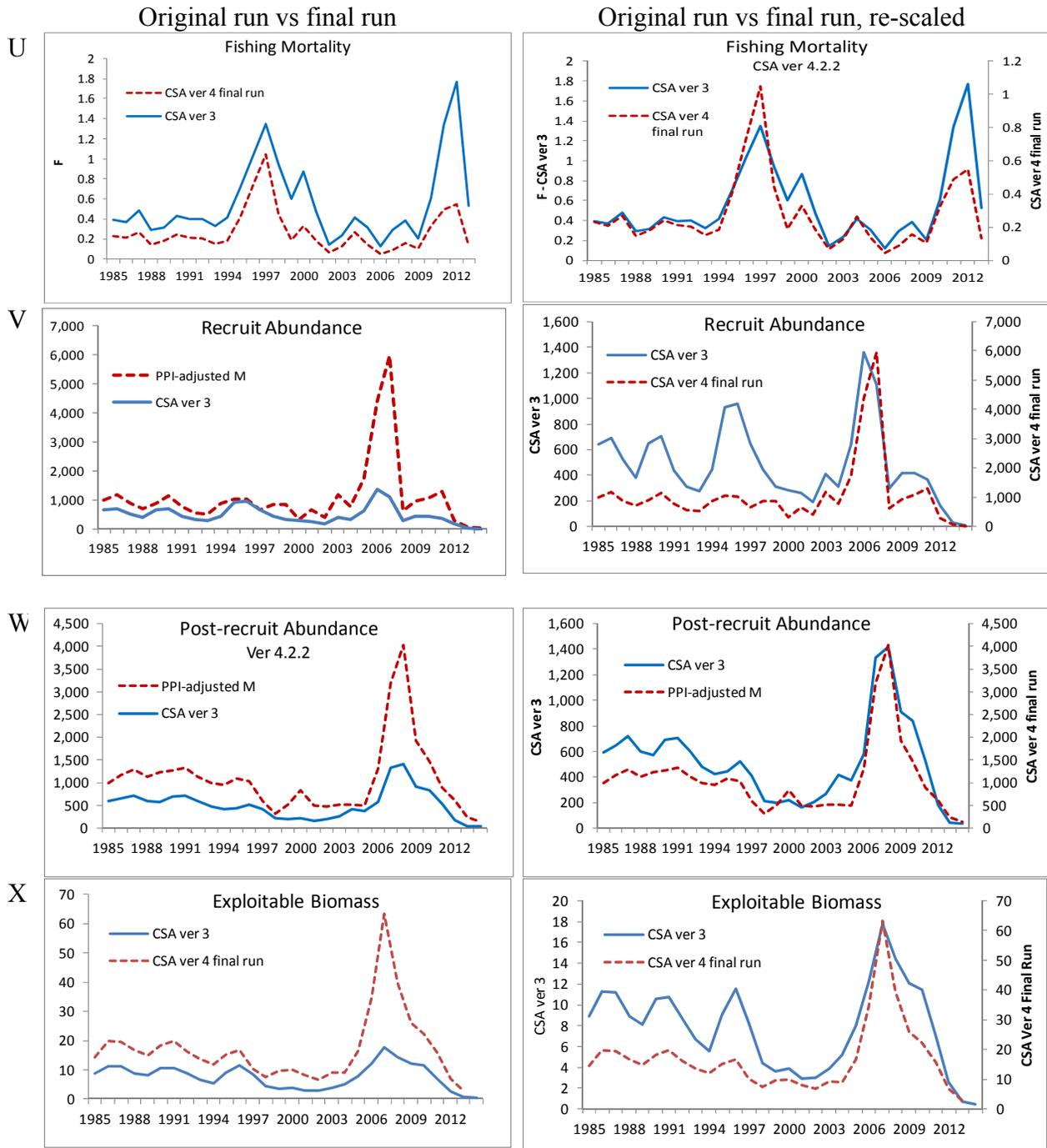
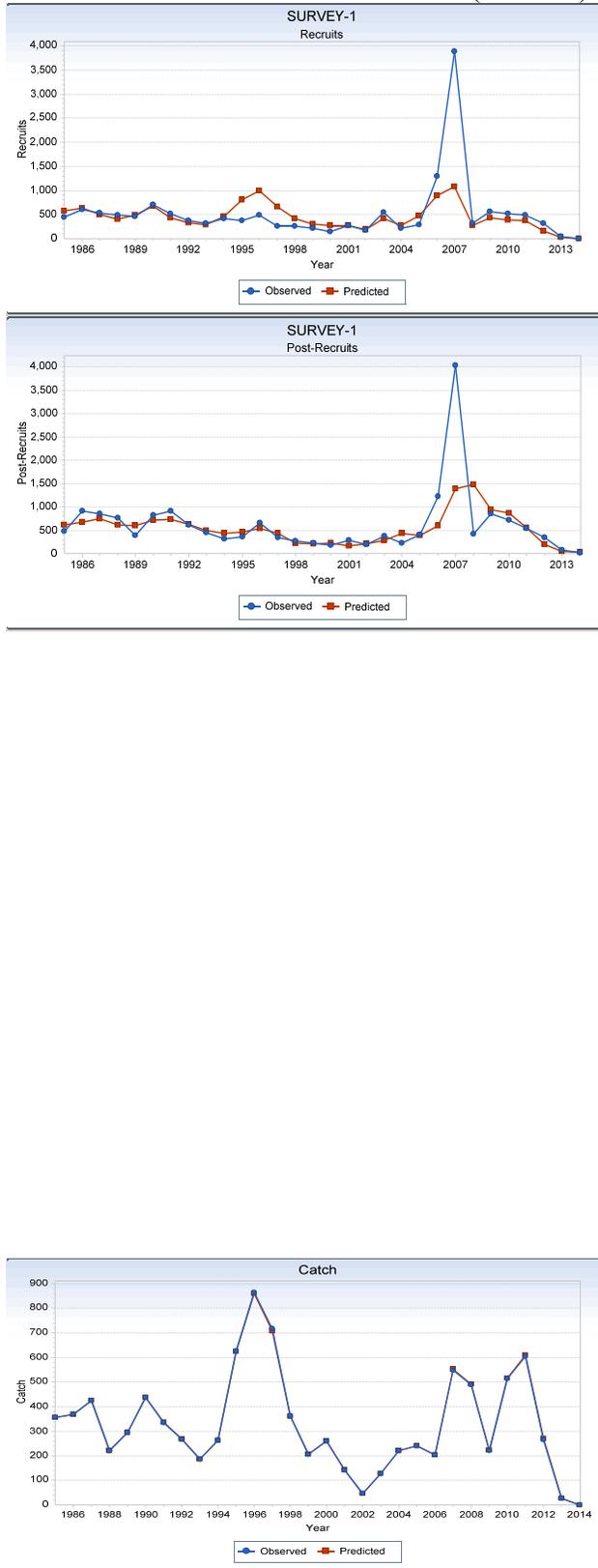


Figure C6.38, continued. Original run (run 1, CSA ver 3.1.1) vs final run (run 6, PPI-adjusted M). Left column: 1 y-axis; right column: 2 y-axes.

2013 Annual Assessment Final Run (M=0.25)



2013 Benchmark Final Run

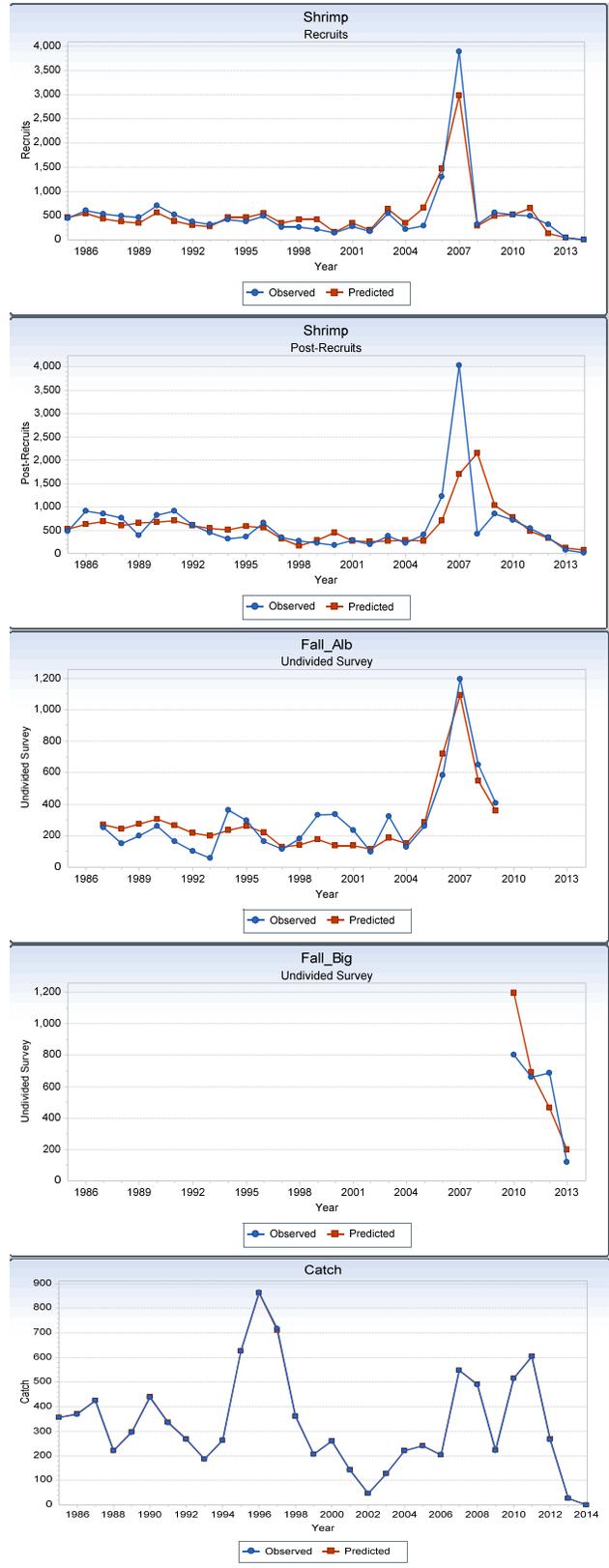


Figure C6.39. Comparison of model fits to data from 2013 annual assessment final model and 2014 benchmark final model.

2013 Annual Assessment Final Run (M=0.25)

2013 Benchmark Final Run

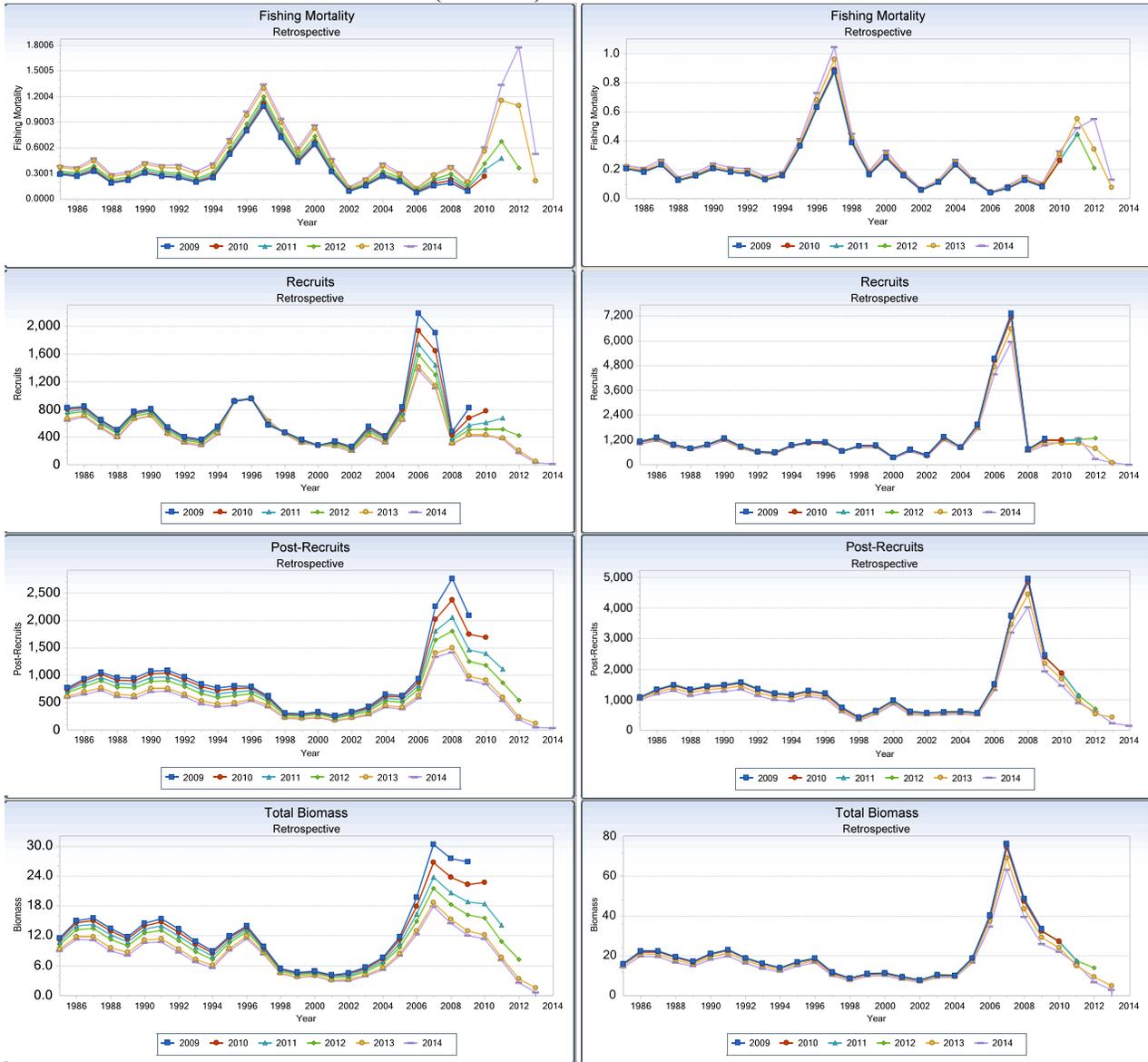


Figure C6.40. Retrospective patterns for 2013 annual assessment update final run implemented in CSA ver. 4.2.2 and benchmark final run.

2013 Annual Assessment Final Run (M=0.25)

2013 Benchmark Final Run

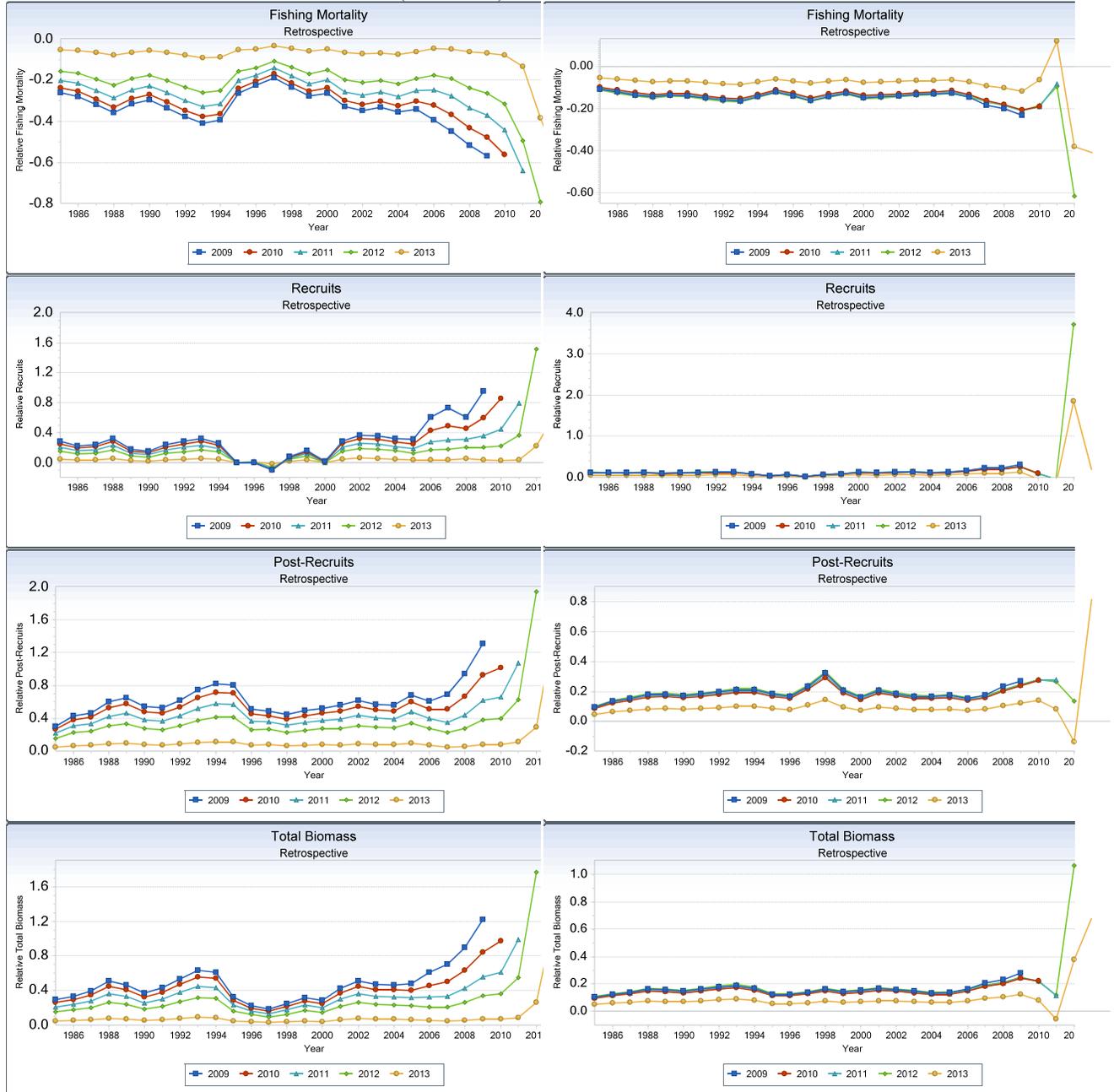


Figure C6.40, continued. Relative retrospective patterns for 2013 annual assessment update final run implemented in CSA ver. 4.2.2 and benchmark final run.

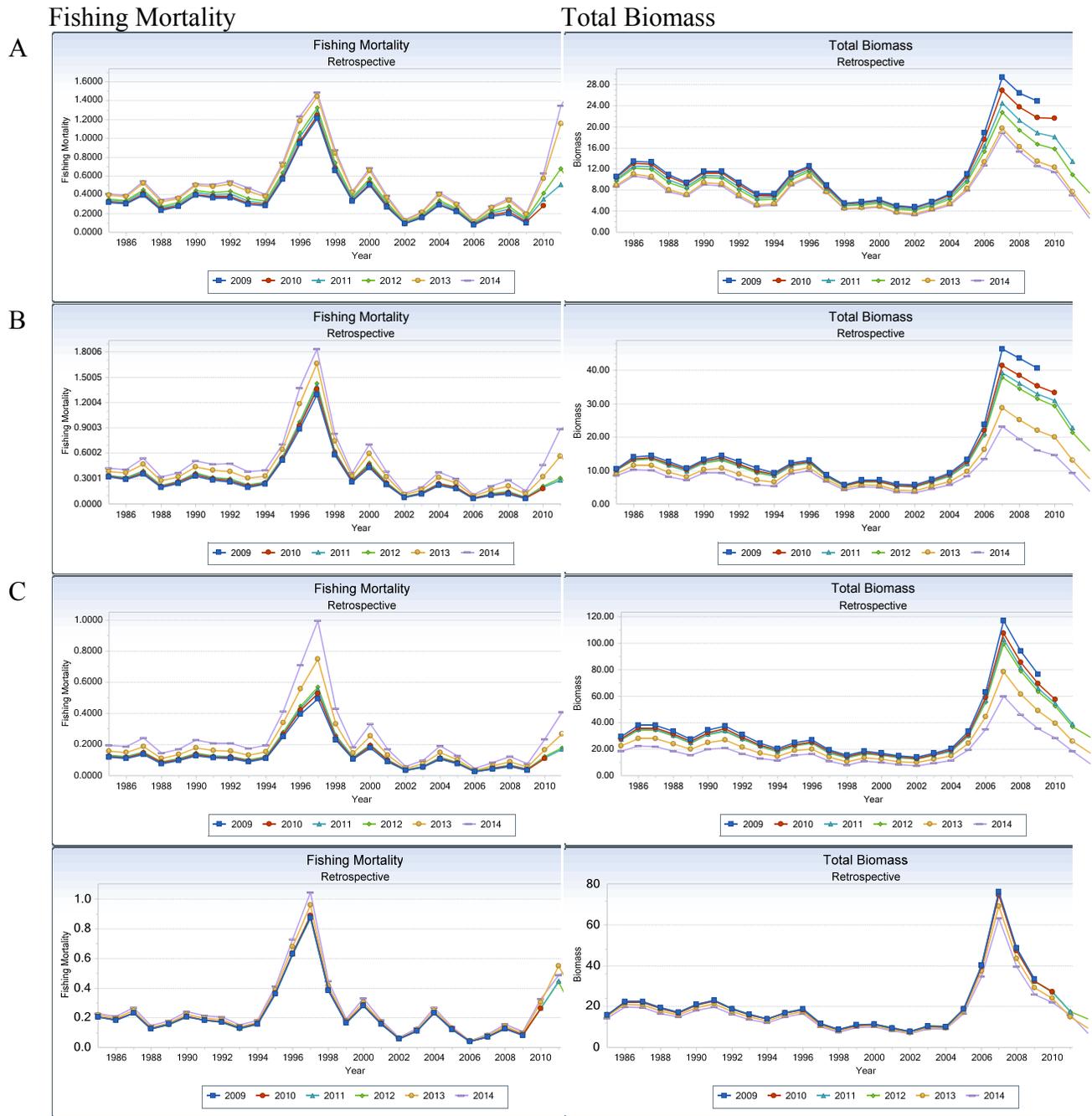


Figure C6.41. Retrospective patterns for fishing mortality and total biomass from incremental changes to 2013 annual assessment model. A. Add fall surveys; B. use adjusted CVs; C. Change to constant $M=0.5$; D. apply PPI-scaled M .

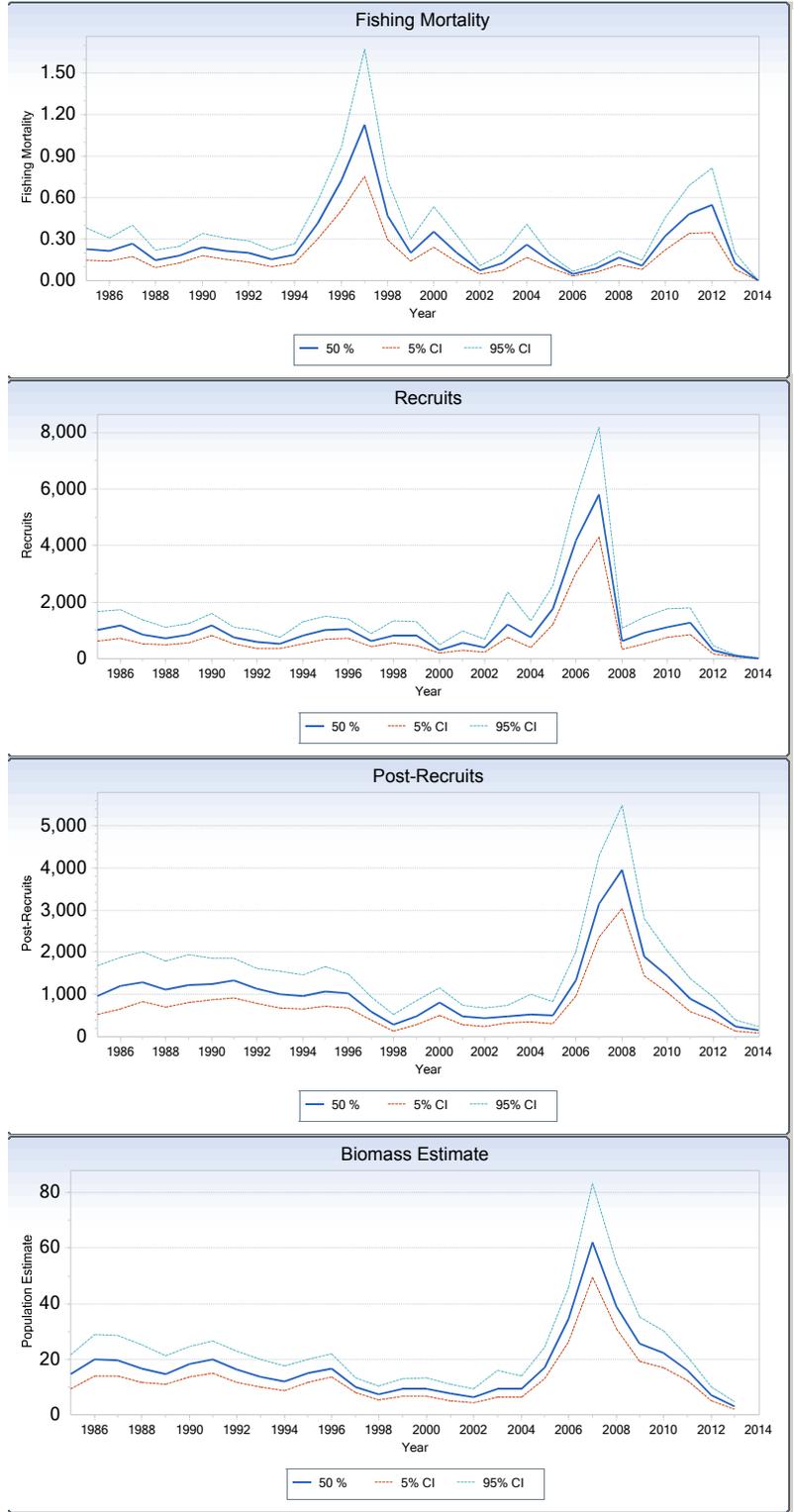


Figure C6.42. MCMC-generated 90% confidence intervals on estimates from final CSA model run.

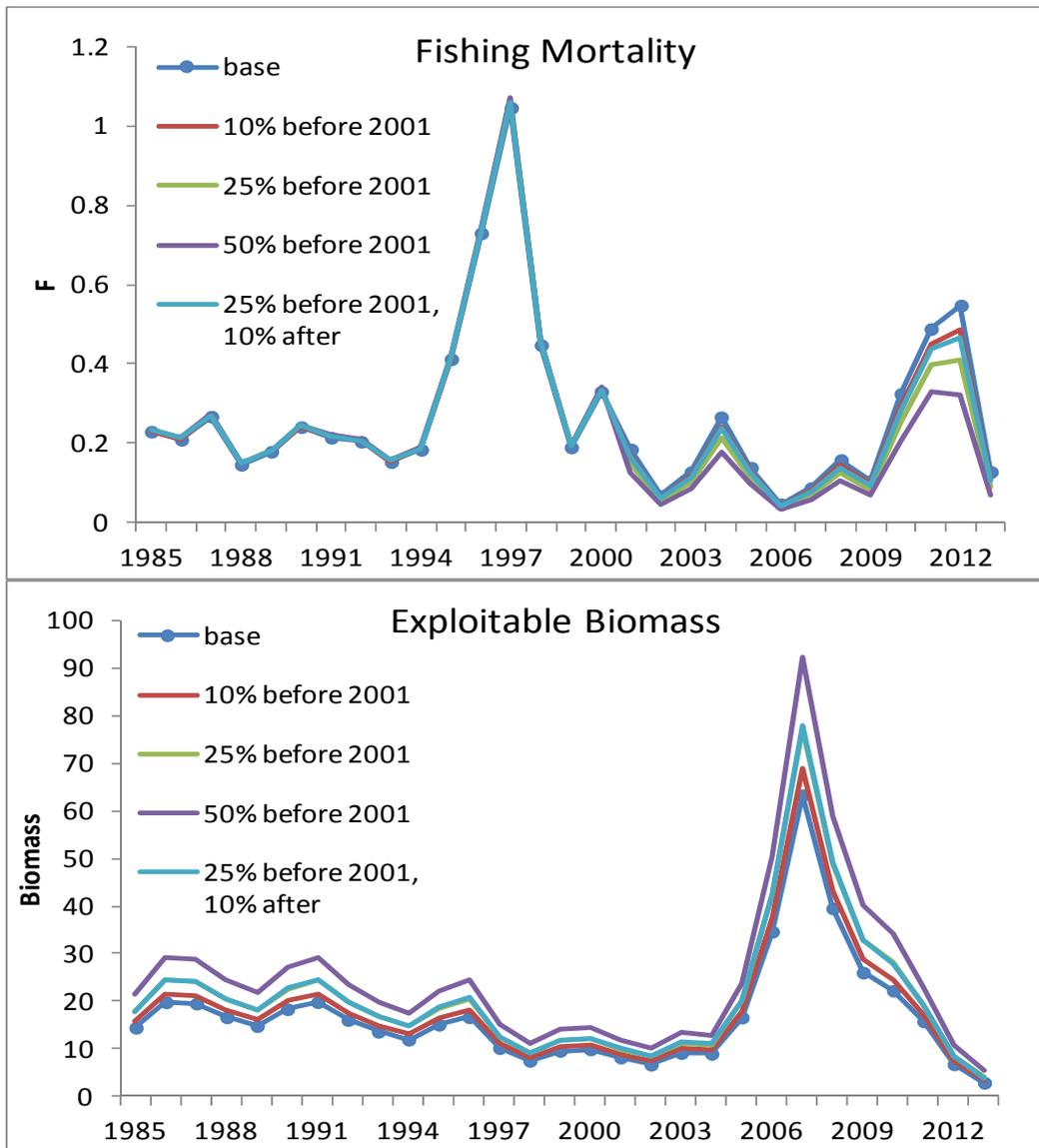


Figure C6.43. Effects on final CSA model estimates of different assumptions on under-reporting of catch. Base assumes no under-reporting.

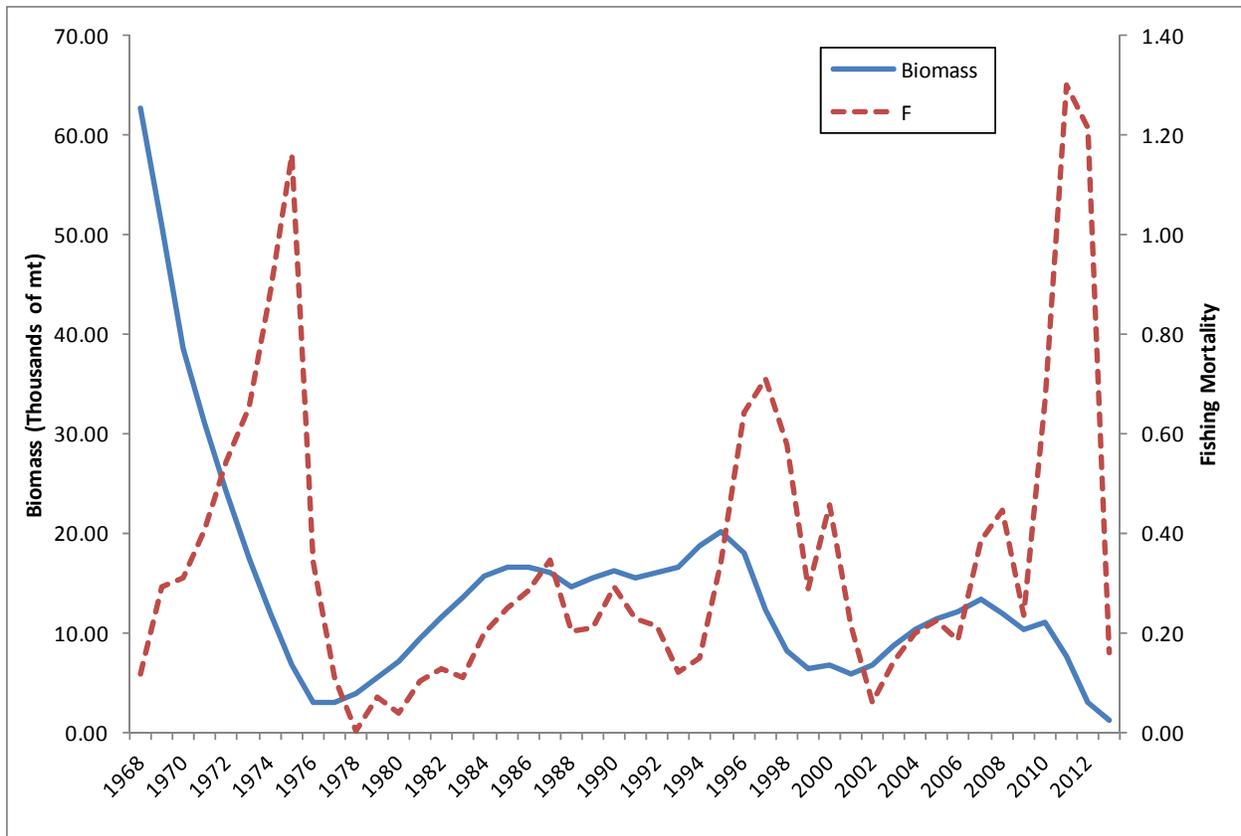


Figure C6.44. Biomass and fishing mortality estimates from the ASPIC surplus production model.

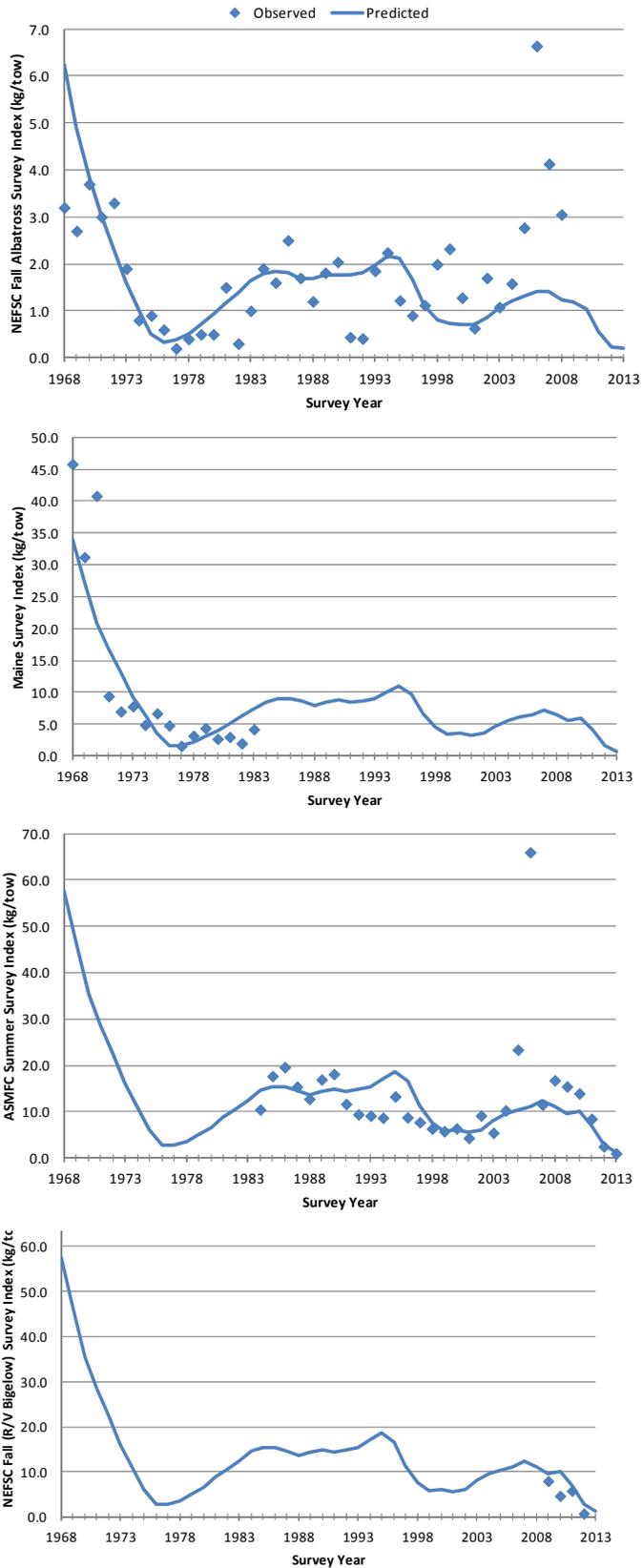


Figure C6.45. Observed and predicted survey values from the ASPIC model.

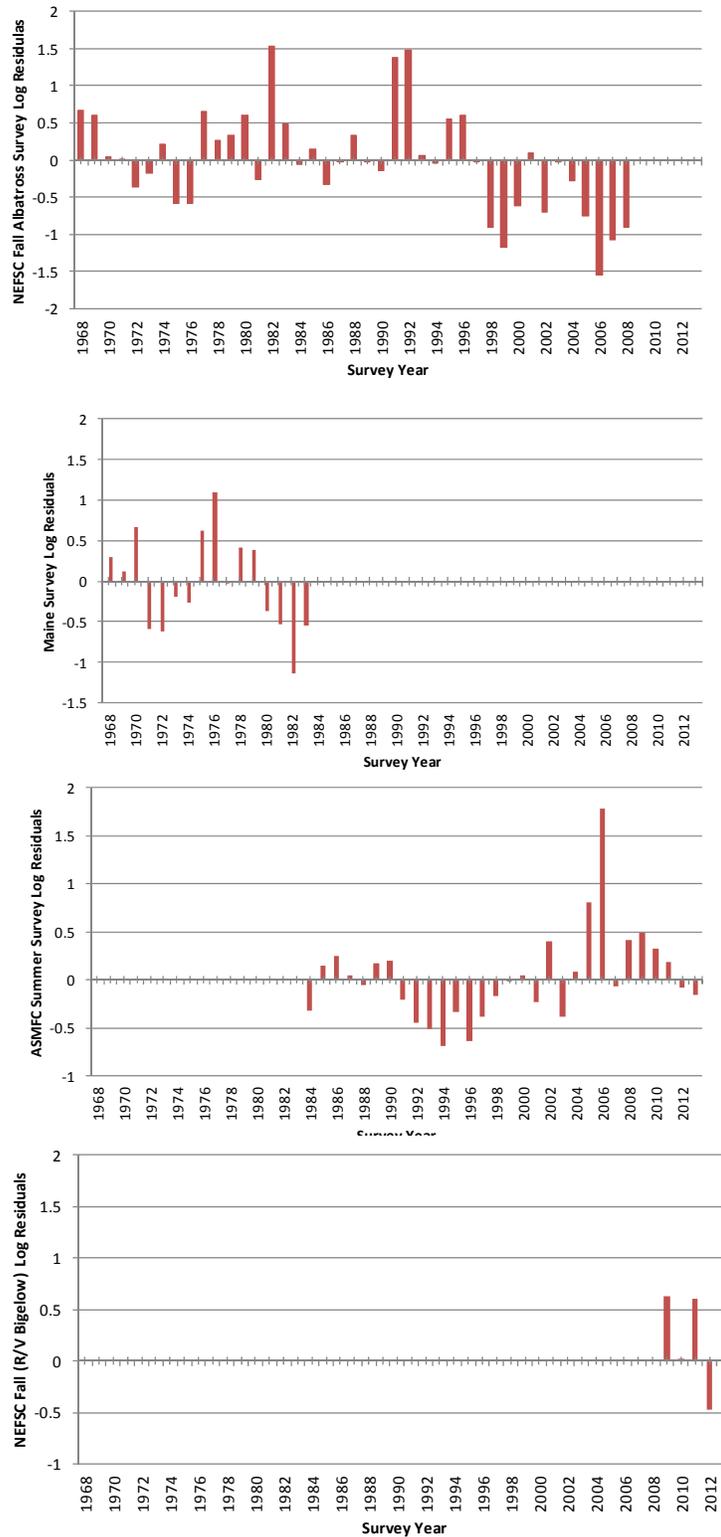


Figure C6.46. Survey residuals from the ASPIC model.

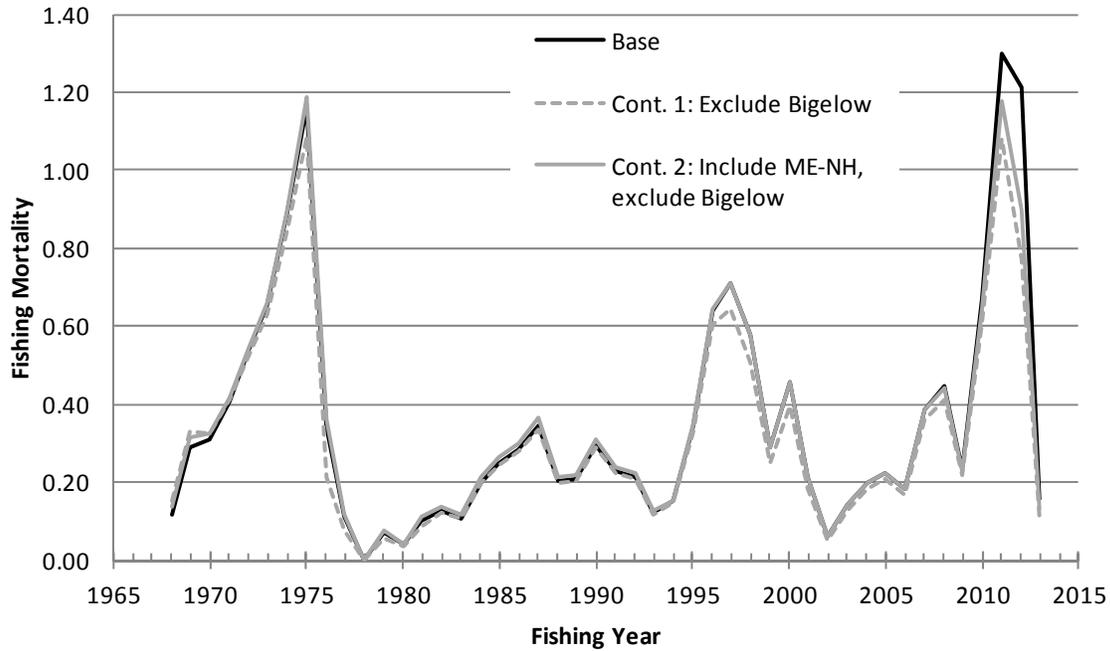


Figure C6.47. ASPIC fishing mortality estimates derived from continuity runs: 1.) excluding NEFSC fall survey conducted on R/V Bigelow (2009-2012), and 2.) including Maine-New Hampshire spring inshore survey (2003-2013) and excluding NEFSC R/V Bigelow fall survey (2009-2012).

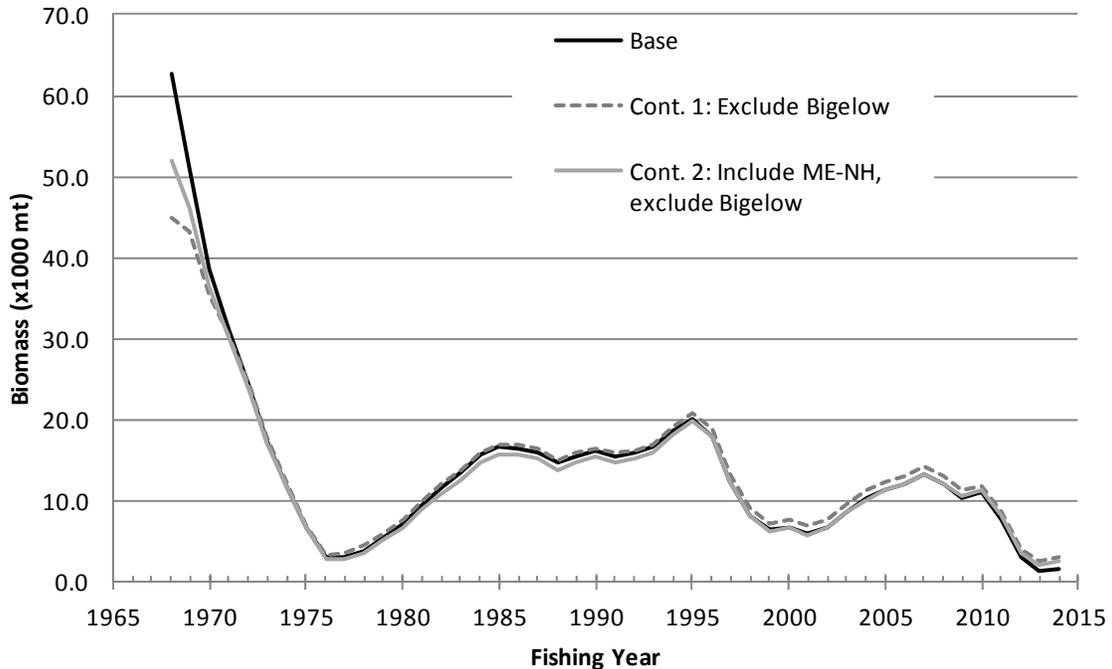


Figure C6.48. ASPIC biomass estimates derived from continuity runs: 1.) excluding NEFSC fall survey conducted on R/V Bigelow (2009-2012), and 2.) including Maine-New Hampshire spring inshore survey (2003-2013) and excluding NEFSC R/V Bigelow fall survey (2009-2012).

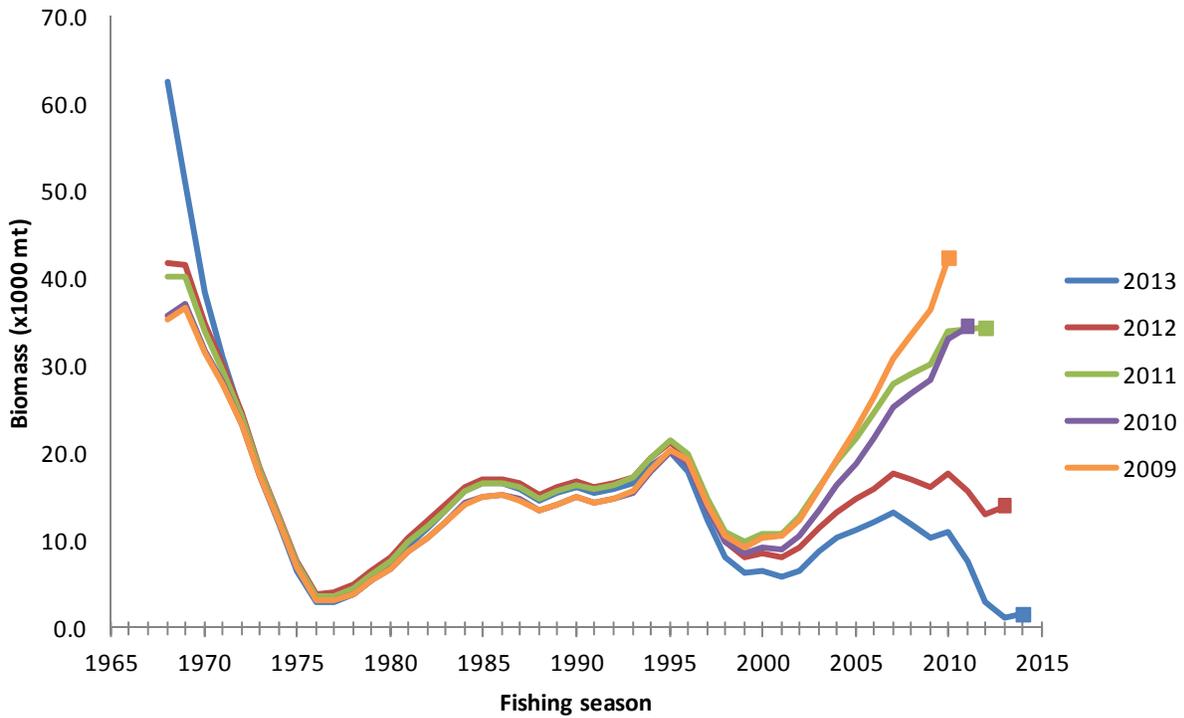
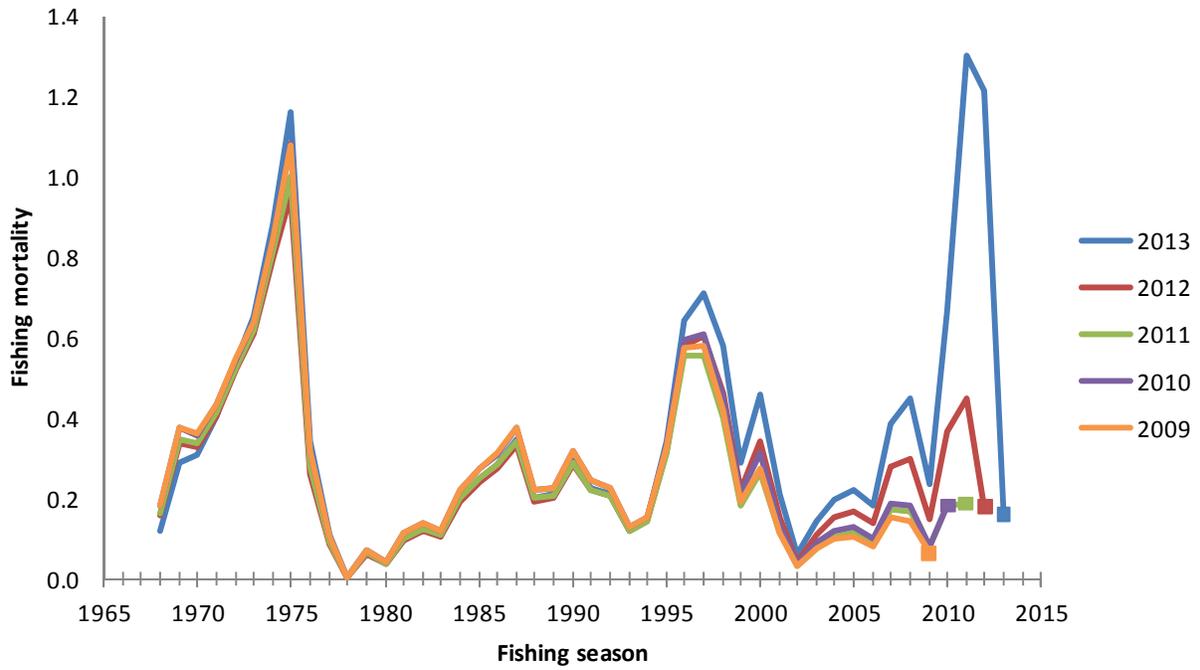


Figure C6.49. Retrospective pattern in fishing mortality (top) and biomass (bottom) from the ASPIC model.

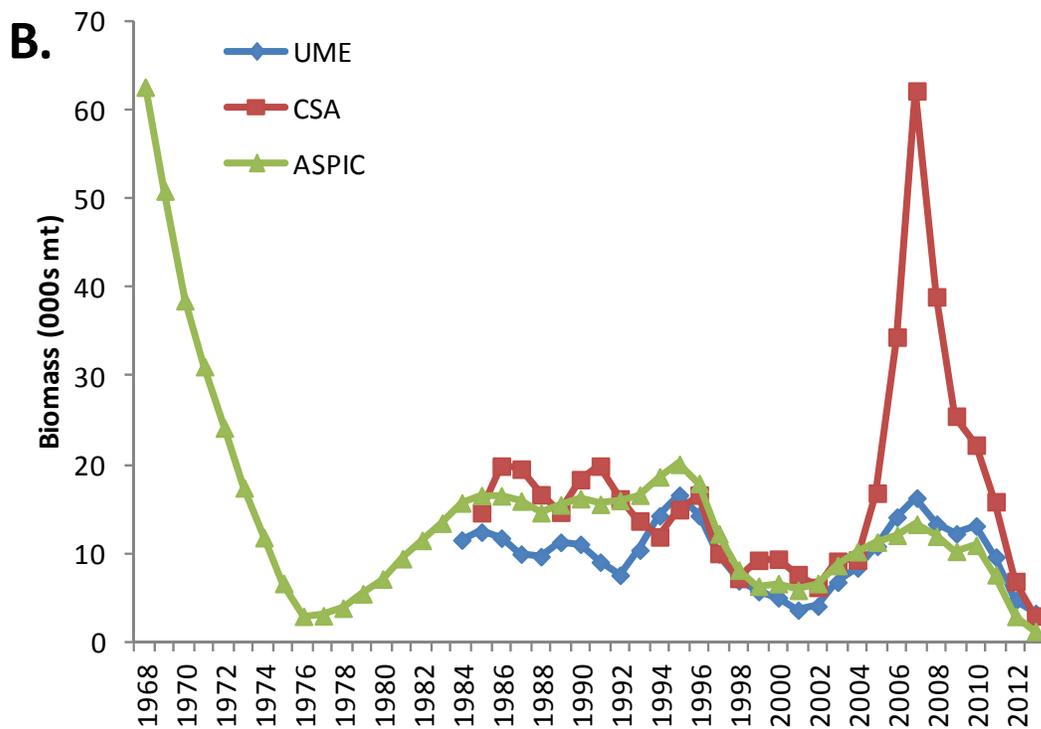
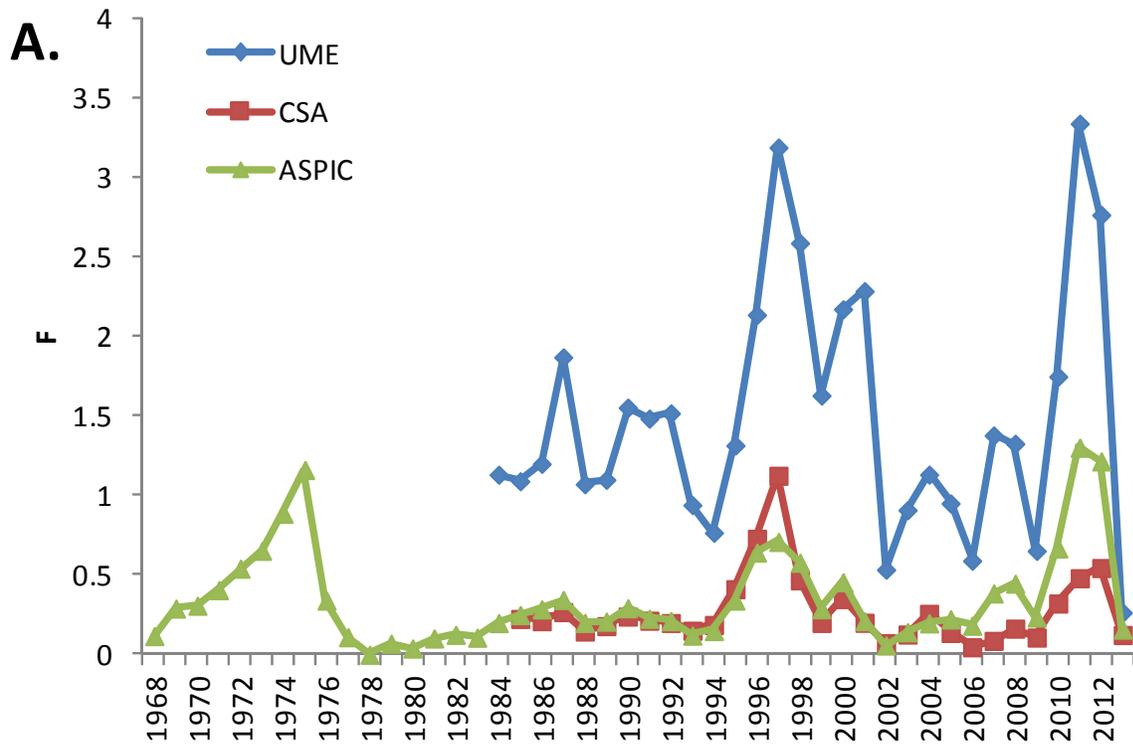


Figure C6.50. Comparison of model estimates of fishing mortality (A) and biomass (B).

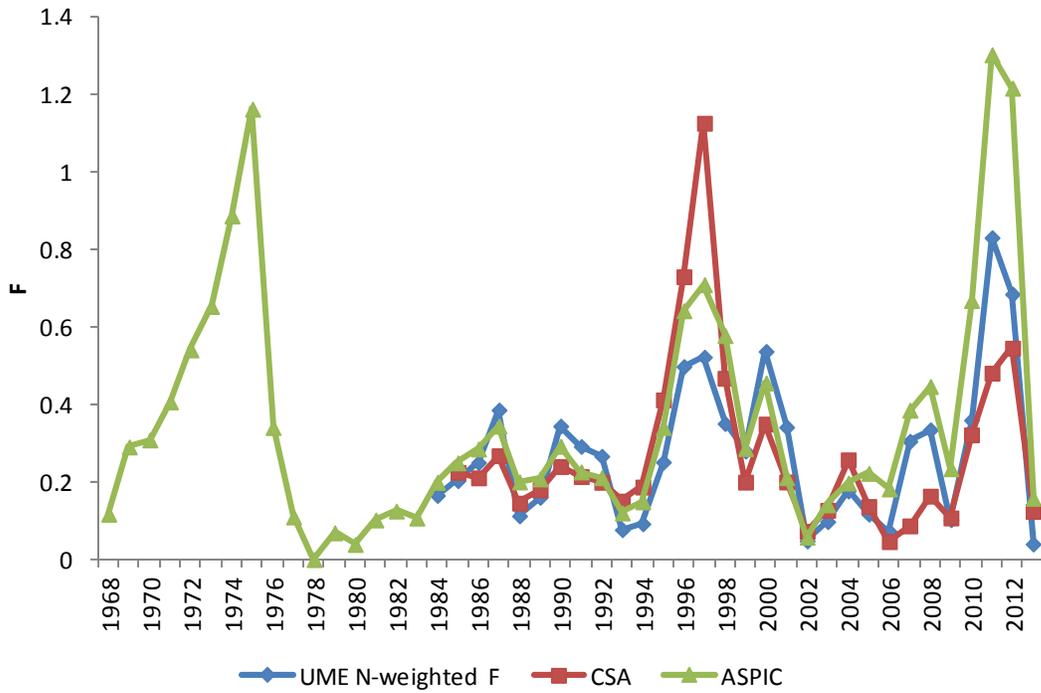


Figure C6.51. Comparison of N-weighted F from UME model with F estimates from CSA and ASPIC model.

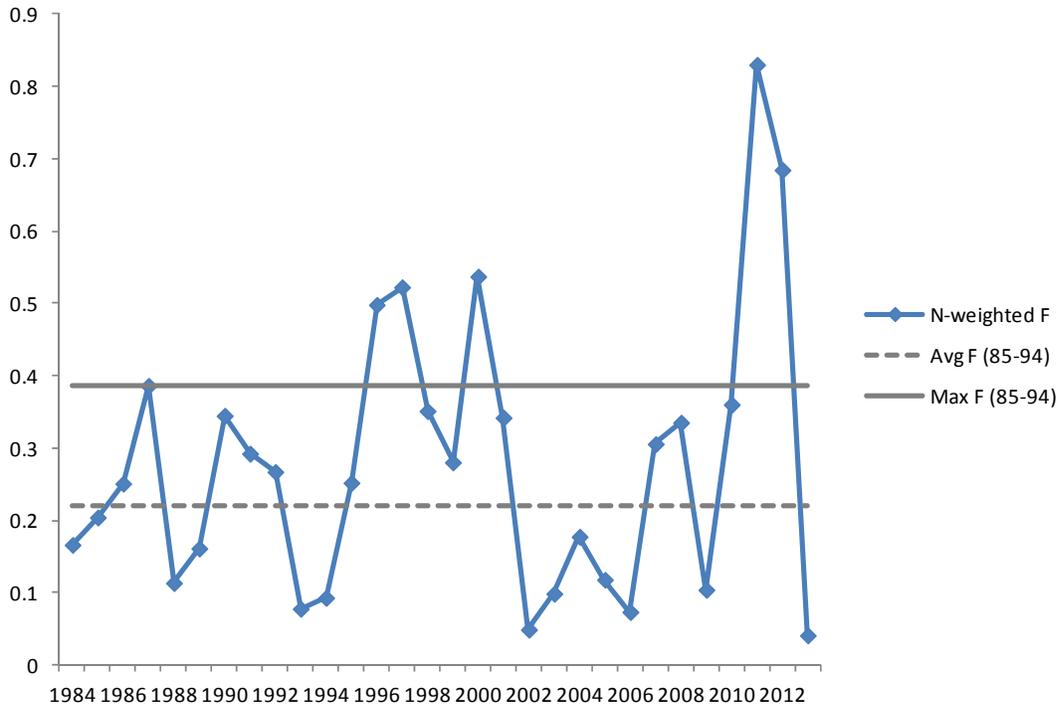


Figure C7.1.A. N-weighted F from the UME model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{\text{threshold}}$ (maximum F from 1985-1994, solid line).

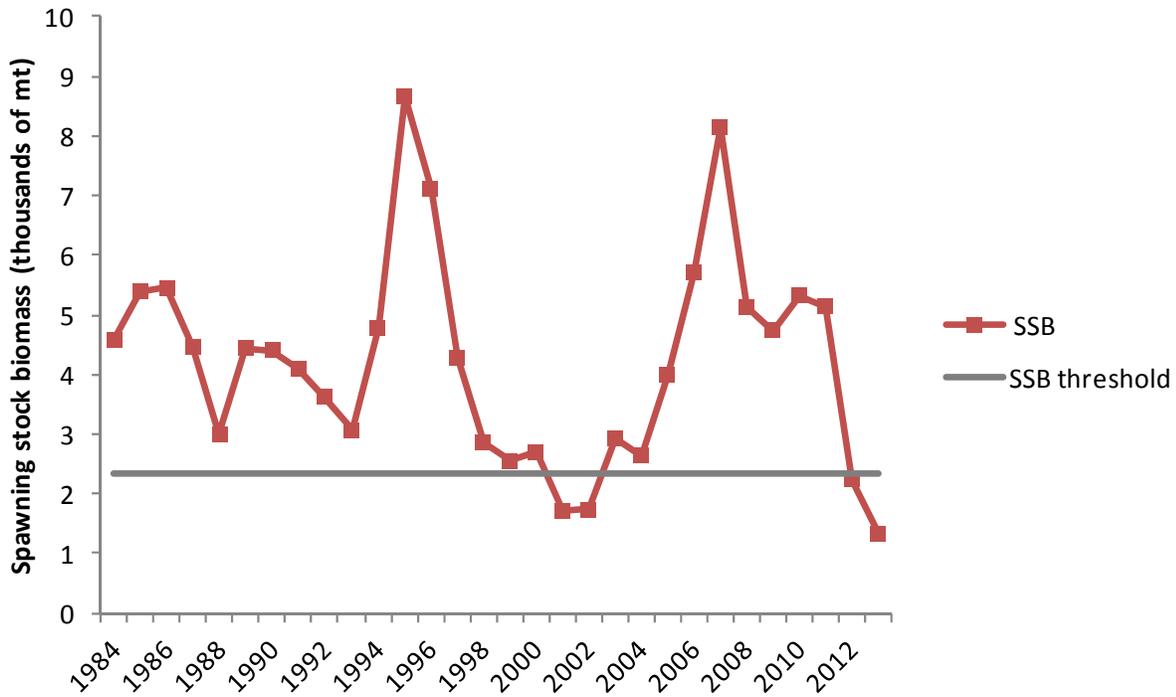


Figure C7.1.B. Spawning stock biomass from the UME model plotted with the historical SSB threshold (solid line).

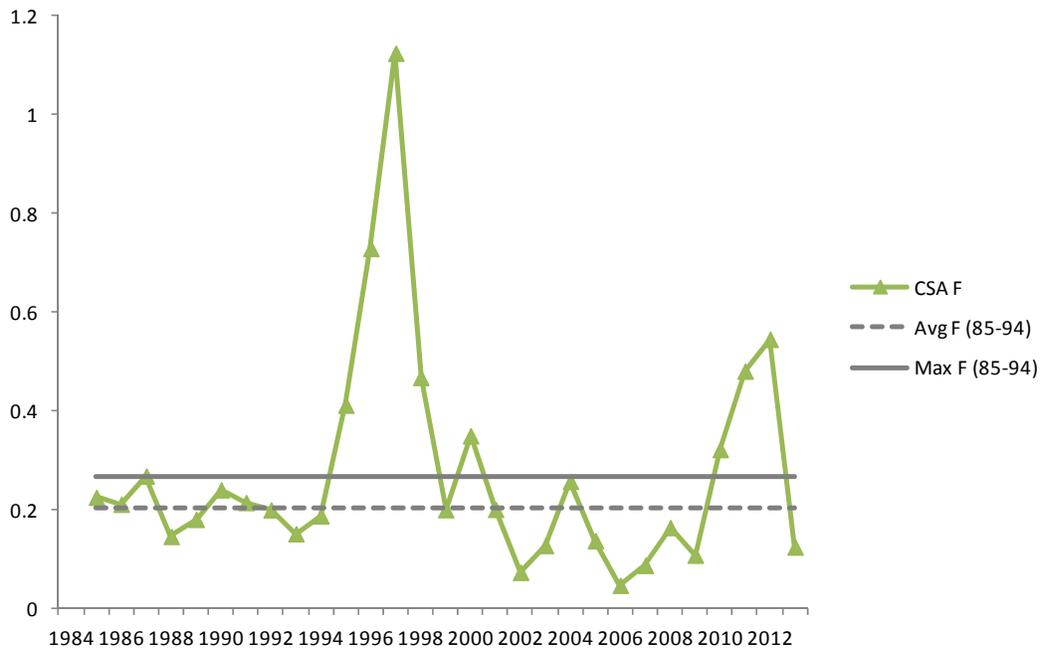


Figure C7.2.A. Fishing mortality estimates from the CSA model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{\text{threshold}}$ (maximum F from 1985-1994, solid line).

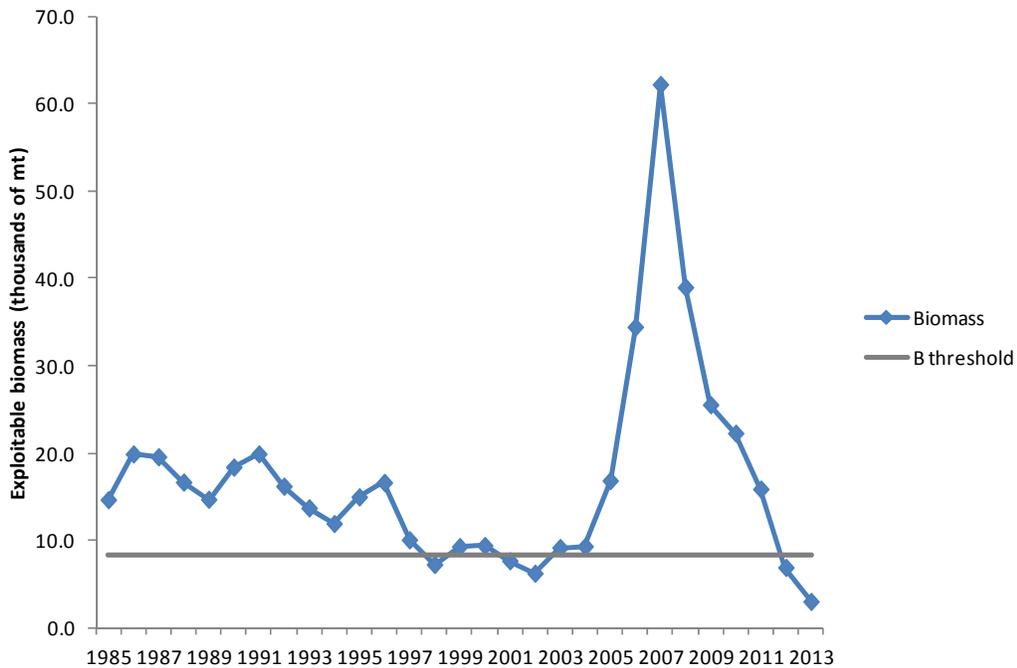


Figure C7.3.B. Exploitable biomass estimates from the CSA model plotted with the historical B threshold (solid line).

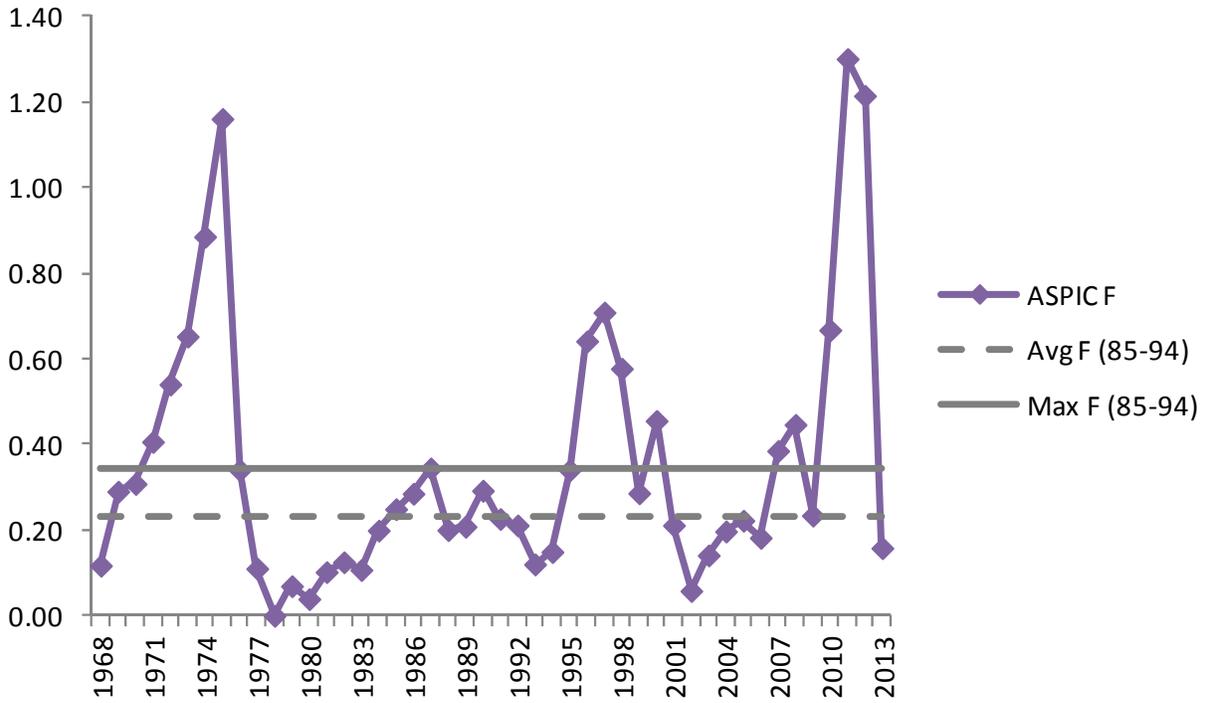


Figure C7.3. Fishing mortality estimates from the ASPIC model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{\text{threshold}}$ (maximum F from 1985-1994, solid line).

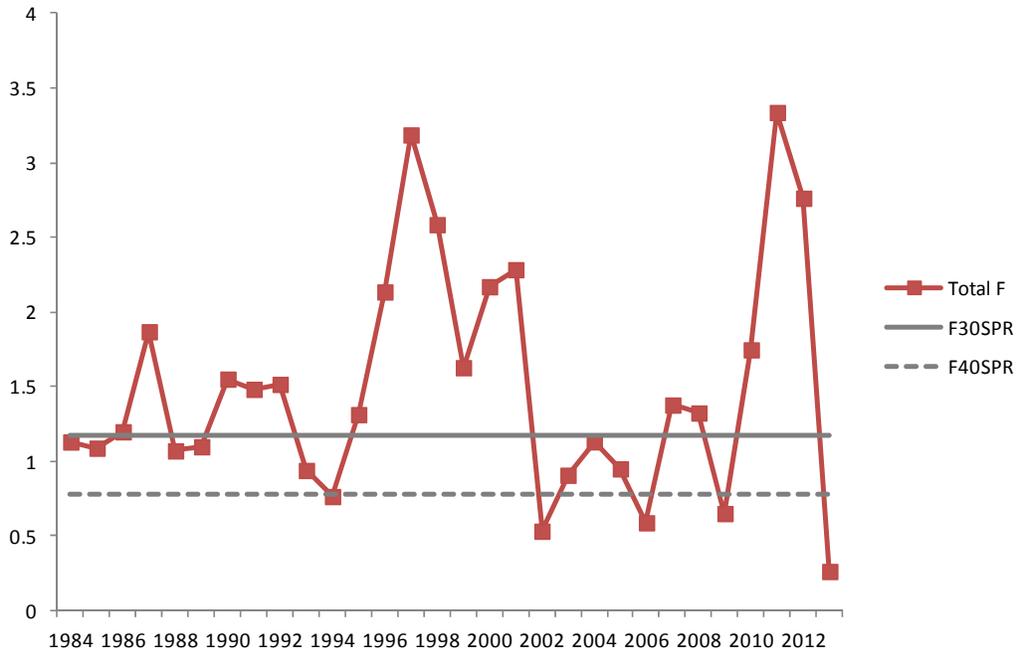


Figure C7.4. Total full F estimated from the UME model plotted with model-based reference points ($F_{30\%SPR}$, solid line, and $F_{40\%SPR}$, dashed line).

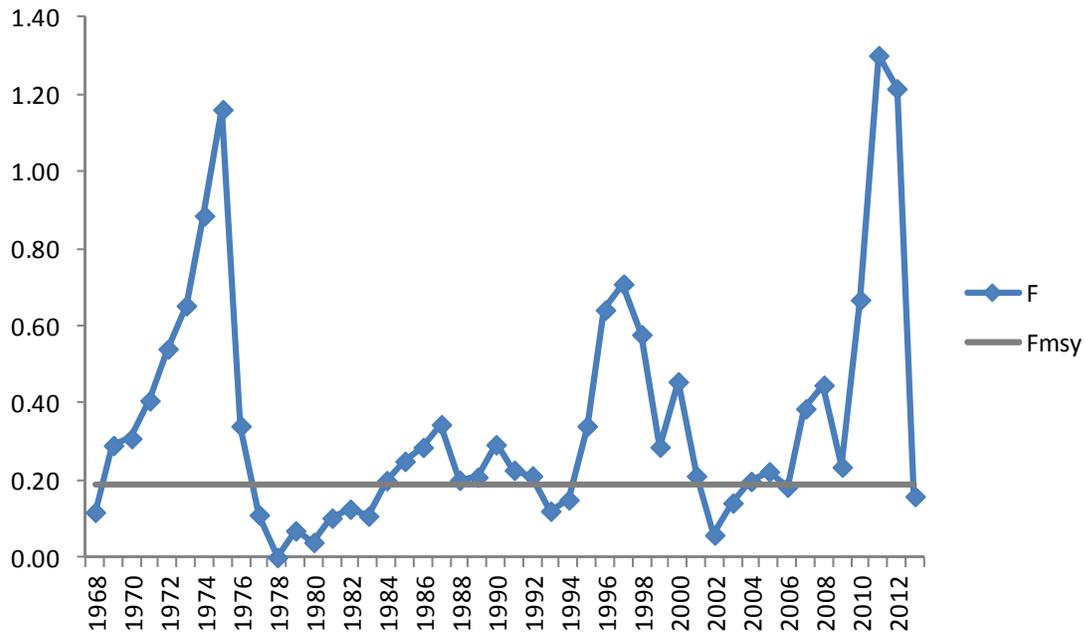


Figure C7.5.A. Fishing mortality estimates from the ASPIC model plotted with model-based reference points (F_{MSY}).

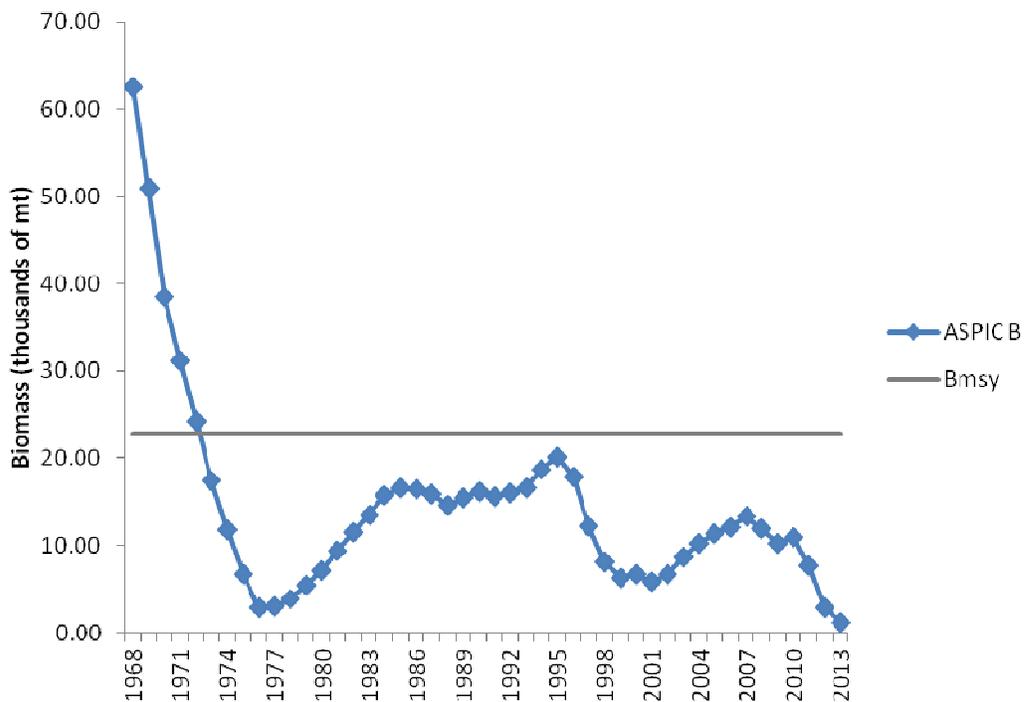


Figure C5.7.B. Biomass estimates from the ASPIC model plotted with model-based reference point (B_{MSY}).

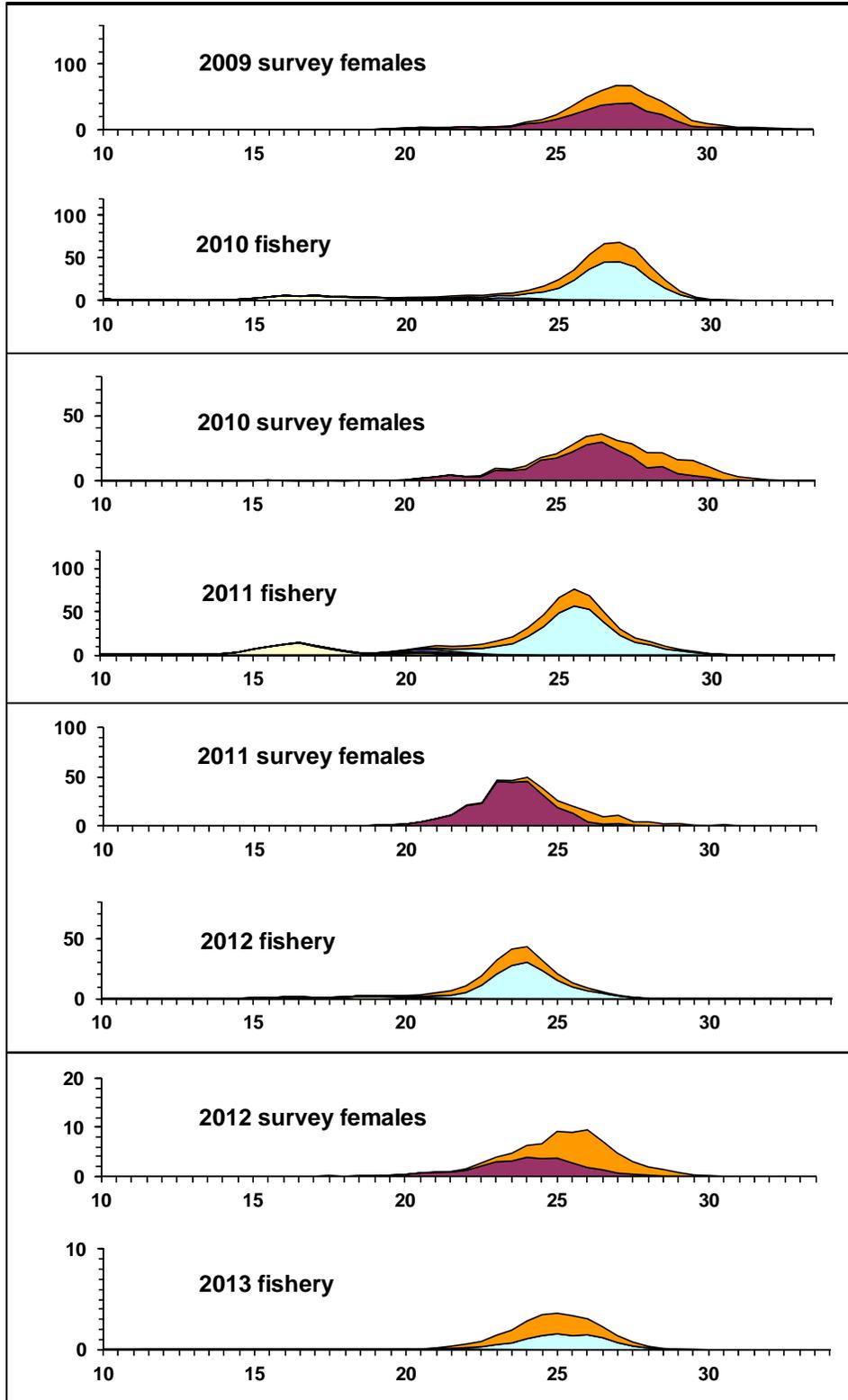


Figure C9.1. Length-frequency distributions of the female northern shrimp from the summer survey and of all sexes and stages in the fishery the following year.

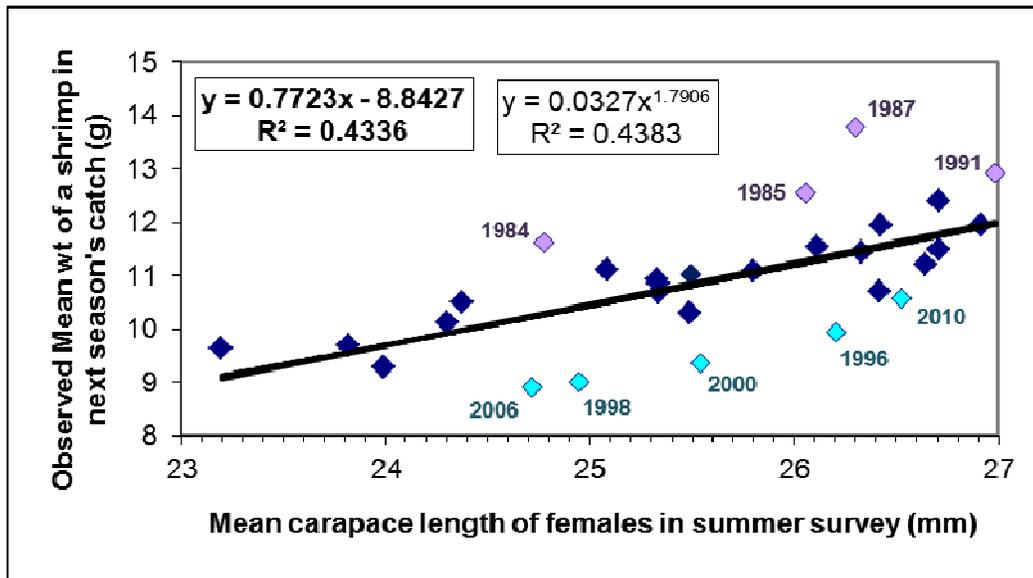


Figure C9.2. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), for survey years 1984 to 2012. An exponential relationship is also calculated. Survey years in which the observed mean weight differs from predicted by more than 1 g (outliers) are indicated.

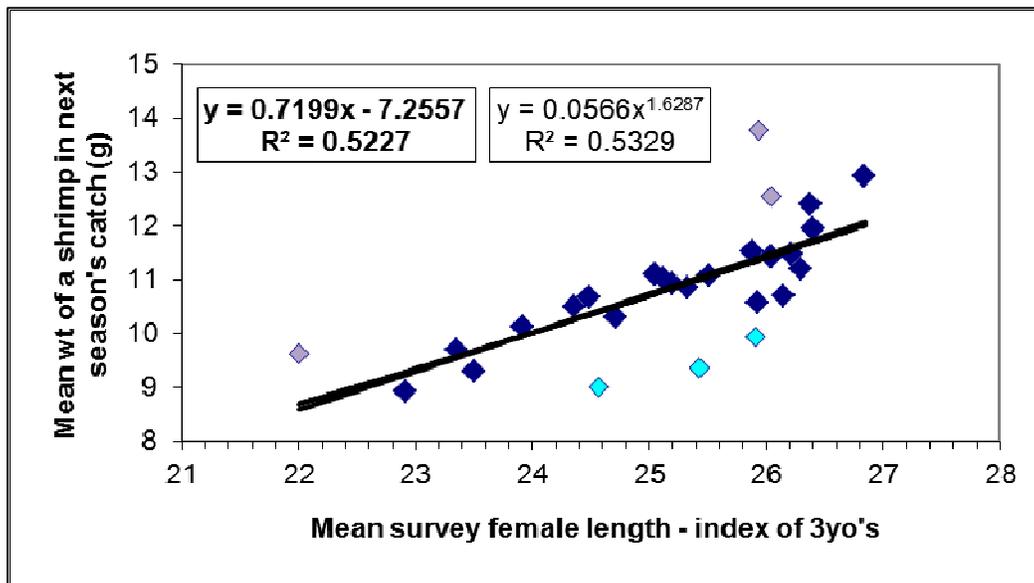


Figure C9.3. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), corrected for the number of 3-y-o's, for survey years 1985 to 2012. An exponential relationship is also calculated. Observed mean weights differing from predicted by more than 1 g (outliers) are indicated.

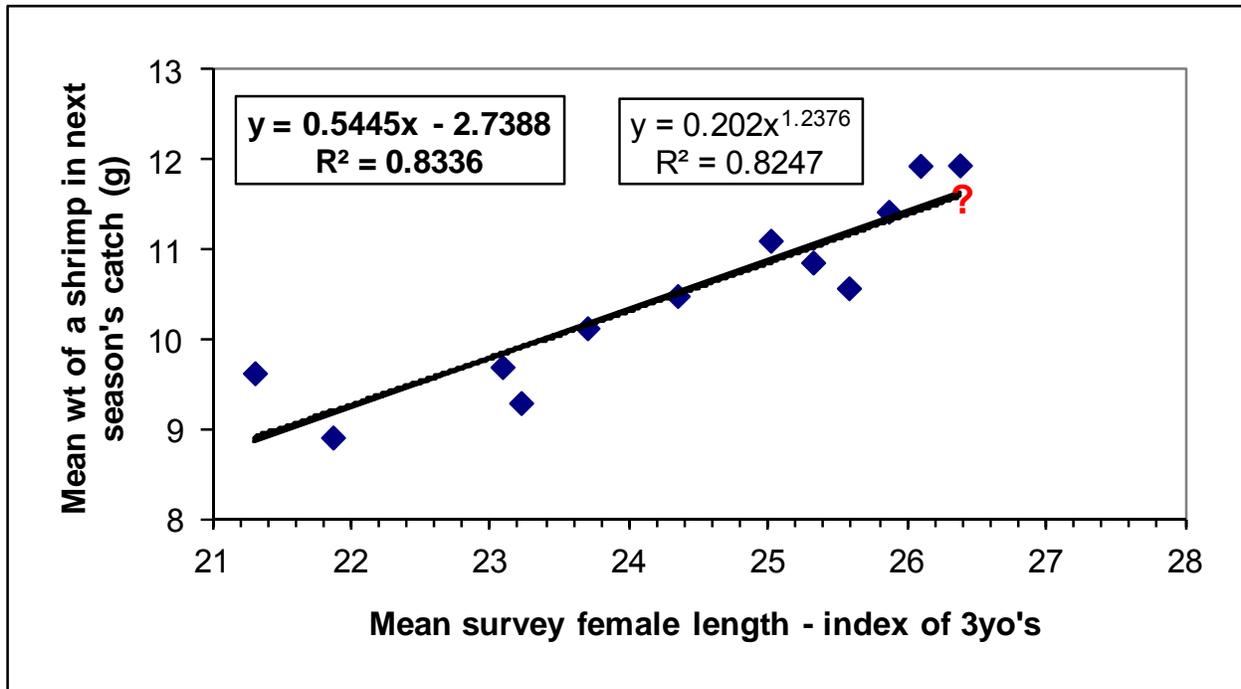


Figure C9.4. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), corrected for the number of 3-y-o's, for survey years 2001 to 2012. An exponential relationship is also calculated. The predicted mean weight (g) of a shrimp in a 2014 fishery is indicated by “?”.