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

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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.

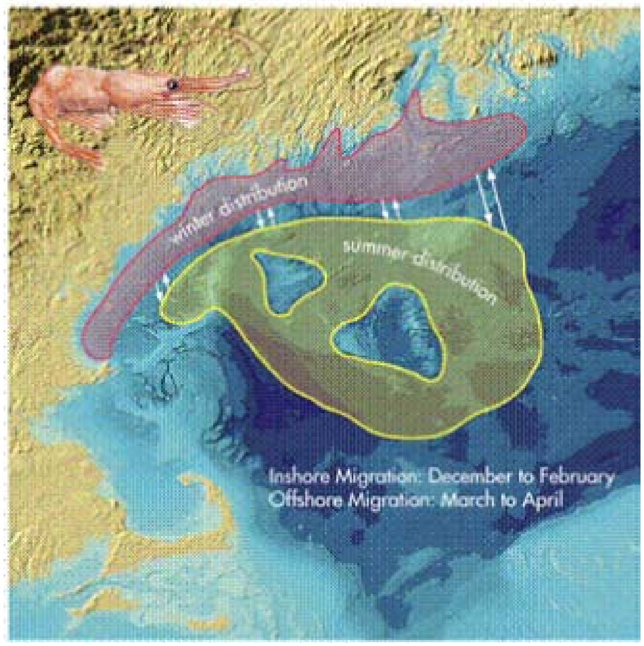
As complements to the length-structured model, the CSA model and the ASPIC model were also used. The CSA model (NMFS Toolbox v. 4.2.2) was updated to use a formal likelihood framework and to allow the use of multiple indices of abundance.

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 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).



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.**

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

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 at 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 680 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 7.9º C during 1906-1948 to an average of 10.4º 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 (5.0º C) was cooler than in 2012 (6.9º C), but still well above the 20th century average (3.4º 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 Iodoine 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/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 Fréchette, 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

	Maine		Massachusetts	New Hampshire
Month	**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 posssible, 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 f 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 Mclnnes (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 rho 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*base or 0.9*base had similar overall fits based on the objective function and likelihood components. Setting selectivity below 0.75*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 ≤1%). Estimates of the survey *q*'s were moderately precise (relative IQs were 5-18%, bias was ≤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 $F_{threshold}$ 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:

$$\bar{F_y} = \frac{\sum_1^{Lmax} F_y \cdot selectivity_L \cdot N_{L,y}}{N_{total,y}}$$

The annual N-weighted Fs for 1985-1994 were averaged to produce the F_{target} = 0.22. The maximum N-weighted F for this time period was $F_{threshold}$ = 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 $SSB_{threshold}$ = 2,335 mt.

SSB_{2013} was estimated as 1,334 mt, below the $SSB_{threshold,}$ 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_{target} = 0.20, with a maximum of $F_{threshold}$ = 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 $B_{threshold}$ = 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_{target} = 0.23, with a maximum of $F_{threshold}$ = 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 $B_{threshold}$ = 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_{305SPR} 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 $0.5B_{MSY}$, 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	$F_{target} = 0.22$ $F_{threshold} = 0.39$	$SSB_{threshold} = 2,335$ mt
UME SPR	$F_{40\%SPR} = 0.78$ $F_{30\%SPR} = 1.17$	n.a.
CSA historical proxy	$F_{target} = 0.20$ $F_{threshold} = 0.27$	$B_{threshold} = 8,300$ mt
ASPIC MSY	$F_{MSY} = 0.19$	$B_{MSY} = 22,800$ 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} [$F_{target} = F_{1985\text{-}94}$ from Amendment 2]
- At the $F_{threshold}$ [$F_{threshold} = F_{1987}$ from Amendment 2]
- Between the F_{target} and $F_{threshold}$

"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:

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

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 x 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 C9.1. 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 C9.3.

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

- <u>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.</u>

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

- <u>Evaluate effectiveness of summer shrimp survey statistical design, including geographic coverage.</u>

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	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations
1988	• Restriction of season to winter and spring • Continuation of mesh regulations	• Open season (183 days) • Continuation of mesh regulations, except 0.25 inch tolerance in codend eliminated
1989	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required in April and May
1990	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required in December, April, and May
1991	• Extension of season to maximum allowed • Continuation of mesh regulations	• Open season (182 days) • Continuation of mesh regulations • Shrimp separator trawls required throughout season
1992	• Restriction of season from January – March • Continuation of mesh regulations	• 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	• Restriction of season from January – March • Continuation of mesh regulations	• 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	• Restriction of season from January – March • Continuation of mesh regulations	• Open season (122 days) December 15, 1993 – April 15, 1994. • Continuation of mesh regulations • Finfish excluder devices
1995	• Restriction of season from January – March • Continuation of mesh regulations	• 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	• Extension of season to maximum allowed • Continuation of mesh regulations	• 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	• Restriction of effort in December, April, and May • Continuation of mesh regulations	• 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

		• Finfish excluder devices required
1998	• Restriction of effort in February – March • Continuation of mesh regulations	• 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	• Restriction of season to 40 days during February – March • Continuation of mesh regulations	• 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	• No fishing; closed season	• Open season (51 days). January 15 – March 15. No fishing on Sundays. • Continuation of mesh regulations • Finfish excluder devices required
2001	• Restriction of season to 61 days • Continuation of mesh regulations	• 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	• No fishing; closed season	• Open season (25 days). February 15 – March 11. • Continuation of mesh regulations • Finfish excluder devices required
2003	• No fishing; closed season	• Open season (38 days). January 15 – February 27. No fishing on Fridays. • Continuation of mesh regulations • Finfish excluder devices required
2004	• No fishing; closed season	• 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	• Landings should not exceed 2,500 metric tons • Continuation of mesh regulations	• 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	• Landings should not exceed 5,200 metric tons • Continuation of mesh regulations	• 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	• No recommendation against 140-day season • Continuation of mesh regulations	• 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	• No recommendation against 152-day season • Maintain fishing mortality at or below the target/threshold	• 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	• Landings should not exceed 5,103 metric tons • Maintain fishing mortality at or below the target/threshold	• Open season (180 days). December 1 – May 29. • Continuation of mesh regulations • No mechanical shakers allowed on vessel
2010	• Landings should not exceed 4,400 to 4,900 metric tons • Maintain fishing mortality at or below the target/threshold	• 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	• Based on favored fishing mortality rate, landings should not exceed 3,200 metrics tons (F = 0.22) or 4,000 metric tons (F = 0.29)	• 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	• Maintain fishing mortality at or below the target value (F = 0.32) • Landings should not exceed 1,834 metric tons	• 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	• Moratorium on fishing • If fishing is allowed, start season after 50% of shrimp have hatched their brood	• TAC of 625 metric tons; divided 17% to trap fishery and 83% to trawl fishery • Trawl fishery start on January 22, 2013with 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	• Moratorium on fishing; the stock has collapsed	• Moratorium on fishing

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

ESTIMATORS OF AGE-CONSTANT NATURAL MORTALITY

INPUT		von B age-length		longevity		maturity		environ.
	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	L_inf	K	t_max	P	a_50	GI	temp	M instantaneous	M annual
Alverson and Carney 1975		M = 3K/(exp[0.38*K*t_max) − 1]		X	X					0.85	0.57
Rikhter and Efanov 1977		M = [1.521/(a_50^0.720)] − 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*ln(K) − 0.279*ln(L_inf/10) + 0.4634*ln(Temp)]	X	X					X	0.59	0.45
Hoenig 1983 (regression)	2	M = exp[1.44 − 0.982*ln(t_max)]			X					0.73	0.52
Hoenig 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*K		X						0.76	0.53
Gunderson and Dygert 1988		M = 0.03 + 1.68*GI						X		NA	NA
Jensen 1996 (theoretical)		M = 1.50*K		X						0.54	0.42
Jensen 1996 (derived from Pauly 1980)		M = 1.60*K		X						0.58	0.44
Gunderson 1997		M = 1.79*GI						X		NA	NA
Hewitt and Hoenig 2005		M = 4.22 ⁄ t_max			X					0.70	0.51
Beverton	5	M = 3*K/[exp(a_50*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 Hoenig (1983)
3 Equation ≈ 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 instantaneous	M(W) - unscaled annual	M(W) - scaled** instantaneous	M(W) - scaled** annual
Lorenzen 1996	M(W) = M_u * W ^ b	0	8	0.3	5.224	0.99	1.33	0.74
Scaled estimate	-M(a)* LN(%-at-max-age)/ΣM(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					
		Age	Length	M(L)	
Method	Equation	*years*	*mm*	*instantaneous*	*annual*
Gislason et al. (2010)	**M**(L)=exp[0.55 − 1.61*ln(L/10) + 1.44*ln(**L_inf**/10)+ln(**K**)]	**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	
21	0.25	Rinaldo (1976)
22	0.25	
23	0.25	
24	0.25	
25	0.25	
26	0.25	
27	0.25	
28	0.25	
29	0.75	Estimated to align with maximum observed age
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

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1985 Season, 166 days, Dec 1 - May 15								
Maine	335.7	851.8	1,095.5	525.1	116.8	21.5	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	11.6	1.3		0.2	216.7
Total	494.4	1,221.9	1,384.2	776.0	175.9	78.5	1.0	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	1.3	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	1.2	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	1.4			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	1.0		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	1.0			100.1
Total	231.7	1,076.3	1,380.2	517.0	167.5	87.2	0.1	3,460.0

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
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	118.3	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	1.2	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.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
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		1,075.2
Mass.		38.5	9.0	1.9		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	1,331.0
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	1,203.7
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	1,344.4
2004 Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off								
Maine	1.8	526.2	945.1	446.4	4.7	2.7	0.04	1,926.9
Mass.		conf	21.3	conf				21.3
N.H.		27.3	94.8	61.1				183.2
Total	1.8	553.5	1,061.1	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	27.5	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

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
2009 Season, 180 days, Dec 1 - May 29								
Maine	134.6	595.9	988.2	560.1	34.9	1.8	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	1.8	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	6,140.8
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 (21 days); 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

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	% of total
2000 Season, 51 days, Jan 17 - Mar 15, Sundays off									
Trawl		731.1	1,354.8	163.6				2,249.47	89%
Trap		28.9	179.6	58.3				266.7	11%
Total	0.0	759.9	1,534.4	221.9	0.0	0.0	0.0	2,516.2	
2001 Season, 83 days, Jan 9 - Apr 30, Mar 18 - Apr 16 off, experimental offshore fishery in May									
Trawl		533.0	360.1	30.9	29.8	0.3		954.0	89%
Trap		42.9	72.6	5.7				121.2	11%
Total	0.0	575.8	432.8	36.6	29.8	0.3	0.0	1,075.2	
2002 Season, 25 days, Feb 15 - Mar 11									
Trawl			263.6	77.2				340.8	87%
Trap			43.2	7.6				50.8	13%
Total	0.0	0.0	306.8	84.8	0.0	0.0	0.0	391.6	
2003 Season, 38 days, Jan 15 - Feb 27, Fridays off									
Trawl		467.2	518.8	0.4			0.6	987.0	82%
Trap		67.5	149.2					216.7	18%
Total	0.0	534.7	668.0	0.4	0.0	0.0	0.6	1,203.7	
2004 Season, 40 days, Jan 19 - Mar 12, Saturdays and Sundays off									
Trawl	1.8	514.0	905.5	430.0	4.7	2.7	0.04	1858.7	96%
Trap		12.2	39.5	16.5				68.1	4%
Total	1.8	526.2	945.1	446.4	4.7	2.7	0.04	1926.9	
2005 Season, 70 days, Dec 19 - 30, Fri-Sat off, Jan 3 - Mar 25, Sat-Sun off									
Trawl	75.0	369.4	770.6	663.6			0.01	1878.5	83%
Trap		conf	132.6	259.0				391.6	17%
Total	75.0	369.4	903.2	922.6	0.0	0.0	0.01	2270.2	
2006 Season, 140 days, Dec 12 - Apr 30									
Trawl	144.1	675.0	733.8	256.9	117.1			1927.0	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	2201.6	
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	

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	% of total
2008 Season, 152 days, Dec 1 - Apr 30									
Trawl	408.5	989.6	1,680.8	603.4	42.6		0.1	3,724.9	82%
Trap	conf	64.1	339.6	380.4	6.7			790.8	18%
Total	408.5	1,053.7	2,020.4	983.8	49.3	0.0	0.1	4,515.8	
2009 Season, 180 days, Dec 1 - May 29									
Trawl	134.3	579.7	780.9	405.4	33.6	1.8	0.2	1,935.9	84%
Trap	0.4	16.2	207.3	154.7	1.3			379.8	16%
Total	134.6	595.9	988.2	560.1	34.9	1.8	0.2	2,315.7	
2010 Season, 156 days, Dec 1 - May 5									
Trawl	263.4	1,488.3	2,091.1	326.3	194.3	33.0	0.4	4,396.7	78%
Trap	conf	194.8	823.4	189.3	conf			1,207.6	22%
Total	263.4	1,683.1	2,914.5	515.6	194.3	33.0	0.4	5,604.3	
2011 Season, 90 days, Dec 1 - Feb 28									
Trawl	720.8	2,194.5	1,728.5	0.5				4,644.4	83%
Trap	1.9	377.7	545.8					925.3	17%
Total	722.7	2,572.2	2,274.3	0.5	0.0	0.0	0.0	5,569.7	
***2012** Season, Trawling Mon,Wed,Fri, Jan 2 - Feb 17 (21 days); Trapping Feb 1-17 (17 days)									
Trawl	0.5	1,130.1	887.1	0.5				2,018.3	91%
Trap			193.1					193.1	9%
Total	0.5	1,130.1	1,080.2	0.5	0.0	0.0	0.0	2,211.4	
***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		54.2	154.6	31.4	0.5			240.7	94%
Trap			12.5	2.2	conf			14.8	6%
Total	0.0	54.2	167.2	33.6	0.5	0.0	0.0	255.5	

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
GROUNDFISH, 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.

Season	Maine			Massachusetts	New Hampshire	Total
	Trawl	Trap	Total			
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.

Fishing Season	Catches sampled (mt)	Number of samples	Sample wts (kg)	Numbers measured
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.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1985 Season, 166 days, Dec 1 - May 15								
Maine	552	1,438	1,979	1,198	260	35		5,462
Mass.	127	269	224	231	92	73		1,016
N.H.	118	135	78	26	22			379
Total	797	1,842	2,281	1,455	374	108	0	6,857
1986 Season, 183 days, Dec 1 - May 31								
Maine	590	1,309	2,798	831	224	133	68	5,953
Mass.	128	235	225	320	194	133	159	1,394
N.H.	156	163	165	51	3		17	555
Total	874	1,707	3,188	1,202	421	266	244	7,902
1987 Season, 182 days, Dec 1 - May 31								
Maine	993	2,373	3,073	2,241	617	340	16	9,653
Mass.	325	354	414	426	283	317	164	2,283
N.H.	67	164	175	95	28		32	561
Total	1,385	2,891	3,662	2,762	928	657	212	12,497
1988 Season, 183 days, Dec 1 - May 31								
Maine	972	2,183	2,720	1,231	193	122		7,421
Mass.	28	326	426	315	26	57		1,178
N.H.	72	231	236	99	3			641
Total	1,072	2,740	3,382	1,645	222	179	0	9,240
1989 Season, 182 days, Dec 1 - May 31								
Maine	958	2,479	2,332	936	249	84		7,038
Mass.	103	479	402	254	297	102		1,637
N.H.	120	369	312	69	16			886
Total	1,181	3,327	3,046	1,259	562	186	0	9,561
1990 Season, 182 days, Dec 1 - May 31								
Maine	1,036	1,710	1,529	1,986	897	238		7,396
Mass.	147	459	273	202	175	118		1,374
N.H.	178	363	284	157	6			988
Total	1,361	2,532	2,086	2,345	1,078	356	0	9,758
1991 Season, 182 days, Dec 1 - May 31								
Maine	568	1,286	2,070	1,050	438	139		5,551
Mass.	264	416	401	231	154	147		1,613
N.H.	279	285	135	82	22	1		804
Total	1,111	1,987	2,606	1,363	614	287	0	7,968
1992 Season, 153 days, Dec 15 - May 15								
Maine	411	1,966	2,700	1,222	318	141		6,758
Mass.	59	337	145	101	41			683
N.H.	96	153	76	29	3			357
Total	566	2,456	2,921	1,352	362	141	0	7,798

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
1993 Season, 138 days, Dec 14 - April 30								
Maine	249	1,102	1,777	1,032	227			4,387
Mass.	60	200	250	185	72			767
N.H.	76	246	275	256	151			1,004
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
Mass.	58	152	147	83	15			455
N.H.	169	228	266	173	18			854
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
Mass.	145	385	275	157	109			1,071
N.H.	189	331	279	359	344			1,502
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
Mass.	299	248	325	269	106	126		1,373
N.H.	331	311	389	248	155	61		1,495
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
Mass.	184	226	245	114	7	1		777
N.H.	277	245	301	218	189	62		1,292
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
Mass.	94	200	148	70	3	1		515
N.H.	141	216	182	134	83	22		778
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
Mass.	39	57	71	9	40			216
N.H.	82	192	213	44	123	21		675
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
Mass.		33	117	32	1			183
N.H.		45	201	87				333
Total	0	975	2,812	766	1	0	0	4,554

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

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total
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		1114	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, 40days, 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
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 (21days); 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.

	Dec	Jan	Feb	Mar	Apr	May	Other	Season Total	%
2000									
Trawl		818	2,073	462				3,353	97%
Trap		79	421	185				685	20%
Total	0	897	2,494	647	0	0	0	4,038	
2001									
Trawl		1,500	1,214	112	43	6		2,875	83%
Trap		183	337	65				585	17%
Total	0	1,683	1,551	177	43	6	0	3,460	
2002									
Trawl			595	236				831	76%
Trap			204	63				267	24%
Total	0	0	799	299	0	0	0	1,098	
2003									
Trawl		850	1,081	1			2	1,934	72%
Trap		264	501					765	28%
Total	0	1,114	1,582	1	0	0	2	2,699	
2004									
Trawl	7	566	965	382	13	14	6	1,953	83%
Trap		81	232	100				413	17%
Total	7	647	1,197	482	13	14	6	2,366	
2005									
Trawl	140	647	953	778			1	2,519	75%
Trap		conf	372	477				849	25%
Total	140	647	1,325	1,255	0	0	1	3,368	
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	
2008									
Trawl	414	1,062	1,393	661	51	0	9	3,590	69%
Trap	conf	233	683	625	51			1,592	31%
Total	414	1,295	2,076	1,286	102	0	9	5,182	
2009									
Trawl	130	705	673	381	32	5	1	1,927	68%
Trap	4	80	449	358	15			906	32%
Total	134	785	1,122	739	47	5	1	2,833	
2010									
Trawl	238	1,230	1,512	447	157	29	1	3,614	65%
Trap	conf	334	1,081	492	conf			1,907	35%
Total	238	1,564	2,593	939	157	29	1	5,521	
2011									
Trawl	577	2,068	1,692	1				4,338	68%
Trap	22	812	1,183					2,017	32%
Total	599	2,880	2,875	1	0	0	0	6,355	
***2012**									
Trawl	1	1,302	1,032	1				2,336	71%
Trap			968					968	29%
Total	1	1,302	2,000	1	0	0	0	3,304	
***2013**									
Trawl		166	621	164	conf			951	82%
Trap			169	39	conf			208	18%
Total	0	166	790	203	0	0	0	1,159	

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
	Inshore (<55F)	Offshore (>55F)	Combined		
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

Fishing Season	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	30.5	31	31.5	32	32.5	33	33.5	34
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
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
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
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
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
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
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
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
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
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
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
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
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	0.00
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
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

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)																								
		<=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
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	0.16	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

Fishing Season	22.5	23	23.5	24	24.5	25	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	31	31	31.5	32	32.5	33	33.5	34
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)																								
		<=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
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	0.00	0.01	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	0.00	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	0.00	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	0.00	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	0.00	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	0.00	0.01	0.00	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	0.00	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	0.00	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	0.00	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	0.00	0.03	0.00	0.06	0.01	0.00	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	0.00	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	0.00	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	0.00	0.00	0.01	0.00

Fishing Season	22.5	23	24	24	24.5	25	25.5	26	26.5	27	27.5	28	29	29	30	30	31	31	32	32	33	33	34	34
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.

		Log$_e$ retransformed				
Year	**N Tows**	**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			
	kg/tow	n	80% CI		kg/tow	n	80% CI	
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 Mean Weight	CV	Mean number	CV		Re-transformed geometric 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	Mclnnes	Equal	Guess
1	Year	1984-2013	3	Standard	3	0.25	2	Mclnnes	Equal	Guess
2	Year	1984-2013	3	Standard	3	0.5	2	Mclnnes	Equal	Guess
3	Year	1984-2013	3	Standard	3	PPI	2	Mclnnes	Equal	Guess
4	Year	1984-2013	3	Under 10%	3	U-shaped	2	Mclnnes	Equal	Guess
5	Year	1984-2013	3	Under 25%	3	U-shaped	2	Mclnnes	Equal	Guess
6	Year	1984-2013	3	TI	3	U-shaped	2	Mclnnes	Equal	Guess
7	Year	1984-2013	3	Standard	3	U-shaped	2	Mclnnes	Survey*5	Guess
8	Year	1984-2013	3	Standard	3	U-shaped	2	Mclnnes	Survey*0.5	Guess
9	Year	1984-2013	3	Standard	3	U-shaped	1	Mclnnes	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	Mclnnes	Equal	Guess
12	Season	1984-2013	3	Standard	3	U-shaped	2	Mclnnes	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) Trawl fleet (2000-2013) Trap fleet (2000-2013)	Logistic Logistic Logistic
Fishing mortality	Instantaneous rates	
Survey data	NEFSC fall ASMFC summer NEFSC Bigelow	1984-2008 (length composition data 1991-2008) 1984-2013 with length frequency data for all years 2009-2012 (length composition data 2009-2012)
Survey selectivity at length	NEFSC fall ASMFC summer NEFSC Bigelow	Logistic Logistic 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 Mclnnes 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 (numbers/biomass/ female biomass)	Mohn's rho for SSB/recruitment/ exploitation rate	F_{max}	F_{MSY}	MSY (mt)	B_{MSY} (mt)	Terminal SSB/B_{MSY}
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	Maxiumum likelihood
Survey inputs	1 series only	mulitple surveys can be used
Catch	assumed known, no error	cv can be varied (but not time depend
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.

		After adjustment		
	Initial	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
		Ad hoc	Rinaldo (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 mortality			Recruit Abundance (millions)			Post-recruit Abundance (millions)			Exploitable Biomass (kt)		
Fishing Year	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.

		M=0.3	M=0.4	Base 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	NEFSC Fall R/V Albatross (kg/tow)	ME Summer (kg/tow)	ASMFC Summer Shrimp (kg/tow)	NEFSC Fall R/V Bigelow (kg/tow)	Catch (mt)		Biomass	ASPIC F	B/Bmsy	F/Fmsy
	ASPIC Model Input						ASPIC Model Results			
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		
						1971-74 ave:	21.13	0.62		
						1985-94 ave:	16.23	0.23		
						2011-2013 (3-yr) ave:	3.96	0.89		

*Catch data are preliminary

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

Fishing Mortality					
	Historical Proxy			Model Based	
	F_{target}	$F_{threshold}$	F_{2013}*		
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 Definition	SARC 45 Value	SARC 58 Definition	SARC 58 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)
25% F_{target}	0.05	64
50% F_{target}	0.1	127
F_{target}	0.2	255

UME	F_{target} = $F_{40\%SPR}$	Yield (mt) avg. weight of shrimp	Yield (mt) calc. weight of shrimp		F_{target} = avg F	Yield (mt) avg. weight of shrimp	Yield (mt) calc. weight of shrimp
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 coeffients a and b by minimizing the sum of the Difference^2 between Observed and Predicted.

X= 0.0016

a= 0.5445
b= -2.7376

Survey year	Mean survey female length (mm)	3yo index (age 1.5 no. per tow in prevous 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

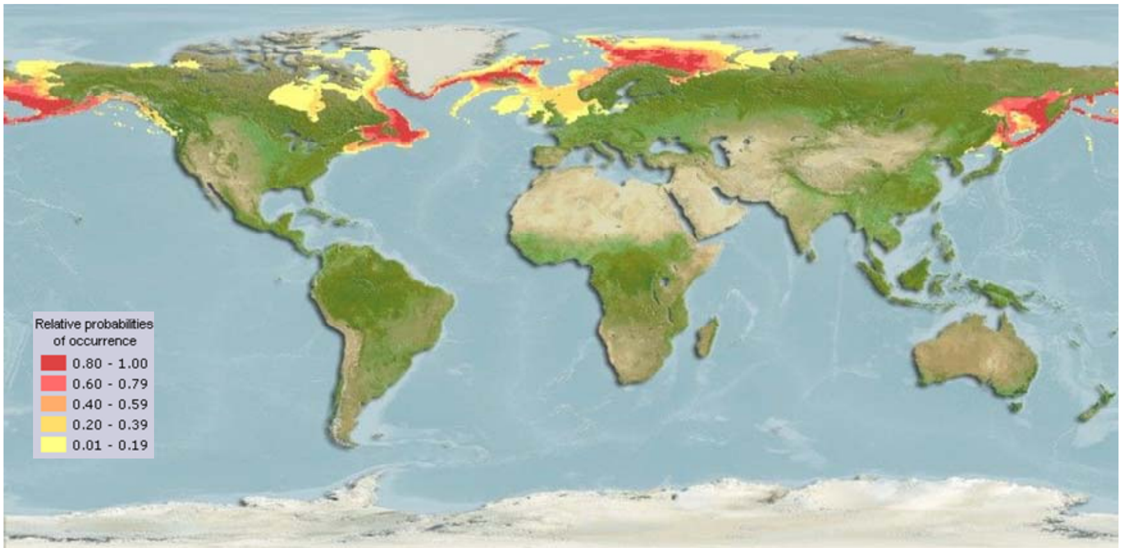


Figure C4.1. Range distribution of northern shrimp with relative probabilities of occurrence (www.aquamaps.org).

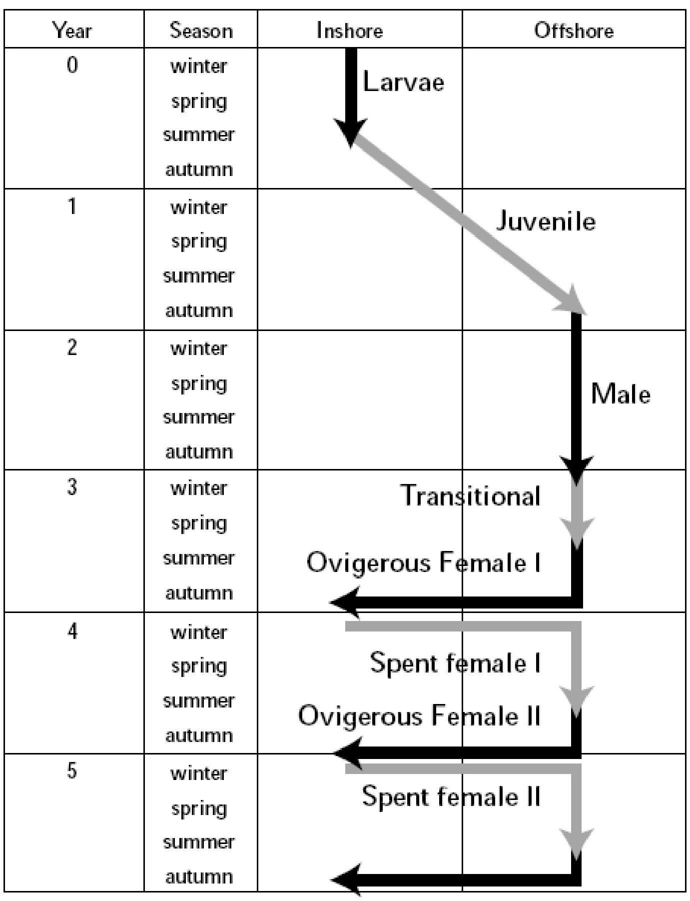


Figure C4.2. Life cycle of northern shrimp in the Gulf of Maine (Clark et al. 2000).

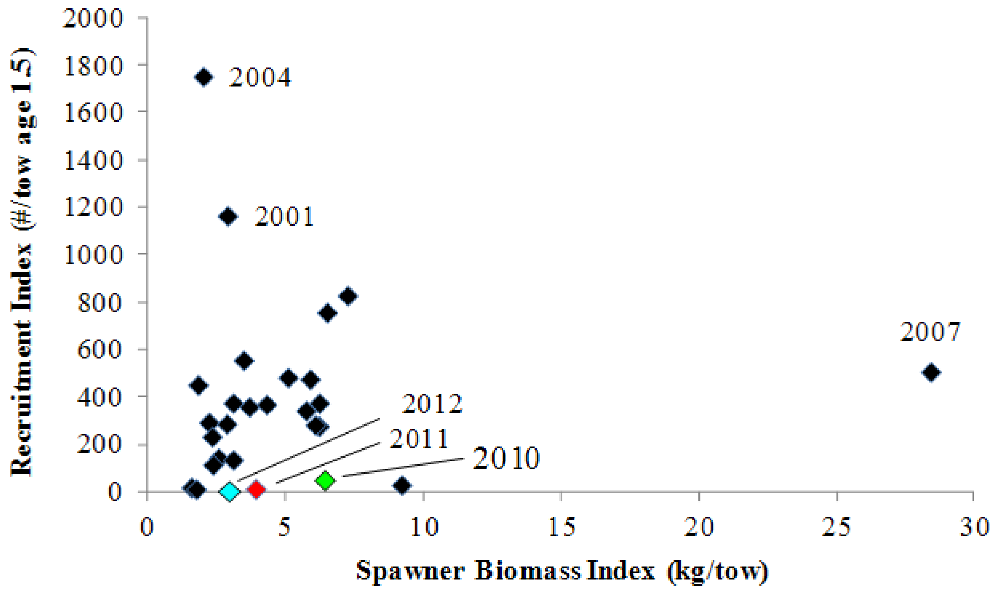


Figure C4.3. Relationship between summer survey index of Gulf of Maine female northern shrimp biomass the summer before spawning to age 1.5 abundance two years later. Year labels indicate the assumed age 1.5 year class.

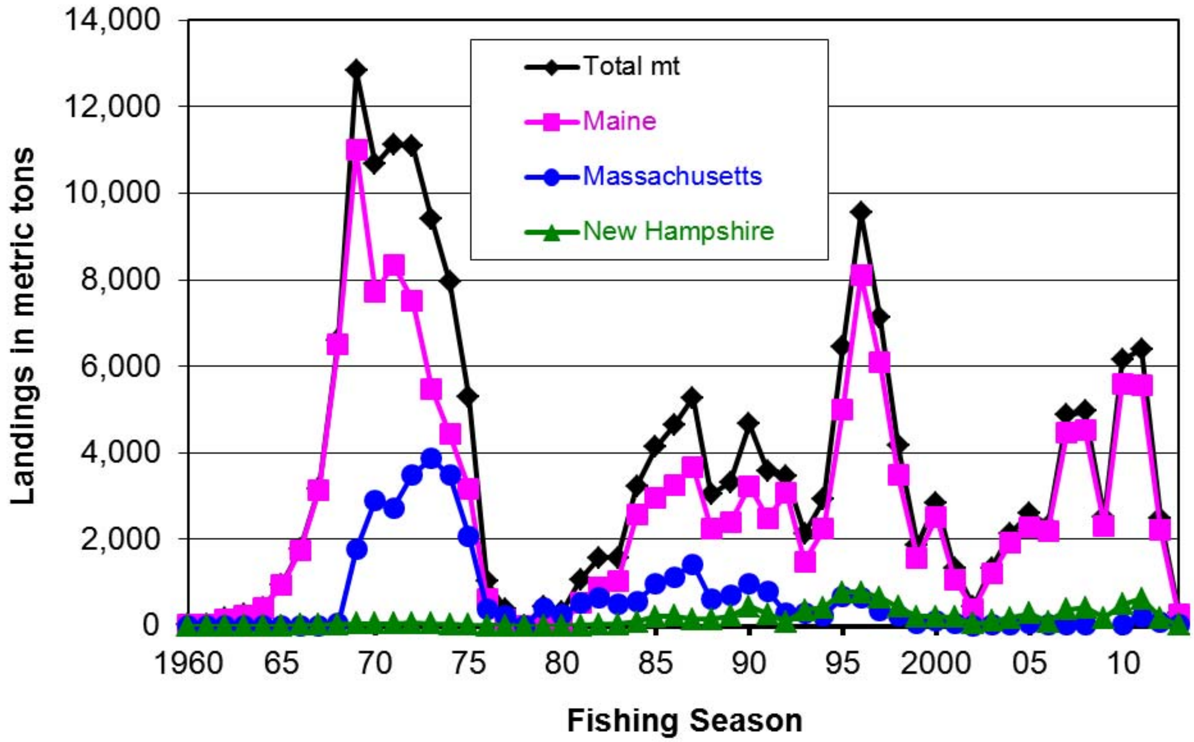
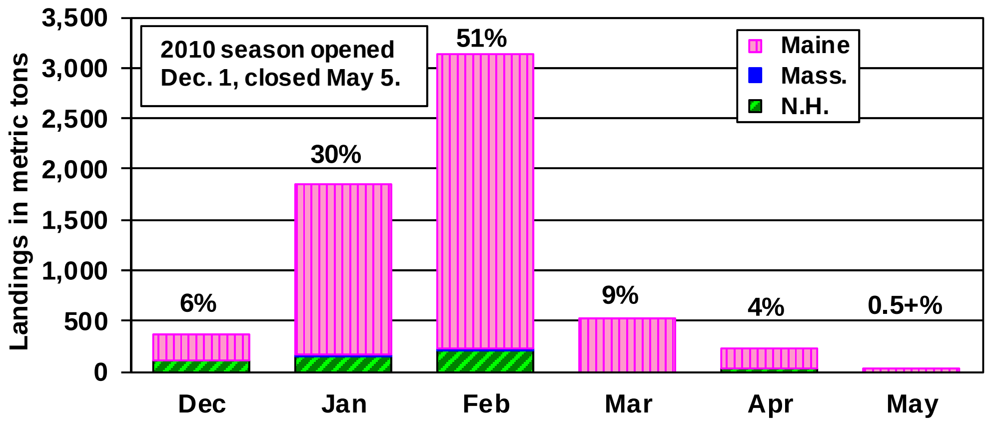


Figure C5.1. Gulf of Maine northern shrimp landings (metric tons, mt) by season and state. MA landings are combined with NH landings in 2009 to preserve confidentiality. 1 mt = 2,205 pounds.



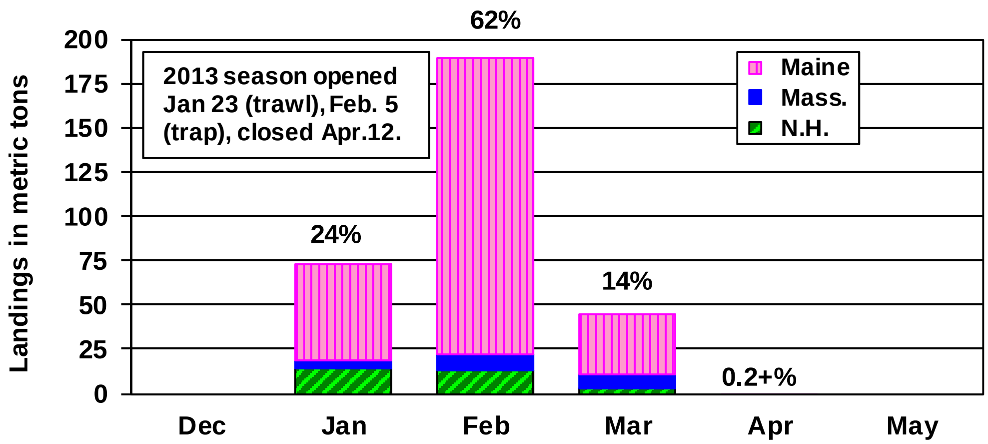


Figure C5.2. Gulf of Maine northern shrimp landings by state and month in the 2010 season (above) and the 2013 season (below) (preliminary data). Landings are in metric tons. 1 mt = 2,205 lbs.

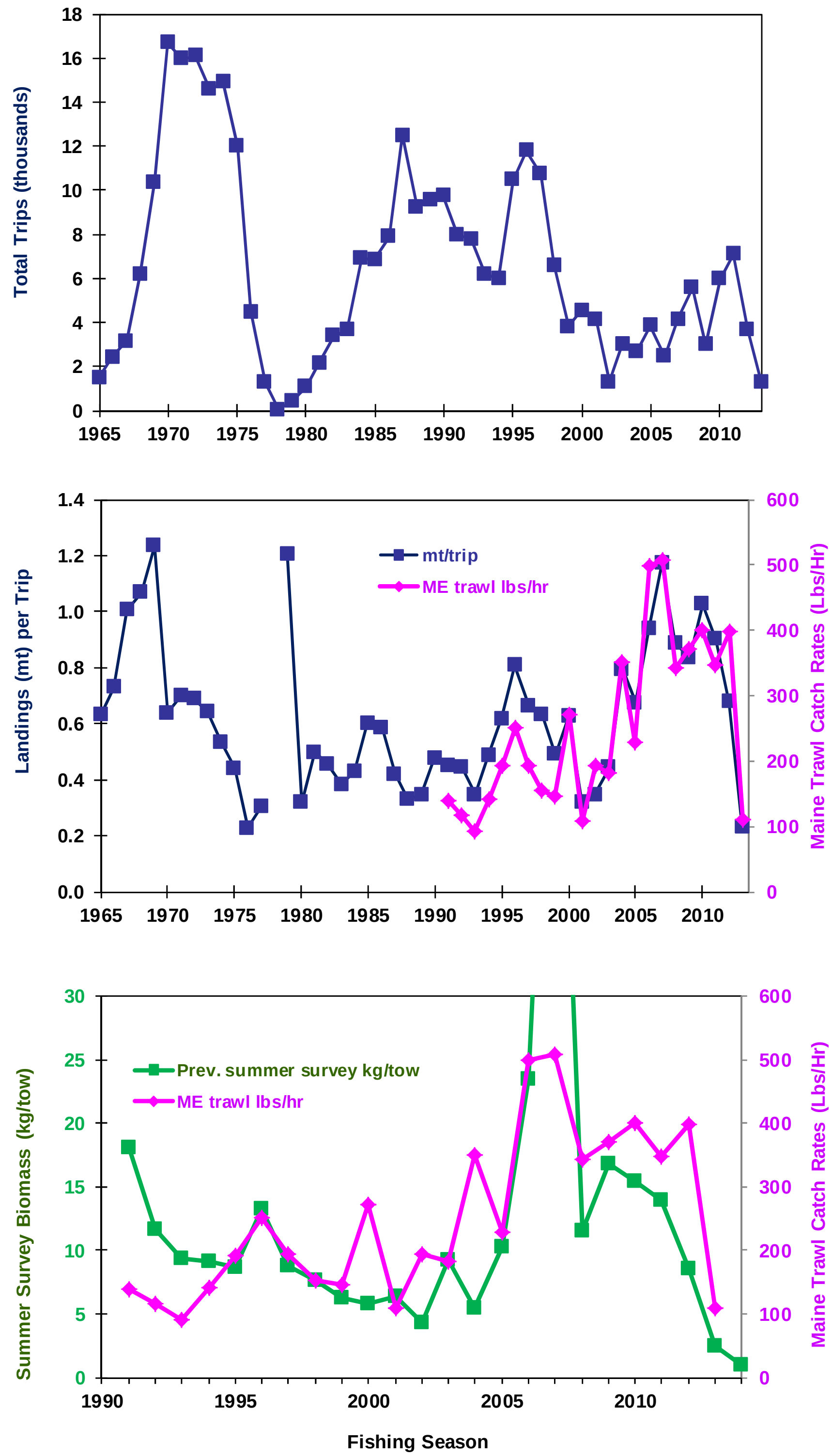


Figure C5.3. Nominal fishing effort (trips) in the Gulf of Maine northern shrimp fishery by season above, catch per unit effort in mt/trip and Maine trawl lbs/hr (middle), and Maine trawl lbs/hr and the previous summer survey index (kg/tow) (below). 2012 and 2013 trip data are preliminary.

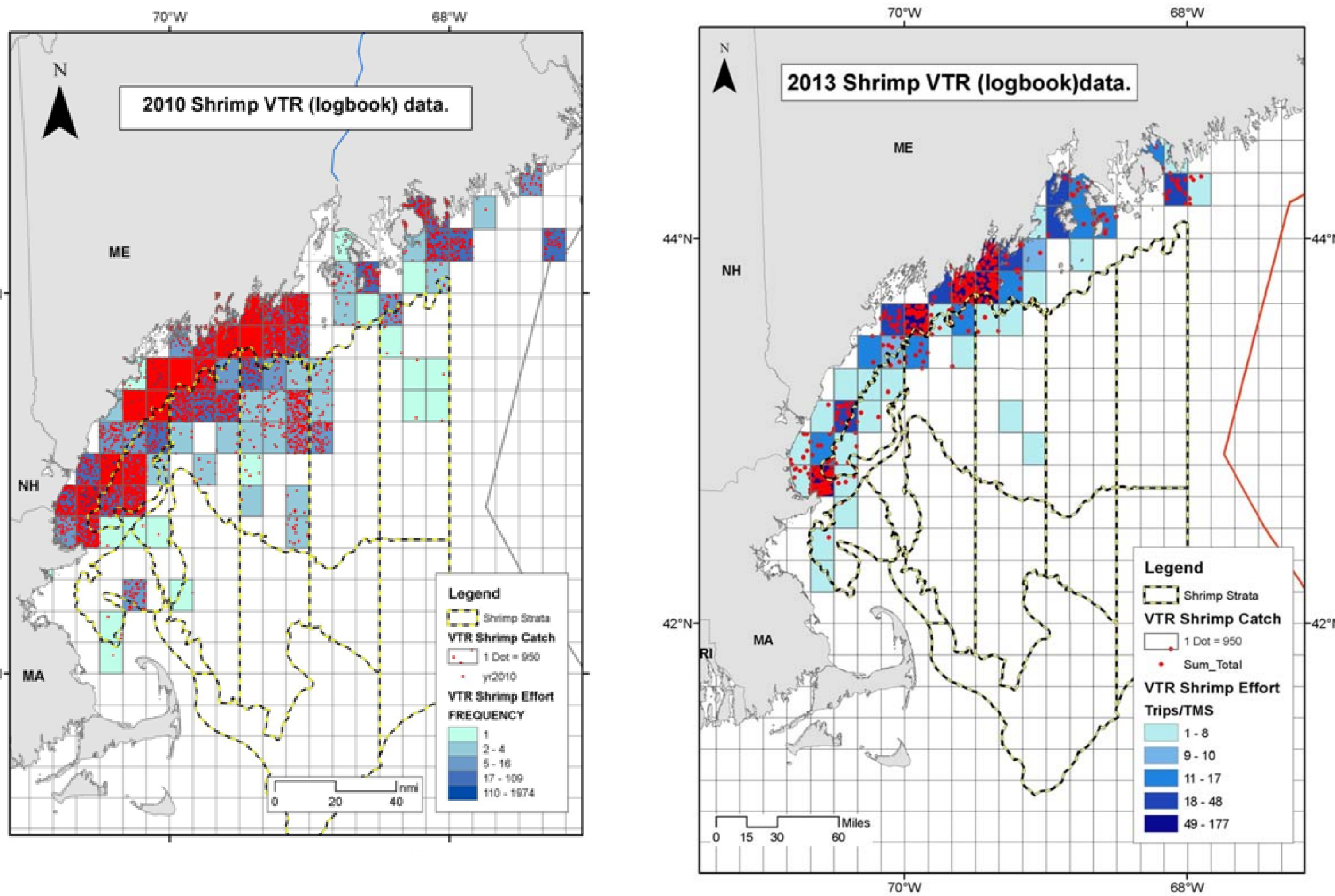


Figure C5.4. Pounds caught and numbers of trips during the 2010 (left) and 2013 (right) northern shrimp fishing seasons by 10-minute-square. Each red dot represents 950 lbs caught; locations of dots within squares are random and do not reflect the actual location of the catch. Number of trips is indicated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

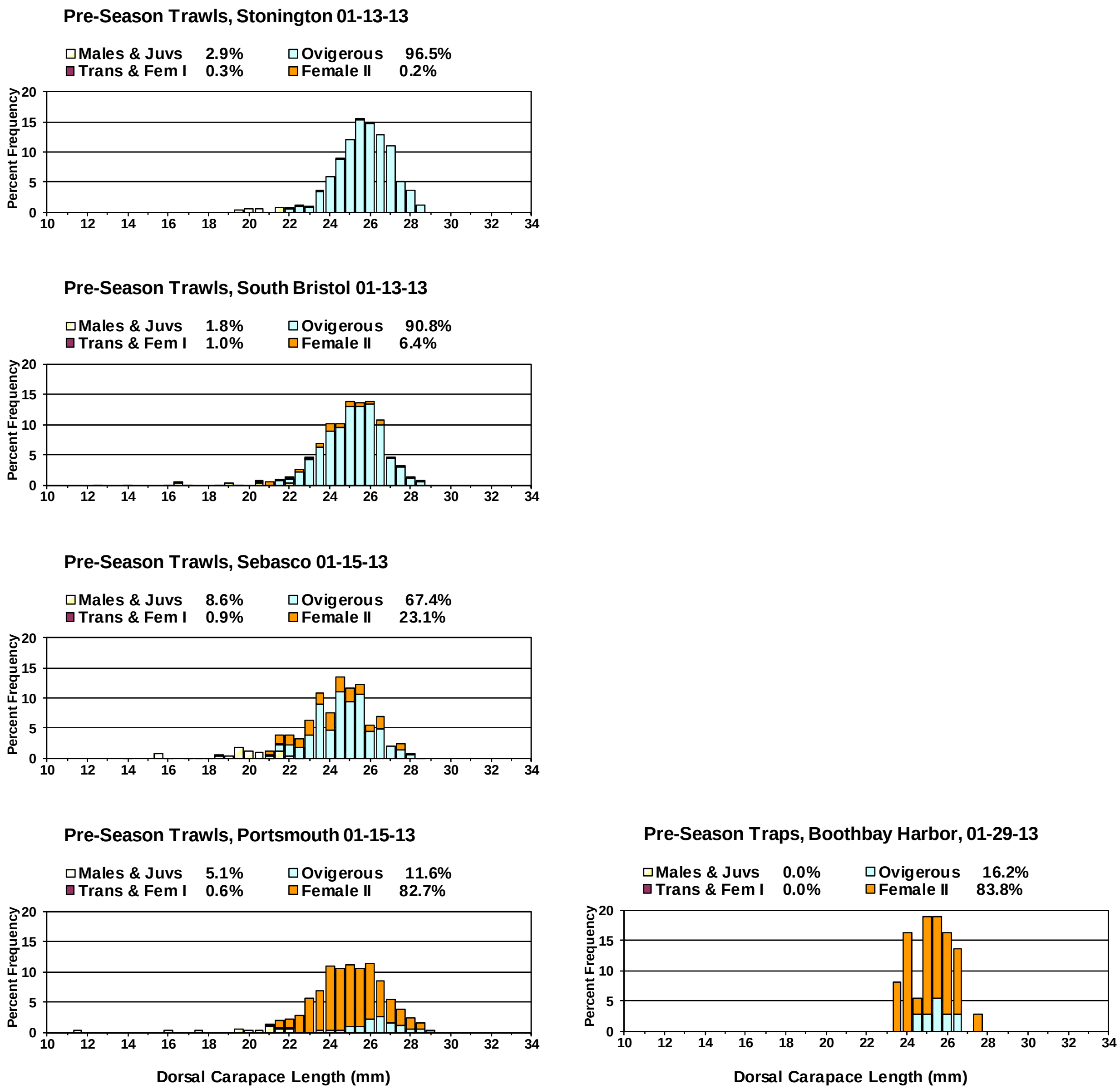


Figure C5.5. Relative length-frequency distributions from samples of northern shrimp from pre-season tows (left) and traps (right), from north (top) to south (bottom).

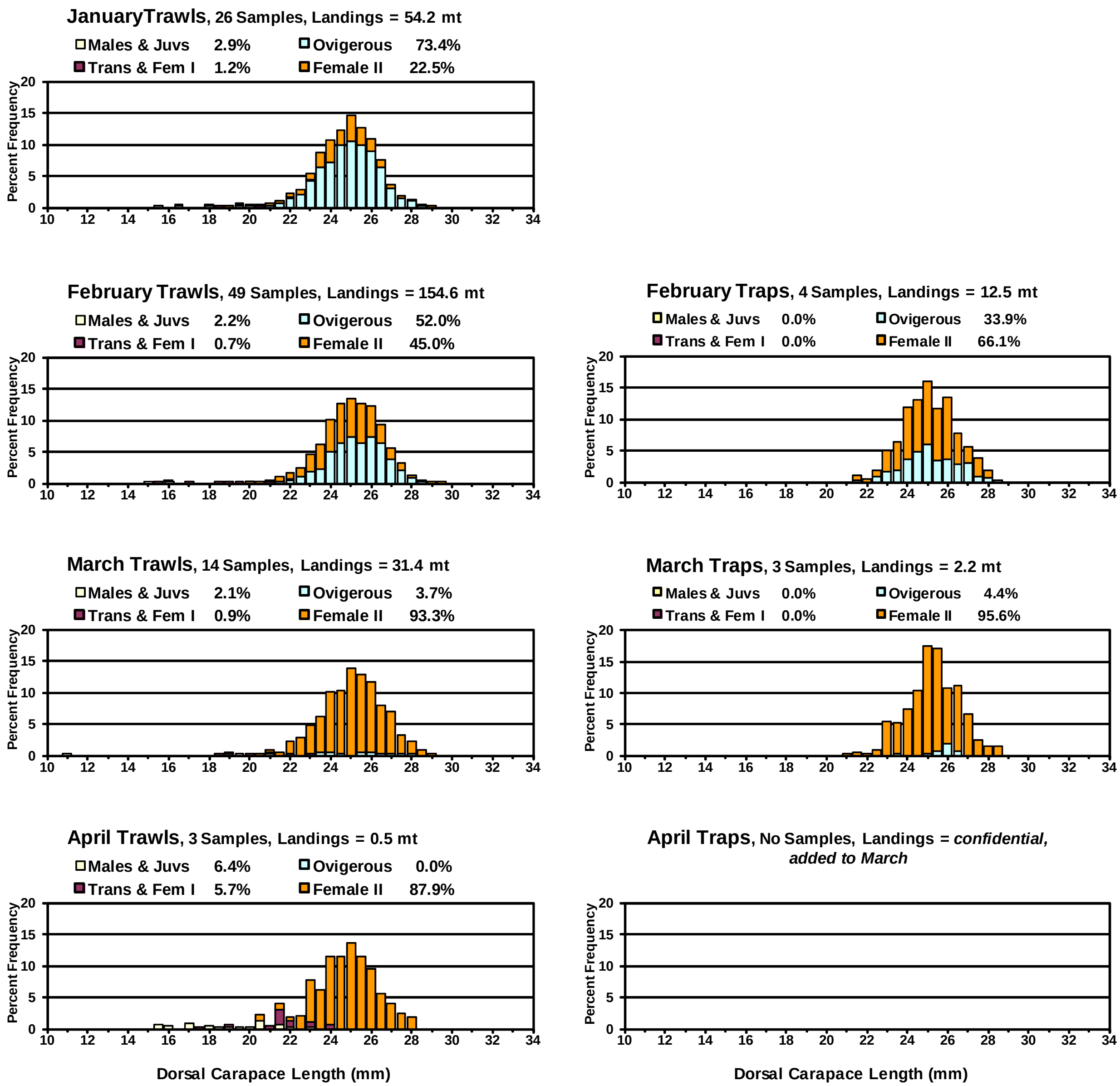


Figure C5.6. Relative length-frequency distributions from samples of Maine northern shrimp catches during the 2013 season by month (top to bottom) and gear, trawls (left) and traps (right). Landings are preliminary. 1 mt = 2,205 lbs.

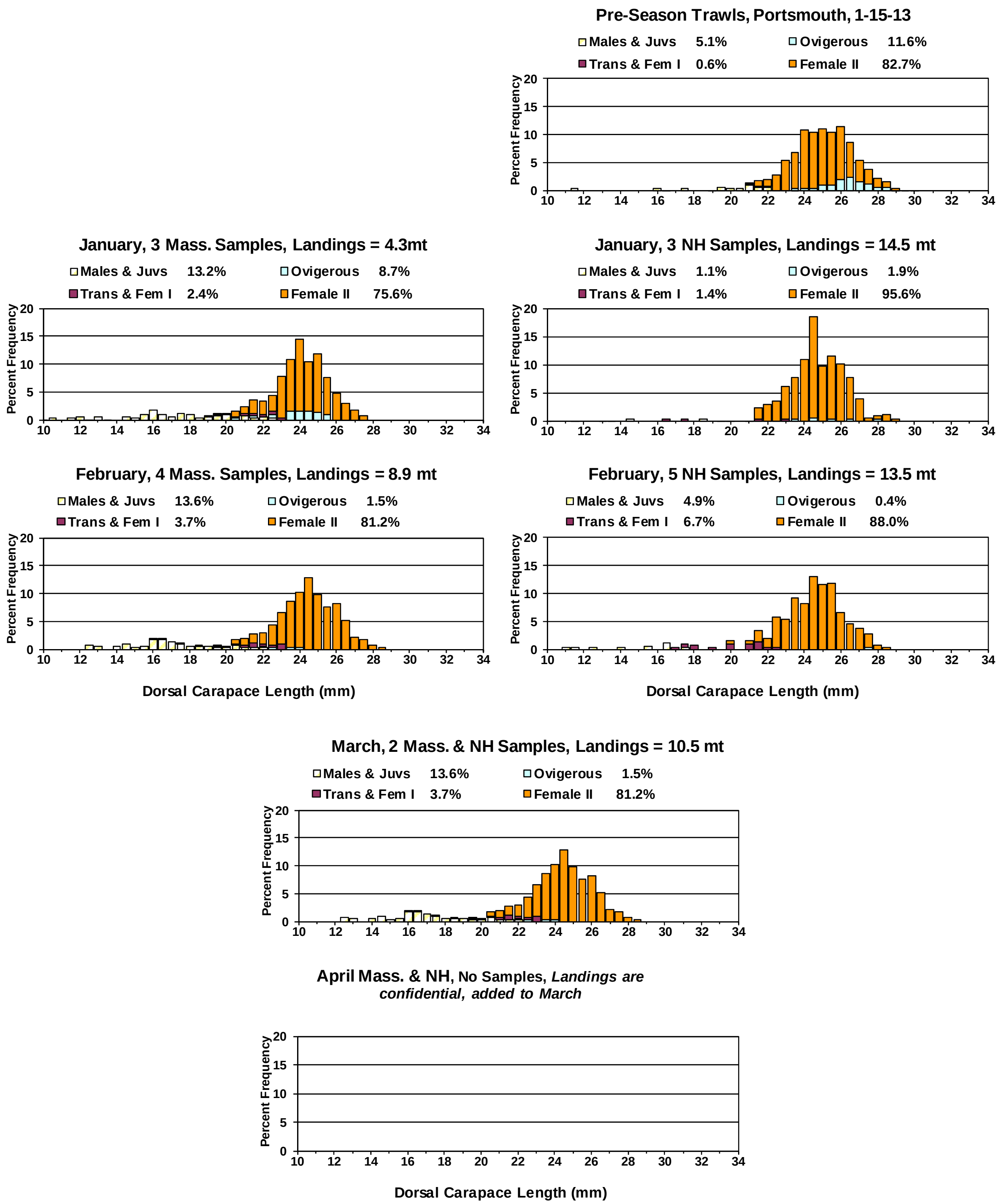


Figure C5.7. Relative length-frequency distributions from samples of Massachusetts (left) and New Hampshire (right) northern shrimp catches during the 2013 season by month (top to bottom). Landings are preliminary. 1 mt = 2,205 lbs.

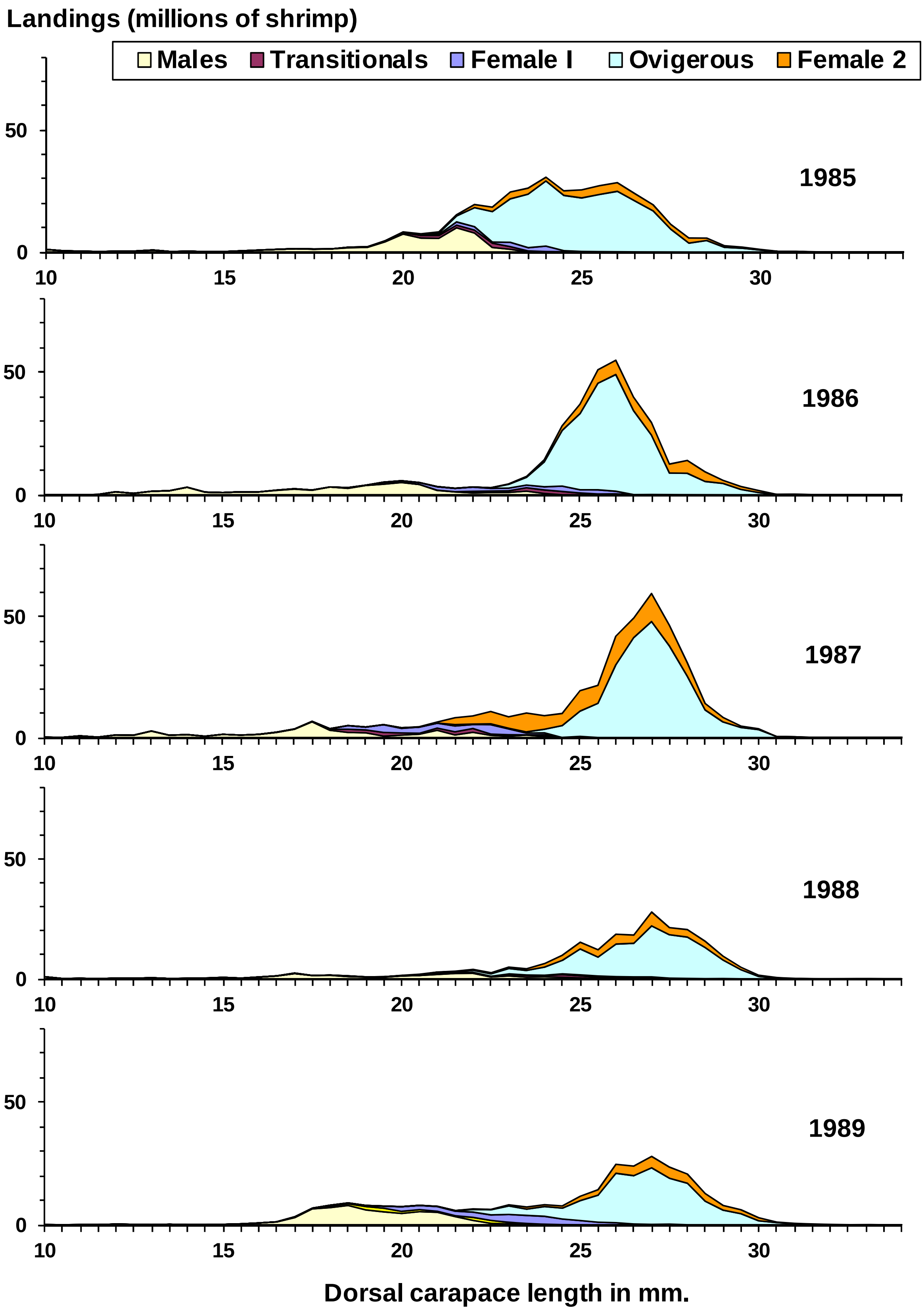


Figure C5.8. Gulf of Maine northern shrimp landings in estimated numbers of shrimp (millions), by length, development stage, and fishing season.

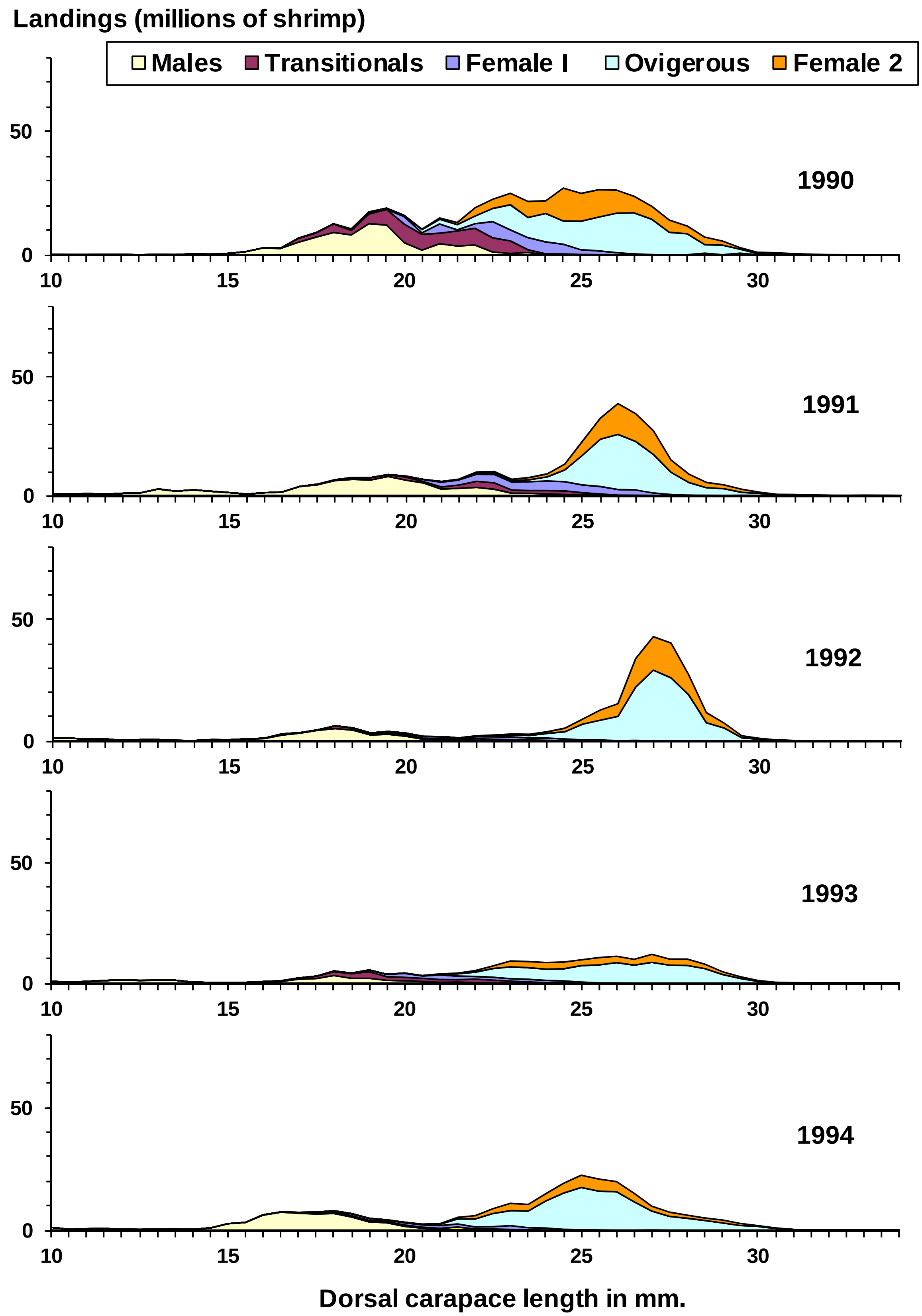


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

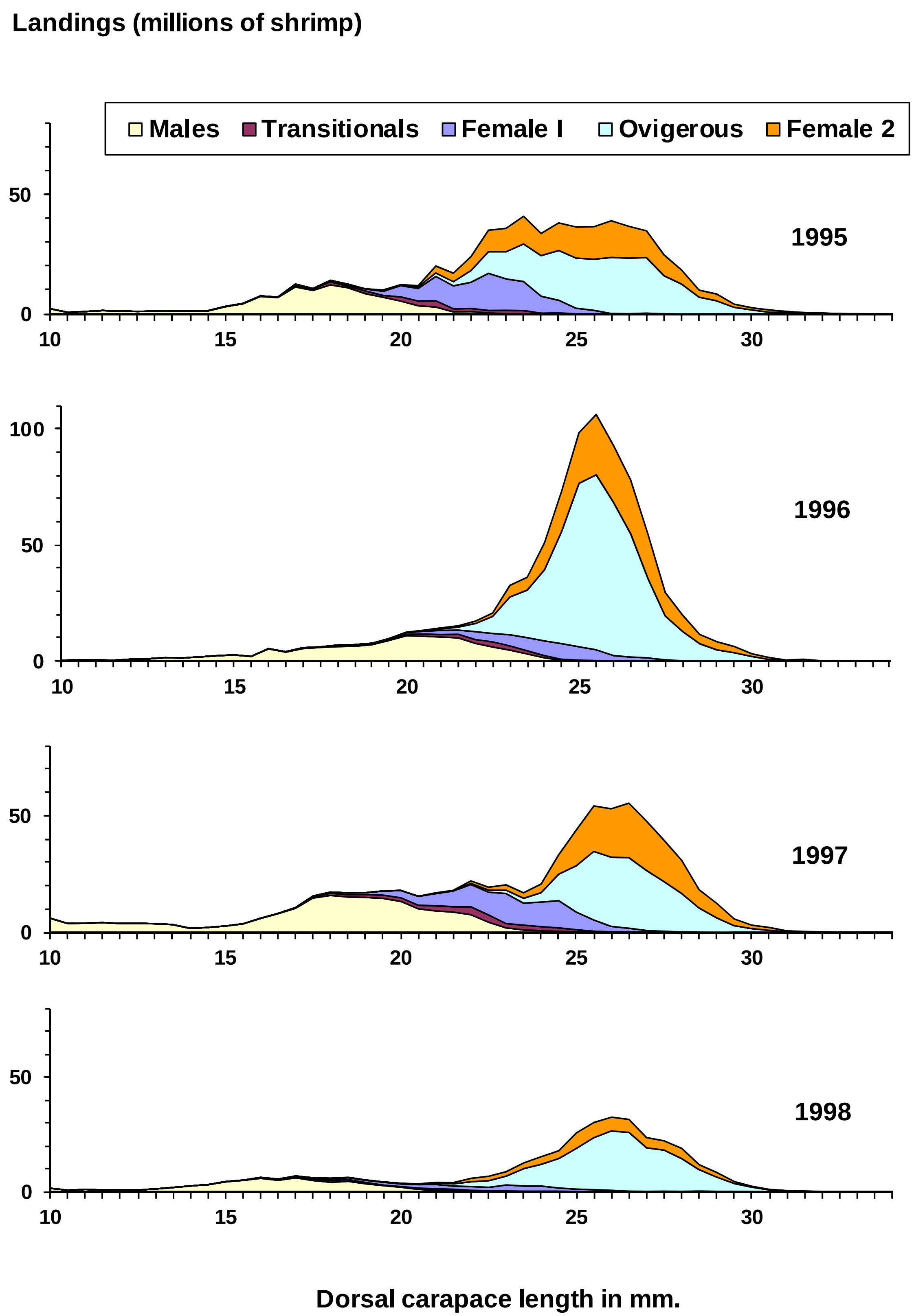


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

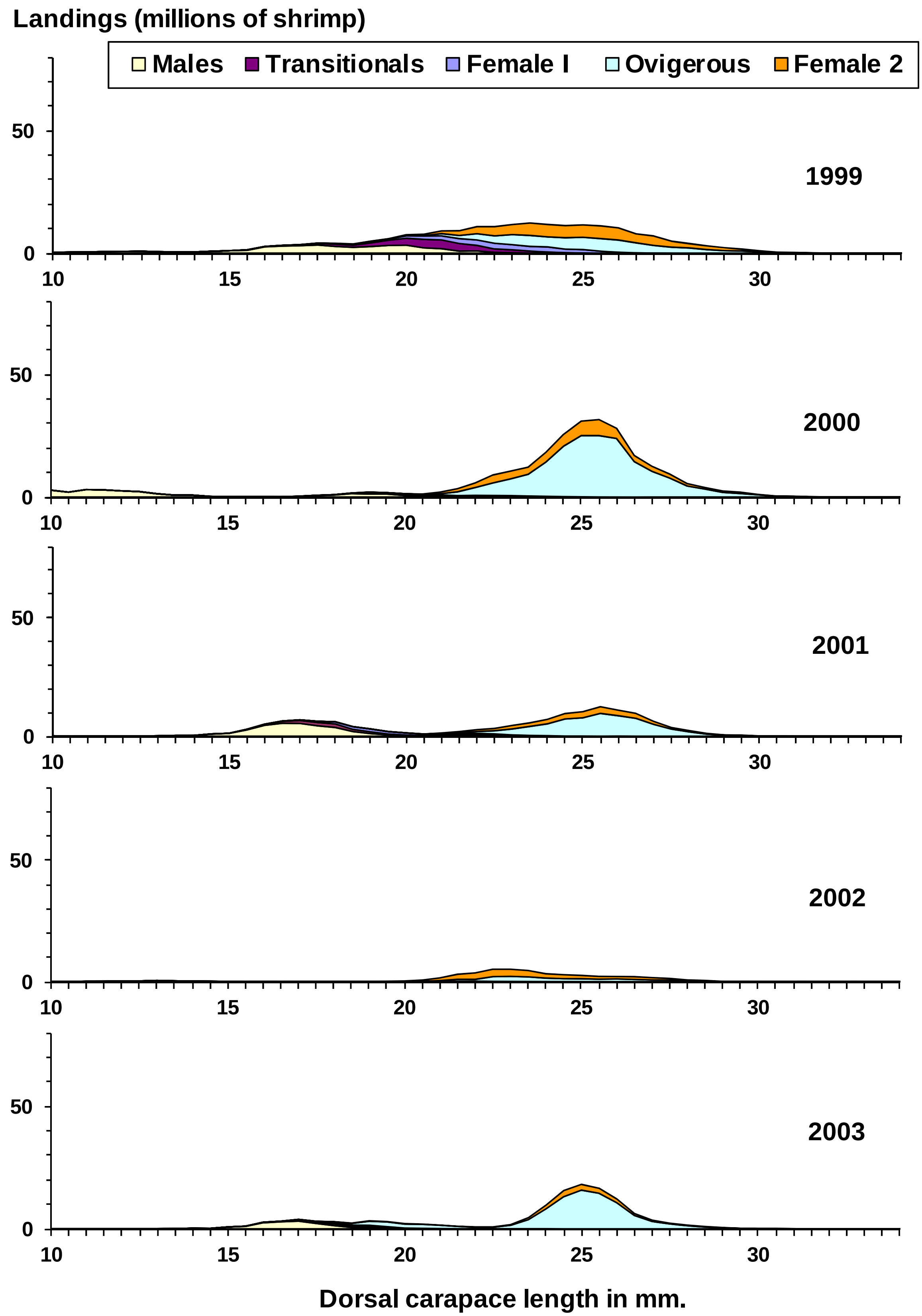


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

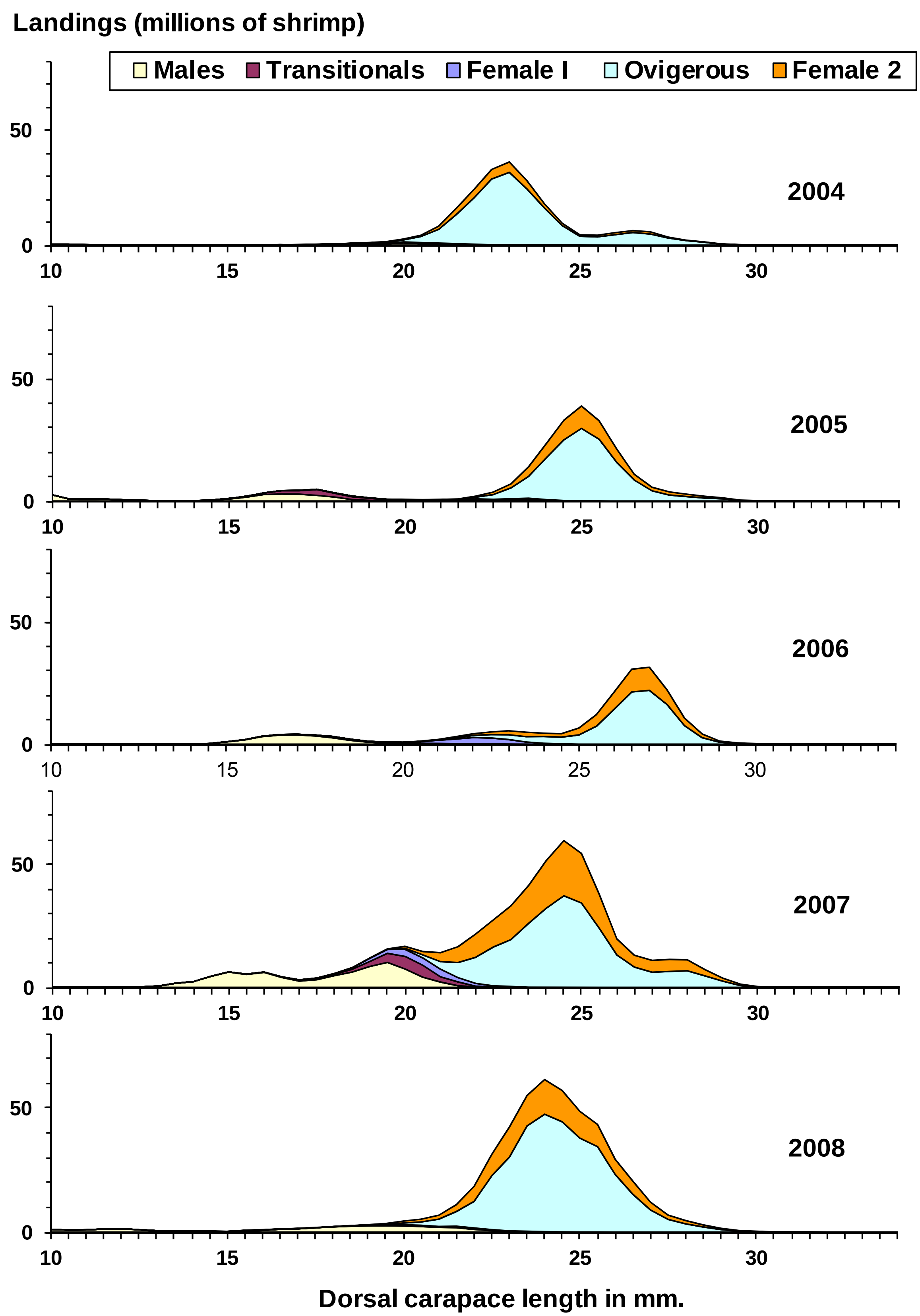


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

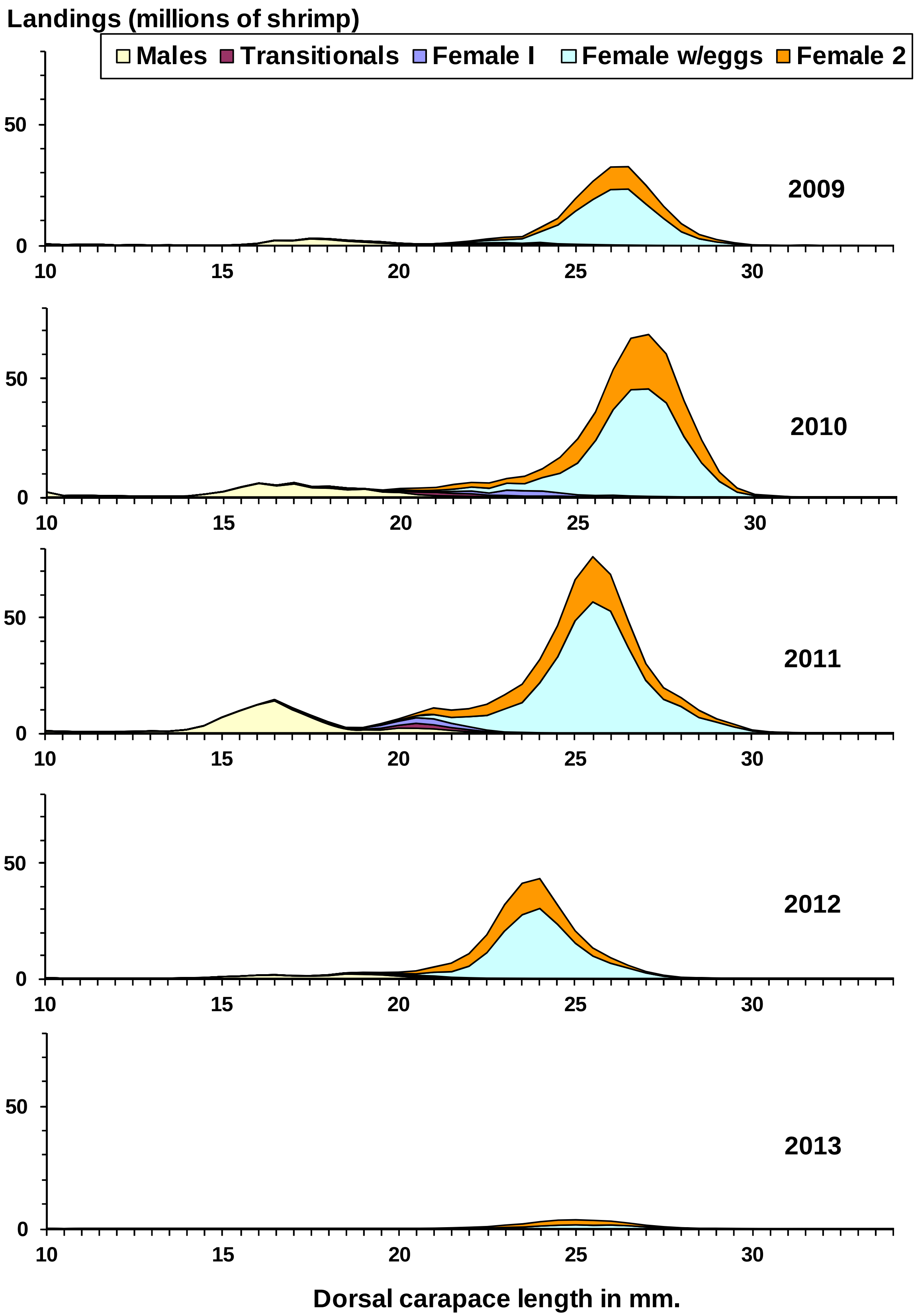


Figure C5.8 continued – Landings in estimated numbers (millions) of shrimp.

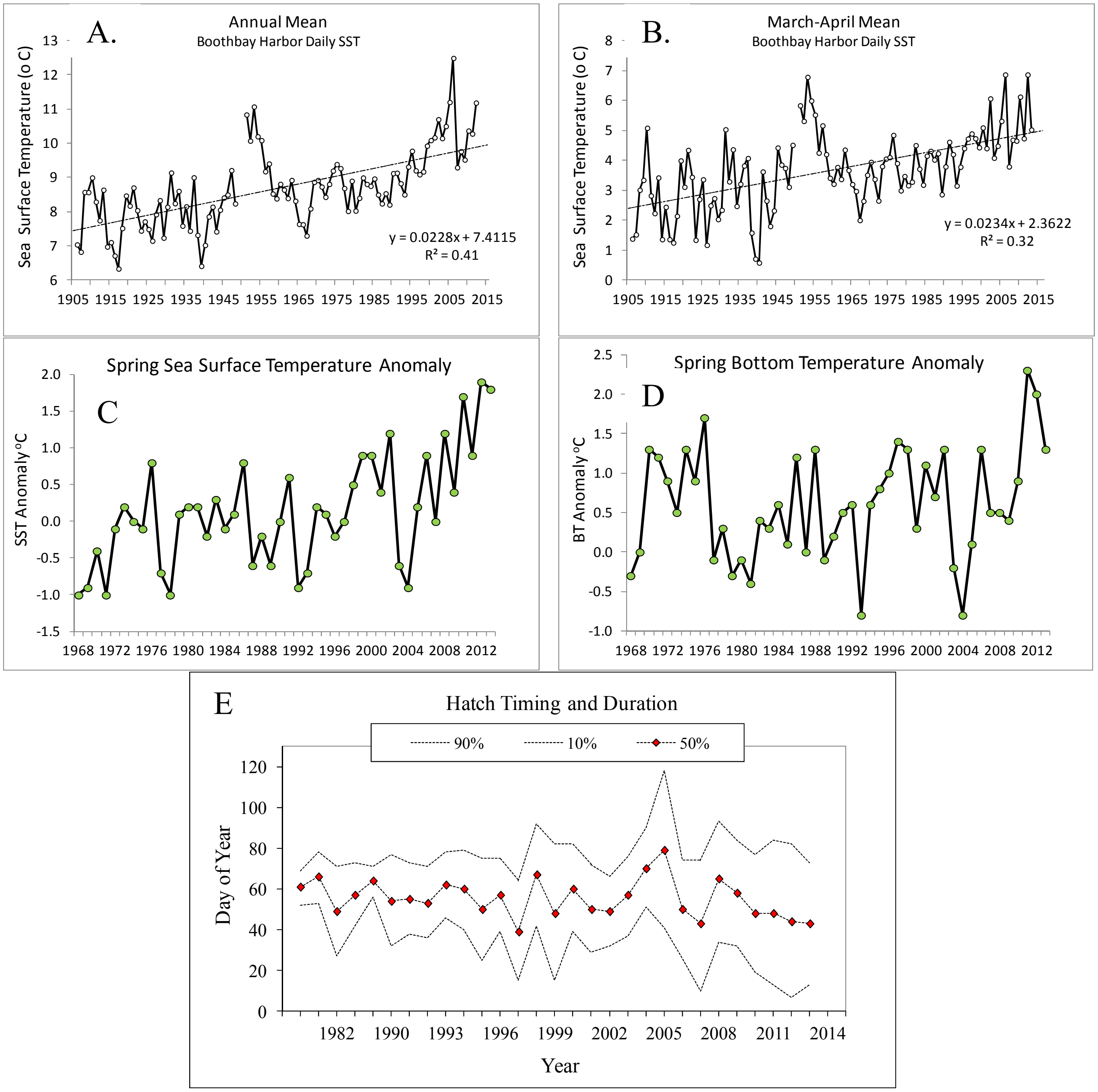


Figure C5.9 (A) Average annual sea surface temperature (SST) at Boothbay Harbor, Maine, during 1906-2013 and (B) average SST during March-April, 1906-2013. (C) Spring sea surface temperature anomaly in shrimp offshore habitat areas from NEFSC trawl surveys, 1968-2013. (D) Spring bottom temperature anomaly 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).

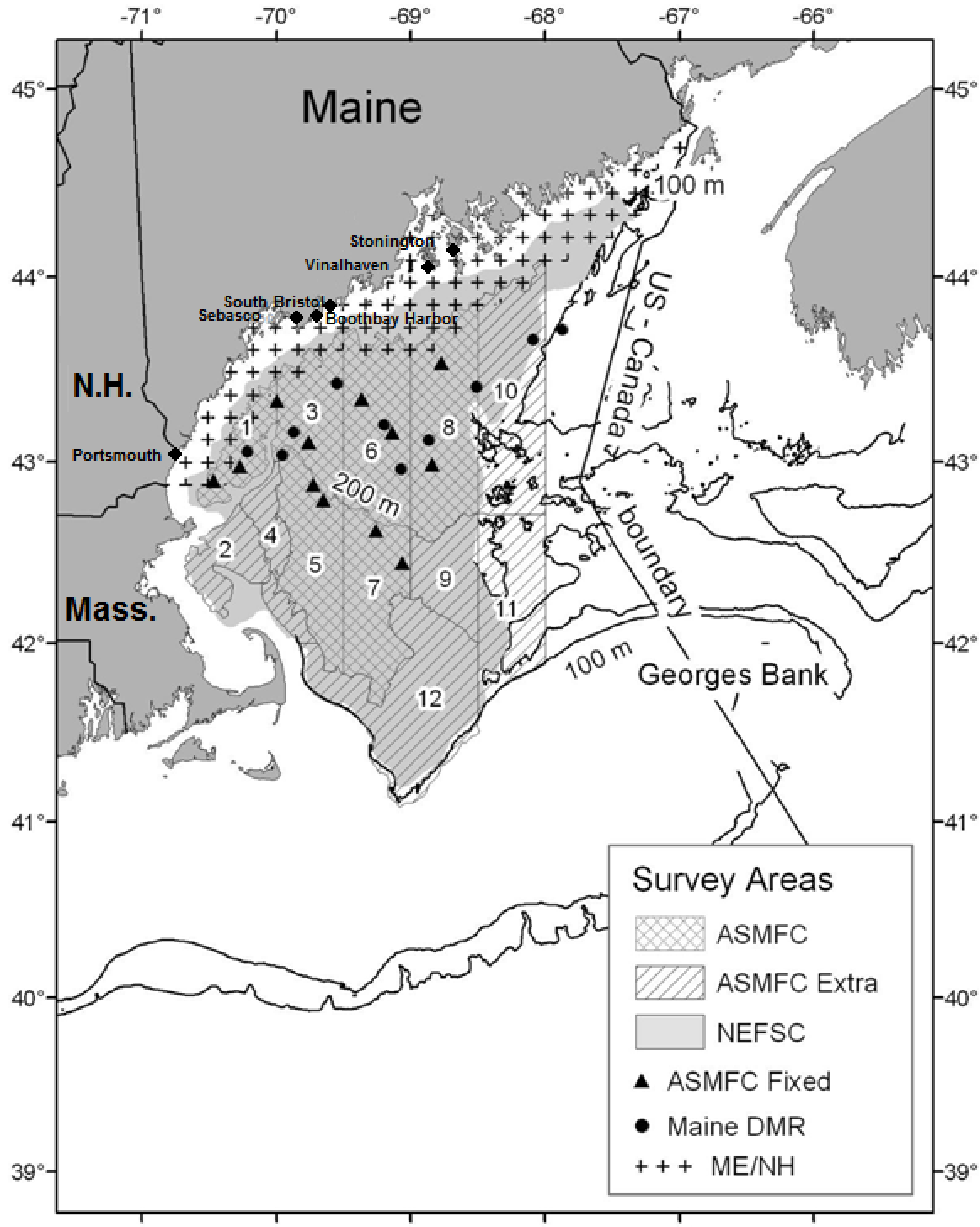


Figure C5.10. Gulf of Maine survey areas and station locations, and harbors mentioned in the text.

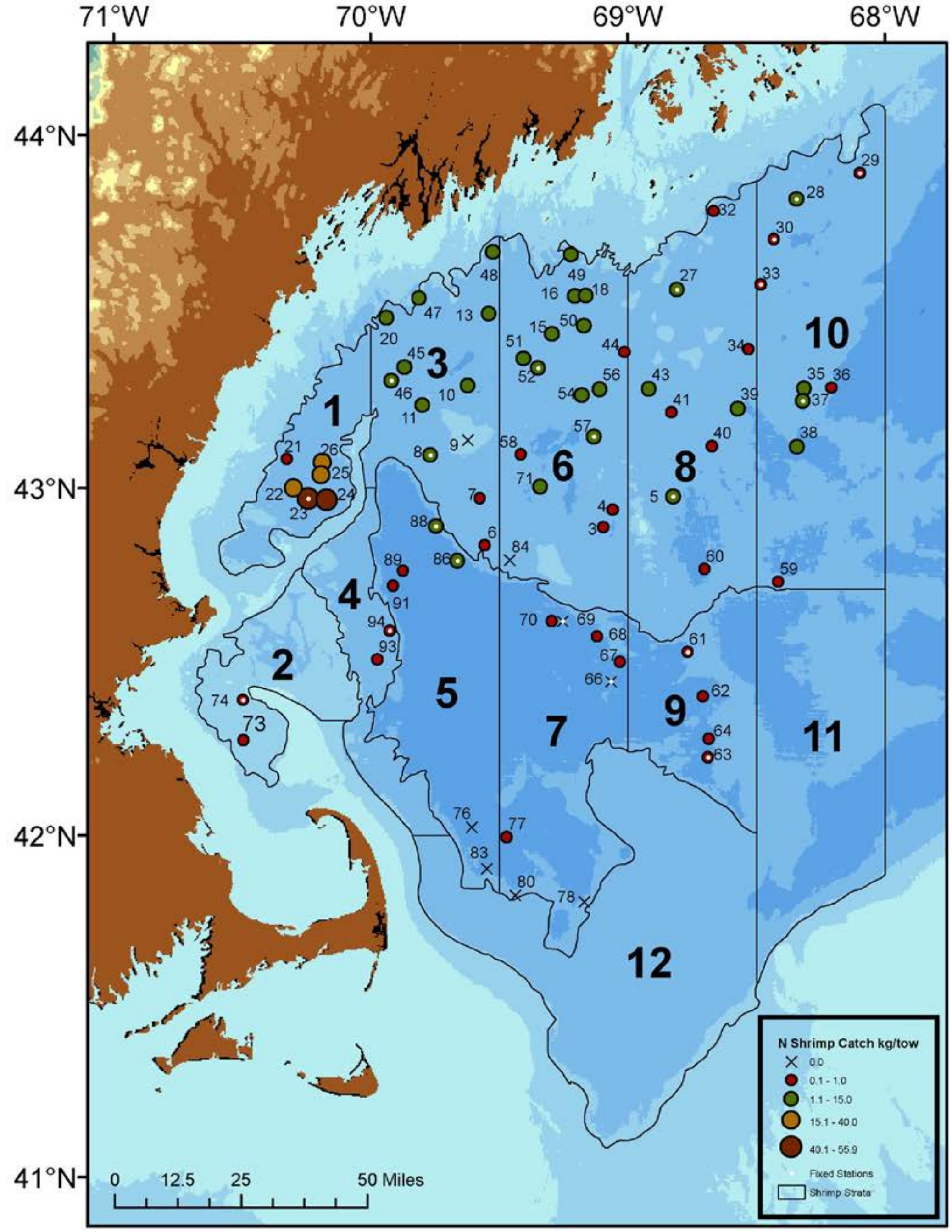


Figure C5.11. State/federal summer northern shrimp survey aboard the *R/V Gloria Michelle*, July 22 – August 14, 2013, fixed and random survey sites and shrimp catches in kg/tow.

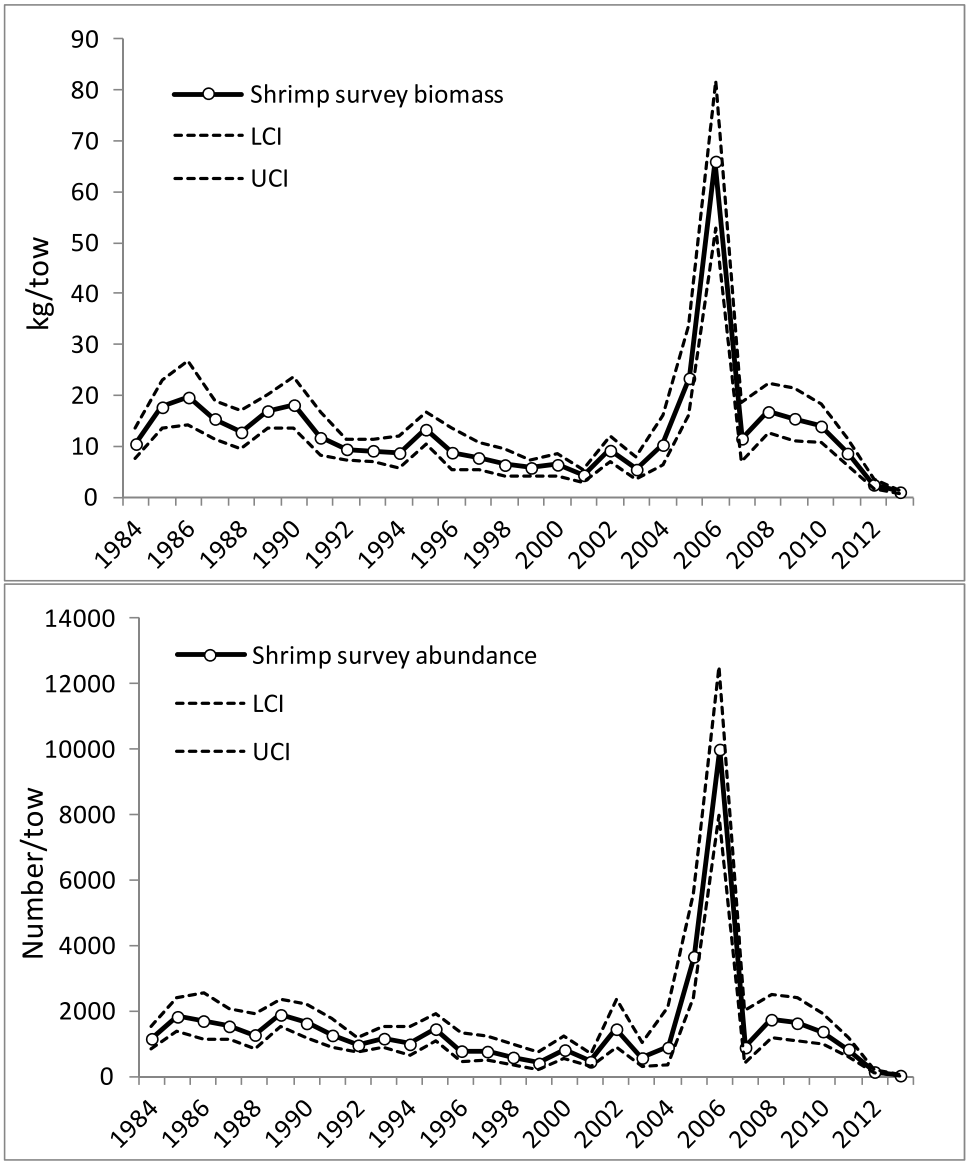


Figure C5.12. Northern shrimp survey indices with 95% confidence intervals from ASMFC summer shrimp survey. LCI lower confidence interval, UCI upper confidence interval.

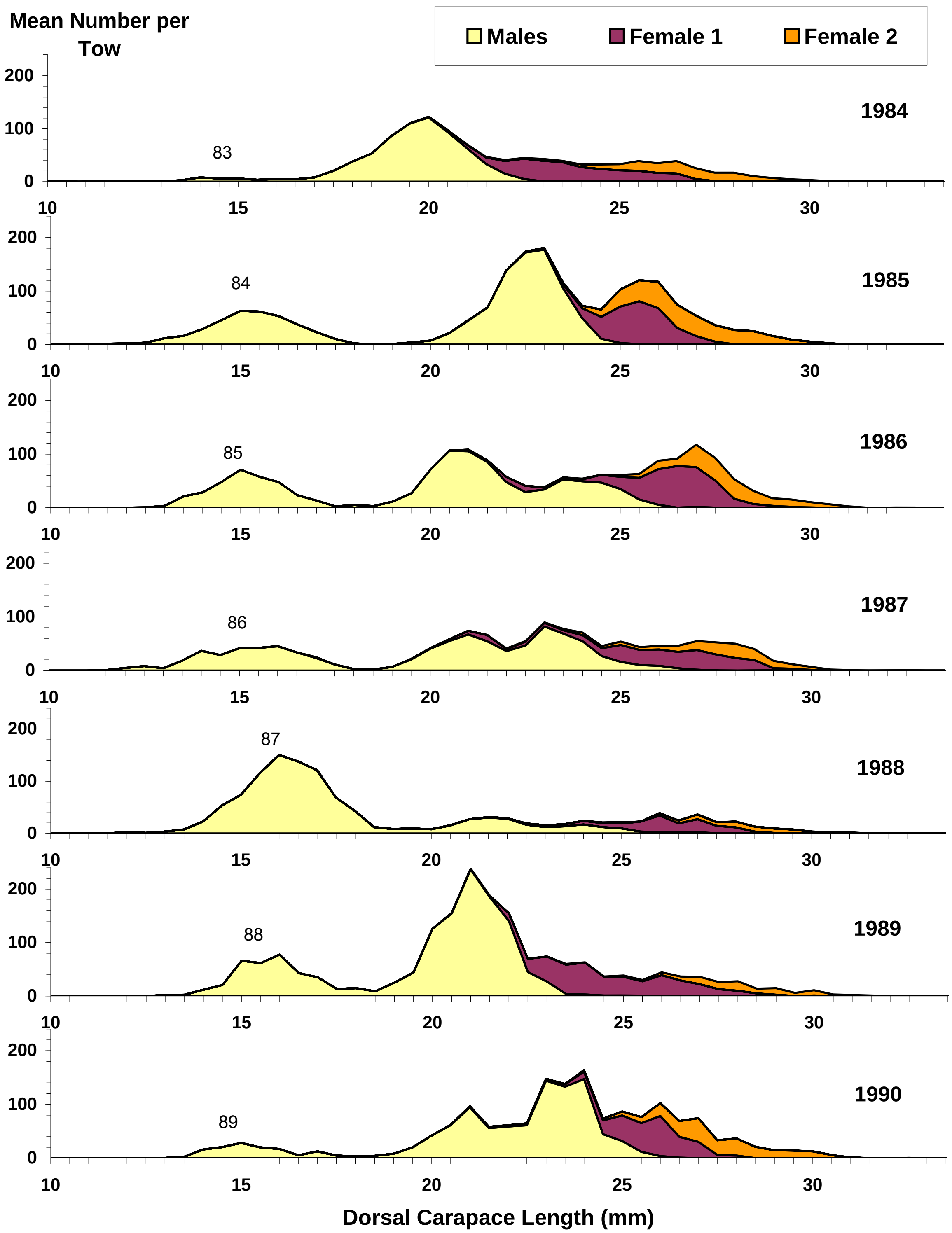


Figure C5.13. Gulf of Maine northern shrimp summer survey mean catch per tow by year, length, and development stage. Two-digit years are year class at assumed age 1.5.

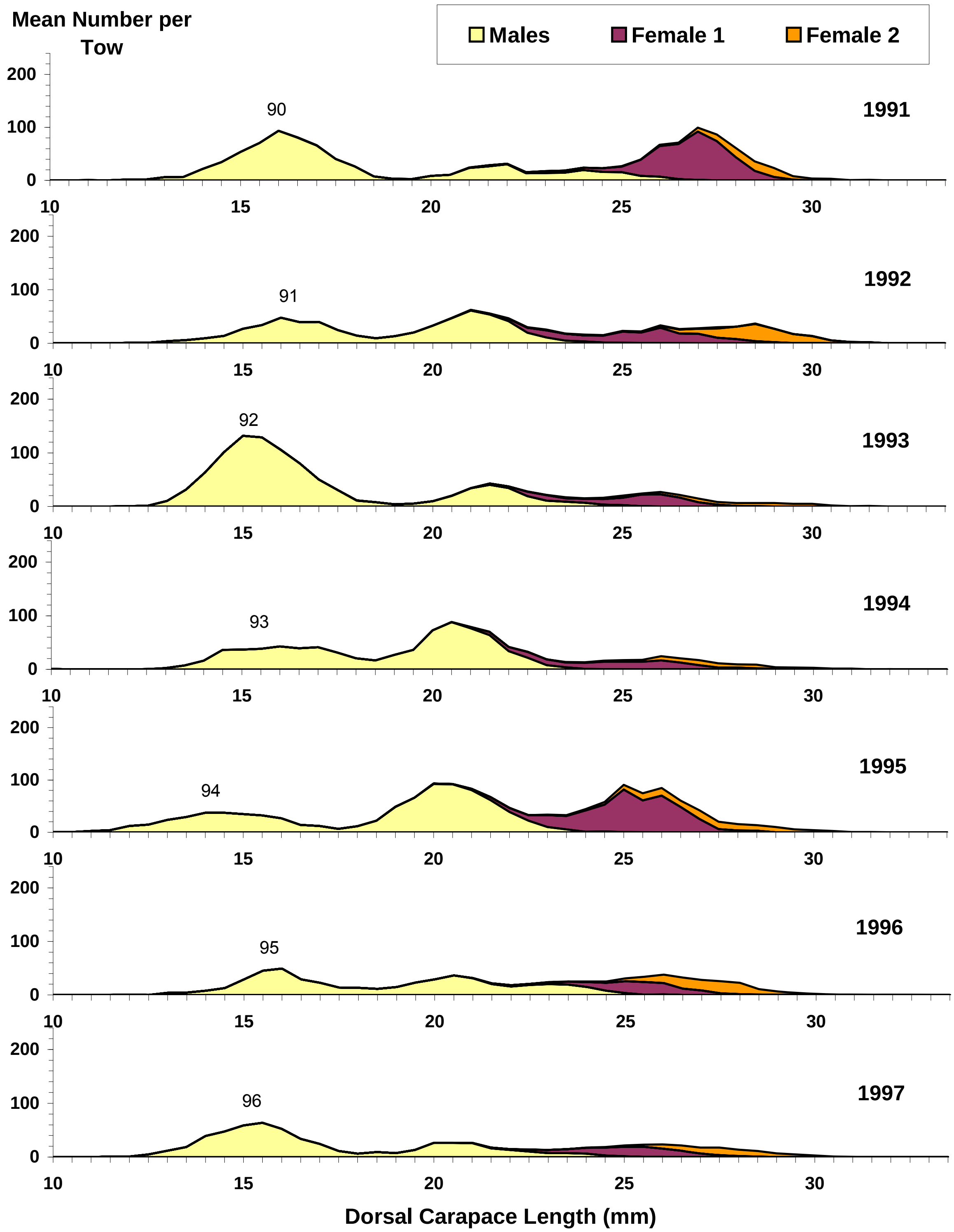


Figure C5.13 continued – summer survey.

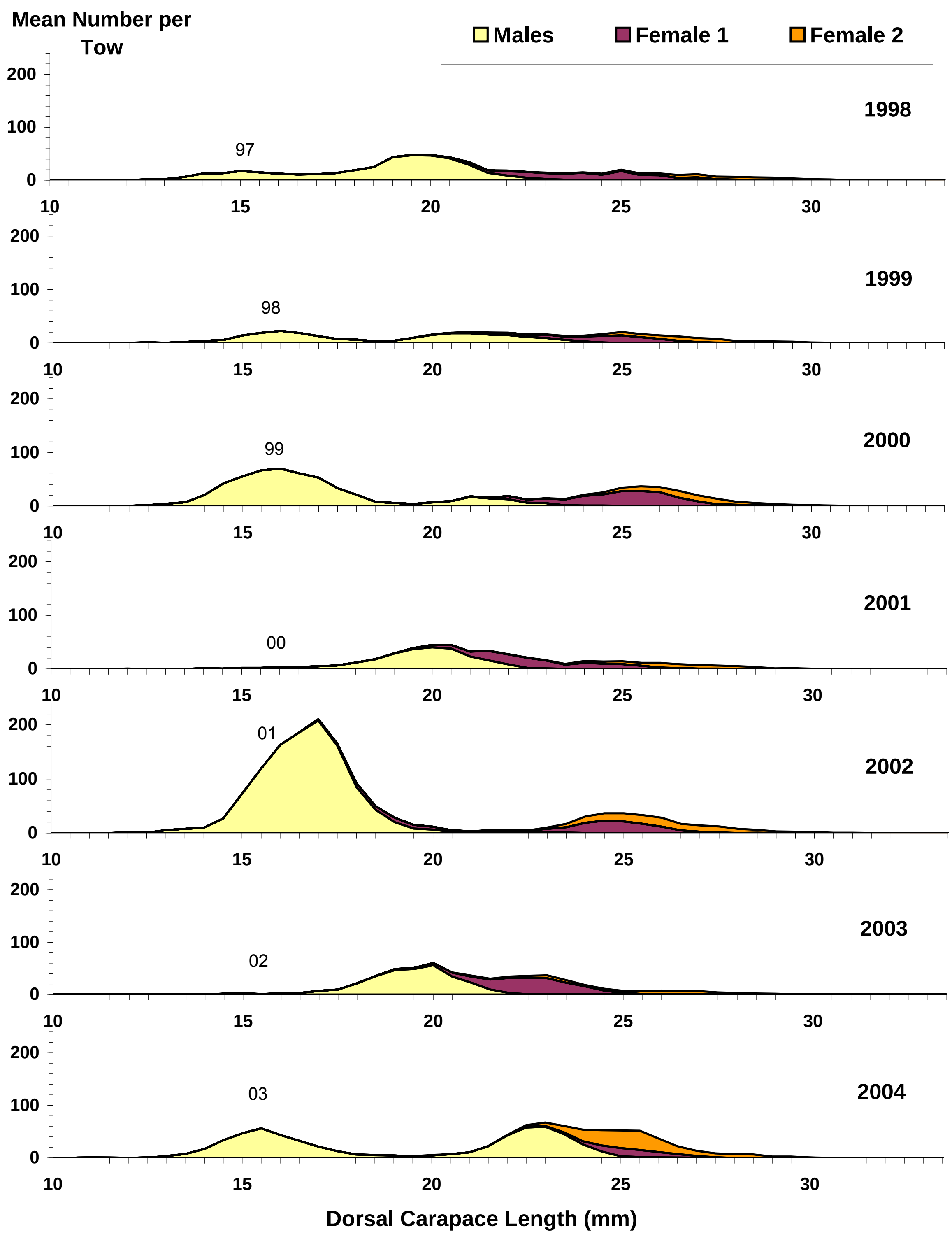


Figure C5.13 continued – summer survey.

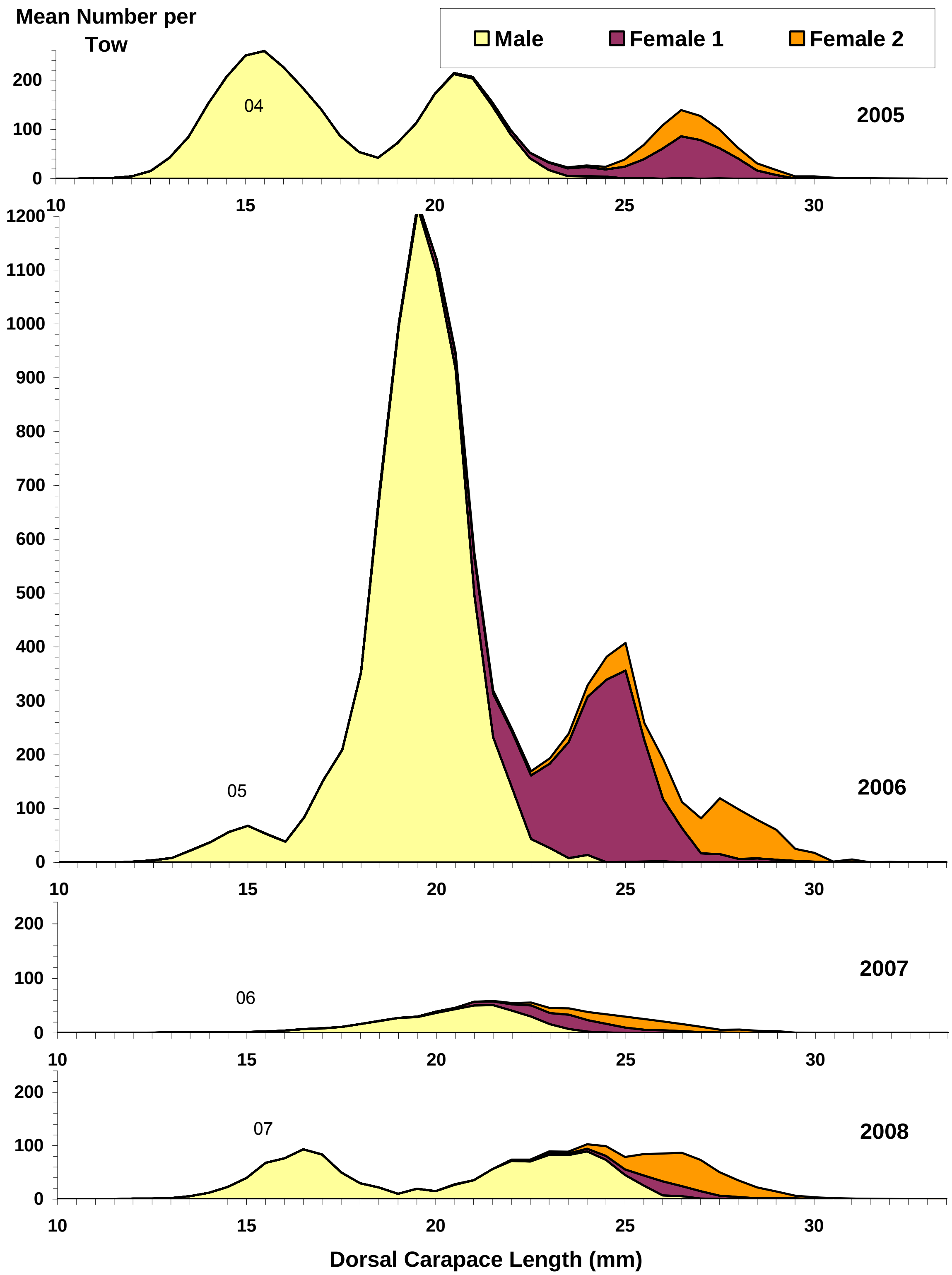


Figure C5.13 continued – summer survey.

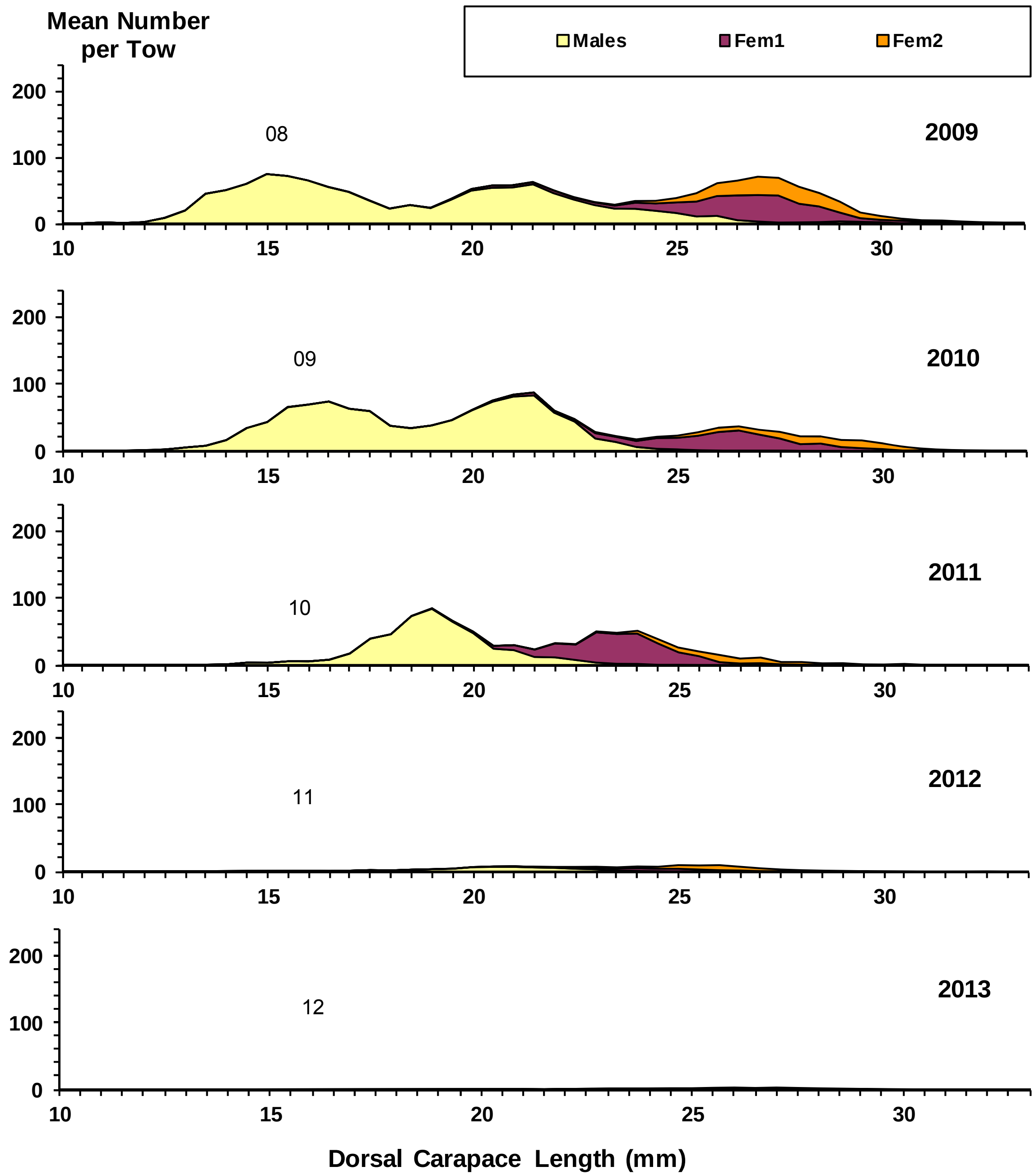


Figure C5.13 continued – summer survey.

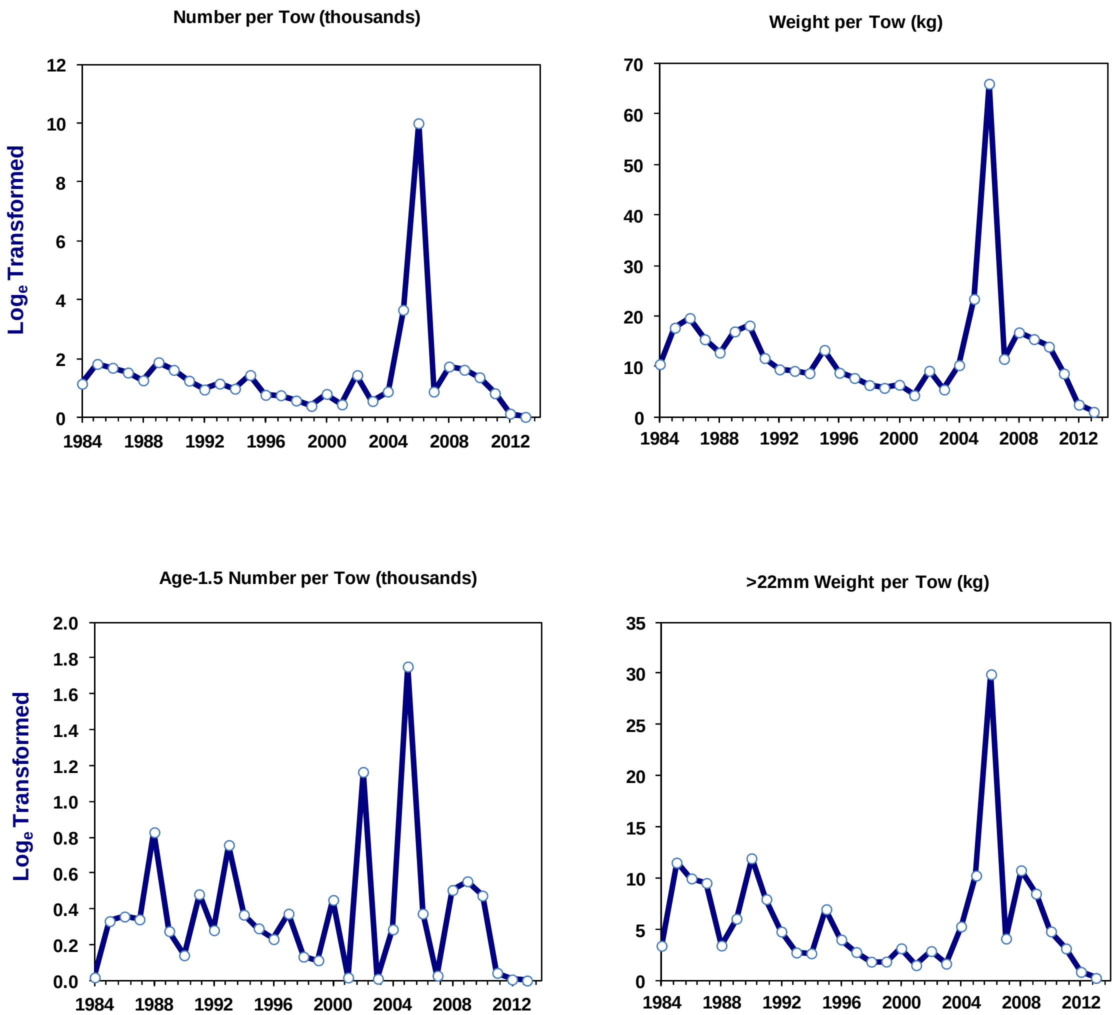


Figure C5.14. Summer survey standardized indices in number and weight for all shrimp (top), age 1.5 (bottom left), and fully-recruited shrimp (bottom right).

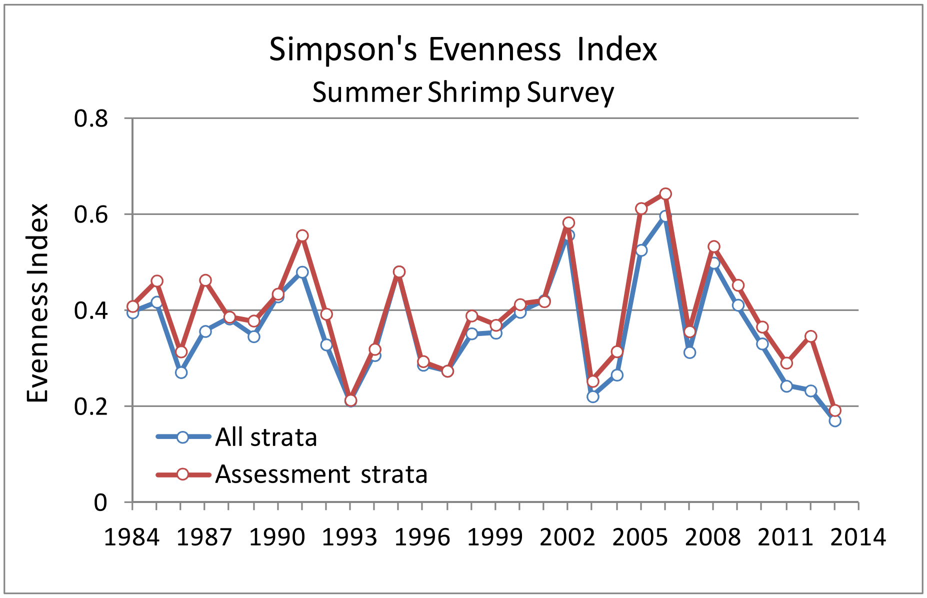


Figure C5.15. Simpson's evenness index (Payne et al. 2005) for northern shrimp in the Gulf of Maine based on summer shrimp survey catches

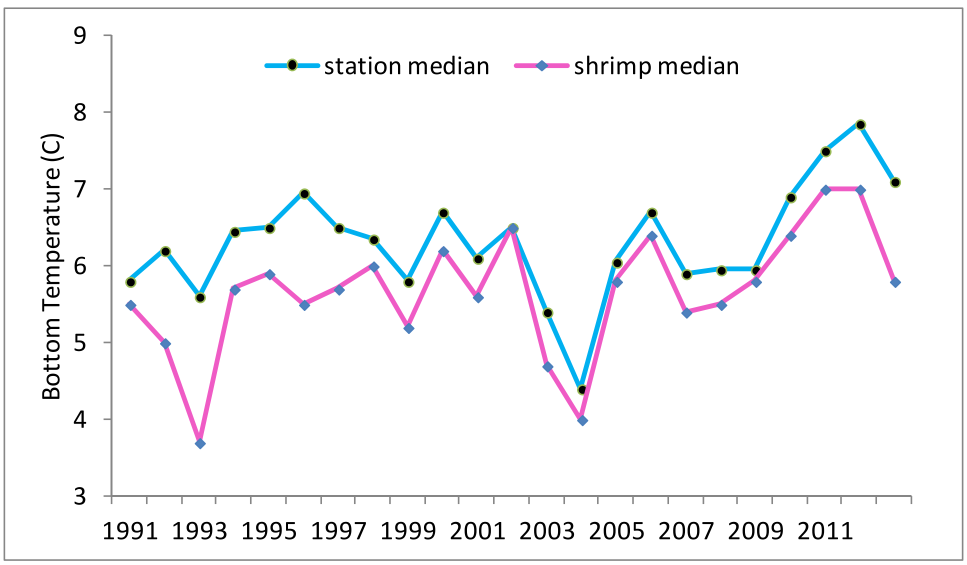


Figure C5.16. Median temperature at sampling stations in summer shrimp survey vs. catch-weighted-median temperature.

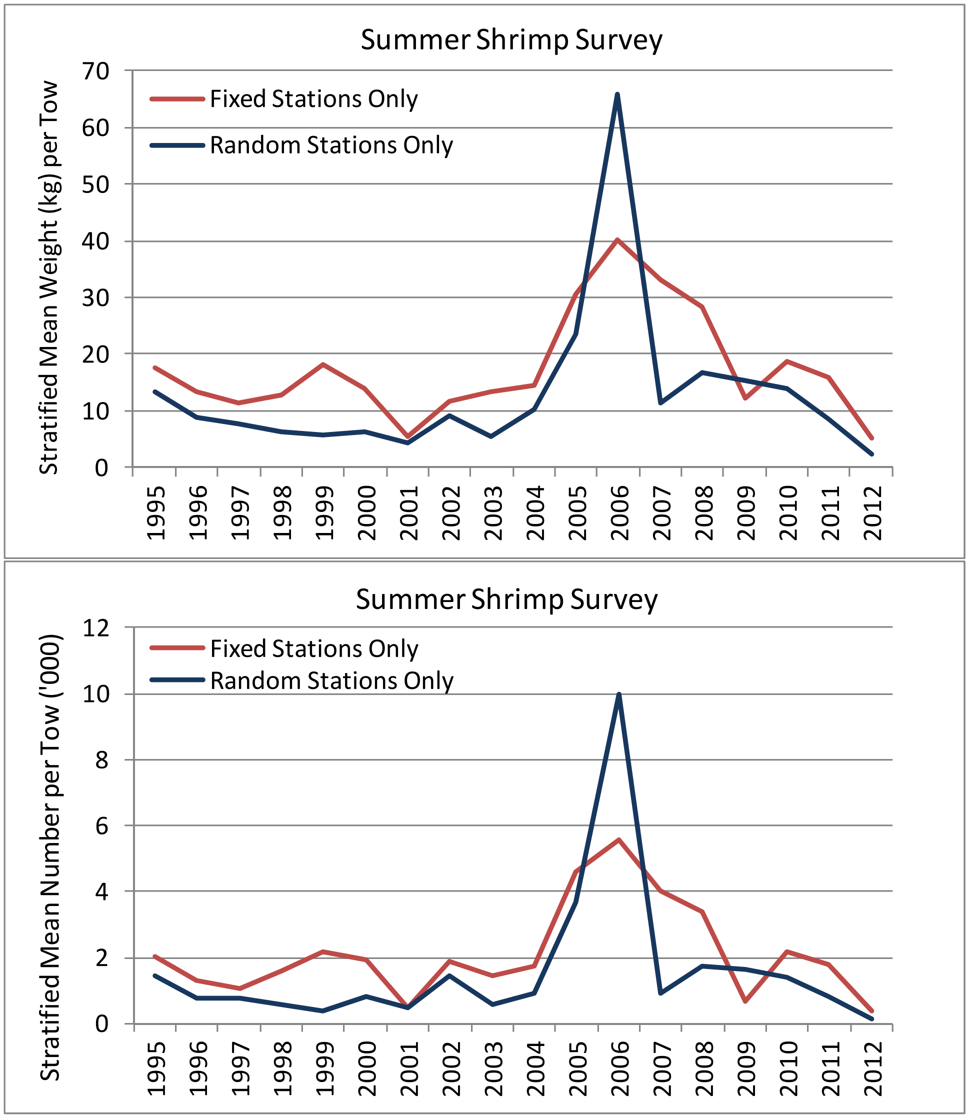


Figure C5.17. Comparison of survey indices from summer shrimp survey based on random stations or fixed stations. All indices $\log_e$ transformed.

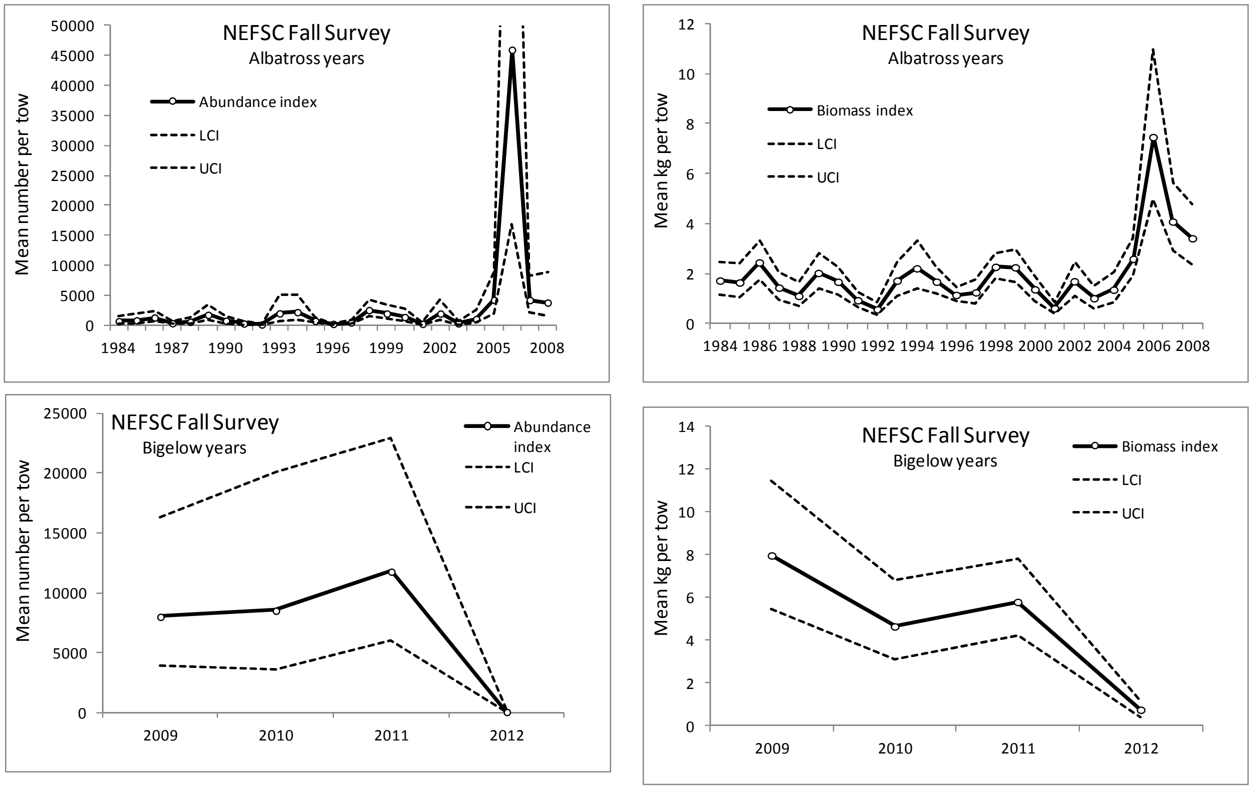


Figure C5.18. Survey indices with 95% confidence intervals for northern shrimp from the NEFSC fall survey, Albatross years (1984-2008) and Bigelow years (2009-2012).

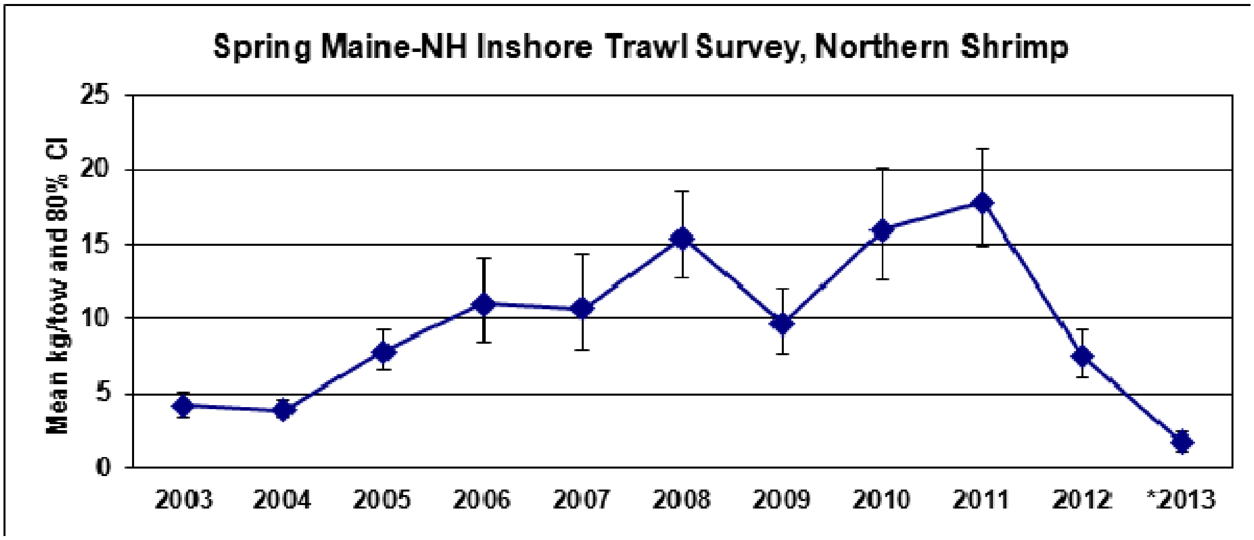


Figure C5.19. Spring Maine-New Hampshire inshore trawl survey northern shrimp biomass indices, with 80% confidence intervals. *2013 data are preliminary.

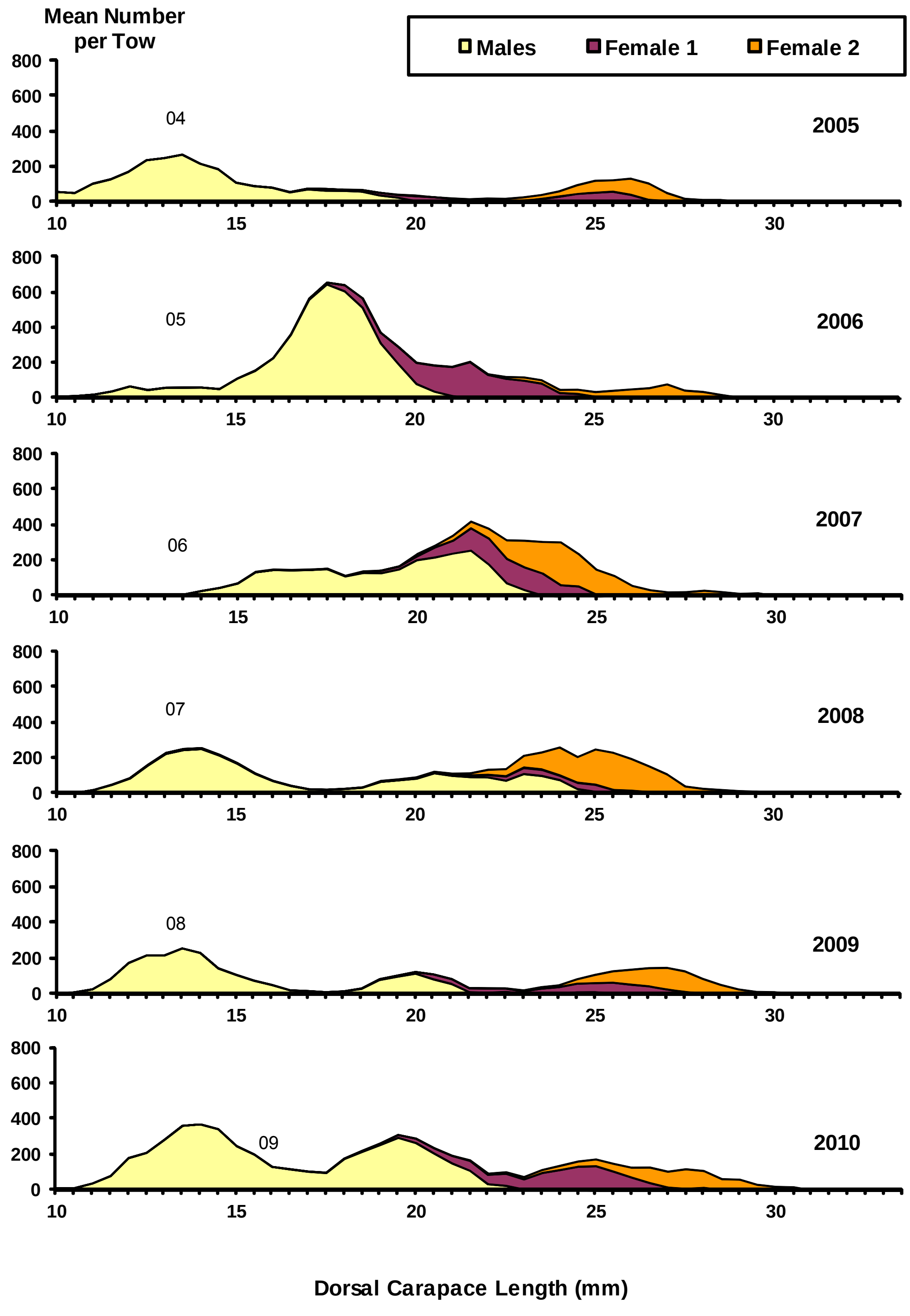


Figure C5.20. Maine-New Hampshire spring inshore survey; northern shrimp untransformed mean catch per tow by year, length, and development stage. Two-digit years are the year class at assumed age 1.

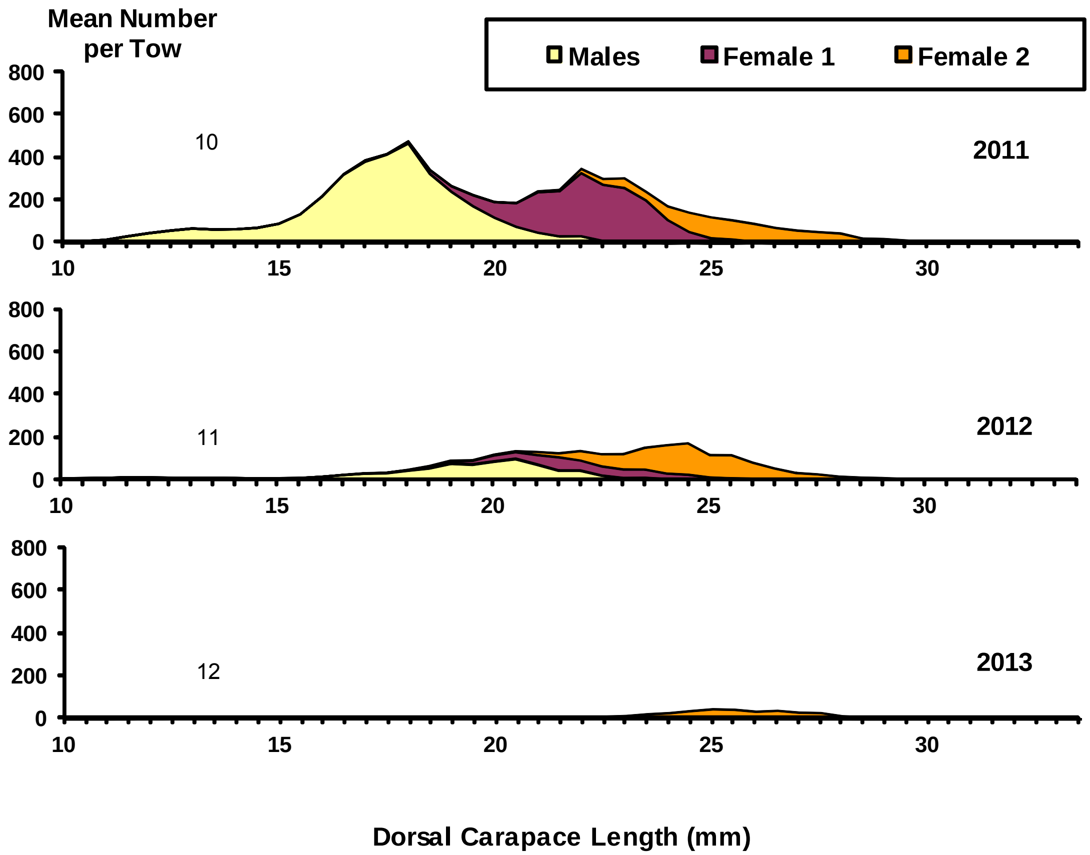


Figure C5.20 continued - ME/NH spring inshore survey.

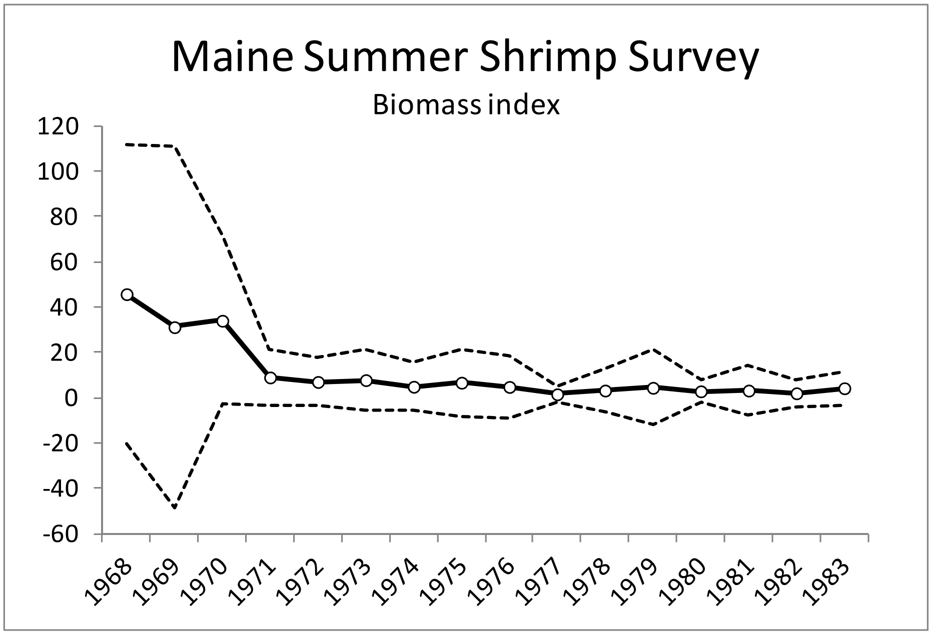


Figure C5.21. Biomass indices and 95% confidence intervals for State of Maine summer shrimp survey conducted during 1968-1983.

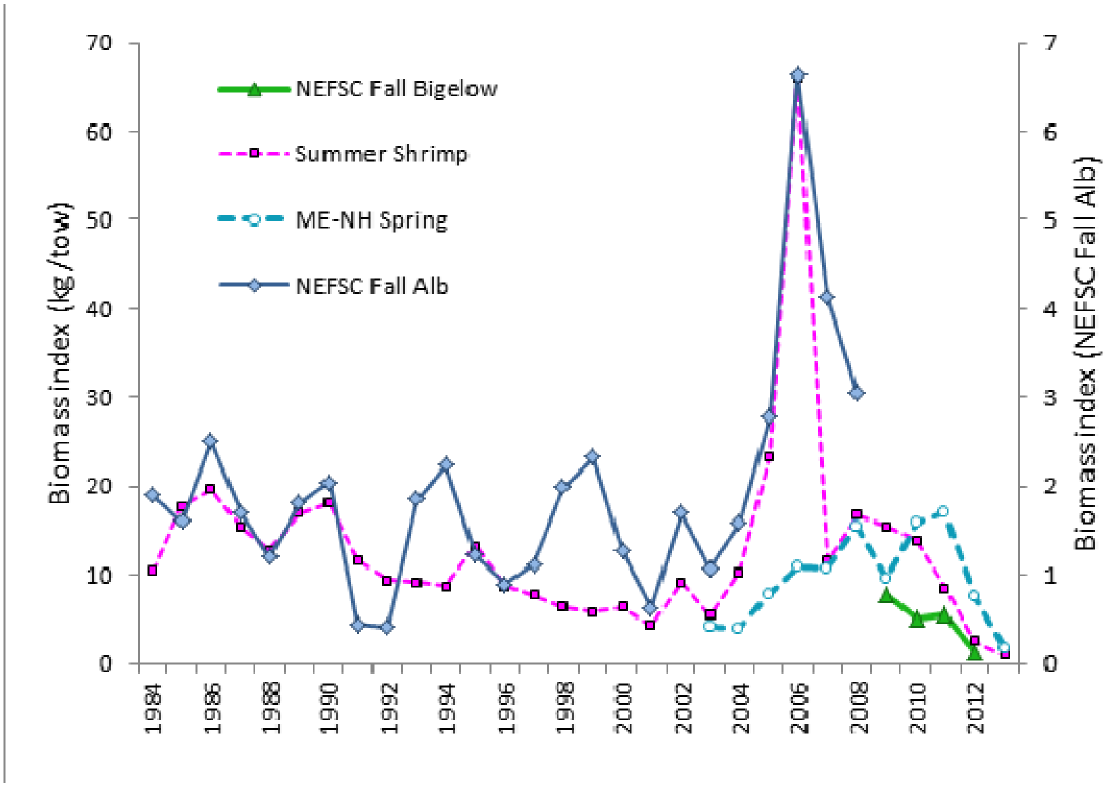


Figure C5.22. Biomass indices (kg/tow) from various northern shrimp surveys in the Gulf of Maine.

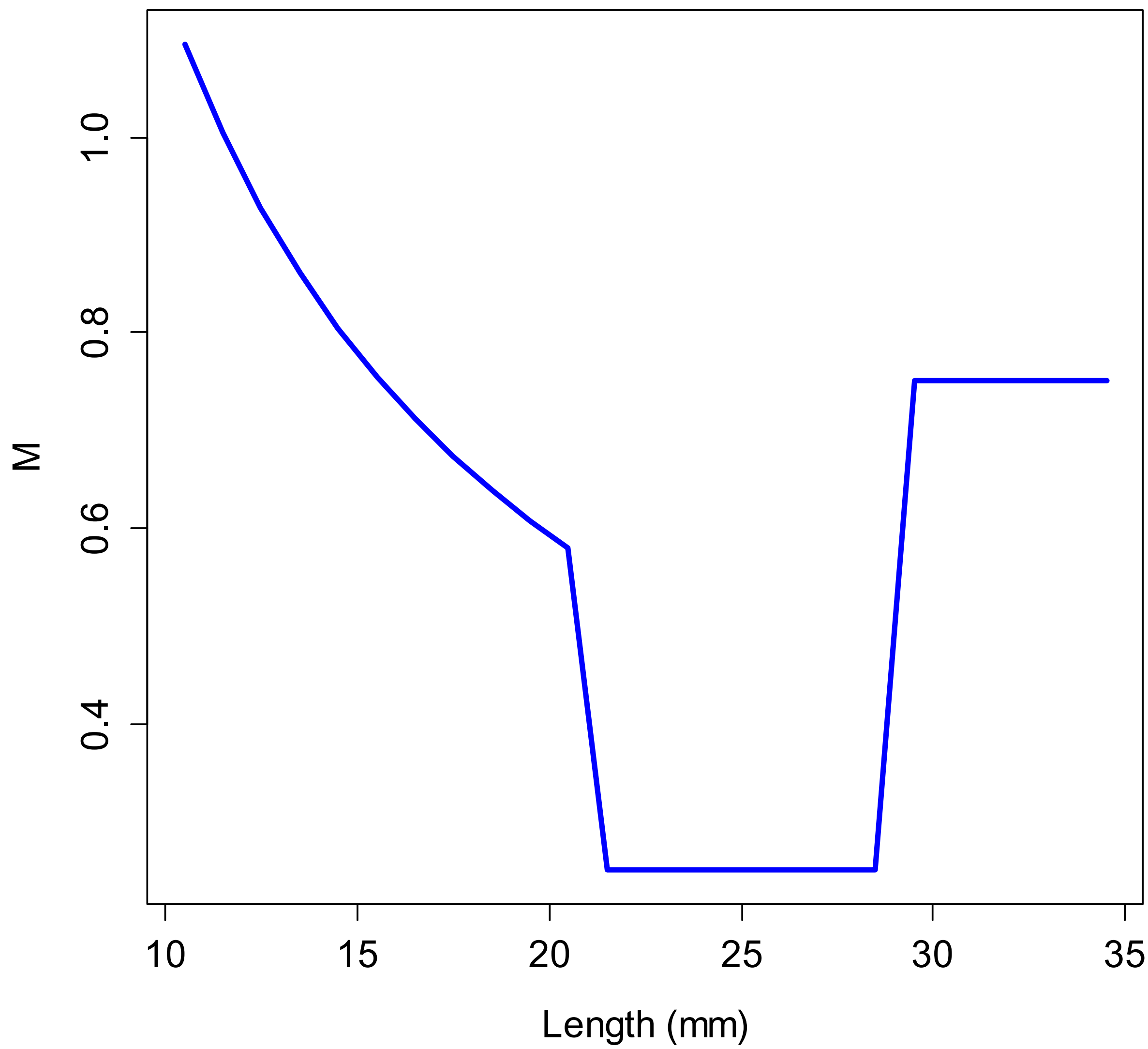


Figure C6.1. Natural mortality (U-shaped) used in the UMaine base run (see table 1).

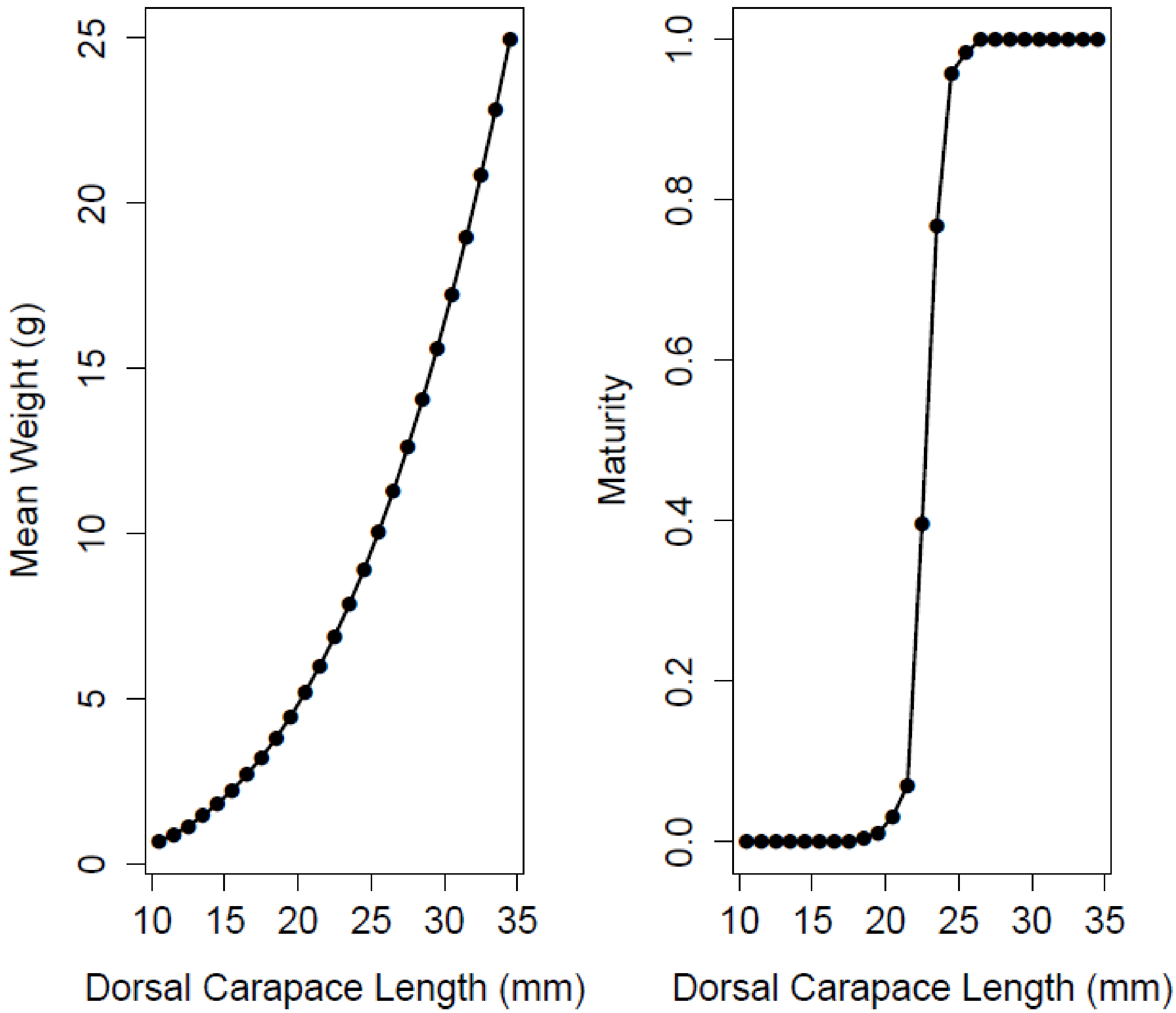


Figure C6.2. Weight-at-length (data were obtained from Haynes and Wigley 1969) and maturity-at-length in 2000 (data were obtained from ASMFC summer survey) of Northern shrimp in the Gulf of Maine.

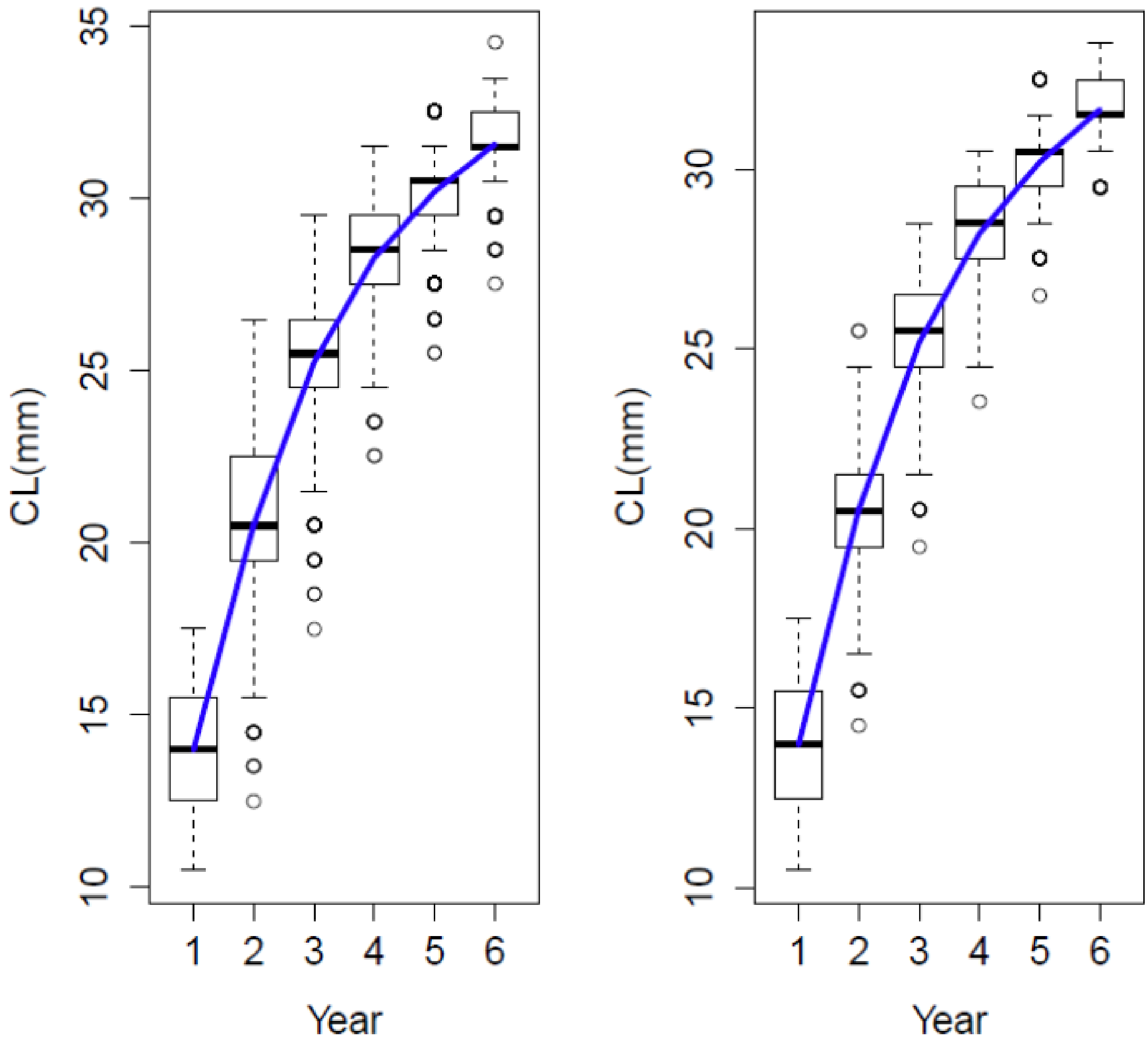


Figure C6.3. Apparent growth of a cohort with no fishing mortality estimated in the UMaine model base run (Left graph is for growth time block 1 and right graph is for growth time block 2 defined in the study to reflect potential impacts of different environment on growth; Table 2). Age values in the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

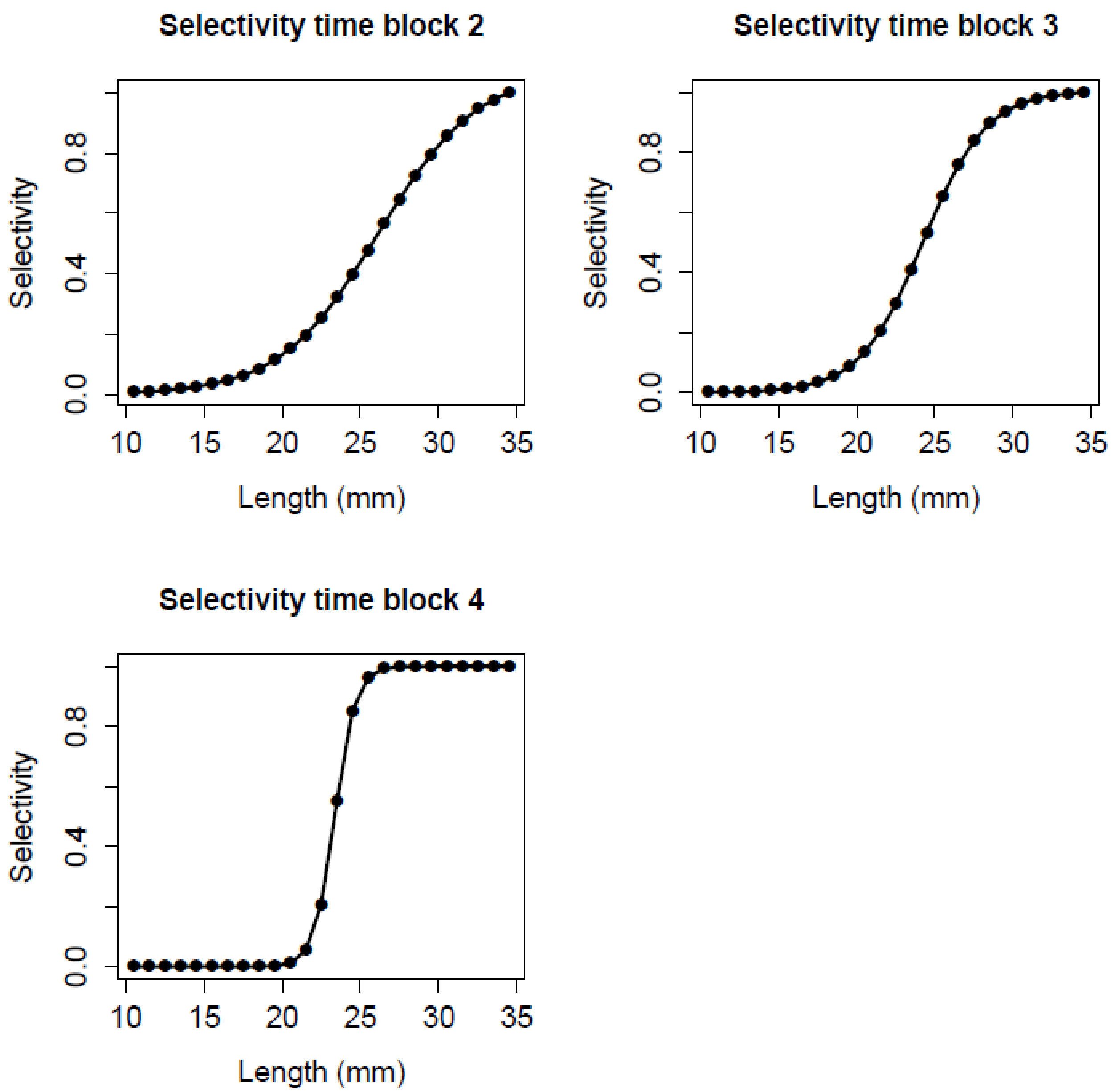


Figure C6.4. Selectivity patterns from the UMaine model base run for each of the fisheries (block 2=mixed fleet; block 3=trawl fleet; block 4=trap fleet).

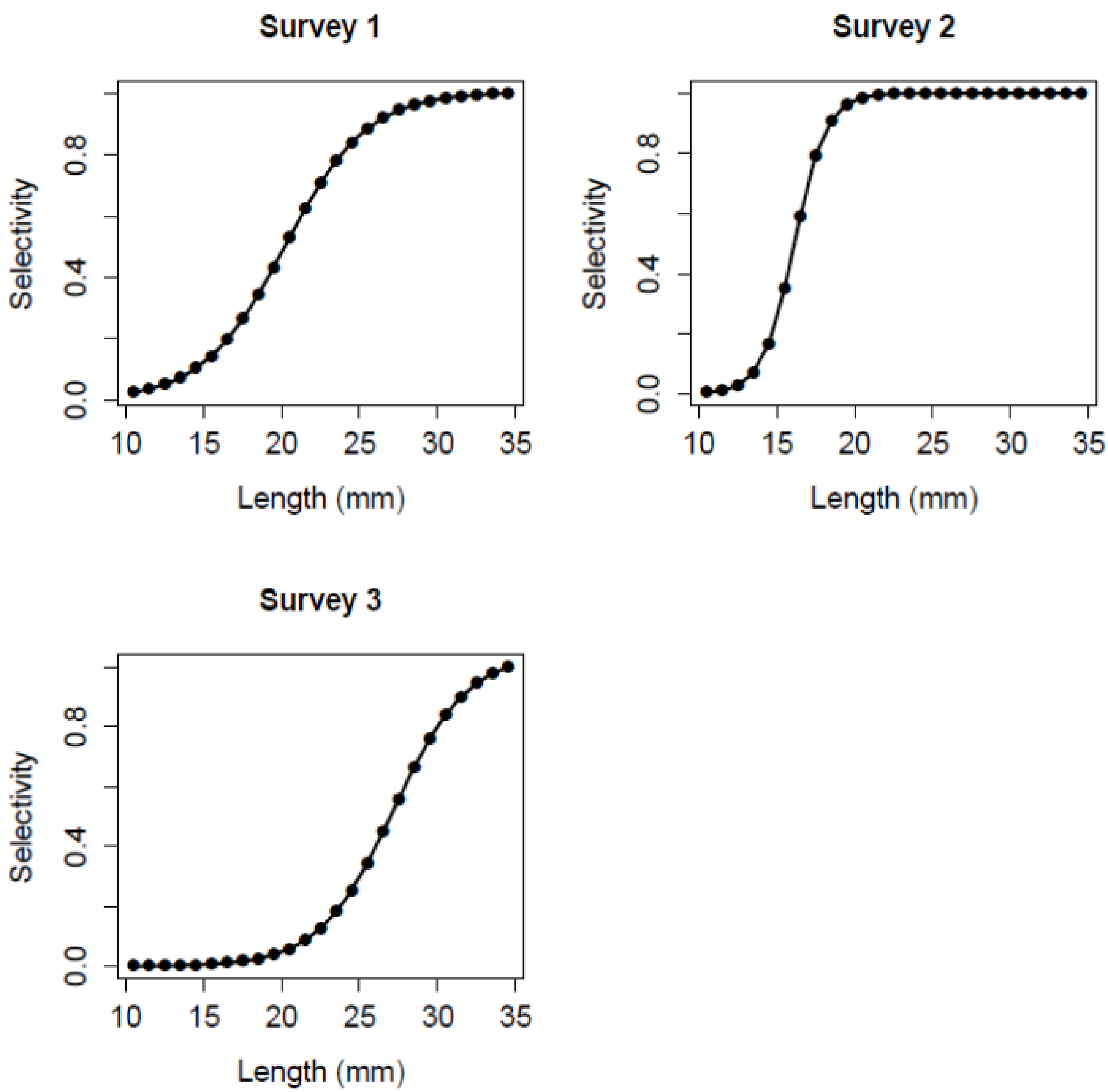


Figure C6.5. Selectivity patterns from the UMaine model base run for each of the surveys (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey)

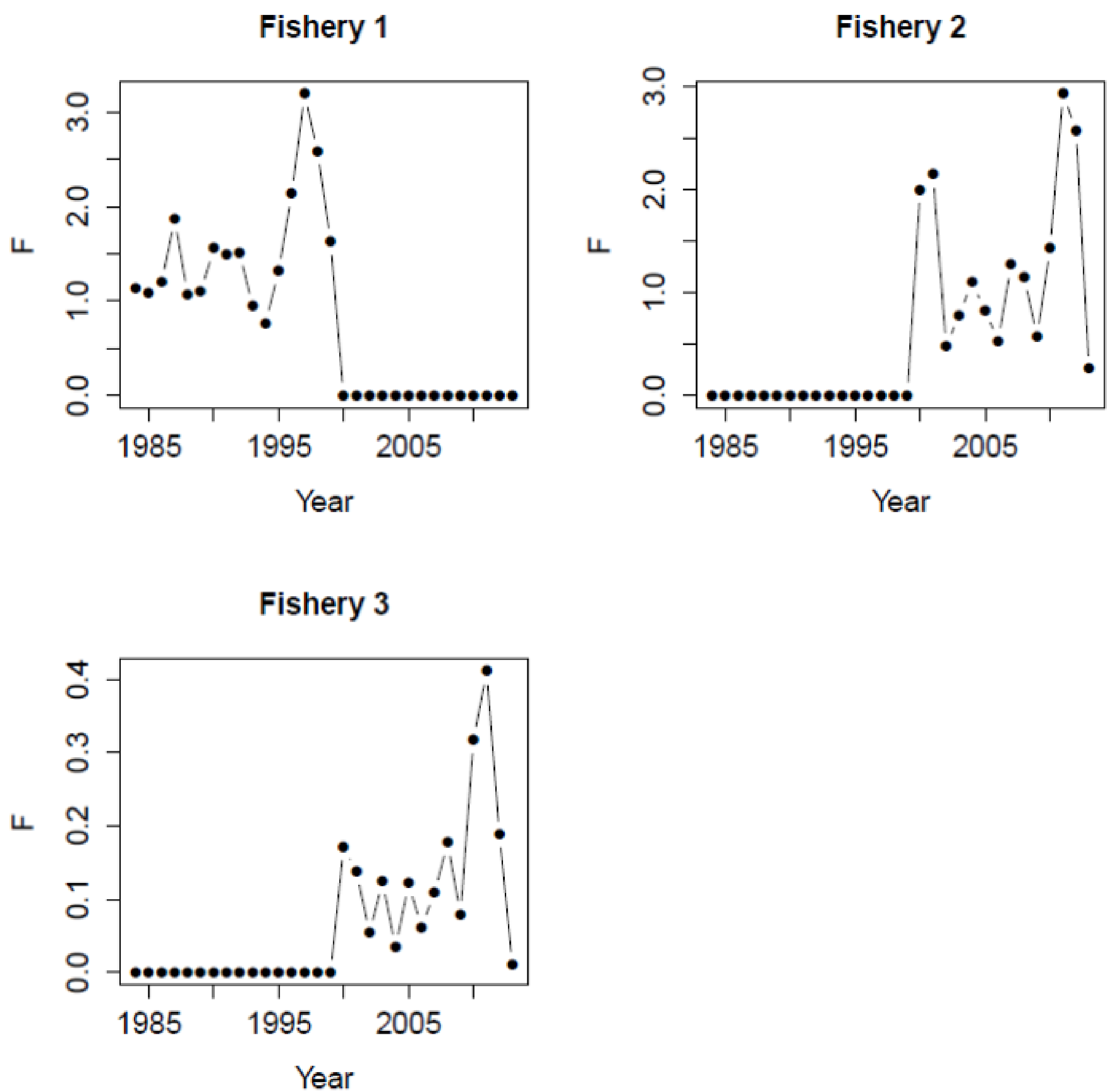


Figure C6.6. Fishing mortality from the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

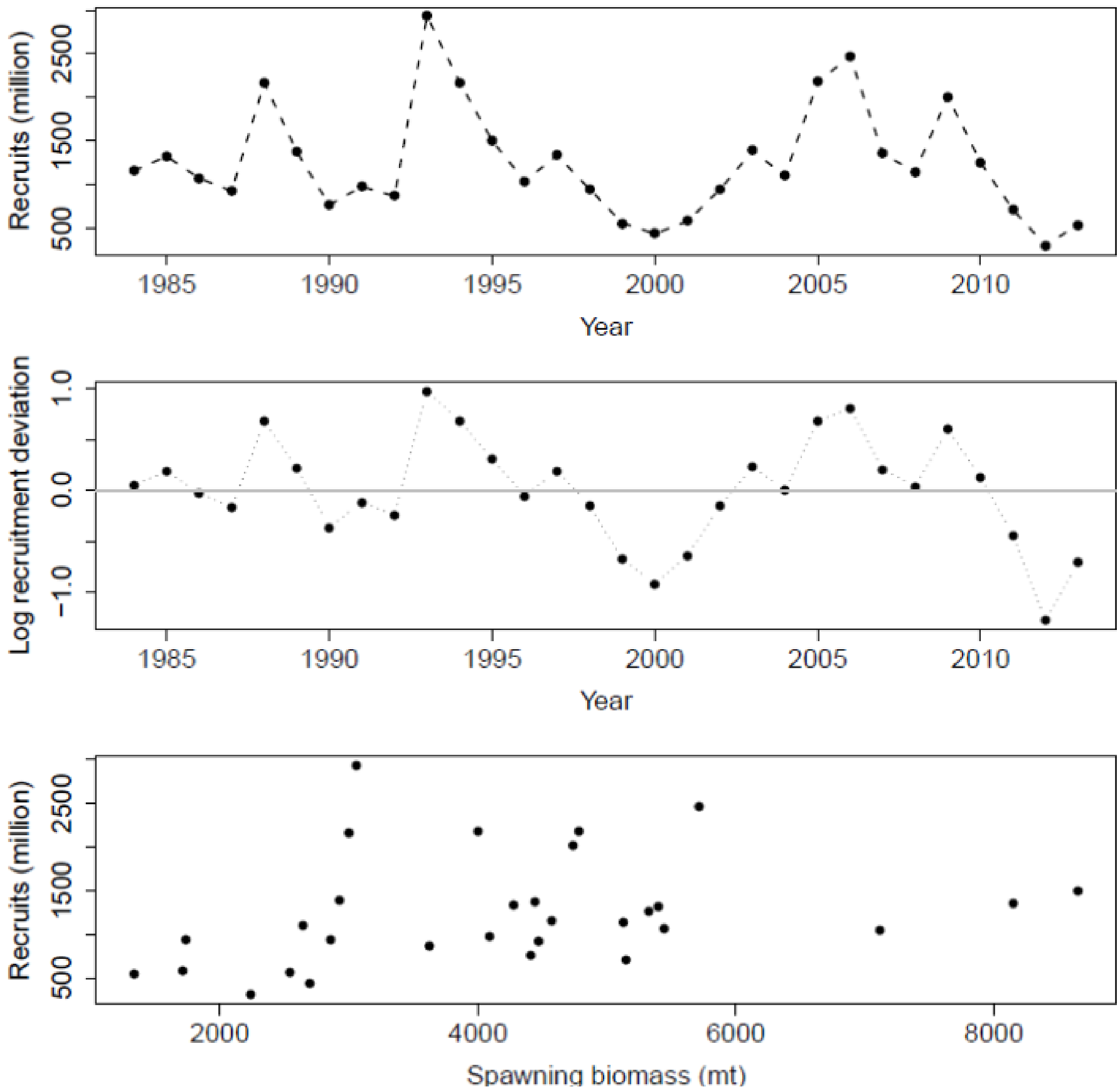


Figure C6.7. Recruitment pattern from UMaine model base run.

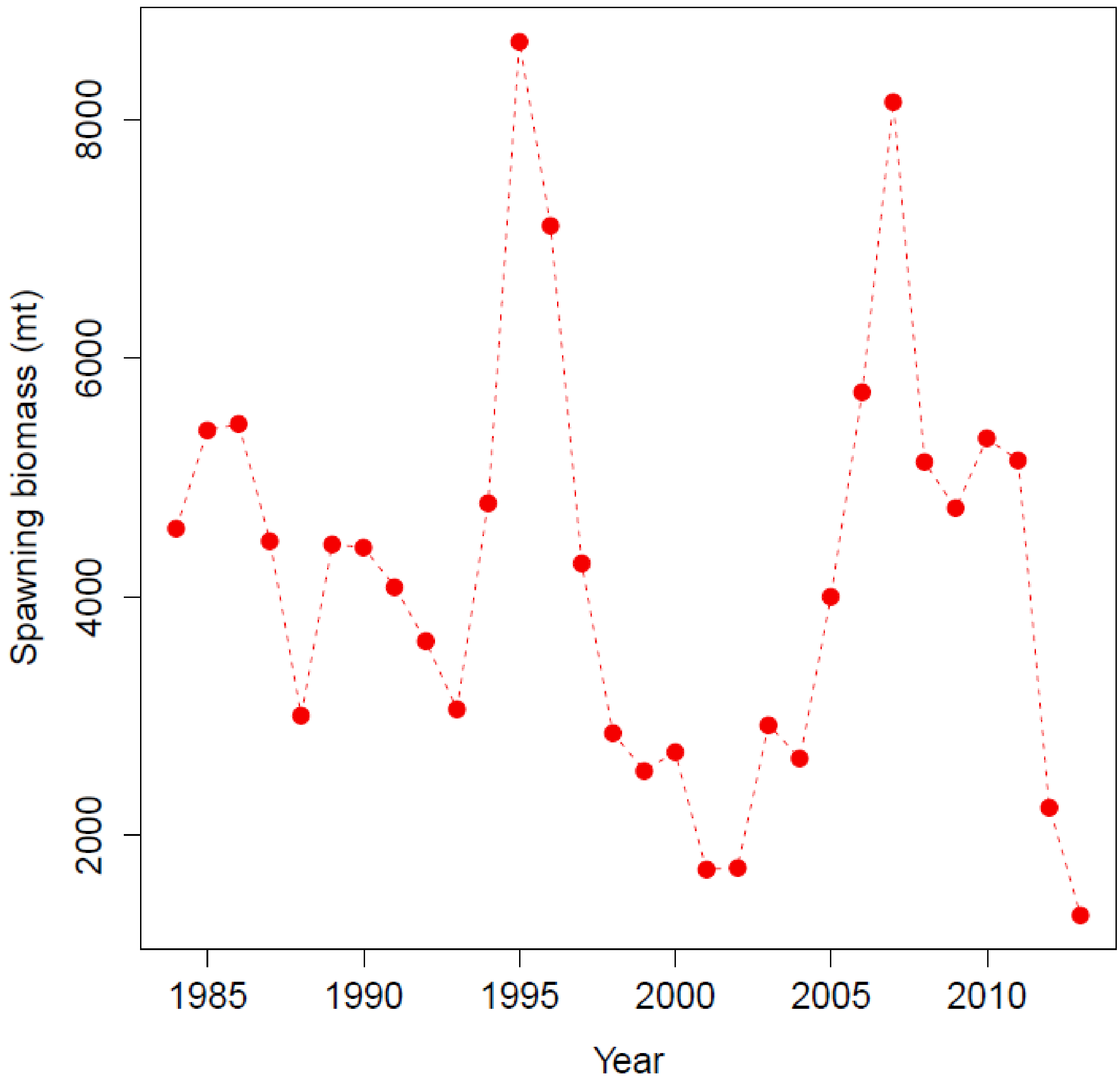


Figure C6.8. Estimates of spawning stock biomass for the UMaine model base run. The spawning stock biomass is measured as the total biomass of females on March 1.

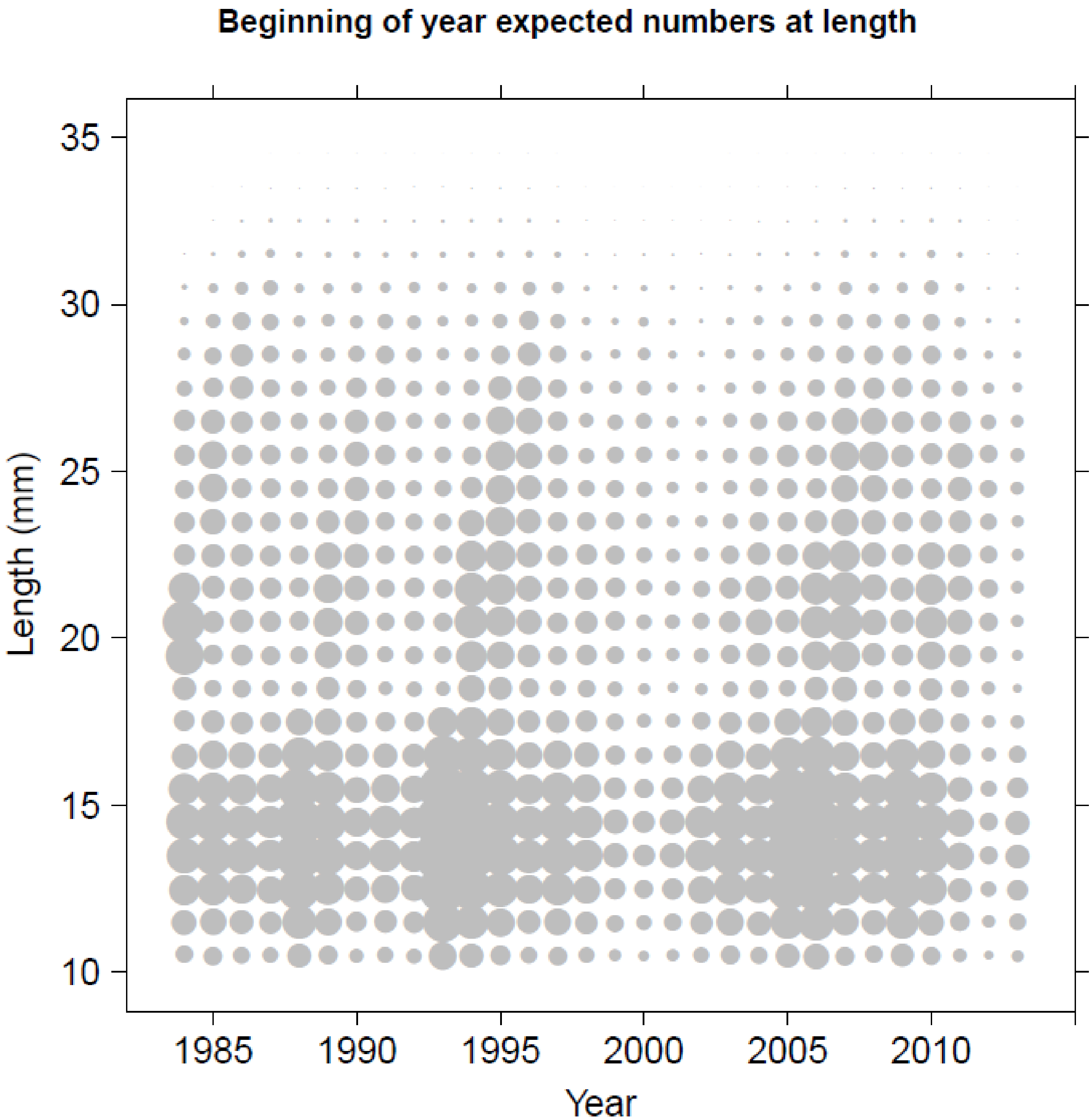


Figure C6.9. "Bubble plot" of the proportion of the estimated abundance at the beginning of each year. Sizes of the bubbles are proportional to the values of abundance.

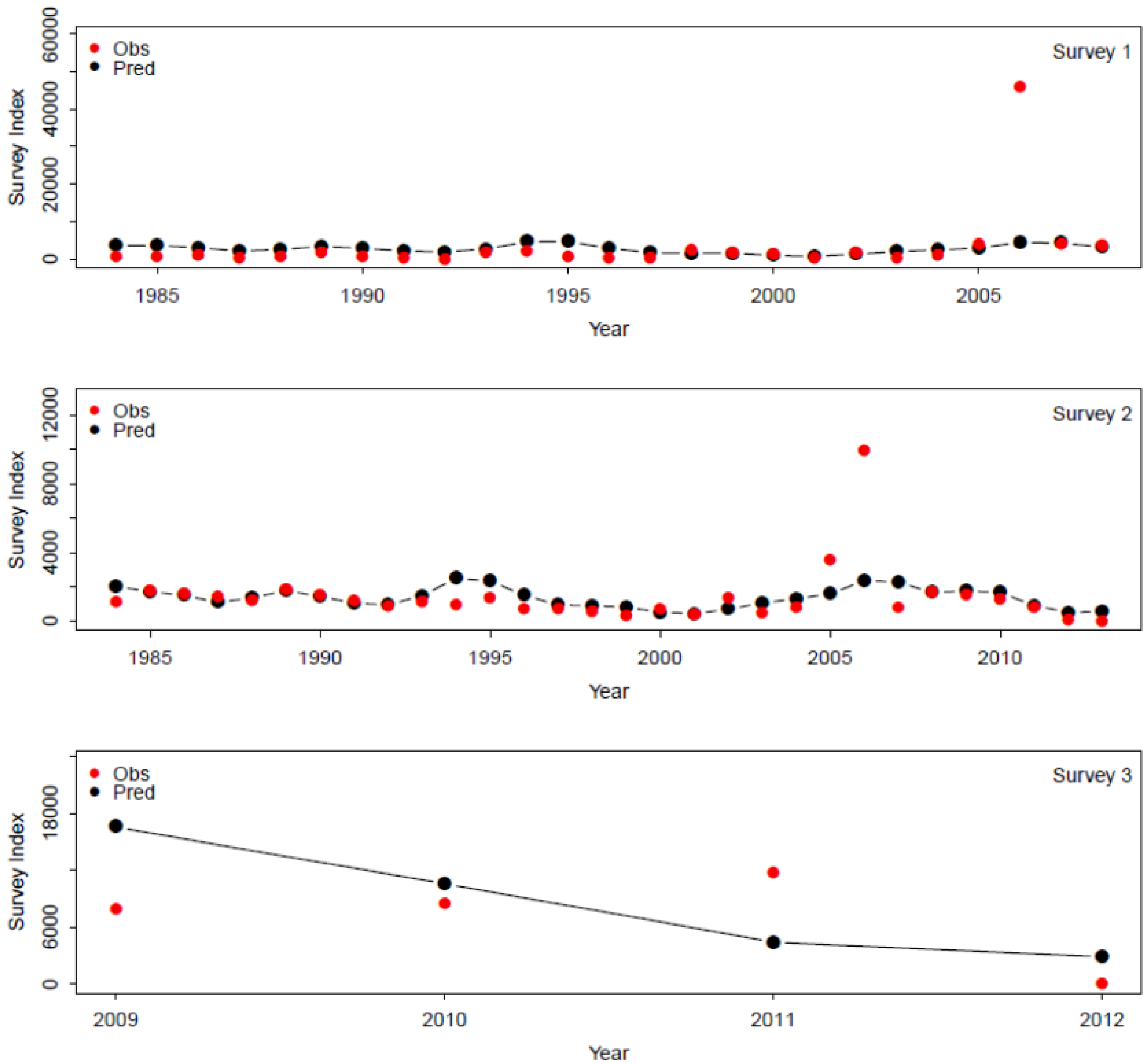


Figure C6.10. Observed (dot) and predicted (line) survey indices for northern shrimp in the UMaine model base run (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey).

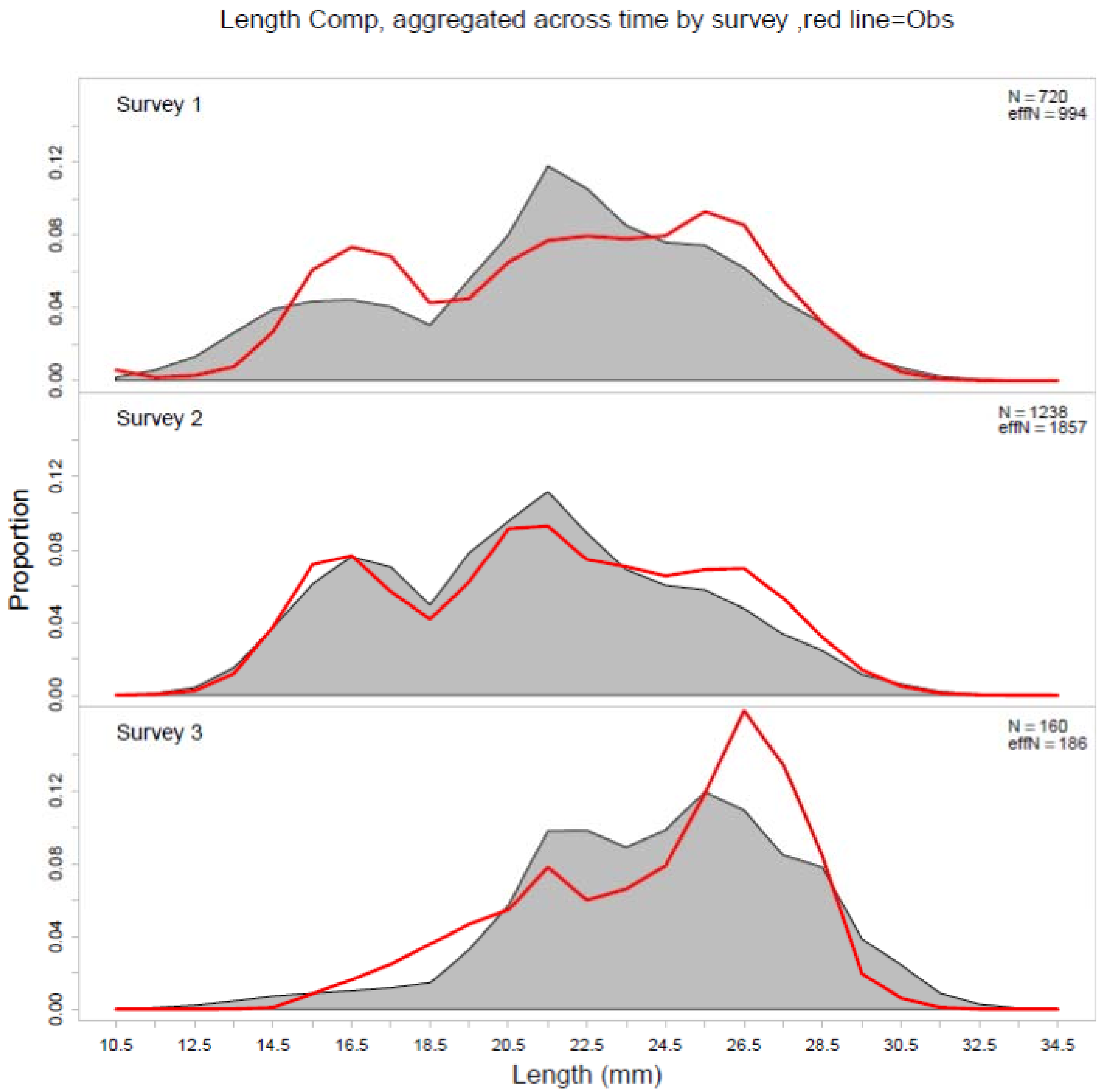


Figure C6.11. Observed (red line) and predicted (in prey) average survey length composition data for northern shrimp in the UMaine model base run (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey).

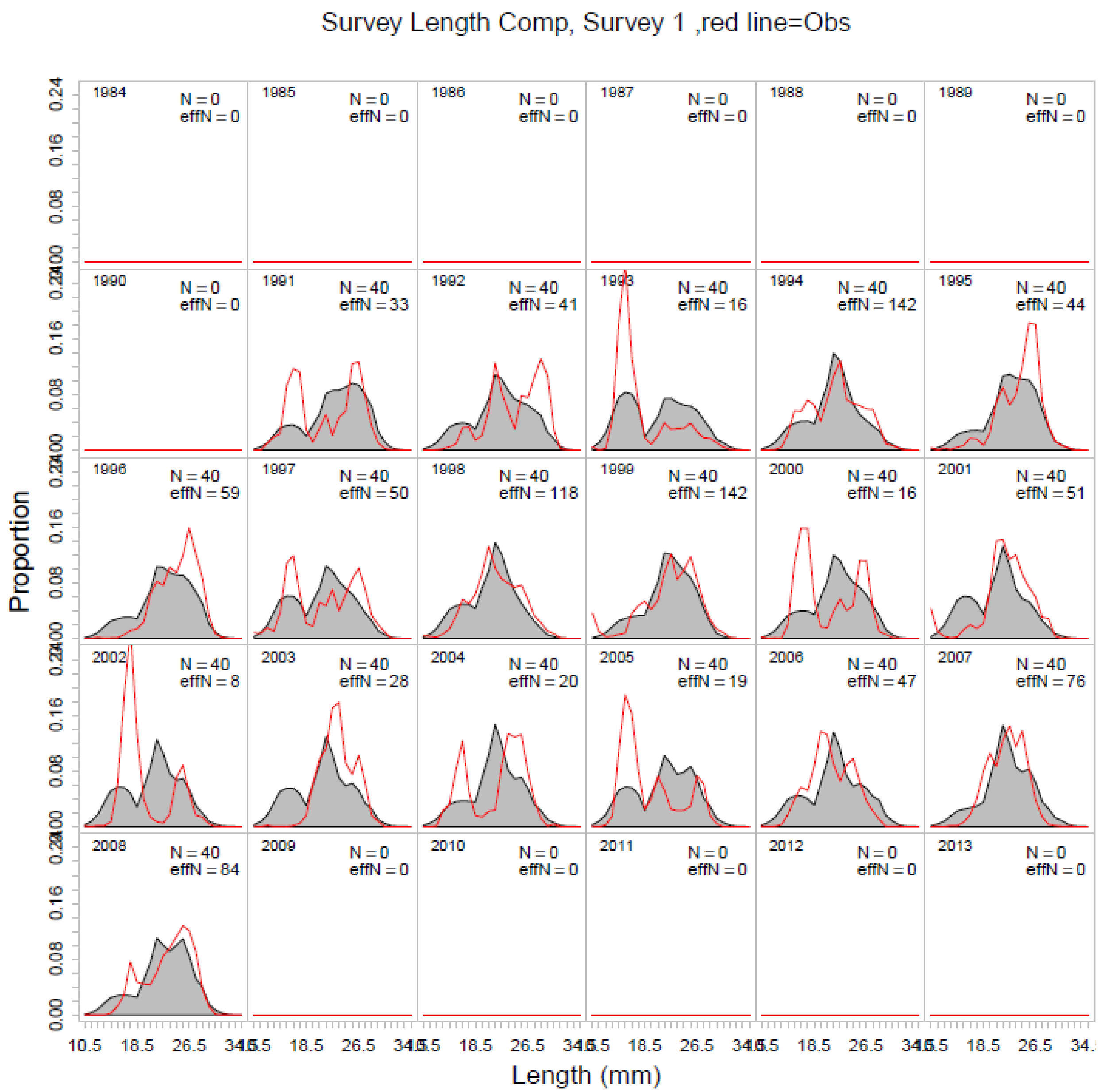


Figure C6.12. Observed (red line) and predicted (in prey) NEFSC fall survey length composition for each year for northern shrimp in the UMaine model base run.

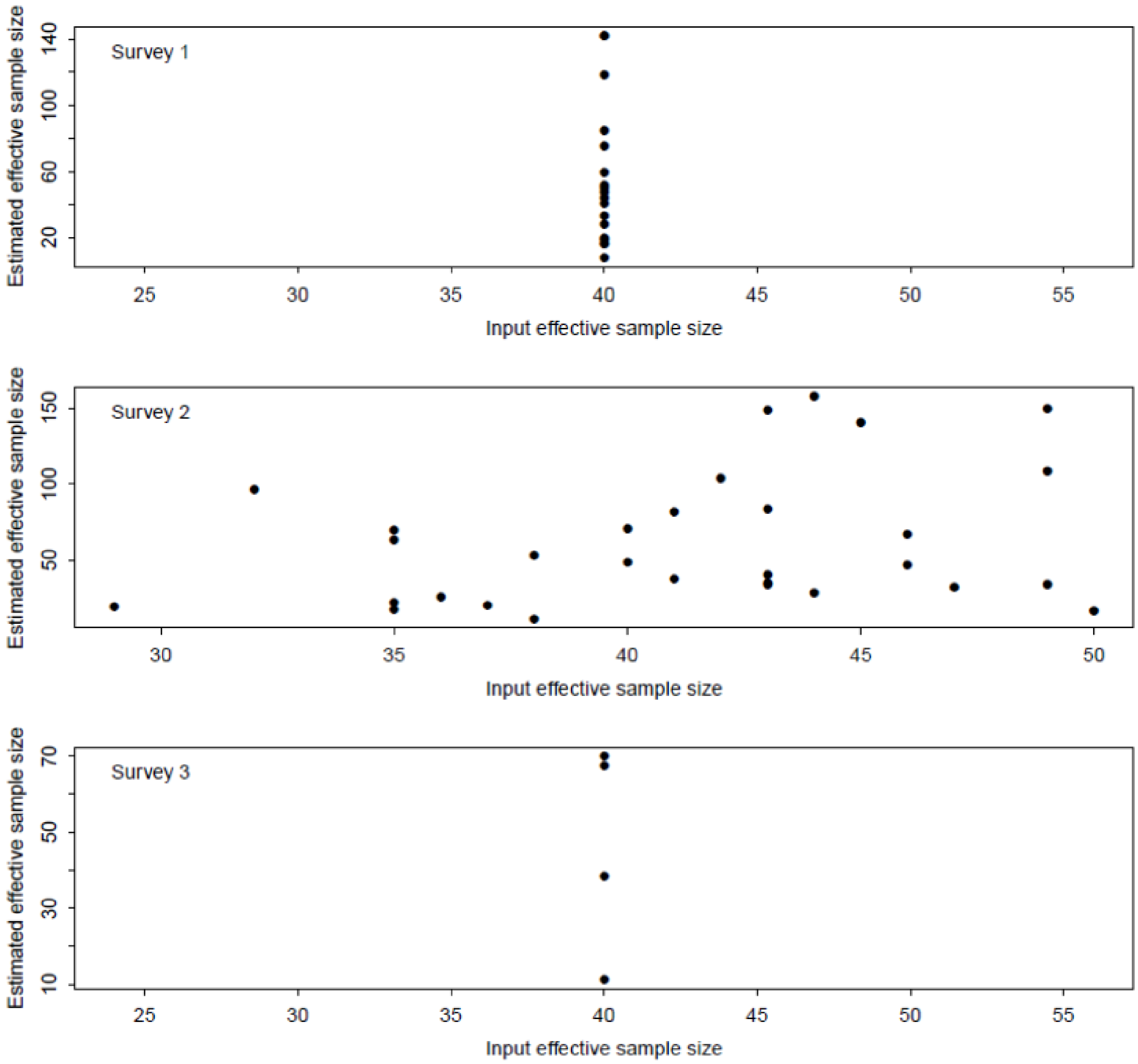


Figure C6.13. Comparison of input effective sample size versus the model estimated effective sample size for the survey indices used in the based run model (survey 1=NEFSC fall survey; survey 2=ASMFC summer survey; survey 3= NEFSC Bigelow survey)

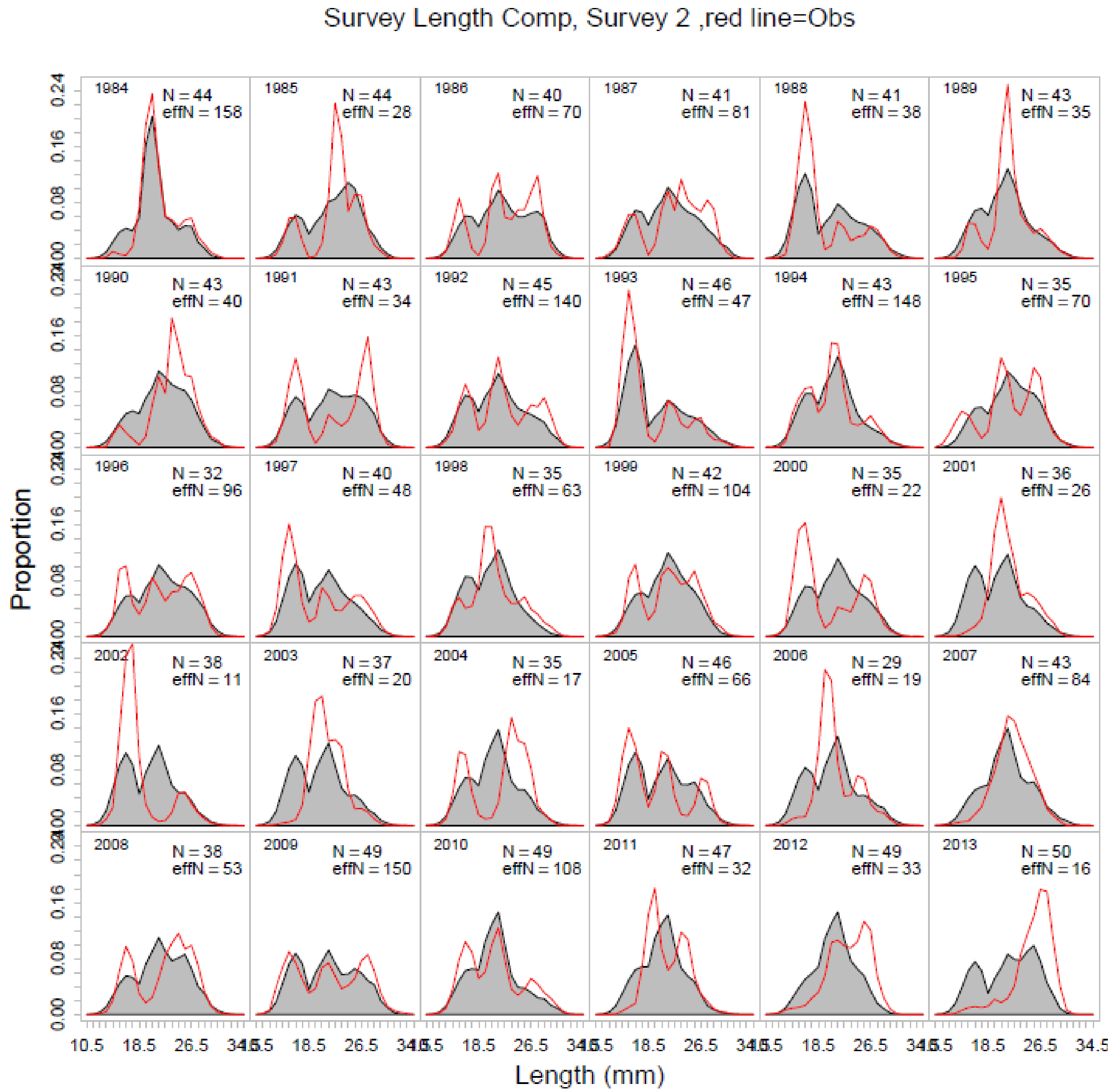


Figure C6.14. Observed (red line) and predicted (in prey) ASMFC summer survey length composition data for each year for northern shrimp in the UMaine model base run.

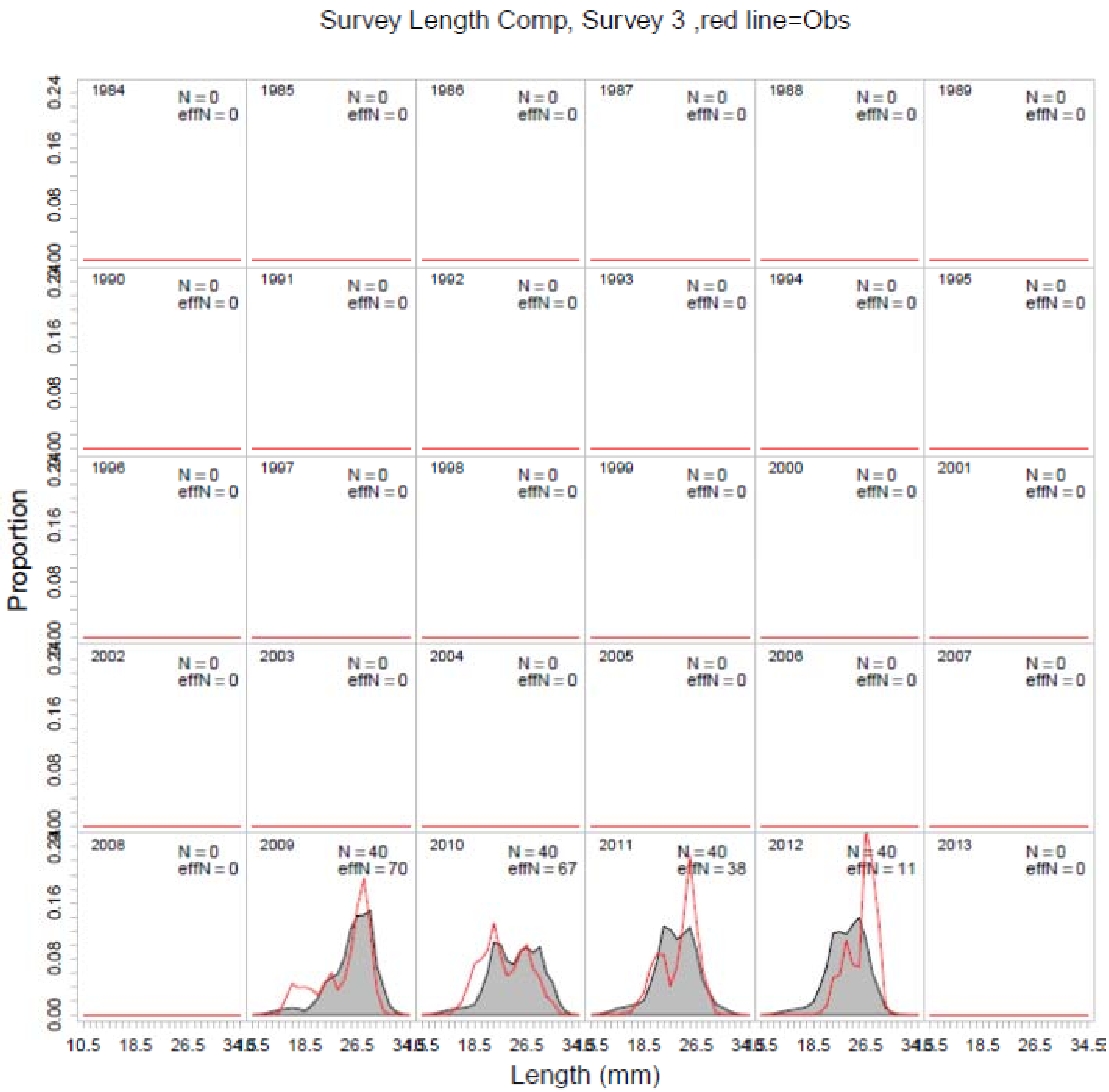


Figure C6.15. Observed (red line) and predicted (in prey) NEFSC Bigelow survey length composition data for each year for northern shrimp in the UMaine model base run.

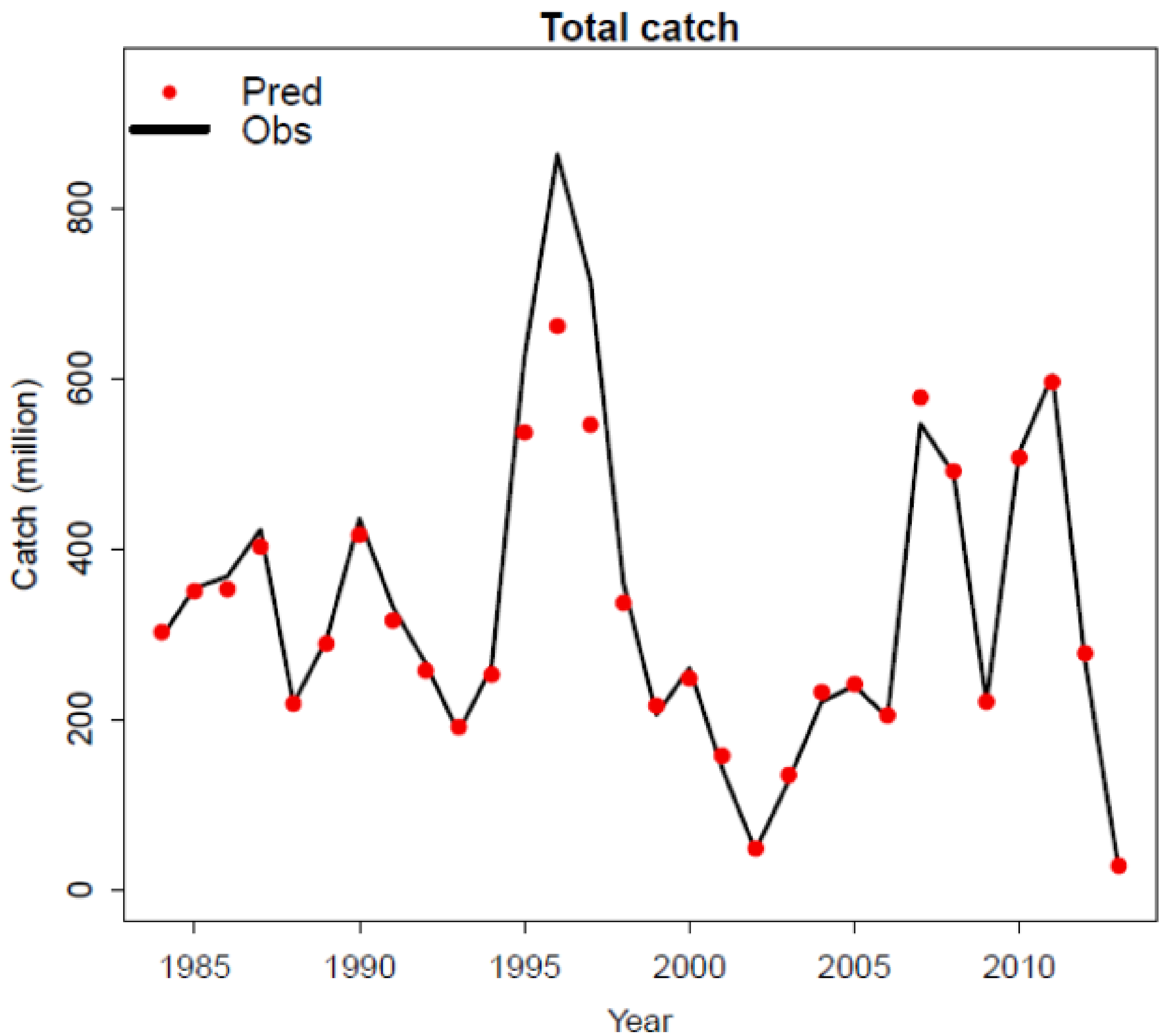


Figure C6.16. Commercial total catch (black line) and predicted values (red dots) for northern shrimp in the UMaine model base run.

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).

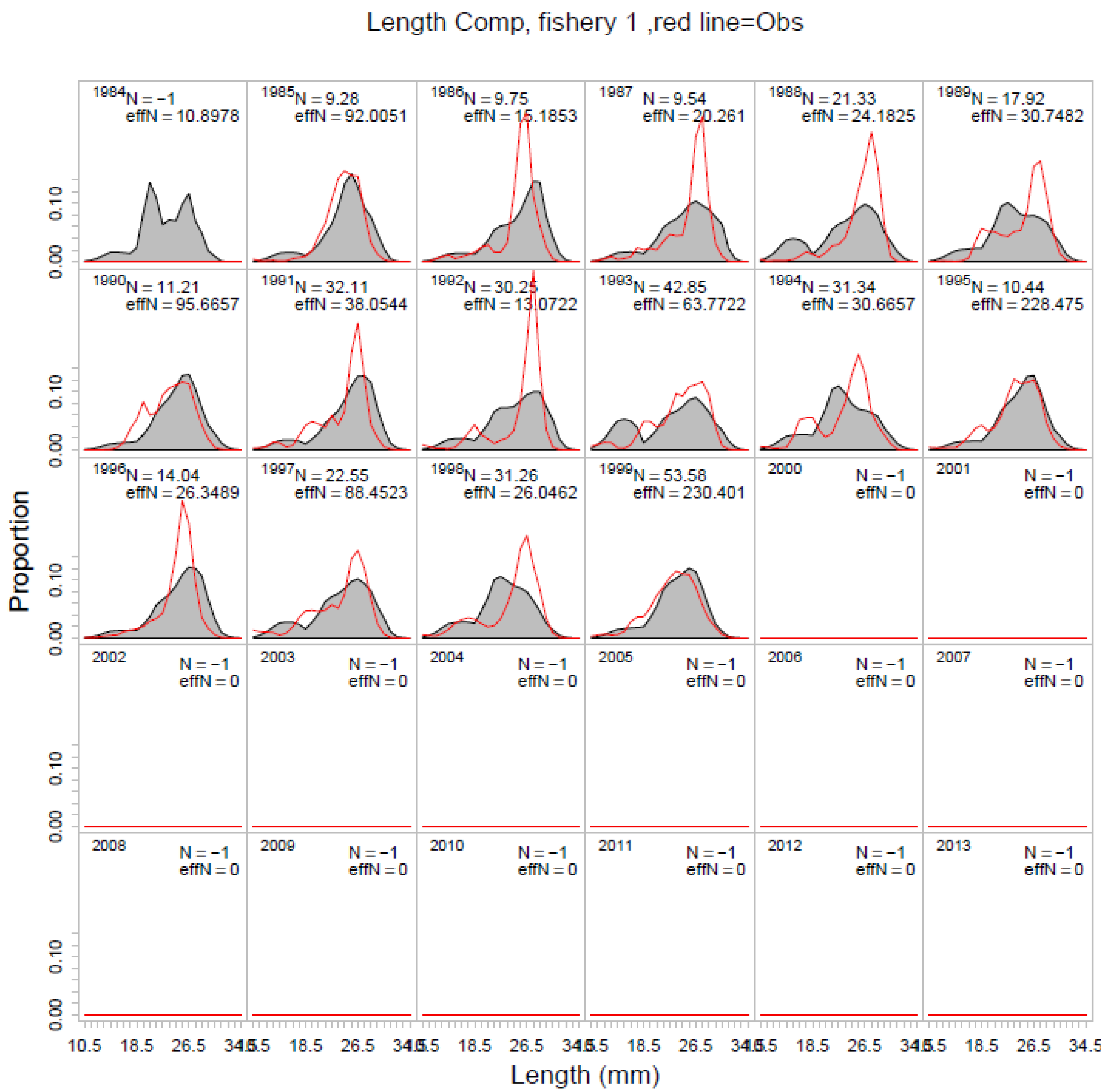


Figure C6.18. Mixed fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

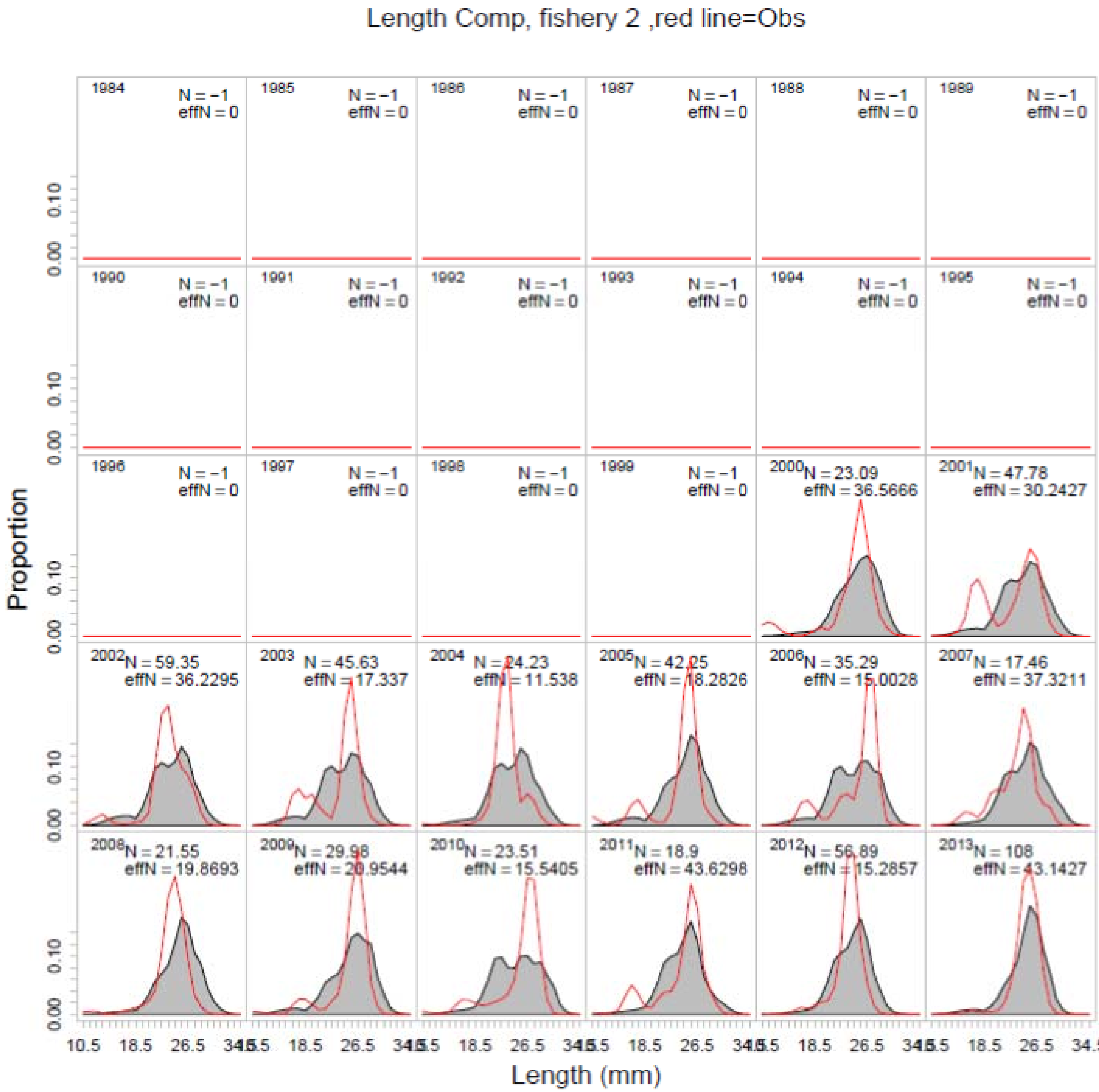


Figure C6.19. Trawl fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

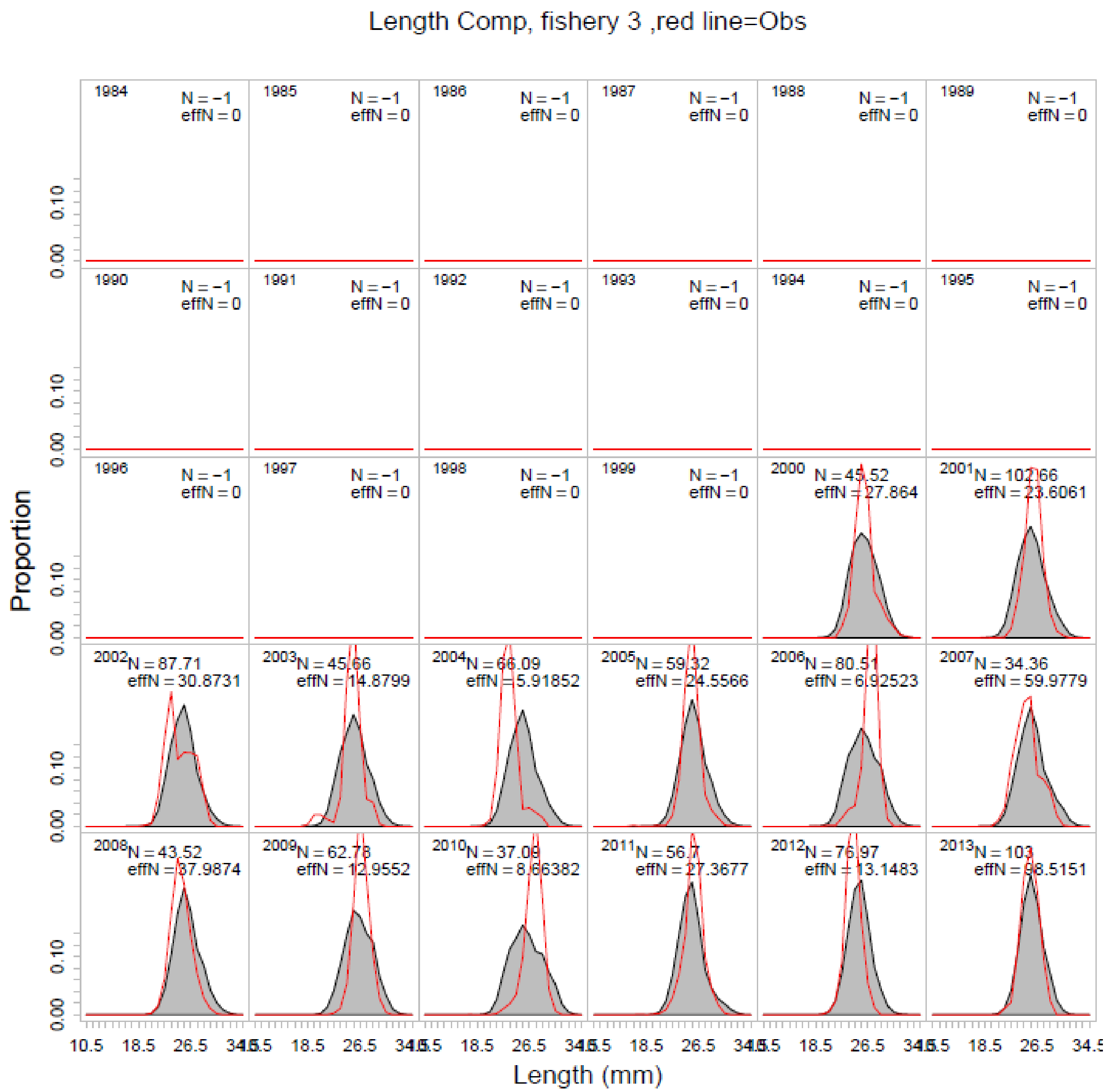


Figure C6.20. Trap fishery length composition data for each year (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

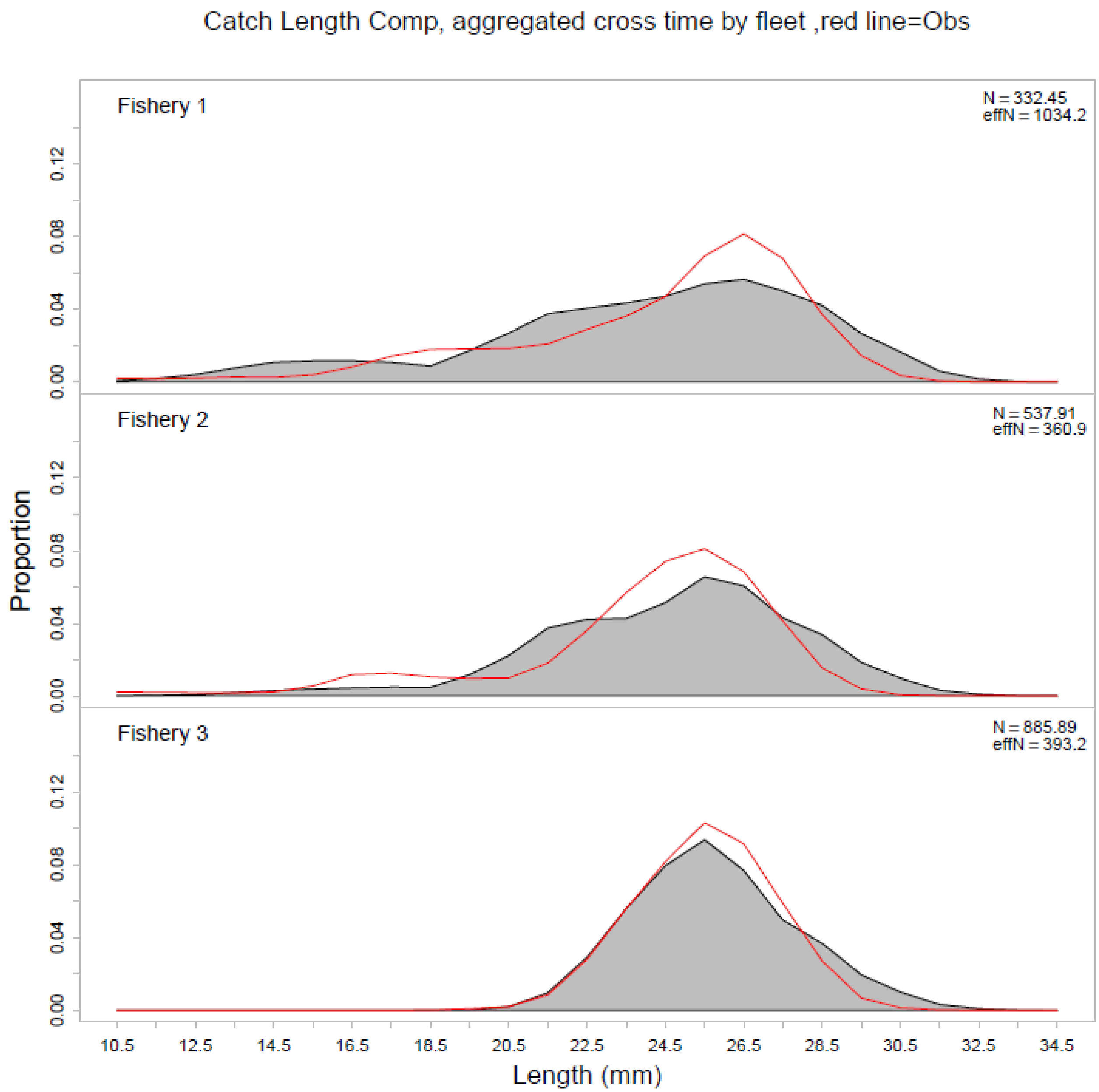


Figure C6.21. Average commercial length composition data (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run (Fishery 1=mixed fishery; Fishery 2=trawl fishery; Fishery 3=trap fishery).

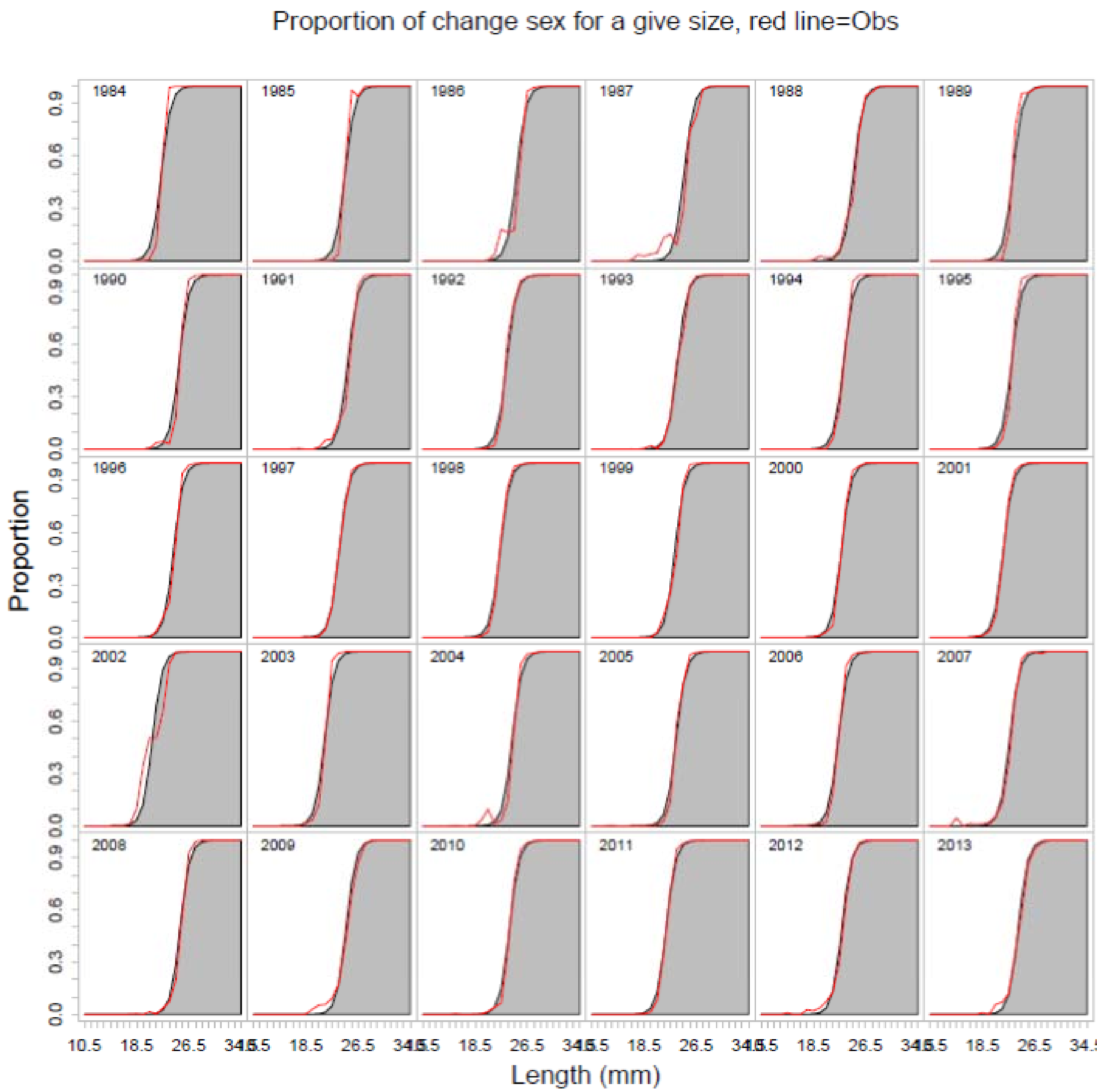


Figure C6.22. Proportion of female data (red line) and predicted values (in grey) for northern shrimp in the UMaine model base run.

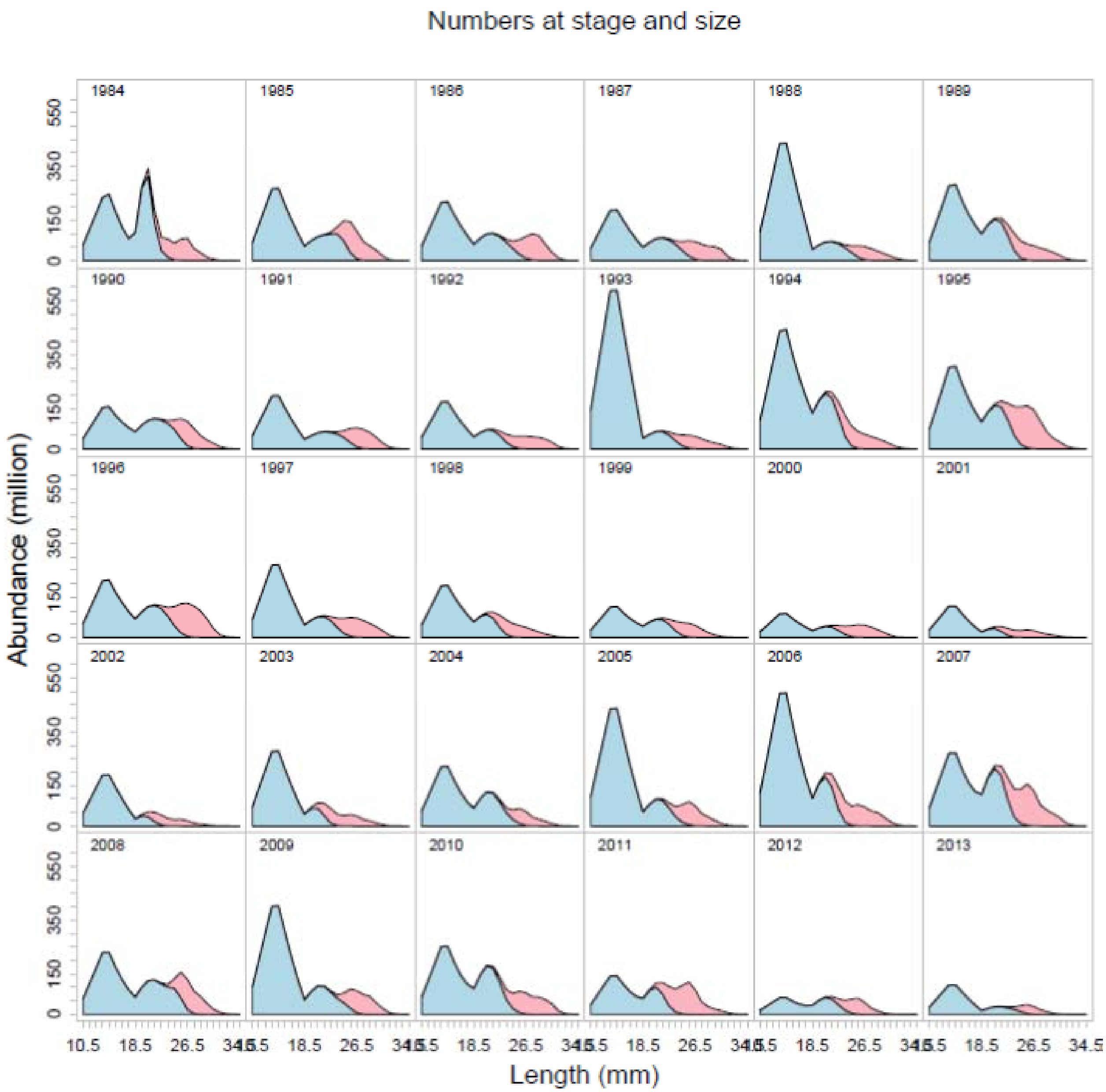


Figure C6.23. Estimated abundance of female (in pink) and non-female (in blue) for each size class at the beginning of each year.

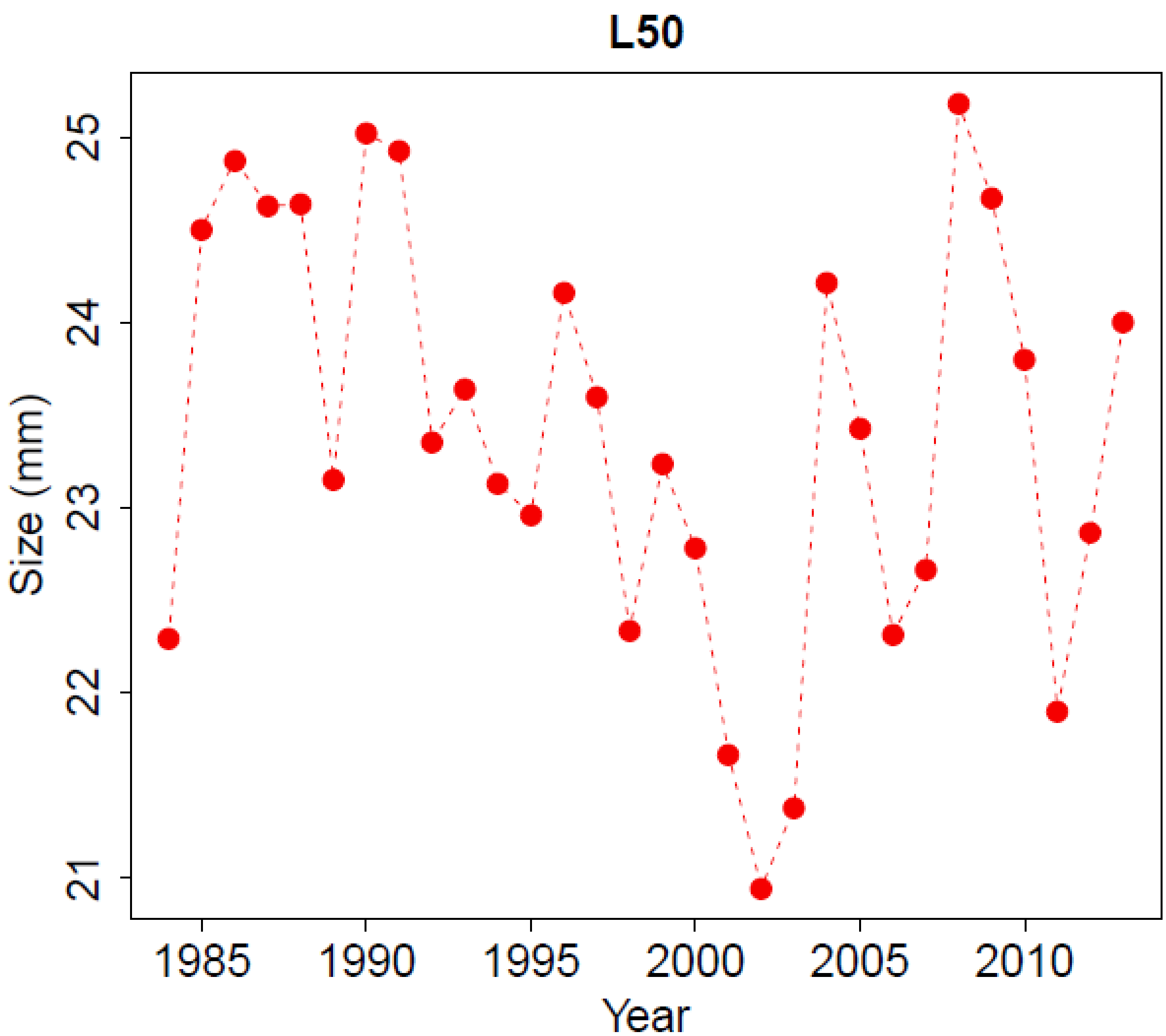


Figure C6.24. Estimated L_{50} (the size at which fifty percents of shrimp change sex to female) for each year from the UMaine model base run.

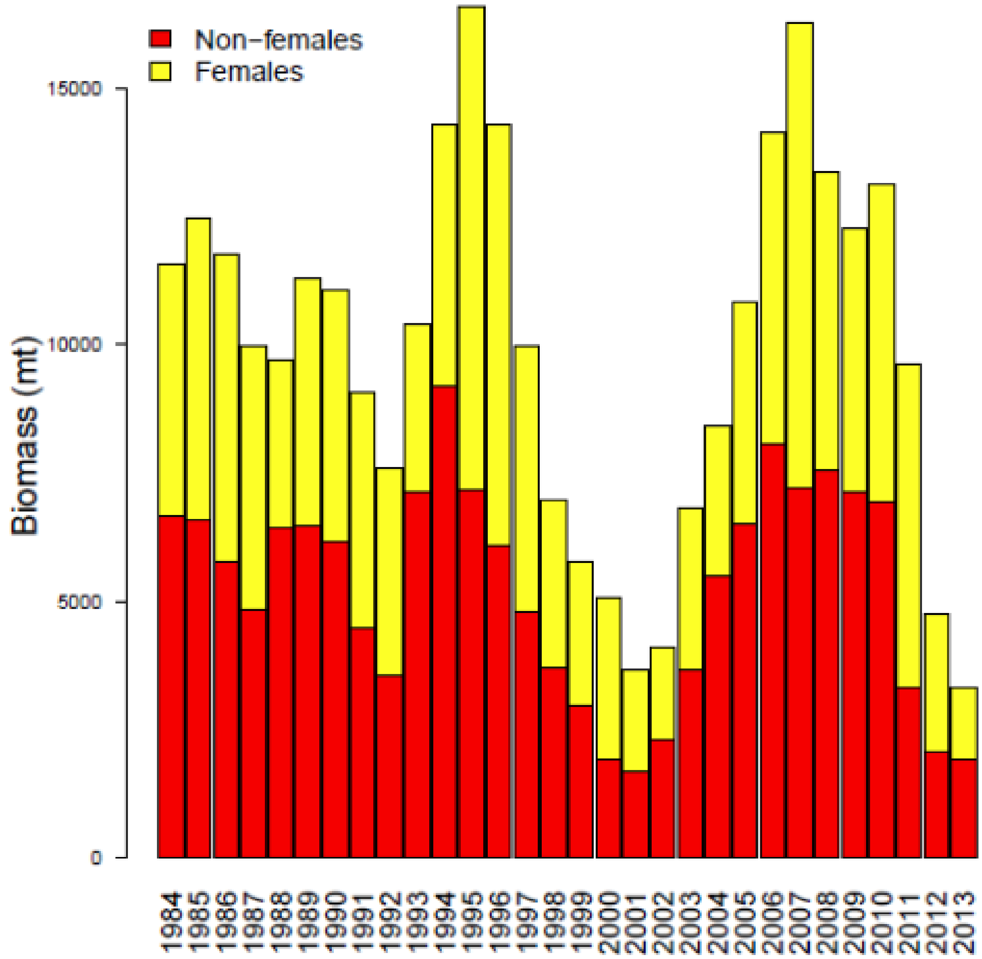


Figure C6.25. Estimates of female biomass (in yellow) and non-female biomass (in red) from the UMaine model base run.

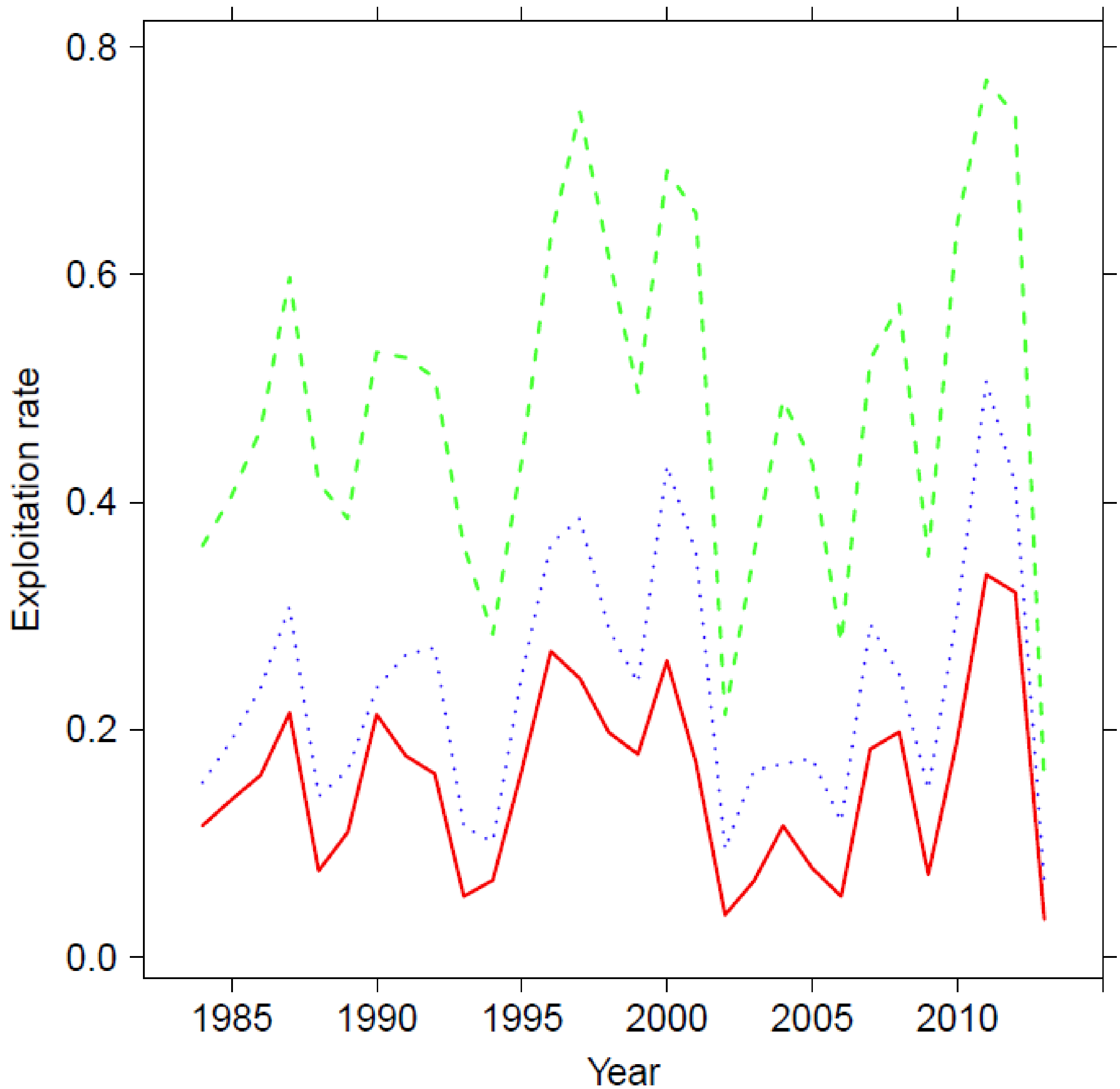


Figure C6.26. Exploitation rates for each year from the UMaine model base run (red line=predicted total catch in numbers/estimates of total numbers; blue line=predicted total catch biomass/estimates of total biomass; green line= predicted total female catch biomass/estimates of female biomass).

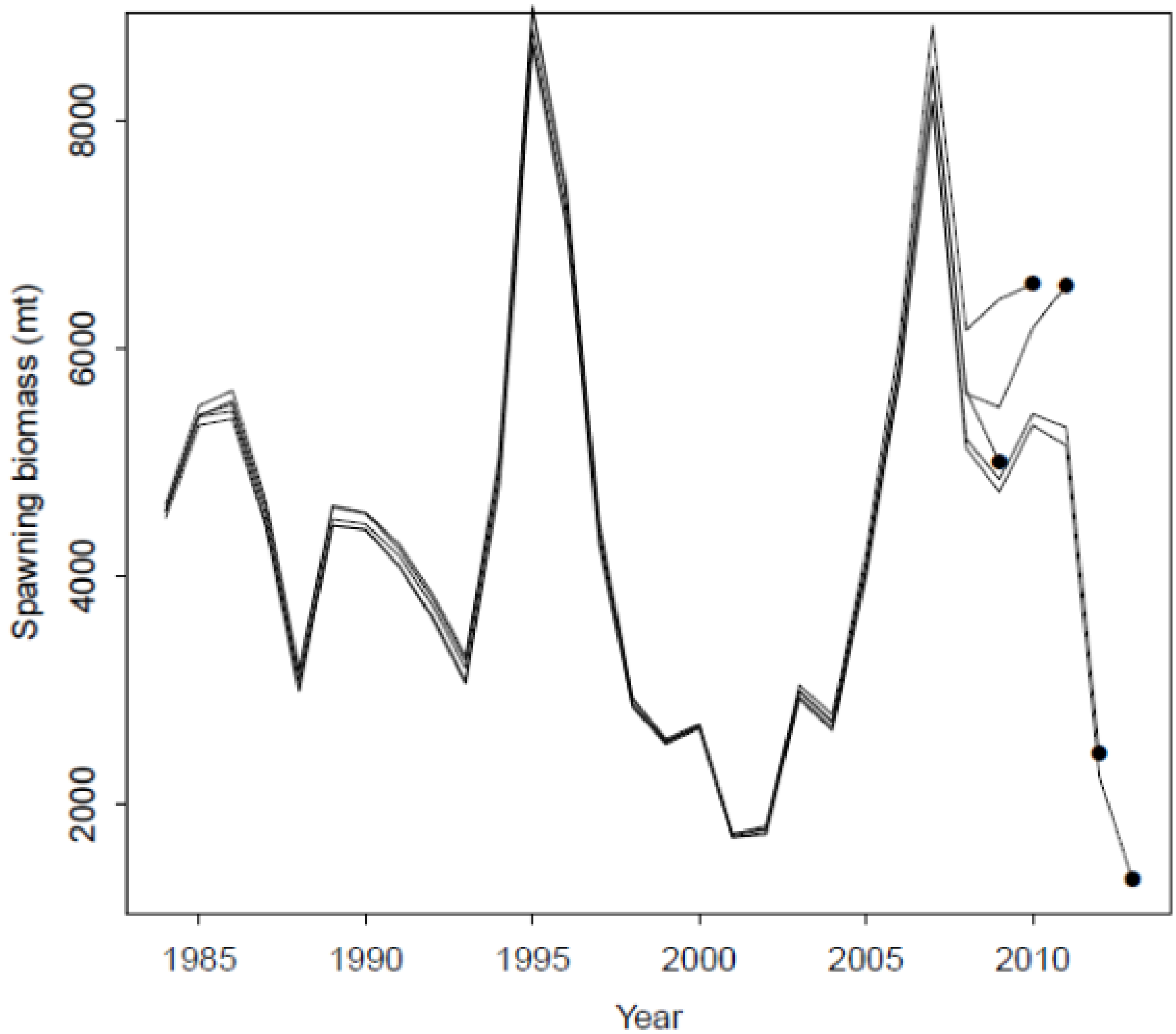


Figure C6.27. Retrospective pattern for spawning stock biomass for the UMaine model base run (Mohn rho=0.22 for 2009 as reference year)

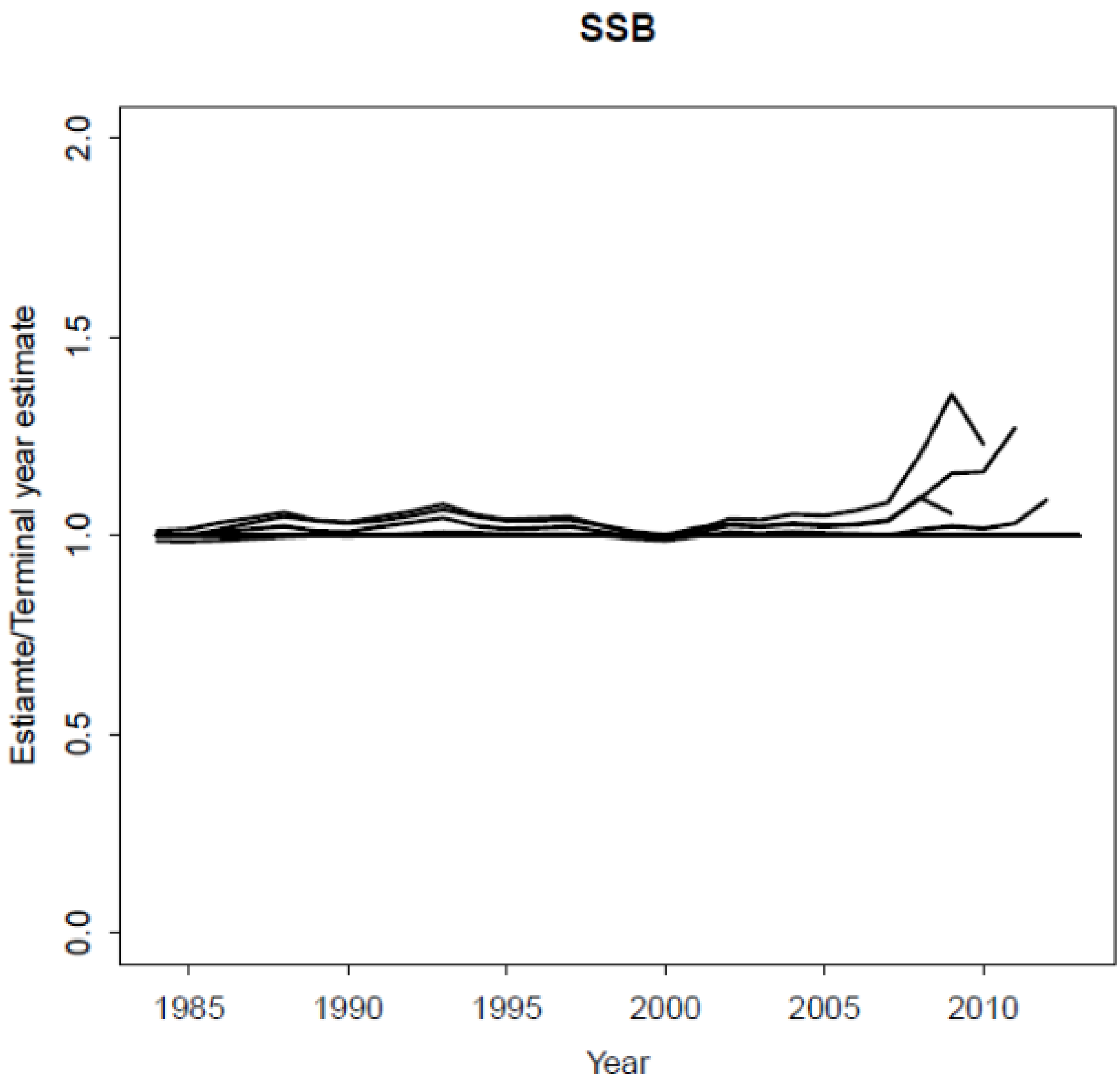


Figure C6.28. Retrospective pattern for spawning stock biomass for the UMaine model base run (Mohn rho=0.22 for 2009 as reference year).

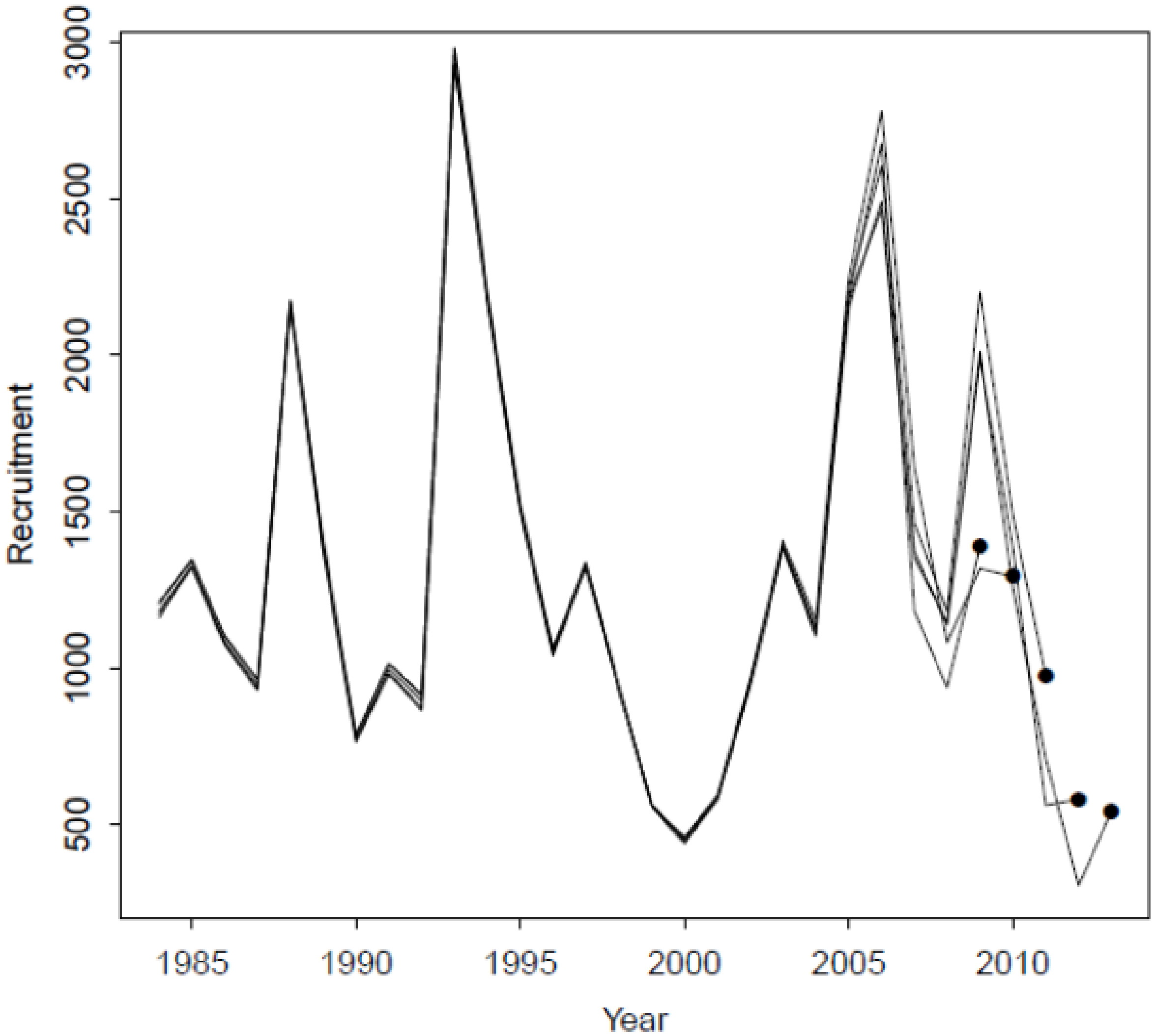


Figure C6.29. Retrospective pattern for recruitment for the UMaine model base run (Mohn rho=0.93 for 2009 as reference year)

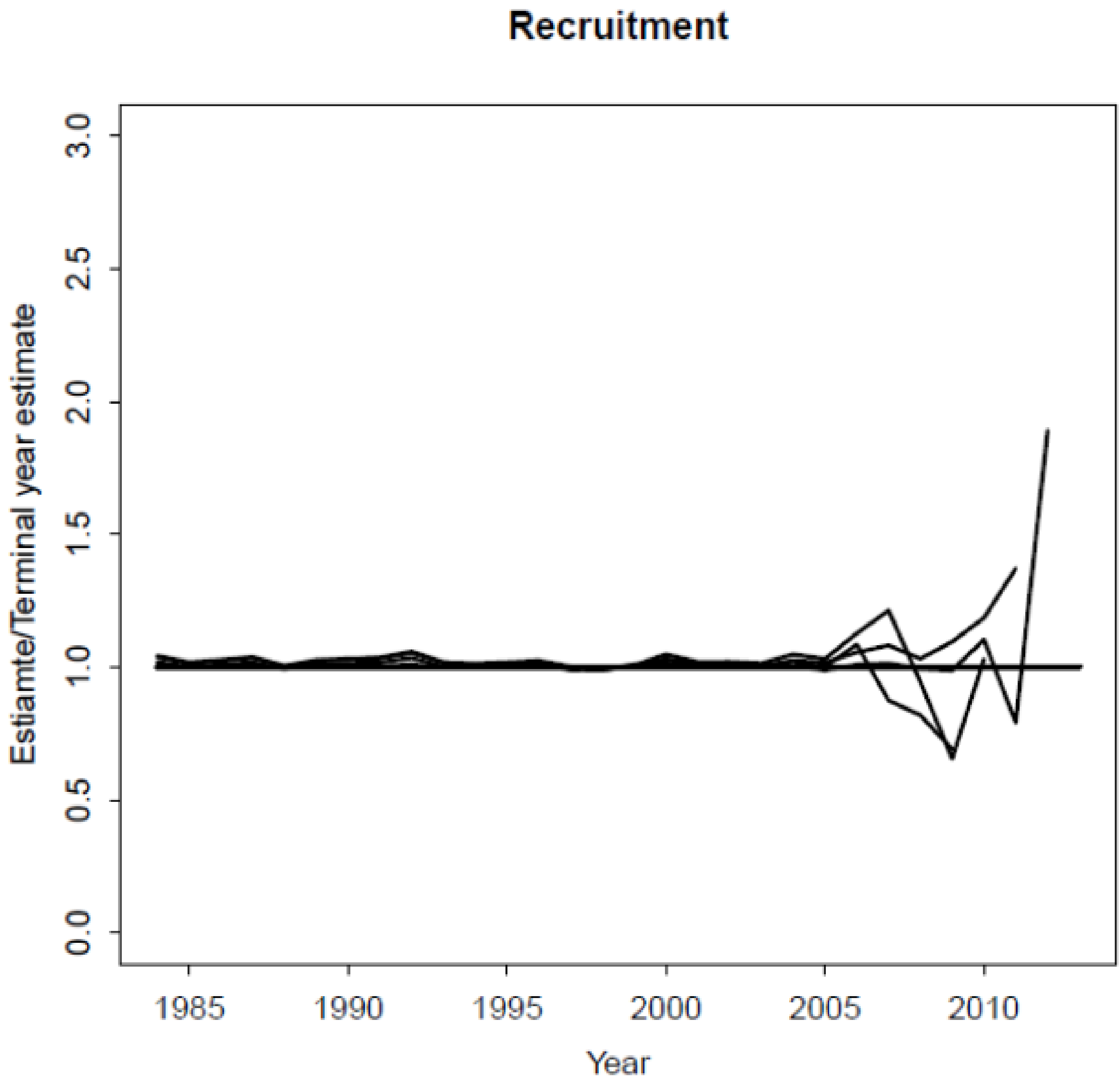


Figure C6.30. Retrospective pattern for recruitment for the UMaine model base run (Mohn rho=0.93 for 2009 as reference year).

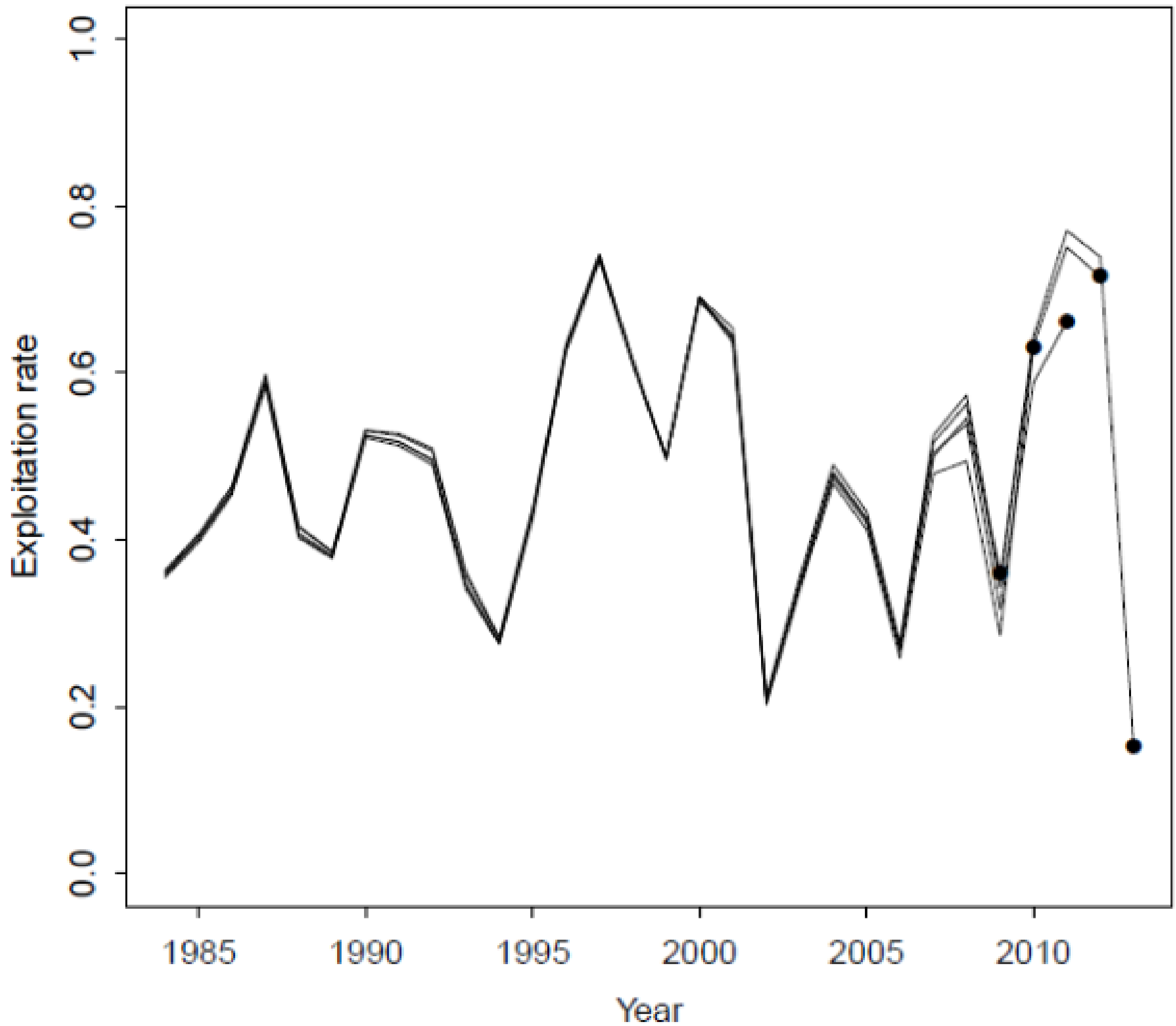


Figure C6.31. Retrospective pattern for exploitation rate (predicted total female catch biomass/estimates of female biomass) for the UMaine model base run (Mohn rho=-0.47 for 2009 as reference year)

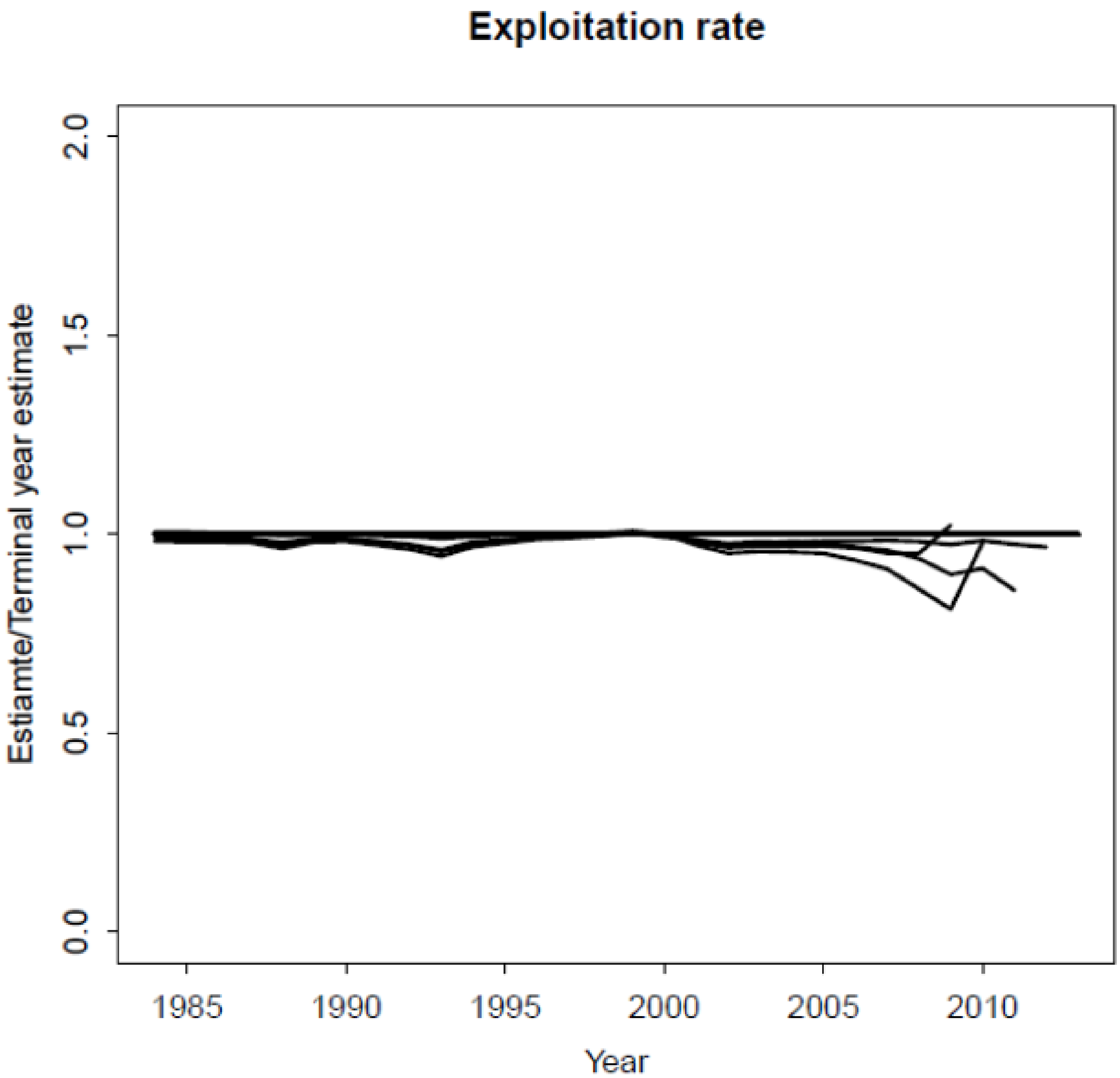


Figure C6.32. Retrospective pattern for exploitation rate (total catch in number/total abundance) for the UMaine model base run (Mohn rho=-0.47 for 2009 as reference year).

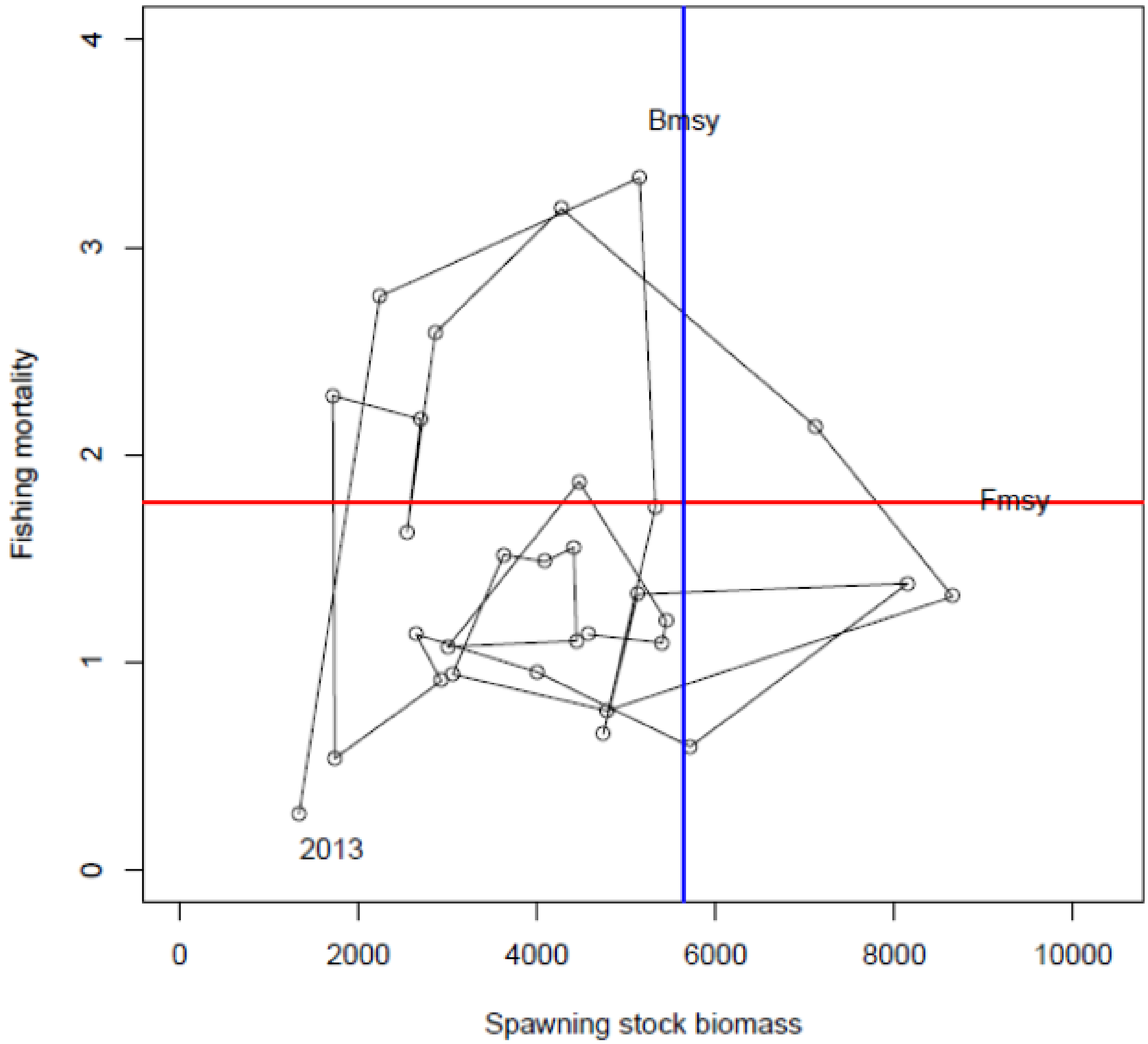


Figure C6.33. Phase plot for the base case. Fishing mortality is the total fishing mortality for fully recruited shrimp. Spawning stock biomass is measured in metric tons. F_{msy} and B_{MSY} for the base case are listed in Table 5.

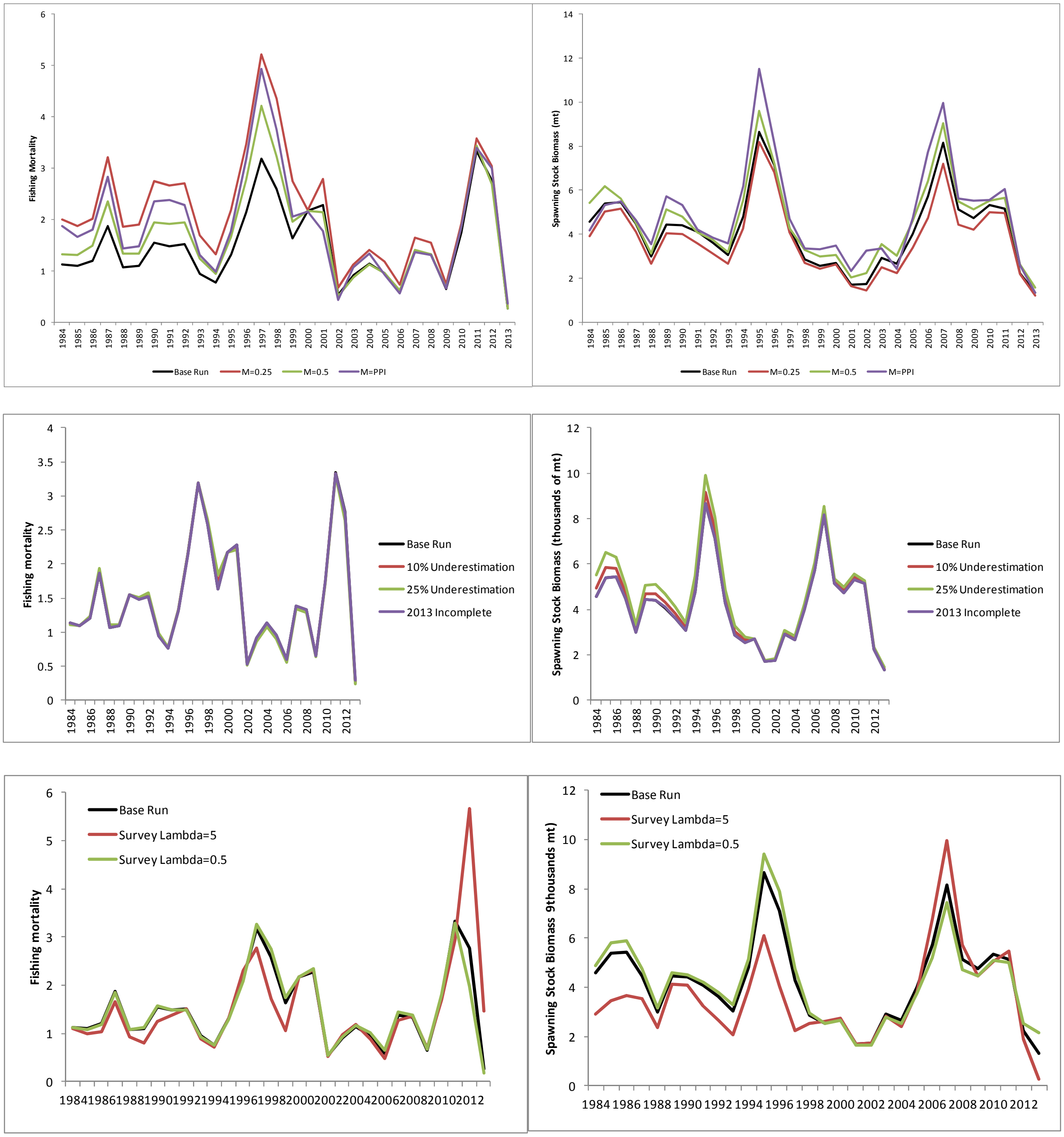
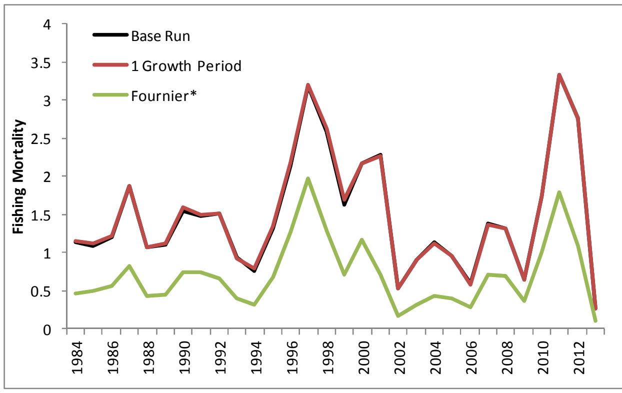


Figure C6.34. Sensitivity runs for UME model examining the effects of assumptions about natural mortality (top), underreporting of catch in the early time period or terminal year (middle), upweighting or downweighting of survey likelihood components relative to total catch (bottom), and choice of growth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



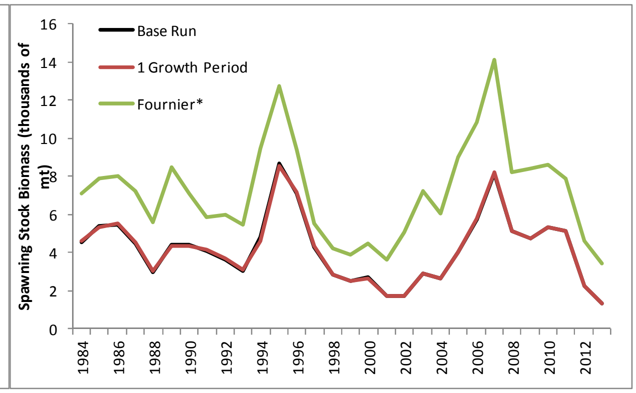


Figure C6.34 cont.

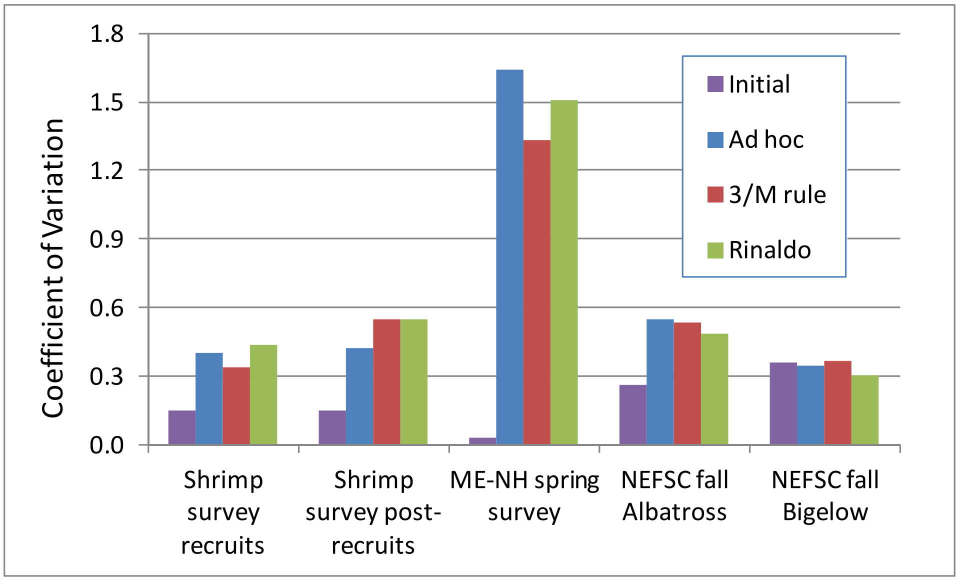


Figure C6.35. Adjustments to observed CV for each survey under different model scenarios for M. 'Initial' is CV estimated from survey data, '3/M rule' and 'Rinaldo' are PPI-scaled values.

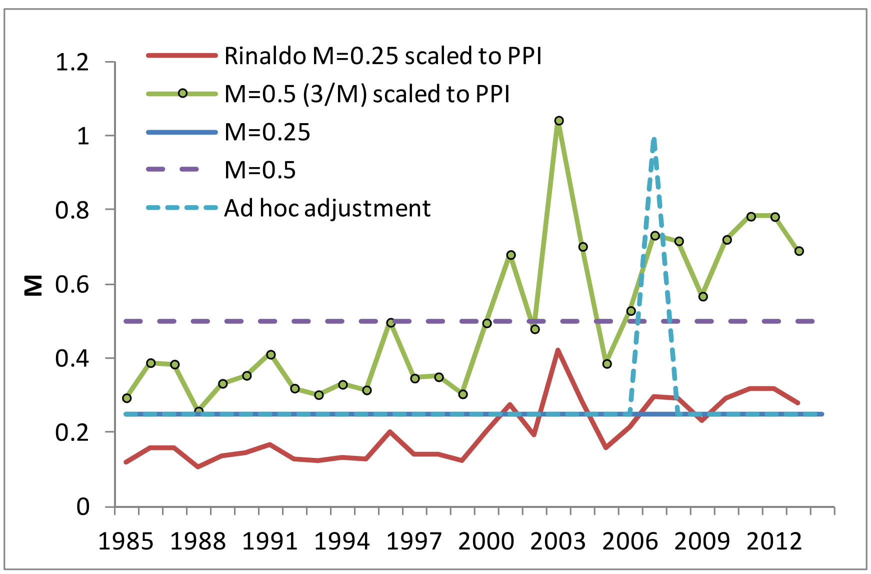


Figure C6.36. Values of natural mortality (M) explored in the CSA modeling framework.

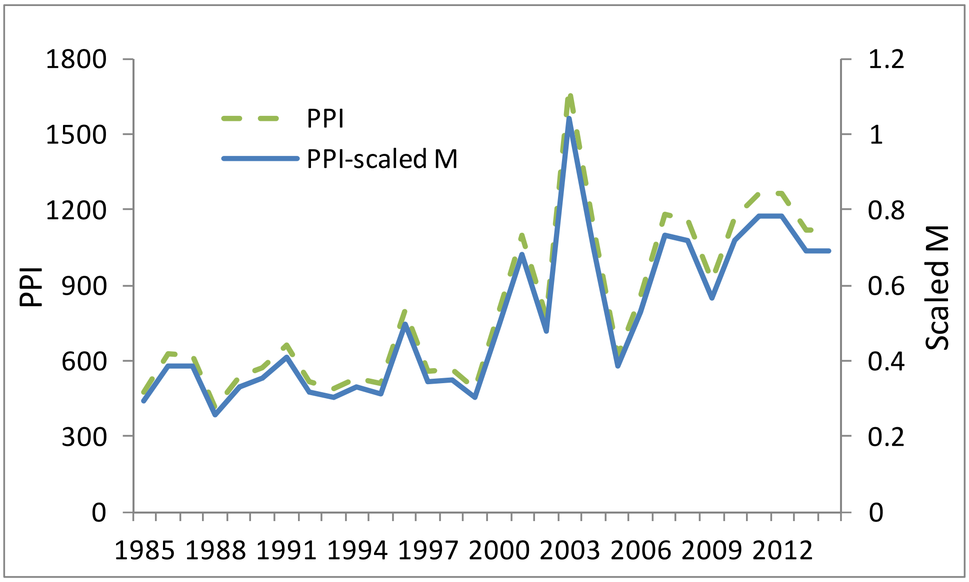


Figure C6.37. Predation pressure index (PPI) and scaled M using baseline M=0.5. For further detail, see Appendix C2.

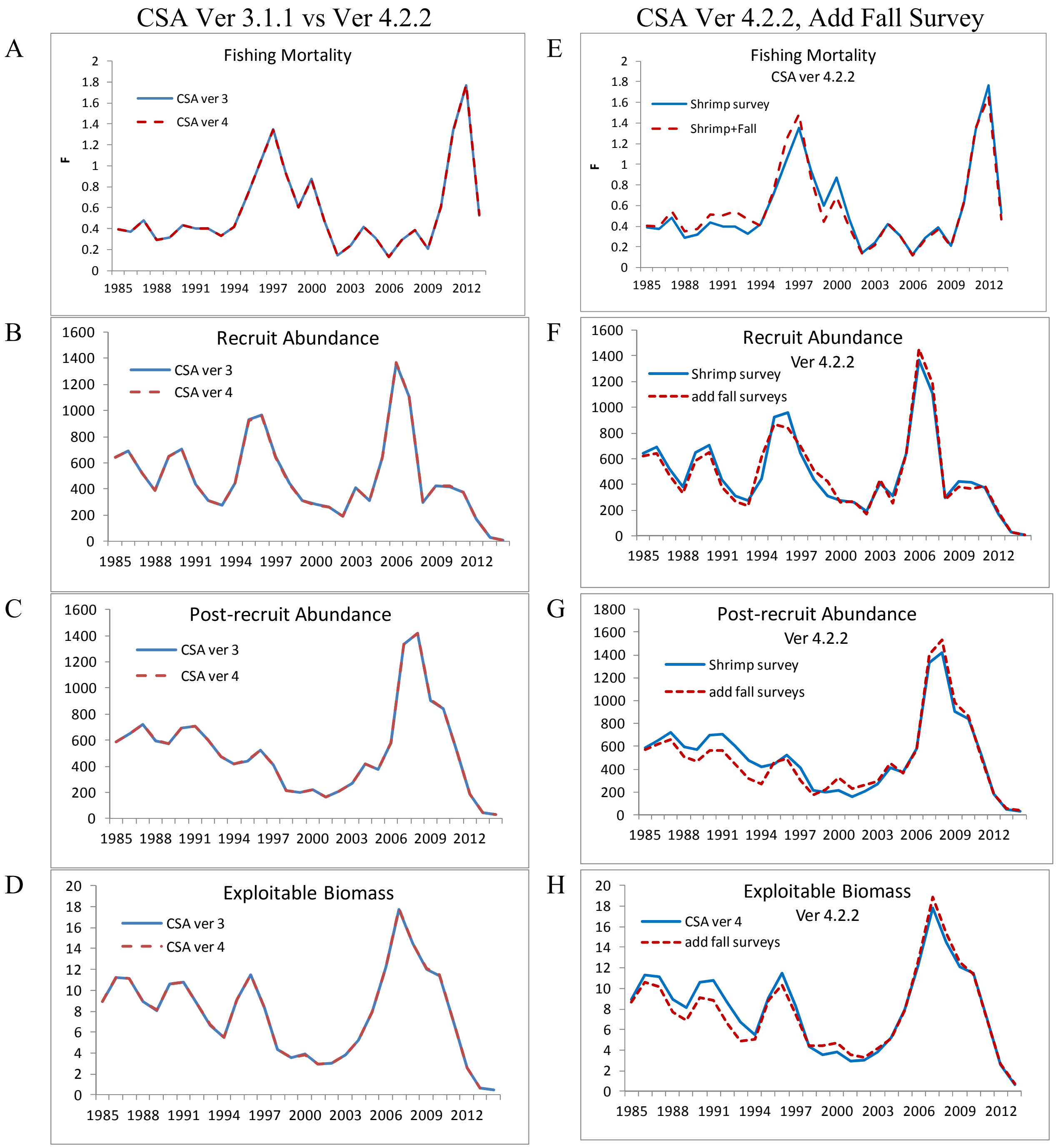


Figure C6.38. A-D: comparison of estimates from CSA version 3.1.1 (run 1) and CSA version 4.2.2 (run 2) using 2013 annual assessment update final CSA run (M=0.25) as basis; E-H: run 2 vs run 3 (additional surveys). Catch CV=0.01 in version 4.2.2. runs (version 3 assumed catch CV=0).

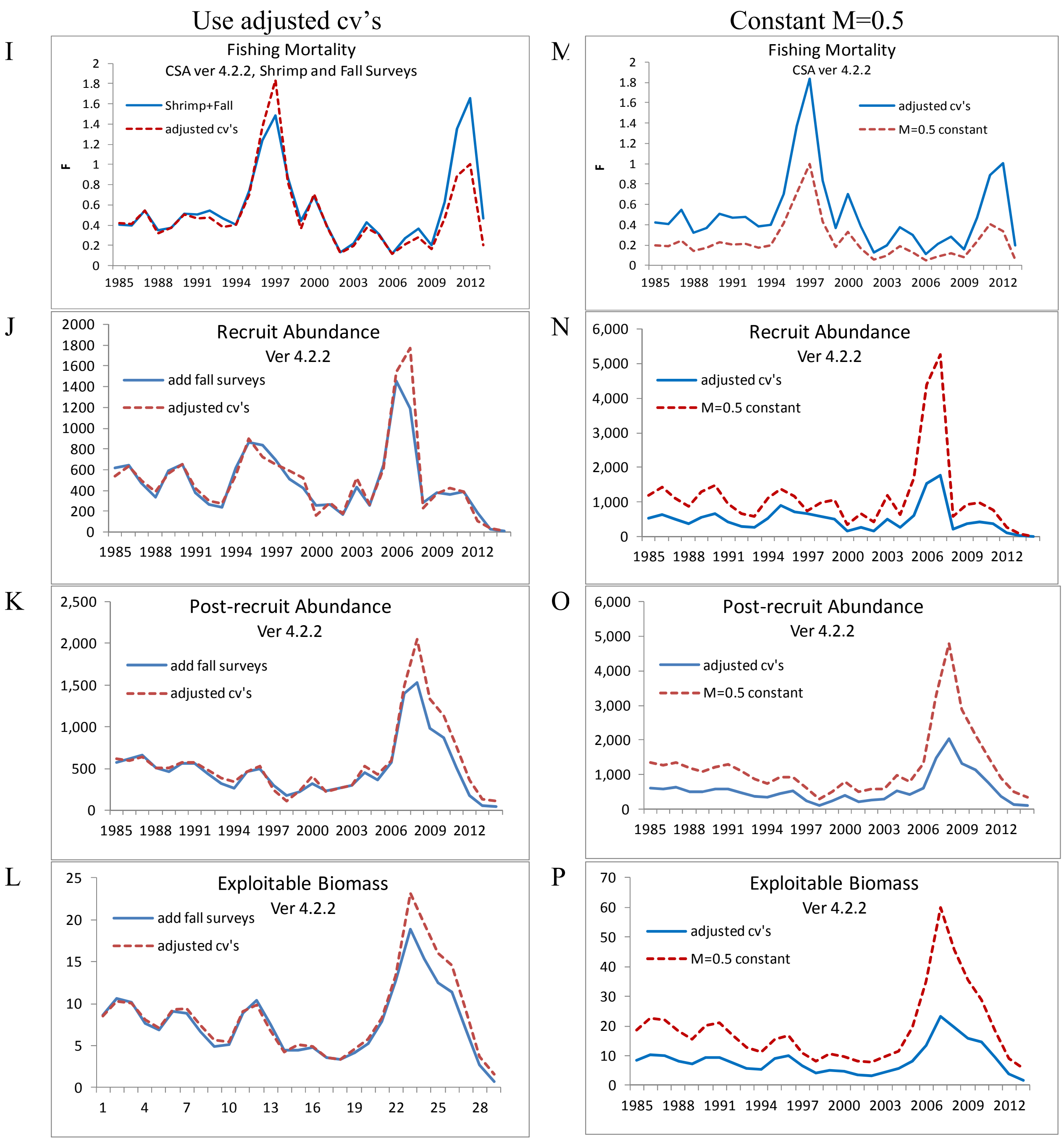


Figure C6.38, continued. I-L: run 3 (includes fall surveys) vs. run 4 (uses adjusted cv's for surveys and catch cv=0.05); M-P: run 4 vs run 5 (constant M=0.5). Catch CV=0.05 in I-P.

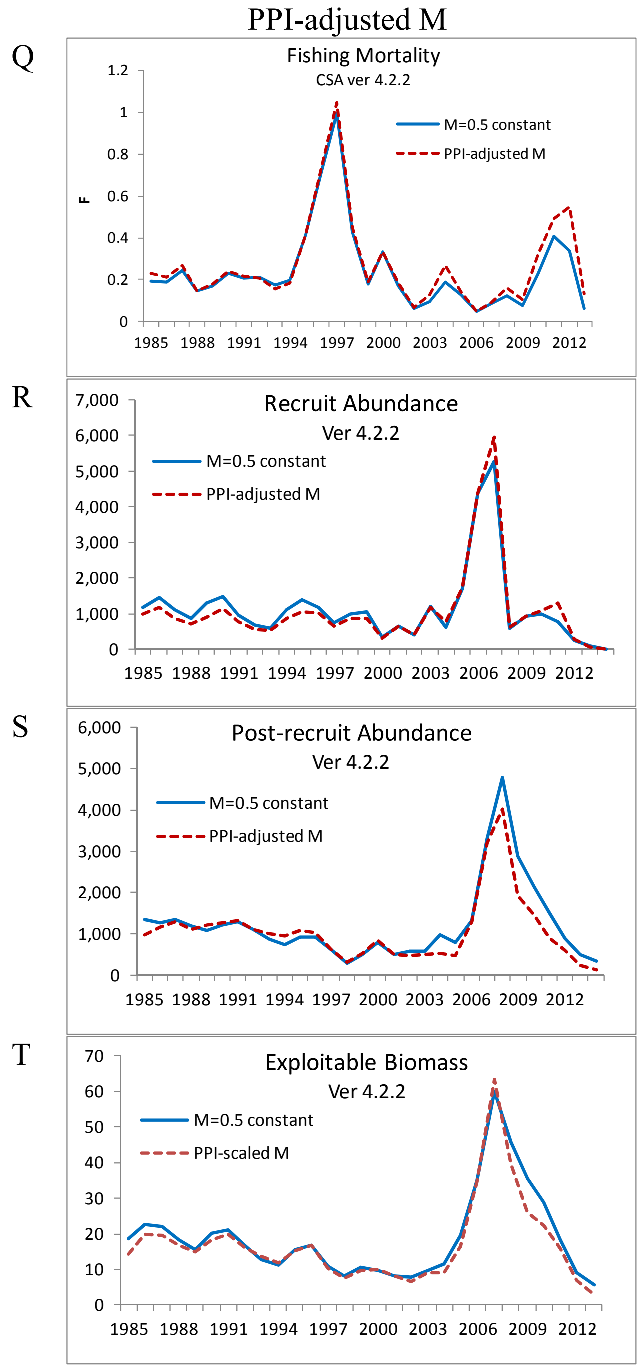


Figure C6.38, continued. Q-T: run 5 (M=0.5, constant) vs. run 6 (PPI-adjusted M using M=0.5 as baseline for adjustments). Catch CV=0.05.

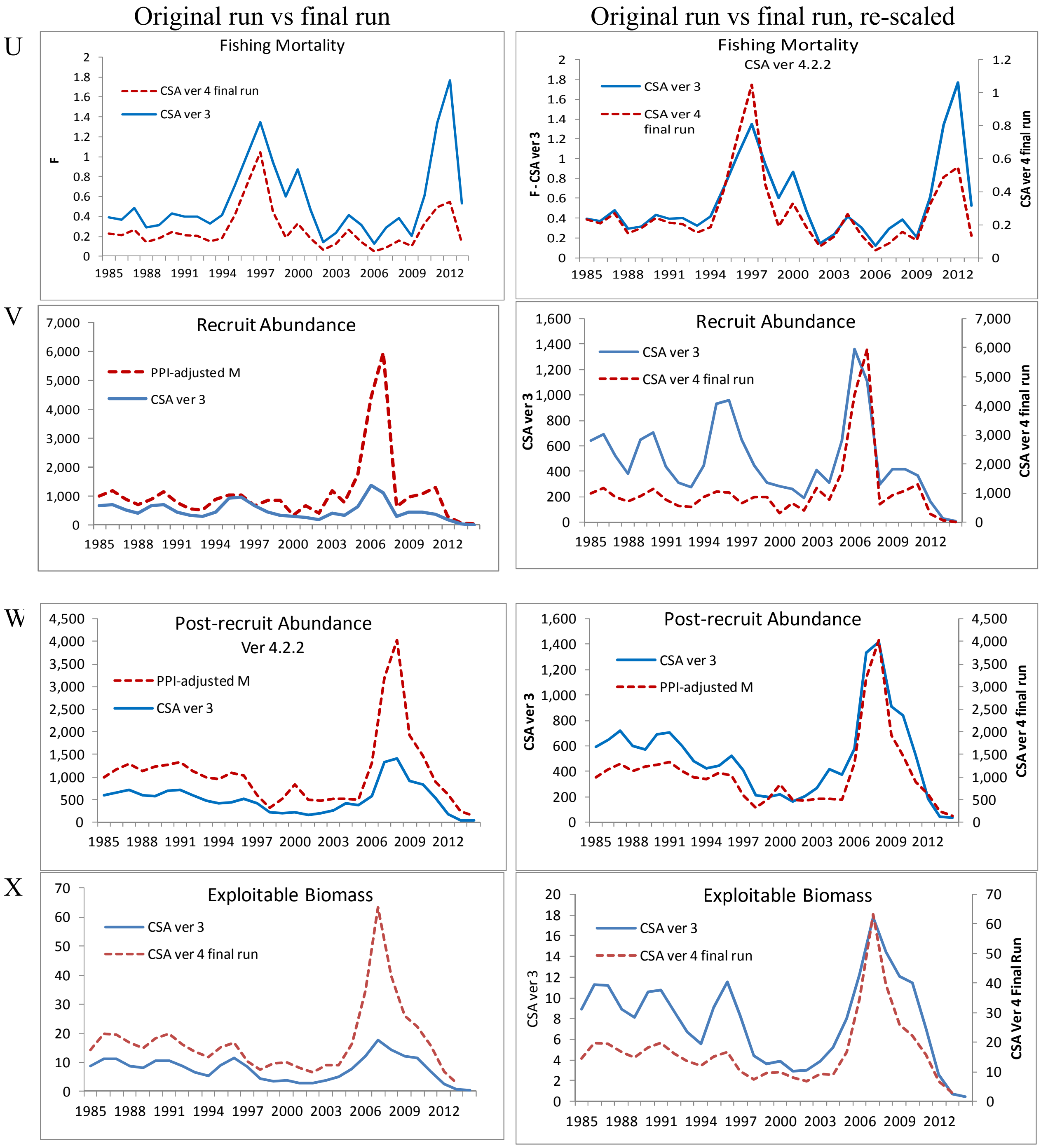


Figure C6.38, continued. Original run (run 1, CSA ver 3.1.1) vs final run (run 6, PPI-adjusted M). Left column: 1 y-axis; right column: 2 y-axes.

2013 Annual Assessment Final Run (M=0.25) | 2013 Benchmark Final Run

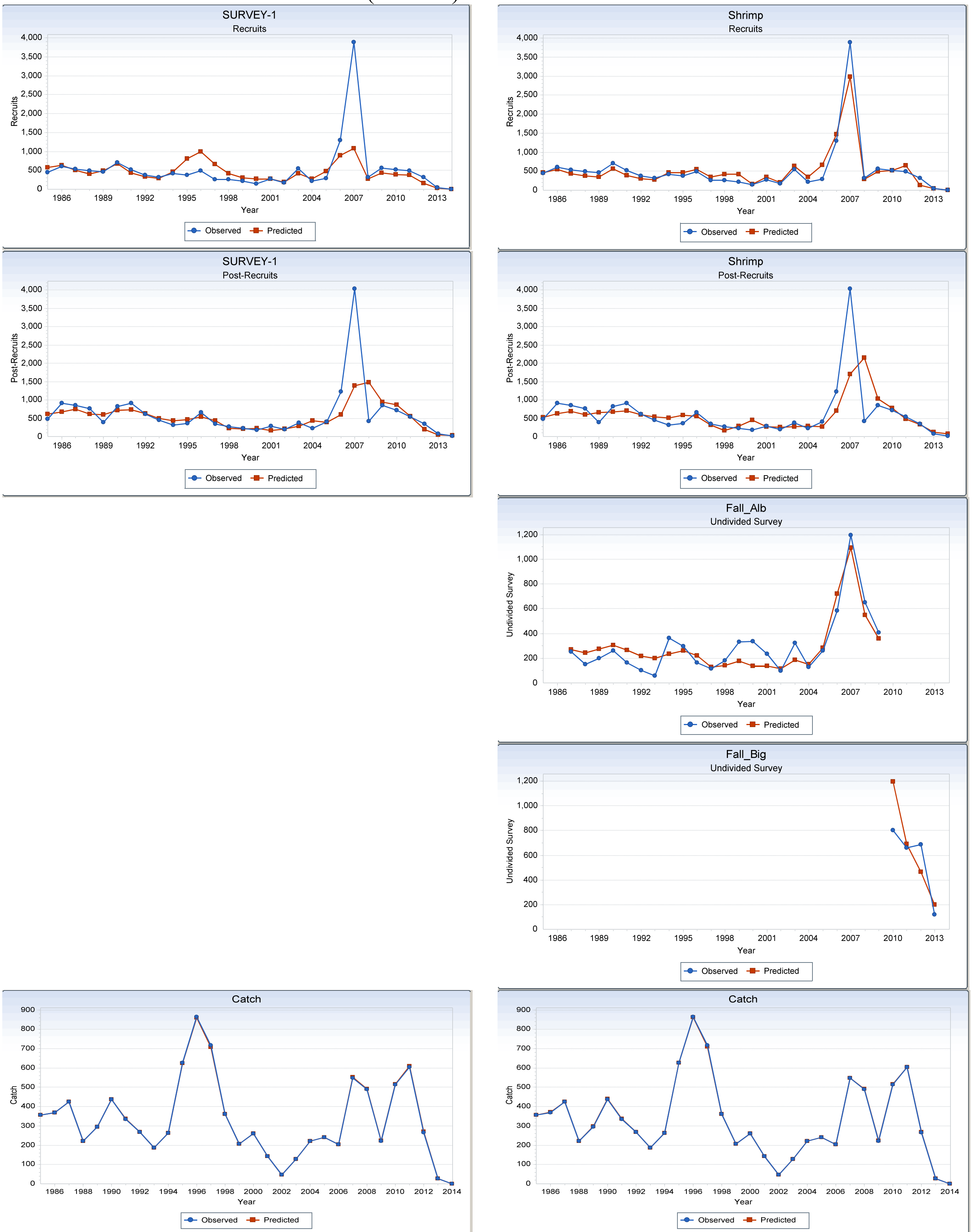


Figure C6.39. Comparison of model fits to data from 2013 annual assessment final model and 2014 benchmark final model.

2013 Annual Assessment Final Run (M=0.25) 2013 Benchmark Final Run

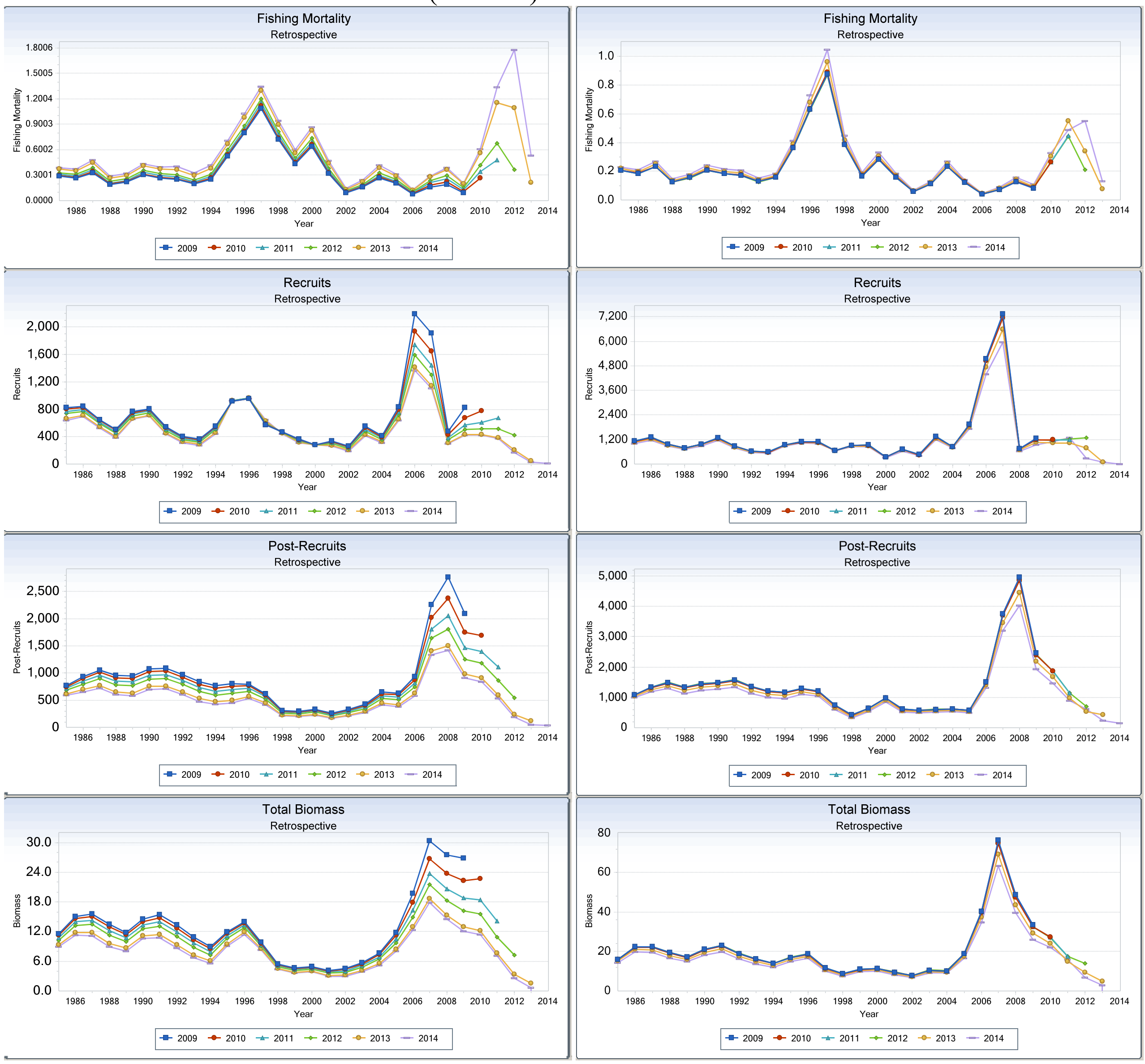


Figure C6.40. Retrospective patterns for 2013 annual assessment update final run implemented in CSA ver. 4.2.2 and benchmark final run.

2013 Annual Assessment Final Run (M=0.25) 2013 Benchmark Final Run

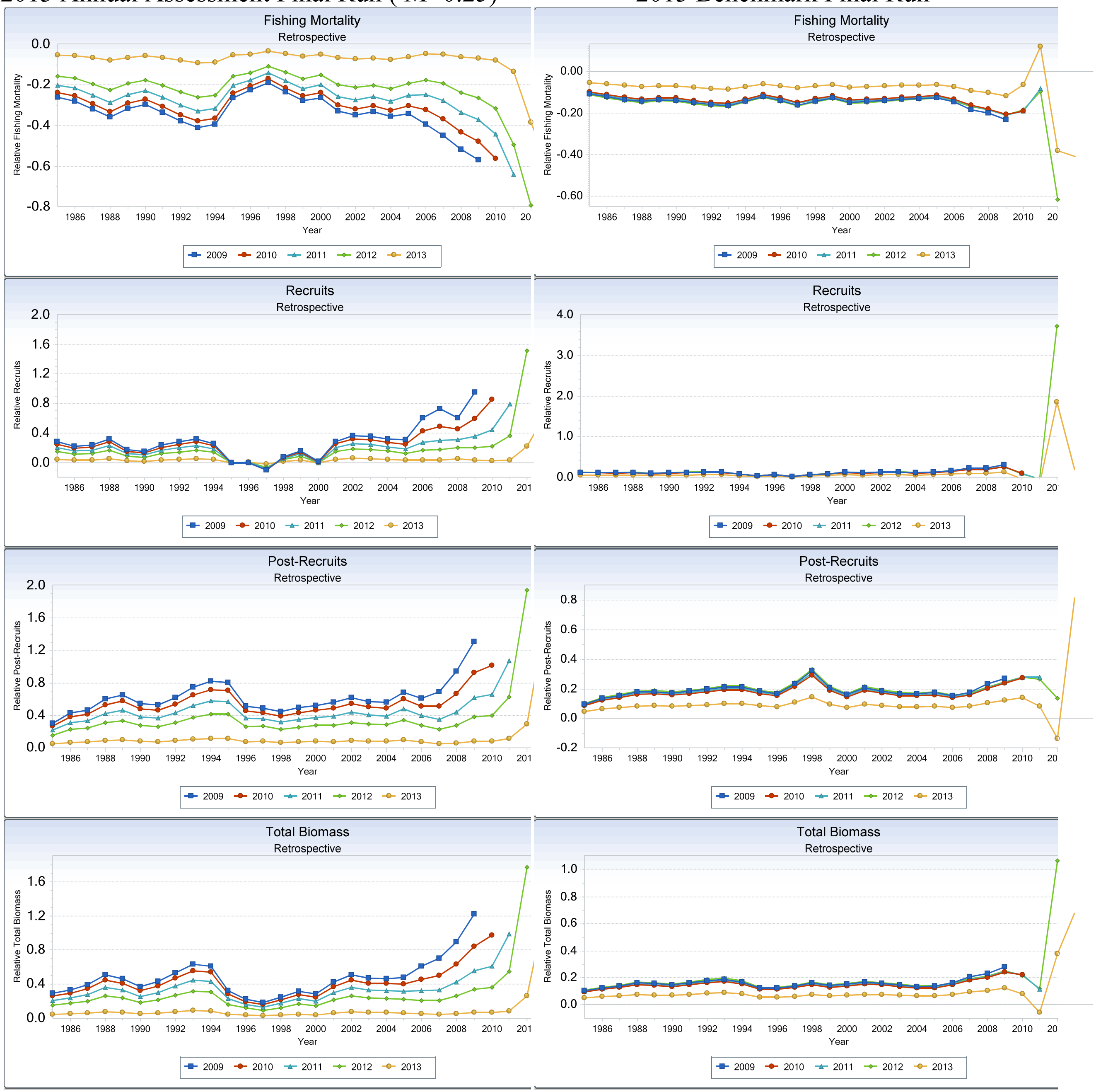


Figure C6.40, continued. Relative retrospective patterns for 2013 annual assessment update final run implemented in CSA ver. 4.2.2 and benchmark final run.

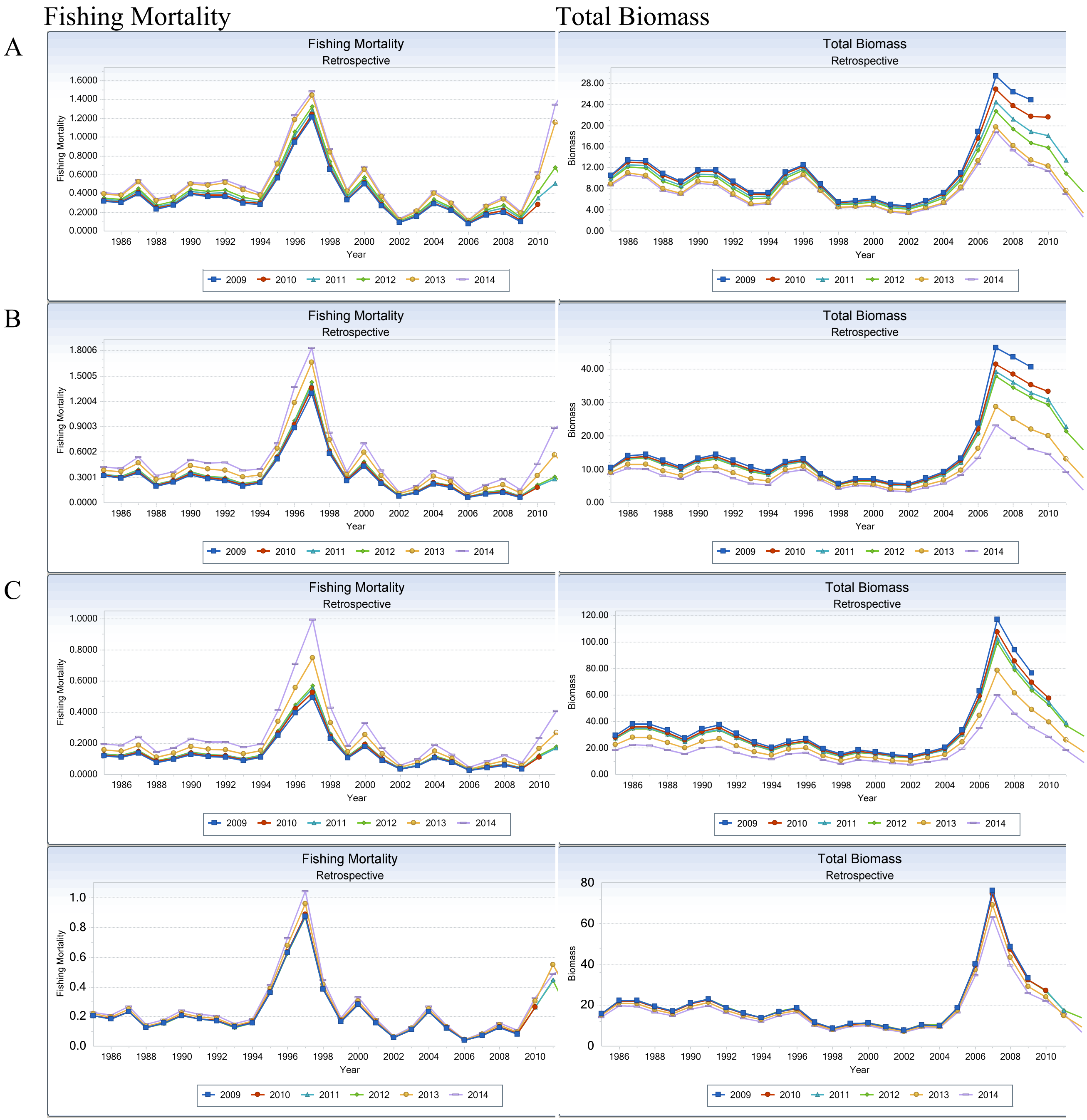


Figure C6.41. Retrospective patterns for fishing mortality and total biomass from incremental changes to 2013 annual assessment model. A. Add fall surveys; B. use adjusted CVs; C. Change to constant M=0.5; D. apply PPI-scaled M.

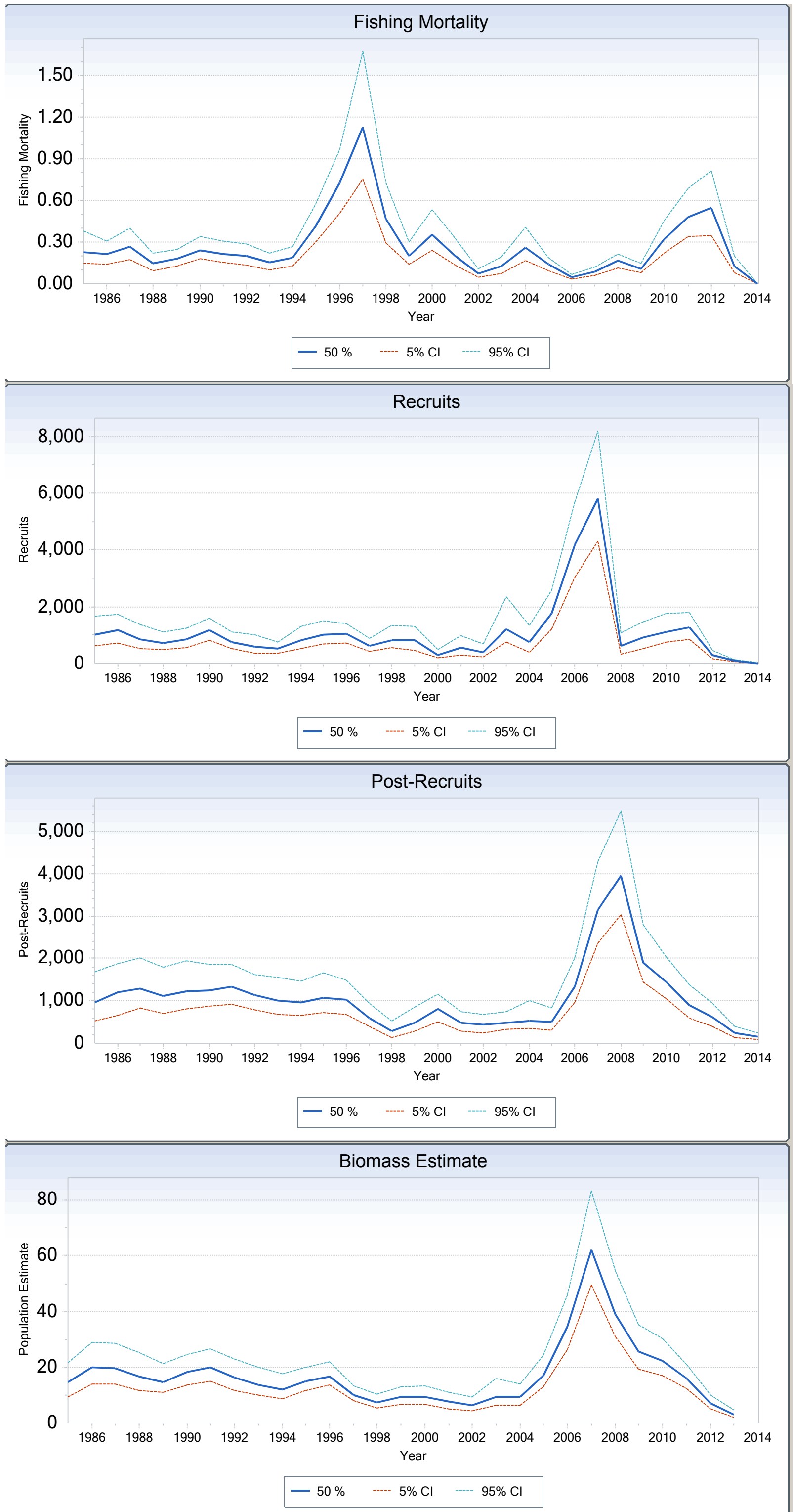


Figure C6.42. MCMC-generated 90% confidence intervals on estimates from final CSA model run.

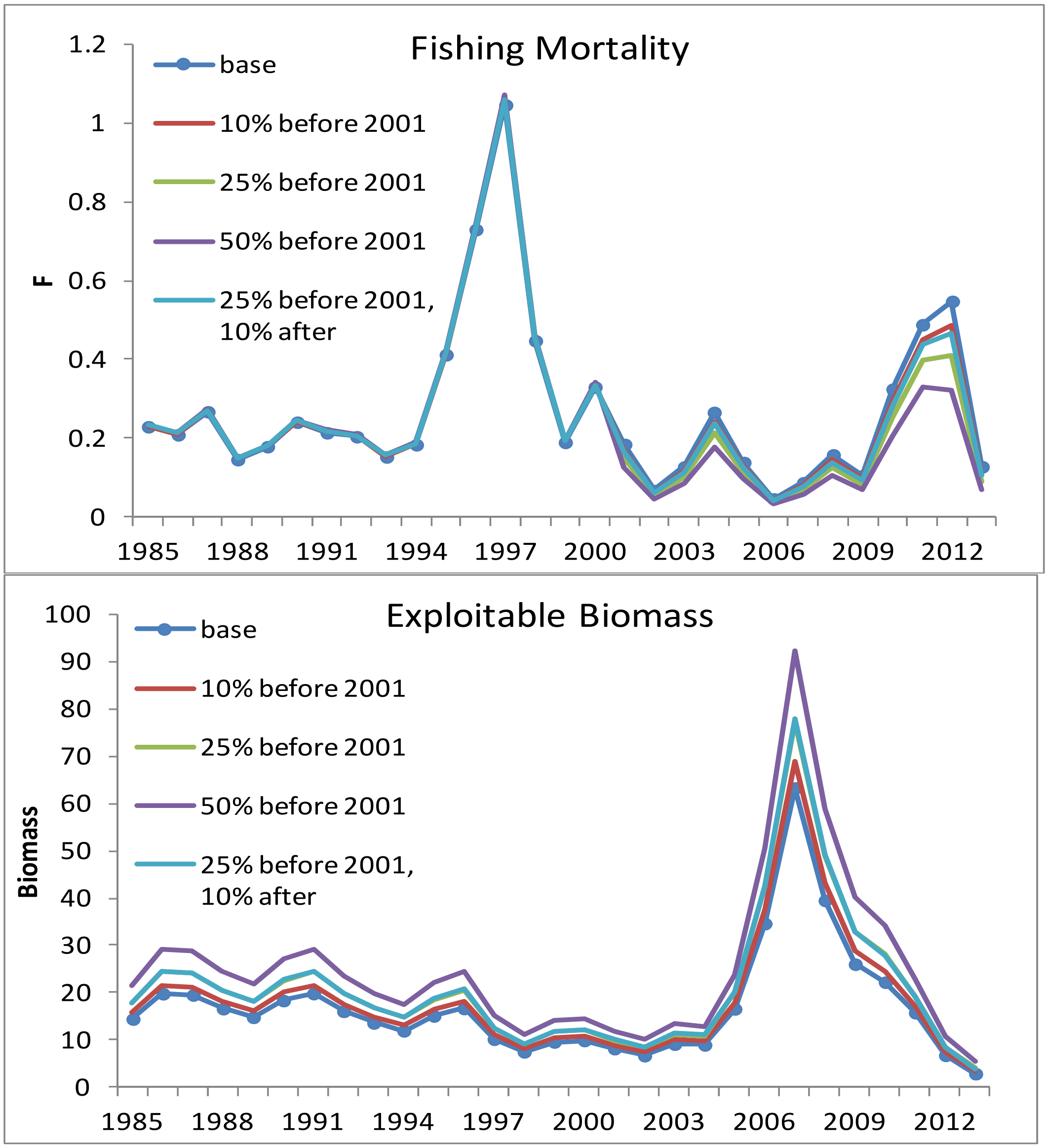


Figure C6.43. Effects on final CSA model estimates of different assumptions on under-reporting of catch. Base assumes no under-reporting.

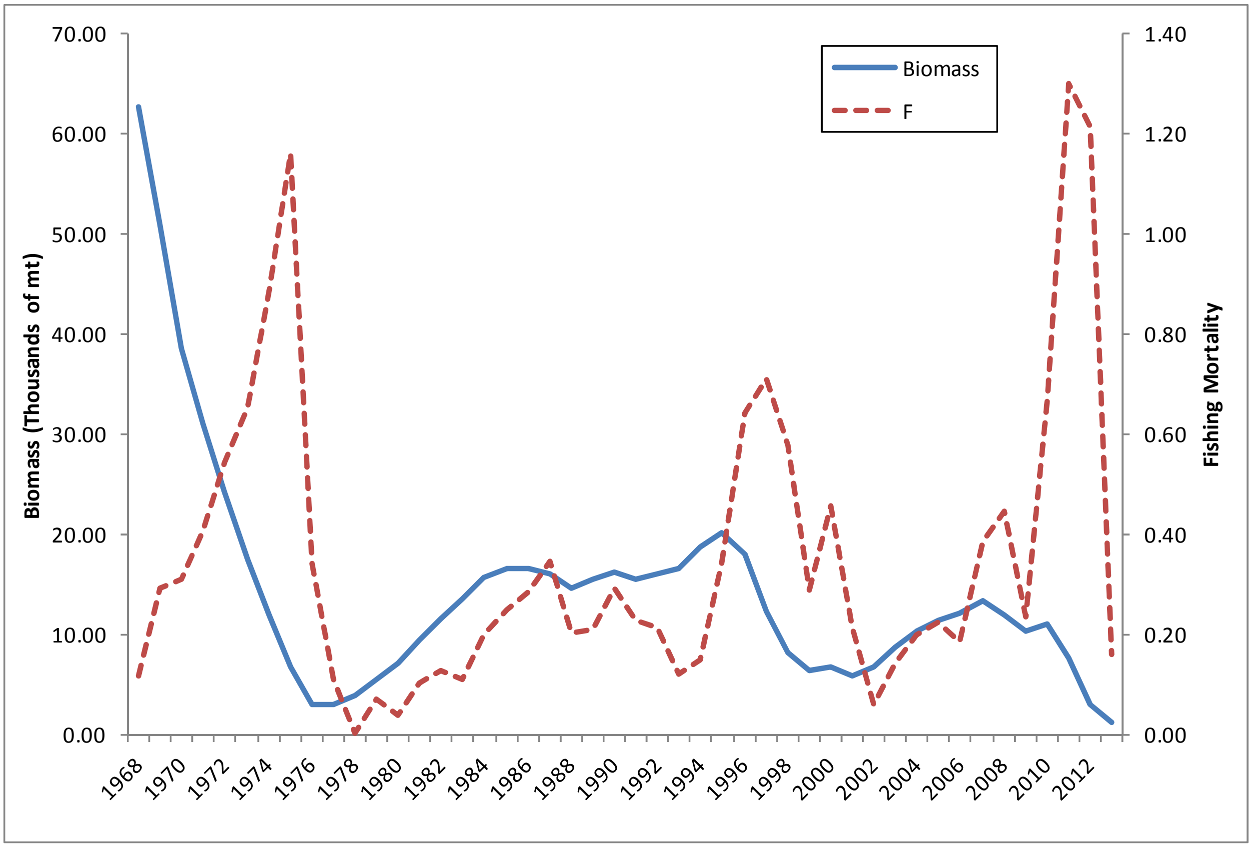


Figure C6.44. Biomass and fishing mortality estimates from the ASPIC surplus production model.

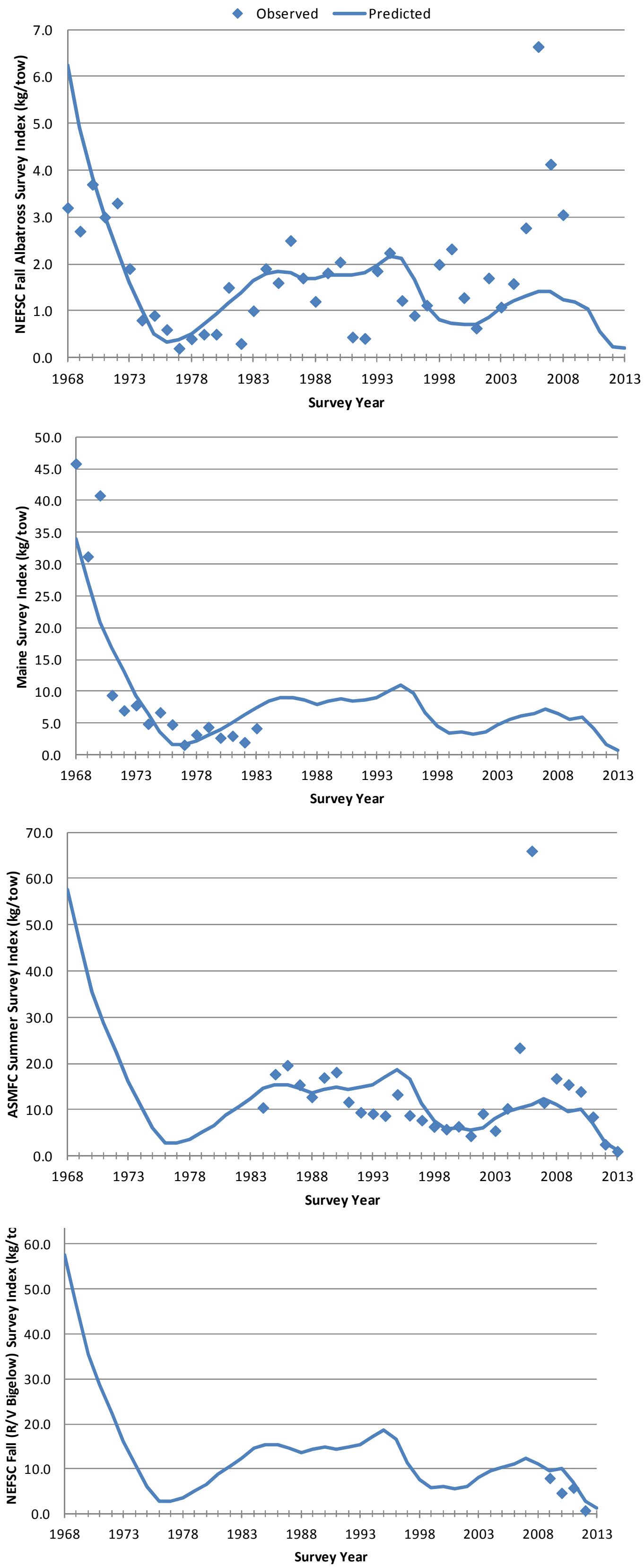


Figure C6.45. Observed and predicted survey values from the ASPIC model.

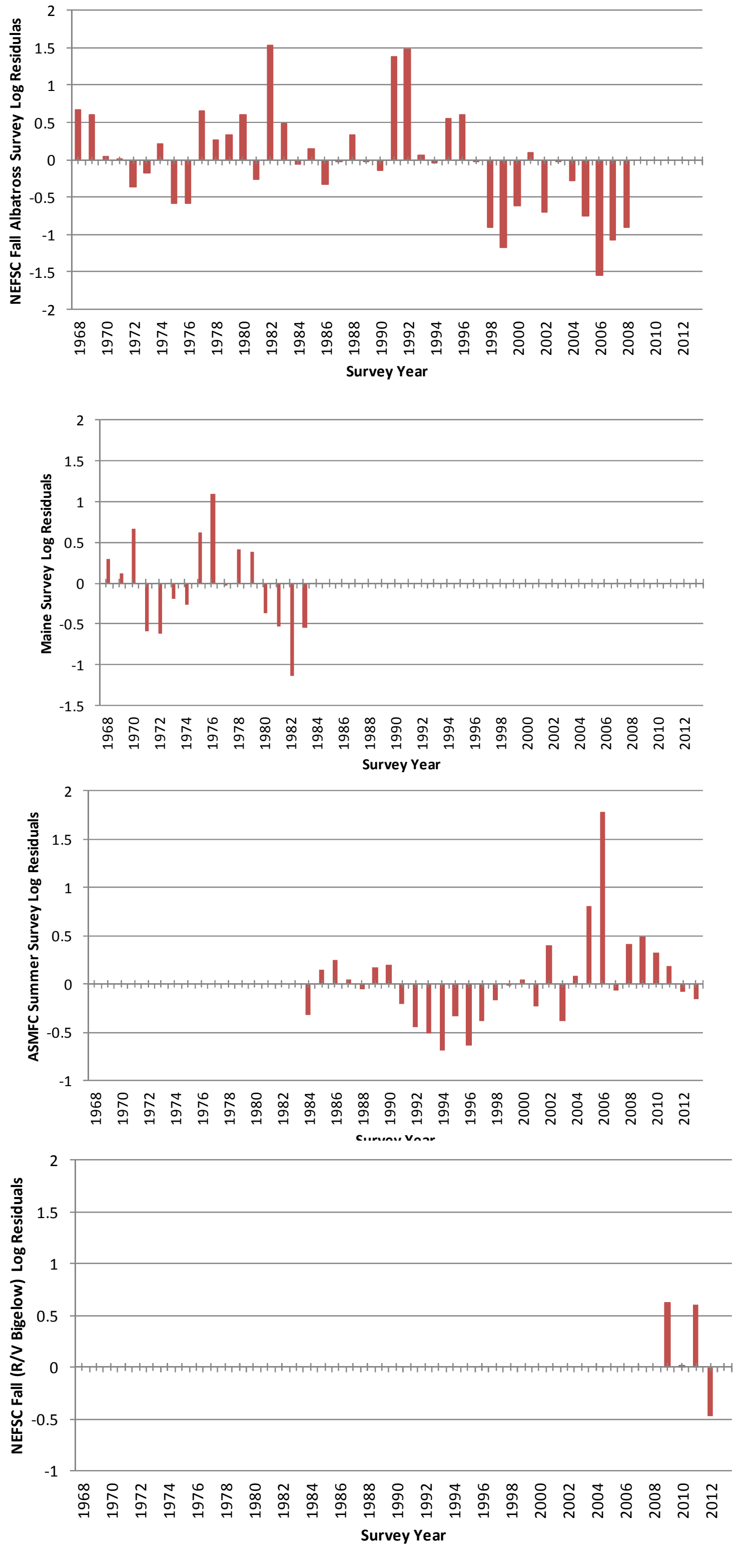


Figure C6.46. Survey residuals from the ASPIC model.

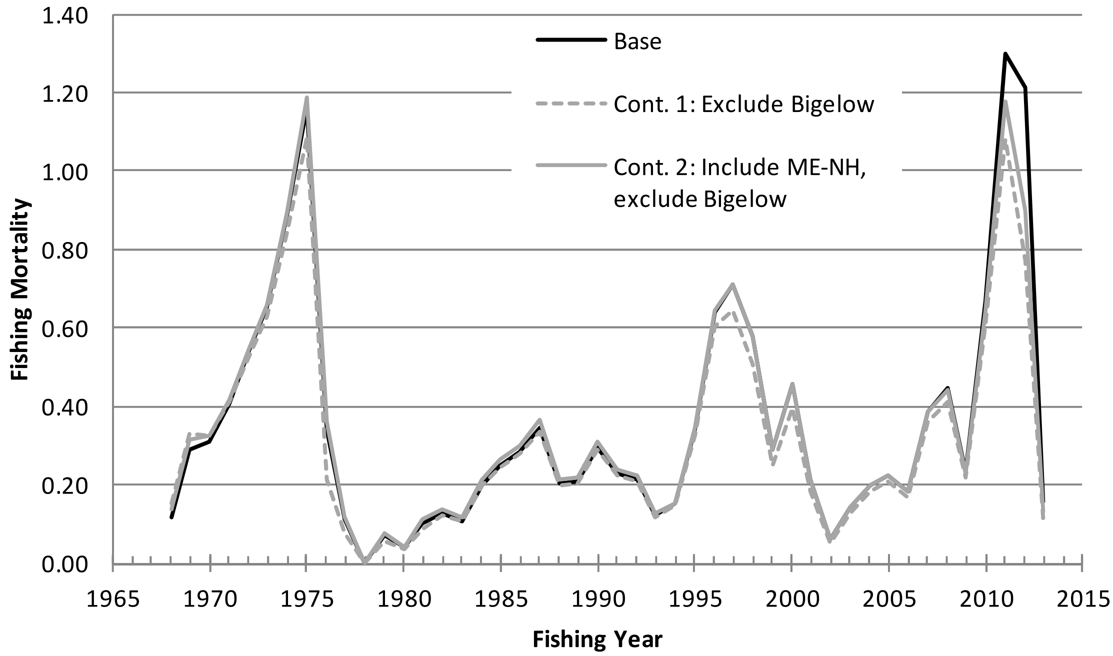


Figure C6.47. ASPIC fishing mortality estimates derived from continuity runs: 1.) excluding NEFSC fall survey conducted on R/V Bigelow (2009-2012), and 2.) including Maine-New Hampshire spring inshore survey (2003-2013) and excluding NEFSC R/V Bigelow fall survey (2009-2012).

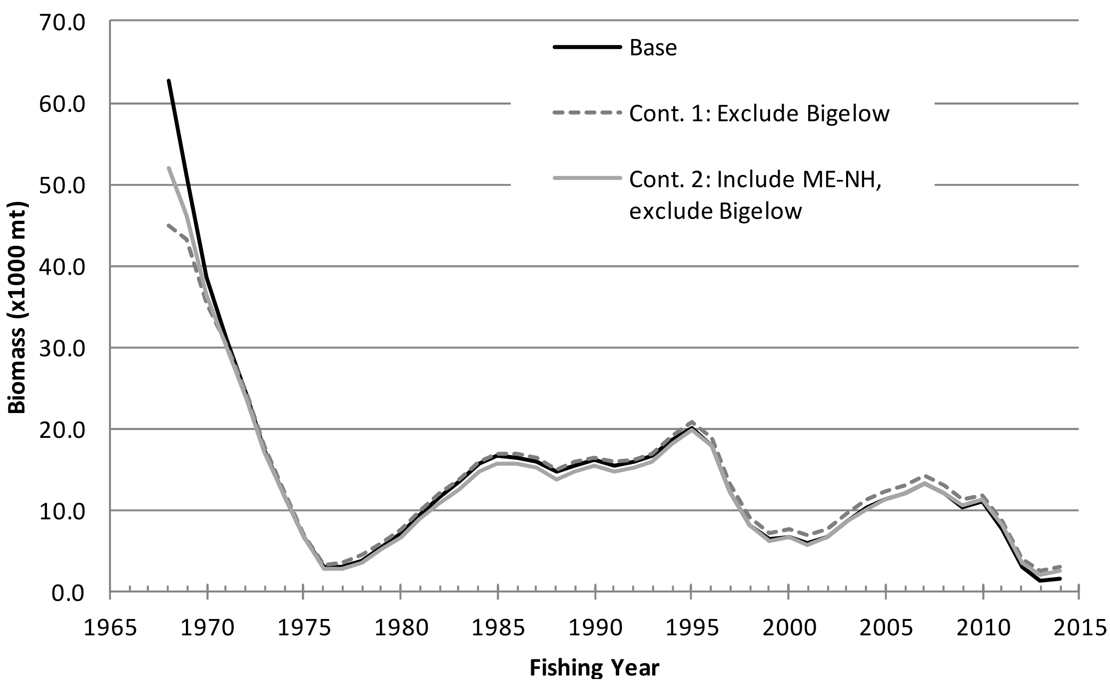


Figure C6.48. ASPIC biomass estimates derived from continuity runs: 1.) excluding NEFSC fall survey conducted on R/V Bigelow (2009-2012), and 2.) including Maine-New Hampshire spring inshore survey (2003-2013) and excluding NEFSC R/V Bigelow fall survey (2009-2012).

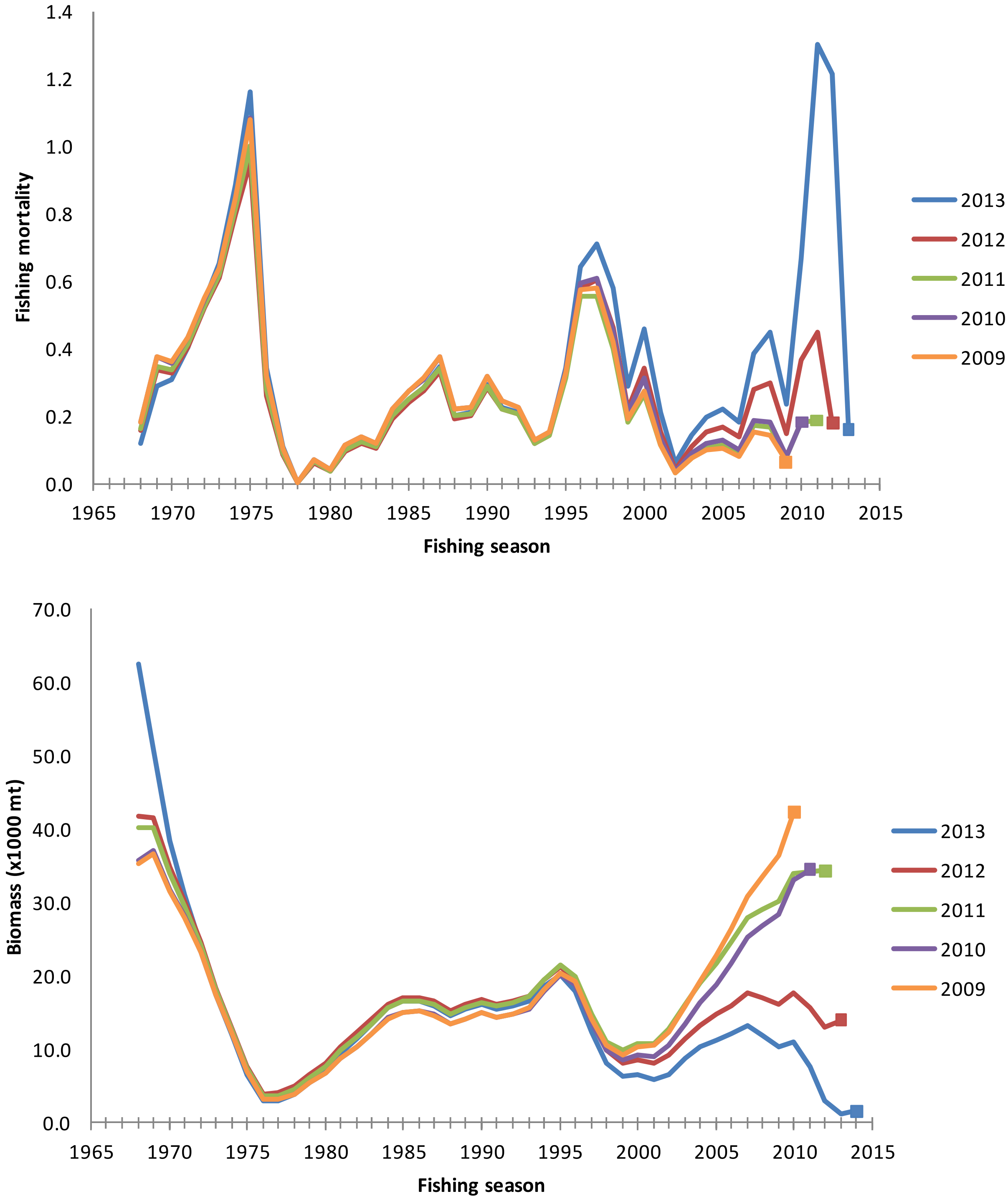


Figure C6.49. Retrospective pattern in fishing mortality (top) and biomass (bottom) from the ASPIC model.

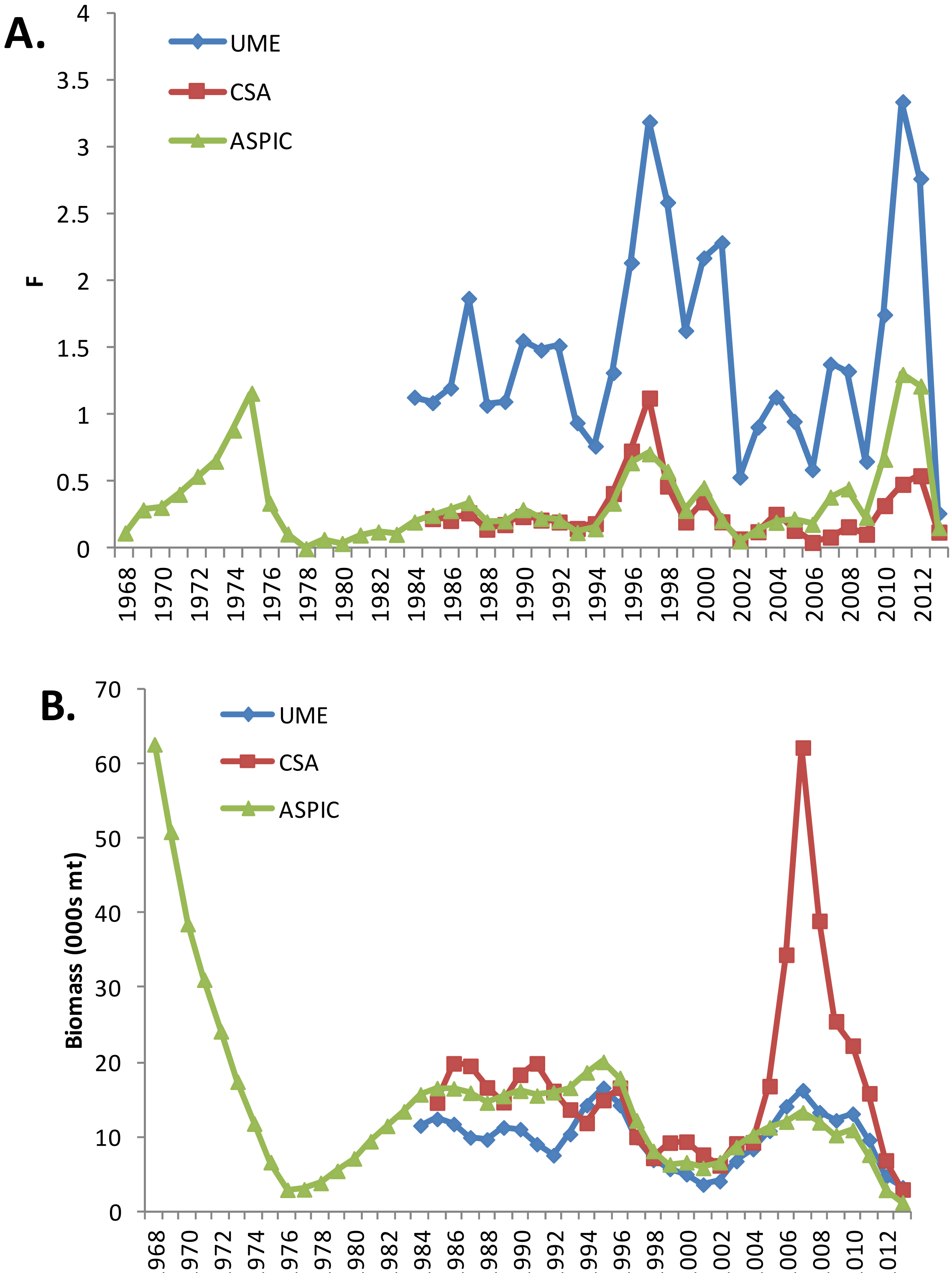


Figure C6.50. Comparison of model estimates of fishing mortality (A) and biomass (B).

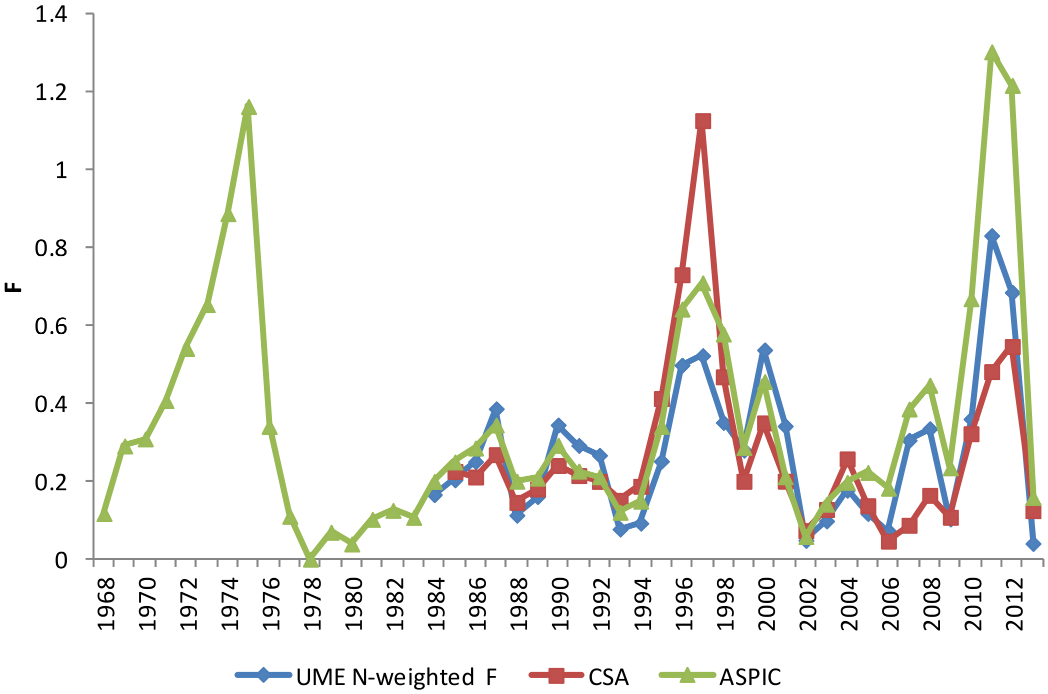


Figure C6.51. Comparison of N-weighted F from UME model with F estimates from CSA and ASPIC model.

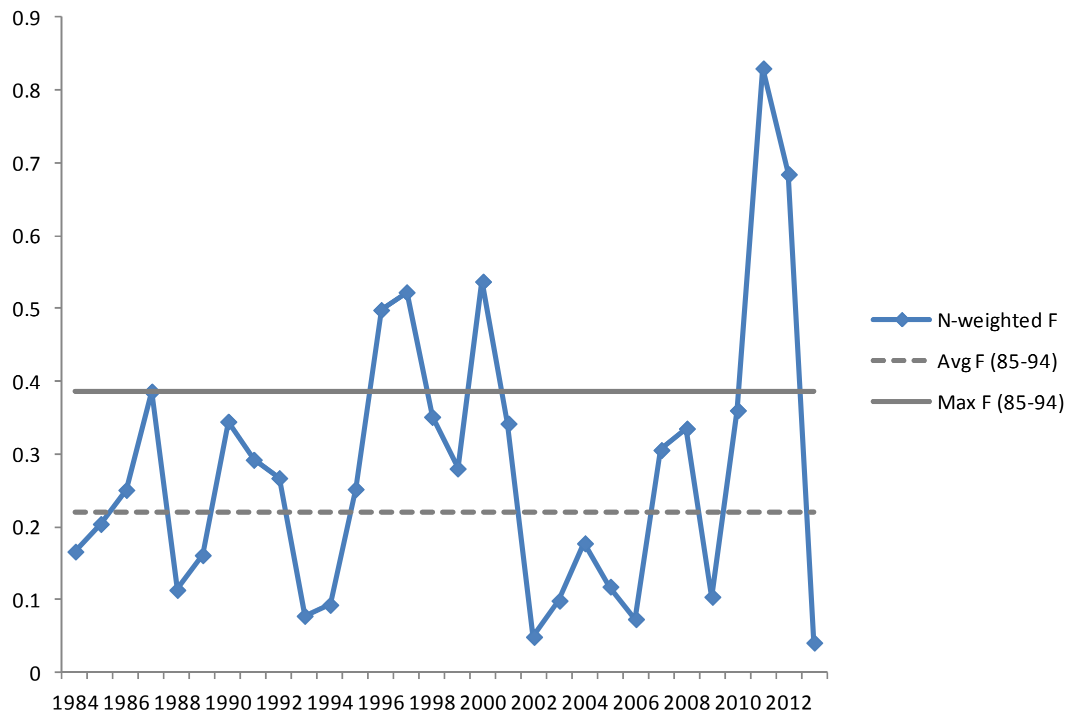


Figure C7.1A. N-weighted F from the UME model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{threshold}$ (maximum F from 1985-1994, solid line).

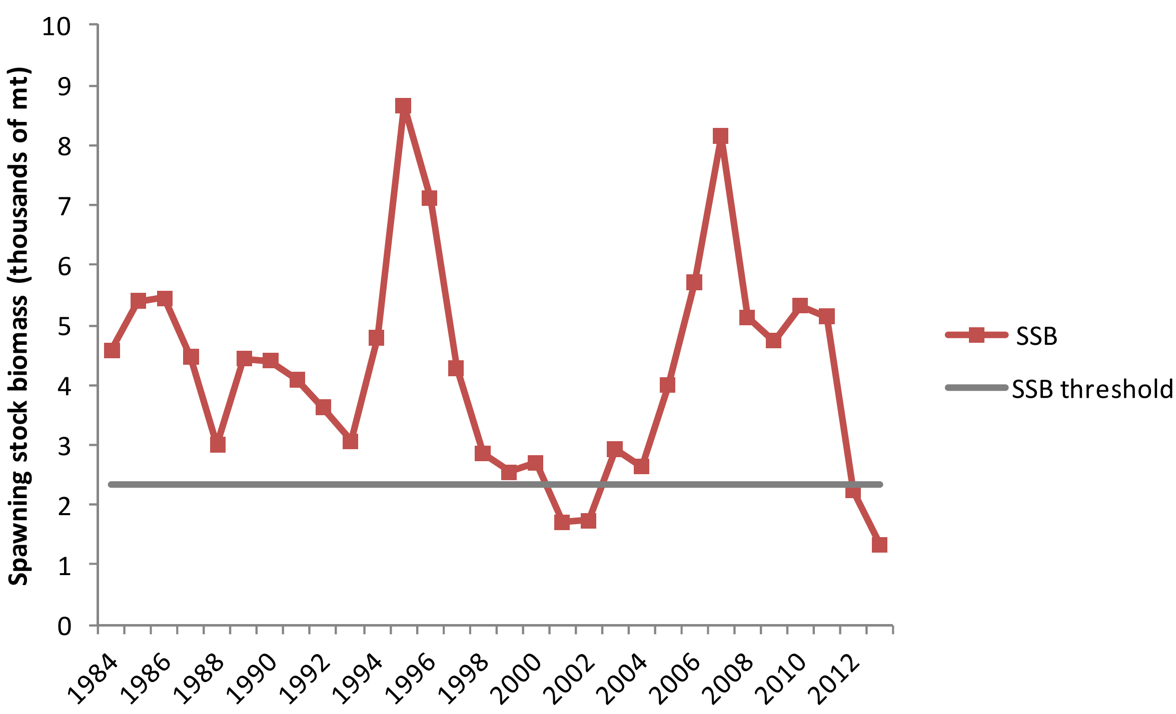


Figure C7.1.B. Spawning stock biomass from the UME model plotted with the historical SSB threshold (solid line).

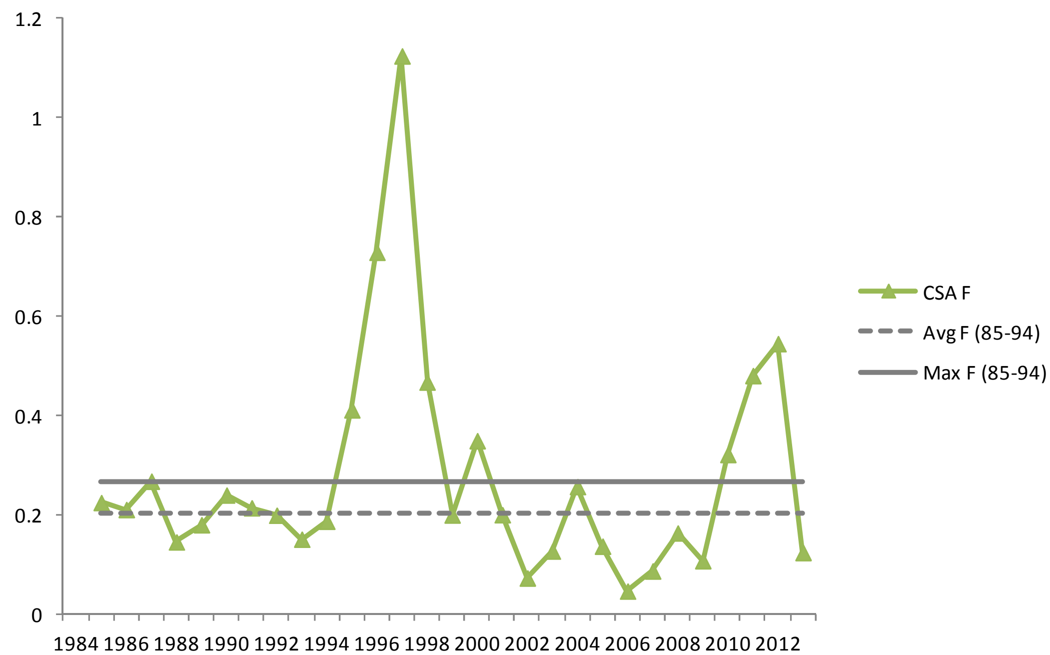


Figure C7.2.A. Fishing mortality estimates from the CSA model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{threshold}$ (maximum F from 1985-1994, solid line).

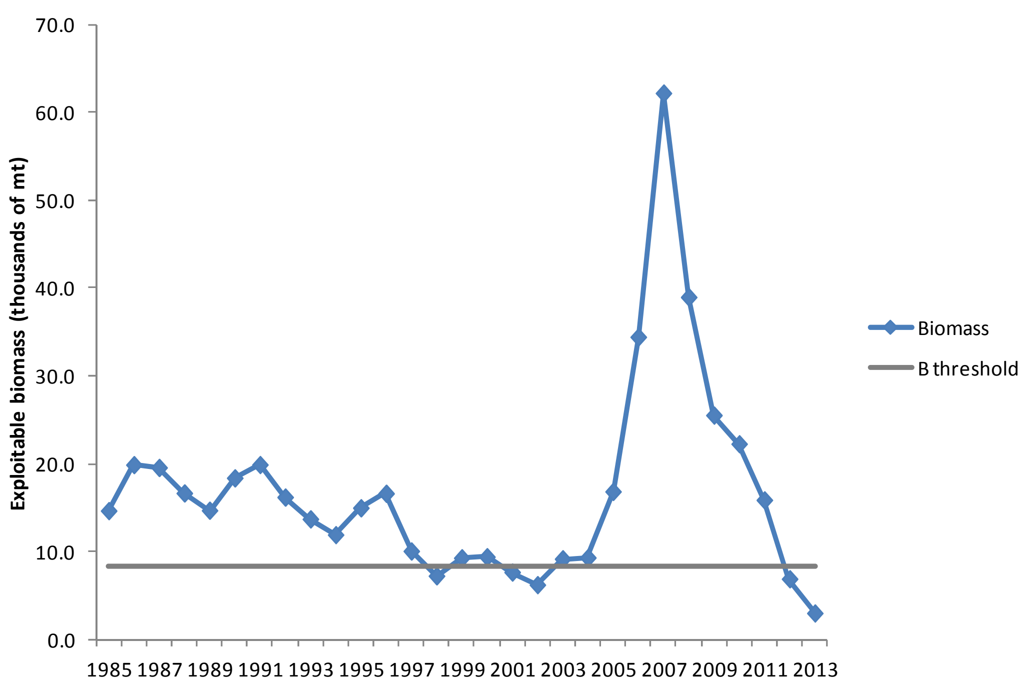


Figure C7.3.B. Exploitable biomass estimates from the CSA model plotted with the historical B threshold (solid line).

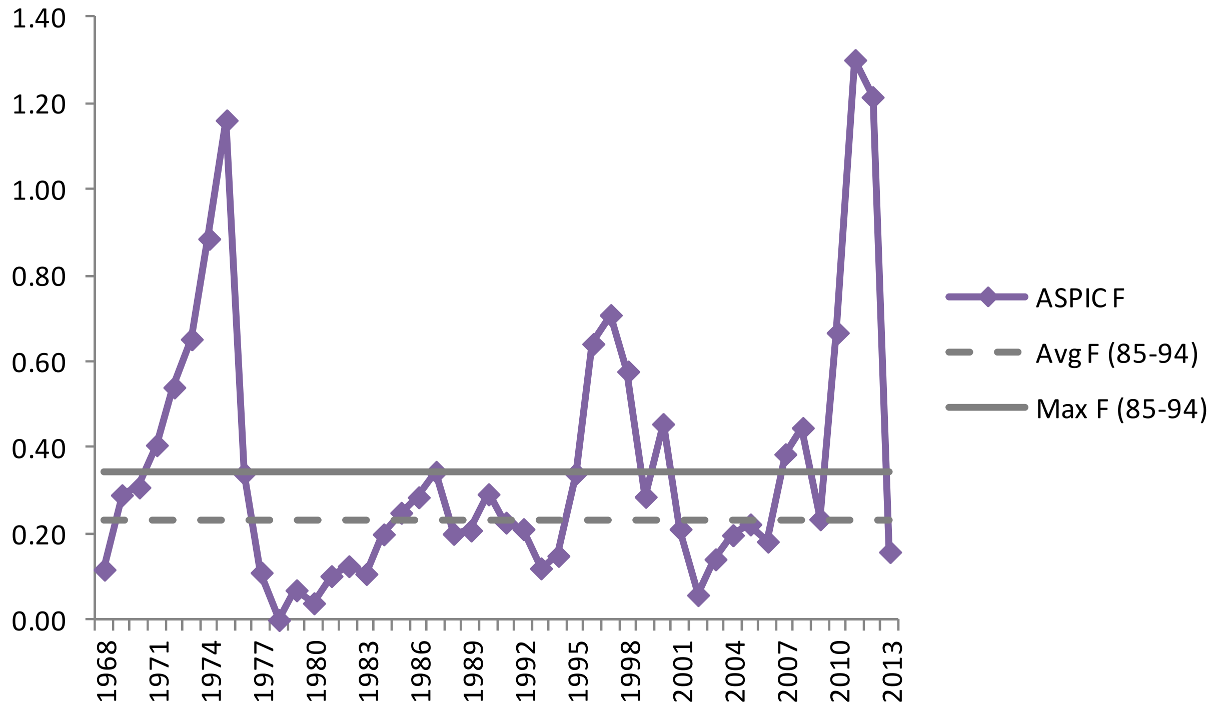


Figure C7.3. Fishing mortality estimates from the ASPIC model plotted with the historical proxy F_{target} (average F from 1985-1994, dashed line) and the $F_{threshold}$ (maximum F from 1985-1994, solid line).

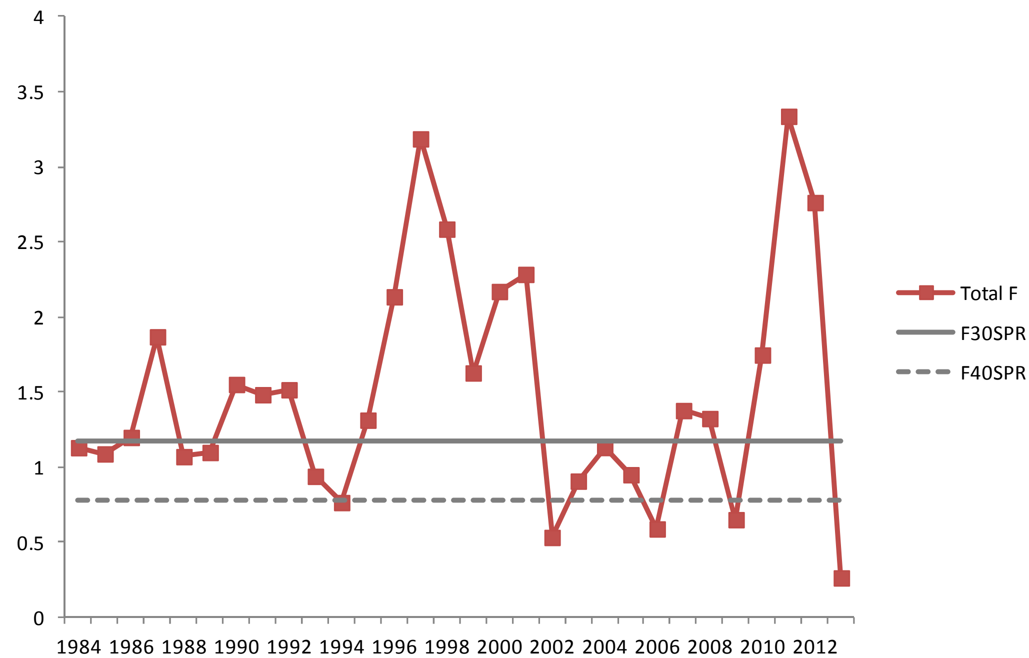


Figure C7.4. Total full F estimated from the UME model plotted with model-based reference points ($F_{30\%SPR}$, solid line, and $F_{40\%SPR}$, dashed line).

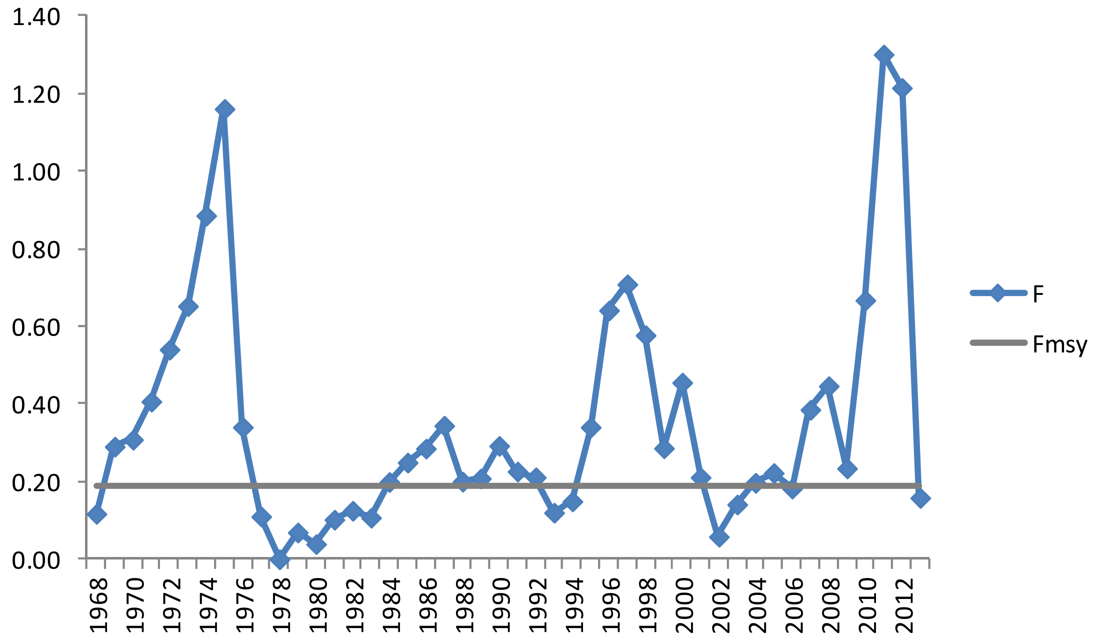


Figure C7.5.A. Fishing mortality estimates from the ASPIC model plotted with model-based reference points (F_{MSY}).

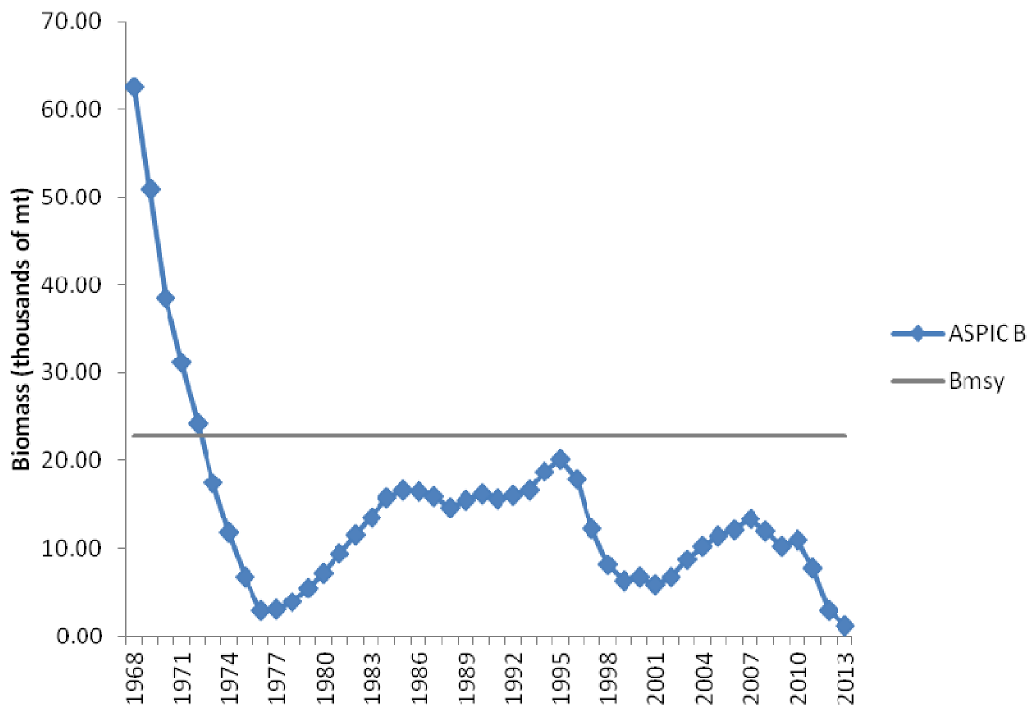


Figure C5.7.B. Biomass estimates from the ASPIC model plotted with model-based reference point (B_{MSY}).

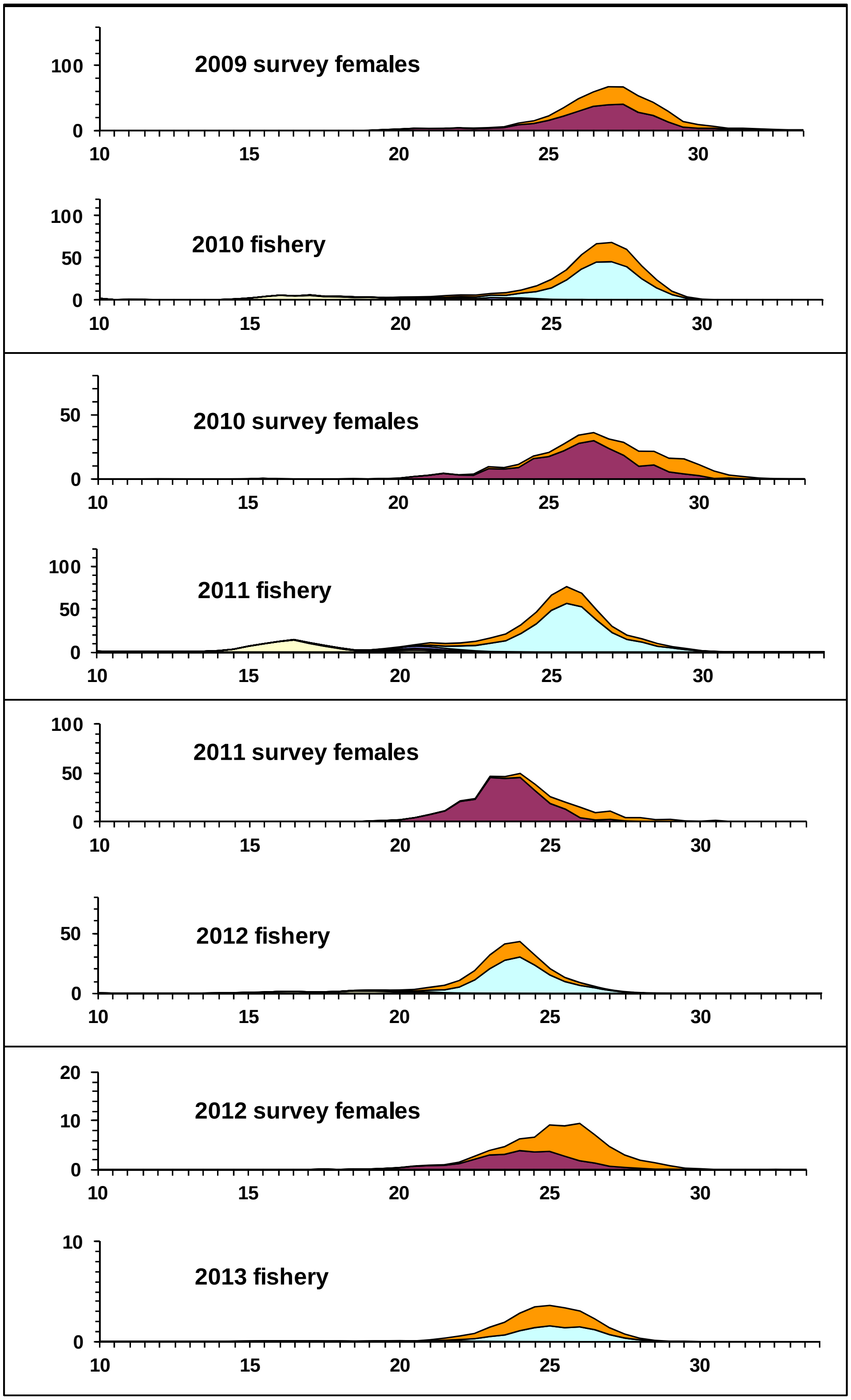


Figure C9.1. Length-frequency distributions of the female northern shrimp from the summer survey and of all sexes and stages in the fishery the following year.

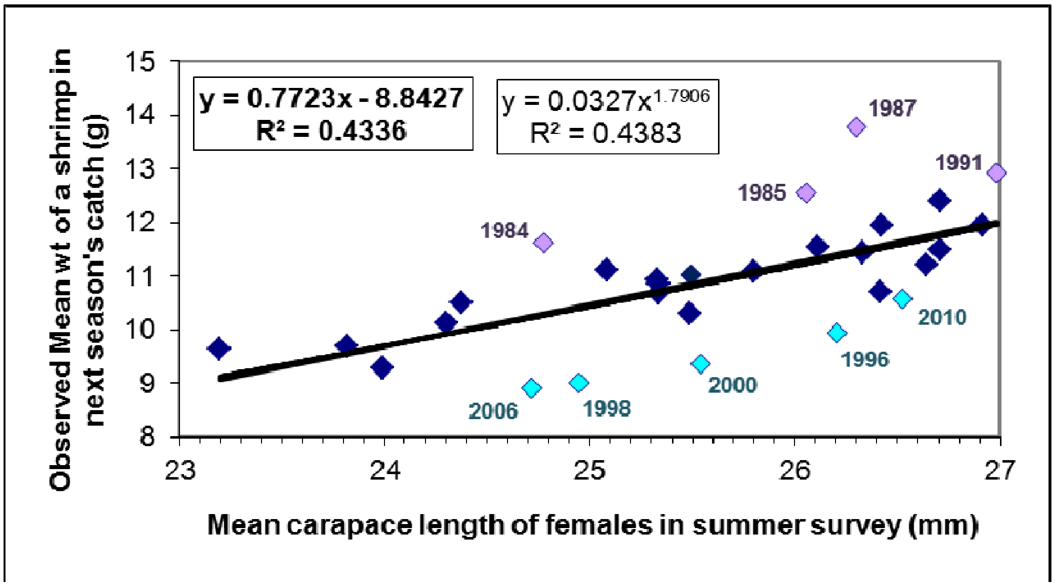


Figure C9.2. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), for survey years 1984 to 2012. An exponential relationship is also calculated. Survey years in which the observed mean weight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

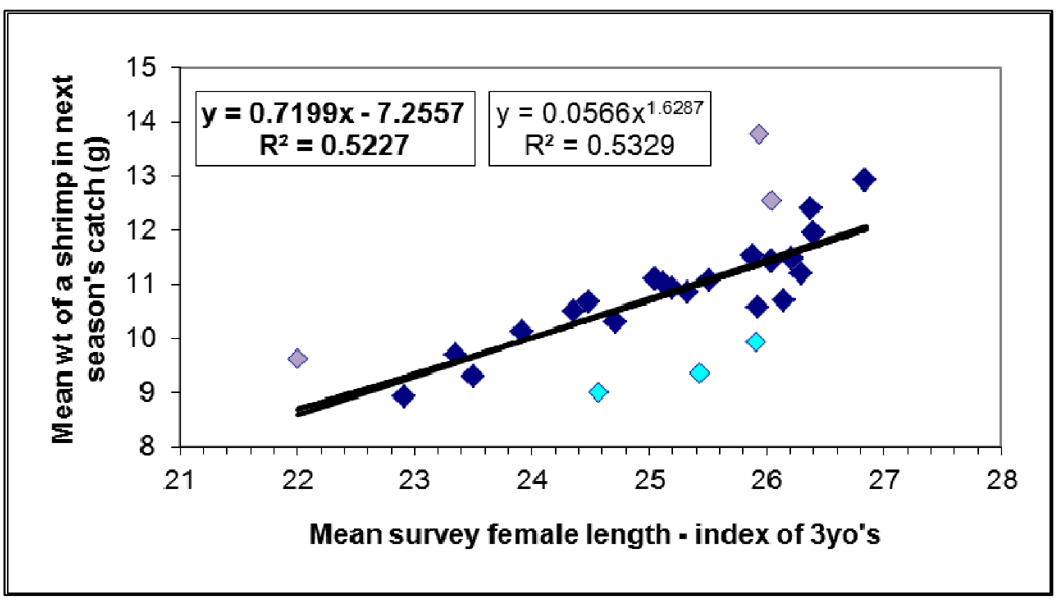


Figure C9.3. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), corrected for the number of 3-y-o's, for survey years 1985 to 2012. An exponential relationship is also calculated. Observed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

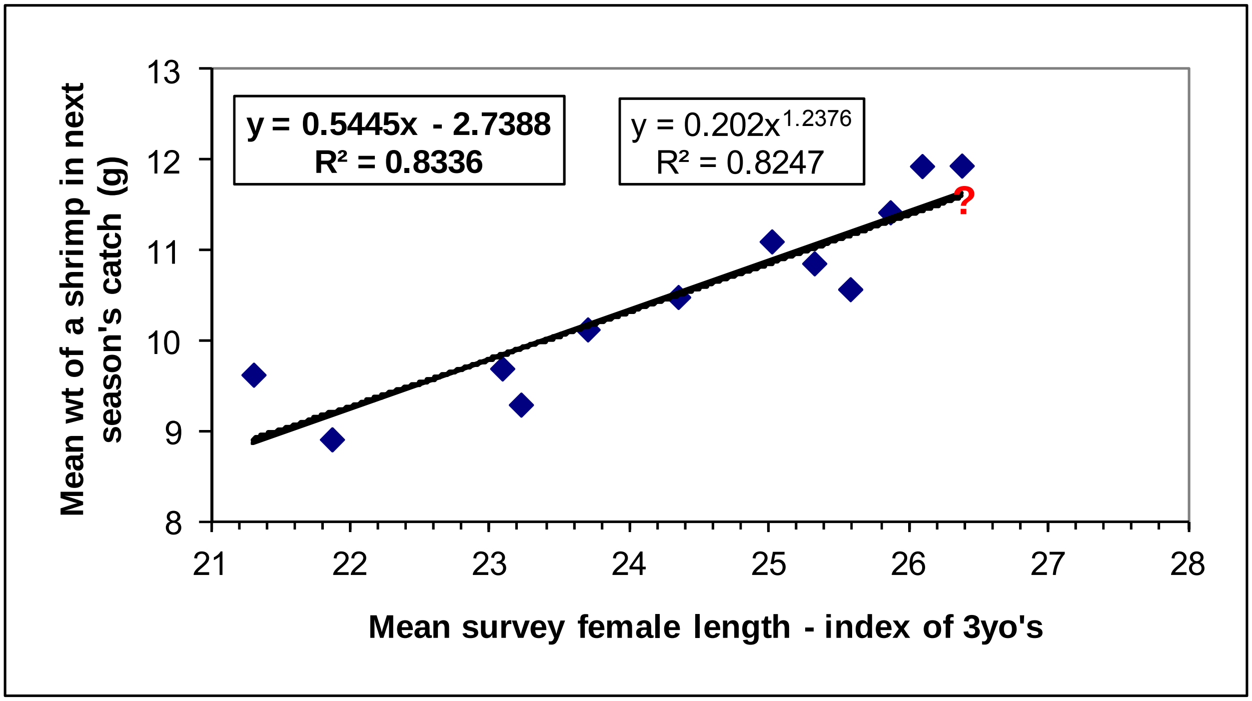


Figure C9.4. Linear relationship between the mean weight of a shrimp in the fishery landings (y) and the mean carapace length of female shrimp in the previous summer survey (x), corrected for the number of 3-y-o's, for survey years 2001 to 2012. An exponential relationship is also calculated. The predicted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

Appendix C1. Technical Documentation and User's Guide for UMaine Northern Shrimp Size-Structured Assessment Model (UME SSAM) version 01

Introduction

Northern Shrimp Size-Structured Assessment Model (NS SSAM) is a size/stage-structured assessment model developed for the northern shrimp stock assessment. It contains a number of options that are described in this User's Guide. The technical documentation provides the basic equations used in the program along with the statistical methods used to develop fit different objective function to fit the model to data. The assessment program has two independent options for the modeling time step, annual and seasonal (season 1= January -March; season 2 = April-June; season 3 = July –September; and season 4 = October – December).

Basic Equations

The description of the model is for the seasonal time step. Models for the annual time step are similar (but simpler for many models). The calculation of the objective functions is described in the next section.

Natural mortality M

Weighted M

The weighted and seasonal M for shrimp of size bin *k*, in year *t*, season *m* is calculated as:

$$M_{k,t,m} = w_t \, w_k M_m \qquad (1)$$

where w_t is pre-specified annual weighting factor, w_k is pre-specified size weighting factor; and M_m is seasonal natural mortality which could be either pre-specified or estimated.

Lorenzen M

The natural mortality for shrimp of size bin *k*, in year *t*, season *m* is calculated:

$$M_{k,t,m} = M_{u,m} W_{k,t}^{b_m} \qquad (2)$$

where $M_{u,m}$ is the natural mortality at unit weight in season *m*; $W_{k,t}$ is the weight at size bin *k*, in year *t*; and b_m is allometric scaling factor. $M_{u,m}$ and b_m are treated as parameters.

Fishing mortality

Fishing mortality is assumed to be separable, meaning it is the product of a year effect (*Fmult*) and selectivity at size (*S*). The fishing mortality for a fleet *f*, year *t*, season *m*, and size bin *k* is calculated as:

$$F_{f,m,t,k} = Fmult_{f,m,t} S_{f,b,k} \qquad (3)$$

The *Fmult* for a fleet *f*, year *t* and season *m* is determined by two sets of parameters, $Fmult_{f,m,1}$, the parameter for first year and each season for that fleet, and $FDev_{f,m,t}$, the deviation of the parameter from the value in the first year for that fleet. Both sets of parameters are estimated in log space:

$$\log(Fmult_{f,m,t}) = \log(Fmult_{f,m-1,t}) + \log(FDev_{f,m,t}) \qquad (4)$$

For a given fleet, multiple time blocks could be specified to allow for time dependence. Within each selectivity block, there are four options/functions for estimating selectivity ($S_{f,b,k}$):

1. estimate parameters for each size bin (one parameter for each size bin)
2. logistic function (2 parameters: a, b)

$$S_{f,b,k} = \frac{1}{1+\exp(b_{f,b}(a_{f,b} - L_k))} \qquad (5)$$

3. double logistic (4 parameters: a, b, c, d)

$$S_{f,b,k} = \frac{1}{1+\exp(b_{f,b}(a_{f,b}-L_k))}(1-\frac{1}{1+\exp(d_{f,b}(c_{f,b}-L_k))}) \quad (6)$$

4. double normal (4 or 6 parameters, details could be found in Methot Jr, Richard D., and Chantell R. Wetzel. "Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management."*Fisheries Research* (2012).)

Note for option 2, 3 and 4, the selectivity at size is divided by the maximum value over all size bins for scaling, making the re-scaled selectivity vector having a maximum value of 1.0 for the defined time block.

Recruitment

Recruitment is modeled as the product of annual recruitment and the proportion of the annual recruitment (R_t) that recruits to each season (λ_m) and each size-class (λ_k):

$$R_{m,t,k} = R_t \lambda_k \lambda_m \quad (7)$$

The proportion of the recruitment in each pre-defined size-class can either be pre-specified or estimated along with the other parameters of the model. The proportion of the recruitment in each season is pre-specified.

Annual recruitment

There are three options to estimate annual recruitment:

1. estimated as free parameters and modeled as:

$$R_t = \overline{R}\, e^{RDev_t} \quad (8)$$

where $RDev_t$ is the recruitment deviation of year t from the expected R (*R_bar*) and treated as bounded parameters, meaning their sum is zero, so that they are centered on the expected R.

2. assumed to be temporally auto-correlated

$$RDev_t = \sqrt{R_h}\, RDev_{t-1} + \sqrt{1-R_h}\, eps_t \quad (9)$$

where R_h is the degree of autocorrelation between recruitments of the neighboring years, and eps_t is $RDev_t$ assuming there is no autocorrelation. R_h and eps_t are parameters.

3. related to spawning stock biomass according to a stock-recruitment relationship (B-H or Ricker)

$$\overline{R}_t = \frac{\alpha SSB_t}{\beta + SSB_t} \quad (10)$$

or

$$\overline{R}_t = \alpha SSB_t e^{-\beta SSB_t} \quad (11)$$

where α and β are parameters and SSB_t is the spawning stock biomass of year t.

Initial conditions

The numbers-at-size at the start of the first year which specifies the state of population when model starts could be specified by eight options:

0. estimate parameters for each size-class
1. pre-specified proportions-at-size (Pia_k) and estimate the total numbers (N) for the first year, the numbers-at-size is calculated as:

$$N_k = Pia_k N \quad (12)$$

2. pre-specified proportions-at-size (Pia_k) and estimate the total numbers (N) for the first year, the numbers-at-size is calculated as:

$$N_k = \frac{e^{Pia_k}}{1+e^{Pia_k}} N \qquad (13)$$

3. assume proportions-at-size (Pia_k) follows a log-normal distribution with mean μ and standard deviation σ and calculated as:

$$Pia_k = \frac{1}{\sqrt{2\pi}\sigma L_k} \exp(-\frac{(\ln(L_k)-u)^2}{2(\sigma)^2}) \qquad (14)$$

   The numbers-at-size is calculated as option 1. N, μ, and σ are the parameters to be estimated.
4. assume proportions-at-size (Pia_k) follows a log-normal distribution as option 3 and the numbers-at-size is calculated as option 2 (3 parameters: N, μ, and σ).
5. assume proportions-at-size (Pia_k) follows a normal distribution with mean μ and standard deviation σ and calculated as:

$$Pia_k = \frac{1}{\sqrt{2\pi}\sigma} \exp(-\frac{(L_k-u)^2}{2(\sigma)^2}) \qquad (15)$$

   The numbers-at-size is calculated as option 1. N, μ, and σ are the parameters to be estimated.
6. assume proportions-at-size (Pia_k) follows a normal distribution as option 5 and the numbers-at-size is calculated as option 2 (3 parameters: N, μ, and σ).
7. assume proportions-at-size (Pia_k) follows a mixture normal distribution consists of three normal distributions to account for multiple peaks:

$$Pia_k = \pi_1 f_1(L_k) + \pi_2 f_2(L_k) + \pi_3 f_3(L_k) \qquad (16)$$

   where $\pi_1+\pi_2+\pi_3=1$, $f_1(L)$, $f_2(L)$ and $f_3(L)$ have a normal form but have different means and variances. The numbers-at-size is calculated as option 1. There are nine parameters in this case, N, μ_1, σ_1, μ_2, σ_2, μ_3, σ_3, π_1, and π_2.

Note for options 3-7, the proportion at size is divided by the summation value over all size bins, resulting in the final proportion vector having the summation of 1.

Growth

Growth transition matrix, determining the probability of an average shrimp growing from a size class into other size-classes, is required in size-based models. NSLSAP allows time dependence in growth transition matrix by setting time blocks (maximum number of time blocks could be the number of time-steps, meaning that time-step specific growth transition matrix could be specified). There are two options for growth transition matrix:

1. estimated externally and pre-specified as inputs
2. derived from VBGF model, estimate VBGF parameters (5 parameters) along with other model parameters

   The expected growth increment during a time-step (season) is assumed to follow a normal distribution with mean and variance calculated as:

$$E(\Delta L_m) = (L_{\infty,b} - L_k)(1.0 - e^{-\alpha_m K_b}) \qquad (17)$$

$$Var(\Delta L_m) = Var(L_{\infty,b})(1-e^{-\alpha_m K_b})^2 + \alpha_m{}^2 (L_{\infty,b} - L_k)^2 Var(K_b) e^{-2\alpha_m K_b} + 2\rho_b \alpha_m SD(L_{\infty,b}) SD(K_b)(1-e^{-\alpha_m K_b})(L_{\infty,b} - L_k) e^{-\alpha_m K_b} \qquad (18)$$

   where $L_{inf,\, b}$, K_b, standard deviation of $L_{inf,\, b}$, K_b, and correlation between $L_{inf,\, b}$, K_b (ρ) are the five parameters could be estimated for a given time block (b). α_m is a input proportion used for partitioning the growth within a year. If α_m=1, the five parameters are seasonal specific, otherwise, they are annual specific and the annual growth is partitioned according to the pre-specified proportion vector (α_m).

If d_{low} and d_{up} are the lower and upper ends of size class d, the probabilities of a shrimp growing from size class k to size class d can be computed as:

$$P_{k->d} = \int_{dlow}^{dup} f(x \mid E(\Delta L), Var(\Delta L))dx \qquad (19)$$

More detailed description could be found in Chen et al.2003.

Population dynamics

The number of shrimp in size bin k at the beginning of year t and season m is calculated as:

$$N_{k,t,m} = N_{k,t,m-1} SV_{k,t,m-1} G_{k,m-1} + R_{k,t,m} \qquad (20)$$

$G_{k,m-1}$ is the growth transition matrix in the previous season; $R_{k,t,m}$ is the recruitment of year t that recruits to season m and size-class k; and $SV_{k,t,m-1}$ is the survival rate for shrimp in size bin k in previous season year t, and calculated as:

$$SV_{k,t,m} = \exp\left(-\left(\sum_f \left(F_{f,m,t,k}\right) + M_{m,t,k}\right)\right) \qquad (21)$$

where $F_{f,m,t,k}$ and $M_{m,t,k}$ could be found in the sections of ***Fishing mortality*** and ***Natural mortality***, respectively.

Stock biomass

Weight-at-size

The weight of a shrimp in size-class k, year t is calculated as:

$$\log\left(W_{t,k}\right) = a_t + b_t \log\left(L_k\right) \qquad (22)$$

where a_t and b_t are inputs.

Maturity-at-size

The proportion of matured shrimp for a size-class k, year t is calculated by a logistic function as:

$$Pm_{t,k} = \frac{G}{1 + \exp\left(-K_t\left(L_k - L_{50\%,t}\right)\right)} \qquad (23)$$

where G_t, K_t and $L_{50\%,t}$ are inputs.

Sex change

Sex change is assumed to be length-dependent and the proportion of shrimps that change sex to female in a given year is modeled by a logistic function:

$$Ps_{t,k} = \frac{1}{1 + \exp\left(-\frac{2\log(3)}{R_{sex}}\left(L_k - L_{50\%,t}\right)\right)} \qquad (24)$$

where $L_{50\%,t}$ and R_{sex} are two sets of parameters to be estimated.

The female biomass for year t could be calculated as:

$$B_t^f = \sum_k N_{t,k} W_{t,k} Ps_{t,k} \qquad (25)$$

The non-female biomass for year t could be calculated as:

$$B_t^{nf} = \sum_k N_{t,k} W_{t,k} \left(1 - Ps_{t,k}\right) \qquad (26)$$

Spawning stock biomass

The spawning stock biomass is calculated based on the population abundance at size (*N*), the weight at size (*W*), proportion of maturity at size (*Pm*), proportion of female at size (*Ps*), and the proportion of the total mortality during the year prior to spawning (p_{SSB}) as:

$$SSB_t = \sum_k N_{t,k} e^{-p_{SSB} Z_{t,k}} W_{t,k} Pm_{t,k} Ps_{t,k} \qquad (27)$$

Predicted catch

Predicted landings in units of numbers of shrimp for each fleet, year, season and size-class are derived from the Baranov catch equation:

$$C^{pred,n}_{f,m,t,k} = \frac{F_{f,m,t,k}}{F_{f,m,t,k} + M_{m,t,k}} (1 - \exp(-(F_{f,m,t,k} + M_{m,t,k}))) N_{t,k,m} \qquad (28)$$

Predicted landings in weight for each fleet, year, season and size-class are calculated:

$$C^{pred,n}_{f,m,t,k} = \frac{F_{f,m,t,k}}{F_{f,m,t,k} + M_{m,t,k}} (1 - \exp(-(F_{f,m,t,k} + M_{m,t,k}))) N_{t,k,m} W_{t,k} \qquad (29)$$

Catchability

Fishery catchability

Time blocks could be set up for fishery catchability, within a block (*b*), the fishery catchability for fleet *f* and season *m* is calculated internally as:

$$\ln(q_{f,m,b}) = \frac{1}{n_b} \sum_b \ln\left(\frac{CPUE^{Obs}_{f,m,t}}{(B^{exploit}_{f,m,t})^{E_{f,m,b}}}\right) \qquad (30)$$

or

$$\ln(q_{f,m,b}) = \ln\left(\frac{1}{n_b} \sum_b \left(\frac{CPUE^{Obs}_{f,m,t}}{(B^{exploit}_{f,m,t})^{E_{f,m,b}}}\right)\right) \qquad (31)$$

where $CPUE^{obs}_{f,m,t}$ is the observed CPUE for fleet *f*, year *t*, and season *m*; n_b is the number of time block for a given fleet; $E_{f,m,b}$ is the power parameter accounting for the nonlinearity; $B^{exploit}_{f,m,t}$ is calculated as:

$$B^{exploit}_{f,m,t} = \sum_k \bar{N}_{m,t,k} S_{b,k} W_{t,k} \qquad (32)$$

$$\bar{N}_{m,t,k} = N_{m,t,k} \frac{1 - e^{-(\sum_f F_{f,m,t,k} + M_{m,t,k})}}{\sum_f F_{f,m,t,k} + M_{m,t,k}} \qquad (33)$$

Survey catchability

Survey catchability which is modeled similar as fleet catchability and calculated internally as:

$$\ln(q_{ind,b}) = \frac{1}{n_b} \sum_b \ln\left(\frac{I^{Obs}_{ind,t}}{B^{Survey}_{ind,t}}\right) \qquad (34)$$

or

$$\ln(q_{ind,b}) = \ln\left(\frac{1}{n_b} \sum_b \frac{I^{Obs}_{ind,t}}{B^{Survey}_{ind,t}}\right) \qquad (35)$$

where $I^{obs}_{ind,t}$ is the observed index for survey *ind*, and year *t*; n_b is the number of time block for a given survey. $B^{survey}_{ind,t}$ is calculated as:

$$B_{ind,t}^{Survey} = \sum_k N_{ind,t,k}^{Survey} W_{t,k} \quad (36)$$

$$N_{ind,t,k}^{Survey} = N_{ind,t,k} S_{ind,t,k} \quad (37)$$

where $S_{ind,t,k}$ is the selectivity of survey *ind*, year *t* and size-class *k*; N_{ind} could be found in the the section of ***Predicted indices*** below.

Predicted indices

The observed indices have two characteristics that are matched when predicted values are computed, the time of year of the index and the units (numbers or biomass). The estimated population numbers at size are modified to the time of the index according to:

$$N_{ind,t,k} = N_{t,k}\left(1-\exp\left(-\left(indmonth/12\right)Z_{t,k}\right)\right) \quad (38)$$

where *indmonth* refers to the end of the month, so *indmonth*=0 is January 1 and *indmonth*=12 is December 31. If the units for an index are biomass, then the N_{ind} values are multiplied by user defined weights at size matrix. The selectivity associated with each index is either matched to a fleet or modeled independently using the same way as the fleet selectivity (4 options: size based, logistic, double logistic or double normal). The final predicted index (I_{pred}) is formed by summing the product of N_{ind} and selectivity values (*S*) over the size classes and multiplying by the catchability (*q*) for the index:

$$Ipred_{ind,t} = q_{ind,t} \sum_k N_{ind,t,k} S_{ind,t,k} \quad (39)$$

Predicted CPUE

The predicted CPUE for fleet *f*, year *t*, and season *m* is calculated as:

$$CPUE_{f,m,t}^{pred} = q_{f,m,b}\left(B_{f,m,t}^{exploit}\right)^{E_{f,m,b}} \quad (40)$$

where $q_{f,m,b}$ is the catchability for fleet *f*, time block *b*, and season *m*; $E_{f,m,b}$ is the power parameter; $B^{exploit}_{f,m,t}$ is calculated as section ***Fishery catchability***.

Predicted length composition

The predicted catch length composition is calculated as:

$$Pc_{f,m,t,k}^{pred} = \frac{C_{f,m,t,k}^{pred}}{\sum_k C_{f,m,t,k}^{pred}} \quad (41)$$

where $Pc^{pred}_{f,m,t,k}$ is the proportion of predicted catch for fleet *f*, year *t*, season *m* and size-class *k*; $C^{pred}_{f,m,t,k}$ is the predicted catch for fleet *f*, year *t*, season *m* and size-class *k*.

The predicted survey length composition is calculated as:

$$Pi_{ind,t,k}^{pred} = \frac{N_{ind,t,k}^{Survey}}{\sum_k N_{ind,t,k}^{Survey}} \quad (42)$$

where $Pi^{pred}_{ind,t,k}$ is the proportion of abundance at the survey time of survey *ind*, year *t*, and size-class *k*.

Reference Points

The program computes a number of common reference points based on estimated or pre-specified selectivity and biological characteristics. The reference points are computed through a bisection algorithm which produces an accuracy of approximately 1E-05. The reference points computed are $F_{0.1}$, F_{MAX}, $F_{30\%SPR}$, $F_{40\%SPR}$, and F_{MSY}. The associated maximum sustainable yield (MSY) and spawning stock biomass at F_{MSY} are also provided.

Objection Function Calculation (Fitting the model)

The overall objective function in NSLSAP is the sum of log likelihood functions linking observed and predicted values of various life history and fishery processes. A penalty function is also included in the overall objective function to exclude biologically unrealistic estimates. There are multiple assumptions for error distributions provided in the calculation of the objective function. All are converted to negative log likelihoods for use in the minimization conducted by ADMB. All log likelihood functions contain constant terms that do not change for any value of the parameters. These constants can be either included or excluded from the objective function. All model fits contain a lambda value that allows emphasis of that particular part of the objective function along with an input coefficient of variation (CV) that is used to measure how strong a particular deviation is. The CV is converted to a variance (σ^2) and associated standard deviation (σ) using the equation

$$\sigma^2 = \ln\left(CV^2 + 1\right) \tag{43}$$

Likelihood functions for length composition

For catch and survey proportion at size, two likelihood functions are available:

1. Multinomial distribution

$$\ln(P) = \ln(ESS\,!) - \sum_k \ln\left(x_k!\right) + ESS \sum_k p_k^{Obs} \ln p_k^{pred} \tag{44}$$

where *ESS* is the input effective sample size and is used to create the number of shrimp in each bin (x_k); $p^{obs}{}_k$ denotes an observed proportion and $p^{pred}{}_k$ denotes the associated predicted proportion. Model estimated *ESS* is calculated as:

$$ESS^{pred} = \frac{\sum_k p_k^{pred}(1 - p_k^{pred})}{\sum_k (p_k^{pred} - p_k^{Obs})^2} \tag{45}$$

2. Robust normal for proportion (Fourier *et al*. 1990)

$$\ln(P) = \sum_k (-\ln(\frac{1}{ESS}\sqrt{2\pi(p_k^{pred}(1 - p_k^{pred}) + \frac{0.1}{SN}}))) + \ln(\exp(-\frac{(p_k^{obs} - p_k^{pred})^2}{2(p_k^{pred}(1 - p_k^{pred}) + \frac{0.1}{SN})\left(\frac{1}{ESS}\right)^2}) + 0.01)) \tag{46}$$

Likelihood functions for others

For catch, CPUE, indices, recruitment deviation and priors, seven log likelihood functions are provided:

1. Robust

$$\ln(P) = -\ln\left(\sqrt{2\pi}\sigma_I^{obs}\right) + \ln\left(\exp\left(-\frac{\left(\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)\right)^2}{2\left(\sigma_I^{obs}\right)^2}\right) + 0.01\right) \tag{47}$$

2. Student t

$$\ln(P) = -\ln\left(\frac{1.32934}{\sqrt{4\pi}}\right) - 2.5\ln\left(\left(\frac{\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)}{2\sigma_I^{obs}}\right)^2 + 1\right) \tag{48}$$

3. Normal distribution for the recruitment deviation

$$\ln(P) = -\frac{\sum(Dev)^2}{2(\sigma_{eps})^2} - \ln\left(\sqrt{2\pi}\sigma_{eps}\right) \quad (49)$$

4. Log normal

$$\ln(P) = -\ln\left(\sqrt{2\pi}\sigma_I^{obs}\right) - \ln\left(I^{obs}\right) - \frac{\left(\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)\right)^2}{2\left(\sigma_I^{obs}\right)^2} \quad (50)$$

5. Log normal without the term for observations

$$\ln(P) = -\ln\left(\sqrt{2\pi}\sigma_I^{obs}\right) - \frac{\left(\ln\left(I^{obs}\right) - \ln\left(I^{pred}\right)\right)^2}{2\left(\sigma_I^{obs}\right)^2} \quad (51)$$

6. Normal

$$\ln(P) = -\ln(\sqrt{2\pi}\sigma_I^{obs}) - \frac{(I^{obs} - I^{pred})^2}{2(\sigma_I^{obs})^2} \quad (52)$$

7. Cauchy distribution

$$\ln(P) = -\ln\left(0.675\sigma\pi\left(1 + \left(\frac{I^{obs} - I^{pred}}{0.675\sigma}\right)^2\right)\right) \quad (53)$$

Penalty

One penalty function is included for the estimated fishing mortality. It's a penalty associated with any F greater than an input maximum value, calculated as $1000*(F\text{-max } F)^2$ for F> max F, where max F should be a maximum fishing mortality level that the user believe possible for the fishery and will be defined by the user.

Users' Guide

Input

The assessment model could operate on either annual time-step or seasonal time-step depending on the user's choice. For each time-step, **9 input files are required** to run the model. Of the 9 input files 3 are common files and 6 are time-step specific files. The names of the files should not be changed.

Appendix C1. Table 1. File names for each time-step.

	COMMON FILES	**ANNUAL TIME-STEP FILES**	**SEASONAL TIME-STEP FIELS**
	Control.DAT	BPR_Data_Year.DAT	BPR_Data_Season.DAT
	Biology_Data.DAT	CatchDataYear.DAT	CatchDataSeason.DAT
	Survey_Data.DAT	GrowthMatrix.DAT	GrowthMatrix.DAT
		Parameters_Ini_Year.DAT	Parameters_Ini_Season.DAT
		Prior_Year.DAT	Prior_Season.DAT
		Porjection_Year.DAT	Projection_Season.DAT
Sub Folder		**Year**	**Season**
Folder	**InputFiles**	**InputFiles**	**InputFiles**

In all these input files, "#" precedes a comment line which will not affect the run.

Summary of data required

- Weight-at-size matrix
- Maturity-at-size matrix
- Survey indices, CV, ESS, length composition
- Proportion of female at size for each year
- Annual catch, CV, ESS, length composition
- Growth matrix or VBGF parameters

Summary of other information for specifying the model

- Time-step
- Number of size bins and lower and upper boundary for each size bin
- Natural mortality weighting factors by size and year
- Number of size bins to which recruitment recruits
- Spawning month
- Initial condition
- Survey selectivity
- Fleet selectivity

Control file (Control.dat)

- Model time-step set-up (1-year; 4-season)
- Number of years
- Number of seasons in each year
- Number of months in each season
- First year of the input data (e.g., 1985)
- First year of the data used for a particular run (any subset of the input data)

- Last year of the data used for a particular run (facilitate retrospective analysis)
- Likelihood constants set-up (1-included in the objective function; 0-excluded)
- Tracking a particular cohort (e.g., 1990; the program will output the dynamic of year class 1990)

Biology data file (Biology_Data.dat)

- Number of size bins
- Lower and upper boundary for each size bin (units of millimeter)
- Parameters of Length-weight relation for calculating weight-at-size matrix

(number of years by 3, the first column is year, the second and third columns are the parameters a_t *and* b_t *in* **Equation 22***)*

- Parameters of maturity-length model for calculating maturity-at-size matrix

(*4 by the number of years, the first column is year, the second, third and fourth columns are the parameters* G_t, K_t *and* $L_{50\%,t}$ *in* **Equation 23**)

- Size weighting factor for natural mortality (w_k in **Equation 1**)
- Annual weighting factor for natural mortality (w_t in **Equation 1**)
- Number of size bins to which recruitment recruits (the length of vector λ_k in **Equation 7**)
- Proportions of the annual recruitment recruits to each season (λ_m *in* **Equation 7***, only be used when time-step is season*)
- Spawning month (defined as the beginning of the month)
- Stock-recruitment relation set-up (1-no functional relation; 2-BH model; 3- Ricker model)
- Initial condition set-up (0-7; see section ***Initial Conditions***)
- Proportions-at-size (Pia_k in **Equations 12 and 13;** *this vector will only be used when the initial condition is set to 1 or 2*)

Survey data file (Survey_Data.dat)

- Number of available survey indices
- Unit of each survey index (1-biomass; 0-numbers)
- Start size bin of selectivity for each survey
- End size bin of selectivity for each survey
- Tuning set-up for each index for a particular run (1-include; 0-not include)
- Likelihood function set-up for length composition data for each survey (1-multinomial [**Equation 44**]; 2-robust normal for proportion [**Equation 46**])
- Likelihood function set-up for index for each survey (1-7; see section ***Likelihood functions for others***)
- Lambda value of composition component in objective function for each survey
- Lambda value of index component in objective function for each survey
- Number of data points for survey indices (e.g., 44: 2 indices * 22 years)
- Survey data matrix (number of rows=number of data points, number of columns=6 + number of size bins)

Year	Index number	Index month	Index value	CV	ESS	Size bin 1	Size bin 2	……	End size bin
		Indmonth in Equation 38			Effective sample size	Survey length composition			

- Lambda value of sex change component in objective function
- Proportions of female at size matrix (number of size bins by number of years)
- Number of survey catchability
- Catchability calculation method set-up (1-**Equation 34**; 2-**Equation 35**)
- Survey catchability time blocks set-up (a matrix of number of years by number of survey catchability plus one)

An example showing two time blocks for each of the two indices (4 blocks total):

year	Index 1	Index 2
1985	1	3
1986	1	3
1987	2	3
1988	2	4

Each cell in the shaded area indicates the time block in which a particular index falls for a particular year. For index 1, there are two time blocks, q1 for 1985-1986 and q2 for 1987-1988. For index 2, there are two time blocks as well, q3 for 1985-1987 and q4 for 1988.

- Fleet selectivity reference (**negative value**-not use fleet selectivity as survey selectivity; **fleet number**-use that particular fleet selectivity as survey selectivity)
- Number of survey selectivity time blocks
- Survey selectivity option for each survey (1-4, same options as fleet selectivity, see section ***Fishing Mortality***)
- Survey selectivity time blocks set-up

Catch data file (CatchDataYear.dat)

- Number of fleets
- Unit of catch for each fleet (0-number[million]; 1-biomass[1000mt])
- Start size bin of selectivity for each fleet
- End size bin of selectivity for each fleet
- Likelihood function set-up for length composition data for each survey (1-multinomial [**Equation 44**]; 2-robust normal for proportion [**Equation 46**])
- Likelihood function set-up for total catch for each fleet (1-7; see section ***Likelihood functions for others***)
- Likelihood function set-up for CPUE for each fleet (1-7; see section ***Likelihood functions for others***)
- Lambda value of composition component in objective function for each fleet
- Lambda value of total catch in objective function for each fleet
- Lambda value of CPUE in objective function for each fleet
- Number of data points for catch data
- Catch data matrix (number of rows=number of data points, number of columns=9 +

number of size bins)

•

Year	Time-step	Fleet number	Total catch	CV of catch	CPUE or effort value	CPUE or effort	CV of CPUE or effort	ESS	…
						1-CPUE 0-effort			Length comp

- Tuning set-up for each CPUE for a particular run (1-include; 0-not include)
- Number of CPUE catchability (time blocks)
- Catchability calculation method set-up (1-**Equation 34**; 2-**Equation 35**)
- CPUE catchability time blocks set-up (same as survey catchability)
- Number of fleet selectivity time blocks
- Fleet selectivity option for each fleet (1-4, see section ***Fishing Mortality***)
- Fleet selectivity time blocks set-up

Growth matrix data file (GrowthMatrix_Year.dat)

- Growth transition matrix set-up (1-use VBGF parameters to derive the growth transition matrix internally, see section of ***Growth***, in this case the VBGF parameters could be estimated along with other model parameters; 0-input growth transition matrix directly)
- Number of growth transition matrices
- Growth proportion for each Season (α_m in **Equation 17**, will not be used when time-step is year)

Biology reference point data file (BPR_Data_Year.dat)

- Maximum value of F in penalty term
- Selectivity set-up for calculating reference point (**-1**-input; **0**-averaged fleet selectivity; **fleet number**-use that particular fleet selectivity)
- Selectivity input (only be used when above option is set to -1)
- Equilibrium period used for calculating reference point
- Reference year for natural mortality (e.g., 20: use the natural mortality of 20th year for calculating reference point)
- Proportions of F for each season (1 for annual time-step)
- Growth matrix set-up (specify which time block of growth matrix will be used for calculating reference point)

Initial value of parameters input file (Parameters_Ini_Year.dat)

- Fleet Selectivity Parameters
- Fishing mortality of the first year for each fleet
- Fishing mortality deviations for each year and fleet (fleet outer loop, year inner loop)
- CPUE catchability power parameter for each time block
- Survey index selectivity parameter for each time block
- Initial condition parameters
- R-S relationship parameters (α and β)
- Recruitment deviations (log scale)
- Recruitment autocorrelation coefficient
- Standard deviation of recruitment deviation in log scale

- Natural mortality
- Lorenzen natural mortality (b_m in **Equation 2**)
- *Linf* for each time block ($L_{inf,\,b}$ in **Equation 17**)
- *K* for each time block (K_b in **Equation 17**)
- Standard deviation of $L_{inf,\,b}$ (**Equation 18**)
- Standard deviation of K_b (**Equation 18**)
- Correlation between $L_{inf,\,b}$ and K_b (**Equation 18**)
- Proportion of recruitment-at-size (λ_k in **Equation 7**)
- L_{50} for each year ($L_{50\%,t}$ in **Equation 24**)
- R_{sex} (R_{sex} in **Equation 24**)

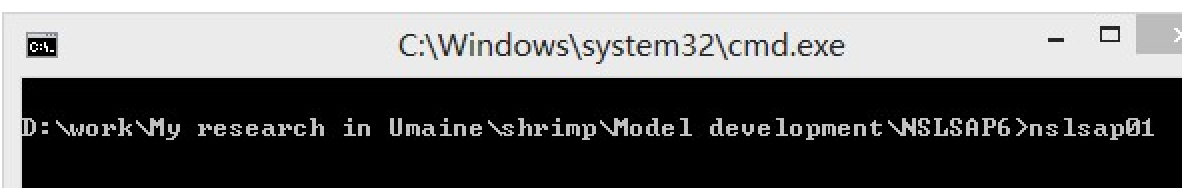
Prior input file (Prior_Year.dat)

Prior file inputs the priors for each parameter for MCMC run. For each parameter, input the mean, lower bound, upper bound, phase (negative value turns off the parameter), standard deviation, lambda, and likelihood function.

Running the model

The NSLSAP01 model is written in ADMB (Automatic Differentiation Model Builder) and the source code could be found in NSLASAP01.tpl file. The process of creating the model with ADMB involves writing, compiling, and testing. An integrated development environment (IDE) allows the user to perform these tasks more efficiently than with a basic editor and a shell. ADMB-IDE is a great tool for modifying the code, compiling the code, and running the model. The manual for ADMB-IDE is available at:
http://www.admb-project.org/tools/admb-ide/manual

Once the code is compiled into an executable file (NSLSAP01.exe) the model could be run in a command window. Shift-Right-clicked on folder which contains the model files in windows explorer to open a command window and then type "nslsap01" into command window to run the model (see the example below). The results will be sent to a series of output files which are described in Output section.



Output

For each run the model produces a series of output files, most of them are standard ADMB output files. The independent variables of the optimization are in a file named NSLSAP01.par (NSLSAP01.bar is an equivalent binary file). A more user-friendly report is in the file NSLSAP01.rep. The estimated standard deviations and correlations are in files named NSLSAP01.std and NSLSAP01.cor. In addition, a report file named "NSLSAP01_1985_2001_1.rep" which indicates the data range and time-step used for that particular run is also produced.

1 **NSLSAP01.rep:** Results for the run, including spawning biomass, numbers-at-length, recruitment, fits to the data, fishing mortality, MSY and related quantities, etc.

2 **NSLSAP01.par:** a standard ADMB output file, giving the objective function value, its gradient (this should be very small if the model has converged) and the parameters estimated/fixed for that run.
3 **NSLSAP01.std:** a standard ADMB output file, with the parameters estimated for that run and their estimated Hessian-based standard deviation.

R program is used to read and plot the ADMB output. Three r code files stored in the model folder were used. The file named "reptoRlist.r" reads the contents of the report file (NSLSAP01.rep) and stores the contents in R in the form of a list object. The file named "PlotFuncs.r" contains all the functions for producing different plots. The file named "OutputPlots.r" is used to call the functions and get the plots. The explanations of that file are as follows:

setwd("D:/work/My research in UMaine/shrimp/Model development/NSLSAP6")
 # set working directory to the folder containing the model files (change to yours by typing the directory in the "")

source("reptoRlist.r")
 # run the r code in reptoRlist.r

filename="NSLSAP01"
 # specify the name of files outputted from ADMB

report<-read.admb(filename)
 # read the contents of the report file (NSLSAP01.rep) and stores the contents in the list object (report)

source("PlotFuncs.r")
 # run the r code in PlotFuncs.r

PlotWL(2000,1)
 # plot weigth-at-length

PlotML(2000)
 # plot maturity-at-length

PlotGM(2000,20)
 # plot growth transition matrix

PlotSelF(2000,1,1)
 # plot fleet selectivity

PlotSelS(2000,1)
 # plot survey selectivity

PlotF(1,1)

 # plot fishing mortality

PlotM(2000)
 # plot natural mortality

PlotR()
 # plot recruitment

PlotSSB()
 # plot spawning stock biomass

PlotAbun()
 # plot numbers-at-length

PlotSLC(1)
 # plot survey length composition

PlotSLCA()
 # plot aggregated survey length composition

PlotSI(1)
 # plot survey index

PlotTC()
 # plot total catch

PlotC(2)
 # plot total catch by fleet

PlotCC(2,1)
 # plot catch length composition

PlotCCA(2)
 # plot aggregated catch length composition

PlotRoSSB(1985,2002,2006,4)
 # plot retrospective error for SSB

PlotSexComp()
 # plot sex composition

PlotFfit()
 # plot the fit of sex change

PlotLfifty()
 # plot the fit of L50

PlotSpB()
 # plot the sex-specific biomass over time

R version 3.0.0 for windows is available at: http://cran.r-project.org/bin/windows/base/

Once you have R installed, open "OutputPlots.r" and run the code you will get the plots.

Appendix C2. Predation Pressure Index

Predation Pressure Index

A simple index of predation pressure on northern shrimp *Pandalus borealis* was developed using survey biomass indices of predators and frequency of occurrence of Pandalids in predator stomachs from food habits sampling conducted during NEFSC spring and autumn bottom trawl surveys. The motivation was to include information on predation on shrimp in the assessment models without having to develop absolute estimates of consumption, which require more detailed calculations and depend on several assumptions in order to scale to absolute estimates.

Methods

Predators of Pandalids were identified based on food habits sampling in the northern shrimp assessment strata in the western Gulf of Maine (NEFSC bottom trawl strata 01240, 0126-1028, 0137-0140) during 1973-2011 spring and fall surveys. Predators were retained in the analysis if at least 100 stomachs containing Pandalids were sampled during all years and spring and fall seasons combined. I used 'collection category' prey taxonomic resolution and prey category 'PANFAM', which included *P. montagui, P. propinquus, Dichelopandalus leptocerus*, and unidentified Pandalids. *P. borealis* was identified to species in only about 3% of stomachs containing Pandalids. In survey catches in the shrimp assessment area, *P. borealis* accounted for 89-93% of the aggregate biomass of *P. montagui, D. leptocerus and P. borealis* on average (fall and summer surveys, respectively, Appendix C2. Figure 1). The Pandalid category excluded Euphausiids and Crangon shrimp.

For each identified predator, I estimated relative frequency of occurrence of Pandalids in predator stomachs (% of stomachs containing Pandalids in fall and spring surveys during 1973-2011). Annual fall biomass indices (NEFSC surveys, stratified mean weight (kg) per tow) were estimated for each predator using only the northern shrimp assessment strata (listed above). The indices from 2009-2012 were converted to 'Albatross units' by applying conversion coefficients for biomass developed for each species (Miller 2010). For Atlantic halibut and pollock, data were insufficient for estimating conversion coefficients (Miller 2010). For halibut, I applied the value used in the most recent assessment, which was the average coefficient for all flatfish species (J. Blaylock, pers. comm.). For pollock, the coefficient was assumed equal to one (Miller 2013 CJFAS).

To calculate the predation pressure index, annual biomass indices for each predator were weighted by the % frequency of occurrence of shrimp (averaged over time for each predator) and then summed across predators to derive an annual index of predation pressure that took into account both the biomass of the predators and how heavily each appeared to prey on shrimp.

$$PPI_{is} = \sum^{j} B_{ijs} * P_j$$

Where

PPI = predation pressure index

i = year

s = season (fall)

j= predator species
B = biomass index
P = proportion of stomachs containing Pandalids

An alternative PPI was explored using annual estimates of percent frequency in each predator's diet (vs. the average over time for each predator) in order to reflect inter-annual variation in predator response to shrimp densities.

$$PPI(2)_{is} = \sum^{ij} B_{ijs} * P_{ij}$$

To reduce the number of predators for this more detailed analyses, we included only predators that contributed more than 1% to the PPI score for all years combined.

The PPI(2) approach required extrapolating to fill in years with missing data for some of the predators (Appendix C2. Table 1). This was done using relationships estimated for years when complete data were available for all 10 species (1999-2010). The relationships were between % frequency for each predator and (1) % freq for all predators with complete time series, (2) shrimp recruitment index or (3) mean shrimp carapace length (Appendix C2. Figure 2).

Complete data for 2011-2012 food habits became available after most of the work on the PPI had been completed, so only the annual PPI (PPI2) was updated for these years.

Results

PPI
Sixty species were recorded with Pandalidae in stomach contents during 1973-2011 NEFSC spring and fall surveys (Appendix C2. Table 1). Of these, 21 had at least 100 sampled stomachs over the time series and were retained for the PPI (Appendix C2. Table 2). Frequency of occurrence of Pandalids in stomachs of these 21 predators ranged 1.2% (American plaice) to 35.7% (barndoor skate) and averaged 8.9% (Appendix C2. Table 2, Appendix C2. Figure 3).

Trends in predator biomass are shown in Figure 4, and aggregate predator biomass for the 21 predator species and trends in the PPI are shown in Figure 5. The PPI index based on the top 10 predators accounted for 96% of the PPI overall (Appendix C2. Table 3) and closely followed trends in the PPI based on all 21 species (Appendix C2. Figure 6). In general, the PPI was lowest during the mid-1980s to mid-1990s, increased after 1999 and has remained relatively high since.

PPI(2)
Filling in the gaps for missing data in the annual diet estimates did not have a strong effect on the annual averages over all predators (Appendix C2. Figure 7). Using annual % diet frequency (PPI(2)) resulted in the same broad trend of generally higher predation pressure after the mid-1990s, but there was a sharp divergence since 2010 (Appendix C2. Figure 8). PPI(2) was related to the annual shrimp recruitment index (Appendix C2. Figure 9). The relationship between %

frequency in the diet and % of diet (Appendix C2. Figure 10) suggests predators may take a higher proportion of the shrimp population when shrimp densities are higher.

Discussion

The approach taken here is very different from the fine-grained approach of Link and Idoine (2009) ("L&I") in which estimates of absolute consumption were developed. The L&I estimates were initially developed for SARC 45 (NEFSC 2007) for comparison with abundance estimates from the assessment models. The intent of the PPI is not to provide consumption estimates, but to give a broad indication of trends in predation pressure that may be factored into assessment models.

Appendix C2. Figure 11A shows a comparison of trends in the PPI and trends in the L&I consumption estimates (thousand mt) . The trends do not match, even when the PPI is based on the same 10 species included in Link and Idoine (2009). If only the 10 species identified by L&I are used to construct the PPI, the trends still do not match (Appendix C2. Figure 11B).

The L&I estimates were based on sampling in the entire Gulf of Maine including portions of the Scotian Shelf (NEFSC strata 01240-01400) to derive swept area estimates of predator abundance and to estimate per capita consumption of Pandalids. L&I noted that abundance changes would likely dominate the scaling of estimates of consumption. Divergent trends in biomass and abundance of the 10 predator species of L&I explains some of the divergence in trends in the PPI and L&I because trends in abundance and biomass do not track closely (Appendix C2. Figure 11). In addition, several influential species were not included in L&I (redfish, spiny dogfish, Atlantic herring, haddock) because of a large gap in sampling of these species early in the time series. Omitting these species from the PPI had a substantial effect on trends in the PPI (Appendix C2. Figure 12).

References

Link, J.S. & J. S. Idoine (2009). Estimates of predator consumption of the northern shrimp *Pandalus borealis* with implications for estimates of population biomass in the Gulf of Maine. North American Journal of Fisheries Management 29: 1567-1583.

Miller T, Das C, Politis P, Long A, Lucey S, Legault C, Brown R, Rago P. 2010. Estimation of */Henry B. Bigelow/* calibration factors. NEFSC Bottom Trawl Survey/ /Calibration Peer Review Working Paper. NEFSC, Woods Hole, MA. 376 p.

Miller, T.J. 2013. A comparison of hierarchical models for relative catch efficiency based on paired-gear data for US Northwest Atlantic fish stocks. Can. J. Fish. Aquat. Sci. 70: 1306–1316.

Appendix C2. Table 1. Complete list of species recorded as having Pandalids in stomach contents during NEFSC spring and fall surveys, 1973-2011.

≥ 100 stomachs (included in PPI)	< 100 stomachs (excluded from PPI)
SILVER HAKE	SUMMER FLOUNDER
ATLANTIC COD	BLACKBELLY ROSEFISH
WHITE HAKE	SMOOTH DOGFISH
RED HAKE	ATLANTIC MACKEREL
LONGHORN SCULPIN	YELLOWTAIL FLOUNDER
LITTLE SKATE	WEAKFISH
FOURSPOT FLOUNDER	ROSETTE SKATE
SPINY DOGFISH	BLACK SEA BASS
WINDOWPANE	OFFSHORE HAKE
SPOTTED HAKE	CLEARNOSE SKATE
WINTER SKATE	AMERICAN SHAD
SMOOTH SKATE	WITCH FLOUNDER
POLLOCK	WINTER FLOUNDER
SEA RAVEN	BLUEBACK HERRING
THORNY SKATE	NORTHERN SEAROBIN
HADDOCK	CUSK
ACADIAN REDFISH	BLUEFISH
ATLANTIC HERRING	OCEAN POUT
BARNDOOR SKATE	STRIPED SEAROBIN
GOOSEFISH	ATLANTIC WOLFFISH
AMERICAN PLAICE	SCUP
ATLANTIC HALIBUT	CUNNER
	FAWN CUSK-EEL
	CHAIN DOGFISH
	MOUSTACHE SCULPIN
	FOURBEARD ROCKLING
	ATLANTIC CROAKER
	GULF STREAM FLOUNDER
	NORTHERN SHORTFIN SQUID
	LONGFIN HAKE
	WRYMOUTH
	STRIPED BASS
	BULLNOSE RAY
	SPANISH MACKEREL
	ATLANTIC SHARPNOSE SHARK
	SPOT
	ALEWIFE
	BUTTERFISH

Appendix C2. Table 2. Overall frequency of occurrence of Pandalids in predator stomachs and percent by volume of Pandalids in stomachs containing Pandalids (unweighted estimate), 1973-2011 spring and fall NEFSC surveys combined.

Predator	Frequency of Occurrence	Avg % of prey that was Pandalids (by wt)	Number stomachs sampled
BARNDOOR SKATE	35.7	22.8	28
SMOOTH SKATE	20.8	15.8	751
WHITE HAKE*	15.5	12.4	6,924
RED HAKE*	13.1	10.5	5,111
ATLANTIC COD*	12.9	8.8	5,311
ATLANTIC HALIBUT	12.5	10.8	192
LITTLE SKATE	11.0	6.4	493
LONGHORN SCULPIN*	9.6	8.2	1,782
THORNY SKATE*	8.6	3.0	1,888
SILVER HAKE*	7.5	6.8	14,157
ACADIAN REDFISH	6.6	6.0	2,375
POLLOCK*	6.4	4.3	1,905
FOURSPOT FLDR*	5.0	4.6	337
WINTER SKATE	4.4	2.3	344
SEA RAVEN*	4.3	3.0	1,487
SPINY DOGFISH	3.5	2.2	6,825
GOOSEFISH	2.9	1.8	2,414
HADDOCK	2.8	1.7	1,985
ATLANTIC HERRING	1.9	1.7	4,527
WINDOWPANE*	1.4	1.2	213
AMERICAN PLAICE	1.2	1.1	5,284

* species included in Link and Idoine (2009)

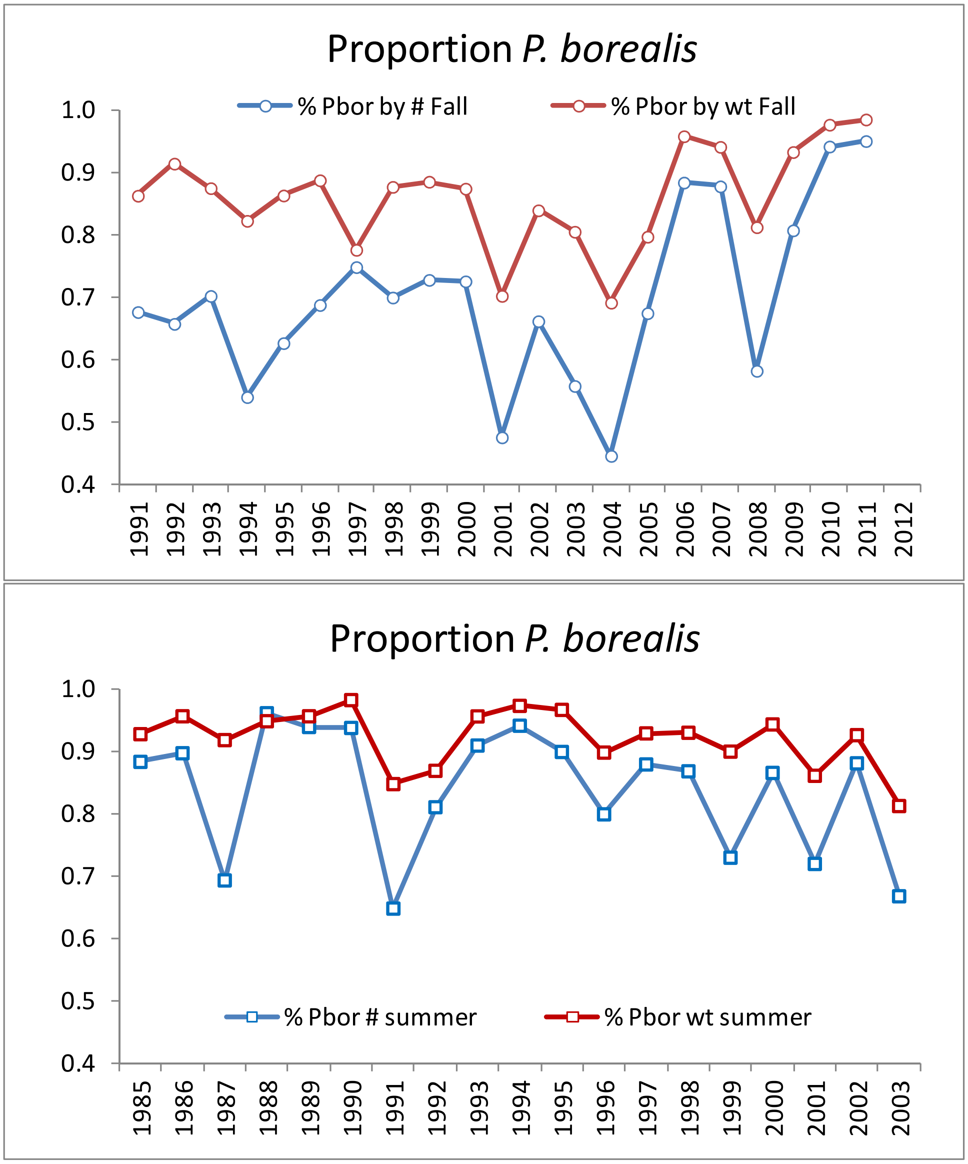
Appendix C2. Table 3. Relative importance of each predator ranked by % contribution to the PPI (A.) averaged over all years, (B.) during 1977-1993 and (C.) during 1994-2010.

A. Predator	% of PPI all years	B. Predator	% of PPI <=1993	C. Predator	% of PPI >1993
ACADIAN REDFISH	20.6%	WHITE HAKE*	23.8%	ACADIAN REDFISH	28.8%
WHITE HAKE*	17.3%	ATLANTIC COD*	19.8%	SPINY DOGFISH	26.3%
SPINY DOGFISH	15.2%	ACADIAN REDFISH	14.0%	WHITE HAKE*	9.2%
ATLANTIC COD*	15.1%	THORNY SKATE*	10.5%	ATLANTIC COD*	9.2%
SILVER HAKE*	7.5%	SILVER HAKE	7.0%	SILVER HAKE	8.2%
THORNY SKATE*	6.4%	SPINY DOGFISH	6.3%	RED HAKE*	5.7%
RED HAKE*	5.1%	POLLOCK*	5.2%	HADDOCK	2.7%
POLLOCK*	3.8%	RED HAKE*	4.7%	ATLANTIC HERRING	2.4%
HADDOCK	3.0%	HADDOCK	3.2%	POLLOCK*	2.1%
ATLANTIC HERRING	1.5%	GOOSEFISH	1.1%	THORNY SKATE*	1.3%
AMERICAN PLAICE	0.8%	AMERICAN PLAICE	1.1%	BARNDOOR SKATE	0.9%
GOOSEFISH	0.8%	ATLANTIC HERRING	0.9%	LONGHORN SCULPIN*	0.8%
SMOOTH SKATE	0.7%	SMOOTH SKATE	0.7%	SMOOTH SKATE	0.6%
LONGHORN SCULPIN*	0.6%	LONGHORN SCULPIN*	0.4%	AMERICAN PLAICE	0.5%
BARNDOOR SKATE	0.6%	WINTER SKATE	0.4%	GOOSEFISH	0.5%
WINTER SKATE	0.3%	BARNDOOR SKATE	0.3%	WINTER SKATE	0.3%
ATLANTIC HALIBUT	0.3%	ATLANTIC HALIBUT	0.3%	ATLANTIC HALIBUT	0.2%
SEA RAVEN*	0.2%	SEA RAVEN*	0.2%	SEA RAVEN*	0.2%
LITTLE SKATE	0.1%	LITTLE SKATE	0.1%	LITTLE SKATE	0.2%
FOURSPOT FLOUNDER*	0.0%	FOURSPOT FLOUNDER*	0.0%	FOURSPOT FLOUNDER*	0.0%
WINDOWPANE*	0.0%	WINDOWPANE*	0.0%	WINDOWPANE*	0.0%

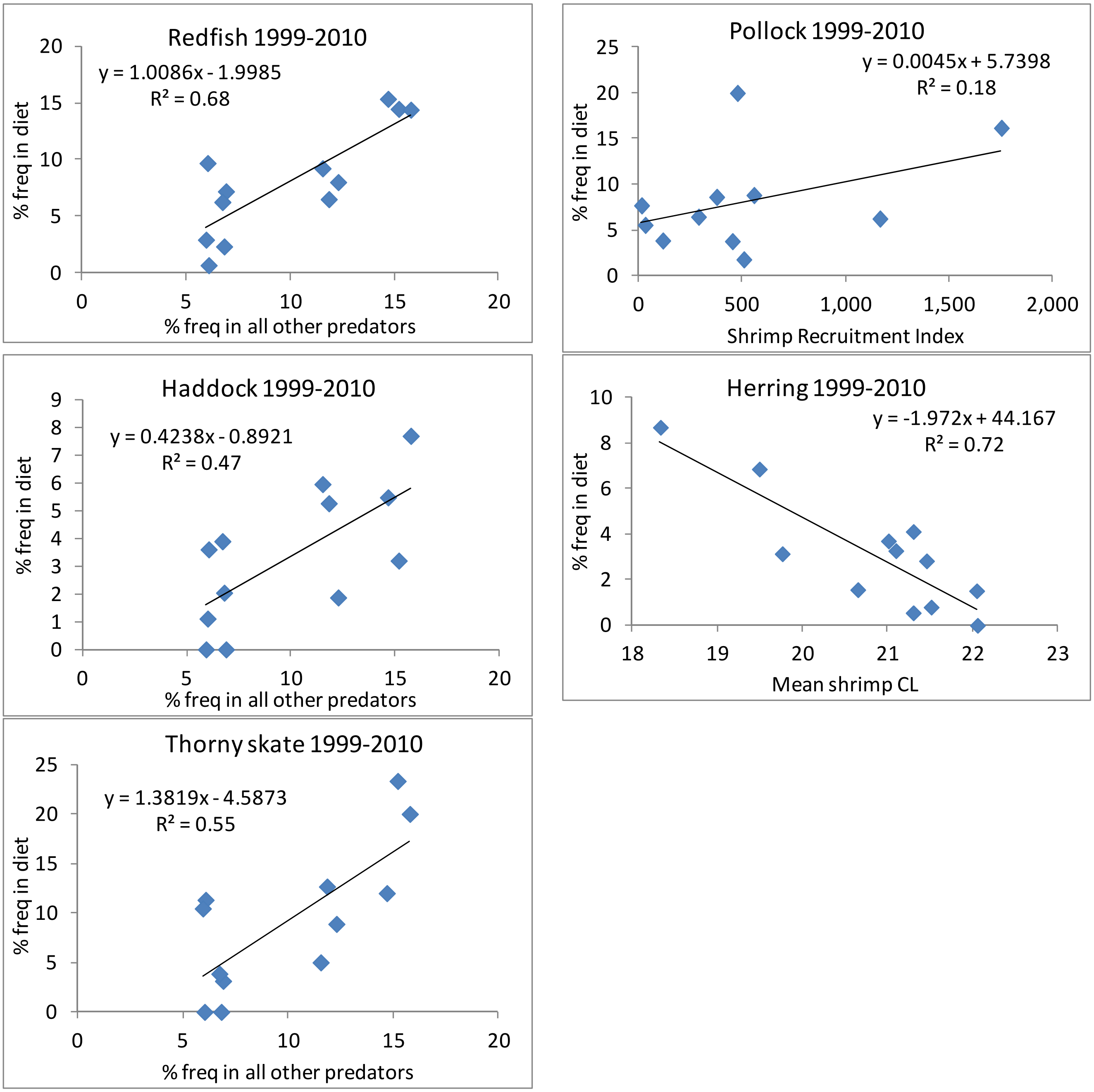
* included in Link and Idoine (2009)

Appendix C2. Table 4. Percent frequency of occurrence of Pandalids in stomachs of predators with highest % contribution to the PPI. Shaded cells were estimated from relationships shown in Figure 2.

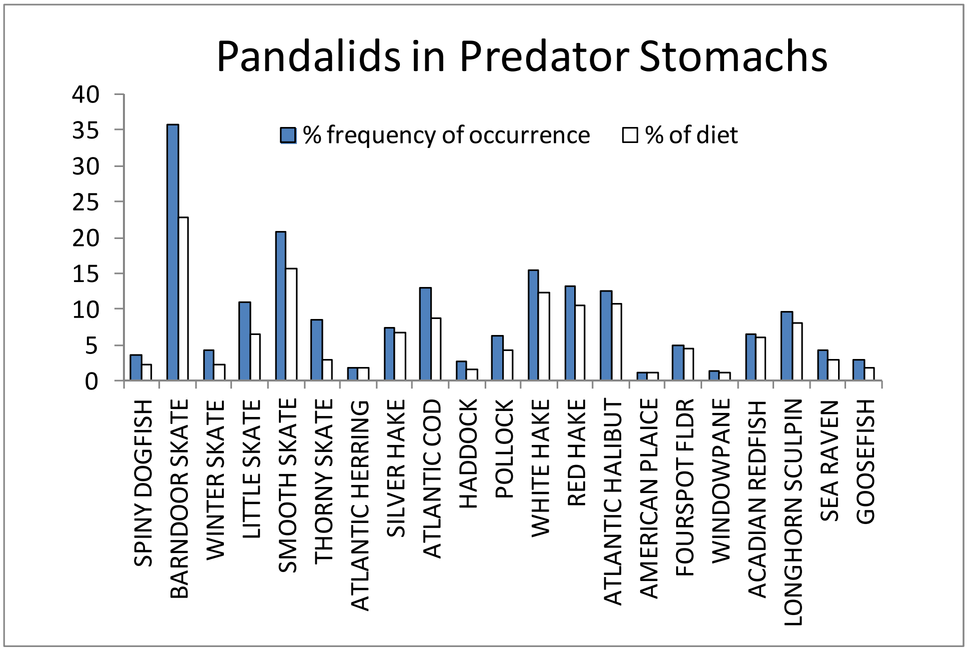
	WHITE HAKE*	RED HAKE*	SILVER HAKE*	ATLANTIC COD*	HADDOCK	POLLOCK*	ACADIAN REDFISH	ATLANTIC HERRING	THORNY SKATE*	SPINY DOGFISH
1984	8.8	4.2	0.0	9.7	0.0	5.8	0.0	1.3	0.9	0.9
1985	3.6	1.9	0.6	5.4	0.0	2.2	3.3	1.3	2.8	1.3
1986	9.0	4.4	2.2	5.6	1.7	7.4	0.0	0.0	1.1	1.6
1987	6.2	8.2	1.8	4.5	0.0	2.4	0.0	0.0	0.0	0.0
1988	13.6	12.7	5.2	2.5	2.1	2.0	0.0	1.3	4.1	1.1
1989	6.4	9.2	3.2	7.8	0.0	1.5	0.0	1.3	3.4	0.5
1990	9.6	17.2	4.3	11.3	2.9	2.6	0.0	0.0	4.5	2.5
1991	23.2	21.7	9.7	15.4	5.3	6.9	12.7	1.3	6.0	2.6
1992	14.4	19.3	5.9	14.4	3.8	2.5	9.1	1.6	8.0	1.2
1993	15.8	16.4	10.6	21.7	4.8	4.4	11.6	0.9	16.5	2.8
1994	22.4	25.0	10.7	24.4	6.6	8.3	15.9	1.0	24.1	6.1
1995	28.9	22.0	15.5	22.5	0.0	7.1	16.6	2.3	8.3	3.3
1996	19.9	12.3	6.1	19.1	4.5	6.8	10.9	3.1	2.7	6.4
1997	8.0	8.5	9.7	21.3	3.3	14.7	8.0	1.2	11.1	2.0
1998	23.0	14.4	11.6	13.3	4.1	13.8	11.6	0.7	15.4	5.1
1999	23.0	18.6	11.5	16.0	3.2	3.8	14.5	0.5	23.3	7.0
2000	18.1	12.3	9.9	16.2	1.9	3.8	8.0	3.1	8.9	5.0
2001	4.5	6.2	11.0	12.4	0.0	5.8	7.2	0.8	3.1	0.5
2002	7.1	5.8	6.6	7.7	1.1	6.3	9.7	8.7	0.0	3.0
2003	8.7	1.1	7.2	7.3	3.6	7.7	0.7	3.3	11.3	6.1
2004	21.3	10.9	9.9	10.6	6.0	6.5	9.2	2.8	5.0	5.1
2005	20.7	16.7	11.1	11.7	7.7	16.2	14.4	6.9	20.0	18.8
2006	27.2	12.6	7.0	17.2	5.5	8.6	15.3	3.7	12.0	9.5
2007	13.2	2.9	2.5	12.9	3.9	5.6	6.3	1.5	3.8	2.3
2008	11.8	7.3	5.1	5.8	2.0	1.8	2.3	0.0	0.0	4.1
2009	15.5	14.7	8.5	13.0	5.3	8.8	6.5	4.1	12.7	7.5
2010	5.5	6.1	5.7	5.5	0.0	20.0	2.9	1.6	10.4	7.0
2011	9.8	7.0	3.4	12.5	0.0	6.7	1.0	0.6	6.7	4.4
2012	5.6	5.3	4.2	3.6	0.7	4.3	1.3	0.5	3.6	3.2



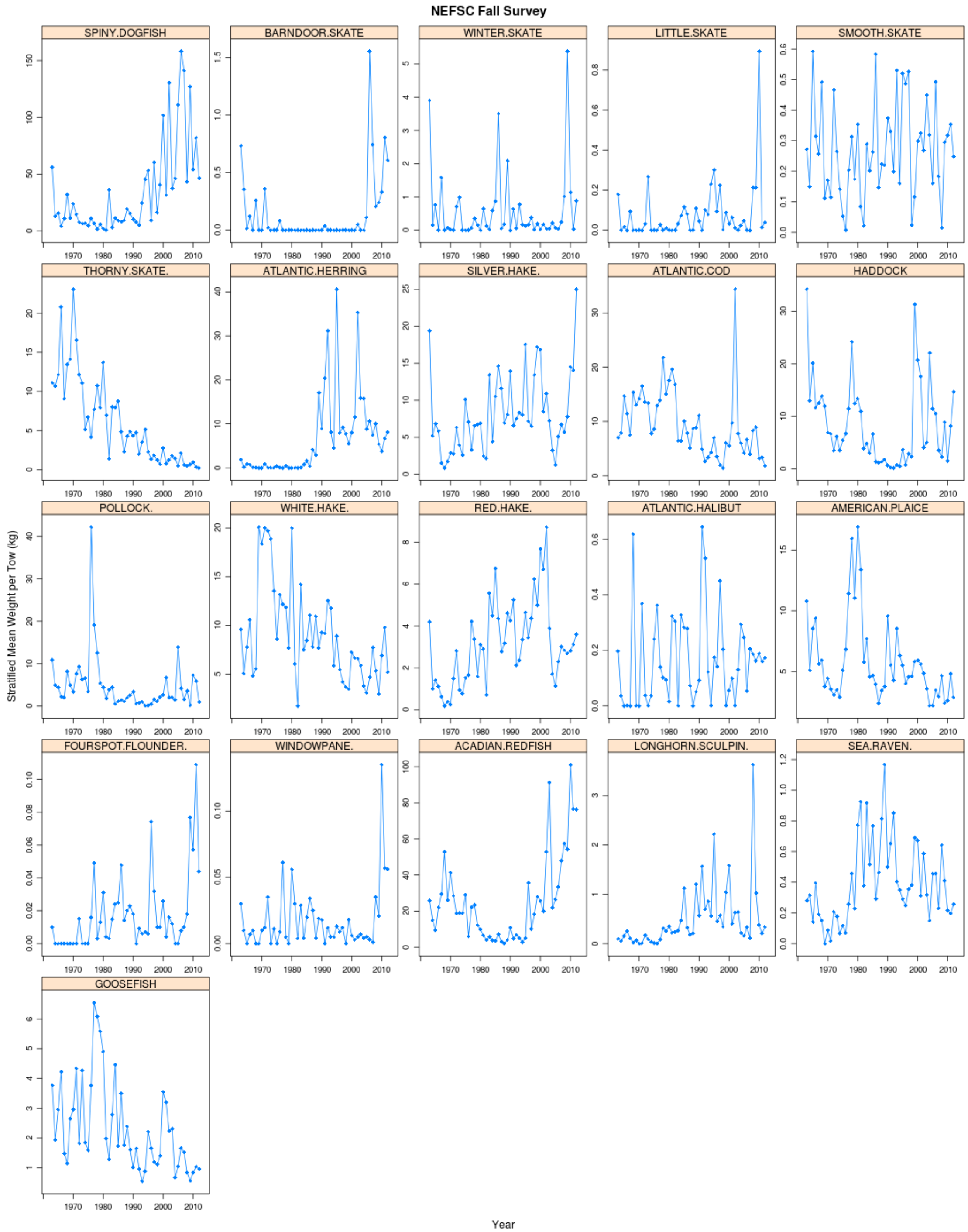
Appendix C2. Figure 1. Proportion of *P. borealis* in surveys (of total Pandalids not including *P. propinquus*), top panel fall survey; bottom panel summer shrimp survey.



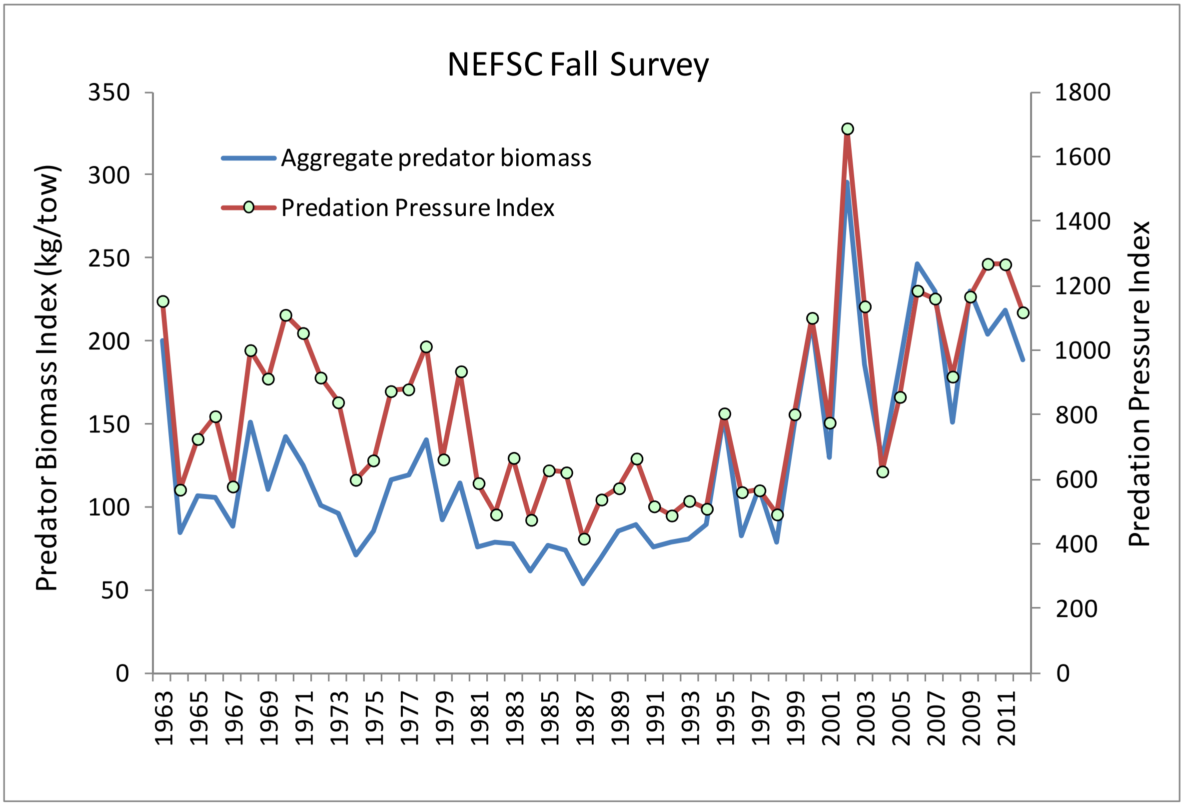
Appendix C2. Figure 2. Relationships used to fill gaps in annual % frequency in diet for predators with missing data during 1984-1998. X-axis labeled "% freq in all other predators" indicates predators with complete time series starting in 1984. CL carapace length.



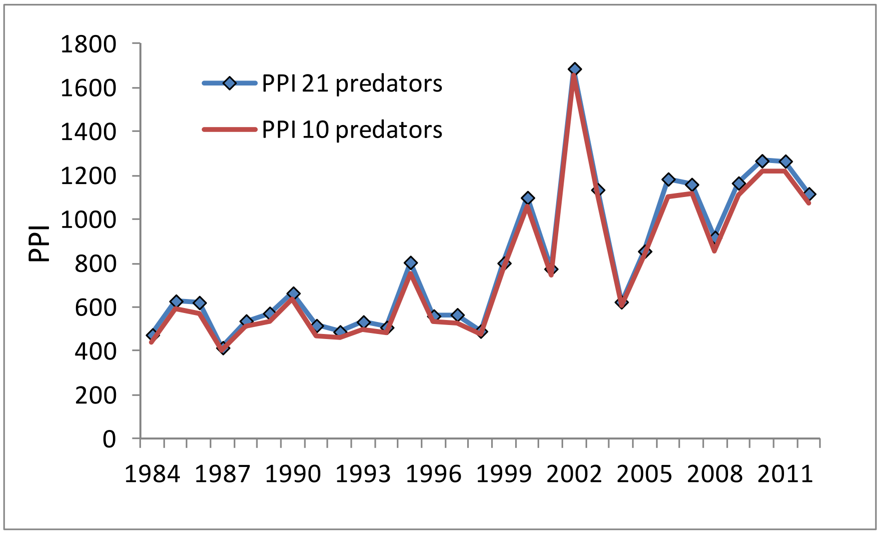
Appendix C2. Figure 3. Overall frequency of occurrence of Pandalids in predator stomachs and percent by volume of Pandalids in stomachs containing Pandalids (unweighted estimate), 1973-2011 spring and fall NEFSC surveys. 2011 data incomplete for some species.



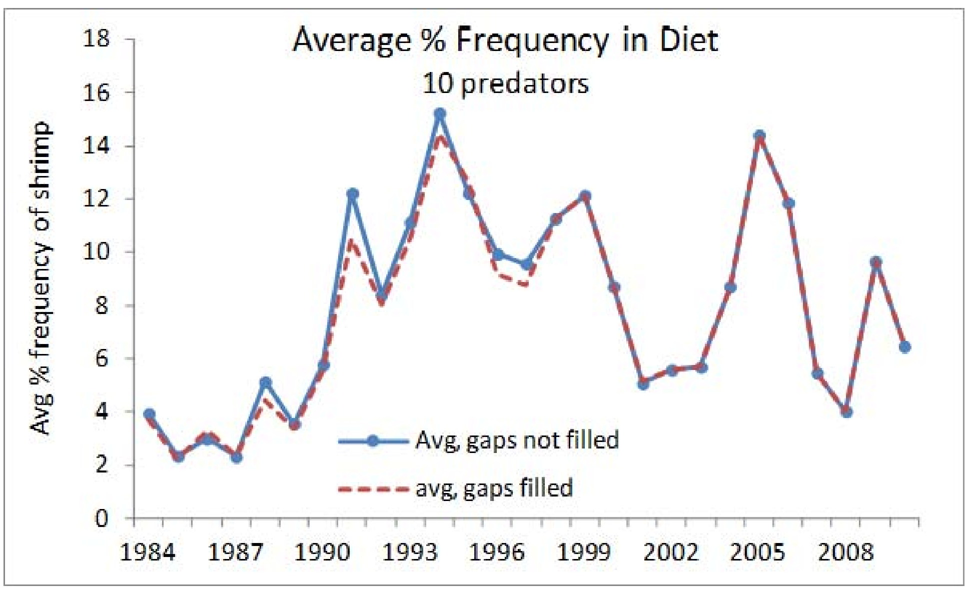
Appendix C2. Figure 4. Biomass indices (stratified mean kg per tow) for 21 predators of Pandalids in the western Gulf of Maine from NEFSC fall bottom trawl surveys. Indices for years after 2008 were adjusted for change in survey methods in 2009.



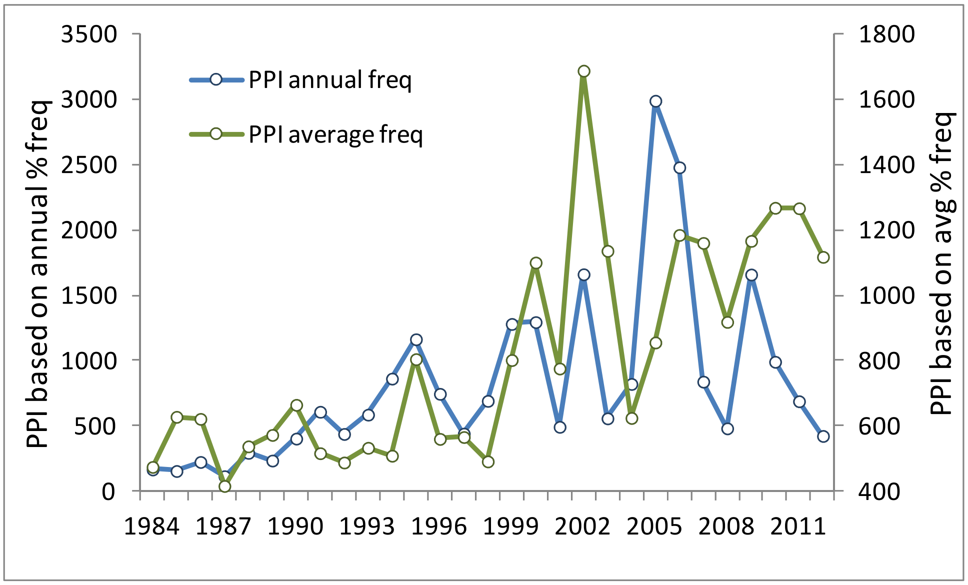
Appendix C2. Figure 5. Aggregate predator biomass indices from NEFSC fall survey (stratified mean kg per tow in shrimp assessment strata) and PPI, 1963-2012.



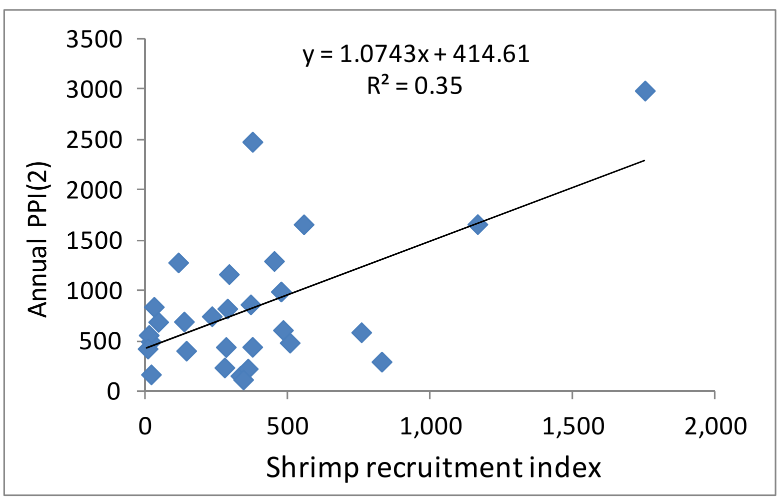
Appendix C2. Figure 6. PPI estimated from 21 species of predators vs. 10 predators that were most influential.



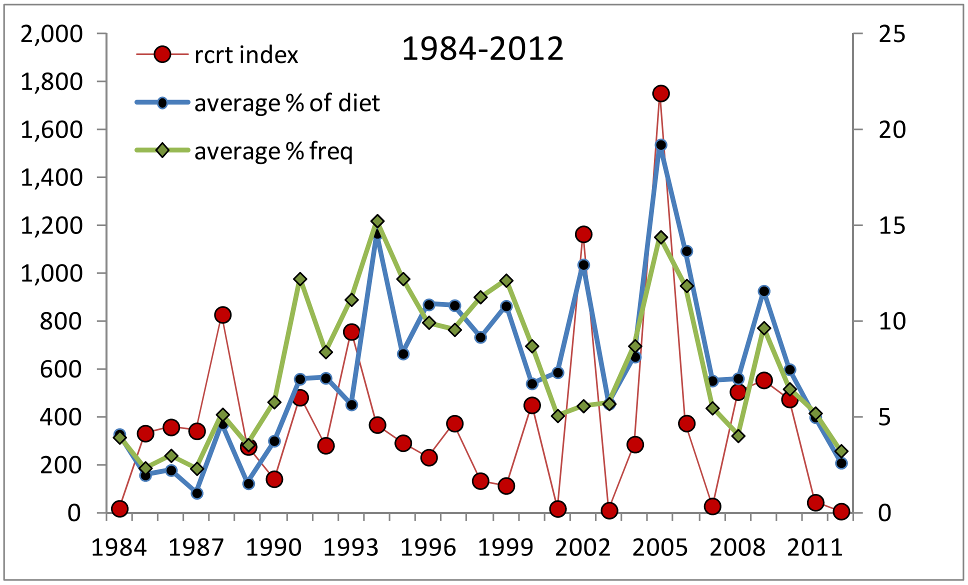
Appendix C2. Figure 7. Average annual % frequency of shrimp in diets of 10 predators with and without missing data filled in for some predators in some years.

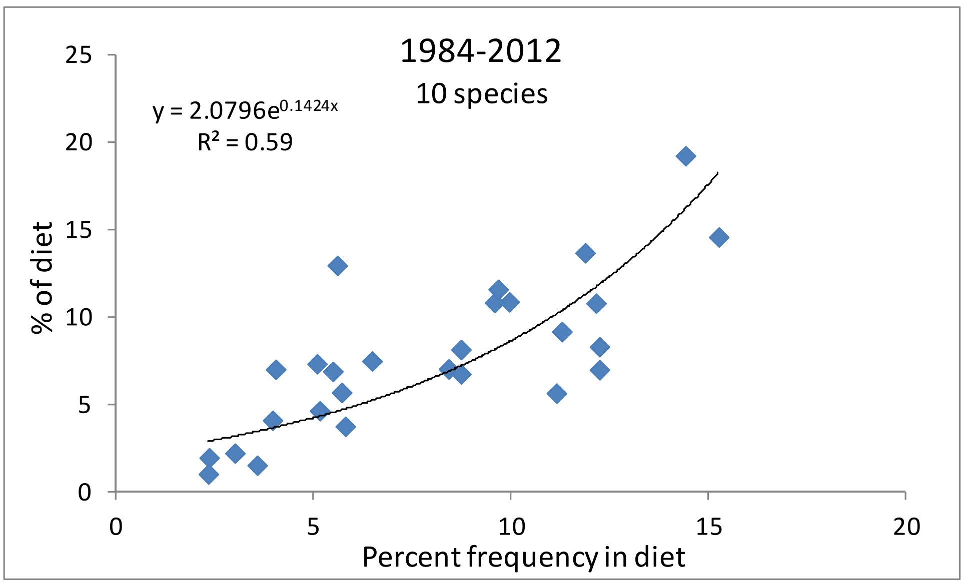


Appendix C2. Figure 8. Comparison of PPI calculated using average % frequency of Pandalids in diet for each predator (averaged over time) vs. using annual % frequency of Pandalids in diet for each predator.



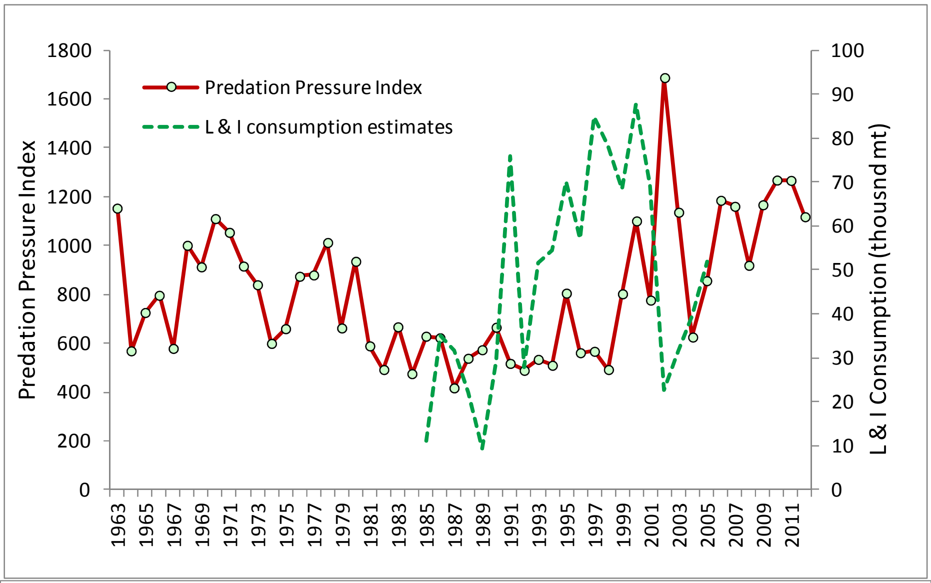
Appendix C2. Figure 9. Relationship between PPI(2) (annual % frequency) and shrimp recruitment index from summer shrimp surveys.



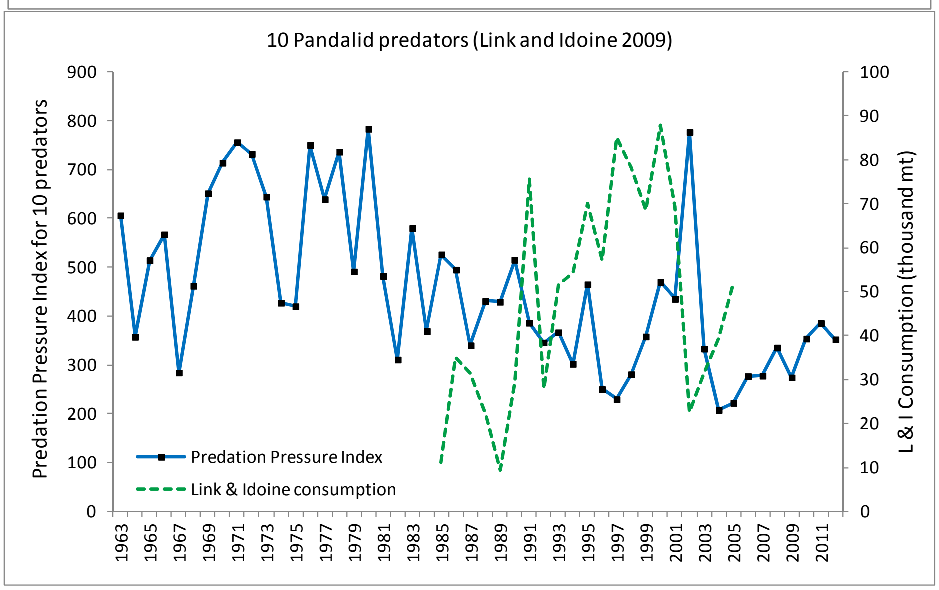


Appendix C2. Figure 10. Top: time series of recruitment indices from summer shrimp survey, % frequency of Pandalids in diet of top 10 predators, and % by volume of Pandalids in diet (unweighted). Bottom: relation between % frequency of Pandalids in diet and % by volume of Pandalids in diet.

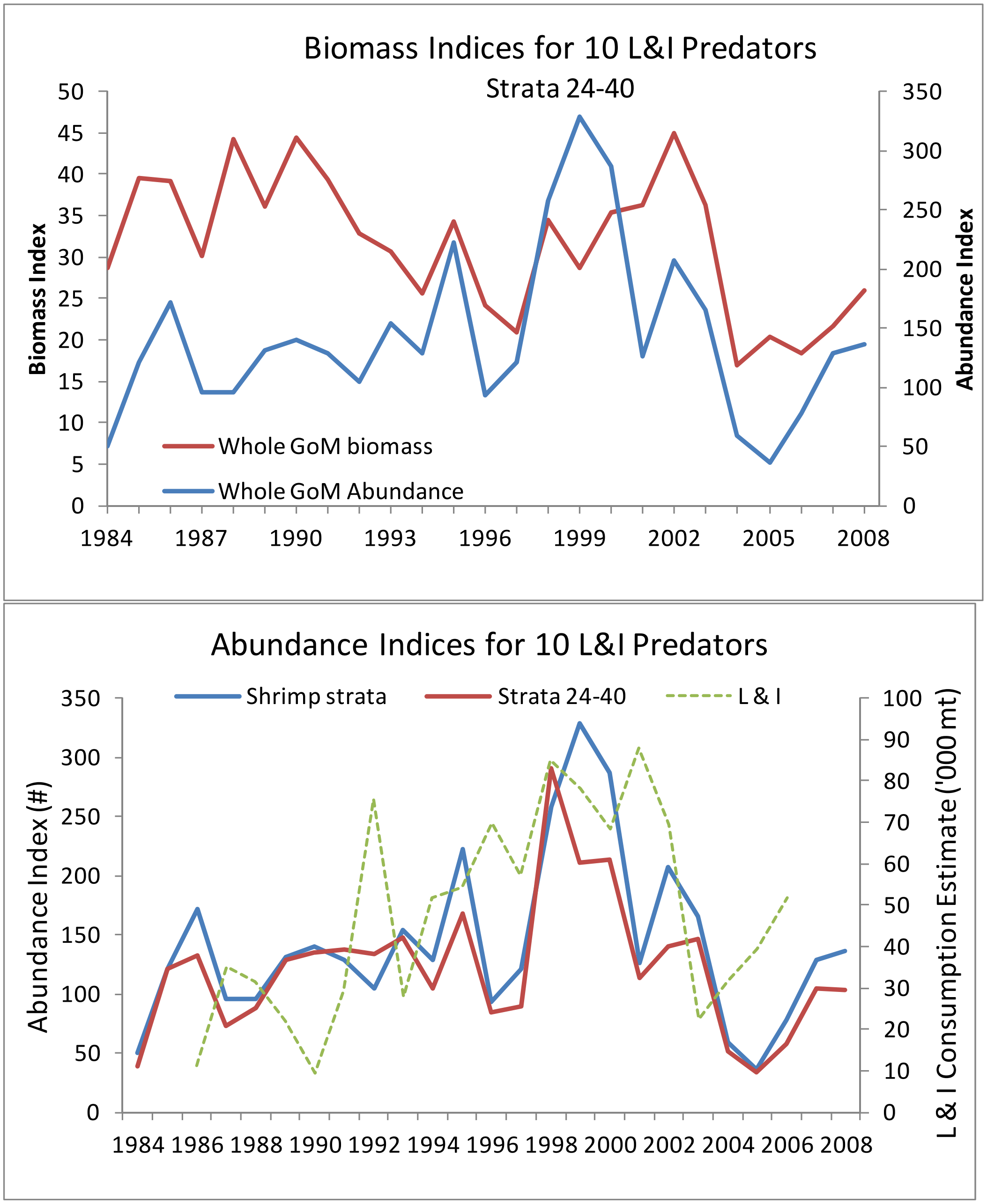
A.



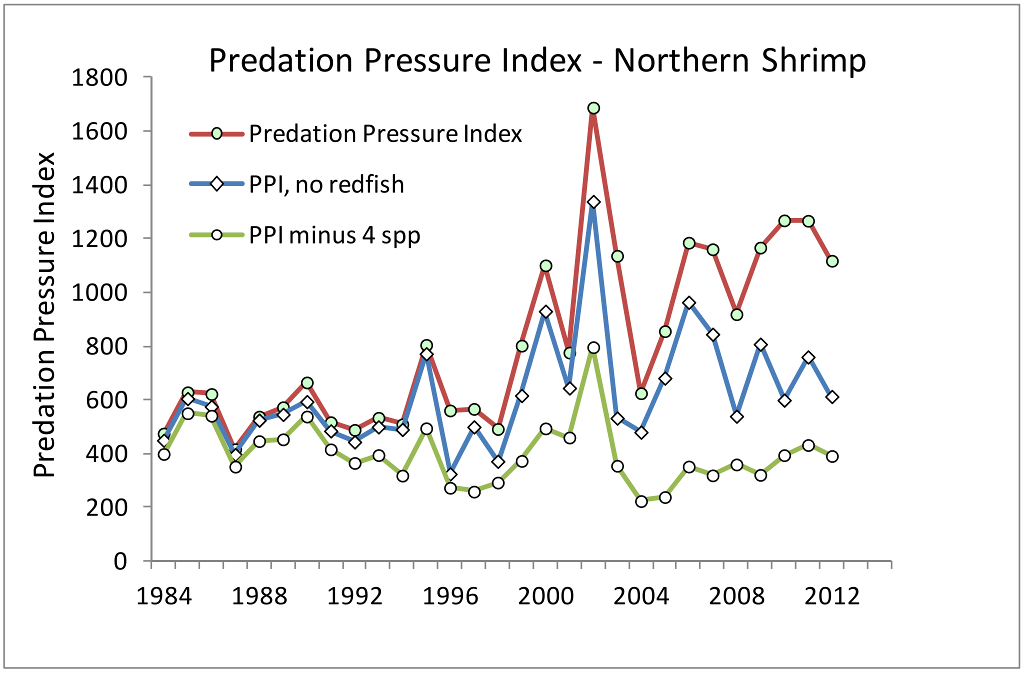
B.



Appendix C2. Figure 11. Comparison of predation pressure index (PPI) based on fall survey biomass indices with estimates of *P. borealis* consumption from Link and Idoine (2009) (L&I). (A.) PPI using 21 identified predators vs. consumption based on 10 predators estimated by L&I; (B.) PPI using only the 10 species identified by L&I vs. consumptions estimates.



Appendix C2. Figure 12. (A) Biomass and abundance for 10 L&I predators for entire Gulf of Maine; (B) abundance indices of the 10 L&I predators for the western Gulf of Maine shrimp assessment strata and the entire Gulf of Maine (strata 01240-01400), with L&I consumption estimates overlaid.



Appendix C2. Figure 13. PPI vs. PPI with redfish not included, and PPI without redfish, dogfish, herring and haddock.

Appendix C3. Technical documentation for Collie-Sissenwine Analysis (CSM, Version 4) stock assessment model

CSA is a relatively simple two-bin stock assessment model that estimates abundance, fishing mortality and recruitment using total catch numbers and survey data (Collie and Sissenwine 1983; Conser 1995). The "recruit" group in the model consists of animals that will recruit at or during the current time step. The "post-recruit" group contains all older individuals. Typically, both groups are assumed fully available to the fishery but this assumption can be relaxed in practice if fishing mortality rates are viewed as rates for fully recruited animals.

CSA (Version 4) used in this assessment was completely reprogrammed in AD-Model Builder during 2013 and is available with a graphical user interface in the NOAA Fisheries Toolbox at http://nft.nefsc.noaa.gov/. The update uses maximum likelihood rather than weighted sums of squares to estimate parameters. Multiple survey indices of two types can be used and the user must supply survey and year specific CVs that measure the precision of survey and catch observations. Pope's approximation is no longer used to simulate the population because accuracy of the approximation degrades at high mortality rates and because Baranov's catch equation (which assumes continuous fishing) works well for pulse fisheries in most cases. As in previous versions, natural morality in each year is specified by the user and not estimable in the model. The updated model does not allow for process errors because their original formulation was problematic and did not improve model performance, they can be difficult to estimate objectively, and because they are no longer required with high fishing mortality rates to avoid negative abundance estimates and numerical problems (Mesnil 2003 and p. 39 in ASMFC 2006).

Population dynamics

Abundance in each year N_y is:

$$N_y = P_y + R_y$$

where R_y is the number of new recruits to the model in year y and P_y is the abundance of all older individuals. Post-recruits are related to total abundance in the previous year:

$$P_y = N_{y-1}e^{-Z_{y-1}}$$

where $Z_y = F_y + M_y$ is the instantaneous annual rate for total mortality, and F_y and M_y are instantaneous annual rates for fishing and natural mortality. Stock biomass is calculated:

$$B_y = N_y b_y$$

where b_y is a mean weight per individual.

Post-recruits in the first year, recruitments and fishing mortality rates are parameters that can be estimated in the model. Natural mortality rates and mean weights are specified by the user and may change over time.

Observations

Predicted catch in number is calculated:

$$\hat{C}_y = \frac{F_y}{Z_y} N_y (1 - e^{-Z_y})$$

Catch weight is:

$$W_y = \hat{C}_y w_y$$

where w_y is the mean weight of individuals in the catch as specified by the user.

There are two types of surveys in the model. A "recruit/post-recruit" survey involves paired indices (one for recruits and the other for post-recruits) derived from the same survey. "Aggregate" surveys involve a single index (for recruits plus post-recruits, recruits only or post-recruits only, but see below in the latter case) from each survey. Recruit/post-recruit surveys involve an assumption about catchability of recruits relative to post-recruits. The aggregate approach is the same as used in most other stock assessment models but using a single selectivity parameter for recruits that can be estimated in the model (the selectivity of post-recruits is assumed equal to one and recruit selectivity can be larger or smaller).[1] Multiple surveys of either type can be used in the same model run. It is probably better, however, to use only one recruit/post-recruit pair at a time because relative catchability assumptions have a very strong effect on model estimates. Relative catchability assumptions for multiple surveys may conflict and cause serious problems with model fit.

Recruit/post-recruit survey data are pairs of survey indices and are derived from a single survey. Post-recruit indices are predicted:

$$\hat{p}_y = q_p P_y$$

where q_p is a catchability coefficient. Recruit indices are predicted:

$$\hat{r}_y = s_p q_p R_y$$

where s_p is a relative catchability parameter for recruits relative to post-recruits. Relative catchability is specified by the user while the catchability for post-recruits q_p is a parameter that can be estimated in the model.

Aggregate surveys are predicted:

$$\hat{u}_y = Q\left(gR_y + P_f\right)$$

where g and Q are selectivity and catchability parameters that can be estimated in the model.

[1] To implement an aggregate survey for post-recruits only, set the recruit selectivity parameter to zero. To implement an aggregate survey for recruits only, fix or estimate the recruit selectivity parameter to be a value much larger than one.

Goodness of fit

Parameters are estimated to minimize the negative log likelihood of the data. The negative log likelihood used to measure goodness of fit to the catch data assumes that measurement errors are log normal :

$$\mathcal{L} = \sum_y \left\{ \ln(s) + 0.5 \left[\frac{\ln(C_y) - \ln(\hat{C}_y)}{s} \right]^2 \right\}$$

where s is a log scale standard deviation based on an assumed CV measurement errors in the catch data that are supplied by the user:

$$s = \sqrt{\ln(CV^2 + 1)}$$

The negative log likelihood for goodness of fit to a survey index also assumes log normal errors but the standard deviation may vary from year to year and among surveys. Using an aggregate survey as an example:

$$\mathcal{L} = \sum_y \left\{ \ln s_y + 0.5 \left[\frac{\ln(u_y) - \ln(\hat{u}_y)}{s_y} \right]^2 \right\}$$

The annual variances are calculated from CVs for measurement errors in each survey observation that are supplied by the user.

The total negative log likelihood used to estimate parameters is:

$$\mathcal{L}_{total} = \sum_j \omega_j \mathcal{L}_j$$

where the ω_j are user specified weights for each type of data in the model. The user specified weights are normally one except during sensitivity or other types of diagnostic analyses.

The user can "tune" variances used in goodness of fit calculations by adjusting the assumed CVs. In particular, the assumed CVs may be adjusted over the course of several runs until the implied CV based on residuals approximately matches the assumed value:

$$CV_{implied} = \sqrt{e^{s^2} - 1}$$

and s^2 is the variance of the log scale residuals.

Variances for model parameters and other model estimates can be calculated in CSA by asymptotic approximation or MCMC analysis. The software produces a comma delimited database file containing data, estimates and diagnostics as well as a separate output file for likelihood profile analysis. The NOAA Fisheries Tool Box GUI produces a number of useful graphics and diagnostics. An R program that creates graphics and additional diagnostics is also available on the Tool Box website.

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Appendix C4. Parameter estimates from CSA final model.

index	name	value	std.dev
1	logrhat	6.91	0.33
2	logrhat	7.06	0.28
3	logrhat	6.77	0.30
4	logrhat	6.56	0.29
5	logrhat	6.79	0.31
6	logrhat	7.05	0.24
7	logrhat	6.66	0.25
8	logrhat	6.33	0.26
9	logrhat	6.25	0.26
10	logrhat	6.76	0.30
11	logrhat	6.95	0.29
12	logrhat	6.92	0.25
13	logrhat	6.49	0.29
14	logrhat	6.75	0.36
15	logrhat	6.75	0.34
16	logrhat	5.76	0.32
17	logrhat	6.46	0.34
18	logrhat	6.01	0.37
19	logrhat	7.08	0.28
20	logrhat	6.65	0.42
21	logrhat	7.45	0.29
22	logrhat	8.39	0.23
23	logrhat	8.69	0.22
24	logrhat	6.43	0.39
25	logrhat	6.85	0.29
26	logrhat	6.99	0.28
27	logrhat	7.16	0.21
28	logrhat	5.61	0.41
29	logrhat	4.40	0.39
30	logrhat	2.65	0.46
31	logf_calc	-1.47	0.26
32	logf_calc	-1.56	0.24
33	logf_calc	-1.32	0.24
34	logf_calc	-1.92	0.25
35	logf_calc	-1.72	0.24
36	logf_calc	-1.42	0.23
37	logf_calc	-1.54	0.24
38	logf_calc	-1.59	0.25
39	logf_calc	-1.88	0.26
40	logf_calc	-1.69	0.25
41	logf_calc	-0.89	0.23
42	logf_calc	-0.32	0.26
43	logf_calc	0.04	0.30
44	logf_calc	-0.80	0.36
45	logf_calc	-1.66	0.24
46	logf_calc	-1.11	0.26
47	logf_calc	-1.69	0.28
48	logf_calc	-2.69	0.26
49	logf_calc	-2.06	0.25
50	logf_calc	-1.32	0.32
51	logf_calc	-1.97	0.26
52	logf_calc	-3.06	0.22
53	logf_calc	-2.43	0.21
54	logf_calc	-1.84	0.22
55	logf_calc	-2.24	0.23
56	logf_calc	-1.12	0.25
57	logf_calc	-0.72	0.22
58	logf_calc	-0.60	0.32
59	logf_calc	-2.05	0.38
60	logf_calc	-16.22	0.38
61	logqhat	-0.6304	0.1614
62	logqhat	-1.9209	0.2062
63	logqhat	0.0540	0.3174
64	logphat1	6.8974	0.4082
65	logsrx[2]	0.0000	0.0002
66	logsrx[3]	-6.9077	0.1925
67	rhat	998.0	328.8
68	rhat	1166.9	332.0
69	rhat	873.8	266.3
70	rhat	705.9	206.1
71	rhat	887.2	272.8
72	rhat	1148.7	270.0
73	rhat	778.0	196.9
74	rhat	560.3	147.7
75	rhat	518.2	136.9
76	rhat	864.5	261.3
77	rhat	1042.0	299.5
78	rhat	1016.9	254.8
79	rhat	657.9	190.0
80	rhat	855.3	304.5
81	rhat	853.5	289.7
82	rhat	317.0	101.7
83	rhat	640.8	220.4
84	rhat	407.6	149.0
85	rhat	1183.2	330.7
86	rhat	769.1	324.5
87	rhat	1721.9	505.7
88	rhat	4386.8	1007.8
89	rhat	5943.9	1335.3
90	rhat	620.7	243.2
91	rhat	944.3	274.6
92	rhat	1084.6	300.9
93	rhat	1286.9	274.1
94	rhat	274.2	113.3
95	rhat	81.7	32.0
96	rhat	14.2	6.5
97	f_calc	0.23	0.06
98	f_calc	0.21	0.05
99	f_calc	0.27	0.06
100	f_calc	0.15	0.04
101	f_calc	0.18	0.04
102	f_calc	0.24	0.05
103	f_calc	0.21	0.05
104	f_calc	0.20	0.05
105	f_calc	0.15	0.04
106	f_calc	0.18	0.05
107	f_calc	0.41	0.10
108	f_calc	0.73	0.19
109	f_calc	1.05	0.31
110	f_calc	0.45	0.16
111	f_calc	0.19	0.05
112	f_calc	0.33	0.09
113	f_calc	0.18	0.05
114	f_calc	0.07	0.02
115	f_calc	0.13	0.03
116	f_calc	0.27	0.09
117	f_calc	0.14	0.04
118	f_calc	0.05	0.01
119	f_calc	0.09	0.02
120	f_calc	0.16	0.04
121	f_calc	0.11	0.02
122	f_calc	0.33	0.08
123	f_calc	0.49	0.11
124	f_calc	0.55	0.18
125	f_calc	0.13	0.05
126	f_calc	0.00	0.00
127	qhat	0.53	0.09
128	qhat	0.15	0.03
129	qhat	1.06	0.33
130	phat	989.68	403.97
131	phat	1177.70	342.27
132	phat	1289.30	334.76
133	phat	1126.60	305.96
134	phat	1223.30	320.03
135	phat	1264.90	319.52
136	phat	1330.60	332.97
137	phat	1127.90	293.97
138	phat	999.42	275.46
139	phat	962.49	266.14
140	phat	1092.60	295.76
141	phat	1031.50	288.23
142	phat	600.48	220.71
143	phat	312.69	151.93
144	phat	525.85	235.60
145	phat	841.41	221.47
146	phat	507.00	155.61
147	phat	483.17	146.02
148	phat	515.08	135.05
149	phat	526.59	140.54
150	phat	491.95	179.47
151	phat	1308.90	364.90
152	phat	3201.80	691.58
153	phat	4026.70	851.99
154	phat	1935.80	461.58
155	phat	1467.80	353.04
156	phat	896.52	264.28
157	phat	611.77	173.23
158	phat	234.16	98.54
159	phat	139.24	56.51
160	phat	76.89	29.34
161	totnum	1987.7	459.9
162	totnum	2344.7	494.3
163	totnum	2163.1	450.3
164	totnum	1832.5	414.2
165	totnum	2110.5	446.0
166	totnum	2413.6	475.2
167	totnum	2108.6	443.9
168	totnum	1688.1	379.4
169	totnum	1517.6	360.1
170	totnum	1827.0	411.7
171	totnum	2134.6	397.6
172	totnum	2048.4	373.1
173	totnum	1258.3	224.7
174	totnum	1168.0	336.6
175	totnum	1379.4	300.5
176	totnum	1158.4	256.6
177	totnum	1147.8	288.8
178	totnum	890.8	218.2
179	totnum	1698.3	399.3
180	totnum	1295.7	363.8
181	totnum	2213.8	537.5
182	totnum	5695.7	1174.0
183	totnum	9145.7	1772.6
184	totnum	4647.5	946.6
185	totnum	2880.1	623.1
186	totnum	2552.4	546.4
187	totnum	2183.4	387.0
188	totnum	885.9	219.3
189	totnum	315.9	112.9
190	totnum	153.4	58.5
191	totbio	14.47	3.49
192	totbio	19.82	4.21
193	totbio	19.56	4.12
194	totbio	16.66	3.83
195	totbio	14.84	3.20
196	totbio	18.37	3.67
197	totbio	19.86	4.23
198	totbio	16.10	3.74
199	totbio	13.65	3.34
200	totbio	11.98	2.74
201	totbio	15.12	2.85
202	totbio	16.69	3.15
203	totbio	10.22	2.01
204	totbio	7.54	2.14
205	totbio	9.62	2.13
206	totbio	9.93	2.26
207	totbio	8.22	2.02
208	totbio	6.73	1.64
209	totbio	9.17	2.07
210	totbio	9.01	2.43
211	totbio	16.62	3.91
212	totbio	34.65	7.01
213	totbio	63.30	12.11
214	totbio	39.53	8.07
215	totbio	26.06	5.67
216	totbio	22.26	4.78
217	totbio	15.80	2.95
218	totbio	6.81	1.69
219	totbio	2.92	1.07
220	totbio		

Appendix C5. Changes to Gulf of Maine Northern Shrimp Data Since the 2007 SAW

Landings data from the NMFS landings database (derived from dealer reports) were queried in 2009 (and again in 2012 without change), and the northern shrimp landings for 1958 through 1999 were updated for the 2013 assessment. See Appendix C5 Table 1 for a comparison. Most changes were small, with a mix of additions and reductions. The greatest change was the addition of 373 mt to the 1996 landings.

Landings data for 2000 through 2006 were queried from the federal and Maine state harvester report data in 2011, and are compared with data from the 2007 SAW in Appendix C5 Table 1. All data differences were additions, with the greatest being the addition of 465 mt in 2000 (which had previously been based on the dealer database) and an additional 446 mt in 2006 (the terminal year at the time of the 2007 SAW), probably due to the receipt of additional, late 2006 harvester reports.

The numbers of vessels in the fishery for recent years (since 1997) was also reported in the 2007 SAW report. In 2011, corrections were made to these data. 1997 through 1999 were compared with the data reported in the 1997 through 1999 NSTC stock assessment reports and one minor modification was made. For 2000 through 2006, the vessel counts were re-calculated from the harvester report database. The most notable differences were for 2003, in which the number of vessels had been over-reported by about 12% in the earlier report, possibly because of double counting of vessels that were in both the federal and Maine state databases, and for 2006, the terminal year for the 2007 report, in which vessels were under-reported by about 17%, probably because of late harvester reporting (Appendix C5 Table 2).

The numbers of trips in the fishery were also re-calculated for 2000 through 2006. In the 2007 report, trap trips for 2000-2006 had not been included, so the total number of trips increased about 15% to 30%. The total trips for 1987 were also adjusted to include a few out-of-season experimental trips, to be consistent with other years (Appendix C5 Table 3).

During 2013, the NSTC reviewed all the port sample data from 1985 through 2012, in an effort to standardize and computerize all data, particularly for Maine, by reviewing raw data sheets and older databases. Data for samples that had not been computerized were found and added, and others were corrected. A few samples that were found to be incomplete in the databases (some lengths missing or the catch or sample weights missing) and for which no raw data sheets could be found were eliminated. The biggest change was the addition of several samples for 1993, which resulted in a 10% increase in the number of shrimp measured for that year (Appendix C5 Table 4).

The NSTC also reviewed and changed the way the port sample data were expanded to landings to estimate the total number of shrimp in catches. In the past, all the samples for each state-month-gear were pooled, and the average weight of a shrimp was calculated by dividing the total weight of the samples by the total number of northern shrimp in those samples, for each state, month, and gear. Then the landings for that state-month-gear were divided by the average weight of one shrimp, to estimate the total number of shrimp in the landings, for each season. In 2013, the NSTC recalculated these estimates for 1985-2013, by first expanding each sample to that sample's catch weight before pooling by state, month and gear. This resulted in larger catches being more heavily weighted in the calculation. This had a relatively small effect, without trend, on the calculation of the mean weight of a shrimp, however. The greatest change was a 6% increase in the mean weight in 1999. (Appendix C5 Table 5).

The changes noted above to the landings data, corrections to the port sample data, and the re-weighting of the sample data, all resulted in changes to the estimated number of shrimp in the landings, used in the CSA model input. Most notable were increases in the 2000-2006 estimates, closely aligned with the increases in reported landings described above, with the largest increase of 19% in 2006 (the terminal year) (Appendix C5 Table 6).

Maine pounds per hour towing data from port interviews were unchanged, except that the 1999 value was corrected from 152 lbs/hr to 147 lbs/hr because of the addition of data for 27 more interviews.

Pounds per trip changed somewhat because of the changes to the total landings and the number of trips described above. Pounds per trip generally declined for 2000-2006 in the 2013 assessment because of the inclusion of trap trips, which usually have a lower mean catch rate per trip than trawl trips (Appendix C5 Table 7).

Minor corrections were made to the ASMFC summer survey data. For the 1985 survey, the retransformed age 1.5 number per tow was corrected from 337 to 332, the >22mm number per tow from 1,184 to 1,169, and the total number per tow from 1,849 to 1,825. For the 2006 survey, the retransformed age 1.5 number per tow was corrected from 423 to 374, the >22mm number per tow from 2,703 to 2,773, and the total number per tow from 9,996 to 9,998.

Appendix C5. Table 1. Northern shrimp landings data (mt) as reported in the 2007 SAW report compared with the 2013 assessment.

	2013		2007 SAW		Difference (mt)	% of 2013
	annual	seasonal	annual	seasonal		
1958	2.2		2.3		-0.1	-4.5%
1959	7.8		7.7		0.1	1.3%
1960	40.9		40.9		0.0	0.0%
1961	30.8		30.9		-0.1	-0.3%
1962	175.7		176.0		-0.3	-0.2%
1963	254.7		254.4		0.3	0.1%
1964	422.5		422.5		0.0	0.0%
1965	949.3		955.0		-5.7	-0.6%
1966	1,766.4		1,766.4		0.0	0.0%
1967	3,171.2		3,171.1		0.1	0.0%
1968	6,610.2		6,610.0		0.2	0.0%
1969	12,824.3		12,823.9		0.4	0.0%
1970	10,669.5		10,669.3		0.2	0.0%
1971	11,129.6		11,129.3		0.3	0.0%
1972	11,095.0		11,094.9		0.1	0.0%
1973	9,404.7		9,404.8		-0.1	0.0%
1974	7,944.7		7,944.7		0.0	0.0%
1975	5,286.6		5,286.7		-0.1	0.0%
1976	1,022.4		1,022.3		0.1	0.0%
1977	381.2		387.2		-6.0	-1.6%
1978	3.3		0.0		3.3	100.0%
1979	438.7		486.5		-47.8	-10.9%
1980	332.8		339.1		-6.3	-1.9%
1981	1,073.9		1,071.2		2.7	0.3%
1982	1,574.3		1,574.5		-0.2	0.0%
1983	1,573.9		1,566.5		7.4	0.5%
1984	3,226.9		3,226.8		0.1	0.0%
1985		4,131.9		4,130.9	1.0	0.0%
1986		4,635.0		4,635.0	0.0	0.0%
1987		5,266.0		5,253.2	12.8	0.2%
1988		3,035.6		3,031.3	4.3	0.1%
1989		3,315.4		3,315.4	0.0	0.0%
1990		4,662.5		4,661.6	0.9	0.0%
1991		3,585.3		3,571.4	13.9	0.4%
1992		3,460.0		3,443.6	16.4	0.5%
1993		2,142.9		2,142.9	0.0	0.0%
1994		2,915.2		2,914.8	0.4	0.0%
1995		6,456.6		6,466.4	-9.8	-0.2%
1996		9,539.4		9,166.1	373.3	3.9%
1997		7,119.5		7,079.1	40.4	0.6%
1998		4,166.8		4,174.4	-7.6	-0.2%
1999		1,865.9		1,816.1	49.8	2.7%
2000		2,855.0		2,389.5	465.5	16.3%
2001		1,331.0		1,329.1	1.9	0.1%
2002		452.7		423.7	29.0	6.4%
2003		1,344.4		1,211.00	133.4	9.9%
2004		2,131.4		1,948.70	182.7	8.6%
2005		2,610.1		2,553.20	56.9	2.2%
2006		2,322.7		1,876.60	446.1	19.2%

Appendix C5. Table 2. Northern shrimp fishery numbers of vessels in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1997	311	310	1	0.3%
1998	260	260	0	0.0%
1999	238	238	0	0.0%
2000	304	285	19	6.3%
2001	275	288	-13	-4.7%
2002	198	200	-2	-1.0%
2003	222	248	-26	-11.7%
2004	192	190	2	1.0%
2005	197	197	0	0.0%
2006	144	119	25	17.4%

Appendix C5. Table 3. Northern shrimp fishery numbers of trips in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1987	12,497	12,285	212	1.7%
1988	9,240	9,240	0	0.0%
1989	9,561	9,561	0	0.0%
1990	9,758	9,758	0	0.0%
1991	7,968	7,968	0	0.0%
1992	7,798	7,798	0	0.0%
1993	6,158	6,158	0	0.0%
1994	5,990	5,990	0	0.0%
1995	10,465	10,465	0	0.0%
1996	11,791	11,791	0	0.0%
1997	10,734	10,734	0	0.0%
1998	6,606	6,606	0	0.0%
1999	3,811	3,811	0	0.0%
2000	4,554	3,335	1,219	26.8%
2001	4,133	3,599	534	12.9%
2002	1,304	1,010	294	22.5%
2003	3,022	2,157	865	28.6%
2004	2,681	2,277	404	15.1%
2005	3,866	3,091	775	20.0%
2006	2,478	1,646	832	33.6%

Appendix C5. Table 4. Numbers of shrimp measured from port samples, as reported in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1985	6,032	5,998	34	1%
1986	6,415	6,259	156	2%
1987	5,699	5,603	96	2%
1988	6,393	6,079	314	5%
1989	8,885	9,351	-466	-5%
1990	8,132	8,248	-116	-1%
1991	15,058	14,611	447	3%
1992	10,225	10,111	114	1%
1993	12,852	11,556	1,296	10%
1994	12,221	11,076	1,145	9%
1995	14,270	13,977	293	2%
1996	28,320	27,903	417	1%
1997	35,033			
1998	23,916			
1999	22,529			
2000	11,458			
2001	14,714	15,091	-377	-3%
2002	5,243	5,243	0	0%
2003	11,805	11,596	209	2%
2004	10,972	10,432	540	5%
2005	19,539	19,539	0	0%
2006	16,218	16,314	-96	-1%

Appendix C5. Table 5. Mean weight of a shrimp (g) in the landings, as used by CSA in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1985	11.6	11.7	-0.1	-0.9%
1986	12.6	12.8	-0.3	-2.2%
1987	12.4	12.4	0.1	0.5%
1988	13.8	13.3	0.5	3.8%
1989	11.2	11.7	-0.5	-4.4%
1990	10.7	10.5	0.1	1.2%
1991	10.7	11.2	-0.4	-4.2%
1992	12.9	13.1	-0.2	-1.6%
1993	11.5	11.0	0.5	4.0%
1994	11.1	10.8	0.3	2.8%
1995	10.3	10.5	-0.2	-2.1%
1996	11.0	11.5	-0.4	-4.0%
1997	9.9	10.0	0.0	-0.1%
1998	11.5	11.2	0.4	3.2%
1999	9.0	8.4	0.6	6.3%
2000	10.9	11.4	-0.5	-4.4%
2001	9.4	9.4	-0.1	-0.6%
2002	9.6	9.5	0.1	0.9%
2003	10.5	10.7	-0.2	-1.4%
2004	9.6	9.8	-0.2	-1.7%
2005	10.9	10.9	0.0	-0.3%
2006	11.4	11.5	0.0	-0.2%

Appendix C5. Table 6. Estimated numbers of shrimp (millions) in landings, as used by CSA in the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1985	356	353	3	1%
1986	369	361	8	2%
1987	424	425	-1	0%
1988	220	228	-8	-4%
1989	296	284	12	4%
1990	437	442	-5	-1%
1991	335	320	15	4%
1992	268	262	6	2%
1993	187	195	-8	-4%
1994	263	270	-7	-3%
1995	627	615	12	2%
1996	865	799	66	8%
1997	716	711		
1998	361	374		
1999	207	215		
2000	261	209		
2001	142	141	1	1%
2002	47	44	3	6%
2003	128	114	14	11%
2004	221	199	22	10%
2005	240	234	6	3%
2006	203	164	39	19%

Appendix C5. Table 7. Mean pounds per trip from the 2007 SAW report compared with the 2013 assessment.

	2013	2007 SAW	Difference	% of 2013
1991	992	988	4	0.4%
1992	978	974	4	0.4%
1993	767	767	0	0.0%
1994	1,073	1,073	0	0.0%
1995	1,360	1,362	-2	-0.1%
1996	1,784	1,714	70	3.9%
1997	1,462	1,454	8	0.6%
1998	1,391	1,317	74	5.3%
1999	1,079	1,067	12	1.1%
2000	1,382	1,444	-62	-4.5%
2001	710	740	-30	-4.2%
2002	765	831	-66	-8.6%
2003	981	1,029	-48	-4.9%
2004	1,753	1,821	-68	-3.9%
2005	1,488	1,541	-53	-3.5%
2006	2,066	2,252	-186	-9.0%

Appendix C6. Additional Model Runs Conducted during SARC58 Review

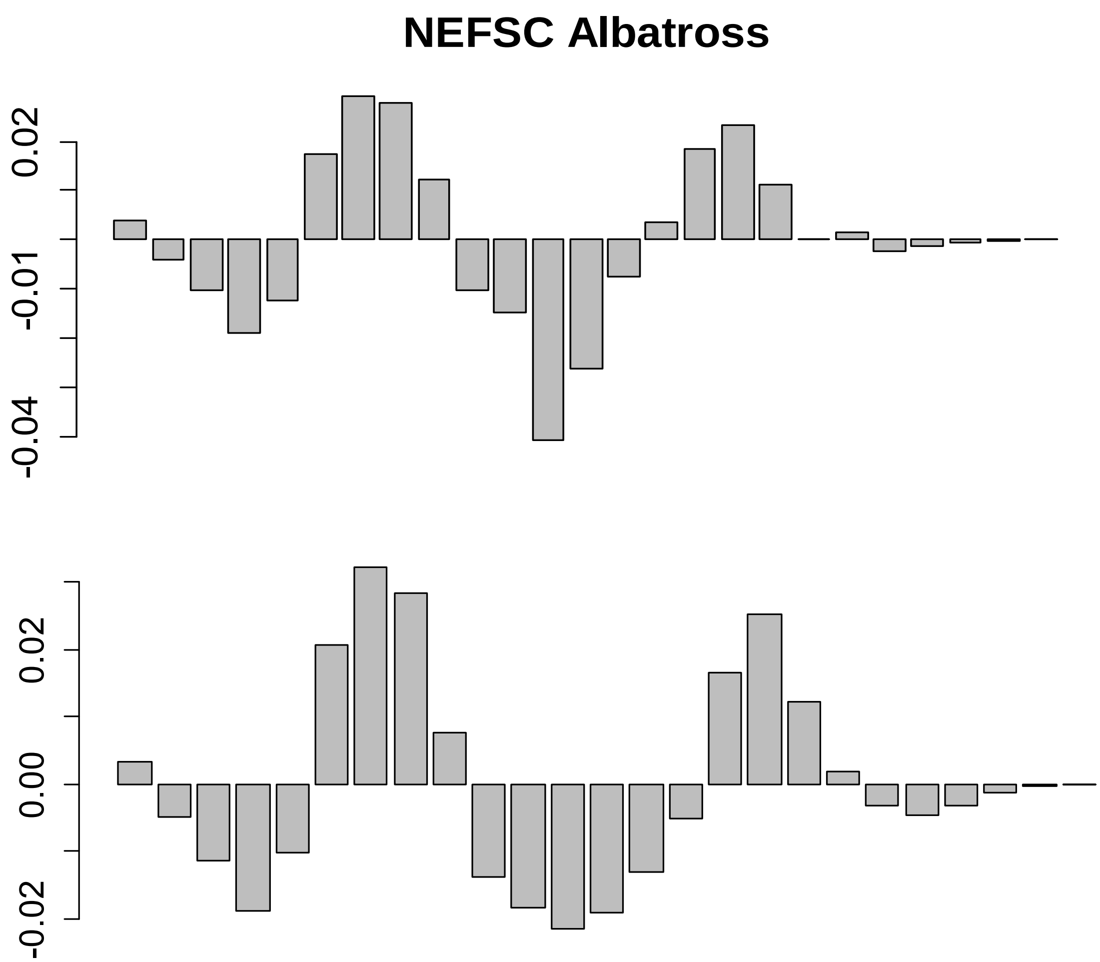
The Panel requested additional runs of the UME and CSA model at the workshop to explore the effects of data weighting on the fit to the indices and model estimates of F.

Table C6.1 Requested and additional weighting schemes for the UME model. All runs were done with M=0.5 for all size classes.

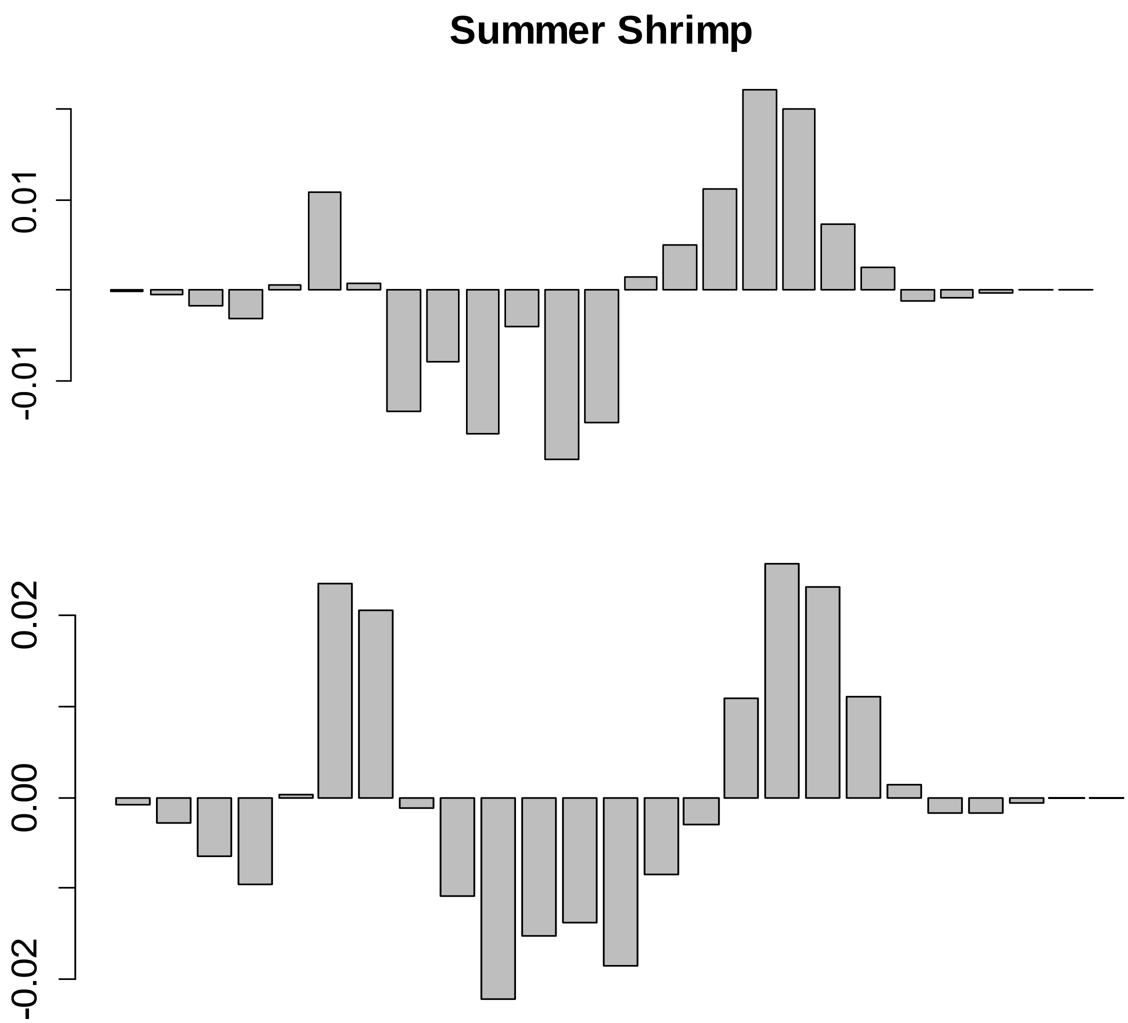
Base Model	Panel Request
Survey λ = 1 **Total catch λ = 1** **Size comp. λ = 1** **Survey CVs = CSA adjusted** **Catch CV = 0.05**	Survey λ = 2 Total catch λ = 0.5 Size comp. λ = 1 Survey CVs = CSA adjusted Catch CV = 0.05

Table C6.2. Base model and additional weighting schemes considered for the CSA model.

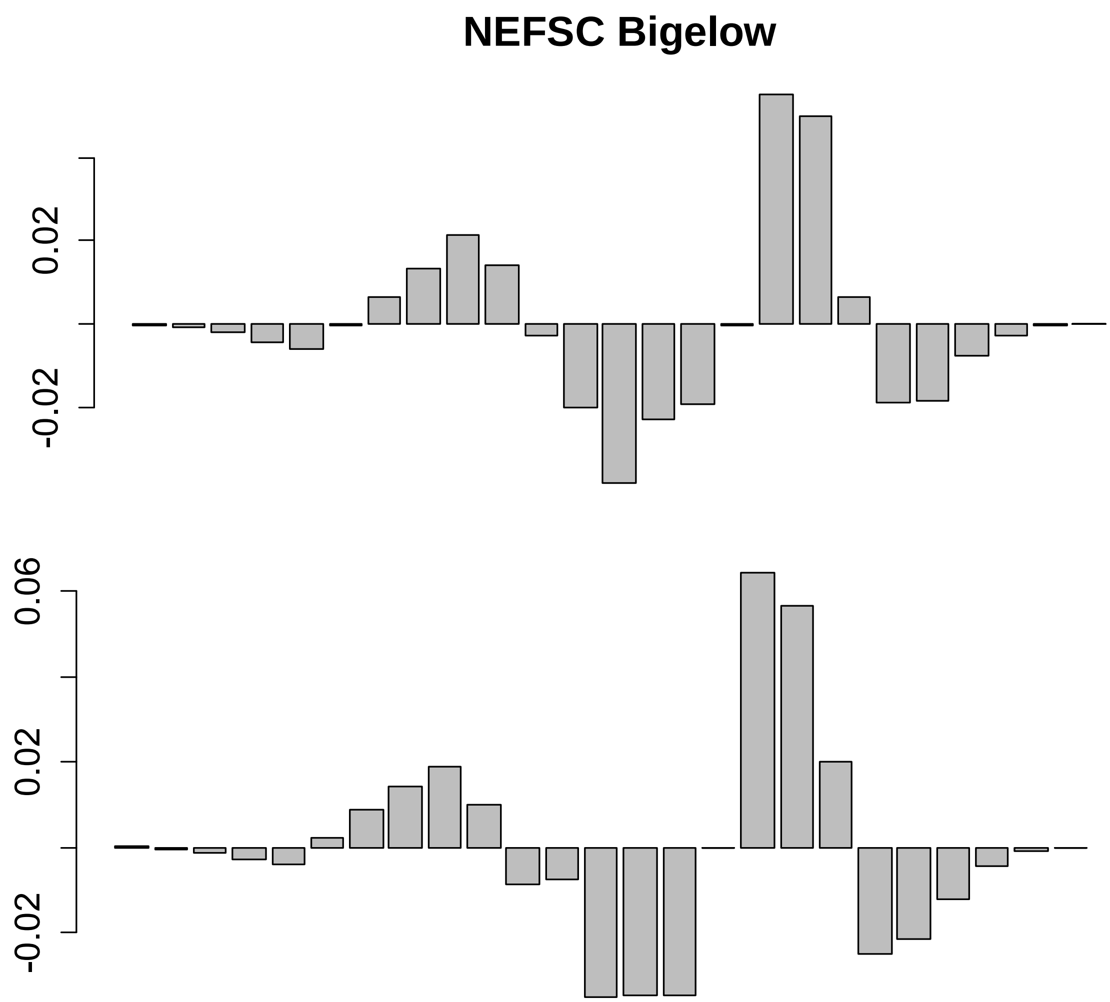
Base Model	Additional Runs	
All survey λ = 1 **Total catch λ = 1** **Survey CVs = CSA adjusted** **M=PPI** **Catch CV = 0.05**	Shrimp survey λ = 2 Total catch λ = 0.5 NEFSC survey λ = 1 Survey CVs = CSA adjusted M=PPI Catch CV=0.2	Shrimp survey λ = 2 Total catch λ = 0.01 NEFSC survey λ = 1 Survey CVs = CSA adjusted M=PPI Catch CV=0.2



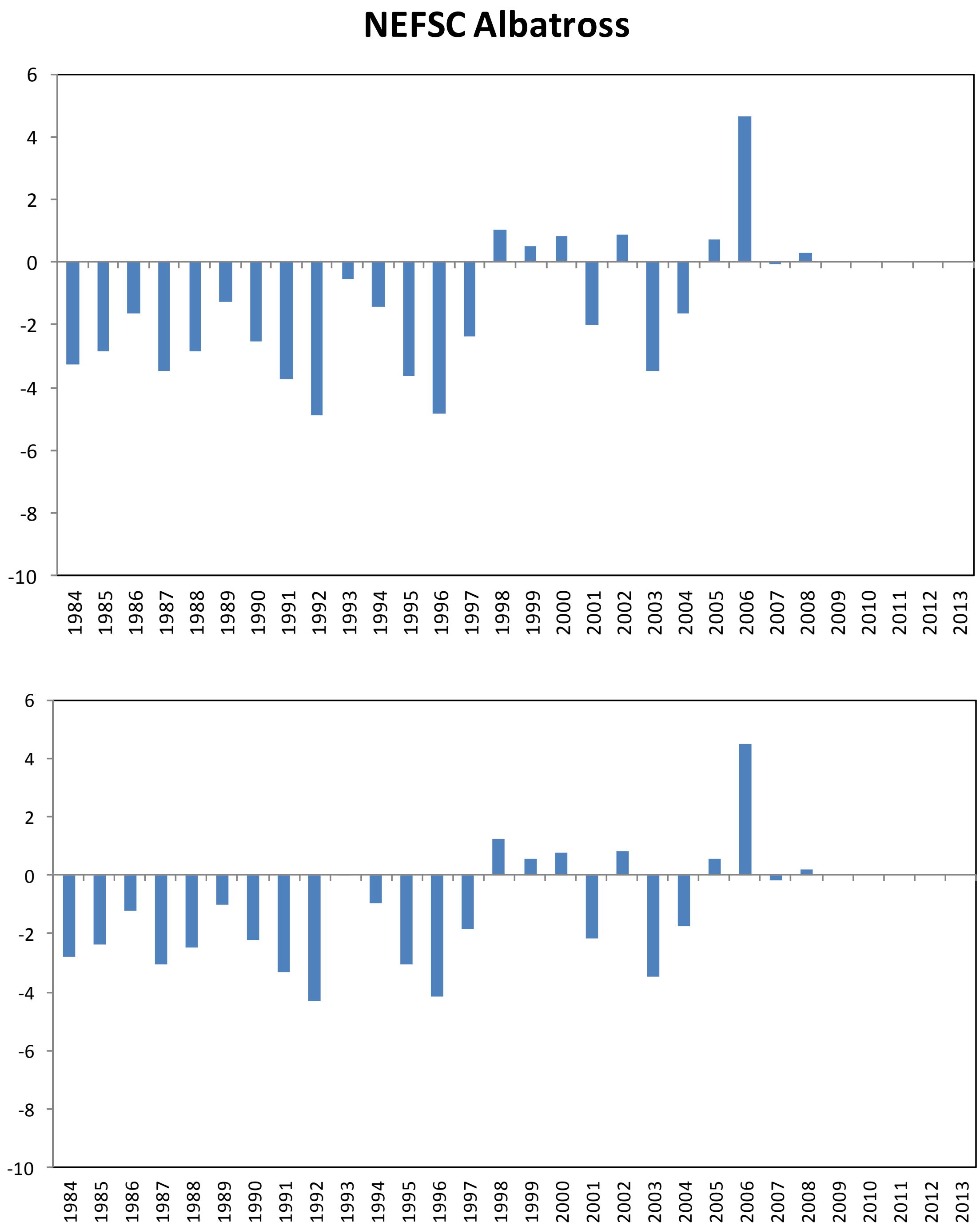
Appendix C6. Figure 1. Average proportion-at-size residuals for the NEFSC Albatross survey (observed - predicted) for the UME base model configuration (top) and the Panel's requested configuration (bottom).



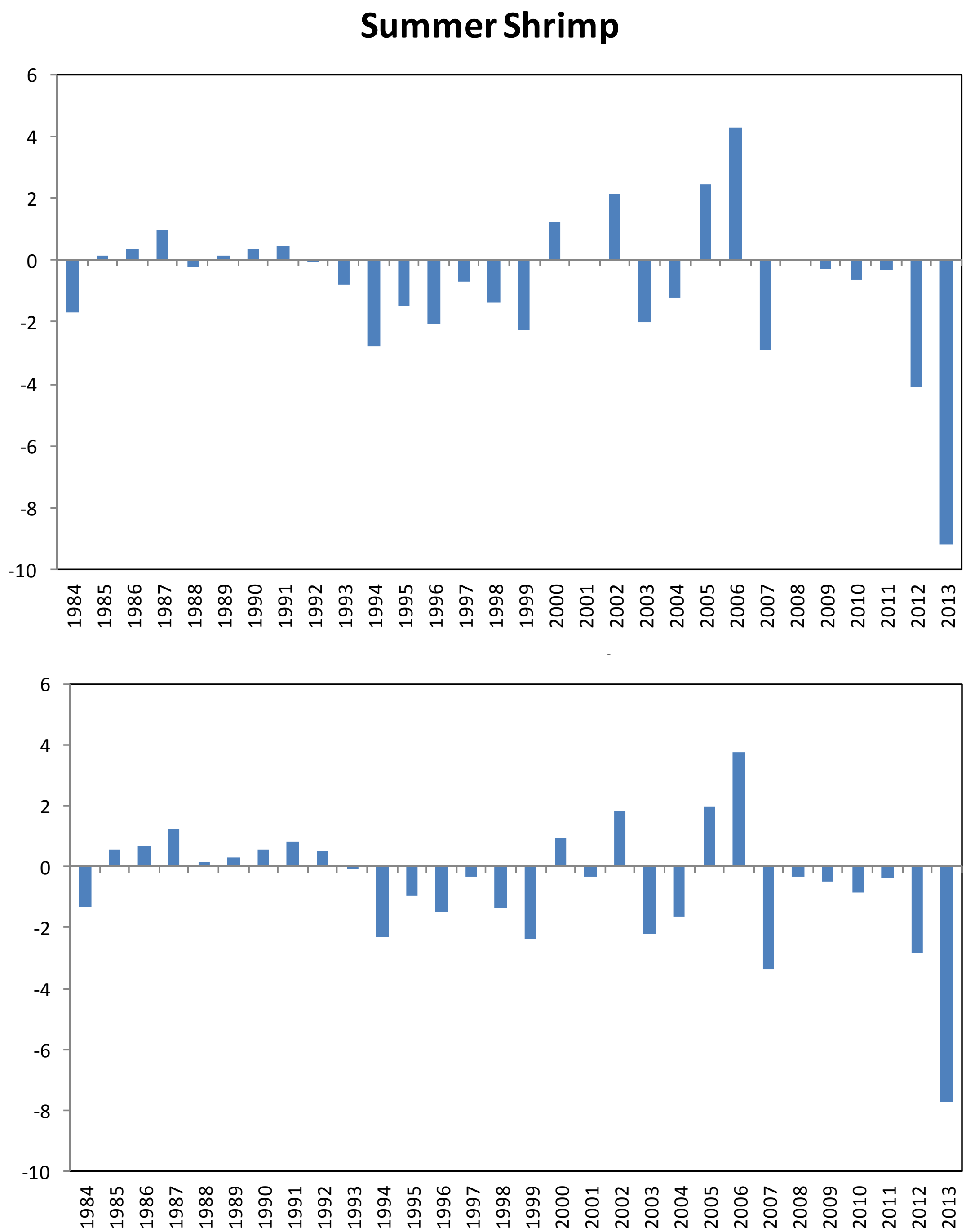
Appendix C6. Figure 2. Average proportion-at-size residuals for the ASMFC summer shrimp survey (observed - predicted) for the UME base model configuration (top) and the Panel's requested configuration (bottom).



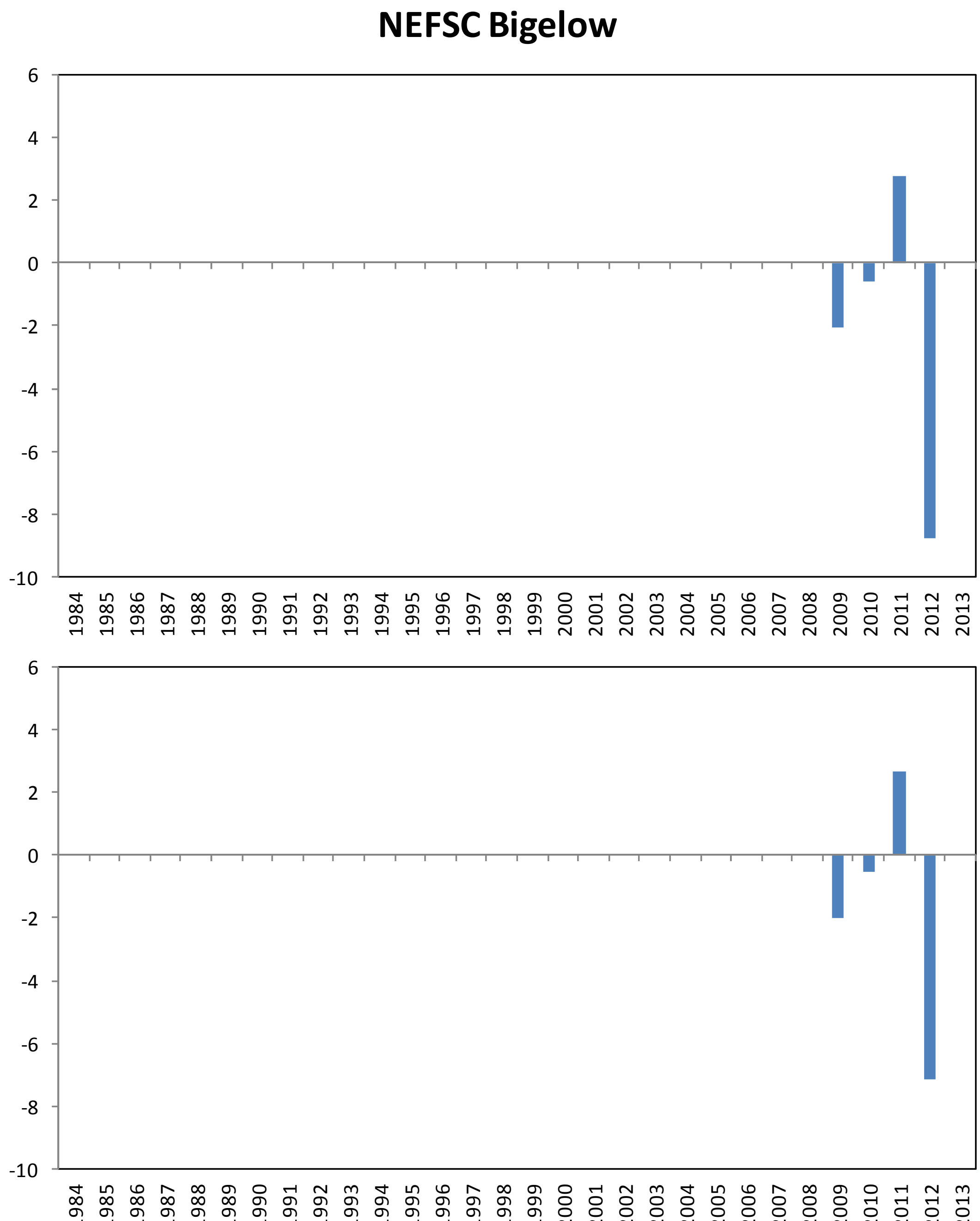
Appendix C6. Figure 3. Average proportion-at-size residuals for the NEFSC Bigelow survey (observed - predicted) for the UME base model configuration (top) and the Panel's requested configuration (bottom).



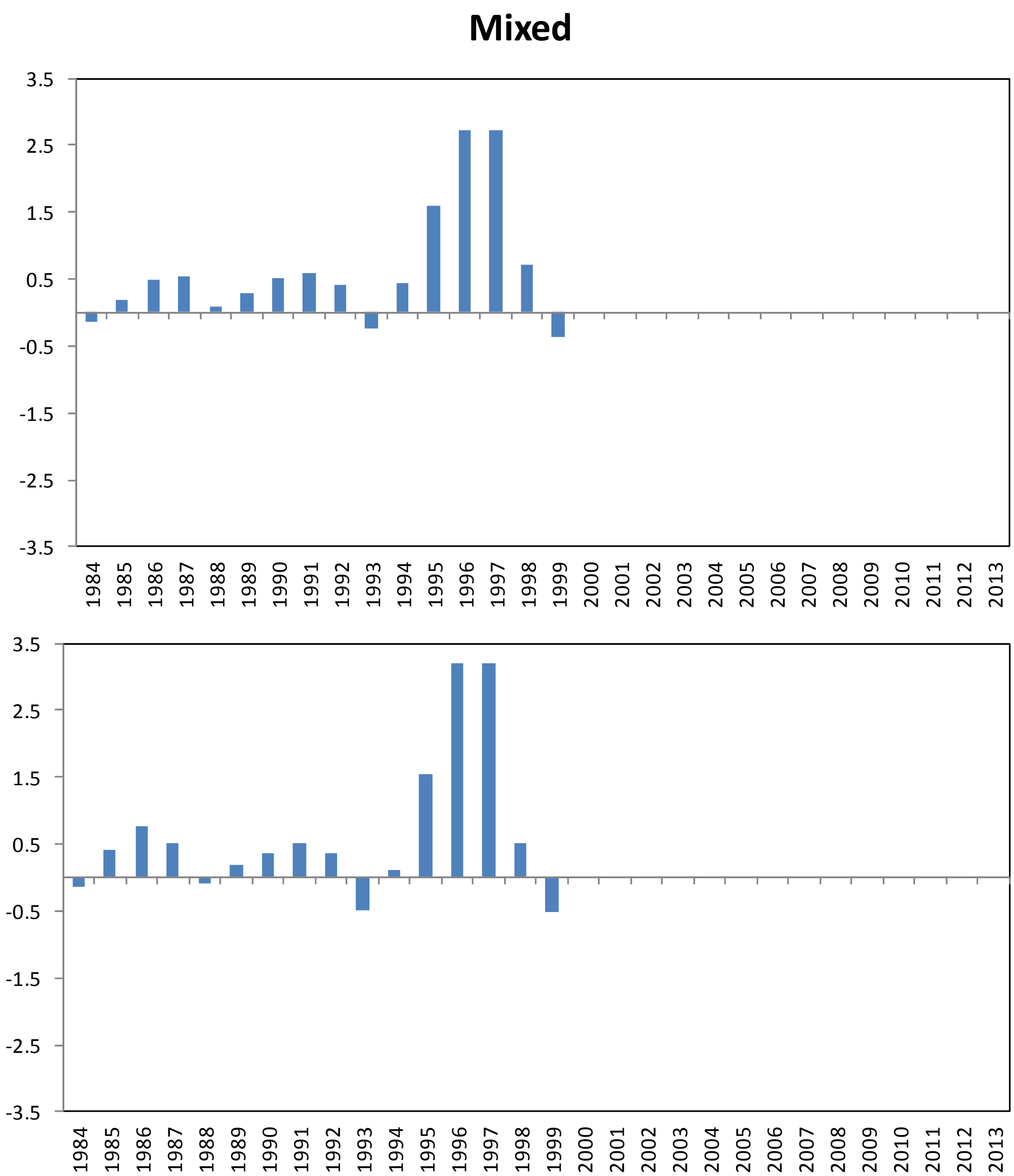
Appendix C6. Figure 4. Standardized residuals for the NEFSC Albatross index for the UME base model configuration (top) and the Panel's requested configuration (bottom).



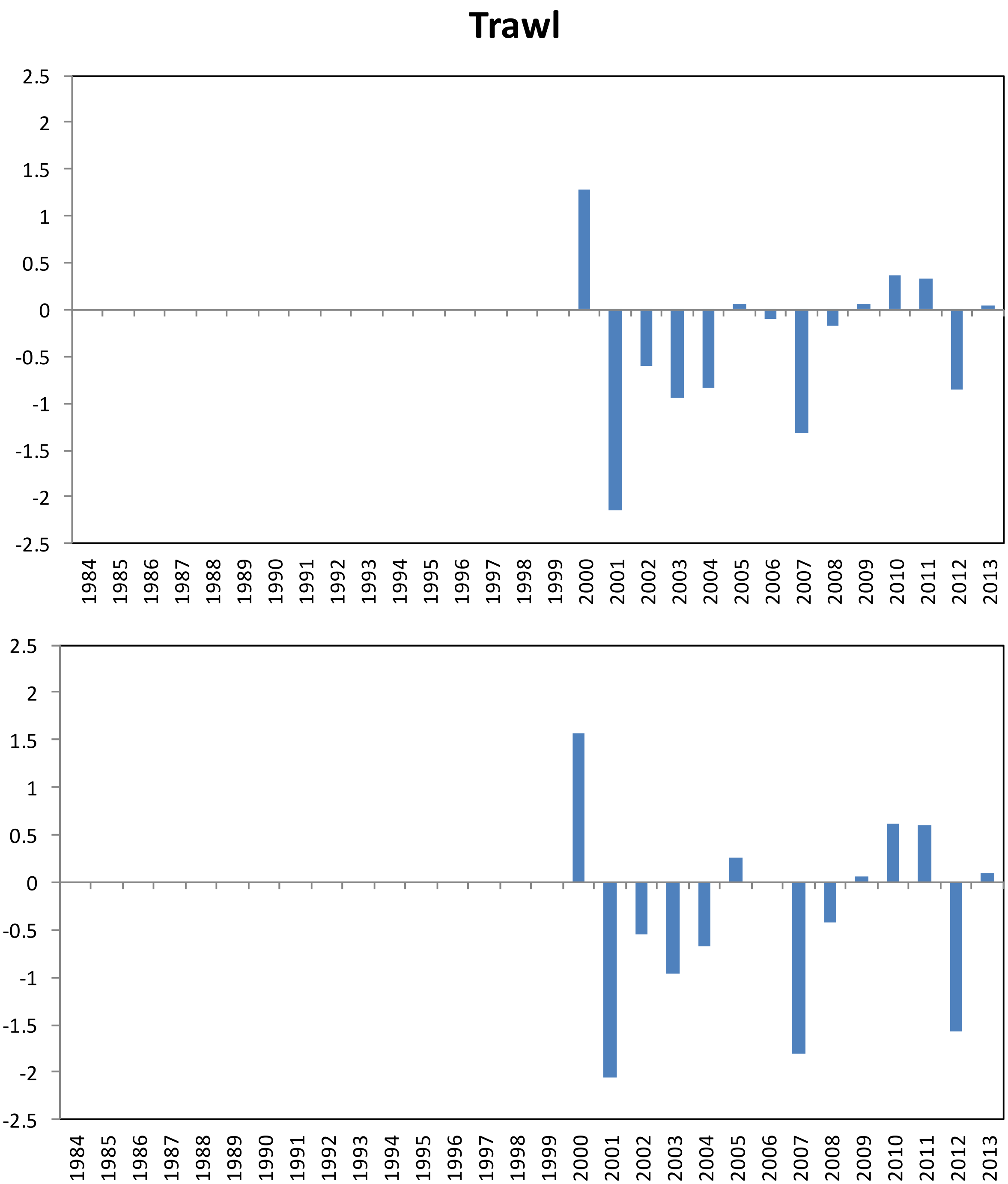
Appendix C6. Figure 5. Standardized residuals for the ASMFC summer shrimp survey index for the UME base model configuration (top) and the Panel's requested configuration (bottom).



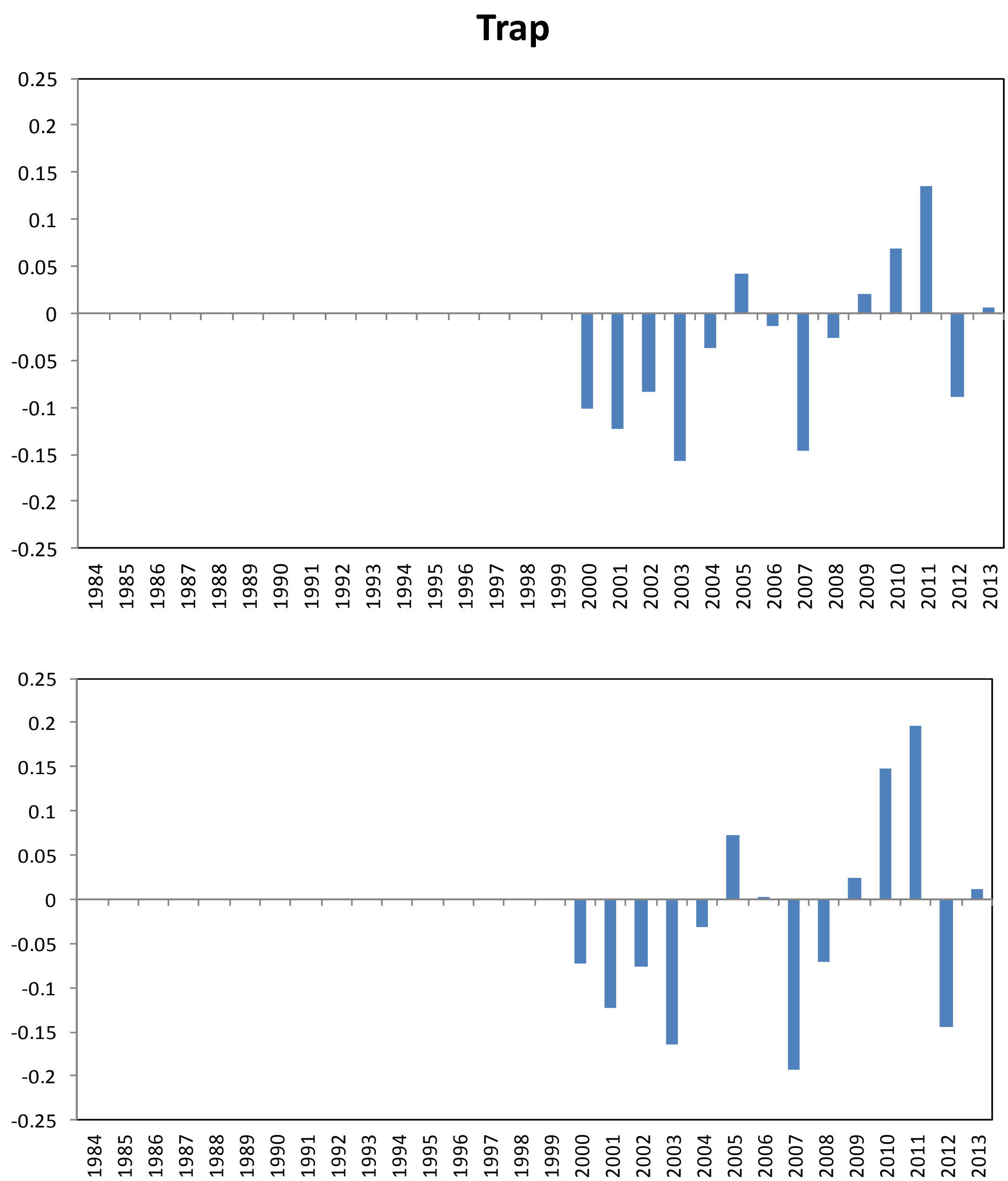
Appendix C6. Figure 6. Standardized residuals for the NEFSC Bigelow survey index for the UME base model configuration (top) and the Panel's requested configuration (bottom).



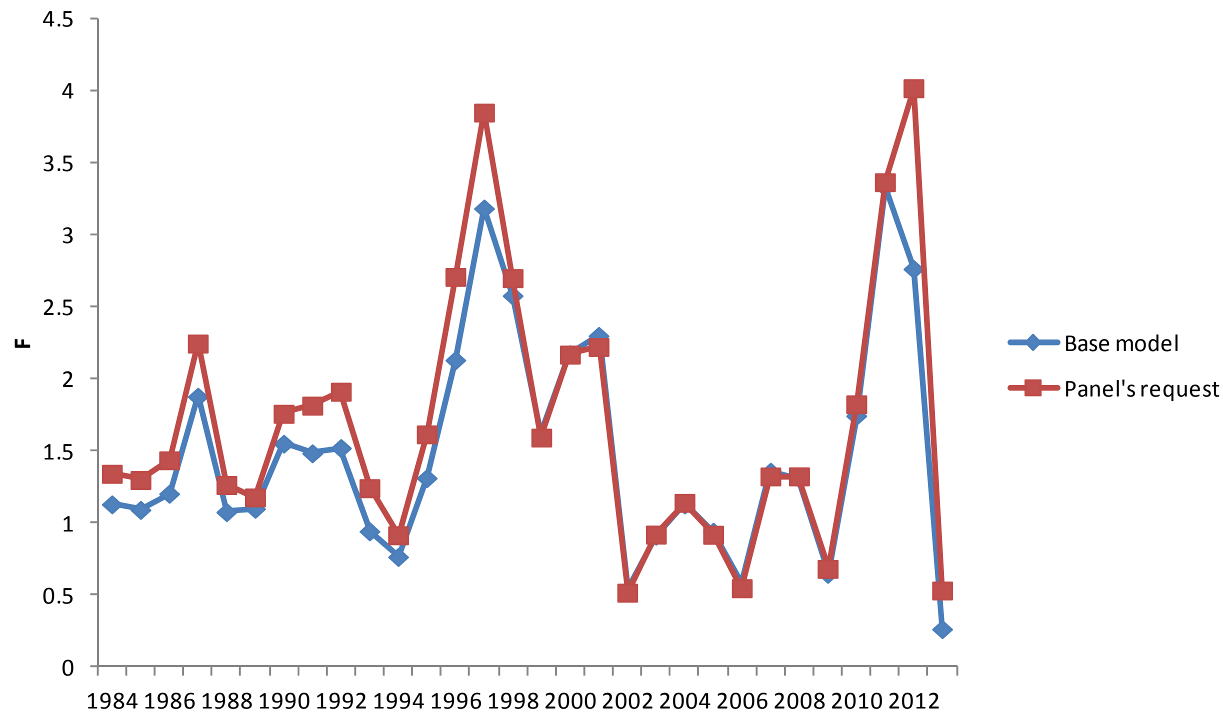
Appendix C6. Figure 7. Standardized residuals for total catch from the mixed fleet for the UME base model configuration (top) and the Panel's requested configuration (bottom).

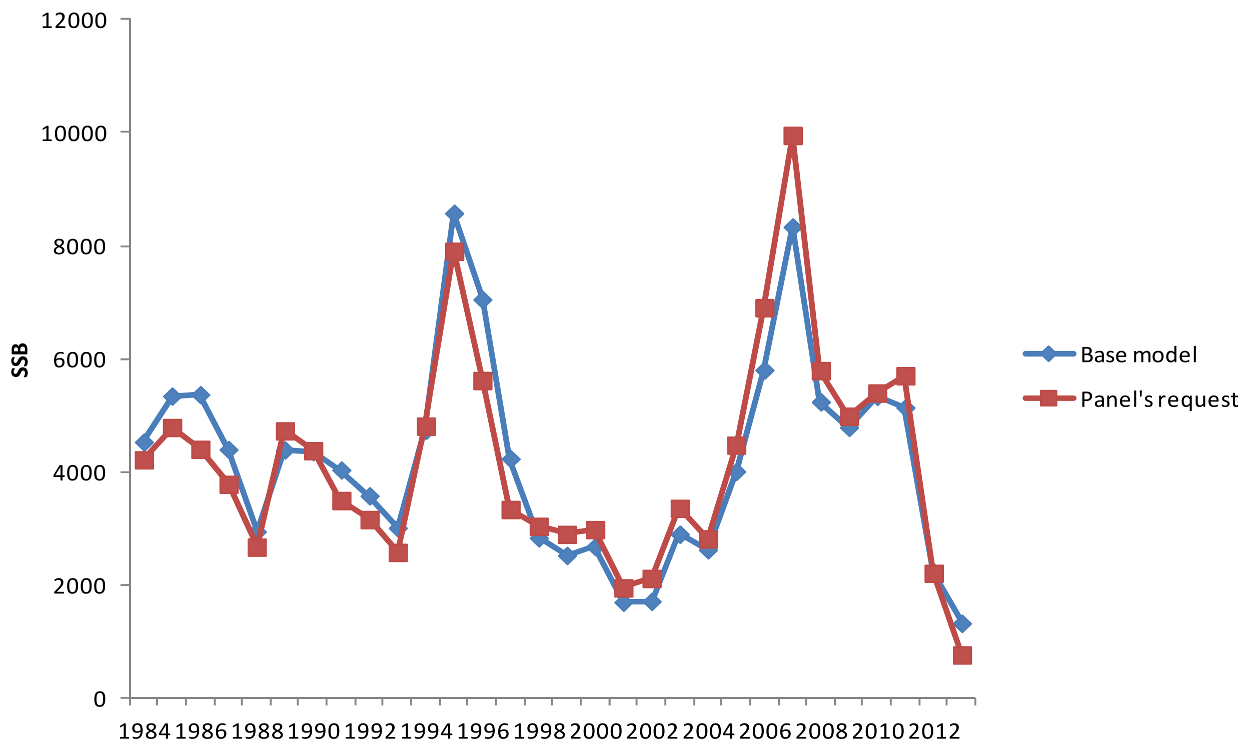


Appendix C6. Figure 8. Standardized residuals for total catch from the trawl fleet for the UME base model configuration (top) and the Panel's requested configuration (bottom).

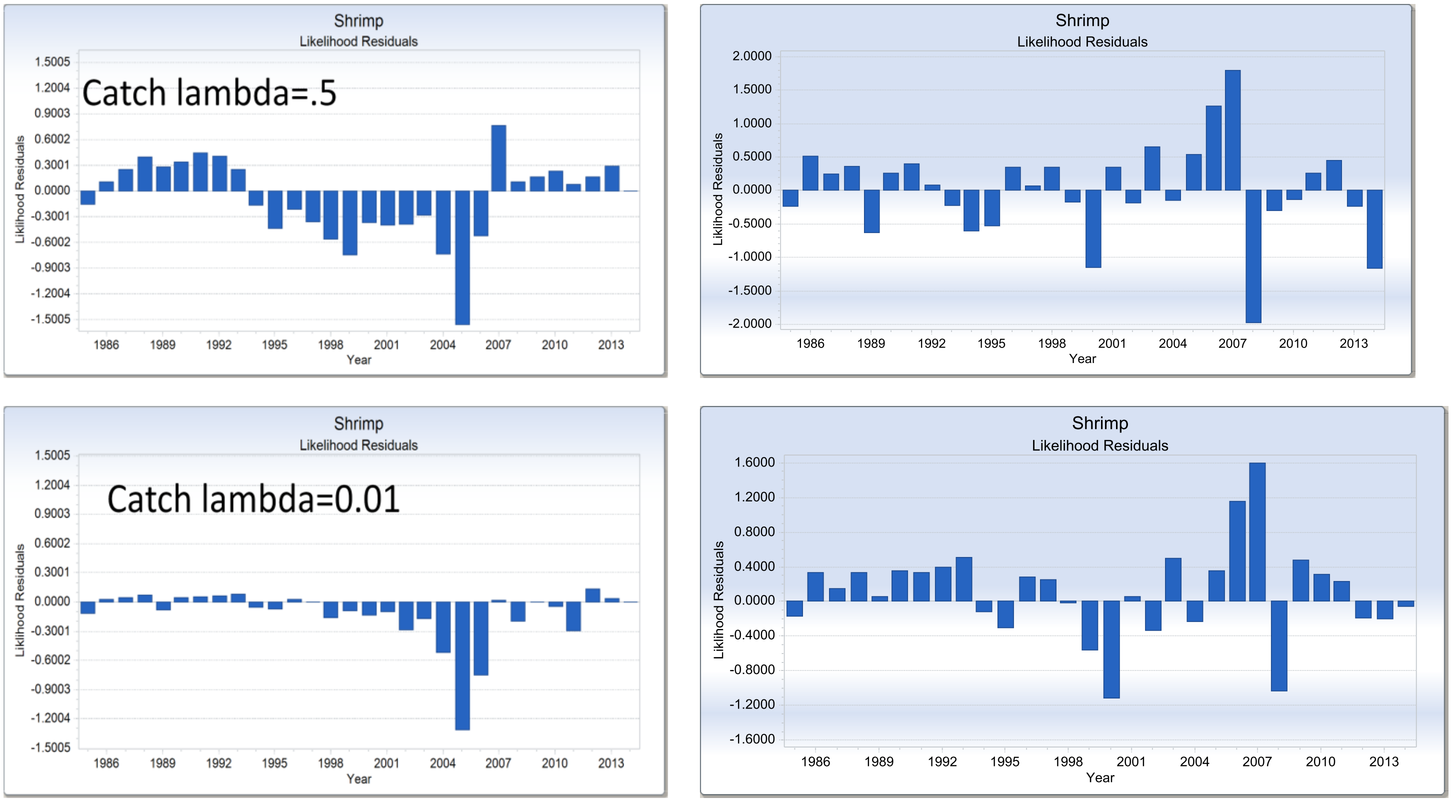


Appendix C6. Figure 9. Standardized residuals for total catch from the trap fleet for the UME base model configuration (top) and the Panel's requested configuration (bottom).

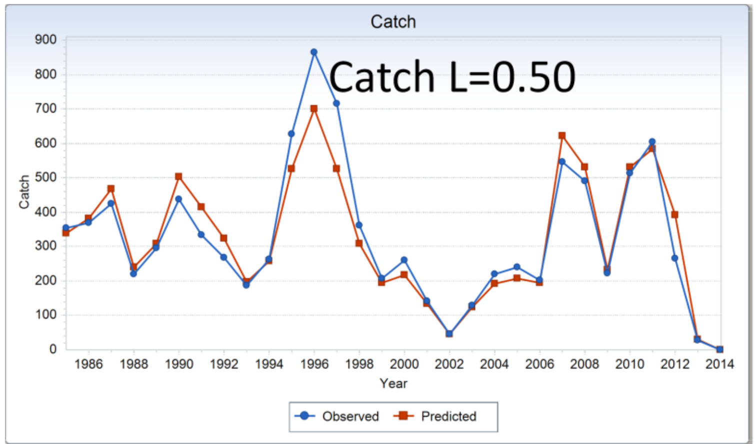


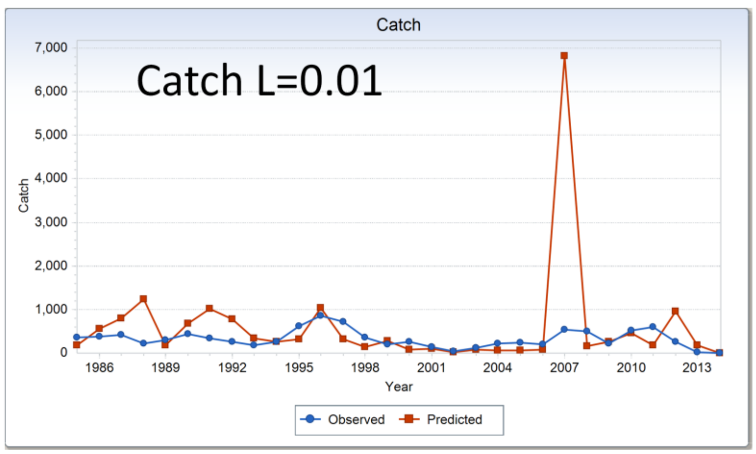


Appendix C6. Figure 10. Model estimates of F (top) and SSB (bottom) for the UME base model configuration and the Panel's requested configuration.

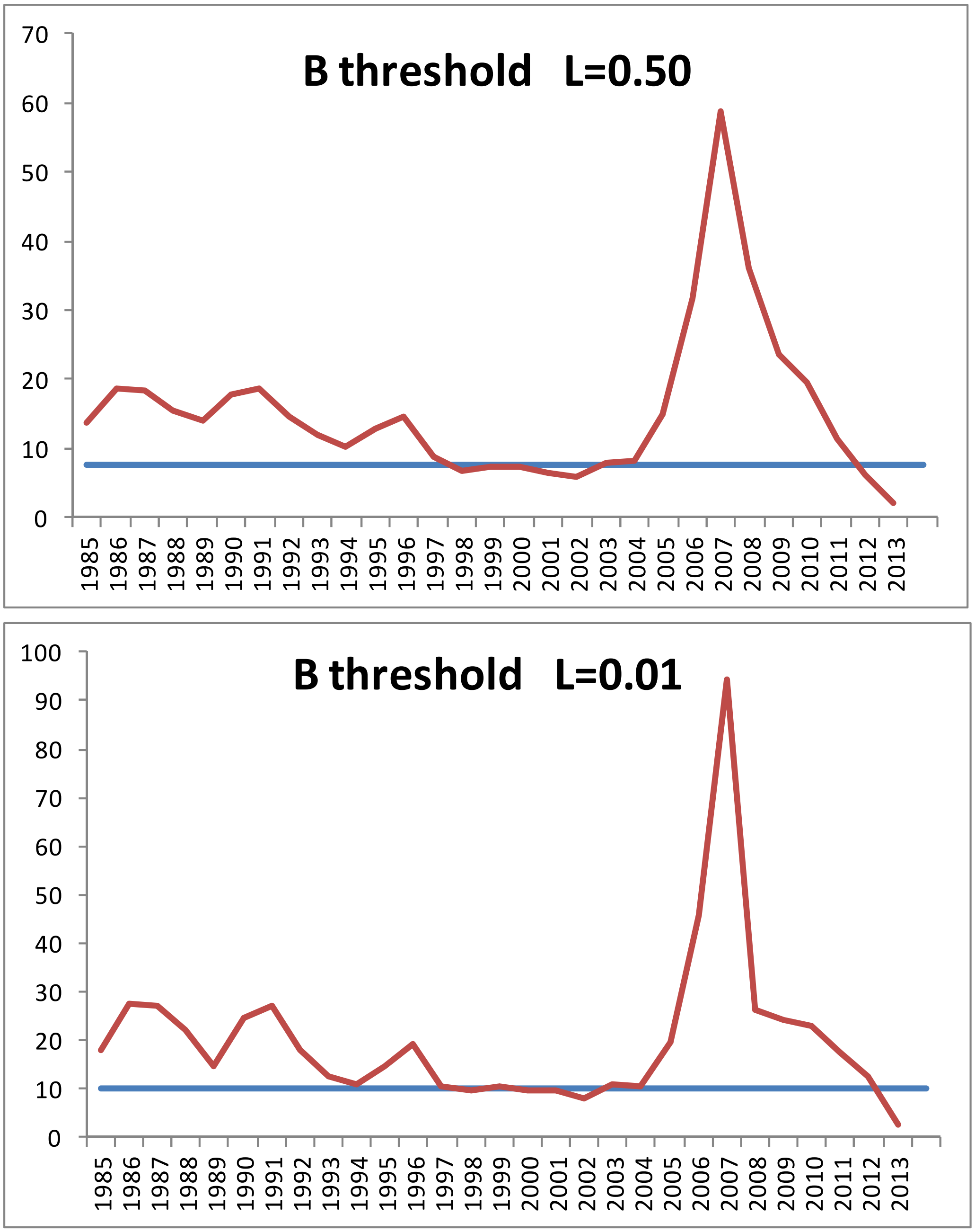


Appendix C6. Figure 11.Standardized residuals from the CSA model for the ASMFC summer shrimp survey index for recruits (left) and post-recruits (right), for different likelihood weights for total catch (λ=0.5, top, and λ=0.01, bottom).

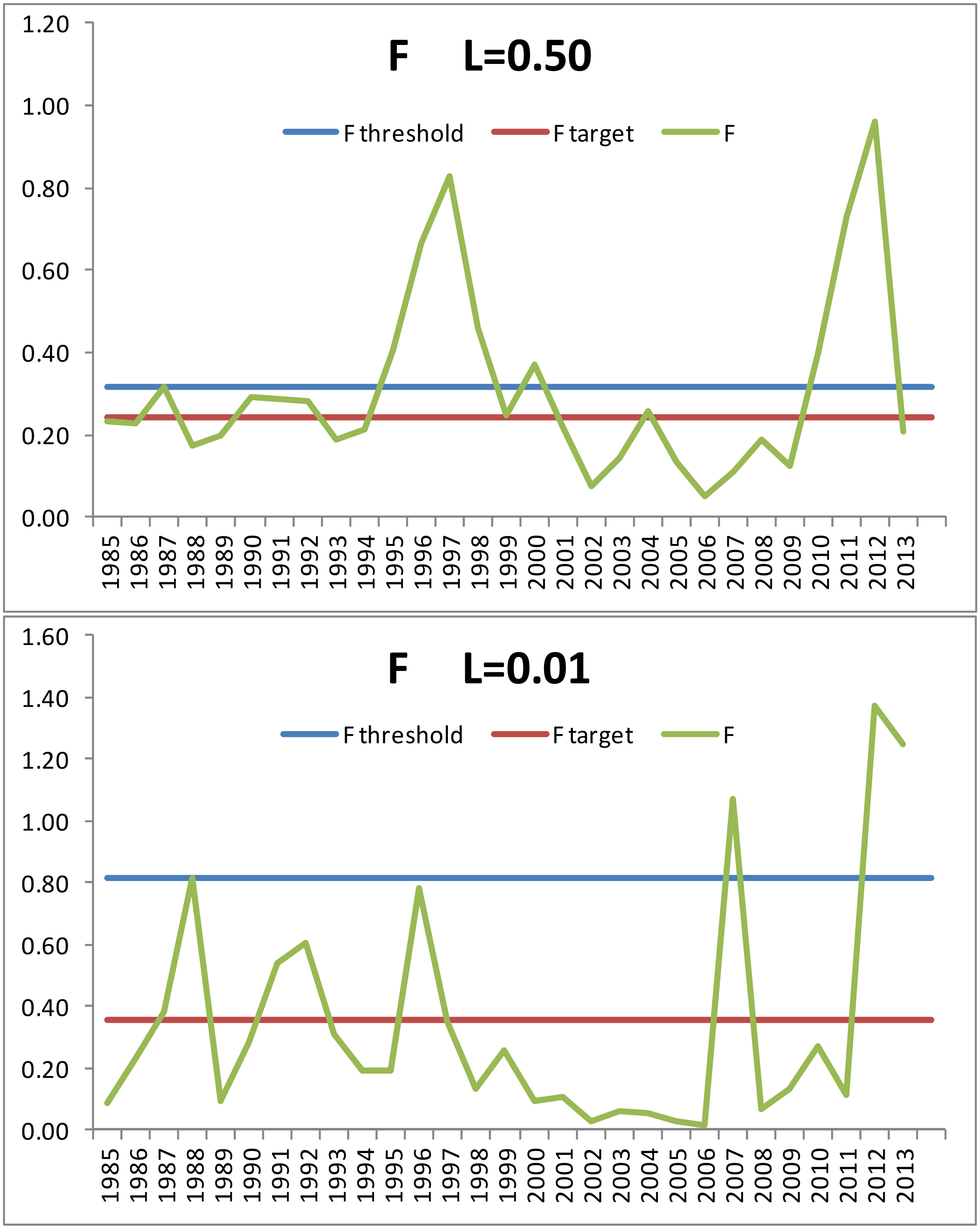




Appendix C6. Figure 12. Observed and predicted total catch from the CSA model for different likelihood weights (λ) on total catch.



Appendix C6. Figure 13. Biomass estimates from the CSA model compared to the biomass threshold estimates for total catch λ=0.5 (top) and total catch λ=0.01 (bottom).



Appendix C6. Figure 14. Fishing mortality estimates from the CSA model compared to the F target and threshold estimates for total catch λ=0.5 (top) and total catch λ=0.01 (bottom).