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Atlantic States Marine Fisheries Commission

American Lobster Stock Assessment for Peer Review

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ASMFC American Lobster Stock Assessment Subcommittee

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Executive Summary

American lobster (*Homarus americanus*) supports one of the most valuable commercial fisheries in the Northeast U.S. with an annual estimated revenue in excess of $350 million in 2004 (NMFS, 2006). The U.S. lobster resource occurs in continental shelf waters from Maine to North Carolina. Three new stocks units have been identified in this assessment based primarily on regional differences in life history parameters. They are the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE). Each stock supports both an inshore and offshore component, however total U.S. lobster landings are primarily comprised of catch from nearshore waters (0 to 12 nautical miles).

The management unit for American lobster is the entire Northwest Atlantic Ocean and its adjacent inshore waters where lobster is found from Maine through North Carolina. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery in state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore), both under the authority of the Atlantic Coastal Fisheries Cooperative Management Act.

Currently, American lobster is managed under Amendment 3 to the Interstate Fishery Management Plan and its subsequent Addenda, I-VII.. The plan is designed to minimize the chance of population collapse due to recruitment failure. The goal of Amendment 3 is to have a healthy American lobster resource and management regime, which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders.

The U.S. lobster fishery is conducted in each of the three stock units -- GOM, GBK, and SNE. Each area has an inshore and offshore component to the fishery. GOM and SNE areas are predominantly inshore fisheries, while the GBK area is predominantly an offshore fishery. Total landings were relatively constant at 14,000 mt through the late 1970s. Since then, landings have doubled, reaching 37-38,000 mt in 1997-98 and dropping to 33,000 mt in 2003.

GOM supports the largest fishery, constituting 74% of the U.S. landings between 1981 and 2003, and 85% between 2001 and 2003. Landings in the GOM were stable between 1981 and 1989, averaging 14,700 mt, then increased dramatically from 1990 (19,200 mt) to 1999 (30,000 mt), remaining at record levels since (2000-2003 average of 30,300 mt).

GBK constitutes the smallest portion of the U.S. fishery, averaging 5% of the landings from 1981 to 2003. During this time period, landings from the GBK fishery have remained stable, varying between 1,100 and 1,700 mt (1981-2003 average of 1,400 mt).

SNE has the second largest fishery, accounting for 21% of the U.S. landings between 1981 and 2003. Landings increased sharply from the early 1980s to the late 1990s, reaching a time series high of 10,054 mt in 1997. Landings remained near the time series high until 1999, when the fishery experienced dramatic declines in landings. From 2000 to 2003, landings accounted for only 12% of the U.S. landings, reaching a time series low of 8% in 2003.

The modeling tools used in this assessment to provide management advice for American lobster were similar to models used in previous assessments. An enhanced version of the Collie-Sissenwine model (CSM, a.k.a. "modified DeLury" in ASMFC 2000) was used to estimate mortality and abundance of male and female lobster in individual areas. A life history model (a.k.a. egg-per-recruit model or EPR in ASMFC 2000) was used to estimate egg production per recruit and other per-recruit reference points for male and female lobster in each stock assessment region used in previous assessments. The life history model was updated with new growth parameters and current management measures.

One of the short comings of the recommended biological reference points is that the status of each stock is solely based on comparison with a relatively recent 22-year trend. In order to corroborate this comparison, trends for a suite of indicators have been examined for the same time period (1982 to present). These indicators were chosen as measures of fishing mortality, stock abundance, and fishery performance. This multiple stock indicator approach or "the traffic light approach" tends to minimize bias/uncertainty by putting equal weight on many indicators, and therefore presents a truer picture of the overall stock status.

The American lobster resource presents a mixed picture, with stable abundance for the GBK stock and much of the GOM stock and decreased abundance and recruitment yet continued high fishing mortality for the SNE stock and Area 514 of the GOM stock.

Current abundance of the GOM stock overall is relatively high compared to the 22-year time series and recent fishing mortality has been comparable to the past; however, recruitment for the southern GOM (area 514) has declined (three of the last four recruitment values have been near record lows) and post-recruit abundance has declined to the historical low. Further restrictions are warranted for Area 514 given the persistence of low recruitment and its effect on total abundance, and by implication, egg production.

The GBK stock appears to be stable; current abundance and fishing mortality are similar to their medians for the 22-year time series. However, the number of traps fished is very high and further increases in effort are not advisable.

The SNE stock abundance is relatively low compared to the 20-year time series and fishing mortality is relatively high; further restrictions are warranted. The declining trend in population abundance is well established and warrants a reduction in fishing mortality.

This assessment recommends a new robust set of biological reference points (BRPs) to be used for the management of American lobster stocks (Table 1). These include median abundance and median fishing mortality, over the fixed time period of 1982-2003, as threshold reference points for each American lobster stock. The assessment further recommends that stock status be determined by comparing the average F and average abundance during the most recent three years to stock-specific median values (computed for the fixed years 1982-2003). Additionally, abundance and fishing mortality targets would be defined by the F value below, and the abundance value above, a minimum of one estimated standard error from the threshold.

Based on the recommended reference points, "overfishing" would occur if the average fishing mortality rate for the three most recent years were higher than the 1982-2003 median threshold. A stock would be “depleted” if average abundance for the three most recent years fell below the 1982-2003 median threshold level. In either of these cases, corrective management action should be implemented.

The GOM stock is in favorable condition based on the recommended BRPs. The stock is above the abundance target and at or near the target F. In terms of the recommended reference points, the GOM lobster stock is not depleted and overfishing is not occurring.

The GBK stock is in a favorable condition based on the recommended BRPs. The stock is above the abundance target and below its fishing mortality target. In terms of the recommended reference points, the GBK stock is not depleted and overfishing is not occurring.

The SNE stock is in poor condition based on the recommended BRPs. The stock is below the abundance threshold and at or near the fishing mortality threshold. In terms of the recommended reference points, it is depleted and at the overfishing threshold. The interpretations of stock status are robust to the levels of M chosen.

Table 1. New recommended target and threshold reference points with stock status variables for lobster in each stock area.

Variable	GOM	GBK	SNE
Fishing mortality			
Fishing mortality threshold	0.76	0.34	0.82
Fishing mortality target	0.67	0.31	0.74
Recent fishing mortality 2001-2003	0.69	0.29	0.84
Recent fishing mortality 2000-2002	0.54	NA	NA
Fishing mortality below threshold?	Yes	Yes	No
Fishing mortality near or below target?	Yes	Yes	No
Abundance			
Abundance threshold	65.58	7.95	22.31
Abundance target	69.62	8.61	23.90
Recent abundance 2001-2003	123.12	9.05	14.01
Recent abundance 2001-2003	126.65	NA	NA
Abundance above threshold?	Yes	Yes	No
Abundance near or above target?	Yes	Yes	No

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Terms of Reference

1. Compile data needed for stock assessment purposes including commercial, recreational, and discards, updating the database to include the most recent information available.

2. Evaluate and revise if necessary the boundaries of the stock assessment areas as outlined in the last peer-reviewed assessment based on objective criteria.

3. For each stock assessment area estimate the current levels and historical trends of factors such as egg production, biomass, abundance, and natural and fishing mortality rates. Characterize uncertainty in estimates.

4. Address and incorporate as applicable recommendations from the 2000 American Lobster Peer Review.

5. Use new models and input parameter estimates developed as appropriate, as well as any input parameter estimates and models used in the last stock assessment.

6. Update the current biological reference point (F10%) and develop additional biological reference points including limits, thresholds and targets for F and biomass if feasible. Characterize uncertainty in stock status.

7. Identify research recommendations to improve future assessments.

1.0 Introduction

The American lobster (*Homarus americanus*) supports one of the most valuable commercial fisheries in the Northeast U.S. with an annual estimated revenue in excess of $350 million in 2004 (NMFS, 2006). The U.S. lobster resource occurs in continental shelf waters from Maine to North Carolina. Three stocks have been identified based primarily on regional differences in life history parameters. They are the Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE). Each stock supports both an inshore and offshore component, however total U.S. lobster landings are primarily comprised of catch from nearshore waters (0 to 12 nautical miles).

1.1 Management unit

The management unit for American lobster is the entire Northwest Atlantic Ocean and its adjacent inshore waters where lobster is found from Maine through North Carolina. The Atlantic States Marine Fisheries Commission (ASMFC) manages the lobster fishery in state waters (0-3 miles from shore) and the National Marine Fisheries Service (NMFS) manages the lobster fishery in federal waters (3-200 miles from shore), both under the authority of the Atlantic Coastal Fisheries Cooperative Management Act. The fishery management plan (FMP) is written to provide for the management of lobster throughout their range. The FMP is designed to specify a uniform program regardless of lines that separate political jurisdictions, to the extent possible. The different management authorities are expected to take necessary actions to apply the provisions of this FMP in waters under their respective jurisdictions. For management purposes, the management unit is subdivided into seven areas that cut across stock boundaries in many cases (Figure 1.1).

1.2 Regulatory History

The ASMFC American Lobster Board approved Amendment 3 to the FMP in December of 1997. The plan is designed to minimize the chance of population collapse due to recruitment failure. The goal of the amendment is to have a healthy American Lobster resource and management regime, which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders.

Amendment 3 defines overfishing for the American lobster resource to occur "when it [any stock] is harvested at a rate that results in egg production from the resource, on an egg-per-recruit basis, that is less that 10% of the level produced by an unfished population" (ASMFC, 1997). The primary management measures used to prevent overfishing include a minimum size, protection of egg bearing females, and trap limits.

Amendment 3 established a framework for area management, which includes industry participation through seven Lobster Conservation Management Teams (LCMT). LCMTs were encouraged to develop recommendations for a management program, which suits the needs of the area while meeting targets established in the plan. The Board adopted a three-phase approach to incorporate the LCMT recommendations, which involved three addenda to Amendment 3. Addendum I incorporated measures from the LCMT proposals directed at effort control. After consideration of the stock assessment and peer review results in ASMFC (2000), the Board initiated the development of Addendum II in August 2000 to continue implementation of the 1998 LCMT proposals. Addendum III incorporates the alternative management measures presented to the Board for the purposes of meeting $F_{10\%}$ by calendar year 2008.

Addendum IV address four different issues of lobster management: a proposal from the Area 3 LCMT; concern about stock conditions in Area 2; new information about vent selectivity; and a desire to change the interpretation of the most restrictive rule.

American Lobster Addendum IV outlines a transferable trap program for Area 3. This program allows Area 3 lobster fishermen to transfer trap tags to other lobster fishermen. Along with other measures, the addendum Area 3 transferability program establishes an overall trap cap and conservation taxes for transferring traps.

Addendum IV includes an interim benchmark goal based on survey information and a Total Allowable Landings to be used as a performance measure. This Addendum includes an effort control program and gauge increases for Area 2.

Addendum IV changes the circular vent size requirement from 2 ½ inches to 2 $^{5}/_{8}$ inches. In addition, vent sizes of 2 $^{1}/_{16}$" rectangular and 2 $^{11}/_{16}$" circular are required for those LCMA's (LCMA 3, 2, OCC) that have scheduled increases to a 3 $^{1}/_{2}$" minimum legal carapace length.

Addendum IV applies the most restrictive rule on an area trap cap basis without regard to the individual's allocation. Fishermen who designate multiple management areas on their permits are bound by the most restrictive management measures of those areas' trap caps. They are allowed to fish the number of traps they are allocated in that most restrictive area.

Addendum V amends the overall trap cap set by Addendum IV based on comments gathered at public hearings expressing concern that the overall trap cap of 2600 may be too high. Addendum V includes an overall trap cap of 2200 with the higher tax imposed when the purchaser owns 1800 to 2200 traps.

Addendum VI replaces two of the effort control measures of Addendum IV, permits and eligibility period. No new Area 2 permits will be distributed after December 31, 2003 and to qualify for an Area 2 permit endorsement, a permit holder must document landings between January 1, 1999 and December 31, 2003.

1.3 Assessment History

The primary models used to assess American lobster stocks since 1992 (NEFSC 1992; NEFSC 1993; NEFSC 1996; ASMFC 2000) are length-based virtual population analysis, the Collie-Sissenwine (a.k.a. modified DeLury) model, and the life history (a.k.a. egg production per recruit or EPR) model. Length-based VPA and the Collie-Sissenwine model (CSM) were used to estimate abundance and fishing mortality rates in the stock using landings and bottom trawl survey data. The life history model was used to calculate egg production per recruit reference points such as $F_{10\%}$, the fishing mortality rate that allows female lobster recruits opportunity, on average, to spawn 10% of the number of eggs that would be spawned in the absence of a fishery. The $F_{10\%}$ reference point has been used consistently in lobster stock assessments to determine if overfishing is occurring. Previous stock assessments generally concluded that fishing mortality rates were high for lobster and above the $F_{10\%}$ reference point in particular, especially in near shore regions that are heavily fished.

Early in 1996, a Lobster Review Panel composed of internationally renowned scientists was convened by ASMFC and NMFS to provide advice on stock structure, stock assessment, abundance changes, management, and benthic ecology (ASMFC 1996). The Panel concurred with NEFSC's (1996) conclusion that the lobster resource was overfished ($F > F_{10\%}$) in all areas. The Panel endorsed the stock assessment methods and stock definitions used by NEFSC (1996) and made a number of recommendations for future research and development.

Conclusions and recommendations in the most recent assessment (ASMFC 2000) were similar to conclusions and results from previous assessments. Lobster in all three stock areas were overfished (i.e. recent fishing mortality rates $> F_{10\%}$) according to the overfishing definition in the Fishery Management Plan for American lobster (ASMFC 1997). Stock assessment committee members agreed that all three stocks were subject to growth overfishing, the fishing mortality rate that maximizes yield in weight per recruit). At that time, the abundance and recruitment levels were high and the majority agreed that recruitment overfishing was not occurring. A number of new assessment approaches were investigated for American lobster.

A panel of reviewers (ASMFC 2000b) generally supported results and conclusions from the last assessment (ASMFC 2000), but noted serious shortcomings in biological and fishery data used to assess the stock, and recommended further work on new modeling approaches.

In preparation for this assessment, the American Lobster Stock Assessment Model Technical Review panel (ASMFC 2004) evaluated the current model and three new potential modeling approaches for lobster based on simulation analysis. Problems were identified in all three new approaches and shortcomings in biological and fishery data were noted. At least one of the new models has been refined to address concerns raised by the review panel and is presented for review with this assessment as an appendix. New models may be used in future assessments but were not used in this assessment to provide management advice.

The review panel agreed that CSM should be used as the primary tool in the current assessment. They noted, however, that estimates of fishing mortality and abundance in absolute terms were difficult to estimate but that trends in abundance and mortality were relatively precise and robust. Based on these observations, the reviewers suggested that the current assessment should be based on estimated trends to the extent possible.

This report contains brief summaries of lobster life history, habitat, descriptions of two new stock assessment regions, descriptions of the fishery and fisheries data, bottom trawl survey abundance indices, technical descriptions of improvements to modeling approaches, stock assessment results, a “stop light” stock status description, information about overfishing, and recommendations for new interim target and threshold reference points for lobster. The options for new target and threshold reference points are based on estimated trends. The stop light status description is new for American lobster. Technical details are presented in a series of appendices.

2.0 Life History

2.1 Age and Longevity

The American lobster is a long-lived species known to reach more than 18 kg (40 pounds) in body weight (Wolff 1978). The age of lobster is unknown because all hard parts are shed and replaced at molting, leaving no accreting material for age determination. Traditionally, scientists estimate the age of lobster based on size, per-molt growth increments, and molt frequencies. Based on this kind of information, Cooper and Uzmann (1980) estimated that the American lobster may live to be 100 years old.

Research using lipofuscin pigment has shown promise for aging western rock lobster, *Panulirus cygnus* (Sheehy et al.1998), European lobster, *Homarus gammarus,* (Sheehy et al.1996) and American lobster, *H. americanus,* (Wahle et al.1996) among other crustaceans and mammals. Recent studies conducted in the UK have accurately aged European lobster using lipofuscin measurements from the eyestalk ganglia (Sheehy and Bannister 2002). A maximum age estimate for the European lobster using this technique was 54 years old (Sheehey et al 1999). These researchers have concluded that changes in lobster body length (mm CL) explained less than 5% of the variation in true age in European lobster. Molting was so erratic and protracted that European lobster between 70 and 80 mm CL required at least five years to fully recruit to legal size (81mm) in the trap fishery off the UK (Sheehy et al 1996). These findings suggest further that as many as five to eight year-classes, rather than two based on length frequencies, recruit to the European lobster trap fishery each year. This technique, although time intensive, may provide valuable information needed to understand recruitment mechanisms in American lobster as well as this species' vulnerability to recruitment overfishing (Sheehy and Sheldon 2001).

2.2 Growth

American lobster grow incrementally in distinct molting events called ecdysis. Although growth appears to entirely take place during molting, lobster actually spend much of their lives preparing for or recovering from molting (Waddy et al. 1995). Growth rates are affected by two separate components, the size increase per molt or molt increment and the frequency of molting. Molt increments are reported as a percent change in carapace length or as the actual change in carapace length per molt. Increments are usually measured from tagged and recaptured lobster or lobster that molted and grew while held in captivity (including those in lobster traps). The frequency of molting is often reported as the probability of lobster at a given size molting in a given year, but is sometimes reported as intermolt duration (the time spent between molts).

The steady state nature of most growth models and lack of data does not permit growth rates to be linked to variable conditions such as nutrient availability (Aiken 1980; Castell and Budson 1974; Bordner and Conklin 1981; Capuzzo and Lancaster 1979), density of lobster (Stewart and Squires 1968; Aiken and Waddy 1978; Van Olst et al. 1980; Ennis 1991), presence of larger more dominant lobster, (Cobb and Tamm,1974, 1975) or variations in temperature (Hughes et al. 1972; Aiken 1977). All of these variables have, however, been shown to influence the frequency of molting and/or the size of molt increments.

Several studies have shown that lobster growth rates decline as food availability and quality decline (Castell and Budson 1974; Bordner and Conklin 1981; Capuzzo and Lancaster 1979). In laboratory studies, higher densities of lobster as well as limited space reduce growth rates (Stewart and Squires 1968; Hughes et al. 1972; Aiken and Waddy 1978; Van Olst et al. 1980; Ennis 1991). Growth rates of smaller lobster appear to be slower when they are in the presence of larger lobster (Cobb and Tamm 1974, 1975).

In general, the frequency of molting increases with temperature (Aiken 1977). Molt increment size was shown to be smaller in blue crabs raised in warmer water (Leffler 1972), and comparisons between the size of molt increments estimated from tagging studies in US offshore waters (Uzmann and Cooper 1977, Fogarty and Idoine 1988) compared to those measured in warmer areas (NUSCO 1999) suggests this also is true of adult lobster. In addition, summer seawater temperature appears to have confounding effects on growth by decreasing the size at which lobster become sexually mature (Templeman 1936, Estrella and McKiernan 1989). Mature females sacrifice somatic growth for ovarian growth, and tend to molt on a slower (at least two-year) cycle, extruding eggs and molting in alternate years (Herrick 1911; Aiken and Waddy 1976). Some studies suggest that a proportion of mature females, particularly first time spawners, molt and extrude eggs during the same season (Aiken and Waddy 1976, 1980, Ennis 1980, Ennis 1984; Robinson 1980, Briggs 1985). The overall consequences of these competing temperature related factors affecting the frequency of molting and the size of molt increments in females is that growth is slower in warmer regions (Section 9.2).

2.2.1 Molt Probability

Many studies based on tag recaptures report intermolt duration in terms of molt probability functions (Cooper and Uzmann 1980; Campbell 1983; Fogarty and Idoine 1988; Tremblay and Eagles 1997). Other authors have reported intermolt durations from laboratory data as simply the time spent between molts (Waddy and Aiken 1986). As lobster get larger, there is a declining probability that molting will occur during a year. Estimates vary between studies and often lack appreciable data for large lobster. A problem encountered when using these functions for modeling growth in this assessment was that they provide little information about intermolt duration of lobster that take longer than a year to molt. One approach is to use the inverse of the average molt probability at size to calculate an average intermolt duration or time spent between molts. However, as the molt probability function approaches zero, the intermolt duration approaches infinity. Since there is no evidence that lobster ever stop molting completely, as some other crustaceans do, this is unrealistic.

The approach used in this assessment was to use the inverse of a molt probability curve to define the maximum average intermolt period at size. Variation of the mean intermolt duration at size was incorporated by using the formula:

$$\text{Year}_{\text{(min-max)}} / (1 / \text{molt probability})$$

where: Year (min) = one for immature females, 2 for mature females
Year (max) = next whole integer larger than or equal to the inverse of molt probability

2.2.2 Molt Increments

The distribution of potential molt increments is important in describing lobster growth. ASMFC (2000) assumed that average molt increments were constant (GBK and GOM) or nearly constant South of Cape Cod Long Island Sound (SCCLIS) for female lobster 55 mm CL or larger. However, these assumptions imply implausibly large average increments (i.e. 11, 13.5 and 10-11 mm in GOM, GBK, and SCCLIS) in lobster as small as 55 mm. A review of growth studies summarized by Fogarty (1995), results in Comeau and Savoie (2001) and tag data for lobster in Long Island Sound (DNC, 2005) indicate that molt increments probably depend on size at molting, sex, and region. Changes in shell morphology at maturity in both sexes suggest that molt increments may change when lobster become sexually mature (Cadrin 1995). Assumptions about molt increments were therefore revised in this assessment to accommodate potential variability among sexes, maturity stages, regions, and sizes.

Data included sex (male or female), measurements of carapace length (CL in mm) before molting, and molt increments (mm) for lobster from: a) Maine Department of Marine Resources tagging studies conducted near Boothbay Harbor in the GOM region during 1983-1994 (unpublished data); b) Rhode Island Department of Environmental Management (unpublished data) shell cast data collected at sea from Rhode Island waters of Narragansett Bay, Rhode Island Sound, and around the east wall of Hudson Canyon during 1991-2002; c) University of Rhode Island (unpublished data) tagging studies in Narragansett Bay (used by ASMFC 2000 for the SCCLIS stock assessment area); and d) National Marine Fisheries Service tagging studies (39-42^{o} N Lat) during the late 1960's and early 1970s (Uzzman et al. 1977, used by Fogarty and

Idoine 1988 and ASMFC 2000) for lobster in the Georges Bank (GBK) region. Rhode Island DFW (RI), University of Rhode Island (URI), and Millstone Nuclear Power Station (DNC) data were combined at the outset to form a dataset for the SNE region.

Tagging data from lobster at liberty more than 365 days were omitted from all data sets to help avoid using data from lobster that may have molted twice. Data from Uzzman et al. for one male lobster with carapace length 155 mm were omitted because the observation might have high leverage and a disproportionate effect on results. There were a number of other "outliers" consisting of relatively small and large molt increments that may have been due to measurement error or, in the case of relatively large increments, double molting.

A relatively objective procedure based on carapace length, regions, and sex was devised for identifying and omitting outliers. The first step was to fit a robust linear regression line to increments (dependent variable) and carapace length (independent variable) data for males and females in each data set.[1] Observations with standardized residuals whose absolute values were greater than a threshold value were omitted from further analysis. Residual and increment plots were made for thresholds ranging 5-10. A threshold value of 6 was chosen because it was the largest value (omitted the least data) that excluded the apparent double molters with relatively large increments. At total of 36 observations for male lobster and 18 observations for female lobster were omitted from the data sets used in modeling.

The molt increment-carapace length model had three parameters for each sex and region:

$$\hat{I} = \begin{pmatrix} \alpha_{r,s} + \beta_{r,s} L & for\ L < \kappa_{r,s} \\ \alpha_{r,s} + \beta_{r,s}\kappa_{r,s} & for\ L \geq \kappa_{r,s} \end{pmatrix}$$

where $\hat{I}$ is the predicted increment for an individual in stock/sex group s, $\alpha_{r,s}$ is an intercept parameter, $\beta_{r,s}$ is a slope parameter, and $\kappa_{r,s}$ is an inflection point parameter. Based on this model, the maximum mean increment for lobster larger than the inflection point is $\max(I_{r,s}) = \beta_{r,s} \kappa_{r,s}$. The standard deviation of increments given carapace length is important and was estimated from residuals after the model was fit to increment and carapace length data using the Solver function in Excel.

Preliminary results indicated that the molt increment-carapace length model was reasonable for the available data. Preliminary parameter estimates were imprecise, however, because the range of carapace lengths in the data for each sex and regions was limited.

Several additional assumptions based on biology of lobster were made to stabilize molt increment-carapace length model results (Table 2.2.2.1 and Figure 2.2.2.1). In particular, the inflection point for females in each area was set at the point where 10% are sexually mature based on maturity parameters (ASMFC 2000). This assumption reflects the fact that growth changes in female lobster at sexual maturity (Cadrin 1995). The inflection point for males was reparameterized so that

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[1] The robust regression line was fit in Splus using `glm(inc ~ cl*BigLabel, family=robust, data=IncDat2)` where BigLabel was an identifier for males and females in each data set.

$\kappa_{r,Male}=P\kappa_{r,Female}$ where the parameter P=1.16 was the same for all regions and estimated along with other parameters in the model. Similarly, the maximum predicted carapace length for males was reparameterized so that $\max(I_{r,Males}) = J \max(I_{r,Females})$ where J=1.26 was the same for all regions and estimated in the model. Finally, the predicted increment at 6 mm (settlement) was set at 2 mm based on Massachusetts hatchery data (J. Idoine, NEFSC unpublished data). Standard deviations for residuals were similar and ranged 1.7-2.3 mm. For the sake of simplicity, the average standard deviation (2.1 mm) was used for both sexes in all regions.

2.3 Reproduction

2.3.1 Maturity

Size at maturity is related to summer water temperature (Waddy et al. 1995). High summer temperatures enhance maturation at small sizes. Fogarty (1995) reviewed maturity studies that defined geographic differences in size at maturity. Early maturation occurs in relatively warm water locations of the Gulf of St. Lawrence and inshore SNE (Aiken and Waddy 1980, 1986; Van Engel 1980; Estrella and McKiernan 1989). However, in deeper, offshore waters off the northeastern U.S. and in the Bay of Fundy maturation occurs at larger sizes (Krouse 1973; Campbell and Robinson 1983; Fogarty and Idoine 1988).

Historically, estimates of the proportion of females that mature at different sizes were derived from mathematical functions (logistic curves or maturity ogives) fit to percent maturity at size data. A major shortcoming of this approach stem from management measures that tend to protect mature females from fishing, once they reach legal size. Thus, the proportions of mature legal-sized females are artificially increased as fishing progresses. This result is an inaccurate profile of the proportion mature at size above the 83 mm legal minimum size. For populations with a high percentage of mature sub-legal females (i.e., in SNE and Long Island Sound), attempts to project a logistic relationship for the entire size range from sublegal sized females have provided mixed results.

In an attempt to refine maturity estimates, ovarian dissections were conducted to stage egg development through evaluation of size and color (Aiken and Waddy 1980). A standard that has been applied is to classify females with egg diameters >0.8 mm as mature. This ovarian staging methodology represents a highly accurate means of evaluating female maturity, but requires the sacrifice of the animal. An alternative technique, cement gland staging, (Aiken and Waddy 1982) was developed which could be done in the field and did not require the sacrificing of animals. Maturity stages are quickly and easily assessed by viewing the degree of engorgement of cement glands on the female pleopods. This method is most accurate when deployed one to two months prior to the spawning season and produces spurious results when deployed at other times of the year. Subsequent problems with stage interpretation and regional variability in results, which may have been due to geographic variation in the proportion of females that molt prior to extrusion in a given year, caused the ASMFC Technical Committee to revert to the more definitive ovarian staging procedure as a standard in 1998.

The states of Maine (ME), Massachusetts (MA), Rhode Island, and New York (NY) provided maturity data for this assessment based on ovarian and cement gland staging. ME and NY used ovarian staging (>0.8 mm diameter) in coastal GOM maturity evaluations, MA used cement gland development data which was verified with ovarian staging, and RI combined ova stage 4 females with ovigerous females as a maturity index. Maturity ogives for each stock were derived from data collected in different locations.

Maturity ogives for each stock were derived from data collected from a number of locations spanning a wide geographic range within each stock. For cases where there were multiple maturity ogives for a stock, the previously calculated ogives were defined by logistic functions*:*

$$Pmat_{CL} = \frac{1}{1+e^{(\alpha+\beta*CL)}}$$

where $Pmat_{CL}$ is the proportion mature at length CL. In the absence of complete raw data to estimate combined ogives, the individual functions were evaluated at one mm intervals, weighted by landings from the sub-areas they represented (based on statistical areas according to where the data were collected) and averaged. The catch weighted points were then used to estimate a logistic maturity ogive to represent the overall stock area. Parameter estimates for the final, average maturity ogives and details for the ogives from each subarea are given below. These are assumed to represent functional maturity

Stock Area	α	β
GOM	21.210	-0.2320
GB	18.256	-0.183
SNE	15.276	-0.2061

Maturity ogives for three regions in the GOM were available. Two were based on ova diameter data collected by the state of Maine. The third was based on several maturity indicators (D. Pezzack, Department of Fisheries and Oceans, Canada, pers. comm.) and represents the offshore section of the GOM. The three ogives indicate that female lobster mature at a smaller size in the inshore southern areas, at slightly larger sizes in the northern inshore areas, and at the largest sizes in the offshore portion of the GOM.

The maturity ogive for Georges Bank stock was based on ovigerous condition (adjusted for the interaction between growth and extrusion) in lobster collected from northern Georges Bank (Cooper and Uzmann 1977; Fogarty and Idoine 1988).

Maturity ogives were available from five regions within the SNE assessment area. They are as follows; Long Island Sound based on a re-analysis ova diameter data from Briggs and M Mushacke (1979), Buzzards Bay based on ova diameter adjusted cement gland data collected by the state of MA, the south shore of Long Island based on ova diameters of lobster collected by the state of NY (Briggs and Mushacke 1980), Block and Hudson Canyons based on ova color (Aiken and Waddy 1982) determined by external observation (without ovarian dissection) from lobster collected in by the state of RI, and Coastal Rhode Island Canyons based on ova color determined by external observation (without ovarian dissection) from lobster collected in by the state of RI.

2.3.4 Fecundity

Fecundity is an important parameter in assessment of the lobster resource, particularly when life history or length structured models are used to estimate biological reference points. Several studies have reported lobster fecundity at size for various locations throughout the range of the species. The earliest work reported was for the Buzzards Bay and Vineyard Sound areas of Massachusetts (Herrick 1896). More recently, lobster fecundity has been described for sites off Newfoundland (Ennis et al 1982), the Bay of Fundy, coastal southwestern and eastern Nova Scotia and Northumberland Strait (Campbell and Robinson 1983), coastal Maine (K. Kelly, in prep.), the offshore canyon areas of the northeastern U.S. (Perkins 1971), coastal Massachusetts (Estrella and Cadrin 1995), and Long Island Sound (Graulich 1991). Saila et al. (1969) published fecundity estimates of combined samples taken from coastal Quebec, Massachusetts, and Rhode Island.

Considerable variation in lobster fecundity at size has been reported for different areas (Ennis 1981; Graulich 1991; Estrella and Cadrin 1995). Variation between studies has been related to differences in collection and/or counting techniques, sample size, seasonal timing of study, and size composition of lobster sampled. Squires (1970) postulated that fecundity varies with geographic location.

Estrella and Cadrin (1995) performed extensive analyses on size-fecundity relations reported from Ennis (1981), Campbell and Robinson (1983), and their own samples collected from three Massachusetts coastal regions in 1987-88 (southern Gulf of Maine, outer Cape Cod, and Buzzards Bay). Southern Gulf of Maine estimates were significantly lower than those from the other two Massachusetts areas. Outer Cape Cod was not significantly different from Buzzards Bay. Size-fecundity relations from some Massachusetts regions were statistically equivalent to those from some Canadian areas. The authors reported that although geographic variation in fecundity could not be ruled out, other factors, such as interannual differences in temperature and environmental variables, and differing methods of collection and handling which contributed to egg loss, confounded definitive conclusions about geographic differences. These authors also performed a rigorous comparison of the historical fecundity data of Vinal Edwards as reported by Herrick (1896) with their own data from southern Massachusetts and found the two sets of fecundity estimates to be nearly equal. Herrick sampled significantly more lobster (4,645) than in any recent studies and covered a broader size range (66-170 mm CL). Predicted egg numbers, estimated from a power curve fit to Herrick's data, range from 16,870 at 100 mm CL to 222,733 at 200 mm CL.

Fecundity estimates for all three stock areas in this assessment were based on Estrella and Cadrin's (1995) analysis of Herrick's data. These estimates were generated from "brown" eggs, and are assumed to represent number of eggs that will hatch.

2.4 Stock Definitions

The ASMFC lobster technical committee recommends changing stock boundaries for the current assessment based on the lobster distribution and abundance, patterns of migration, location of spawners, and the dispersal and transport of larvae. Breaking from the previous two assessments of American lobster (ASMFC 2000, NEFSC 1996), the committee has adopted three stock areas: Gulf of Maine (GOM), Georges Bank (GBK), and Southern New England (SNE) (Figure 2.4.1 and 2.4.2). SNE replaces the South of Cape Cod and Long Island Sound (SCCLIS) stock in the last assessment. Georges Bank (GBK) replaces the Georges Bank and South (GBS) stock in the last assessment. The boundaries of the GOM are unchanged from previous assessments, while GBK is split from other offshore areas and SNE is a combination of southern inshore and offshore waters. The new and old stock definitions are described in terms of bottom trawl survey strata in Table 6.2.1 and in terms of statistical areas used to report landings in Table 6.2.5.

Previous assessments have noted the exchange between southern New England inshore waters and the offshore canyons and recommended that stock boundaries be reconsidered for the current assessment (ASMFC 2000, NEFSC 1993). The interchange of larvae, sub-adults, and adults between the previous stock assessment areas SCCLIS and GBS was described in various studies (Saila and Flowers 1968; Cooper and Uzmann 1971; Uzmann et al. 1977; Fograty et al. 1980; Briggs 1985; Cobb et al. 1989; Katz et al. 1994, NUSCO 1999). A Technical Committee review of new maturity at size data for offshore Southern New England indicates that maturity at size in offshore Southern New England is more similar to inshore Southern New England than Georges Bank.

The linkage between inshore and offshore SNE could have potential effects on the resilience of the inshore areas to intense fishing effort. Katz et al. (1994) indicated that larval swimming abilities coupled with prevailing oceanographic conditions make larval transport possible over long distances. Fogarty (1998) modeled a hypothetical inshore-offshore system and demonstrated a qualitative change in the system resilience under this scenario, even with low larval subsidies.

The proposed break of GBK from SNE can further be substantiated by investigating patterns of migration, size composition, and maturity on or near Georges Bank. Evidence of directed migration of adults between offshore canyon and shallow areas on Georges Bank proper suggest cross shelf movements (deep to/from shallow) are more pronounced than along shelf movements (north to south) in this area. There is little evidence that lobster originating on Georges Bank cross the Great South Channel located between Georges Bank and Cape Cod (Cooper and Uzmann 1971 and Estrella and Morrisey 1997). Watson (per com) confirmed earlier studies of Skud (1969) that Georges Bank consistently has a larger size composition than southern Canyons, inshore SNE, or GOM. Additionally, the presence of juvenile lobster NEFSC trawl surveys in shallow water on Georges Bank suggest an enclosed recruitment cell because it is very unlikely that these juvenile lobster migrated from inshore areas (Krouse 1981). Finally, Georges Bank has a larger size of maturity than GOM and SNE (Little and Watson 2005, Skud 1966).

2.5 Natural Mortality

All assessment models are sensitive to the values chosen for natural mortality (*M*) and to the interaction between *M* and other parameters (Vetter 1988, Bannister and Addison 1986). Uncertainty in the nature of M for American lobster is compounded by the fact that accurate aging techniques have not yet been developed to determine a reliable maximum age for inshore and offshore stocks (see section 2.1). For this reason, previous assessments have adopted the convention of holding *M* constant over time and among all size and age groups (Quinn and Deriso 1999). A constant *M* is usually chosen using some life history criteria such as longevity, growth rate, and age at maturity (Hoenig 1983, Pauly 1980). American lobster's many traits fostering a relatively long life span and slow reproduction have led to the species' classification as "k-selected" with low natural mortality after the larval stage. A low and stable natural mortality rate seems reasonable for American lobster inhabiting stable environments in offshore canyons where they can attain very large size (>190 mm CL, Thomas 1973). A value of M = 0.15 was assumed for all recruit and fully recruited (legal size) lobster in previous assessments (Fogarty and Idoine 1988). The same convention was applied in this stock assessment except for SNE where there is evidence of an increase in natural mortality during some recent years.

A low and stable natural mortality rate seems less certain for inshore lobster stocks south of Cape Cod. Environmental fluctuations can often be highly stressful and selective pressures may favor earlier reproduction over a shorter life span. Growing evidence (Lapoint et al. 1989) demonstrates that natural mortality may vary inversely with body size (Boudreau and Dickie 1989, Jones and Shanks 1990); may be under direct control of biotic and abiotic factors (Sparholt 1990); and density-dependent factors (Vetter 1988, Addison 1986, Munro 1974). Additionally, the effects of disease can be as profound as predation or exploitation (Anderson and May 1979, Hart 1990). Disease outbreaks can produce significant losses in all life history stages (Bayer et al. 1993, Stewart 1980). A widespread die-off of lobster in Long Island Sound in the fall of 1999 caused the Secretary of Commerce to declare a commercial fishery failure in the Sound in January 2000. Research conducted by the University of Connecticut (Mullen et al 2003) indicated that a protozoan parasite, *Neoparamoeba pemaquidensis*, was the immediate cause of the die-off. This parasite is known to be present in marine waters from the Gulf of Maine to Long Island Sound prior to the 1999 die-off (O'Kelly and Gillevet 2004), however the virulence of the disease was increased by high water temperatures in concert with hypoxia. In light of these biological factors and the documented mortalities in Long Island Sound, a range of natural mortality rates were used in assessment models for the Southern New England stock during 1997-2003.

2.6 Shell Disease

External bacteria that digest the minerals in a lobster’s shell cause shell disease. Since lobster routinely clean themselves, the disease occurs most commonly on the back carapace and claws where they can't easily reach. The same suite of bacteria causes shell disease in the wild from Maine to New York (Chistoserdov et al. 2004). Calculating a mortality risk associated with shell disease is difficult. Lab studies have shown that lobster with shell disease can heal themselves by molting out of the diseased shell and replacing it with a new healthy one. However, if the disease bacteria become thick enough to penetrate completely through a lobster's shell, internal lesions lead to a compromised immune system or death. Ecdysone, a hormone that controls the molting process in lobster, has been found at levels well above normal in shell diseased lobster, indicating that severe cases of the disease may interfere with normal molting (Laufer a 2004). An increase in shell disease prevalence may be an indication of above normal stresses in the lobster populations. Since the disease is most prevalent in eggbearing females (see below), early molting may cause declines in reproduction.

2.6.1 Prevalence of Shell Disease

Monitoring of shell disease prevalence has been carried out with increasing intensity over the past 20 years. Biologists in the states of Connecticut, New York, Rhode Island, Massachusetts, New Hampshire, and Maine record the occurrence of shell disease in lobster examined during commercial sea sampling. Connecticut and Rhode Island biologists also record prevalence in lobster captured in their research trawl surveys. The longest monitoring program began in 1984 by biologists studying the lobster population in the area surrounding the Millstone Power Plant in eastern Long Island Sound (DRS 2005). The first record of the disease in that area was in 1988, and then not again until 1997. Prevalence has increased since the late 1990's in all state waters from Massachusetts south to New York, reaching 20-30% of all observed animals in some years (Table 2.7.1). New Jersey has no monitoring program, but fishermen have reported shell disease in that state. New Hampshire began a monitoring program in 2001, however few diseased lobster have been observed. Shell disease was noted for the first time in Maine in April 2003 during Maine DMR field observations. During the 2003 and 2004 sampling season, 93 lobster were recorded as having shell disease, which represents less than 0.01% of lobster examined by Maine DMR staff. More than 50% of shell disease observations were made during one sea sampling trip in the June 2004 when 22 of 426 lobster measured (5%) were scored as having shell disease.

In response to the increased occurrence of shell disease in the late 1990s, biologists from Massachusetts, Rhode Island, Connecticut, and New York held a workshop in June 2000 (DRS 2003) to develop a uniform protocol for assessing the severity and proportion of lobster affected with shell disease syndrome. The participants agreed that with an established index it would be possible to compare relative lobster health among several jurisdictions. It would also be possible to get a more complete coastal picture of the prevalence, severity, and progression of shell disease along the range of the lobster resource. The index established during this workshop is applied by taking into account the percent coverage of shell disease on the total surface area of the lobster. The categories were designed to be broad in scope to reduce subjectivity. They are: 0 = no disease, 1 = 1 – 10 % of the shell surface, 2 = 11 – 50 % and 3 = > 50%. In instances where it is difficult to distinguish between two indices the severity (depth) of the shell erosion is taken into consideration when assigning the index.

In Southern New England eggbearing females represent the majority of diseased animals. In the worst years, prevalence of the disease exceded 80% of all observed eggbearing females. Since 2001, when documentation of disease severity was standardized, the bulk of lobster observed with severe shell disease (scale 3, >50% coverage) were eggbearing females.

Tag return data in Long Island Sound (Simpson et al. 2003) were examined for changes in the occurrence of shell disease during days at large from 2001 to 2003. Return records for 2,647 lobster contained enough information to examine the retention and acquisition rates of shell disease. The average time between release and recapture for these animals was 148 days. Of the 2,647 returns, 392 lobster were tagged with shell disease and 2,255 were tagged without shell disease. For those lobster tagged without shell disease, 186 of 2,255 animals, or 8.2%, were recaptured with shell disease. This disease acquisition rate was calculated over a 41 month period (August 2001-December 2004). Interim calculations for each year resulted in similar percentage acquisition rates. For those lobster tagged with shell disease, 244 of 392 animals, or 62.2% were recaptured still showing the disease. These acquisition and retention rates should be considered minimum values since fishers are more likely to forget to report shell condition ('false no') than to report it erroneously ('false yes'). Lobster tagged with severe levels of shell disease (scale 3, >50% coverage) appeared to be mixed at random among those with less severe levels of the disease. Movement patterns (km/day at large and direction) of lobster recaptured with shell disease were not different from those that did not have signs of the disease. For additional information on shell disease see the New England Aquarium Shell Disease Symposium.

3.0 Fishery Description

3.1 Brief history of the lobster fishery

American lobster is often mentioned in documents about New England colonies as an abundant species and a dependable source of bait and food. Wood (1635) commented on lobster abundance that “their plenty makes them little esteemed and seldom eaten”. Numerous citations indicate that lobster were easily captured in Canada and New England and were used for food, bait, and fertilizers. Early fisheries were conducted by hand, dip net, and gaffs in shallow waters along the shoreline (Nicosia and Lavelli 1999). Lobster were also taken in a labor-intensive fishery using hoop nets along the shoreline. Wooden lath traps became the dominant gear by 1840 and were set using row boats and sail boats. Use of gasoline powered engines began around 1905.

Rathbun (1887) described the lobster fishery as beginning around 1800 along the coast of Massachusetts, in particular on Cape Cod and near Boston. The initial fishery supplied large lobster (> 3 lb) for the fresh market located in New York and Boston. The fishery was conducted in shallow, near-shore areas. Smack boats cruised the coast catching lobster and/or buying lobster from local fishermen. They carried the catch to Boston and New York Markets. When declining catch rates of marketable lobster was unable to supply the markets, the fishery expanded to New Hampshire and Maine waters in the 1840s. A second market for “small” lobster (between 2-3 lb) for canning developed in Maine. Canning began in 1843 and twenty-three canneries were operating in Maine by 1880. In 1855, market lobster were 3 lb or greater, culls for the cannery market were between 2 and 3 lb, and lobster less than 2 lbs were discarded. Rathburn reported the following “average” size, in total length, at the four principle markets for lobster in the early 1880’s:

Portland, Maine	10.5” TL	(92 mm CL)
Boston, Massachusetts	11-11.5” TL	(97-101 mm CL)
New Haven, Connecticut	10.5” TL	(92 mm CL)
New York, New York	10.5-15” TL	(92-133 mm CL)

From 1870 to 1880, the lobster fishery experienced declines in catch per trap and average size of lobster. The fishery responded by expanding the area fished, increasing the number of pots set, extending the fishing season, and fishing single pots instead of trawls in order to cover more area. As average size of the catch declined, markets adjusted by lowering the size of acceptable lobster. Similar trends occurred throughout the range of the lobster fishery. In Buzzard Bay (SNE stock), lobster averaged 3 lb (approx 120 mm carapace length) in 1840 and 2.5 lb in 1880. Today, an average lobster landed from Buzzards Bay weighs 1.5 lb.

A comparison of length frequency also confirms that size structure in the inshore waters was wider in the 19th century than today. Length frequency of lobster captured in Buzzards Bay (Woods Hole) in 1894 and 2002 and length frequency of egg bearing females taken from Vineyard Sound/ Coxes ledge in 1894 and Buzzards Bay in 2002 are shown in Figures 3.1.1 and

3.1.2. Despite concerns about declining size of the catch in the 19th century, the size structure in 1890's was much broader in Buzzards Bay than is found today.

The decline in lobster landings coastwide led states to implement minimum sizes and closed seasons. The decline of the fishery seen in Massachusetts' waters spread coastwide. The New Jersey fishery was carried out extensively in the 1860's, but was nearly wholly abandoned as unprofitable by 1870, despite proximity to the largest lobster market in New York. Even with indication of a revival in 1872, the lobster fishery in New Jersey remains small to the present time. The fishery in New York and Hell Gate was also extensively carried on before becoming abandoned due to unprofitable landings. The Provincetown fishery was abandoned except for men that were too old to participate in alternative fisheries. Large decreases in landings, catch rate, and average size was noted in Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine.

The decline caused the implementation of a series of management regulations in Maine (78.9 mm carapace length April 1 to August 1, remainder of year 92.3 mm, closed season August 15-October 1), New Hampshire (92.3 mm), Massachusetts (92.3 mm, closed season June 20-Sept 20), Rhode Island (87.8 mm), Connecticut (87.8 mm), and New York (92.3 mm). Maine also instituted protection on berried females.

Landings, average size, and catch per trap continued to decline over the next twenty years in all states and Canada. In Massachusetts, the number of lobster (> 92mm) per trap declined from 80 per trap in the early 1880's to approximately 30 per trap in 1907 (Figure 3.1.3). In comparison, the catch per trap of lobster > 92 mm in Massachusetts fishery in 1995-1999 ranged from 5 to 7 per trap. Concerns about the growing crisis in the fishery led to a Convention in 1903 to develop recommendations for uniform legislation in states to protect lobster. Representatives from Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, and Canada attended. Lobster stocks were considered to be in critical state with declines in average size of the catch and catch per trap haul. Management measures under consideration were increases in minimum size, slot limits, gear modifications to change selectivity, closed seasons, trap limits, v-notching protection for females, limited access to permitted fishermen only, and hatchery stock enhancement through hatchery propagation. The slot limit was advocated to increase egg production by protecting the larger, more fecund lobster. Protection of berried females and prohibition of landing shelled lobster meat were enacted.

The Convention of 1903 failed to establish uniform regulations because of a concern to tailor regulations to meet local conditions. Enforcement of existing regulations was considered to be problematic everywhere. Scientists also noted the inadequacy of landing statistics. In general, scientists believed that stock declines were fishing related and that landings were increasing due to increased effort, technological improvements, and spatial and temporal expansion of the fishery. The comparative impact of fishing mortality and natural mortality rates through predation and disease on abundance was debated.

States responded to the crisis in various ways. Rhode Island and Massachusetts dropped the minimum size to 78.9 mm carapace length. Connecticut raised the minimum size from 78.9 mm to 79.3 mm. In 1907, Maine increased the size limit to 4.75" total back shell. From 1907 onward, states implemented many small changes in the minimum size, protection for egg bearing females, and prohibition on landing lobster meat. Maine instituted a maximum carapace length. Voluntary v-notching programs were enacted in Maine and Massachusetts. Landings remained low, averaging approximately 5,000 tons (t) from the 1920 through 1940. Total landings increased slowly from 1940 through 1970, averaging near 14,000 t through the late 70's. Landings have since doubled and are near 37,000 t in recent years.

Otter trawl vessels generally took landings from the offshore areas. Landings were generally less than 50 t through 1946. The offshore trap fishery intensified after the mid-1965 with 2,500 t landed from the offshore canyons in 1965. The deepwater trap fishery has dominated offshore landings since 1972. The size distribution of lobster in the offshore fishery was much wider than the inshore fishery with more large lobster. Skud (1969) concluded that, "canyons that were more heavily fished had lower catch per trap and a smaller mean size". He also reported that the modal size of lobster from Veatch and Lydonia Canyons was smaller in 1965-67 than in 1956 and the decrease in size was greatest in Veatch Canyon. The length frequency of lobster in Hudson Canyon was similar to Veatch Canyon in 1965-1967. A comparison of length structure in Veatch Canyon in 1965-1967 with length frequency in Hudson Canyon in 1991 and 2003 (Figure 3.1.3) indicates continued truncation of the length frequency, although some of the changes can be attributed to differential gear selectivity. In 2003, 80% of lobster from Hudson Canyon were within 1 molt group of the minimum legal size.

Several observations can be drawn from reviewing lobster history. Large lobster were found in inshore shallow water throughout the range of the lobster. Declines in size structure and catch per trap that occurred in the 1880's were attributed to increased fishing effort throughout the range of the fishery. These declines were initially local (Boston- Provincetown) and then spread coast wide. Terms such as commercial extinction were in use in 1903. Low productivity, as measured by landings, extended for long periods. In particular, coast wide landings declined over a 25-year period (1889-1915) and remained low for another 50 years. By 1999, landings in the United States and Canada reached historic highs (Fogarty and Gendron, 2004). The debate about relative importance of fishing and other factors such as predation and degraded habitats was well established at the turn of the 20th century. Echoes of that debate remains today. Most of the current management measures under consideration today (minimum sizes, v-notching, closed season, maximum size, slot limits, trap limits, protection of egg bearing lobster) were either discussed or implemented over 100 years ago. In many cases, regulations such as minimum sizes and closed season are less restrictive today than 100 years ago.

3.2 Current Status

The U.S. lobster fishery is conducted in each of the three stock units proposed in this assessment; the Gulf of Maine, Georges Bank, and Southern New England. Each area has an inshore and offshore component to the fishery, with the inshore fishery dominating in the Gulf of Maine and Southern New England, and the offshore fishery dominating in the Georges Bank stock unit. The Gulf of Maine supports the largest fishery, constituting 74% of the U.S landings between 1981 and 2003, and 85% from 2001 to 2003. Southern New England has the second largest fishery accounting for 21% of the U.S. landings between 1981 and 2003. This fishery has experienced dramatic declines in landings and has accounted for only 12% of the U.S. landings from 2000 to 2003, reaching a time series low of 8% in 2003. Georges Bank constitutes the smallest portion of the U.S. fishery, averaging 5% of the landings from 1981 to 2003. During this time period the Georges Bank fishery has remained stable.

The total number of fishing permits issued (Table 3.2) in the U.S. lobster fishery has remained fairly stable over the time series, ranging from 10,813 to 12,790, with a median value of 11,884. This pattern is not homogeneous among states. The states of Connecticut, Maine, and Massachusetts have exhibited declines in the number of licenses issued from highs observed in the early to mid- 1980's. The number of permits issued in Rhode Island and New Hampshire have varied without trend from the beginning of the time series to the late 1990's, and have experienced notable increases (17% and 8% respectively) from 2000 to 2004. These increases are due to the lack of a limited entry scheme in these jurisdictions. The state of New York had a sharp increase in the number of permits issued from the early 1980's to the mid-1990's, reaching the high of 1,265 permits in 1994. Subsequently, the number of permits issued dropped dramatically from 1995 to 2003 reaching levels last observed in the early 1980's. These declines are due to regulatory changes including license moratoria.

Lobster traps are the primary gear type employed in the U.S. lobster fishery. Between 1981 and 2003 traps accounted for an average of 98% of the total landings. All other gear types (otter trawl, gill net, dredge, SCUBA) account for the remaining 2% of the total landings. The standard unit of fishing effort is difficult to define in the American lobster fishery. The relationship between the number of traps fished and fishing effort is not simple or linear. Many factors affect the catch rates of lobster traps including location, bait, trap design, soak time, temperature, and the presence of other animals (Cobb, 1995). This complicates the relationships between catches or CPUE and abundance /or densities, as well as between effort and mortality (Miller, 1989, 1990; Karnofsky and Price, 1989; Addison and Bell, 1997; Addison and Bannister, 1998). A comprehensive description of the factors affecting lobster catchibility and trap efficiency is provided in *ASMFC 2000 Lobster Stock Assessment for Peer Review*. The number of trap hauls or trap haul set over days is a relatively robust estimate of fishing effort; however these data are not currently collected by all states. For this reason the number of traps fished is presented instead of the number of trap hauls. The number of traps fished are reflective of trends in fishing effort, but should not be interpreted as absolute estimates of effective fishing effort or as measures of trends in fishing mortality.

The operational characteristics of the U.S. lobster fishery have changed significantly in recent decades. There have been substantial increases in trap numbers, average trap size, and average boat size. The primary type of trap used in the fishery has changed from the traditional wood lathe traps to wire mesh traps. Advances in radar, sonar, and navigational electronics have increased the efficiency of fishing vessels. Each of these factors affects catch rates and overall yield of the U.S. lobster fleet (Miller, 1995).

3.2.1 Gulf of Maine

The Gulf of Maine fishery is primarily carried out by fisherman from the states of Maine, Massachusetts, and New Hampshire. This fleet is comprised mainly of small vessels (22 and 42 feet) that make day trips in nearshore waters (less than 12 miles). The Gulf of Maine also has a smaller-scale offshore fishery comprised of larger boats that make multi-day trips.

Commercial lobster landings in the Gulf of Maine were stable between 1981 and 1989 averaging 14,600 metric tons, then increased dramatically from 1990 (19,200 mt) to 1999 (30,000 mt), and have remained at record high levels since (1999 to 2003 mean = 30,281 mt) (Table and Figure 3.2.1.1). The increase in landings in the GOM was dominated by catch from the state of Maine, which tripled between 1981 and 2003. These increases were particularly strong in the mid-coast portion of the state. Landings from New Hampshire varied without trend around a mean of 613 metric tons between 1981 and 2003. Massachusetts's landings increased from 1981 to 1990, remained high between 1991 and 2000 (averaging 4,979 mt), and have declined to a time series low in 2003 (3,448 mt).

The number of traps fished in the Gulf of Maine was fairly stable between 1982 and 1993 averaging approximately 2.3 million traps. Since 1993 there has been a dramatic increase in the number of traps, reaching a time series high of 3.6 million traps in 2003 (Table and Figure 3.2.1.2). In the Maine fishery, traps varied without trend around an average of 2 million between 1982 and 1993, and then increased reaching a time series high of 3.1 million in 2003. The trend in the Massachusetts portion of the fishery is quite different. Traps increased substantially from a time series low in 1982 (247,000 traps) to a time series high in 1991 (399,000 traps), and have remained fairly stable averaging 382,000 traps between 1992 and 2003. Effort data for the New Hampshire fishery is only available from 1989 to present, during which traps fished varied without trend around an average of 44,000.

3.2.2 Georges Bank

Fisherman from the states of Massachusetts and Rhode Island primarily carry out the Georges Bank fishery, with a smaller number of participants from Connecticut and New Hampshire. This fleet is comprised of larger vessels (55 to 75 feet) that make multi-day trips. Georges Bank also has a smaller-scale inshore fishery comprised of smaller boats that make day trips along the outer arm of Cape Cod.

Commercial lobster landings in the GBK stock unit have generally varied between 1200 and 1600 metric tons since the early 1980's (1981 to 2003 mean = 1,380 mt) (Table and Figure 3.2.2.1). Catch from the state of Massachusetts comprised the majority of the GBK landings, averaging 67% of the total from 1981 to 2003. This proportion has increased in the later part of the time series, whereby Massachusetts accounted for greater than 80% of the landings from 2001 to 2003. Rhode Island accounted for the second largest proportion of landings on GBK (1981 to 2003 mean = 28%), however, this proportion has declined over the coarse of the time series reaching a low of 7% in 2003. Prior to 1993, New Hampshire did not have consistent landings in GBK. From 1993 to 2003 NH landings were stable, averaging 113 metric tons. Landings from all other states comprised less than 5% of the GBK landings throughout the time series.

The number of traps fished on Georges Bank is not well characterized, due to a lack of mandatory reporting, and/or a lack of the appropriate resolution in the reporting system. Massachusetts is the only state that has a time series of effort data for this stock. As such, Massachusetts data are presented here as an index of relative effort for the Georges Bank stock. The number of traps fished on Georges Bank increased steadily from early 1980's to the mid-

1990's, reaching a time series high in 1994 (47,000 traps) (Table and Figure 3.2.2.2). From 1994 to 2003 the number of traps has varied without trend around a mean of 44,000 traps.

3.2.3 Southern New England

The Southern New England fishery is carried out by fisherman from the states of Connecticut, Massachusetts, New York, and Rhode Island, with smaller contributions from the states of New Jersey, Delaware, and Maryland. This fleet is comprised mainly of small vessels (22 and 42 feet) that make day trips in nearshore waters (less than 12 miles). Southern New England also has a considerable offshore fishery comprised of larger boats (55' to 75') that make multi-day trips to the canyons along the continental shelf. Between 1981 and 2003 the inshore and offshore portions of this fishery accounted for 75% and 25% respectively of the total SNE landings.

Commercial landings in the Southern New England stock increased sharply from the early 1980's to the late 1990's, reaching a time series high of 10,054 metric tons in 1997. Landings remained near time series highs until 1999, then declined dramatically back to levels observed in the early 1980's (Table and Figure 3.2.3.1). The majority of the catch in SNE is landed by Rhode Island (1981 to 2003 mean = 37 %), followed by New York (23%), Connecticut (16%), Massachusetts (14%), and New Jersey/Delaware/Maryland/Virginia (10%) in descending order. Landings trends among states within the SNE stock were generally similar to the overall trend. One notable exception is New York, where the increase in the late 1990's and decline in the early 2000's are much more dramatic.

The number of traps fished in SNE increased five fold from the early 1980's to the late 1990's, reaching a time series high of 800,000 traps in 1999, and has declined by 50% between 2000 and 2003 (Table and Figure 3.2.3.2). New York accounted for the majority of the total number of traps fished in SNE (1981 to 2003 mean = 37%), followed by RI (32%), CT (16%) and Massachusetts (15%) in decreasing order.

4.0 Habitat

4.1 Temperature

Water temperatures exert significant influence on reproductive and developmental processes of lobster. Temperatures must reach 8-10 °C during winter in order to maintain a balance between the synchronization of the molt and ovarian development cycles in female lobster (Aiken and Waddy 1985). In northern waters, warmer winter temperatures favor molting but cause oocyte resorption (Aiken and Waddy 1986). Photoperiod has been implicated as a factor governing spawning (Nelson et al. 1983).

Temperature has a strong effect on embryonic development with the onset of hatching varying with year, location, and the temperature history of females (Aiken and Waddy 1986). Since temperature can affect the rate at which the embryo assimilates lipids, delayed hatching may result in depletion of lipid reserves. Lipid Reserves are important to survival during the pelagic larval stages. The duration of the planktonic phase is dependent upon seawater temperature. Huntsman (1923, 1924) found that larvae hatched in water less than 15°C developed much more slowly than those hatched in warmer water. Time from hatching to stage IV is approximately 10 days at 22-24°C and nearly two months at 10°C, while at 5°C larvae generally die without reaching stage IV (Templeman 1936).

Temperature also has a significant impact on benthic juvenile and adult lobster growth, survival, and reproduction. Aiken and Waddy (1986) reported that juvenile and adult lobster are found seasonally in waters ranging from 0^0C to 25^0C. Tolerance of high temperatures depends on acclimation, but tolerance to any temperature declines as optimal dissolved oxygen and salinity levels decrease. In the laboratory, lobster acclimated to 15.5^0C demonstrated a behavioral avoidance of temperatures above 19^0C (Crossin et al. 1998). In another lab study lobster held at 21^0C and 23^0C had significantly higher respiration rates than those held at 18^0C and 19.5^0C (Powers et al. 2004). These high respiration rates were considered stressful. Even normal respiration rates can become problematic because high water temperatures often combine with hypoxia, and sometimes the release of sulfides and ammonia into the water column from enriched sediments (Robohm et al. 2003). This combination of events can often be lethal for lobster and other benthic invertebrates. It appears that temperature effects are nonlinear and that a distinct thermal threshold exists at 20^0C.

On a larger ocean-wide scale, small increases in annual average seawater temperature over the last 40 years may have caused significant changes in the survival of both lobster and their predators. Several long-term data sets show that average seawater temperature off Massachusetts has increased 0.04^0C /yr from 1970 to 2002 (Nixon et al. 2004). Oviatt (2004) also examined this coastal warming trend along with fisheries data from Narragansett Bay, RI, and found that a decline in boreal bottom fish was closely followed by an increase in decapod abundance including several species of crab and lobster. She concluded that the warming trend had resulted in northern demersal fish species being replaced by southern pelagic species. During the 1990s the lack of predatory demersal finfish resulted in increased lobster survival throughout the area.

4.2 Currents

In contrast to the gradual development of fish, crustaceans pass through a series of distinct larval stages that are punctuated by molts. It is within these larval stages where principal forcing agents such as wind stress, tides, differences in water mass density, and directed swimming can impact the distribution and abundance of marine crustaceans and our interpretations of stock structure (Epifanio and Garvine 2001).

American lobster eggs are carried on the abdomen of the female for 9 to 12 months before hatching. The female releases prelarvae over the course of several days, sometimes accompanied by female movement, and molt into positively buoyant 1st stage zoeal larvae. The 1st, 2^{nd}, and 3rd stage zoeal larvae remain planktonic for approximately 15-30 days and are variably distributed throughout the water column (Harding et al., 1987). In their 4th stage, they metamorphose to postlarvae. The developing larvae and postlarvae can be transported considerable distances (e.g., Katz et al. 1994). Neustonic postlarvae actively swim at the surface for 10 to 30 days (Cobb et al., 1989), before making the transition from pelagic to benthic habitats.

The Gulf of Maine is a semienclosed marginal sea with several deep basins, strong tidal currents, and a generally cyclonic circulation. Scotian Shelf water enters along the south coast of Nova Scotia and exits primarily along the northern edge of Georges Bank and secondarily through the Great South Channel (Brooks 1985). Larval transport is one mechanism to link inshore (coastal) and offshore (basin) lobster. Fogarty (1998) calculated that a modest amount of offshore larval supply could add significantly to the resiliency of inshore areas. With hatching occurring over the period of two months, beginning generally in late June in southern areas and a month later in northern areas, conditions experienced by developing larvae can be very different. Favorable conditions for larvae can greatly increase development time and when coupled with the typical physical forcing factors observed within the Gulf of Maine, a delivery mechanism of competent larvae to nearshore nursery grounds is developed (Incze et al. 1998).

As larvae develop in the summer on Georges Bank, a strong cyclonic gyre tightens increasing residence time to 50 days inside the 100 m isobath (GLOBEC 1997). Wind and eddy events may periodically transport larvae off of Georges, but they are unlikely to strongly impact the supply of larvae to coastal Nova Scotia and other northern areas of the Gulf of Maine (Harding et al. 2005).

The Southern New England stock area is characterized by lower tidal currents than the Gulf of Maine and Georges Bank. Consequently, drift was found to be highly wind dependent, with tidal currents only influencing short term movements. Fogarty (1983) observed peak larval densities following periods of onshore winds in the days preceding sampling in Block Island Sound and identified offshore areas and Long Island Sound as possible larval sources. Lund and Stewart (1970) suggest higher concentrations of larvae in western Long Island Sound were a result of surface currents, creating a larval retention area. This notion of oceanographic forcing is confirmed in a recent review by Epifanio and Garvine (2001), who suggest that larval transport is primarily influenced by onshore wind stress and water density differences along the Atlantic continental shelf.

4.3 Salintiy

The impermeable egg membrane may provide some measure of protection for the embryo against low salinity because embryos require a longer adaptation time to low salinity than hatchlings or prelarvae (Charmantier and Aiken 1987). Larval lobster are sensitive to salinity below 20 ppt and swim to greater depths to avoid lower salinity surface waters. In contrast, juveniles and adults can tolerate a broader range of salinity, from 15-32 ppt (Harding 1992). Larval stages I-III were more adaptable to low salinity than stage IV (Charmantier et al. 1984) and less resistant to elevated salinity than postlarvae and juveniles (Charmantier et al. 1985). No stage III or IV larvae survived salinity below 12.5 ppt. No larval molting occurred beyond a salinity of approximately 40 ppt. Changes in salinity present a greater problem for pelagic larvae than for benthic juveniles and adults because they are more directly exposed to rainfall (Aiken and Waddy 1986), although excessive runoff can lower bottom salinity and cause mortality. Lobster prefer higher salinity (20-25 ppt) over lower (10-15 ppt) (Jury et al. 1994). Males tolerate lower estuarine salinity better than females, a fact that explains why males are more abundant in trawl surveys in the inner reaches of Narragansett Bay than in the outer bay (Castro, 1998a.).

4.4 Dissolved Oxygen

Adult lobster demonstrate a behavioral avoidance of dissolved oxygen (DO) levels below 2 ppm (Howell and Simpson 1994, Robohm et al. 2003). As juvenile and adult lobster prepare to molt they are more susceptible to low DO because oxygen consumption peaks at molting (Penkoff and

Thurberg 1982). Oxygen consumption also increases with stress, feeding, increased activity, and water temperature (McLeese 1956). Miller et al. (1992) found that larval lobster appear twice as sensitive as juveniles and adults to reduced DO. However, since larvae are planktonic, spending a good deal of time in the upper water column, encountering low DO would be a rare event.

4.5 Substrate

During settlement, 4th stage post-larvae exhibit strong habitat selection behavior and seek small shelter-providing substrates (Hudon 1987; Wahle and Steneck 1991, 1992; Incze et al. 1998; Palma et al. 1999). The highest abundance of newly settled lobster is in cobble beds (Wahle and Steneck 1991; Cobb and Wahle 1994; Palma et al. 1999) but they have been found at low densities in marsh grass root mats in southern New England (Able et al.1988). Young of the year lobster are rare or absent from sediment substrates and eel grass habitats although early benthic phase lobster (sensu Steneck 1989; Wahle and Steneck 1991 for lobster < 40 mm CL) are not.

Early benthic phase lobster are cryptic and quite restricted in habitat use (Wahle and Steneck 1991; Lawton and Lavalli 1995). They usually do not emerge from their shelters until reaching about 25 mm CL (Wahle 1992; Cobb and Wahle 1994). Larger, but still immature, adolescent phase lobster are found on a variety of bottom types, usually characterized by an abundance of potential shelters. Inshore, they are found in greatest abundance in boulder areas (Cooper and Uzmann 1980) but they also seek shelter under large algae such as kelp (Bologna and Steneck 1993). Adolescent phase lobster also live on relatively featureless substrate where juvenile population densities are generally low (Palma et al.1999). Juvenile densities are high in shallow water, (0-30 ft) on sand, and mud substrate in inshore Massachusetts waters (Estrella, personal communication).

5.0 Data Sources

5.1 Fisheries Dependent

5.1.1 Sea-sample/Port Sampling Data Collection Methods

5.1.1.1 Survey Methods

Maine Port and Sea Sampling Programs

Since 1966, port sampling has occurred during ten randomly selected days each month from April through December. Port samplers survey lobster dealers along the entire coast who buy from at least five commercial lobstermen. This survey is designed to produce unbiased estimates of catch, effort, sex, and size distribution of the landed catch for the entire fishery on a monthly and annual basis. Recorded data includes number of traps hauled during each trip, number of days traps were immersed, total weight of catch, number of lobster caught, and hydrographic information. Ten lobster from each boat are randomly selected to provide individual length and weight data, as well as sex, claw, and shell condition.

A sea sampling program was started in 1985 during the months of May through November aboard commercial lobster vessels using observers to record data. Prior to 1998, sea sampling was limited to only three locations with repeated trips made aboard the same vessels. This program was expanded in 1998 to sample each of Maine's seven lobster management zones three times a month. Biological data include carapace length (mm), cull status, sex, egg development stage, second abdominal width, v-notch/mutilation condition, presence and condition of eggs, and molt condition. In 2003, shell disease scoring for each lobster was incorporated into sampling protocol. In past assessments, port sampling was used to estimate size distribution of landings by area, however; in this assessment port and sea sampling lengths have been combined by statistical area and month as the legal size distribution has been shown to be comparable between the two programs (Scheirer et al 2004).

New Hampshire

New Hampshire (NH) lobster harvesters have been reporting annual inshore lobster landings data since 1969 to the New Hampshire Fish and Game Department (NHFG). Between 1969 and 1985 mandatory annual reports from all lobster harvesters were compiled to produce annual lobster harvest totals. Since 1986, a random selection (RSL) of a percentage of commercial licensed lobster harvesters and all new entrants into the lobster fishery are required to report harvest and effort data. The reported data are expanded to reflect the total estimated inshore landings of lobster. The RSL reports require the following information on a per trip basis and are submitted monthly: month and day fished, number of gear fished (both monthly and daily totals), area fished, average set over days/pot, weight of harvest, gear size, did fish or did not fish, and incidental catch. The reports submitted by the new entrants are submitted yearly and reflect estimated monthly catch and effort instead of daily information from New Hampshire inshore waters. The NMFS has also collected landings data from a portion of NH's lobster dealers through either volunteer annual seafood dealer reports and/or mandatory reporting of landings data from federally permitted vessels. Some of these federally permitted lobster harvesters may also fish in state waters. Because of the differences in data collection, the inshore lobster landings data between NMFS and NHFG do not agree. The NMFS data are generally inconsistent in it's representation of inshore landings since 1981. Some years appear to have the offshore landings data mixed in with the inshore landings thereby inflating inshore landings data. In other years the inshore data are dramatically lower than NHFG estimates, possibly due to the decrease in volunteer federal reporting by NH dealers of lobster landings data. Despite these differences in landings data, total monthly landings from the NMFS weighout and canvass database were used to calculate landings data for this recent stock assessment.

Massachusetts

The Division of Marine Fisheries has conducted a commercial lobster trap-sampling program since 1981 to collect both biological and CPUE data. Six fixed regions that include all three stock areas are sampled at least once per month from May-November by observers aboard commercial boats. Recorded data includes carapace length (mm), sex, shell hardness, culls and/or other shell damage, external gross pathology, mortality, presence of extruded ova on females, trap locations (latitude and longitude), and water depth (from chart plots) for legal and sub-legal lobster.

Rhode Island

The RI Department of Environmental Management has conducted an inshore and offshore trap sea-sampling program since 1990. Sampling areas include Narragansett Bay, Rhode Island Sound, mid-continental shelf areas (30-60 fathoms), and canyon areas (70-200 fathoms). Collected data include catch (weight and number), effort (number of trap-hauls, set-over days), trap type, bait type, bottom type, depth, trap location (LORAN), surface and bottom water temperature, carapace length, sex, presence and developmental stage of extruded eggs, relative fullness of egg mass, shell hardness (molt status), cull status, shell damage/disease, and mortality.

Connecticut

Sea sampling trips have been conducted with commercial trap fishermen since 1982 within Long Island Sound. From 1982-1989, the eastern and western basins were sampled. Beginning in 2000, expanded sampling effort include the central basin for a minimum of 27 samples per year. Biological information is recorded for all lobster of all sizes in as many trap hauls as possible. These data include: carapace length (to the nearest mm), sex, shell hardness, relative fullness of egg mass, developmental stage of eggs, cull status, and any signs of shell damage or disease. From 1992-98, pleopods were taken from a large number of females for cement gland staging to determine length at maturity.

New York

NY State Department of Environmental Conservation sea sampling data are collected on cooperating commercial vessels in Long Island Sound (area 611) and the Atlantic Ocean side of Long Island (areas 612 and 613). Data collected include catch, size, sex, egg status, shell disease, soak time, and water quality. Additional analysis of the fishery has been conducted using information supplied on lobster permit applications, such as catch, pots fished, area fished, and number of participants. Fishing effort (number of traps used) can be calculated from this information. Sampling in areas 612 and 613 has always been sporadic and sampling in area 611 was very poor during 1995-1998, and 2003.

5.1.1.2 Data Resolution and Sampling Intensity

Fishery dependent sampling, via port and sea-sampling programs, are used to characterize the size distribution of commercial landings. Inshore lobster landings from US territorial waters are well characterized because of standardized fishery dependent sampling programs conducted by the state agencies of Connecticut, Rhode Island, Massachusetts, New Hampshire, and Maine. However, offshore lobster landings are poorly characterized due to lack of sampling. This difference between the characterization of inshore and offshore landings is evident when the relative sampling intensity (=landings/# of lobster sampled) in each NMFS statistical area are examined. Each area can be classified into one of three categories based on the quartile ranking of its relative sampling intensity. The categories of intensity are: low = less than the 25th percentile; moderate = between the 25th and 75th percentile; high = greater than the 75th percentile (Figure 5.1.1.2 and Tables 5.1.1.2.1-5.1.1.2.3). The Gulf of Maine is the best characterized, followed by Southern New England and Georges Bank respectively.

5.1.1.3 – Gap Filling and Expansions

To account for “gaps” (temporal and spatial categorical without biological samples used to estimate biological properties of landings), a number of adjustments were made to the landings data. These adjustments were made to ensure that all landings data used in the assessment had associated statistical area, month, and year information. In the 2005 assessment the decisions listed below were used to fill areal and temporal gaps in the landings and size distribution data. All of these decisions are captured in the metadata of the ASMFC lobster database.

*Landings with un-assigned statistical areas were allocated based on the proportion of landings in all statistical areas over the surrounding 5-year period (two years before the year being filled and two years after).

*Landings with un-assigned months were allocated based on a monthly proportion of the ten-year average landings in that statistical area. (1990 to 1999).

*Areas that had commercial landings without complementary size distribution data were filled by applying the size distribution from the next closest statistical area within that stock unit to the landings, or by applying the size distribution from the next closest year within that statistical area to the landings.

These decision rules were used by all jurisdictions with the exception of New York and Rhode Island, which because of poor data resolution needed to perform additional modifications. For details on gap filling decision rules used in these two states see Appendix I

As a result of poor data resolution in the offshore area, the ASMFC lobster technical committee was forced to characterize offshore landings from a very large area based on a limited number of samples, from disjointed time periods, and from a limited number of discrete offshore areas. This has the potential to introduce bias into fishing mortality estimates in areas that have a significant offshore component, such as Georges Bank. This problem was highlighted by the 2004 ASMFC lobster model review panel who stated "the data available are woefully inadequate for the management needs of this fishery, and that the primary limitation on the ability to manage is lack of data rather than choice of models."

Once all landings (lbs) data were assigned an appropriate size distribution they were expanded to a total catch in numbers. This was accomplished by apportioning the landings in a month/statistical area combination by sex, based on the weight-based sex ratio observed in biological samples for that area. Then the total weight of the catch for each sex was divided by the biological sample weight to develop a sex/month/area/year specific expansion factor. Finally, the total number landed by sex/area/month/year was derived by multiplying the expansion factor by the number sampled in each sex/area/month/year.

5.1.2 Commercial Landings

Maine

Lobster landings information from dealers is compiled in the NMFS weigh out and canvass database by port and month. Landings reporting is voluntary by dealers only; harvesters have no obligation to report catch statistics. A look up table was supplied by Maine DMR to ASMFC to link NMFS port codes with statistical area. For all years it was assumed that port codes sufficiently characterizes the spatial distribution of landings in Maine. Landings information has been voluntary and collected inconsistently over the years. During the 1990s, the Maine lobster fishery was in a period of rapid growth. New dealers were buying significant quantities of lobster in locations where previously minor fisheries existed, seasonal dealers began buying lobster out of trucks/vans and lobster smacks, and most importantly Canadian processing plants began buying excess lobster from Maine. Given the magnitude of the changes in the fishery it is very likely that significant landings were missed through the voluntary landings reporting program of the late 1990s, it is estimated on a preliminary basis that the reported landings have underreported Maine landings by 25-35% from 1997 to 2003 (Wilson et. al 2004).

1981-2000: NMFS funded DMR staff to collect landings from dealers based on mandatory reporting requirements for Federal Permits and an annually updated dealer list. Non-federal dealers reporting were voluntary and were aggregated together by port. There was not consistent updating and follow through of dealer lists and reports.

2001-2003: DMR coordinates landings with NMFS. Non-federal landings are still voluntary, but are now tracked permanently through DMR/NMFS dealer database. Compliance of reporting from known dealers was approximately 65%, this does not reflect an equal percentage of landings.

2004: Implemented mandatory dealer reporting system to identify licensed dealers who buy from harvesters (first point of contact). Landings will be reported as aggregate landings by month. There remain problems with identifying dealers who buy from harvesters who do not have licenses (out-of-state and restaurants), as well as fishermen who directly sell their catch to consumers and non-commercial harvest.

New Hampshire

Total monthly landings from the NMFS weighout and canvass database were used to calculate landings.

Massachusetts

Commercial lobstermen (coastal, offshore, and seasonal or student) receive a detailed annual catch report form with their license renewal application. This report requests the following information on a monthly basis: method of fishing; number and type of gear used; effort data (set-over days, number of trips per month, etc.); pounds of lobster caught; areas fished; principal ports of landing; and information relative to the vessels and traps used in the fishery. All Massachusetts lobster statistical reporting areas align with NMFS statistical reporting areas in sum for inshore areas, and in total for offshore areas. Recreational fishermen are asked to report on their license renewal application form the number of lobster taken during the previous year and the maximum number of traps fished.

Rhode Island

Commercial lobster fishery landings data prior to April 1994 were collated directly from the NMFS weighout and canvass database. Allocation of monthly April 1994 – December 1998 RI lobster landings by Statistical area were based on the 1989-1993 average monthly proportions of annual landings by area. January-March 1994 landings were not allocated in this manner as complete landings data were available for these months. In 1999, Rhode Island initiated a lobster catch/effort logbook reporting program as part of the Atlantic Coastal Cooperative Statistics Program (ACCSP). This data is used in conjunction with NMFS Vessel Trip Report (VTR) landings data system to calculate total Rhode Island lobster landings by statistical area. The submission of commercial lobster catch/effort data is mandatory.

Connecticut
Landings are recorded in the NMFS database as landings at state ports. CT also records landings by resident fishermen in any port (inside or outside CT) by means of a mandatory logbook system that provides catch and effort information from 1979 to the present for all commercial license holders. This mandatory monthly logbook system provides a detailed daily catch by species, area, and gear as well as port landed, traps hauled, set over days, and hours trawled (for draggers). The log book provides a means to look at fundamental changes in the operating characteristics of the lobster fishery within Long Island Sound. Since 1995, the program has required fishermen to report information on the sale and disposition of the catch, including the state or federal permit number of the dealer to whom they sold their catch. Seafood dealers are also required to report all of their individual purchases from commercial fishermen using either the NOAA form *Purchases from Fishing Vessels,* a C*onnecticut Seafood Dealer Report, Abbreviated Form for Lobster Transactions Only*, or through the ACCSP's Standard Atlantic Fisheries Information System. A quality assurance program has been established to verify the accuracy of reported statistics through law enforcement coverage and electronic crosschecking of fisherman catch reports, law enforcement boarding reports, and seafood dealer reports.

New York
New York (NY) commercial lobster landings from 1981 through 2003 are from the NMFS databases. Landings data collected through New York's annual recall survey were not used to estimate NY's landings for this assessment because raw data was not available to determine unexpanded landings throughout the time series, though it was used to apportion landings from unknown areas.

To apportion the landings from unknown areas, the proportion of total landings that were harvested from area 611 and the Atlantic Ocean was determined from New York's annual recall survey. This survey is attached to each year's license application for renewal. Fishermen applying for a new lobster license are requested to complete the survey with information on the previous year's catch and effort. To prevent duplication of reporting by captain and crew members who may also hold commercial permits, fishermen are requested to report their status as captain or crew and to report only catch taken under the authority of their own permit, which would be otherwise unreported. Each years proportions were calculated from a 5-year average (centered on the year being estimated if possible), using the following equation (5-year average landings by area) / (total 5-year average landings). There is some concern that using 5-year average will mask a possible change in effort by area due to the Long Island Sound lobster (LIS) die off in recent years. The annual proportion of NY landings from LIS has decreased from 92% in 1999 to 77% in 2003. Averaging masks the landings decrease.

New Jersey
New Jersey collects no landings data for American lobster. The National Marine Fisheries Service collects landings data for lobster in New Jersey.

5.1.3 Size Structure of Commercial Catches
Sea sampling of commercial catches showed a consistent size range for legal size in the Gulf of Maine from 1981 to 2003 (Figure 5.1.3.1). Median size varied only two millimeters (87mm to 89mm CL) over the time series, as did size at the 75^{th} percentile. Nine-nine percent of the

landings encompass approximately 60% of the size range, with an extreme left skew where the largest 1% of the catch encompasses the remaining 40% of the size range. The size range of the legal catch sampled on Georges Bank also varied without trend from 1981-2003, though the median length varied about 10% (92mm to 99mm CL) (Figure 5.1.3.2). The largest 1% encompassed 24% of the size range on average. The size range of the legal catch sampled in Southern New England declined in the earliest years of the time series, then stabilized at median values of 87-88mm CL after 1989 (Figure 5.1.3.3). The largest 1% of the catch encompassed approximately 20% of the size range in 1981-1986, then increased to 35% on average.

5.2 Recreational Catch

The states of New Hampshire, Rhode Island, Connecticut, and New York's recreational lobster landings information is presented below. The recreational landings are generally only a few percent of the states total landings. Lobster are mainly harvested by traps and diving recreationally. These landings were not included in the assessment due to their low numbers and the difficulty in characterizing the length structure.

New Hampshire

Recreational lobster fishing in New Hampshire represents those harvesters that fish with 5 traps or less with no sale of harvested lobster allowed. Recreational lobster harvest catch and effort data have been collected along with the commercial lobster harvest for inshore lobster landings. Between 1969 and 1985 mandatory annual reports from all lobster harvesters in instate waters were compiled to produce annual lobster harvest totals. Since 1986, a random selection (RSL) of a percentage of recreational licensed lobster harvesters and all new recreational entrants into the instate lobster fishery are required to report harvest and effort data. The reported data are expanded to reflect the total estimated inshore landings of lobster. The RSL reports require the following information on a per trip basis and submitted monthly: month and day fished, number of gear fished (both monthly and daily totals), area fished, average set over days/pot, weight of harvest, gear size, did fish or did not fish and incidental catch. The reports submitted by the new entrants are submitted yearly and reflect estimated monthly catch and effort instead of daily information. Recreational lobster catch in New Hampshire inshore waters from 1989-2004 averaged 0.5% (range of 0.2%-0.8%) of the total New Hampshire inshore lobster landings with licenses making up 32% (range of 26%-35%) of the total New Hampshire inshore lobster licenses.

Rhode Island

Prior to the implementation of the Rhode Island / ACCSP catch/effort logbook data collection program in 1999, no catch/effort data were collected regarding the Rhode Island recreational lobster trap and lobster diver fisheries. Since 1999, recreational lobster trap and lobster diver license holders have been asked to provide their monthly lobster catch and effort data in a report that is submitted annually. The submission of recreational lobster catch/effort data is voluntary. During the period 1999-2004, RI recreational lobster landings have averaged 0.22% of the total RI lobster landings.

Connecticut

Recreational lobster catch in Connecticut waters was historically about 10% of the commercial catch (50-130 thousand lobster). Since 1992, it has declined to 2-3% (15-40 thousand lobster).

Approximately one in four license holders capture lobster diving while three out of four set pots (average number 6-7). Total pots fished declined from 5,800-9,500 in 1983-1993 to less than 4,200 since the die off in 1999. The number of license holders has also declined from 2,608 in 1983 to 885 in 2003. Until 1999, approximately 70% license holders actually fished; that percentage declined to 53-58% since 2000.

New York

Recreational lobster license holders are required to complete an annual recall landings survey for the previous year when they apply for their current year's license. This data has been collected since 1998. Recreational lobster catch in New York from 1998 – 2004 averaged 0.3% (range of 0.1%-0.8%) of the total New York landings. The number of licenses ranged from 1,728 in 1998 to 882 in 2000. On average, 63% of the harvest was from traps and 35% from diving.

5.3 Fishery Independent Survey Data

5.3.1 Data Collection Methods

Data used in this assessment were obtained from bottom trawl surveys conducted by the Northeast Fisheries Science Center (NEFSC) on the continental shelf as well as from inshore bottom trawl surveys conducted by the states of Connecticut, Massachusetts, Rhode Island. Surveys conducted by the states of Maine and New Jersey over a shorter time period were also included. NMFS, MA, RI, and CT conduct trawl surveys during the spring and fall. To be consistent with previous assessments and to avoid using spring survey data where catchability may vary substantially due to temperature, stock assessment model analyses (see Section 8) for all stock areas and for all sub-areas except one were based on fall survey data only. Trawl survey data for lobster in this assessment are tabulated using delta distribution techniques (Pennington 1986) to avoid problems due to "zero" tows (e.g. survey tows containing no lobster). More detailed information on survey area and timing, years surveyed, sampling design, gear, and methods for each survey is presented below. Refer to table 5.3.1.1 for the relative sampling intensity of each survey.

5.3.1.1 Survey Methods

National Marine Fisheries Service

The Northeast Fisheries Science Center bottom trawl survey began in 1967. This survey is generally conducted in September and October. Lobster data used in this assessment are from the autumn survey since 1982.

The NMFS bottom trawl survey utilizes a stratified random sampling design that provides estimates of sampling error or variance. The study area, which now extends from the Scotian shelf to Cape Hatteras including the Gulf of Maine and Georges Bank is stratified by depth. The stratum depth limits are < 9 m, 9-18 m, >18-27 m, >27-55 m, >55-110 m, >110-185 m, and >185-365 m. Most strata are further subdivided into sampling units to achieve a more even sampling distribution across the area covered by the survey.

Stations are randomly selected within strata, the number of stations in the stratum being proportional to stratum area. The total survey area is 283,137 km^2. About 320 hauls are made per survey, equivalent to one station for about every 885 km^2.

Most survey cruises were conducted using the R/V ALBATROSS IV, a 57-meter (m) long stern trawler, however some cruises were made on the 47-m stern trawler R/V DELAWARE II. On most spring, summer, and autumn survey cruises, a standard, roller rigged #36 Yankee otter trawl was used.

The standardized #36 Yankee trawls are rigged for hard-bottom with wire foot rope and 0.5 m roller gear. All trawls were lined with a 1.25 cm stretched mesh liner. BMV oval doors were used on all surveys until 1985 when a change to polyvalent doors was made (catch rates are adjusted for this change). Trawl hauls are made for 30 minutes at a vessel speed of 3.5 knots measured relative to the bottom (as opposed to measured through the water).

Maine

Trawl survey data has been limited historically in nearshore waters along the Maine coast. In the 1990s, two trawl surveys were conducted by the Maine DMR to assess local fish populations in mid-coast Maine (Stat Area 513). In 2000, a comprehensive inshore trawl survey was initiated along the coast of Maine and continues today.

The first survey was done during 1992-1994 using a ¾ whiting trawl (51' headrope, 39' footrope) with a 2-inch mesh and a ½ inch liner in the cod end from a 80' research vessel, the R/V Argo Maine. Fixed stations were located on trawlable bottom in four different depth strata (0-22, 23-35, 36-45 and 46-55 fathoms) along six transects between Frenchman Bay and Ipswich Bay, MA. Replicate tows (usually three) were made at each of four stations on all six transects in May-July and September-October 1992 and on transects 3,4, and 5 in December 1992-April 1993, July-October 1993, and January-April 1994. A total of 434 tows were made between May 1992 and April 1994.

The second survey was conducted using the same trawl in a much smaller survey area between Pemaquid Point and eastern Casco Bay in the mid-coast region during 1996-1998. All tows were 20-minute tows. Fixed stations were located on towable bottom in a variety of substrate types and depths near the mouth of the Kennebec River, the second largest river system in Maine. Trawling was done by local fishermen using two different 40-50' commercial trawlers in the fall of 1996, the spring of 1997, and the spring of 1998. A total of 447 tows were made during the four cruises. Fall sampling was conducted between September and November and spring sampling between March and June. No survey was carried out in 1995.

In both surveys during the 1990s, lobster caught during each tow were counted (not sexed) and a total weight was recorded. Thus, there is no information on sex or size group. However, mean weight per individual provides some information on the average size of lobster caught in different depth strata and years. Possible effects of limiting the survey area during 1996-1998 was removed by comparing catch rates for the 1992-1994 mid-coast stations with the 1996-1998 catch rates. Mean catch rates were calculated as simple arithmetic means for all tows, including tows that did not catch lobster. This survey was discontinued in 1999.

In the fall of 2000, the Maine/New Hampshire inshore trawl survey was initiated. The inshore trawl survey is conducted during the spring and fall of each year, same as that of the NMFS offshore surveys. It is a stratified random design modeled after the NMFS and Massachusetts

Department of Marine Fisheries (MADMF) surveys. The design includes four depth strata: 5-20 fathoms, 21-35 fathoms, 36-55 fathoms, greater than 56 fathoms (its outer boundary roughly delineated by the 12-mile limit), and 5 regions based on oceanographic, geologic, and biological features. The fourth stratum was added in the spring of 2003. It expands the coverage area to equal that area covered by the ASMFC and allows some overlap between this survey and the NMFS offshore survey area. It also slightly reduces the sampling pressure in the shallower strata, which has been of concern to fixed gear fishermen in the past. To randomize the survey area (~4000 NM^2,square nautical mile), each depth stratum was divided into 1 NM^2 sampling grids. A target of 100 stations was selected for sampling in each survey resulting in a sampling density of about 1 station / 40 NM^2. This density compares to NMFS 1 station / 260 NM^2 and Massachusetts' 1 station / 19 NM^2. The number of stations per stratum was allocated in proportion to each stratum's area. When a station is encountered that cannot be towed, an alternate tow is selected nearby over similar depth.

For a full description of the gear please see Chen et al. (2005 in press). A standard trawl tow, 20 minutes duration, was made at each station. Shorter tow times were accepted under certain circumstances. Tow speed was maintained at 2.1 to 2.3 knots and tow direction was oriented toward the tidal current whenever possible. All sampling was conducted during the day. After each tow, the net was brought aboard and emptied onto a sorting table. All individuals were identified and sorted by species. All lobster were immediately separated and processed while the rest of the catch was sorted. Total weights (by sex), carapace length (mm), shell condition, presence and stage of eggs, V-notch condition, and trawl damage were recorded. All lobster were measured and are recorded in electronic format for analysis.

Results of the two surveys in the 1990s were presented for the first time in the 2000 assessment. The current inshore survey is not being used in any of the assessment models, other than the length structured model described in Appendix II; owing to the short time duration of the survey.

New Hampshire

Since the fall of 2000, the states of New Hampshire and Maine have been conducting an Inshore Bottom Trawl Survey in order to collect abundance and biological information on groundfish, lobster, and other marine organisms from the shore out to the 12-mile limit in the hopes of establishing a long-term fishery independent monitoring program. Refer to Maine's description of this independent survey for details.

Massachusetts

Massachusetts Division of Marine Fisheries has conducted a biannual trawl survey since 1978 in state waters from the New Hampshire to the Rhode Island borders, including Cape Cod Bay and Nantucket Sound pre-determined trawl sites were allocated randomly in proportion to stratum area, although some sites were relocated because of concentrations of fixed gear or untowable bottom. Sampling occurred in May and September each year aboard either the vessel F/V Francis Elizabeth (1978-81) or the vessel R/V Gloria Michelle (1982-2004). Each tow was made at 2.5 knots with a ¾ size North Atlantic type two-seam otter trawl (11.9 m headrope, 15.5 m footrope), rigged with a 19.2 m chain sweep with 7.6 cm rubber discs, 18.3 m bottom legs of 9.5 mm chain, 19.2 m wire top legs, and 1.8 x 1.0 m 147 kg wooden trawl doors. The net contained a 6.4 mm mesh cod end liner to retain small fish. The standard tow duration was 20 minutes. Tows of less than 20 minutes, but greater than or equal to 13 minutes were accepted with the catch data expanded to the 20 minute standard. Total weight and length-frequency, surface and bottom water temperatures, and salinity data were recorded, age and growth material, maturity observations, and pathology observations were collected as well.

Rhode Island

Rhode Island Department of Environmental Management (RIDEM) research trawl surveys began in 1968 and have been modified over time, but all data used in this assessment were collected with the same or similar gear. Initial sampling occurred at four fixed locations monthly; since 1977, surveys included a mixture of fixed and random sampling stations as well as spring and fall sampling. Sampling is conducted with a ¾ high-rise heavy-duty bottom trawl towed for 20 minutes at 2.5 knots. Sampling areas include Narragansett Bay and Rhode and Block Island Sounds. Collected data include carapace length, sex, shell hardness, presence of extruded ova, bottom and surface water temperature, sea conditions, and wind speed/direction.

URI has also sponsored a trawl survey since 1967 in Narragansett Bay (West Passage). Fixed sites are sampled weekly. Early work recorded total number and weights of lobster along with bottom temperature, but no size or sex information for individual lobster. Since May 1994, data collection has included sex, size, cull and molt status, and evident disease. Data from this survey were not used in this assessment and are not presented in this report because of compatibility constraints due to sampling design. See Castro (1998b) for a summary of lobster data obtained from this survey.

Connecticut

The CT Department of Environmental Protection Marine Fisheries Division has conducted a spring trawl survey in Long Island Sound since 1986 and a fall survey since 1984. The sampling gear employed is a 14 m otter trawl (9.1 m headrope, 14 m footrope) with 102 mm mesh in the wings and belly, 76 mm mesh in the tail piece, and 51 mm mesh codend towed at 3.5 knots for 30 minutes from a 12.8 m research vessel (1984-89) or the 15.2 m research vessel *John Dempsey* (1990-present). Forty stations are sampled monthly during a spring survey (April, May, June) and a fall survey (September and October) for a total of 200 samples taken annually. The trawl survey employs a stratified random sampling design with four depth strata (0-9 m, 9.1-18.2 m, 18.3-27.3 m, 27.4+m) and three bottom substrate types (sand, mud, and transitional). The sampling area is divided into 1.85 x 3.7 km (1 x 2 nautical mile) sites and includes all trawlable LIS waters between New London and Greenwich, CT. Sampling intensity is one station per 68 km^2 (20 square nautical miles) or less.

Biological data recorded for each tow include total weight (1992- present), carapace length (to the nearest mm), sex, shell hardness, relative fullness of egg mass, developmental stage of eggs, cull status, and any signs of shell damage (new or old) or disease. From 1992-98, pleopods were taken from a large number of females for cement gland staging to determine length at maturity.

Millstone Environmental Laboratory staff have conducted a research pot survey since 1978 in the vicinity of Millstone Nuclear Power Station in eastern Long Island Sound (DNR 2005). Size composition, molt frequency, and molt increment data were used in this assessment.

New Jersey

The New Jersey Division of Fish and Wildlife has conducted a groundfish survey along the New Jersey coast since August 1988. The survey area is about 1800 square miles of coastal waters between Sandy Hook, NJ and Cape Henlopen, DE and from a depth of 18 to 90 ft. The area is divided into 15 strata that are bounded by the 30, 60, and 90 ft isobaths. The survey design is stratified random. Since 1990, cruises have been conducted five times a year - in January, April, June, August, and October. Two 20-minute tows are made in each stratum, plus one more in each of the nine larger strata, for a total of 39 tows per cruise in all months except January, when the additional tows are omitted. The trawl gear is a two seam three-in-one trawl (so named because all the tapers are three to one) with 12 cm mesh in the wings and belly and 7.6 cm in the codend with a 6.4 mm liner. The headrope measures 25 m and the footrope 30.5 m. Rubber cookies measuring 2 3/8 inch in diameter are used on the trawl bridles, ground wires, and footrope. Five different vessels have been used to conduct the surveys to date. Data from this survey were not utilized in this assessment owing to the small area represented by the survey.

5.3.1.3 Development ofAbundance Indices

In Collie-Sissenwine and related stock assessment models for lobster, “recruits” are lobster that are not legal size at the time of the survey but are expected to molt and grow to legal size during the next year. Post-recruits are legal size at the time of the survey. Together, recruits and post-recruits constitute the fishable abundance of lobster that will contribute catch to the fishery during the current year. Recruit and post-recruit abundance indices for lobster were calculated from survey catch at length (i.e. total delta mean numbers per tow prorated to one mm CL size groups based on stratified mean proportions in each length group). Note that a time series of recruit abundance indices for modeling will contain lobster of somewhat different sizes if the minimum legal size changed. In some descriptive analyses presented below, a simpler definition of recruits based on a constant range of lengths (72-83 mm) was used.

Bottom trawl survey indices for post-recruits are relatively simple to calculate. In particular, the post-recruit index P_t is the sum of mean numbers per tow for all length groups larger than or equal to legal size in year t.

Bottom trawl survey indices for recruits are more difficult to calculate because they depend on the abundance of sublegal lobster in the survey, survey timing relative to the annual molt cycle, the probability of molting (which depends partly on maturity), probability of molting to legal size (which depends on stock region, sex and initial size), and legal size during the year of the survey. Recruit index calculations must be accurate because the relative magnitude of the recruit and post-recruit indices together with the “q-ratio” determine the average level of estimated mortality in stock assessment models for lobster. In addition, assumptions about growth and maturity must be the same as in reference point models so that mortality and abundance estimates are comparable with reference point calculations.

Algorithm for recruit index calculations

There are four key assumptions in calculating recruit indices for lobster from numbers of sublegal size lobster in survey catches: 1) all immature sublegal lobster will molt at least once; 2) 50% of sublegal mature females will be egg bearing in a given year and will therefore not molt that year (the other 50% will molt); 3) only immature lobster are able to molt twice a year (double molt); and 4) the survey takes place before the major molt when growth is most likely to occur.

The user must supply values for parameters in molt increment models that describe the range of molt increments in lobster that molt. In this assessment, molt increment models for lobster were based on normal distributions with constant variance and with mean growth increments linked to size before molting (Section 2.2). Normal distributions for growth increments were truncated at increments where the cumulative normal distribution was 0.025 and 0.0975 (see below). The truncation prevents implausible growth patterns with final size either too large or too small relative to initial size.

The first step is to calculate the growth matrix **MI**, which describes carapace length after one molt, given starting size in the survey. The following calculations are carried out separately for each sex and survey area.

1) Select a range of initial length groups that includes all possible recruits (e.g., 50 mm – legal size)
2) For each 1 mm bin in the range of initial sizes:
    a. Calculate the mean and variance of molt increments based on growth increment model parameters (Section 2.2)
    b. From the mean and variance, evaluate a normal cumulative distribution function (*CDF*) and probability density function (*PDF*) for the range of possible increments
    c. Based on the desired level of truncation, drop growth increment bins from the *CDF* and *PDF*. For example to truncate for approximate 95% coverage, remove bins with cumulative probability below 0.025 and bins with cumulative probability above 0.975.
    d. Standardize the remaining bins so that the truncated *PDF* sums to one (i.e. divide the original probability in each bin by the sum of the truncated probabilities).
    e. Use the truncated and standardized *PDF* to assign increment probabilities to the corresponding cells in **MI**. For example, if a lobster starting at 61 mm CL had a 4.36% probability of a 6 mm increment, then the probability that a 61 mm lobster would reach 67 mm is $MI(61,67) = 0.0436$.

Once the growth model is available for each sex and survey area, the following steps are carried out using the survey data for each year. The survey data (delta mean numbers per tow by 1 mm length bins) for one survey, one year, and one sex are in the vector **SRI**.

a. Separate **SRI** into potential recruits (**Pot_R**) and legal size "fully recruited" (**FR**) components based on minimum legal size during the year of the survey.
b. Determine which lobster in **Pot_R** will molt at least once based on the key assumptions listed above. Specifically:
    i. Calculate the number of mature lobster at each length by multiplying each element in the **Pot_R** vector by the corresponding element in the vector of maturity at length. Subtract the mature lobster **NMAT** from **Pot_R**.

ii. Calculate the number of mature egg bearing lobster (**EB**) by multiplying each cell in **NMAT** by 0.5. EB lobster will not molt this year. The remaining 50% of mature lobster will molt, but only once. This step is relevant only in calculations for females.
iii. Multiply each element in **Pot_R** (after EB lobster are removed as described above) by the corresponding probability of double molting (**PDmlt**). The resulting vector is subtracted from **Pot_R** and stored in the vector **DMLT**. These lobster will molt twice during the following year.
iv. What remains in **Pot_R** are the immature lobster that will molt once. To this, add the number of mature lobster that will molt once (0.5 **NMAT**, see above) to calculate the total number of lobster that will molt once. Now, **Pot_R** contains all lobster that will molt once, and **DMLT** those that will molt twice.
v. Multiply the vector **Pot_R** by the growth matrix **MI** to calculate the new vector of numbers at size for lobster that molted once.
vi. Multiply **DMLT** by **MI** twice to calculate the vector of new numbers at size for lobster that molted twice.

Calculate the new size distribution for all lobster that molted by adding corresponding elements in the vectors for lobster that molted once and the vector for lobster that molted twice. Sum the result for all legal sizes to calculate the recruit index for the current year.

5.3.2 Abundance Index Trends

Generally, fishery-independent survey catches of lobster from Maine to New Jersey show an increase in the abundance of recruit-size lobster in the 1990s, followed by an abrupt decline in the southern surveys and smaller or no decline in the northern surveys. Legal-size abundance in most surveys follows a trend similar to recruit abundance.

In Gulf of Maine waters, the NMFS Survey (Figure 5.3.2.1) again saw a rise in recruit abundance in the 1990s followed by a decline. Abundance of legal size lobster in this survey has shown an increasing trend since 1994. Survey abundance in the Massachusetts GOM survey showed above average recruit abundance from 1994-2000, however abundance declined to very low values in 2003-2004 (Figure 5.3.2.2). Legal-size abundance has shown no strong trends however their abundance also dropped to time-series lows in 2002-2004. The short time series generated by the Maine Survey shows a decline in both size classes in 2004 compared to values recorded in 2000-2003 (Figure 5.3.2.3).

The Georges Bank NMFS Survey (Figure 5.3.2.4) indices show very little variability in abundance in both size classes over the time series (1982-2004). Recruit abundance was above average in 2002-2003 while abundance in legal-size was at a time-series high in 2002.

In Southern New England waters, all three state surveys of inshore waters (Rhode Island, Connecticut, New Jersey) show a rise in recruit abundance (72-83mm CL) in the 1990s followed by a decline to very low values of both size groups after 1998 (Figures 5.3.2.5 to 5.3.2.7). Abundance trends recorded in the Rhode Island and Connecticut fall surveys for both size classes are significantly correlated (ts=0.47-0.65, df=18, $p<0.05$). Trends recorded in the New Jersey fall survey correlate with Connecticut and Rhode Island trends for legal-size lobster only (ts=0.52-

0.57, df=15, p<0.05). Trends in offshore waters recorded by the NMFS SNE Survey (Figure 5.3.2.8) also show a rise in recruit abundance in 1996-1997, followed by a decline.

5.3.3 Size Structure of Survey Catches

The size composition of lobster taken in research trawl surveys was compared for animals 50mm CL and greater. Catch by sex in all six surveys varied without trend from 1981-2003. NMFS Survey catches in the Gulf of Maine were smaller for females (median lengths 73-108mm CL) but similar for males (median lengths 76-100mm CL) (Figures 5.3.3.1 and 5.3.3.2). Massachusetts Survey catches in southern Gulf of Maine were noticeably smaller over the time series for both sexes (median female lengths 62-77mm CL, median male lengths 68-73mm CL) (Figure 5.3.3.3 and 5.3.3.4). Median lengths for NMFS Survey catches on Georges Bank varied from 83-119mm CL for females and 76-97mm CL for males (Figures 5.3.3.5 and 5.3.3.6).In Southern New England, size frequencies seen in the three regional surveys showed a difference between off shore and nearshore average lengths. Median values in the offshore SNE NMFS Survey (females 63-86mm CL, median male lengths 63-80mm CL) (Figures 5.3.3.7 and 5.3.3.8) were larger than median values for catches in the two inshore surveys in Rhode Island (females 62-69mm CL, median male lengths 61-73mm CL) (Figures 5.3.3.9 and 5.3.3.10) and Connecticut/New York (females 62-70mm CL, median male lengths 66-71mm CL) (Figures 5.3.3.11 and 5.3.3.12) waters.

5.3.4 Settlement Indices

Newly settled lobster is the youngest benthic life stage which quantitative data exists. Egg bearing female lobster hatch eggs in the summer and the larvae follow with a 6-8 week planktonic life phase (Ennis 1995). After settlement to the bottom, the newly metamorphosed lobster can be sampled by divers using air-lift suction samplers (Wahle and Incze 1997). A standardized survey of this type has been conducted at stations in mid-coast Maine since 1989 and Rhode Island since 1990. As part of a New England wide initiative, additional surveys exist along southern New Brunswick, coastal Maine (since 2000), and Cape Cod and Buzzards Bays (since 1995) but were not considered in this assessment due to the short times series and proximity to the assessment areas in the case of the New Brunswick series (Wahle et al. 2003). Rick Wahle of the Bigelow Laboratory for Ocean Sciences in Maine provided settlement data.

Settlement was measured by taking suction samples (Wahle and Steneck 1991) of natural cobble substrates. Settlement strength was defined as the abundance of newly settled lobster (0+ year class: <10 mm CL in ME, <13 mm CL in RI) in cobble nurseries after the end of the settlement season (mid-August in Rhode Island and early-September in Maine).

Density estimates of newly settled lobster were investigated for evidence of variability in regional settlement strength and temporal trends that could be used at some point to predict landings in the fishery. This approach has been used successfully for the western Australian rock lobster, *Panulirus cygnus* fishery (Phillips et al. 1994). The Australian fishery predicts nearly 75% of their landings based on the long-term relationship between the settlement of the puerulus (the pelagic, postlarval stage) on artificial collectors and the size of the commercial catch four years later.

In Maine, observations in any given year have been found to be indicative of settlement patterns in a wider area than just the sampling sites. Particular sites that get an especially strong settlement signal are good predictors of settlement at other sites in the region the same year (Palma et al. 1999). The similarity in trends in Maine suggests that settlement varies similarly on a regional basis. These trends enhance the possibility that annual sampling could provide sufficient data for documenting temporal changes in year class size and, possibly, for forecasting changes in the abundance of recruits before their entry into the fishery.

Earlier studies have demonstrated annual differences in the abundance of newly settled young-of-year lobster reliably foretell the number of 1-year-olds in the nurseries a year later (Wahle and Incze 1997, Wahle et al. 2003). The extent to which trends in settlement will eventually affect landings in any given year depends on the survival of juvenile lobster after settlement, variability in their growth, and the number of year classes that contribute to the size group that recruits into the fishery. Mixing of year classes dampens year-to-year fluctuations in recruitment that would otherwise be caused by variable settlement densities. Based on current growth information, lobster in mid-coast Maine are likely to enter the fishery at the age of 6-8 years. modal analysis of size-frequency distributions estimate year-class size ranges, but uncertainty remains in defining size at age.

The Maine data suggest settlement was low and below the 25th quartile in 3 of 5 years during the period from 1995 to 2000. Since 2001, settlement densities have returned to levels above the median, which are similar to levels observed in 1989 through 1994. Settlement of Rhode Island lobster was high in 1990 and 1991 but declined thereafter with 2 of the last five years below the 25th quartile (Table 5.3.4.1, Figure 5.3.4.1). If settlement relates to the harvestable stock in future years, the expectation of a dip in recruitment to the fishery would be expected in the Gulf of Maine. The declining pattern of settlement in Southern New England would predict low levels of recruitment to the fishery in coming years.

6.0 Methods

6.1 Stock assessment models

Based on an extensive independent review (ASMFC 2004), the modeling tools used in this assessment to provide management advice for American lobster were similar to models used in previous assessments. An enhanced version of the Collie-Sissenwine model (CSM, a.k.a. “modified DeLury” in ASMFC 2000) was used to estimate mortality and abundance of male and female lobster in individual areas. Where necessary, sex-and area specific estimates were combined to obtain estimates for female and male lobster combined or to obtain estimates for larger regions. A life history model (a.k.a. egg-per-recruit model or EPR in ASMFC 2000) was used to estimate egg production per recruit and other per-recruit reference points for male and female lobster in each stock assessment region.

ASMFC (2004) reviewed preliminary versions of three new lobster stock assessment models and identified significant performance issues. Some of the new models were reformulated based on advice from the review panel and are presented in the appendices for additional review and potential future use.

6.1.1 Collie-Sissenwine Model (CSM)

In CSM for lobster, recruit abundance (R_t) is the number of sublegal size individuals alive at the start of a year that would grow to legal size and recruit to the fishery during the year if they survived. Post-recruits (P_t) are the number of legal size individuals alive at the start of the year. Catch data are assumed to be accurate in CSM and survey data are assumed to have lognormal measurement errors. Mortality rates are for the total stock $N_t = R_t + P_t$. Natural mortality rates in each time step (M_t) are specified as input data and may vary over time. Abundance index data are assumed to measure abundance or recruits and post-recruits at the beginning of the year. The "*q*-ratio" (a selectivity parameter for abundance index data, see below) is assumed known and specified by the user).

The last (most recent or "terminal year") estimates are among the least precise in most stock assessment models. Recruit abundance is estimated in CSM for the terminal year but the estimate is just the recruit index for the last year scaled up to population abundance (the terminal recruit index is not included in goodness of fit calculations and there is no residual). Post-recruit abundance in the last year is probably more reliable because it is estimated with a residual and included in goodness of fit calculations. Total abundance for the terminal year is not reliable for lobster because recruits comprise the stock in most areas.

Abundance index data

The current version of CSM uses one relative abundance index (e.g. a time series of mean numbers per tow from a bottom trawl survey) for recruits and one relative abundance index for post-recruits in each year. The relationship between absolute abundance of post-recruits and relative abundance of post recruits (p_t) measured by abundance data is:

$$p_t = qP_t$$

where is q is a scaling parameter or "catchability coefficient". The relationship between absolute and relative abundance of recruits is:

$$r_t = q\phi R_t$$

where the q-ratio ϕ measures catchability of recruits relative to post-recruits. Relative catchability in this context is equivalent to the survey selectivity or the survey partial recruitment vector in other models.

Pope approximation vs. exponential mortality calculations

The original formulation of the CSM used Pope's (1972) approximation to model population dynamics. As mortality rates increase, however, the accuracy of Pope's approximation deteriorates (Pope 1972) and the approximation becomes difficult to use because negative abundance levels sometimes occur in calculations. Accuracy and negative abundance levels in calculations are a practical problem for lobster because mortality rates appear to be relatively high in most stocks; therefore, the CSM was modified for this assessment to optionally use "exact" exponential mortality calculations in place of the Pope approximation. The exponential mortality approach was used exclusively for lobster in this assessment.

Based on the exponential mortality model and relationships between stock and abundance indices, population dynamic calculations in CSM are carried out in units of relative abundance:

$$p_{t+1} = n_t e^{-Z_t + \varepsilon_t}$$

Where $n_t = \left(p_t + \dfrac{r_t}{\phi} \right)$, F_t, M_t, and $Z_t = F_t + M_t$ are instantaneous annual rates for fishing, and ε_t is an optional process error (see below) that may represent variability in natural mortality or other biological factors not explicitly included in the model. F_t is calculated by trial and error so that $\dfrac{C_t}{q} = \dfrac{F_t\left(1 - e^{-Z_t}\right)n_t}{Z_t}$ where C_t is the observed catch data.

Process errors

Process errors ε_t were set to zero in CSM for lobster in this assessment for two reasons. Models without process errors may be more robust (Mesnil 2003). Secondly, in practical terms, process errors were no longer required in fitting CSM for lobster when exponential mortality calculations were used in place of the Pope approximation.

The first issue related to process errors were the current CSM does not account for process errors in calculating fishing mortality rates. Estimates of fishing mortality depend on estimates of M. In the exponential mortality model calculations, annual process errors are equivalent to annual changes in natural mortality. To see this, write $M_t = m_t + \varepsilon_t$, where m_t is the natural mortality rate specified in the input file and ε_t is the estimated process error. Accurate calculation of fishing mortality rates should be based on $M_t = m_t + \varepsilon_t$, rather than m_t alone.

Second, process errors in the current implementation of the CSM do not necessarily average zero. The average value of e^{ε_t} will not necessarily average one, particularly as process error variance increases. Thus, in the current implementation, the average natural mortality rate in calculations is effectively higher than specified by the user in the input file.

Goodness of fit

In the CSM regarding abundance and catch data, a Levenberg-Marquardt algorithm is used to find parameter estimates (R_t, P_1, q, and ε_t) that minimize a weighted sum of squares. For lobster and a CSM model with N years of abundance index data and no process errors, there were N +1 parameters to estimate (i.e. N -1 recruit parameters plus one initial post-recruit abundance parameter plus one survey catchability parameter). The number of abundance index observations used to estimate parameters is N-1 (for recruits) + N (for post-recruits).

The weighted sum of squares used to measure goodness of fit is:

$$\Re = \lambda_\varepsilon \sum_{t=1}^{n} \varepsilon_t^{\,2} + \lambda_\eta \sum_{t=1}^{n-1} \eta_t^{\,2} + \lambda_\delta \sum_{t=1}^{n} \delta_t^{\,2}$$

where the user-specified weights (λ_ε=0 for lobster, λ_η, λ_δ) are for residuals stemming from process errors (ε) and independent measurement errors in abundance index data for recruits (η) and post-recruits (δ). Assuming lognormal measurement errors, residuals in CSM models for lobster were:

$$\eta_t = \left[\ln(r_t) - \ln(\tilde{r}_t)\right]$$

Measurement error residuals for post-recruits are calculated in an analogous manner.

Bootstrapping

A variety of bootstrap approaches are available for estimating the precision of abundance and fishing mortality estimates from CSM. Bootstrap runs for lobster in this assessment used abundance index data constructed using the "lognormal without bias"[2] option in CSM. For example:

$$\tilde{r}_t^{\,j} = r_t e^{\delta\sigma}$$

where $\tilde{r}_t^{\,j}$ is a simulated survey datum for year t in bootstrap iteration j, r_t is a predicted survey value from the original model fit, δ is drawn from a standard normal distribution, and σ is the standard deviation for all of the residuals in the model.

Confidence intervals for model estimates are based on the distribution of bootstrap estimates. For example, the 10th and 90th percentiles of the bootstrap estimates of recruitment can be used as bounds for an 80% confidence interval around R_t. Bootstrap model runs (< 1% of all cases) that do not converge or that converged to absurdly high abundance estimates are discarded.

Blending Procedure for Stock Regions Not Covered by One Survey

A potential problem exists with SNE (previously SCCLIS) and GOM stock areas where trends measured by NMFS survey in offshore areas were not the same as trends in nearshore areas, where most fishing occurs. In these cases, abundance and fishing mortality rate estimates would likely be biased if spatial differences were ignored. As shown below, it is straightforward to add abundance estimates for areas covered by different surveys and to calculate fishing mortality rates based on combined catch and combined abundance. Special procedures are required, however, to derive bootstrap variance estimates for the combined abundance and fishing mortality estimates. The last assessment (ASMFC 2000) used a "blending" approach to form abundance and mortality estimates for entire stock regions and to blend bootstrap results for stock regions covered by individual surveys.

The blending approach in ASFMC (2000) was based on combining CSM bootstrap estimates and was limited by the software to a maximum of 200 per survey area per sex and survey area. All possible combinations of 200 bootstrap runs for each survey area were used. In total there were up to 200^3=8 million combined bootstrap estimates for male and female lobster in SNE (previously SCCLIS) stock region (with three survey areas) and 200^2=40 thousand bootstrap estimates for each sex in the GOM stock region (with two survey areas). Probability distributions for original estimates of blended abundance and fishing mortality were based on distributions of the blended bootstrap estimates.

CSA software used in the current assessment has been improved in many aspects, and the number of bootstrap runs has been increased. This assessment used 2000 bootstrap runs as the standard. Using the earlier approach, this would result in 2 million possible combinations for an area with two surveys (e.g., GOM), and 8 billion for an area with three surveys (e.g., SNE). It

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[2] In fact, the simulated data are biased because, for example, the expected value of $\tilde{r}_t^{\,j}$ is $r_t e^{0.5\sigma^2}$. The bias does not affect bootstrap abundance or mortality estimates, however, because the simulated abundance data measure trends only and because the relative magnitude of the abundance indices is not changed (both abundance indices are biased by the same amount).

would be difficult to process such a large number of combinations, so a new method was developed.

The blending approach used in this assessment, like the one used previously, is based on separate CSA models run for each of the areas covered by state and federal surveys. Survey model runs used state or federal survey data and fishery catch data from the same survey area. As shown in the equations below, abundance estimates for entire stock areas were calculated by summing estimates for survey areas. Fishing mortality rate estimates for entire stock areas were obtained as abundance-weighted averages of the fishing mortality rate estimates for survey areas.

This approach provides maximum benefits for stock assessment of American lobster because it makes full use of survey data, reduces bias in fishing mortality and abundance estimates, and provides information about fishing mortality rates and abundance trends in survey areas and stock regions. Moreover, bootstrap variance estimates for entire stock regions are generated. The technique assumes that surveys: 1) occur at the same time of the year; 2) individually represent trends in part of the stock area; 3) collectively represent the entire stock area; and 4) that landings from the entire stock area can be split into portions associated with each sub-area.

Bootstrap procedures were used to compute probability distributions for abundance and fishing mortality rate estimates for each survey area. Probability distributions for GBS stock regions (covered entirely by the NEFSC survey) and individual survey areas in SNE and GOM stock regions were calculated based on standard methods (e.g. NMFS 1996) and 2000 bootstrap runs per original CSA run. In some cases, a few bootstrap runs failed to converge and were discarded (only converged bootstrap runs were used to compute variances).

Variance estimates for blended estimates and whole stock regions were based on 8000 randomly selected tuples (sets of two or three random numbers, one for each survey area CSA run). These random numbers ranged from 1 to the number of converged bootstrap runs for each CSA set. As an example, for SNE (with 3 survey areas) and each variable (abundance, F, etc.), if the selected tuple was (31, 1730, 861), then bootstrap observations for the entire stock region used would be the 31st value from the 1st survey area, 1730th from the 2nd survey area, and the 861st from the 3rd survey area.

In explicit terms, individual members of the set of blended bootstrap iterations for recruit abundance (R_c), fully recruited abundance (N_c), total abundance (A_c), annual fishing mortality (F_c) in each stock region *c* were computed:

$$R_C(t,k) = \sum_{i=1}^{I} R(t,i,k) \qquad \forall\, k$$

$$N_C(t,k) = \sum_{i=1}^{I} N(t,i,k) \qquad \forall\, k$$

$$A_C(t,k) = \sum_{i=1}^{I} \left[R(t,i,k) + N(t,i,k)\right] \qquad \forall k$$

$$F_C(t,k) = \frac{\sum_{i=1}^{I} \left[\mathrm{N(t,i,k)} + \mathrm{R(t,i,k)} \right] * \mathrm{F(t,i,k)}}{\sum_{i=1}^{I} \left[\mathrm{N(t,i,k)} + \mathrm{R(t,i,k)} \right]} \qquad \forall k$$

$$\overline{F}_C(t,k) = \frac{\sum_{i=1}^{I} \left\{ \left[\overline{\mathrm{N}}\mathrm{(t,i,k)} + \overline{\mathrm{R}}\mathrm{(t,i,k)} \right] * \overline{\mathrm{F}}\mathrm{(t,i,k)} \right\}}{\sum_{i=1}^{I} \left[\overline{\mathrm{N}}\mathrm{(t,i,k)} + \overline{\mathrm{R}}\mathrm{(t,i,k)} \right]} \qquad \forall\, k$$

where t is the survey year, k is one of the blended bootstrap estimates (formed from all combinations of converged bootstrap results for each survey area), and $\forall\, k$ means for all k=8000 combinations. All of the blended bootstrap estimates for a stock area were sorted so that the median and associated confidence intervals (e.g., 80th with bounds at the lower 10 and upper 90 percentile) were easy to calculate. Additionally, the distribution of the full 8000 realizations was characterized by the mean, variance, standard deviation, and confidence intervals based on an assumed normal distribution and standard formulae (see below)

mean $\qquad \bar{x} = \frac{\sum x_i}{n}$

variance $\qquad s^2 = \frac{\sum (x_i - \bar{x})^2}{n-1}$

standard deviation $\qquad s = \sqrt{s^2}$

80th CI $\qquad CI_{80} = \bar{x} \pm (1.282 * s)$

90th CI $\qquad CI_{90} = \bar{x} \pm (1.645 * s)$

95th CI $\qquad CI95 = \bar{x} \pm (1.96 * s)$

6.1.2 Life History Model

The life history model was used for the "turn of the crank" assessment results. Changes have been made to the model since the last assessment in 2000. The life history model is described in Appendix III.

6.2 Configuration of CSM

All CSM for lobster in this assessment used fall survey years (October-September) because: 1) fall survey data generally provide the best estimates of relative abundance; 2) the current version CSM does not accommodate multiple surveys for recruits or post-recruits; and 3) when using the catch equation in CSM, surveys are assumed to occur at the beginning of the year. Fall survey data are generally considered most reliable because water temperatures that effect lobster catchability are relatively warm and less variable in the fall (ASMFC 2000).

Time periods covered by CSMs for lobster in this assessment were fall survey years 1984-2004 for SNE and fall survey years 1982-2004 for GOM and GBK. These periods include all years with consistent and reliable landings and survey data. These periods were used for computing average, median, and quartile estimates.

CSM were run for either females or males only because of differences between the sexes in population trends, management measures, growth parameters, and because the current version of CSM does not accommodate both sexes simultaneously.

Abundance estimates for female and male lobster combined were calculated by summing CSM abundance estimates for both sexes. Fishing mortality estimates for males and females combined were calculated as abundance-weighted averages of the CSM fishing mortality estimate for each sex. CV's for combined estimated were approximated using sex-specific CVs from bootstrapping or blending (Section 6.1) in standard formulas for sums and weighted means.

Bootstrap runs for CSM models in this assessment used 2000 iterations. As described in Section 6.1.1, process errors were set to zero. The catch equation was used instead of Pope's approximation in all runs.

Stock regions and survey areas

Lobster in GOM, GBK, and SNE stock assessment regions were modeled separately because of differences among regions in population trends and biological parameters. For modeling, it was necessary to break GOM and SNE stock assessment regions down further into "survey areas" because neither stock region is covered by a single bottom trawl survey. Bottom trawl surveys conducted by CT, RI, and the NEFSC have minimal overlap but, as a group, cover most of SNE region. Similarly, surveys conducted by MA and NEFSC cover most of the GOM region. On this basis, CSMs were applied to the GOM-MA and GOM-NEFSC survey areas in the Gulf of Maine and to the SNE-CT, SNE-RI and SNE-NEFSC survey areas in SNE (Table 6.2.1).

Abundance and fishing mortality estimates for the entire GOM or SNE stock assessment regions were calculated by adding abundance estimates for constituent survey areas or as abundance-weighted averages of fishing mortality in constituent survey areas. CVs and confidence intervals for males or females only in the GOM or SNE stock regions were calculated by a blending procedure (Section 6.1).

Obsolete stock regions and survey areas

The last stock assessment (ASMFC 2000) used different stock assessment regions and survey areas that are now obsolete. In particular, ASMFC (2000) used SCCLIS and GBS stock assessment regions in place of SNE and GBK. The survey areas in SCCLIS based on bottom trawl surveys were: SCCLIS-CT (same as SNE-CT), SCCLIS-RI (same as SNE-RI) and SCCLIS-NEFSC. CSM runs were fit to data for the obsolete stock survey areas and stock assessment regions to evaluate effects on estimates due to changing stock areas.

Survey bottom trawl data

Survey index data for lobster in this assessment (Table 6.2.2) were from stratified delta mean numbers per tow in the survey, prorated into one mm size groups. In practical terms, stock regions are defined by the survey strata used to tabulate abundance index data (Table 6.2.1). For lobster in this assessment, the recruit and post-recruit indices were from the same bottom trawl survey with recruits and post-recruits distinguished by the legal size in each year, which varied over time and among areas and regions (Table 6.2.3). Post-recruit indices were the delta-mean number of legal size lobster. Recruit indices were based on abundance of sublegal lobster in the survey and assumptions about the length-, region- and sex-specific probability of growing to legal size during the next 12 months (Section 2.2). Survey data for recruits and post-recruits were given equal weight in parameter estimation ($\lambda_\eta=\lambda_\delta=1$).

The abundance index for male post-recruits in the RI fall survey during 2002 was zero because no lobster were captured. Zeroes are not allowed in CSM and were filled by averaging survey data from adjacent years.

Landings

Sex-specific landings data for lobster (numbers landed, Table 6.2.4) were available by month for relatively large statistical reporting areas that do not coincide with survey areas. For modeling, landings in statistical areas were assigned to stock regions and survey areas (Table 6.2.5) based on spatial overlap and familiarity with the fishery.

Landings data for the terminal year (2004) were imprecise because official statistics were complete only through the end of calendar year 2004 and included only the first quarter of survey year 2004. To make full use of 2004 bottom trawl survey data in modeling, landings during 2004 were approximated as c/p where c was landings during October-December 2004 and p was the average percent of survey year landings during October-December (Table 6.2.6). It was important to use data for 2004 to make abundance and fishing mortality estimates for 2003 as reliable as possible.

Assumed parameters

Following ASMFC (2000), the assumed natural mortality rate was M=0.15 y^{-1} in all years with the exception of model runs for SNE. Sea sample data, landings, shell disease incidence and severity, bottom temperatures exceeding 20^o C, and widespread anecdotal evidence indicates that natural mortality increased in SNE after 1996 (see Appendix IV). Therefore, model runs for SNE-CT, SNE-RI and SNE-NEFSC were run with M=0.15 y^{-1} during years up to 1996 and with constant values of M=0.15 (no change), 0.40, 0.65, and 0.90 y^{-1} during 1997-2003. Because the magnitude of the increase in natural mortality was uncertain, a wide range of values was assumed during 1997-2003 in order to bracket the actual values (see Appendix IV)

Following the review in ASMFC (2000) q-ratios (which measure survey catchability of recruits relative to post-recruits) were assumed to be 0.5 for NEFSC surveys and 1.0 for Connecticut, Rhode Island and Massachusetts. Although many factors affect q-ratio assumptions (ASMFC 2000), in brief, state surveys are carried out in coastal areas where small lobster may be relatively common and with bottom trawls equipped with bottom gear that make capture of small lobster more probable. NEFSC surveys, in contrast, are carried out further offshore with relatively large roller gear that is probably less efficient for small lobster.

7.0 CSM and life history model results

CSM models provide information about lobster abundance and fishing mortality in terms of both absolute scale and trends. Trend estimates are more robust and a recent review of modeling approaches for lobster (ASMFC 2004) recommended that trends be used as the basis for this assessment. Based on the review, scale of CSM estimates (e.g. the level of fishing mortality and abundance in absolute terms) is estimated with less certainty than trends.

Although CSM estimates of scale for lobster are less certain than estimates of trend, a number of practical results suggest that the scale estimates may be useful. Mortality estimates for males tend to higher than for females in the same area. This pattern in model results is reasonable because management measures protect v-notched and ovigerous females. CSM mortality estimates are highest in coastal areas of SNE off Connecticut and Rhode Island. Relatively high mortality estimates are compatible with survey and fishery length composition data for these areas, which are truncated with few large lobster (inshore landings are mostly new recruits). Relatively high mortality estimates for coastal areas are also compatible with relatively high fishing intensity (fishing effort) near shore.

Trends in estimated fishing mortality and abundance are described in the sections of this report that follow. Estimates for recent years used to determine stock status (averages during 2001-2003 or 2000-2003) are summarized in Table 7.0.1.

Residual plots

A variety of residual plots is presented in this assessment for CSM results but residual patterns do not necessarily indicate poor model performance. A review of individual runs from the simulation analyses conducted for the ASMFC model review (ASMFC 2004) showed that residual patterns (runs of positive or negative residuals) were common in CSM fits using simulated data with correlated measurement errors when the model was performing well based on mean squared error. In fact, simulation analyses showed that CSM performance actually improves slightly (lower mean squared error) with correlated measurement errors. However, simulation analysis also showed serial changes in growth and natural mortality could reduce the reliability (percent bias) and precision (root mean squared error) of fishing mortality and abundance estimates.

Fishing mortality-abundance plots

In this assessment, fishing mortality-abundance (FN) plots are presented for lobster (sexes combined) in each stock assessment region. FN plots are scatterplots with fishing mortality during each year on the y-axis and total abundance estimates during each year on the x-axis. FN plots summarize trends in F and abundance in a convenient fashion and have been used widely in fisheries stock assessment and management during recent years. FN plots in this assessment include a vertical line showing median abundance and a horizontal line showing median fishing mortality.

FN plots are similar to tables because they show the number of observations in each of four conditions or "quadrants" (see below). A chi-square test for 2 x 2 contingency tables (incorporating Yates correction for continuity) was used to test the null hypothesis of no relationship between the fishing mortality and abundance. In interpreting results, it is important to remember that a significant statistical association does not necessarily imply the existence of a biological or cause-and-effect relationship.

Quadrants in FN plots

N < median N F > median F	N > median N F > median F
N < median N F < median F	N > median N F< median F

Organization of results

Results (a brief description plus table and figures) are presented for each of the three major stock assessment regions (GOM, GBK, and SNE) in terms of females and males combined and then for females only and males only. Sex-specific results for GBK are directly from CSM runs while results for GOM and SNE are blends based on CSM results for one or both sexes in two or three survey areas (Section 6.1). Blended results for SNE are given for a range of assumed natural mortality rates during 1997-2003 because of uncertainty regarding natural mortality during recent years.

7.1 Gulf of Maine

Abundance and recruitment estimates for GOM (Tables 7.1.1 to 7.1.5 and Figures 7.1.1 to 7.1.3) during 2003 were strongly influenced by very low catches of recruit lobster in Massachusetts and NEFSC surveys during 2003. Managers are advised that recruitment may have been low during 2003 but there is considerable uncertainty about the true recruitment level. Fortunately, recruitment estimates for 2003 had little effect on stock status which were based on average abundance and fishing mortality during the most recent three years (2001-2003).

A number of factors suggest that low survey recruit abundances for GOM may be anomalous measurements due to environmental effects on survey catchability. Post-recruitment abundance in 2004 did not decline drastically as might be expected if there had been no recruitment in 2003. Anecdotal information (the summer fishery was delayed) indicates that environmental conditions may have been atypical during 2003 when fall surveys took place. Maine inshore trawl survey does not show a dramatic drop from 2002 to 2003 (Figure 5.3.2.3). Other factors suggest that recruitment may have been very low during 2003. In particular, recruitment was very low in both the NEFSC and Massachusetts survey during 2003. Cool water is thought to reduce lobster catchability but bottom temperatures were normal to high during the NEFSC survey in 2003. Recruit and post-recruit indices normally tend to track together due to common environmental effects on survey catchability. In the 2003 NEFSC survey, however, recruit abundance declined independently of post-recruit abundance. Finally, larval settlement data collected in coastal areas off Massachusetts were low during 1996-1998. Links between settlement and recruitment to the fishery have not been clearly established, but low settlement during 1996-1998 might cause low recruitment to the fishery 5-7 years later.

GOM and NEFSC survey area

Trends in GOM as a whole and in the NEFSC survey area within GOM are very similar because abundance in the area surveyed by Massachusetts is low (Tables 7.1.1 to 7.1.5 and Figures 7.1.1 and 7.1.3). NEFSC recruit indices for male and female lobster combined increased during 1982-2000 and declined to a low level in 2003. Trends in estimated abundance of females were similar to trends for males during 1982-1997. After 1997, female abundance increased more rapidly than male abundance. As described above, mortality, and abundance estimates for 2003 are suspect. Landings in the Gulf of Maine were stable between 1981 and 1987, then increased steadily from 1988 to 1999, and have remained at record high levels since.

Abundance estimates for male and female lobster from CSMs generally increased over time, but declined abruptly in 2003. Post-recruit abundance increased steadily during 1982-2003. Total estimated abundance increased over time, but declined in 2003. The proportion of the fishable stock composed of recruits in GOM as a whole varied without trend and averaged about 60%.

Fishing and total mortality for males and females combined varied without trend between 1982 and 1993, then declined steadily until 2002 before increasing abruptly during 2003. Fishing mortality rates for females only declined after 1995, but varied without trend for males. Annual exploitation rates declined steadily during 1982-2002, but increased abruptly in 2003. Landings, recruits, post-recruits, and the stock as a whole are roughly 50% female.

Massachusetts survey area (Statistical Area 514)

Trends in the Massachusetts survey area within GOM were distinctly different from trends in the NEFSC survey area and in GOM as a whole (Table 7.1.5 and Figure 7.1.3). In particular, recruitment appears to have varied without trend while total abundance declined due to relatively high fishing mortality rates typical of lobster in coastal areas. Fishing mortality rates were high but varied without trend from 1982 to 1998, then increased in 1999 and have remained above the median since that time. Lobster in Area 514 were mostly new recruits (75% on average). Landings increased from 1981 to 1990, remained high between 1991 and 2000, and have declined to a time series low in 2003. Landings, recruits, post-recruits, and the stock as a whole are roughly 50% female.

Goodness of fit

Residuals from recruit abundance indices for lobster in GOM (NEFSC and Massachusetts survey areas) had serial correlation (Figures 7.1.4 - 7.1.7). There was a tendency to under predict recruitment for female lobster in the Massachusetts survey area. As in the GOM, CSMs for lobster in GOM fit abundance data for post-recruits (which are relatively precise) better than abundance data for recruits.

7.2 Georges Bank

Abundance of male and female recruits and male post-recruits in GBK during 1982-2003 varied without trend (Table 7.2.1 to 7.2.3 and Figure 7.2.1). Female post-recruits increased. Total abundance varied without trend and was relatively stable. The proportion of the fishable stock composed of recruits varied without trend and averaged about 40%.

Landings in GBK were stable and varied without trend. Fishing mortality for the whole stock (sexes combined) varied without trend during 1982-1995 and declined thereafter. Male fishing mortality rates varied without trend but were higher than female fishing mortality rates. Female fishing mortality rates varied without trend until 1999 and were at or near time series lows in recent years. Annual exploitation rates (total landings over total abundance) varied without trend during 1982-1995 and declined slightly thereafter.

Overall, females comprised 48 % of landings, 60% of recruits, 79% of the post recruits, and 71% of the stock. There was a slight increasing trend over time in proportion female for post-recruits and total stock. Higher proportions of post-recruit females may be due to higher mortality in males and management measures that protect females (i.e. protection of ovigerous females and v-notching).

Goodness of fit

Residuals (Figures 7.2.2 and 7.2.3) from recruit abundance indices for lobster in GBK had serial correlation. CSMs for GBK fit abundance data for post-recruits (which are relatively precise) better than abundance data for recruits.

7.3 Southern New England

Recent empirical evidence suggests M increased after 1996 for Southern New England Stock, although the magnitude of the change is unknown. In order to test the sensitivity of the model results to changes in M, the Lobster Stock Assessment Committee set M in the period of 1997 to 2003 to 0.15 (no change), 0.40, 0.65, and 0.90. Trends in abundance and fishing mortality were relatively robust to changes in M after 1997.

Results with M=0.15-0.9 during 1997-2003

The most important stock assessment variables (recruit abundance, post-recruit abundance, total abundance, F, Z, and exploitation rates) from each run were converted to trends and plotted for comparison (Table 7.3.1; Figure 7.3.1). Recruit abundance estimates in all runs varied without trend until 1994 and then increased to a peak levels during 1995-1998. All runs show recruitment declining to low levels during 2001 to 2003. Post-recruit abundance estimates in all runs varied without trend until 1996, then increased to a peek in 1997 and declined thereafter to a time series low in 2003. Total abundance in all runs fluctuated near average levels during 1984-1995, increased from 1996 to 1998 and declined afterwards. Recruits were 61-72% of the fishable stock.

Exploitation rates are presented in Figure 7.3.1 but are difficult to interpret when natural mortality changes, because they depend on both natural and fishing mortality. In particular, exploitation rates do not measure fishing pressure in a consistent fashion when natural mortality rates change over time. In model runs with M greater than 0.15 during recent years, exploitation rates varied without trend prior to 1996 and were below average after 2000. In contrast, exploitation rates from the run with constant natural mortality during recent years were near average after 2000.

FN plots (Figure 7.3.2) were sensitive to assumptions about natural mortality to the extent that trends in abundance were sensitive to natural mortality. Potential management advice was robust because recent stock abundance was always well below median and proposed target levels and because recent fishing mortality was always at or near median and above proposed target levels.

Details

For simplicity, details and other stock assessment results are presented only for the run with M=0.65 during 1997-2003 (Table 7.3.2 and Figure 7.3.3). Presentation of results for *M*=0.65 does not imply choice of a best estimate of natural mortality.

Landings increased steadily, reached all time highs during 1996-1998, and then declined to the time series low in 2003. Sex ratios in the SNE stock area were relatively stable. Females comprise about 56% of landings, 58% of recruits, 75% of post-recruits, and 66% of the total fishable stock.The fraction of the fishable stock comprised of recruits was fairly stable and about 60% in all years. Fishing mortality rates were higher for males than females but both varied without trend. Total mortality varied without trend to 1994, increased to a peak 1999, and then declined to levels that were about average during 2000-2003.

Goodness of fit

Residual plots generally suggest adequate model fit for lobster in runs for SNE. Residuals for recruit indices (Figures 7.3.4 to 7.3.9) from models with *M*=0.65 during recent years showed serial correlation. CSMs for SNE fit abundance data for post-recruits (which are relatively precise) better than abundance data for recruits. There was a very large residual for both sexes (females in particular, Figures 7.3.6 and 7.3.9) for post-recruits in the RI survey area in 2002 and pronounced serial correlation in recruit residuals beginning in 1998 due to the anomalously low 2002 post-recruit indices and increased natural mortality after 1996. In effect, the model overestimated recruits beginning in 1998 to generate enough post-recruits to support the observed catches in recent years.

7.4 Sensitivity analyses

Based on simulation analysis (Jacobson 2004), the scale of CSM abundance and mortality estimates for lobster are precise and accurate, if underlying assumptions are met and model performance (in terms of mean square error) actually improves when recruit and post-recruit indices in the same year have correlated measurement errors as is likely for lobster (Jacobson 2004). The CSM used in the simulation analysis was an older version (with Pope's approximation and process errors). Fishing mortality rates were low in simulations relative to the actual stocks. Results should be sufficient, however, to appreciate the sensitivity of CSM results for lobster in this assessment to the factors considered. The simulations showed that estimated trends in abundance and mortality are very robust to errors in assumptions. The simulations also showed, however, that the scale of CSM estimates for lobster may be biased by incorrect assumptions about growth, survey *q*-ratio, natural mortality, and lack of correspondence between the natural biological year in lobster and fall survey years generally assumed in modeling. CSM, model configuration, and biological assumptions were updated for this assessment and problems with scale were probably reduced, but uncertainty remains concerning most factors. In particular, problems inherent in using fall survey years have not been resolved. Based on simulation analyses in Jacobson (2004), use of fall survey years causes fishing mortality rates to be under estimated and abundance levels to be over estimated.

ASMFC (2000) showed that recent fishing mortality rates and goodness of fit to survey data are very sensitive to assumptions about the q-ratio. Relatively high q-ratios (i.e. 1) result in lower estimates of fishing mortality and higher estimates of abundance. Goodness of fit to survey data is generally better at relatively high q-ratios but the q-ratio is not estimable as a parameter in CSM because goodness of fit declines monotonically over the range of feasible values. The q-ratio estimate used in CSM runs for the CT and RI surveys are likely more reliable than the estimate used for NEFSC surveys but both estimates are based on all available data (ASMFC 2000).

Natural mortality
Model runs for SNE with M=0.15 during 1984-1997 and M=0.15 (no change), 0.4, 0.65, or 0.9 in later years showed that trends, fishing mortality rates, and management advice were robust to assumptions about recent M. *T*here were differences among runs in the scale of abundance estimates (Section 7.3).

Weights on abundance indices
CSMs used in this assessment are relatively simple. With the exception of biological and q-ratio assumptions described above, the only important option is the relative magnitude of weights placed on pre-recruit and recruit abundance index data in calculating goodness of fit.

Recruit and post-recruit abundance indices for lobster are derived from the same bottom trawl surveys, but post-recruit indices are probably less variable because they include more individual lobster, more length groups, and larger lobster that have higher catchability. Moreover, post-recruit index calculations do not involve adjustments to the survey data for maturity and growth that contribute errors. In application to lobster, CSMs tend to fit post-recruit abundance index data better than recruit abundance index data, as might be expected.

To calculate the potential importance of the survey index weighting factors, runs were done for females in each survey area (*M*=0.4 during 1997-2003 in SNE) using weights λ_η=0.25, 1 or 4 and λ_δ=1, where λ_η is the weight on the sums of squares for recruits and λ_δ is the weight for post-recruits. Average fishing mortality and average abundance during 2000-2003 were calculated in each case and compared to results using the default weights λ_η=1, λ_δ=1. Results (Table 7.4.1) show that recent abundance and fishing mortality estimates were most sensitive (relative range > 25%) to assumptions about weights for the RI and NEFSC survey areas in SNE, where survey data are relatively imprecise.

7.5 Retrospective analyses

Retrospective analyses (Figures 7.5.1 to 7.5.4) were carried out for female abundance and fishing mortality in all three stock regions (results for males would probably be similar). For SNE, retrospective calculations were carried out with *M*=0.15 and 0.9 y^{-1} during 1997-2003 (the lower and upper bounds in runs for recent natural mortality) and *M*=0.15 in all earlier years. Retrospective patterns in absolute and relative estimates were evaluated separately because the latter are more robust in many respects and may be particularly important for lobster in this assessment.

Estimates of absolute abundance and fishing mortality from CSM runs for GOM and GBK show a strong retrospective pattern overestimating F and underestimating M in the terminal year. Results for SNE show a smaller retrospective bias in the run with a higher M in the terminal six years, except for trends in relative abundance (Figure 7.5.3 and 7.5.4). Abundance and fishing mortality estimates for other areas were stable with little retrospective pattern.

Compared to absolute estimates, retrospective patterns in relative abundance and fishing mortality estimates were increased for GOM, reduced for GBK, and remained roughly the same for SNE. Retrospective patterns improved or remained the same in GBK and SNE because additional years of data had little effect on the overall mean and variance. The "shifting baseline" effect in trend results for GOM illustrate problems potentially involved in using medians from short time series as reference points.

In general, retrospective patterns in CSM results from this assessment were not as substantial as with real and simulated data in Jacobson (2004). Improvements were likely due to improvements to the CSM (i.e. elimination of the Pope approximation for calculating population dynamics in stocks with high mortality rates) and data improvements.

7.6 Life history model results

According to Amendment 3 of the Interstate Fishery Management Plan for American Lobster (ASMFC 1997), $F_{10\%}$ reference points are used in lobster management to determine if the stocks are "overfished".[3] The utility of $F_{10\%}$ estimates in this assessment is reduced if the scale of fishing mortality estimates from CSM is not reliable. The sensitivity of $F_{10\%}$ results to input parameters were investigated in ASMFC (2000) but not in this assessment using the new model. Uncertainty and variance in $F_{10\%}$ results were evaluated by Chen and Wilson (2002) but not in this assessment. Despite uncertainties, life history model calculations (Appendix III) are useful in themselves and a standard tool in stock assessment work. Moreover, the life history model has been and continues to be widely used in analysis of management options for lobster.

7.7 "Turn of the crank" assessment

Turn of the crank assessment results can be use to: 1) reevaluate conditions described in the last assessment (ASMFC 2000); 2) evaluate effects of new management measures; and 3) determine effects of new models and data on fishing mortality and $F_{10\%}$ estimates.

Turn of the crank calculations were complicated by changes in stock assessment regions and improvements to models and parameters. In particular, the last assessment (ASMFC 2000) used the Gulf of Maine, Georges Bank and South stock assessment region, and the South of Cape Cod and Long Island Sound region. Changes in stock assessment regions are important enough to affect management advice because of spatial differences in biology and mortality. Changes in the

[3] Based on modern usage, F10% is reference point that identifies overfishing (fishing mortality rates too high), rather than overfished (depleted) stock conditions.

life history model used to calculate $F_{10\%}$ reference points, improvements to the CSM used to calculate fishing mortality rates, and new estimates for growth parameters are also important.

The turn of the crank assessment was carried out in several steps. All calculations were for stock regions (GOM, GBS, and SCCLIS) used in ASMFC (2000) and were carried out using updated models and growth parameters. In the first step, $F_{10\%}$ was calculated for each region assuming management measures in place during 1988. In the second step, $F_{10\%}$ was calculated for each region assuming current management measures. Finally, average fishing mortality during 2001-2003 was recalculated for each region.

Encounter rates at $F_{10\%}$ and percent of maximum egg production under different sets of management conditions may be more useful than $F_{10\%}$ itself in interpreting effects of management actions. $F_{10\%}$ reference points under different management measures are difficult to compare because changes in v-notching and legal size modify the size-selectivity of the fishery. Encounter rates measure effective fishing effort or fishing intensity during life history model calculations as the rate at which lobsters encounter traps. Fishing mortality is always less than the corresponding encounter rate because some lobsters caught in traps escape or are released. At a given encounter rate, different management measures will result in different levels of fishing mortality to the extent that the catch and fishery selectivity is increased or decreased by the management measures.

Results (Table 7.7.1) indicate that $F_{10\%}$ threshold values of 0.28, 0.20, and 0.37 (line 3 Table 7.7.1) for GOM, GBS and SCCLIS correspond to old $F_{10\%}$ threshold values of 0.34, 0.29 and 0.84 (line 1 Table 7.7.1) when comparing the updated life history model with new growth parameters to the model used in the previous assessment. Based on results from the new model and changes in management measures from 1998 to current (lines 3-4) $F_{10\%}$ thresholds changed by 11% for GOM, 11% for GBS and -3% for SCCLIS. As described above, however, $F_{10\%}$ values are difficult to use in comparing effects of management measures. In terms of fishing intensity, which is more easily compared, management measures increased the encounter rate at $F_{10\%}$ by 41% for GOM, 3% for GBS, and 4% for SCCLIS. The new current $F_{10\%}$ threshold values are 0.31 (GOM), 0.21 (GBS), and 0.36 (SSCLIS). Updated estimates of average fishing mortality during 2001-2003 were 0.65 or 4.3% for GOM, 0.21 or 10% for GBS, and 1.06 or 5.4% for SCCLIS. Based on the overfishing definition in Amendment 3 overfishing is occurring in both the GOM and SCCLIS stock areas and is not occurring in GBS stock area.

8.0 Stock Indicators

In addition to standard fishing mortality and abundance population parameter estimates used to judge stock status relative to reference points, a number of "common sense" stock indicators were examined. These stock indicators can be used to corroborate model results and provide additional information about the overall health of each stock. In general, the stock indicators need to be interpreted cautiously due to the short time series. The inshore fishery has been prosecuted for over 100 years and the offshore for over 50 years. The stock indicators in this assessment are representative of the most recent 25 years and may not be reflective of the entire productive range of the stock.

Sometimes referred to as the "traffic light" approach, the multiple indicators bring a variety of monitoring results, results from traditional stock assessment models, and fishery indices into management advice. This offers transparency of the method and purpose to all stakeholders. The implied advantage of taking a multiple stock indicator approach is that any one indicator is always associated with uncertainty as to what change means relative to stock status, but additional indicators, especially when obtained from independent observations, and when considered in total, will tend to reflect the true state of the stock (Caddy 2004, Koeller et al. 2000).

Three categories of indicators were generated: mortality indicators, abundance indicators, and fishery performance indicators. The annual value of each stock indicator time series was categorized as positive, neutral, or negative based on its quartile ranking. Mortality indicators were classified as follows; annual values that were less than the 25th percentile were classified as "positive", annual values between the 25th and 75th percentile were classified as "neutral", and annual values that were greater than the 75th percentile were classified as "negative". Abundance indicators were classified as follows; annual values that were less than the 25th percentile were classified as "negative", annual values between the 25th and 75th percentile were classified as "neutral", and annual values that were greater than the 75th percentile were classified as "positive". Fishery performance indicators were classified in the same manner as abundance indicators, with the exception of the number of traps fished, which were classified like a mortality indicator. The strengths of this approach are that the use of percentiles is objective and the focus on trends is robust to many biological and modeling assumptions. Similar to the proposed reference points, this method allows for a "relative" comparison of stock status.

8.1.1 Mortality Indicators

The assessment provides trends in the instantaneous rate of fishing mortality (F) and total abundance that are used to evaluate stock status with respect to the proposed threshold and target reference points. In addition to trends in fishing mortality, we provide the following indicators of mortality: trends in instantaneous rate of total mortality (Z), exploitation rate (u), mean length in survey, and recruits as a percentage of exploitable stock. In the case of Southern New England Stock, where natural mortality rate was assumed to have increased by unknown magnitude after 1996, we also provide trends in the expectation of natural death (v). The stock indicators by year are characterized by location in quartile in the time series distribution:

	≤ 25th percentile	Between 25th and 75th percentile	≥ 75th percentile
Exploitation rate (u)	Positive	neutral	negative
Z model	Positive	neutral	negative
Expectation of natural death (v)	Positive	neutral	negative
Mean length ≥ 83 mm	Negative	neutral	positive
Recruits as % of exploitable stock	Positive	neutral	negative

Trends in instantaneous total mortality are taken from the model estimates, track the total mortality rate, and account for both fishing and natural mortality rate. The rate of exploitation is the proportion of the exploitable population at the beginning of the year, which is caught or killed by the fishery, and can range from 0 to 1. It can be considered that the probability of being killed by the fishery is a function of instantaneous rates of fishing, total Z, and natural mortality rates. In cases where M changes during the time series, the relationship between instantaneous fishing mortality rate and u is complicated by changes in M. Similarly, the expectation of natural death is the proportion of the population at the beginning of the year which dies from natural deaths and can take on values ranging from 0 to 1. Similar to rate of exploitation, the expectation of v is a function of instantaneous rates of F, M, and Z. For Southern New England, M was assumed to be 0.15 from 1984 through 1996, thereafter, a range of M's (0.15 (no change), 0.40, 0.65, and 0.90) were assumed from 1997-2003.

Mean length in the survey of lobster ≥ 83 mm was also selected as a stock indicator of mortality. In this case, mean length represents the size structure of survey post-recruits at the end of the fishing year and represents the effect of mortality on the length structure of survivors at the end of the year. Higher mortality rates should result in lower mean length. However, the mean length is also influence by the strength of recruitment, and a strong recruitment may also lower mean length. Recruits, as a percentage of exploitable stock, is also used as an indicator of mortality. Higher percentages of recruits in the population are consistent with higher total mortality rates on fully recruited lobster. However, the percent recruits are influenced by strength of recruitment (a strong pulse of recruitment could lower mean size). Recruits, as a percentage of total population, could indicate the dependency of fishery on recruitment.

8.1.2 Abundance Indicators

Four indicators were generated to assess the relative abundance, the total spawning potential, and the year class strength (YOY) of each stock. These indicators include; recruit abundance, post-recruit abundance, spawning stock abundance index, and a settlement index. The recruit abundance is the number of lobster (male and female combined) in the stock, estimated by the Collie-Sissewine model, which will recruit to the fishery by the end of the fishing year. The post-recruit abundance is the number of lobster (male and female combined) in the stock, estimated by the Collie-Sissewine model, which are fully recruited to the fishery at the beginning of the fishing year. The spawning stock abundance index is the number of female lobster in the stock that are/or will be sexually mature by the end of the fishing year (see section 8.1.2.1 for description). The settlement index is an annual estimate of the relative mean density of young of the year lobster for each stock

8.1.2.1 Spawning Stock Abundance Index

The spawning stock abundance index reflects the reproductive potential of the stock in a given year. It is calculated using the following expression:

$$\mathbf{SSI} = (\sum(\mathbf{N}_{l<83mm} * \mathbf{P}_{ml<83mm})/ \sum(\mathbf{N}_{l<83mm} * N_r)) + (\sum(\mathbf{N}_{l>83mm} * \mathbf{P}_{ml>83mm})/ \sum(\mathbf{N}_{ll>83mm} * N_{pr}))$$

Where:

$\mathbf{N}_{l<83mm}$ = the mean number per tow at 1 mm increments below minimum legal size
$\mathbf{P}_{ml<83mm}$ = the proportion sexually mature at 1 mm increments below minimum legal size
N_r = the recruit abundance
$\mathbf{N}_{l>83mm}$ = the mean number per tow at 1 mm increments above minimum legal size
$\mathbf{P}_{ml>83mm}$ = the proportion sexually mature at 1 mm increments above minimum legal size
N_{pr} = the post-recruit abundance

8.1.3. Fisheries Performance Indicators

Four indicators were used to describe the performance of the fishery in each stock area during the 1982 through 2003 assessment period: effort, landings, mean length of the catch, and gross CPUE. The number of traps in each stock area was used as an indicator of effort. The number of traps does not account for how many traps were actually deployed in the fishery, the average set-over-days, or changes in gear efficiency/design. An accurate accounting of trap numbers for Georges Bank were unavailable, as such annual changes in traps originating from Massachusetts' were used as a proxy for the entire stock area. Landings were assigned to each stock area, and represent a common indicator of fishery performance. The mean annual length of landed lobster was generated for each stock area, unidentified landings by location and in some cases underreporting of landings can introduce error in estimates. Finally, pounds landed divided by the number of traps fished were used as a gross measure of CPUE as a fishery performance indicator.

8.2 Stock Indicator Results

The results of this analysis are described below for GOM, GBK, and SNE, each with a corresponding time series table in the table section. For SNE, an additional summary table is provided with 2001 - 2003 average estimates for each mortality and abundance indicator for a range of natural mortality levels (M = 0.15 (no change), 0.4, 0.65, 0.9). Additional stock indicator time series tables are provided for sub-areas within the Gulf of Maine (southern Gulf of Maine- MA 514) and Southern New England (Long Island Sound – CT/NY 611, Rhode Island Coastal waters – RI-539) in Appendix V.

8.2.1 Gulf of Maine (Table 8.2.1)

The mortality indicators for the recent years are all positive. Exploitation rate, total mortality, mean length, and percent of the exploitable stock comprised of recruits are below the 75th percentile for 2001 to 2003 when compared to the time series. The abundance indicators for the recent years are all positive. Settlement indicators for the recent years are positive, but low settlement observed in the mid 1990s may predict reduced recruitment to the fishery in future years. The fishery performance indicators have been positive for recent years with the exception an increasing number of traps, which are a negative indicator

8.2.2 Georges Bank (Table 8.2.2)

The status of the Georges Bank stock and the fishery have been relatively stable since 1983, this must be considered when interpreting the stop light results. The mortality indicators for the recent years (2001 to 2003) are all positive or neutral. Exploitation rate and total mortality (Z) fall below the 25th percentile for the terminal three years. The mean length and percent of the exploitable stock comprised of recruits fall between the 25th and 75th percentile during this period. The abundance indicators for the recent years are neutral (recruit abundance) or positive (spawning stock index and full recruit abundance) reflecting the stability of the stock. The variation within the time series is modest. The fishery performance indicators for recent years are negative or neutral. The estimates of traps in the terminal years fall above the 75th percentile and are solely based on Massachusetts levels that may not reflect the true levels of effort in the GBK stock area.

8.2.3 Southern New England (Tables 8.2.3.1 and 8.2.3.2)

Mortality rates are uncertain in recent years and there is a fair amount of empirical evidence that suggests natural mortality rates have increased. In response, natural mortality rates (M) ranging from 0.15 (no change) to 0.9 were used between 1997 and 2003 to demonstrate the sensitivity of the stock indicators to this parameter. Mortality stock indicators range from negative to positive during the terminal three years depending on the specific indicator and level of M described. Both exploitation and fishing mortality are neutral to positive. Note, however, that exploitation rates and fishing mortality measure different things when natural mortality changes as probably occurred in SNE during some recent years (Section 8.1.1). Consequently, exploitation rates for SNE are relatively difficult to interpret as measures of fishing pressure. The expectation of natural death was positive (M =0.15 (no change)) and negative for all other scenarios (M = 0.4, 0.65, 0.9). Mean length derived from surveys did not change with different M scenarios and was positive for the terminal years. The percent of exploitable stock comprised of recruits was neutral (M = 0.15 (no change), 0.4, 0.65,0.9). The abundance indicators were robust to assumptions of M and were negative (spawning stock abundance index, recruit abundance, full-recruit abundance) to neutral (settlement index) for all scenarios in the terminal three years. The fishery performance indicators were negative (landings, gross CPUE) and neutral (traps, mean length) for the period of 2001 to 2003 (Tables 8.2.3.1 and 8.2.3.2).

9.0 Biological Reference Points (BRPs)

Based on technical issues identified by reviewers (ASMFC 2004) and results of this assessment, the Lobster Stock Assessment Committee (LSAC) recommends a new robust set of biological reference points that could be used for this assessment of American lobster stocks. The limitations of biological (Fogarty and Gendron, 2004), fisheries dependent, and independent data need to be improved. Problems with stock assessment models used to estimate fishing mortality also need to be resolved. Given these concerns, the LSAC and the model review panel (ASMFC 2004) recommend new reference points, with overfishing and overfished definitions, as an interim approach. Details and results based on current and recommended reference points are given below.

9.1 Current overfishing definition

The current overfishing definition for lobster was adopted by ASMFC in Amendment 3 of the Interstate Fishery Management Plan for American Lobster (ASMFC 1997). According to the current definition, a lobster stock is “overfished” if recent fishing mortality rates exceed $F_{10\%}$. $F_{10\%}$ is one member of a commonly used family of biological reference points. In recent stock assessments (ASMFC 2000), fishing mortality rates were estimated using CSM and $F_{10\%}$ was estimated using the life history model.

The Lobster Stock Assessment Model Review Panel (ASFMC 2004) found that the scale of fishing mortality and abundance estimates from CSM runs are sensitive to uncertain parameters and modeling conventions. Uncertainty about the scale of fishing mortality estimates makes use of the current overfishing definition problematic. The review panel recommended that management advice in the current stock assessment be based on estimated trends in abundance and fishing mortality. The new recommended reference points in Section 9.2 are the LSAC’s response to this advice.

The LSAC decided to not present $F_{10\%}$ values for new stock areas because of potential problems in scale when comparing $F_{10}\%$ to fishing mortality estimates from CSM runs. However, "turn of the crank" assessment results in Section 7.7 can be used to apply the current overfishing definition to stock assessment regions used in the last assessment (ASMFC 2000).

Critique of the Single Reference Point ($F_{10\%}$) Approach

The current overfishing definition ($F_{10\%}$) is insufficient from a technical point of view because it does not distinguish between a depleted stock (at low abundance) and a stock where overfishing is occurring (fishing mortality rates are too high). In addition, a single %MSP does not distinguish between management targets, thresholds, and limits. Targets are BRPs that identify desirable conditions in the fishery. Thresholds are BRPs that identify situations where corrective management action is desirable. Limit reference points are BRPs that identify situations requiring relatively drastic corrective action. Clear distinctions between BRPs uses by managers as targets, thresholds, and limits are an essential component of modern fisheries management.

Although probably intended as a threshold BRP, $F_{10\%}$ has been used as a management target because managers have tried to reduce fishing mortality rates to the $F_{10\%}$ level for many years (ASMFC 1997). $F_{10\%}$ is associated with a low level of egg production per recruit and is likely not suitable as a management target, although it might be appropriate as a threshold reference point.

Precision of the current $F_{10\%}$ is strongly affected by uncertainty in estimates of both recent fishing mortality and other parameters (Chen and Wilson 2002). At present, recent fishing mortality is estimated using CSM and $F_{10\%}$ is estimated using the lobster life history model (Section 7). The size structure model (Appendix II), currently in testing, estimates both recent fishing mortality and $F_{10\%}$ in the same model and may prove robust for lobster.

The chief technical advantage in $F_{10\%}$ is that the magnitude of fishing mortality rates are evaluated relative to a standard value based on life history information. In other words, it can be used to determine if fishing mortality rates are "high" or "low" in a quantitative or qualitative sense relative to the biology of lobster and approaches used in other fisheries. A number of modifications described in Section 6 were made to CSM for lobster following the Lobster Stock Assessment Model Review (ASMFC 2004). However, simulations to measure model performance have not been carried out and the scale of CSM estimates remains uncertain.

9.2 Recommended New Reference Points

The LSAC recommends median abundance and median fishing mortality as threshold reference points for American lobster. Following conventions in the last assessment, it is recommended that stock status relative to these reference points be determined by comparison to average F and abundance during the most recent three years. The SAC proposes defining abundance and fishing mortality targets separated from the thresholds by a minimum of one estimated standard error (as described below). This standard error corresponds to the measurement error typical of a three-year average fishing mortality rate or abundance value used in status determination. These targets are designed to reduce the risk associated with exceeding the thresholds due to uncertainty in the three-year average estimates. The recommended minimum separation between targets and thresholds is based entirely on the statistical precision of estimates and does not incorporate inherent variability of the stocks or other factors that may affect risk to the stock or fishery. These targets allow for a 84 percent chance that a stock apparently at its target actually exceeds the threshold. The LSAC makes no recommendations regarding other BRPs that might be used as management limits in the lobster fishery, although limits are worth considering.

Calculation of Standard Error –Separation of Thresholds and Targets

Median fishable abundance (recruits + post-recruits) and median fishing mortality are recommended as threshold reference points for each lobster stock assessment region in this assessment. This means that managers should attempt to increase abundance of stocks when recent abundance (averaged over the last three years) falls below the threshold or target levels. Managers should attempt to reduce fishing mortality if recent fishing mortality levels (averaged over the last three years) are above the median threshold or target levels.

Overfishing definitions involve policy choices that are not in the terms of reference for this assessment. However, based on the recommended reference points and depending on details in the definitions, "overfishing" would occur if fishing mortality rates were substantially higher than the median threshold. A stock would be "depleted" according to the definition if abundance fell below the median threshold level. In either of these cases, corrective management action should be implemented.

The proposed management target for abundance of American lobster is the median level plus one standard deviation of measurement error. The proposed management target for fishing mortality is median fishing mortality minus one standard deviation of measurement error. Approximate standard deviations (s) for measurement errors in the three-year average of fishing mortality rates and abundance were computed in this assessment as:

$$s = \frac{\sigma}{\sqrt{3}}$$

where σ is the median standard deviation of the individual estimates. The median standard deviation for individual estimates was approximated as the product of the median CV for individual estimates (from bootstrapping) and the median of the best annual estimates for all years.

The recommended targets are separated from the corresponding threshold by a minimum distance to reduce the probability that a stock actually at the target would be mistakenly estimated beyond the threshold and to protect biological productivity. Based on a normal distribution, a stock at a target would have slightly less than one chance in six of being mistakenly identified as being beyond the median reference point.[4] Managers are encouraged to use larger offsets than one standard deviation, between targets and median thresholds if policy allows because larger offsets would provide additional protection against overfishing and depleted stock conditions and erroneous conclusions about stock status.

[4] The cumulative probability for a standard normal distribution in the tails beyond 1 standard deviation is about 0.16. Thus, a stock actually at it's target would be mistakenly identified as being at or beyond the median threshold reference point 16% of the time, or in slightly less than one out of six cases.

Reference points (including medians and standard errors for management) proposed for lobster in the GOM, GBK, and SNE stock regions were based on trends in estimated fishing mortality and abundance from CSM (Section 7). Trends for GOM and GBK were estimated using data for 1982-2003. Trends for SNE were estimated using data for 1984-2003. LSAC recommends that the proposed reference points (including medians and standard errors) should not be changed until the next benchmark stock assessment is completed.

Fishing mortality-abundance plots and a summary were used to depict stock status for this assessment. In FN plots, the time series of estimated fishing mortality rates is plotted on the y-axis against the time series of fishable abundance estimates on the x-axis. Lines are drawn across the plot at the level of the median fishing mortality (the fishing mortality threshold) and at the median less one standard deviation (the fishing mortality target). Another set of lines is drawn down the plot at the median abundance level (the abundance threshold) and at the median plus one standard deviation (the abundance target). Recent fishing mortality and recent abundance (three year averages) are computed and plotted. The position of recent fishing mortality and recent abundance relative to the targets and thresholds depicts the status of the stock.

Stock status using new biological reference points.

Based on results in Table 9.2.1 and Figure 9.2.1, the GOM stock is in favorable condition based on the recommended BRPs. The stock is above the abundance target and at or near the target F. In terms of the recommended reference points, the GOM lobster stock is not depleted and overfishing is not occurring.

The GBK stock is in a favorable condition based on the recommended BRPs (Table 9.2.1 and Figure 9.2.2). The stock is above the abundance target and below its fishing mortality target. In terms of the recommended reference points, the GBK stock is not depleted and overfishing is not occurring.

The SNE stock is in poor condition based on the recommended BRPs (Table 9.2.1 and Figure 9.2.3). The stock is below the abundance threshold and at or near the fishing mortality threshold. In terms of the recommended reference points, it is depleted and at the overfishing threshold. The interpretations of stock status are robust to the levels of M chosen (Figure 9.2.3).

Critique of new recommended reference points

The strengths of recommended approach include: 1) simplicity and transparency; 2) use of medians, which are robust to noisy data and changes in model assumptions; 3) estimates of absolute fishing mortality and abundance are not required; 4) results focused on trends, which are robust to many biological assumptions and can be calculated in most stock assessment models; and 5) results are based on recent history experienced by all constituents.

The weaknesses of the recommended approach include: 1) recommended reference points provide advice relative to the stock response to fishing mortality levels are limited to the period covered by the assessment; 2) reference points do not provide any information regarding optimal exploitation levels with respect to yields, recruitment, risk, and economic yield; 3) these time series do not include the historical range of productivity experienced by the stocks; 4) ancillary information outside the stock assessment model is not completely utilized.

10.0 Recommendations and Findings

The advice contained within this section is based on the new reference points, stock indicators, and stock definitions presented in this document. The SAC recommends that the ASMFC Lobster Management Board adopt the new stock definitions and reference points, and use them as a basis to currently manage all three stocks of American lobster in U.S. territorial waters. The SAC also recommends that the ASMFC lobster board redefine management area boundaries so that they match, or completely fall within, stock unit boundaries. It is not possible to provide robust management advice for management areas that span multiple stock areas due to differences in stock trends, biological parameters, and management measures in adjacent areas.

10.1 Evaluation of Current Stock Status Based on Biological Reference Points

Gulf of Maine
The good conditions in the GOM stock indicate that recent mortality rates are sustainable. However, effort indicators are negative. This high effort is concurrent with high stock abundance, and is not likely to be supportable if abundance returns to median levels.

Conditions are poor in southern GOM (Area 514). The mortality rates are above the threshold and abundance is below the threshold in Area 514 (Figure7.1.3). Managers should consider alternate approaches to reducing fishing mortality and rebuilding stock abundance in this portion of the Gulf of Maine.

Georges Bank
The good conditions in the Georges Bank stock indicate that recent mortality rates are sustainable. However, effort indicators are negative for the stock and further increases in effort are not advisable.

Southern New England
In light of the poor stock conditions observed in Southern New England, the SAC recommends reducing fishing mortality to the target level and rebuilding stock abundance to the target level. The response of the population will also depend on recruitment strength and magnitude of natural mortality. Other mortality factors need to be continually addressed.

10.2 Research Recommendations

New research and expansion of existing monitoring programs in the following areas would provide information needed to improve future stock assessments:

Age and Growth
All assessments of lobster stock status have been based on analyses of length data. Age is assumed by applying per-molt growth increments and molt frequencies to the length data. Based on these analyses, the American lobster has been treated as an extremely long-lived animal, reaching a reproductive maximum at a relatively old age. These assumptions are justified but are

based on no actual age data. Applying aging techniques developed in England and Australia for lobster and other crustaceans would greatly improve our understanding of how many year-classes support the current trap fishery, how length relates to age, and how variable the age structure is over stock area and time.

Ecosystem-based Management

NOAA's 2004 Strategic Plan for Fisheries Research recommends the inclusion of ecosystem and environmental information in all stock assessments. Further examination of lobster mortality not related to the fishery would provide a better understanding of factors limiting productivity and longevity. Topics should include: predator/prey interactions and community structure, climatic shifts in ocean currents and temperature, and toxic substances causing chronic stress or disease.

Fishery-Dependent Information

Accurate and comparable landings are the principal data needed to assess the impact of fishing on lobster populations. The quality of current landings data is not consistent spatially or temporally. Standardized mandatory reporting of landings data resource-wide would improve the assessment. Aligning stock management areas with area designations for landings is necessary. Enhanced sea sampling and port sampling to create a more complete record of biological characteristics of the catch and harvest would also improve the usefulness of these data. This is especially needed in offshore waters.

Fishery-Independent Information

There is a need to develop consistent techniques that monitor distribution and abundance of lobster independent of the fishery. Current methods (e.g. trawls) are limited in area (gear conflicts) and habitat sampled (unable to access complex bottom). Additional methodologies should be investigated that cover a wide range of sizes and habitats. These could include ventless traps, dive/ROV, and settlement surveys.

Investigation of Historical Levels of Stock Production

It has been pointed out that one limitation of the proposed reference points is the period covered by the assessment. Investigations of past levels of stock size and size structure could provide additional insight in to setting reference points that relate to the full range of stock productivity.

Investigation of Trans-boundary Assessments

Investigate conducting joint US and Canadian assessments.

Model Development

Size based models should be examined to determine their ability to match length frequencies and other biological characteristics observed in local lobster populations. Additionally, the utility of using yield and spawning biomass per recruit and surplus production models should be evaluated through simulation as a basis for developing alternative reference points.

11.0 Literature Cited

Able, K., Heck, K.L., Fahay, M.P. and Roman, C.T. 1988. Use of salt-marsh peat reefs by small juvenile lobsters on Cape Cod, Massachusetts. Estuaries, 11: 83 - 86.

Addison, J.T. 1986. Density dependent mortality and the relationship between size composition and fishing effort in lobster populations. Can. J. Fish. Aquat. Sci. 43:2360-2367.

Addison, J.T. and Bannister, R.C.A. 1998. Quantifying potential impacts of behavioral factors on crustacean stock monitoring and assessment: modeling and experimental approaches. *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Edited by: G.S. Jamieson and A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci. 125: 167-177.

Addison, J.T. and Bell, M.C. 1997. Simulation modelling of capture processes in trap fisheries for clawed lobsters. Mar. Freshwater Res. 48: 1035-1044.

Aiken, D. E. 1977. Molting and growth in decapod crustaceans with particular reference to the lobster *(Homarus americanus).* Div. Fish. Oceanogr. Circ. (Aust., CSIRO) No.7, pp. 41-73.

Aiken, D.E. 1980. Molting and growth. *In* The biology and management of lobsters. Edited by Cobb, J.S. and B.F. Phillips, Vol. 1, pp.91 - 162. Academic Press, New York.

Aiken, D.E., and Waddy, S.L. 1976. Controlling growth and reproduction in the American lobster. Proc. Annu. Meet. – World Maric. Soc. 7, 415 - 430.

Aiken, D.E., and Waddy, S.L. 1978. Space, density and growth of lobster *(Homarus americanus).* Proc. Annu. Meet. – World Maric. Soc. 9, 461 – 467.

Aiken, D.E., and Waddy, S.L. 1980. Reproductive biology *In* The biology and management of lobsters Edited by Cobb, J.S. and B.F. Phillips, Vol. 1, pp.275 - 275. Academic Press, New York.

Aiken, D.E., and Waddy, S.L. 1982. Cement gland development, ovary maturation and reproductive cycles in the American lobster, *(Homarus americanus).* J. Crust. Biol. 2, 315 – 327.

Aiken, D.E., and Waddy, S.L. 1985. Production of seed stock for lobster culture. Aquaculture, 44, 103 – 114.

Aiken, D.E., and Waddy, S.L. 1986. Environmental influence on recruitment of American lobster *(Homarus americanus)*:a perspective. Can. J. Fish Aquat. Sci. 43:2258 –2270.

Anderson, J.R. and May, R.M. 1979. Population biology of infectious disease. Part 1.

Nature 280:361 – 367.

Atlantic States Marine Fisheries Commission (ASMFC). 1997. Amendment 3 to the Interstate Fishery Management Plan for American lobster. Atlantic States Marine Fisheries Commission Fishery Management Report No. 29.

Atlantic States Marine Fisheries Commission (ASMFC) 2000. American lobster stock assessment report. NO. 00-01.

Atlantic States Marine Fisheries Commission (ASMFC). 2000b. Terms of reference and advisory report for the American lobster stock assessment peer review. Atlantic States Marine Fisheries Commission Stock Assessment Peer Review Report No. 00-01.

Atlantic States Marine Fisheries Commission (ASMFC). 2004. American lobster stock assessment model technical review, terms of reference and panel report. Atlantic States Marine Fisheries Commission Special Report No. 82.

Bannister, R.C.A. and Addison, J.T. 1986. Effects of assumptions about the stock-recruitment relationship on a lobster *(H. gammarus)* stock assessment. Can. J. Fish Aquat. Sci. 43: 2353-2359.

Bayer, R. Hodkins, H., Loughlin, M. and Prince, D. 1993. Lobster health manual. Maine Sea Grant Publication MSG-E-93-13. 10 pps.

Bologna, P. and Steneck, R. 1993. Kelp beds as habitat for the American lobster, *Homarus americanus*. Mar. Ecol. Prog Ser. 100: 127-134.

Bordner, C.E. and Conklin, D.E. 1981. Food consumption and growth of juvenile lobsters. Aquaculture 24:285-300.

Botero, L. and Atema, J. 1982. Behavior and substrate selection during larval settling In the lobster, *Homarus americanus*. J. Crust. Biol. 2: 59-69.

Boudreau, P. R. and L. M. Dickie. 1989. Biological model of fisheries production based on physiological and ecological scaling of body size. Can. J. Fish. Aquat. Sci. 46:614-623.

Brooks, D.A. (1985) Vernal circulation in the Gulf of Maine. J. Geophys. Res. 90:4687-4705.

Caddy, J.F. (2004) Current usage of fisheries indicators and reference point, and their potential application to management of fisheries for marine invertebrates. Can. J. Fish. Aquat. Sci. 61:1307-1324

Cadrin, S.X. 1995. Discrimination of American lobster (*Homarus americanus*) stocks off southern New England on the basis of secondary sex character allometry. Can. J. Fish. Aquat. Sci. 52: 2712-2723.

Campbell, A. 1983a. Growth of tagged lobsters off Port Maitland, Nova Scotia, 1946-80. Can. Tech. Rep. Fish Aquat Sci. 1232:1-10.

Campbell, A. 1983b. Growth of tagged American lobsters, *Homarus americanus,* in the Bay of Fundy. Can. J. Fish. Aquat. Sci 40: 1667 – 1675.

Campbell, A. and Robinson, D.G. 1983. Reproductive potential of three American lobster, *Homarus americanus* stocks in the Canadian Maritimes. Can. J. Fish. Aquat. Sci., 40:1958-1967.

Capuzzo, J.M. and. Lancaster, B.A. 1979. The effects of diet on the growth energetics of postlarval lobsters *Homarus americanus*. Woods Hole Oceanogr. Inst. Tech.Rep. WHOI-79-55.

Castell, J.D. and. Budson, S.D. 1974. Lobster nutrition: The effect on *Homarus americanus* of dietery protein levels. J. Fish. Res. Board Can. 31:1363-1370.

Castro, K.M. 1998a. Summary of URI trawl survey information for the American lobster, *Homarus americanus*, in Rhode Island. URI Fisheries Center Technical Report 1-98.

Castro, K.M. 1998b. Rhode Island lobster tagging report: growth and migration. URI Fisheries Center Technical Report 2-98.

Charmantier, G.M., Charmantier-Daures, M., and Aiken, D.E. 1984. Variation des capcites osmoregulatrices des larves et postlarves de *Homarus americanus*, H. Milne Edwards, 1837. C.R. Acad. Sc. Paris, T 299, Series III, no 20:863-866.

Charmantier, G.M., Charmantier-Daures, M., and Young-Lai, W.W. 1985. Lethal and sublethal effects of potash brine on different stages of the lobster, *Homarus americanus*. Can. Tech. Rep. Fish. Aquat. Sci. 1344:13 pp.

Charmantier, G and Aiken, D.E. 1987. Intermediate larval and postlarval stages of *Homarus americanus,* H. Milne Edwards, 1837 (Crustacea:Decapoda). J. Crust. Biol. 7: 525 –

Chen, Y., and Wilson. C. 2002. A simulation study to evaluate impacts of uncertainty on the assessment of American lobster fishery in the Gulf of Maine. Can. J. Fish. Aquat. Sci. 59: 1394-1403.

Chistoserdov, A., R. Smolowitz, S. Gubbala, A. Hsu, and F. Mirasol, 2004. Bacterial assemblages involved in the development and progression of shell disease in the American lobster, *Homarus americanus*. Presentation given at the Fourth Long Island Sound Lobster Health Symposium, CT Sea Grant, May 3, 2004.

Cobb, J.S. 1995. Interface of ecology, behavior and fisheries *In* Biology of the lobster *Homarus americanus.* Edited by J.F. Factor. Pp: 139-152. Academic Press

Cobb, J.S. and Tamm, G.R. 1974. Social conditions increase intermolt period in juvenile lobsters. J. Fish. Res. Board Can. 32: 141 – 143.

Cobb, J.S. and Tamm, G.R. 1975. Dominance status and molt order in lobsters *Homarus americanus.* Mar. Behav. Physiol. 3: 119 – 124.

Cobb, J.S. and Caddy, J.F. 1989. The population biology of decapods *In* Marine invertebrate fisheries: their assessment and management. Editor: J.F. Caddy. Pgs:327-374. John Wiley and Sons, New York.

Cobb, J. S., Wang, D. Campbell, D. B., and Rooney, P. 1989. Speed and direction of swimming by postlarvae of the American lobster. Trans. of the Amer. Fish. Soc. II 8: 82 - 86.

Cobb, S., and Wahle, R. 1994. Early life history and recruitment processes of clawed lobsters. Brill, E.J., Crustaceana. 67: 1 - 25.

Comeau, M. and F. Savoie (2001) Growth increment and molt frequency of the American lobster, *Homarus americanus*, in the southwestern Gulf of St. Lawrence. J. Crust. Biol. 21 (4) 923-936.

Cooper, R.A. and Uzmann, J.R. 1971. Migrations and growth of deep-sea lobsters, *Homarus americanus*. Science 171: 288-290.

Cooper, R. A. and Uzmann, J.R. 1980. Ecology of juvenile and adult *Homarus. In* The biology and management of lobsters. Vol. 2. Edited by Cobb, J. S. and Phillips, R. Academic Press, New York. pps. 97 - 141.

Crossin, G., S. Jury, W. Watson III, 1998. Behavioral thermoregulation in the American lobster *Homarus americanus*. J. Exp. Biology, 201:365-374.

Dominion Nuclear Connecticut (DNC). 2003, 2005. Lobster studies. In: Monitoring the marine environment of Long Island Sound at Millstone Power Station, Waterford, CT, Annual Reports 2003 and 2005.

Dominion Resource Services (DRS), 2003. Monitoring the Marine Environment of Long Island Sound at Millstone Power Station. Annual Report 2002, prepared by the staff of Millstone Environmental Laboratory, 282 p.
See also: http://www.seagrant.sunysb.edu/lilobsters/ShellDiseaseWorkshop/LISLI-ShellDiseaseWkshp.htm

Dominion Resource Services (DRS), 2005. Monitoring the Marine Environment of Long Island Sound at Millstone Power Station. Annual Report 2004, prepared by the staff of Millstone Environmental Laboratory, 284 p.

Ennis, G. P. 1980. Size- maturity relationships and related observations in Newfoundland populations of the lobster, *Homarus americanus*. Can. J. Fish. Aquat. Sci. 37: 945 – 956.

Ennis, G.P. 1981. Fecundity of the American lobster, *Homarus americanus*, in Newfoundland waters. Fish. Bull. 79(4): 796 – 800.

Ennis, G.P. 1984. Small scale seasonal movements of the American lobster *Homarus americanus.* Trans. Amer. Fish. Soc. 113:336-338.

Ennis, G.P. 1995. Larval and postlarval ecology. IN: Factor JR (ed) Biology of the Lobster *Homarus americanus.* Academic Press, San Diego, p 23-46.

Ennis, G.P. 1991. Annual variation in egg production in a Newfoundland population of the American lobster, *Homarus americanus. In* Crustacean Issues Edited by F.R. Schram, Vol. 7, Crustacean Egg Production Edited by A. Wenner and A. Kuris, pp. 291-299. Balkema , Rotterdam, The Netherlands.

Epifanio, C.E. and R.W. Garvine (2001) Larval transport on the Atlantic Continental Shelf of North America: a review, Estuarine, Coastal and Shelf Science. 52:51-77.

Estrella, B.T. Personal communitcation. MA Division of Marine Fisheries.

Estrella, B.T. and McKiernan, D.J. 1989. Catch-per-unit effort and biological parameters from the Massachusetts coastal lobster, *Homarus americanus* resource: Description and Trends. NOAA Technical Report. NMFS 81, 21pp.

Estrella, B.T. and. Cadrin, S.X. 1995. Fecundity of the American lobster, *Homarus americanus* in Massachusetts coastal waters. ICES Mar. Sci. Symp., 199: 61-72.

Estrella, B.T. and Morrissey, T. D. 1997. Seasonal movement of offshore American lobster, *H. americanus*, tagged along the eastern shore of Cape Cod, Massachusetts. Fishery Bulletin 95: 466-476.

Fogarty M.J, D.V.D. Borden and H.J. Russell (1980) Movements of tagged American lobster, *Homarus americanus,* off Rhode Island. Fih Bull. 78:771-780.

Fogarty, M.J. 1983. Distribution and relative abundance of the American lobster, *Homarus americanus* larvae: A review. NOAA Tech Rep. NMFS SSRF 775, 3- 8.

Fogarty, M.J. 1995. Populations, fisheries and management *In* Biology of the lobster *Homarus americanus.* Edited by J.F. Factor. Pgs: 111-138 Academic Press

Fogarty, M. J. 1998. Implications of migration and larval interchange in American lobster stocks, spatial structure and resilience *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Edited by G.S. Jamieson and A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci. 125:273-283.

Fogarty, M.J. and Gendron. 2004. Biological reference points for American lobster (*Homarus americanus*) populations: limits to exploitation and the precautionary approach. Canadian Journal of Fish and Aquatic Sciences61(8): 1392-1403

Fogarty, M.J. and Idoine, J.S. 1988. Application of a yield and egg production model based on size to an offshore American lobster population. Trans. Am. Fish. Soc. 117:350-362.

GLOBEC. 1997. The Georges Bank Ecosystem. www.usglobec.org/reports

Graulich, K.A. 1991. New York State Department of Environmental Conservation American Lobster Investigations in New York Waters. Project 3-IJ-11 Completion Report.

Harding, G.C. 1992. American lobster, *Homarus americanus:* A discussion paper on their environmental requirements and the known anthropogenic effects on their populations. Can. Tech. Rep. Fish Aquat. Sci. 1887.

Harding G.C., K.F. Drinkwater, C.G. Hannah, J.D. Pringle, J. Prena, J.W. Loder, S. Pearre Jr. and W.P. Vass (2005) Larval lobster (*Homarus americanus*) distribution and drift in the vicinity of the Gulf of Maine offshore banks and their probable origins. Fish Oceangr. 14(2):112-137.

Harding, G. C., Pringle, J. D., Vass, P. W., Pearre, S. Jr., and Smith, S.J. 1987. Vertical distribution and daily movements of larval lobsters *Homarus americanus* over Browns Bank, Nova Scotia. Marine Ecol. Prog. Ser. 41: 29 - 41.

Hart, B.L. 1990. Behavioral adaptations to pathogens and parasites: five strategies. Neuroscience and Biobehavioral Reviews 14:273-294.

Herrick, F.H. 1896. The American lobster: a study of its habits and development. Bulletin U.S. Fish. Comm., 15: 1 – 252.

Herrick, F.H. 1911. History and importance of the lobster fisheries in brief. Bulletin of the Bureau of Fisheries.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fisheries Bulletin US 82:898-903.

Howell, P. and D. Simpson. 1994. Abundance of mairne resources in relation to dissolved oxygen in Long Island Sound. Estuaries 17(2):394-402.

Hudon, C. 1987. Ecology and growth of postlarval and juvenile lobster, *Homarus americanus*, off Iles de la Madeleine (Quebec). Can. J. Fish. Aquat. Sci. 44: 1855 – 1869.

Hughes, J.T., Sullivan, J., and Schlesser, R.A. 1972. Enhancement of lobster growth. Science 177: 1110 – 1111.

Huntsman, A. G. 1923. Natural lobster breeding. Bull. of the Biological Board of Canada. 5: 1 - 11.

Huntsman, A. G. 1924. Limited factors for marine animals 2: resistance of larval lobster to extremes of temperature. Can. Biol. fisheries. 2: 91 - 93.

Idoine, J. 1998. American lobster. pp. 120 –122 *In* Status of Fishery Resources off the Northeastern United States for 1998. NOAA Tech. Memo. NMFS-NE-115. Edited by S.H. Clark.

Incze, L. S., Wahle, R. A. and Palma, A. 1998. Advection and settlement rates in a benthic invertebrate: recruitment to the first benthic stage in *Homarus americanus.* ICES Journal of Mar. Sci. 1-29.

Jacobson, L.D. 2004. Performance of the Collie-Sissenwine stock assessment model in simulated lobster stock assessments (with corrections). *For*: American Lobster Stock Assessment Model Technical Review, December 2004.

Jones, R. and A. M. Shanks. 1990. An estimate of natural mortality for North Sea haddock. J. Cons. Explor. Mer. 47:99-103

Ju, S.J., Secor., D.H., and Harvey, H.R. 1999. Use of extractable lipofuscin for age determination of blue crab, *Callinectes sapidus*. Mar. Ecol. Prog. Ser. 185:171-179.

Jury, S.H., Kinnison, M.T., Howell, W.H., and Watson, W.H. III. 1994. The behavior of lobsters in response to reduced salinity. J. Exp. Mar. Biol. Ecol. 180:23-27.

Karnofsky, E.B. and Price, H.J. 1989. Behavioral response of the lobster *Homarus americanus* to traps. Can. J. Fish. Aquat. Sci. 46: 1625-1632.

Katz, C. H., Cobb, J. S. and Spaulding, M. 1994. Larval behavior, hydrodynamic transport, and potential offshore - to inshore recruitment in the American lobster, *Homarus americanus.* Mar. Ecol. Prog. Ser. 103: 265 - 273.

Kelly, K.H., *in prep*. Fecundity of American lobster, *Homarus americanus,* from coastal Maine waters.

Koeller, P., Savard, L., Parsons, D.G., and Fu C. (2000) A precautionary approach to assessment and management of shrimp stocks in Northwest Atlantic. J. Northwest Atl. Fish. Sci. 27:235-246.

Krouse, J. S. 1981. Movement, growth, and mortality of American lobsters, *Homarus americanus,* tagged along the coast of Maine. NOAA Technical Report. 747: 1 - 12.

Lawton, P. and Lavalli, K. L. 1995. Postlarval, juvenile, adolescent and adult ecology *In* Biology of the lobster, *Homarus americanus*,. Edited by: Factor, J. R. Pgs: 47 - 88 Academic Press, Inc.

Leffler, C. W., 1972. Some effects of temperature on the growth and metabolic rate of jevenile blue crabs, Callinectes sapidus, in the laboratory. Marne Biology 14: 104-110.

Little, Susan A. and Watson III, Winsor H. 2005. Differences in the size at maturity of female american lobsters, *Homarus americanus*, captured throughout the range of the offshore fishery. Journal of Crustacean Biology. 24(4):585-592.

Lund, W.A. and L.L. Stewart (1970) Abundance and distribution of larval lobsters, *Homarus americanus*, off the coast of southern New England.

McLeese, D.W. 1956. Effects of temperature, salinity and oxygen on the survival of the American lobster. J. Fish. Res. Board Can. 13: 247 – 272.

Mesnil, B. 2003. The Catch-Survey Analysis (CSA) method of fish stock assessment: an evaluation using simulated data. Fisheries Research. 63(2):193-212.

Miller, R.J. 1989. Catchability of American lobsters, *(Homarus americanus)* and rock crabs *(Cancer irroratus)* by traps. Can. J. Fish. Aquat. Sci. 46: 1652-1657.

Miller, R.J. 1990. Effectiveness of crab and lobster traps. Can. J. Fish. Aquat. Sci. 47: 1228-1251.

Miller, D.C., Poucher, S.L., and Coiro, L.L. 1992. Development of dissolved oxygen criteria for Long Island Sound: The acute effects database. Long Island Sound Research Conference, October 23-24; Southern Connecticut State University: abstract.

Munro, J.L. 1974. The biology, ecology, exploitation and management of Carribean reef fishes. Scientific report of the ODA/UNI fisheries ecology research project 1962-1973. Part VI. The biology, ecology and bioeconomics of Carribean reef fishes - crustaceans. Univ. West Indies Zool. Dep Res. Rep 3, 1-57.

Nicosia, F and K. Lavalli. 1999. Homarid Lobster Hatcheries: Their history and role in research, management and aquaculture. Marine Fisheries Review 61 (2).

Northeast Fisheries Science Center (NEFSC). 1992. American lobster. In: Report of the 14th Northeast Regional Stock Assessment Workshop (14th SAW). Northeast Fisheries Science Center Reference Document 92-07.

NEFSC (Northeast Fisheries Science Center). 1993. Report of the 16th Northeast Regional Stock Assessment Workshop (16th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. 93-18; 107 p.

NEFSC (Northeast Fisheries Science Center). 1996. Report of the 22nd Northeast Regional Stock Assessment Workshop (22nd SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. 96-13; 242 p.

NEFSC (Northeast Fisheries Science Center). 2001. Status of Fishery Resources off the Northeastern United States – Fisheries Economic Trends

Nelson, K., Hedgecock, D., Heyer, B., and Nunn, T. 1983. On the nature of short range growth inhibition in juvenile lobsters (*Homarus*). J. Exp. Mar. Biol. Ecol. 72:83-89.

Nixon, S., S. Granger, B. Buckley, M. Lamont, and B. Rowell, 2004. A one hundred and seventeen year coastal water temperature record from Woods Hole, Massachusetts. Estuaries 27(3):397-404.

NUSCO (Northeast Utilities Service Company). 1994

NUSCO (Northeast Utilities Service Company). 1999. Lobster studies. Pages 11-34 *In* Monitoring the marine environment of Long Island Sound at Millstone Nuclear Power Station. Waterford, Connecticut. Annual Report 1998.

O'Kelly, C. 2004. Immune and endocrine compromise in American lobsters. Proceedings of the Long Island Sound Lobster Health Symposium. October 4, 2004, University of NY Stony Brook.

Oviatt, C., 2004. The changing ecology of temperate coastal waters during a warming trend. Estuaries 27(6):895-904.

Palma, A. T., Steneck, R. S. and Wilson, C. 1999 Settlement-driven, multiscale demographic patterns of large benthic decapods in the Gulf of Maine. J. Exp. Mar. Biol. Ecol. 241:107-136.

Pauly, D. 1980. On the relationship between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons. Int. Explor. Mer. 39:175-192.

Penkoff , S.J. and Thurberg, F.P. 1982. Changes in oxygen consumption of the American lobster, *Homarus americanus*, during the molt cycle. Comp. Biochem. Physiol. 72(4): 621-622.

Pennington, M. 1986. Some statistical techniques for estimating abundance indices from trawl surveys. Fish. Bull. 84: 519-525.

Perkins, H. 1971. Egg loss during incubation from offshore northern lobsters (Decapoda, Homaridae). US Fish and Wildlife Service Fishery Bulletin 69:451-453.

Phillips, BF and Booth, JD Design, use, and effectiveness of collectors for catching the puerulus stage of spiny lobsters. Reviews in Fisheries Science. Vol. 2, no. 3, pp. 255-289. 1994.

Powers, J., Lopez, G., Cerrato, R. & A. Dove. 2004. Effects of thermal stress on Long Island Sound lobsters, *H. americanus.* Proceedings of the LIS Lobster Research Initiative Working Meeting. 3-4 May, 2004, University of CT Avery Point, Groton, CT.

Quinn, T. J. and R. B Deriso. 1999. Quantitative Fish Dynamics. Oxford University Press, New York, Oxford, 542 pages.

Rathbun, R. 1884. Notes on the decrease of lobsters. Transactions of The American Fish Cultural Association, Thirteenth Annual Meeting, New York.

Robinson, D.G. 1980. History of the lobster fishery on the eastern shore of Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 94:8-23.

Robohm, R., and A. Draxler. 2003. Effects of environmental stressors on disease susceptibility in lobsters: A controlled laboratory study. Proceedings of the Long Island Sound Lobster Research Initiative Working Meeting, January 16-18, 2003, University of CT Avery Point, Groton, CT.

Saila, S.B. and Flowers, J.M. 1968. Movements and behavior of berried female lobsters displaced from offshore areas to Narragansett Bay Rhode Island. J Cons. Int Explor. Mer. 31: 342- 351.

Saila, S.B., Flowers, J.M. and Hughes, J.T. 1969. Fecundity of the American lobster, *Homarus americanus.* Trans. Am. Fish. Soc., 98: 537-539.

Scheirer, K., Y. Chen, and C. Wilson, 2004, A Comparative Study of American Lobster Fishery Sea and Port Sampling Programs in Maine: 1998-2000, *Fisheries Research*, 68:343-350.

Sinoda, M. and T. Kabayasi. 1969. Studies on the fishery of zuwai crab in the Japan Sea. Efficiency of the toyama kago in capturing the benzi-zuwai crab. Bull. Jpn. Soc. Sci. Fish. 35:948-956.

Skud, B.E. (1966) The effect of fishing on size composition and sex ratio of offshore lobster stocks. FiskDir. Skr. Ser. HavUnders., 16:295-309.

Skud, B. E., and Perkins, H.C. 1969. Size composition, sex ratio, and size at maturity of offshore northern lobsters. U.S. Fish and Wildlife Service Special Scientific Report. 598: 1-10.

Sheehy, M.R.J., Shelton, P.M.J., Wickins, J.F., Belchier, M., and E. Gaten. 1996. Ageing the European lobster, *Homarus gammarus* by the lipofuscin in its eyestalk ganglia. Mar. Ecol Prog. Ser. 143:99-111.

Sheehy, M.R., Caputi, N., Christopher, C., and M. Belchier. 1998. Use of lipofuscin for resolving cohorts of western rock lobster (Panulirus cygnus) Can. J. Fish. Aquat. Sci. 55: 925-936.

Sheehy, M.R., Bannister, R.C.A., Wickens, J.F., and Shelton, P.M.J. 1999. New perspectives on the growth and longevity of the European lobster, *Homarus gammarus*. Ca. J. Fish. Aquat. Sci. 56:1904-1915.

Sheehy MRJ and Bannister RCA (2002) Year-class detection reveals climatic modulation of settlement strength in the European lobster, *Homarus gammarus*. Can. J. Fish. Aquat. Sci. 59:1132-1143

Simpson, D., Giannini C., Gottschall K., Howell P., and Pacileo D. 2003. Lobster Tagging Study. Job 4. In: Assessment and Monitoring of the American Lobster Resource and Fishery in Long Island Sound. NOAA / NMFS Fisheries Disaster Relief Grant NA16FW1238, Semi-Annual Performance Report , 79 p.

Skud, B. E. 1969. The effect of fishing on size composition and sex ratio of offshore lobster stocks. FiskDir. Skr. Ser HavUnders, 15 295-309.

Sparholt, H. 1990. Improved estimates of the natural mortality rates on nine commercially important fish species included in the North Sea multispecies VPA model. J. Cons. Int. Explor. Mer. 46: 211-223.

Steneck, R. S. 1989 . The ecological ontogeny of lobsters: in situ studies with demographic implications. *In* Proc. Lobster Life History Workshop, Edited by: I. Kornfield. Orono, Me. 1:30 - 33.

Stewart, J.E. 1980. Diseases In The biology and management of lobsters Vol 1. Physiology and Behavior. Edited by J.S. Cobb and B.F. Phillips. Pgs 301-344. Academic Press, New York.

Stewart, J.E. and Squires, H. J. 1968. Adverse conditions as inhibitors of ecdysis in the lobster, *Homarus americanus*. J. Fish Res. Board Can. 25: 1763 – 1774.

Squires, H. J. 1970. Lobster (*Homarus americanus*) fishery and ecology in Port au Port, Newfoundland, 1960-65. Proc.natn.Shellfish.Assn.:60:22-39

Templeman, W. 1936. Further contributions to mating in the American lobster. J. Biol. Board Can. 2:339–342.

Thomas, J.C. 1973. An analysis of the commercial lobster, *H. americanus* fishery along the coast of Maine, August 1966-December 1970. NOAA Tech Report, NMFS SSRF-667.

Tremblay, M.J. and M.D. Eagles. 1997. Molt timing and growth of the lobster *H. americanus* off Northeastern Cape Breton Island, Nova Scotia. J. Shellfish Research 16(2): 383-394.

Uzmann, J.R.; R.A. Cooper; and Pecci, K.J. 1977. Migration and dispersion of tagged lobsters, *Homarus americanus* on the New England continental shelf. NOAA Tech. Rep. NMFS SSRF-705.

Van Olst, J.C., Carlberg J.M. and Hughes, J.T. 1980. Aquaculture. *In* The Biology and Management of Lobsters Edited by J.S. Cobb and B.F. Phillips, Vol. 2, pp. 333 – 384. Academic Press, New York.

Vetter, E.F. 1988. Estimation of natural mortality in fish stocks: A review. Fishery Bulletin 86(l): 25-43.

Waddy, S.L. and Aiken, D.E. 1986. Multiple fertilization and consecutive spawning in large American lobsters, *Homarus americanus*. Canadian Journal of Fish and Aquatic Sciences. Vol. 43:2291-2294.

Waddy, S.L., Aiken, D.E. and deKleijn, D.P.V. 1995. Control of growth and reproduction In The biology of the lobster. Edited by J. Factor. Pgs 217-266. Academic Press.

Wahle, R.A. and Steneck, R.S. 1991. Recruitment habitats and nursery grounds of the American lobster, *Homarus americanus:* A demographic bottleneck? Mar. Ecol. Prog Ser. 69, 231 – 243.

Wahle, R.A. and Steneck, R.S. 1992. Habitat restrictions in early benthic life: experiments on habitat selection and in situ predation with the American lobster. J. Exp. Mar. Biol. Ecol. 157:91-114.

Wahle, R.A., Tully, O., and O' Donovan, V. 1996. Lipofuscin as an indicator of age in crustaceans: analysis of the pigment in the American lobster, *H. americanus*. Mar. Ecol. Prog. Ser. 138:117-123.

Wahle, R. and Incze, L. 1997. Pre- and post-settlement processes in recruitment of the American lobster. J. Exp. Mar. Biol. and Ecol. 217: 179 - 207.

Wahle, R.A., Incze, L.S. and Fogarty, M.J. 2003. First projections of American lobster fishery recruitment using a settlement index and variable growth. Bull. Mar. Sci. 74: 101-114.

Watson , Winsor H. 2004. Person communication.

Wilson C.W. M.Gosselin, D.A. Libby, H. Bray and G. Robinson (2004) Maine Landings Issues, Issue paper for consideration by the ASMFC Lobster Technical Committee. August 2004, 9 pp.

Wolff, T. 1978. Maximum size of lobsters (Homarus) (Decapoda, Nephropidae). Crustaceana. 34: 1 - 14.

Wood, W. 1635. "New England's Prospect." The Cotes, London. Edited by A.T. Vaughan and reprinted by University of Massachusetts Press, Amherst, Massachusetts, 1

Table 2.2.2.1. Molt increment-carapace length (CL) models for male and female lobsters in the GOM, GBK and SCCLIS stock areas fit to tagging data for each region based on assumptions described in footnotes.
Predicted increments a 50 ml CL are shown for comparison.

Region	Sex	Increment at 6 mm CL (mm)	CL at Inflection (κ, mm)	Maximum Mean Increment (mm)	Increment at 50 mm CL (mm)	SD (mm)	Number Tagging Observations	Minimum CL in Data (mm)	Maximum CL in Data (mm)	Intercept Parameter (α)	Slope Parameter (β)	Source of Tagging Data
GOM	Female	2	82	12	8	2.0	201	25	80	1.2288	0.1285	ME DMR
GOM	Male	2	95	14	8	2.2	289	25	79	1.2236	0.1294	ME DMR
GBK	Female	2	75	14	10	1.7	106	68	140	0.9657	0.1724	Cooper and Uzzman
GBK	Male	2	87	18	11	2.1	63	63	115	0.8319	0.1947	Cooper and Uzzman
SNE	Female	2	64	9	7	2.3	293	30	94	1.3006	0.1166	RI Inshore and Offshore (T. Angel & K. Castro)
SNE	Male	2	74	11	8	2.3	482	53	98	1.1775	0.1371	RI Inshore and Offshore (T. Angel & K. Castro)

Notes:

1) Inflection point for females in all areas set at CL where 10% are sexually mature (a rough estimate of the size at onset of sex maturity).
2) Inflection point for males in all areas set at the inflection point for females * P, where P = 1.16 was estimated.
3) Maximum mean increment estimated for females in all stocks.
4) Maximum mean Increment for males = maximum female increment * J, where J = 1.26 was estimated.
5) Increment at 6 mm CL set at 2 mm based on Massachusetts hatchery data.
6) Tag data for lobsters at liberty longer than 1 year were omitted.
7) "Outliers" (including potential double molters) were excluded if the absolute value of standardized residuals from robust linear regression lines was > 6.
8 The standard deviation (SD) is for residuals around the assumed molt increment-caprapace length model.
9) By agreement, the average standard deviation (2.1 mm) will be used in modeling growth for both sexes in all areas.
10) Maximum mean increments or females (at large sizes), a single offset parameter for male inflection points, and a single offset parameter for male maximum mean increments were estimated by minimizing sums of squares (5 parameters estimated).

Table 2.7.1. Prevalence of shell disease in lobsters observed in commercial trap catch and research trawl catch. Percentages are annual for each year and statistical area.
Area 611 percentages include data recorded from research trap catches in the area surrounding Millstone Power Station (DRS 2005).

	CT/NY	RI		MA			NH	ME
Area:	**611**	**616**	**539**	**538**	**521**	**514**	**513**	**511-513**
Year								
1992	0.5%							
1993	0.5%							
1994	0.8%							
1995	1.1%							
1996	1.1%	0.0%	0.3%					
1997	1.0%	0.0%	4.3%					
1998	1.5%	0.2%	19.0%	23.8%				
1999	5.0%	0.8%	20.3%	20.5%				
2000	6.6%	1.7%	21.8%	9.4%	0.0%	3.7%		
2001	6.9%	2.2%	22.6%	11.6%	2.2%	6.5%	0.03%	
2002	9.8%	3.1%	30.4%	25.9%	0.4%	5.5%	0.2%	
2003	12.6%	3.1%	24.9%	29.0%	0.9%	3.9%	0.3%	0.04%
2004	11.0%	2.6%	27.9%	29.0%	0.9%	3.9%	0.2%	0.04%

Table 3.2. Number of commercial lobster licenses issued by state, 1981 - 2004.

Year	CT	MA	ME	NH	NJ	NY	RI	Total
1981	659	2,118	8,548	302	*NA*	393	*NA*	12,020
1982	678	2,052	8,891	323	*NA*	380	*NA*	12,324
1983	649	2,169	8,895	337	*NA*	446	*NA*	12,496
1984	642	2,367	8,730	307	*NA*	521	*NA*	12,567
1985	693	2,417	7,879	302	*NA*	556	*NA*	11,847
1986	623	2,514	6,875	332	*NA*	559	*NA*	10,903
1987	578	2,641	6,730	313	*NA*	551	*NA*	10,813
1988	612	2,627	6,804	318	*NA*	959	*NA*	11,320
1989	595	2,556	7,215	327	*NA*	945	*NA*	11,638
1990	606	2,465	6,706	299	*NA*	994	1,177	12,247
1991	611	2,399	6,940	286	*NA*	1,067	1,270	12,573
1992	547	2,357	6,162	267	*NA*	1,171	1,394	11,898
1993	544	2,338	6,176	263	*NA*	1,211	1,007	11,539
1994	499	2,260	6,196	287	*NA*	1,265	980	11,487
1995	513	2,205	7,449	311	*NA*	995	1,317	12,790
1996	445	2,149	7,027	310	*NA*	932	1,075	11,938
1997	427	2,145	7,101	303	*NA*	888	1,089	11,953
1998	441	2,099	6,887	311	*NA*	761	1,597	12,096
1999	419	2,099	6,753	297	*NA*	746	1,087	11,401
2000	389	2,075	6,880	309	87	657	1,487	11,884
2001	352	2,070	6,838	325	95	600	1,512	11,792
2002	344	2,086	6,792	339	109	554	1,398	11,622
2003	286	2,057	6,812	349	109	506	1,403	11,522

Table 3.2.1.1. Gulf of Maine landings in metric tons by state from 1981 to 2003.
Other= New Jersey, Delaware, Maryland, and Virginia.

Year	MA	ME	NH	Other	RI	Total
1981	4,152	10,266	360			14,777
1982	3,992	10,310	366			14,669
1983	4,638	9,836	594			15,069
1984	4,219	8,866	712			13,797
1985	4,890	9,129	539			14,558
1986	4,454	8,935	427			13,816
1987	4,425	8,957	570			13,952
1988	4,328	9,861	508			14,696
1989	5,459	10,600	649			16,708
1990	5,761	12,732	752			19,244
1991	5,420	13,966	817		13	20,215
1992	4,874	12,170	694			17,738
1993	4,554	13,574	673		1	18,802
1994	5,392	17,667	596	215		23,869
1995	5,375	16,877	710	39		23,001
1996	5,127	16,367	628	33		22,155
1997	4,750	21,329	544	103		26,726
1998	3,973	21,336	460	68		25,836
1999	5,115	24,265	525	134		30,038
2000	5,208	25,953	658	26		31,845
2001	3,664	22,053	780	21		26,517
2002	4,158	28,860	781	6		33,806
2003	3,448	24,986	754	10		29,198
1981 to 2003 mean	4,668	15,604	613	65	7	20,915
2001 to 2003 mean	3,757	25,300	772	12	N/A	29,840
3 yr. % change from mean	-19.53%	62.13%	25.93%	-81.42%	N/A	42.68%

Table 3.2.1.2. Number of traps reported fished by state in the Gulf of Maine stock unit*.

Year	Maine	Massachusetts	New Hampshire	Total
1982	2,143,000	247,415	*NA*	2,390,415
1983	2,340,000	259,642	*NA*	2,599,642
1984	2,175,000	275,165	*NA*	2,450,165
1985	1,766,000	313,758	*NA*	2,079,758
1986	1,595,000	331,713	*NA*	1,926,713
1987	1,909,000	356,169	*NA*	2,265,169
1988	2,053,000	356,689	*NA*	2,409,689
1989	2,001,000	351,584	44,357	2,396,941
1990	2,130,000	378,703	37,074	2,545,777
1991	2,015,000	399,010	30,701	2,444,711
1992	2,012,000	388,415	34,122	2,434,537
1993	1,806,000	370,641	45,937	2,222,578
1994	2,408,000	373,641	39,718	2,821,359
1995	2,605,000	377,305	43,629	3,025,934
1996	2,470,248	389,492	48,621	2,908,361
1997	2,593,271	383,506	60,045	3,036,822
1998	2,820,648	389,933	47,650	3,258,231
1999	3,038,604	379,970	43,203	3,461,777
2000	2,773,361	384,581	44,629	3,202,571
2001	2,959,969	375,807	52,895	3,388,671
2002	3,080,844	394,820	39,845	3,515,509
2003	3,189,471	383,055	50,540	3,623,066

* New Hampshire data is the estimated number of commercial lobster traps fished in state waters.

Table 3.2.2.1 Georges Bank landings in metric tons by state from 1981 to 2003.
Other= New Hampshire, New Jersey, Delaware, Maryland, and Virginia.

Year	CT	MA	ME	NH	Other	NY	RI	Total
1981		596				25	522	1,143
1982		590				1	682	1,273
1983		591			5		852	1,447
1984		748					747	1,496
1985		746		3			740	1,489
1986		624	3				616	1,243
1987		828					488	1,316
1988		931				95	391	1,417
1989		964					362	1,326
1990		1,026				7	397	1,430
1991		936					644	1,580
1992		1,131					572	1,703
1993		1,124		95			326	1,545
1994		1,013		153	97		180	1,443
1995		925		122	19		149	1,215
1996	1	864		112	10		147	1,134
1997	1	937		97	34		161	1,229
1998	1	938		82	34		156	1,212
1999		1,112		102	31		227	1,472
2000	4	871		117	30		192	1,214
2001	4	1,140		139	15		124	1,422
2002	2	1,315		139	6		107	1,568
2003	1	1,188		135	6		96	1,427
1981 to 2003 mean	2	919	3	108	26	32	386	1,380
2001 to 2003 mean	2	1,214	N/A	138	9	N/A	109	1,472
3 yr. % change from mean	25.70%	32.12%	N/A	27.57%	-65.14%	N/A	-71.79%	6.68%

Table 3.2.2.2. Number of traps reported fished by state in the Georges Bank Stock Unit.
Other= New Hampshire, New York, Connecticut, New Jersey, Delaware, Maryland, and Virginia.

	Rhode Island	**Massachusetts**	**Other**	**Total**
1982	*NA*	27,560		27,560
1983	*NA*	28,922		28,922
1984	*NA*	30,651		30,651
1985	*NA*	34,950		34,950
1986	*NA*	36,950		36,950
1987	*NA*	39,674		39,674
1988	*NA*	39,732		39,732
1989	*NA*	39,163		39,163
1990	*NA*	35,891		35,891
1991	*NA*	36,784		36,784
1992	*NA*	38,745		38,745
1993	*NA*	43,041	*NA*	43,041
1994	*NA*	47,894	*NA*	47,894
1995	*NA*	44,480	*NA*	44,480
1996	*NA*	42,008	*NA*	42,008
1997	*NA*	40,974	*NA*	40,974
1998	*NA*	45,327	*NA*	45,327
1999	60,060	47,941	*NA*	108,001
2000	55,170	41,464	*NA*	96,634
2001	59,199	40,899	*NA*	100,098
2002	53,050	47,387	*NA*	100,437
2003	54,285	42,834	*NA*	97,119

Table 3.2.3.1. Southern New England landings in metric tons by state from 1981 to 2003.
Other= New Jersey, Delaware, Maryland, and Virginia.

Year	CT	MA	Other	NY	RI	Total
1981	366	432	324	379	327	1,828
1982	399	527	457	508	757	2,649
1983	750	608	414	548	1,468	3,788
1984	815	678	530	593	1,638	4,254
1985	626	579	600	563	1,592	3,960
1986	569	590	627	643	1,955	4,383
1987	713	578	722	520	1,924	4,457
1988	872	628	771	713	1,768	4,752
1989	942	674	997	1,064	2,263	5,940
1990	1,200	909	1,066	1,549	2,895	7,620
1991	1,213	934	799	1,419	2,721	7,086
1992	1,149	813	573	1,203	2,496	6,233
1993	987	868	445	1,210	2,499	6,008
1994	974	979	254	1,794	2,757	6,757
1995	1,153	980	637	3,018	2,283	8,070
1996	1,310	976	321	4,268	2,255	9,130
1997	1,572	1,168	818	4,027	2,469	10,054
1998	1,684	1,098	716	3,867	2,392	9,757
1999	1,177	989	650	3,203	3,473	9,492
2000	629	739	541	1,357	2,941	6,207
2001	600	748	255	931	1,896	4,430
2002	482	750	117	653	1,633	3,636
2003	303	454	92	430	1,474	2,754
1981 to 2003 mean	891	770	553	1,498	2,082	5,793
2001 to 2003 mean	462	651	155	672	1,668	3,607
3 yr. % change from mean	-48.18%	-15.43%	-72.02%	-55.18%	-19.88%	-37.75%

Table 3.2.3.2. Number of traps reported fished by state in the Southern New England Stock Unit

	CT	MA	NY	RI	Total
1981	15,815	41,395	48,295	46,952	152,457
1982	14,831	44,123	43,977	42,055	144,986
1983	19,998	46,303	59,808	195,900	322,009
1984	46,994	49,072	77,599	227,000	400,665
1985	48,025	55,954	88,332	211,625	403,936
1986	50,061	59,156	77,429	199,500	386,146
1987	54,524	63,518	76,729	215,925	410,696
1988	61,646	63,610	101,790	209,500	436,546
1989	60,842	62,700	143,320	183,450	450,312
1990	78,122	53,768	137,504	217,150	486,544
1991	80,138	59,922	155,276	243,900	539,236
1992	82,433	58,406	187,661	300,689	629,189
1993	89,647	62,615	237,117	*NA*	389,379
1994	88,345	71,472	269,419	*NA*	429,236
1995	93,467	71,269	252,581	*NA*	417,317
1996	104,123	71,830	314,297	*NA*	490,250
1997	107,689	76,717	335,860	*NA*	520,266
1998	127,998	83,166	370,437	*NA*	581,601
1999	132,450	83,394	380,235	241,351	837,429
2000	107,656	68,162	244,812	221,458	642,088
2001	107,485	66,096	250,243	194,699	618,523
2002	112,222	78,715	180,189	173,297	544,423
2003	100,019	63,534	124,040	153,729	441,322

Table 5.1.1.2.1. Relative sampling intensity (# lengths/ landings) for the Gulf of Maine stock by Statistical Reporting Area and Calendar Year
(white < median, light gray ≥ median and ≤ 75th percentile, dark gray > 75th percentile).

	464	465	511	512	513	514	515
1980							
1981			0.0001	0.0002	0.0001	0.0012	0.0000
1982	0.0000		0.0001	0.0002	0.0001	0.0012	0.0000
1983	0.0023		0.0002	0.0001	0.0003	0.0012	0.0000
1984	0.0015	0.0000	0.0002	0.0001	0.0007	0.0015	0.0000
1985	0.0027	0.0000	0.0005	0.0002	0.0002	0.0029	0.0014
1986	0.0000		0.0003	0.0002	0.0004	0.0034	0.0000
1987	0.0016		0.0007	0.0002	0.0004	0.0033	0.0000
1988	0.0000		0.0002	0.0003	0.0004	0.0030	0.0000
1989	0.0000		0.0006	0.0002	0.0005	0.0030	0.0000
1990			0.0000	0.0003	0.0003	0.0031	0.0000
1991			0.0003	0.0002	0.0007	0.0032	0.0001
1992			0.0002	0.0002	0.0004	0.0031	0.0000
1993	0.0064	0.0240	0.0005	0.0002	0.0003	0.0028	0.0044
1994	0.0109	1.0267	0.0001	0.0001	0.0004	0.0024	0.0256
1995	0.0000	0.0287	0.0003	0.0001	0.0005	0.0030	0.0028
1996	0.0129	0.0000	0.0003	0.0002	0.0005	0.0029	0.0025
1997	0.0018	0.0000	0.0002	0.0002	0.0003	0.0059	0.0000
1998	0.0000	0.0000	0.0009	0.0003	0.0005	0.0035	0.0000
1999	0.0041	0.0000	0.0007	0.0004	0.0009	0.0024	0.0000
2000	0.0000	0.0000	0.0020	0.0014	0.0030	0.0028	0.0002
2001	0.0000	0.0000	0.0019	0.0019	0.0044	0.0033	0.0000
2002	0.0000	0.0000	0.0011	0.0020	0.0030	0.0034	0.0000
2003	0.0000	0.0000	0.0025	0.0024	0.0037	0.0044	0.0000

= low intensity
= moderate intensity
= high intensity

Table 5.1.1.2.2. Relative sampling intensity (# lengths/ landings) for the Georges Bank stock by Statistical Reporting Area and Calendar Year
(white < median, light gray ≥ median and ≤ 75th percentile, dark gray > 75th percentile).

	521	522	524	525	526	561	562
1980							
1981	0.0066	0.0000	0.0000	0.0000	0.0000		
1982	0.0108	0.0000	0.0000	0.0000	0.0000		
1983	0.0159	0.0000	0.0014	0.0004	0.0000		
1984	0.0090	0.0058	0.0028	0.0015	0.0001		
1985	0.0105	0.0016		0.0008	0.0007	0.0000	0.0000
1986	0.0084	0.0000		0.0007	0.0008	0.0000	0.0000
1987	0.0099	0.0000		0.0019	0.0008	0.0000	0.0000
1988	0.0097	0.0000		0.0015	0.0010	0.0018	0.0000
1989	0.0079	0.0000		0.0010	0.0006	0.0000	0.0004
1990	0.0064	0.0000		0.0003	0.0013	0.0000	0.0108
1991	0.0046	0.0000		0.0007	0.0019	0.0000	0.0000
1992	0.0065	0.0000		0.0006	0.0023	0.0000	0.0024
1993	0.0050	0.0000		0.0005	0.0017	0.0000	0.0005
1994	0.0049	0.0000		0.0010	0.0000	0.0000	0.0000
1995	0.0047	0.0021		0.0018	0.0000	0.0000	0.0000
1996	0.0052	0.0001		0.0059	0.0004	0.0000	0.0038
1997	0.0045	0.0003		0.0000	0.0000	0.0000	0.0000
1998	0.0044	0.0003		0.0000	0.0051	0.0000	0.0000
1999	0.0037	0.0167		0.0008	0.0011	0.0329	0.0168
2000	0.0047	0.0003		0.0000	0.0000	0.0000	0.0000
2001	0.0051	0.0000		0.0000	0.0000	0.0000	0.0000
2002	0.0046	0.0000		0.0004	0.0000	0.0000	0.0001
2003	0.0052	0.0000		0.0001	0.0004	0.0000	0.0002

= low intensity
= moderate intensity
= high intensity

Table 5.1.1.2.3. Relative sampling intensity (# lengths/ landings) for the Southern New England stock by Statistical Reporting Area and Calendar Year (white < median, light gray ≥ median and ≤ 75th percentile, dark gray > 75th percentile).

	537	538	539	611	612	613	614	615	616	621	622	623	625	626
1980				0.0000		0.0000							0.0000	
1981	0.0000	0.0038	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000	0.0000	0.0000		0.0000	0.0000
1982	0.0000	0.0021	0.0000	0.0021	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1983	0.0006	0.0046	0.0000	0.0053	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000
1984	0.0004	0.0043	0.0000	0.0038	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000
1985	0.0004	0.0048	0.0000	0.0097	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000
1986	0.0004	0.0101	0.0000	0.0058	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000		0.0000	0.0009
1987	0.0004	0.0090	0.0000	0.0057	0.0000	0.0000	0.0000		0.0016	0.0000	0.0000	0.0478	0.0000	0.0000
1988	0.0004	0.0111	0.0000	0.0055	0.0000	0.0000	0.0000		0.0013	0.0000	0.0000		0.0000	0.0000
1989	0.0002	0.0089	0.0000	0.0039	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000		0.0000	0.0000
1990	0.0008	0.0193	0.0005	0.0030	0.0000	0.0000	0.0000	0.0000	0.0068	0.0000	0.0000	0.0000	0.0000	0.0000
1991	0.0019	0.0175	0.0081	0.0020	0.0000	0.0000	0.0000	0.0000	0.0390	0.0000	0.0000	0.0000	0.0000	0.0000
1992	0.0018	0.0238	0.0045	0.0023	0.0000	0.0000	0.0000	0.0000	0.0263	0.0000	0.0000	0.0000	0.0000	0.0000
1993	0.0001	0.0282	0.0048	0.0052	0.0000	0.0002	0.0000	0.0000	0.0340	0.0000	0.0000	0.0000	0.0000	0.0000
1994	0.0000	0.0085	0.0033	0.0047	0.0011	0.0008	0.0000	0.0000	0.0455	0.0000	0.0000	0.0010	0.0000	0.0000
1995	0.0001	0.0072	0.0055	0.0007	0.0002	0.0004	0.0000	0.0000	0.0825	0.0000	0.0000	0.0000	0.0000	0.0004
1996	0.0000	0.0072	0.0062	0.0008	0.0000	0.0000	0.0000	0.0017	0.1408	0.0000	0.0000	0.0000	0.0000	0.0000
1997	0.0003	0.0056	0.0042	0.0006	0.0000	0.0000	0.0000	0.0000	0.1125	0.0000	0.0000	0.0000	0.0000	0.0000
1998	0.0009	0.0078	0.0044	0.0011	0.0000	0.0000	0.0000	0.0052	0.1056	0.0000	0.0000	0.0000	0.0000	0.0000
1999	0.0002	0.0101	0.0034	0.0032	0.0002	0.0000	0.0000	0.0000	0.0790	0.0000	0.0000	0.0000	0.0000	0.0000
2000	0.0002	0.0287	0.0032	0.0080	0.0003	0.0000	0.0000	0.0000	0.1011	0.0000	0.0000	0.0000	0.0000	0.0000
2001	0.0000	0.0199	0.0041	0.0165	0.0001	0.0000	0.0000	0.0000	0.1163	0.0000	0.0000	0.0000	0.0000	0.0000
2002	0.0001	0.0124	0.0042	0.0161	0.0034	0.0000	0.0000	0.0000	0.1493	0.0000	0.0000	0.0000	0.0000	0.0000
2003	0.0004	0.0256	0.0054	0.0114	0.0038	0.0000	0.0000	0.0000	0.1963	0.0000	0.0000	0.0000	0.0000	0.0000

= low intensity

= moderate intensity

= high intensity

Table 5.3.1.1. Sampling seasons and strata used in fishery-independent surveys. The years given with each survey are those examined during this assessment process.

Survey (yrs)	Seasons	Strata (N)	Annual Samples
NMFS (1982-present)	Spring (March-April) Fall (Sept-Oct)	Statistical Area (44) Depth (7)	320
Maine (2000-present)	Spring (May) Fall (October-November)	Region (5) Depth (4)	92-115
Massachusetts (1982-present)	Spring (May) Fall (September)	Region (5) Depth (6)	163-199
Rhode Island (1984-present)	Spring (May) Fall (September)	Region (3) Depth (?)	60-139
Connecticut (1984-present)	Spring (Apr-Jun) Fall (Sept-Oct)	Depth (4) Bottom Type (3)	102-200
New Jersey (1988-present)	Spring (April and June) Fall (October)	Region (5) Depth (3)	186

Table 5.3.4.1. Densities (individuals m^{-2}) of newly settled lobster in mid-coast Maine and Rhode Island for the period of 1989 through 2004.
Settlement data were provided by Rick Wahle, Bigelow Laboratory for Ocean Sciences, W. Boothbay Harbor, ME.

Year	Mid-coast, ME	Rhode Is.	SE-Midcoast ME	SE RI
1989	1.64		0.38	
1990	0.79	1.26	0.22	0.15
1991	1.53	1.50	0.32	0.07
1992	1.31	0.63	0.33	0.19
1993	0.44	0.51	0.17	0.15
1994	1.59	1.23	0.40	0.34
1995	0.66	0.33	0.21	0.10
1996	0.47	0.15	0.25	0.10
1997	0.46	0.99	0.28	0.20
1998	0.13	0.57	0.08	0.19
1999	0.65	0.93	0.31	0.23
2000	0.13	0.34	0.06	0.08
2001	2.08	0.75	0.64	0.29
2002	1.38	0.26	0.41	0.09
2003	1.75	0.79	0.61	0.2
2004	1.75	0.42	0.63	0.14

Median	1.05	0.63
25th Quartile	0.4675	0.38
75th Quartile	1.6025	0.96

Table 6.2.1 Stock region and survey area definitions used in CSM models for lobster, with survey strata used to calculate abundance indices from bottom trawl survey data.

Stock Region or Survey Area	Strata
GOM-NEFSC	01260-01300; 01360-01400; 03590 03610; 03650 03660 (NEFSC survey strata)
GOM-MA	09250 and 09360 (MA survey strata)
GBK	01090-01250 (NEFSC survey strata)
SNE-NEFSC	01010-01080; 01610-01760; 03450-03550 (NEFSC survey strata)
SNE-CT (same as SCCLIS-CT)	See CTDEP (2004, p. 63 and Fig. 2.1)
SNE-RI (same as SCCLIS-RI)	1-11 (Rhode Island survey strata)
GBS (obsolete)	01010-01040; 01060-01250; 01610-01760 (NEFSC survey strata)
SNE-NEFSC (obsolete)	01050; 03450-03550 (NEFSC survey strata)

Table 6.2.2. Fall abundance index data (stratified delta mean number per tow) for recruit and post-recruit lobsters used in CSM models.

The indices based on data from fall bottom trawl surveys carried out by the Northeast Fisheries Science Center (NEFSC), Massachusetts (MA), Connecticut (CT), and Rhode Island (RI).

	Georges Bank		Gulf of Maine - NEFSC		Gulf of Maine - MA		SNE - CT		SNE - RI		SNE - NEFSC	
Year	**Recruits**	**Post-recruits**	**Recruits**	**Post-recruits**	**Recruits**	**Post-recruits**	**Recruits**	**Post-recruits**	**Recruits**	**Post-recruits**	**Recruits**	**Post-recruits**
Females												
1982	0.1219	0.5442	0.1313	0.0727	2.4261	1.8400						
1983	0.1193	0.4537	0.2722	0.3756	4.8781	1.7160						
1984	0.1701	0.3910	0.1145	0.2211	2.9880	1.4560	3.4139	2.1634	0.3367	0.2116	0.1047	0.2997
1985	0.1391	0.3423	0.3123	0.6463	6.2190	2.2660	1.7266	0.7193	0.3776	0.0153	0.1576	0.1540
1986	0.2055	0.5132	0.3935	0.3507	2.2018	0.5940	2.8009	1.5794	0.2494	0.0368	0.1098	0.0853
1987	0.1694	0.3212	0.1063	0.2475	0.5672	0.3670	3.2686	1.5896	0.9626	0.3234	0.0295	0.2125
1988	0.1216	0.5459	0.4258	0.3089	1.5706	0.2870	1.8456	1.0280	0.5803	0.2193	0.1120	0.1484
1989	0.0917	0.4947	0.3726	0.3600	2.1781	0.5670	1.4968	0.4341	0.6997	0.2851	0.2195	0.1339
1990	0.1853	0.4005	0.4749	0.3486	9.0423	2.2140	2.9346	1.2936	0.6729	0.1640	0.1529	0.3123
1991	0.1132	0.6766	0.5334	0.4062	4.1979	0.5930	3.4608	1.2762	0.4559	0.1928	0.0702	0.2011
1992	0.2348	0.4884	0.2094	0.1860	3.0880	0.7540	3.1583	1.2873	0.8307	0.2508	0.1534	0.2765
1993	0.1067	0.5179	0.2002	0.3959	1.5012	0.2370	5.0434	1.1574	1.0692	0.2098	0.0615	0.1796
1994	0.0407	0.5031	0.7902	0.7729	7.1235	1.3440	3.9914	1.7682	0.5620	0.3371	0.0089	0.0704
1995	0.0901	0.4993	0.3525	0.6563	6.0704	0.7890	3.6833	0.9068	0.8507	0.1116	0.1298	0.1425
1996	0.0677	0.4357	1.0749	1.0305	6.3208	0.7530	4.1995	1.8828	1.4334	0.2087	0.4054	0.3842
1997	0.1580	0.5168	0.6943	0.7041	3.3165	0.1910	10.1690	2.5986	1.1209	0.3182	0.3003	0.2144
1998	0.1162	0.5617	0.7508	0.6142	4.7754	0.4280	3.9298	0.8102	0.3916	0.0821	0.1574	0.2306
1999	0.0696	0.6644	0.9894	1.5797	3.8790	0.6160	4.1473	0.6411	0.2686	0.1000	0.0628	0.1176
2000	0.1424	0.5120	0.6793	0.8486	4.9864	1.0210	2.8770	0.7661	0.3676	0.1057	0.1812	0.1842
2001	0.1086	0.9447	0.4202	0.7149	0.8218	0.3680	2.5275	0.5282	0.5075	0.1428	0.0812	0.2400
2002	0.1629	1.2752	0.4337	1.9344	3.4441	0.5900	0.6436	0.0966	0.0276	0.0187	0.0455	0.0876
2003	0.1408	0.6345	0.0704	1.0959	0.2960	0.2360	1.0838	0.0510	0.2165	0.1716	0.0444	0.0966
2004	0.0481	0.8286	0.6746	0.9587	0.5020	0.1410	1.1458	0.1599	0.2573	0.1304	0.0338	0.1392

Table 6.2.2 (cont.)

Year	Georges Bank		Gulf of Maine - NEFSC		Gulf of Maine - MA		SNE - CT		SNE - RI		SNE - NEFSC	
	Recruits	Post-recruits	Recruits	Post-recruits	Recruits	Post-recruits	Recruits	Post-recruits	Recruits	Post-recruits	Recruits	Post-recruits
Males												
1982	0.1278	0.3578	0.0779	0.1247	2.2779	1.5840						
1983	0.1982	0.3647	0.2652	0.3351	4.8846	2.0460						
1984	0.1448	0.3530	0.0525	0.1066	3.6067	2.4220	4.4724	1.9108	1.4139	0.1597	0.2426	0.1534
1985	0.1101	0.2716	0.3284	0.3821	6.5283	2.2210	2.6247	0.7649	0.8228	0.1941	0.1973	0.1667
1986	0.3375	0.3083	0.3448	0.5028	2.8290	1.9090	4.8640	3.2857	1.2255	0.2366	0.1821	0.0875
1987	0.3496	0.2635	0.1513	0.3588	0.7859	0.2450	5.4636	1.3626	1.2448	0.1900	0.0749	0.1704
1988	0.1344	0.5564	0.2893	0.1808	1.7403	0.6690	3.1940	1.2476	1.3930	0.2242	0.1187	0.0886
1989	0.2336	0.4954	0.5354	0.3594	2.8152	0.9850	4.4164	1.3138	2.7099	0.4558	0.2756	0.1787
1990	0.1578	0.3042	0.6417	0.5454	10.3328	2.4570	6.4051	2.4042	1.3595	0.4544	0.1700	0.1568
1991	0.1545	0.2749	0.3439	0.5820	5.0157	2.6640	10.0453	1.5602	2.1254	0.2846	0.1438	0.2116
1992	0.2160	0.2353	0.3177	0.2361	3.2004	1.0760	10.7156	3.6358	1.4001	0.2926	0.2317	0.2368
1993	0.1178	0.1771	0.2549	0.3902	2.1438	0.4580	11.6317	1.4799	2.9139	0.4874	0.1610	0.1264
1994	0.1581	0.2575	0.9040	0.8571	8.0703	1.9770	10.4722	2.9217	3.1464	0.7112	0.0625	0.0423
1995	0.1015	0.1353	0.6237	1.0672	6.2732	1.6560	9.5443	2.9769	3.1438	0.3582	0.1549	0.1241
1996	0.0963	0.2234	1.2598	1.0284	6.9266	1.5440	7.5815	1.2573	4.5909	0.7126	0.5470	0.4013
1997	0.2562	0.3626	0.5781	0.5015	3.7135	1.2450	21.3437	3.7992	5.4356	1.0816	0.4678	0.2200
1998	0.1853	0.3045	0.5953	0.8130	3.5216	0.4900	10.4382	1.6546	2.5983	0.2102	0.3412	0.2079
1999	0.1344	0.4337	0.8160	0.7735	5.7539	1.2880	13.5572	2.4189	1.4205	0.3122	0.2232	0.1150
2000	0.2478	0.2905	0.9746	0.5972	6.1497	1.1630	7.5202	1.1868	0.8774	0.2625	0.2452	0.0998
2001	0.1798	0.2583	0.3921	0.3825	1.0177	0.3880	7.0463	0.4875	1.9639	0.1229	0.1412	0.1221
2002	0.2884	0.5784	0.4458	0.7595	3.7377	0.5730	2.4398	0.1432	0.6905	0.0000	0.0652	0.0531
2003	0.2415	0.1900	0.1638	0.5437	0.4484	0.2690	2.3076	0.1614	0.7384	0.1414	0.0731	0.0700
2004	0.1048	0.1705	0.7489	1.2770	1.0029	0.1380	2.5075	0.3721	0.8632	0.0617	0.0639	0.0926

Table 6.2.3. Minimum legal size (CL, mm) used in calculation of recruit abundance indices for lobster in CSM runs.

Year	GBK	GOM	SNE-NEFSC	SNE-RI	SNE-CT
1982	81	81			
1983	81	81			
1984	81	81	81	81	81
1985	81	81	81	81	81
1986	81	81	81	81	81
1987	81	81	81	81	81
1988	82	82	82	82	81
1989	83	83	83	83	82
1990	83	83	83	83	82
1991	83	83	83	83	83
1992	83	83	83	83	83
1993	83	83	83	83	83
1994	83	83	83	83	83
1995	83	83	83	83	83
1996	83	83	83	83	83
1997	83	83	83	83	83
1998	83	83	83	83	83
1999	83	83	83	83	83
2000	83	83	83	83	83
2001	83	83	83	83	83
2002	84	83	84	84	83
2003	85	83	85	85	83
2004	86	83	86	86	83

Table 6.2.4. Landings data (millions of lobsters) used in CSM.

The titles reflect the stock area of the landings and the associated fisheries independent survey Data for the 2003 survey year are imprecise and based on reported landings during October-December 2003 and the average proportion of landings during October-December.

	Georges Bank-NEFSC		Gulf of Maine - NEFSC		Gulf of Maine - MA		SNE - CT		SNE - RI		SNE - NEFSC	
Survey Year	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**	**Females**	**Males**
1982	0.9013	1.024169	9.14337	9.152954	4.16263	3.73964						
1983	0.8522	0.7510	8.0578	8.4417	4.2387	4.0913						
1984	0.9234	1.0151	9.2827	8.4339	4.3320	4.0857	1.3642	0.6833	0.6527	0.3879	2.3790	2.4059
1985	0.9003	0.9165	8.6550	8.4622	4.3650	4.2403	1.2135	0.5860	0.7016	0.2448	2.7806	2.5012
1986	0.9013	0.9319	7.9839	8.0165	4.0050	4.2312	1.4505	0.7541	0.6906	0.3819	2.8352	2.5972
1987	0.9452	1.1318	8.3446	9.0324	4.0355	4.3553	1.5001	0.9984	0.6110	0.2983	2.8538	2.4439
1988	0.8250	0.9442	9.8476	9.5477	4.6054	4.7910	1.8123	1.1950	0.8779	0.4197	3.5625	3.0971
1989	0.9478	1.0231	11.2634	10.3832	5.6010	5.6365	2.2115	1.1778	1.0490	0.4297	4.0063	3.9373
1990	1.0344	1.3247	12.2654	13.3453	4.8617	5.1924	2.8255	0.8432	0.9356	0.7106	4.3346	4.0317
1991	0.9594	1.3538	11.5367	11.7246	3.8115	4.3604	1.8048	1.4261	0.7552	0.5768	3.1530	2.9650
1992	1.1638	1.3771	11.2429	11.5861	3.9929	4.3342	2.2174	1.4263	0.7214	0.6448	3.2228	2.9531
1993	1.1537	1.3068	13.5948	15.2895	4.3226	4.2309	2.2407	1.8252	1.0181	0.7765	2.9812	2.6286
1994	1.0083	0.7879	16.1457	15.5115	4.5088	4.9897	3.9194	2.8573	0.9209	0.8813	3.0816	2.9240
1995	1.0515	0.7679	13.8265	14.0246	4.5622	4.0293	6.1117	2.6552	0.9423	0.8024	2.7225	2.4538
1996	1.0967	0.7697	16.6467	18.0043	4.6032	4.2140	6.1438	3.5864	1.0919	0.7645	3.5892	3.0263
1997	1.0770	0.8300	18.5811	19.3311	4.2402	3.3527	7.1760	2.4733	1.1139	0.7734	3.7048	3.0801
1998	1.0700	0.8488	20.9232	18.0764	4.0851	3.9450	5.0754	3.0296	1.2584	1.1390	3.8122	3.3189
1999	0.9143	1.0171	24.0706	22.4332	5.3405	4.1556	1.7054	2.3553	1.1768	1.1864	3.1875	3.2577
2000	0.9264	1.0309	19.1584	20.0115	3.9911	3.1453	1.4975	1.2279	0.8839	0.8163	2.2944	2.0110
2001	0.9842	1.1493	22.0389	23.4471	4.1215	2.9441	1.1096	1.0564	0.6344	0.6434	1.9732	1.7789
2002	1.0340	0.8767	19.6970	20.9606	3.7596	2.3842	0.5111	0.6603	0.5488	0.5781	1.2970	1.4813
2003	1.0112	0.8778	26.4116	29.2058	3.4426	2.5822	0.5313	0.5828	0.7985	0.5019	1.3156	1.4236

Table 6.2.5. Assignment of statistical areas for landing data to stock regions and survey areas used in modeling.

Stock region-survey area	Statistical Reporting Areas for Landings
GBK	521, 522, 523, 524, 525, 526, 541, 542, 543, 561, 562
GOM-MA	514
GOM-NEFSC	464, 465, 511, 512, 513, 515
SNE-CT	611
SNE-NEFSC	533, 534, 537, 538, 612, 613, 614, 615, 616, 621, 622, 623, 624, 625, 626, 627, 631, 632, 635, 701
SNE-RI	539
GBS (old)	521, 522, 523, 524, 525, 526, 533, 534, 537, 539 (50% to SCCLIS-RI and 50% to GBS), 541, 542, 543, 561, 562, 612, 613, 614, 615, 616, 621, 622, 623, 624, 625, 626, 627, 631, 632, 635, 701
SCCLIS-CT (old)	611
SCCLIS-RI (old)	539 (50% to SCCLIS-RI and 50% to GBS)
SCCLIS-NEFSC (old)	538

Table 6.2.6. Average percent of total survey year landings during October-December 1982-2003.

Stock	Females	Males
GBK	0.31	0.35
GBS-(old)	0.28	0.29
GOM-MA	0.48	0.41
GOM-NEFSC	0.35	0.28
SNE-CT	0.19	0.27
SNE-NEFSC	0.24	0.25
SNE-RI	0.22	0.30
SCCLIS-CT (old)	0.19	0.27
SCCLIS-RI (old)	0.22	0.30
SCCLIS-NEFSC (old)	0.11	0.15

Table 7.0.1. Estimates of recent abundance (sexes combined) and fishing mortality (sexes combined and females only) for lobster stock assessment regions (top) and survey areas within stock assessment regions (bottom) based on CSM runs.
Recent estimates are averages during 2001-2003 in most cases. Estimates of recent conditions for GOM were affected by low catches of recruit lobsters in the NEFSC and Massachusetts surveys during the fall of 2003 that may be anomalous. Therefore, averages for 2000-2002 are presented also for GOM. Natural mortality rates in SNE probably increased to some extent during some years after 1996. Therefore, recent averages for SNE are given from models with assumed natural mortality rates of M=0.15 y^{-1} during 1984-1996 and either M=0.4, 0.65 or 0.9 y^{-1} during 1997-2003. The range of M values probably brackets the range of possible natural mortality rates after 1996 but natural mortality rates were not estimated in this assessment. Conditions show for the entire GOM and SNE stock areas are average values and conditions in survey areas within regions (i.e. GOM-NEFSC, GOM-514, SNE-CT, SNE-RI, and SNE-NEFSC) vary widely with higher fishing mortality rates in survey areas closest to shore. Surveys areas are arranged in the table in order of offshore to inshore.

Region/Area	**Abundance (Sexes combined, millions)**	**Fishing Mortality (Sexes combined, y^{-1})**	**Fishing Mortality (Females only, y^{-1})**
Stock Assessment Regions			
Georges Bank (GBK)	9.1	0.29	0.17
Gulf of Maine (GOM, 2001-2003)	123.1	0.69	0.65
Gulf of Maine (GOM, 2000-2002)	126.7	0.54	0.47
Southern New England (SNE, M=0.15 y^{-1})	10.0	1.04	0.70
Southern New England (SNE, M=0.4 y^{-1})	12.0	0.92	0.61
Southern New England (SNE, M=0.65 y^{-1})	14.0	0.84	0.57
Southern New England (SNE, M=0.9 y^{-1})	16.2	0.78	0.54
Survey areas			
GOM-NEFSC	115.4	0.64	0.59
GOM-514	7.7	2.2	2.3
SNE-NEFSC (M=0.15 and 0.9 y^{-1})	6.5 - 11.0	0.76 - 0.55	0.49 – 0.38
SNE-RI (M=0.15 and 0.9 y^{-1})	1.8- 2.9	1.7 - 1.3	1.16 - 0.93
SNE-CT (M=0.15 and 0.9 y^{-1})	1.7 – 1.9	2.5 – 2.3	2.3 – 1.7

Table 7.1.1. CSM and data based stock assessment results for female and male lobsters in GOM.

Year	Recruit Abund. (Millions)	CV	Post-recruit Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y-1)	CV	3-Year Average (y-1)	Natural Mortality (M, y-1)	Total Mortality (Z, y-1)	Landings (millions)	Landings / Total Abund.	Stock Fraction Recruits	Landings Fraction Female	Recruits Fraction Female	Post-recruits Fraction Female	Stock Fraction Female
1982	32.90	0.15	13.09	0.23	45.99	0.10		0.93	0.20		0.15	1.08	26.20	0.57	0.72	0.51	0.57	0.38	0.52
1983	37.85	0.15	15.58	0.24	53.43	0.10		0.69	0.19		0.15	0.84	24.83	0.46	0.71	0.50	0.49	0.53	0.50
1984	23.99	0.21	23.17	0.20	47.16	0.10	48.86	0.90	0.20	0.84	0.15	1.05	26.13	0.55	0.51	0.52	0.59	0.50	0.55
1985	34.01	0.16	16.63	0.25	50.64	0.10	50.41	0.78	0.20	0.79	0.15	0.93	25.72	0.51	0.67	0.51	0.44	0.59	0.49
1986	30.68	0.18	19.99	0.22	50.67	0.10	49.49	0.71	0.19	0.80	0.15	0.86	24.24	0.48	0.61	0.49	0.52	0.47	0.50
1987	21.02	0.18	21.43	0.20	42.45	0.10	47.92	1.04	0.21	0.84	0.15	1.19	25.77	0.61	0.50	0.48	0.45	0.51	0.48
1988	39.48	0.15	13.01	0.27	52.49	0.11	48.53	0.88	0.21	0.88	0.15	1.03	28.79	0.55	0.75	0.50	0.51	0.48	0.50
1989	42.74	0.14	18.83	0.24	61.56	0.09	52.17	0.85	0.20	0.92	0.15	1.00	32.88	0.53	0.69	0.51	0.47	0.51	0.48
1990	39.39	0.16	22.85	0.21	62.24	0.09	58.76	0.94	0.19	0.89	0.15	1.09	35.66	0.57	0.63	0.48	0.50	0.45	0.48
1991	33.79	0.18	20.91	0.22	54.69	0.11	59.50	0.95	0.21	0.91	0.15	1.10	31.43	0.57	0.62	0.49	0.54	0.47	0.51
1992	40.96	0.17	18.29	0.27	59.25	0.11	58.73	0.82	0.23	0.90	0.15	0.97	31.16	0.53	0.69	0.49	0.44	0.55	0.47
1993	46.44	0.16	22.49	0.25	68.93	0.11	60.96	0.86	0.22	0.88	0.15	1.01	37.44	0.54	0.67	0.48	0.49	0.46	0.48
1994	69.76	0.15	25.01	0.25	94.77	0.11	74.32	0.62	0.21	0.77	0.15	0.77	41.16	0.43	0.74	0.50	0.47	0.48	0.48
1995	35.69	0.24	43.76	0.20	79.45	0.12	81.05	0.67	0.23	0.72	0.15	0.82	36.44	0.46	0.45	0.50	0.58	0.46	0.51
1996	61.92	0.18	34.92	0.24	96.84	0.12	90.35	0.65	0.22	0.65	0.15	0.80	43.47	0.45	0.64	0.49	0.49	0.52	0.50
1997	51.36	0.21	43.47	0.22	94.83	0.12	90.37	0.72	0.23	0.68	0.15	0.87	45.51	0.48	0.54	0.50	0.54	0.52	0.53
1998	66.01	0.21	39.87	0.25	105.88	0.14	99.18	0.65	0.23	0.67	0.15	0.80	47.03	0.44	0.62	0.53	0.58	0.55	0.57
1999	67.48	0.21	47.93	0.26	115.41	0.13	105.37	0.74	0.23	0.70	0.15	0.89	56.00	0.49	0.58	0.53	0.55	0.61	0.58
2000	63.71	0.22	47.95	0.27	111.66	0.14	110.98	0.59	0.24	0.66	0.15	0.74	46.31	0.41	0.57	0.50	0.52	0.63	0.57
2001	72.11	0.21	53.56	0.25	125.67	0.13	117.58	0.60	0.24	0.64	0.15	0.75	52.55	0.42	0.57	0.50	0.55	0.62	0.58
2002	82.73	0.17	59.90	0.23	142.63	0.09	126.65	0.43	0.18	0.54	0.15	0.58	46.80	0.33	0.58	0.50	0.43	0.64	0.52
2003	21.38	0.191	79.69	0.138	101.07	0.109	123.12	1.05	0.24	0.69	0.15	1.20	61.64	0.61	0.21	0.48	0.33	0.53	0.48
Median 82-03	40.22	0.18	23.01	0.24	65.58	0.11	67.64	0.76	0.21	0.78	0.15	0.91	36.05	0.50	0.62	0.50	0.50	0.52	0.50
Min 82-03	21.02	0.14	13.01	0.14	42.45	0.09	47.92	0.43	0.18	0.54	0.15	0.58	24.24	0.33	0.21	0.48	0.33	0.38	0.47
Max 82-03	82.73	0.24	79.69	0.27	142.63	0.14	126.65	1.05	0.24	0.92	0.15	1.20	61.64	0.61	0.75	0.53	0.59	0.64	0.58
Mean 01-03	58.74	0.19	64.38	0.20	123.12	0.11	122.45	0.69	0.22	0.63	0.15	0.84	53.67	0.45	0.46	0.49	0.43	0.60	0.53

Table 7.1.2. CSM and data based stock assessment results for female lobsters in GOM.

Year	Recruit Abund. (Millions)	CV	Post-recruit Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y^{-1})	CV	3-Year Average (y-1)	Natural Mortality (M, y^{-1})	Total Mortality (Z, y^{-1})	Landings (millions)	Landings / Total Abund.	Stock Fraction Recruits
1982	18.77	0.24	4.94	0.48	23.72	0.18		0.91	0.28		0.15	1.06	13.31	0.56	0.79
1983	18.44	0.29	8.22	0.41	26.65	0.19		0.68	0.28		0.15	0.83	12.30	0.46	0.69
1984	14.21	0.33	11.64	0.36	25.85	0.17	25.41	0.82	0.27	0.80	0.15	0.97	13.61	0.53	0.55
1985	15.11	0.31	9.76	0.38	24.88	0.18	25.79	0.82	0.27	0.77	0.15	0.97	13.02	0.52	0.61
1986	16.07	0.31	9.48	0.40	25.55	0.18	25.43	0.70	0.26	0.78	0.15	0.85	11.99	0.47	0.63
1987	9.45	0.34	11.00	0.34	20.45	0.19	23.63	1.03	0.29	0.85	0.15	1.18	12.38	0.61	0.46
1988	20.16	0.27	6.31	0.48	26.47	0.19	24.16	0.87	0.28	0.87	0.15	1.02	14.45	0.55	0.76
1989	20.23	0.28	9.56	0.43	29.78	0.17	25.57	0.92	0.27	0.94	0.15	1.07	16.86	0.57	0.68
1990	19.55	0.30	10.19	0.42	29.74	0.17	28.67	0.95	0.26	0.91	0.15	1.10	17.13	0.58	0.66
1991	18.12	0.32	9.93	0.42	28.05	0.19	29.19	0.87	0.28	0.92	0.15	1.02	15.35	0.55	0.65
1992	18.04	0.34	10.07	0.44	28.11	0.22	28.63	0.86	0.31	0.90	0.15	1.01	15.24	0.54	0.64
1993	22.88	0.30	10.26	0.48	33.15	0.21	29.77	0.86	0.30	0.86	0.15	1.01	17.92	0.54	0.69
1994	33.08	0.30	12.11	0.48	45.19	0.21	35.48	0.67	0.30	0.80	0.15	0.82	20.65	0.46	0.73
1995	20.84	0.39	19.93	0.40	40.77	0.23	39.70	0.66	0.30	0.73	0.15	0.81	18.39	0.45	0.51
1996	30.54	0.35	18.22	0.42	48.76	0.22	44.91	0.63	0.30	0.65	0.15	0.78	21.25	0.44	0.63
1997	27.53	0.38	22.50	0.41	50.02	0.23	46.52	0.67	0.31	0.65	0.15	0.82	22.82	0.46	0.55
1998	38.35	0.35	22.12	0.43	60.46	0.23	53.08	0.58	0.31	0.63	0.15	0.73	25.01	0.41	0.63
1999	37.35	0.38	29.05	0.41	66.40	0.22	58.96	0.64	0.30	0.63	0.15	0.79	29.41	0.44	0.56
2000	33.39	0.41	30.14	0.42	63.53	0.24	63.47	0.49	0.32	0.57	0.15	0.64	23.15	0.36	0.53
2001	39.35	0.37	33.40	0.38	72.75	0.22	67.56	0.49	0.30	0.54	0.15	0.64	26.16	0.36	0.54
2002	35.18	0.38	38.56	0.35	73.74	0.17	70.01	0.42	0.19	0.47	0.15	0.57	23.46	0.32	0.48
2003	7.02	0.408	41.89	0.248	48.91	0.214	65.13	1.05	0.309	0.65	0.15	1.20	29.85	0.61	0.14
Median 82-03	20.19	0.33	11.32	0.41	31.46	0.20	32.63	0.76	0.29	0.78	0.15	0.91	17.52	0.50	0.63
Min 82-03	7.02	0.24	4.94	0.25	20.45	0.17	23.63	0.42	0.19	0.47	0.15	0.57	11.99	0.32	0.14
Max 82-03	39.35	0.41	41.89	0.48	73.74	0.24	70.01	1.05	0.32	0.94	0.15	1.20	29.85	0.61	0.79
Mean 01-03	27.18	0.39	37.95	0.33	65.13	0.20	67.57	0.65	0.27	0.55	0.15	0.80	26.49	0.43	0.39

Table 7.1.3. CSM and data based stock assessment results for male lobsters in GOM.

Year	Recruit Abund. (Millions)	CV	Post-recruit Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y^{-1})	CV	3-Year Average (y-1)	Natural Mortality (M, y^{-1})	Total Mortality (Z, y^{-1})	Landings (millions)	Landings / Total Abund.	Stock Fraction Recruits
1982	14.13	0.33	8.14	0.45	22.27	0.19		0.96	0.30	0.30	0.15	1.11	12.89	0.58	0.63
1983	19.41	0.28	7.36	0.45	26.77	0.18		0.69	0.27	0.27	0.15	0.84	12.53	0.47	0.73
1984	9.77	0.38	11.53	0.35	21.30	0.18	23.45	0.98	0.29	0.29	0.15	1.13	12.52	0.59	0.46
1985	18.89	0.30	6.87	0.46	25.76	0.20	24.61	0.75	0.29	0.29	0.15	0.90	12.70	0.49	0.73
1986	14.61	0.37	10.51	0.42	25.12	0.20	24.06	0.73	0.28	0.28	0.15	0.88	12.25	0.49	0.58
1987	11.57	0.34	10.43	0.41	21.99	0.20	24.29	1.04	0.31	0.31	0.15	1.19	13.39	0.61	0.53
1988	19.32	0.31	6.70	0.52	26.02	0.21	24.38	0.88	0.31	0.31	0.15	1.03	14.34	0.55	0.74
1989	22.51	0.30	9.27	0.49	31.78	0.20	26.60	0.77	0.29	0.29	0.15	0.92	16.02	0.50	0.71
1990	19.83	0.32	12.66	0.42	32.49	0.17	30.10	0.93	0.27	0.27	0.15	1.08	18.54	0.57	0.61
1991	15.67	0.36	10.98	0.41	26.65	0.20	30.31	1.03	0.30	0.30	0.15	1.18	16.09	0.60	0.59
1992	22.92	0.35	8.22	0.52	31.14	0.25	30.09	0.79	0.34	0.34	0.15	0.94	15.92	0.51	0.74
1993	23.56	0.35	12.22	0.53	35.78	0.23	31.19	0.87	0.33	0.33	0.15	1.02	19.52	0.55	0.66
1994	36.68	0.32	12.90	0.53	49.58	0.23	38.83	0.58	0.31	0.31	0.15	0.73	20.50	0.41	0.74
1995	14.84	0.46	23.83	0.39	38.67	0.25	41.35	0.69	0.34	0.34	0.15	0.84	18.05	0.47	0.38
1996	31.37	0.36	16.70	0.47	48.08	0.23	45.44	0.68	0.33	0.33	0.15	0.83	22.22	0.46	0.65
1997	23.83	0.44	20.97	0.44	44.80	0.23	43.85	0.78	0.33	0.33	0.15	0.93	22.68	0.51	0.53
1998	27.66	0.38	17.76	0.48	45.42	0.24	46.10	0.73	0.34	0.34	0.15	0.88	22.02	0.48	0.61
1999	30.14	0.39	18.88	0.48	49.01	0.23	46.41	0.86	0.34	0.34	0.15	1.01	26.59	0.54	0.61
2000	30.31	0.40	17.81	0.52	48.12	0.25	47.52	0.72	0.36	0.36	0.15	0.87	23.16	0.48	0.63
2001	32.76	0.42	20.16	0.50	52.92	0.26	50.02	0.76	0.37	0.37	0.15	0.91	26.39	0.50	0.62
2002	47.56	0.37	21.34	0.53	68.89	0.23	56.65	0.45	0.30	0.30	0.15	0.60	23.34	0.34	0.69
2003	14.36	0.589	37.80	0.347	52.16	0.250	57.99	1.04	0.356	0.36	0.15	1.19	31.79	0.61	0.28
Median 82-03	21.17	0.36	12.44	0.46	34.14	0.23	35.01	0.77	0.31	0.31	0.15	0.92	18.30	0.51	0.62
Min 82-03	9.77	0.28	6.70	0.35	21.30	0.17	23.45	0.45	0.27	0.27	0.15	0.60	12.25	0.34	0.28
Max 82-03	47.56	0.59	37.80	0.53	68.89	0.26	57.99	1.04	0.37	0.37	0.15	1.19	31.79	0.61	0.74
Mean 01-03	31.56	0.46	26.43	0.46	57.99	0.25	54.89	0.75	0.34	0.34	0.15	0.90	27.17	0.48	0.53

Table 7.1.4. CSM and data based stock assessment results for female and male lobsters in GOM (areas covered by NEFSC survey).

Year	Recruit Abund. (Millions)	CV	Post-recruit Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y-1)	CV	3-Year Average (y-1)	Natural Mortality (M, y-1)	Total Mortality (Z, y-1)	Landings (millions)	Landings / Total Abund.	Model Fraction Recruits	Landings Fraction Female	Recruits Fraction Female	Post-recruits Fraction Female	Stock Fraction Female
1982	24.95	0.18	7.70	0.29	32.65	0.13		0.91	0.25		0.15	1.06	18.30	0.56	0.76	0.50	0.59	0.25	0.51
1983	26.74	0.19	11.34	0.31	38.08	0.13		0.62	0.25		0.15	0.77	16.50	0.43	0.70	0.49	0.49	0.53	0.50
1984	15.38	0.29	17.60	0.24	32.98	0.14	34.57	0.86	0.25	0.80	0.15	1.01	17.72	0.54	0.47	0.52	0.63	0.51	0.57
1985	25.14	0.20	12.14	0.32	37.28	0.13	36.11	0.67	0.26	0.72	0.15	0.82	17.12	0.46	0.67	0.51	0.44	0.62	0.50
1986	24.41	0.22	16.35	0.26	40.76	0.12	37.00	0.54	0.25	0.69	0.15	0.69	16.00	0.39	0.60	0.50	0.51	0.50	0.50
1987	12.01	0.29	20.35	0.21	32.36	0.13	36.80	0.85	0.28	0.69	0.15	1.00	17.38	0.54	0.37	0.48	0.46	0.51	0.49
1988	28.44	0.20	11.91	0.30	40.36	0.14	37.82	0.72	0.27	0.70	0.15	0.87	19.40	0.48	0.70	0.51	0.52	0.50	0.51
1989	28.31	0.20	16.92	0.27	45.22	0.12	39.31	0.72	0.26	0.76	0.15	0.87	21.65	0.48	0.63	0.52	0.46	0.52	0.48
1990	27.84	0.22	19.04	0.24	46.87	0.12	44.15	0.87	0.25	0.77	0.15	1.02	25.61	0.55	0.59	0.48	0.54	0.44	0.50
1991	25.82	0.23	16.86	0.28	42.68	0.14	44.93	0.87	0.26	0.82	0.15	1.02	23.26	0.54	0.60	0.50	0.54	0.52	0.53
1992	33.90	0.19	15.41	0.32	49.31	0.14	46.29	0.68	0.28	0.81	0.15	0.83	22.83	0.46	0.69	0.49	0.43	0.58	0.48
1993	34.97	0.22	21.46	0.26	56.42	0.13	49.47	0.79	0.27	0.78	0.15	0.94	28.88	0.51	0.62	0.47	0.49	0.46	0.48
1994	58.86	0.18	22.05	0.29	80.91	0.13	62.21	0.54	0.26	0.67	0.15	0.69	31.66	0.39	0.73	0.51	0.48	0.49	0.48
1995	26.39	0.31	40.49	0.21	66.88	0.15	68.07	0.59	0.28	0.64	0.15	0.74	27.85	0.42	0.39	0.50	0.61	0.46	0.52
1996	53.44	0.21	31.94	0.26	85.38	0.14	77.73	0.57	0.27	0.57	0.15	0.72	34.65	0.41	0.63	0.48	0.50	0.54	0.51
1997	43.66	0.25	41.60	0.24	85.26	0.14	79.18	0.65	0.27	0.60	0.15	0.80	37.91	0.44	0.51	0.49	0.52	0.53	0.53
1998	56.10	0.25	38.53	0.26	94.62	0.15	88.42	0.58	0.27	0.60	0.15	0.73	39.00	0.41	0.59	0.54	0.60	0.56	0.58
1999	56.97	0.25	45.56	0.27	102.52	0.15	94.14	0.67	0.27	0.63	0.15	0.82	46.50	0.45	0.56	0.52	0.55	0.61	0.58
2000	56.71	0.24	45.50	0.29	102.22	0.15	99.79	0.53	0.28	0.60	0.15	0.68	39.17	0.38	0.55	0.49	0.52	0.63	0.57
2001	64.90	0.23	51.92	0.26	116.82	0.14	107.19	0.55	0.27	0.58	0.15	0.70	45.49	0.39	0.56	0.48	0.54	0.63	0.58
2002	76.27	0.18	58.69	0.24	134.95	0.10	118.00	0.39	0.20	0.49	0.15	0.54	40.66	0.30	0.57	0.48	0.41	0.65	0.51
2003	15.73	0.25	78.65	0.14	94.38	0.12	115.38	0.99	0.27	0.64	0.15	1.14	55.62	0.59	0.17	0.47	0.24	0.53	0.48
Median 82-03	28.37	0.22	20.90	0.26	52.86	0.13	55.84	0.67	0.27	0.68	0.15	0.82	26.73	0.46	0.60	0.49	0.51	0.52	0.51
Min 82-03	12.01	0.18	7.70	0.14	32.36	0.10	34.57	0.39	0.20	0.49	0.15	0.54	16.00	0.30	0.17	0.47	0.24	0.25	0.48
Max 82-03	76.27	0.31	78.65	0.32	134.95	0.15	118.00	0.99	0.28	0.82	0.15	1.14	55.62	0.59	0.76	0.54	0.63	0.65	0.58
Mean 01-03	52.30	0.22	63.09	0.21	115.38	0.12	113.52	0.64	0.24	0.57	0.15	0.79	47.25	0.43	0.43	0.48	0.40	0.60	0.52

Table 7.1.5. CSM and data based stock assessment results for female and male lobsters in GOM (Statistical Area 514; areas covered by Massachusetts survey).

Year	Recruit Abund. (Millions)	CV	Post-recruit Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y-1)	CV	3-Year Average (y-1)	Natural Mortality (M, y-1)	Total Mortality (Z, y-1)	Landings (millions)	Landings / Total Abund.	Model Fraction Recruits	Landings Fraction Female	Recruits Fraction Female	Post-recruits Fraction Female	Stock Fraction Female
1982	7.95	0.34	5.39	0.44	13.33	0.20		1.00	0.34		0.15	1.15	7.90	0.59	0.60	0.53	0.51	0.56	0.53
1983	11.11	0.28	4.24	0.47	15.35	0.19		0.86	0.34		0.15	1.01	8.33	0.54	0.72	0.51	0.49	0.52	0.50
1984	8.61	0.32	5.57	0.39	14.18	0.18	14.29	1.00	0.32	0.95	0.15	1.15	8.42	0.59	0.61	0.51	0.52	0.48	0.51
1985	8.86	0.27	4.50	0.42	13.36	0.16	14.30	1.17	0.30	1.01	0.15	1.32	8.61	0.64	0.66	0.51	0.45	0.49	0.46
1986	6.27	0.31	3.64	0.41	9.91	0.16	12.48	2.12	0.25	1.43	0.15	2.27	8.24	0.83	0.63	0.49	0.60	0.36	0.51
1987	9.01	0.20	1.08	0.83	10.09	0.16	11.12	2.10	0.27	1.80	0.15	2.25	8.39	0.83	0.89	0.48	0.44	0.67	0.46
1988	11.04	0.20	1.09	0.88	12.13	0.17	10.71	1.70	0.28	1.97	0.15	1.85	9.40	0.77	0.91	0.49	0.49	0.36	0.48
1989	14.43	0.20	1.91	0.70	16.34	0.16	12.85	1.31	0.31	1.70	0.15	1.46	11.24	0.69	0.88	0.50	0.50	0.43	0.49
1990	11.55	0.23	3.81	0.48	15.36	0.15	14.61	1.23	0.30	1.41	0.15	1.38	10.05	0.65	0.75	0.48	0.40	0.48	0.42
1991	7.96	0.28	4.05	0.39	12.01	0.16	14.57	1.28	0.31	1.27	0.15	1.43	8.17	0.68	0.66	0.47	0.54	0.28	0.45
1992	7.07	0.26	2.88	0.49	9.95	0.16	12.44	2.13	0.27	1.55	0.15	2.28	8.33	0.84	0.71	0.48	0.49	0.41	0.47
1993	11.48	0.21	1.03	0.91	12.51	0.18	11.49	1.29	0.31	1.57	0.15	1.44	8.55	0.68	0.92	0.51	0.50	0.39	0.49
1994	10.90	0.23	2.96	0.53	13.86	0.17	12.11	1.30	0.31	1.57	0.15	1.45	9.50	0.69	0.79	0.47	0.45	0.45	0.45
1995	9.30	0.25	3.27	0.48	12.56	0.17	12.98	1.32	0.31	1.30	0.15	1.47	8.59	0.68	0.74	0.53	0.52	0.40	0.49
1996	8.48	0.23	2.98	0.48	11.45	0.14	12.63	1.88	0.27	1.50	0.15	2.03	8.82	0.77	0.74	0.52	0.48	0.37	0.45
1997	7.70	0.23	1.87	0.56	9.57	0.17	11.19	1.82	0.28	1.67	0.15	1.97	7.59	0.79	0.80	0.56	0.63	0.17	0.54
1998	9.91	0.22	1.35	0.75	11.26	0.18	10.76	1.41	0.30	1.70	0.15	1.56	8.03	0.71	0.88	0.51	0.50	0.47	0.49
1999	10.52	0.23	2.37	0.58	12.89	0.17	11.24	1.51	0.30	1.58	0.15	1.66	9.50	0.74	0.82	0.56	0.58	0.44	0.55
2000	6.99	0.29	2.45	0.56	9.44	0.18	11.20	1.60	0.30	1.51	0.15	1.75	7.14	0.76	0.74	0.56	0.56	0.52	0.55
2001	7.22	0.25	1.64	0.66	8.85	0.18	10.39	1.84	0.28	1.65	0.15	1.99	7.07	0.80	0.82	0.58	0.60	0.52	0.58
2002	6.47	0.25	1.21	0.76	7.68	0.17	8.66	1.87	0.29	1.77	0.15	2.02	6.14	0.80	0.84	0.61	0.60	0.57	0.59
2003	5.64	0.219	1.04	0.789	6.68	0.144	7.74	2.83	0.226	2.18	0.15	2.98	6.02	0.90	0.84	0.57	0.58	0.49	0.57
Median 82-03	8.74	0.24	2.66	0.55	12.07	0.17	11.80	1.46	0.30	1.57	0.15	1.61	8.36	0.73	0.77	0.51	0.50	0.46	0.49
Min 82-03	5.64	0.20	1.03	0.39	6.68	0.14	7.74	0.86	0.23	0.95	0.15	1.01	6.02	0.54	0.60	0.47	0.40	0.17	0.42
Max 82-03	14.43	0.34	5.57	0.91	16.34	0.20	14.61	2.83	0.34	2.18	0.15	2.98	11.24	0.90	0.92	0.61	0.63	0.67	0.59
Mean 01-03	6.44	0.24	1.30	0.74	7.74	0.16	8.93	2.18	0.27	1.87	0.15	2.33	6.41	0.83	0.83	0.59	0.59	0.53	0.58

Table 7.2.1. CSM and data based stock assessment results for female and male lobsters in GBK.

Year	Recruit Abund. (Millions)	CV	Post-recruit Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y-1)	CV	3-Year Average (y-1)	Natural Mortality (M, y-1)	Total Mortality (Z, y-1)	Landings (millions)	Landings / Total Abund.	Stock Fraction Recruits	Landings Fraction Female	Recruits Fraction Female	Post-recruits Fraction Female	Stock Fraction Female
1982	2.39	0.30	4.18	0.21	6.57	0.14		0.39	0.15		0.15	0.54	1.93	0.29	0.36	0.47	0.61	0.67	0.65
1983	2.60	0.28	3.88	0.21	6.48	0.14		0.31	0.14		0.15	0.46	1.60	0.25	0.40	0.53	0.51	0.73	0.64
1984	2.73	0.27	4.10	0.20	6.82	0.14	6.62	0.38	0.14	0.36	0.15	0.53	1.94	0.28	0.40	0.48	0.64	0.68	0.66
1985	2.42	0.28	4.09	0.20	6.50	0.15	6.60	0.38	0.15	0.36	0.15	0.53	1.82	0.28	0.37	0.50	0.65	0.75	0.71
1986	3.56	0.24	3.92	0.21	7.49	0.15	6.94	0.32	0.16	0.36	0.15	0.47	1.83	0.24	0.48	0.49	0.56	0.80	0.69
1987	4.18	0.22	4.75	0.20	8.93	0.13	7.64	0.29	0.14	0.33	0.15	0.44	2.08	0.23	0.47	0.46	0.48	0.75	0.62
1988	2.35	0.31	5.77	0.18	8.12	0.14	8.18	0.27	0.14	0.29	0.15	0.42	1.77	0.22	0.29	0.47	0.63	0.68	0.67
1989	2.47	0.29	5.36	0.18	7.83	0.14	8.30	0.32	0.14	0.30	0.15	0.47	1.97	0.25	0.32	0.48	0.47	0.73	0.65
1990	3.60	0.24	4.92	0.20	8.52	0.13	8.16	0.38	0.15	0.33	0.15	0.53	2.36	0.28	0.42	0.44	0.68	0.71	0.70
1991	2.73	0.27	5.16	0.19	7.89	0.14	8.08	0.43	0.16	0.38	0.15	0.58	2.31	0.29	0.35	0.41	0.53	0.80	0.71
1992	4.65	0.20	4.67	0.21	9.32	0.13	8.58	0.39	0.15	0.40	0.15	0.54	2.54	0.27	0.50	0.46	0.65	0.84	0.75
1993	2.91	0.25	5.69	0.18	8.60	0.13	8.61	0.42	0.14	0.42	0.15	0.57	2.46	0.29	0.34	0.47	0.54	0.87	0.76
1994	1.57	0.35	5.14	0.18	6.71	0.15	8.21	0.36	0.15	0.39	0.15	0.51	1.80	0.27	0.23	0.56	0.38	0.88	0.76
1995	2.52	0.27	4.12	0.22	6.64	0.15	7.31	0.36	0.15	0.38	0.15	0.51	1.82	0.27	0.38	0.58	0.59	0.85	0.75
1996	2.12	0.30	4.04	0.22	6.15	0.16	6.50	0.40	0.16	0.38	0.15	0.55	1.87	0.30	0.34	0.59	0.53	0.82	0.72
1997	4.42	0.22	3.58	0.25	8.00	0.15	6.93	0.30	0.15	0.36	0.15	0.45	1.91	0.24	0.55	0.56	0.66	0.78	0.72
1998	3.31	0.25	5.12	0.20	8.44	0.14	7.53	0.29	0.14	0.33	0.15	0.44	1.92	0.23	0.39	0.56	0.62	0.77	0.71
1999	1.95	0.33	5.49	0.19	7.44	0.16	7.96	0.35	0.16	0.31	0.15	0.50	1.93	0.26	0.26	0.47	0.56	0.76	0.71
2000	4.38	0.22	4.62	0.22	9.00	0.15	8.29	0.28	0.15	0.31	0.15	0.43	1.96	0.22	0.49	0.47	0.68	0.80	0.74
2001	3.09	0.26	5.95	0.19	9.03	0.15	8.49	0.32	0.15	0.32	0.15	0.47	2.13	0.24	0.34	0.46	0.58	0.82	0.74
2002	3.21	0.27	5.81	0.20	9.02	0.16	9.02	0.27	0.15	0.29	0.15	0.42	1.91	0.21	0.36	0.54	0.69	0.83	0.78
2003	3.08	0.29	6.00	0.21	9.09	0.17	9.05	0.27	0.17	0.29	0.15	0.42	1.89	0.21	0.34	0.54	0.66	0.85	0.79
Median 82-03	2.82	0.27	4.84	0.20	7.95	0.14	8.12	0.34	0.15	0.34	0.15	0.49	1.92	0.26	0.37	0.48	0.60	0.79	0.71
Min 82-03	1.57	0.20	3.58	0.18	6.15	0.13	6.50	0.27	0.14	0.29	0.15	0.42	1.60	0.21	0.23	0.41	0.38	0.67	0.62
Max 82-03	4.65	0.35	6.00	0.25	9.32	0.17	9.05	0.43	0.17	0.42	0.15	0.58	2.54	0.30	0.55	0.59	0.69	0.88	0.79
Mean 01-03	3.13	0.27	5.92	0.20	9.05	0.16	8.85	0.29	0.16	0.30	0.15	0.44	1.98	0.22	0.35	0.51	0.64	0.83	0.77

Table 7.2.2. CSM and data based stock assessment results for female lobsters in GBK.

Year	Recruit Abund. (Millions)	CV	Post-recruits Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y^{-1})	CV	3-Year Average (y^{-1})	Natural Mortality (M, y-1)	Total Mortality (Z, y-1)	Landings (millions)	Landings / Total Abund.	Total Survey	Landings / Total Survey	Survey Z	Stock Recruit / Total Abund.	Survey Recruit / Total Survey
1982	1.45	0.30	2.80	0.23	4.25	0.16		0.26	0.18		0.15	0.41	0.90	0.21	0.79	1.14	0.55	0.34	0.31
1983	1.33	0.30	2.83	0.21	4.16	0.16		0.25	0.19		0.15	0.40	0.85	0.20	0.69	1.23	0.57	0.32	0.34
1984	1.73	0.28	2.80	0.21	4.53	0.16	4.32	0.25	0.18	0.25	0.15	0.40	0.92	0.20	0.73	1.26	0.76	0.38	0.47
1985	1.58	0.29	3.05	0.21	4.63	0.17	4.44	0.23	0.19	0.24	0.15	0.38	0.90	0.19	0.62	1.45	0.19	0.34	0.45
1986	1.98	0.29	3.15	0.21	5.13	0.17	4.76	0.21	0.19	0.23	0.15	0.36	0.90	0.18	0.92	0.98	1.06	0.39	0.44
1987	1.99	0.28	3.58	0.21	5.57	0.16	5.11	0.20	0.18	0.21	0.15	0.35	0.95	0.17	0.66	1.43	0.19	0.36	0.51
1988	1.48	0.30	3.92	0.20	5.40	0.17	5.37	0.18	0.18	0.20	0.15	0.33	0.82	0.15	0.79	1.05	0.47	0.27	0.31
1989	1.17	0.31	3.89	0.20	5.06	0.18	5.35	0.22	0.20	0.20	0.15	0.37	0.95	0.19	0.68	1.40	0.53	0.23	0.27
1990	2.45	0.27	3.48	0.22	5.93	0.16	5.47	0.21	0.18	0.20	0.15	0.36	1.03	0.17	0.77	1.34	0.13	0.41	0.48
1991	1.46	0.31	4.15	0.20	5.61	0.17	5.53	0.20	0.19	0.21	0.15	0.35	0.96	0.17	0.90	1.06	0.61	0.26	0.25
1992	3.04	0.24	3.94	0.22	6.97	0.15	6.17	0.20	0.16	0.20	0.15	0.35	1.16	0.17	0.96	1.21	0.62	0.44	0.49
1993	1.57	0.30	4.93	0.18	6.50	0.15	6.36	0.21	0.16	0.20	0.15	0.36	1.15	0.18	0.73	1.58	0.37	0.24	0.29
1994	0.60	0.33	4.52	0.18	5.12	0.17	6.20	0.24	0.19	0.22	0.15	0.39	1.01	0.20	0.58	1.72	0.16	0.12	0.14
1995	1.49	0.29	3.48	0.22	4.97	0.18	5.53	0.26	0.20	0.24	0.15	0.41	1.05	0.21	0.68	1.55	0.44	0.30	0.27
1996	1.13	0.31	3.30	0.23	4.43	0.19	4.84	0.31	0.22	0.27	0.15	0.46	1.10	0.25	0.57	1.92	0.10	0.25	0.24
1997	2.93	0.25	2.80	0.26	5.73	0.18	5.04	0.23	0.20	0.26	0.15	0.38	1.08	0.19	0.83	1.29	0.39	0.51	0.38
1998	2.05	0.28	3.94	0.22	5.99	0.17	5.38	0.21	0.19	0.25	0.15	0.36	1.07	0.18	0.79	1.35	0.18	0.34	0.29
1999	1.09	0.33	4.16	0.21	5.25	0.19	5.66	0.21	0.21	0.22	0.15	0.36	0.91	0.17	0.80	1.14	0.45	0.21	0.17
2000	2.98	0.26	3.68	0.24	6.66	0.18	5.97	0.16	0.19	0.19	0.15	0.31	0.93	0.14	0.80	1.16	-0.17	0.45	0.36
2001	1.80	0.31	4.87	0.21	6.68	0.18	6.20	0.17	0.20	0.18	0.15	0.32	0.98	0.15	1.16	0.85	-0.09	0.27	0.19
2002	2.21	0.31	4.84	0.22	7.05	0.19	6.79	0.17	0.20	0.17	0.15	0.32	1.03	0.15	1.60	0.65	0.93	0.31	0.20
2003	2.02	0.331	5.11	0.223	7.13	0.201	6.95	0.17	0.219	0.17	0.15	0.32	1.01	0.14	0.92	1.10	0.10	0.28	0.31
Median 82-03	1.66	0.30	3.78	0.21	5.49	0.17	5.50	0.21	0.19	0.21	0.15	0.36	0.97	0.18	0.79	1.25	0.42	0.32	0.31
Min 82-03	0.60	0.24	2.80	0.18	4.16	0.15	4.32	0.16	0.16	0.17	0.15	0.31	0.82	0.14	0.57	0.65	-0.17	0.12	0.14
Max 82-03	3.04	0.33	5.11	0.26	7.13	0.20	6.95	0.31	0.22	0.27	0.15	0.46	1.16	0.25	1.60	1.92	1.06	0.51	0.51
Mean 01-03	2.01	0.32	4.94	0.22	6.95	0.19	6.65	0.17	0.21	0.17	0.15	0.32	1.01	0.15	1.23	0.87	0.31	0.29	0.23

Table 7.2.3. CSM and data based stock assessment results for male lobsters in GBK.

Year	Recruit Abund. (Millions)	CV	Post-recruits Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y^{-1})	CV	3-Year Average (y^{-1})	Natural Mortality (M, y-1)	Total Mortality (Z, y-1)	Landings (millions)	Landings / Total Abund.	Total Survey	Landings / Total Survey	Survey Z	Stock Recruit / Total Abund.	Survey Recruit / Total Survey
1982	0.94	0.34	1.37	0.28	2.31	0.15		0.64	0.22		0.15	0.79	1.02	0.44	0.61	1.67	0.52	0.41	0.42
1983	1.27	0.28	1.05	0.29	2.32	0.16		0.43	0.21		0.15	0.58	0.75	0.32	0.76	0.99	0.77	0.55	0.52
1984	0.99	0.31	1.30	0.25	2.29	0.14	2.31	0.64	0.20	0.57	0.15	0.79	1.02	0.44	0.64	1.58	0.86	0.43	0.45
1985	0.83	0.31	1.04	0.27	1.87	0.16	2.16	0.74	0.23	0.60	0.15	0.89	0.92	0.49	0.49	1.86	0.47	0.44	0.45
1986	1.58	0.27	0.77	0.33	2.36	0.18	2.18	0.55	0.24	0.64	0.15	0.70	0.93	0.40	0.98	0.95	1.32	0.67	0.69
1987	2.19	0.24	1.17	0.32	3.36	0.15	2.53	0.45	0.20	0.58	0.15	0.60	1.13	0.34	0.96	1.18	0.55	0.65	0.73
1988	0.87	0.36	1.85	0.23	2.72	0.16	2.81	0.47	0.21	0.49	0.15	0.62	0.94	0.35	0.83	1.14	0.51	0.32	0.33
1989	1.30	0.30	1.47	0.25	2.77	0.15	2.95	0.50	0.20	0.47	0.15	0.65	1.02	0.37	0.96	1.06	1.15	0.47	0.49
1990	1.15	0.31	1.44	0.25	2.59	0.13	2.69	0.79	0.21	0.59	0.15	0.94	1.32	0.51	0.62	2.14	0.81	0.44	0.51
1991	1.28	0.26	1.01	0.29	2.29	0.13	2.55	0.99	0.22	0.76	0.15	1.14	1.35	0.59	0.58	2.32	0.91	0.56	0.53
1992	1.62	0.22	0.73	0.35	2.35	0.13	2.41	0.98	0.22	0.92	0.15	1.13	1.38	0.59	0.67	2.06	1.33	0.69	0.65
1993	1.34	0.23	0.76	0.34	2.10	0.12	2.25	1.08	0.21	1.02	0.15	1.23	1.31	0.62	0.41	3.17	0.47	0.64	0.57
1994	0.97	0.26	0.62	0.34	1.58	0.16	2.01	0.76	0.23	0.94	0.15	0.91	0.79	0.50	0.57	1.37	1.44	0.61	0.55
1995	1.03	0.26	0.64	0.33	1.67	0.16	1.79	0.67	0.23	0.84	0.15	0.82	0.77	0.46	0.34	2.27	0.41	0.62	0.60
1996	0.99	0.28	0.73	0.31	1.72	0.17	1.66	0.65	0.24	0.69	0.15	0.80	0.77	0.45	0.42	1.85	0.14	0.57	0.46
1997	1.49	0.26	0.77	0.32	2.27	0.17	1.89	0.50	0.22	0.61	0.15	0.65	0.83	0.37	0.87	0.95	1.06	0.66	0.59
1998	1.26	0.29	1.19	0.28	2.45	0.15	2.15	0.46	0.20	0.54	0.15	0.61	0.85	0.35	0.68	1.26	0.44	0.51	0.55
1999	0.86	0.33	1.33	0.24	2.18	0.16	2.30	0.69	0.23	0.55	0.15	0.84	1.02	0.47	0.70	1.45	0.88	0.39	0.38
2000	1.40	0.26	0.94	0.31	2.35	0.15	2.33	0.63	0.22	0.60	0.15	0.78	1.03	0.44	0.79	1.31	1.11	0.60	0.63
2001	1.29	0.27	1.07	0.28	2.36	0.14	2.30	0.73	0.21	0.69	0.15	0.88	1.15	0.49	0.62	1.86	0.07	0.55	0.58
2002	1.00	0.30	0.97	0.29	1.98	0.16	2.23	0.64	0.23	0.67	0.15	0.79	0.88	0.44	1.16	0.76	1.81	0.51	0.50
2003	1.06	0.314	0.89	0.303	1.95	0.184	2.10	0.65	0.255	0.68	0.15	0.80	0.88	0.45	0.67	1.30	1.37	0.54	0.72
Median 82-03	1.20	0.28	1.03	0.29	2.30	0.15	2.27	0.65	0.22	0.62	0.15	0.80	0.98	0.45	0.67	1.41	0.84	0.55	0.54
Min 82-03	0.83	0.22	0.62	0.23	1.58	0.12	1.66	0.43	0.20	0.47	0.15	0.58	0.75	0.32	0.34	0.76	0.07	0.32	0.33
Max 82-03	2.19	0.36	1.85	0.35	3.36	0.18	2.95	1.08	0.25	1.02	0.15	1.23	1.38	0.62	1.16	3.17	1.81	0.69	0.73
Mean 01-03	1.12	0.30	0.98	0.29	2.10	0.16	2.21	0.68	0.23	0.68	0.15	0.83	0.97	0.46	0.82	1.31	1.08	0.53	0.60

Table 7.3.1. Estimates and trends in estimates for lobsters (sexes combined) in SNE assuming M=0.15 (no change) during 1984-1996 and M=0.15 (no change), 0.4, 0.65, 0.9 y-1 during 1997-2003.
Trends were calculated from the original estimates by subtracting the series mean and dividing by the series standard deviation. All abundances in millions. Mortality estimates are instantaneous annual rates.

	Estimated Total Abundance				**Estimated Trend in Total Abundance**				**Estimated Recruit Abundance**				**Estimated Trend in Recruit Abundance**			
Year	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**
1984	14.53	15.37	16.11	16.69	-0.76	-0.83	-0.85	-0.85	8.42	8.81	9.16	9.44	-0.88	-0.93	-0.95	-0.94
1985	14.49	15.57	16.51	17.24	-0.76	-0.80	-0.80	-0.80	9.19	9.55	9.86	10.09	-0.73	-0.80	-0.84	-0.86
1986	18.31	19.05	19.79	20.43	-0.13	-0.30	-0.41	-0.49	13.18	13.00	12.95	12.95	0.06	-0.18	-0.38	-0.51
1987	14.74	15.53	16.31	16.97	-0.72	-0.80	-0.83	-0.83	6.97	7.13	7.27	7.39	-1.16	-1.22	-1.23	-1.20
1988	17.00	17.81	18.60	19.26	-0.35	-0.48	-0.55	-0.60	12.27	12.41	12.53	12.63	-0.12	-0.29	-0.44	-0.55
1989	23.21	24.30	25.26	26.04	0.69	0.46	0.24	0.07	18.59	18.99	19.29	19.50	1.12	0.88	0.58	0.31
1990	23.95	25.07	26.05	26.81	0.81	0.57	0.33	0.15	15.70	15.89	16.04	16.14	0.55	0.33	0.09	-0.11
1991	19.89	21.02	22.00	22.77	0.13	-0.01	-0.15	-0.25	11.78	11.96	12.11	12.23	-0.22	-0.37	-0.50	-0.60
1992	21.40	22.20	22.94	23.59	0.39	0.16	-0.04	-0.17	14.07	13.90	13.81	13.79	0.23	-0.02	-0.25	-0.40
1993	21.35	21.97	22.62	23.24	0.38	0.12	-0.07	-0.21	13.17	13.11	13.12	13.18	0.05	-0.16	-0.35	-0.48
1994	19.86	20.44	21.04	21.58	0.13	-0.10	-0.26	-0.37	11.98	12.03	12.07	12.09	-0.18	-0.36	-0.51	-0.61
1995	25.11	26.50	27.92	29.15	1.00	0.78	0.56	0.38	21.28	22.19	23.11	23.87	1.65	1.45	1.15	0.85
1996	30.19	33.53	37.11	40.33	1.85	1.79	1.65	1.48	22.89	25.03	27.40	29.57	1.96	1.95	1.80	1.56
1997	28.76	36.24	45.00	54.06	1.61	2.18	2.59	2.84	19.40	24.01	29.71	36.01	1.28	1.77	2.15	2.35
1998	25.64	30.97	36.44	41.47	1.09	1.42	1.57	1.59	17.55	20.94	25.15	29.92	0.91	1.23	1.46	1.60
1999	18.29	21.78	25.42	29.39	-0.13	0.10	0.26	0.40	12.24	14.70	18.08	22.50	-0.13	0.12	0.40	0.68
2000	14.87	18.98	23.85	29.28	-0.70	-0.31	0.07	0.39	10.83	14.39	19.14	24.65	-0.40	0.06	0.56	0.95
2001	12.12	14.95	17.89	20.85	-1.16	-0.89	-0.64	-0.44	7.27	9.06	11.30	13.97	-1.10	-0.88	-0.62	-0.38
2002	8.80	10.39	11.88	13.39	-1.71	-1.54	-1.35	-1.18	4.91	5.97	7.33	9.00	-1.57	-1.43	-1.22	-1.00
2003	9.08	10.58	12.27	14.21	-1.66	-1.52	-1.31	-1.10	6.13	7.57	9.44	11.65	-1.33	-1.15	-0.90	-0.67
Mean	19.08	21.11	23.25	25.34	0.00	0.00	0.00	0.00	12.89	14.03	15.44	17.03	0.00	0.00	0.00	0.00
Std. Dev.	6.01	6.94	8.40	10.12	1.00	1.00	1.00	1.00	5.09	5.63	6.64	8.06	1.00	1.00	1.00	1.00

Table 7.3.1 (cont.)

	Estimated Post-recruit Abundance				**Estimated Trend in Post-recruit Abundance**				**Estimated Annual Exploitation Rate**				**Estimated Trend in Annual Exploitation Rate**			
Year	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**
1984	6.12	6.56	6.95	7.25	-0.04	-0.23	-0.30	-0.32	0.54	0.51	0.49	0.47	-0.78	-0.38	-0.02	0.17
1985	5.30	6.02	6.65	7.15	-0.47	-0.46	-0.41	-0.34	0.55	0.52	0.49	0.47	-0.59	-0.32	-0.06	0.10
1986	5.13	6.05	6.85	7.47	-0.56	-0.45	-0.34	-0.25	0.48	0.46	0.44	0.43	-1.80	-1.29	-0.69	-0.35
1987	7.76	8.40	9.04	9.58	0.83	0.57	0.43	0.38	0.59	0.56	0.53	0.51	-0.02	0.42	0.59	0.64
1988	4.72	5.40	6.06	6.63	-0.78	-0.73	-0.61	-0.50	0.65	0.62	0.59	0.57	0.82	1.34	1.36	1.29
1989	4.62	5.31	5.98	6.54	-0.83	-0.77	-0.64	-0.53	0.55	0.53	0.51	0.49	-0.62	-0.13	0.23	0.40
1990	8.25	9.18	10.01	10.67	1.09	0.91	0.77	0.70	0.57	0.55	0.53	0.51	-0.33	0.18	0.48	0.61
1991	8.10	9.06	9.89	10.54	1.01	0.86	0.73	0.66	0.54	0.51	0.49	0.47	-0.85	-0.44	-0.07	0.14
1992	7.33	8.30	9.14	9.80	0.60	0.53	0.47	0.44	0.52	0.50	0.49	0.47	-1.08	-0.51	-0.04	0.20
1993	8.18	8.86	9.50	10.05	1.05	0.77	0.60	0.52	0.54	0.52	0.51	0.49	-0.85	-0.21	0.23	0.42
1994	7.88	8.41	8.97	9.49	0.90	0.58	0.41	0.35	0.73	0.71	0.69	0.68	2.20	2.95	2.77	2.50
1995	3.82	4.31	4.82	5.28	-1.25	-1.20	-1.05	-0.90	0.62	0.59	0.56	0.54	0.51	0.94	0.98	0.93
1996	7.31	8.50	9.71	10.76	0.59	0.62	0.67	0.73	0.60	0.54	0.49	0.45	0.17	0.13	0.00	-0.06
1997	9.37	12.22	15.29	18.05	1.68	2.23	2.63	2.90	0.64	0.51	0.41	0.34	0.70	-0.49	-1.14	-1.35
1998	8.09	10.04	11.29	11.55	1.01	1.28	1.23	0.96	0.69	0.57	0.48	0.43	1.48	0.57	-0.09	-0.36
1999	6.05	7.08	7.34	6.89	-0.07	0.00	-0.16	-0.42	0.70	0.59	0.51	0.44	1.73	0.92	0.21	-0.22
2000	4.04	4.59	4.71	4.63	-1.14	-1.08	-1.09	-1.09	0.59	0.46	0.37	0.30	-0.08	-1.24	-1.70	-1.81
2001	4.84	5.89	6.59	6.88	-0.71	-0.52	-0.43	-0.43	0.59	0.48	0.40	0.35	0.03	-0.89	-1.21	-1.28
2002	3.88	4.42	4.55	4.39	-1.22	-1.15	-1.15	-1.17	0.58	0.49	0.43	0.38	-0.23	-0.77	-0.86	-0.89
2003	2.95	3.01	2.82	2.56	-1.71	-1.76	-1.75	-1.71	0.57	0.49	0.42	0.36	-0.38	-0.79	-0.96	-1.08
Mean	6.19	7.08	7.81	8.31	0.00	0.00	0.00	0.00	0.59	0.53	0.49	0.46	0.00	0.00	0.00	0.00
Std. Dev.	1.89	2.31	2.84	3.36	1.00	1.00	1.00	1.00	0.06	0.06	0.07	0.09	1.00	1.00	1.00	1.00

Table 7.3.1 (cont.)

	Estimated Fishing Mortality				**Estimated Trends in Fishing Mortality**				**Estimated Total Mortality**				**Estimated Trends in Total Mortality**			
Year	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**	**M=0.15**	**M=0.4**	**M=0.65**	**M=0.9**
1984	0.87	0.81	0.75	0.72	-0.87	-0.78	-0.65	-0.55	1.02	0.96	0.90	0.87	-0.87	-0.96	-0.93	-0.89
1985	0.91	0.82	0.75	0.70	-0.70	-0.71	-0.67	-0.62	1.06	0.97	0.90	0.85	-0.70	-0.92	-0.94	-0.91
1986	0.72	0.68	0.65	0.62	-1.64	-1.50	-1.31	-1.16	0.87	0.83	0.80	0.77	-1.64	-1.50	-1.28	-1.12
1987	1.03	0.94	0.88	0.82	-0.10	0.05	0.13	0.16	1.18	1.09	1.03	0.97	-0.10	-0.35	-0.52	-0.61
1988	1.16	1.07	1.00	0.95	0.60	0.83	0.92	0.96	1.31	1.22	1.15	1.10	0.60	0.23	-0.10	-0.30
1989	0.91	0.85	0.80	0.77	-0.68	-0.51	-0.34	-0.22	1.06	1.00	0.95	0.92	-0.68	-0.77	-0.77	-0.76
1990	0.96	0.89	0.84	0.80	-0.46	-0.27	-0.10	0.04	1.11	1.04	0.99	0.95	-0.46	-0.59	-0.64	-0.66
1991	0.87	0.80	0.75	0.72	-0.90	-0.79	-0.65	-0.53	1.02	0.95	0.90	0.87	-0.90	-0.98	-0.93	-0.88
1992	0.87	0.82	0.78	0.75	-0.91	-0.69	-0.48	-0.33	1.02	0.97	0.93	0.90	-0.91	-0.90	-0.84	-0.80
1993	0.92	0.88	0.84	0.81	-0.62	-0.32	-0.09	0.05	1.07	1.03	0.99	0.96	-0.62	-0.62	-0.63	-0.65
1994	1.50	1.41	1.34	1.27	2.32	2.86	3.05	3.08	1.65	1.56	1.49	1.42	2.32	1.73	1.02	0.54
1995	1.09	1.00	0.92	0.86	0.25	0.38	0.40	0.39	1.24	1.15	1.07	1.01	0.25	-0.10	-0.38	-0.52
1996	1.03	0.87	0.75	0.67	-0.06	-0.36	-0.66	-0.86	1.18	1.02	0.90	0.82	-0.06	-0.66	-0.94	-1.01
1997	1.13	0.91	0.76	0.67	0.43	-0.16	-0.60	-0.82	1.28	1.31	1.41	1.57	0.43	0.60	0.78	0.93
1998	1.33	1.12	1.00	0.93	1.42	1.09	0.89	0.88	1.48	1.52	1.65	1.83	1.42	1.53	1.57	1.59
1999	1.45	1.24	1.10	1.00	2.04	1.81	1.58	1.32	1.60	1.64	1.75	1.90	2.04	2.07	1.93	1.76
2000	1.03	0.83	0.69	0.60	-0.08	-0.64	-1.05	-1.33	1.18	1.23	1.34	1.50	-0.08	0.25	0.54	0.72
2001	1.10	0.93	0.81	0.74	0.29	-0.06	-0.26	-0.37	1.25	1.33	1.46	1.64	0.29	0.67	0.95	1.10
2002	1.05	0.93	0.87	0.82	0.01	-0.01	0.09	0.17	1.20	1.33	1.52	1.72	0.01	0.72	1.14	1.31
2003	0.98	0.90	0.82	0.76	-0.33	-0.24	-0.20	-0.26	1.13	1.30	1.47	1.66	-0.33	0.54	0.99	1.14
Mean	1.05	0.94	0.86	0.80	0.00	0.00	0.00	0.00	1.20	1.17	1.18	1.21	0.00	0.00	0.00	0.00
Std. Dev.	0.20	0.17	0.16	0.15	1.00	1.00	1.00	1.00	0.20	0.23	0.30	0.39	1.00	1.00	1.00	1.00

Table 7.3.2. CSM model and data based stock assessment results for female and male lobsters in SNE (M=0.65).

Year	Recruit Abund. (Millions)	CV	Post-recruit Abund. (Millions)	CV	Total Abund. (Millions)	CV	3-Year Average (millions)	Fishing Mortality (F, y-1)	CV	3-Year Average (y-1)	Natural Mortality (M, y-1)	Total Mortality (Z, y-1)	Landings (millions)	Landings / Total Abund.	Stock Fraction Recruits	Landings Fraction Female	Recruits Fraction Female	Post-recruits Fraction Female	Stock Fraction Female
1984	9.16	0.20	6.95	0.28	16.11	0.13		0.75	0.17		0.15	0.90	7.87	0.49	0.57	0.56	0.54	0.76	0.64
1985	9.86	0.21	6.65	0.27	16.51	0.13		0.75	0.18		0.15	0.90	8.03	0.49	0.60	0.58	0.63	0.72	0.67
1986	12.95	0.17	6.85	0.28	19.79	0.11	17.47	0.65	0.14	0.72	0.15	0.80	8.71	0.44	0.65	0.57	0.61	0.75	0.66
1987	7.27	0.20	9.04	0.21	16.31	0.12	17.54	0.88	0.16	0.76	0.15	1.03	8.71	0.53	0.45	0.57	0.56	0.74	0.66
1988	12.53	0.18	6.06	0.27	18.60	0.12	18.23	1.00	0.17	0.84	0.15	1.15	10.96	0.59	0.67	0.57	0.54	0.78	0.62
1989	19.29	0.17	5.98	0.31	25.26	0.13	20.06	0.80	0.17	0.89	0.15	0.95	12.81	0.51	0.76	0.57	0.64	0.70	0.65
1990	16.04	0.17	10.01	0.27	26.05	0.11	23.30	0.84	0.15	0.88	0.15	0.99	13.68	0.53	0.62	0.59	0.61	0.75	0.66
1991	12.11	0.18	9.89	0.25	22.00	0.12	24.44	0.75	0.16	0.80	0.15	0.90	10.68	0.49	0.55	0.53	0.53	0.76	0.63
1992	13.81	0.19	9.14	0.25	22.94	0.11	23.66	0.78	0.15	0.79	0.15	0.93	11.19	0.49	0.60	0.55	0.64	0.73	0.67
1993	13.12	0.16	9.50	0.22	22.62	0.09	22.52	0.84	0.14	0.79	0.15	0.99	11.47	0.51	0.58	0.54	0.58	0.81	0.67
1994	12.07	0.13	8.97	0.20	21.04	0.09	22.20	1.34	0.15	0.99	0.15	1.49	14.58	0.69	0.57	0.54	0.38	0.83	0.57
1995	23.11	0.13	4.82	0.33	27.92	0.11	23.86	0.92	0.16	1.03	0.15	1.07	15.69	0.56	0.83	0.62	0.67	0.64	0.66
1996	27.40	0.16	9.71	0.28	37.11	0.13	28.69	0.75	0.17	1.00	0.15	0.90	18.20	0.49	0.74	0.59	0.64	0.72	0.66
1997	29.71	0.17	15.29	0.26	45.00	0.13	36.68	0.76	0.16	0.81	0.65	1.41	18.32	0.41	0.66	0.65	0.67	0.73	0.69
1998	25.15	0.14	11.29	0.27	36.44	0.11	39.52	1.00	0.14	0.84	0.65	1.65	17.63	0.48	0.69	0.58	0.59	0.73	0.63
1999	18.08	0.15	7.34	0.28	25.42	0.12	35.62	1.10	0.14	0.95	0.65	1.75	12.87	0.51	0.71	0.47	0.50	0.72	0.57
2000	19.14	0.21	4.71	0.33	23.85	0.17	28.57	0.69	0.17	0.93	0.65	1.34	8.73	0.37	0.80	0.54	0.66	0.73	0.68
2001	11.30	0.19	6.59	0.32	17.89	0.15	22.39	0.81	0.14	0.87	0.65	1.46	7.20	0.40	0.63	0.52	0.61	0.79	0.68
2002	7.33	0.23	4.55	0.30	11.88	0.17	17.87	0.87	0.17	0.79	0.65	1.52	5.08	0.43	0.62	0.46	0.46	0.83	0.61
2003	9.44	0.209	2.82	0.377	12.27	0.171	14.01	0.82	0.174	0.84	0.65	1.47	5.15	0.42	0.77	0.51	0.58	0.77	0.62
Median 82-03	13.03	0.17	7.14	0.27	22.31	0.12	22.91	0.82	0.16	0.84	0.15	1.05	11.08	0.49	0.64	0.56	0.60	0.75	0.66
Min 82-03	7.27	0.13	2.82	0.20	11.88	0.09	14.01	0.65	0.14	0.72	0.15	0.80	5.08	0.37	0.45	0.46	0.38	0.64	0.57
Max 82-03	29.71	0.23	15.29	0.38	45.00	0.17	39.52	1.34	0.18	1.03	0.65	1.75	18.32	0.69	0.83	0.65	0.67	0.83	0.69
Mean 01-03	9.36	0.21	4.65	0.33	14.01	0.16	18.09	0.84	0.16	0.83	0.65	1.49	5.81	0.42	0.67	0.50	0.55	0.80	0.63

Table 7.4.1. Sensitivity of recent abundance and fishing mortality estimates for female lobster to the weight λ_η placed on recruit abundance data.
The weight on post-recruit abundance data λ_δ=1 in all cases. Runs for SNE survey areas used M=0.4 y-1 during 1997-2003. Runs were preliminary and results with λ_δ=1 may differ from best estimates. Percent range was computed as the absolute value of the range divided by the estimate with λ_δ=1. Preliminary models were used for sensitivity analysis; point estimates may differ from final estimates elsewhere in the assessment.

	Weight on Recruit Abundance Index (λ_η)			Percent Range
Survey area	0.25	1	4	
Average Abundance 2001-2003 (millions)				
GBK	7.28	6.95	6.33	14%
GOM-MA	4.48	5.43	4.58	2%
GOM-NEFSC	61.87	60.63	60.42	2%
SNE-CT	0.84	0.85	0.87	4%
SNE-NEFSC	3.60	4.19	4.69	26%
SNE-RI	0.89	1.12	1.12	21%
Average Fishing Mortality 2001-2003 (y^{-1})				
GBK	0.16	0.17	0.19	16%
GOM-MA	2.30	1.81	2.67	20%
GOM-NEFSC	0.57	0.59	0.62	8%
SNE-CT	2.32	2.25	2.08	10%
SNE-NEFSC	0.60	0.49	0.43	36%
SNE-RI	1.83	1.16	1.22	52%

Estimate	GOM	GBS	SCCLIS
Results from last assessment for comparison			
$F_{10\%}$ (with encounter rate at $F_{10\%}$ in parentheses) using old life history model, old growth parameters, and 1998 management measures (from ASMFC 2000, p. 73)	0.34 (0.63)	0.29 (0.44)	0.84 (1.4)
Average female F during 1995-1997 (with percent maximum egg production per recruit in parentheses) using old CSM and old growth parameters (from ASMFC 2000)	0.74 (3.2%)	0.41 (6.2%)	1.25 (8.3%)
New turn of the crank assessment results			
$F_{10\%}$ (with encounter rate at $F_{10\%}$ in parentheses) using updated life history model, growth parameters, and 1998 management measures	0.28 (0.56)	0.20 (0.30)	0.37 (0.69)
$F_{10\%}$ (with encounter rate at $F_{10\%}$ in parentheses) using updated life history model, updated growth parameters, and current management measures	0.31 (0.79)	0.21 (0.31)	0.36 (0.72)
Average female F during 2001-2003 (with percent maximum egg production per recruit in parentheses) using updated CSM model and growth parameters	0.65 (4.3%)	0.21 (10%)	1.06 (5.4%)

Table 7.7.1. Turn of the crank stock assessment results for comparison to results from the last stock assessment (ASMFC 2000).

Management measures during 1998 include: 1) GOM: 83 mm minimum size, 1 $^{15}/_{16}$ inch escape vent, 127 mm maximum size affecting 71% of catch, and 35% v-notching (if 71% of catch is affected by regulations and 50% of fishermen v-notch, then the v-notching rate is approximately 0.71 x 0.5 or 35%); 2) GBS: 83 mm minimum size, and 1 $^{15}/_{16}$ inch escape vent; and 3) SCCLIS: 83 mm minimum size, and 1 $^{15}/_{16}$ inch escape vent. Current management measures include: 1) GOM: 83 mm minimum size, 1 $^{15}/_{16}$ inch escape vent, 127 mm maximum size affecting 100% of catch, and 100% v-notching; 2) GBS: 86 mm minimum size and 2 inch escape vent; and 3) SCCLIS: 83 mm min size and 2 inch escape vent. Maturity parameters from ASMFC (2000) used in all model runs.

Table 8.2.1 Stock indicators for the Gulf of Maine stock area during 1982-2003.
The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

Stock Indicators - GOM	*Mortality Indicators*				*Abundance Indicators*				*Fishery Performance Indicators*			
	1. Exploitation Rate (catch/abundance)	2. Z (model)	3. Mean Length (survey 83mm +)	4. Percent of the Exploitable Stock Comprised of Recruits (surveys)	5. Spawning Stock Abundance Index	6. Recruit Abundance (sexes combined Model)	7. Full Recruit Abundance (blended/sex combined index)	8. Settlement Index Central GOM (Mid-Coast Maine)	9. Effort (traps)	10. Landings (mt)	11. Mean Length (Landings)	12. Gross CPUE (pounds per trap fished)
1982	0.57	1.08	98.8	0.71	2.43	32.95	13.16		2,390,415	14,669	89.35	13.53
1983	0.57	1.08	92.9	0.72	3.83	32.90	13.09		2,599,642	15,069	89.35	12.78
1984	0.46	0.84	96.7	0.71	5.42	37.85	15.58		2,450,165	13,797	89.12	12.41
1985	0.55	1.05	96.3	0.51	9.35	23.99	23.17		2,079,758	14,558	89.02	15.43
1986	0.51	0.93	96.8	0.67	6.97	34.01	16.63		1,926,713	13,816	89.06	15.81
1987	0.48	0.86	92.1	0.61	5.20	30.68	19.99		2,265,169	13,952	88.83	13.58
1988	0.61	1.19	93.1	0.50	5.02	21.02	21.43		2,409,689	14,696	88.45	13.45
1989	0.55	1.03	96.5	0.75	4.21	39.48	13.01	1.64	2,396,941	16,708	88.68	15.37
1990	0.53	1.00	92.6	0.69	7.28	42.74	18.83	0.77	2,545,777	19,244	88.92	16.67
1991	0.57	1.09	92.4	0.63	7.24	39.39	22.85	1.54	2,444,711	20,215	88.97	18.23
1992	0.57	1.10	97.4	0.62	6.05	33.79	20.91	1.30	2,434,537	17,738	88.89	16.06
1993	0.53	0.97	97.0	0.69	7.35	40.96	18.29	0.45	2,222,578	18,802	89.19	18.65
1994	0.54	1.01	92.8	0.67	6.26	46.44	22.49	1.61	2,821,359	23,869	89.45	18.65
1995	0.43	0.77	97.4	0.74	7.39	69.76	25.01	0.66	3,025,934	23,001	89.51	16.76
1996	0.46	0.82	95.8	0.45	13.21	35.69	43.76	0.47	2,908,361	22,155	89.17	16.79
1997	0.45	0.80	103.1	0.64	12.06	61.92	34.92	0.46	3,036,822	26,726	89.28	19.40
1998	0.48	0.87	95.7	0.54	15.67	51.36	43.47	0.14	3,258,231	25,836	89.49	17.48
1999	0.44	0.80	100.2	0.62	13.33	66.01	39.87	0.65	3,461,777	30,038	89.78	19.13
2000	0.49	0.89	95.1	0.58	20.45	67.48	47.93	0.13	3,202,571	31,845	90.05	21.92
2001	0.41	0.74	101.4	0.57	18.06	63.71	47.95	2.08	3,388,671	26,517	89.74	17.25
2002	0.42	0.75	102.9	0.57	24.32	72.11	53.56	1.38	3,515,509	33,806	89.78	21.20
2003	0.33	0.58	107.3	0.58	30.61	82.73	59.90	1.75	3,623,066	29,198	89.9	17.77
2001-03 Avg.	0.39	0.69	103.8	0.57	24.33	72.85	53.80	1.74	3,509,082	29,840	90	19
Median	*0.49*	*0.89*	*96.75*	*0.62*	*7.35*	*40.96*	*22.85*	*1.03*	*2,599,642*	*20,215*	*89.28*	*16.79*
25th	*0.45*	*0.81*	*96.6*	*0.58*	*5.57*	*33.84*	*18.42*	*0.47*	*2,400,128*	*14,789*	*89*	*15*
75th	*0.55*	*1.04*	*98.5*	*0.69*	*13.30*	*63.26*	*42.57*	*1.57*	*3,161,134*	*26,347*	*90*	*19*

Table 8.2.2 Stock indicators for the Georges Bank stock area during 1982-2003.
The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

Stock Indicators GBK	*Mortality Indicators*				*Abundance Indicators*			*Fishery Performance Indicators*			
	1. Exploitation Rate (catch/abundance)	2. Z (model)	3. Mean Length (Survey - 83+ legals only)	4. Percent of the Exploitable Stock Comprised of Recruits (surveys)	5. Spawning Stock Abundance Index	6. Recruit Abundance (sexes combined Model)	7. Full-recruit Abundance (blended/sex combined index)	8. Effort Index (# traps fished on GBK by MA only)	9. Landings	10. Mean Length (Landings)	11. Gross CPUE (pounds per trap fished)
1982	0.29	0.54	113.26	0.36	2.02	2.39	4.18	27,560	1,273	99.34	101.87
1983	0.25	0.46	116.10	0.40	1.74	2.60	3.88	28,922	1,447	102.53	110.31
1984	0.28	0.53	104.62	0.40	1.49	2.73	4.10	30,651	1,496	104.72	107.59
1985	0.28	0.53	111.75	0.37	2.43	2.42	4.09	34,950	1,489	101.54	93.89
1986	0.24	0.47	107.02	0.48	1.64	3.56	3.92	36,950	1,243	97.82	74.15
1987	0.23	0.44	110.45	0.47	2.18	4.18	4.75	39,674	1,316	98.93	73.14
1988	0.22	0.42	107.29	0.29	2.43	2.35	5.77	39,732	1,417	98.24	78.61
1989	0.25	0.47	113.62	0.32	2.90	2.47	5.36	39,163	1,326	98.79	74.66
1990	0.28	0.53	112.50	0.42	2.62	3.60	4.92	35,891	1,430	97.97	87.87
1991	0.29	0.58	111.63	0.35	3.11	2.73	5.16	36,784	1,580	97.48	94.69
1992	0.27	0.54	113.48	0.50	2.88	4.65	4.67	38,745	1,703	96.73	96.90
1993	0.29	0.57	109.86	0.34	3.45	2.91	5.69	43,041	1,545	95.15	79.13
1994	0.27	0.51	113.46	0.23	3.51	1.57	5.14	47,894	1,443	95.35	66.41
1995	0.27	0.51	118.07	0.38	2.76	2.52	4.12	44,480	1,215	96.59	60.23
1996	0.30	0.55	123.80	0.34	2.85	2.12	4.04	42,008	1,134	96.86	59.50
1997	0.24	0.45	110.49	0.55	1.84	4.42	3.58	40,974	1,229	95.1	66.13
1998	0.23	0.44	115.35	0.39	3.14	3.31	5.12	45,327	1,212	95.27	58.93
1999	0.26	0.50	119.39	0.26	3.31	1.95	5.49	47,941	1,472	101.11	67.71
2000	0.22	0.43	115.11	0.49	2.84	4.38	4.62	41,464	1,214	96.41	64.55
2001	0.24	0.47	116.95	0.34	3.83	3.09	5.95	40,899	1,422	96.53	76.65
2002	0.21	0.42	117.18	0.36	3.92	3.21	5.81	47,387	1,568	99	72.97
2003	0.21	0.42	111.64	0.34	4.20	3.08	6.00	42,834	1,427	99.77	73.43
2001-03 Avg.	0.22	0.44	115.25	0.35	3.99	3.13	5.92	43,707	1,472	98.4	74
Median	*0.25*	*0.47*	*113.46*	*0.36*	*2.85*	*2.91*	*4.92*	*40,899*	*1,427*	*97.97*	*74.35*
25th	*0.23*	*0.45*	*113.36*	*0.34*	*2.24*	*2.43*	*4.10*	*36,825*	*1,250*	*96.5*	*67*
75th	*0.28*	*0.53*	*115.91*	*0.42*	*3.27*	*3.50*	*5.46*	*42,989*	*1,484*	*99.3*	*92*

Table 8.2.3.1 Stock indicators for the Southern New England stock are during the period of 1984 through 2003 at four different levels of M (0.15 (no change), 0.4, 0.65 and 0.9).
The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series

Stock Indicators SNE M = 0.15	Modeled natural mortality	*Mortality Indicators*					*Abundance Indicators*				*Fishery Performance Indicators*			
		1. Exploitation Rate (catch/abundance)	2. Z (model)	3. v (expection of natural death)	4. Mean Length (Survey - 83+ legals only)	5. Percent of the Exploitable Stock Comprised of	6. Spawning Stock Abundance Index (m=0.15)	7. Recruit Abundance (sexes combined	8. Full-recruit Abundance (blended/sex combined index)	9. Settlement Index Rhode Island Sound	10. Effort(traps)	11. Landings	12. Mean Length (Landings)	13. Gross CPUE (pounds per trap fished)
1984	0.15	0.54	1.02	0.09		0.58	5.21	8.42	6.12		206,254	4,254	90.7	45.48
1985	0.15	0.55	1.06	0.09		0.63	4.908	9.19	5.30		234,603	3,960	88.4	37.22
1986	0.15	0.48	0.87	0.10	94.71	0.72	5.160	13.18	5.13		216,000	4,383	88.3	44.74
1987	0.15	0.59	1.18	0.09	94.72	0.47	6.522	6.97	7.76		218,963	4,457	87.6	44.88
1988	0.15	0.65	1.31	0.08	97.98	0.72	5.665	12.27	4.72		269,178	4,752	87.7	38.92
1989	0.15	0.55	1.06	0.09	93.73	0.80	7.101	18.59	4.62		351,329	5,940	88.5	37.27
1990	0.15	0.57	1.11	0.09	95.93	0.66	8.634	15.70	8.25	1.25	330,766	7,620	88.7	50.79
1991	0.15	0.54	1.02	0.09	94.28	0.59	7.289	11.78	8.10	1.49	372,465	7,085	89.2	41.94
1992	0.15	0.52	1.02	0.09	95.15	0.66	7.356	14.07	7.33	0.63	435,720	6,233	88.8	31.54
1993	0.15	0.54	1.07	0.09	97.79	0.62	8.291	13.17	8.18	0.51	538,842	6,008	88.7	24.58
1994	0.15	0.73	1.65	0.07	93.18	0.60	7.353	11.98	7.88	1.23	612,304	6,757	88.2	24.33
1995	0.15	0.62	1.24	0.09	92.21	0.85	6.418	21.28	3.82	0.33	578,426	8,070	87.9	30.76
1996	0.15	0.60	1.18	0.09	93.47	0.76	9.240	22.89	7.31	0.15	702,420	9,130	87.7	28.65
1997	0.15	0.64	1.28	0.08	88.94	0.67	9.864	19.40	9.37	0.99	750,434	10,054	87.7	29.54
1998	0.15	0.69	1.48	0.08	92.54	0.68	8.455	17.55	8.09	0.57	826,038	9,757	87.8	26.04
1999	0.15	0.70	1.60	0.07	93.62	0.67	5.731	12.24	6.05	0.92	845,862	9,492	87.6	24.74
2000	0.15	0.59	1.18	0.09	91.69	0.73	5.057	10.83	4.04	0.34	559,786	6,207	87.9	24.44
2001	0.15	0.59	1.25	0.09	89.59	0.60	5.011	7.27	4.84	0.75	568,583	4,430	87.9	17.18
2002	0.15	0.58	1.20	0.09	94.88	0.56	4.033	4.91	3.88	0.25	441,096	3,636	88.1	18.17
2003	0.15	0.57	1.13	0.09	94.97	0.68	3.365	6.13	2.95	0.79	313,616	2,754	88.6	19.36
2001-03 Avg.		0.58	1.19	0.09	93.15	0.61	4.136	6.11	3.89	0.60	441,098	3,606	88.2	18.24
Median		*0.58*	*1.18*	*0.09*	*93.73*	*0.66*	*6.42*	*12.24*	*6.05*	*0.63*	*441,096*	*6,008*	*88.2*	*29.5*
25th		*0.55*	*1.06*	*0.09*	*92.70*	*0.60*	*5.13*	*9.00*	*4.69*	*0.39*	*302,507*	*4,419*	*87.7*	*24.5*
75th		*0.63*	*1.26*	*0.09*	*94.95*	*0.72*	*7.59*	*16.17*	*7.94*	*0.97*	*586,895*	*7,732*	*88.6*	*39.7*

Table 8.2.3.1 continued.

Stock Indicators SNE M = 0.4	Modeled natural mortality	*Mortality Indicators*					*Abundance Indicators*				*Fishery Performance Indicators*			
		1. Exploitation Rate (catch/abundance)	2. Z (model)	3. v (expection of natural death)	4. Mean Length (Survey - 83+ legals only)	5. Percent of the Exploitable Stock Comprised of Recruits (surveys)	6. Spawning Stock Abundance Index	7. Recruit Abundance (sexes combined Model)	8. Full-recruit Abundance (blended/sex combined index)	9. Settlement Index Rhode Island Sound	10. Effort(traps)	11. Landings	12. Mean Length (Landings)	13. Gross CPUE (pounds per trap fished)
1984	0.15	0.51	0.96	0.09		0.57	5.61	8.81	6.56		206,254	4,254	90.7	45.48
1985	0.15	0.52	0.97	0.09		0.61	5.55	9.55	6.02		234,603	3,960	88.4	37.22
1986	0.15	0.46	0.83	0.09	94.71	0.68	5.87	13.00	6.05		216,000	4,383	88.3	44.74
1987	0.15	0.56	1.09	0.08	94.72	0.46	7.07	7.13	8.40		218,963	4,457	87.6	44.88
1988	0.15	0.62	1.22	0.08	97.98	0.70	6.25	12.41	5.40		269,178	4,752	87.7	38.92
1989	0.15	0.53	1.00	0.08	93.73	0.78	7.77	18.99	5.31		351,329	5,940	88.5	37.27
1990	0.15	0.55	1.04	0.08	95.93	0.63	9.40	15.89	9.18	1.25	330,766	7,620	88.7	50.79
1991	0.15	0.51	0.95	0.09	94.28	0.57	8.12	11.96	9.06	1.49	372,465	7,085	89.2	41.94
1992	0.15	0.50	0.97	0.08	95.15	0.63	8.10	13.90	8.30	0.63	435,720	6,233	88.8	31.54
1993	0.15	0.52	1.03	0.07	97.79	0.60	8.81	13.11	8.86	0.51	538,842	6,008	88.7	24.58
1994	0.15	0.71	1.56	0.07	93.18	0.59	7.78	12.03	8.41	1.23	612,304	6,757	88.2	24.33
1995	0.15	0.59	1.15	0.08	92.21	0.84	7.09	22.19	4.31	0.33	578,426	8,070	87.9	30.76
1996	0.15	0.54	1.02	0.09	93.47	0.75	10.82	25.03	8.50	0.15	702,420	9,130	87.7	28.65
1997	0.40	0.51	1.31	0.21	88.94	0.66	13.06	24.01	12.22	0.99	750,434	10,054	87.7	29.54
1998	0.40	0.57	1.52	0.19	92.54	0.68	10.69	20.94	10.04	0.57	826,038	9,757	87.8	26.04
1999	0.40	0.59	1.64	0.17	93.62	0.67	7.01	14.70	7.08	0.92	845,862	9,492	87.6	24.74
2000	0.40	0.46	1.23	0.19	91.69	0.76	6.49	14.39	4.59	0.34	559,786	6,207	87.9	24.44
2001	0.40	0.48	1.33	0.17	89.59	0.61	6.38	9.06	5.89	0.75	568,583	4,430	87.9	17.18
2002	0.40	0.49	1.33	0.18	94.88	0.57	4.81	5.97	4.42	0.25	441,096	3,636	88.1	18.17
2003	0.40	0.49	1.30	0.19	94.97	0.72	3.74	7.57	3.01	0.79	313,616	2,754	88.6	19.36
2001-03 Avg.		0.49	1.32	0.18	93.15	0.63	4.98	7.53	4.44	0.60	441,098	3,606	88.2	18.24
Median		*0.52*	*1.15*	*0.09*	*93.73*	*0.61*	*7.07*	*13.00*	*6.56*	*0.63*	*441,096*	*6,008*	*88.2*	*29.5*
25th		*0.50*	*0.99*	*0.08*	*92.70*	*0.59*	*6.15*	*9.43*	*5.38*	*0.39*	*302,507*	*4,419*	*87.7*	*24.5*
75th		*0.56*	*1.31*	*0.18*	*94.95*	*0.70*	*8.29*	*16.67*	*8.59*	*0.97*	*586,895*	*7,732*	*88.6*	*39.7*

Table 8.2.3.1 continued.

Stock Indicators SNE M = 0.65	Modeled natural mortality	*Mortality Indicators*					*Abundance Indicators*				*Fishery Performance Indicators*			
		1. Exploitation Rate (catch/abundance)	2. Z (model)	3. v (expection of natural death)	4. Mean Length (Survey - 83+ legals only)	5. Percent of the Exploitable Stock Comprised of Recruits (surveys)	6. Spawning Stock Abundance Index	7. Recruit Abundance (sexes combined Model)	8. Full-recruit Abundance (blended/sex combined index)	9. Settlement Index Rhode Island Sound	10. Effort(traps)	11. Landings	12. Mean Length (Landings)	13. Gross CPUE (pounds per trap fished)
1984	0.15	0.49	0.90	0.10		0.57	5.95	9.16	6.95		206,254	4,254	90.7	45.48
1985	0.15	0.49	0.90	0.10		0.60	6.10	9.86	6.65		234,603	3,960	88.4	37.22
1986	0.15	0.44	0.80	0.10	94.71	0.65	6.47	12.95	6.85		216,000	4,383	88.3	44.74
1987	0.15	0.53	1.03	0.09	94.72	0.45	7.60	7.27	9.04		218,963	4,457	87.6	44.88
1988	0.15	0.59	1.15	0.09	97.98	0.67	6.80	12.53	6.06		269,178	4,752	87.7	38.92
1989	0.15	0.51	0.95	0.10	93.73	0.76	8.37	19.29	5.98		351,329	5,940	88.5	37.27
1990	0.15	0.53	0.99	0.10	95.93	0.62	10.05	16.04	10.01	1.25	330,766	7,620	88.7	50.79
1991	0.15	0.49	0.90	0.10	94.28	0.55	8.81	12.11	9.89	1.49	372,465	7,085	89.2	41.94
1992	0.15	0.49	0.93	0.10	95.15	0.60	8.73	13.81	9.14	0.63	435,720	6,233	88.8	31.54
1993	0.15	0.51	0.99	0.10	97.79	0.58	9.30	13.12	9.50	0.51	538,842	6,008	88.7	24.58
1994	0.15	0.69	1.49	0.08	93.18	0.57	8.23	12.07	8.97	1.23	612,304	6,757	88.2	24.33
1995	0.15	0.56	1.07	0.09	92.21	0.83	7.77	23.11	4.82	0.33	578,426	8,070	87.9	30.76
1996	0.15	0.49	0.90	0.10	93.47	0.74	12.43	27.40	9.71	0.15	702,420	9,130	87.7	28.65
1997	0.65	0.41	1.41	0.35	88.94	0.66	16.58	29.71	15.29	0.99	750,434	10,054	87.7	29.54
1998	0.65	0.48	1.65	0.32	92.54	0.69	12.49	25.15	11.29	0.57	826,038	9,757	87.8	26.04
1999	0.65	0.51	1.75	0.31	93.62	0.71	7.81	18.08	7.34	0.92	845,862	9,492	87.6	24.74
2000	0.65	0.37	1.34	0.36	91.69	0.80	7.89	19.14	4.71	0.34	559,786	6,207	87.9	24.44
2001	0.65	0.40	1.46	0.34	89.59	0.63	7.55	11.30	6.59	0.75	568,583	4,430	87.9	17.18
2002	0.65	0.43	1.52	0.33	94.88	0.62	5.31	7.33	4.55	0.25	441,096	3,636	88.1	18.17
2003	0.65	0.42	1.47	0.34	94.97	0.77	4.01	9.44	2.82	0.79	313,616	2,754	88.6	19.36
2001-03 Avg.		0.42	1.49	0.34	93.15	0.67	5.62	9.36	4.65	0.60	441,098	3,606	88.2	18.24
Median		*0.49*	*1.07*	*0.10*	*93.73*	*0.65*	*7.81*	*12.95*	*6.95*	*0.63*	*441,096*	*6,008*	*88.2*	*29.5*
25th		*0.44*	*0.92*	*0.10*	*92.70*	*0.59*	*6.72*	*10.94*	*6.04*	*0.39*	*302,507*	*4,419*	*87.7*	*24.5*
75th		*0.51*	*1.47*	*0.32*	*94.95*	*0.72*	*8.93*	*19.18*	*9.55*	*0.97*	*586,895*	*7,732*	*88.6*	*39.7*

Table 8.2.3.1 continued.

Stock Indicators SNE M = 0.9	Modeled natural mortality	*Mortality Indicators* 1. Exploitation Rate (catch/abundance)	2. Z (model)	3. v (expection of natural death)	4. Mean Length (Survey - 83+ legals only)	5. Percent of the Exploitable Stock Comprised of Recruits (surveys)	*Abundance Indicators* 6. Spawning Stock Abundance Index	7. Recruit Abundance (sexes combined Model)	8. Full-recruit Abundance (blended/sex combined index)	9. Settlement Index Rhode Island Sound	*Fishery Performance Indicators* 10. Effort(traps)	11. Landings	12. Mean Length (Landings)	13. Gross CPUE (pounds per trap fished)
1984	0.15	0.47	0.87	0.10		0.57	6.21	9.44	7.25		206,254	4,254	90.7	45.48
1985	0.15	0.47	0.85	0.10		0.59	6.50	10.09	7.15		234,603	3,960	88.4	37.22
1986	0.15	0.43	0.77	0.10	94.71	0.63	6.92	12.95	7.47		216,000	4,383	88.3	44.74
1987	0.15	0.51	0.97	0.10	94.72	0.44	8.03	7.39	9.58		218,963	4,457	87.6	44.88
1988	0.15	0.57	1.10	0.09	97.98	0.66	7.25	12.63	6.63		269,178	4,752	87.7	38.92
1989	0.15	0.49	0.92	0.10	93.73	0.75	8.84	19.50	6.54		351,329	5,940	88.5	37.27
1990	0.15	0.51	0.95	0.10	95.93	0.60	10.54	16.14	10.67	1.25	330,766	7,620	88.7	50.79
1991	0.15	0.47	0.87	0.10	94.28	0.54	9.33	12.23	10.54	1.49	372,465	7,085	89.2	41.94
1992	0.15	0.47	0.90	0.10	95.15	0.58	9.22	13.79	9.80	0.63	435,720	6,233	88.8	31.54
1993	0.15	0.49	0.96	0.10	97.79	0.57	9.72	13.18	10.05	0.51	538,842	6,008	88.7	24.58
1994	0.15	0.68	1.42	0.08	93.18	0.56	8.62	12.09	9.49	1.23	612,304	6,757	88.2	24.33
1995	0.15	0.54	1.01	0.09	92.21	0.82	8.34	23.87	5.28	0.33	578,426	8,070	87.9	30.76
1996	0.15	0.45	0.82	0.10	93.47	0.73	13.78	29.57	10.76	0.15	702,420	9,130	87.7	28.65
1997	0.9	0.34	1.57	0.45	88.94	0.67	19.81	36.01	18.05	0.99	750,434	10,054	87.7	29.54
1998	0.9	0.43	1.83	0.41	92.54	0.72	13.52	29.92	11.55	0.57	826,038	9,757	87.8	26.04
1999	0.9	0.44	1.90	0.40	93.62	0.77	8.24	22.50	6.89	0.92	845,862	9,492	87.6	24.74
2000	0.9	0.30	1.50	0.47	91.69	0.84	9.31	24.65	4.63	0.34	559,786	6,207	87.9	24.44
2001	0.9	0.35	1.64	0.44	89.59	0.67	8.45	13.97	6.88	0.75	568,583	4,430	87.9	17.18
2002	0.9	0.38	1.72	0.43	94.88	0.67	5.65	9.00	4.39	0.25	441,096	3,636	88.1	18.17
2003	0.9	0.36	1.66	0.44	94.97	0.82	4.30	11.65	2.56	0.79	313,616	2,754	88.6	19.36
2001-03 Avg.		0.36	1.68	0.44	93.15	0.72	6.13	11.54	4.61	0.60	441,098	3,606	88.2	18.24
Median		*0.47*	*1.01*	*0.10*	*93.73*	*0.67*	*8.45*	*13.18*	*7.25*	*0.63*	*441,096*	*6,008*	*88.2*	*29.5*
25th		*0.41*	*0.89*	*0.10*	*92.70*	*0.58*	*7.17*	*11.98*	*6.60*	*0.39*	*302,507*	*4,419*	*87.7*	*24.5*
75th		*0.50*	*1.59*	*0.42*	*94.95*	*0.74*	*9.42*	*22.84*	*10.17*	*0.97*	*586,895*	*7,732*	*88.6*	*39.7*

Table 8.2.3.2 Stock Indicators for all runs of M ((0.15 (no change), 0.4, 0.65 and 0.9).

Stock Indicators Comparison SNE	2001 to 2003 Mean			
	M = 0.15	M = 0.4	M = 0.65	M = 0.9
Mortality Indicators				
1. Exploitation Rate (catch/abundance)	0.58	0.49	0.42	0.36
2. Z (model)	1.19	1.32	1.49	1.68
3. v (expection of natural death)	0.09	0.18	0.34	0.44
4. Mean Length (Survey - 83+ legals only)	93.15	93.15	93.15	93.15
5. Percent of the Exploitable Stock Comprised of Recruits (surveys)	0.66	0.63	0.67	0.72
Abundance Indicators				
6. Spawning Stock Abundance Index (m = 0.15)	4.136	4.98	5.62	6.13
7. Recruit Abundance (sexes combined Model)	6.11	7.53	9.36	11.54
8. Full-recruit Abundance (blended/sex combined index)	3.89	4.44	4.65	4.61
9. Settlement Index Rhode Island Sound	0.60	0.60	0.60	0.60
Fishery Performance Indicators				
10. Effort(traps)	441,098	441,098	441,098	441,098
11. Landings	3,606	3,606	3,606	3,606
12. Mean Length (Landings)	88.2	88.2	88.2	88.2
13. Gross CPUE (pounds per trap fished)	18.24	18.24	18.24	18.24

Table 9.2.1. New recommended target and threshold reference points with stock status variables for lobster in each stock area.

Recent fishing mortality rates and abundances are averages for sexes combined during 2001-2003. Estimates for 2003 in GOM were affected by Massachusetts and NEFSC bottom trawl survey data that may be anomalously low. Therefore, average fishing mortality and abundance during 2000-2002 was also calculated for GOM. For simplicity, results for SNE are presented only for the run with natural mortality M=0.65 during 1997-2003. Presentation of results for M=0.65 does not imply choice of a best estimate of natural mortality. Management advice assuming other levels of natural mortality was the same.

Variable	GOM	GBK	SNE
Fishing mortality			
Fishing mortality threshold	0.76	0.34	0.82
Fishing mortality target	0.67	0.31	0.74
Recent fishing mortality 2001-2003	0.69	0.29	0.84
Recent fishing mortality 2000-2002	0.54	NA	NA
Fishing mortality below threshold?	Yes	Yes	No
Fishing mortality near or below target?	Yes	Yes	No
Abundance			
Abundance threshold	65.58	7.95	22.31
Abundance target	69.62	8.61	23.90
Recent abundance 2001-2003	123.12	9.05	14.01
Recent abundance 2001-2003	126.65	NA	NA
Abundance above threshold?	Yes	Yes	No
Abundance near or above target?	Yes	Yes	No

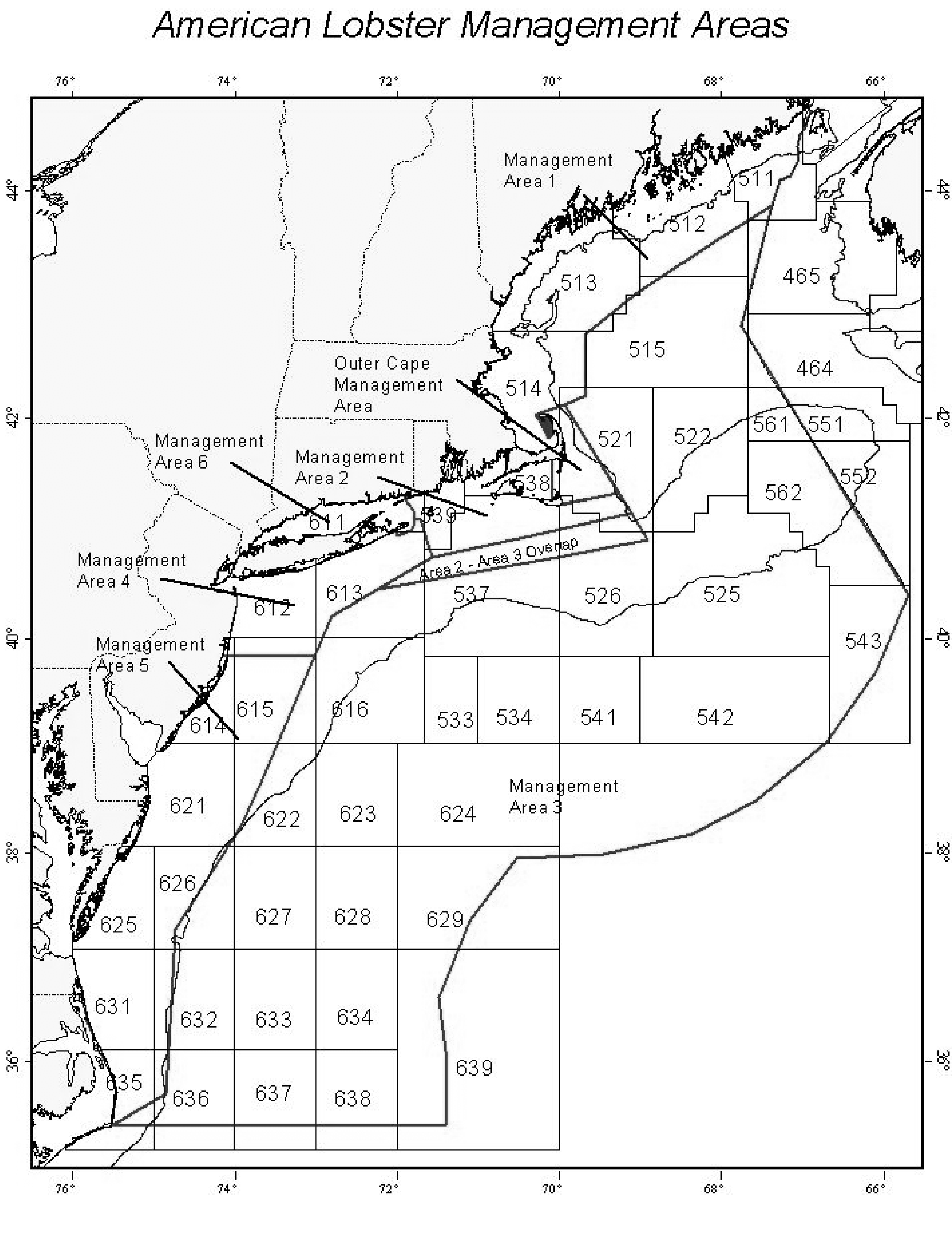


Figure 1.1. American Lobster Management Areas.

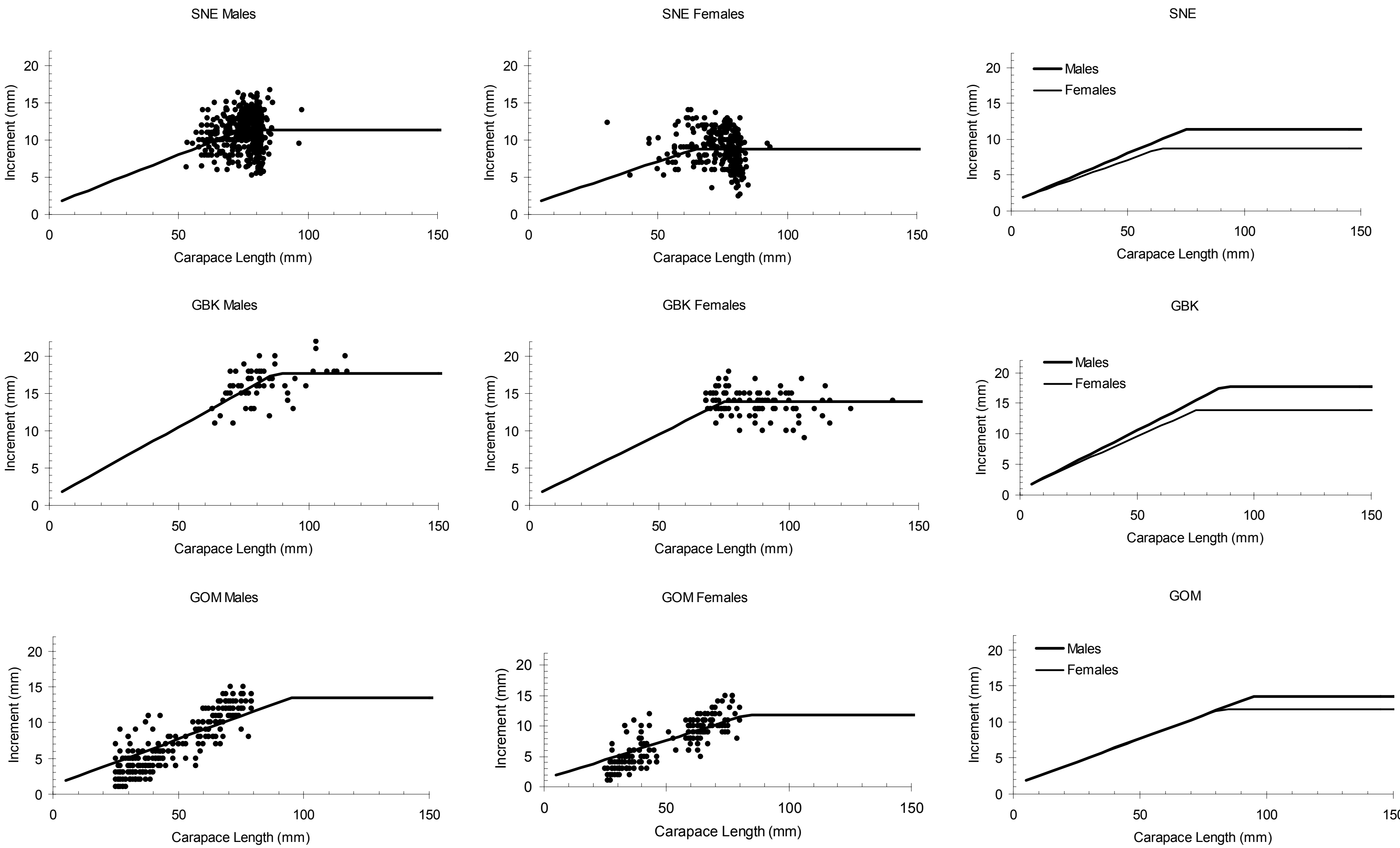


Figure 2.2.2.1. Molt increment models fit to tagging data for American lobster.

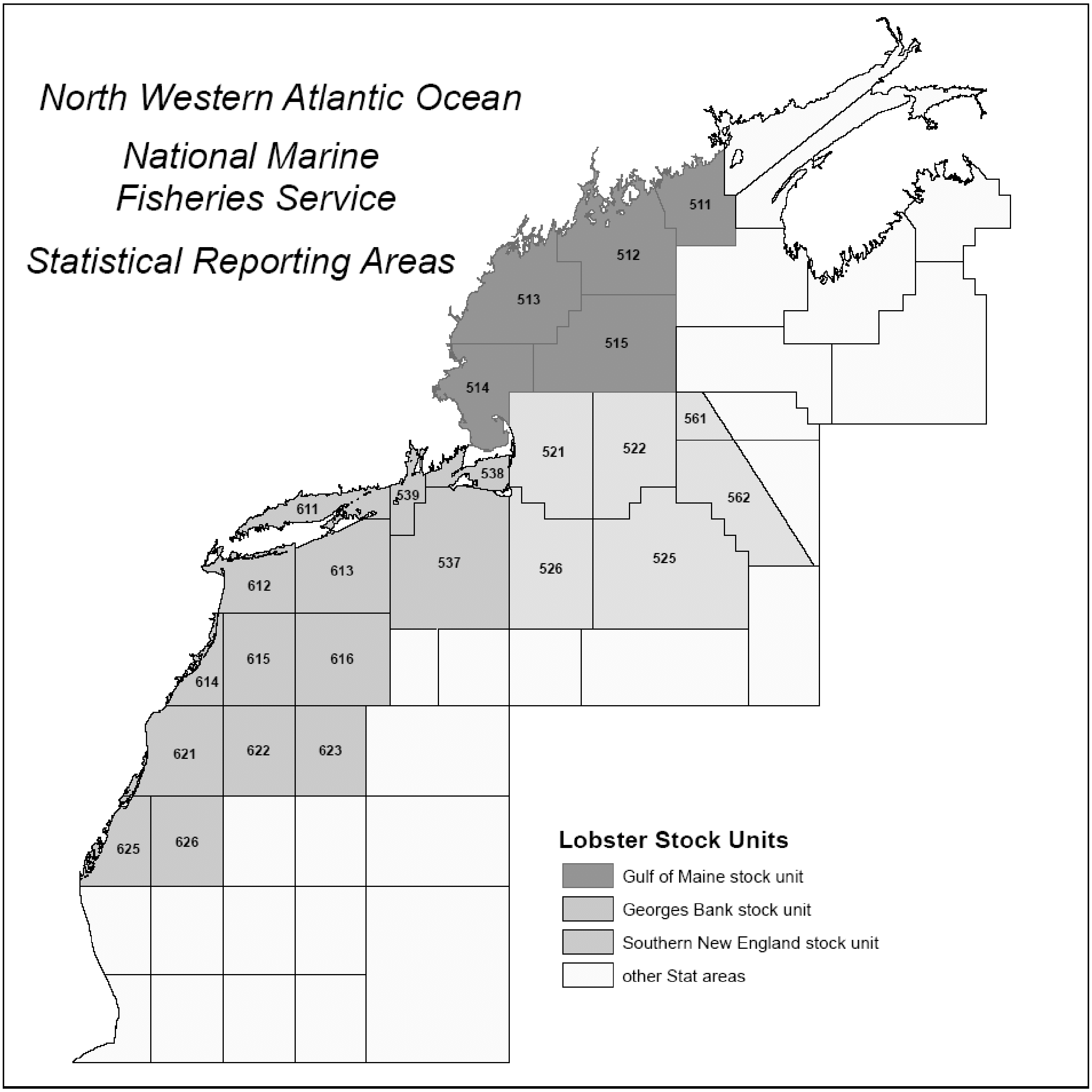


Figure 2.4.1 New stock unit definitions for GOM, GBK, and SNE

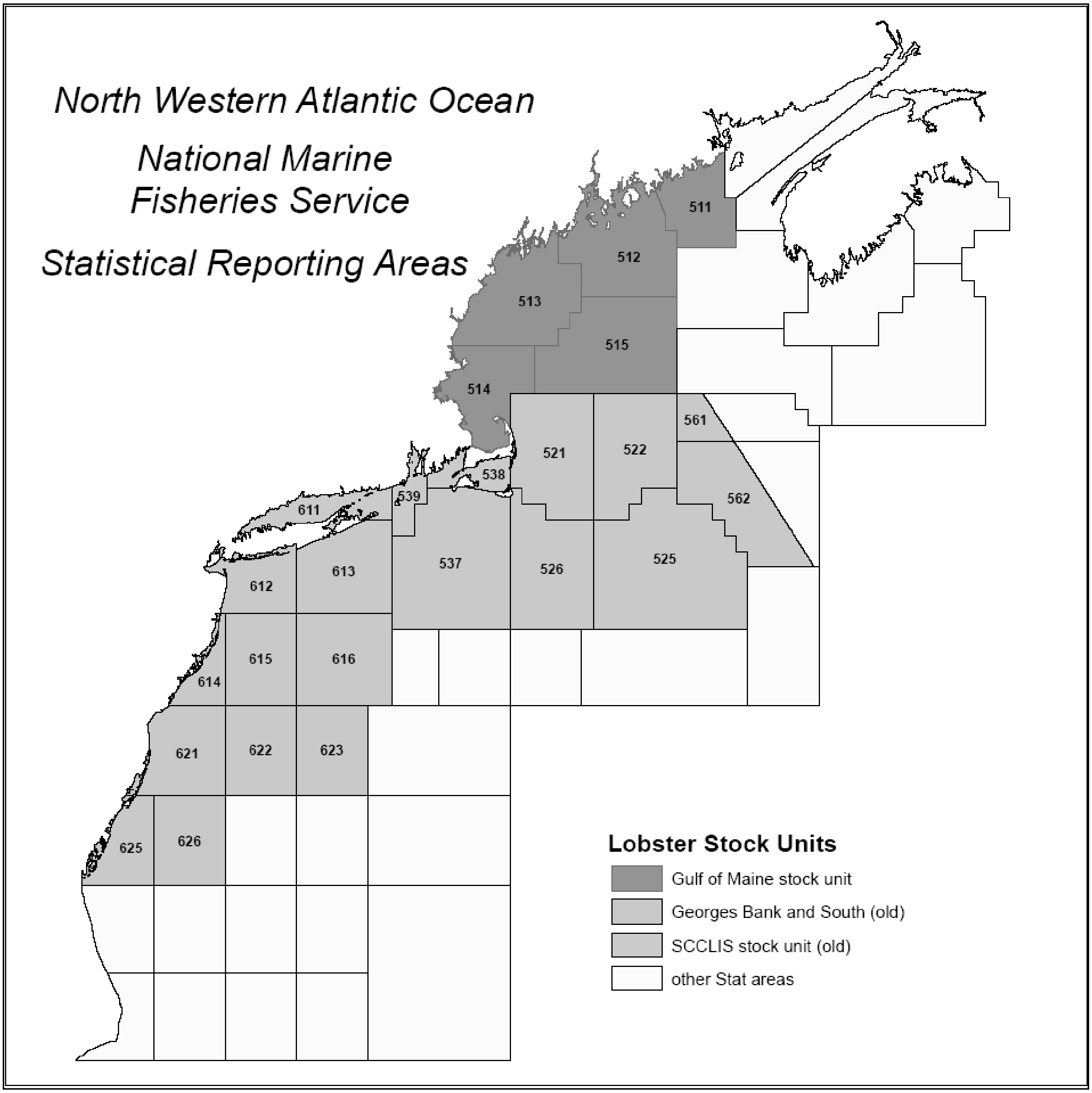


Figure 2.4.2. Previous stock unit definitions used in management since 1994, including GOM, GBS, and SCCLIS.

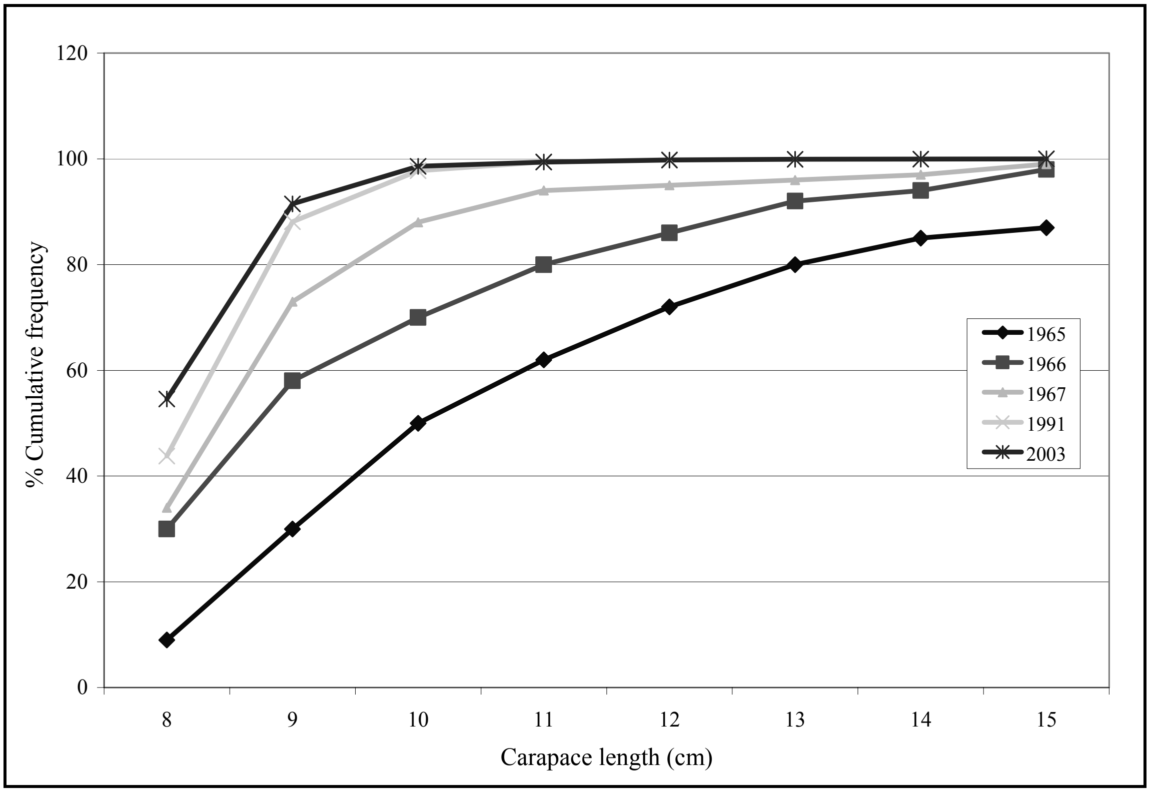


Figure 3.1.1. Historical comparison of cumulative % size frequency of American lobster on Veatch Canyon 1965-1967 (trawls) and 1991 and 2003 (traps).

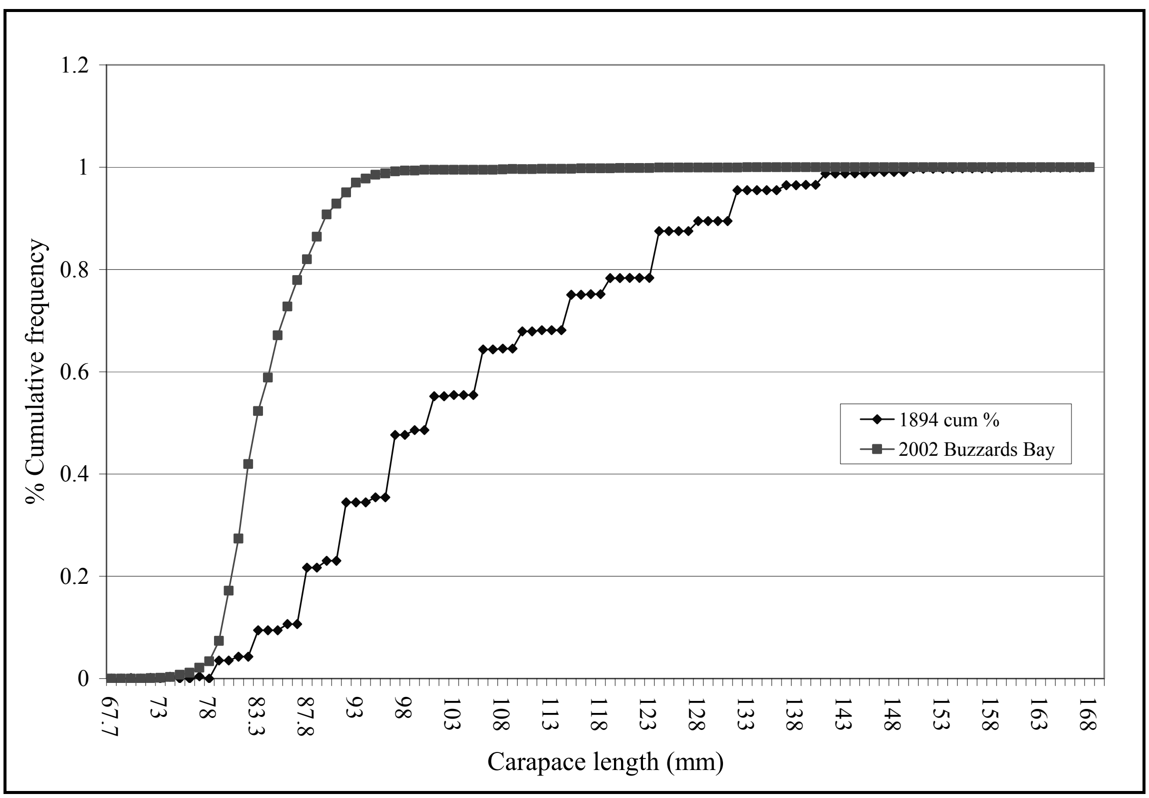


Figure 3.1.2. Comparison of percent cumulative length frequency of eggers from Vineyard Sound/ Coxes Ledge 1894 and Buzzard Bay in 2002.

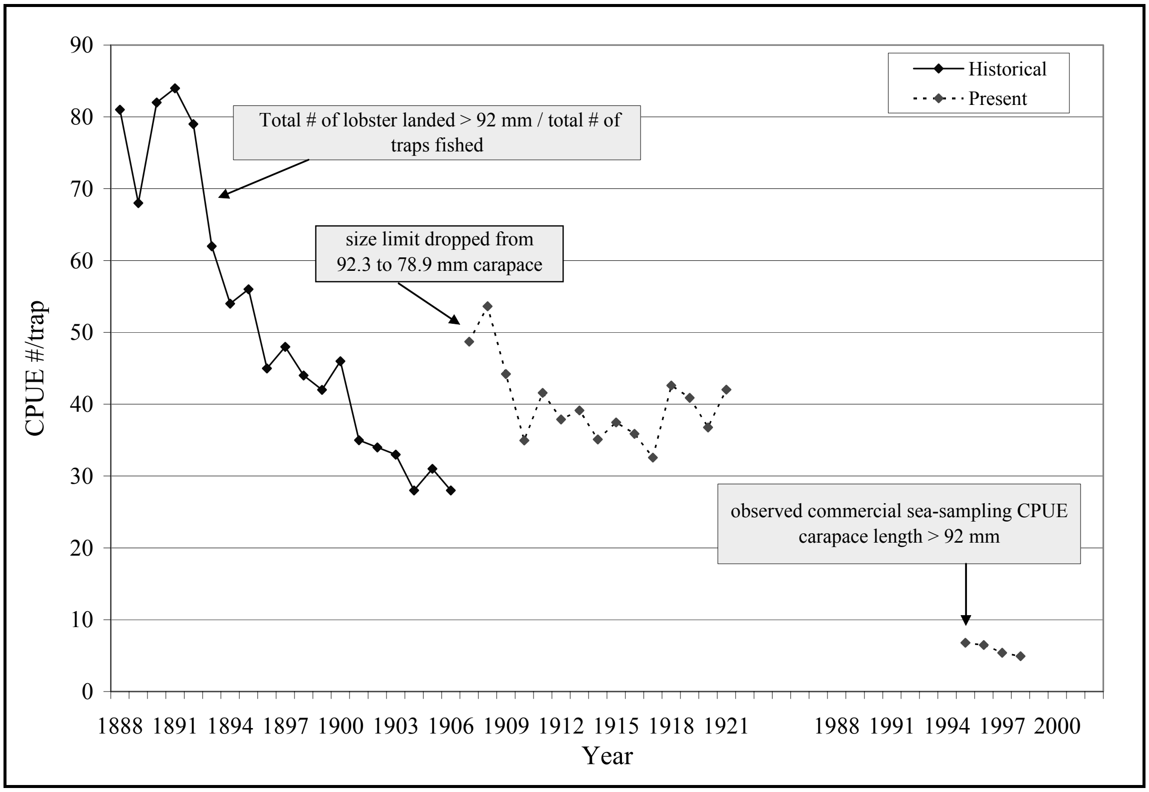


Figure 3.1.3 Annual CPUE (total # landed / total # traps) of lobster 92 mm and greater 1880-1921, and 1995-1998 in Massachusetts coastal waters.

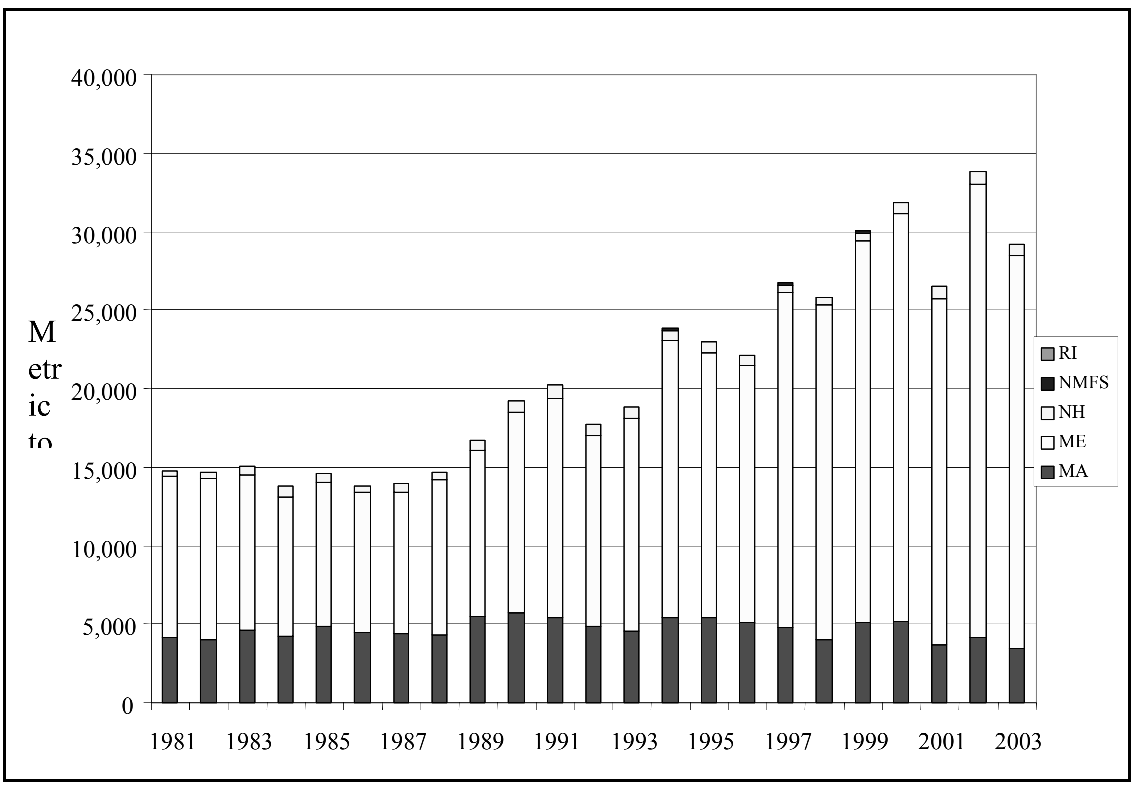


Figure 3.2.1.1 Gulf of Maine landings (mt) by state 1981 to 2003.

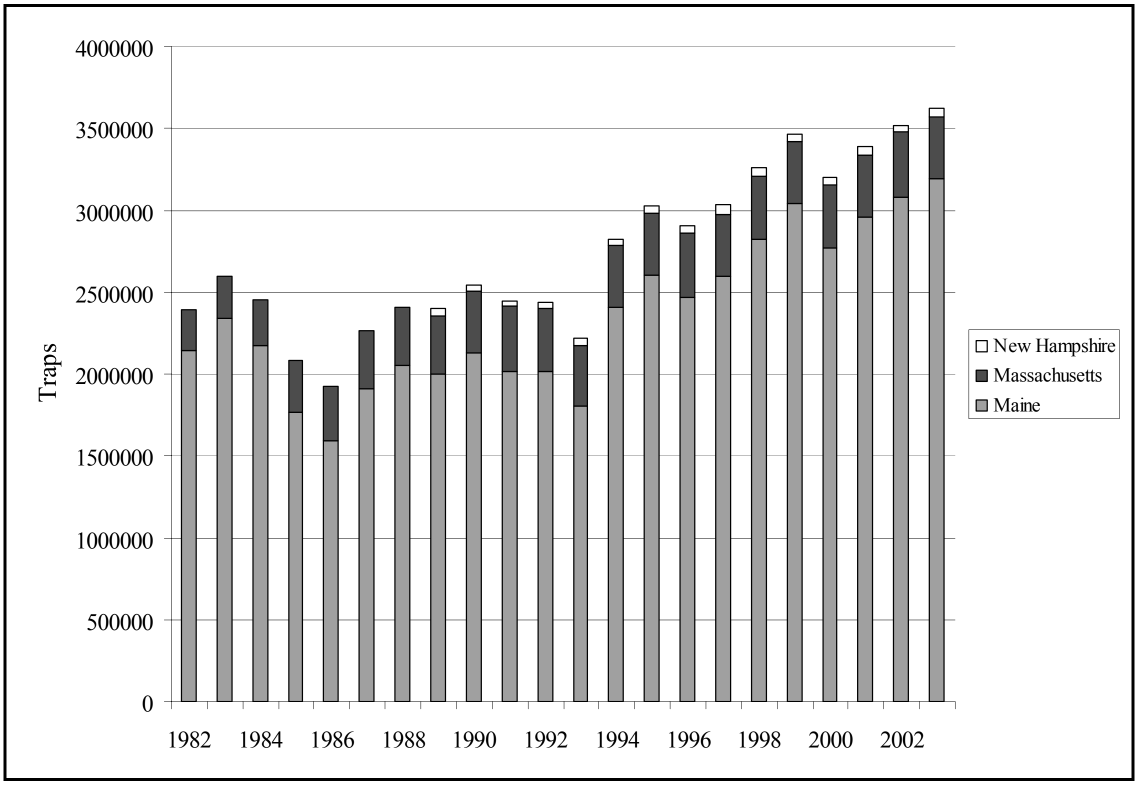


Figure 3.2.1.2. Number of traps reported fished by state in the Gulf of Maine stock unit.

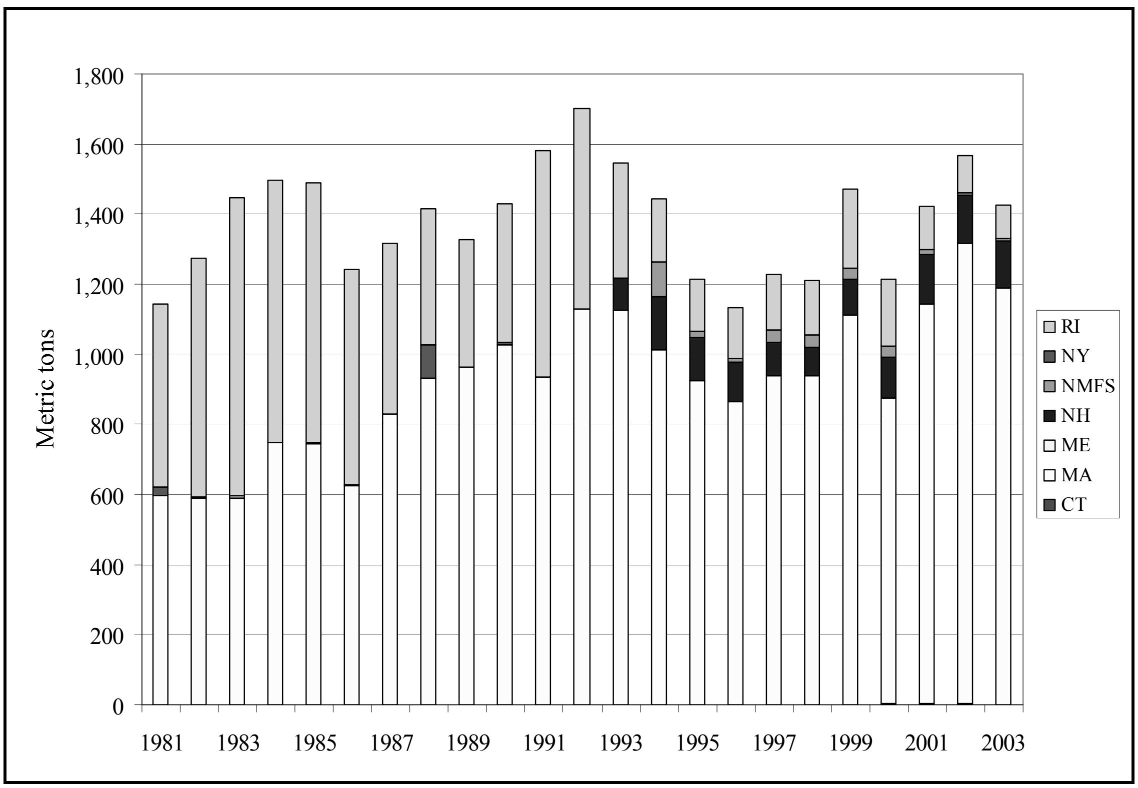


Figure 3.2.2.1 Georges Bank landings (mt) by state, 1981 to 2003.

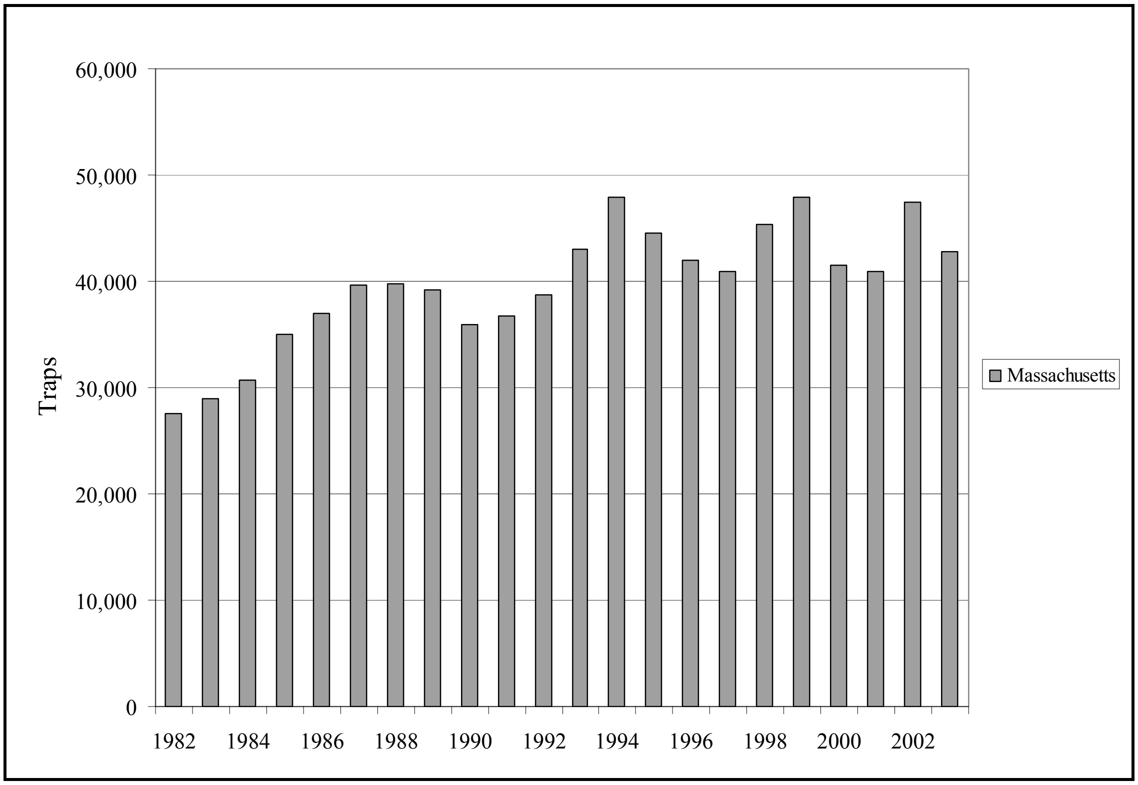


Figure 3.2.2.2. Number of traps reported fished on Georges Bank by Massachusetts as an index of effort.

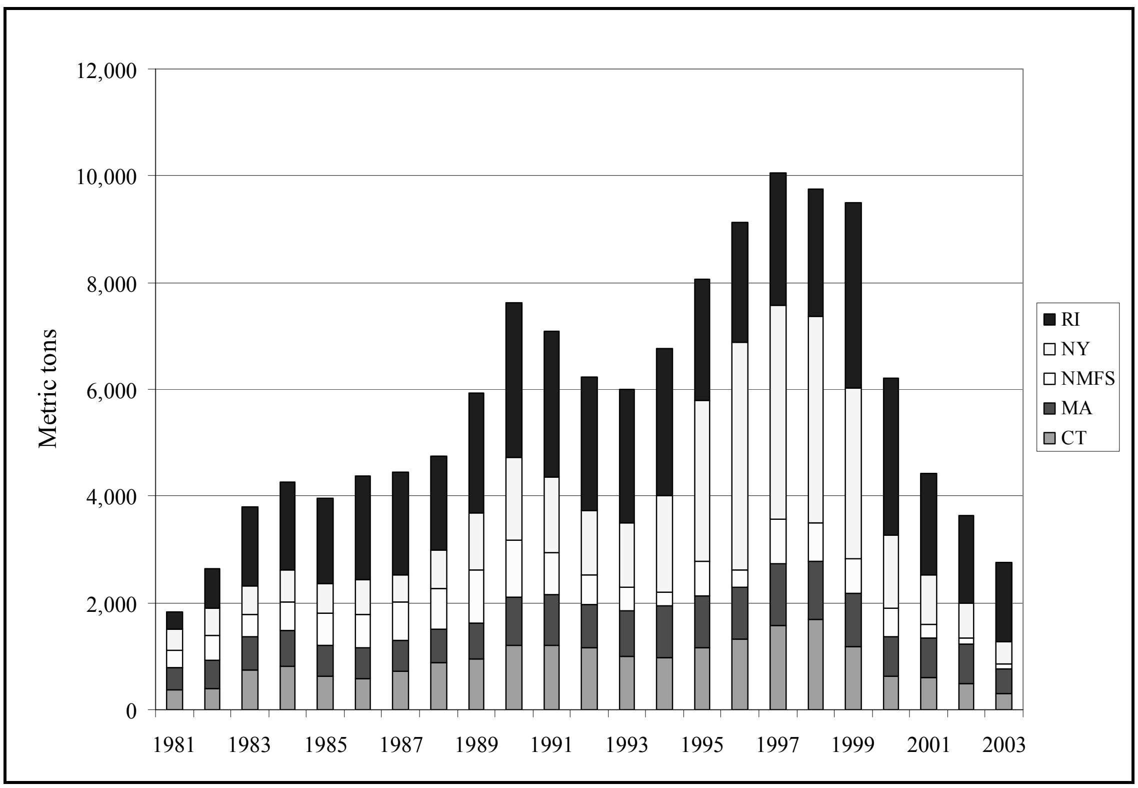


Figure 3.2.3.1 Southern New England landings (mt) by state from 1981 to 2003.

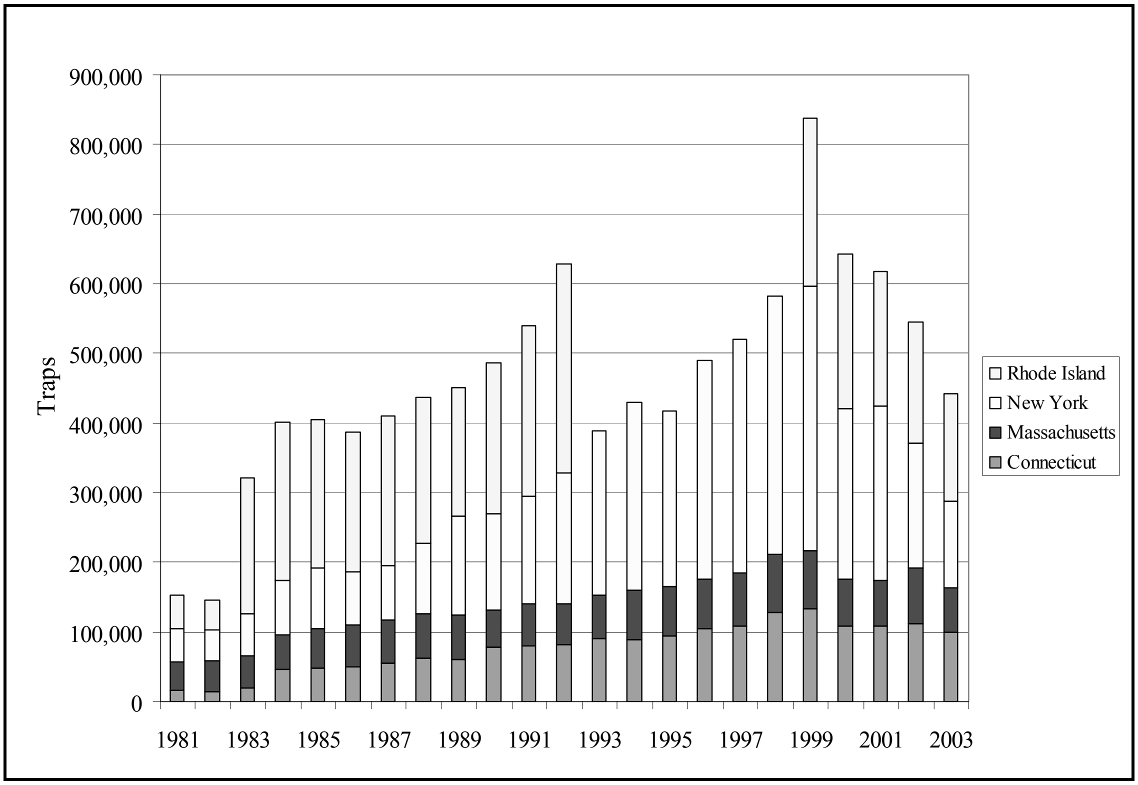


Figure 3.2.3.2. Number of traps reported fished by state in the Southern New England Stock unit.

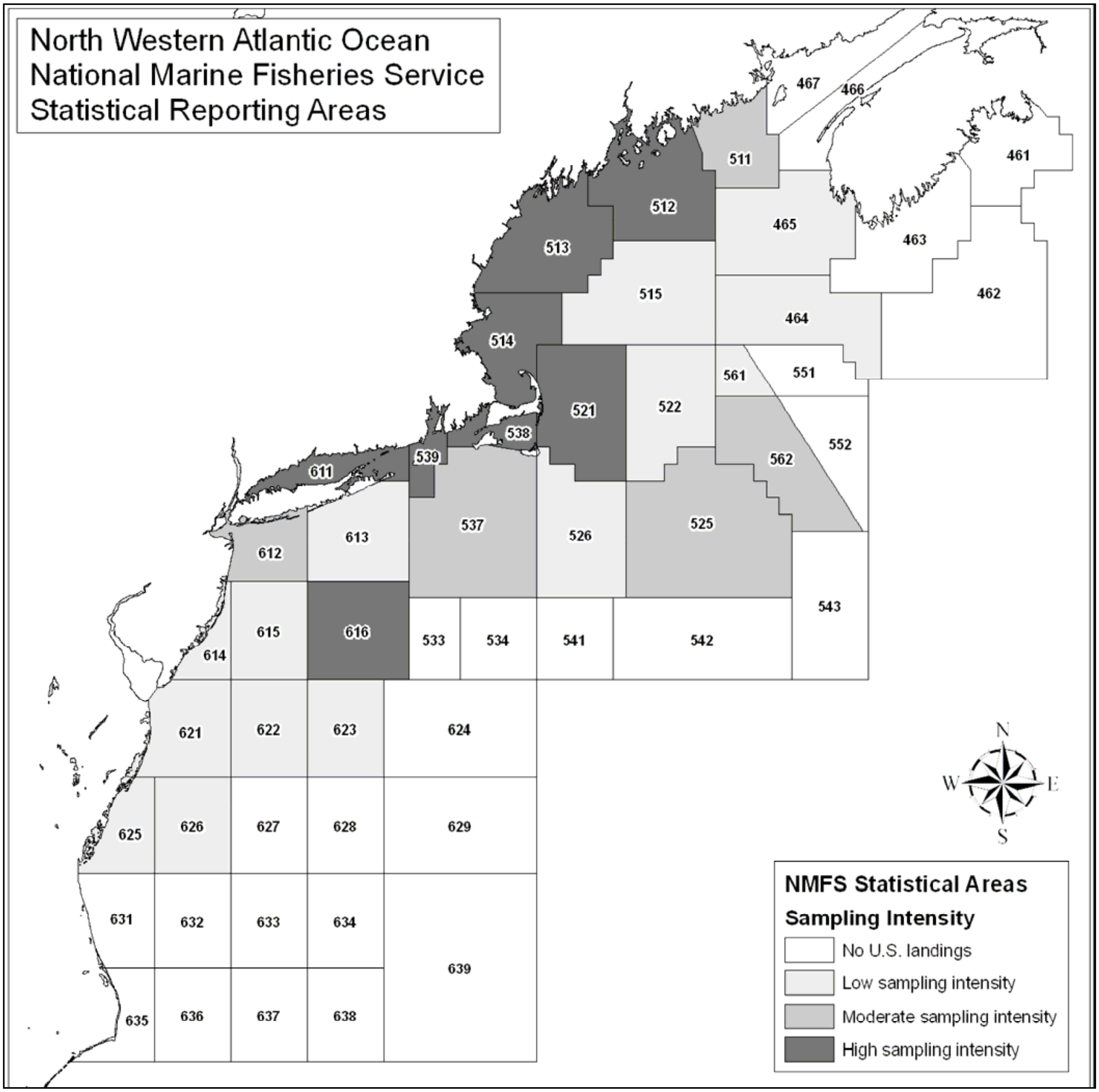


Figure 5.1.1.2. Map depicting relative fisheries dependent sampling intensity of American lobsters in North Western Atlantic NMFS Statistical reporting areas 1999 to 2003:
light gray = less than the 25th percentile; medium gray = between the 25th and 75th percentile; dark gray = greater than the 75th percentile.

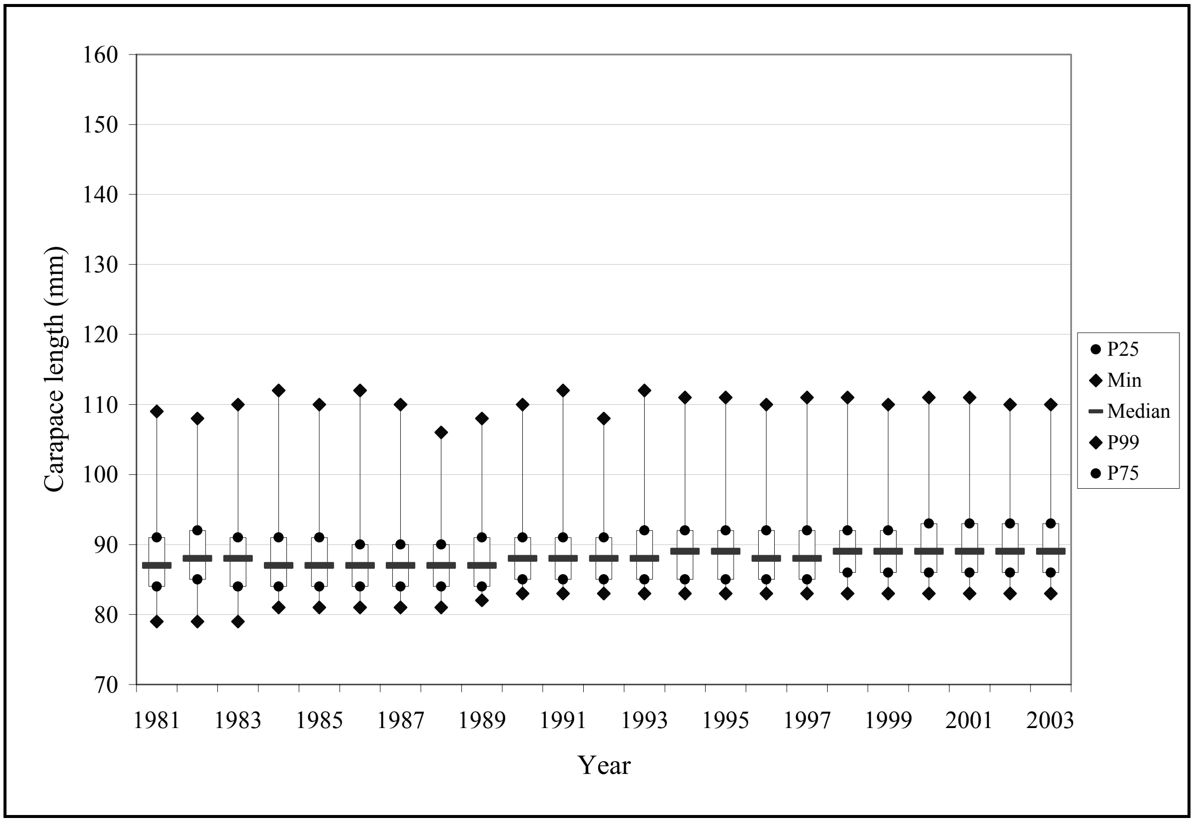


Figure 5.1.3.1. Size structure of commercial catches in the Gulf of Maine.

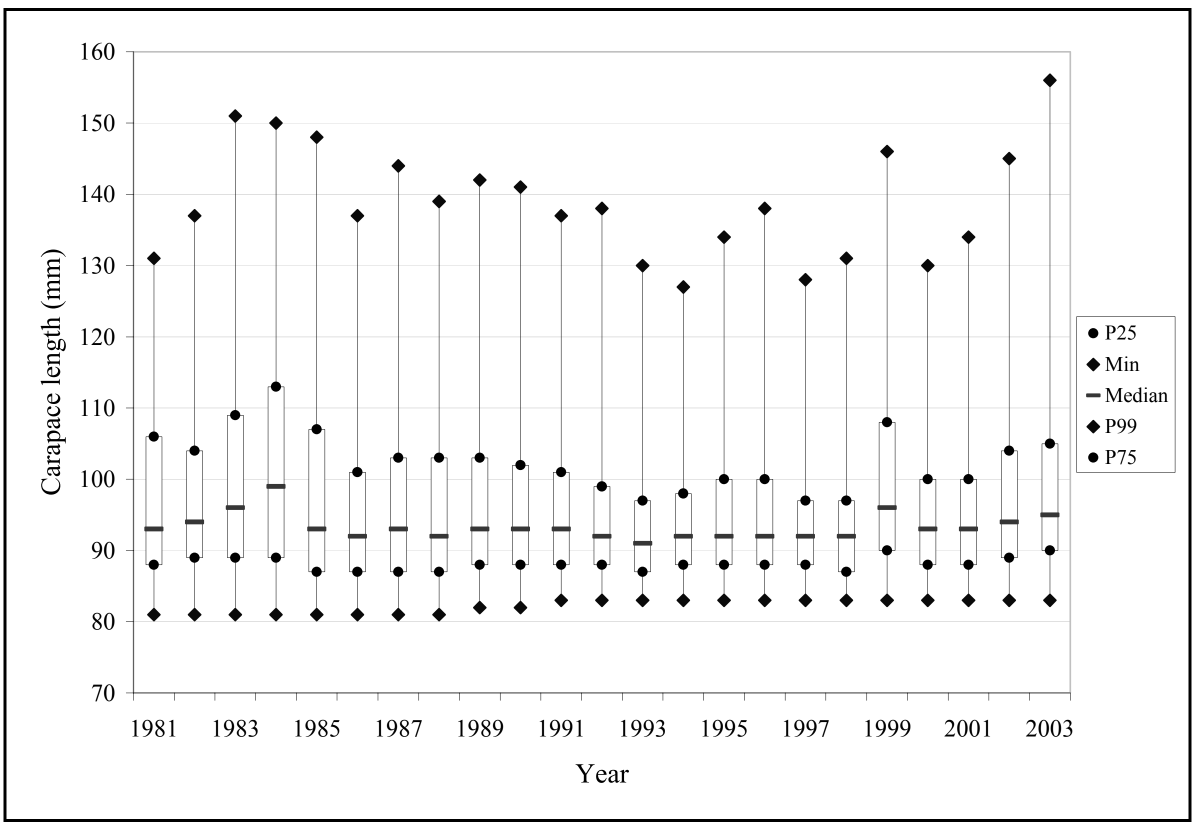


Figure 5.1.3.2. Size structure of commercial catches in Georges Bank.

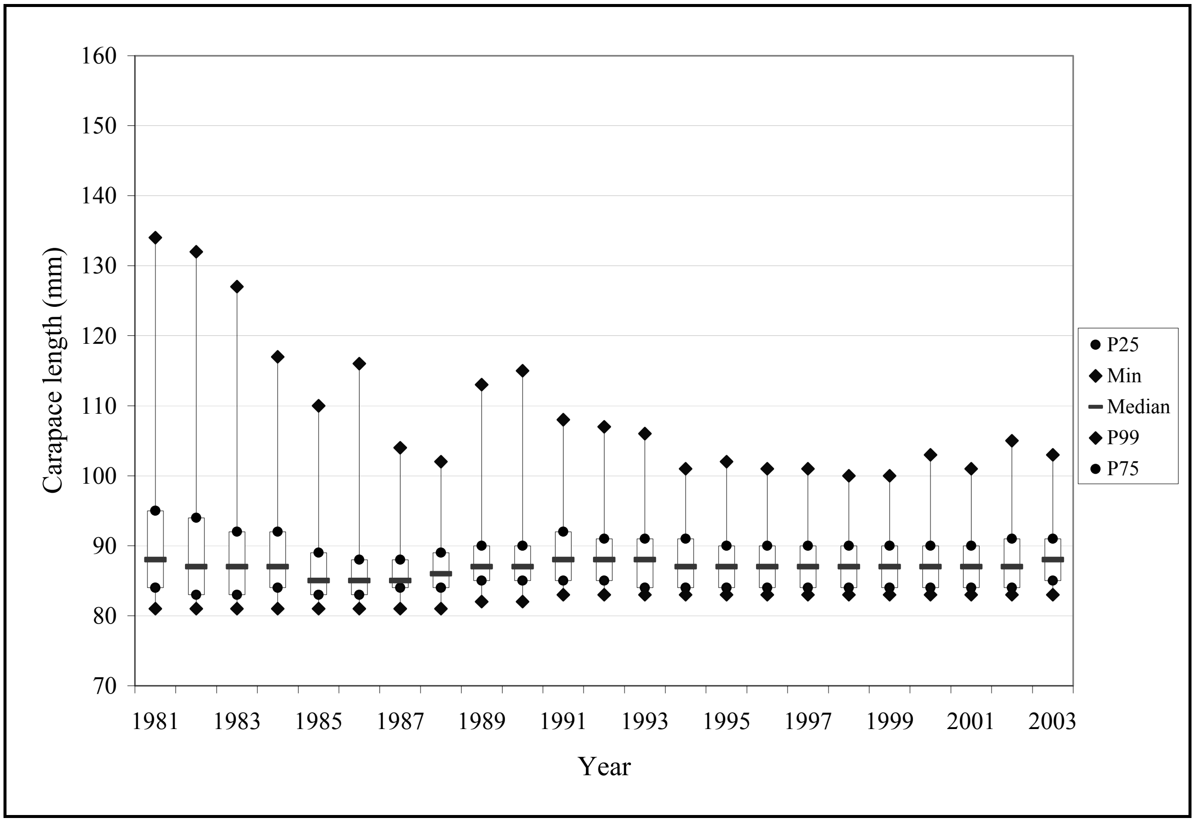


Figure 5.1.3.3. Size structure of commercial catches in Southern New England.

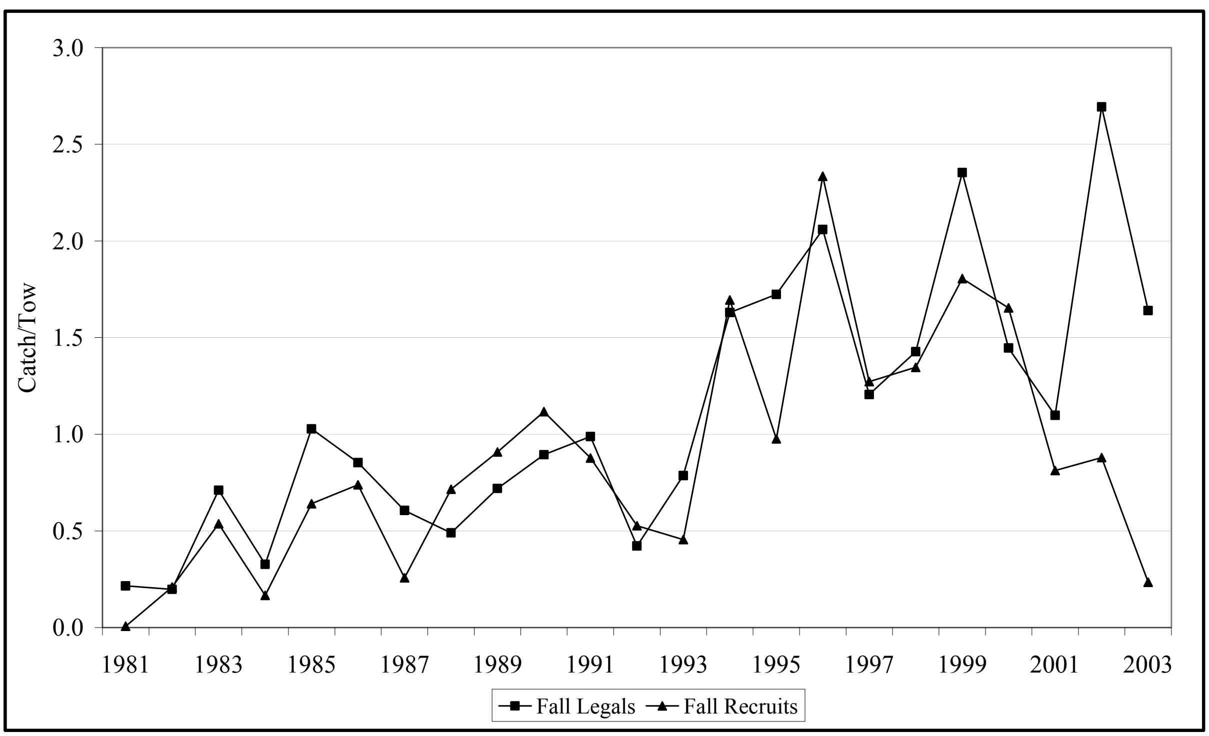


Figure 5.3.2.1. NMFS GOM Trawl Survey Abundance Indices Legal and Recruit Lobster

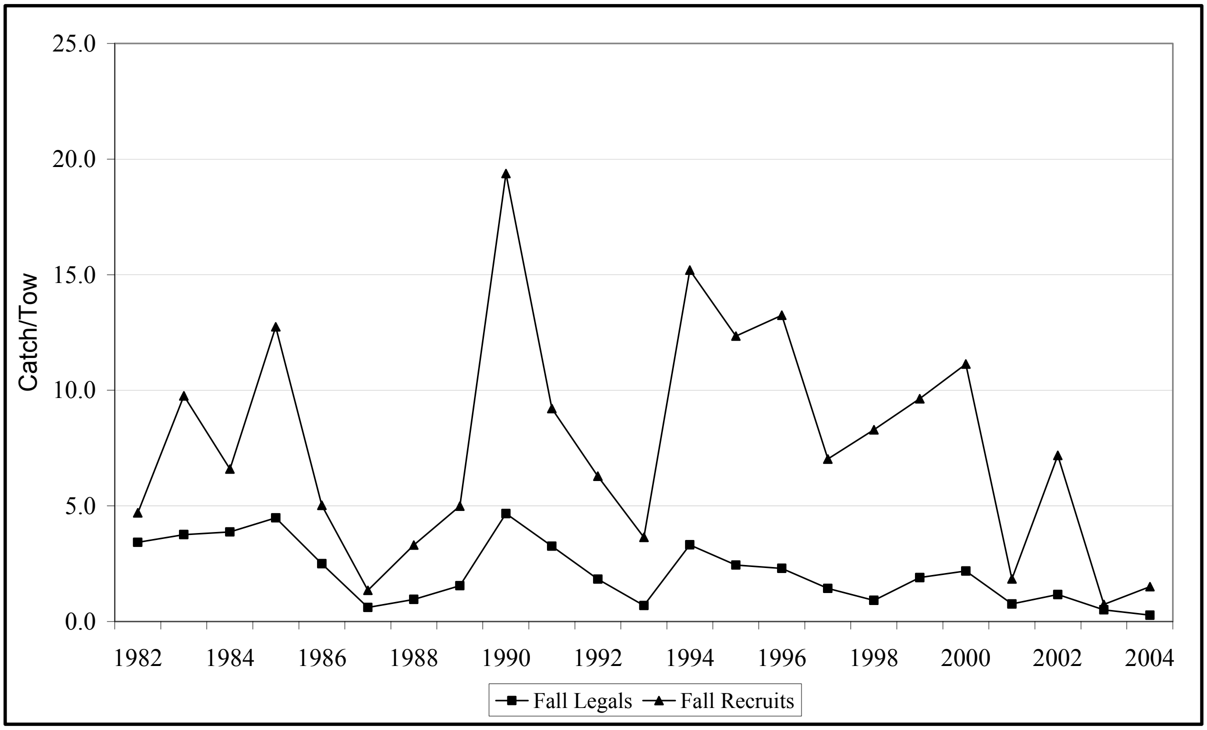


Figure 5.3.2.2. Massachusetts GOM Trawl Survey Abundance Indices Legal and Recruit Lobster

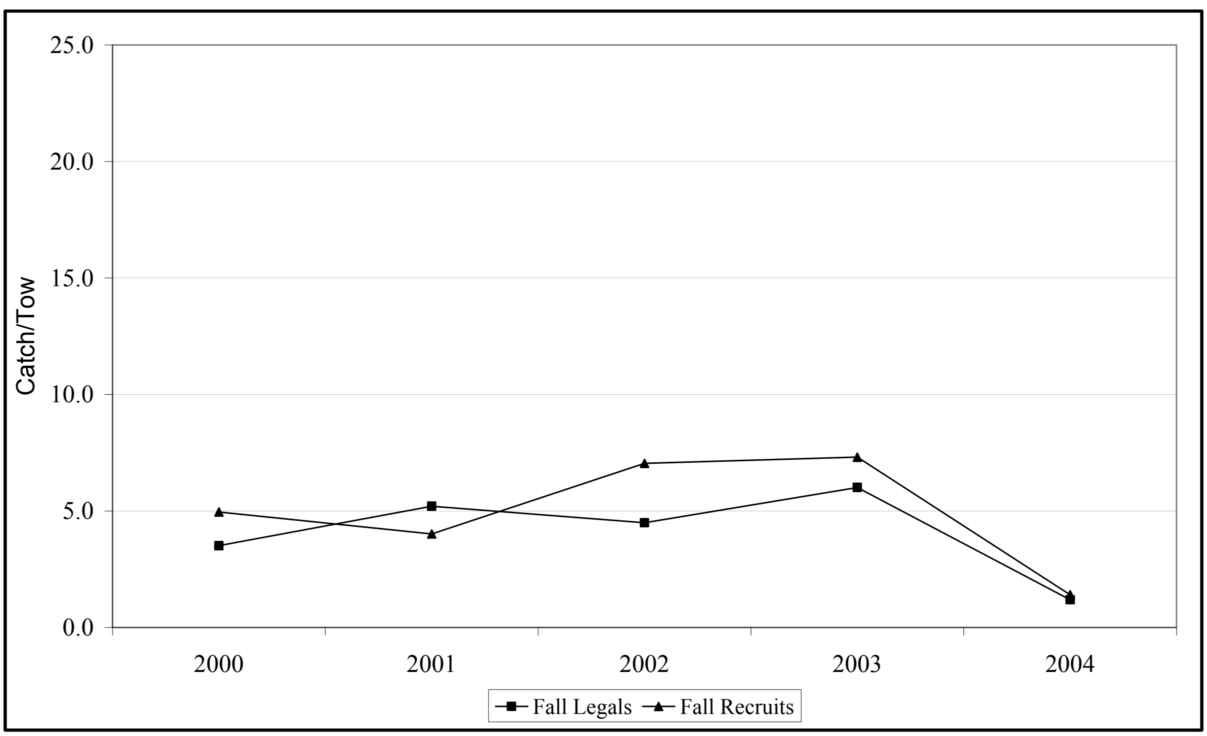


Figure 5.3.2.3. Maine GOM Trawl Survey Abundance Indices Legal and Recruit Lobster

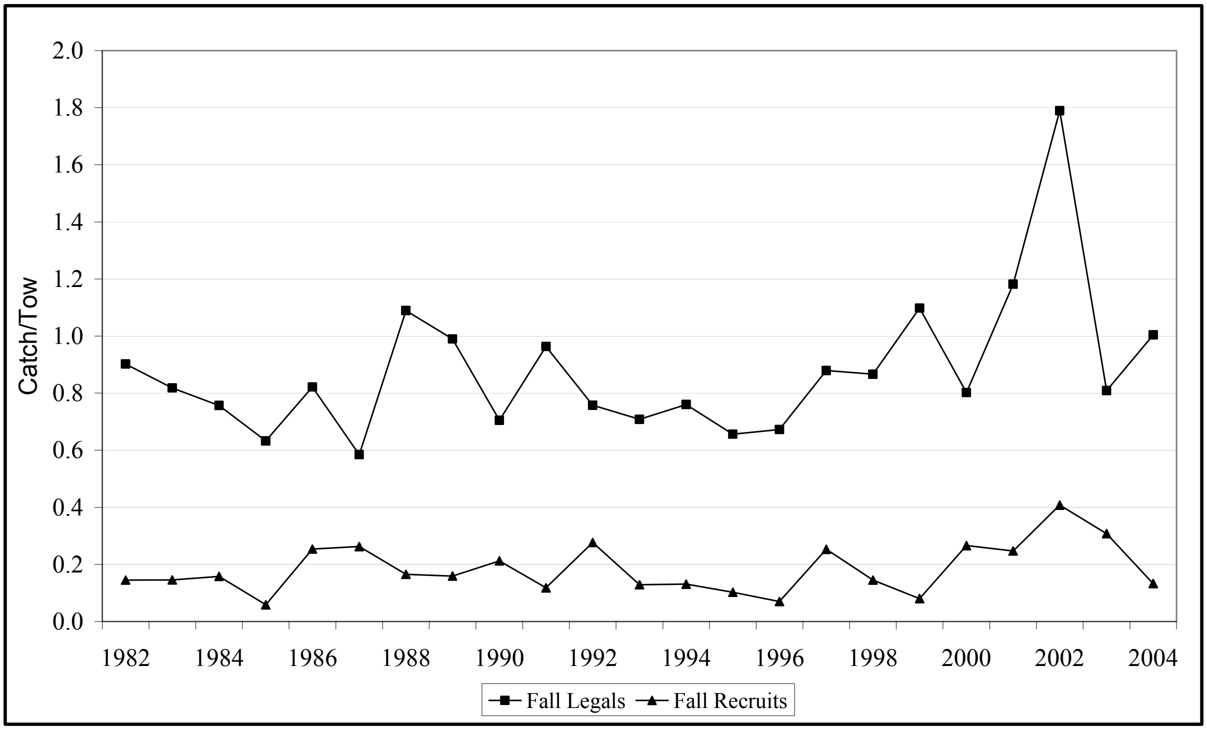


Figure 5.3.2.4. NMFS Georges Bank Trawl Survey Abundance Indices Legal and Recruit Lobster

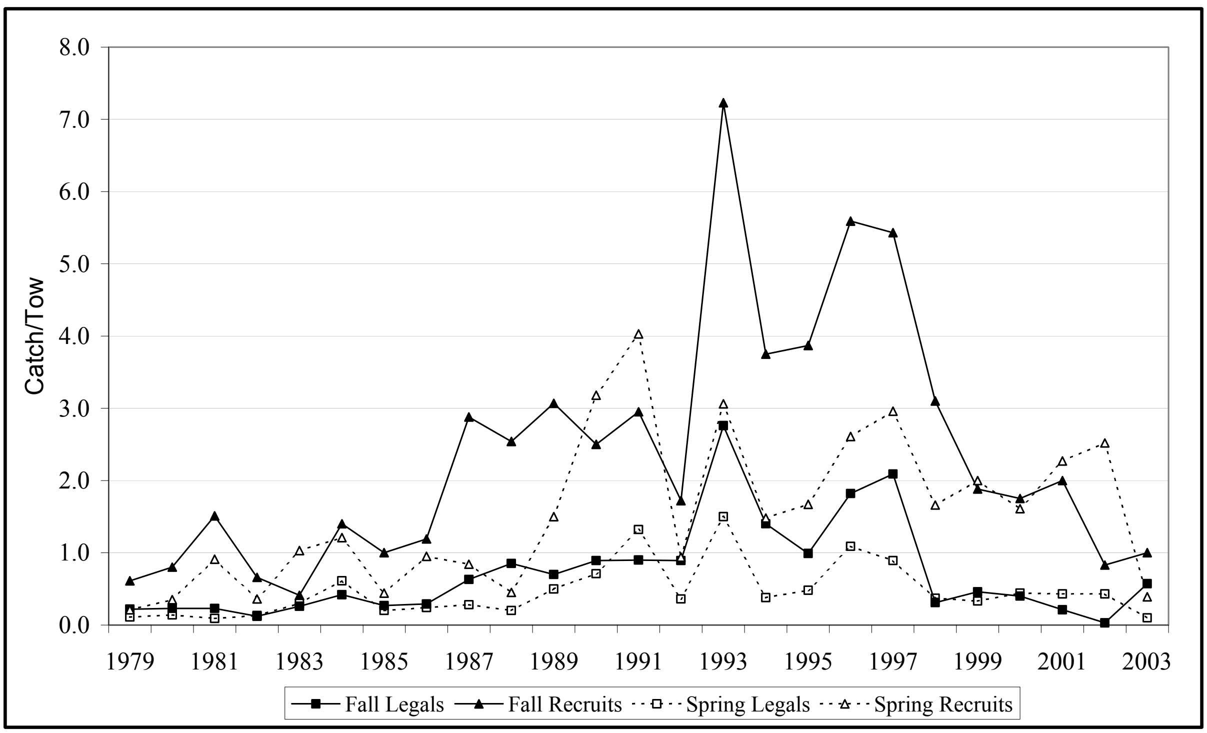


Figure 5.3.2.5. Rhode Island Trawl Survey Abundance Indices Legal and Recruit Lobster

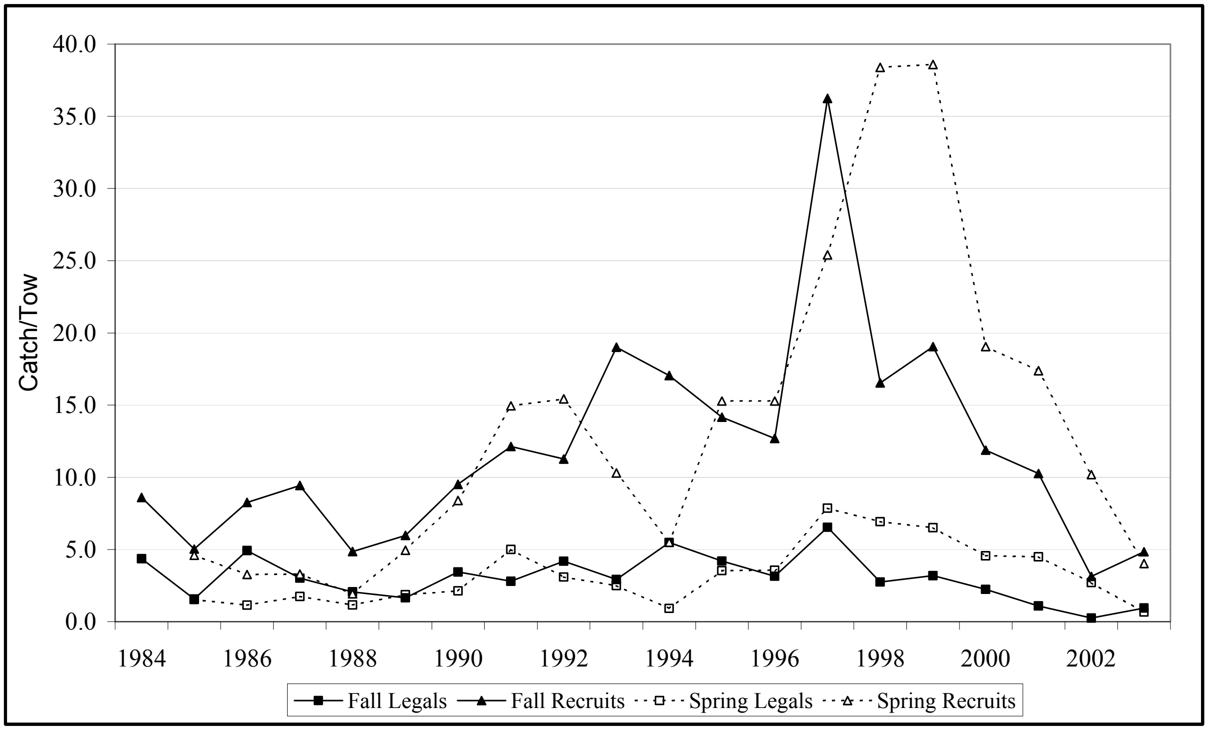


Figure 5.3.2.6. Connecticut Trawl Survey Abundance Indices Legal and Recruit Lobster

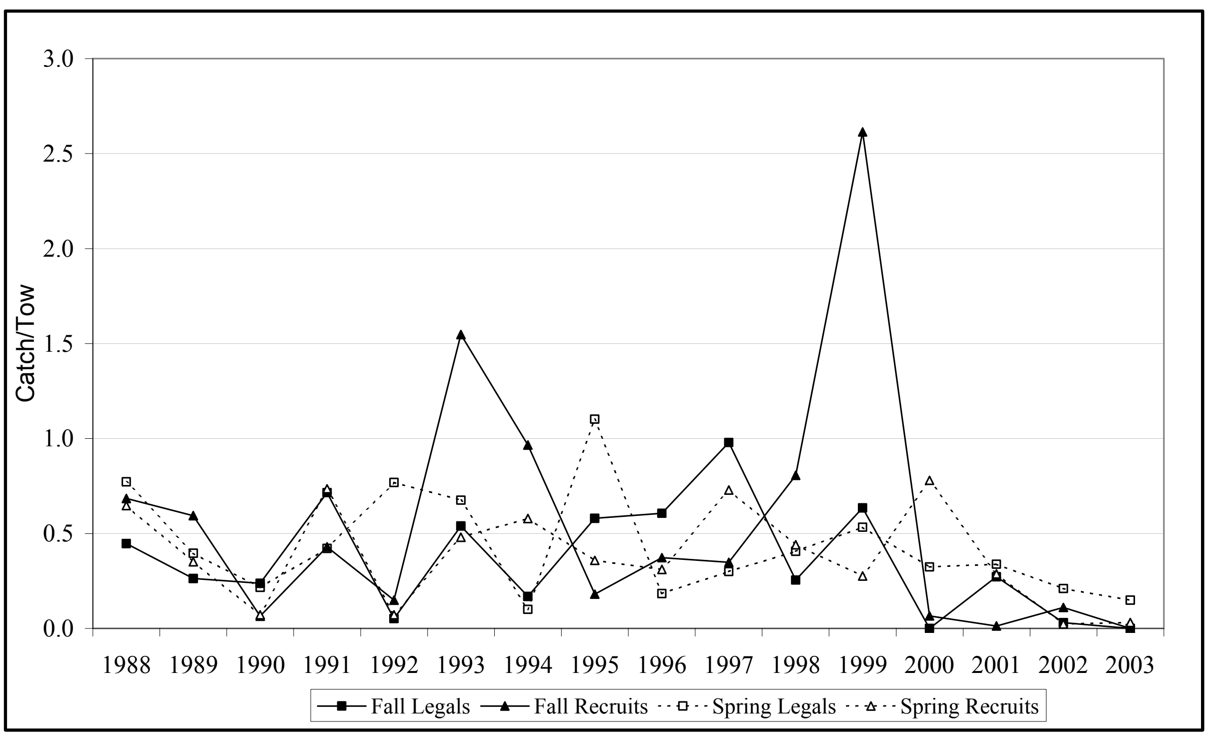


Figure 5.3.2.7. New Jersey Trawl Survey Abundance Indices Legal and Recruit Lobster

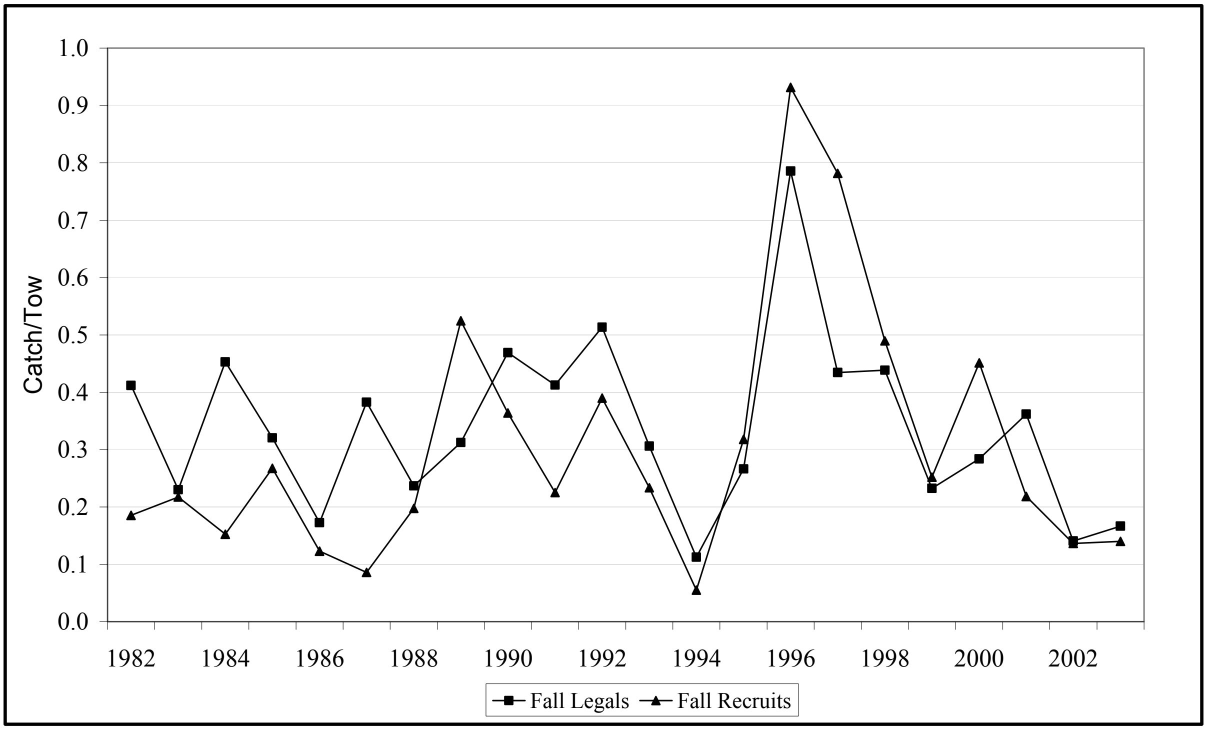


Figure 5.3.2.8. NMFS SNE Trawl Survey Abundance Indices Legal and Recruit Lobster

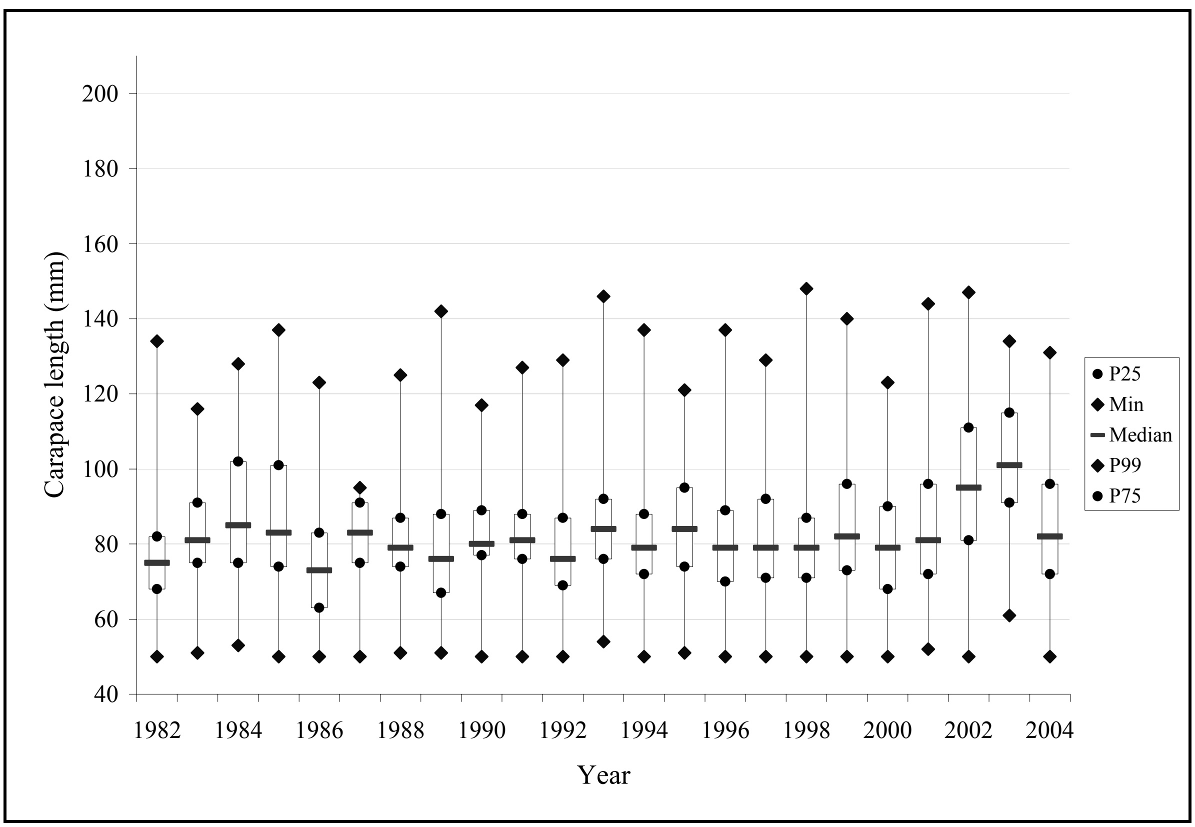


Figure 5.3.3.1. Female lobsters taken in the fall NEFC Survey Gulf of Maine Stock Area

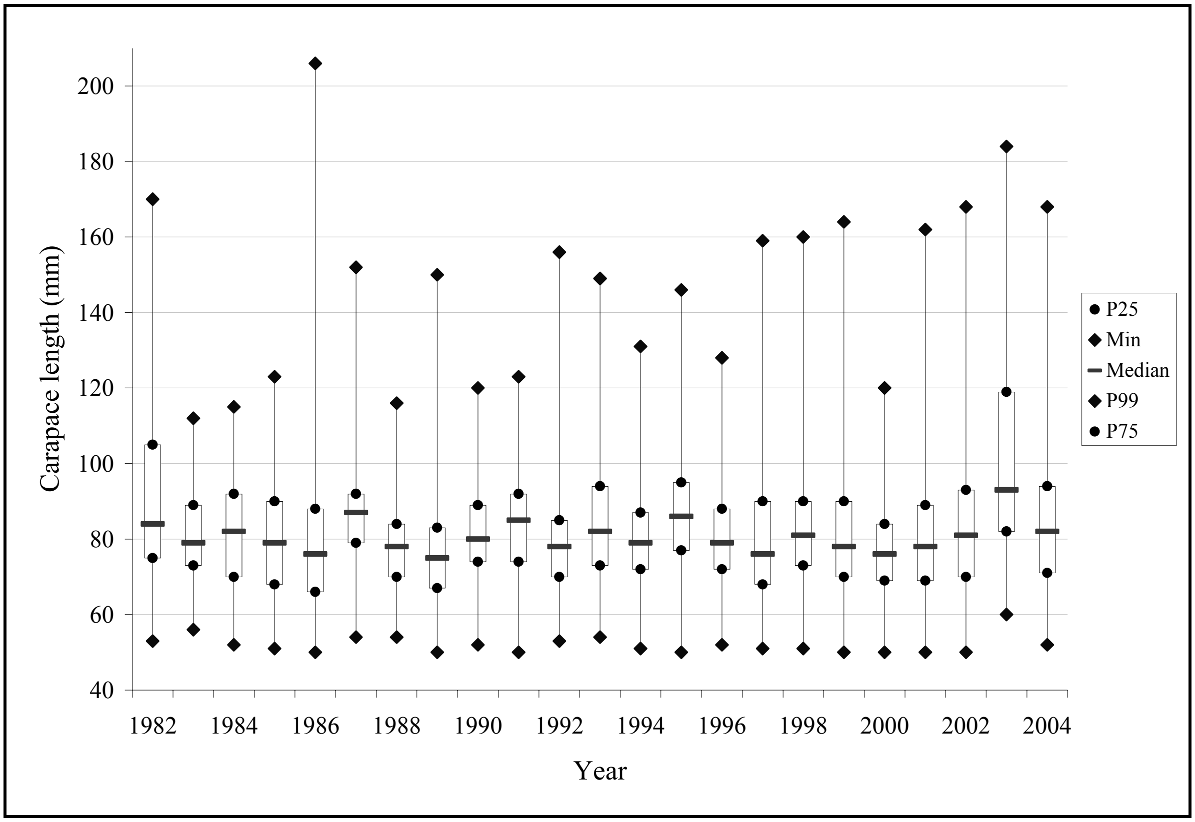


Figure 5.3.3.2. Male lobsters taken in the fall NEFC Survey Gulf of Maine Stock Area

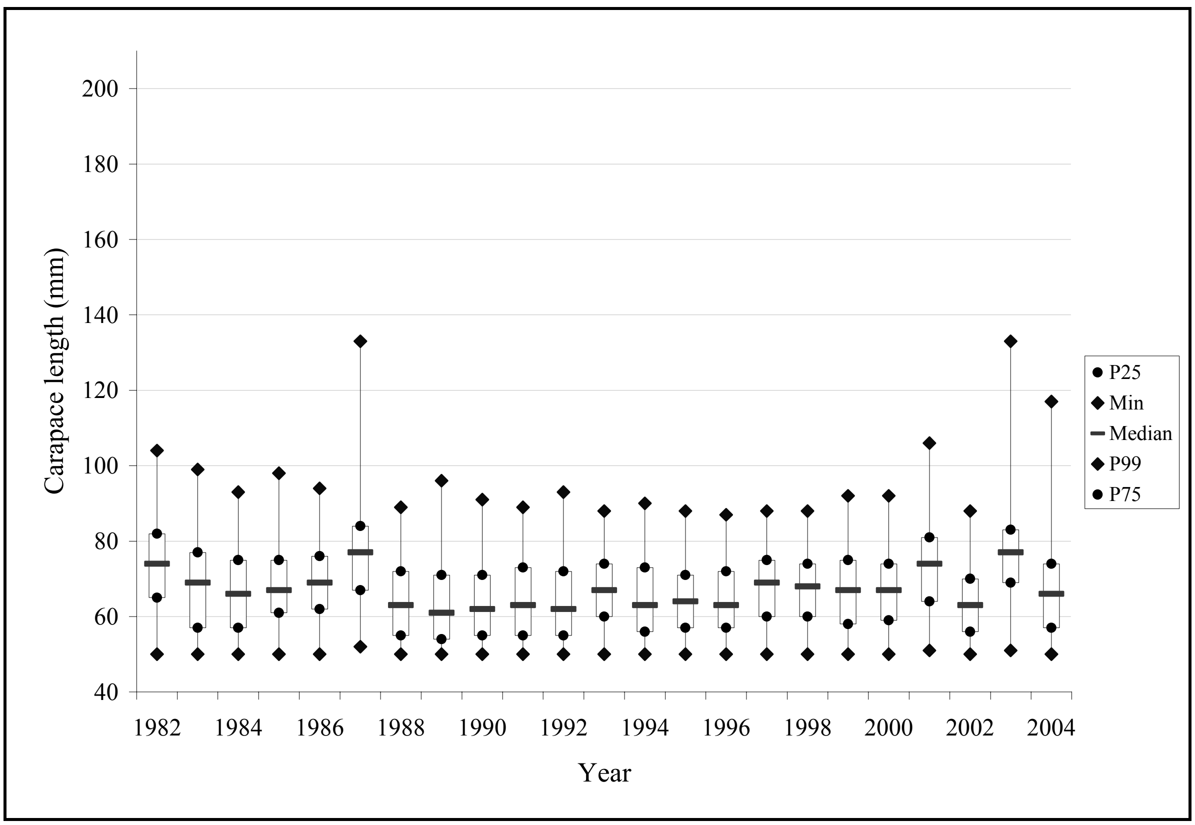


Figure 5.3.3.3. Female lobsters taken in the fall MA Survey Gulf of Maine Stock Area

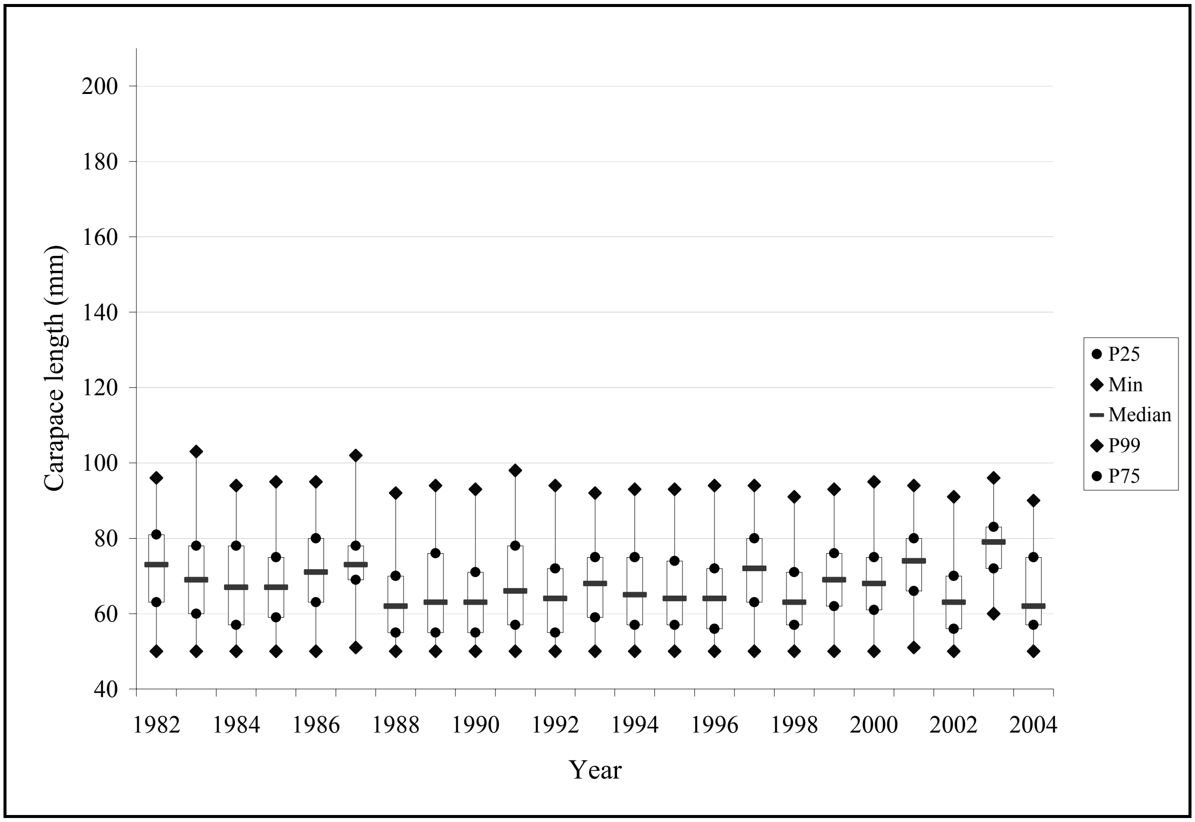


Figure 5.3.3.4. Male lobsters taken in the fall MA Survey Gulf of Maine Stock Area

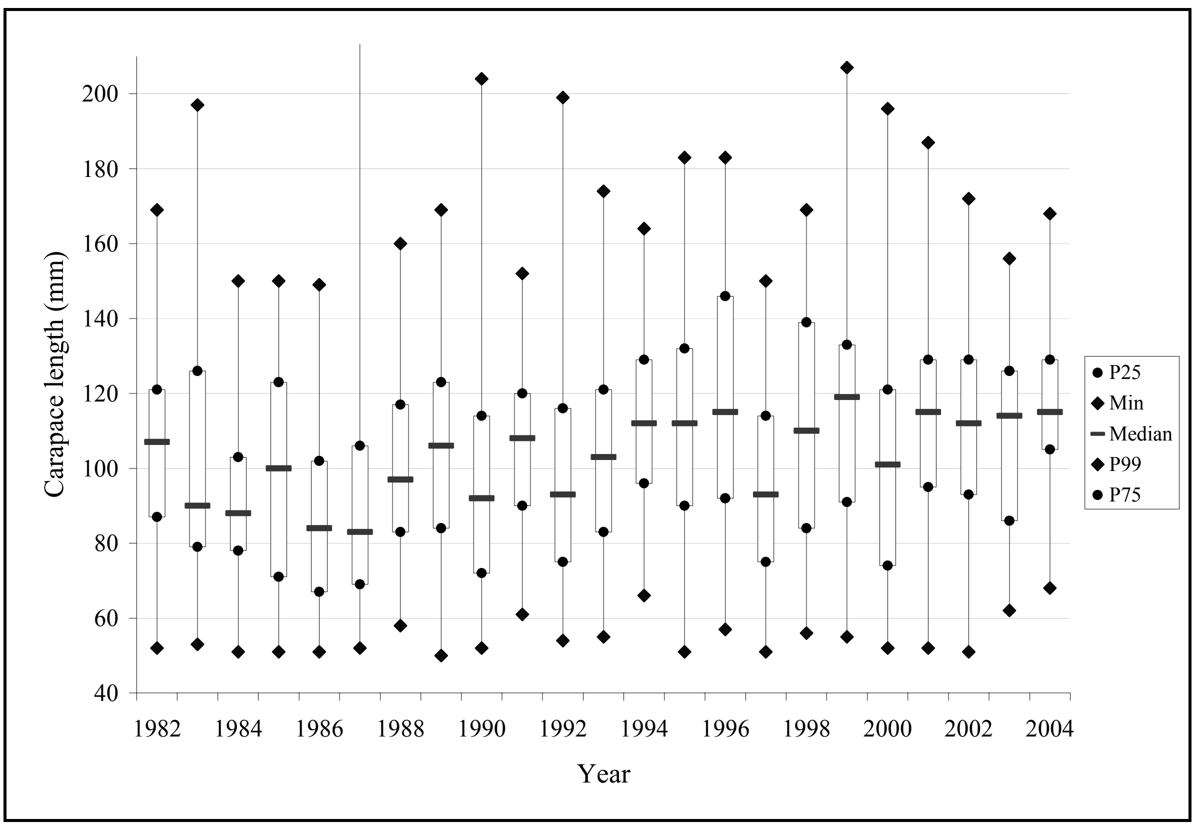


Figure 5.3.3.5. Female lobsters taken in the fall NEFC Survey Georges Bank Stock Area

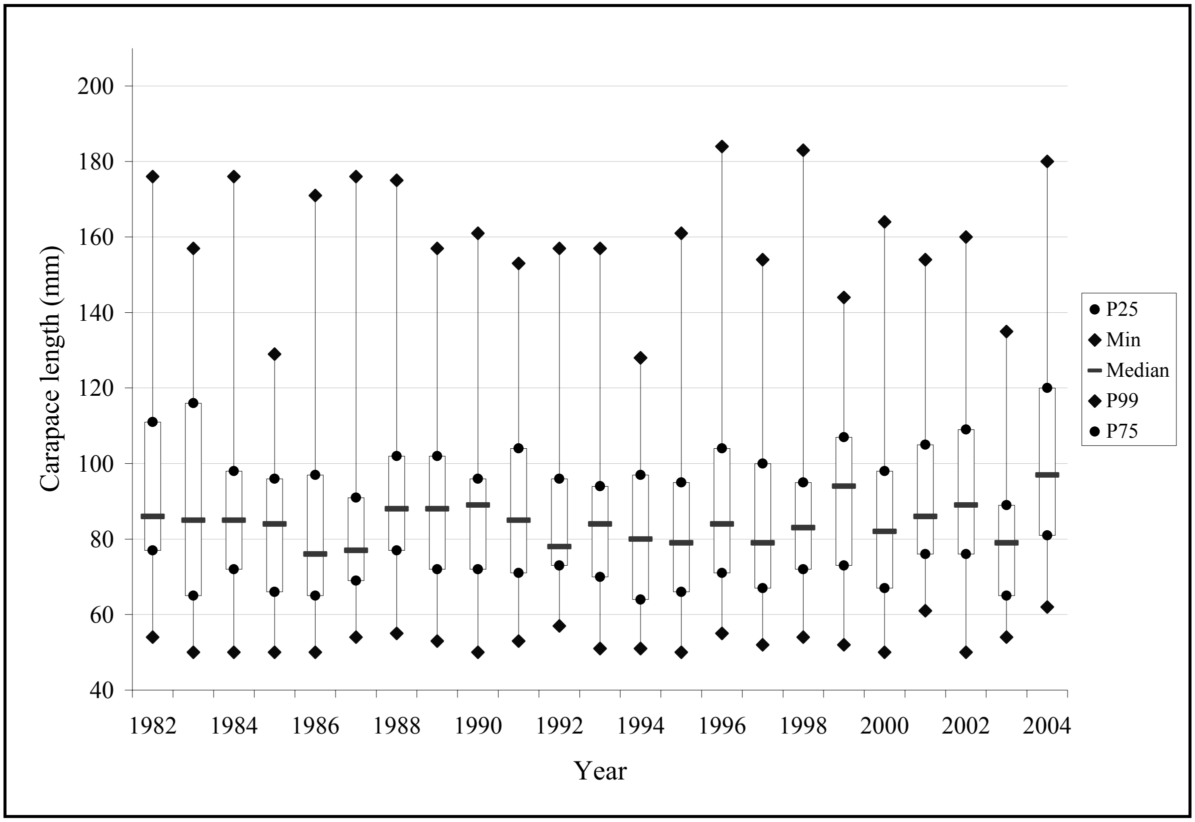


Figure 5.3.3.6. Male lobsters taken in the fall NEFC Survey Georges Bank Stock Area

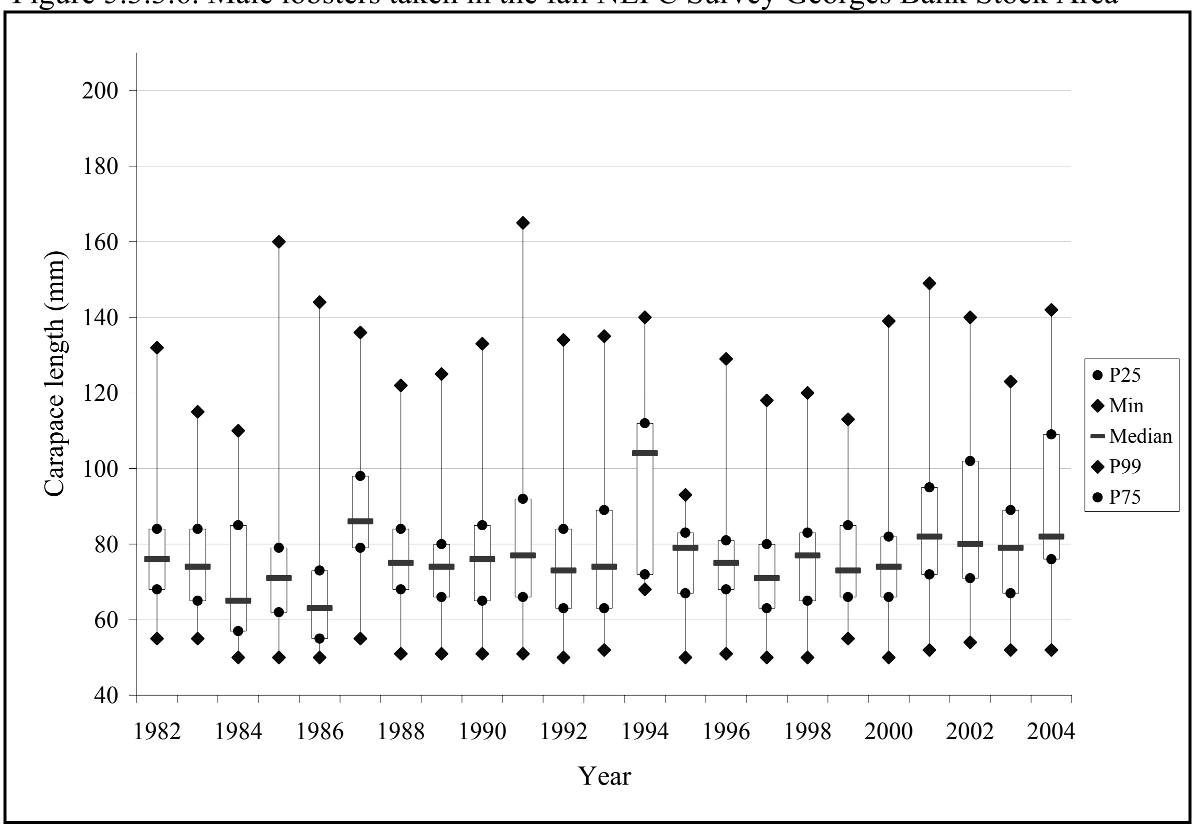


Figure 5.3.3.7. Female lobsters taken in the fall NEFC Survey Southern New England Stock Area

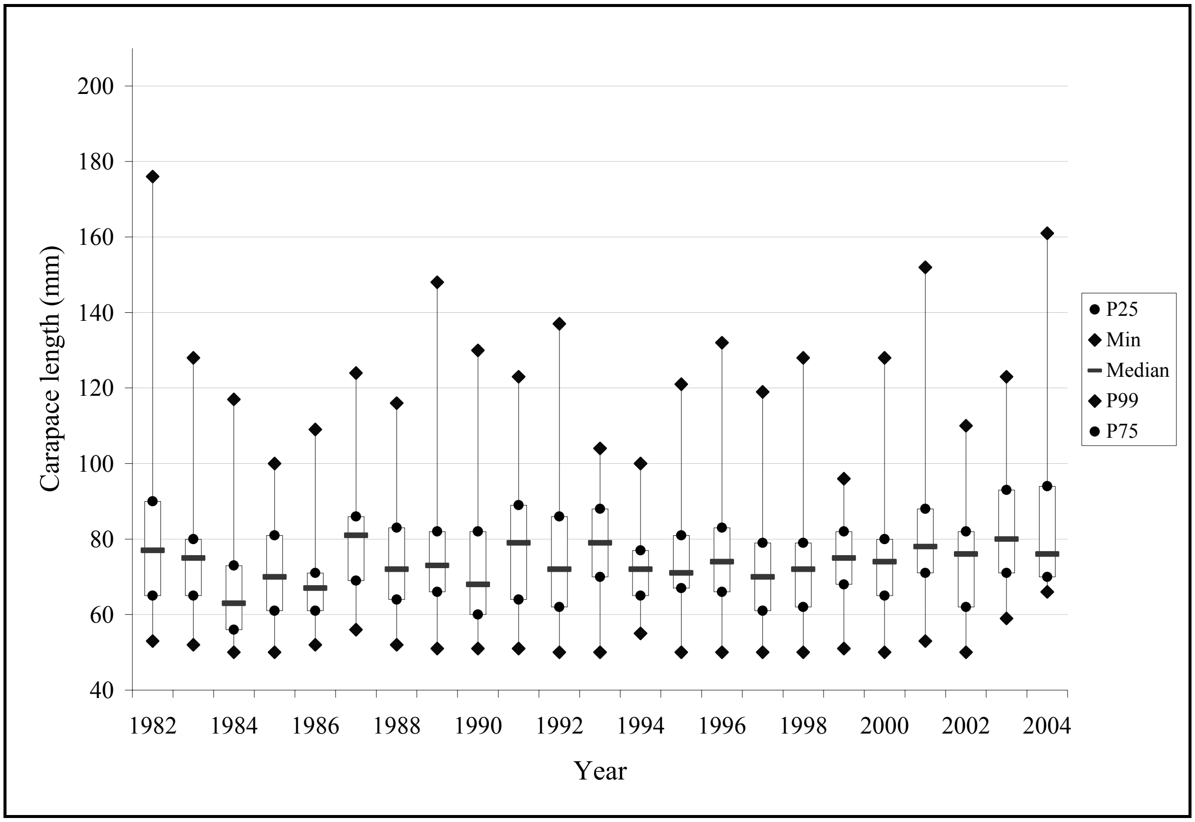


Figure 5.3.3.8. Male lobsters taken in the fall NEFC Survey Southern New England Stock Area

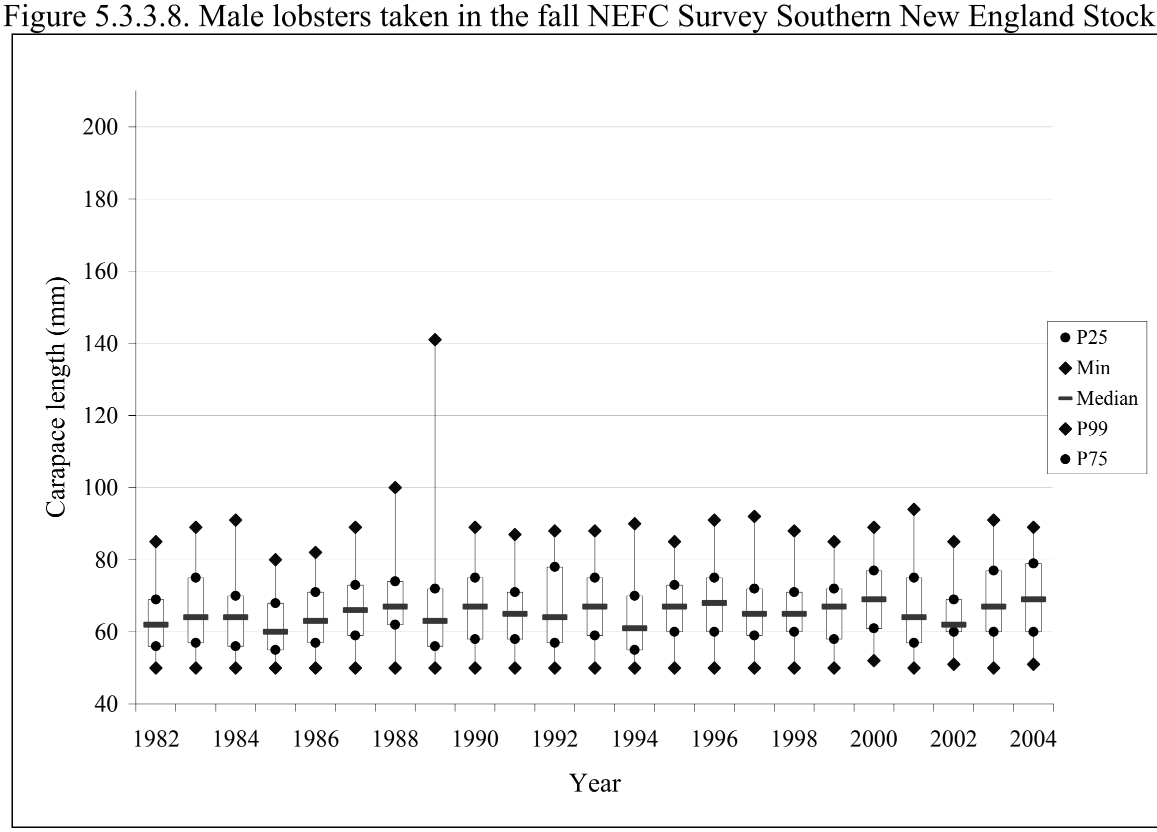


Figure 5.3.3.9. Female lobsters taken in the fall RI Survey Southern New England Stock Area

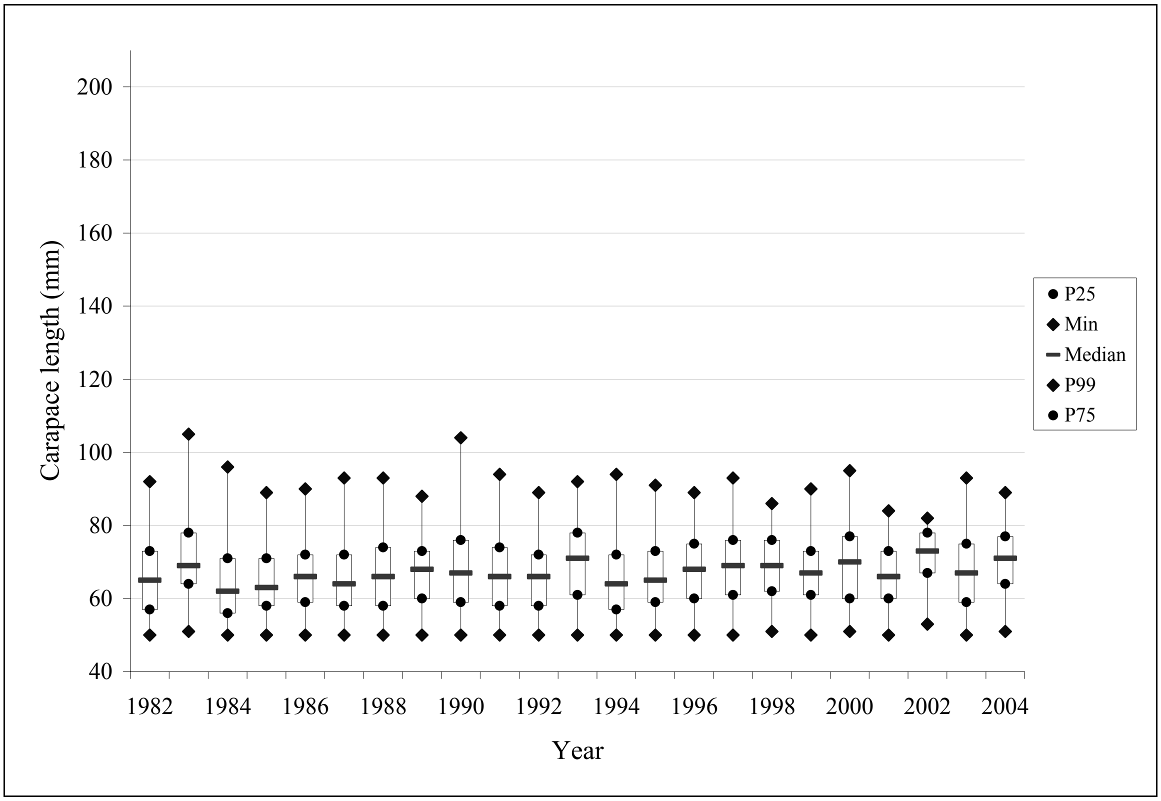


Figure 5.3.3.10. Male lobsters taken in the fall RI Survey Southern New England Stock Area.

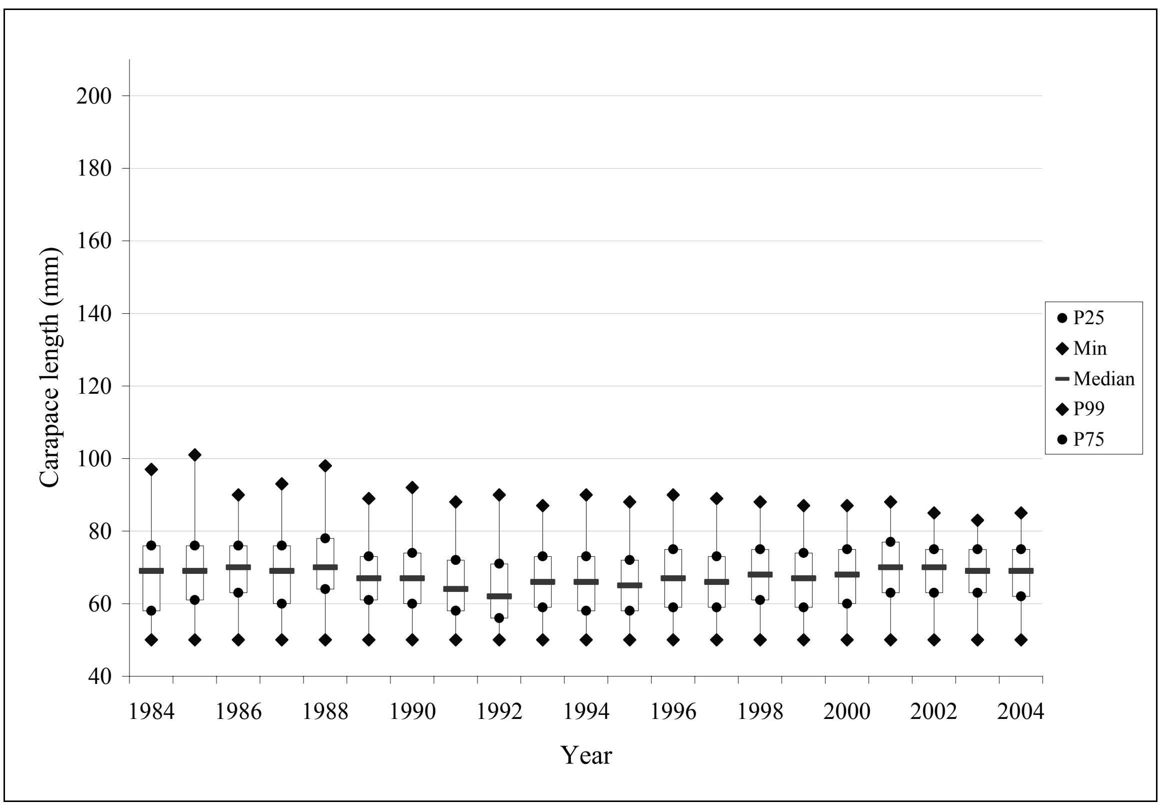


Figure 5.3.3.11. Female lobsters taken in the fall CT Survey Southern New England Stock Area.

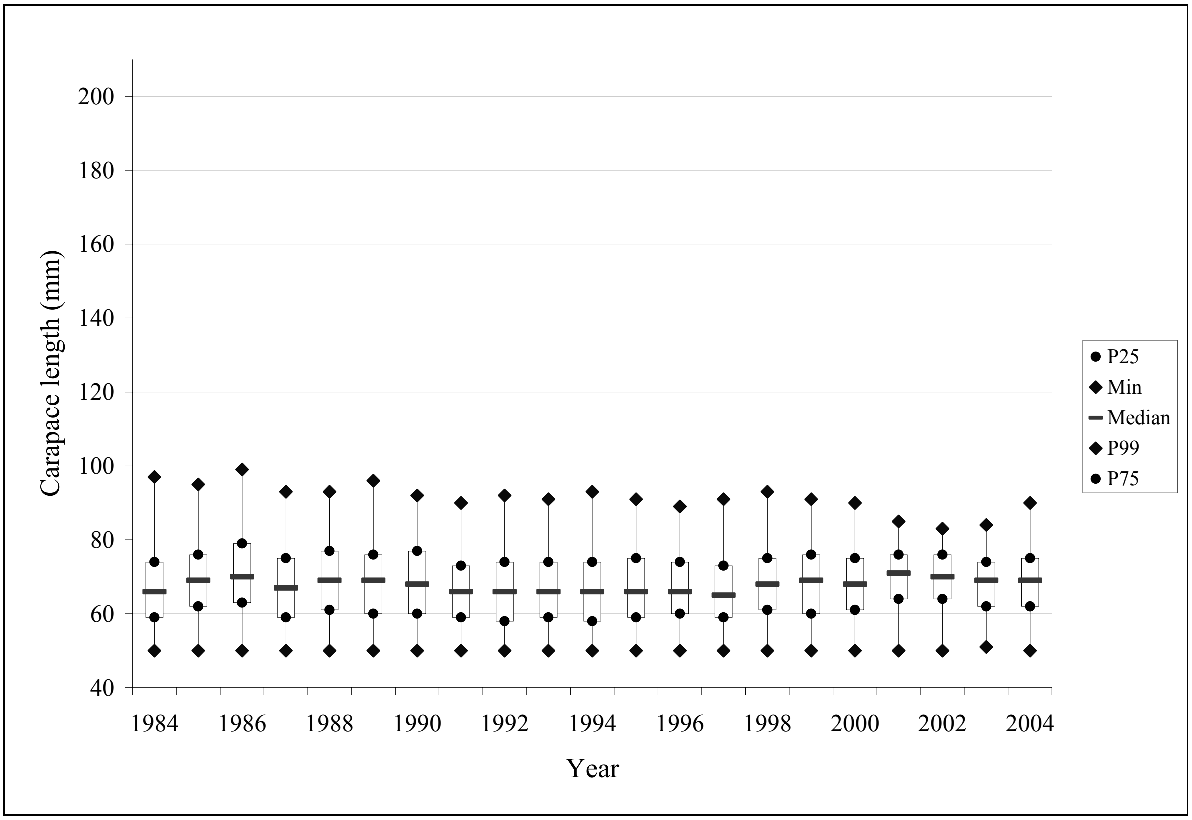


Figure 5.3.3.12. Male lobsters taken in the fall CT Survey Southern New England Stock Area

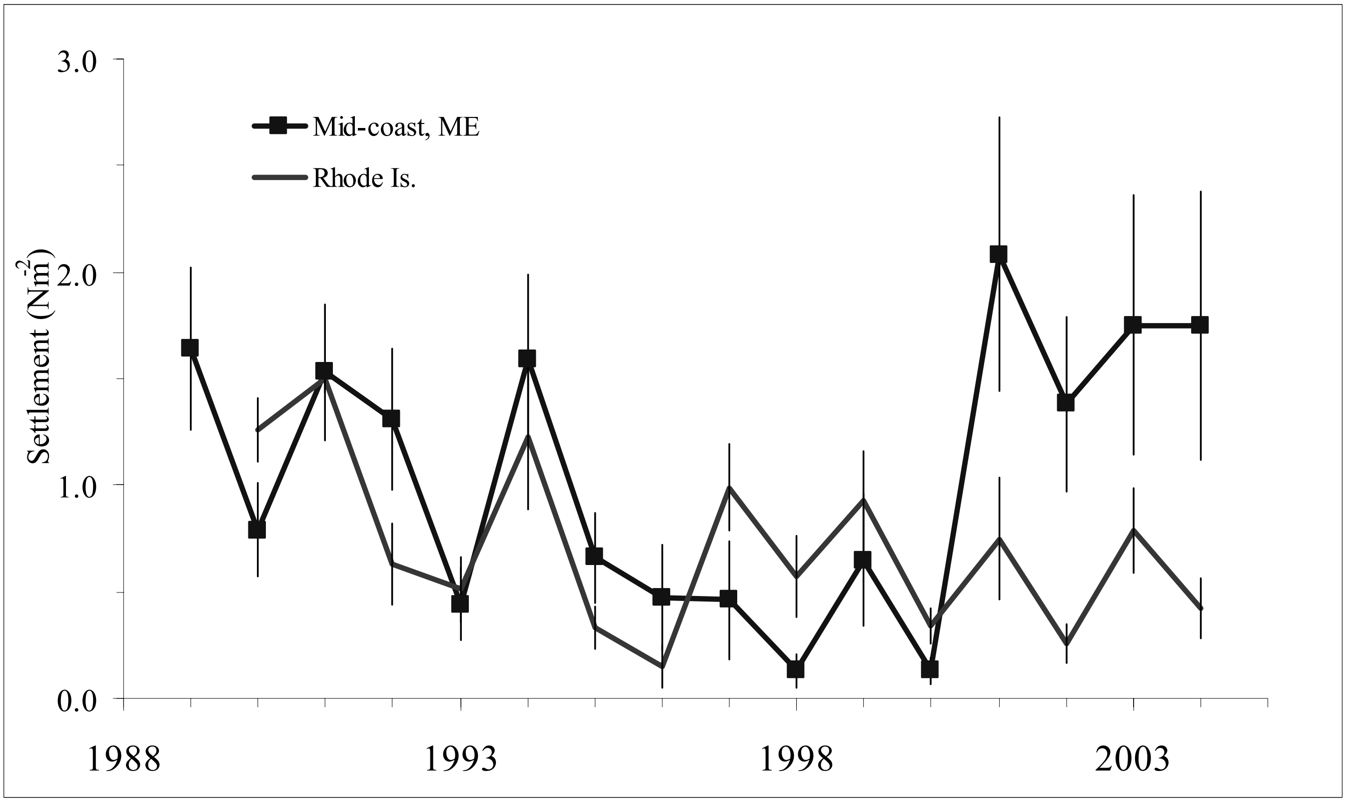


Figure 5.3.4.1. Densities (individuals m^{-2}) of newly settled lobster in mid-coast Maine and Rhode for the period of 1989 through 2004.
Settlement data were provided by Rick Wahle, Bigelow Laboratory for Ocean Sciences, W. Boothbay Harbor, ME. Error bars indicate yearly standard error between sampling locations within each region.

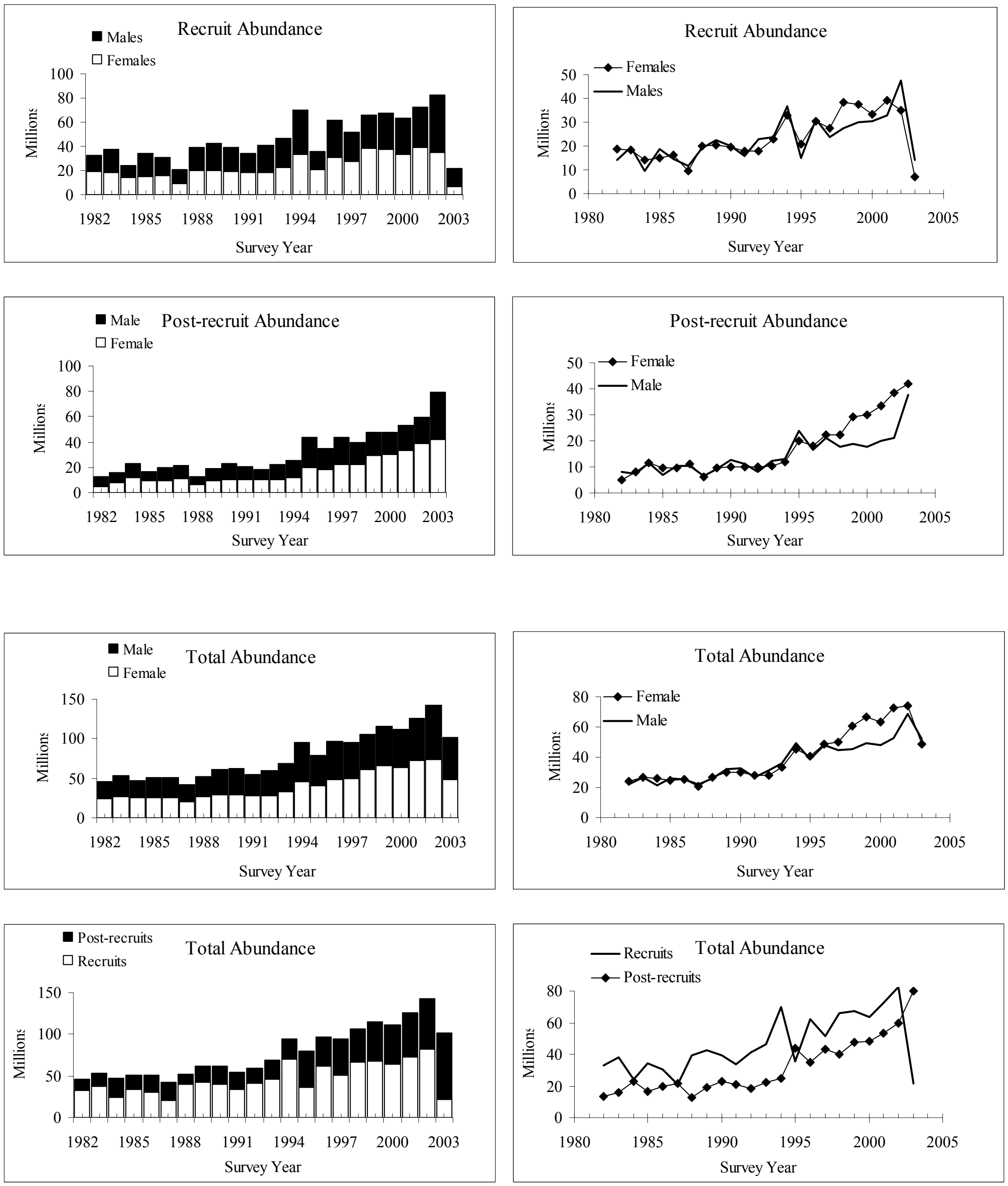


Figure 7.1.1. Population dynamics for male and female lobsters in GOM.

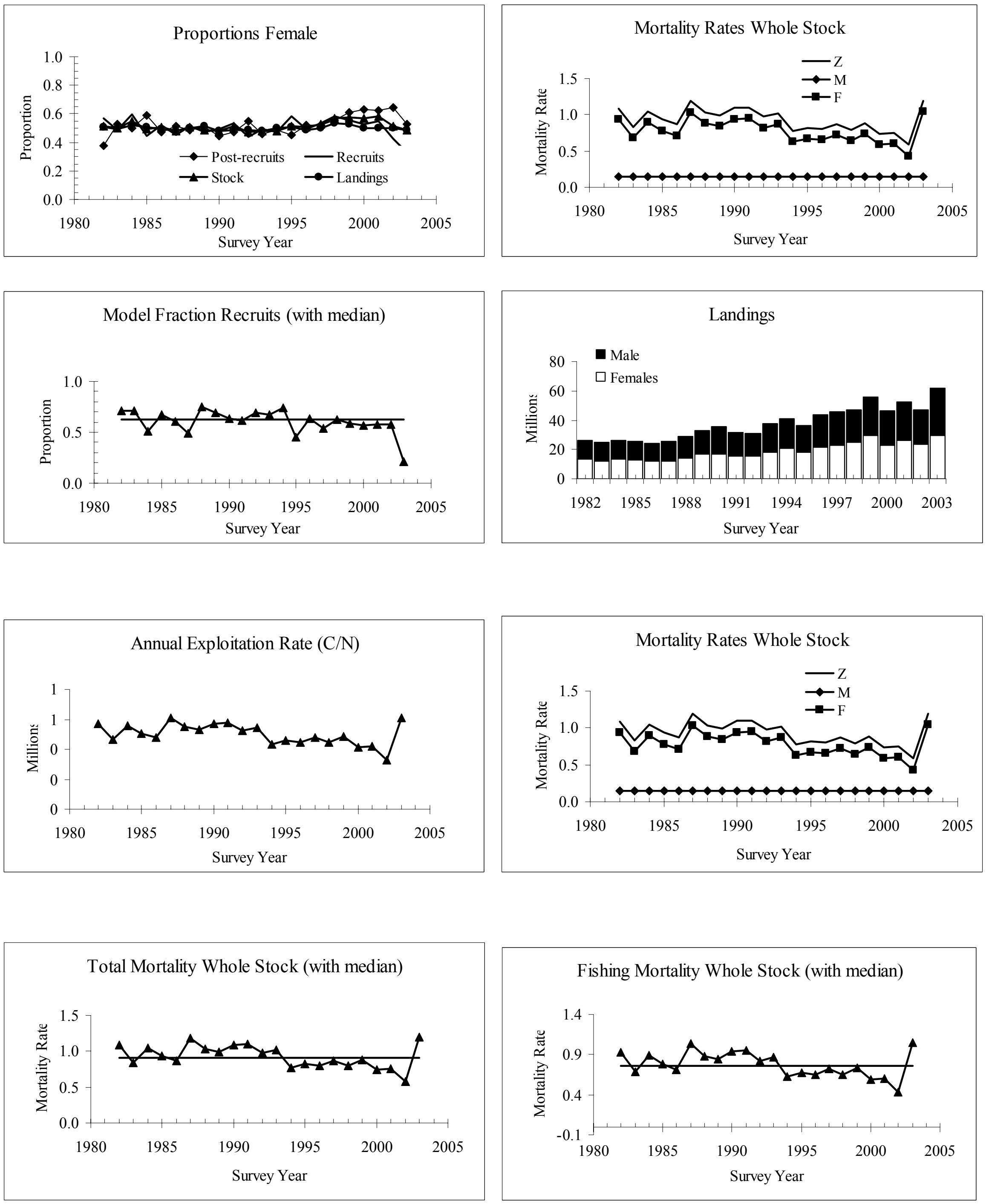
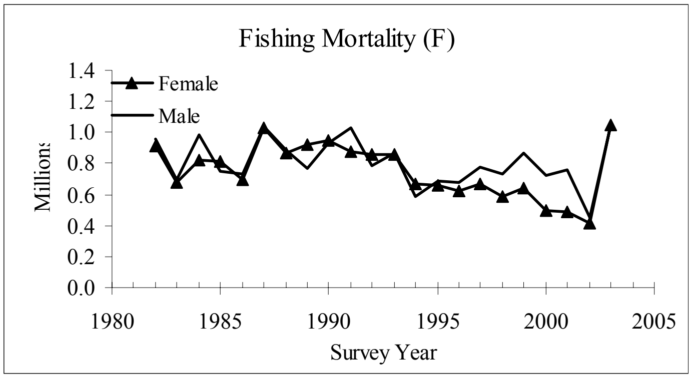
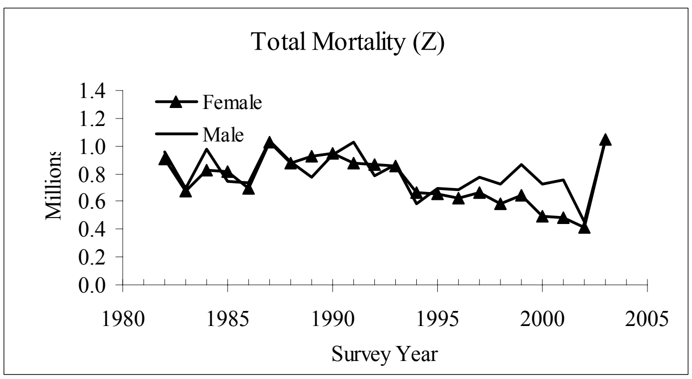


Figure 7.1.1. Population dynamics for male and female lobsters in GOM (cont.)





F-abundance history for lobster (both sexes) in GOM. Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard error (proposed management targets). The dark black circle shows average abundance and F during 2001-2003. The p-value from a chi-square contingency test for the null hypothesis that F and N estimates are independent was p=0.01 (1 df, with Yates correction).

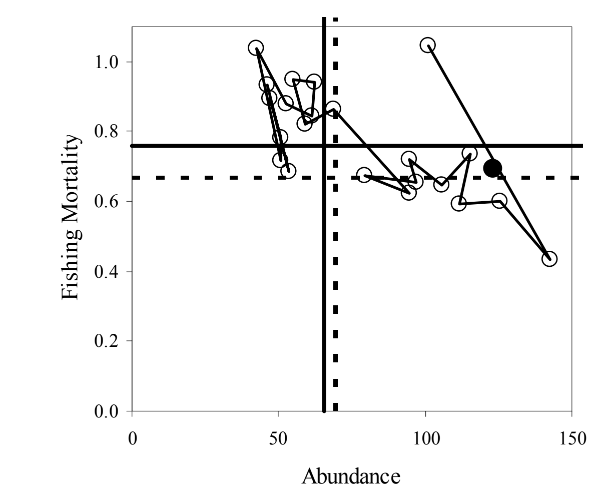


Figure 7.1.1. Population dynamics for male and female lobsters in GOM (cont.).

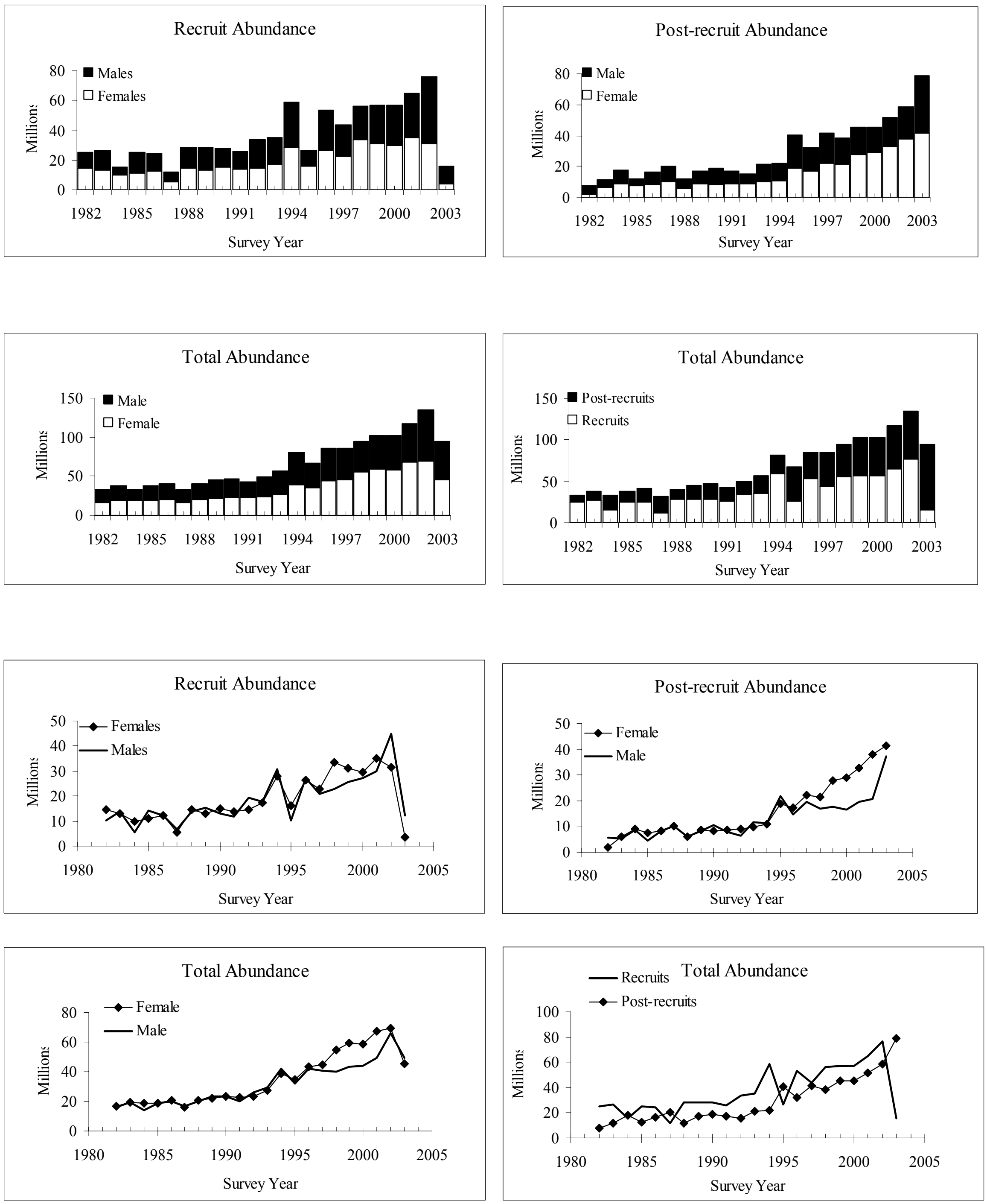


Figure 7.1.2. Population dynamics for male and female lobsters in GOM (areas covered by NEFSC survey).

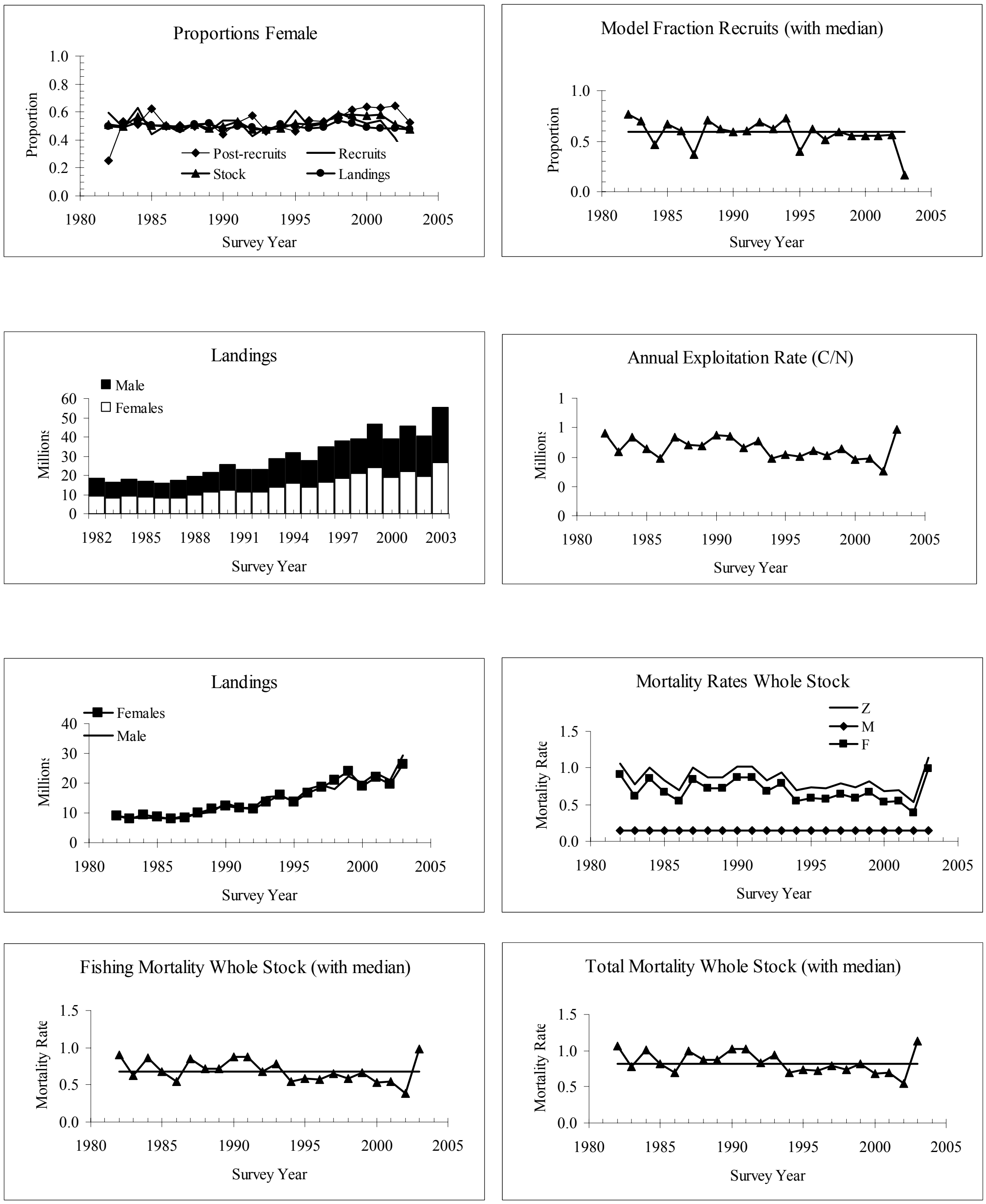
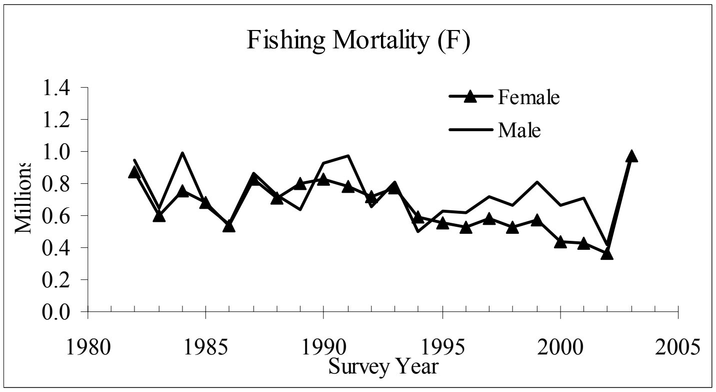
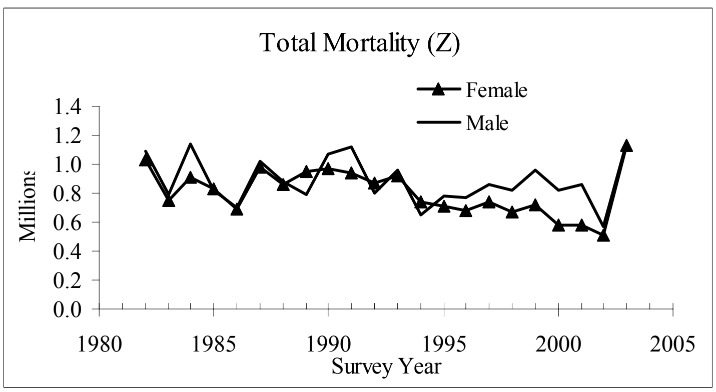


Figure 7.1.2. Population dynamics for male and female lobsters in GOM (areas covered by NEFSC survey) (cont.).



F-abundance history for lobster (both sexes) in GOM (areas covered by NEFSC survey). Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard error (proposed management targets). The dark black circle shows average abundance and F during 2001-2003.



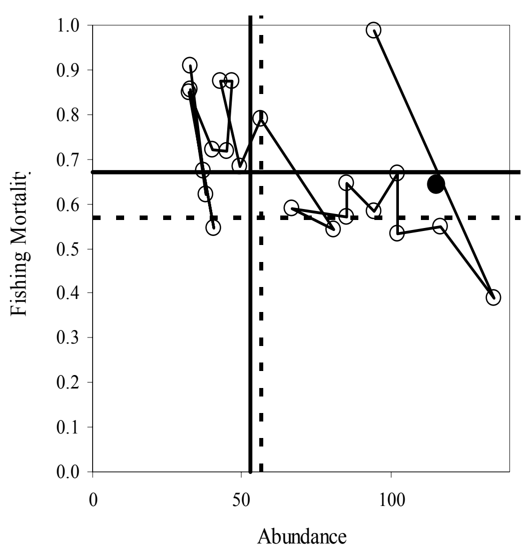


Figure 7.1.2. Population dynamics for male and female lobsters in GOM (areas covered by NEFSC survey) (cont.).

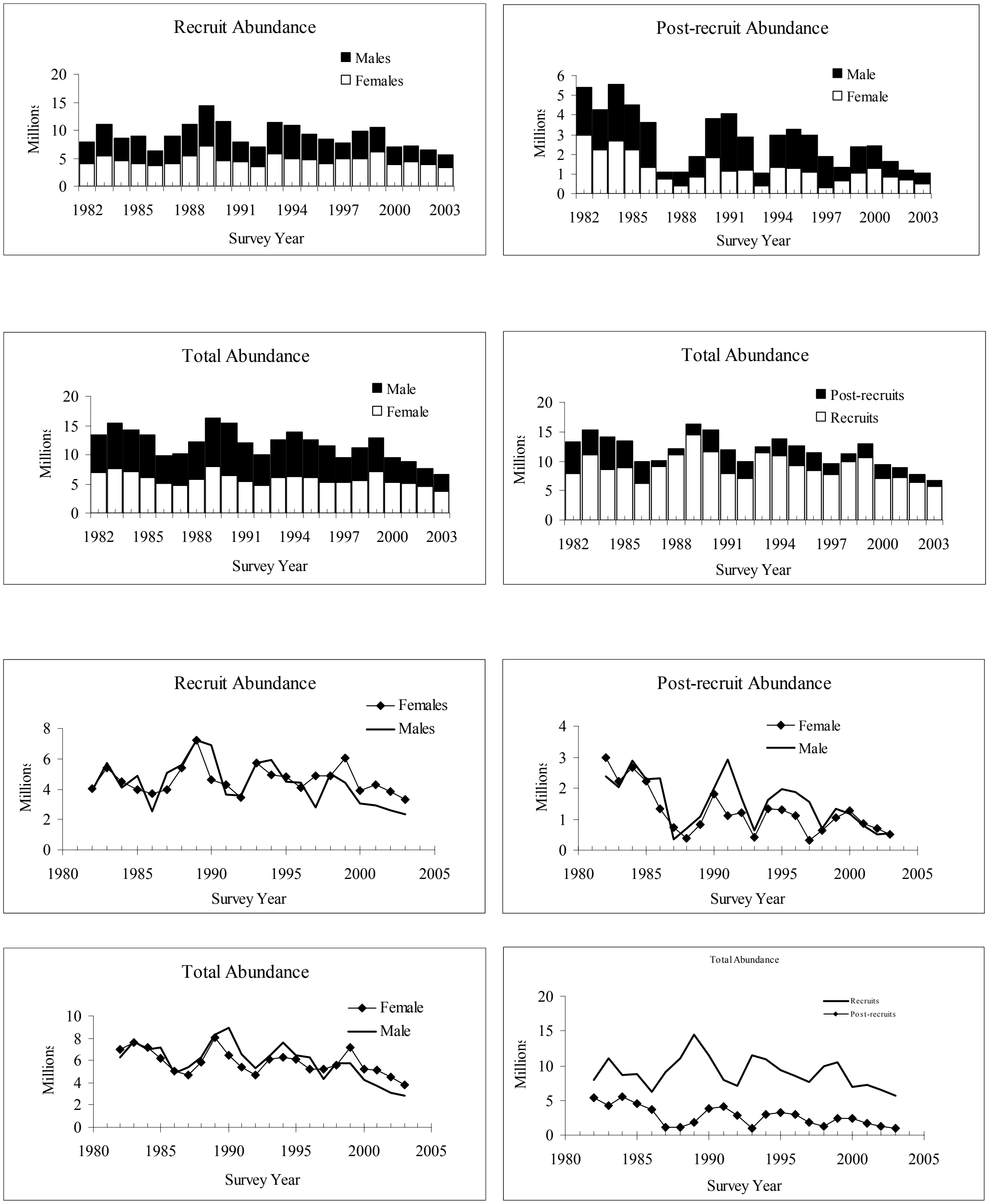


Figure 7.1.3. Population dynamics for male and female lobsters in GOM (Statistical Area 514; areas covered by Massachusetts survey).

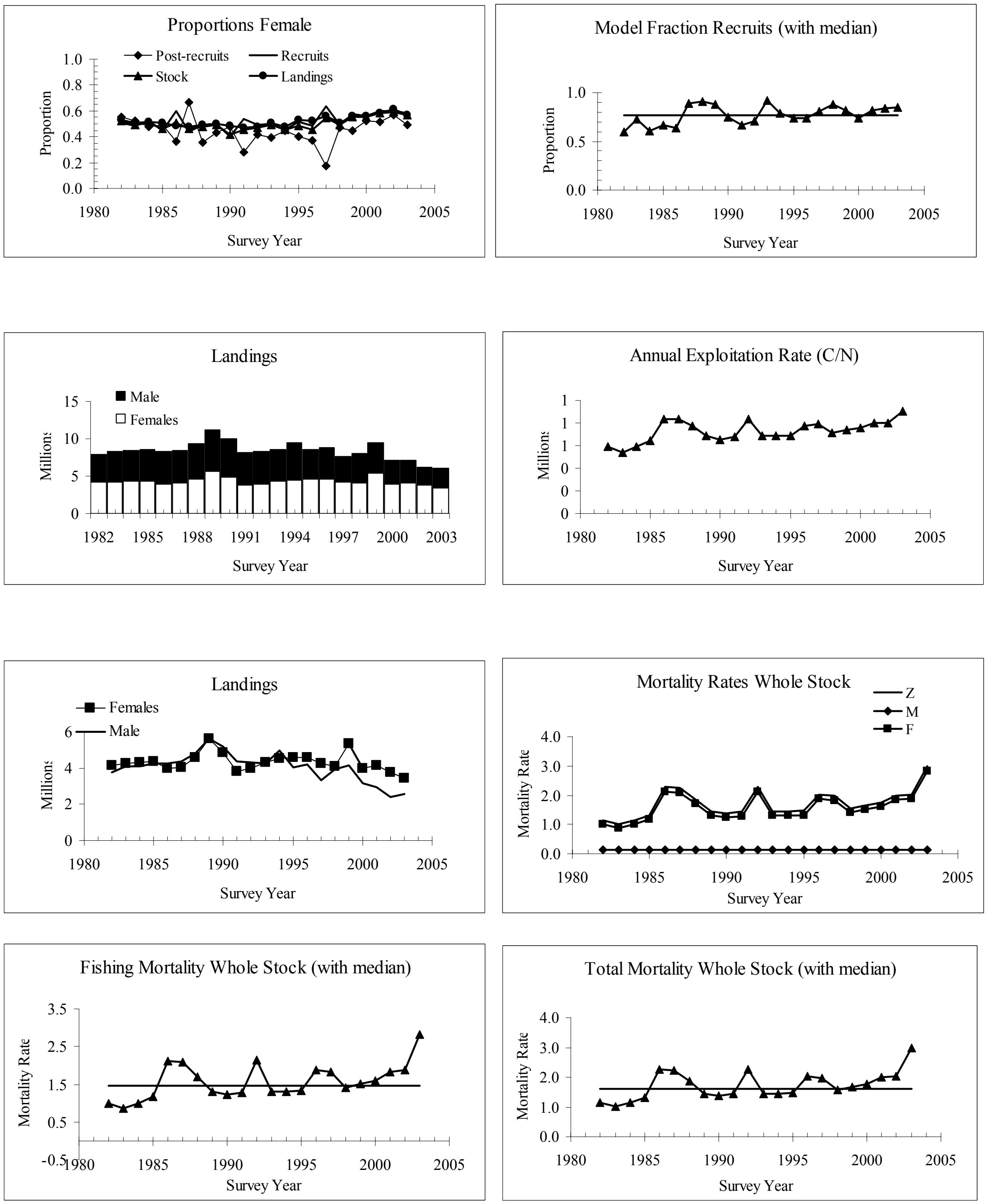
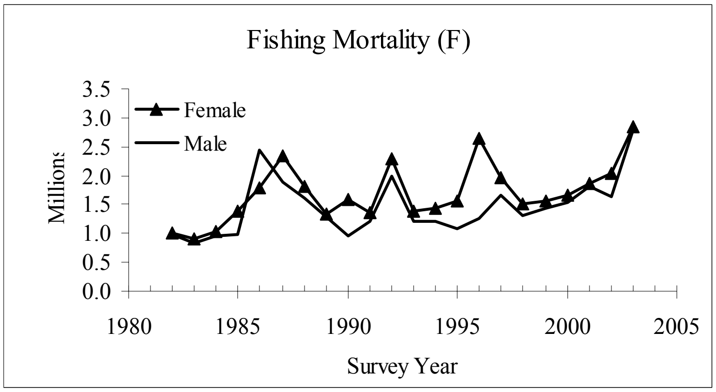
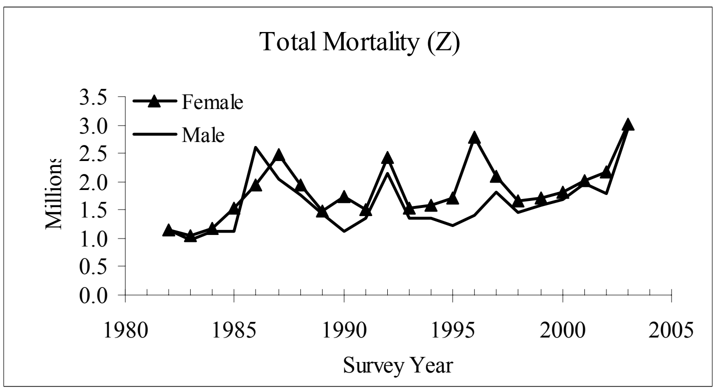


Figure 7.1.3. Population dynamics for male and female lobsters in GOM (Statistical Area 514; areas covered by Massachusetts survey) (cont.).





F-abundance history for lobster (both sexes) in GOM (Statistical Area 514; areas covered by Massachusetts survey). Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard error (proposed management targets). The dark black circle shows average abundance and F during 2001-2003.

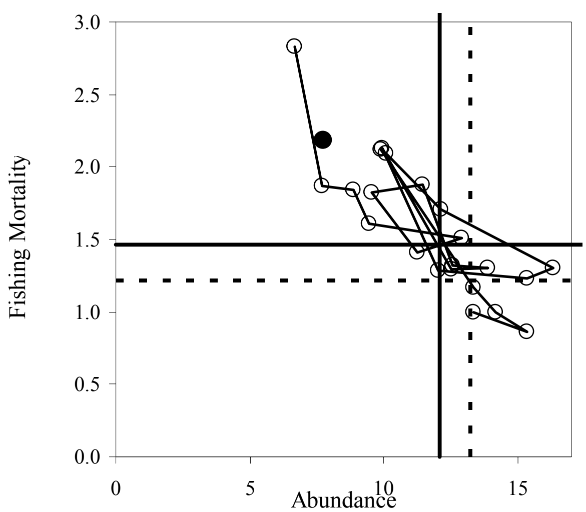


Figure 7.1.3. Population dynamics for male and female lobsters in GOM (Statistical Area 514; areas covered by Massachusetts survey) (cont.).

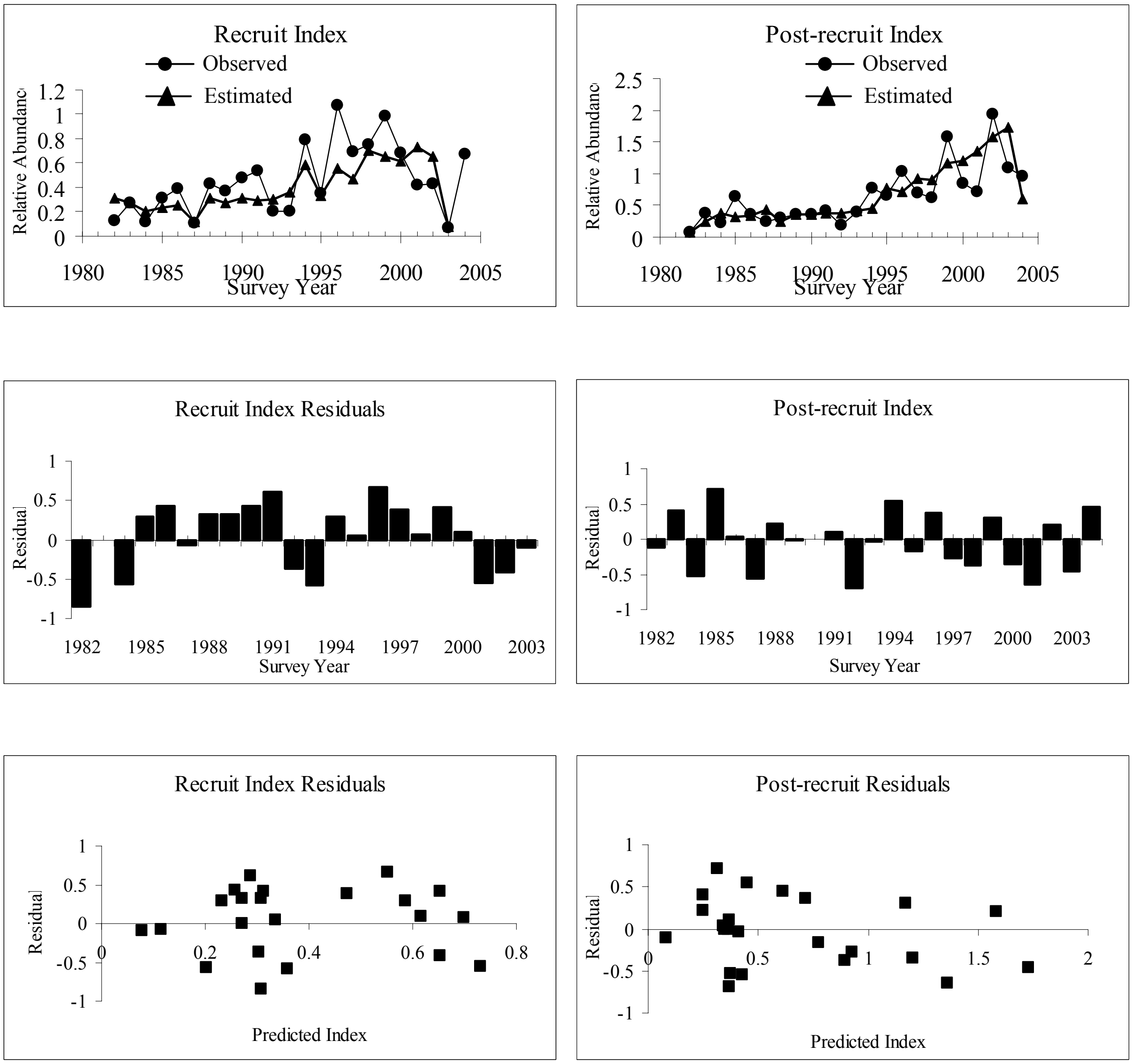


Figure 7.1.4. Abundance indices, fitted values and residuals for female lobsters in GOM (area covered by NEFSC survey).

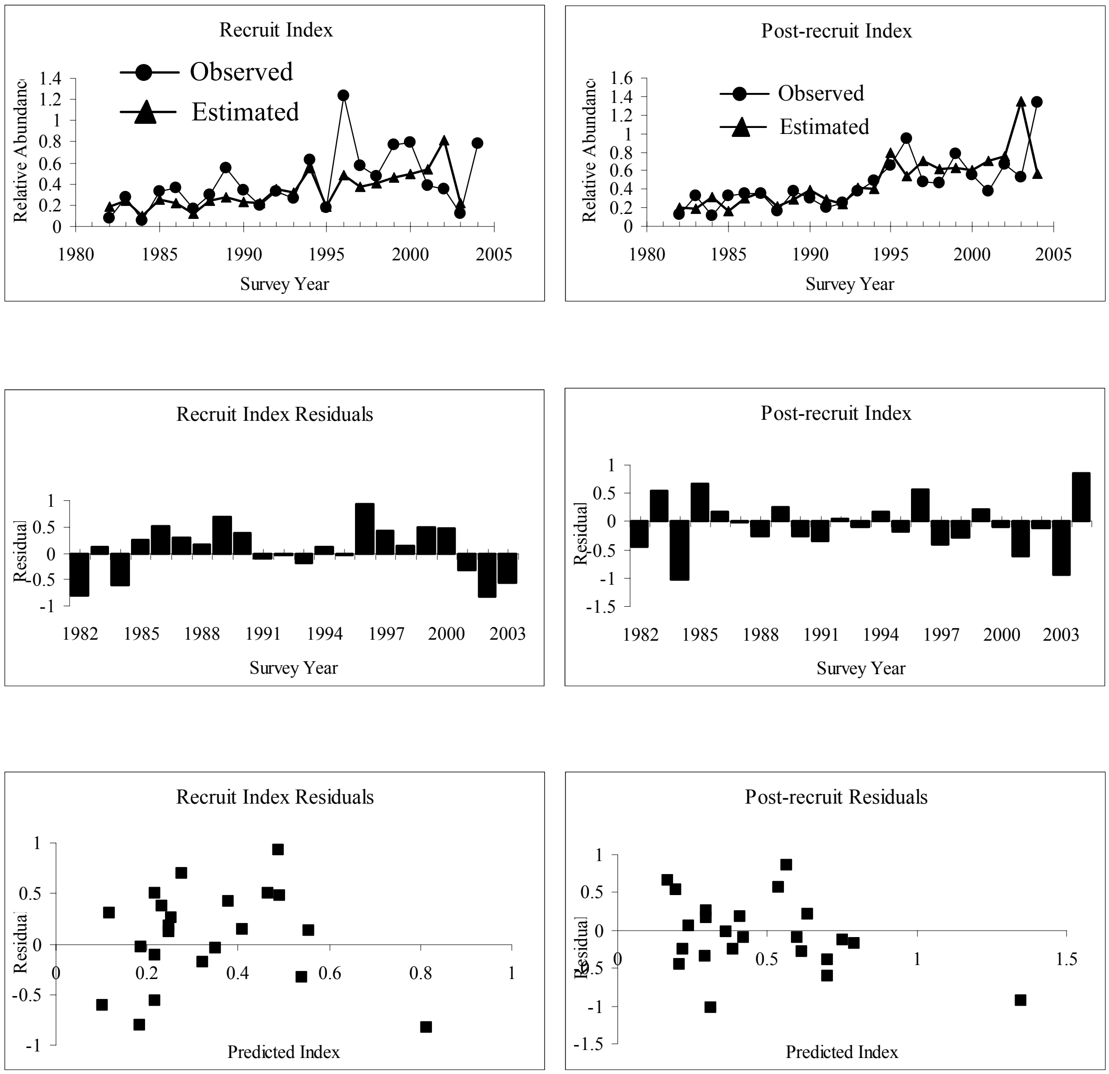


Figure 7.1.5. Abundance indices, fitted values and residuals for male lobsters in GOM (area covered by NEFSC survey).

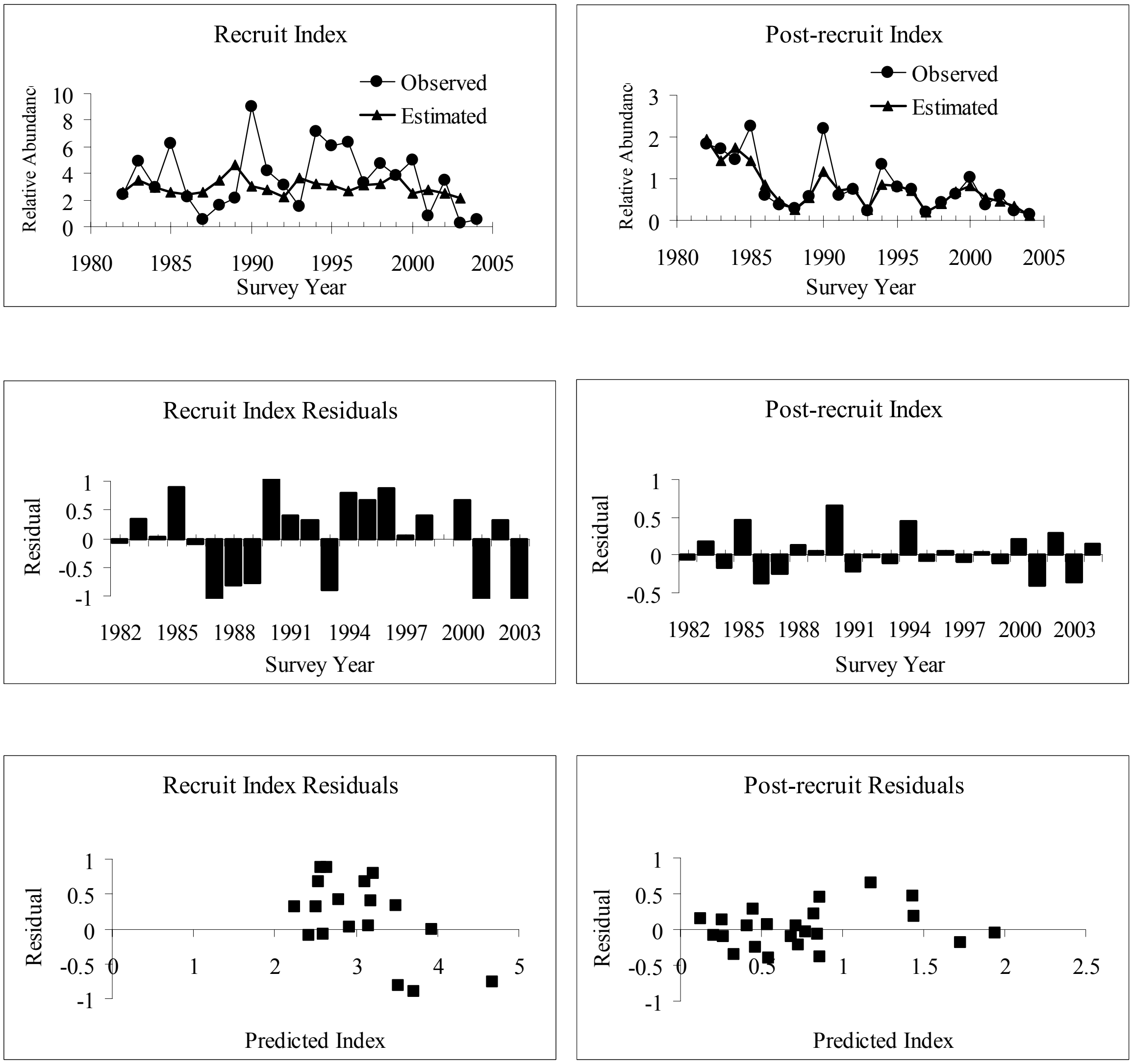


Figure 7.1.6. Abundance indices, fitted values and residuals for female lobsters in GOM (Statistical Area 514; area covered by Massachusetts survey).

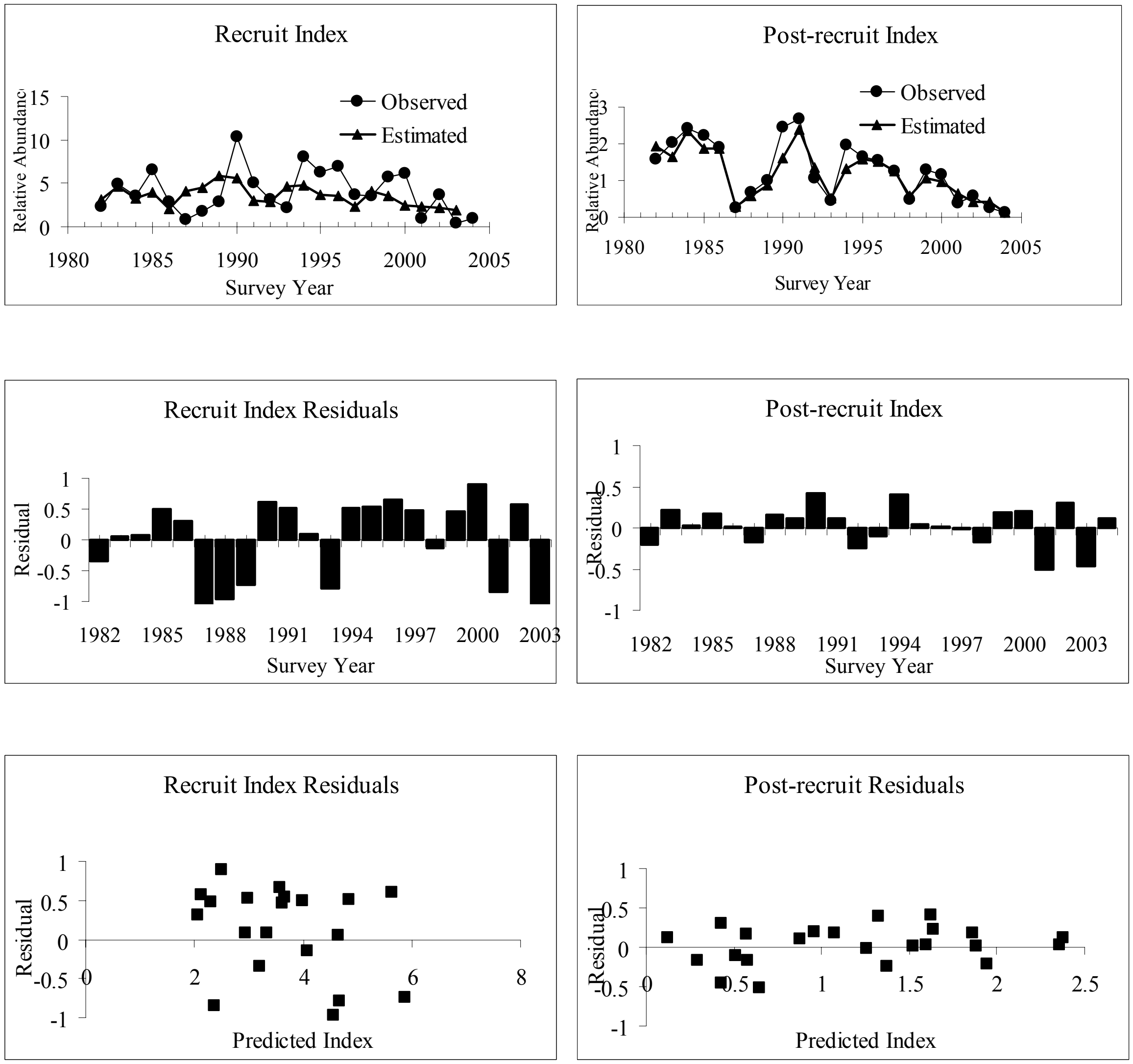


Figure 7.1.7. Abundance indices, fitted values and residuals for male lobsters in GOM (Statistical Area 514; area covered by Massachusetts survey).

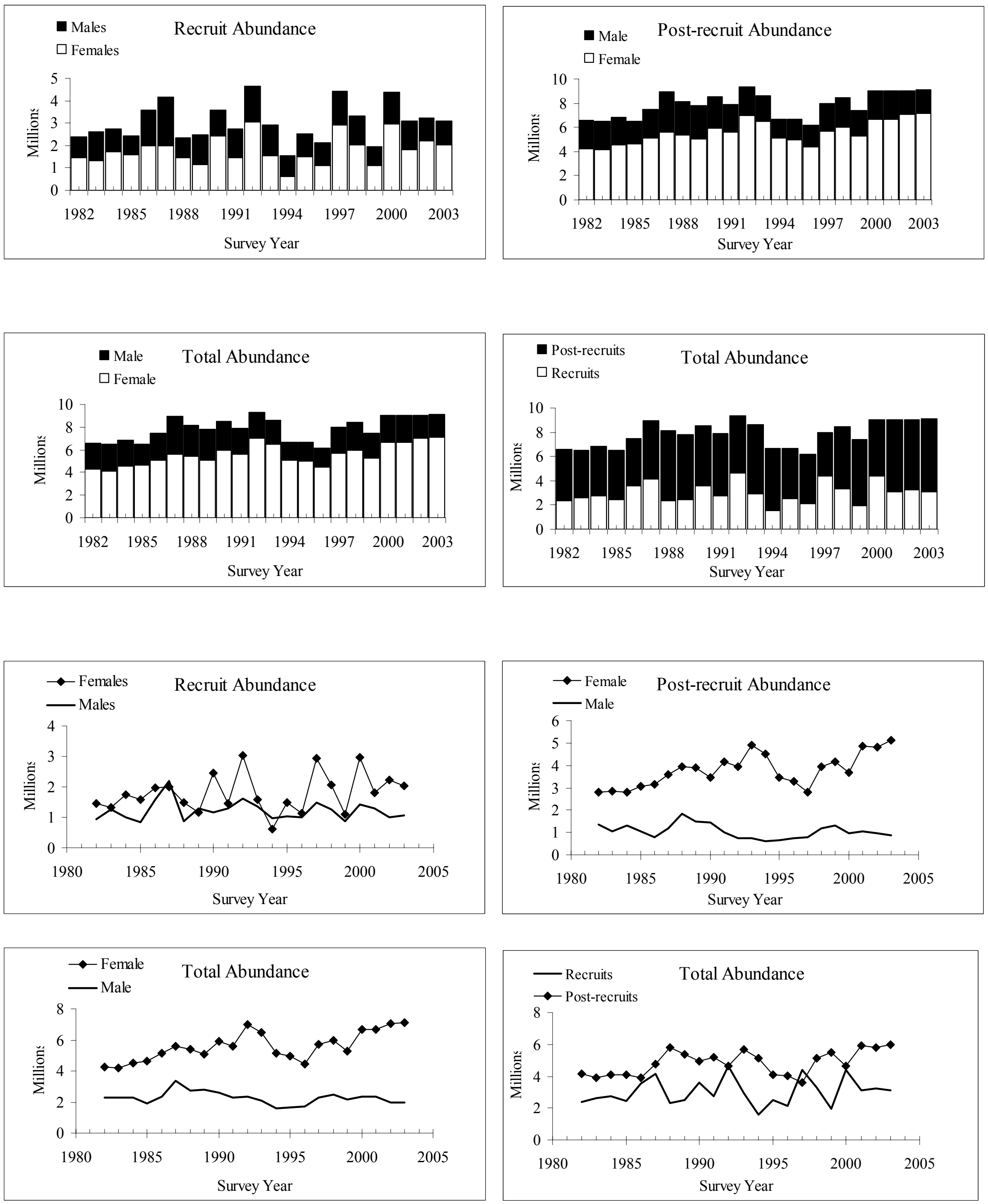


Figure 7.2.1. Population dynamics for male and female lobsters in GBK.

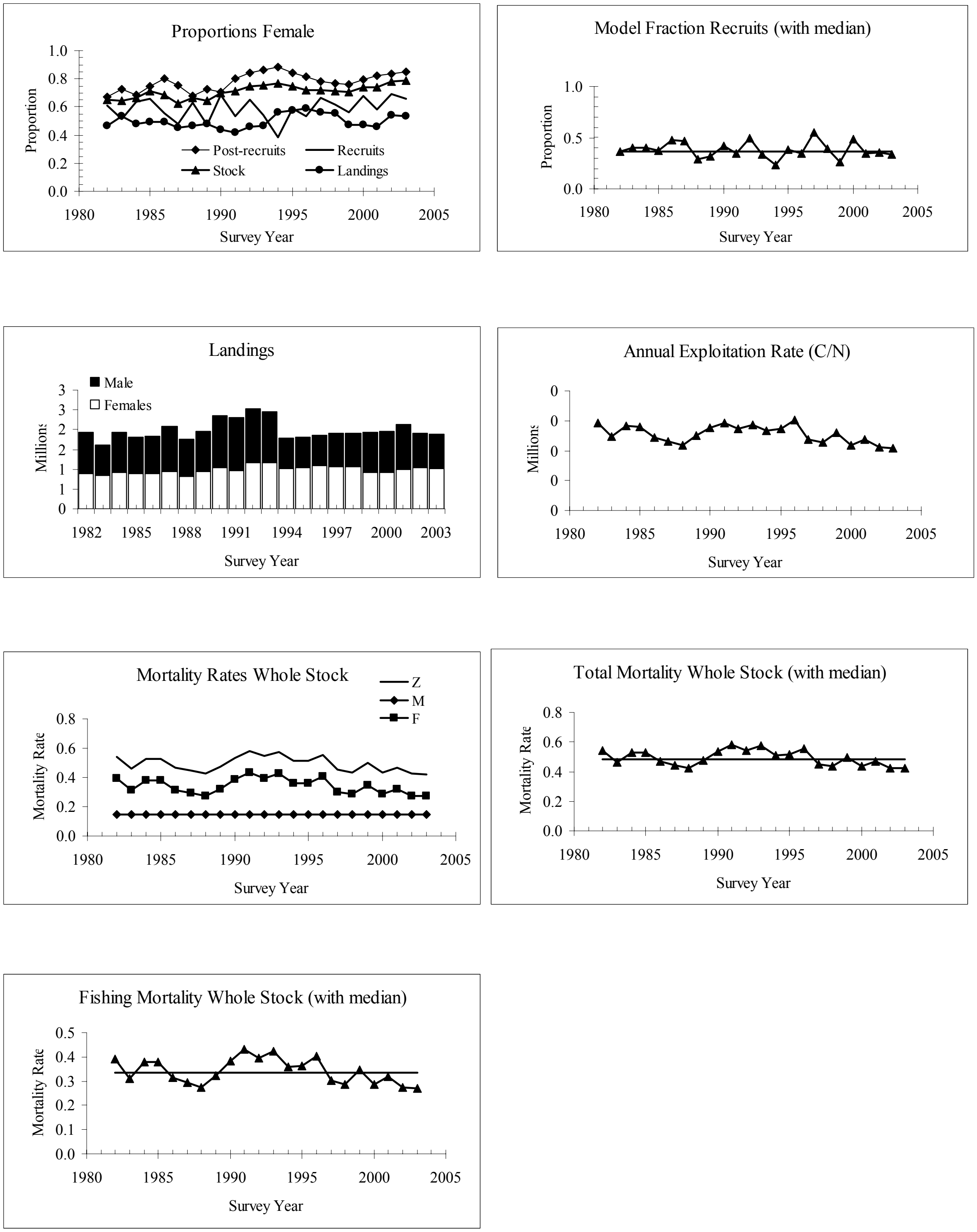
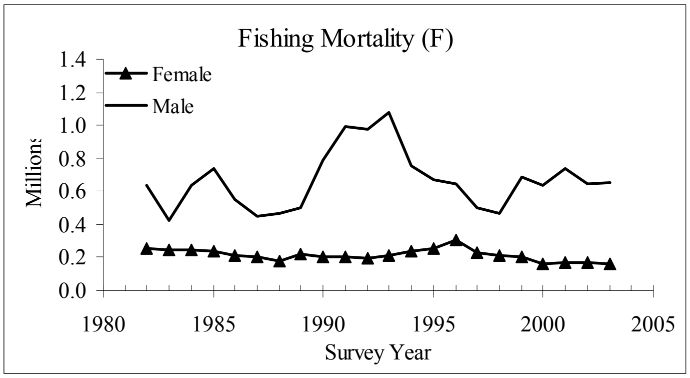
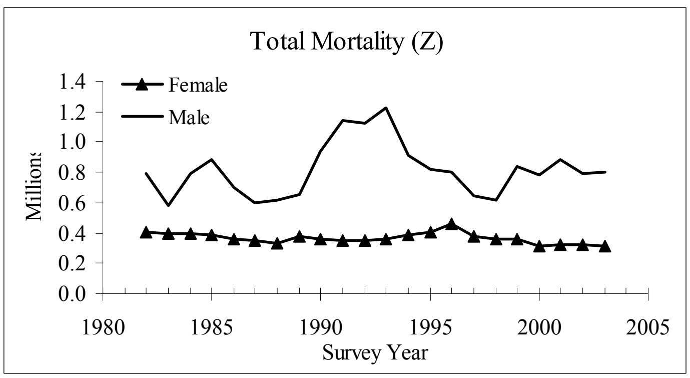
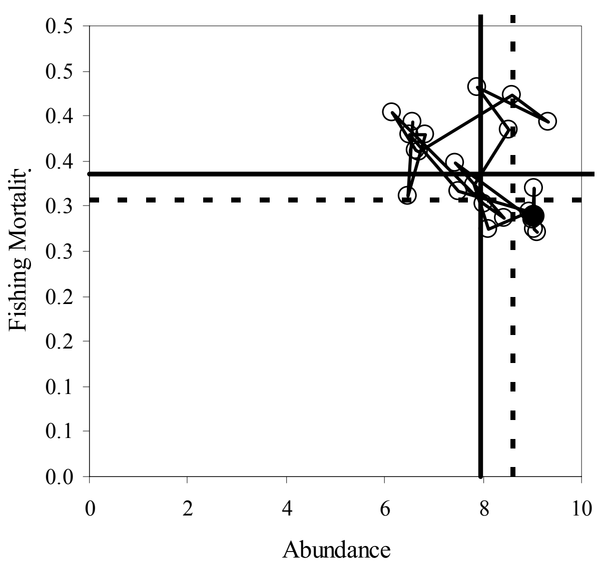


Figure 7.2.1. Population dynamics for male and female lobsters in GBK (cont.).







F-abundance history for lobster (both sexes) in GBK during 1982-2003. Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard error (proposed management targets). The dark black circle shows average abundance and F during 2001-2003. The p-value from a chi-square contingency test for the null hypothesis that F and N estimates are independent was p=0.09 (1 df, with Yates correction).

Figure 7.2.1. Population dynamics for male and female lobsters in GBK (cont.).

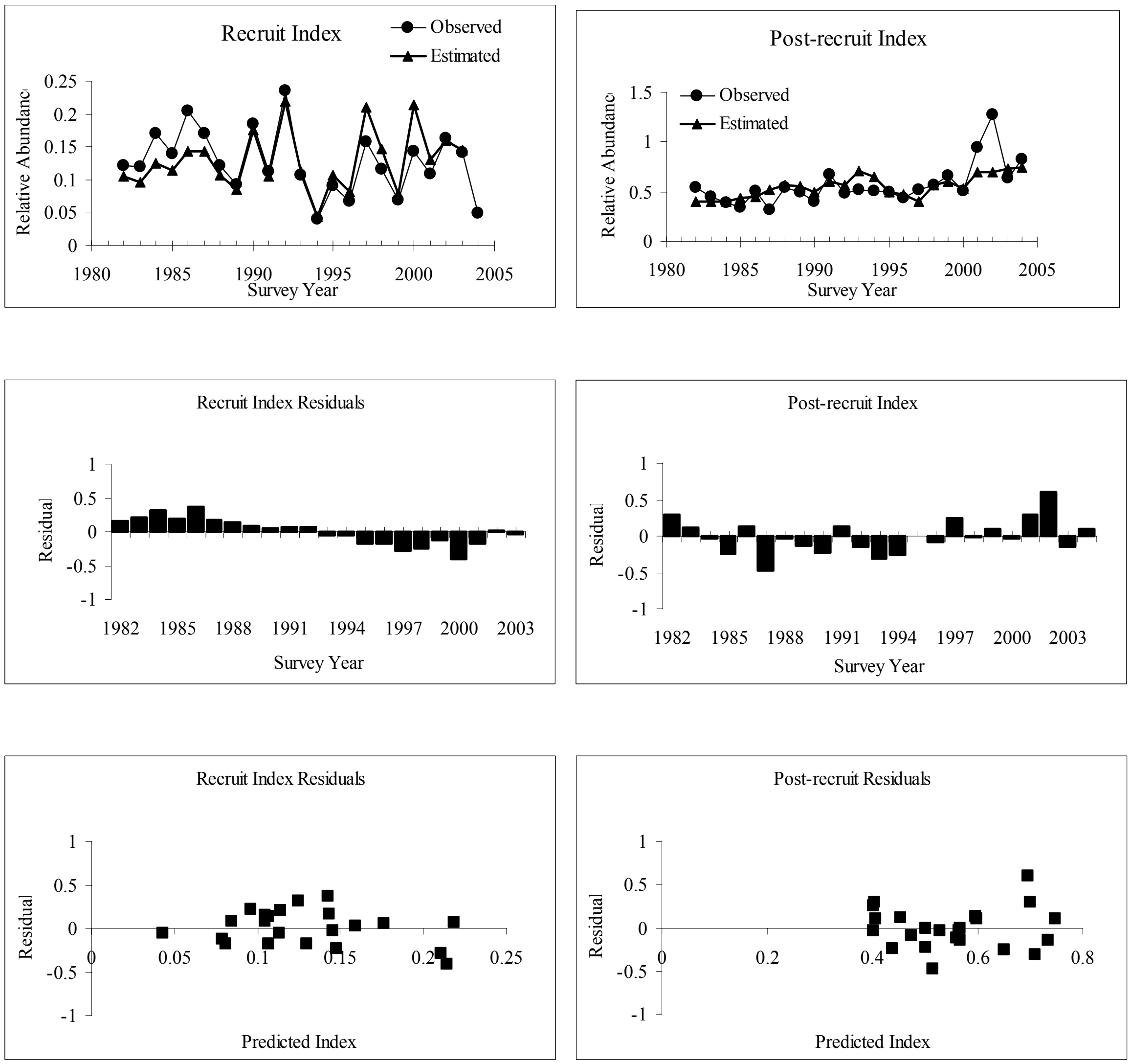


Figure 7.2.2. Abundance indices, fitted values and residuals for female lobsters in GBK.

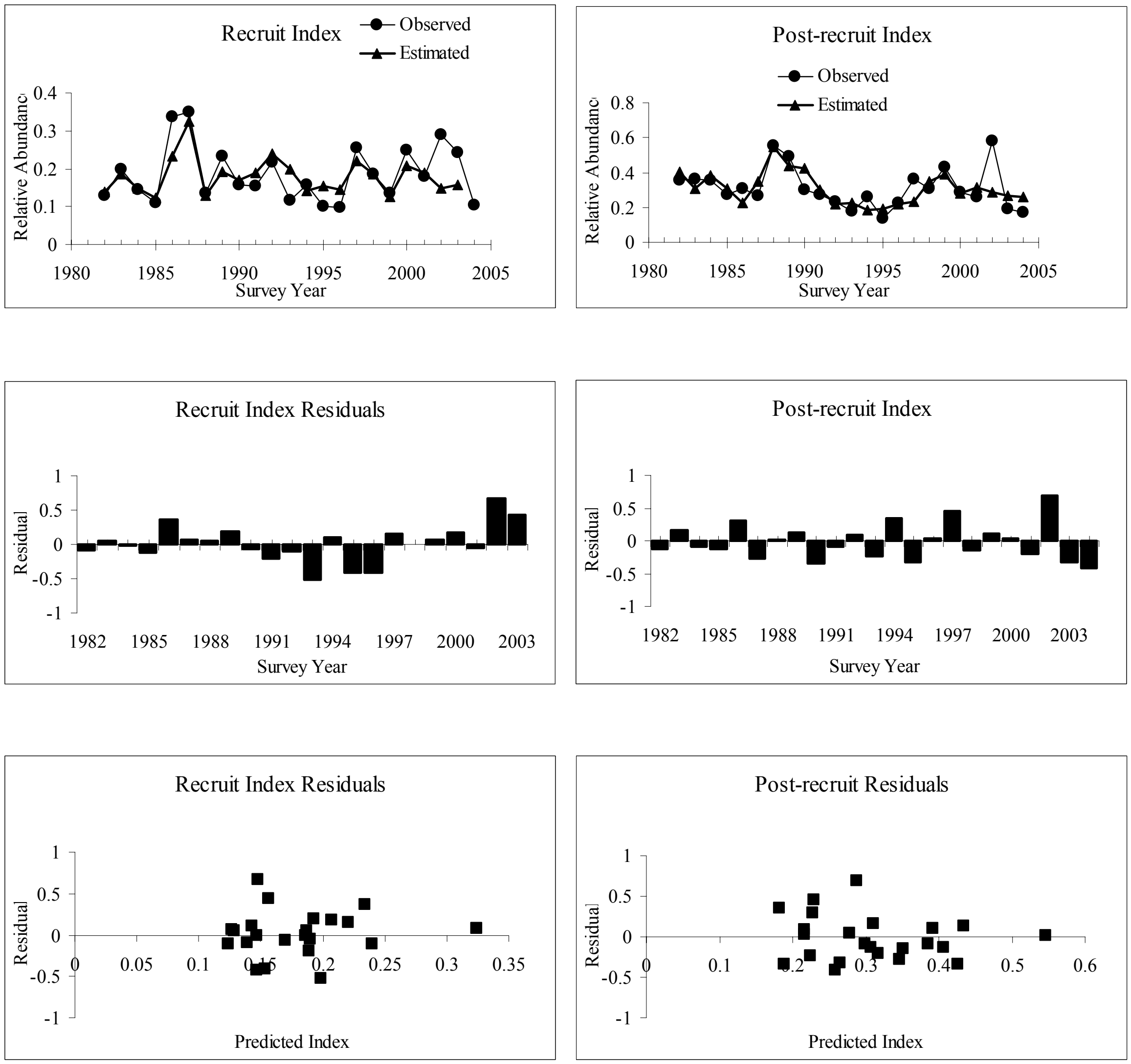


Figure 7.2.3. Abundance indices, fitted values and residuals for male lobsters in GBK.

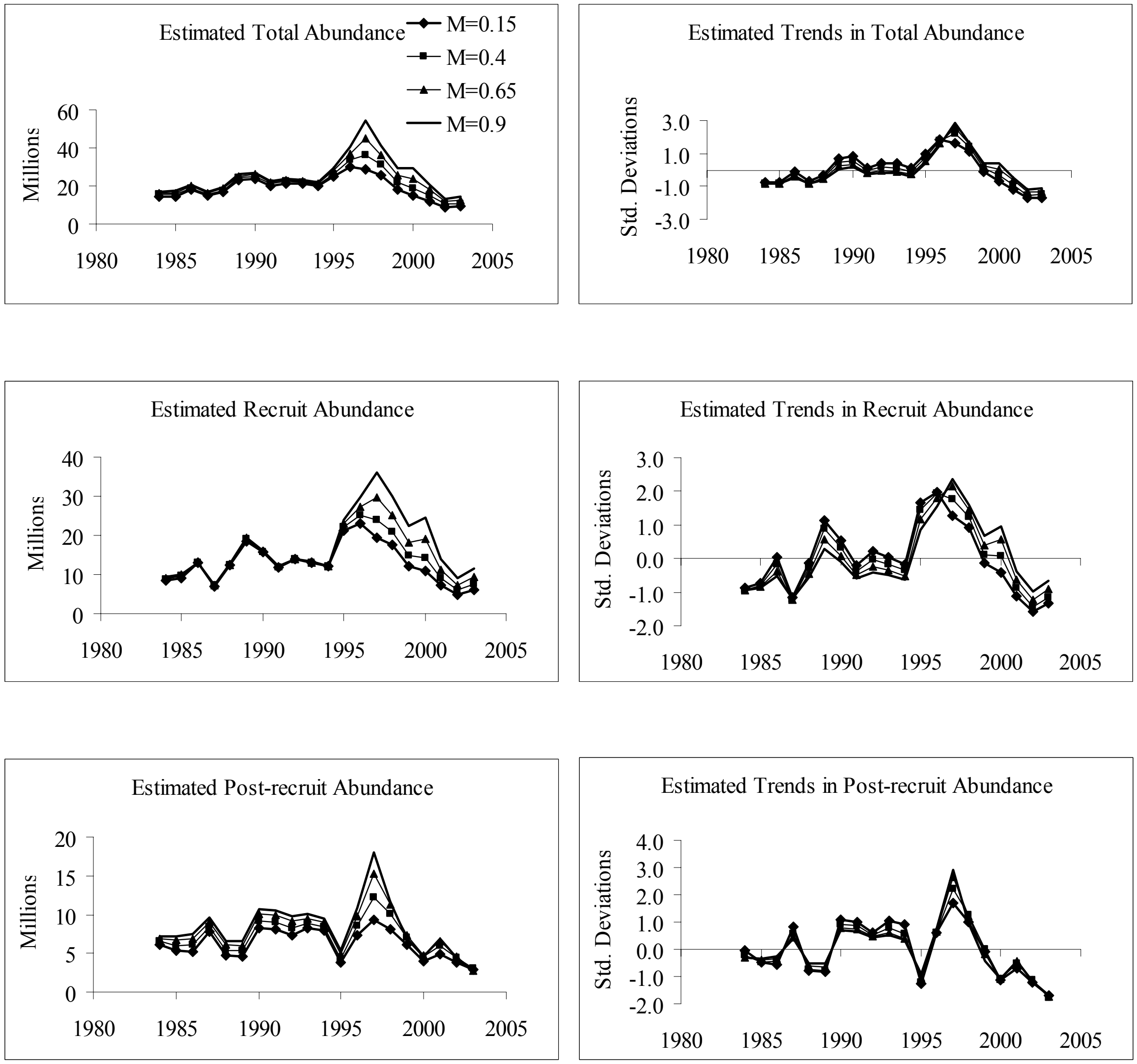


Table 7.3.1. Estimates and trends in abundance and mortality for male and female lobsters in SNE with M=0.15(no change) during 1984-1996 and M=0.15 (no change), 0.4, 0.65, 0.9 y-1 during 1997-2003.

Trends were calculated from the original estimates by subtracting the series mean and dividing by the series standard deviation.

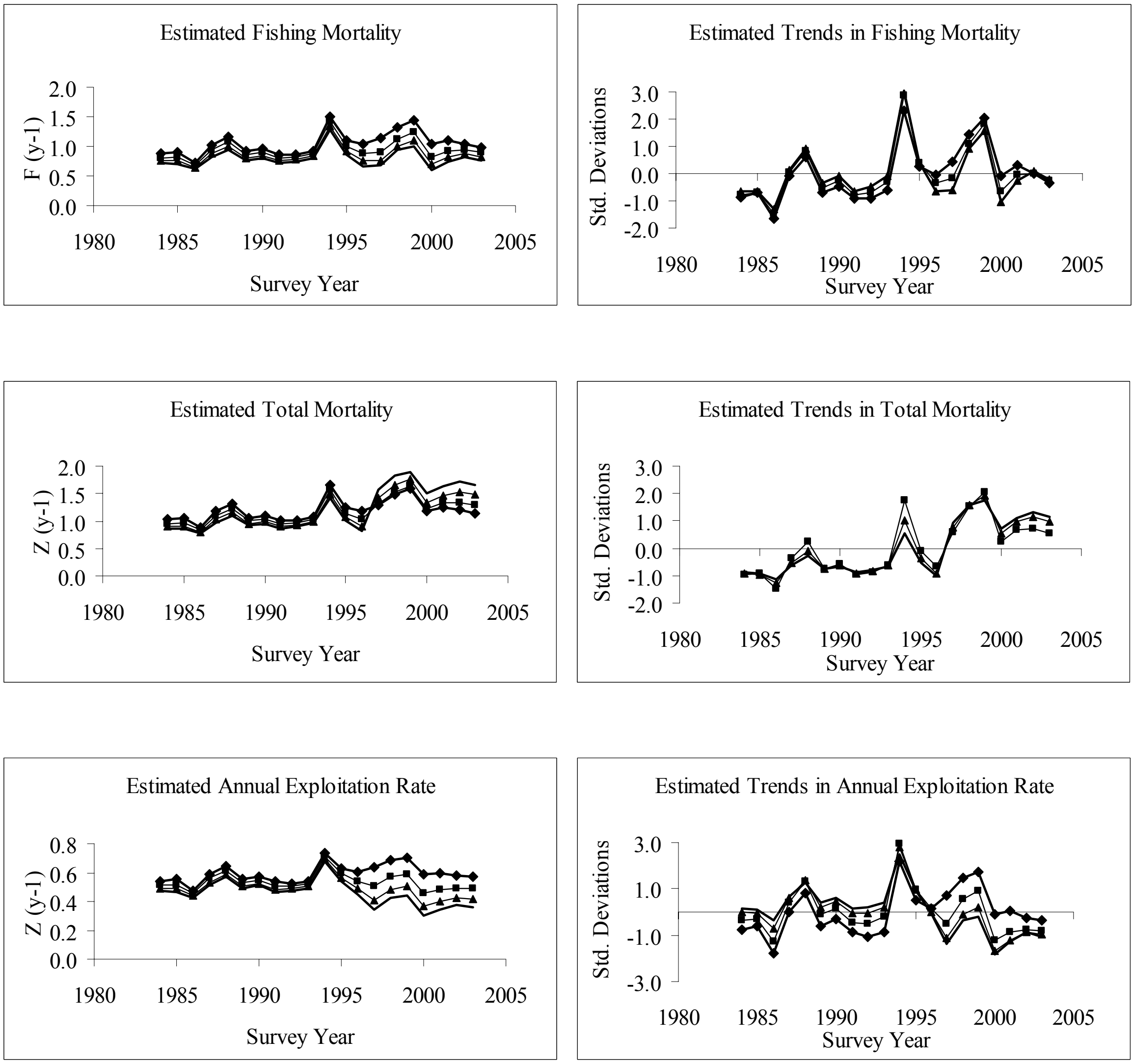
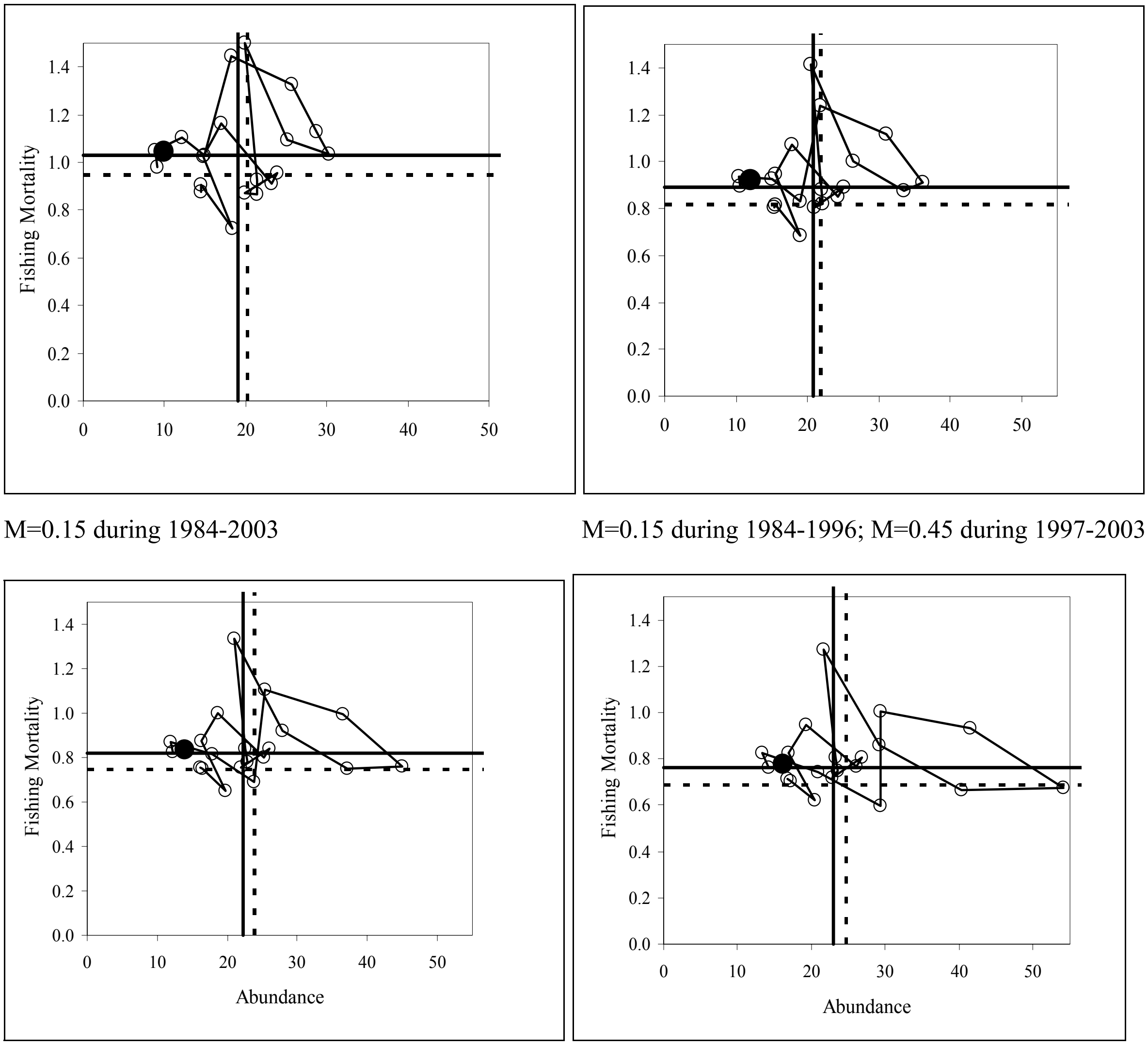


Figure 7.3.1 (continued)



M=0.15 during 1984-2003

M=0.15 during 1984-1996; M=0.45 during 1997-2003

M=0.15 during 1984-1996; M=0.65 during 1997-2003

M=0.15 during 1984-1996; M=0.9 during 1997-2003

Figure 7.3.2. F-abundance history for lobster (both sexes) in SNE assuming different levels of natural mortality (M) during 1997-2003.

Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard error.

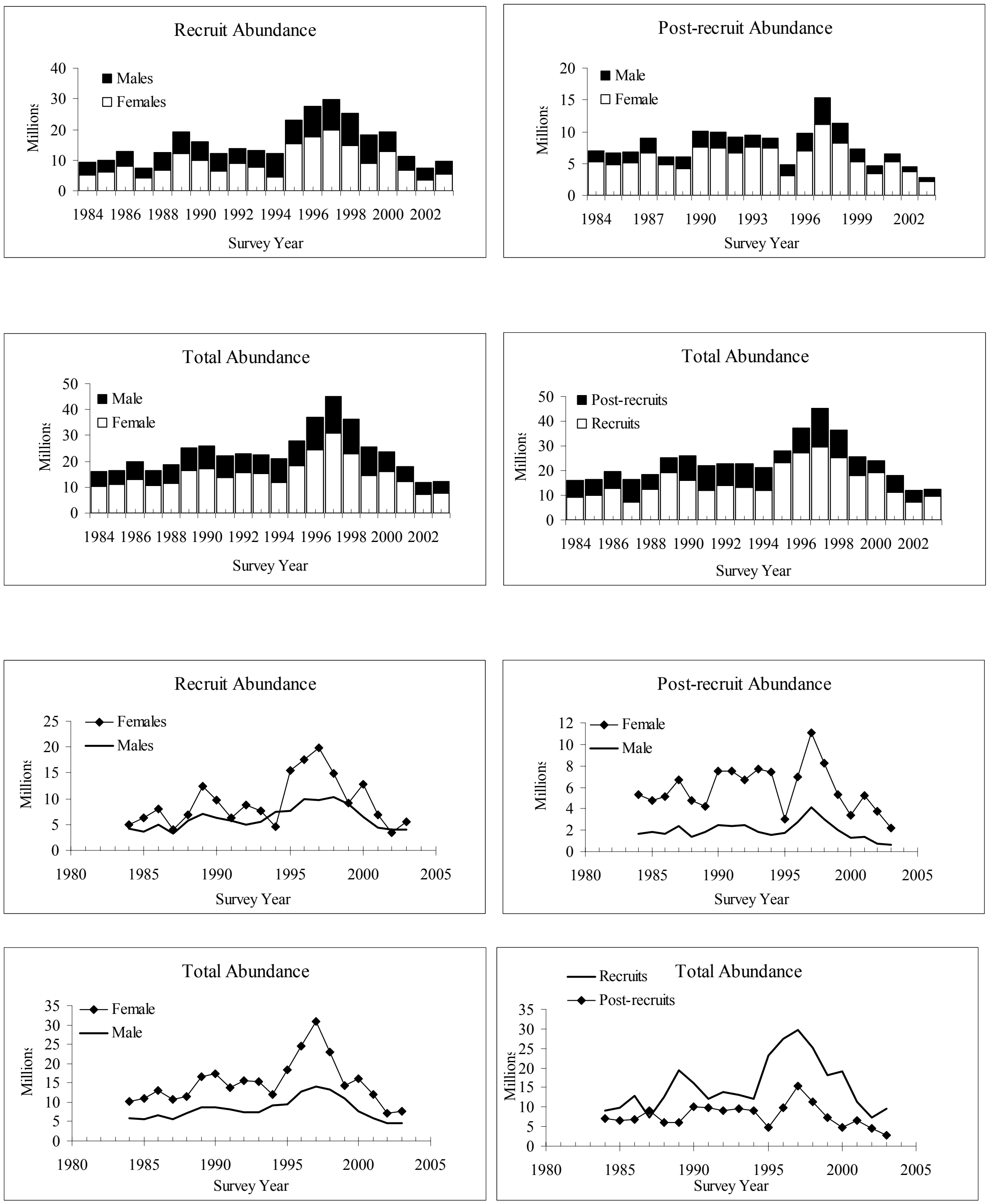


Figure 7.3.3. Population dynamics for male and female lobsters in SNE (M = 0.65).

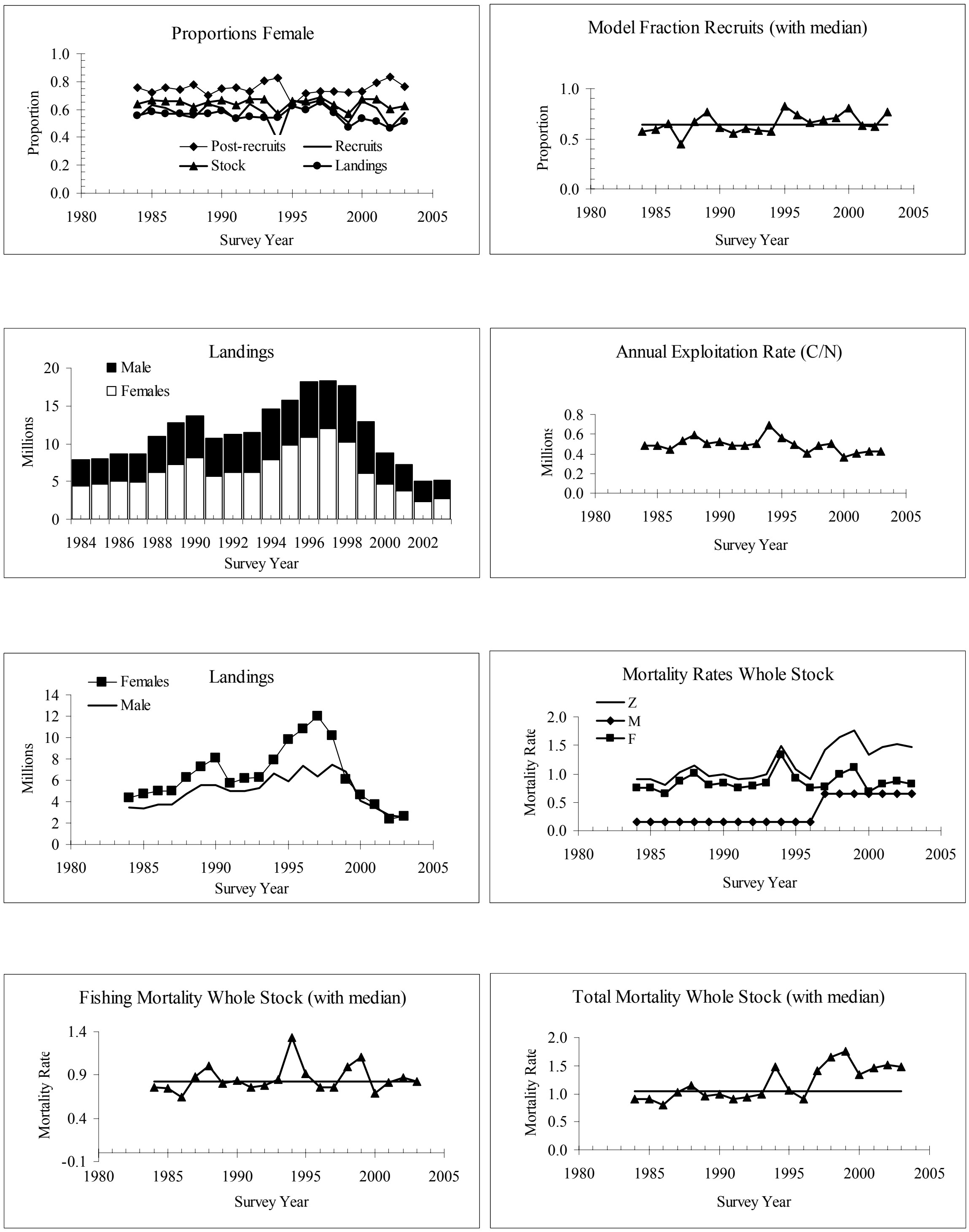
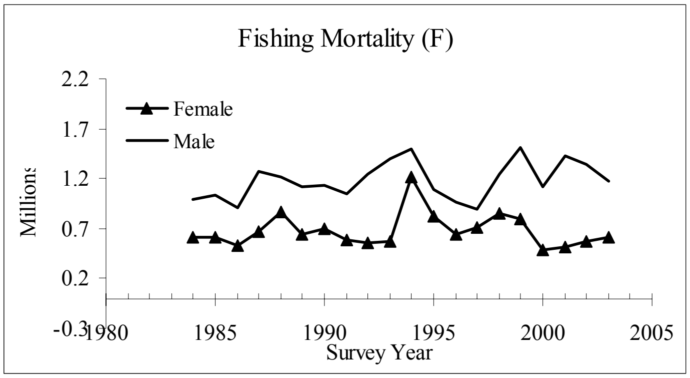
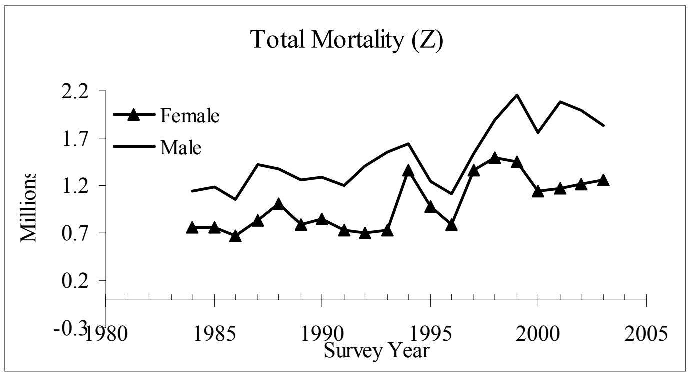


Figure 7.3.3. Population dynamics for male and female lobsters in SNE (M=0.65). (cont.)





F-abundance history for lobster (both sexes) in SNE (M=0.65). Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard error (proposed management targets). The dark black circle shows average abundance and F during 2001-2003.

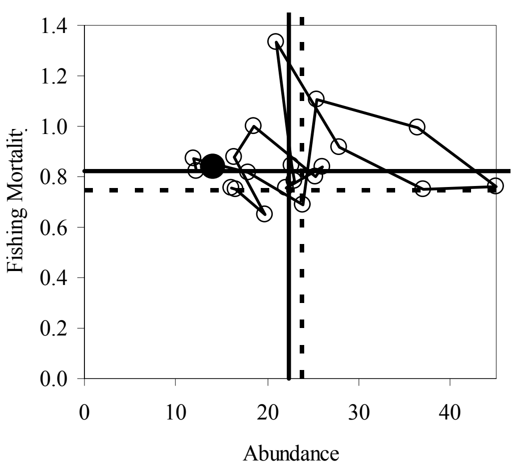


Figure 7.3.3. Population dynamics for male and female lobsters in SNE (M=0.65). (cont.)

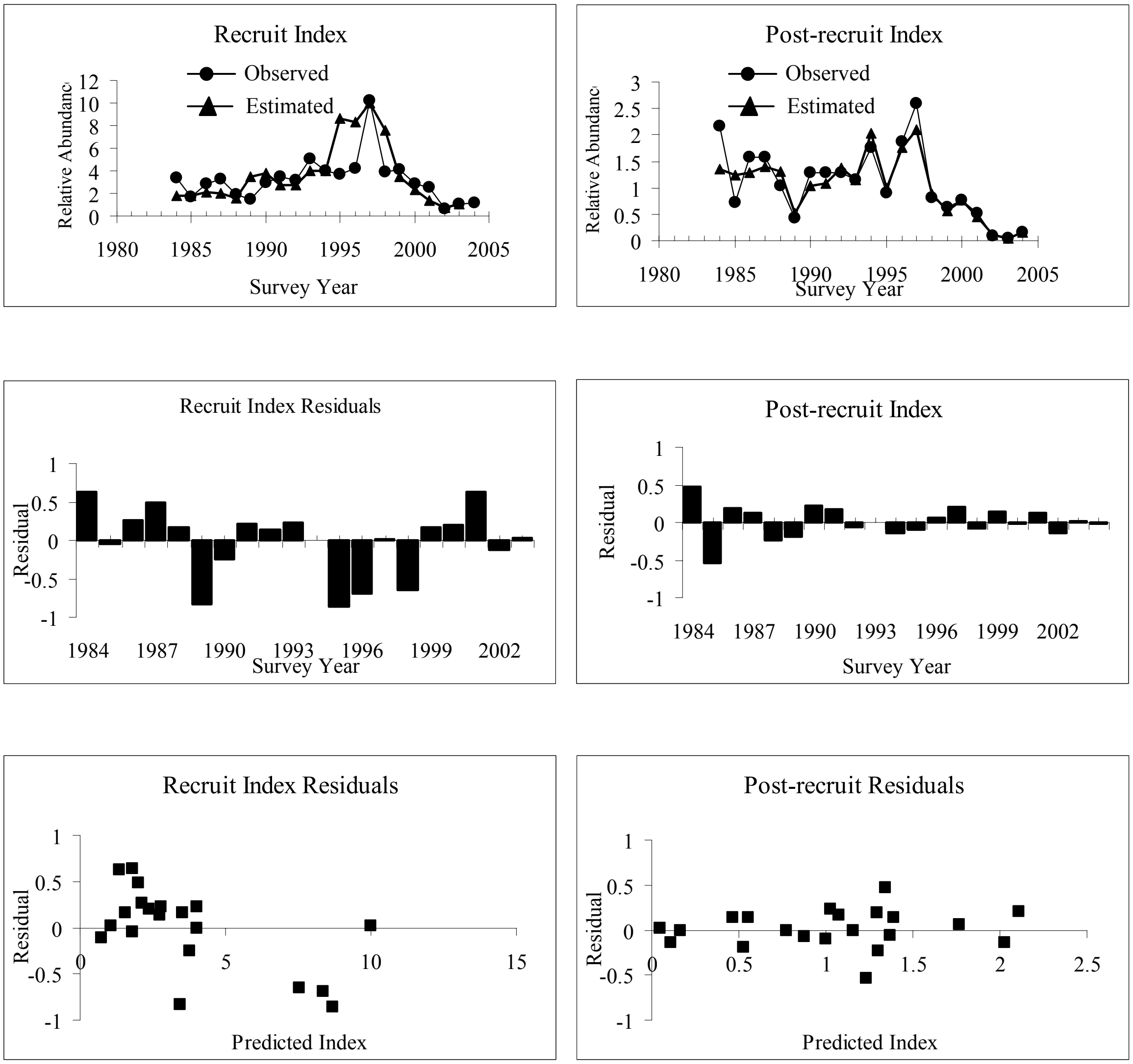


Figure 7.3.4. Abundance indices, fitted values and residuals for female lobsters in SNE (CT survey area, M=0.65 after 1996).

Use of M=0.65 is for illustrative purposes only and does not imply that M=0.65 is a reliable estimate. Residual patterns were similar using other natural mortality rates.

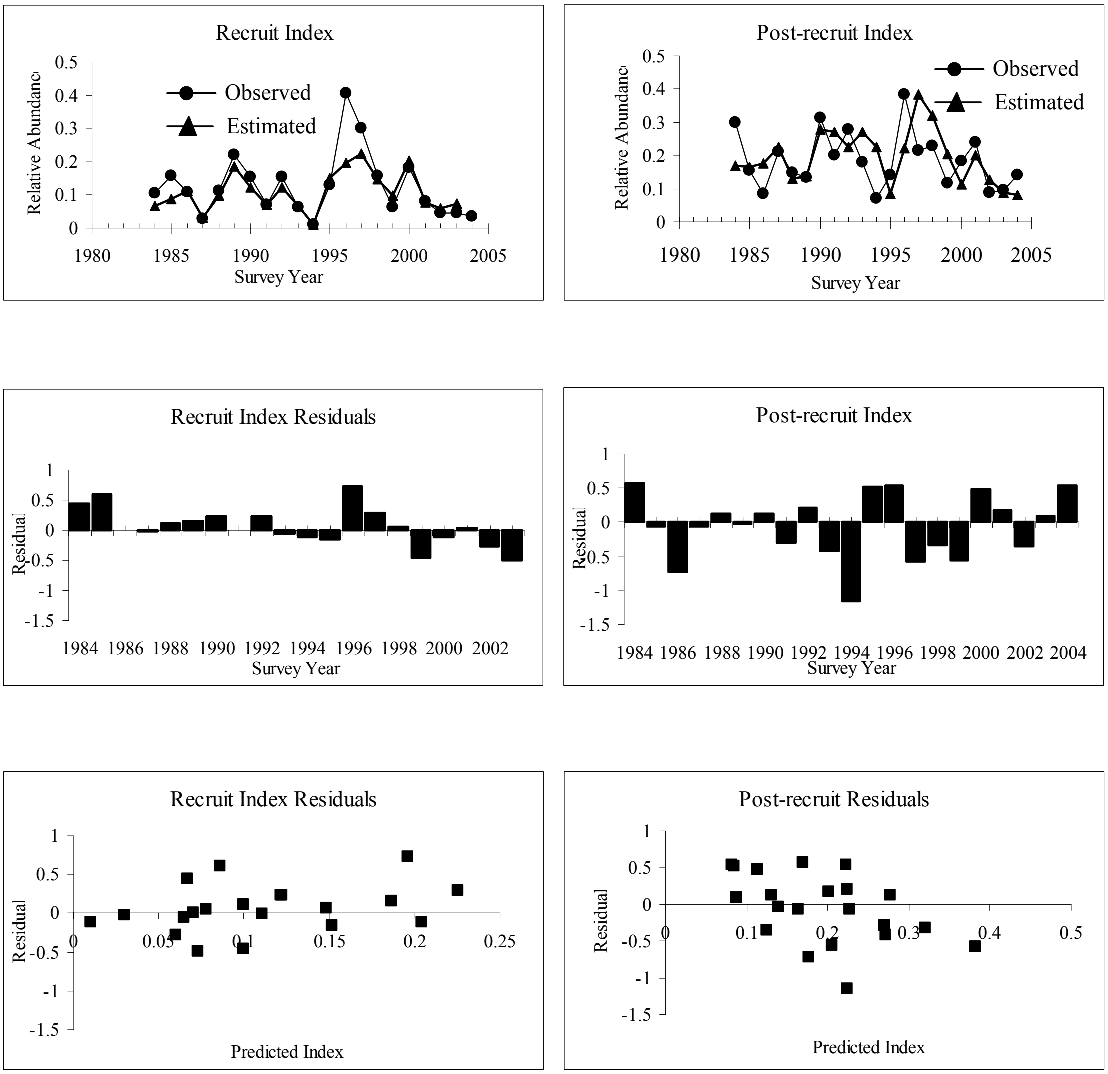


Figure 7.3.5. Abundance indices, fitted values and residuals for female lobsters in SNE (NEFSC survey area, M=0.65 after 1996).

Use of M=0.65 is for illustrative purposes only and does not imply that M=0.65 is a reliable estimate. Residual patterns were similar using other natural mortality rates.

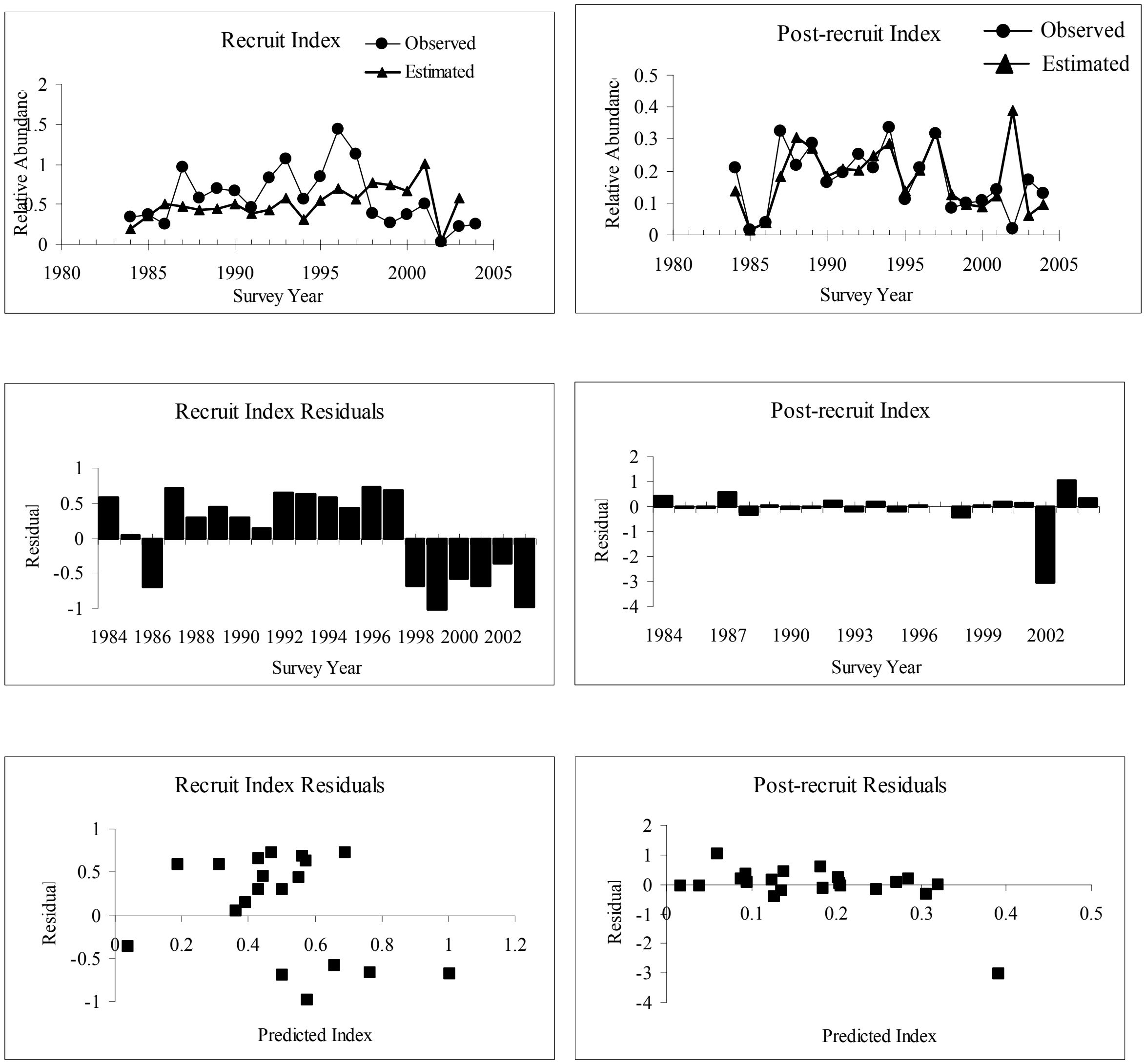


Figure 7.3.6. Abundance indices, fitted values and residuals for female lobsters in SNE (RI survey area; M=0.65 after 1996).

Use of M=0.65 is for illustrative purposes only and does not imply that M=0.65 is a reliable estimate. Residual patterns were similar using other natural mortality rates.

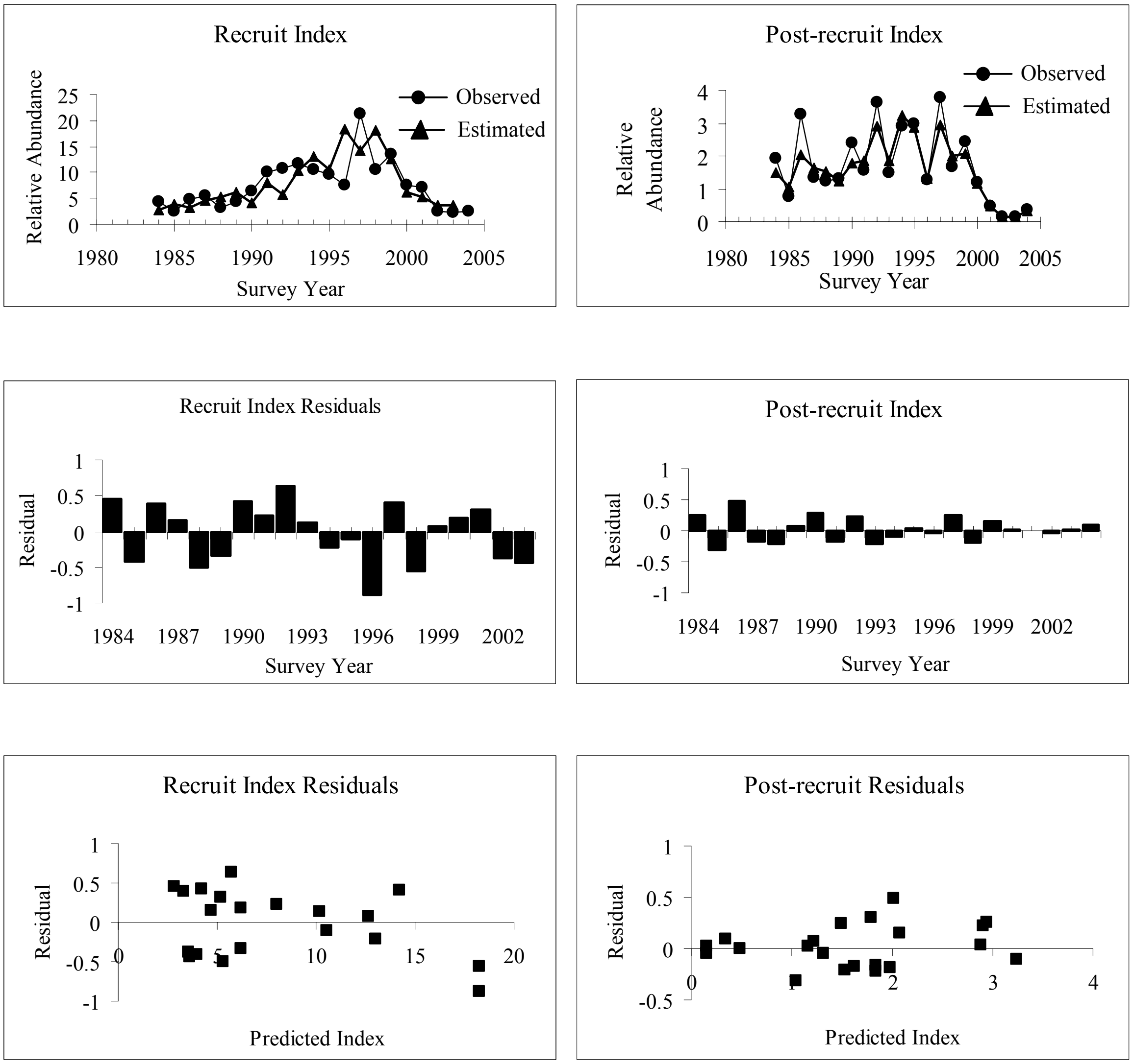


Figure 7.3.7. Abundance indices, fitted values and residuals for male lobsters in SNE (CT survey area; M=0.65 after 1996).

Use of M=0.65 is for illustrative purposes only and does not imply that M=0.65 is a reliable estimate. Residual patterns were similar using other natural mortality rates.

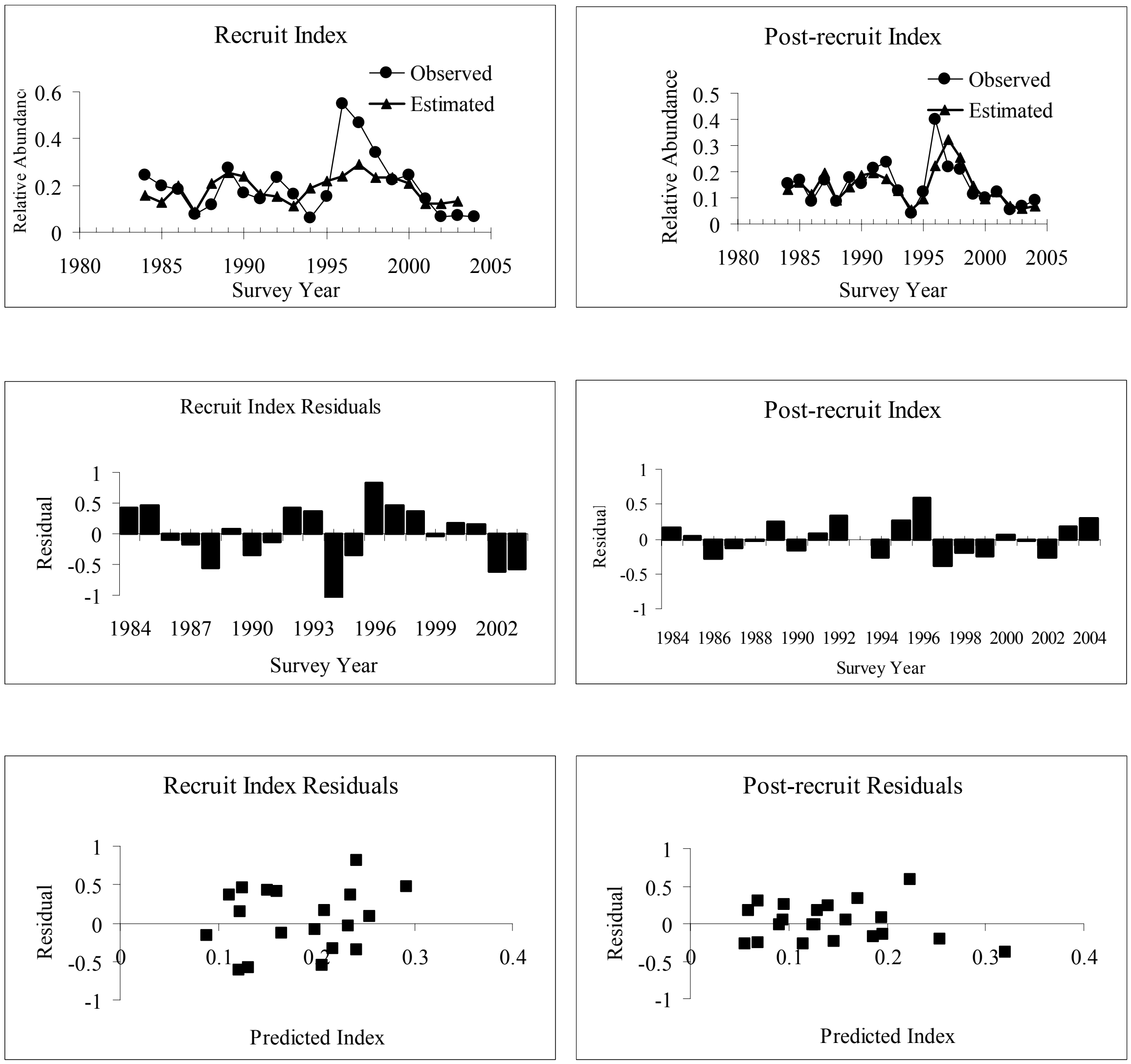


Figure 7.3.8. Abundance indices, fitted values and residuals for male lobsters in SNE NEFSC (M=0.65 after 1996).

Use of M=0.65 is for illustrative purposes only and does not imply that M=0.65 is a reliable estimate. Residual patterns were similar using other natural mortality rates.

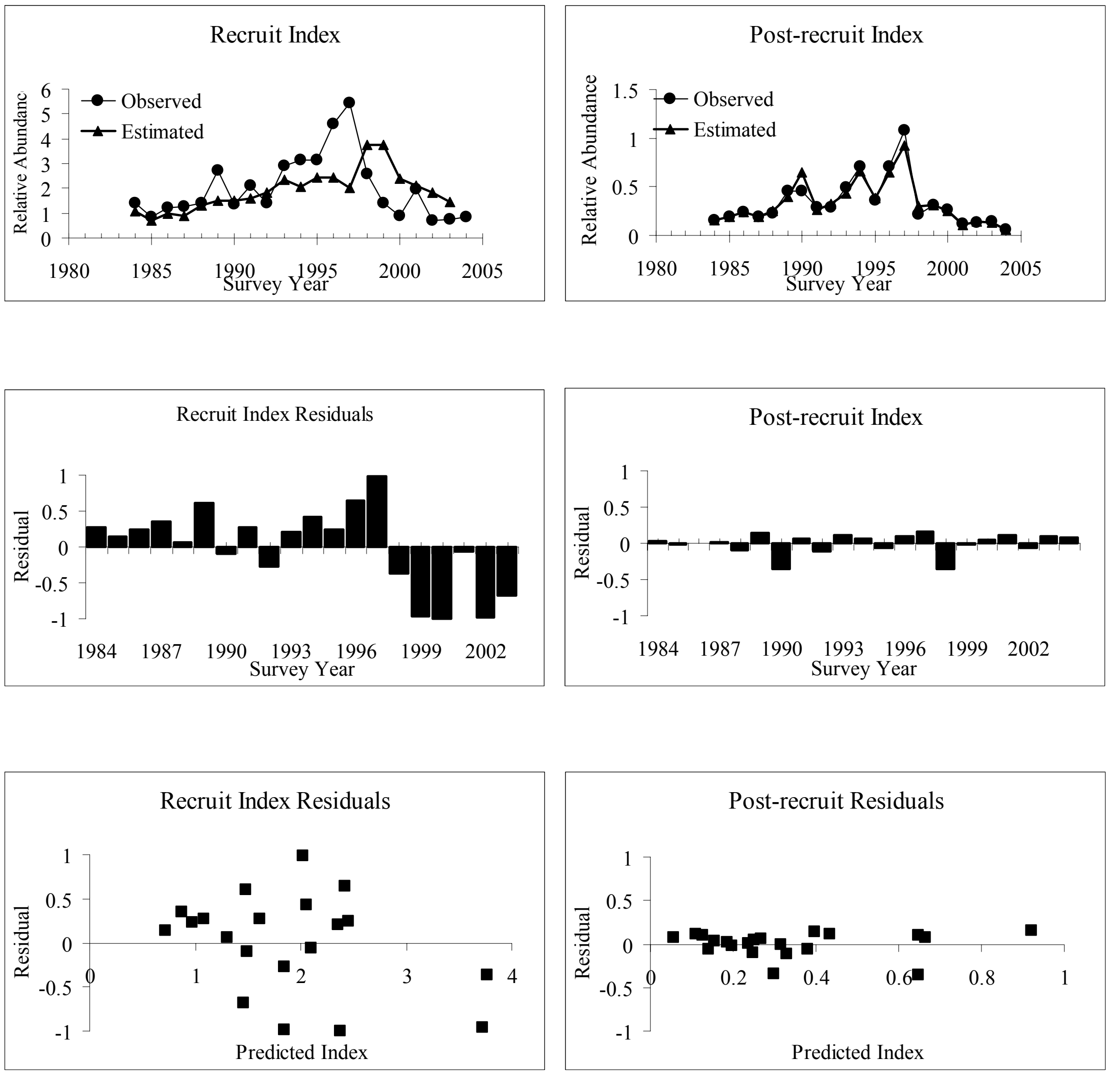


Figure 7.3.9. Abundance indices, fitted values and residuals for male lobsters in SNE (RI survey area; M=0.65 after 1996).

Use of M=0.65 is for illustrative purposes only and does not imply that M=0.65 is a reliable estimate. Residual patterns were similar using other natural mortality rates.

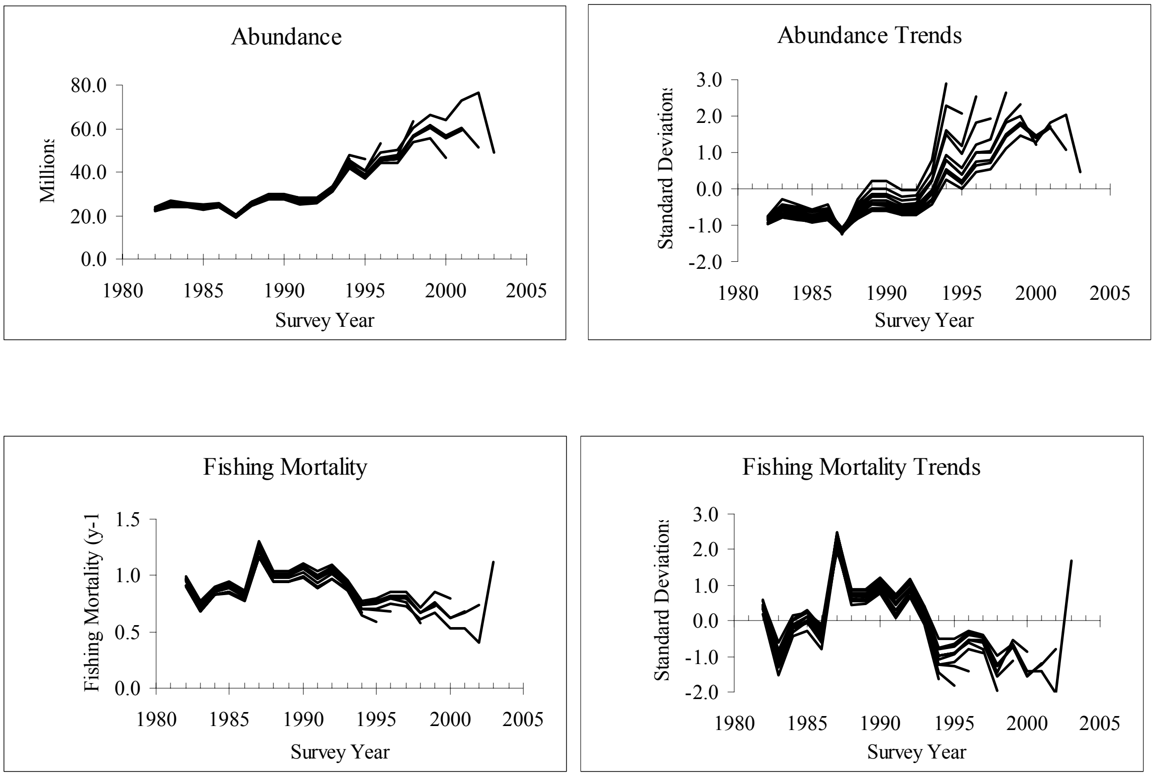


Figure 7.5.1. Retrospective patterns in absolute and trend estimates of abundance and fishing mortality for 0.15 lobsters in GOM.
Trend estimates were calculated by subtracting the time series mean and dividing by the time series standard deviation.

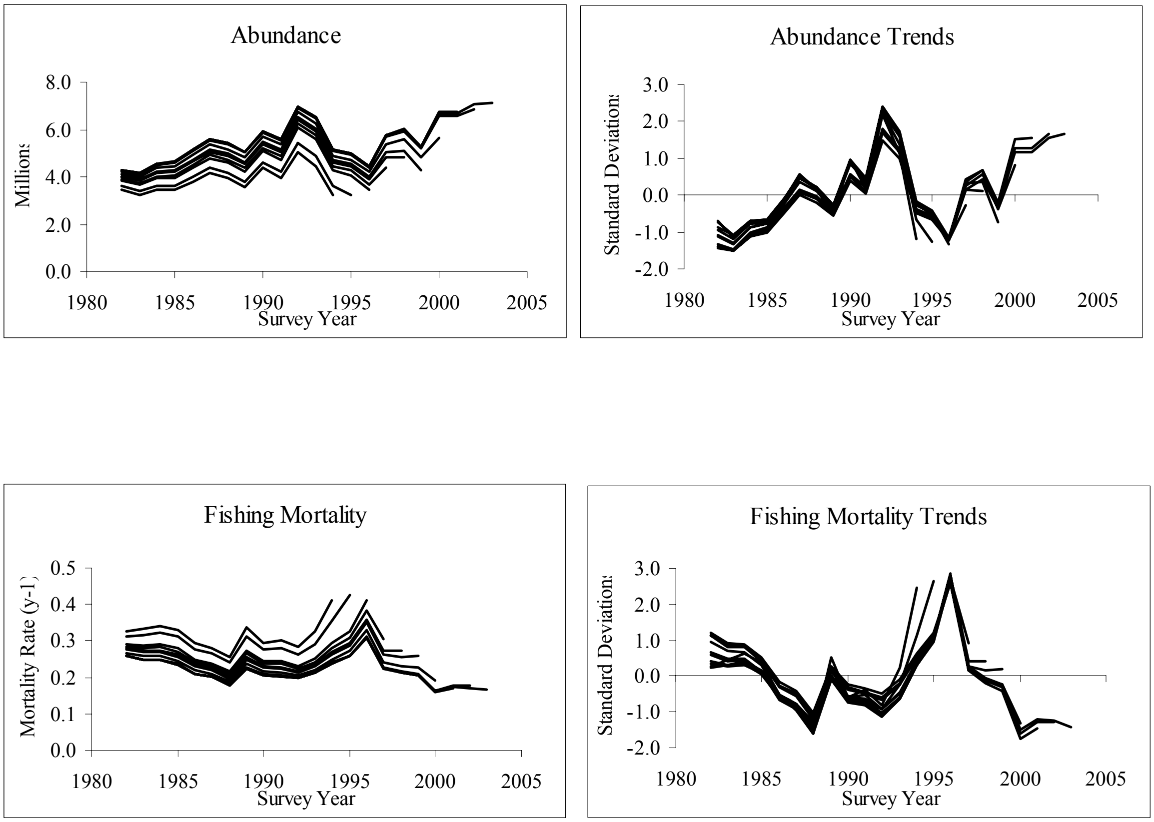


Figure 7.5.2. Retrospective patterns in absolute and trend estimates of abundance and fishing mortality for female lobsters in GBK.
Trend estimates were calculated by subtracting the time series mean and dividing by the time series standard deviation.

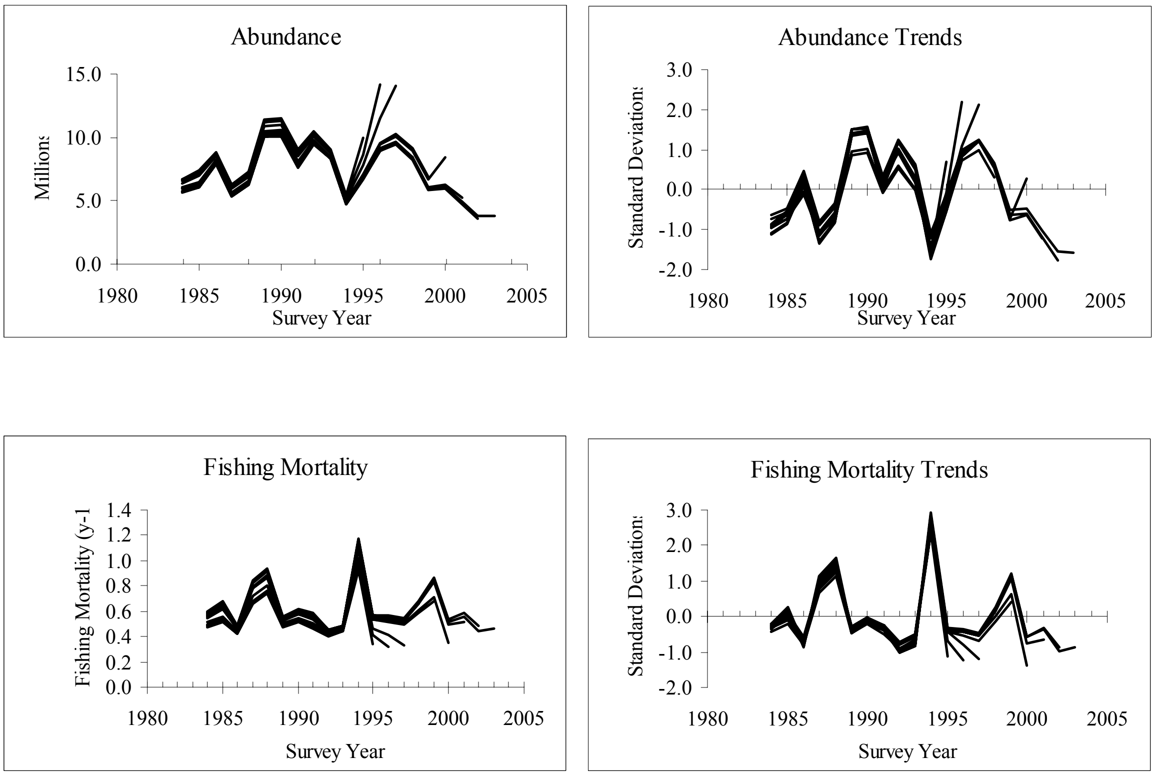


Figure 7.5.3. Retrospective patterns in absolute and trend estimates of abundance and fishing mortality for female lobsters in SNE with M = 0.15 in all years.
Trend estimates were calculated by subtracting the time series mean and dividing by the time series standard deviation.

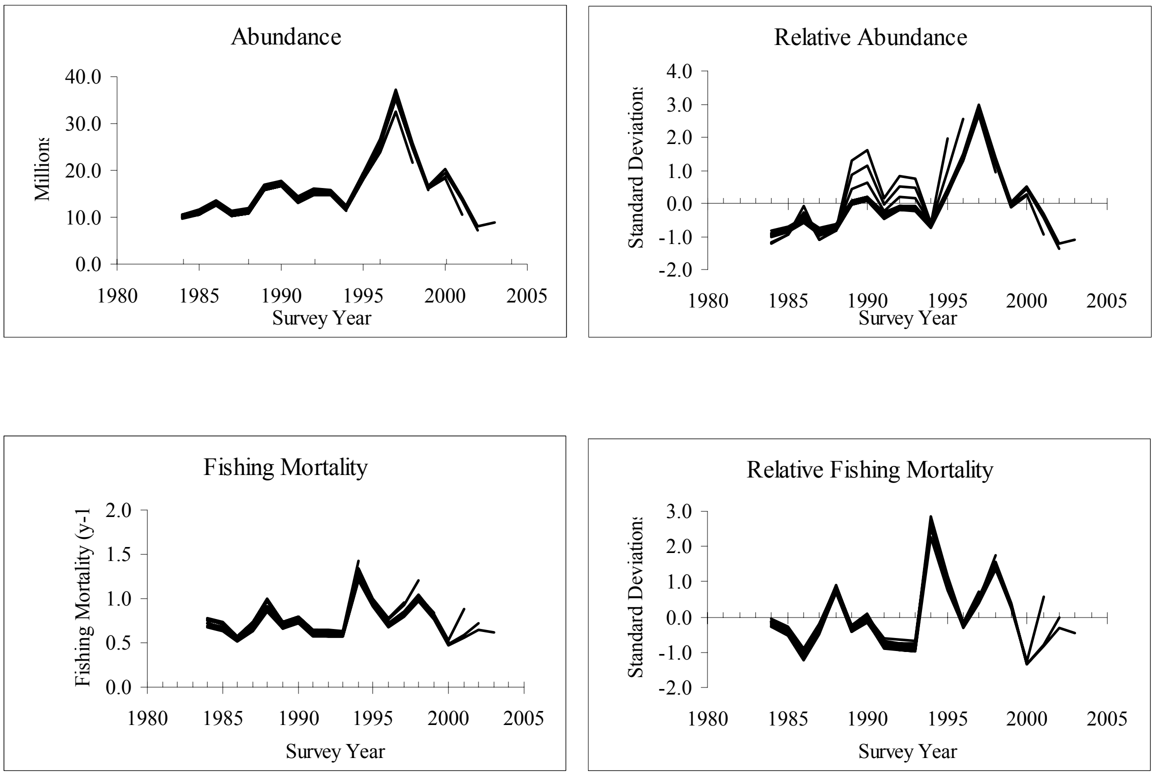


Figure 7.5.4. Retrospective patterns in absolute and relative estimates of abundance and fishing mortality for female lobsters in SNE with M = 0.9 during 1997-2003 and M=0.15 in earlier years.

Relative estimates were calculated by subtracting the time series mean and dividing by the time series standard deviation.

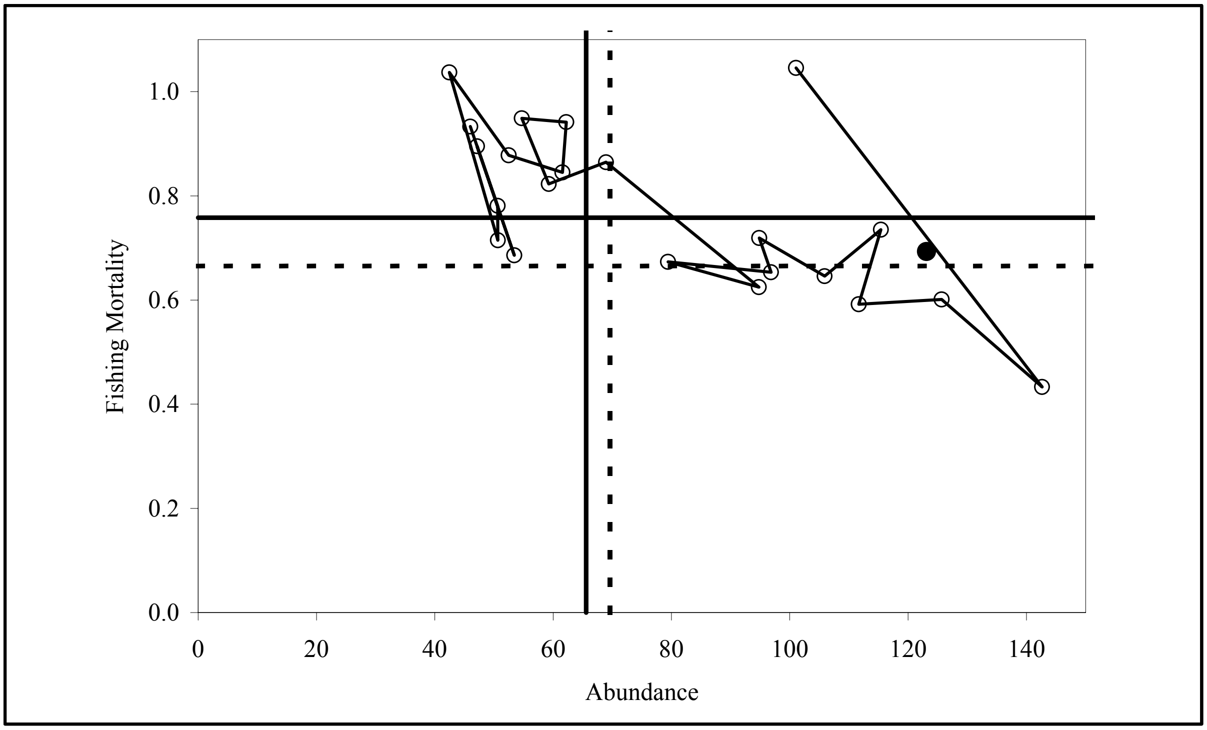


Figure 9.2-1. Fishing mortality-abundance (FN) plot for lobster (both sexes) in GOM. Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard error (proposed management targets). The dark black circle shows average abundance and F during 2001-2003. The p-value from a chi-square contingency test for the null hypothesis that F and N estimates are independent was p=0.01 (1 df, with Yates correction).

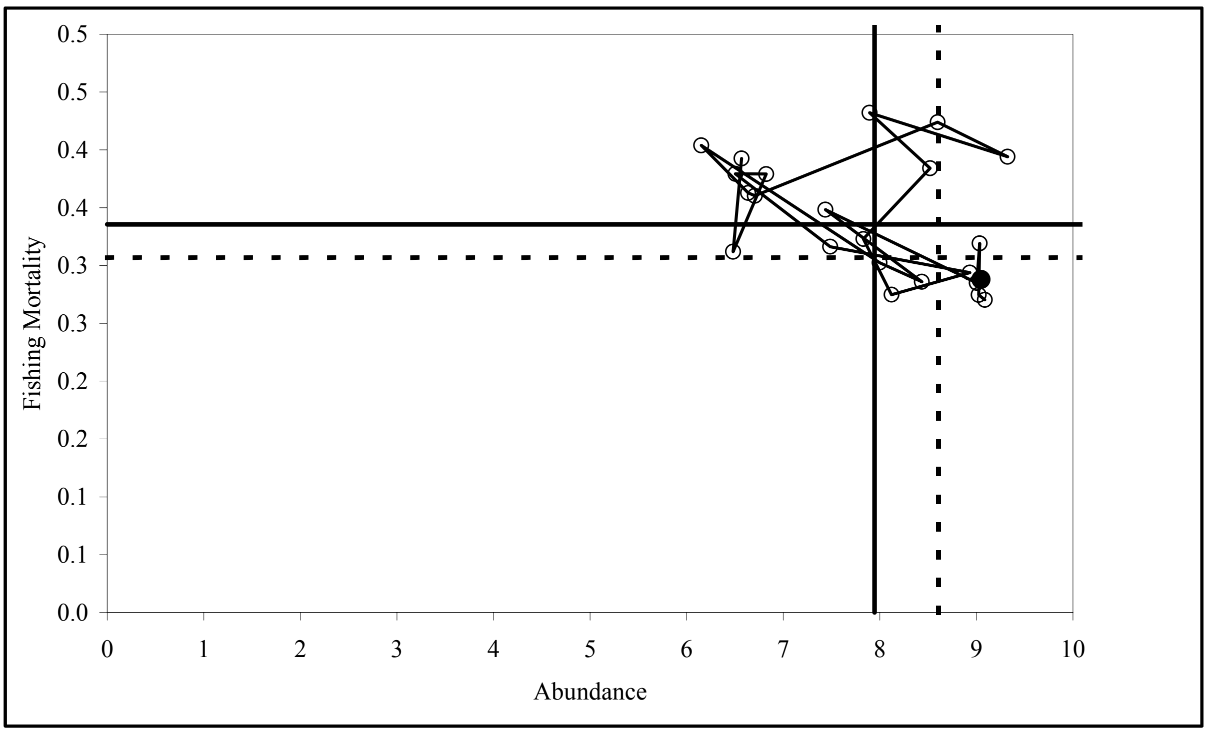


Figure 9.2-2. Fishing mortality-abundance (FN) plot for lobster (both sexes) in GBK during 1982-2003.
Heavy dark lines are medians (proposed management thresholds).
Dashed lines are medians plus or minus one standard error (proposed management targets). The dark black circle shows average abundance and F during 2001-2003. The p-value from a chi-square contingency test for the null hypothesis that F and N estimates are independent was p=0.09 (1 df, with Yates correction).

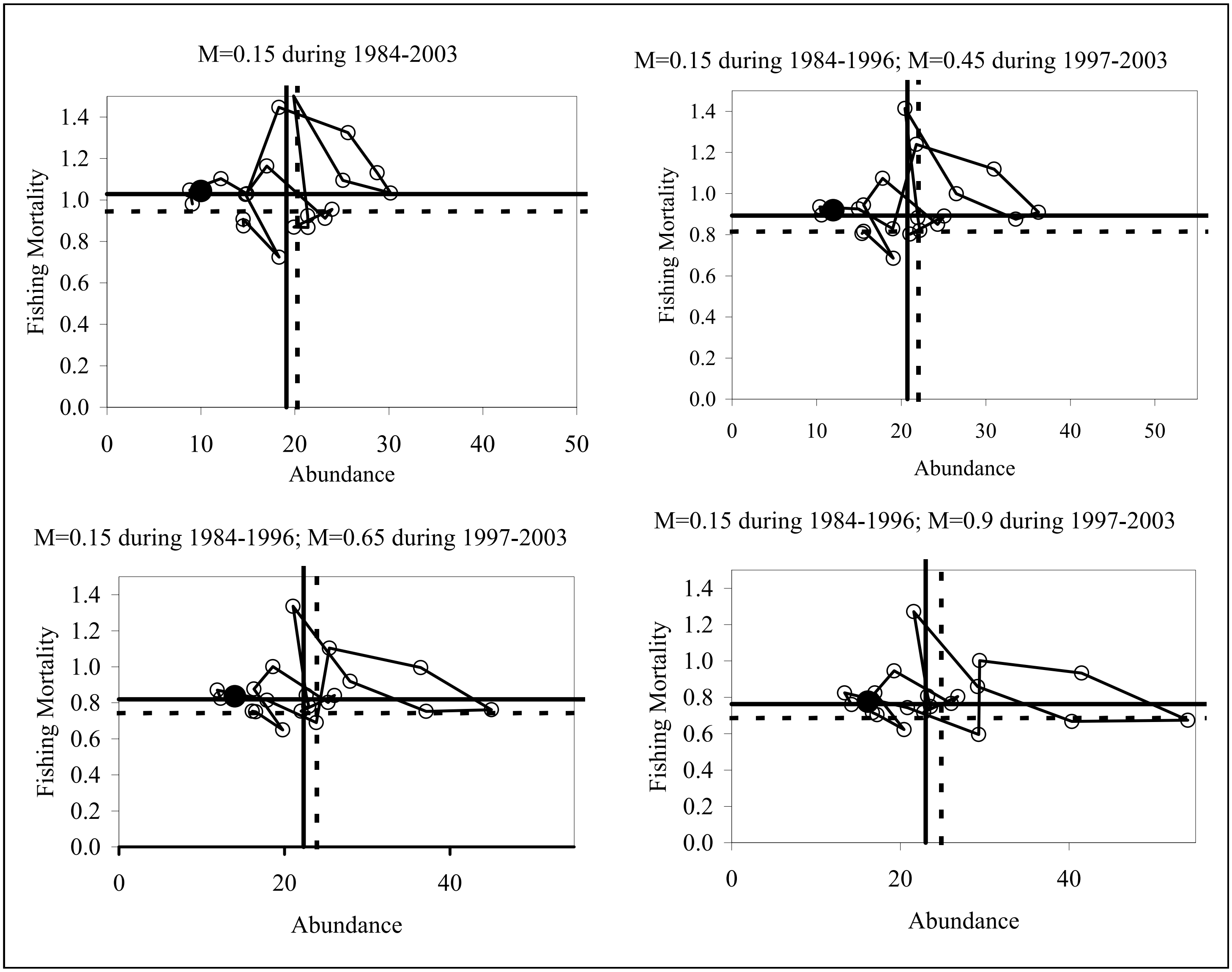


Figure 9.2-3. Fishing mortality-abundance (FN) plots for lobster (both sexes) in SNE assuming different levels of natural mortality (M) during 1997-2003.
Heavy dark lines are medians (proposed management thresholds). Dashed lines are medians plus or minus one standard deviation for measurement errors. The solid dark circle shows recent fishing mortality and abundance (averages during 2001-2003).

Appendix I: Additional Gap Filling Description

Rhode Island Gap Filling Decision Rules

Allocation was based on 1) 1994-1997 adjusted by year - 2 to year +2 known values for static cal area by month; unknown area added to known area in relation to monthly landings of known area from year - 2 to year + 2; 2) using the proportion by month/Area values for 1994 - 1997 from step 1, and 2003 (see 2003 below), estimate a composite proportion by month/area. Then apply this to all years (1994 - 2003) by multiplying each year's total landings by the composite proportion by month/Area matrix.
2003:proportion within month by Area from logbook was multiplied by proportion by month/Total to get 2003 estimate of proportion by month/area.

Because the database did not have capability to enter data for Statistical Areas 612, 614, 615 and 625 for Rhode Island in 1994, the following was done:

May & Sept 612 were added to May & Sept 613
July 614 was added to July 616
Sept 615 was added to Sept 616
Jan 625 was added to Jan 626

New York and Connecticut Gap Filling Procedure

I. Unknown Area Gap Filling

New York

The unknown area landings apportioned to 611 were added to the NMFS NY 611 landings. New York landings recorded by NMFS in Atlantic Ocean statistical areas have only been consistent in areas 612 and 613 through the whole timeseries. The unknown area landings apportioned to Atlantic Ocean were applied to areas 612 and 613. To determine the amount to add to 612 and 613 yearly proportions were calculated from a 5 year-average for both 612 and 613 using NMFS NY landings for those areas. These landings were then added to the original NMFS NY landings for those areas.

<u>Connecticut</u>

1. CT had very little unknown landings (3,759 lbs, almost all in 1980).
2. Unknown landings were apportioned to statistical area using proportions by area calculated as 5 year average. The majority of CT landings were in statistical area 611 (>90%).

II. Unknown Month Gap Filling

<u>Connecticut</u>

1. There were no unknown months in the CT landings database

<u>New York</u>

Landings by area in the unknown month category were apportioned. Landings from area 611 in the unknown month category were apportioned using CT area 611 data. CT was chosen since there were no landings in the unknown month category in the CT 611 landings database, while the NY 611 data had a large portion of the 1990 - 1999 landings in the unknown month category. Landings from Atlantic Ocean statistical areas 612, 613, 616, and 537 were apportioned using the same monthly average value. The NMFS NY landings for areas 612, 613, 616, and 537 were combined to determine the 1990 – 1999 monthly average. This was then applied to the landings in the unknown month category for those areas to apportion them by month. These areas were combined since none of the areas alone had adequate samples of landings by month for the time series. The final area that NY had landings in the unknown month category was 539. This area is off Rhode Island. NY did not have adequate data to estimate proportions by month so that 1990 – 1999 monthly average determined by Rhode Island for area 539 was used to apportion NY 539 landings by month.

1. **Other Stat Areas** -Georges Bank (GBK) statistical areas were removed (521 - 526) to be gap filled with other GB landings
2. South of Cape Cod (SCC) (538 and 539) were removed to be gap filled with other SCC landings
3. All other statistical areas were lumped together (excluding 521-526, 538, 539, and 611), and lumped as Atlantic Ocean (AO) landings.

4. The unknown landings apportioned to AO were added to the NMFS NY AO combined landings by month.
5. Proportion by month were calculated as the (1990-1999 monthly average) / (1990 - 1999 Total average)
6. The apportioned unknown NY AO month landings were added to the NY AO data adjusted for unknown area.
7. Total AO (NY and CT) landings by month were calculated by adding the CT AO and adjusted (area and month) NY AO together.

Appendix II: Size Structure Model

Developing, testing and applying a size-structured stock assessment model for the American lobster, *Homarus americanus*

A report prepared for Atlantic States Marine Fisheries Commission

by

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Executive summary

We describe the structure of the proposed sex-specific length-structured stock assessment model; evaluate the performance of the proposed assessment model, which has been modified based on the ASMFC Lobster Model Peer-review Committee, using the simulated lobster fishery under different simulation scenarios developed by the ASMFC Lobster Model Development Subcommittee; and apply the proposed model to field data compiled for the GOM lobster stock. The assessment model is coded with ADMB and is available from the authors upon the request.

This study suggests that the proposed model can capture the dynamics of the lobster population in the presence of various errors. It provides an effective new approach to modeling the population dynamics of the American lobster in northeast USA.

The proposed model was applied to the seasonal sex-specific data compiled by the ASMFC for the GOM lobster fishery from 1981 to 2003. As requested by ASMFC Lobster Technical Committee, we only report the results up to 1999. The study suggests that the legal abundance and biomass of female lobsters tend to be higher than those of males. Despite heavy fishing, legal abundance and biomass of the lobster stock in GOM had been increasing since 1980s, as a result of large increase in recruitment. The legal stock abundance, legal stock biomass, and recruitment in late 1990s were all much higher than those in 1980s. It should be noted that the recruitment defined in this model differs from the "recruitment to the lobster fishery" that we are usually referred to. Because of the high abundance, the exploitation rates of recent years were much lower than those of early years despite high landing. As expected, there were large seasonal variations in legal stock abundance, biomass, and exploitation rate. The exploitation rate of females tended to be lower than that of males in most seasons, probably as a result of conservation measures.

The model is used as a demonstration only in this stock assessment. To avoid being mis-interpreted and stay as a demonstration in this assessment, we did not include any calculation of biological reference points such as F10% which can be calculated internally by the model.

Introduction

Over the last 20 years the American lobster fishery was assessed using the Collie-Sissenwine (catch-survey) model (CS) (formerly referred to as DeLury model) which estimates fishing mortality from a time series of catch and abundance index derived from the National Marine Fisheries Service (NMFS) trawl survey program (Collie and Sissenwine 1983; Conser 1995; NEFSC 1996). The status of the stock is then determined by comparing the estimated fishing mortality with a biological reference point $F_{10\%}$ which is the rate of the fishing mortality that reduces the expected egg production for a cohort of female lobsters to 10% of that produced in the absence of a fishery and is separately estimated from an egg-per-recruit model (Fogarty and Idoine 1988).

In the previous assessment, this approach had yielded a conclusion on the status of lobster stock inconsistent with many studies and field observations (NEFSC 1995; ASMFC 2000), raising the questions of the ability of the current stock assessment model in describing the complex fishery and population biology of American lobster; suitability of using NMFS survey data alone which mainly focus on offshore areas but only have a few stations in inshore areas where more than 2/3 landings occur (Chen et al. 2005); $F_{10\%}$ as the only management biological reference point, and compatibility of fishing mortality estimated from the CS model and $F_{10\%}$ (Chen and Wilson 2002). This called for the development of alternative approaches to assessing the lobster fishery (e.g., ASMFS 2000). The development of a biologically detailed and realistic stock assessment model seems desirable and is also consistent with the calls by National Research Council (NRC 1997, 1999) for applying multiple stock assessment models of different complexities in assessing fisheries resources.

A length-structured sex-specific model had been developed to describe the dynamics of the American lobster population (Chen et al. 2005). The model was tested with the simulation scenarios developed by the ASMFC Lobster Model Development Subcommittee and Lobster Stock Assessment Committee (ASMFC 2004a). The model, however, has been reviewed recently by a peer-review panel organized by the ASMFC Lobster Technical Committee. The panel has made several recommendations for improving the performance of the model (ASMFC 2004b). We have modified the model according to the comments.

The modified model had not been tested extensively, an essential step in developing a stock assessment model. Thus, we need to evaluate the performance of the new version of the model modified based on the ASMFC Lobster Model Peer Review Committee under different scenarios of population dynamics.

The ASMFC lobster model review panel recommends that we continue developing and testing the model and that the modified model be used in future lobster stock assessment. Because of extensive data requirement, the model is only ready for the GOM lobster stock in this current stock assessment.

In this report we describe the structure of the proposed sex-specific length-structured stock assessment model; evaluate the performance of the proposed assessment model using the simulated lobster fishery under different simulation scenarios developed by the ASMFC Lobster Model Development Subcommittee; and apply the proposed model to field data compiled for the GOM lobster stock. The assessment model is coded with ADMB and is available from the authors upon request.

The proposed assessment framework consists of a full version of Bayesian estimator. The Bayesian estimator has been fully tested and is fully functional. However, because of the time constraint, we did not include a detailed description of the Bayesian estimator in this report.

Methods

The population model described below differs from the model published in Chen et al (2005) in that we had made some major changes based on the comments given by the ASMFC Lobster Model Review Panel (ASMFC 2004b). Essentially, we have adopted all the comments recommended by the Panel in modifying the model structure and model parameterization except for one suggestion which asks us to increase the width of size bin (or equivalently to reduce the number of size bins) in grouping the lobsters. We did not increase the width of size bins (or decrease the number of size bins) because the change will make the width of size bins larger than the smallest molting increment making some individuals unable to grow out a size bin for long time (rather biological unrealistic). We were advised to take an individual-based approach or track individual lobster growth, but this will significantly increase the complexity of the model that has already been considered by the panel as complex. Our detailed and point-to-point replies to the panels' comments are described after the model and simulation description.

Developing population models

The population model developed in this study includes stochastic length-structured, sex-specific models describing the dynamics of the lobster population and fishery (referred to as population dynamics models) and observational models used to relate the population dynamics models with observations made in surveys and fishery. The population dynamics model includes a series of submodels describing various processes of the lobster life history and fishery. The modeling time step is season (Winter: January - March; Spring: April - June; Summer: July - September; and Fall: October - December) . The model structure is derived from modifying the model described in Chen et al. (2005) according to the comments given by the peer review panel. Detail description of the model can be found in Appendix I. The main components of the proposed Bayesian stock assessment framework are described in Fig. 1, and the main features of the model is summarized in Table 1.

Assessing the performance of the lobster population model

The proposed stock assessment framework consists of several composnents including stock assessment model, database, statistical estimator, and risk analysis (Fig. 1). The simulation study is, however, focused on the assessment of stock assessment model. The other components are also critically important (Francis 1992, Hilborn et al. 1993, FAO 1995, Punt and Hilborn 1997, McAllister, M. K. and Kirkwood 1998, Walters 1998), but will be evaluated in the future.

Many mathematical models have been developed to describe the dynamics of fish populations. For a given fishery, an optimal model can only be identified through an extensive simulation study. Only through an extensive simulation study can we identify if a stock assessment model performs well in describing the dynamics of a fish population, quantify the impacts of quality and quantity of input data on the assessment results, and identify when the model may fail (Hilborn and Walters 1992, Quinn and Deriso 1999, Chen and Rajakaruna 2003, Kanaiwa et al. 2005). Without such a study, we only have limited knowledge about the performance of a population model in describing the lobster population dynamics.

The simulation study, however, cannot be done with actual fisheries data because we don't know the true underlying population dynamics in the lobster fishery. We need to simulate a lobster fishery using information collected in the lobster fishery, and then apply the proposed population models to the simulated lobster fishery and compare the differences. Because this is a simulated lobster fishery, we know the true fishery parameters. By comparing the true parameters with those estimated using the proposed assessment models we can evaluate the performance of the proposed model in retrieving the true fishery parameters. We can simulate a series of "lobster fishery" with different temporal variations in key fishery parameters (e.g. abundance, fishing mortality, recruitment, natural mortality etc.), and apply the models to all these fisheries. If the model consistently performs well in retrieving the true built-in temporal patterns of population dynamics in the simulation, we can conclude this model performs well. Through such an extensive simulation study, we can identify situations where the model may fail and identify key factors that may influence the performance of the model. The design of the simulation study is described in Figure 2. The description and testing of the Lobster Simulator is described in Appendix II.

To facilitate the comparison of the models with different mathematical formulations, an individual-based Lobster Simulator was developed. This simulator mimics the detailed life history and fishery processes an individual lobster may go through in its life span (Kanaiwa et al. 2005). The Lobster Simulator was parameterized with the information obtained in previous study (ASMFC 2000, Kanaiwa et al. 2005). Using the Simulator, ASMFC Lobster Model Development and Stock Assessment subcommittees developed eight simulation scenarios with different patterns of population dynamics (Table 2). These scenarios cover different temporal patterns of recruitment (Fig. 3), natural mortality, and errors in data (Table 2).

To simulate a fishery as realistically as possible, we run the Lobster Simulator for 60 years with constant recruitment and without fishing mortality to make the population approach equilibrium. This was followed by 24 years of fishing with an annual nominal fishing mortality rates of 0.8 (equivalent to the rate of encountering traps; ASMFC 2000) mimicking the American lobster fishery in the Gulf of Maine. The simulated fishery that was used in testing the model started in year 85 and completed in year 100 (thus 16 years of data are used in the simulation) with encountering rates similar to those of the GOM lobster stock (ASMFC 2004a)

The output data from the Simulator include fishery-dependent and fishery-independent size frequency data and abundance index data. Random errors were added to simulated CPUE, abundance index, and size frequency data to reflect the measurement errors.. The errors for CPUE, catch and survey abundance indices were defined by the following equation:

$$X_i = \mu e^{\varepsilon_i} \qquad \varepsilon_i \in N(0, \sigma^2)$$

where X is "observed" CPUE, catch or survey indices with errors, μ is the "true" value of either of these quantities, ε is an error term following normal distribution with mean of 0 and standard deviation of σ. The CVs were defined as 30% for catch, CPUE, and inshore survey abundance index and offshore survey abundance index (Table 2). The standard deviation of σ was calculated by the following equation,

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

Thus σ is actually 0.2936 for a CV of 30% .

Errors associated with both fishery-dependent and fishery-independent length frequency data were assumed to follow multinomial distributions. A subsampling approach (Chen 1996) was used to generate the multinomial errors. The effective sample size in parameter estimation is defined as 50 to reflect large variation often associated with the length frequency data in fisheries.

Only those that are successfully converged in the maximum likelihood estimation were included in the results. For each scenario, the first 100 successfully converged simulation runs were kept for further analyses.

The initial values that were required for starting the maximum likelihood estimation were set differently from the "true" values. For example, the initial values of parameters R_{dev} were all set to 0 or 0.1 for all the years (thus assuming no temporal trend in recruitment).

The number of parameters to be estimated in the model is summarized in Table 3. The parameters to be estimated include eight density-dependent parameters (8 γ 's for four seasons and two sexes); four parameters determining the selectivity of the two surveys (two sets of a_j and $l_{50,j}$ for NMFS survey and Maine DMR inshore survey; MA survey was not used in the simulation, but used in the application), two parameters defining initial abundance of females and males, four parameters defining initial size composition for female and males, average recruitment $\overline{R}$, one recruitment deviation for each year (*eps*$_t$ in equation 2, Appendix I) that partially determines R_{dev_t} (16 parameters for 16 years), standard deviation of the estimated recruitment σ_{R_t} (only used for adjusting in Equation 1 (Appendix I), estimated independently from R_t, and was not used to restrain R_t), autocorrelation coefficient describing the degree of autocorrelation between the two consecutive years R_h, natural mortality M, and two parameters determining the fishing selectivity S_k^{other} (i.e, μ_S, σ_S^2). Thus, for a simulated fishery with 16 years of data, there are altogether 40 parameters to be estimated, a huge reduction in the number of parameters to be estimated compared with the old version of the model (122 parameters to be estimated for the old version of the model; ASMFC 2004a). Natural mortality is divided into two components, average mortality M1 applied to all individuals and molting mortality M2 only applied to individuals that molt. As suggested by the Peer Review Panel (ASMFC 2004b), a prior distribution function was assumed for natural mortality M1 and M2 in the parameter estimation. M1 is assumed to follow a lognormal distribution with mean and standard deviation of 0.1 and 0.1 and the lower and upper boundary values of 0 and 0.2 (annually). M2 (i.e., extra mortality resulting from each molting event) is assumed to be uniform distribution with the low and upper boundary of 0 and 0.1 (each molting). True M1 is 0.1, while true M2 is 0.05. The prior distributions of M1 and M2 are used in the parameter estimation.

A large number of key fishery statistics can be yielded as outputs from modeling separately for females and males. In this paper, we included size frequency distribution of the first season, annual recruitment, seasonal legal stock abundance, seasonal legal stock biomass, and seasonal exploitation rate calculated as the ratio of landings versus legal stock abundance. The simulation results are summarized using the following two measures:

(1) $$Percentage\ bias\ (PB) = \frac{\sum_i \frac{\hat{\beta}_i - \beta}{\beta}}{N} 100\%$$

(2)

$$Pecentage\ Rooted\ Mean\ Square\ Error\ (PRMSE) = \frac{RMSE}{True\ value} = \frac{\sqrt{\sum_i \left(\hat{\beta}_i - \beta\right)^2 / N}}{\beta} 100\%$$

where *i* is the ith run that is successfully converged, $\hat{\beta}$ and β are "estimated" and "true" parameters, respectively, *N* is the total number of successful runs (i.e., 100). For each scenario, we calculated the PB and PRMSE for each season to evaluate how estimation errors vary with time. We also calculated the PB and PRMSE of estimates averaged over all the seasons. PB indicates estimation bias and PRMSE includes measures for both estimation biases and estimation variations among simulation runs.

Applying the proposed model to the GOM lobster fishery

The proposed model was applied to the seasonal data compiled by the ASMFC for the GOM lobster fishery from 1981 to 2003. The data used include seasonal and sex-specific catch and its size composition, NMFS fall and spring survey abundance indices and their size compositions, Maine DMR inshore survey abundance indices and their survey indices (only for the four most recent years), and MASS inshore survey indices and their size compositions. The effective sample sizes used in the parameter estimation were obtained from Dr. Larry Jacobson (NEFSC), Carl Wilson (Maine DMR), and Robert Glenn (MASS DMF). Detailed input data compiled for the application can be obtained from the authors at the School of Marine Sciences, University of Maine, Orono, ME 04469 or from ychen@maine.edu. Because of the limited spatial coverage of the MASS inshore survey, we assume one tenth weight to the MASS survey data, compared with the weight for other survey data.

M1 is assumed to follow a lognormal distribution with mean and standard deviation of 0.1 and 0.1 and the lower and upper boundary values of 0 and 0.2 (annually). M2 for each molting is assumed to have a uniform distribution with the low and upper boundary of 0 and 0.1.

Since outliers are likely to exist in data, we used log-normal robust method in establishing likelihood function (see Appendix I; Berger 1985, Chen et al. 2000).

This model is still in the process of being tested, and thus the use of the model in this stock assessment is for demonstration only. The interpretation of its management implication should be avoided.

Detailed replies to the comments given by the ASMFC Lobster model review panel

The model review panel provided some detailed and constructive comments with respect to this sex-specific size-structured model. As we have shown above in model description, we have adopted most of the comments in modifying the model. Our detailed and point-to-point replies are summarized as follows.

The review panel: (a) Length sample sizes greater than 350 imply more precision than typically found for real length data because variation is added by spatial heterogeneity. We recommend that the analysts estimate effective sample sizes for the lobster size data and weight the size data with these values during parameter estimation. We also recommend that the analysts test a range of values of effective sample sizes common to our experience, 10, 50, and 100.

Our reply: We agree with the panel. However, because the limited time we have and extensive time requirement for the simulation, we only used effective size of 50 in the simulation study reported in this report. A PhD student (in Chen's lab at the University of Maine) is currently testing the impacts of effective sizes using 10 and 100 as effective sample sizes.

The review panel: (b) Reduce the number of sizes estimated in the initial size composition. The descending limb of either age or length compositions typically provides little information on year-class strength (i.e. they appear similar from year to year). We suggest three alternatives for reducing the number of sizes estimated in the initial size composition:

1) estimate abundance of an intermediate size, then compute abundance of larger size classes from abundance of the intermediate size using an equation like equation 10 on page 9 of Chen et al. 2004; 2) pool large size classes (Deriso et al. 1985, 1989; Kimura 1989, 1990; Sigler 1999); 3) fit a two-parameter function to the initial size composition.
Our reply: We agree with the panel. This can substantially reduce the number of parameters to be estimated and improve the model performance. We have explored the three approaches suggested by the panel, and found the third one (i.e., using a two-parameter function to describe the initial size composition) tends to be a better approach. Thus, as described in the appendix I, we used two two-parameter functions (i.e., equations 3b and 3c) to describe the initial size compositions for females and males, respectively.

The review panel: (c) The current configuration of the size-structured model is a multi-size compartment model. In contrast, the current model used in the stock assessment (CSM) is a two-size compartment model. An intermediate step between the CSM model and a multi-size compartment model is a compartmental model with a few size groups. We recommend that the analysts first estimate parameters with the size-structured model configured with a few size groups. This intermediate step will help the analysts better understand the results of a multi-size compartment model and will help educate managers and the fishing community.
Our reply: We did not increase the width of size bins (or decrease the number of size bins) because the change will make the width of size bins larger than the smallest molting increment making some individuals unable to grow out a size bin for long time (rather biological unrealistic). We were advised to take an individual-based approach or track individual lobster growth, but this will significantly increase the complexity of the model that has already been considered by the panel as complex. Our detailed and point-to-point replies to the panels' comments are described after the model and simulation description.

The review panel: (d) The size-structured model provides a formal structure for representing growth (i.e. growth transition matrix), whereas the Collie-Sissenwine model requires external structuring of the data to account for growth transitions. We recommend the analysts explore combining the two approaches for the purpose of describing recruitment and possibly residence time in a second size compartment of a three-compartment model. The largest pooled size group could be fitted without making assumptions about selectivity by following the CSM approach. Most importantly, the typical observation of an ~80-90% drop in abundance from the second to the third size compartment may encapsulate the depletion effect of the fishery, thus estimating abundance without having to model the full size structure of the population.

Our reply: This will encounter a problem same as the one described above (need to have a three compartment model with large size bins). It is true that current fishing mortality removes a large proportion of individuals just growing over the minimum legal size, which makes modeling dynamics of lobsters in other size classes less important. However, this may not always be the case in future. Lack of a formal and systematic approach may result in errors when the fishing pattern changes in future (e.g., changes in selectivity and minimum legal size).

The review panel: (e) Natural mortality is difficult to estimate. We recommend incorporation of a prior probability distribution for natural mortality into the estimation model.

Our reply: We agree with the panel. We have incorporated a prior probability distribution for natural mortality in the estimation model (see the description of the population model).

The review panel: (f) We recommend that analysts estimate lobster growth rates from existing mark-recapture data. The growth transition matrix and size increment per year could be estimated. One approach is to fit the size-structured model (or a version of it) to the tagging data.

Our reply: Estimating growth transition matrix inside the population model would work well for a population model of low complexity (e.g., models for the New Zealand paua fishery, Breen et al. 2000). However, we have found that the inclusion of the estimation of growth transition matrix in an already complex model may reduce the performance of the model. This is why we estimated growth transition matrix outside the population model (i.e., use growth transition matrix as input data of the population model). The growth transition matrix used in the simulation study reported in this study is the one estimated based on parameters used in the EPR model (ASMFC 2000, 2004a) (because the new growth data derived from the tagging study were not available when we did the simulation). The growth transition matrix used in analyzing the field data is derived from the tagging data with size-dependent molting increments (data were obtained from Dr. Joe Idoine and based on the work by Dr. Larry Jacobson and Carl Wilson).

The review panel: (g) Scatterplots shown in the oral presentation demonstrate a strong positive correlation between average recruitment and natural mortality, but not fishery catchability and natural mortality. This likely occurs because fishery catchability is hyperstable (asymptotic relationship between fishery catch rate and lobster abundance) and the correlation instead occurs between the exponent parameter and natural mortality. Though not shown explicitly, survey catchability was not correlated with natural mortality. This does not make sense, especially given that average recruitment was correlated with natural mortality. We recommend that the analysts determine why survey catchability and natural mortality are not correlated, as expected.
Our reply: In fact, for the old version of the model, when we plotted the survey catchability against natural mortality, we did find they were highly correlated. We don't know how the panel derive the conclusion that M is not related to suvey q (they did ay "explicitly", and we guess that they assume suvey q is not related to M because we reported that survey q is not related to the fishery q and fishery q is not related to M). In the modified model, to reduce the number of parameters to be estimated, we no longer estimate fishery and survey catchability coefficients, rather we calculated catchability with abundance and survey/fishery abundance indices (see equations 12 and 13 in appendix I).

The review panel: (h) Penalty functions typically are used to speed up parameter estimation without affecting estimated parameter values. We recommend that the analysts check that penalty function values do not affect parameter estimates.
Our reply: Currently we used penalty function to avoid having estimates that could result in an exploitation rate over 1.0 in any year (i.e., you can fish more lobsters than the lobsters available). We have exploited the impacts of different penalty functions that are built-in in ADMB are used by others (e.g., ADMB codes for the New Zealand paua model; Breen et al. 2000). We found little differences in the parameter estimation among different penalty functions.

The review panel: (i) The analysts model "other" selectivity with a normal distribution. We recommend that the analysts consider other functions to represent "other" selectivity and justify their final choice in biological terms. The analysts provided estimates of these values independently of the report; the parameters were not well-estimated.

Our reply: There are four components in selectivity including gear selectivity, legal switch, V-notching, and selectivity due to other reasons. Legal switch determines that the selectivity outside the legal size range is 0. Thus, the value of "other" selectivity can only influence the selectivity for lobsters within legal size range. The normal density function we used to model "other" selectivity has two parameters, mean size and standard deviation. The mean size determines the central location of the curve while the standard deviation determines how the "other" selectivity curve decreases in probability away from the mean size. Depending on the location of mean size value, the "other" selectivity curve modeled by the normal function can take any shape within the legal size range (this is the size range that matters, and selectivity in the other size range is zero no matter what values other selectivity has). Thus the normal function can effectively reflect any probability that may have with the other selectivity. It is true that the selectivity was not well modeled in old version of the model (ASMFC 2004a) as pointed out by the panel. However, the modified version of model can yield accurate estimates of the selectivity for all the scenarios tested in this study (see figures in results section).

The review panel: (j) Exploitation rate is computed as catch divided by estimated abundance. This implies that fishing mortality occurs in one instant of time and that catch is estimated without error. In fact, fishing mortality occurs over several months. The simplifying assumption of fishing mortality at one instant of time is reasonably accurate for low fishing mortality rates. However fishing mortality rate is high for lobster. We recommend that the analysts explore the sensitivity of parameter estimates to this assumption. The analysts can choose to assume catch has error with small variance, i.e. close to exact, if it seems reasonable. We note that parameter estimation likely will be faster if fishing mortality is estimated in a later “phase” of the estimation.
Our reply: We agree with the panel. We have run some simulation on the robust of the modle performance with respect to biased and random errors in catch (e.g., Chen et al. 2005, and some scenarios in this report). From the limited studies we did so far, the model appears hold its performance. However, we realize some more extensive studies may be necessary. A PhD student in Chen's lab at the University of Maine is currently running more simulation study to test the impacts of different levels of errors in catch on the performance of the model in the parameter estimation. It should also be realized that the

time step of the model is season, not year, which may alleviate the potential problem pointed out by the panel.

The review panel: (k) The relationship between fishery catch rate and lobster abundance is modeled as an exponential function. The function implies that lobster traps can “saturate” at high lobster abundance such that the catch rate remains unchanged once lobster abundance reaches a high-enough level. Understanding the catch rate – abundance relationship and, more generally, the interaction of the target species with the gear is essential for resource assessment (Gunderson 1993). We recommend that experiments be conducted to understand this relationship (e.g. Sigler 2000).
Our reply: It is well known that the lobster trap may be saturated at high lobster abundance. However, no quantified relationship has been developed. Carl Wilson and his colleagues are currently conducting an experiment which may shed some light on this issue. The we made the power parameters much smaller than 1 in the simulation, implying the existence of trap saturation at high lobster abundance. The fact that the model can well estimate the power parameters suggests that the proposal model can capture such a relationship between lobster abundance and fishery abundance index (i.e., CPUE).

Results and discussion
For scenario I (Table 2), the mean values of size frequency distributions for the first year described the true size frequency distribution well except for those of large individuals which may result from an artifact of simulation (accumulation of large oversized lobsters as a result of pre-testing runs before the final 16 years (Fig. 4a). Biases were large for the first few size classes, but decreased quickly, and then became large for large size classes (Fig. 4a). The large biases for large size classes might result from the fact that there were few lobsters in these size classes and small differences in estimates tended to result in relatively large percentage biases. The PRMSE were large for the first few size classes, but dropped quickly with sizes. The patterns of error distributions across size classes were similar for female and male lobsters. The estimated annual recruitment mimicked the temporal patterns of the true recruitment with small biases (Fig. 4b). The estimated legal stock abundances for both males and females were almost identical to those of the true values in most seasons (Fig. 4c). The estimation errors tended to increase with time and become larger for the more recent years. Like the legal stock abundance, the mean values of legal stock biomass

estimates closely follow the true values of legal stock biomass over all the seasons and the fluctuation reflected seasonal variations in legal stock biomass (Fig. 4d). The built-in NMFS survey selectivity was mimicked by the predicted survey selectivity curve (Fig. 4e). Similar to the legal stock abundance and biomass, the mean values of the estimated exploitation rate, calculated as the ratio of landings over legal stock abundance, were similar to those of the true values for most seasons and for both females and males (Fig. 4f). The mean and median values of the estimation bias (PB) and estimation error (PRMSE) over all seasons were presented in Table 4 and Table 5, respectively.

For other scenarios, patterns in the average estimates, biases, and estimation errors were similar to those for Scenario I for the estimated size frequency distribution of the first season, recruitment, legal stock abundance, legal stock biomass, and exploitation rate (Figs 5-11). Estimates of key population parameters have larger errors for Scenarios III and IV compared with those for other scenarios, suggesting that biases in growth parameters tend to have large negative impacts on the model performance. A sudden and continuing increase in M which is not explicitly considered in modeling (i.e., Scenario VIII) also tend to increase errors in estimating legal abundance and stock biomass for the time period in which M increases (Fig. 11c and 11d). The model does have the capacity to include a vector describing the temporal trend of M. If we know the temporal trend of M (such as for Long Island lobster stock), this vector can be used to overcome the problem and substantially reduce the estimation errors resulting from temporal patterns in M. Impacts of other errors tend to have less impact on the performance of the proposed model (Tables 4 and 5). For Scenario V, which is same as Scenario I except there are random errors in M in simulating data (Table 5), temporal patterns and magnitudes in the average estimates, biases, and estimation errors were all similar to those for Scenario I for the estimated size frequency distribution of the first season, recruitment, legal stock biomass, legal stock biomass, and exploitation rate. This suggests that the random variations in natural mortality would not influence the quality of parameter estimation. The temporal patterns of recruitment can be well estimated by the proposed model for all scenarios tested in this study.

This study shows that the proposed population model is robust to observation errors. Large estimation errors in size composition estimated for the first season in the assessment may result from the artifact of the simulation design. If there is no bump in size distribution curve, which arises from the impacts of the maximum legal size over time, such as those shown in Figs. 4-11, the errors can be substantially reduced.

The analysis of retrospective errors is presented in Table 6. This was done for scenario I except there was no observation error. By comparing the legal abundances for year 12 estimated in assessment year 12 with those estimated in assessment years 13, 14, 15, and 16, we can identify if there is retrospective error problem in the parameter estimation. The analysis shows that the retrospective error is not an issue for the data set tested in this study (Table 6).

We applied the proposed model to the field data compiled for the GOM lobster stock. The results were shown in Figures 12 to 16 for the size-specific stock abundance in the first season of the assessment (i.e., winter 1981; Fig. 12), legal abundance (Fig. 13), legal biomass (Fig. 14), recruitment (Fig. 15), and exploitation rate (Fig. 16), respectively. Although we applied the model to data from 1981 to 2003, we were asked by the ASMFC Lobster Technical Committee to only present the results up to 1999 because the model is used as a demonstration only in this assessment. The study suggests that the legal abundance and biomass of female lobsters tend to be higher than those of males (Figs 13 and 14). Despite heavy fishing, legal abundance and biomass of the lobster stock in GOM had been increasing since 1980s, as a result of large increase in recruitment. The legal stock abundance, legal stock biomass, and recruitment in late 1990s were all much higher than those in 1980s (Figs 13, 14 and 15). It should be noted that the recruitment described in this study is the number of the lobsters growing into the size group of 53 to 68 mm CL and differs from the "recruitment to the lobster fishery" that we are usually referred to. These lobsters still need some time to grow becoming recruitment to the lobster fishery. Because of the high abundance, the exploitation rates of recent years are much lower than those of early years despite of high landing (Fig. 16). As expected, there were large seasonal variations in legal stock abundance, biomass, and exploitation rate (Figs. 13, 14, and 16). The exploitation rate of females tended to be lower than that of males in most seasons, probably as a result of conservation measures (Fig. 16).

The difference in abundance between small female and male lobsters may be too large to be biologically realistic, and may result from the fact that we may not have enough information to break down the total size-specific abundance between females and males in the first year. Thus, the differences in the key fisheries parameters between females and males in the early years should be interpreted with cautions. The impacts of the estimates in the first year decrease with the time, making the comparison between females and males in recent years more realistic. In the future more information may be needed to overcome this problem.

The comparisons of the predicted and observed key fisheries statistics are presented in figures 17 to 21. It appears that the predicted values follow the general patterns of the observed values. Lack of fitting in some years may result from the fact that a robust estimator was used in the parameter estimation which is not sensitive to atypical values. Lack of systematic patterns of the median values of the differences between observed and predicted size compositions may suggest that the model fits the data well. However, we do need to realize that a robust estimator is used in fitting the model to size composition data (Chen et al. 2000).

The selectivity curves were estimated for the three survey programs (Fig. 22). NMFS tends to select for large individuals, while Maine DMR and MASS inshore surveys tend to be highly selective for small individuals (Fig. 22). This is consistent with lobsters observed in these programs (Chen et al. 2005).

In summary, we have modified the model based on the comments given by the ASMFC Lobster Model Peer-review Committee, and this study suggests that the proposed model can capture the dynamics of the lobster population in the presence of various errors. It provides an effective new, power, and flexible framework to modeling the population dynamics of the American lobster in northeast USA. Detailed report of the Bayesian estimator and F10% estimation, both of which have been incorporated into the proposed model, will be published in peer reviewed journals in late 2005 or early 2006.

Acknowledgement

We would like to thank ASMFC Lobster Model Development Subcommittee, Technical Committee, Stock Assessment Subcommittee for their supports in the model development and testing. Comments and helps from Dr. Larry Jacobson (NMFS), Dr. Paul Breen (NIWA, New Zealand), Kim McKnown (NY DEC), Dr. Joe Idoine (NMFS), Robert Glenn (MA DMF), Dr. Jim Wilson, Dr. Vic Crecco (CT DEP), Penny Howell (CT DEP), Steve Correia (MA DMF), Lobster Model Review Panel, and an anonymous reviewer (for Chen et al. 2005) have greatly improved the work. The financial support of the work is provided by the Maine Sea Grant, Maine DMR, and ASMFC.

Table 1. Summary of the main features for the proposed stock assessment framework.

Sex-specific and Size-specific;

Using fishing season as time step (winter, spring, summer, fall);

Major molting in summer and double molting for small lobsters in fall;

Considering four size-dependent selection processes in the fishery: gear, legal sizes, V-notching, and all other reasons;

No functional relationship assumed for SSB and subsequent recruitment;

Considering possible autocorrelation of recruitments in different years;

Estimating F10% and Fcur from the same framework, making them comparable;

Allowing for data from different survey programs;

Accounting for size-specific selectivity of survey programs;

Natural mortality inputted with a defined prior distribution in the parameter estimation;

Able to account for size-specific differences in natural mortality;

Providing uncertainty estimates for risk analyses using Bayesian estimator;

Coping with missing data in a time series of data (but not for catch which is a driving force in population dynamics);

Providing historical and current biomass and abundance estimates, making it possible to evaluate if the lobster is overfished;

Providing choices of robust likelihood functions that is not sensitive to outliers in data.

Table 2. The parameters in the proposed population model that need to be estimated in modeling. The number of the parameters is determined by the number of years of data available. This table is made based on 16 years of data available to the assessment.

Parameter	Numbers	
Density-dependent parameters γ in Eq. 12 (4 seasons x 2 sexes)	8	
Parameters defining two survey selectivity curves Eq. 16	4	
Sex- and size-specific abundance in the first year	6	
Parameters determining the recruitment in Eq.1 and 2 (for 16 years)		19
Natural mortality	1	
Parameters for determining selectivity curve of the fishery (eq. 7)	2	
Total number of parameters to be estimated	40	

Table 3. The design of simulation study for testing the performance of the proposed sex-specific length-structured stock assessment model. The simulation scenarios are developed by the ASMFC Model Development Subcommittee. The first year of recruitment is the same for all the scenarios and the temporal pattern of the recruitment is described in Fig. 2.

No.	R Patterns	Bias in molting Incr.	Error in survey	Error in catch & CPUE	Process error
I	GOM	None	CV=30%	CV=30%	None
II	GOM	None	CV=30%	Biased, 25% higher 1st 5yrs 10% higher rest years, CV=30%	None
III	GOM	Positively biased	CV=30%	CV=30%	None
IV	GOM	Negatively biased	CV=30%	CV=30%	None
V	GOM	None	CV=30%	CV=30%	Errors in M
VI	4X up (11 yrs) 4X down (4 yrs)	None	CV=30%	CV=30%	None
VII	Flat (11yrs) 4X down(4 yrs)	None	CV=30%	CV=30%	None
VIII	Flat(11yrs) 4X down(4yrs)	None	CV=30%	CV=30%	M increase in last 5 yrs

Table 4. Percentage of bias (PB) of key parameters estimated using the proposed model for different simulation scenarios. PB is calculated using Equation (1). R = recruitment defined in the text, F_TA = total abundance for females, M_TA = totakl abundance for males, F_LA = legal abundance for females, M_LA = legal abundance for males, F_LB = legal biomass for females, M_LB = legal biomass for males, F_E = exploitation rate calculated as the ratio of catch versus legal abundance for females, M_E = exploitation rate calculated as the ratio of catch versus legal abundance for males, and M = natural mortality.

Scenarios	Statistics	Parameters									
		R	F_TA	M_TA	F_LA	M_LA	F_LB	M_LB	F_E	M_E	M
I	mean	-1	-13	-8	-16	-14	-20	-13	20	17	-7
	median	-5	-11	-6	-14	-12	-17	-12	16	14	
II	mean	-1	-12	-7	-13	-10	-18	-10	13	10	-7
	median	-6	-12	-6	-11	-10	-16	-11	11	10	
III	mean	19	18	28	16	22	10	23	-13	-17	-9
	median	16	18	30	17	23	13	24	-14	-18	
IV	mean	-18	-38	-36	-39	-39	-42	-38	68	65	-6
	median	-26	-38	-35	-38	-40	-40	-38	62	66	
V	mean	-2	-15	-8	-19	-13	-23	-12	24	16	-6
	median	-6	-14	-5	-17	-12	-21	-12	21	13	
VI	mean	4	-8	-3	-14	-10	-18	-9	17	11	-7
	median	-1	-7	-4	-13	-10	-16	-10	15	11	
VII	mean	2	-5	-1	-11	-8	-15	-8	14	10	-7
	median	2	-4	-2	-11	-10	-14	-9	13	11	
VIII	mean	-10	-6	-5	-9	-10	-12	-9	16	15	21
	median	-8	-9	-7	-15	-13	-19	-13	18	15	

Table 5. Percentage of rooted mean squared error (RMSE) of key parameters estimated using the proposed model for different simulation scenarios. RMSE is calculated using Equation (2).

Scenarios	Statistics	Parameters									
		R	F_TA	M_TA	F_LA	M_LA	F_LB	M_LB	F_E	M_E	M
I	mean	23	13	9	16	14	20	14	21	18	
	median	21	12	6	14	13	18	13	17	15	
II	mean	23	13	8	14	11	18	11	16	14	
	median	21	12	6	11	11	16	12	12	11	
III	mean	30	20	29	18	24	14	25	15	19	
	median	27	19	30	18	24	14	25	15	19	
IV	mean	31	38	36	40	39	42	38	68	65	
	median	29	38	35	38	40	40	39	62	66	
V	mean	23	15	9	19	14	24	13	25	17	
	median	22	14	6	17	12	22	12	21	14	
VI	mean	12	9	5	14	10	18	10	18	12	
	median	9	8	5	13	11	16	11	15	12	
VII	mean	11	7	5	12	10	16	9	16	11	
	median	7	6	5	11	10	15	9	13	12	
VIII	mean	19	15	13	22	20	25	20	24	21	
	median	11	11	9	16	16	20	15	19	18	

Table 6a

Male legal abundance in year 12 estimated in different assessment years

	Assessment year				
	16	15	14	13	12
Estimates	18505.2	18665.1	18908.0	19232.9	19729.2
% of bias	-3.0	-2.2	-0.9	0.8	3.4

Table 6b

Female legal abundance

	Assessment year				
	16	15	14	13	12
Estimates	23564.6	23749.1	24289.2	24571.2	25221.3
% of bias	2.3	3.1	5.4	6.6	9.5

Figure 1. The flowchart of the proposed Bayesian stock assessment framework.

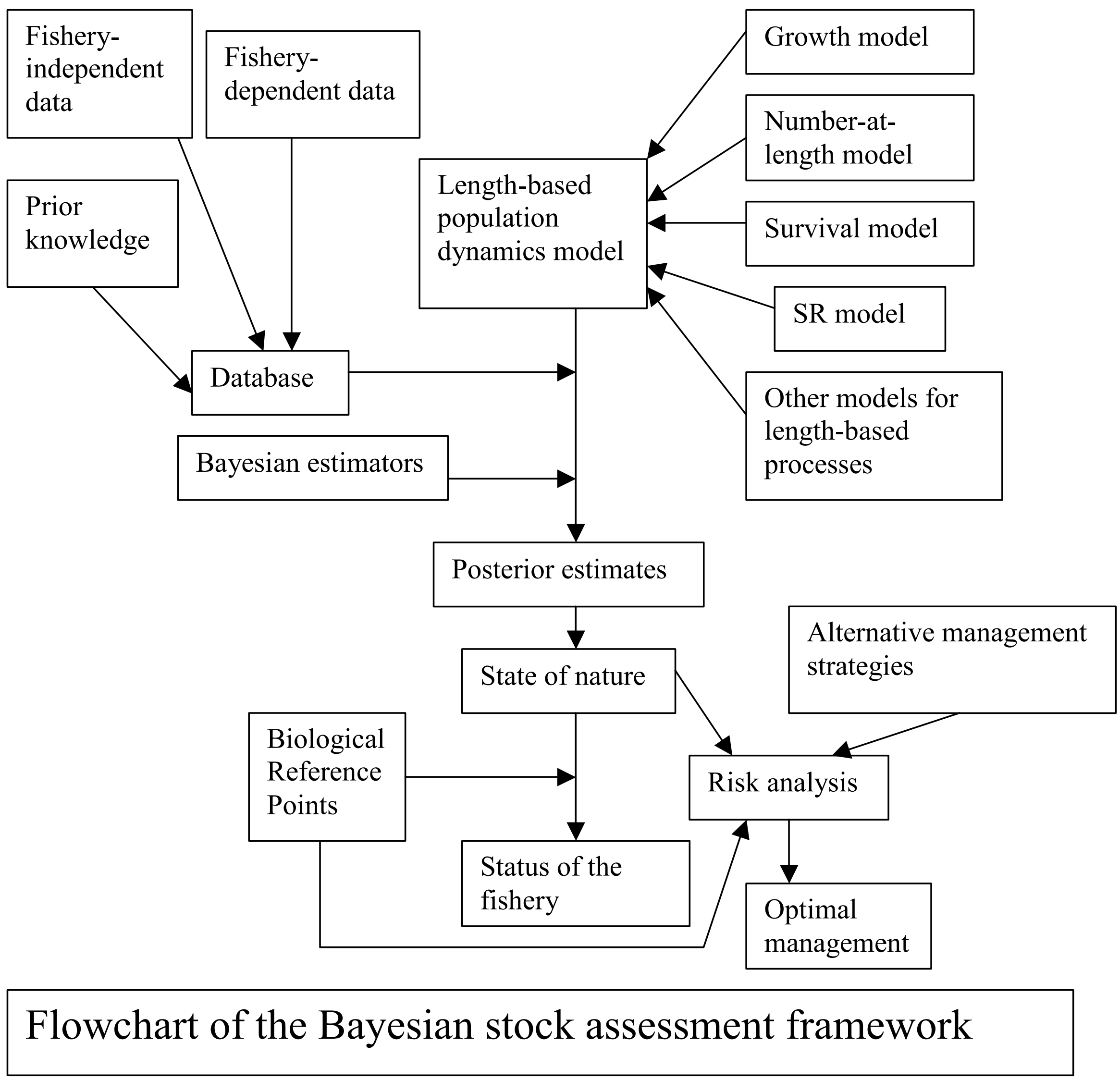


Figure 2. The design of the simulation study. The description and testing of the Lobster Simulator are described in Appendix II.

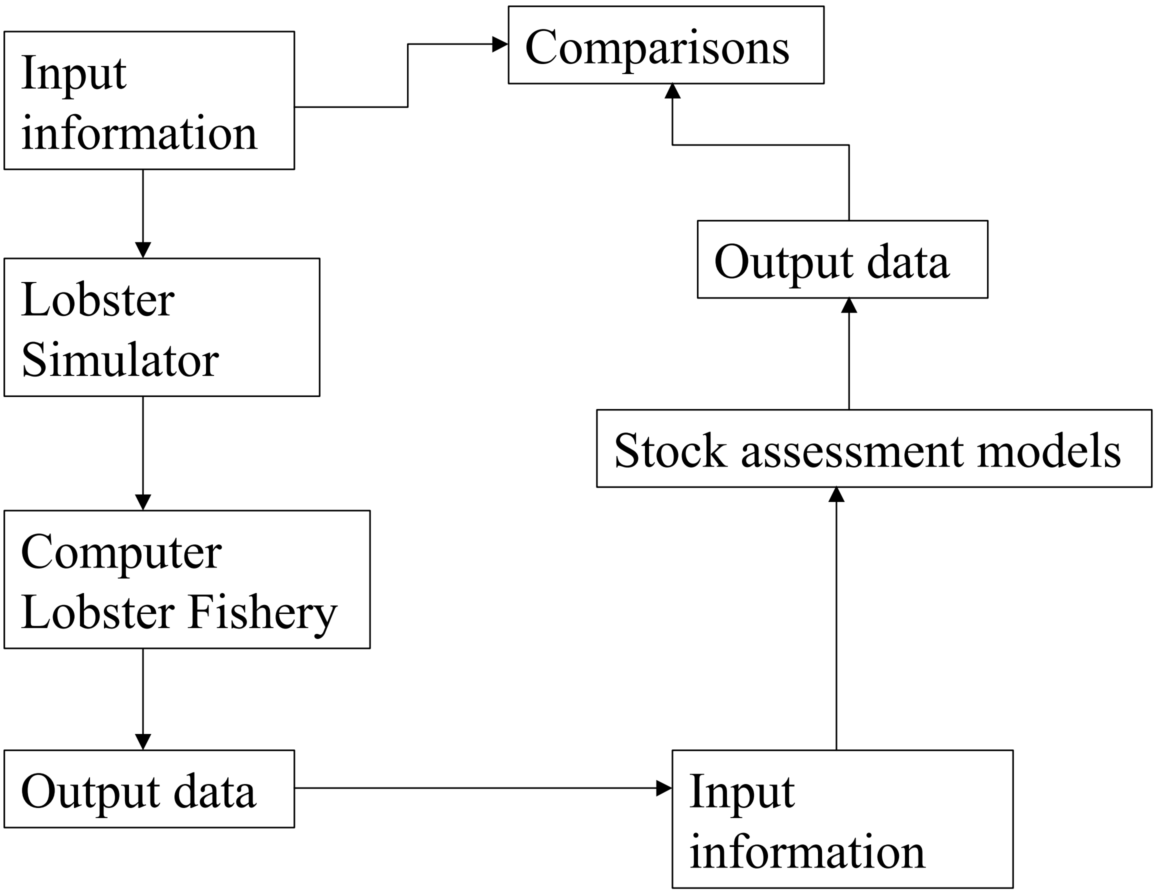


Figure 3. Temporal pattern of recruitment for each scenario.

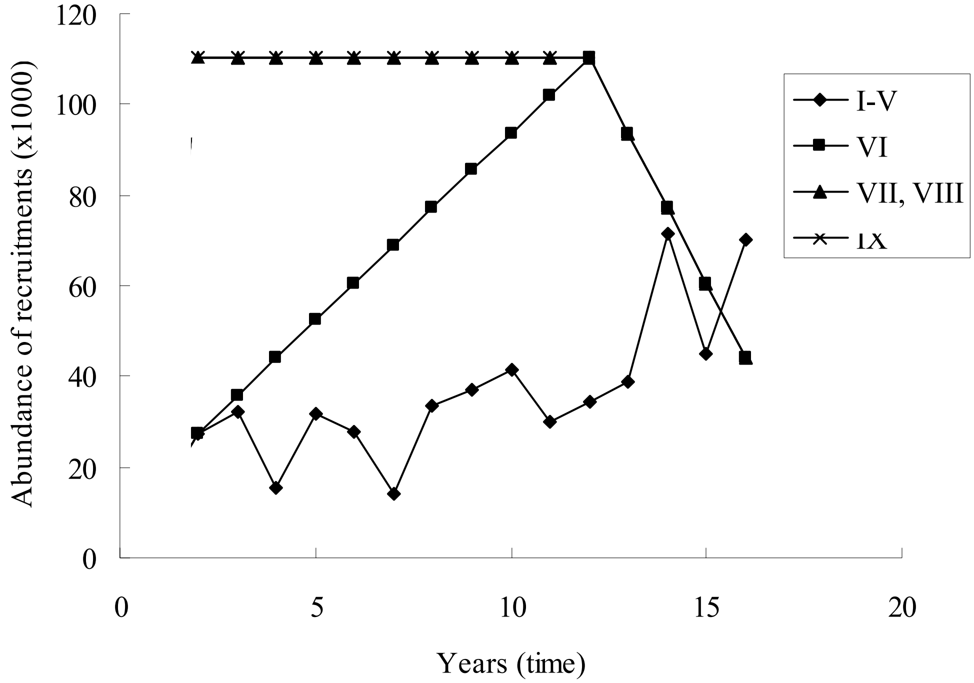


Figure 4a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for Scenario I.

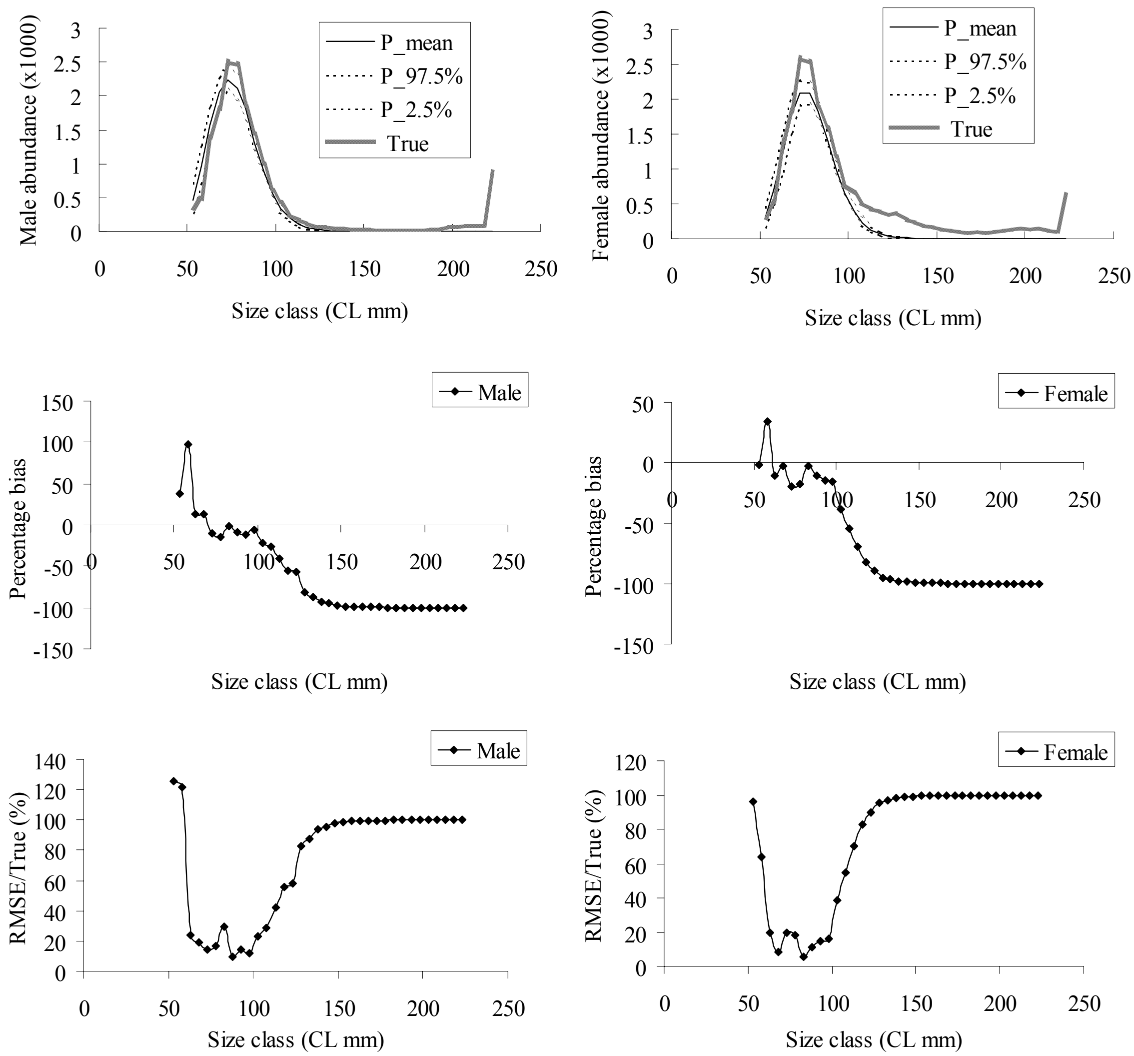


Figure 4b. Recruitment estimation for Scenario I.

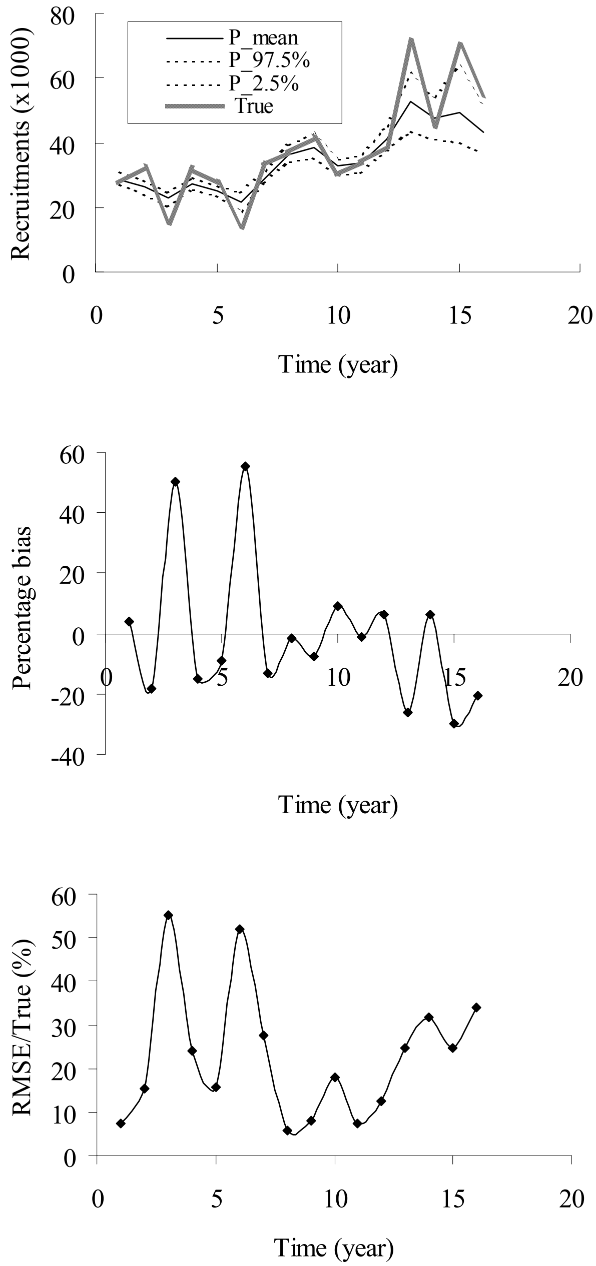


Figure 4c. The estimation of legal stock abundance of lobster for Scenario I.

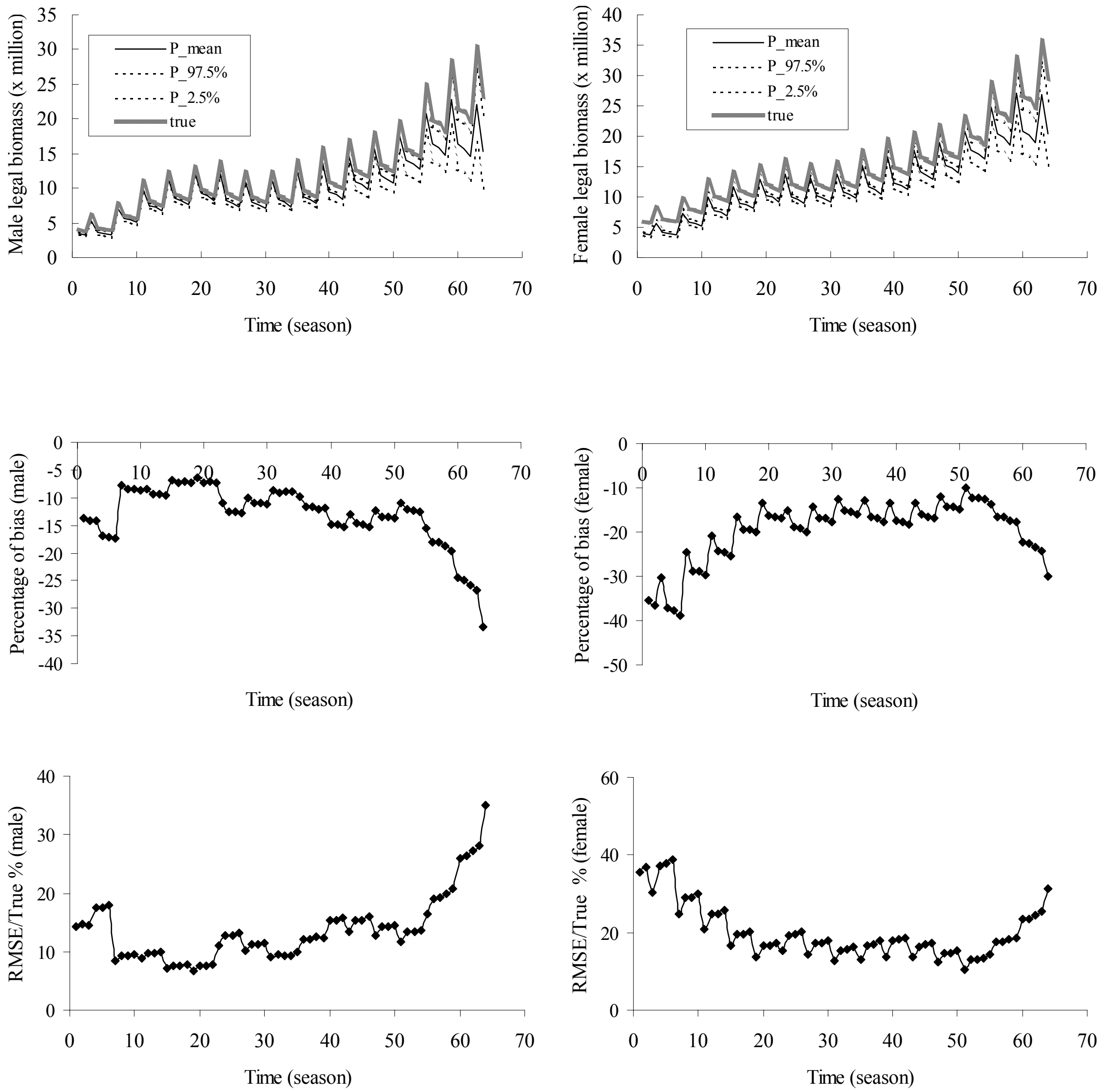


Figure 4d. The estimation of legal stock biomass for simulation Scenario I.

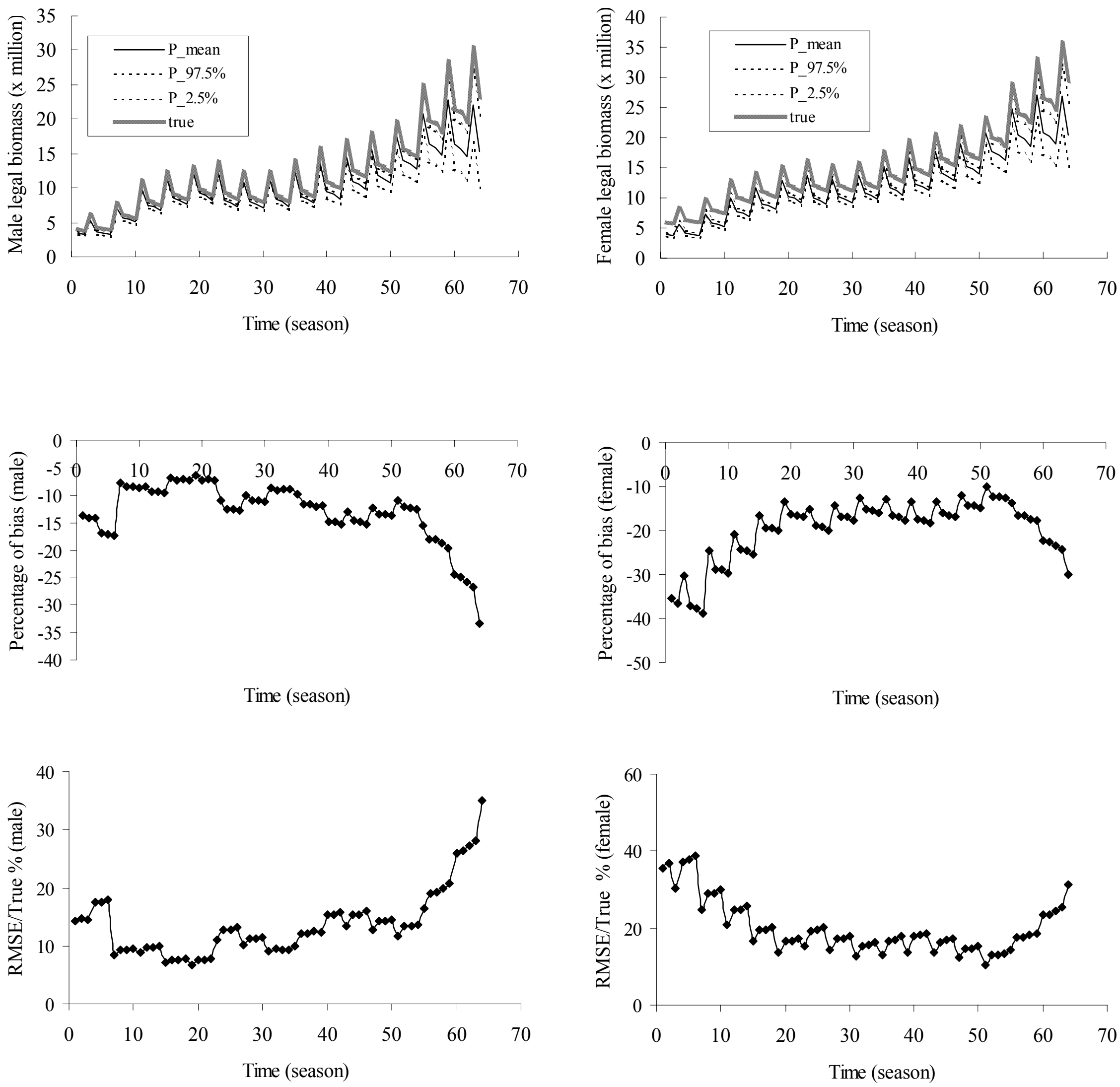
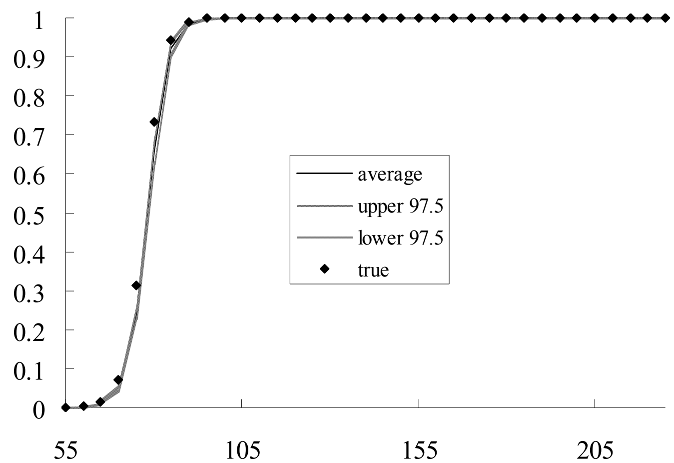


Figure 4e. The predicted and observed selectivity for simulation Scenario I.



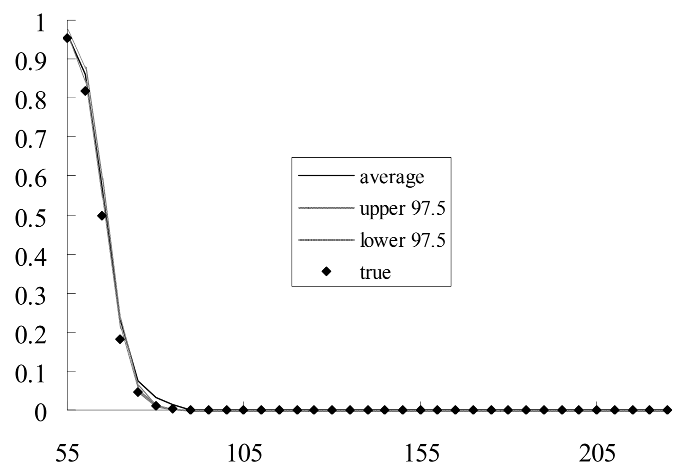


Figure 4f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario I.

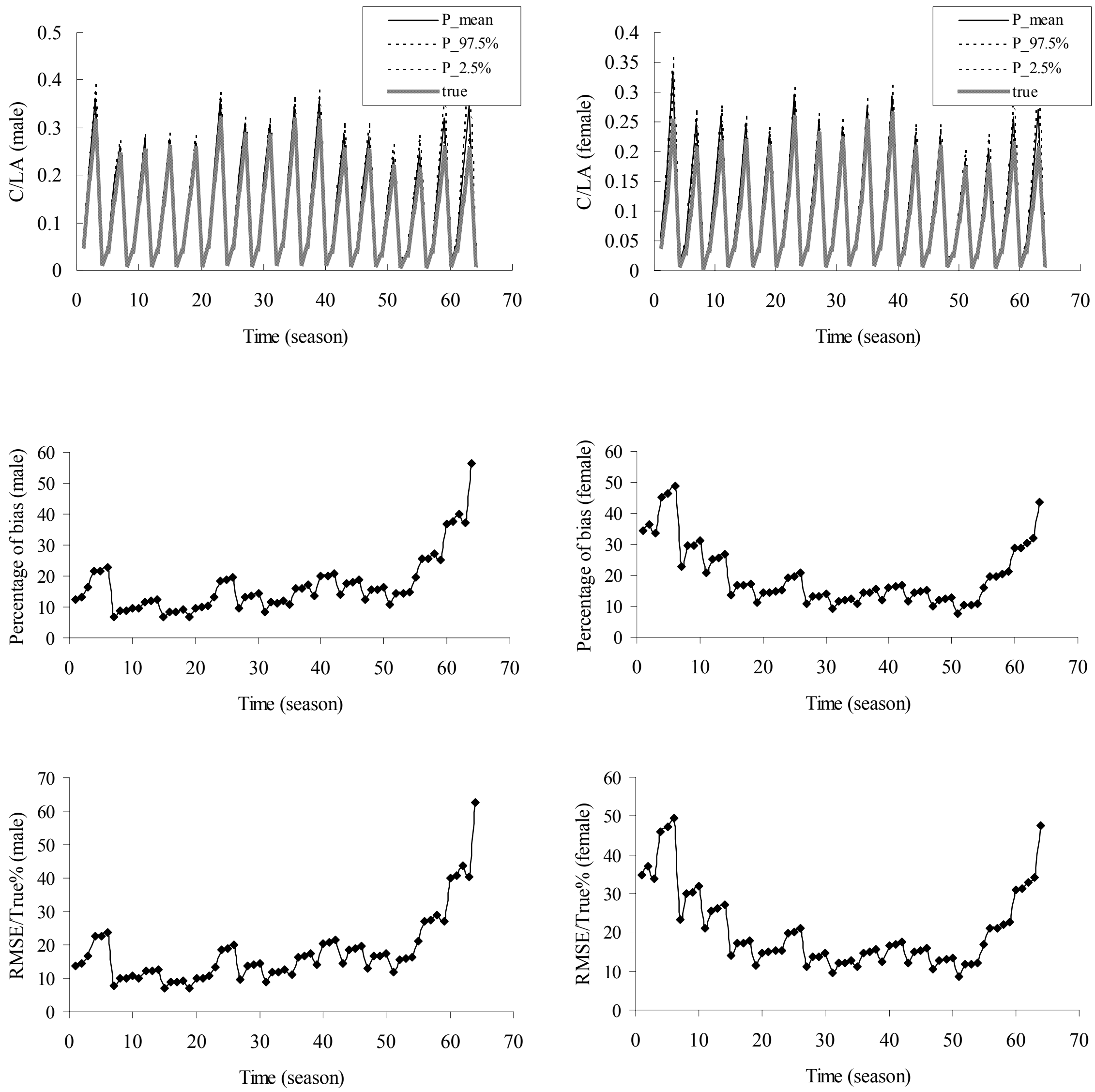


Figure 5a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for simulation Scenario II.

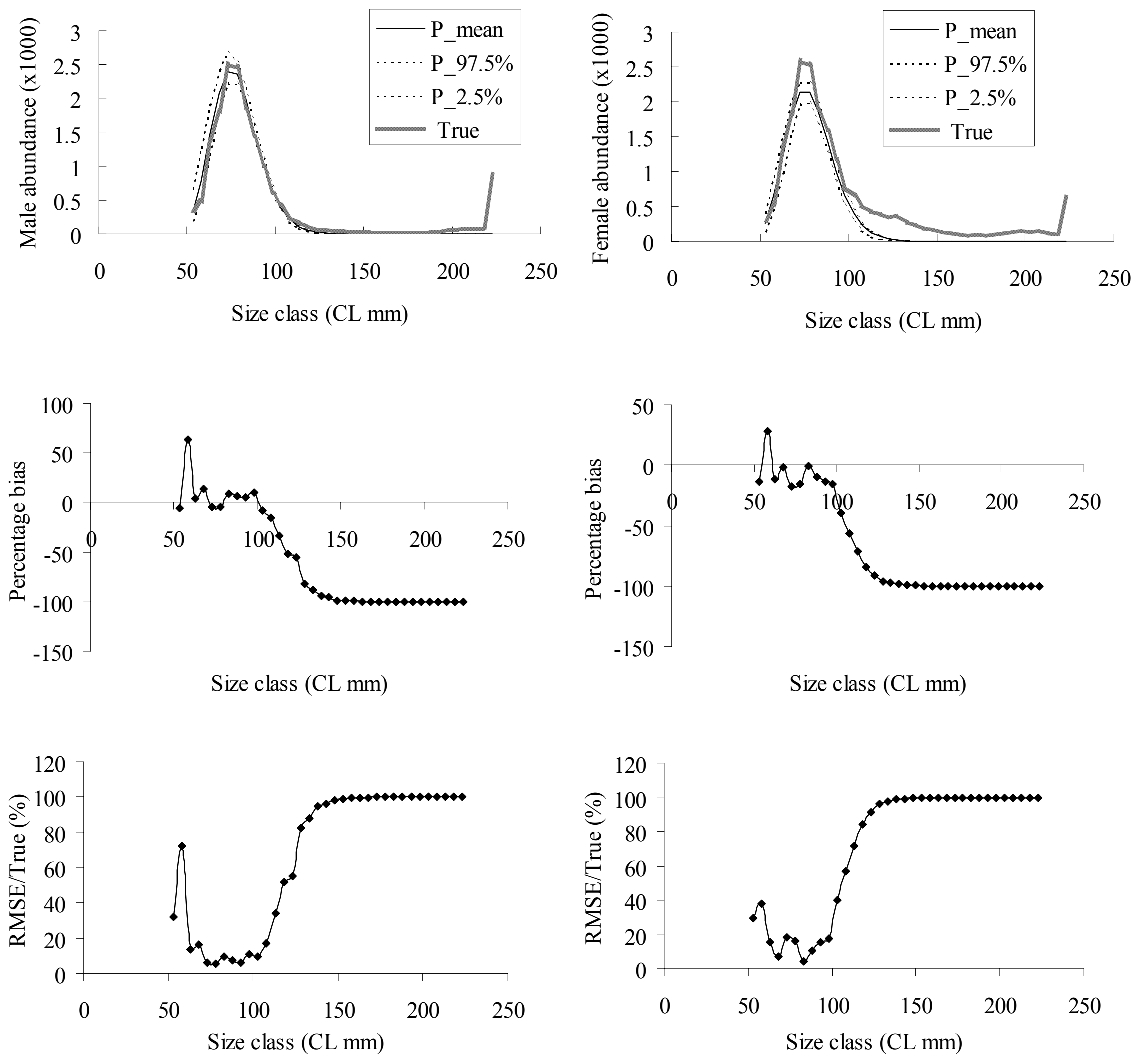


Figure 5b. Recruitment estimation for simulation Scenario II.

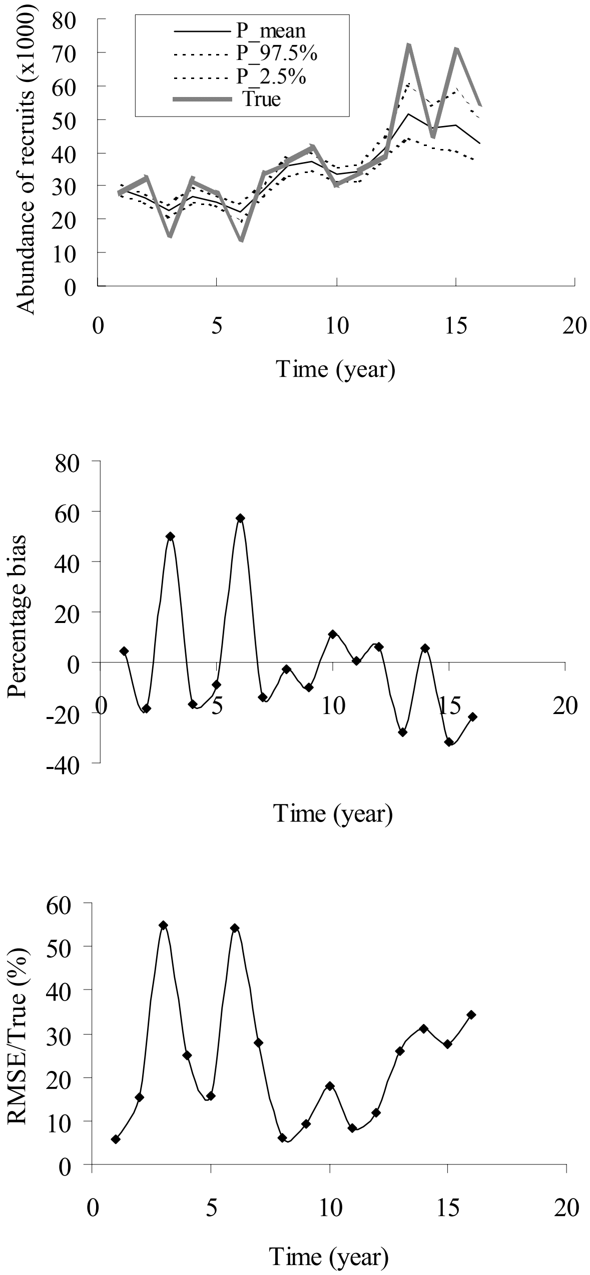


Figure 5c. The estimation of legal stock abundance of lobster for simulation Scenario II.

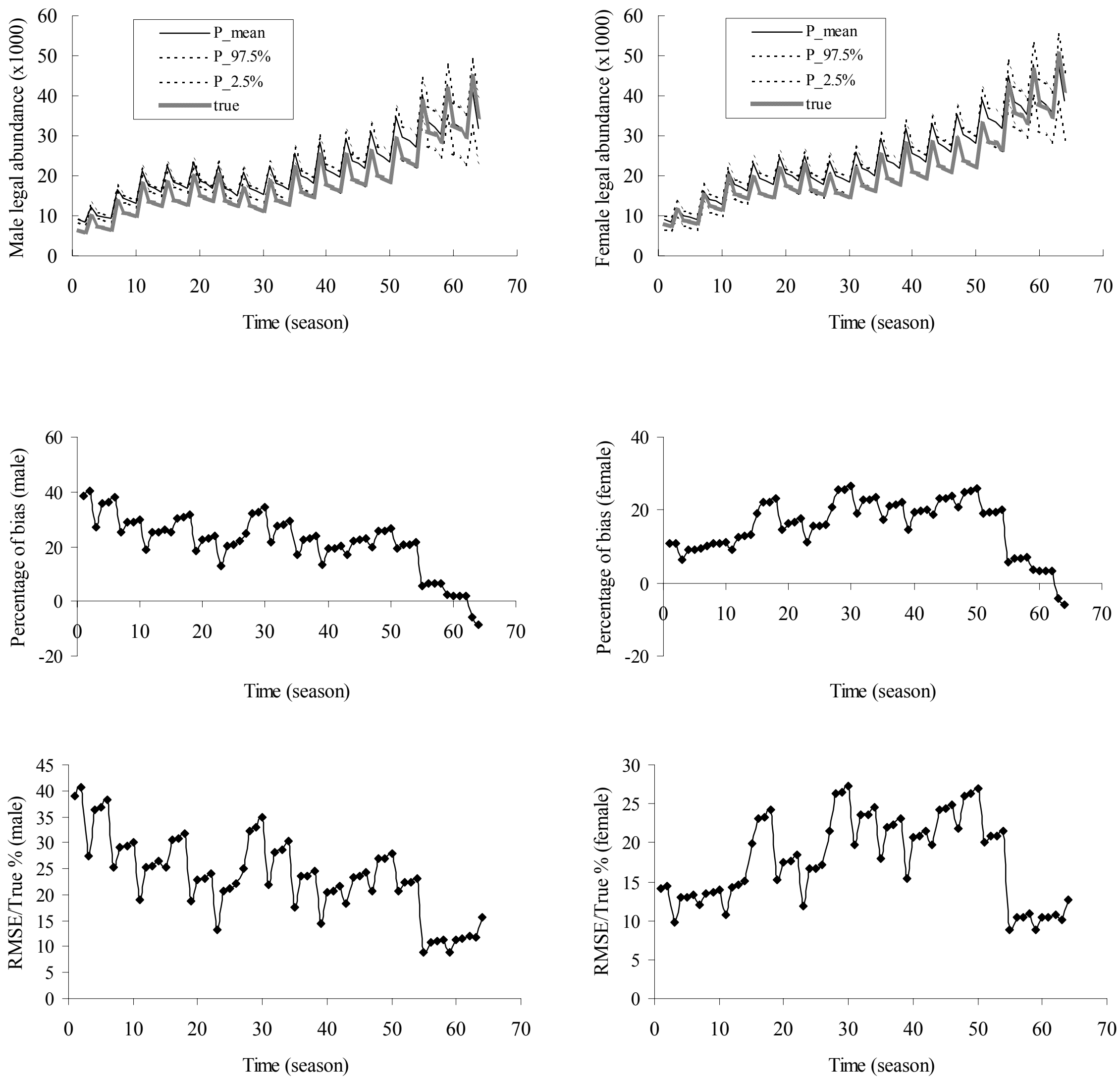


Figure 5d. The estimation of legal stock biomass for simulation Scenario II.

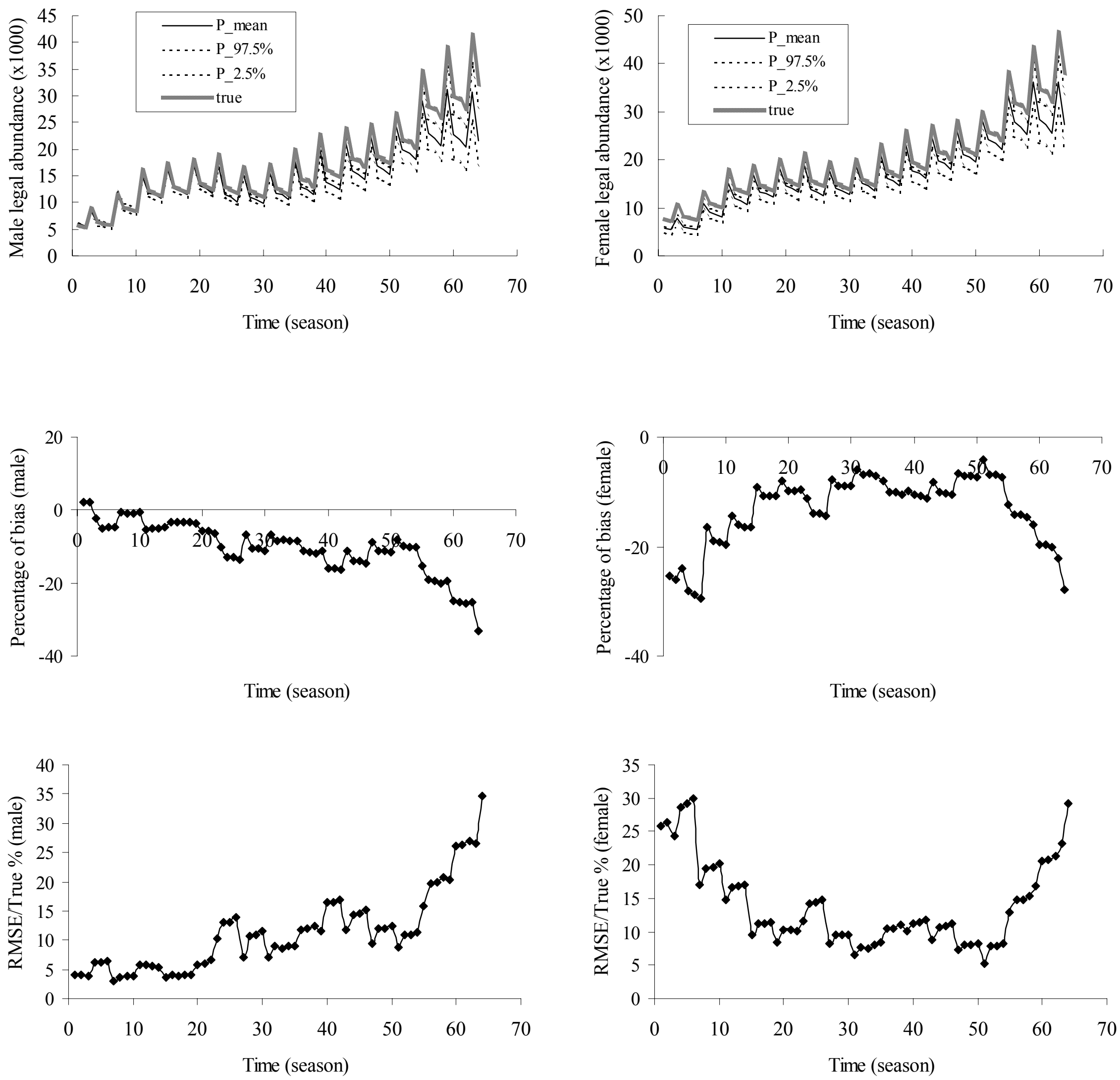
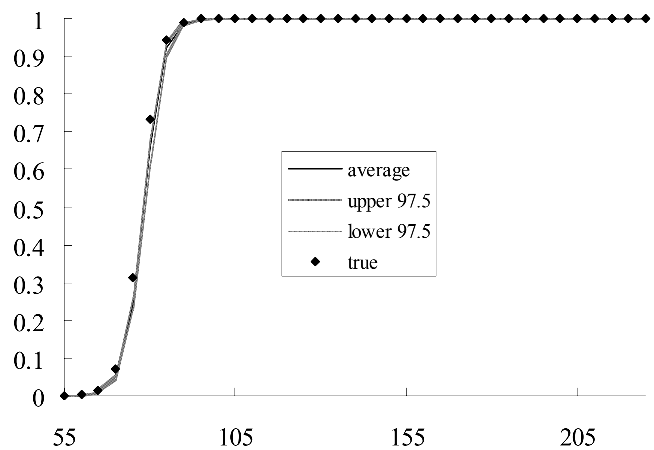


Figure 5e. The predicted and observed selectivity for simulation Scenario II.



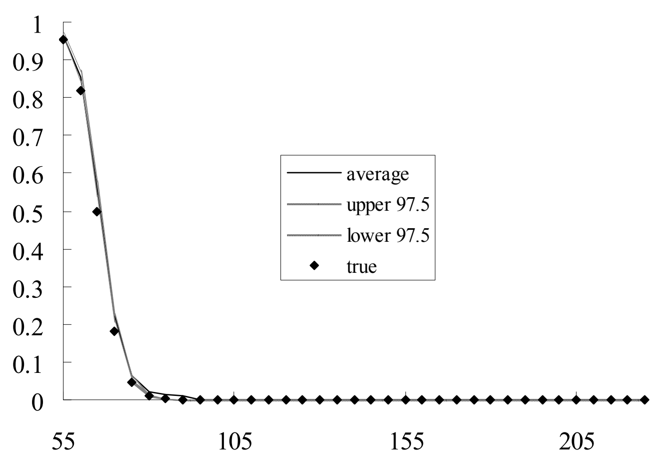


Figure 5f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario II.

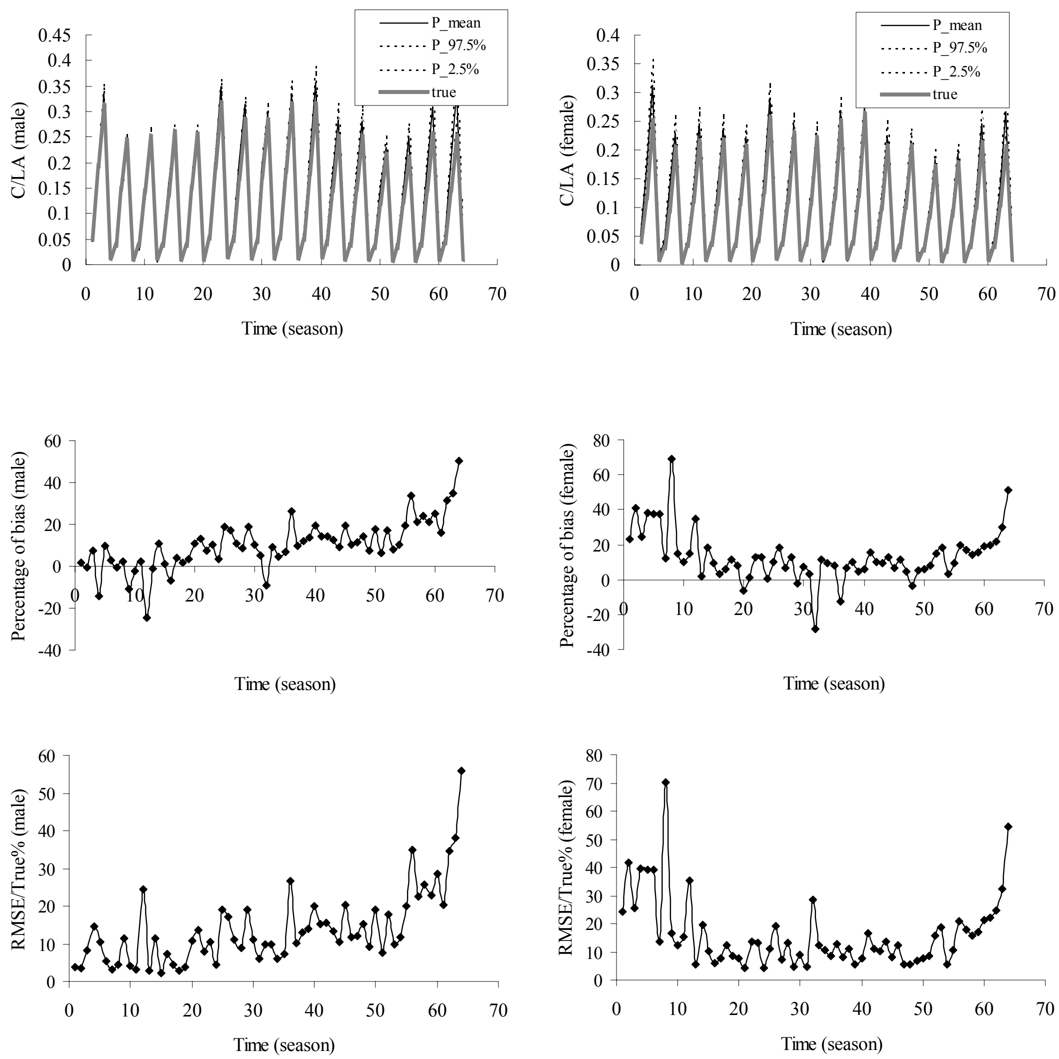


Figure 6a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for simulation Scenario III.

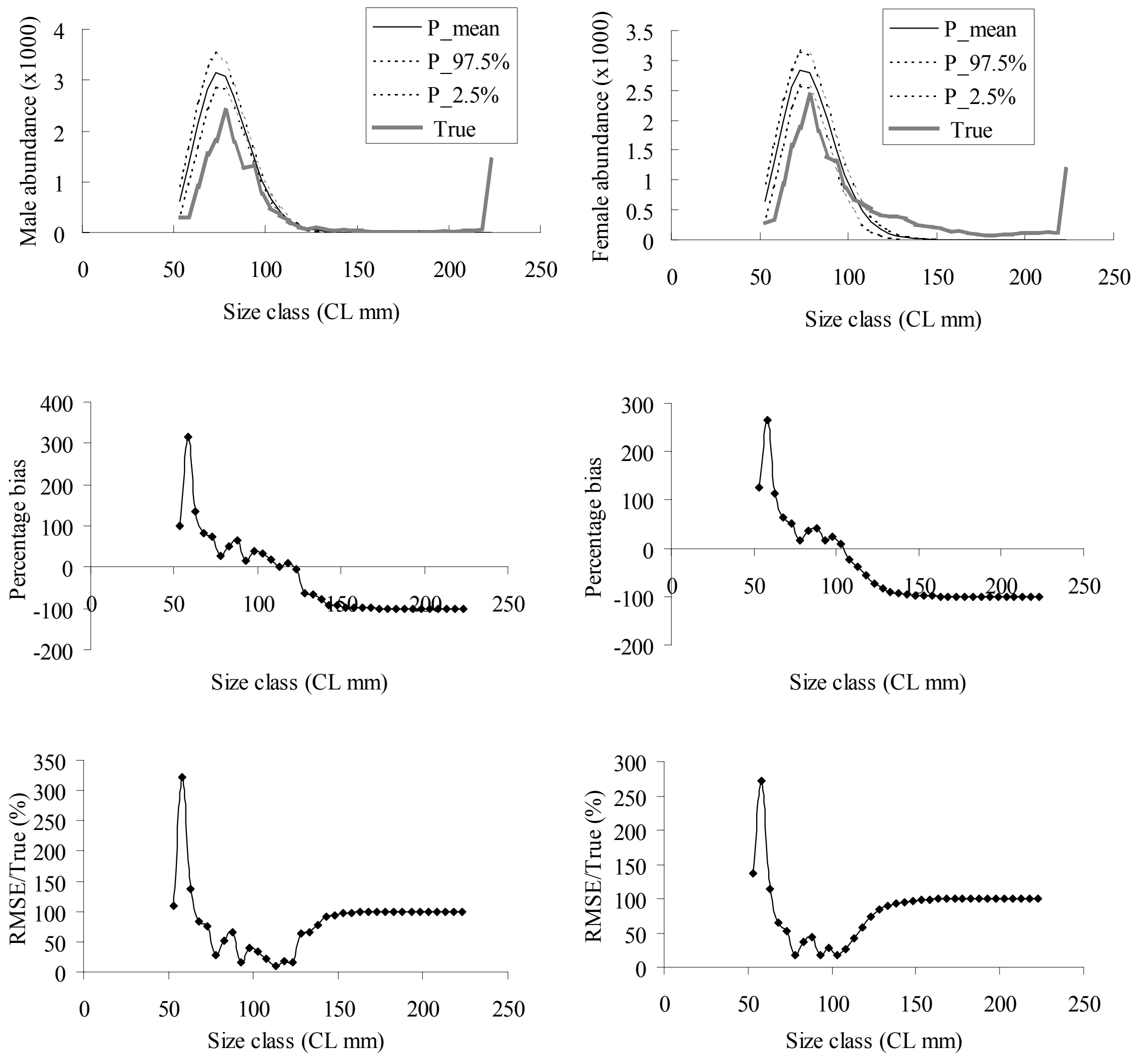
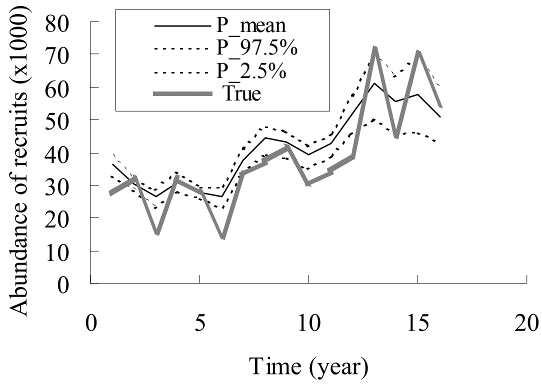
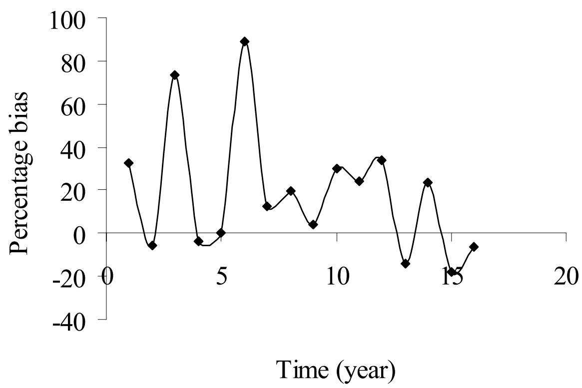


Figure 6b. Recruitment estimation for simulation Scenario III.





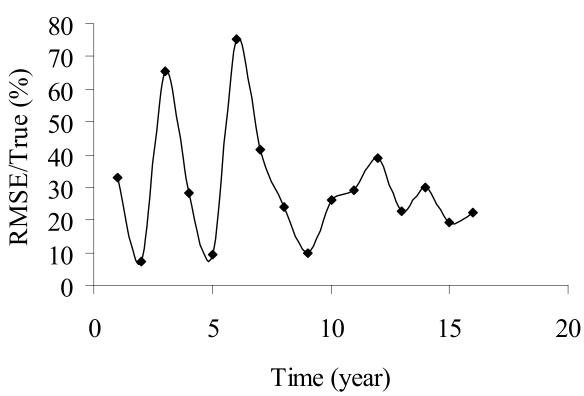


Figure 6c. The estimation of legal stock abundance of lobster for simulation Scenario III.

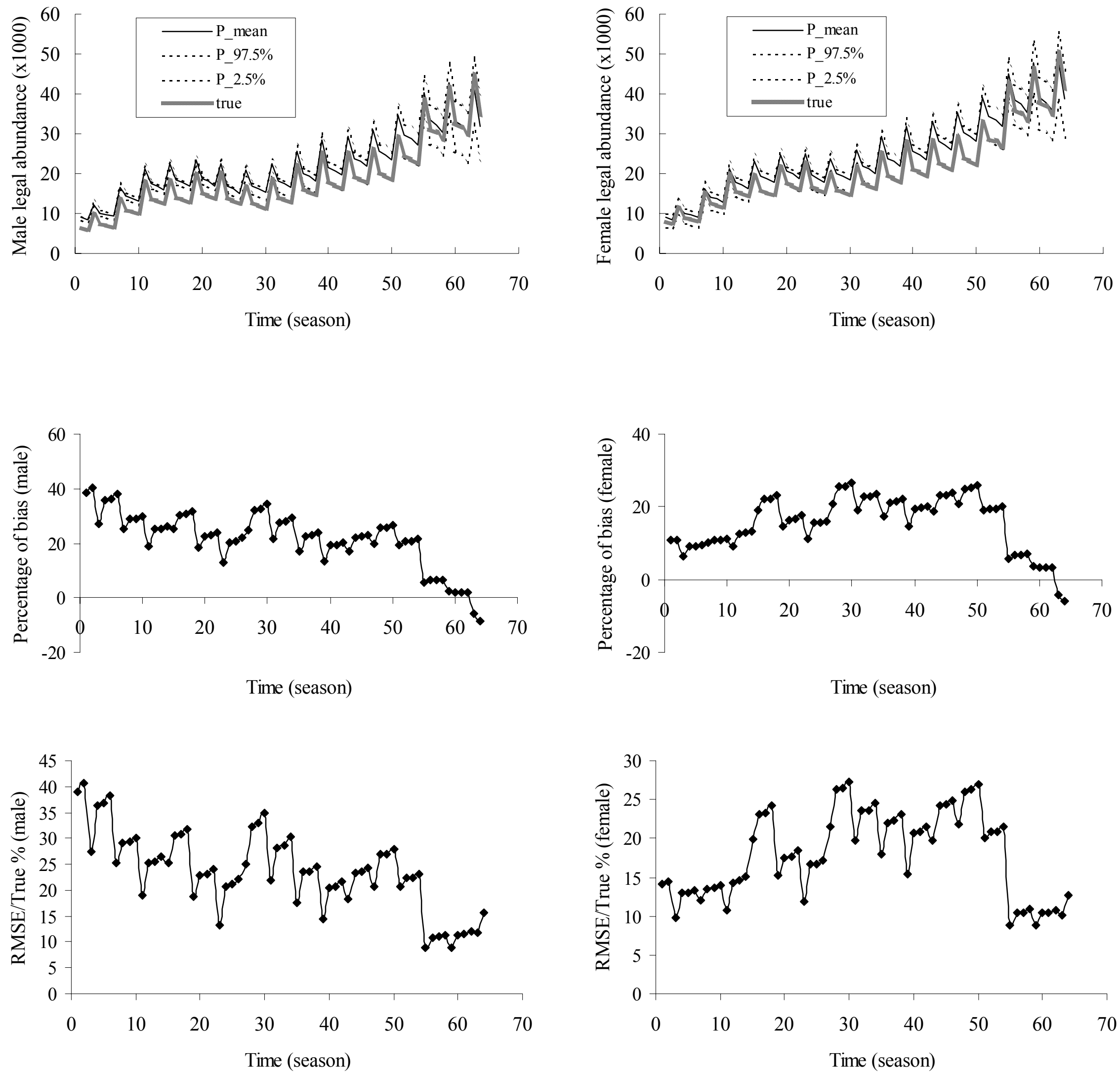


Figure 6d. The estimation of legal stock biomass for simulation Scenario III.

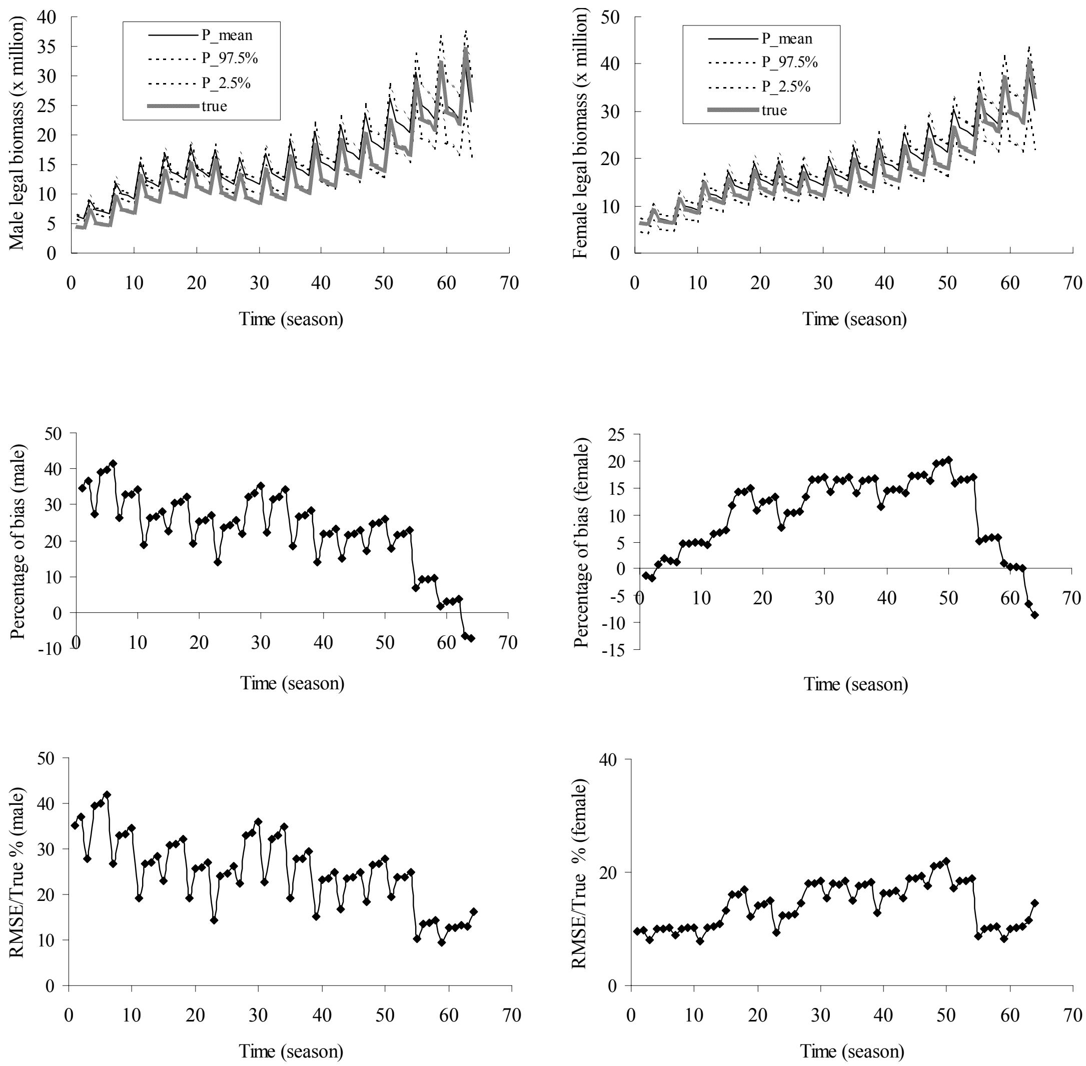
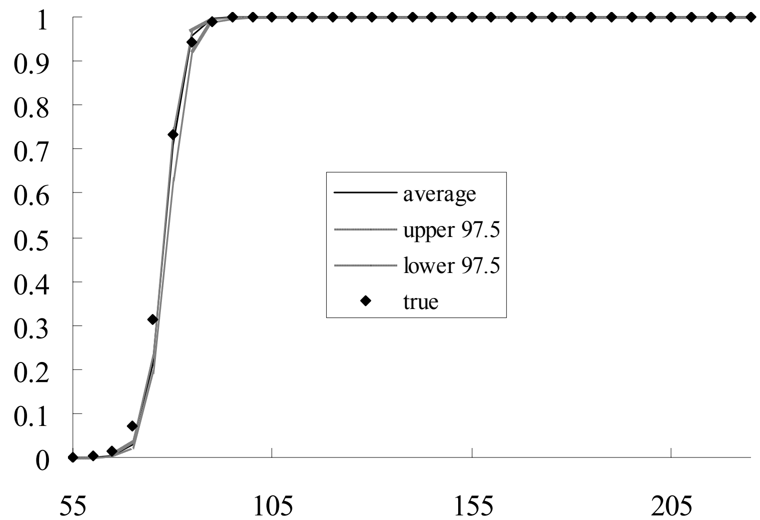


Figure 6e. The predicted and observed selectivity for simulation Scenario III.



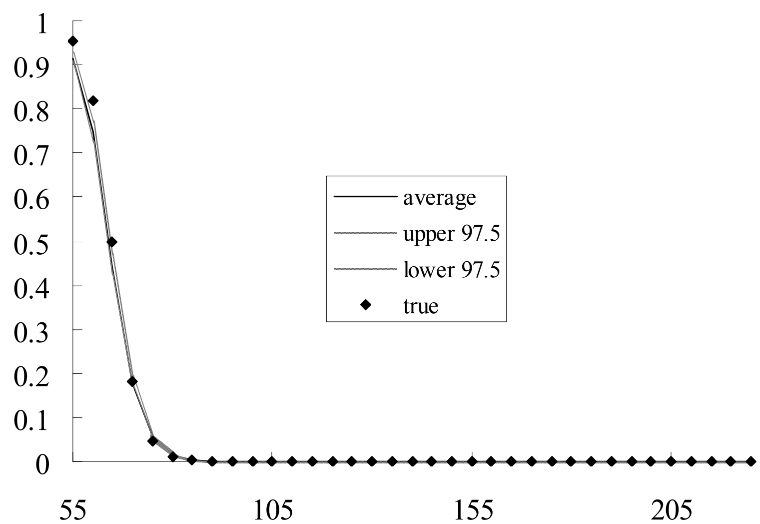


Figure 6f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario III.

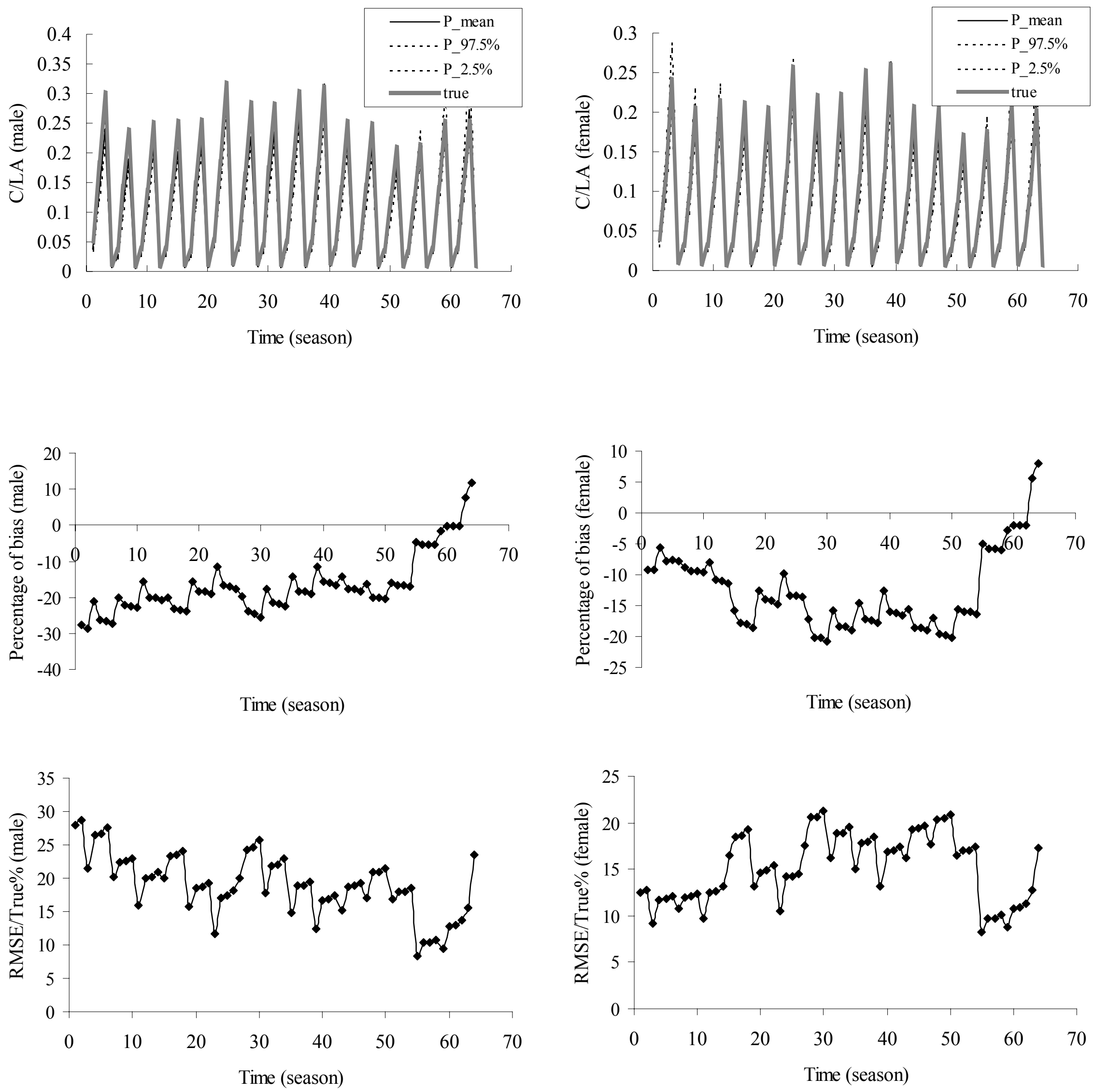


Figure 7a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for simulation Scenario IV.

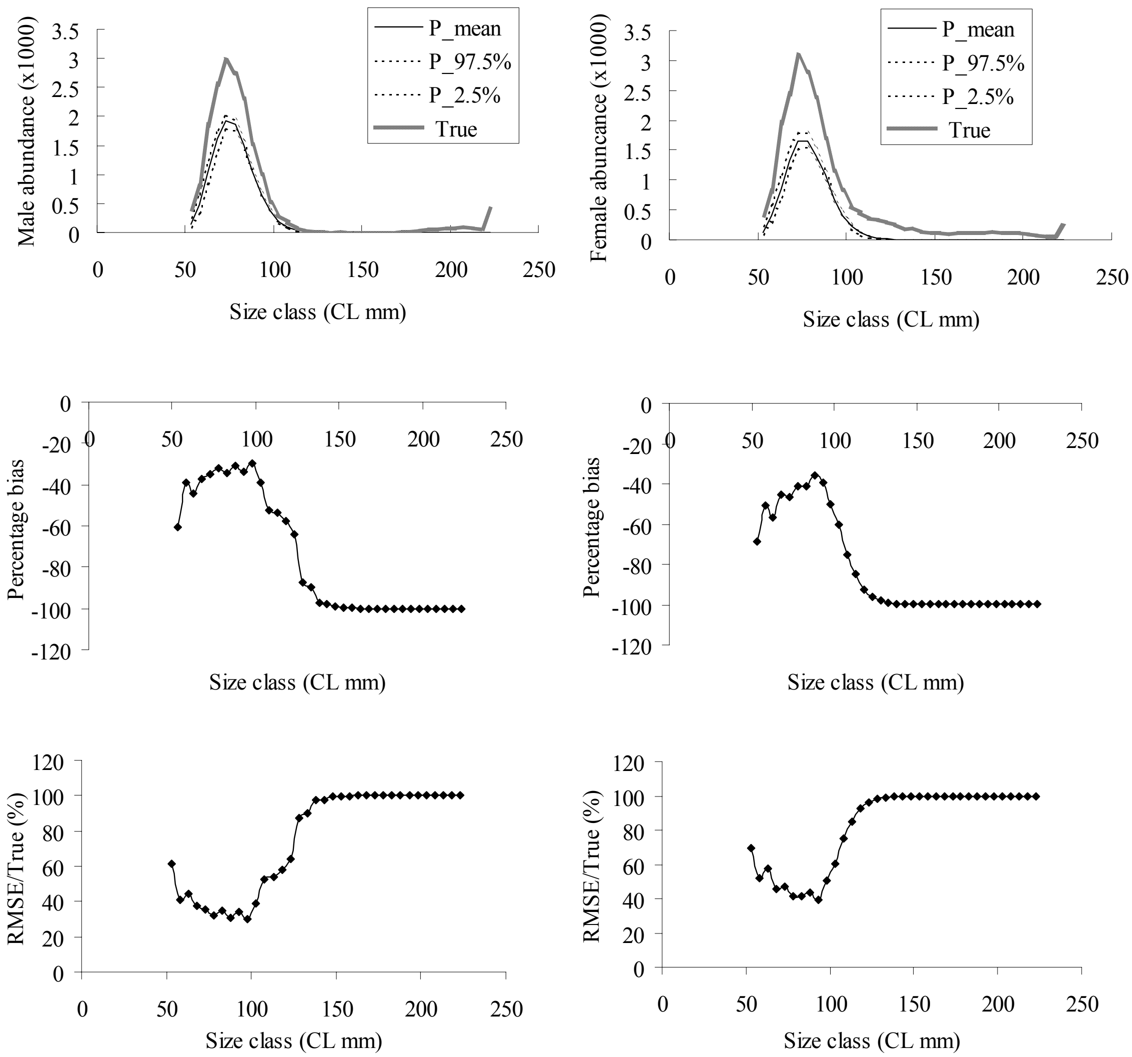


Figure 7b. Recruitment estimation for simulation Scenario IV.

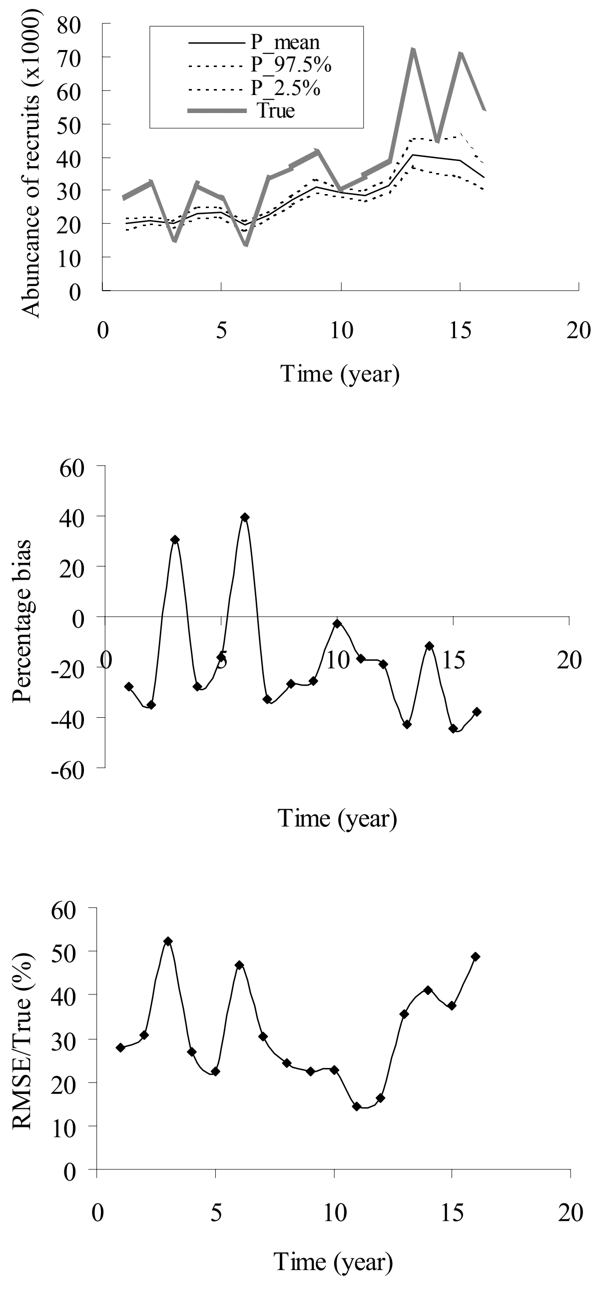


Figure 7c. The estimation of legal stock abundance of lobster for simulation Scenario IV.

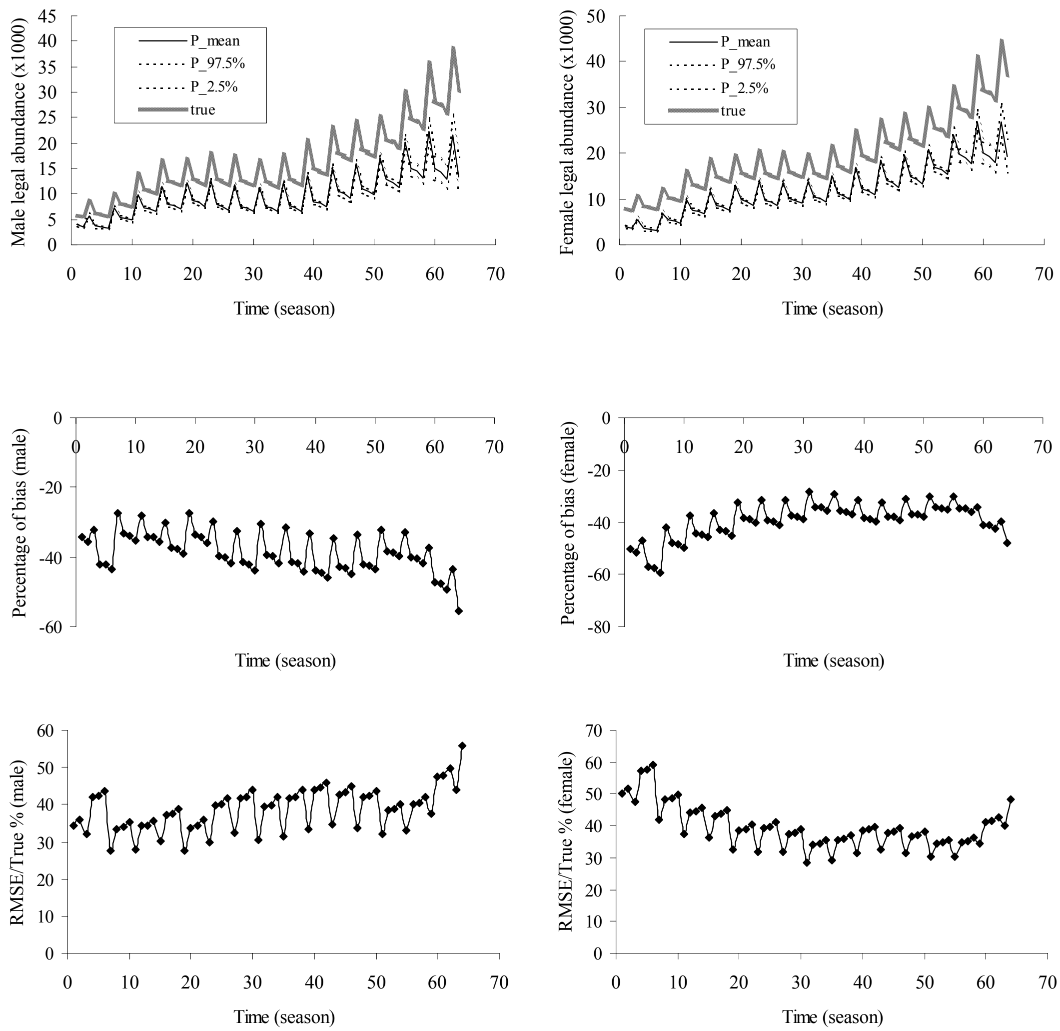


Figure 7d. The estimation of legal stock biomass for simulation Scenario IV.

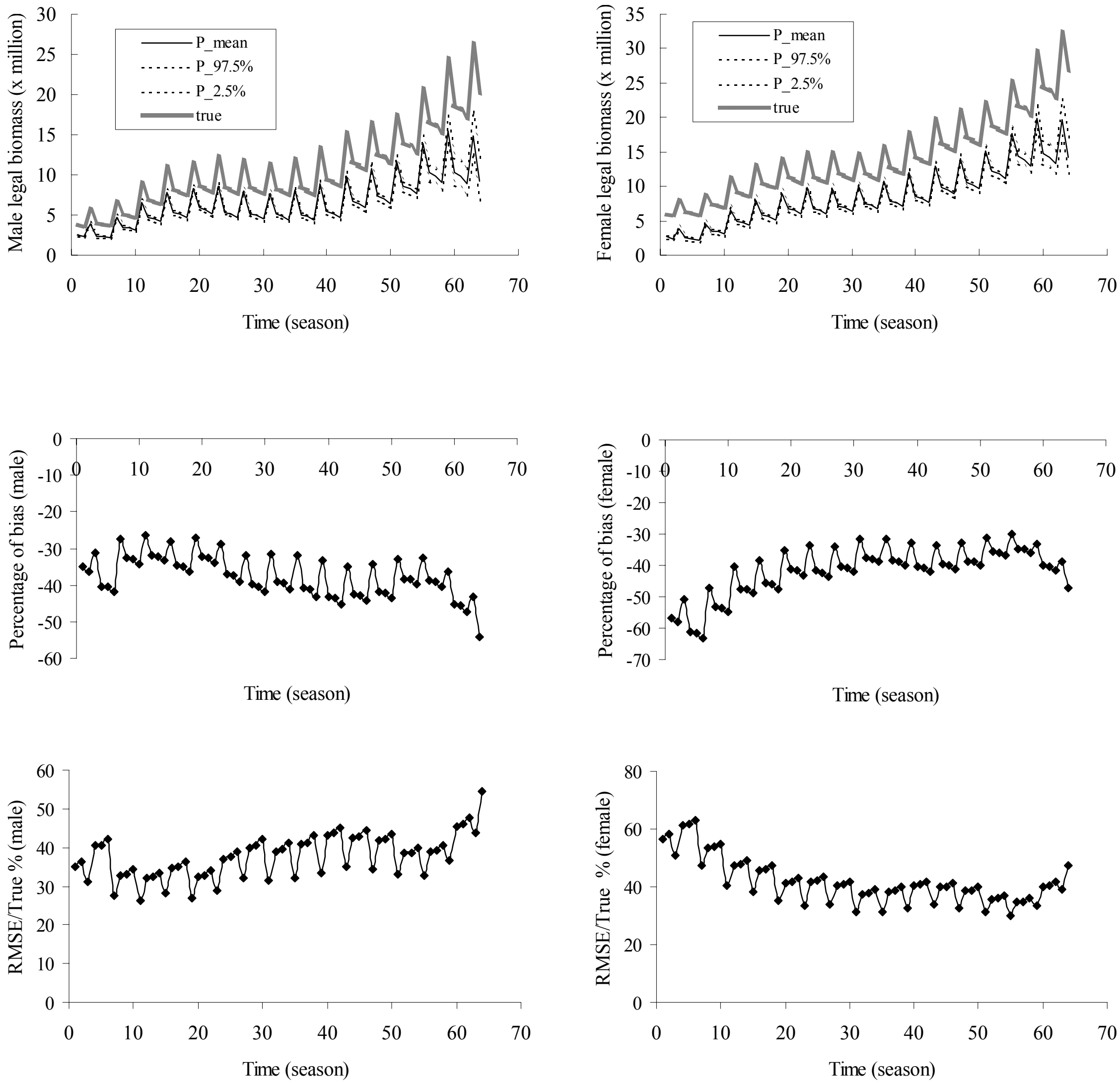


Figure 7e. The predicted and observed selectivity for simulation Scenario IV.

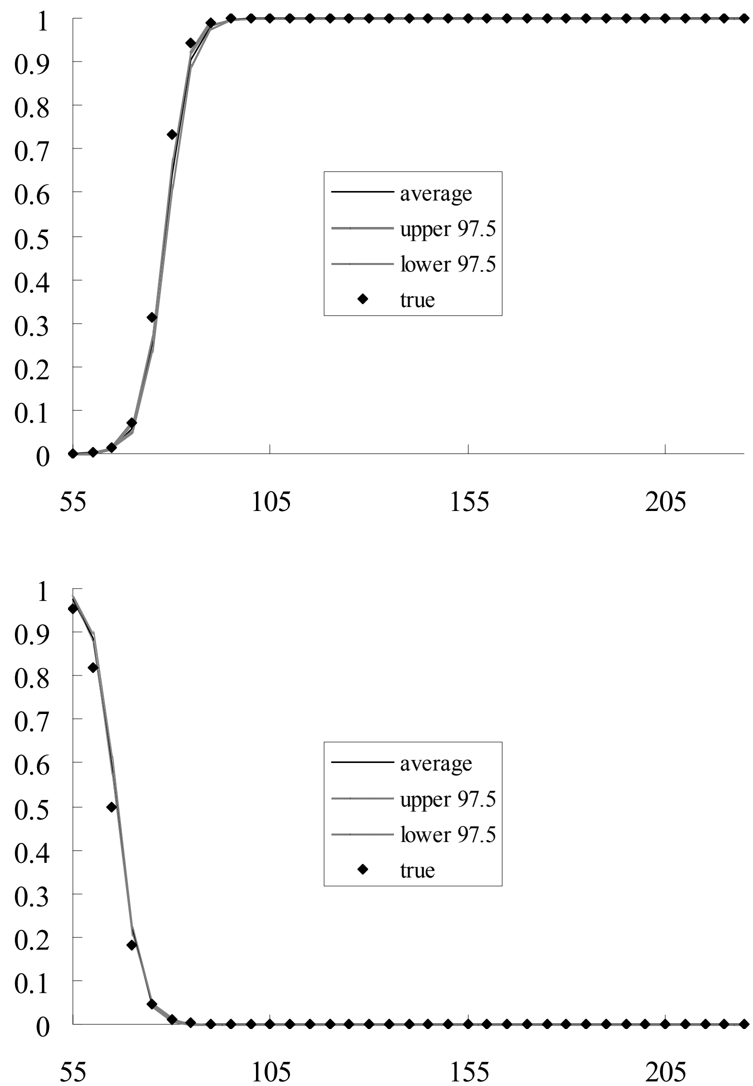


Figure 7f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario IV.

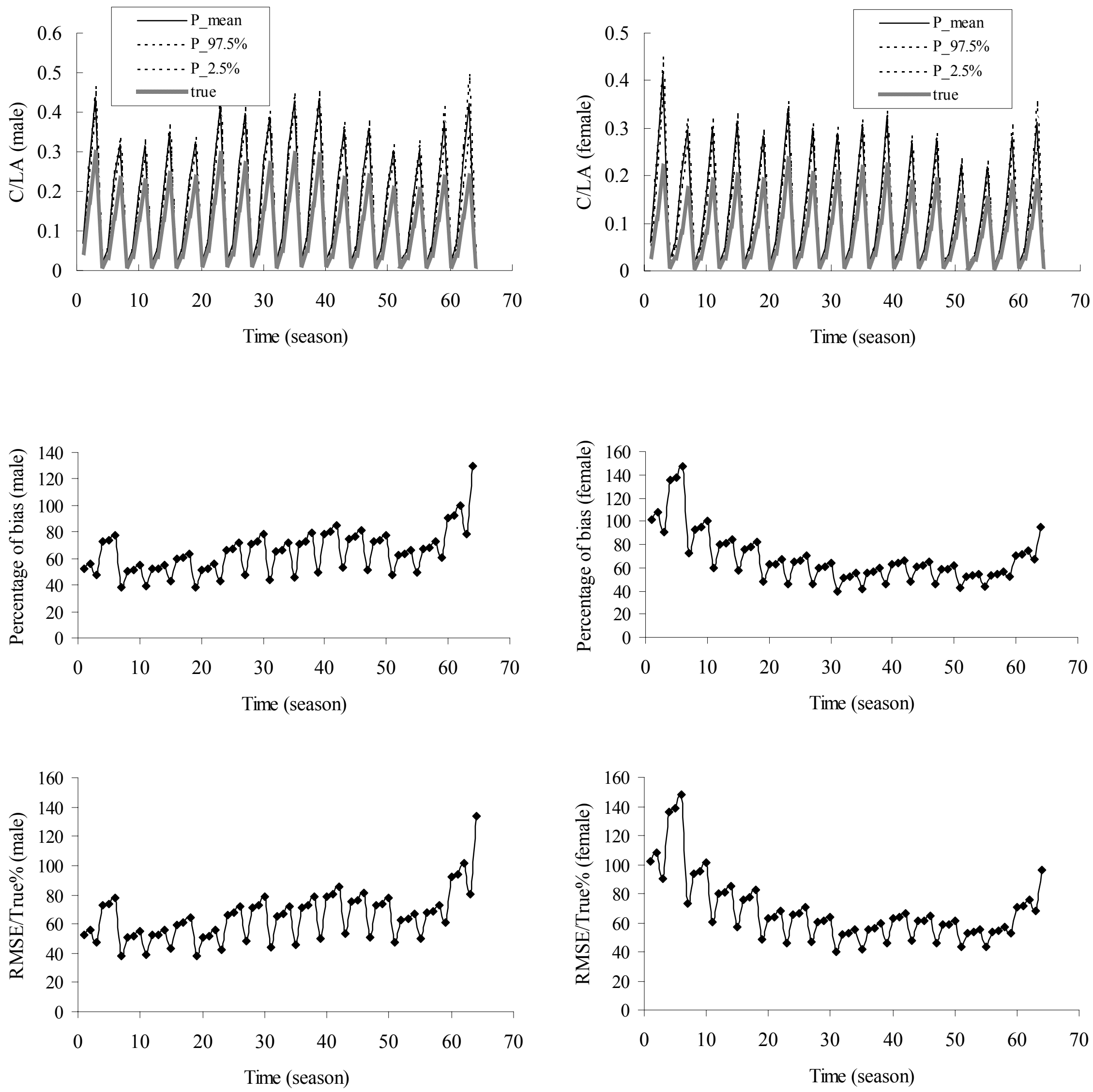


Figure 8a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for simulation Scenario V.

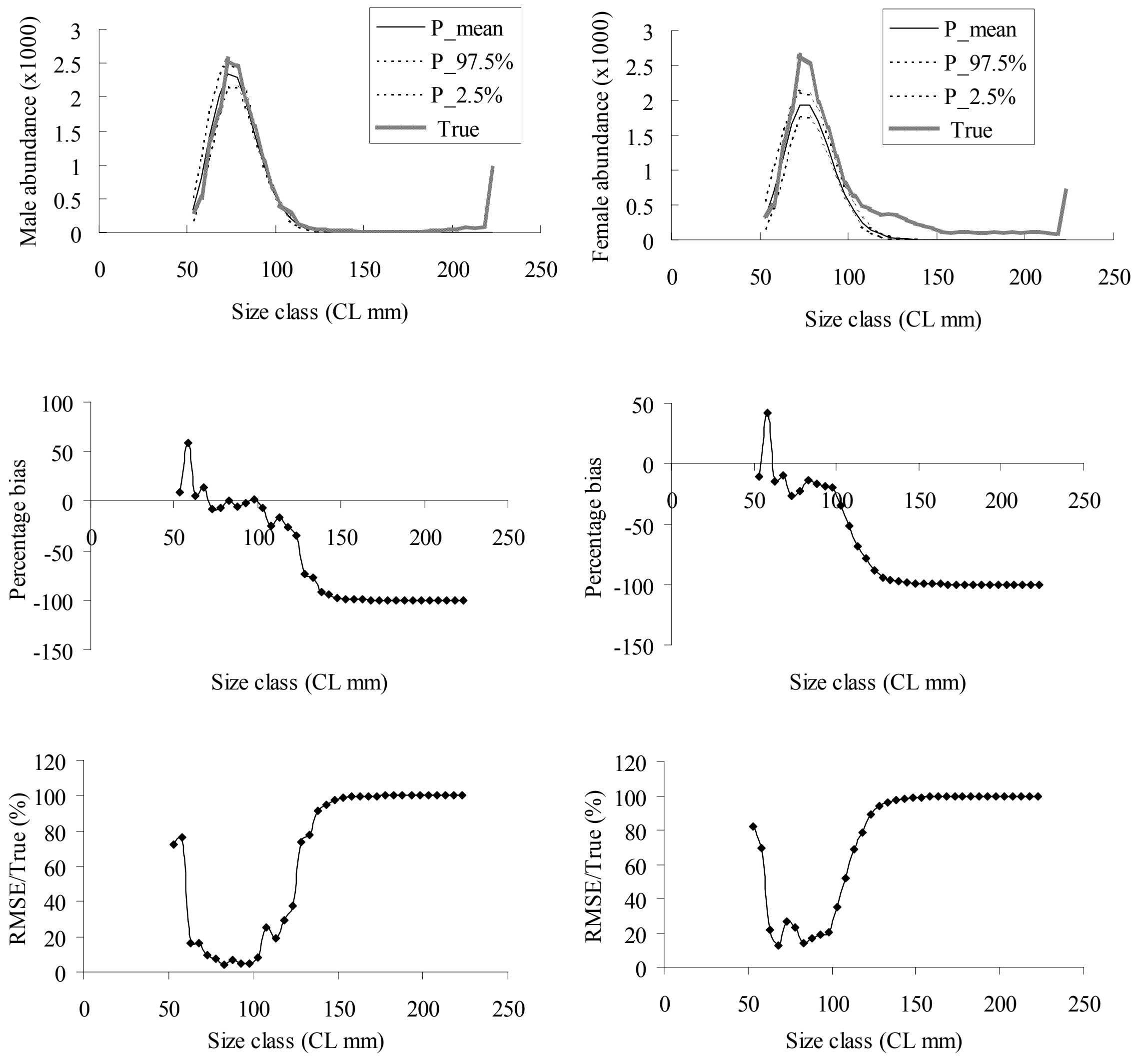


Figure 8b. Recruitment estimation for simulation Scenario V.

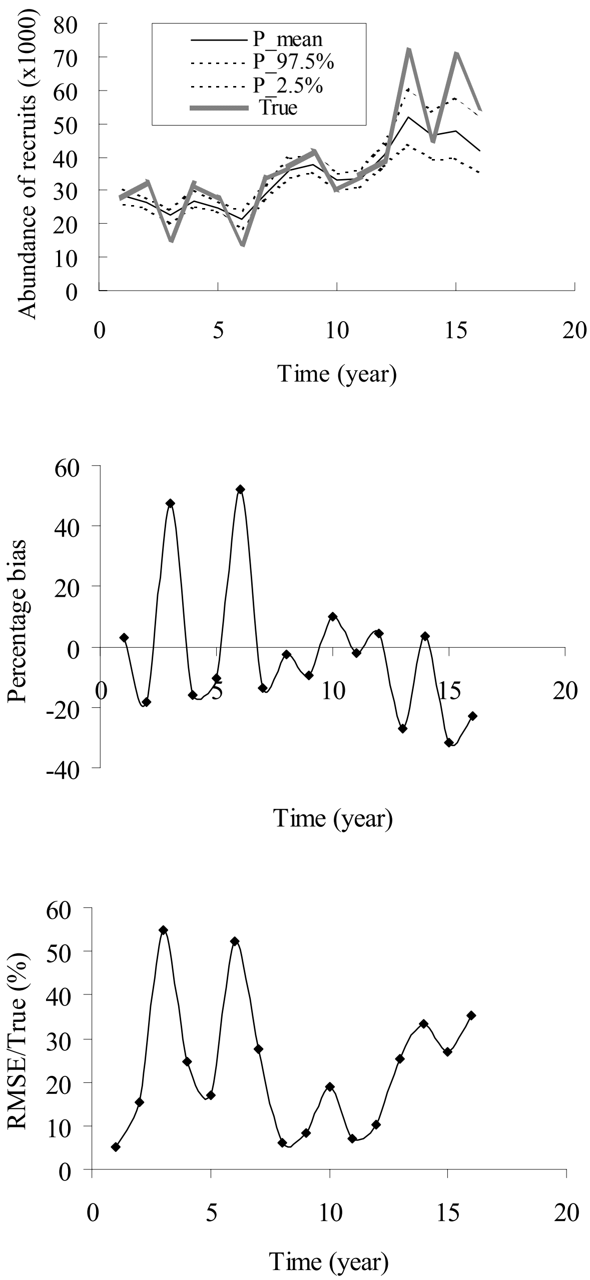
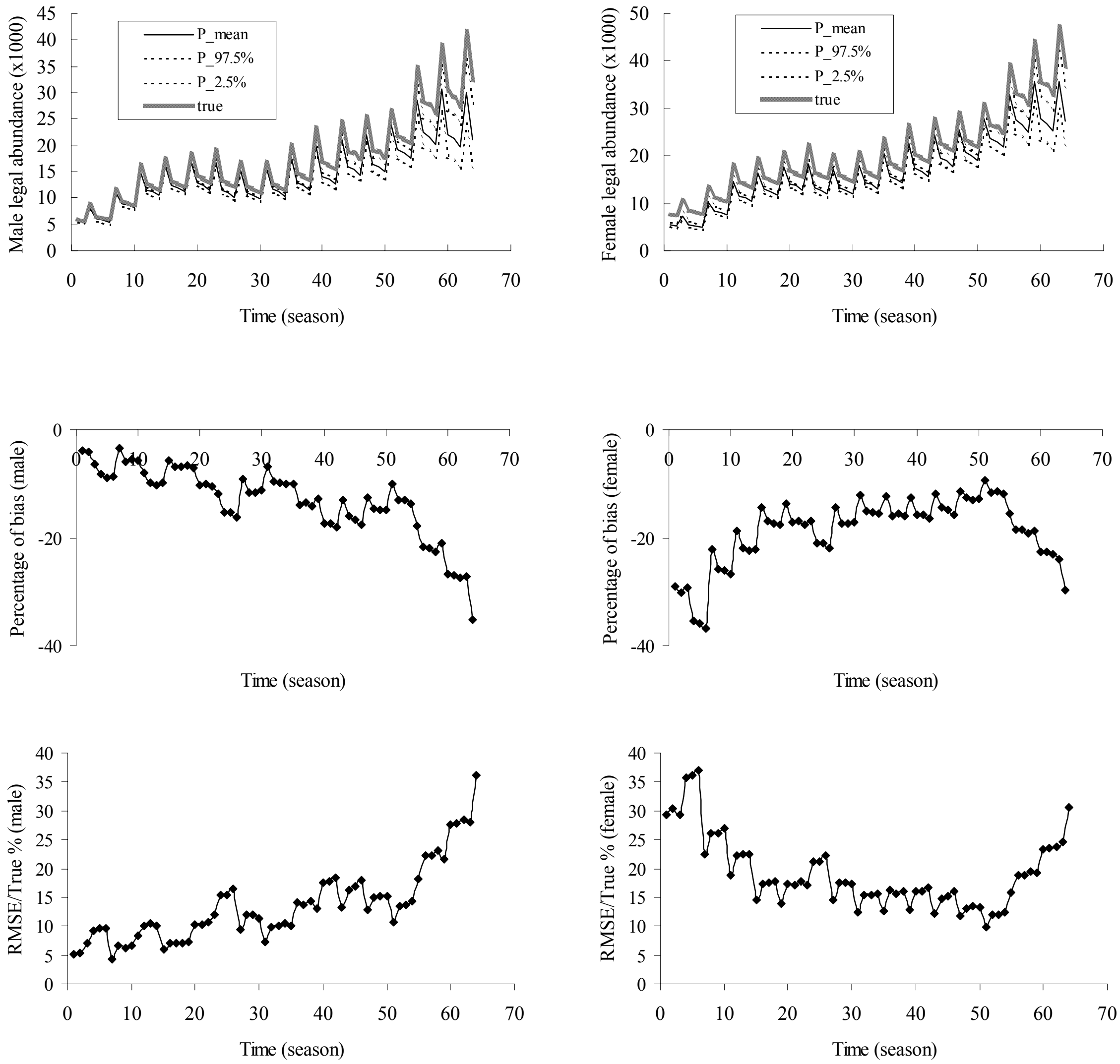


Figure 8c. The estimation of legal stock abundance of lobster for simulation Scenario V.



Male legal abundance (x1000)
P_mean
P_97.5%
P_2.5%
true
Time (season)
Female legal abundance (x1000)
P_mean
P_97.5%
P_2.5%
true
Time (season)
Percentage of bias (male)
Time (season)
Percentage of bias (female)
Time (season)
RMSE/True % (male)
Time (season)
RMSE/True % (female)
Time (season)

Figure 8d. The estimation of legal stock biomass for simulation Scenario V.

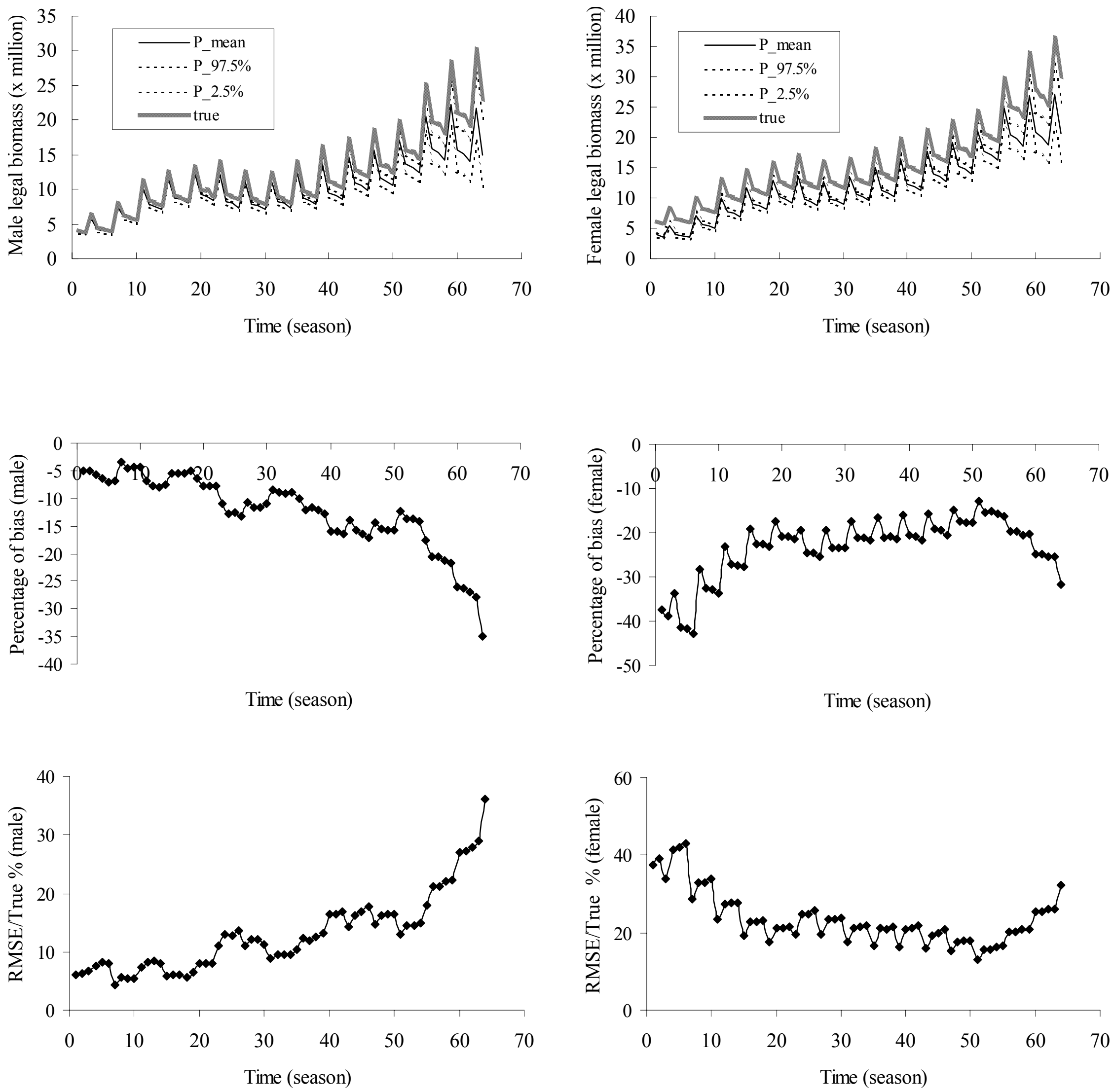
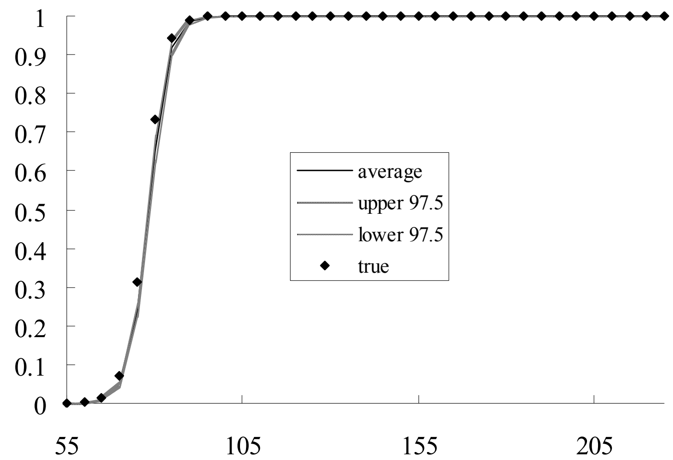


Figure 8e. The predicted and observed selectivity for simulation Scenario V.



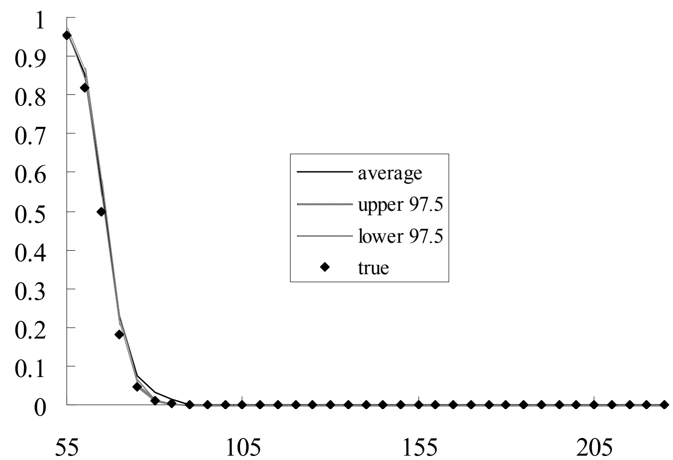


Figure 8f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario V.

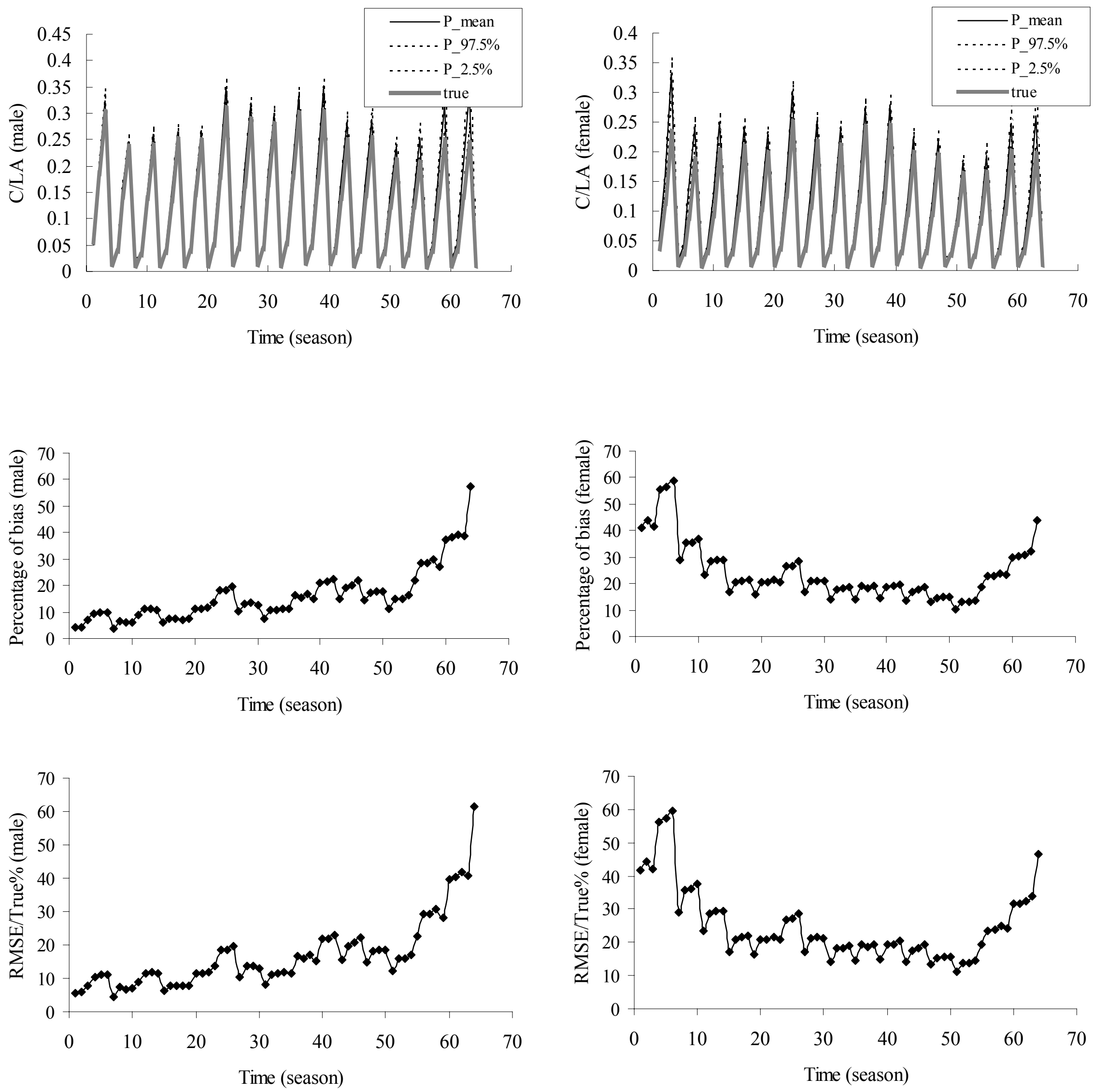


Figure 9a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for simulation Scenario VI.

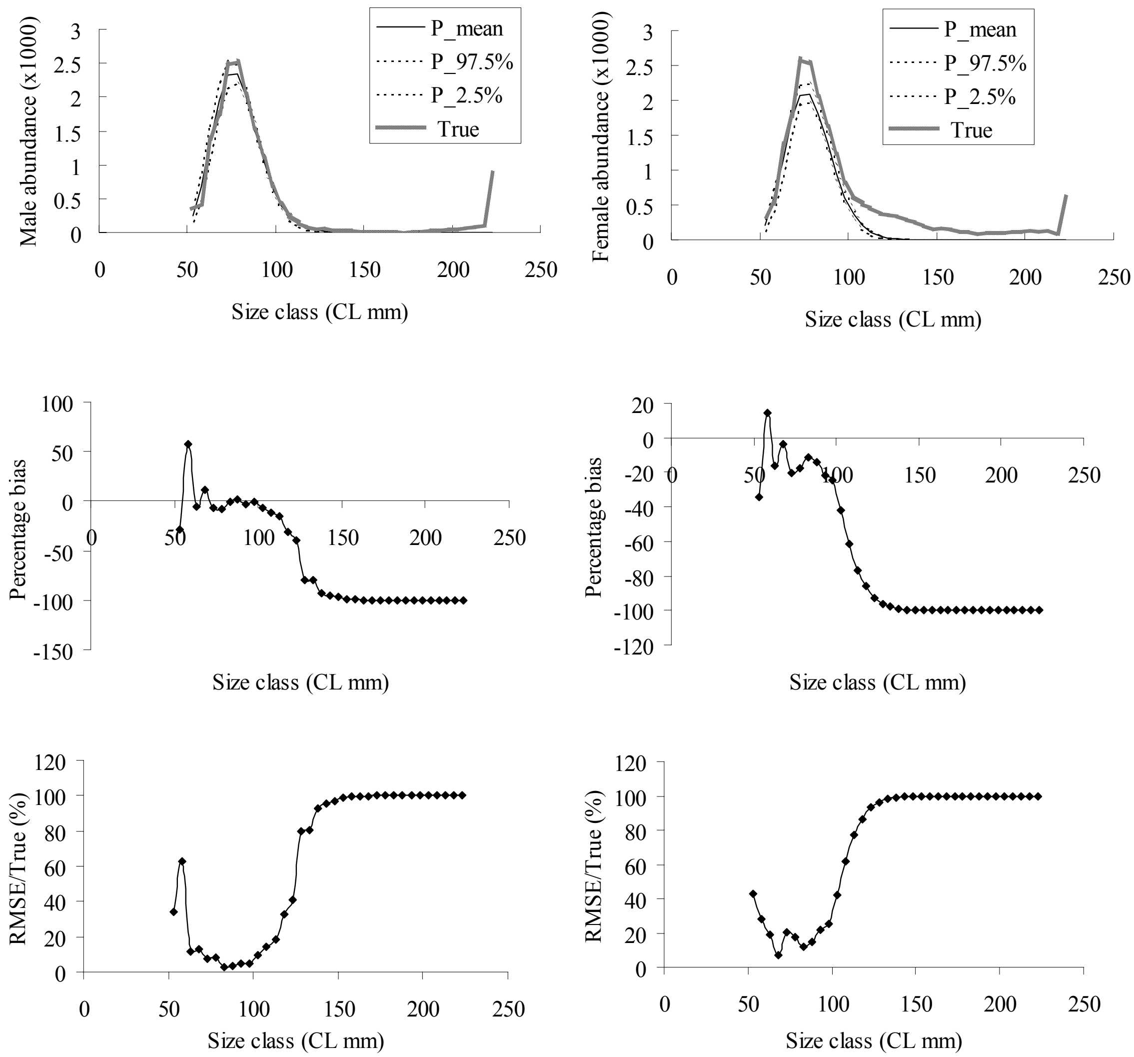


Figure 9b. Recruitment estimation for simulation Scenario VI.

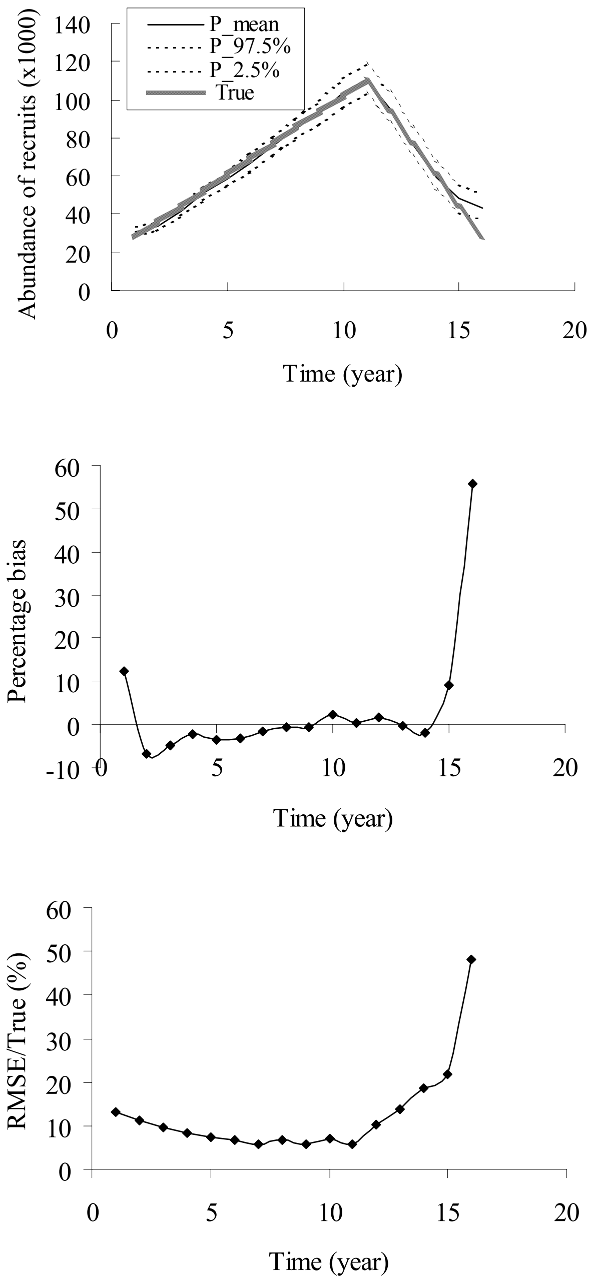


Figure 9c. The estimation of legal stock abundance of lobster for simulation Scenario VI.

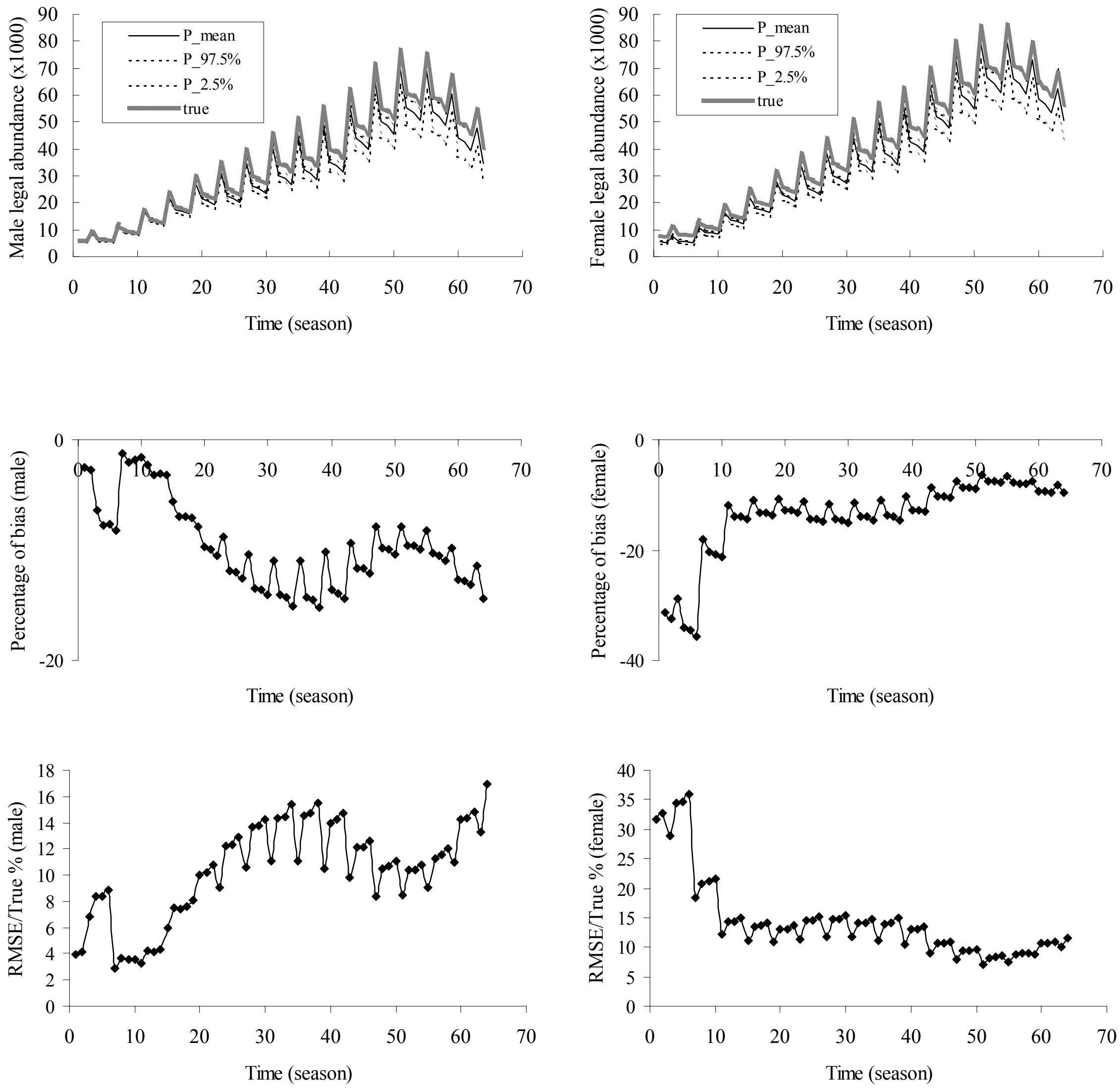


Figure 9d. The estimation of legal stock biomass for simulation Scenario VI.

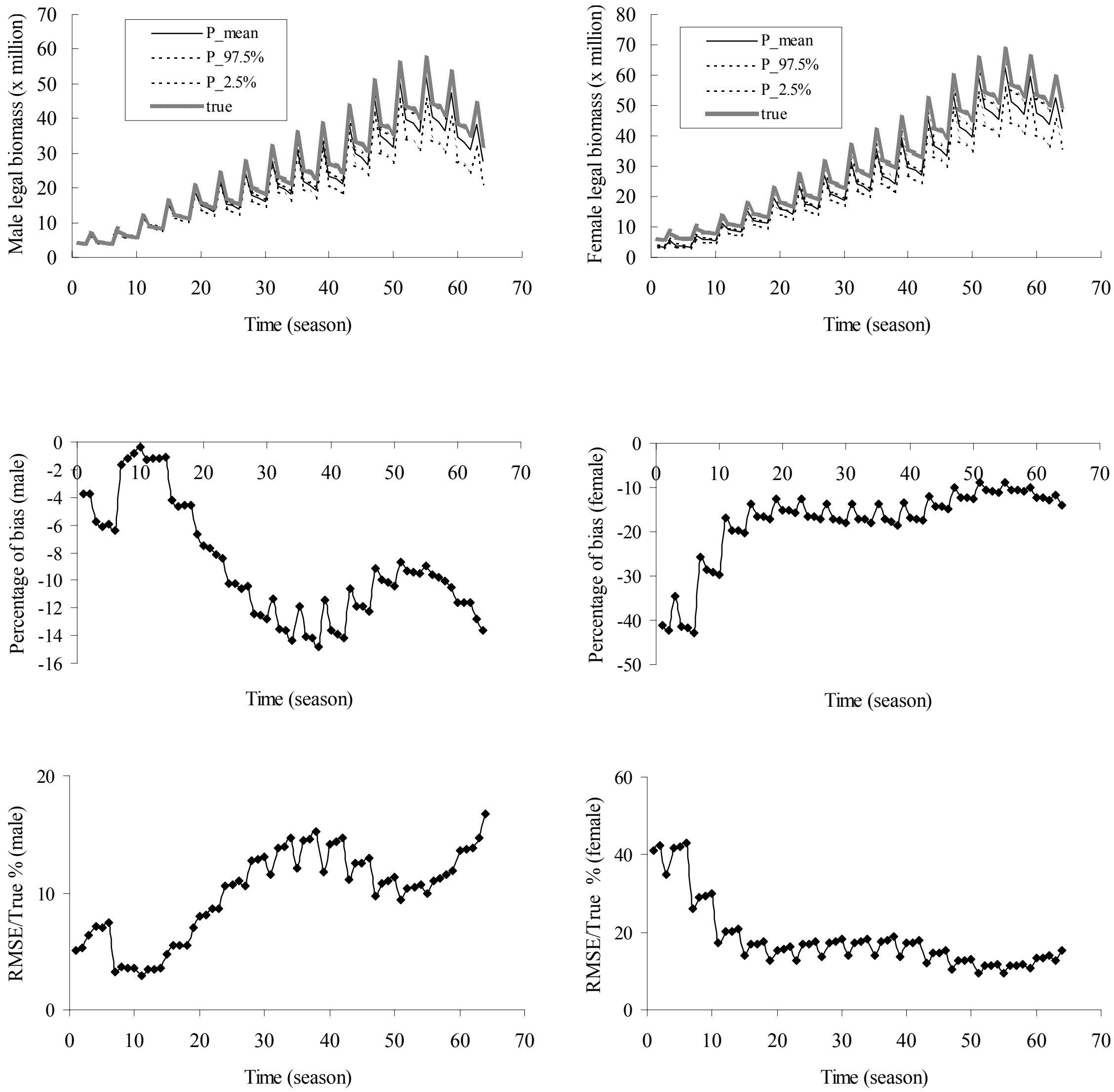


Figure 9e. The predicted and observed selectivity for simulation Scenario VI.

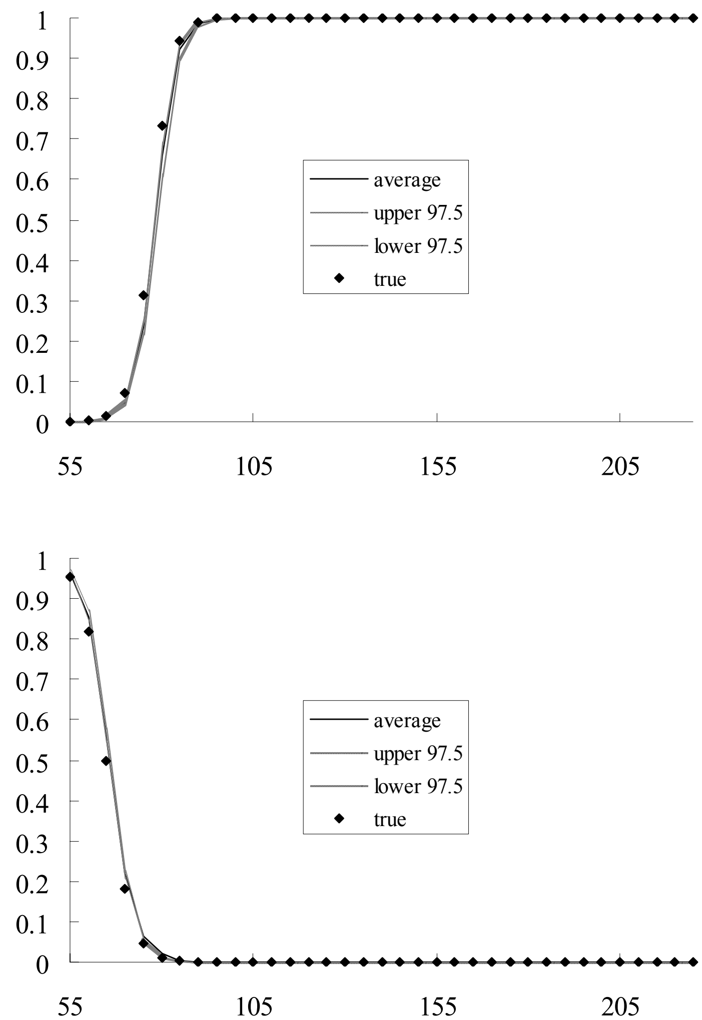


Figure 9f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario VI.

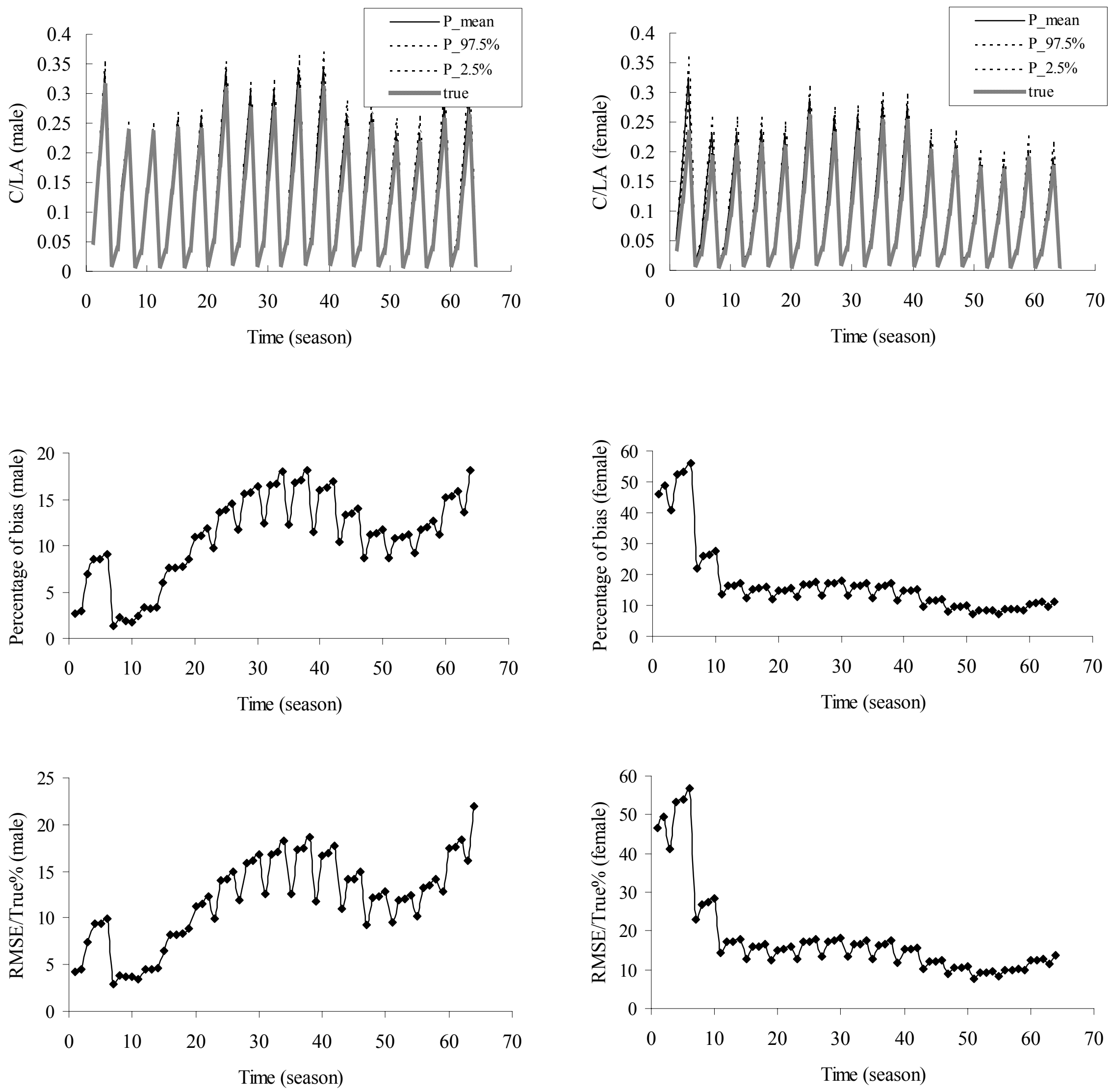


Figure 10a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for simulation Scenario VII.

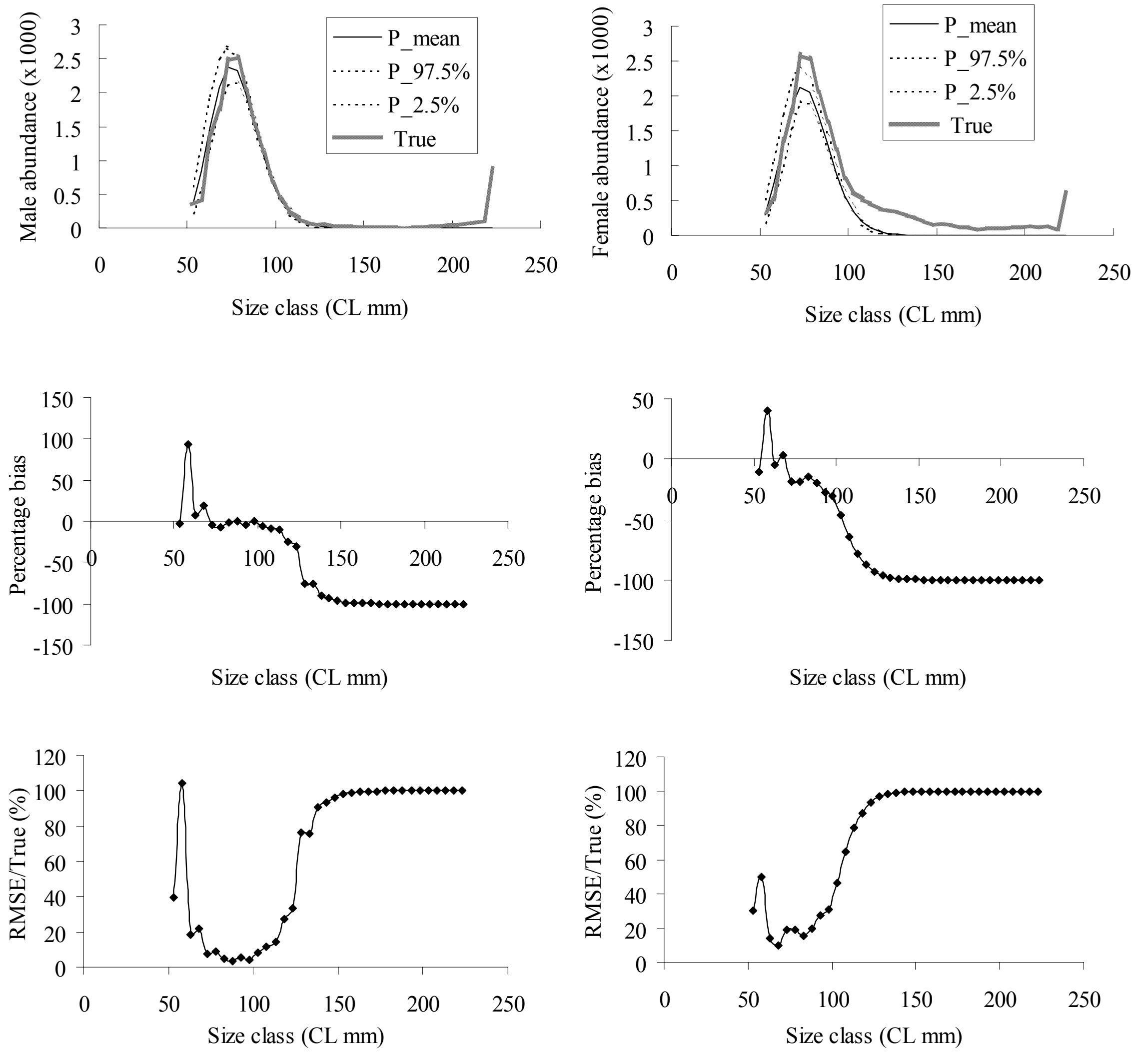


Figure 10b. Recruitment estimation for simulation Scenario VII.

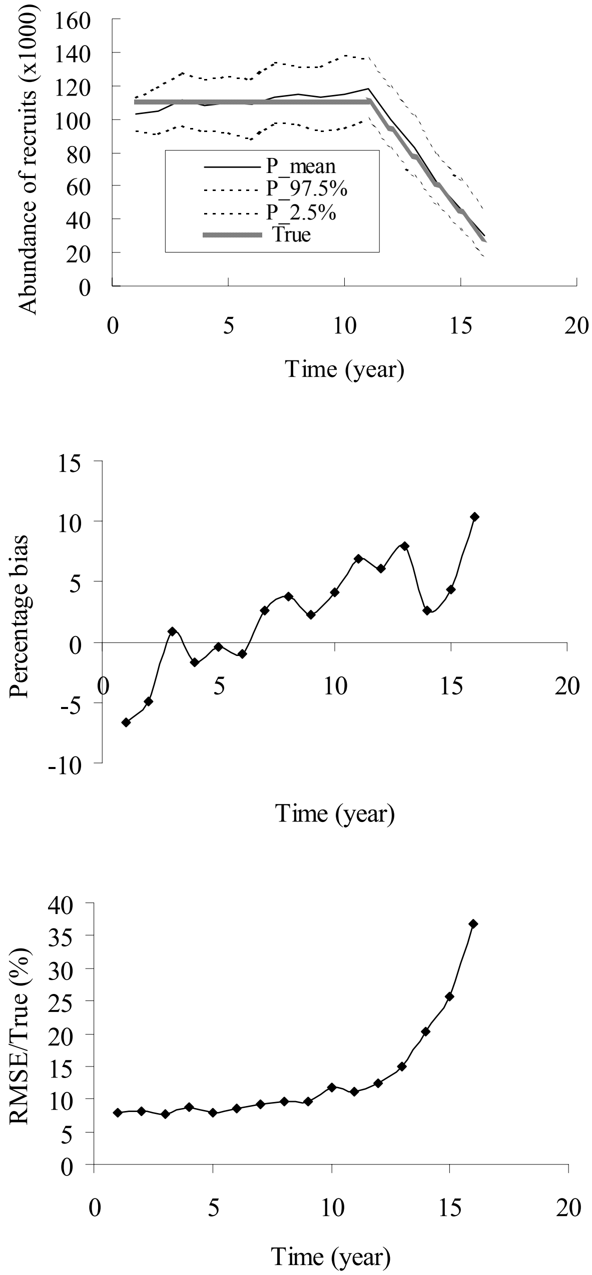


Figure 10c. The estimation of legal stock abundance of lobster for simulation Scenario VII.

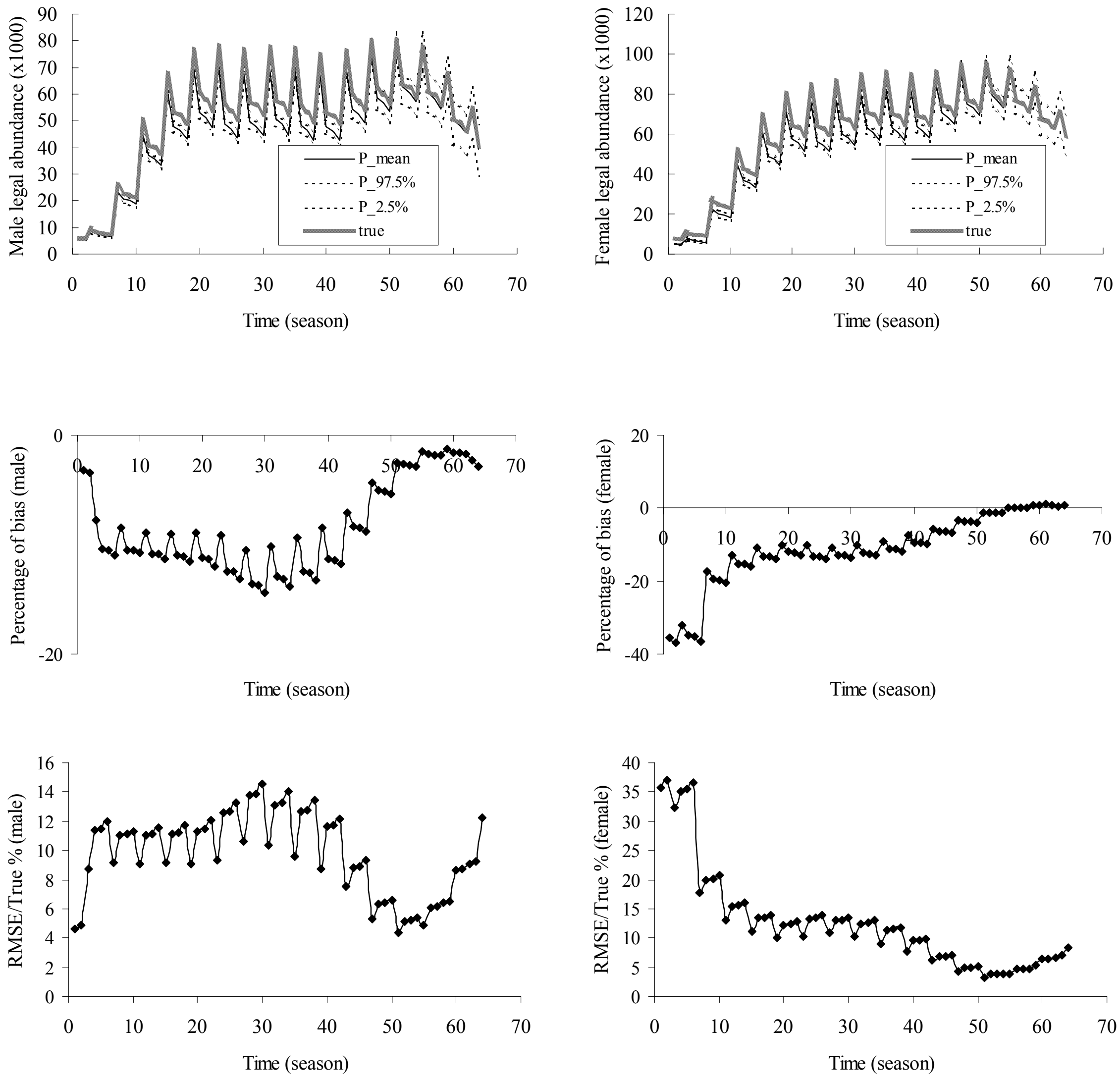


Figure 10d. The estimation of legal stock biomass for simulation Scenario VII.

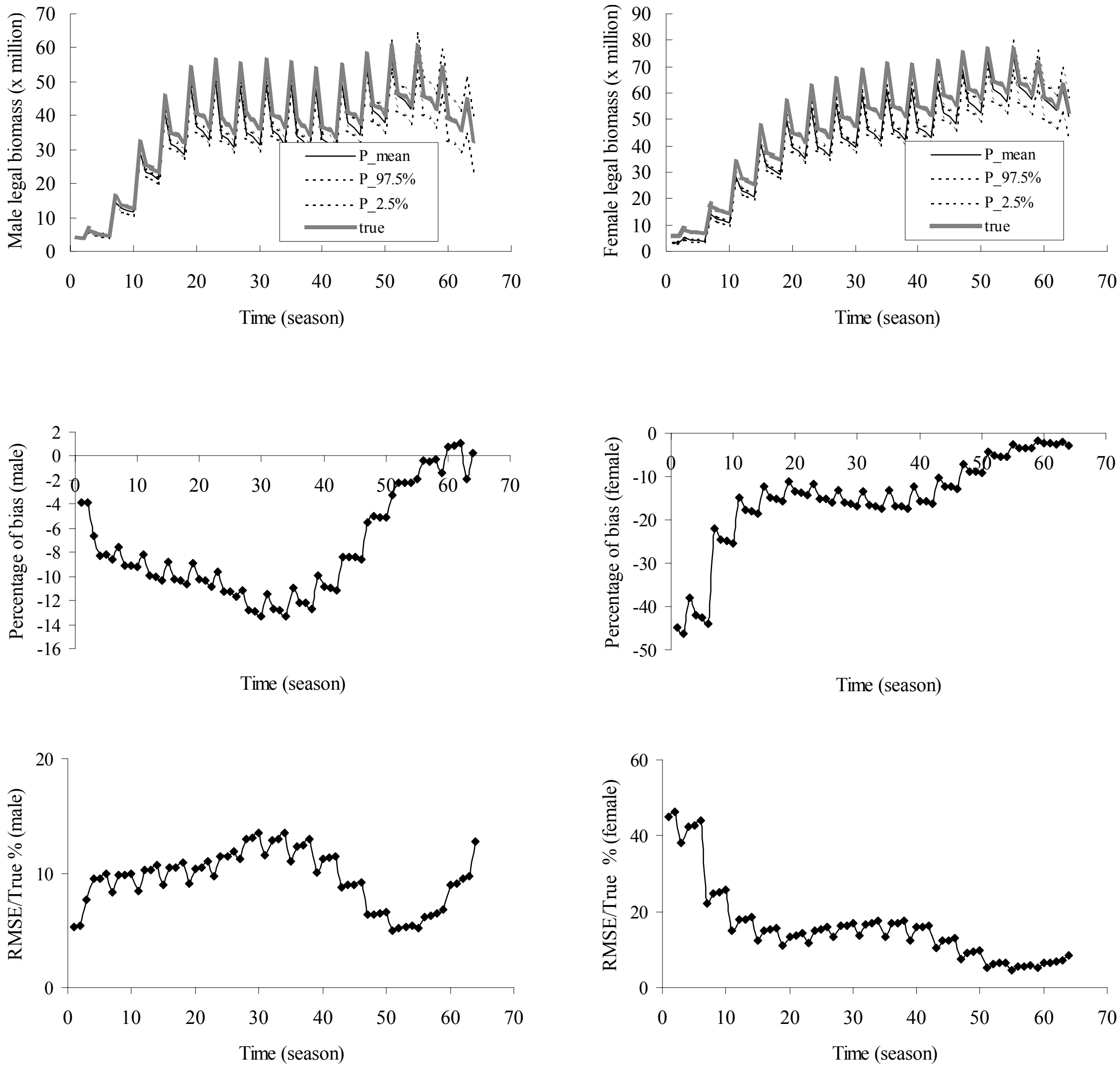


Figure 10e. The predicted and observed selectivity for simulation Scenario VII.

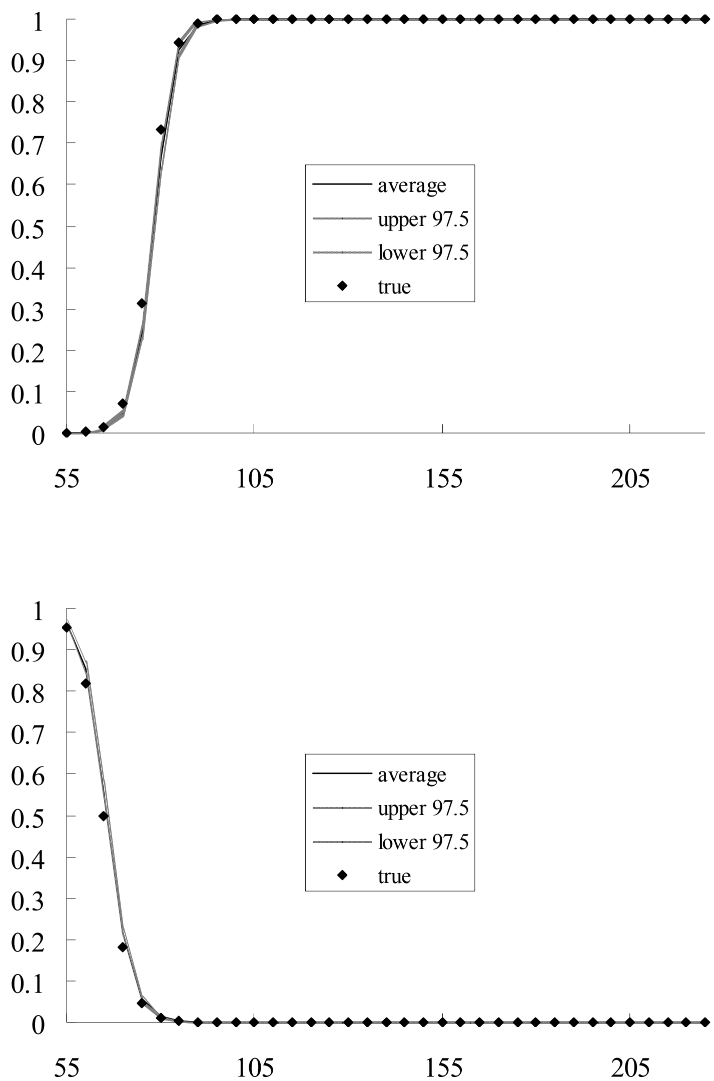


Figure 10f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario VII.

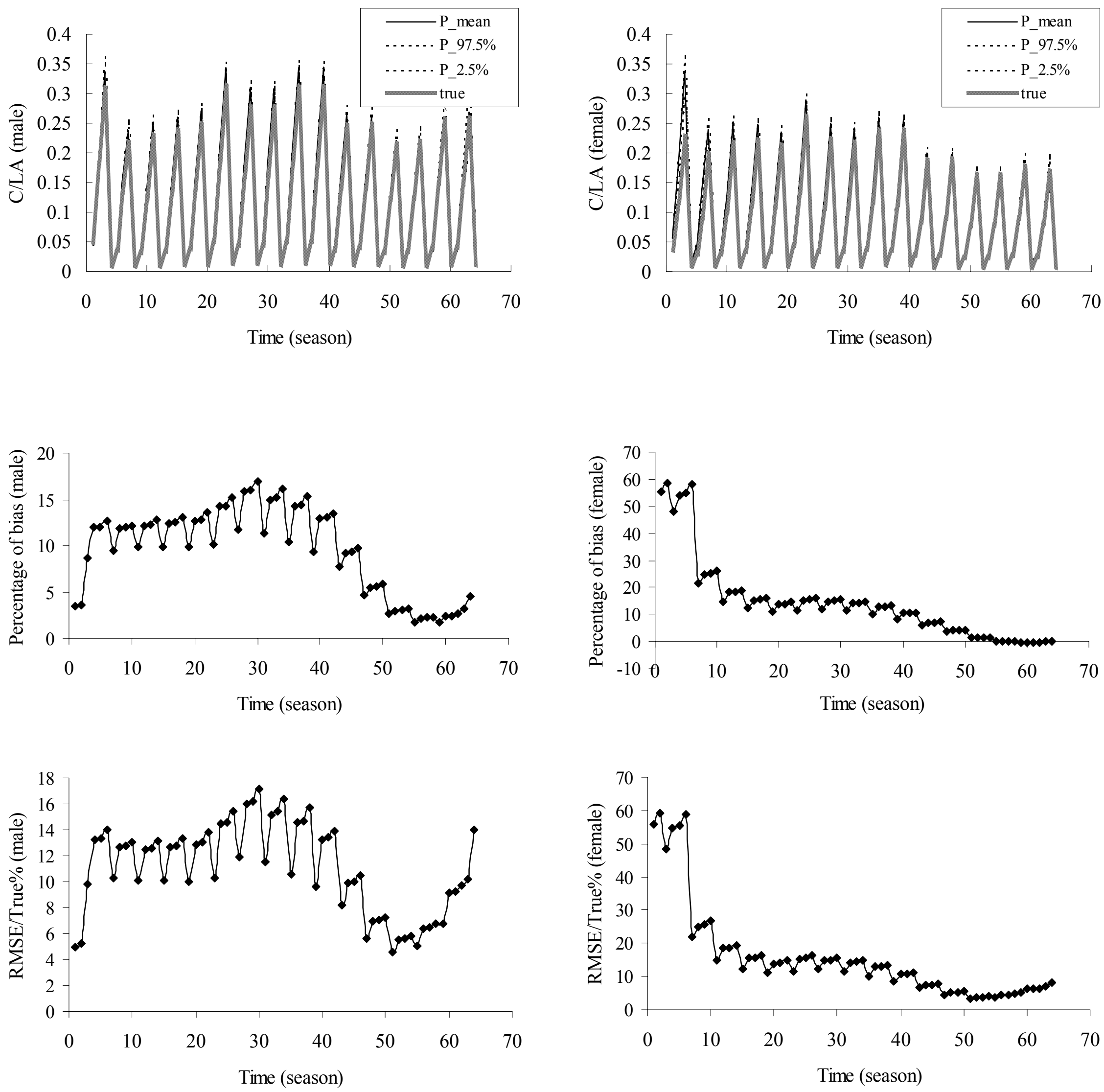


Figure 11a. Estimation of the size-frequency distribution at the beginning of the first season in the assessment for simulation Scenario VIII.

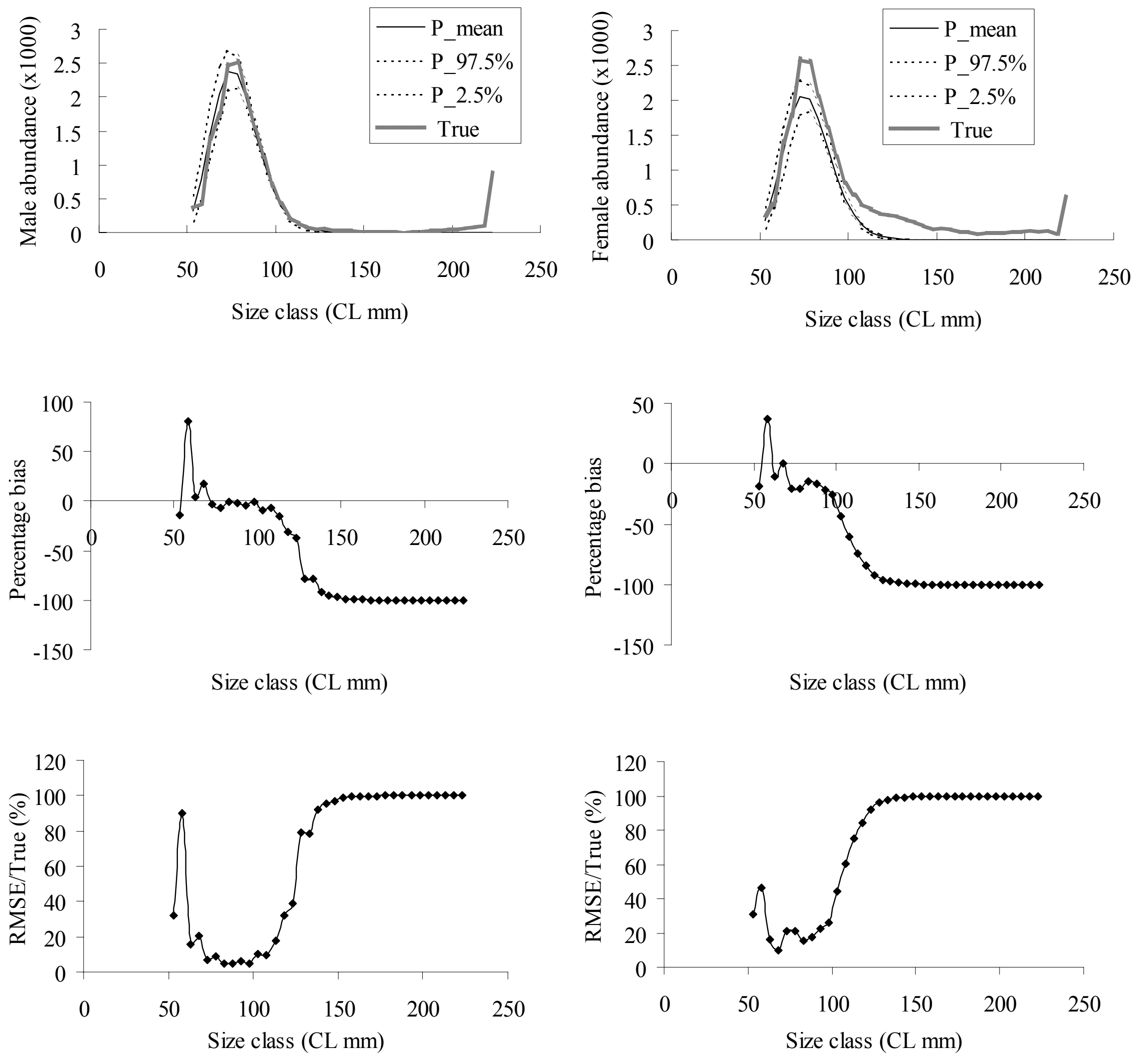
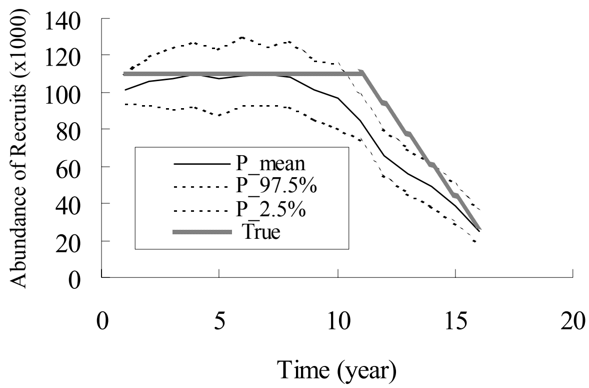


Figure 11b. Recruitment estimation for simulation Scenario VIII.



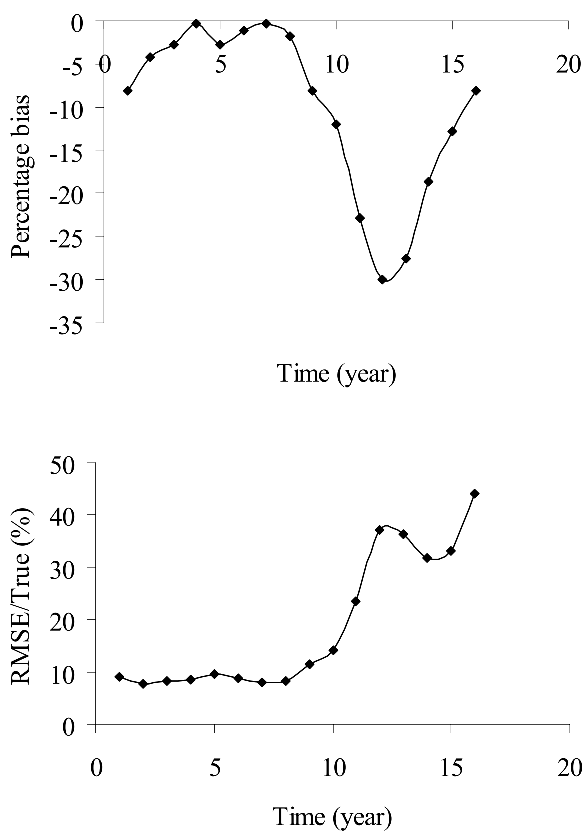


Figure 11c. The estimation of legal stock abundance of lobster for simulation Scenario VIII.

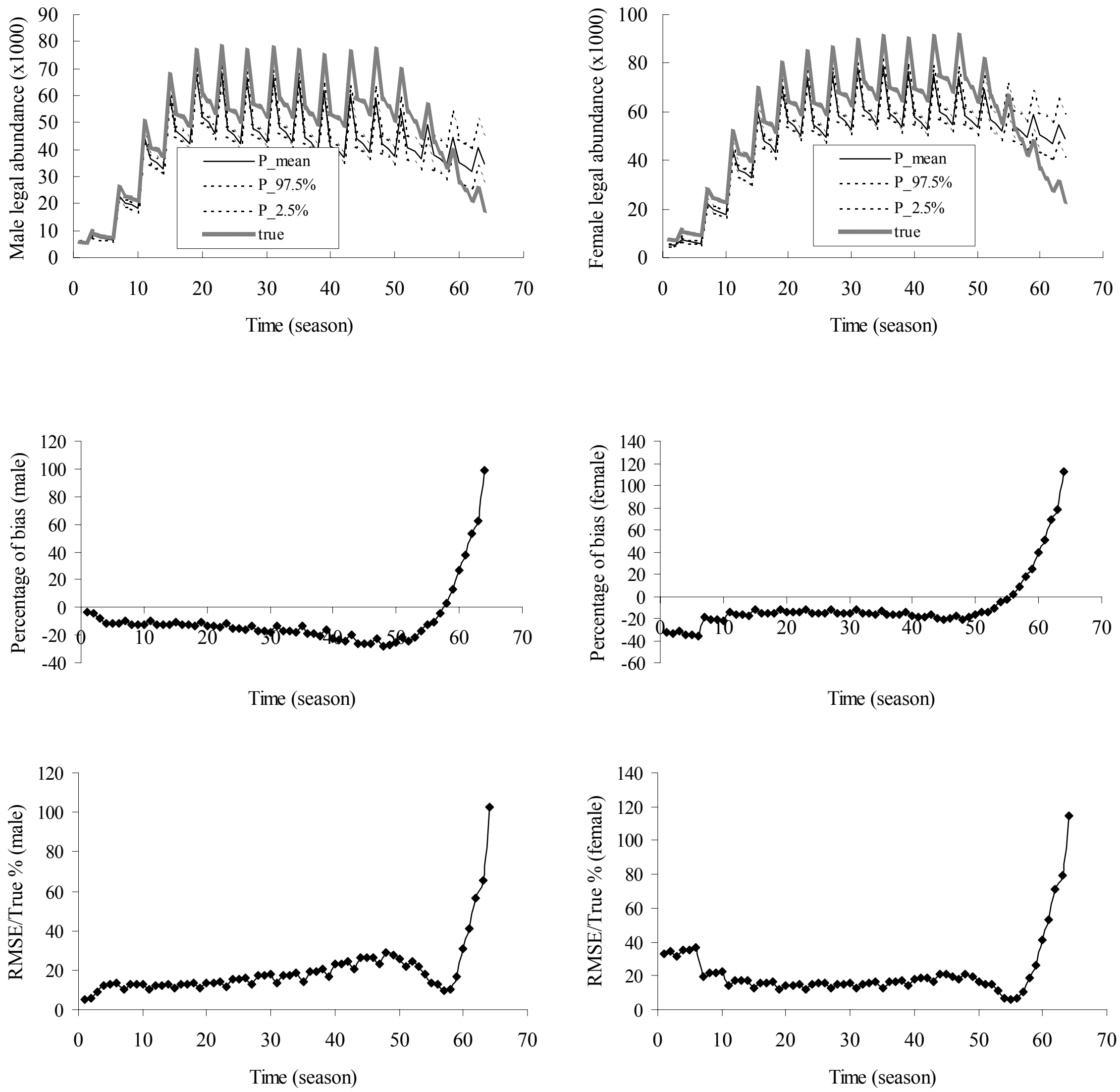

Male legal abundance (x1000)
Time (season)
P_mean
P_97.5%
P_2.5%
true
Female legal abundance (x1000)
Time (season)
P_mean
P_97.5%
P_2.5%
true
Percentage of bias (male)
Time (season)
Percentage of bias (female)
Time (season)
RMSE/True % (male)
Time (season)
RMSE/True % (female)
Time (season)

Figure 11d. The estimation of legal stock biomass for simulation Scenario VIII.

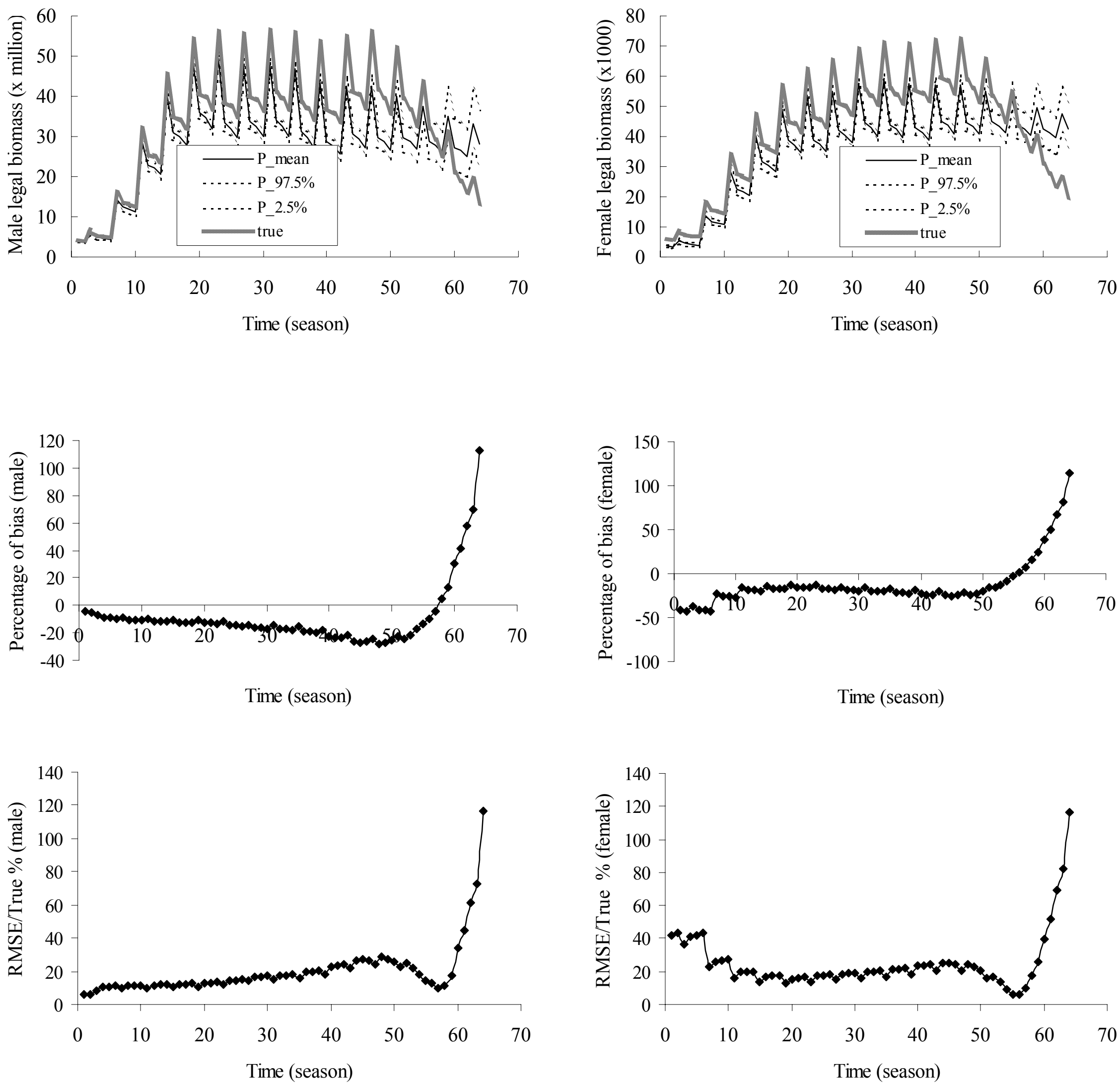
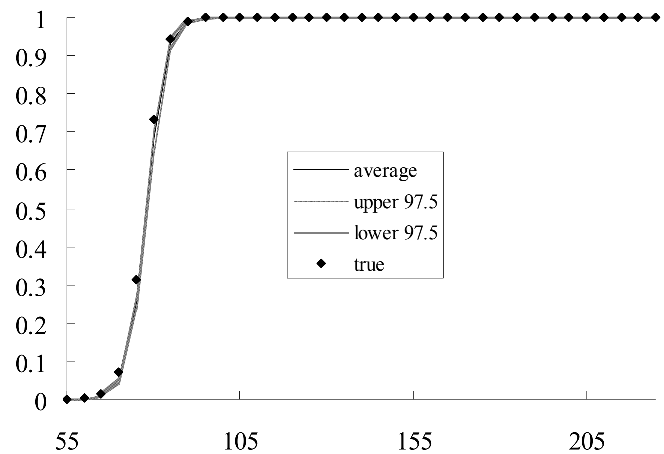


Figure 11e. The predicted and observed selectivity for simulation Scenario VIII.



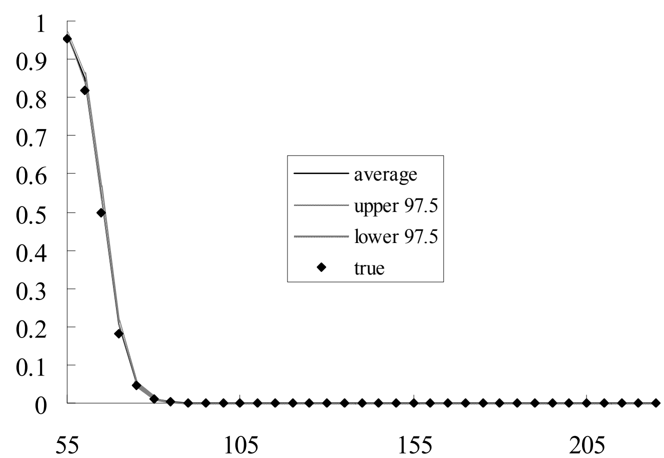


Figure 11f. The estimation of exploitation rate (catch/legal abundance) for simulation Scenario VIII.

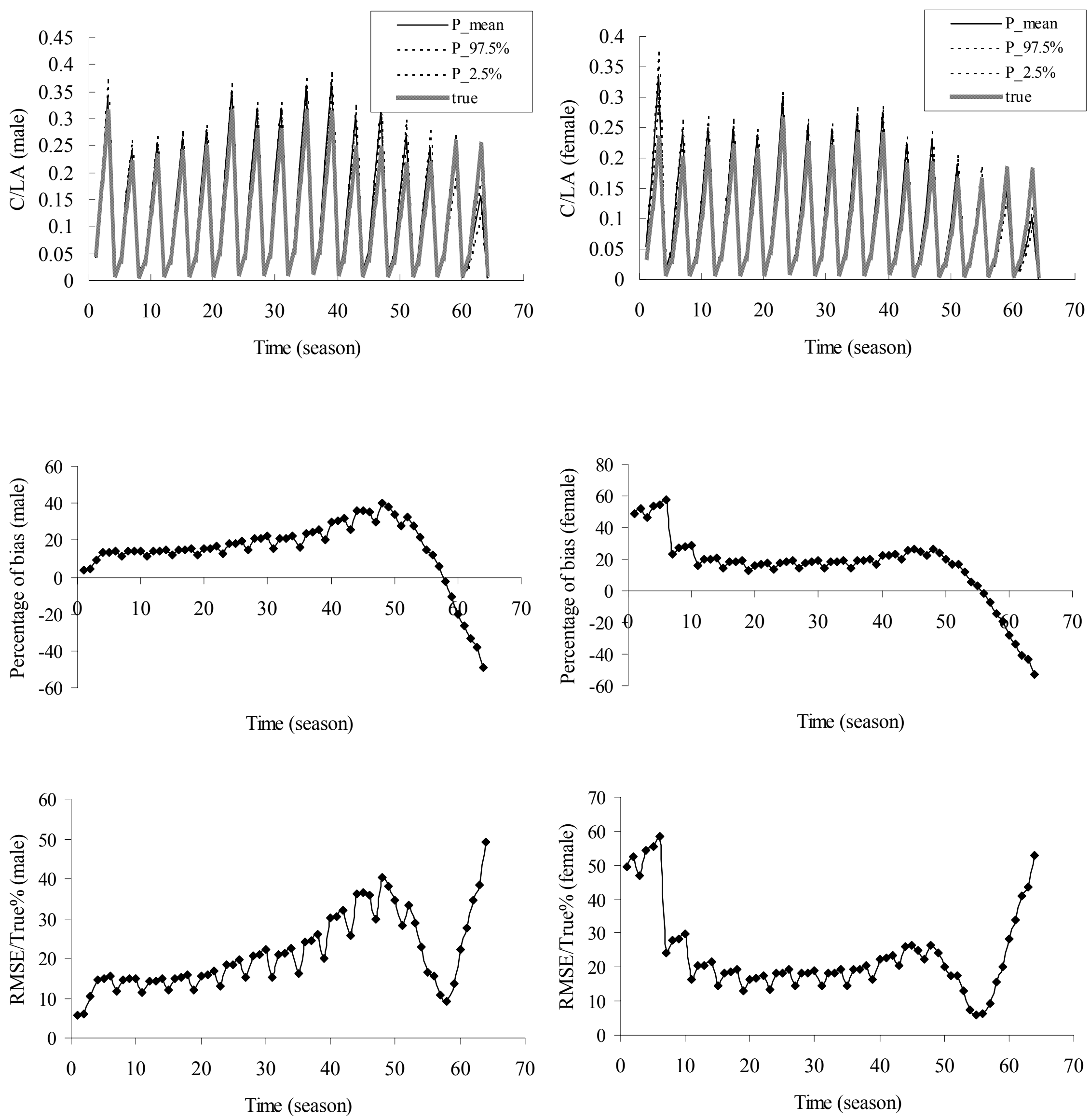


Figure 12. Estimated size-specific abundance in the beginning of the winter 1981 for females and males. CL = carapace length (mm)

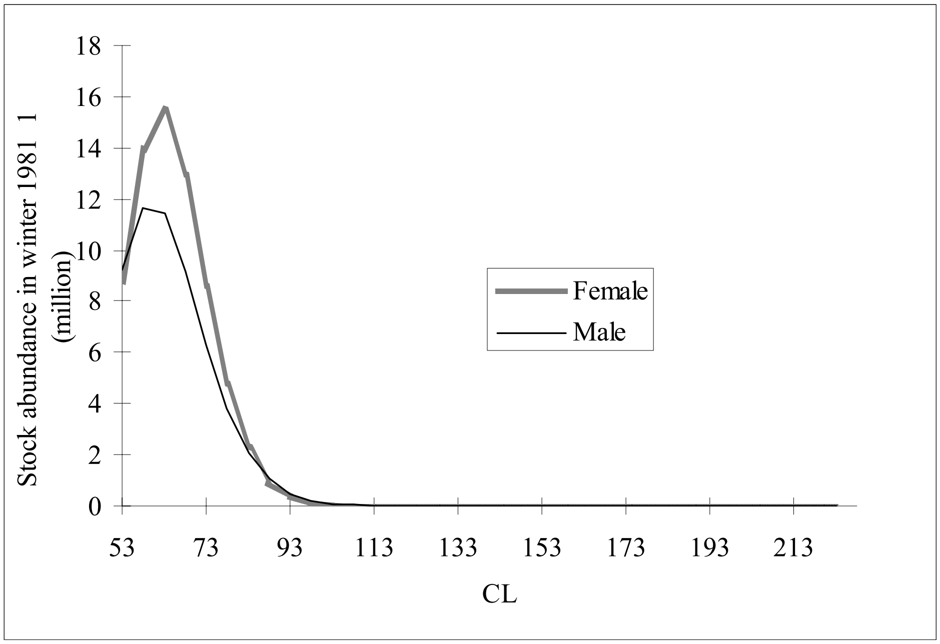


Figure 13. Estimated legal abundance for females and males. Time is season starting from winter 1981, spring 1981, ..., and the last season we are asked to include is fall 1999 (i.e., Oct. - Dec. 1999).

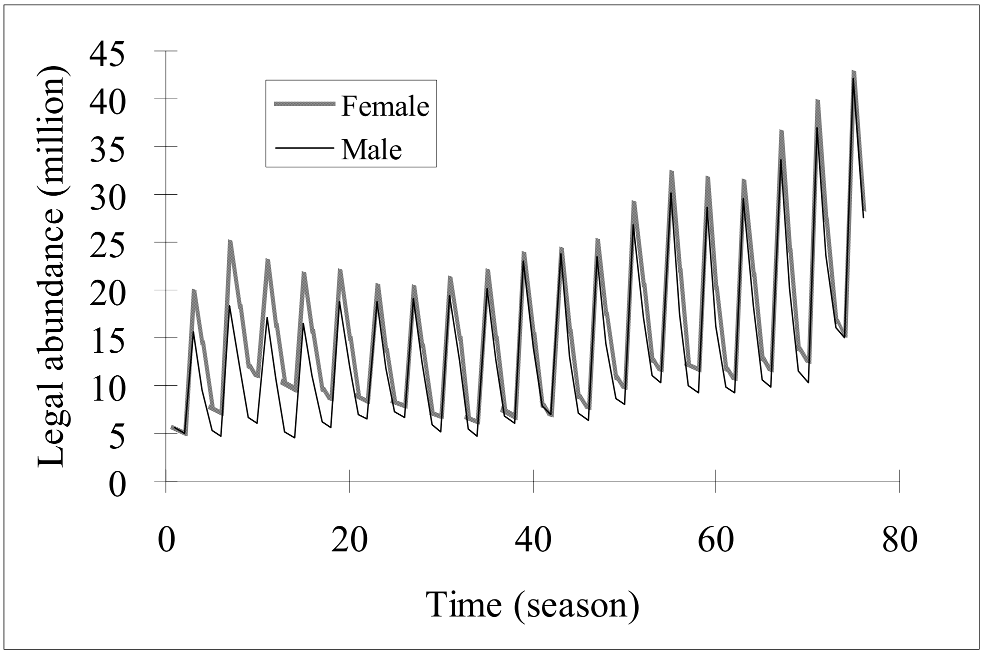


Figure 14. Estimated legal biomass for females and males. Time is season starting from winter 1981, spring 1981, ..., and the last season we are asked to include is fall 1999 (i.e., Oct. - Dec. 1999).

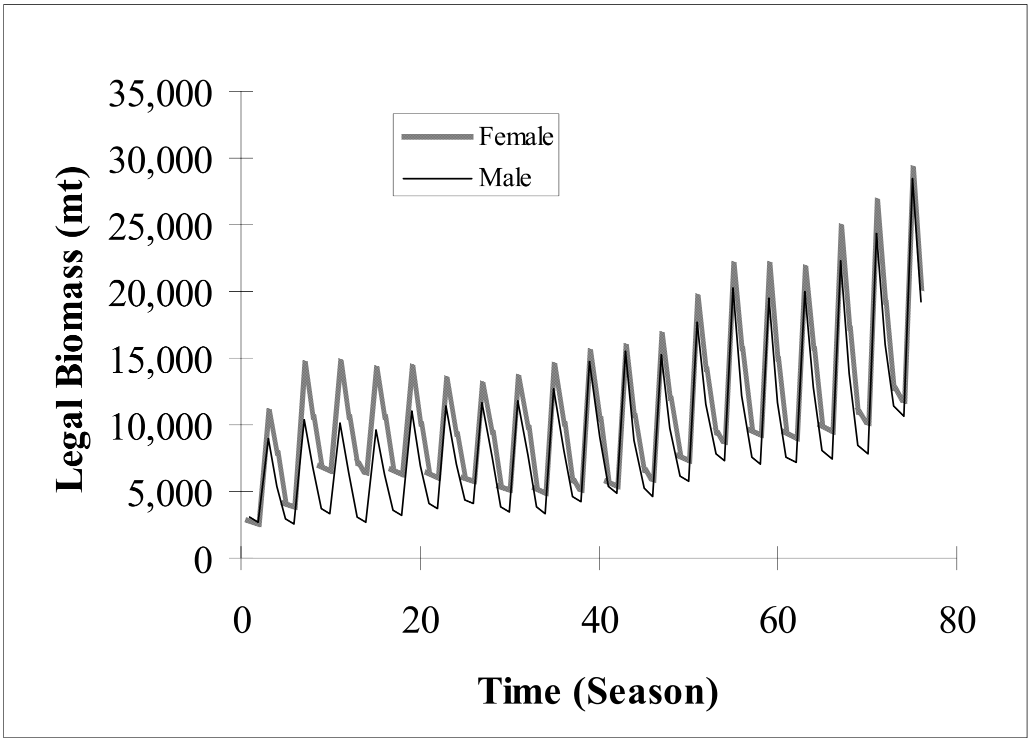


Figure 15. Estimated recruitment (in number, see text for recruitment definition) from 1981 to 1999.

Figure 16. Seasonal variations in exploitation rate for males and females. Time is season starting from winter 1981, spring 1981, ... and the last season we are asked to include is fall 1999 (i.e., Oct. - Dec. 1999).

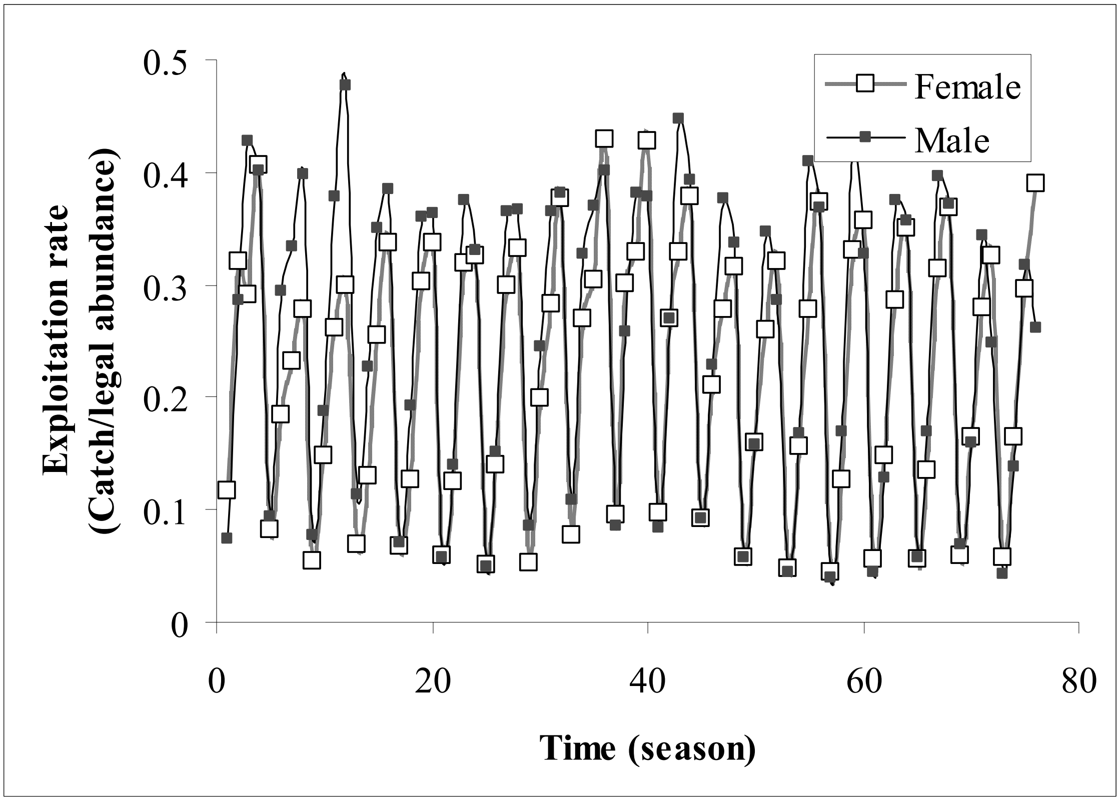


Figure 17. Observed and predicted abundance indices of the NMFS spring and fall surveys for females and males. A robust estimator (Chen et al. 2000) was used in the parameter estimation.

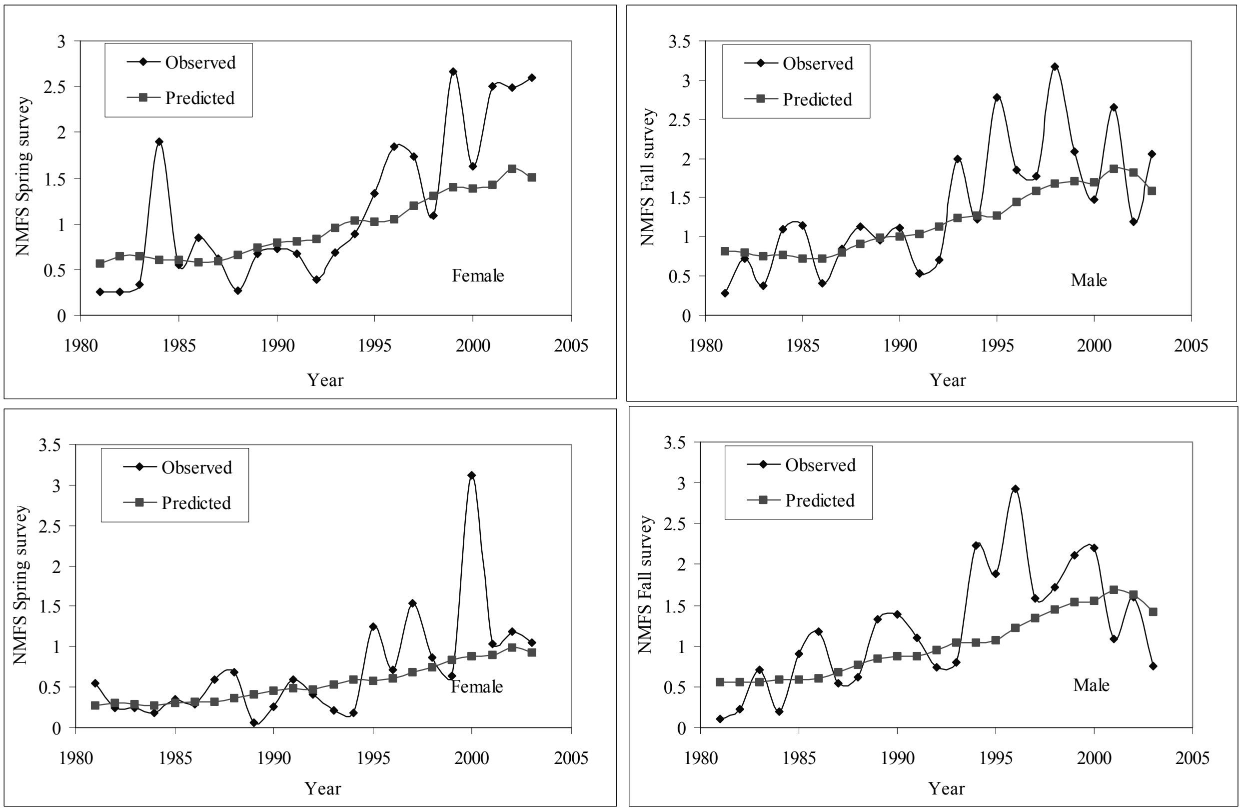


Figure 18. Observed and predicted abundance indices of the Maine DMR inshore spring and fall surveys for females and males. A robust estimator (Chen et al. 2000) was used in the parameter estimation.

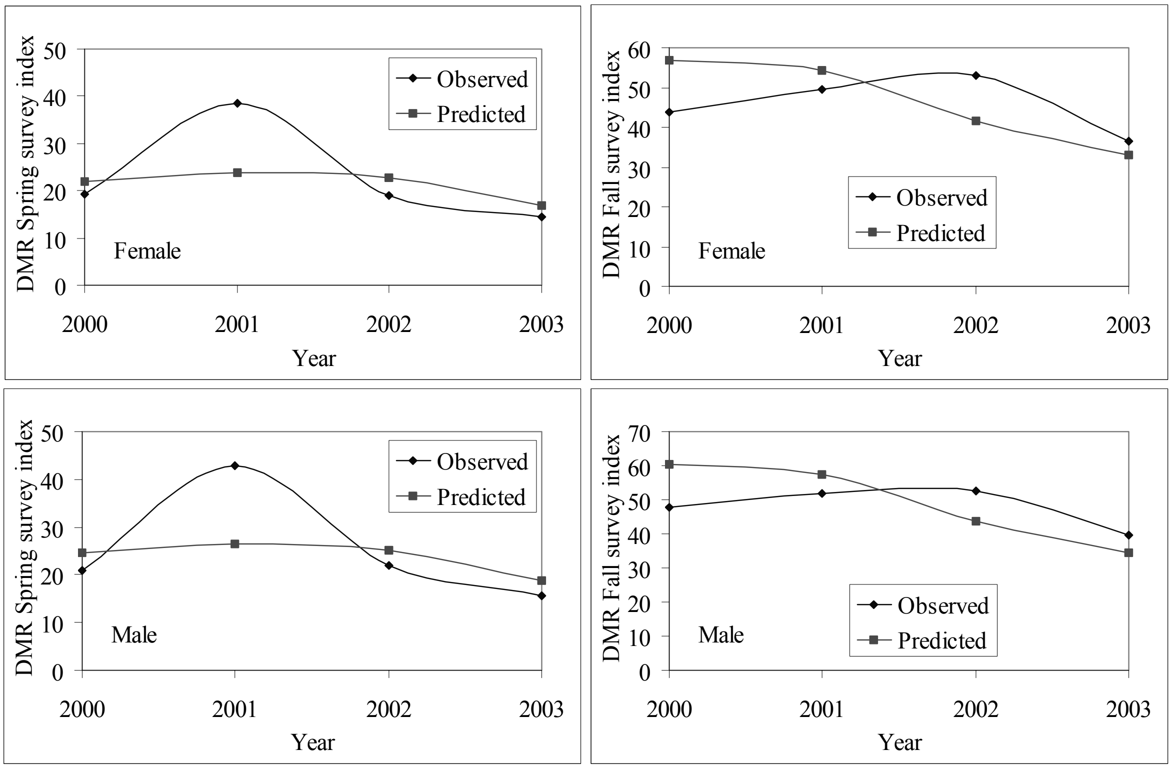


Figure 19. Differences (D) between the predicted and observed size compositions of landings. S1 = winter, S2 = spring, S3 = summer, S4 = fall. M = males, F = females, Median = median value of Ds across all years, Min = minimum value of Ds across all years, and Max = maximum value of Ds across all years.

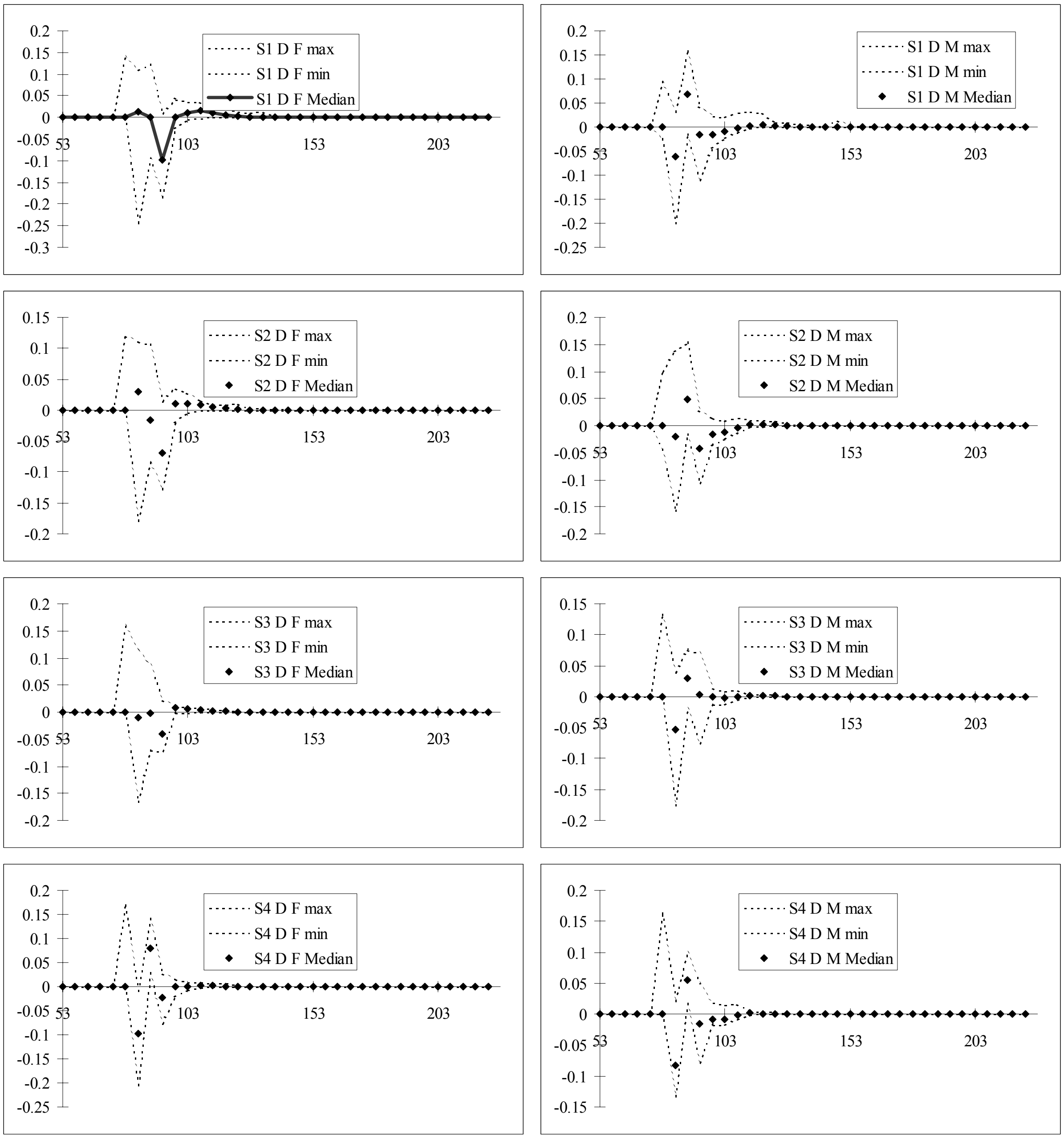


Figure 20. Differences (D) between the predicted and observed size compositions of the NMFS surveys. S2 = spring, S4 = fall. M = males, F = females, Median = median value of Ds across all years, Min = minimum value of Ds across all years, and Max = maximum value of Ds across all years.

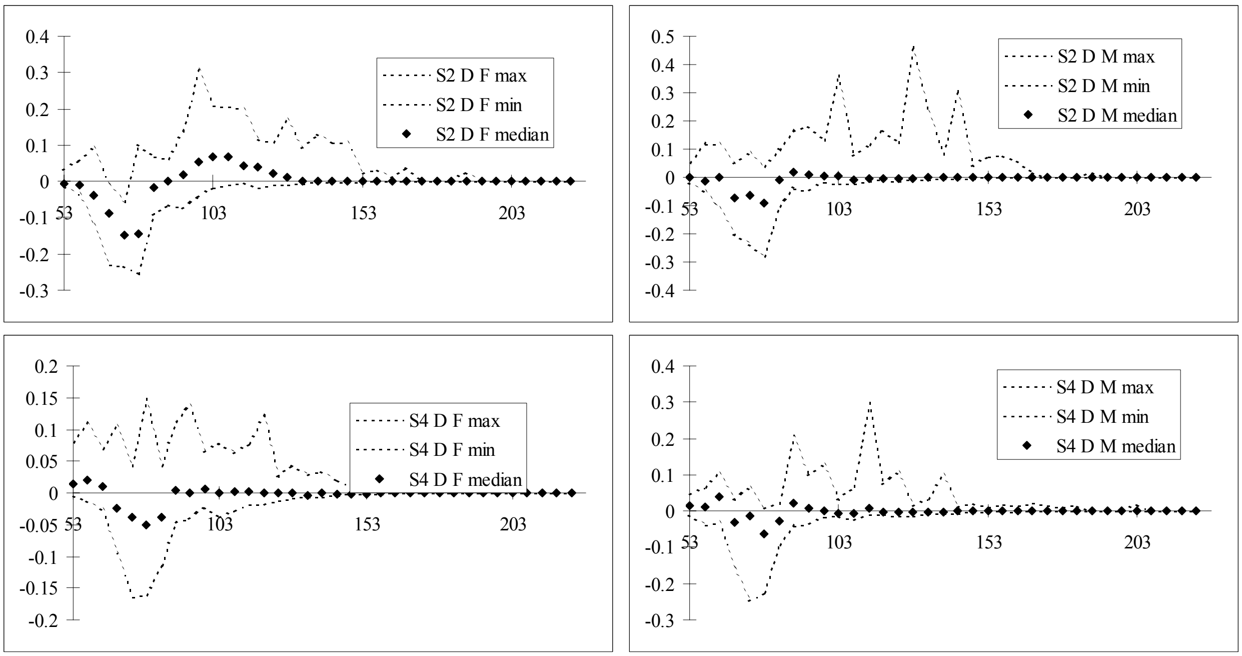


Figure 21. Differences (D) between the predicted and observed size compositions of the Maine DMR surveys from year 2000 to year 2003. S2 = spring, S4 = fall. M = males, F = females, Median = median value of Ds across all years,

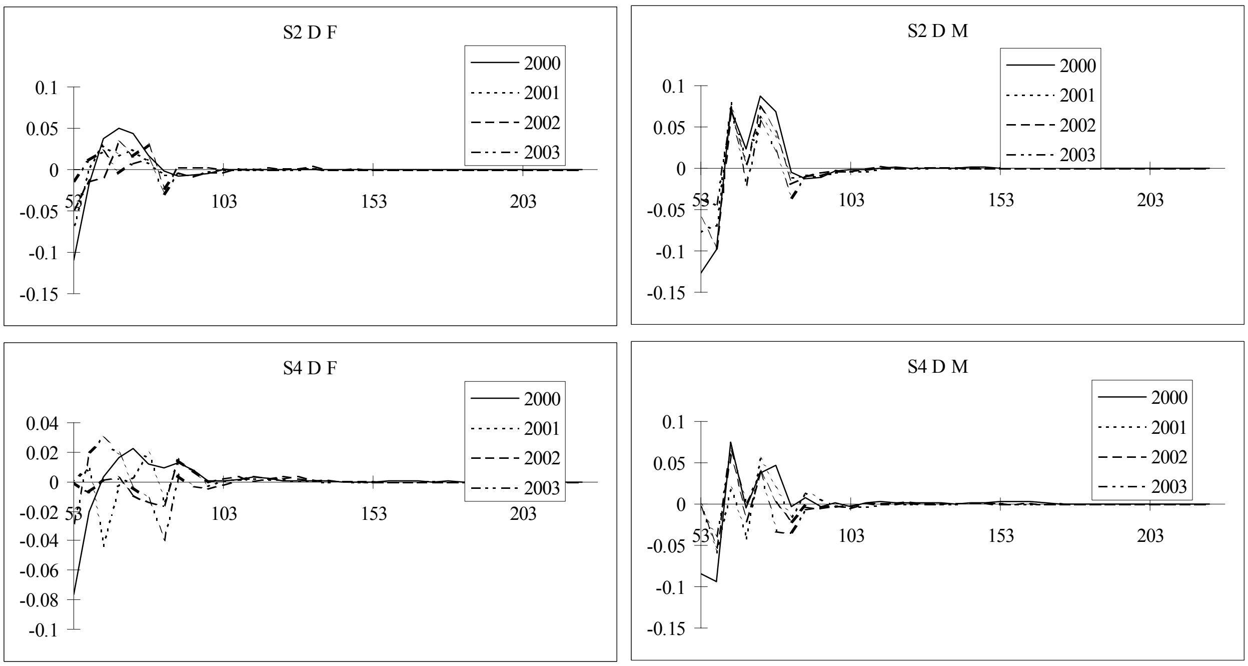
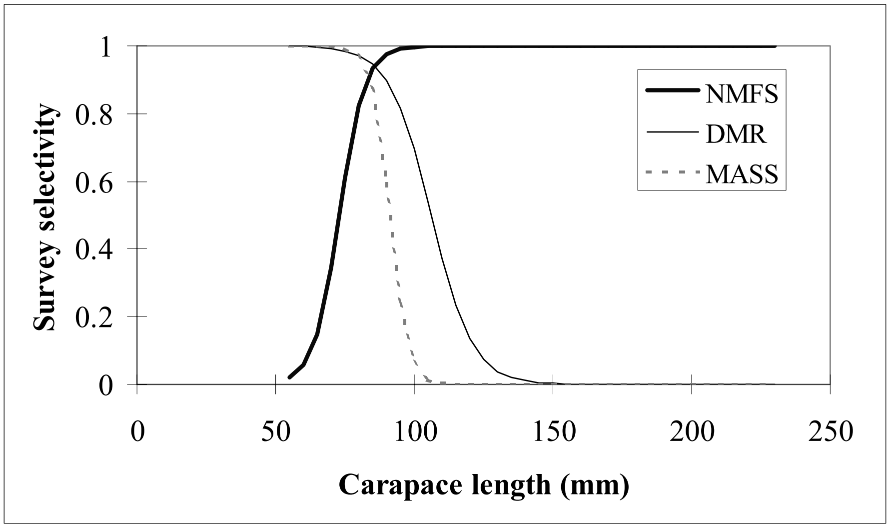


Figure 22. Survey selectivity curves estimated for the three survey programs.



References

ASMFC (Atlantic States Marine Fisheries Commission). 2000. American lobster stock assessment report. ASMFC American Lobster Stock Assessment Sub-Committee. Washington D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 2004a. ASMFC American lobster Technical Model Review Materials, Washington, D.C.

ASMFC (Atlantic States Marine Fisheries Commission). 2004b. American Lobster Stock Assessment Model Technical Review, Terms of Reference and Panel Report, December 2004. ASMFC Special Report No. 82, Washington D.C.

Berger, J. O. 1985. Statistical Decision Theory and Bayesian Analysis. New York, Spring-Verlag.

Breen, P.A., Andrew, N. L., and Kendrick, T. H. 2000. The 2000 stock assessment of paua (*Haliotis iris*)in PAU 5B using an improved Bayesian length-based model. *New Zealand Fisheries Assessment Report 2000/48*.

Chen, Y. 1996. 1996. A Monte Carlo study on impacts of the size of subsample catch on estimation of fish stock parameters. Fisheries Research 26:207-223.

Chen, Y. and Fournier, D. 1999. Impacts of atypical data on Bayesian inference and robust Bayesian approach in fisheries. *Can. J. Fish. Aquat. Sci. 56*:1525-1533

Chen, Y., Breen, P. and Andrew, N. 2000. Impacts of outliers and mis-specification of priors on Bayesian fisheries stock assessment. *Can. J. Fish. Aquat. Sci. 57*:2293-2305.

Chen, Y. and H. Rajakaruna. 2003. Impacts of quantity and quality of fisheries data on stock assessment. Proceedings of the 3rd World Fisheries Congress, American Fisheries Society, Bethesda, MD.

Chen, Y., M. Kanaiwa, and C. Wilson. 2005. Developing a Bayesian stock assessment framework for the American lobster fishery in the Gulf of Maine. New Zealand Journal of Freshwater and Marine Sciences (Special issue on Lobster Biology and Management) 39(3): 645-660.

Chen, Y., S. Sherman, C. Wilson, J. Sowles, and M. Kanaiwa. 2005. A comparison of two fishery-independent survey programs in characterizing population structure of American lobster, *Humarus americanus*, in the Gulf of Maine. Fishery Bulletin (in press)

Chen, Y.; Wilson, C. 2002. A simulation study to evaluate impacts of uncertainty on the assessment of American lobster fishery in the Gulf of Maine. *Canadian Journal of Fisheries Aquatic Sciences 59*:1394-1403

Collie, J. S.; Sissenwine, M. P. 1983. Estimating population size from relative abundance data measured with error. *Canadian Journal of Fisheries and Aquatic Sciences 40*: 1871-1879.

Conser, R. J. 1995. A modified DeLury modeling framework for data limited assessment: bridging the gap between surplus production models and age-structured models. A working paper for the ICES Working Group on Methods of Fish Stock Assessment, Copenhagen, Denmark.

FAO 1995. Part 1. Guidelines on the precautionary approach to capture fisheries and species introductions. *FAO Fish. Tech. Pap. 350/1*.

Fogarty, M. J.; Idoine, J. S. 1988. Application of a yield and egg production model based on size to an offshore American lobster population. *Transactions of American fisheries Society 117*:350-362.

Fournier, D. A. 1996. AUTODIFF. A C++ aray language extension with automatic differentiation for use in nonlinear modeling and statistics. Otter Res. Ltd., Nanaimo, BC, Canada

Fournier, D., Sibert, J. R., Majkowski, J. and Hampton, J. 1990. MULTIFAN: a likelihood-based method for estimating growth parameters and age composition from a multiple length frequency data set illustrated using data for southern bluefin tuna (*Thunnus maccoyii*). *Can. J. Fish. Aquat. Sci. 47*:301-317.

Francis, R. I. C. C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (Hoplostethus atlanticus) on the Chatham Rise, New Zealand. *Can. J. Fish. Aquat. Sci. 49*:922-930.

Hilborn, R., Pikitch, E. K. and Francis, R. C. 1993. Current trends in including risk and uncertainty in stock assessment and harvest decisions. *Can. J. Fish. Aquat. Sci. 50*: 874-880.

Hilborn, R. and Walters, C. 1992. Quantitative fisheries stock assessment: choice, dynamics, and uncertainty. Chapman and Hall, New York.

Kanaiwa, M., Chen, Y., Hunter, M., 2005, Assessing stock assessment framework for the green sea urchin fishery in Maine, USA. Fisheries Research (in press)

McAllister, M. K. and Kirkwood, G. P. 1998. Using Bayesian decision analysis to help achieve a precautionary approach for managing developing fisheries. *Can. J. Fish. Aquat. Sci. 55:*2642-2661.

Northeast Fisheries Science Center (NEFSC). 1996. Report of the 22nd Northeast Regional stock assessment workshop (22nd SAW): Stock assessment Review Committee (SARC) consensus summary of assessments. Northeast Fisheries Science Center Reference Document 96-13: 242 p

NRC (National Research Council). 1997.Improving fish stock assessments. National Academy Press, Washington, D.C.

NRC (National Research Council). 1999. Sustaining marine fisheries. National Academy Press, Washington, D.C.

Punt, A. E. and Hilborn, R. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. *Rev. Fish. Biol. Fish. 7*:35-63.

Quinn, T. and Deriso, R. B. 1999. Quantitative fish dynamics. Oxford University Press, Oxford, UK.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Board of Canada. Bulletin 191*.

Sheehy, M.R.J. 2001.Implications of protracted recruitment for perception of the spawner-recruit relationship. *Can. J. Fish. Aquat. Sci. 58:*641-644.

Taylor, B. L., Wade, P.R., Stehn, R. A. and Cochrane, J. E. 1996. A Bayesian approah for classification criteria for Spectacled Eiders. *Ecol. Appl. 6*: 1077-1089.

Walters, C. J. 1998. Evaluation of quota management policies for developing fisheries. *Can. J. Fish. Aquat. Sci. 55*:2691-2705.

Appendix I: Description of the proposed model

Length-structured stock assessment models

The population model developed in this study is a stochastic length-structured, sex-specific model describing the dynamics of the lobster population and fishery (referred to as population dynamics model) and an observational model used to relate the population dynamics models to observations made in surveys and fishery. The population dynamics model includes a series of submodels describing various processes of the lobster life history and fishery. The modeling time step is a season (i.e., Winter = January -March, Spring = April - June, Summer = July - September; and Fall = October - December). The key submodels are described below.

Recruitment model

Because of lack of information, we assume no functional relationship between spawning stock biomass (SSB) and subsequent recruitment (Sheehy 2001). We estimate an average recruitment for all the years considered in the assessment ($\overline{R}$), and thus the recruitment of a given year can be estimated as:

$$R_t = \overline{R}\ \exp(R_{dev_t} - 0.5\sigma^2_{R_t}) \qquad (1)$$

where R_t is the recruitment for year *t*, R_{dev_t} is the recruitment deviation from the mean value for year *t* and can be calculated as:

$$R_{dev_t} = \sqrt{R_h}\,R_{dev_{t-1}} + \sqrt{1-R_h}\,R_{dev_t} \qquad (2)$$

and σ_{R_t} is the standard deviation of the estimated recruitment for all the years included in the assessment. Parameter R_h is an autocorrelation coefficient describing the degree of autocorrelations of recruitment of one year with the recruitment of previous year. Its values range from 0 to 1, respectively, indicating no autocorrelation and perfect autocorrelation of the recruitment in years *t* and *t*-1 (Breen et al. 2000). For a given fishing year, recruitment occurs in summer and autumn, associated with major and minor molting events respectively. The minor molting occurs to a defined proportion of small individuals that have their second molt after the major molt.

Modeling population dynamics

Thirty-five size classes are defined, starting from 53 mm carapace length (CL) with a width of 5 mm. The choice of 5 mm for size class width is determined by the fact that the lobsters in most size classes have minimum molting increment of equal or larger than 5 mm; (ASMFC 2000, Joe Idoine personal communications).

The lobster fishery started in 1800, but reliable information is not available from the early stage of the fishery. Thus we cannot model the lobster population dynamics from the time when they can be treated as a virgin population. We need to include parameters that describe size composition of the lobster stock in the first year defined in the assessment ($p^i_{k,1}$) and initial population size (N^i_1), where *i* indicates sex and *k* indexes size class. Thus, the number of lobsters in size class k in the beginning of the first assessment season can be calculated as:

$$N^i_{k,1} = p^i_{k,1}N^i_1 \qquad i \in \{f, m\} \qquad (3a)$$

Initially, we estimated both $p_{k,1}^{i}$ (35 size classes for each sex =70 parameters to be estimated) and N_1^i (one parameter for each sex = two parameters to be estimated). The ASMFC Lobster Model Peer Review Committee suggests using a log-normal density distribution function to describe $p_{k,1}^{i}$. Thus, we have

$$op_{k,0}^{i} = \frac{1}{\sqrt{2\pi}\sigma_i} \exp\left(-\frac{(\ln L_k^i - \ln l_i)^2}{2\sigma_i^2} \right) \qquad (3b)$$

$$p_{k,0}^{i} = \frac{op_{k,0}^{i}}{\sum_k op_{k,0}^{i}} \qquad (3c)$$

Equation (3c) is used to standardize the value of $op_{k,1}^{i}$ calculated from the log-normal function in Equation (3b) to ensure the summation of $p_{k,1}^{i}$ over all size classes is 1. This reduces the number of parameters to be estimated for $p_{k,1}^{i}$ from 70 to four (i.e., l_i and σ_i for females and males). Thus, six parameters need to be estimated for defining $N_{k,1}^{i}$ in Equation (3a).

Without sex-specific natural mortality before the first size class, we assume a sex ratio of recruitment to the model of 0.5. The recruitment is equally divided among the first three size classes, considering the maximum increment in a molt can reach 16 mm. Thus, we have:

$$N_{1,t}^{f} = N_{1,t}^{m} = N_{2,t}^{f} = N_{2,t}^{m} = N_{3,t}^{f} = N_{3,t}^{m} = \frac{R_t}{6} \qquad (4)$$

The pre-season total biomass, $B_t^{total,i}$, and pre-season legal biomass, $B_t^{legal,i}$, in year *t* for sex *i* can be estimated as

$$B_t^{total,i} = \sum_k N_{k,t}^{i} w_k^i \qquad (5a)$$

$$B_t^{legal,i} = \sum_k N_{k,t}^{i} P_{k,t}^{i} w_k^i \qquad (5b)$$

$$N_t^{legal,i} = \sum_k N_{k,t}^{i} P_{k,t}^{i} \qquad (5c)$$

where w_k^i is the weight of the lobster in size *k*, and $P_{k,t}$ is a switch (0 for size classes below the minimum legal size or above the maximum legal size, and 1 for legal size classes). The exploitation rate, U_t^i, can then be calculated as

$$U_t^i = \frac{LC_t^i}{B_t^{legal,i}} \qquad i \in \{f, m\} \qquad (6a)$$

$$U_t^i = \frac{LC_t^i}{N_t^{legal,i}} \qquad (6b)$$

where LC_t^i is the landings in year *t* observed in the fishery measured in biomass (6a) or in number (6b). U in equations (6a) and (6b) is the biomass-based exploitation rate (Equation 6a) and number-based exploitation rate (Equation 6b). No size impact is considered in calculating the overall exploitation rate using Equation 6. If this exploitation rate is used for each size class, it implicitly assumes that the fishing effort is uniformly applied to lobsters of all sizes. This assumption is rather unrealistic because the spatial distribution of lobsters tends to be size-dependent and/or fishing effort is targeted to and selective for certain sizes of lobsters. Thus, we need to estimate size-specific exploitation rates.

The following approach was used for estimating size-specific exploitation rate $U^i_{k,t}$. Taking into consideration various size-specific selectivity processes, the overall selectivity for lobsters of size *k* in time *t*, $S^i_{k,t}$, can be estimated as:

$$S^i_{k,t} = S^{gear,i}_{k,t}(1 - S^{cons,i}_{k,t})S^{other}_k P_{k,t} \qquad i \in \{f, m\} \qquad (7)$$

where $S^{gear,i}_{k,t}$ is the gear selectivity coefficient describing the proportion of lobster in size *k* time *t* encountering and then retained in traps , $S^{cons,i}_{k,t}$ is the selectivity resulting from the conservation measures such as V-notching and protection of egg-bearing lobsters and describes the proportion of the lobsters in size *k*, sex *i*, and time *t* caught in traps, but thrown back to waters due to the conservation measures, and S^{other}_k is the selectivity resulting from reasons other than gear selectivity, conservation measures and legal sizes for lobsters in size *k* to the fishery. The values of $S^{gear,i}_{k,t}$ and $S^{cons,i}_{k,t}$ vary with time, and are provided as input data. The S^{other}_k is assumed to be the same over time and between sexes and follow a normal distribution function $N(\mu_S, \sigma_S^2)$. The values of the normal distribution function are standardized to range from 0 to 1. The μ_S and σ_S^2 determine the shape and location of the S^{other}_k, and subsequently determine this selectivity coefficient for different sizes of lobsters. They are parameters being estimated in modeling. Because the overall selectivity $S^i_{k,t}$ is the products of four selectivity coefficients and the legal switch has values of 1 for legal sized lobsters and 0 for lobsters outside legal size ranges, the impacts of $S^{gear,i}_{k,t}$, $S^{cons,i}_{k,t}$, and S^{other}_k on overall selectivity $S^i_{k,t}$ are limited to lobsters of legal sizes ($S^i_{k,t}$ is 0 for all other size classes because of $P_{k,t}$). All these three selectivity coefficients have values from 0 to 1. Thus, the exploitation rate for lobsters of sex *i* in size class *k* in year *t*, $U^i_{k,t}$, can be estimated as:

$$U^i_{k,t} = U^i_t S^i_{k,t} \qquad (8)$$

where U^i_t is calculated from Equation 6. The use of the above equation ensures the predicted and observed catches are the same (i.e., $\sum_k C^i_{k,t} = LC^i_t$). Thus the size-specific exploitation rate $U^i_{k,t}$ is calculated as the proportion of the total stock biomass removed from size class *k* in year *t*. The exploitation rate derived in Equation 8 is biomass-based if U^i_t in Equation (6a) is used, and is abundance-based (i.e., number-based) if Equation (6b) is used.

The survival rate from fishing, $SV^i_{k,t}$, can then be calculated as:

$$SV^i_{k,t} = 1 - U^i_{k,t} \qquad (9)$$

The number of lobsters in size class *k* in year *t*, $N^i_{k,t}$, is calculated as

$$N^i_t = SV^i_{t-1} N^i_{t-1}{}' G^i e^{-M^i} \qquad (10)$$

where $\boldsymbol{G}$ is the size-specific growth transition matrix and *M* is the instantaneous rate of natural mortality. Because of the complexity of the framework, growth transition matrix is determined outside the framework based on size-specific molting frequency and molting increment defined by ASMFC Lobster Stock Assessment Subcommittee. The average growth curve is presented in Fig. 4. Equation 10 is used in projecting the change in the number of lobsters in the stock from one year to the next year.

Model predictions

Using the above population dynamics models we can simulate a model lobster fishery. The following predictions can be made from the simulated model fishery -

Legal-sized lobster biomass: $B_t^{legal,i} = \sum_k P_{k,t} N_{k,t}^i w_k^i$ (11a)

Legal-sized lobster abundance: $N_t^{legal,i} = \sum_k P_{k,t} N_{k,t}^i$ (11b)

Fishery CPUE in weight: $I_{t,m}^{pred,i} = q_{1,m}^i \left(B_t^{legal,i}\right)^{\gamma_m}$ (12a)

Fishery CPUE in number: $I_{t,m}^{pred,i} = q_{1,m}^i \left(N_t^{legal,i}\right)^{\gamma_m}$ (12b)

where *m* indexes season, fishery catchability $q_{1,m}^i$ is calculated as for biomass-based

$$q_{1,m}^i = \exp\left(\frac{\sum_t \ln(I_{t,m}^i) - \sum_t \gamma_m \ln(B_t^{legal,i})}{n}\right) \quad (12c)$$

or for abundance-based

$$q_{1,m}^i = \exp\left(\frac{\sum_t \ln(I_{t,m}^i) - \sum_t \gamma_m \ln(N_t^{legal,i})}{n}\right) \quad (12d)$$

where γ in Equation 12 is a density-dependent parameter, and equations (12) and (13) implicitly assume that catchability differs among seasons and between sexes in the fishery and survey.

Abundance index for survey program *j*: $IS_{j,t,m}^{pred,i} = q_{2,j,m}^i \psi_{k,j} B_t^{total,i}$ (13a)

$IS_{j,t,m}^{pred,i} = q_{2,j,m}^i \psi_{k,j} N_t^{total,i}$ (13b)

where Equations (13a) and (13b) correspond to biomass and abundance-based survey indices, respectively, $j \in$ {NMFS survey, DMR inshore survey, and MA inshore survey} and surveys' catchability $q_{2,j,m}^i$ can be calculated as

$$q_{2,j,m}^i = \exp\left(\frac{\sum_t \ln(IS_t^i) - \sum_t \ln(\psi_{k,j} B_t^{total,i})}{n}\right) \quad (13c)$$

$$q_{2,j,m}^i = \exp\left(\frac{\sum_t \ln(IS_t^i) - \sum_t \ln(\psi_{k,j} N_t^{total,i})}{n}\right) \quad (13d)$$

and $\psi_{k,j}$ in Equation 13 is the proportion of lobsters in size class *k* that is covered by survey program *j*, and can be described by the following logistic curve:

$$\psi_{k,j} = \frac{1}{1+\exp(a_{k,j}(l_{k,j} - l_{50}))} \tag{14}$$

Size composition of catch in the fishery:
$$Cp_{k,t}^{pred,i} = \frac{P_{k,t} N_{k,t}^{pred,i}}{\sum_k P_{k,t} N_{k,t}^{pred,i}} \tag{15}$$

Size composition of catch in the survey:
$$p_{k,j,t}^{pred,i} = \frac{N_{k,t}^{pred,i} \psi_{k,j}}{\sum_k N_{k,t}^{pred,i} \psi_{k,j}} \tag{16}$$

In the simulation and application, we used the number (abundance)-based data in the parameter estimation.

Observational models

A group of observational models are developed to relate the predictions from the above dynamics models with the observations made in the fishery. The differences between the predicted and observed output variables in the observational models are assumed to be random and follow certain statistical distributions, which are then used to formulate the likelihood functions needed in the Bayesian parameter estimation. The following observational models are developed -

Catch per unit of effort in the fishery:
$$I_t^{obs,i} = I_t^{pred,i} \exp(\varepsilon_t) \tag{17}$$

Survey abundance index:
$$IS_t^{obs,i} = IS_t^{pred,i} \exp(\varepsilon_t) \tag{18}$$

Size composition of catch in the survey:
$$p_{k,t}^{obs,i} = p_{k,t}^{pred,i} + \varepsilon_t \tag{19}$$

Size composition of catch in the fishery:
$$Cp_{k,t}^{obs,i} = Cp_{k,t}^{pred,i} + \varepsilon_t \tag{20}$$

Error terms ε in Equations 17 and 18 are assumed to follow normal distributions, and error terms ε in Equations 19 and 20 are assumed to have multinomial distributions (Fournier et al. 1990).

Likelihood functions

Three different likelihood functions used in Chen et al. (2000) are considered: normal (a), robust normal (b), and *t*-distribution (c) functions. The following likelihood functions are formulated based on the observational models listed above:

$$p(I_t^{obs,i} \mid I_t^{pred,i}) = \prod_i \prod_t \left[\frac{1}{\sqrt{2\pi}\hat{\sigma}_{I_t^{obs,i}}} \exp\left\{ -\frac{\left(\ln(I_t^{obs,i}) - \ln(I_t^{pred,i})\right)^2}{2(\hat{\sigma}_{I_t^{obs,i}})^2} \right\} \right] \tag{21a}$$

$$p(I_t^{obs,i} \mid I_t^{pred,i}) = \prod_i \prod_t \left[\frac{1}{\sqrt{2\pi}\hat{\sigma}_{I_t^{obs,i}}} \exp\left\{ -\frac{\left(\ln(I_t^{obs,i}) - \ln(I_t^{pred,i})\right)^2}{2(\hat{\sigma}_{I_t^{obs,i}})^2} \right\} + 0.01 \right] \tag{21b}$$

$$p(I_t^{obs,i} \mid I_t^{pred,i}) = \prod_i \prod_t \left[\frac{1.329}{\sqrt{4\pi}} \left\{ 1 - \frac{\left(\ln(I_t^{obs,i}) - \ln(I_t^{pred,i})\right)^2}{4(\hat{\sigma}_{I_t^{obs,i}})^2} \right\}^{-2.5} \right] \tag{21c}$$

$$p(IS_t^{obs,i} \mid IS_t^{pred,i}) = \prod_i \prod_t \left[\frac{1}{\sqrt{2\pi}\hat{\sigma}_{I_t^{obs,i}}} \exp\left\{ -\frac{\left(\ln(IS_t^{obs,i}) - \ln(IS_t^{pred,i})\right)^2}{2(\hat{\sigma}_{I_t^{obs,i}})^2} \right\} \right] \tag{22a}$$

$$p(IS_t^{obs,i} \mid IS_t^{pred,i}) = \prod_i \prod_t \left[\frac{1}{\sqrt{2\pi}\hat{\sigma}_{I_t^{obs,i}}} \exp\left\{ -\frac{\left(\ln(IS_t^{obs,i}) - \ln(IS_t^{pred,i})\right)^2}{2(\hat{\sigma}_{I_t^{obs,i}})^2} \right\} + 0.01 \right] \quad (22b)$$

$$p(IS_t^{obs,i} \mid IS_t^{pred,i}) = \prod_i \prod_t \left[\frac{1.329}{\sqrt{4\pi}} \left\{ 1 - \frac{\left(\ln(IS_t^{obs,i}) - \ln(IS_t^{pred,i})\right)^2}{4(\hat{\sigma}_{I_t^{obs,i}})^2} \right\}^{-2.5} \right] \quad (22c)$$

For the size composition data, a robust function (Fournier et al. 1990, Fournier 1996, Chen et al. 2000) described below is used,

$$L(Cp_{k,t}^{obs,i}) = \prod_t \prod_k \frac{1}{\sqrt{2\pi Cp_{k,t}^{obs,i}(1 - Cp_{k,t}^{obs,i}) + 0.1/\pi}} \exp\left[\frac{-N_{k,t}^i (Cp_{k,t}^{obs,i} - Cp_{k,t}^{pred,i})^2}{2\left\{Cp_{k,t}^{obs,i}(1 - Cp_{k,t}^{obs,i}) + 0.1/\pi\right\}} + 0.01 \right] \quad (23)$$

$$L(p_{k,t}^{obs,i}) = \prod_t \prod_k \frac{1}{\sqrt{2\pi p_{k,t}^{obs,i}(1 - p_{k,t}^{obs,i}) + 0.1/\pi}} \exp\left[\frac{-N_{k,t}^i (p_{k,t}^{obs,i} - p_{k,t}^{pred,i})^2}{2\left\{p_{k,t}^{obs,i}(1 - p_{k,t}^{obs,i}) + 0.1/\pi\right\}} + 0.01 \right] \quad (24)$$

Prior distributions

Two types of prior distributions are used, non-informative and informative. Uniform distributions with lower and upper boundaries are assumed for the non-informative priors. For the informative priors, the distribution functions used include normal and log-normal with lower and upper boundaries (i.e., truncated normal or log-normal distributions). These two distribution functions are, however, sensitive to misspecifications (Chen et al. 2000). Because of lack of confidence in our prior knowledge about certain parameters, the Cauchy distribution function is used for informative priors (Chen et al. 2000). It can be written as:

$$f(Y) = \left[\pi\lambda \left\{ 1 + \left(\frac{Y - \theta}{\lambda} \right)^2 \right\} \right]^{-1} \quad (\theta = \mu,\ \lambda = 0.675\sigma) \quad (25)$$

The parameters with assigned priors include $Y \in \overline{R}_0$, $a_{k,j}$, $l_{k,j}$, M^i and R_{dev_t}.

Whether a parameter has a non-informative or informative prior is determined by the reliability and details of prior knowledge we have on the parameter. The prior knowledge of fishery parameters comes from different sources including lobstermen's experience, results derived from previous studies on the lobster fishery, and knowledge of the parameters for similar species and fisheries. Uniform distributions are used for non-informative priors.

Estimation of $F_{10\%}$

Under the equilibrium, the egg production (EGG) at fishery mortality (F) can be calculated as:

$$EGG(F) = \sum_k N_{b,k}^f (F) \alpha_{fec} (L_k)^{\beta_{fec}} \quad (26)$$

where $N_{b,k}^{f}(F)$ is the number of female lobsters at fishing mortality of F estimated from the population model for an equilibrium population simulated using the parameters estimated in the population model with the average recruitment ($\overline{R}$, Equation 1). $F_{10\%}$ is then estimated, iteratively, from the following equation

$$EGG(F)\big|_{F=F_{10\%}} = 0.1EGG(F)\big|_{F=0}$$

Appendix II.

Developing and testing an individual-based fishery simulator for the American lobster, *Homarus americanus*

The objective of this study is to develop an individual-based lobster simulator to mimic the complex life history and fishing processes in the American lobster fishery. We parameter the proposed simulator with the information collected in many previous studies for the Gulf of Maine lobster fishery and evaluate the lobster simulator in its ability to describe the lobster population dynamics. Using the proposed simulator, we simulated various simulation scenarios for testing the performance of the proposed sex-specific length-structured stock assessment model.

The development of individual-based lobster simulator

We used a probabilistic approach to simulate the life of individual lobster. This is done by expressing various components of the model equations as random Bernoulli trials. For example, rather than calculating the number of lobsters that survive natural mortality by

$$N_{t+1} = N_t e^{-M}$$

where M is the instantaneous rate of natural mortality, we simulate natural mortality acting on N_t individual lobsters,

$$\textit{for } 1 \textit{ to } N_t : \textit{if } U(0,1) \le 1 - e^{-M} \textit{ then } N_{t+1} = N_t - 1$$

where $U(0,1)$ is a uniform distributed random number between 0 and 1. We refer this approach as an individual-based Lobster Simulator. This simulator simulates the life of each lobster in a population subject to the fishery.

The smallest size considered in the Simulator is 53 mm carapace length (CL). For each time step (i.e., season), a certain number of recruits are added to the population as recruitment. Because a lobster only grows when it molts, the initial size of a recruit is randomly chosen from a uniform distribution ranging from 53mm to the size of 53 plus the maximum increment per molt. At each time step, each lobster has a probability of being caught in the fishery, dying of natural mortality, growing and maturing, and for females, becoming egg-bearing, V-notched, and/or losing V-notching mark due to molting (Fig. 1). The probabilities and processes of these events and their interactions are derived from previous studies and represent our best understanding of the American lobster biology (ASMFC 2000), which is agreed upon by the Atlantic States Marine Fisheries Commission Lobster Model Development Subcommittee and Lobster Stock Assessment Subcommittee. When a lobster is caught in the fishery in the Simulator, it needs to be examined for size (against minimum and maximum legal sizes), and, if it is a female, to be checked to see if it was V-notched before or if it is egg-bearing lobster that needs to be V-notched. If a lobster is legal to be kept, its sex and size is recorded to generate catch and size-frequency data. V-notched lobsters are protected from fishing for two molts because a V-notching mark becomes invisible in two molts. Egg bearing lobsters are protected from harvesting and need to be V-notched. The molting frequency of mature female lobsters is influenced by maturation. The egg-bearing period of a female lobster lasts for 6 months with an extra three months of recovery. During the egg-bearing and recovery period, the lobster will not molt due to the diversion of energy to maturation. Lobster experiences major molting event in summer, and a small proportion of small lobsters that have molted once in summer also experience a second molt in the following fall. As a result, recruitment only occurs in summer and fall. The details of these life history and fishery process is detailed in a flowchart (Fig. 1).

Each individual lobster entering into the Simulator goes through all the processes again and again until it dies due to natural cause or is landed as part of catch. For a given season, the natural mortality and fishing mortality do not occur concurrently, and growth occurs after fishing and natural moralities. Because of the use of random Bernoulli trials, some levels of process errors exist in the simulated fishery. Bookkeeping is done by examining each individual and adding it to the legal biomass and landings where appropriate. The exploitation rate is calculated as the proportion of the catch over the legal stock biomass.

Parameterization of the Lobster Simulator

The values of the parameters in the Simulator were obtained from the ASMFC American Lobster Stock Assessment Report which summarizes all previous research on the American lobster in the northeast USA (ASMFC 2000). The summary of the key lobster parameters and their values used in the Lobster Simulator is presented below.

<u>Size class</u>

The input data and all the processes in the Lobster Simulator use 1 mm of size bin, while output data are grouped in the size bin of 5 mm starting from 53 mm (i.e., 53- 58, 58-63, 63-68, ……,). Lobsters in the first six size bins are smaller than the minimum legal size, and are thus sublegal lobsters. The largest size class is the size bin from 223-228 mm CL.

<u>Weight-Length relationship</u>

The weight-length relationship used in the Simulator to calculate stock biomass is described as $W_L = 0.001167L^{2.9194}$, where L is carapace length for each lobster.

<u>Probability of CL increment per molt</u>

Size increment per molt varies with sex and size, respectively. The average size increment per molt for males is defined as:

$$\overline{\Delta L_L} = 1.2236 + 0.1294L, \qquad if\ L < 95$$

$$\overline{\Delta L_L} = 1.2236 + 0.1294 * 95 = 13.5166, \qquad else$$

and for females is

$$\overline{\Delta L_L} = 1.2288 + 0.1285L, \qquad if\ L < 82$$

$$\overline{\Delta L_L} = 1.2288 + 0.1285 * 82 = 11.7658, \qquad else$$

The probability of having a specific size increment per molt is then defined by a normal distribution N($\overline{\Delta L_L}, \sigma^2$) truncated by the lower and upper boundaries at the probabilities of 0.025 and 0.975. The $\overline{\Delta L_L}$ is defined in the above equations for males and females, and σ has a value of 2.1 for both males and females.

<u>Molting probability</u>

The molting probability is size-specific. There is no difference in molting probability between females and males before they become mature. After females reach maturity, they tend to divert their energy to maturation, which then slows down their growth. The probability of molting for a sized male lobster in a given year was developed in the ASMFC last stock assessment (Fig. 2; ASMFC 2000). Males with CL smaller than 71mm experience one major molting (i.e. in summer) every year. For males with CL between 71 mm and 105 mm, molting occurs at least once every two years. For males with CL from 106 to 114 mm, from 115 to 119 mm, from 120 mm to 123 mm, from 124 mm to 126 mm, and from 127 mm to larger sizes, molting occurs at least once every three, four, five, six, and seven years, respectively (Fig. 2). For a female, the molting probability could also follow the molting probability of males described in Figure 3 if the female is not engaged in a spawning activity (i.e., not bearing eggs, not in the period of recovery from egg bearing; Fig. 1). This results in mature females of a given size molting less frequently than the males of the same size (see Fig. 2).

Probability of double molting

For a given year, the proportion of lobsters that molt in summer have a chance to molt again in the following fall. This molting event is often referred to as double molting. The probability of double molting varies with the lobster sizes. For lobsters larger than 83 mm, the probability of having a double molting in a year is 0. For lobsters smaller than 82mm, the probability is calculated from the following equation

Probability of double molting = $0.00012L^2 - 0.03092L + 1.73777$.

Recruitment

Recruits are defined as the number of lobsters entering into sizes of 53 to 69 mm (because the maximum molting increment is 16 mm. Recruitment only occurs in summer and fall, corresponding to major and double molting, respectively. Sex ratio of new recruits into the sizes of 53 to 69 is defined as 1:1 because of lack of the evidence of sex-specific mortality prior to 53 mm CL. The ratio of recruits into the sizes of 53 to 69 between summer (major molting) and fall (double molting) is 1:0.33, corresponding to double molting probability. Thus, for a given year, the total recruits divided into the four seasons as spring =0%, summer=75.19%, fall=24.81%, winter=0%. Recruits will be evenly divided among 16 size classes of 53 to 69. Time series of recruits used for different simulation scenarios are defined for different simulation scenarios.

Natural mortality

Natural mortality (M) is divided into two components, average M applied to every individual regardless of their molting condition and molting M which is only applied to individuals whenever they molt. The average M is set to be 0.10, and molting M is set to be 0.05 for every molting (ASMFC 2000). Thus, for lobsters with double molts in a given year, their natural mortality is 0.2, while for lobsters that do not molt in a given year, their natural mortality is 0.1. No difference is assumed for lobsters of different sizes in average M and molting M.

Size-specific proportion of maturity

The probability of a lobster becoming mature is related to the size of the lobster. The relationship between size and proportion of maturity is described by a logistic model written as $P_M(L) = \frac{1}{1+e^{-0.232(L-L50)}}$. Parameter $L50$ is the size at which 50% of lobsters become mature. It is set at 91.422 mm.

Fishery selectivity

Three selectivity processes are defined in the lobster fishery. They include gear selectivity, selection due to management regulations, and selectivity due to reasons other than gears and regulations. The gear selectivity has been estimated from field experiment. For lobsters smaller than or equal to 81 mm CL, the gear selectivity is 0; for lobsters of size ranges from 82 to 86 mm CL (inclusive), the selectivity is 0.035, 0.286, 0.414, 0.517, and 0.758, respectively; and for lobsters equal to or larger than 87, the selectivity is 1. The minimum and maximum legal sizes are 83 and 127 mm in the Gulf of Maine, thus, the regulation selectivity is 0 for lobsters smaller than 83 mm or larger than 127 mm, but 1 for lobsters of sizes between 83 and 127 mm CL (inclusive). We have limited information on the fishery selectivity due to reasons other than gears and regulations. We assume that this general selectivity follow log-normal distribution with mean of 4.745 and standard deviation of 0.5. This assumption implies that the general selectivity is low for large and small lobsters, but high for medium sized of lobsters, which is consistent with the field observations that small and large lobsters tend to stay in more complex habitats and are thus difficulty to be targeted and caught. The fact that the fishermen tend to set up their traps in places where they are most likely to capture legal sized lobsters (i.e., medium size ranges) also qualitatively supports this assumed distribution. In fact, because of regulation selectivity is 0 for lobsters with size ranges outside of 83 to 127 mm, the general selectivity is only effective for the legal sized lobsters.

Fishing mortality rate

Because of selectivity and conservation measures used in the fishery, the fishing mortality may not lead to landings in the fishery. We used nominal fishing mortality to define encountering rate, which describes the rate of lobsters encountering traps, and is assumed to be the same for female and male lobsters. The actual fishing mortality is the nominal fishing mortality rate discounted by various selectivity processes and returns of lobsters to sea due to conservation measures. The high and low nominal fishing mortality rates are 0.8 and 0.4, respectively. Fishing effort varies greatly among seasons corresponding to the intensity of lobster activity. Because we calculate fishing mortality for a year period of time, but time unit used in the Simulator is season. We need to divide fishing mortality among seasons using seasonal distributions of fishing effort. Based on historical catch data and their relative seasonal compositions, we assume the following season distribution of fishing effort in a given year: spring=0.08, summer=0.32, fall=0.58, and winter=0.02.

Evaluation of key factors on lobster population dynamics using the Simulator

Eight scenarios were considered in using the Lobster Simulator for testing impacts of various life history and fishery processes (Table 1). For scenario I, we show how one cohort of lobsters changes in size over time, which can help understand the potential interactions between growth and maturation. We use Scenario II to illustrate the impacts of natural mortality on the dynamics of lobster cohort. Scenario III has a constant recruitment with natural and fishery mortality. By comparing Scenario III and IV, we can show the impacts of V-notching on the population dynamics. Scenario V should the impacts of an increase in natural mortality on population dynamics. Scenario VI shows the impact of sudden changes in recruitment (a sudden decrease of 50%). Scenarios VII and VIII show the impact of changes in molting increment and size at maturity, respectively. By comparing the results for Scenarios VII and VIII with Scenario III, we can identify how an increase in growth (VII) and early maturation (VIII) may influence the population dynamics.

To simulate a fishery as realistically as possible, we started with 25 years of lobster population dynamics with constant recruitment and without fishing mortality to make the population approaching equilibrium. The fishery was then simulated according to the conditions set for each simulation scenario (Table 1) starting in year 26 and complete in year 100.

Results

The dynamics of total stock abundance and sex ratio varied with scenarios (Fig. 3). Stock abundance and sex ratio did not change over time for Scenario I because the cohort was subject to no mortality. The stock abundance decreased exponentially for Scenario II, and only a small number of lobsters were still alive at the end. For this scenario, the sex ratio did not vary much in the beginning when the abundance was high, but moved away from 0.5 when the abundance was low, suggesting there were more females than males. This resulted from a slightly higher overall natural mortality for males because mature females molt less frequently than mature males due to maturation and are thus subject to small molting natural mortality. Under the constant R and natural and fishing mortalities, total abundance tended to reach equilibrium over time and sex ratio slightly favored for females (Scenario III). The total abundance tended to be slightly lower and sex ratio closer to 1:1 if there was no V-notching practice in the fishery (Scenario IV). As expected, an increase in natural mortality reduced the total abundance, but increased the proportion of female lobsters in the population (Scenario V). The total abundance decreased with decreasing R with sex ratio moving to above 0.5 (Scenario VI). Changes in molting increment (Scenario VII) and maturity size (Scenario VIII) seemed to have little impacts on the abundance, but a decrease in size at maturity influenced the sex ratio with more females in the population, probably as a result of the protection of females in smaller sizes.

The average inter-molt duration was mainly influenced by the maturation and mortality rates (Fig. 4). The plot includes the theoretical inter-molt duration which was calculated from molting probability of lobsters in a given size without considering the impacts of maturation. For a given size, the theoretical inter-molt duration was compared with the inter-molt duration calculated as an average, for females and males separately, of time durations that all individuals of the given size took between the two molts. In the case with no mortality, females had longer inter-molt duration than theoretical one because of impacts of maturation while inter-molt duration for males was identical to the theoretical one (Scenario I). In the presence of natural mortality, average inter-molt duration become shorter because individuals that have longer inter-molt duration is more likely to die before molting (Scenario II). Fishing could influence the inter-molt duration of lobsters of legal size ranges (Scenario III). An increase in molting increment tended to result in an decrease in inter-molt duration only for legal-size females (VII). Changes in size-at-maturity could only affect intermolt duration of females, with a decrease resulting in an increase in the duration mainly for legal-sized lobsters (Scenario VIII).

The average carapace length of lobster population could be influenced by mortality, maturation, and V-notching (Fig. 5). For the first two scenarios, the average CL increased with time as the cohort of lobster advanced in size over time. Females tended to have smaller average CL because they had longer average inter-molt duration and made fewer molts, compared with males. For the scenarios with constant recruitment, the average CL increased initially and reached the highest value, followed by a slide decrease, leading to asymptotic level. Fishing mortality reduced the average CL of both females and males. The reduction was larger for males because V-notching protected certain portion of females from fishing mortality (compared III with IV). Without V-notching, the average CL of females and males became almost identical (Scenario IV). For the scenario of increasing natural mortality, the difference in the average CL between females and males was also becoming smaller (Scenario V). Both recruitment and molting increment had the impacts of the average CL (Scenarios VI and VII). The decrease in size at maturity (Scenario VIII) made more female lobsters being protected in V-notching process, which results in large differences in the average CL between females and males.

The dynamics of female ratios in the population and landings could be influenced by many factors (Fig. 6). Because of V-notching which was only applied to female lobsters, the sex ratio of population was biased toward females and the sex ratio of landing was biased to males. However, without V-notching (Scenario IV), the sex ratio became almost 1:1 for both population and landing. Increasing natural mortality reduced the bias of sex ratios of population and landing (Scenario V). Reduction in size at maturity affected V-notching which in turn biased the sex ratio of population towards females and sex ratio of landing towards males (Scenario VIII).

The proportion of V-notched females in the population was 0 for the first 100 seasons because there was no fishing mortality and no lobster could be caught and V-notched. After the first 100 seasons, the proportion of V-notched females in the population increased initially with fishing mortality, followed by a decrease, and then approached to a stable level (Fig. 7). An increase in natural mortality tended to reduce the proportion of V-notched females (Scenario V). A decrease in size at maturity tended to increase the proportion of V-notched females in the population, but did not have a large impact on the ratio of V-notched females and mature female abundance (Scenario VIII).

The dynamics of spawning stock biomass (SSB) were also influenced by factors identified in this study (Fig. 8). In the absence of any mortality, the SSB from one cohort increased exponentially (Scenario I). For other scenarios, the SSB increased in the first 100 seasons when there was only natural mortality, and followed by a decrease in SSB as a result of fishing mortality. Lack of V-notching practice reduced SSB (Scenario IV). An increase in natural mortality reduced SSB (Scenario V). An increase in molting increment and a reduction in size at maturity also resulted in an increase in SSB (Scenarios VII and VIII).

Discussion

The simulation results show that the proposed Simulator performs well in describing the population dynamics of the lobster. Many results derived in the simulation can be qualitatively expected, which suggests that the Simulator can yield results that are biologic al realistic. The simulation helps us better understand the interactions of various key processes in life history and fishery and how they may affect the population dynamics.

With a constant recruitment, all parameters evaluated in this study can reach a stable value after 25years except for SSB which needs more time to reach equilibrium. This may result from SSB being more related to size structure than other parameters. Size structure tended to take more time to reach a stable state, compared with other parameters.

Average inter-molt duration is one of most important parameter in determining the growth of lobster. Growth of female lobsters is influenced by maturation. This makes the average inter-molt duration of females longer than the theoretical one and that for males. The largest differences between theoretical inter-molt duration and that of females at around 100mm may result from the highest proportion of females lobsters that bear eggs and take long time to molt at the size. The average inter-molt duration appears to be affected by level of mortality (Fig. 4). If there is mortality, the average inter-molt duration of both females and males differs from the theoretical one. Thus, when we estimate the inter-molt duration or molting probability in a given time period and size class, we need to consider the impacts of mortality.

The dynamics of average CL of the population is an important population characteristic. This study shows, not surprisingly, that it can be affected by factors such as fishing mortality, recruitment, molting increment, and V-notching. This may suggest that we should monitor the changes in average CL of the lobster population, which may allow us to identify some key changes in lobster population structure due to fishing and recruitment. By comparing Scenarios III and IV, we can find the impacts of V-notching on various key population and fishery parameters. The impacts of V-notching on the total abundance and catch are small (Fig. 3 and 9), but on female ratio of both population and catch are large. It can also affect SSB. No functional relationship is assumed between SSB and recruitment in this model. Thus, SSB does not change recruitment. If recruitment changes with SSB, the impacts of V-notching could be larger than what we observed in this simulation. V-notching is also found to be effective in maintaining a higher average CL of females. The difference in female ratio between the population and landing also reflects the impacts of V-notching measure. Thus, this study shows V-notching is a useful and effective managing strategy for conserving the lobster population.

This study shows the interactions of various key life history and fishery processes and how such interactions may influence the population dynamics. the study also shows how important some key life history and fishery parameters are in determining the population dynamics of lobster. The impacts of some factors such as natural mortality and recruitment are simple and can be expected, but impacts of others may not be so obvious such as growth and V-notching.

Many mathematical models have been developed to describe the dynamics of fish populations. For a given fishery, an optimal model can only be identified through an extensive simulation study. Only through an extensive simulation study we can identify if a stock assessment model performs well in describing the dynamics of a fish population, quantify the impacts of quality and quantity of input data on the assessment results, and identify when the model may fail (NRC 1997, 1999). Without such a study, we only have limited knowledge about the performance of a population models in describing the lobster population dynamics. This study, however, cannot be done with actual data because we don't know the true population dynamics of an actual fishery.

To evaluate and compare he performance of these models in describing the American lobster population dynamics, a simulation study is necessary. Thus, for the American lobster, we need to simulate a lobster fishery using information collected in the lobster fishery, and then apply all candidate stock assessment models to the simulated lobster fishery and compare their performance in retrieving the key parameters that characterize the population dynamics of simulated lobster fishery and are built-in in the simulation. Because this is a simulated lobster fishery, we know the true fishery parameters. By comparing the true parameters with those estimated using the two assessment models we can identify which model can retrieve the true fishery parameters (and thus performs better). We can simulate a series of “lobster fishery” with different temporal variations in key fishery parameters (e.g. abundance, fishing mortality, recruitment etc.), and apply candidate models to all these fisheries.

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Table II-1. The description of simulation scenarios. Fishing mortality starts after the first 25years in Scenario IV-XII.

Scenarios	Description	Purpose
I (I)	One cohort without any mortality	Interactions between growth and maturation
II (II)	One cohort with constant M	Impacts of M on cohort
V (III)	Constant R with M and high F	Impacts of M and F
VI (IV)	As scenario V but without V-notching	Impacts of V-notching
VII (V)	As scenario V but M increase once and decrease back	Impacts of changes in M
VIII (VI)	Constant R followed by a sudden decrease in R by 50% with high F	Impacts of changes in R
X (VII)	As scenario V but with a 2mm increase in increment/molt	Impacts of changes in growth
XII (VIII)	As scenario V but length at maturity L50 was reduced by 10%	Impacts of changes in maturation

Figure II-1. Flowchart of the Lobster Simulator. The t_{max} is the maximum inter-molt duration.

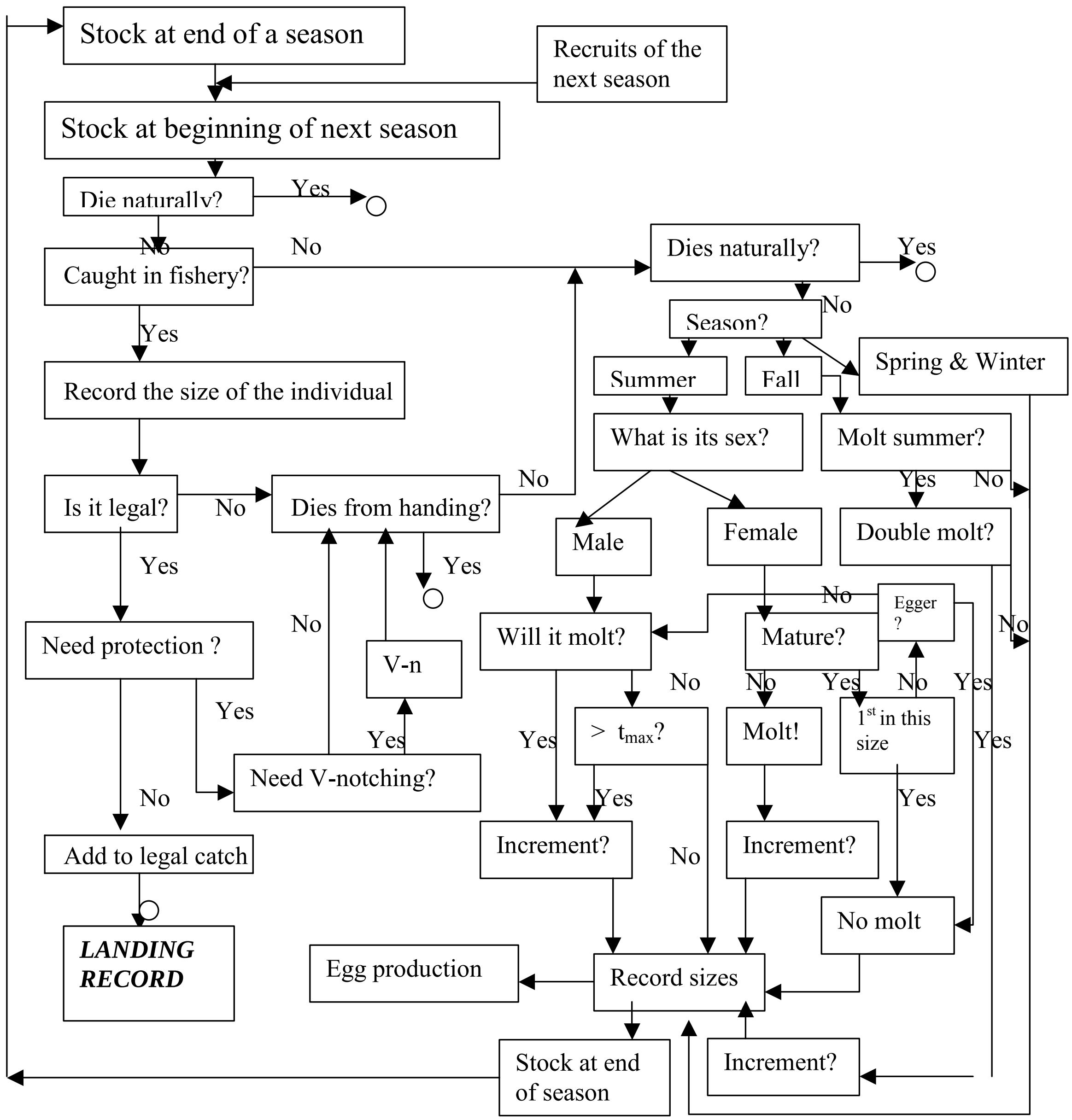


Figure II-2. Size-specific molting probability. Individuals with CL smaller than 70mm has the same molting probability as that for 70 mm and ones with CL larger than 129mm has the same molting probability as that for 129mm.

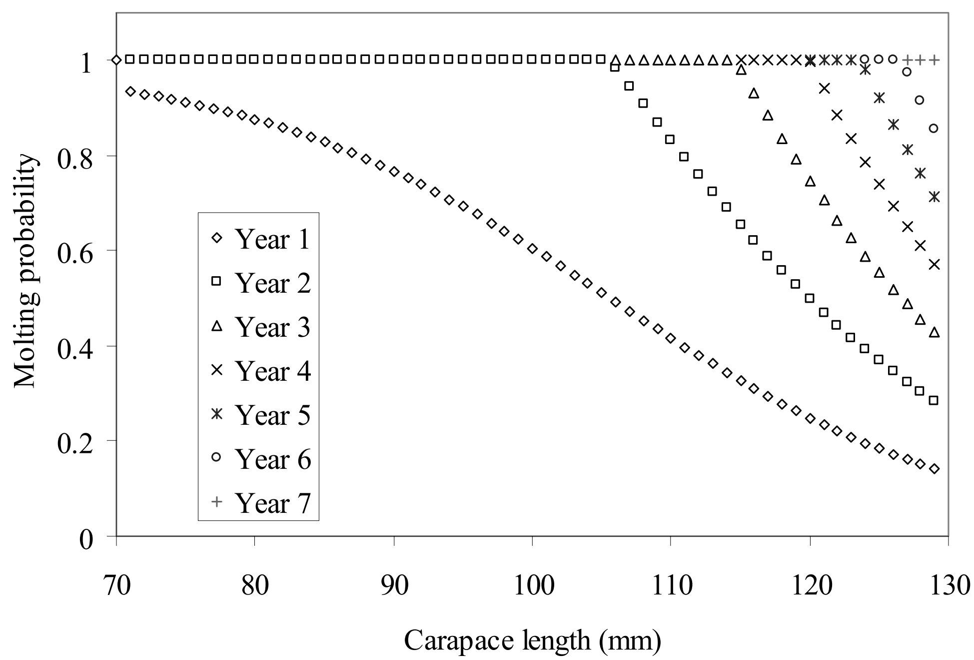


Figure II-3. The dynamics of total stock abundance and sex ratio for different simulation scenarios.

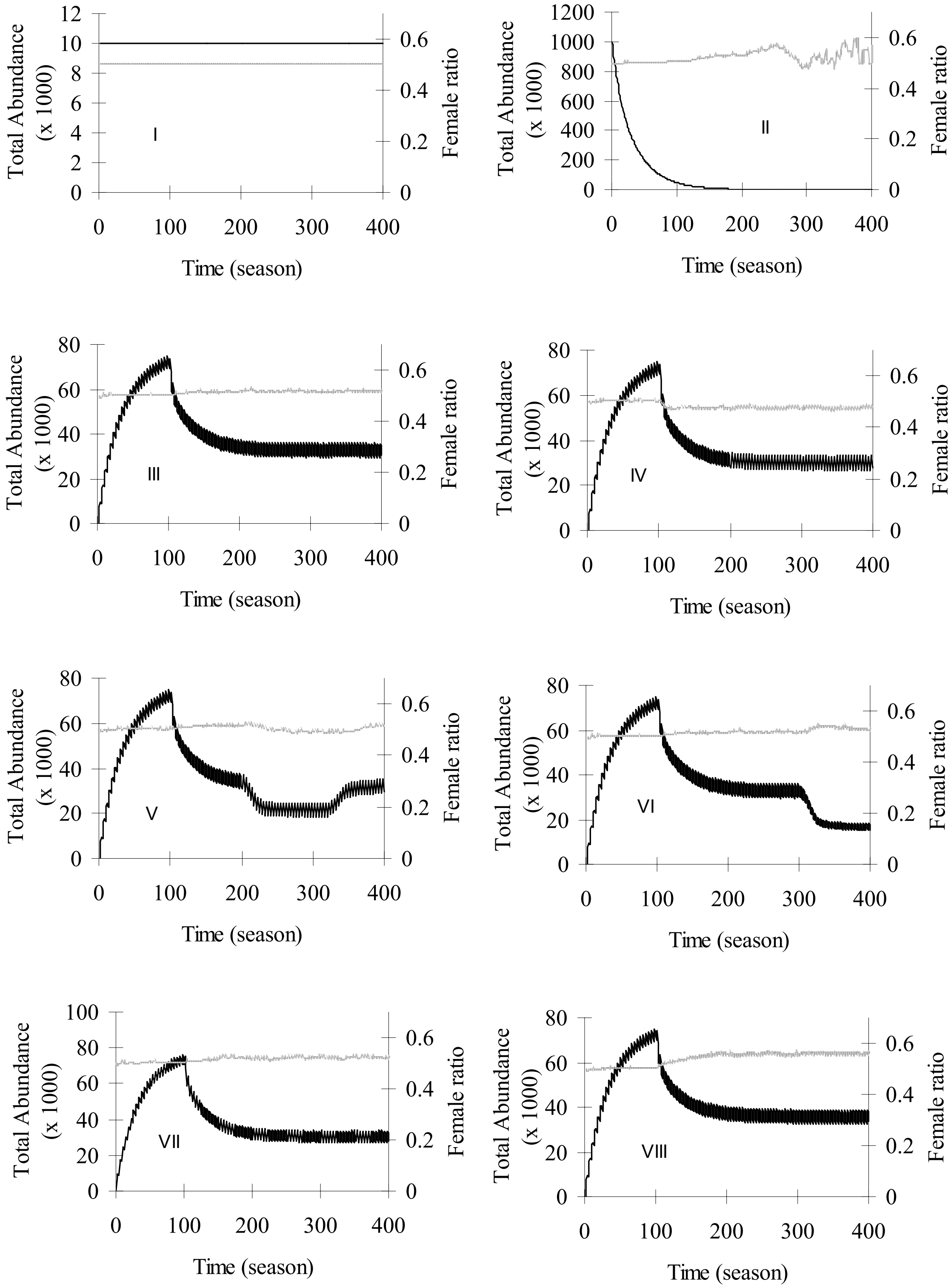


Figure II-4. The average inter-molt duration calculated for different simulation scenarios.

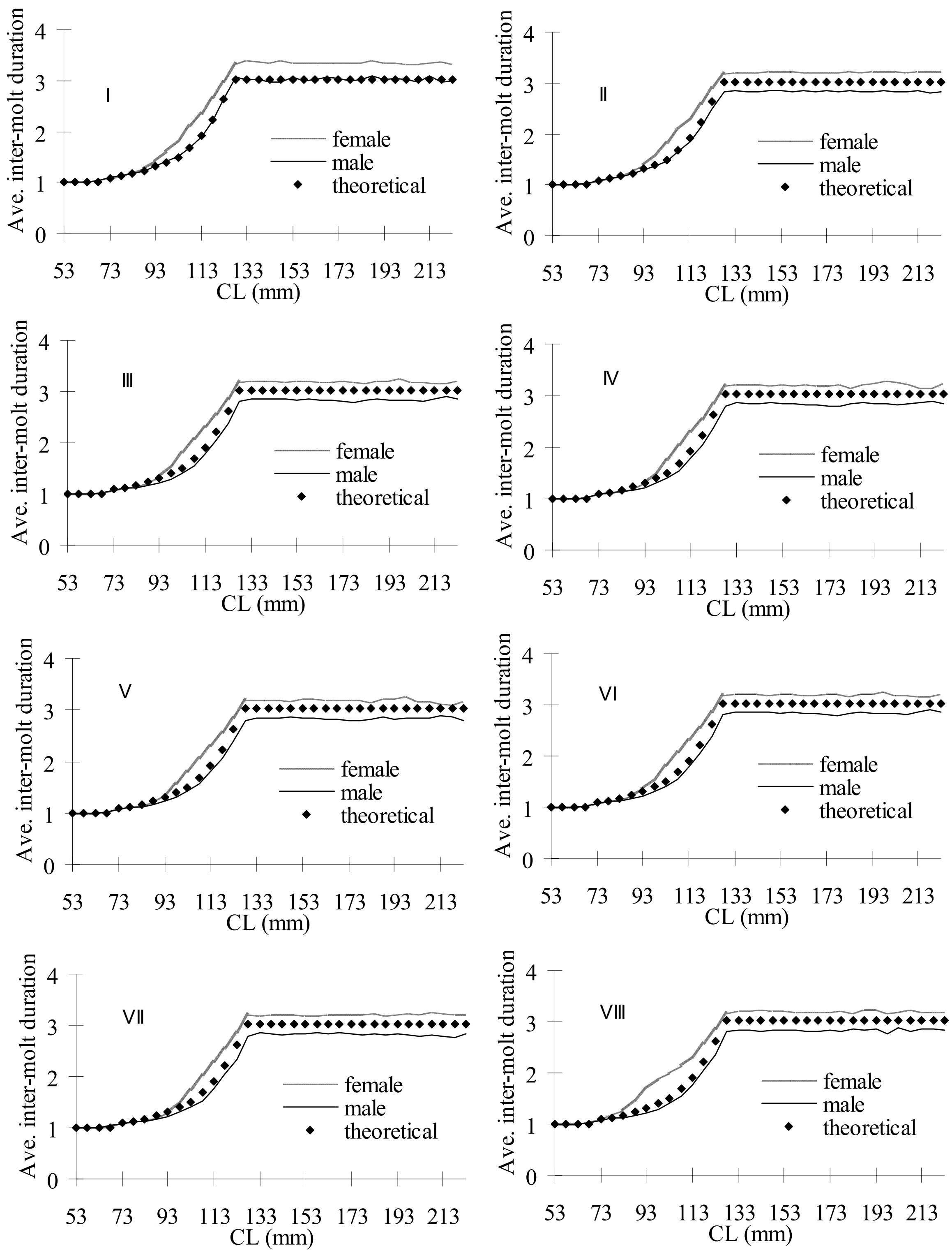


Figure II-5. The average carapace length of lobster in the population for different simulation scenarios.

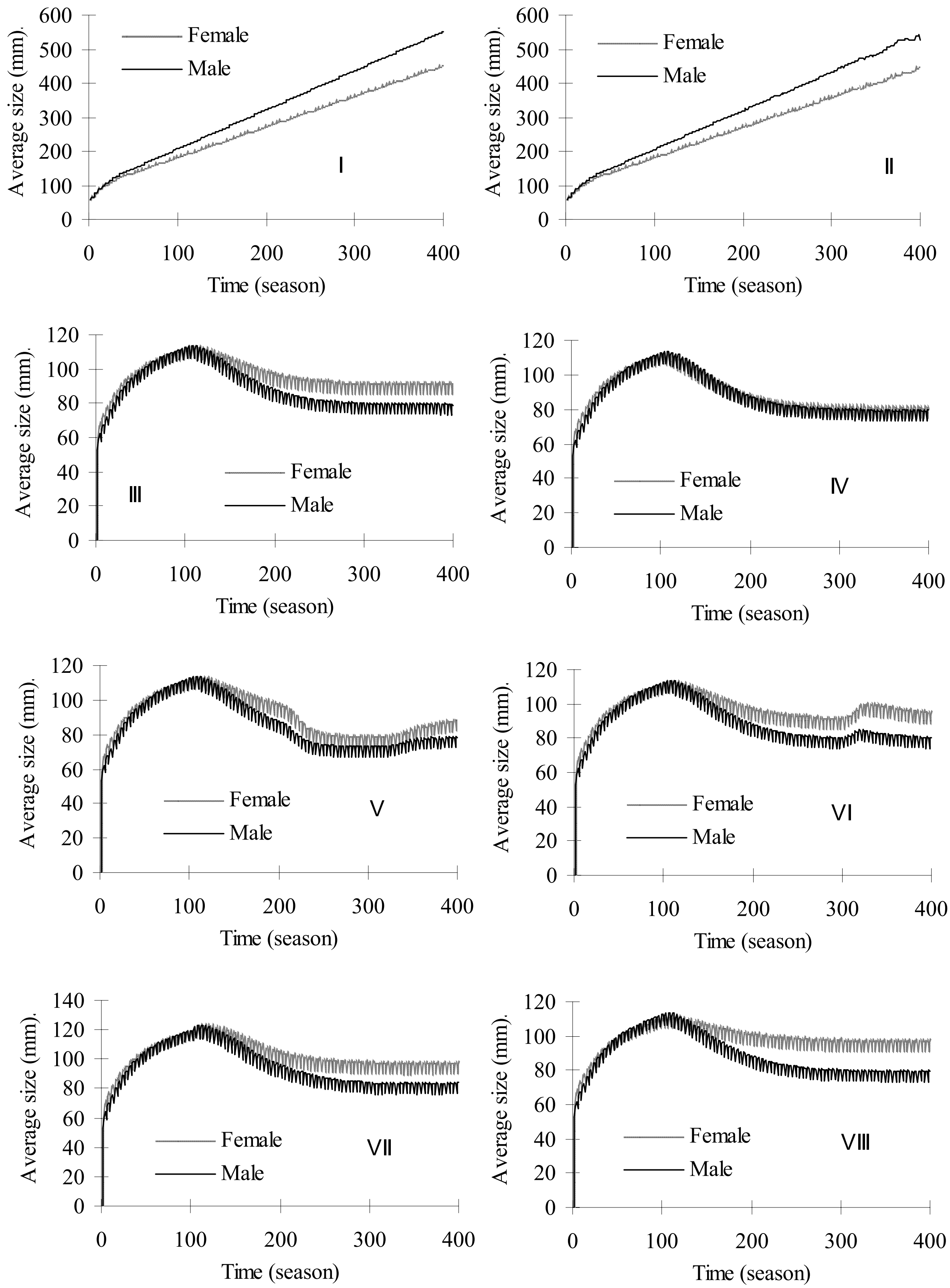


Figure II-6. The dynamics of female ratios in the population and landings for different simulation scenarios.

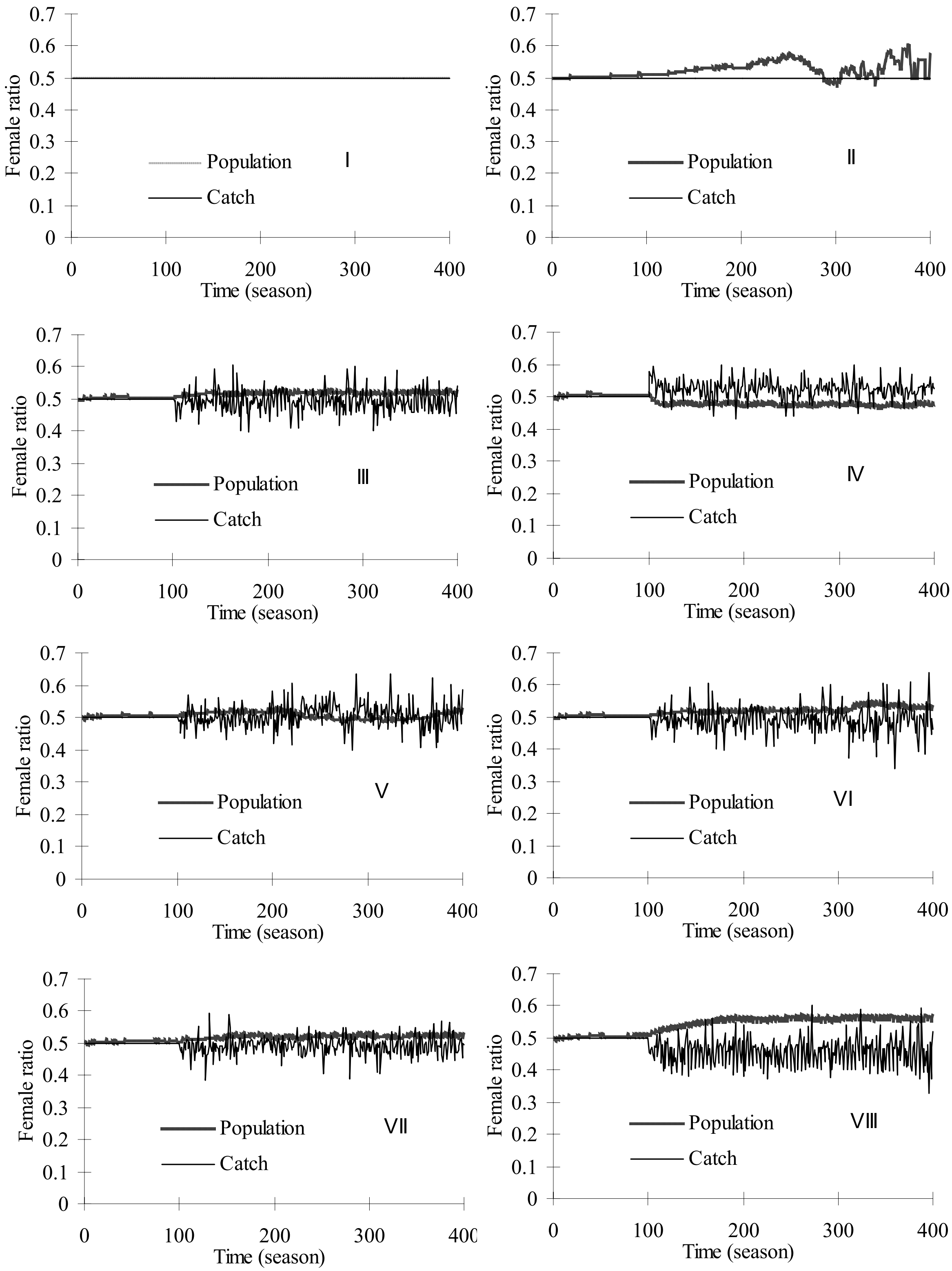


Figure II-7. The dynamics of the proportion of V-notched females in the population for different simulation scenarios.

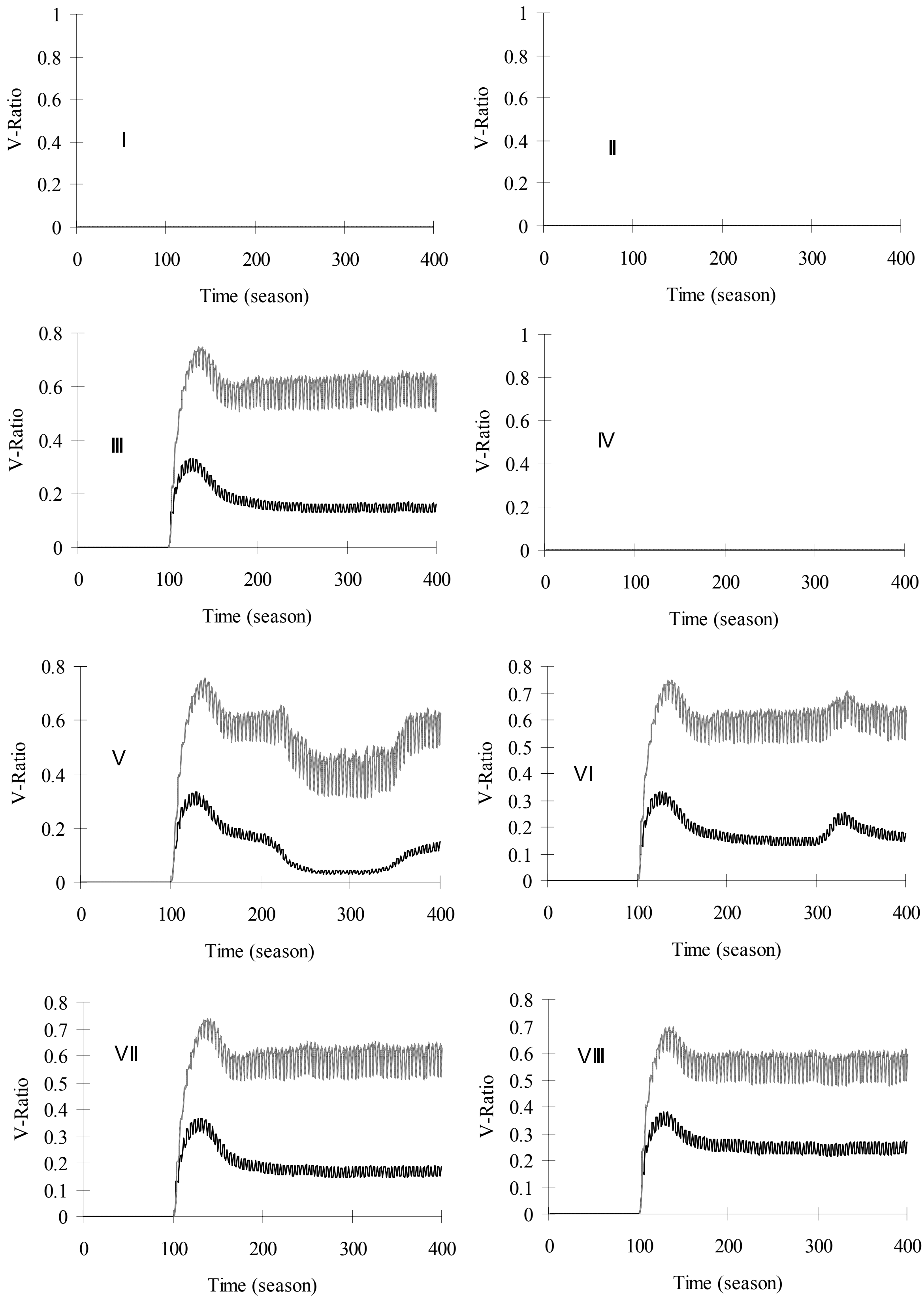
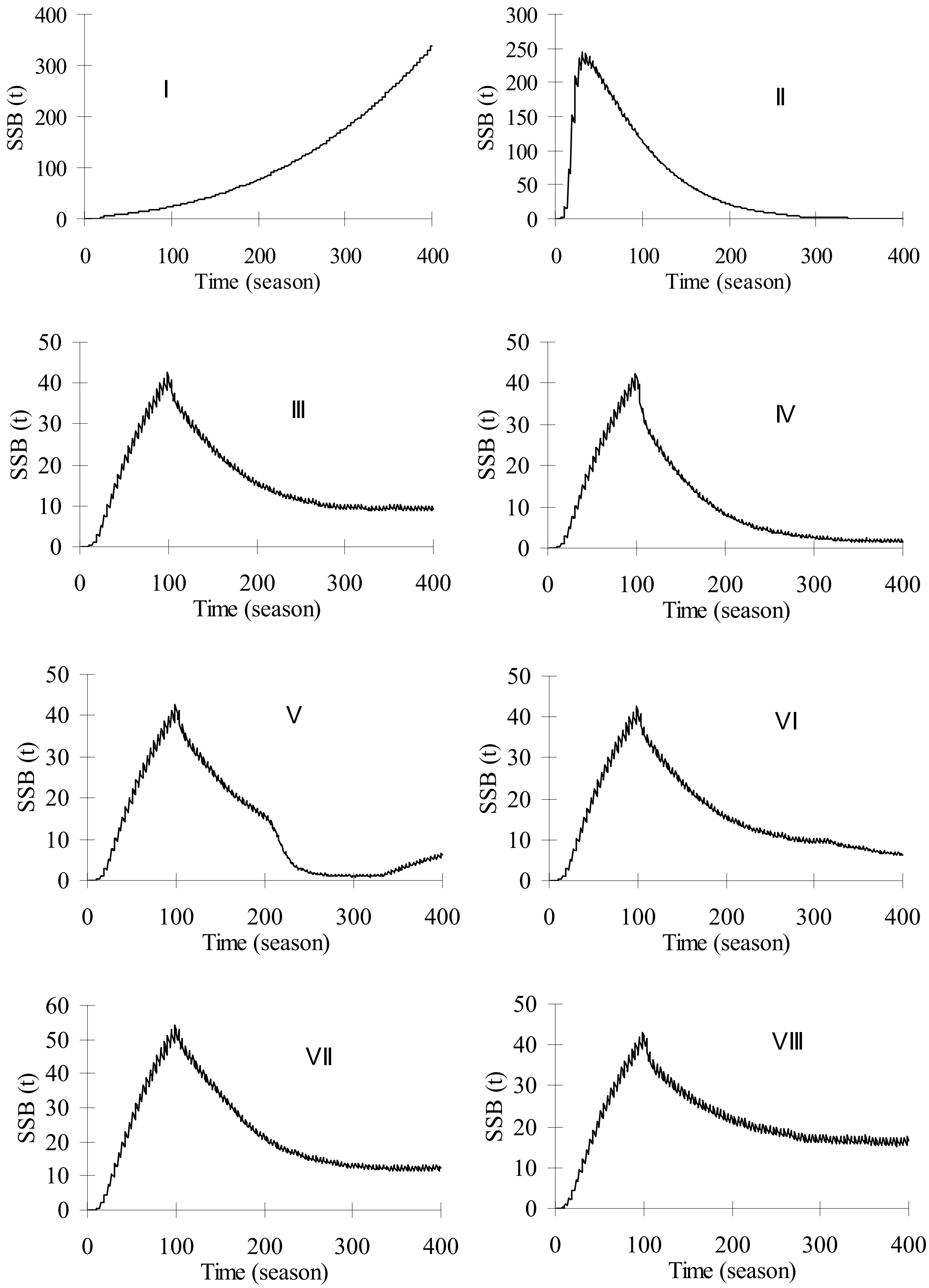


Figure II-8. The dynamics of spawning stock biomass for different simulation scenarios.



Appendix III: Egg Per Recruit Model

Introduction

A cohort simulation model, using population dynamics parameters for lobsters, was developed to examine current as well as additional biological reference points of lobsters (e.g., yield and egg production) under different life history patterns and/or management and harvesting regimes. This is an extension of the model used and reviewed in recent assessments of American lobsters (NEFSC 1996; ASMFC 2000). The model can be used to examine reference points and analyze complex management measures. This model version also includes simulation of male life history providing opportunity for a more comprehensive evaluation of yield reference points.

Model Overview

Conventional egg production(or SSB) and yield per recruit models are not useful for lobster because age determination is difficult, growth in length is not continuous and the relationship between size and annual egg production is complicated. The model used in this study (Idoine et al, in prep) incorporates sex and size-specific annual molt probabilities, assumptions about intermolt duration, molt increments, maturity schedules, fecundities and length-weight relationships. Calculations incorporate interactions between reproduction and growth (e.g. female lobsters suspend molting and growth when they are carrying eggs); size specific management measures (e.g., harvesting gear retention based on escape vents; and maximum and minimum size regulations), as well as temporal (within year) harvesting strategies (e.g., seasonal differences in effort intensity). This description has emphasis on the model itself and not the values of specific input parameters.

General Components:

- Discrete growth of lobsters is determined by molt increment and molt frequency.
- The molt increments are sex and size specific distributions of lengths, with associated probabilities.
- The molt frequency has two components, the maximum interval (or intermolt duration), and the proportion of lobsters of a given size that will molt each year
- Maturity and molt frequency interact (molt frequency decreases with the onset of maturity and size). For females, egg production generally occurs during the second year at size, therefore precluding molting in the first year at size for mature females.
- Sex and size specific vulnerability to removal by fishing as well as other management protections (e.g., egg bearing and v-notch prohibitions; minimum and maximum size; slot limits) are incorporated.
- Seasonal partitioning of fishing effort and life history events.
- Capture rates are determined by the product of retention by gear (traps) and a nominal fishing (or encounter) rate.
- F and M are calculated at the end of each model run.

Model Specifics

Each model run is based on a cohort that includes both male and female lobsters. The size groups are 1mm carapace length (CL) . The model simulates growth and mortality and keeps track of the number of survivors, number of natural deaths, numbers landed, number mature, number v-notched, number molting and egg production by sex and size group in each time step over the lifetime of the cohort. The use of a monthly time step allows investigation of temporal aspects of fishing strategies' implementation of management measures and seasonal biological characteristics. The interannual relationship of fishing and lobster growth and reproduction may also be examined.

Model Inputs and Parameters

Time Steps

The model is currently parameterized to incorporate from 1 to 12 defined time steps within a year. The obvious constraint is that the total proportions of interannual time steps sum to 1.0.

Nominal Encounter Rate:

The nominal encounter rate is a measure of the rate at which individual lobsters encounter and enter traps.

Time Step Distribution Of Capture Rate

The model requires the user to partition annual nominal encounter rates by time step. This is analogous to the partitioning of effort during a year.

Maturity

Maturity in this model refers to functional maturity (Idoine 2003, see Appendix B) for both females and males. Therefore, the model assumes that if a female molts into a size at which she becomes mature, she will mate, and if she survives, extrude eggs the following year and hatch those eggs within approximately nine months after extrusion. It is also assumed that there are sufficient capable males to perform the necessary matings to achieve this. Currently, the only male life history change for the onset of maturity is in terms of molting frequency

Natural Mortality

Natural mortality for lobsters in the model is partitioned into hard shell and soft-shell components. Soft-shell natural is applied only during time step when a lobster molts. Lobsters that do not molt in a particular year are affected by only hard-shell mortality. Lobsters that molt are subjected to an additional soft-shell mortality at the time of each molt. Small lobsters molt more frequently than large lobsters and therefore have a higher natural mortality rate in the model. Average (abundance weighted) natural mortality rates are calculated for the cohort of lobsters (by sex and for sexes combined). The input hard-shell and soft-shell mortality rates are size and sex specific, but are germane only to lobsters of that sex and size, the population rates are the result of the resultant size structure from the lifetime of the cohort.

Growth: Molt Increments

These are the assumed increases in size gained by a molt. These can be described as discrete (a single value) or a distribution of values with associated probabilities. These are input as size and sex specific parameters.

Growth: Molting Frequency for Lobsters

The frequency of molting is affected by a combination of several factors. At small sizes lobsters molt many times a year, but the frequency declines as size increases. Within the size range currently used in the model (> 50 mm CL), it is assumed that there is a maximum of two molts per year (see double molting below). The model assumes that immature lobsters will molt at least once every year. With the onset of maturity, an increasing fraction of energy reserves are devoted to gonadal rather than somatic growth. For female lobsters this process abruptly shifts the minimum intermolt duration to two years (mature lobsters molt, mate, wait a full year, and then extrude eggs, consequently mature lobsters have a minimum of a two-year intermolt period). Male lobsters also increase their intermolt period, probably due to maturity. However, it is not assumed that they follow the path of females and forgo molting in the first year at size. There are no eggs involved, so the slowing of growth is less pronounced for males.

Another factor affecting molt frequency is the maximum intermolt period, defined as the longest amount of time a lobster of a given size will take to molt. Research from Canadian stocks (D. Pezzack, DFO, pers. comm.) indicated that the absolute maximum intermolt period should be no more than seven years, based on the need to replace the carapace due to injury, fouling, wear, vulnerability to disease and other factors. For a discussion on methods used to determine these values see the 2000 ASMFC assessment report (ASMFC 2000).

Molt frequency then depends on the maximum duration at a given size and the proportion of lobsters that molt during each of those years (the annual molt probability).

Escape Vent Retention Rates

Size-specific retention rate parameters define the probability of lobster retention by the gear (traps) given encounter. Escape vents are designed to allow lobsters below the minimum legal size to escape. Based on studies by Massachusetts DMF and Maine DMR (Krouse et al, 1994,1998; Estrella and Glenn 2003), the size specific retention rates for various escape vent configurations can be used to define this. Currently, the model does not address the reality that the use of escape vents can actually increase the effective effort of harvesters by reducing cull time. It is also assumed that this rate applies to all encounters (e.g., a lobster that escapes from one trap does walk into another and get caught.

V-Notching

V-notching is the practice of marking lobsters by cutting a notch in their tail. By regulation, v-notched lobsters cannot be landed. The model assumes that some berried females that are captured are V-notched and those are always returned alive to the water. In the model it is also assumed that the V-notch mark is discernible (legally) through two molts, and all V-notched animals are fully protected. Two parameters are used to simulate V-notching in the model. The first parameter measures the proportion of lobstermen that V-notch. The second parameter measures the proportion of ovigerous females that are captured by practicing lobstermen and actually V-notched (i.e. the conditional probability of V-notching given capture by a fisher that V-notches).

Minimum/Maximum Size Limits

Regulations can limit the minimum and or maximum size of lobsters landed. Similarly to the v-notch regulation, these can be specified, based on the proportion of the stock that affected by this measure.

Fecundity

The number of eggs expected to be produced (on average) by a female of a given size.

Length-Weight Relationship

The expected weight (in g) for a given size (mm CL) and sex lobster.

States and Movement:

Females

The model has seven states that define female lobster life history. The numbers of lobsters in each state and time step are tracked separately.

1) GP: general population… these may be immature or mature, but not mated, egg bearing, nor v-notched. GP lobsters that are captured are protected from harvesting only by size limits.

2) KU: internally fertilized. A mature lobster, just molted and presumed to have mated. No protections from harvesting other than size (see GP's above).

3) EB: Egg bearing, having extruded one year after mating (KU's transition into EB's). In the US and Canada, EB's are protected from harvest, in the UK/Irish fishery for *H. gammarus*, this protection does not exist. This protection could be modified/reduced to examine less than 100% adherence to the regulation. EB's remain in this state until hatching, and those EB's that survive will hatch their eggs at that point and contribute to the cohort egg production.

4) VN: v-notched lobsters. These are EB's that have notches applied at a rate equal to the product of a notching rate and the capture rate (applied to the proportion of EB's encountered in the traps). Eggs are released from the VN's at hatching (just like the EB's). Since VN's came from EB's, they start in their second year at size. The model assumes the notch lasts 2 molts, and in those areas where it occurs, VN's are protected from harvesting.

5) KUVN: v-notched lobsters that have molted once moved into the second molt of the notch's lifespan, and because they are mature, will mate.

6) VN_2: KUVN lobsters that released their eggs and did not molt are in the second molt of the notch's lifespan. When they molt, the notch disappears (as far as protection is concerned) and they will mate and become KU's, with the vulnerability described in (2) above.

7) DM: double molters, immature lobsters that molt twice in one year. It is assumed that immature lobsters molt every year, and some molt twice.

Males lobsters are described using two states:

1. GP: general population… these may be immature or mature. GP lobsters that are captured are protected from harvesting only by size limits.

2. DM: double molters, immature lobsters that molt twice in one year. It is assumed that immature lobsters molt every year, and some molt twice.

The basic flow of animals between states is as follows:

For Females:

1) Lobsters that molt from the general population (GP) will, if mature, mate, thereby becoming internally fertilized (KU). If they are immature, they will remain GP's for additional years based on the molt probability/maximum years to molt schedule.

2) KU's that survive become egg bearing (EB), in their 2nd year at size (assuming they take a bout a year to extrude).

3) EB's may become v-notched (VN) or remain EB's for nine months of their second year at that size. After releasing their eggs, they return to GP's at second year at size. The following year they may subsequently molt and mate (they are mature), or remain at size for additional years based on the molt probability/maximum years to molt schedule.

4) VN's are generated from EB's, and therefore at least in their second year at size. During the first 9 months of that year, they are also egg bearing. The year following their egg release they may molt and mate (they are mature) to become internally fertilized v-notched (KUVN), or they may stay at size for additional years based on the molt probability/maximum years to molt schedule.

5) VN_2 are mature females that have had a notch for 2 molts. They are assumed to be mature (since they have already carried eggs) and therefore, when they molt they will lose their notch, and will mate and become KU's.

6) Double molters (DM) are special cases of GP's that are immature and molt twice a year.

This is shown in Figure 1.

For Males:

1) Lobsters molt from and remain in the general population (GP) with the exception of those molting more than once a year (DM's)

2) Double molters (DM) are special cases of GP's that are immature and molt twice a year.

Life History Events

There are six events that control the life history in this model. They are:

1) Primary molt: This defines the molting period during the year for those lobsters that are going to molt at least once in a given year. The first (or only) molt of the year will occur during this period. This event can be discrete (i.e., all animals subject to it will molt at once) or protracted (molting will occur over multiple time steps). Currently this is parameterized as a cumulative probability. For example, if it is assumed that molting occurs over three months, the inputs would require the percent of molters molting in the first month; the percent of those remaining that will molt in their second month and the remainder in the final month. The final month value, therefore, must be 1.0 to molt all remaining lobsters scheduled to molt. This event is parameterized for males and females separately, and thereby molting can be synchronous or staggered by sex.

2) Second molt: This defines the second molting period of the year for those lobsters that are going to molt twice in a given year. It is applied only to those lobsters that molted once and are previously parameterized to double molt (see DM's above). As with the primary molt, this can be discrete or protracted. It is also is parameterized for males and females separately, and thereby molting can be synchronous or staggered by sex.

3) V-notching: This is the event that applies a v-notch to egg bearing females (EB's) based on the v-notch rate parameter. It is only applied during time steps in which fishing is occurring. The v-notch rate is the proportion of captured EB's that are notched. Thus the product of the capture rate and v-notch rate in a given time step is applied to the current population of EB's. V-notching is discrete in all of the time steps during which there is fishing effort, there it takes the values of 1.0 or 0.0. Current this event applies only to females.

4) Death: The event determines mortality on all states and during all time steps. Natural mortality is applied (see above) in every time step, but fishing mortality is set to 0.0 in those

time steps during which there is no fishing effort (e.g., closed seasons). This applies to both sexes.

5) Extrusion: This event moves females that have mated previously (KU's) to egg bearing (EB's). As with molting events this may be discrete or protracted.

6) Hatch: This is event that generates egg production (the surviving EB's and VN's with eggs (KUVN's) release their eggs as larvae). EB's return to the general population (GP's) while KUVN's with eggs become VN's without eggs.

Capture rates and Mortalities

The model may be run over a range of nominal fishing values. These values (>=0.0) are modified for each time step (by the percent of annual effort attributed to that time step) and a sex and size selectivity parameter for the trap retention is used in the simulated fishery.

In this model for lobsters, it is important to distinguish between "nominal" encounter, capture, retention and fishing mortality rates.

- The nominal encounter rate is a measure of the rate at which individual lobsters encounter and enter traps.

Capture rates measure the rate at which individual lobsters enter traps without leaving. Capture rates are less than encounter rates because escape vents allow small lobster to leave traps. Capture rates depend, in part, on size because large lobsters are unable to leave traps through escape vents.

The capture rate (cap_f) is defined as :

$$cap\_f_{is,cl,it} = f_{nom} * eff_{it} * pf_{is,cl}$$

Where:

is = sex;

cl = carapace length (mm);

it = the interannual time step;

fnom = the nominal fishing rate;

eff_{it} = the proportion of effort in the it^{th} time step; and

$pf_{is,cl}$ = the retention rate of the gear for sex is, size cl

This describes the rate at which lobsters of a given size and sex will be brought to the surface (handled) to be kept, v-notched (and discarded) or discarded based on management/fishery dependent measures. These capture rates are applied to all lobsters.

- Retention rates are based on management regulations and fishery behavior. Legal requirements (minimum and maximum size, prohibition of landing berried lobsters, and v-notch protections) as well as size specific and/or other quality considerations affect release of captured lobsters. Only those lobsters retained and "landed" are removed from the model population.

When used to generate landings due to fishing, these capture rates are modified by legal size constraints (minimum and maximum); egg bearing and v-notched protections; market considerations such as shell condition (e.g., soft-shell). The applied fishing rate ($f_{is,cl,it}$) is the same as the capture rate (cap_f)

$$f_{is,cl,it} = f_{nom} * eff_{it} * pf_{is,cl}$$

however, in these cases, fishing mortality (f) is applied only to those lobsters vulnerable to being landed. The remainder are discarded and currently are assumed to survive.

Encounter, retention, and landing qualifier parameters in the model can be changed to simulate management measures and/or harvest strategies. This process is equivalent to combining a recruitment vector (or partial f) with a discard rate, in which there is a sex and size specific vulnerability to harvesting. The lobster fishery is more complex. In some populations, legal size restrictions are accompanied by constraints on harvesting certain life history stages (e.g., protection of egg-bearing females). An additional complication is the fact that the egg-bearing period varies with size within a female's duration at a given size. The reproductive cycle of female lobster is assumed to follow a pattern associated with molting. The female molts, and if mature, mates while soft-shelled. She then extrudes fertilized eggs (becoming "berried") the following year. She carries these eggs for approximately 9 – 11 months, releases them as they hatch as larvae. In this general case, the females protection from harvest is only during the time she is berried, or approximately 9 - 11 months of the first two years at a given mature size. As the female gets larger, her molting/mating frequency declines. In this way, the proportion of time spent at size for which protection is afforded to berried females declines as the female gets larger (older). Since females are not berried throughout a given year, the manner in which fishery operates throughout the year can create additional variation in the partial F associated with this protection.

In contrast to nominal encounter and capture rates, fishing mortality rates measure the rate at which lobsters are landed and killed. Fishing mortality rates are usually less (and never greater) than capture rates because management measures (e.g. maximum and minimum size limits, restrictions on landing berried or v-notched females) require that some lobsters caught in traps be released. Market considerations (soft-shell, certain size preferences, etc.) may lead to additional discarding of captured lobsters. At present, the management restrictions on male lobsters are size dependent only. As a result, retention rates and fishing mortality are generally equal. Market considerations (i.e., voluntary discards) could lower the fishing mortality so long as there were minimal mortality associated with discarding.

Calculations of Population Mortality Rates

Population mortalities are calculated at the end of a cohort lifetime. For each year in the life of a cohort, population size, deaths by fishing and natural mortality that occurred during that period are recorded. Mortalities are calculated on legal (or vulnerable) portions of the population by sex, and for sexes combined for each year.

Mortality rates can be calculated in multiple ways based on the information recorded for each model run. A method that casts the solution almost exactly as mortalities are calculated in the CSA is shown below.

Each model year records the number of lobsters (by sex) that:

1. those alive (N_S) at sizes less than the legal minimum (CL_{min});
2. those alive (N_L) at sizes greater than or equal to $CL_{min;}$
3. those that died (D_{SM}) due to natural mortality at sizes less than (CL_{min});
4. those that died (D_{LM}) due to natural mortality sizes greater than or equal to CL_{min};
5. those that died due to fishing (D_{yld})

Utilizing a mass balance approach:

$$N_{S,t+1} = N_{S,t} - D_{SM,t} - T_{L,t+1}$$

where:

$N_{S,t+1}$ is the number of sublegals at time t+1
$N_{S,t}$ is the number of sublegals at time t
$D_{S,t}$ is the number of sublegals that died during time t
$T_{L,t+1}$ is the number of sublegals that grew into legal size between t and t+1 = RECRUITS

$$T_{L,t+1} = abs\left(N_{S,t+1} - N_{S,t} + D_{S,t}\right)$$

and

$$\hat{Z} = -\ln\left(\frac{\sum N_{L,t}}{\sum T_{L,t} + \sum N_{L,t-1}}\right)$$

Summing:

For all time steps (t) where $\hat{Z}$ >0

$$TT_L = \sum T_{L,t}$$

$$TN_L = \sum N_{L,t}$$

$$TP_L = \sum N_{L,t-1}$$

$$TD_{LM} = \sum D_{LM,t}$$

$$TD_{yld} = \sum D_{yld,t}$$

then

$$\overline{Z} = -\ln\left(\frac{TN_L}{TT_L + TP_L}\right)$$

$$\widetilde{M} = \frac{\overline{Z}}{\left(1 + \frac{TD_{yld}}{TD_{LM}}\right)}$$

$$\widetilde{F} = \overline{Z} - \widetilde{M}$$

Biological Reference Points

Biological reference points (e.g. F10%, F_{max}) for lobster were calculated in the Life History model in relation to fishing mortality of the cohort. These F's are comparable to estimates of fishing mortality for lobster stocks from the modified Catch-Survey (CSA) model. They are calculated for males and females separately as well as combined. In addition to egg production and yield per recruit, reference points currently output are measures of relative CPUE (RCPUE), mean size/weight in the landings, revenue per recruit, and landings composition by market category for males and females and sexes combined.

The RCPUE (Figure 2) is a measure of efficiency that is the ratio of two catch per unit effort values within one set of management conditions, or between multiple sets. The unit of effort in this case is the $F_{nominal}$ as a proxy for a unit of effective effort, and the catch is simply the yield achieved by that rate with whatever management measure and harvesting strategies were assumed for the simulation. Comparing the ratios gives an indication of the cost (in terms of effort) of obtaining yield at higher levels of effort. Considering, for example, high and low levels of effort:

$$RCPUE_{L:H} = \left(\frac{Y_L}{f_{nom_L}}\right) * \left(\frac{Y_H}{f_{nom_H}}\right)$$

where:

Y_L is the yield at a low rate of effort

f_{nom_L} is a low rate of effort

Y_H is the yield at a high rate of effort

f_{nom_H} is a high rate of effort

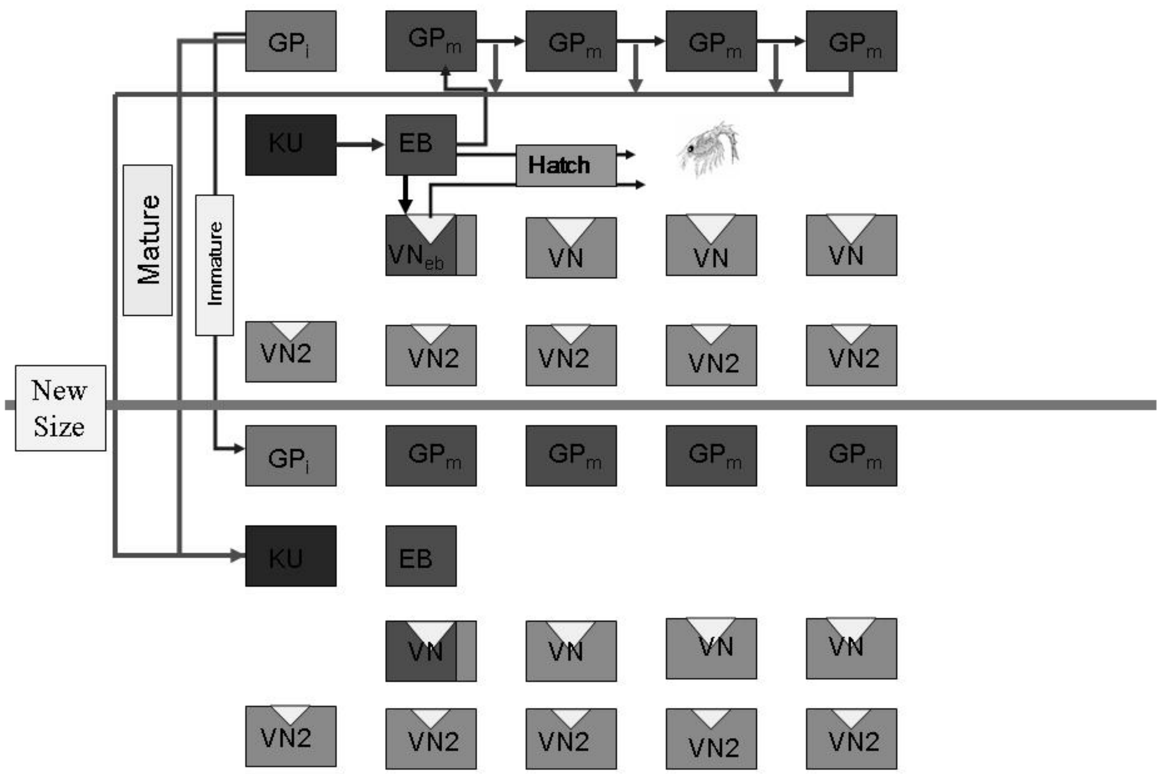


Figure 1. Flow of female lobsters where:

GP_i = General Population immature
GP_m = General Population mature
KU = Mated, but eggs not extruded
EB = Egg bearing
VN_{eb} = V-notched and egg bearing
VN = V-notched (first molt of notch)
VN2 = V-notched (second and last molt)

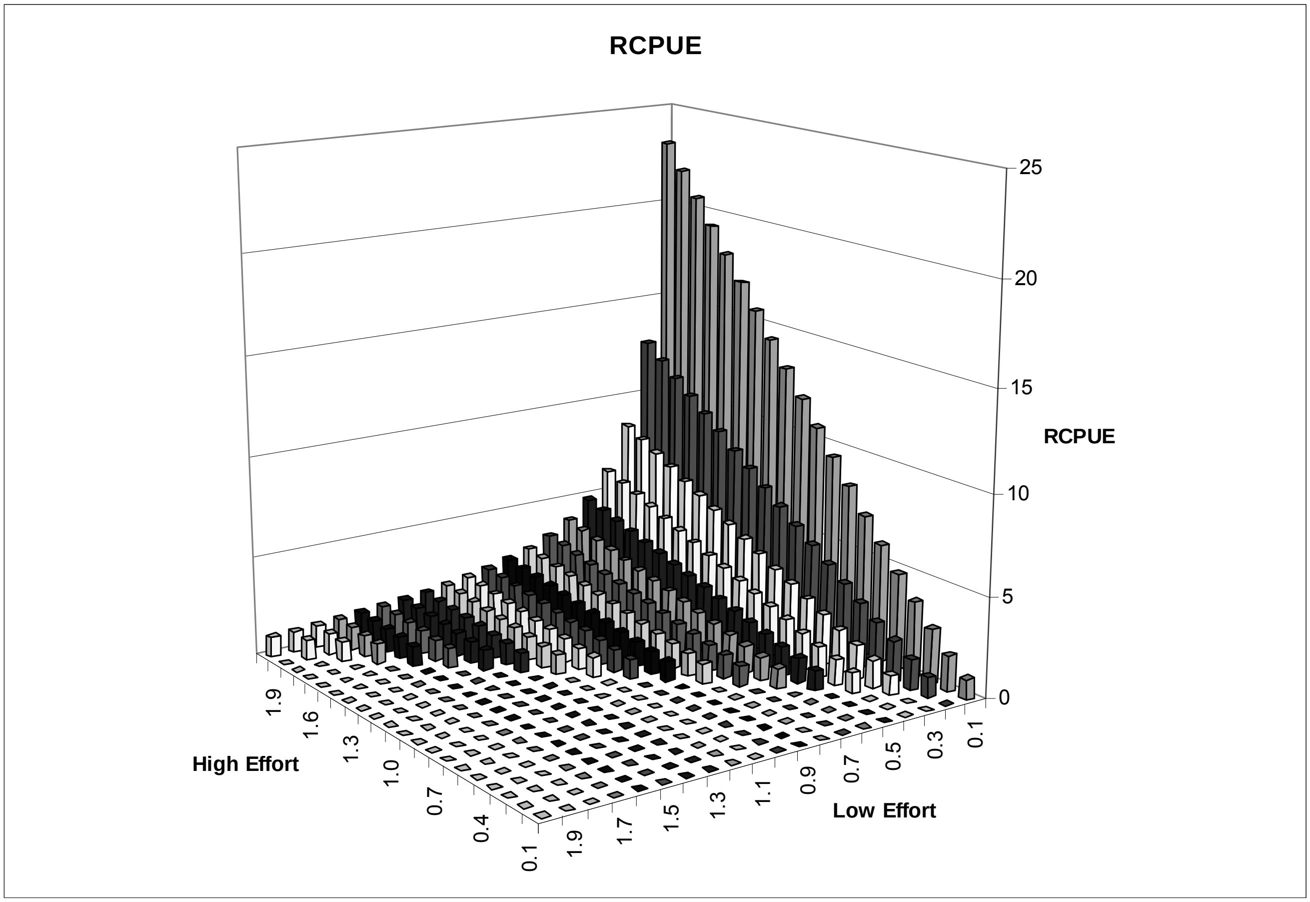


Figure 2: Relative CPUE between low and high fishing effort (see text).

References

ASMFC (Atlantic States Marine Fisheries Commission). 2000. American lobster stock assessment report for peer review. Stock Asses. Rep. No. 00-01 (Supplement). Atlantic States Marine Fisheries Commission, Washington, DC

Estrella, B.T. and R.P. Glenn. 2003. Lobster Trap Escape Vent Selectivity. Completion Report, April 2, 2003. NOAA/NMFS Unallied Science Project. Grant Number NA16FL2446, 34p.

Idoine, J. 2003. The use of maturity information in a current life history model based on the growth of female and male clawed lobster. Pp. 14-15, In Comeau, M. (ed.). 2003. Workshop on lobster (Homarus americanus and H. gammarus) reference points for fishery management held in Tracadie-Sheila, New Brunswick, 8-10 September 2003: Abstracts and proceedings. Can. Tech. Rep. Fish. Aquat. Sci. 2506: vii + 35p.

Krouse, J.S. and M. Brown, K. Kelly, G. Nutting, D. Parkhurst, Jr., F. Pierce, and G. Robinson. 1988. Lobster Stock Assessment Project 3-IJ-6. Maine Dept. Mar. Res. p. 17-19.

Krouse, J. S., and K. Kelly, G. Nutting, D. Parkhurst, Jr., G. Robinson, and B. C. Scully. Maine Department of Marine Resources Lobster Stock Assessment Project. “Gear Selectivity Study”: Annual Report 1993 –1994. p. 18 – 22.

Northeast Fisheries Science Center. 1996. Report of the 22nd Northeast Regional Stock Assessment Workshop (22nd SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. Doc. 96-13; 242 pp.

Appendix A

INPUT FILES:

fort.8:

1) 0 0 0
2) 55 280 1.0 1.0 0.0 0.0 0.5
3) 150 12 0.08333 0.08333 0.08333 0.08333 0.08333 0.08333 0.08333 0.08333 0.08333 0.08333 0.08333 0.08339
4) 1.0 0.0
5) 83 83 127 127 83
6) 0.1281 0.2374 0.2230 0.1873 0.0894 0.0377 0.0104 0.0047 0.0052 0.0122 0.0289 0.0357
7) 5 83 89 95 105 120 2.0 2.2 2.4 2.6 2.8
8) Chix
9) Qtrs
10) Hlfs
11) 2lbs
12) >3lb

1. switches to control what output files are written (under normal conditions: **0 , 1, 0**)

2. minimum and maximum sizes in the population, proportion of minimum mm size legal[1] for males and females; proportion of lobsters at or above maximum size that are legal[2] for males and females; and v-notching rate[3]

3. maximum number of years for simulation to run[4] ; number of time steps in a year; decimal-year duration of each time step

4. proportions[5] of molting mortality applied at size before molt; and after molt

5. minimum legal size (males, females); maximum legal size (males, females); size to use for beginning cutpoint of mortality calculations (usually the same as the minimum size)

6. effort partitioning for time steps defined in (3) above (must add to 1.0)

7. number of market categories, minimum size for each category, $/lb for each category

8. … end names for market categories

Footnotes:
1) if minimum size is not a whole mm (e.g., 3 ¼ in = 82.55 mm) this could be used to apply F to 45% of the 82mm size group, rather than rounding off the minimum size effect to the next highest (83mm).
2) used if only a proportion of the area modeled applies the maximum size (or as a compliance factor)

3) proportion of berried females encountered (in the model) that are v-notched
4) to stop runaway model (lest all lobsters aren't dead by a reasonable time)
5) proportions that die before and after increasing in size

fort.9 ("events.dat")

```
0.25 0.50 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 !#1molt1males
0.0 0. 0.25 0.50 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 !#1molt1females
0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 !#1molt2males
0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 !#1molt2females
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 !#1vnotchmales
1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 !#1vnotchfemales
1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 !#1deathmales
1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 !#1deathfemales
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 !#5extrusionmales
0.0 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 !#5extrusionfemales
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 !#6hatchmales
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0     !#6hatchfemales
```

for each time step (see (3) in fort.8 above):

1. molt1 males: primary molt (cumulative proportion during molting period)
2. molt1 females: primary molt (cumulative proportion during molting period)
3. molt2 males: double molt for the year (cumulative proportion during molting period)
4. molt2 females: : double molt for the year (cumulative proportion during molting period)
5. vnotch males (1 = yes, 0 = no)
6. vnotch females (1 = yes, 0 = no)
7. death males (1 = yes, 0 = no)
8. death females (1 = yes, 0 = no)
9. extrusion males (nonsense… 0… here for symmetry)
10. extrusion females (cumulative proportion during extrusion period)
11. hatch males (nonsense… 0… here for symmetry)
12. hatch females (cumulative proportion during hatching period)

fort.18:

```
1) 55 11
2) 149.38      145.97 142.67 131.12 119.68 104.83 89.98   74.58   59.29   47.3    35.2
3) 55 11
4) 149.38      145.97 142.67 131.12 119.68 104.83 89.98   74.58   59.29   47.3    35.2
```

1. smallest size for initial input, number of consecutive size classes (males)
2. initial input for each size class defined above (males)
3. smallest size for initial input, number of consecutive size classes (females)
4. initial input for each size class defined above (females)

fort.98 (“male.inp”)

1. carapace length; proportion mature; proportion double molters; maximum intermolt (integer years); partial f; hard-shell mortality; soft-shell mortality; weight ; annual molt probability (for 1 – maximum intermolt)

2. above repeated from minimum size to maximum size in population (see record 2 in fort.8)

fort.99 (“female.inp”)

1. carapace length; proportion mature; proportion double molters; maximum intermolt (integer years); partial f; hard-shell mortality; soft-shell mortality; fecundity; weight; annual molt probability (for 1 – maximum intermolt)

2. above repeated from minimum size to maximum size in population (see record 2 in fort.8)

fort.86(“mminc.inp”) & fort.87(“fminc.inp”)

1) 55,6,11, 0.0338,0.0568,0.0863,0.1147,0.1368,0.1432,0.1368,0.1147,0.0863,0.0568,0.0338

.
.
.

end)

for each mm CL, males and females separately, CL, minimum molt increment, number of 1 mm increments, proportion of lobsters increasing size by molting n mm (consecutive intervals from minimum to minimum + number of intervals – 1)

Appendix B:

From: *Workshop on lobster (Homarus americanus and H. gammarus) reference points for fishery management held in Tracadie-Sheila, New Brunswick, 8-10 September 2003: Abstracts and proceedings. Can. Tech. Rep. Fish. Aquat. Sci. 2506: vii + 35p.*

8 Session on Models

Lobster maturity and fecundity information for models

The use of maturity information in a current life history model based on the growth of female and male clawed lobsters

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A current life history model that is a basis for reference point evaluation is based on the growth of female and male lobsters, variability in growth rates and size specific estimates of: maturity, molt frequency and molt increment, fecundity and weight, vulnerability to fishing (both capture and landing aspects). Fishing strategies are based management regulations and harvesters practices. Regulations set the "rules", size limits, various protections (e.g., prohibiting landing of berried or v-notched animals), seasons, etc. Harvesters then work within these rules by concentrating fishing in certain areas and during certain parts of the year. Since lobster growth and expression of maturity (i.e., carrying eggs externally) can fluctuate during the year, it is beneficial to be able to describe this form of life history when overlaying fishing strategies of concern. The model described below offer the ability to examine the interaction between maturity and growth, and extend analyses to the interaction of the life history and harvesting strategies for clawed lobsters.

MODEL

The life history model describes growth of lobsters based on the interaction of molt frequency and molt increment. There are links between molting and maturity (especially for females) since energy devoted to production of eggs and the physical constraints of carrying eggs externally for a period of time retard the frequency of molting for functionally mature lobsters. Growth and reproduction are currently described by six life history events that are temporally (within a year) distinct for each event and sex. These events include:

1. Primary molting (for those that will molt in a given year)
2. Second molt (for those that will molt twice in a given year)
3. V-notching
4. Death (both M and F)
5. Egg extrusion
6. Egg hatch

The timing can be discrete (all animals complete an event in one time step) or protracted (proportions of population completing an event over two or more time steps). It utilizes a time step appropriate for defining these events (i.e., the life history of clawed lobsters) and the interaction of the range of fisheries that occur. This time step should be set at the finest level of detail for which data are available for a population of clawed lobsters. Size specific information on functional maturity, molting schedules, growth increments, fecundity, weight as well as fishery descriptions (seasonal timing of effort, gear retention characteristics, size limits and other protections) are needed to generate reference point calculations. These maturity schedules needs are described below.

MATURITY

The life history/reference point model assumes there are differences between "physiological" and "functional" maturity. Physiological maturity implies that a female could produce eggs at a given size, while functional maturity implies a female will produce eggs at a given size. Some of the factors that can affect difference include size, age, fishing pres-sure and associated size composition of population, region/environment, and genetics. Since there is some link between maturity and growth the model employs the functional form.

MATURITY INFORMATION REQUIRED BY THE MODEL

Functional maturity interacts with growth and in part determines vulnerability to fisheries for lobsters. Females that are berried are not legal to land in *Homarus americanus* fisheries and are the focus of v-notching. Therefore, when the lobsters are berried becomes important in assessing management measures and how effective they would be under different harvesting strategies. Clearly, information about life history and maturity must be specific to the region being examined. In addition, there are temporal aspects that must be addressed. By size, there is the need for estimates of:

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• the molt cycle for both males and females, maximum number of years until all lobsters at a size will molt, what proportion will molt in each year of this maximum, when during the year molting will occur (e.g., which month(s)?)for females: which year(s) of a given molt cycle females will carry eggs (e.g., year 2, year 1, year 2&3…) and what proportions for each?

• when during year she will extrude (e.g., which month(s)?) and what proportions for each?

• when she will hatch eggs (e.g., which month(s)?) and what proportions for each?

These last two estimates will determine duration of berried period, and therefore the periods of protection/vulnerability based on presence of some management regulations. The effectiveness of many management measures is dependent upon the interaction and individual effectiveness of all measures.

Appendix IV: Estimating trends in natural mortality for lobster using a modified Collie-Sissenwine model

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Introduction

The most recent stock assessments of American lobster (ASMFC 2000) assumed that natural mortality rates among pre-recruit, recruit and legal-size lobsters were low and constant (M = 0.15) across all stock areas based largely on scientific consensus. A low and fixed natural mortality rate seems plausible for American lobster inhabiting stable environments in offshore canyons. However, the magnitude and trend in M seems less certain for inshore lobster stocks. A great deal of empirical evidence points to a serial change in M at the southern end of the species' range. This uncertainty in the nature of M is compounded by the fact that accurate aging techniques have not yet been developed to determine a reliable maximum age for inshore and offshore American lobster stocks. This approach was developed to measure serial trends in M, and is therefore consistent with a primary recommendation by a Model Peer Review (ASMFC 2004) that M and F estimates be de-couples from Z in the standard Collie-Sissenwine Model (CSM). The approach does require one, or several, assumed starting (equilibrium) M values, but involves no additional data except a time series of landings and survey indices. The approach can therefore be applied to landings and survey indices from all stock areas to test the current hypothesis that M has not varied throughout the time series of the assessment (1982-2003).

In this report, we recommend the use of a two-stage approach to test the hypothesis that natural mortality (M) for American lobster is constant. In the first stage, we introduce a simple graphical approach to explore the null hypothesis that natural mortality (M) of Gulf of Maine (GOM) and Long Island Sound (LIS) lobsters is either constant or varies without trend from 1982 to 2004. The alternative hypothesis is that natural mortality (M) is time varying whereby Mt values follow some serial trend at some point during the time series. To test the null hypothesis of constant M for the GOM and LIS stocks, we recommend plotting total mortality (Zt) rates from the original CSM with M = 0.15, and relative fishing mortality (relFt) rates against time. If trends in Zt and relFt are roughly parallel by inspection then the null hypothesis of constant M is accepted. In this case, natural mortality (M) can be held constant in the original CSM and fishing mortality (Ft) can be derived by subtraction (i. e. Ft = Zt – constant M). On the other hand, if trends in Zt and relFt intersect or greatly diverge over time then the alternative hypothesis of time varying M is accepted thereby triggering the second stage of the analysis. In this second stage, we recommend the use of a modified CSM (MCSM) to estimate the time series of Ft and Mt independently as described in detail below. The MCSM is applied here for discussion purposes only to lobster landings and survey indices from Area 611 (Long Island Sound) and Gulf of Maine lobster stocks.

Approach

To use the graphical approach, total mortality (Zt) was estimated from 1982 to 2003 by the original CSM model under an assumed constant M. Next, relative fishing mortality relFt rates were derived each year as a ratio of lobster landings (Ct) in number to the average survey index (avInd) in number of legal and recruit-size lobsters in year t and t+1:

$$\text{RelFt} = \text{Ct} / \text{Index} \qquad (1)$$

where: Index = mean survey index in year t (indt) and t+1 (indt+1).

The null hypothesis that M is constant for the GOM and LIS stocks is then tested by plotting Zt against relFt. If trends in Zt and relFt are parallel by inspection from 1982 to 2003, then the hypothesis of constant M is accepted and the original CSM with constant M is used to estimate Ft. However, if plots of Zt and relFt diverge or intersect across one another, then the alternative hypothesis that M is time varying is accepted thereby triggering the use of the modified CSM (MCSM).

To run the MCSM, an average catchability coefficient (Q) is computed over a specified time period where M is assumed to be in equilibrium. This average Q is then used to scale survey indices of legal-size lobsters to units of total stock size in numbers (Nt) from which annual exploitation (ut) rates were derived as a ratio of annual landings (Ct) in numbers to annual stock size (Nt). Having estimates of Zt and ut, the standard catch equation (Ricker 1975) is used to estimate a time series of instantaneous fishing (Ft) and natural mortality rates: Mt = Zt – Ft. This approach attempts to de-couple Ft from Zt to examine the hypothesis that a trend in Mt is embedded in the trend in Zt. This approach was first introduced for stock assessment of striped bass using annual coast-wide tagging data (Crecco 2003, Hoenig et al. 2004)

Methods

Abundance indices of recruit and legal size lobsters from the CT DEP LIS Trawl Survey, for males and females combined, for 1985-2003 were to used to represent the relative abundance of the harvested stock. Spring (April-June) and fall (September-October) survey data were used in separate runs of the Collie-Sissenwine model (CSM).

Calendar year landings were used with spring abundance indices, while landings for the following year (t+1) were used with fall indices. Catch (C) in pounds was converted to numbers using the length-weight relationship from the last assessment (ASMFC 2000). Landings data for 1985-2003 are approximate as the length-weight conversion was under discussion at the time of this writing. Landings during 2004 were approximated based on preliminary data at 1.5 million lobsters, sexes combined. Model estimates for the terminal year (2004) are imprecise and should be ignored. Trends in estimates are probably more reliable than the absolute value of estimates (ASFMC 2004) and the precision of estimates in absolute terms has not been evaluated. Therefore, the emphasis is on estimating trends.

The period 1985-1996 was chosen as a baseline period. Since the baseline or equilibrium natural mortality (M*base*) during this time period is not known with certainty, a range of values from 0.1 to 0.3 were examined to determine the sensitivity of this method to the initial value of M*base*. These values bracketed the fixed value of M (0.15) used in the last assessment (ASMFC 2001). Each of these initial values was input into the CS model as a fixed value for the baseline period 1985-1996 so that the model could compute three estimates of total mortality (Zt) for the baseline period.

Each of the three baseline Zt estimates were then used to compute total population size at the beginning of the fishing year (Nt) and annual exploitation (ut) as the ratio of catch (C) and population size; instantaneous fishing and natural (non-fishing) mortality (Mt) rates after Ricker (1975):

$$Nt = (\text{Recruit Index} + \text{Legal Index}) / Q \qquad (2)$$
$$ut = C / Nt \qquad (3)$$
$$Ft = (ut * Zt) / (1- \exp\text{-}Zt) \qquad (4)$$
$$Mt = Zt – Ft \qquad (5)$$

Note that ut in equation (3) is not the same value as RelFt in equation (1).

The catchability coefficient (Q) for the baseline period was computed by iteration such that the average M for the baseline period equaled the chosen M*base* value (0.1, 0.2, 0.3). Three Q*base* values were computed corresponding to each chosen M*base.*

The standard CSM requires input of a constant M and then estimates stock size and Z by computing Q. This standard approach was modified so that the baseline Q value was input as a fixed variable (+/- 0.02). This modified model (MCSM) was then run using the entire time series (1985-2003), once for each of the three contrained Q*base* values to obtain a time series (1985-2003) of total instantaneous mortality (Zt) estimates. These Zt estimates were used in equations (2)-(5) above to obtain Mt and Ft for all years.

Results

A plot of Z, computed using the standard CSM under an assumption of constant M (0.2), and relative F showed a lack of parallelism (Figure 1) after 1997 for the Long Island Sound (LIS) population. This lack of correspondence indicated either a serial change in M or a serial increase in error. Since circumstances causing a serial increase in error after 1997 but not before seem unlikely, the possibility of a serial change in M after 1997 was examined.

The three M*base* values resulted in Q*base* values that were very similar (Table 1). Values of Mt for the baseline period generated with the constrained Q*base* in the second run were nearly identical to the values obtained from the first baseline run. All three baseline values resulted in a very similar trend in M estimates (Tables 2-4) for the recent period (1997-2003). In all cases, estimates of M peaked in 1999 and 2002 corresponding to documented mortality events in Long Island Sound (Sea Grant 2005).

Survey catch data for 63-72 mm animals, which were not used in modeling, were compared to trends in projected “pre-recruit” abundance as a crude check on the plausibility of the absolute Mt estimates. The average annual molt increment for lobsters in LIS is about 11 mm (ASMFC 2000). Lobsters reach legal size at 83 mm during recent years and, based on the 11 mm annul molt increment assumption, recruit lobsters would be mostly 72-82 mm and pre-recruits would be about 61-71 mm. When trends in projected pre-recruits were compared to survey data for lobsters (sexes combined) 63-72 mm during the previous year, the trends in survey data were similar to projected abundance although the values were almost always lower (Figures 2-3). The match implies that trends in the estimated are plausible if somewhat low.

All runs showed that natural mortality increased steadily after 1996, peaked in 1999-2002 and then possibly declined to an intermediate level in 2003. For all baseline values, estimates of the mean M for the recent period ranged from 0.77-0.97. This range is quite small considering the uncertainty associated with the estimates. In terms of biological plausibility, these average estimates represent a nine-fold increase over a base value of 0.1, a four-fold increase over a base of 0.2, and only a three-fold increase over a base value of 0.3.

Application of MCSM to the Gulf of Maine

Landings from the Gulf of Maine (GOM) and NMFS Inshore Trawl Survey abundance indices for the years 1982-2003 were used to compare results of the MCSM approach applied to another area. These computations were made to examine the assumption that natural mortality in this area is constant over time and to explore whether false trends might be created by the MCSM. GOM data analyses were the same as described above for Area 611, except that the observed values of recruit abundance for both seasons were doubled following the procedures described for the NMFS GOM Inshore Trawl Survey in the last assessment (ASMFC 2001).

The resulting estimates corroborated the consensus that natural mortality has varied without trend over the entire time period examined. Estimates of total mortality and relative F parallel each other (Figure 4). Annual and decade average values for Z, F, and M are very similar between the standard CSM and the MCSM output for both seasons (Tables 5-6).

Literature Cited

ASMFC 2000. American lobster stock assessment report for peer review. Stock Assessment report no. 00-01.

ASMFC 2004. American lobster stock assessment model technical review. Terms of reference and panel report. Special report no. 82.

Crecco, V. A. 2003. Method of estimating fishing (F) and natural mortality rates from total mortality (Z) and exploitation (u) rates for striped bass. Report submitted to the ASMFC Striped Bass Technical Committee, October 2003, 39pages.

CT DEP 2000. Impact of 1999 Lobster Mortalities in Long Island Sound. CT DEP Marine Fisheries Office, Old Lyme, CT. 47 p.

Hoenig, J. M., D. Hepworth, R. Latour, and P. Sadler. 2004. Fishing mortality of striped bass in the Chesapeake: a report to the Atlantic States Marine Fisheries Commission Striped Bass Technical Committee. Report submitted to the ASMFC Striped Bass Tech Committee, Sept. 21, 2004, 16 pages.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish Res Bd. Can. Bulletin 191, Ottawa Canada, 382 pages.

Sea Grant, 2005. Proceedings of the Long Island Sound Lobster Health Symposium, October 4, 2004. Long Island Sound Lobster Research Initiative.

Table 1: Comparison of seasonally separated estimates of catchability (Q) using three values of baseline natural mortality (M). The standard deviation (SD) of the bootstrap Q estimates listed are the result of 200 runs of the model.

Season	Equilibrium M	Q	SD
Spring	0.1	1.49	0.797
	0.2	1.37	0.796
	0.3	1.25	0.789
Fall	0.1	1.86	0.611
	0.2	1.71	0.612
	0.3	1.56	0.618

Table 2: Estimates of stock size and mortality for the LIS lobster population from spring and fall indices assuming baseline natural mortality = 0.1. For each year, annual catch (C) and LIS trawl survey index (Index = legal plus recruit sizes, averaged spring-fall), and total mortality (Z) from the CS model are used to estimate population size (N), annual exploitation (U), annual total mortality (A), instantaneous fishing mortality (F) and instantaneous natural mortality (M).

Equilibrium M=0.1 SPRING DATA								
Q=	1.49							
				(from CSM)				
	C	Index=	N=Index/Q	Z	U=C/N	A	F=(U*Z)/A	M
1985	1.91382	5.694622	3.821894	1.160159	0.50	0.69	0.85	0.31
1986	2.040859	4.178794	2.80456	1.081985	0.73	0.66	1.19	-0.11
1987	2.041539	5.5077	3.696443	1.070026	0.55	0.66	0.90	0.17
1988	2.724573	3.377471	2.266759	1.325982	1.20	0.73	2.17	-0.84
1989	3.125378	6.981072	4.685283	1.179625	0.67	0.69	1.14	0.04
1990	3.468531	10.75323	7.216932	1.048925	0.48	0.65	0.78	0.27
1991	3.50831	16.89135	11.33648	1.154419	0.31	0.68	0.52	0.63
1992	3.594288	14.9183	10.01228	1.608139	0.36	0.80	0.72	0.89
1993	3.30682	8.853124	5.941694	1.824928	0.56	0.84	1.21	0.61
1994	4.661554	5.304367	3.559978	1.361607	1.31	0.74	2.40	-1.04
1995	7.113785	15.11859	10.1467	1.505717	0.70	0.78	1.36	0.15
1996	9.647846	15.30982	10.27504	1.321244	0.94	0.73	1.69	-0.37
1997	9.74237	26.86218	18.02831	1.376521	0.54	0.75	1.00	0.38
1998	9.265582	35.19467	23.62059	1.424433	0.39	0.76	0.74	0.69
1999	7.448455	34.73464	23.31184	1.61366	0.32	0.80	0.64	0.97
2000	3.256135	17.77703	11.93089	1.137509	0.27	0.68	0.46	0.68
2001	2.571871	18.4965	12.41376	1.20924	0.21	0.70	0.36	0.85
2002	1.882523	10.94913	7.348408	1.484953	0.26	0.77	0.49	0.99
2003	1.154494	4.053393	2.720398	1.134986	0.42	0.68	0.71	0.43
			Means					
			1985-1997	1.31	0.68	0.72	1.22	0.09
			1998-2003	1.33	0.31	0.73	0.57	0.77

Equilibrium M=0.1 FALL DATA								
Q=	1.86							
	Catch (C)			(from CSM)				
	for t+1	Index	N=Index/Q	Z	U=C/N	A	F=(U*Z)/A	M
1985	2.040859	5.750287	3.091552	0.891986	0.66014	0.59	1.00	-0.11
1986	2.041539	12.39893	6.666089	0.843229	0.306257	0.57	0.45	0.39
1987	2.724573	11.51732	6.192105	1.044407	0.440007	0.65	0.71	0.34
1988	3.125378	7.221275	3.882406	1.477418	0.805011	0.77	1.54	-0.06
1989	3.468531	7.584813	4.077856	1.236939	0.850577	0.71	1.48	-0.25
1990	3.50831	12.88785	6.928949	1.27424	0.506326	0.72	0.90	0.38
1991	3.594288	16.1583	8.687257	1.058406	0.413743	0.65	0.67	0.39
1992	3.30682	18.62328	10.01252	1.048807	0.330269	0.65	0.53	0.52
1993	4.661554	19.02821	10.23022	1.019537	0.455665	0.64	0.73	0.29
1994	7.113785	18.93611	10.1807	1.464137	0.698752	0.77	1.33	0.13
1995	9.647846	16.91264	9.092816	1.937027	1.06104	0.86	2.40	-0.46
1996	9.74237	14.68364	7.894431	1.651948	1.234081	0.81	2.52	-0.87
1997	9.265582	37.34479	20.07784	2.02661	0.461483	0.87	1.08	0.95
1998	7.448455	16.60828	8.929184	2.059928	0.83417	0.87	1.97	0.09
1999	3.256135	20.53168	11.03854	1.515793	0.294979	0.78	0.57	0.94
2000	2.571871	12.18725	6.552283	1.894129	0.392515	0.85	0.88	1.02
2001	1.882523	10.44105	5.613465	2.719297	0.335358	0.93	0.98	1.74
2002	1.154494	3.287112	1.767265	2.44	0.653266	0.91	1.75	0.69
2003	1.15	3.541178	1.903859	1.629178	0.604036	0.80	1.22	0.41
			Means					
			1985-1997	1.31	0.63	0.71	1.18	0.13
			1998-2003	2.04	0.52	0.86	1.23	0.82

Table 3: Estimates of stock size and mortality for the LIS lobster population from spring and fall indices assuming baseline natural mortality = 0.2. For each year, annual catch (C) and LIS trawl survey index (Index = legal plus recruit sizes, averaged spring-fall), and total mortality (Z) from the CS model are used to estimate population size (N), annual exploitation (U), annual total mortality (A), instantaneous fishing mortality (F) and instantaneous natural mortality (M).

Equilibrium M=0.2 SPRING DATA								
Q=	1.37							
				(from CSM)				
	C	Index=	N=Index/Q	Z	U=C/N	A	F=(U*Z)/A	M
1985	1.91382	5.694622	4.156658	1.164738	0.46	0.69	0.78	0.39
1986	2.040859	4.178794	3.050215	1.100813	0.67	0.67	1.10	0.00
1987	2.041539	5.5077	4.020219	1.093324	0.51	0.66	0.84	0.26
1988	2.724573	3.377471	2.465307	1.343667	1.11	0.74	2.01	-0.67
1989	3.125378	6.981072	5.095673	1.190392	0.61	0.70	1.05	0.14
1990	3.468531	10.75323	7.849072	1.059289	0.44	0.65	0.72	0.34
1991	3.50831	16.89135	12.32945	1.154077	0.28	0.68	0.48	0.67
1992	3.594288	14.9183	10.88927	1.563848	0.33	0.79	0.65	0.91
1993	3.30682	8.853124	6.462134	1.781652	0.51	0.83	1.10	0.69
1994	4.661554	5.304367	3.871801	1.375813	1.20	0.75	2.22	-0.84
1995	7.113785	15.11859	11.03547	1.499277	0.64	0.78	1.24	0.25
1996	9.647846	15.30982	11.17505	1.32999	0.86	0.74	1.56	-0.23
1997	9.74237	26.86218	19.60743	1.370693	0.50	0.75	0.91	0.46
1998	9.265582	35.19467	25.68954	1.407641	0.36	0.76	0.67	0.74
1999	7.448455	34.73464	25.35375	1.563332	0.29	0.79	0.58	0.98
2000	3.256135	17.77703	12.97594	1.118776	0.25	0.67	0.42	0.70
2001	2.571871	18.4965	13.50109	1.179041	0.19	0.69	0.32	0.85
2002	1.882523	10.94913	7.992064	1.395556	0.24	0.75	0.44	0.96
2003	1.154494	4.053393	2.958681	1.110179	0.39	0.67	0.65	0.46
		2.98781						
			Means					
			1985-1997	1.31	0.63	0.72	1.13	0.18
			1998-2003	1.30	0.29	0.72	0.51	0.78

Equilibrium M=0.2 FALL DATA								
Q=	1.71							
	Catch (C)			(from CSM)				
	for t+1	Index	N=Index/Q	Z	U=C/N	A	F=(U*Z)/A	M
1985	2.040859	5.750287	3.362741	0.914672	0.606903	0.60	0.93	-0.01
1986	2.041539	12.39893	7.250833	0.870507	0.281559	0.58	0.42	0.45
1987	2.724573	11.51732	6.735273	1.05958	0.404523	0.65	0.66	0.40
1988	3.125378	7.221275	4.222968	1.469546	0.74009	0.77	1.41	0.06
1989	3.468531	7.584813	4.435563	1.24659	0.781982	0.71	1.37	-0.12
1990	3.50831	12.88785	7.536752	1.267031	0.465494	0.72	0.82	0.45
1991	3.594288	16.1583	9.449297	1.058379	0.380376	0.65	0.62	0.44
1992	3.30682	18.62328	10.89081	1.046713	0.303634	0.65	0.49	0.56
1993	4.661554	19.02821	11.12761	1.034541	0.418918	0.64	0.67	0.36
1994	7.113785	18.93611	11.07375	1.45751	0.642401	0.77	1.22	0.24
1995	9.647846	16.91264	9.890432	1.919116	0.975473	0.85	2.19	-0.27
1996	9.74237	14.68364	8.586925	1.654057	1.134559	0.81	2.32	-0.67
1997	9.265582	37.34479	21.83906	1.985983	0.424267	0.86	0.98	1.01
1998	7.448455	16.60828	9.712446	2.032303	0.766898	0.87	1.79	0.24
1999	3.256135	20.53168	12.00683	1.498246	0.27119	0.78	0.52	0.97
2000	2.571871	12.18725	7.127045	1.864883	0.360861	0.85	0.80	1.07
2001	1.882523	10.44105	6.105874	2.654019	0.308313	0.93	0.88	1.77
2002	1.154494	3.287112	1.922288	2.394939	0.600583	0.91	1.58	0.81
2003	1.15	3.541178	2.070864	1.609451	0.555324	0.80	1.12	0.49
			Means					
			1985-1997	1.31	0.58	0.71	1.08	0.22
			1998-2003	2.01	0.48	0.85	1.12	0.89

Table 4: Estimates of stock size and mortality for the LIS lobster population from spring and fall indices assuming baseline natural mortality = 0.3. For each year, annual catch (C) and LIS trawl survey index (Index = legal plus recruit sizes, averaged spring-fall), and total mortality (Z) from the CS model are used to estimate population size (N), annual exploitation (U), annual total mortality (A), instantaneous fishing mortality (F) and instantaneous natural mortality (M).

Equilibrium M=0.3 SPRING DATA								
Q=	1.25							
				(from CSM)				
	C	Index=	N=Index/Q	Z	U=C/N	A	F=(U*Z)/A	M
1985	1.91382	5.694622	4.555698	1.177188	0.42	0.69	0.71	0.46
1986	2.040859	4.178794	3.343035	1.125876	0.61	0.68	1.02	0.11
1987	2.041539	5.5077	4.40616	1.123594	0.46	0.67	0.77	0.35
1988	2.724573	3.377471	2.701977	1.365569	1.01	0.74	1.85	-0.48
1989	3.125378	6.981072	5.584858	1.206877	0.56	0.70	0.96	0.24
1990	3.468531	10.75323	8.602582	1.07494	0.40	0.66	0.66	0.42
1991	3.50831	16.89135	13.51308	1.159296	0.26	0.69	0.44	0.72
1992	3.594288	14.9183	11.93464	1.527365	0.30	0.78	0.59	0.94
1993	3.30682	8.853124	7.082499	1.742584	0.47	0.82	0.99	0.76
1994	4.661554	5.304367	4.243494	1.393807	1.10	0.75	2.04	-0.64
1995	7.113785	15.11859	12.09487	1.49856	0.59	0.78	1.14	0.36
1996	9.647846	15.30982	12.24785	1.34255	0.79	0.74	1.43	-0.09
1997	9.74237	26.86218	21.48975	1.368937	0.45	0.75	0.83	0.54
1998	9.265582	35.19467	28.15574	1.392389	0.33	0.75	0.61	0.78
1999	7.448455	34.73464	27.78771	1.51221	0.27	0.78	0.52	0.99
2000	3.256135	17.77703	14.22162	1.102089	0.23	0.67	0.38	0.72
2001	2.571871	18.4965	14.7972	1.150429	0.17	0.68	0.29	0.86
2002	1.882523	10.94913	8.759302	1.317897	0.21	0.73	0.39	0.93
2003	1.154494	4.053393	3.242714	1.094889	0.36	0.67	0.59	0.51
		2.98781						
			Means					
			1985-1997	1.32	0.57	0.73	1.03	0.28
			1998-2003	1.26	0.26	0.71	0.46	0.80

Equilibrium M=0.3 FALL DATA								
Q=	1.56							
	Catch (C)			(from CSM)				
	for t+1	Index	N=Index/Q	Z	U=C/N	A	F=(U*Z)/A	M
1985	2.040859	5.750287	3.709863	0.941254	0.550117	0.61	0.85	0.09
1986	2.041539	12.39893	7.948029	0.901729	0.256861	0.59	0.39	0.51
1987	2.724573	11.51732	7.382895	1.077787	0.369039	0.66	0.60	0.47
1988	3.125378	7.221275	4.629022	1.461508	0.67517	0.77	1.28	0.18
1989	3.468531	7.584813	4.86206	1.256479	0.713387	0.72	1.25	0.00
1990	3.50831	12.88785	8.26144	1.261883	0.424661	0.72	0.75	0.51
1991	3.594288	16.1583	10.35788	1.062487	0.34701	0.65	0.56	0.50
1992	3.30682	18.62328	11.938	1.050993	0.276999	0.65	0.45	0.60
1993	4.661554	19.02821	12.19757	1.05231	0.382171	0.65	0.62	0.43
1994	7.113785	18.93611	12.13853	1.450697	0.58605	0.77	1.11	0.34
1995	9.647846	16.91264	10.84143	1.897889	0.889905	0.85	1.99	-0.09
1996	9.74237	14.68364	9.41259	1.654014	1.035036	0.81	2.12	-0.46
1997	9.265582	37.34479	23.93897	1.941736	0.38705	0.86	0.88	1.06
1998	7.448455	16.60828	10.64633	2.000252	0.699626	0.86	1.62	0.38
1999	3.256135	20.53168	13.16133	1.480942	0.247402	0.77	0.47	1.01
2000	2.571871	12.18725	7.812338	1.832788	0.329206	0.84	0.72	1.11
2001	1.882523	10.44105	6.692978	2.578946	0.281268	0.92	0.78	1.79
2002	1.154494	3.287112	2.107123	2.343649	0.547901	0.90	1.42	0.92
2003	1.15	3.541178	2.269986	1.588278	0.506611	0.80	1.01	0.58
			Means					
			1985-1997	1.31	0.53	0.72	0.99	0.32
			1998-2003	1.97	0.44	0.85	1.00	0.97

Table 5: Comparison of mortality trends computed from the Gulf of Maine spring data using the standard Collie-Sissenwine Model and the modified model (MCSM).

Standard Collie-Sissenwine			
Spring	Mortality	Estimates	
Year	Total Mortality	Natural Mortality	Fishing Mortality
1982	0.745	0.15	0.595
1983	0.657	0.15	0.507
1984	0.406	0.15	0.256
1985	0.586	0.15	0.436
1986	0.670	0.15	0.520
1987	0.581	0.15	0.431
1988	0.556	0.15	0.406
1989	0.523	0.15	0.373
1990	0.630	0.15	0.480
1991	0.563	0.15	0.413
1992	0.452	0.15	0.302
1993	0.487	0.15	0.337
1994	0.943	0.15	0.793
1995	0.468	0.15	0.318
1996	0.458	0.15	0.308
1997	0.438	0.15	0.288
1998	0.398	0.15	0.248
1999	0.429	0.15	0.279
2000	0.311	0.15	0.161
2001	0.264	0.15	0.114
2002	0.284	0.15	0.134
2003	0.241	0.15	0.091
Means:			
1981-2003	0.50	0.15	0.35
1981-1992	0.58	0.15	0.43
1993-2003	0.43	0.15	0.28

MCSM with M=0.15 SPRING DATA								
Q=	0.113							
	Catch (C)	Index	N=Index/Q	(from CSM) Z	U=C/N	A	F=(U*Z)/A	M
1982	2.55772	0.620682	5.492761	0.745416	0.47	0.53	0.66	0.08
1983	2.636788	0.588343	5.206575	0.656537	0.51	0.48	0.69	-0.03
1984	2.434951	0.57486	5.087257	0.406401	0.48	0.33	0.58	-0.18
1985	2.597726	2.280842	20.18444	0.585663	0.13	0.44	0.17	0.42
1986	2.469169	0.914622	8.094	0.670227	0.31	0.49	0.42	0.25
1987	2.517379	1.648691	14.59019	0.581325	0.17	0.44	0.23	0.35
1988	2.685827	1.282145	11.34642	0.55649	0.24	0.43	0.31	0.25
1989	2.985717	0.938115	8.301903	0.523457	0.36	0.41	0.46	0.06
1990	3.329438	1.077139	9.532204	0.630177	0.35	0.47	0.47	0.16
1991	3.488646	1.636207	14.47971	0.562571	0.24	0.43	0.32	0.25
1992	3.077867	1.176379	10.41043	0.451525	0.30	0.36	0.37	0.08
1993	3.225534	0.712141	6.302133	0.486552	0.51	0.39	0.65	-0.16
1994	4.057106	0.917972	8.123646	0.943299	0.50	0.61	0.77	0.17
1995	3.902662	2.749088	24.32821	0.468312	0.16	0.37	0.20	0.27
1996	3.805892	2.26857	20.07584	0.458191	0.19	0.37	0.24	0.22
1997	4.572827	4.064118	35.96565	0.438207	0.13	0.35	0.16	0.28
1998	4.387477	3.200689	28.32468	0.39837	0.15	0.33	0.19	0.21
1999	5.060294	2.123282	18.79011	0.429466	0.27	0.35	0.33	0.10
2000	5.309987	6.29254	55.68619	0.310731	0.10	0.27	0.11	0.20
2001	4.467218	3.071375	27.18031	0.264423	0.16	0.23	0.19	0.08
2002	5.689525	4.253807	37.64431	0.283631	0.15	0.25	0.17	0.11
2003	4.893427	3.998337	35.38351	0.241336	0.14	0.21	0.16	0.09
		Means:	1982-2003	0.50	0.27	0.39	0.36	0.15
			1982-1992	0.58	0.32	0.44	0.42	0.15
			1993-2003	0.43	0.22	0.34	0.29	0.14

Table 6: Comparison of mortality trends computed from the Gulf of Maine fall data using the standard Collie-Sissenwine Model and the modified model (MCSM).

Standard Collie-Sissenwine			
Fall	Mortality	Estimates	
Survey	Total	Natural	Fishing
Year	Mortality	Mortality	Mortality
1983	1.185	0.15	1.035
1984	1.087	0.15	0.937
1985	1.070	0.15	0.920
1986	0.921	0.15	0.771
1987	0.799	0.15	0.649
1988	1.252	0.15	1.102
1989	1.011	0.15	0.861
1990	0.938	0.15	0.788
1991	0.941	0.15	0.791
1992	1.224	0.15	1.074
1993	0.953	0.15	0.803
1994	0.883	0.15	0.733
1995	0.732	0.15	0.582
1996	0.770	0.15	0.620
1997	0.654	0.15	0.504
1998	0.792	0.15	0.642
1999	0.717	0.15	0.567
2000	0.804	0.15	0.654
2001	0.808	0.15	0.658
2002	0.669	0.15	0.519
2003	0.957	0.15	0.807
Means:			
1983-2003	0.91	0.15	0.76
1983-1992	1.04	0.15	0.89
1993-2003	0.79	0.15	0.64

MCSM with M=0.15 FALL DATA								
Q=	0.535							
Survey Yr	Catch (C) for t+1	Index	N=Index/Q	(from CSM) Z	U=C/N	A	F=(U*Z)/A	M
1983	1.807536	1.785536	3.33745	1.185	0.54	0.69	0.92	0.26
1984	0.67419	0.661868	1.237136	1.087	0.54	0.66	0.89	0.19
1985	2.251088	2.309721	4.317236	1.070	0.52	0.66	0.85	0.22
1986	2.211028	2.329955	4.355056	0.921	0.51	0.60	0.78	0.14
1987	1.136648	1.121454	2.096176	0.799	0.54	0.55	0.79	0.01
1988	1.917724	1.92007	3.588916	1.252	0.53	0.71	0.94	0.31
1989	2.596198	2.535565	4.739374	1.011	0.55	0.64	0.87	0.14
1990	2.276342	3.127115	5.845075	0.938	0.39	0.61	0.60	0.34
1991	2.067362	2.742847	5.126817	0.941	0.40	0.61	0.62	0.32
1992	1.526888	1.476168	2.759193	1.224	0.55	0.71	0.96	0.26
1993	1.719696	1.696392	3.170826	0.953	0.54	0.61	0.84	0.11
1994	4.106308	5.018228	9.379865	0.883	0.44	0.59	0.66	0.22
1995	2.383736	3.675836	6.870721	0.732	0.35	0.52	0.49	0.24
1996	6.598526	6.728167	12.57601	0.770	0.52	0.54	0.75	0.02
1997	3.718862	3.750405	7.010103	0.654	0.53	0.48	0.72	-0.07
1998	3.52297	4.119267	7.699564	0.792	0.46	0.55	0.66	0.13
1999	5.881694	5.963875	11.14743	0.717	0.53	0.51	0.74	-0.02
2000	4.340092	4.753539	8.88512	0.804	0.49	0.55	0.71	0.09
2001	2.714998	2.721894	5.087652	0.808	0.53	0.55	0.78	0.03
2002	4.176632	4.452931	8.323236	0.669	0.50	0.49	0.69	-0.02
2003	2.013357	2.107911	3.940021	0.957	0.51	0.62	0.79	0.16
		Means:	1983-2003	0.91	0.50	0.59	0.76	0.15
			1983-1992	1.04	0.51	0.64	0.82	0.22
			1993-2003	0.84	0.49	0.56	0.72	0.11

Figure 1: Comparison of relative fishing mortality and total mortality for Area 611 (Long Island Sound). Total mortality was computed using the standard CSM under the assumption of constant M=0.2.

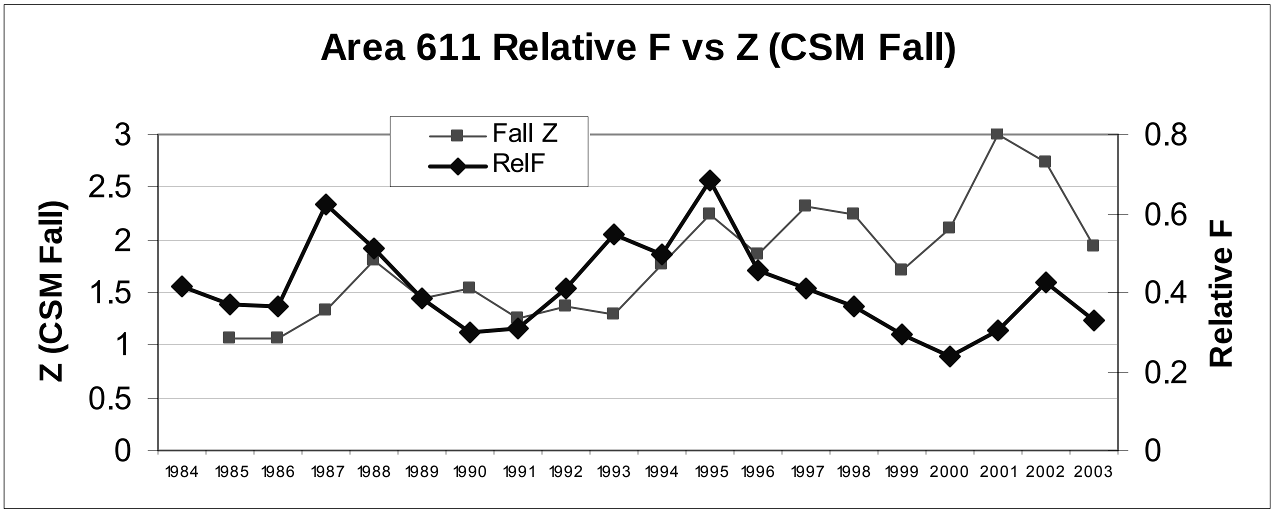


Figure 2: Comparison of observed pre-recruit abundance indices from spring and fall survey catches and backcasted estimates using three baseline M values.

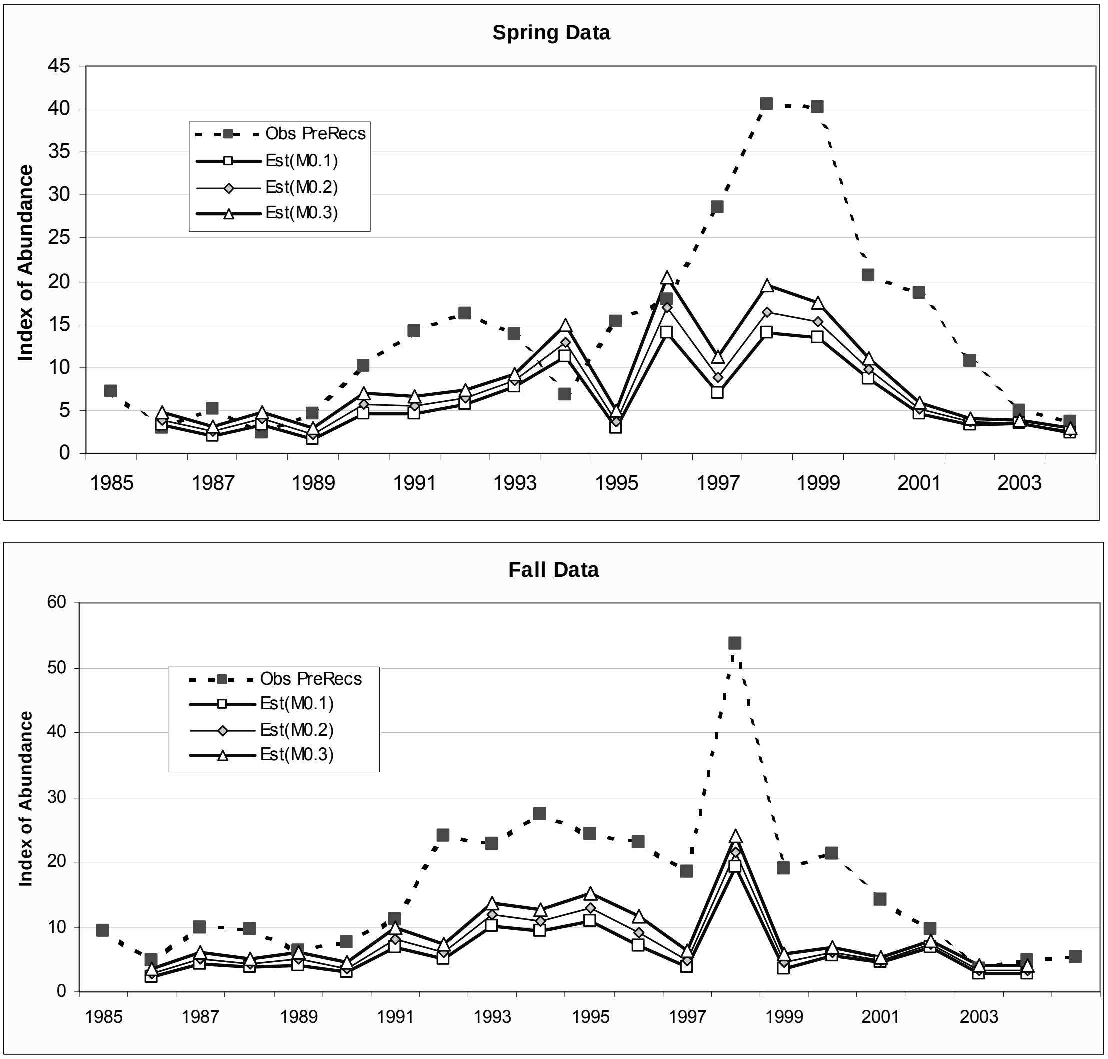
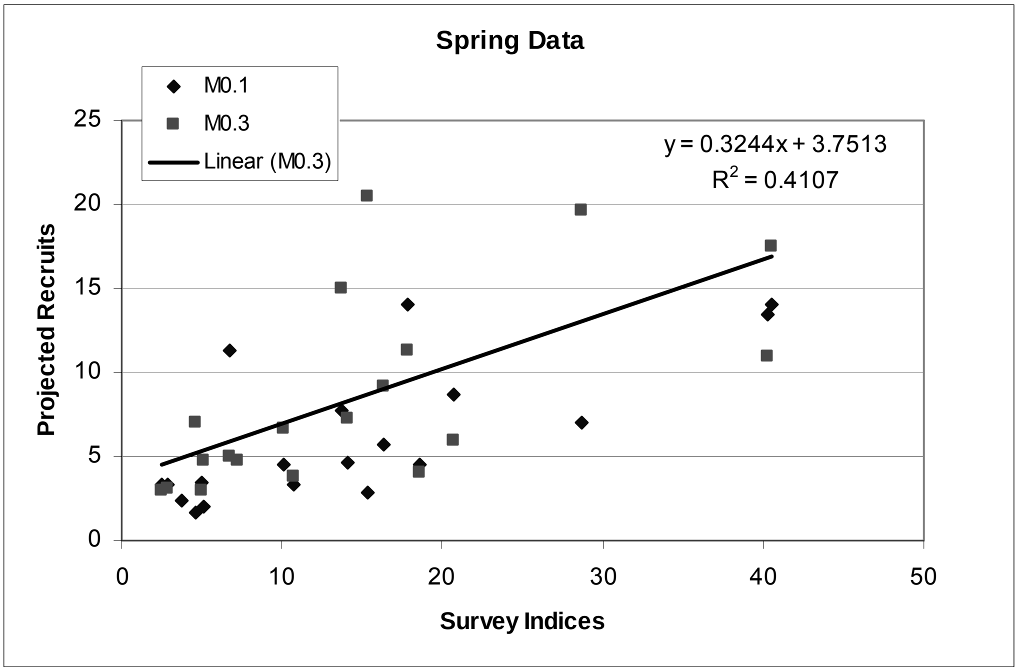


Figure 3: Plot comparison of observed abundance of pre-recruits and backcasted abundance with an assumed baseline M = 0.1 and M=0.3. The linear relationship is shown for M=0.3.



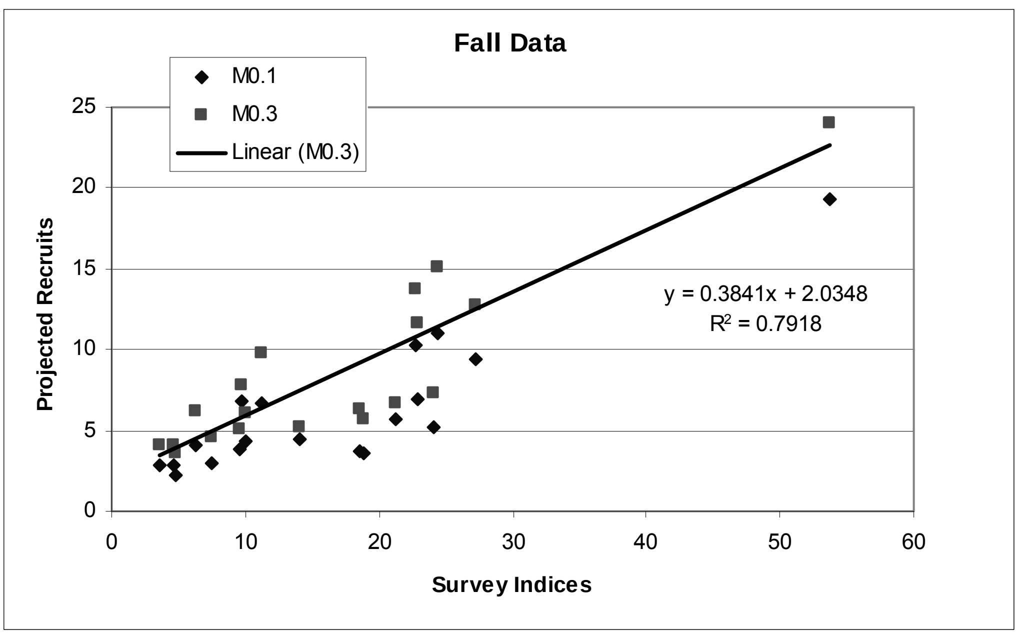
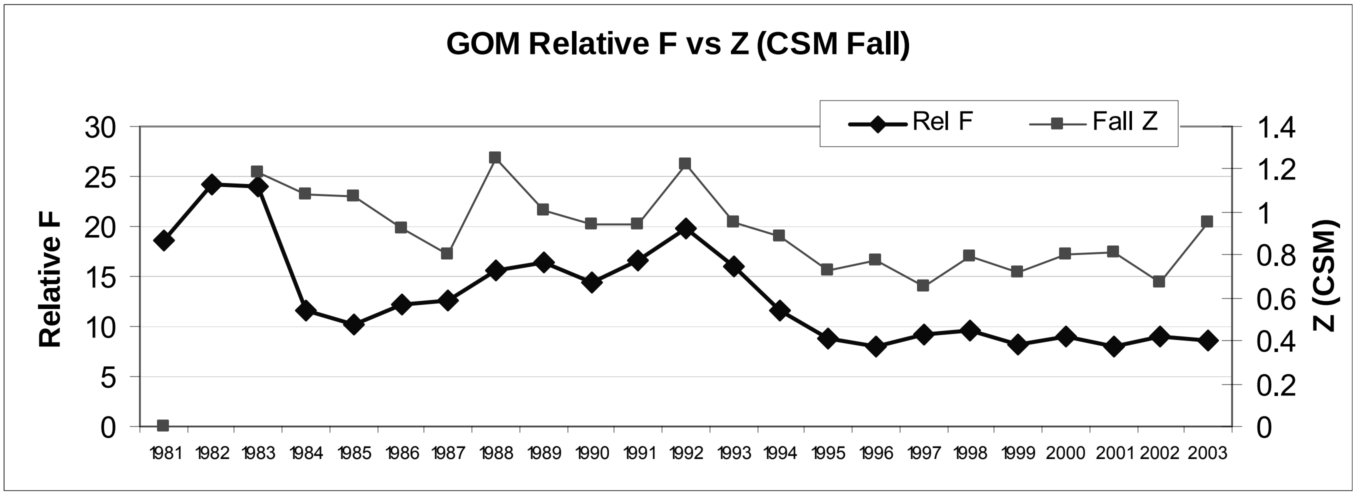


Figure 4: Comparison of relative fishing mortality and total mortality for the Gulf of Maine. Total mortality was computed using the standard CSM under the assumption of constant M=0.15.



A Review of Estimating trends in natural mortality using a Modified Collie-Sissenwine model (Howell and Crecco, 4/28/2005)

By

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May 11, 2005

The purpose of this paper is to provide greater detail as to mechanism that the proposed Collie-Sissenwine Model uses to estimate M. This paper is strictly a review of the robustness of model to estimate M. I make no claims as to trends and magnitude of natural mortality in Long Island Sound.

The authors propose the following equation to estimate M

(1) $M_t = Z_t - U_t Z_t / A_t$

Where:

Z_t is the total mortality estimated using a population estimates from the Collie-Sissenwine model.

(2) $\mathbf{Z = -\log (P_{t+1}/(P_t + R_t))}$

where P_{t+1} is the population estimate for the post recruits in year t+1
and $(P_t + R_t)$ is the population estimate for exploitable population in year t

$\mathbf{A_t}$ is calculated using :

(3) $\mathbf{A_t = (1\text{-}exp^{Z}{}_t)}$

Exploitation (U) is estimated using survey index scaled by the q from the model run:

(4) $\mathbf{U = C_t / (S_t / Q)}$

Where C_t = catch in year t
S= survey index
Q= catchability coefficient for the timeseries

Q is initially estimated from a shortened timeseries of data, and then applied to the full dataset. Q is then further modified to make average M over the shortened timeseries = to mean of assumed input M.

Since Z_t, Ct, A_t are determined by the model run (with assumed M input), it is clear that the estimate of M in a given year is a function of Q and the survey index.
If population estimates from the model are used, estimated M will equal the input M. The estimate of M is therefore dependent upon the Q and the survey index.

Howell and Crecco represent the relationship between true population, N_t and the survey using the following equation:

(5) $\mathbf{N_t = S_t / Q}$

where N_t = true population, S_t = survey index , and Q is a catchability coefficient.

This formulation is true only if the survey index indexes the population perfectly and without error. Otherwise, the relationship between Survey and the true population could be rewritten as follows:

$$\textbf{(6)}\ \mathbf{N_t = S_t / Q_t - E_t}$$

Where E is measurement error term.

The sources of measurement error could be a function of sampling variation, or could be impacted changes in availability or catchability. Note that equation 6 becomes equation 5 when the error term is zero.

Equation 6 can be rearranged as:

$$\textbf{7)}\quad \mathbf{S_t/Q = (N_t + E_t)}$$

$$\textbf{8)}\quad \mathbf{S_t = Q(Nt + E_t)}$$

In terms of the Modified Collie Sissenwine, N_t is the population estimate from the model, Q is the average catchability, and the E is a residual. In this case, the error term is a function not only of survey measurement error, but includes other sources of error such as misspecification of M, errors catch, correlated errors in survey etc. Substituting equation 7 illustrates exactly what the components are actually driving the estimate of M.

$$\textbf{(9)}\quad \mathbf{F = C_t / (Nt+E_t)Q\ Z_t/A_t}$$

Where N_t is the population estimate from the model,
Z_t is the total mortality estimated from the model
A_t= annual mortality (converted from Z from the model)
E_t = error or survey residual in year t
Q =catchability coefficient (note that this Q is inverse (1/Q) from estimate from model 1/Q from the model.
F= instantaneous fishing mortality
C_t = catch in year t

In this case, the Q is the catchability coefficient for the entire timeseries.

For any given year, N_t ,Z_t,and A_t are CSM outputs. Catch is an input and is the same as the input in the CSM model. Only Q and E_t vary in the equation used to estimate M. In this form, the components of M are quite apparent: E_t and Q. Since Q is constant for the timeseries, Q should scale the timeseries of M estimates. The actual trend in M is a function of the trend in E_t. Again, the error in this formulation is a function of the observation errors around the inputs to the model. The annual error (or residual) has many components. It includes survey measurement error, variation in survey catchability or availability (year effects), misspecification of M in the model, error in annual catch, not accounting for immigration/ emigration in the population, and so forth. In the

Howell-Crecco proposal, all of error is assigned to M. Under a different assumption, all the error could be assigned to annual variation in Q. If a priori information is available, error could be partitioned into various components.

Examination of the results presented in Howell and Crecco illustrate these issues. I used their example run using spring indices, M=0.20 and Q estimated as 1.37. I varied the Q estimate from 1.37 and compared the timeseries trend in M using correlation analysis and compared the scale using average M by period and for the entire timeseries. Results are shown in Table 1. The high correlation values among the various timeseries of M estimates (Table 1) and the changes in estimates of mean M (Table 2) show that the value of Q acts to scale the trends in M, but does not impact the trend in M. .

The relationship between trends in residuals (E_t)and trends in the estimates of M are also demonstrated from analysis provided by Howell and Crecco. For simplification, I will use residuals between model estimates of total population $N_t = (P_t + R_t)$ and the survey estimates of total population. Note that the model actually assigns residuals to Post recruits and recruit index. The actual equation should be written:

$$\textbf{(10) } N_t = (P_t + E_{pt})Q + (R_t + E_{Rr})/Q.$$

Where: P_t = Post recruit survey index
E_{pt} = error in Post-recruit survey
R_t = Recruit survey
E_{Rt} = error in the recruit survey

The relationship between M estimates and model residuals on arithmetic scale are shown in Figure 2. Note the significant relationship between M estimates and residuals between N_t and the S_tQ. The Collie-Sissenwine model used a log normal error structure. Figure 3 shows the relationship between residuals (equation 11) on a log scale (Ln (S_t/Q) – Ln (N_t). An estimate of annual catchability can be estimated using log ratio of population estimate to survey index, scaled by Q (Equation 12). These residuals on a log scale can be considered as an annual Q or a deviation in Q from the average Q:

$$\textbf{(11) } E = \ln(S_t/Q) - \mathrm{Ln}(N_t)$$

$$\textbf{(12) } Q_t = \mathrm{Ln}(N_t/(S_t/Q))$$

Having renamed this as a annual deviation in Q, I plot the relationship between Q_t and M in Figure 4. Note the similarity in fit between estimated M and ln residuals or annual catchability. Mathematically, the residuals in a log scale are the inverse of the annual catchability (Q_t). Note the similarity in fit between figures 3 and 4 but the difference in the sign of the slope.

This fuller examination of modified Collie-Sissenwine as proposed by Howell and Crecco clearly demonstrate what the model is doing. Predictions from the algebra are consistent with relationships between Q, E_t (or Q_t), and M. The conclusion is clear: trends in M are strictly a function of error. The proposed method only works if **all the**

error in the model is assigned to M. This explains the model's poor ability to "estimate M" during the shortened period when M is assumed to have a constant value, and Q is adjusted to make average M during period equal the assumed M. Summary statistics of the estimate of M during the 85-96 period from Howell and Crecco's "best" spring run, (with M in the 85-96 period assumed to be 0.20) is shown in Table 3. The coefficient of variation around the mean estimate of M for 1985-1996 for their "best" run is 331%.

Simulation

I examined the robustness of their method using simulated data. The simulated population had natural mortality rate of 0.15 for the entire timeseries. Survey and catch data followed trends similar to that observed in the Long Island Sound Fishery. Errors in post recruits and recruit surveys were correlated 0.80. I applied the Modified Collie-Sissenwine method to these data to estimate M.

A timeseries of estimates of M are shown in Figure 8. Estimates of M from 1985-1996 averaged 0.15 (range -0.39 to 0.64) with a CV of 217% (Table 4) from 1985-1996. Over the entire timeseries, M estimates averaged 0.29 with a CV of 153%. In addition, M during 1996-2003 averaged 0.64, three times the true M (0.15). The method is unable to estimate either trend or magnitude of M.

The relationship between estimated M and residuals is shown in Figure 7 and the relationship between estimated M and Q_t is shown in Figure 8. These relationships are similar to that demonstrated in the Howell-Crecco example. The relationship between trends in annual catchability (Q_t) and estimated M is also similar to what was seen in the Howell-Crecco analysis. However, in the simulated dataset and modeling exercise, none of the error is related to misspecification of natural mortality.

In designing the simulation data, I asked only that survey trends and catch be similar to trends seen in the Long Island Fishery and that the indices have a strong correlation (0.8). I chose this particular dataset (#500) at random from a series of 1000 datasets.
The timeseries of estimated M from Howell-Crecco paper and estimated M from the simulated data are plotted in Figure 9. Note the similarity in trend and magnitude of the M estimates. Both are related to error. In the case of the actual Long Island Sound data, misspecification of M may explain part of the residual error. In the case of simulated data, all of the error is related to correlation of errors among surveys indices.

The simulated survey indices had high correlation in errors (strong year effects). The relationship between % change in annual survey indices (total population, year t to t+1) and the estimation of M in year T is shown in Figure 10. Here estimated M is highly correlated with the % change in total survey biomass. The method estimates high M when the survey is declining and low M when the survey is increasing. The estimate of M appears to be consistent with directionality of survey (declines, high M; increases, low M), although there is no reason that populations could increase with an increase in M, or decrease with a declining M. In fact, the pattern observed in the simulated population is a function of the correlated errors between post recruit and recruit survey indices and can be seen in the residual plots of the surveys (Figures 11 and 12). The correlated errors in the survey and trends in catch force an increasing trend in the recruit residuals (Figure 12). The trend in estimates of M corresponds to this trend in residuals. An analyst may be tempted to ascribe the residual pattern to misspecification of M, but in this case, the assumption would be incorrect In this simulated dataset, none of the patterns in residuals, or trends in the survey are related to changes in M. This exercise illustrates the difficulty of assigning model errors to particular sources of error without additional information.

Simulation II with M varying in later period.
I also ran a second simulation where M=0.015 from 1985-1996. M increases from 1996 to 1999 and remains high to 2002. Other factors in this simulation were the same as in first simulation For purposes of the simulation, I have used 0.15 throughout the simulation. I followed used the proposed modified Collie-Sissenwine to estimated M through-out the timeseries.

Results are shown in Table 5 and Figures14 and 15. The relationship between estimated M and residuals (or Qt) are similar to the relationship found for the constant M simulation and the Connecticut data example (Figures 16-17). As in previous simulations, estimates of M during the period when M is assumed to be stable are highly variable with a CV of 353% during 1985-1996. Estimated M increases after 1998, with estimates of M biased low (-36%) in the 1998-2002 period. Over the entire 1985-2002 period, the estimated M deviated from the true mean by 184% and was biased low (mean bias -19%). Several questions remain as to how to interpret the results. The method used the 1985-1996 period because M was expected to increase after 1996. The method missed the doubling of M in 1997 and tripling of M in 1998 from the baseline of 1996. Would the low estimated M in 1997 and 1998 suggest that the model be reiterated or rejected? The high estimated Ms in 1999-20001 are similar in magnitude to estimated M's in 1989, and 1996. Are those M's also high or are they noise around the true value of 0.15? Without knowing the underlying truth, can an analyst determine whether the increase in estimated M is picking up a signal from misspecification M in the model, or is the increasing trend in M a function of correlated error (as increase in estimated M in the first simulation) or, more likely, some combination of both.

Conclusions
In the Connecticut dataset and the two simulated datasets, the trend in estimates of M are a function of residuals or deviations in catchability. In application to real datasets, the residuals themselves are a function of sampling measurement error, correlated errors in survey, mis-specification of M and other data (e.g., catch?) and model misspecification. The question is whether the portion of the residual caused by mis-specification of M can be recovered when other sources of error. Without additional information, the sources of variation can not be separated. The analyst has no way to provide confidence that the estimates of M are robust and are not a function of something else, e.g., correlated errors in surveys. Figure 19 shows the M estimates for three datasets. In one dataset, true M does not vary. In another dataset, M increases substantially after 1996. In the third dataset, true M is unknown. Could an analyst select the series that matches the true increase in M? Without external information about trend in M, the best this method can do is assign the trend in M to residuals (or Q_t). M and Q_t are hopelessly confounded.

Table 1. Correlation coefficients between timeseries of estimated M under various values of Q.

	Q=1.00	*Q=1.37*	*Q=1.47*	*Q=1.57*	*Q= 2.00*
Q=1.00	1.00				
Q=1.37	0.99	1.00			
Q=1.47	0.99	1.00	1.00		
Q=1.57	0.98	1.00	1.00	1.00	
Q= 2.00	0.97	0.99	1.00	1.00	1.00

Table 2. Mean natural mortality values under various values of Q

	Q=1.00	*Q=1.37*	*Q=1.47*	*Q=1.57*	*Q= 2.00*
Mean 85-97	0.49	0.18	0.10	0.02	-0.34
Mean 98-2003	0.92	0.78	0.75	0.71	0.55
Mean 85-2003	0.62	0.37	0.30	0.24	-0.06

Table 3. Summary statistics from the estimate of M during 85-96 period when M is assumed to be 0.20. Based on Howell and Crecco run using spring indices, M=0.2, and Q=1.37.

Period	Mean M	Variance	Standard deviation	CV
85-96	0.16	0.28	0.51	331%
85-97	0.18	0.26	0.51	281%
98-2003	0.78	0.04	0.19	25%
85-2003	0.37	0.27	0.52	139%

Table 4. Summary statistics for estimates of M from simulated data. True M=0.15. Percent difference calculated as 100*(estimated-true)/true

Time period	True M	Mean estimated M	CV	Mean % difference from true M[1]	Mean absolute % difference from true M
1985-1996	0.15	0.15	228%	0	183
1985-1997	0.15	0.09	452%	-42	210
1998-2003	0.15	0.64	44%	325	325
1985-2003	0.15	0.29	153%	93	252

1. Method finds Q such that mean estimated M in 1985-1996 time period= assumed M in model.

Table 5. Summary statistics for estimates of M from simulated data. True M=0.15 until 1997, and increases thereafter. Percent difference calculated as 100*(estimated-true)/true

Time period	True M	Mean estimated M	CV	Mean % difference from true M[1]	Mean absolute % difference from true M
1985-1996	0.15	0.15	353%	0%	245%
1985-1997	0.17	0.12		-13%	239%
1998-2002	0.84	0.44		-36%	42%
1985-2002	0.35	0.25		-19%	184%

[1]Method finds Q such that mean estimated M in 1985-1996 time period= assumed M in model

Figure 1. Trends in M by varying Q. Based on Howell and Crecco run using spring indices, M=0.2, and Q=1.37.

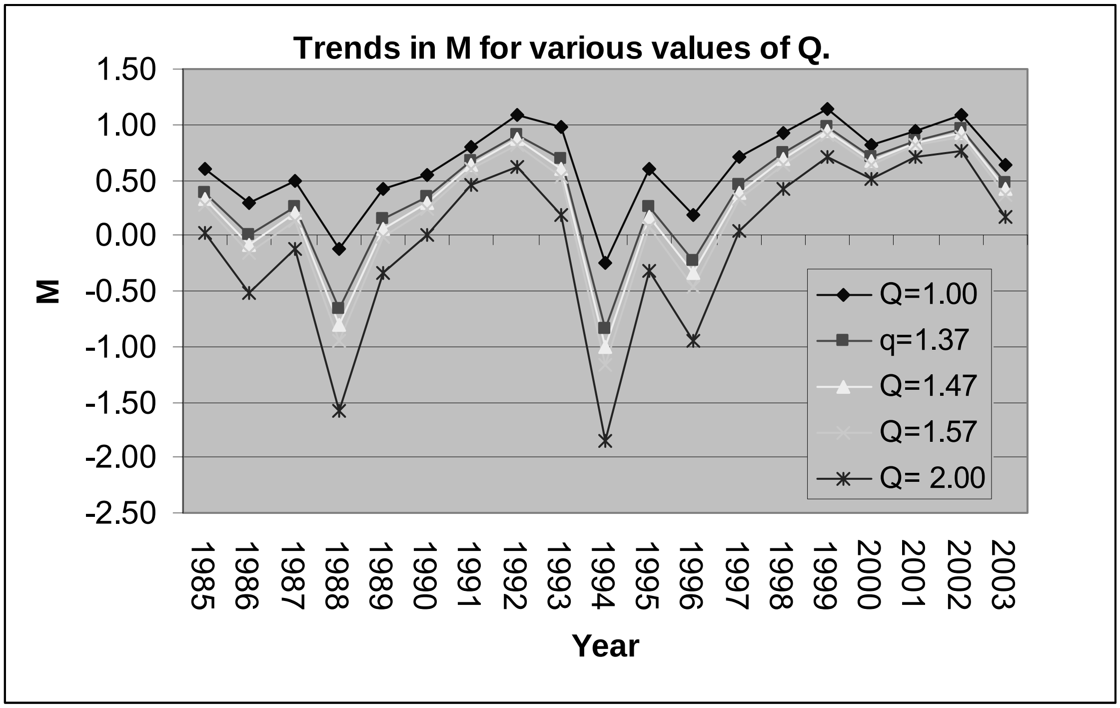


Figure 2. Scatter plot of M and residuals of total population estimates and survey index (S_t /Q). Based on Howell and Crecco run using spring indices, M=0.2, and Q=1.37.

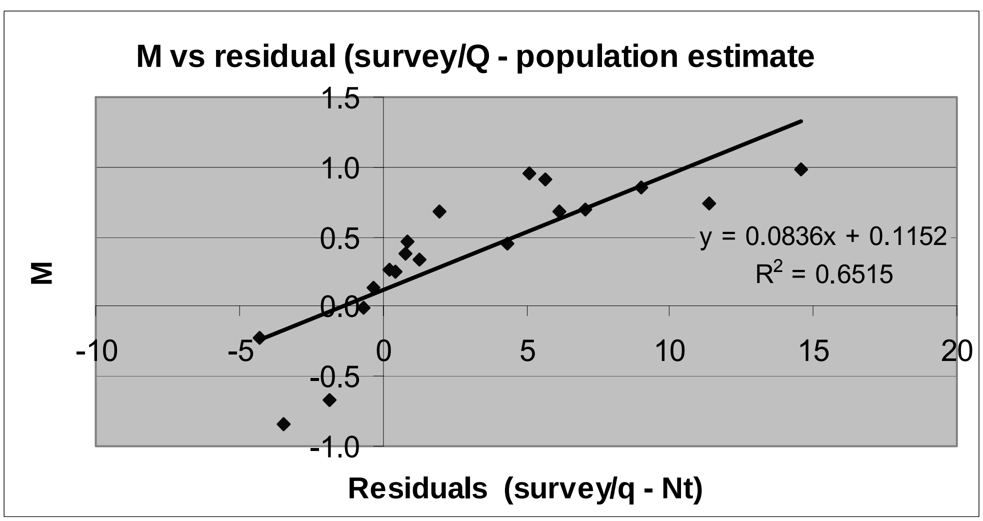


Figure 3. Scatter plots of M and residuals from ln survey index, scaled by Q and the total population estimates. Based on Howell and Crecco run using spring indices, M=0.2, and Q=1.37

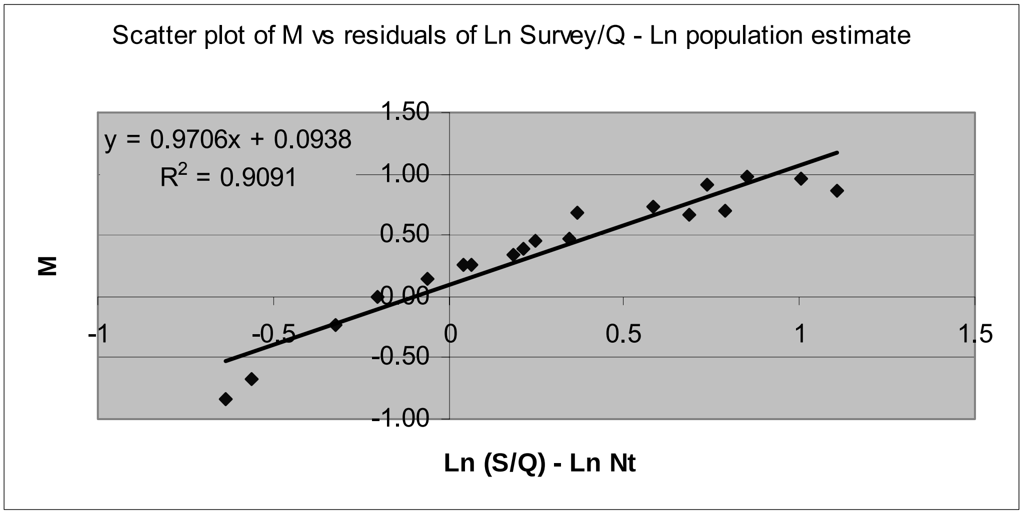


Figure 4. Scatterplot of M and annual Q_t (defined as natural log ($Nt/(S_t/Q)$)). Based on Howell and Crecco run using spring indices, M=0.2, and Q=1.37

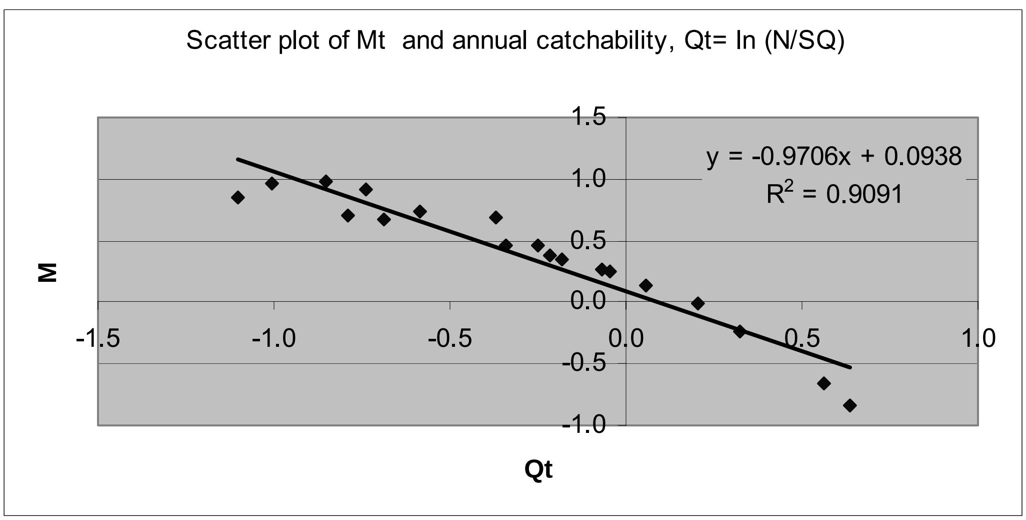


Figure 5. Time series of estimated M and M assumed in the modified Collie-Sissenwine model. Based on Howell and Crecco run using spring indices, M=0.2, and Q=1.37.

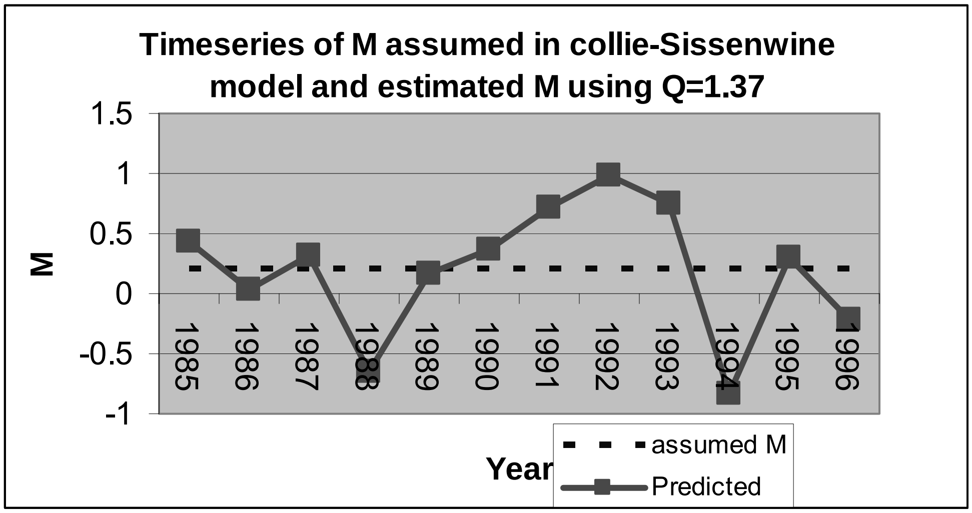


Figure 6. Time series of true M and M estimated using modified Collie-Sissenwine generated from simulated populations with fix M and survey indices with correlated errors.

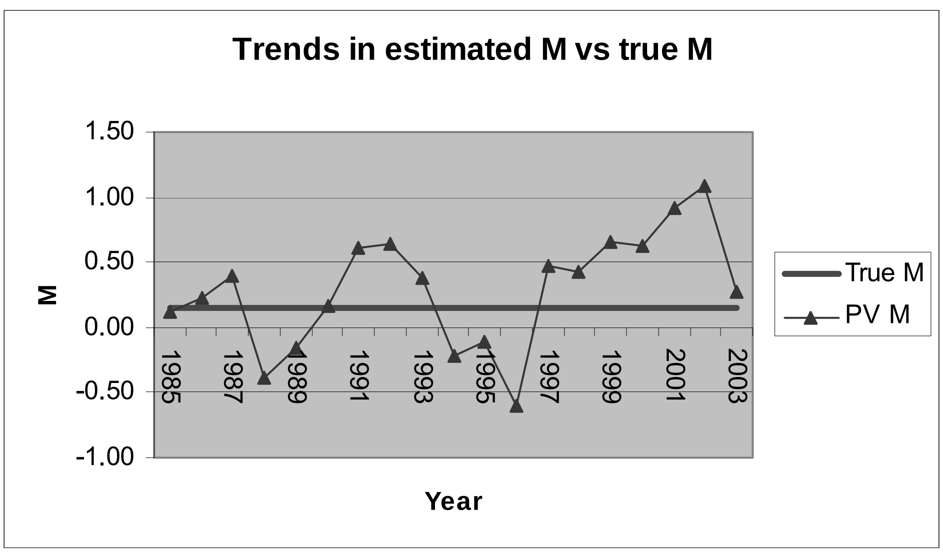


Figure 7. Scattter plot of M estimates and survey residuals (S_t/Q_t) – N_t from simulated population with constant M.

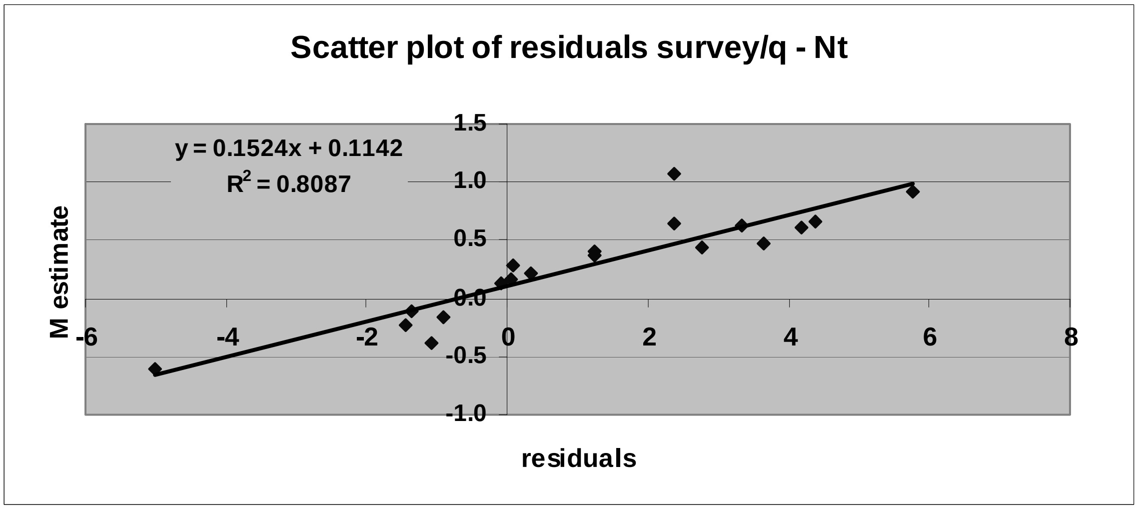


Figure 8. Scatter plot of estimated M against annual catchability coefficient, Qt estimated as Ln ($N_t/(S_t/Q)$). From simulated data with constant M.

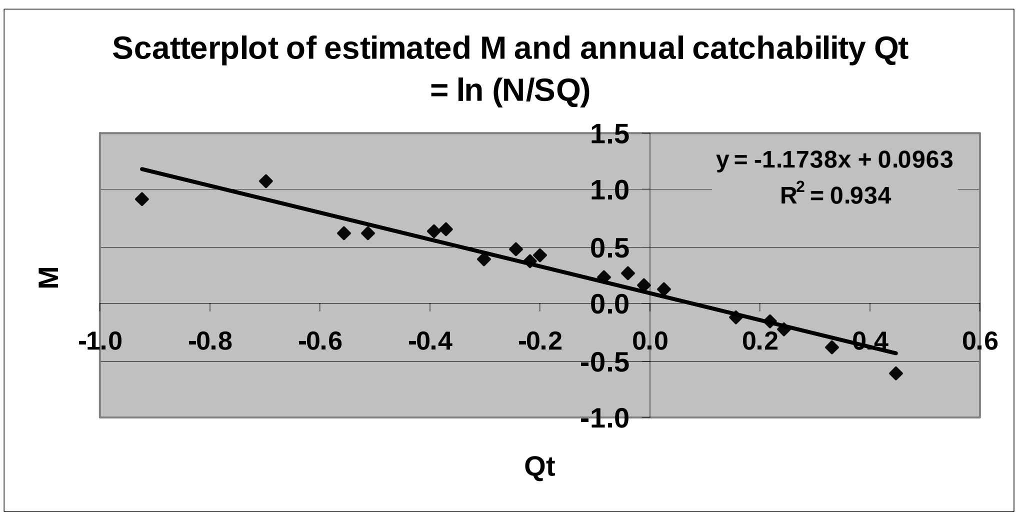


Figure 9. Comparison of trends in estimated M using modified Collie-Sissenwine. CT data is based on spring survey, M=0.20. Simulated data has known M=0.15.

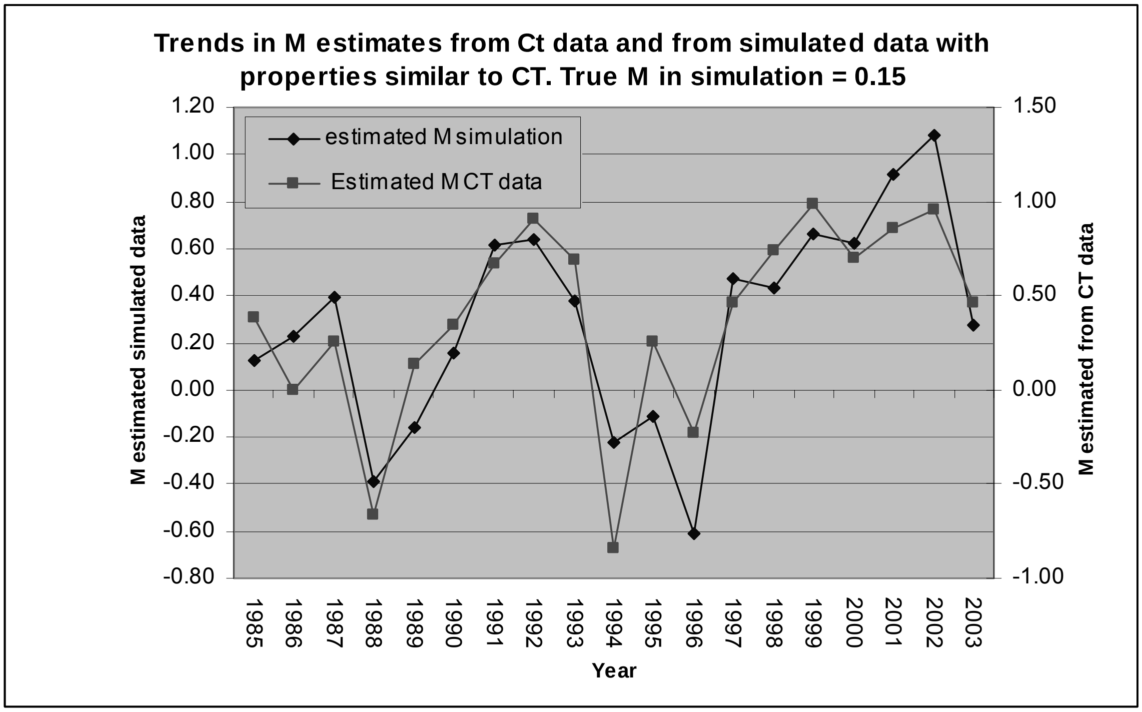


Figure 10. Scatterplot of M estimates in year T and % change in survey index between year t and t+1. Simulated data has known M=0.15.

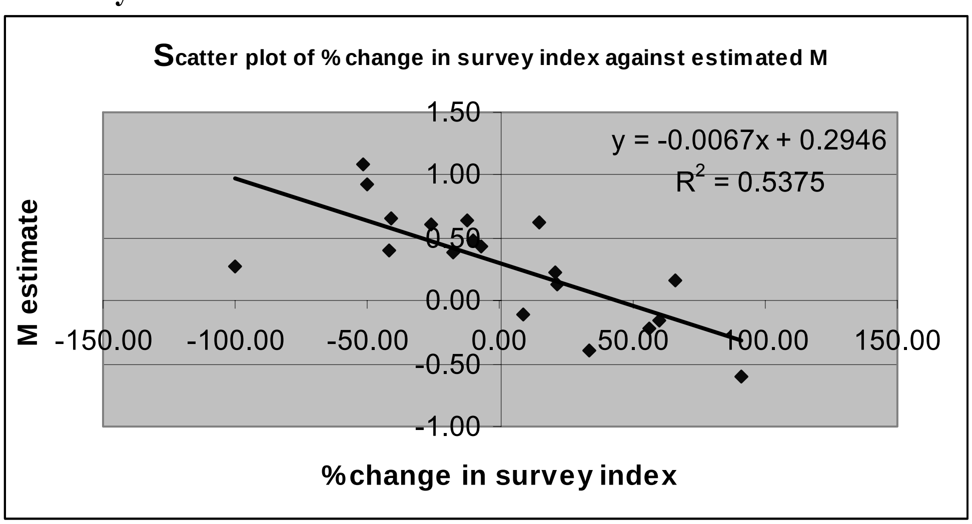


Figure 11. Plots of residual for Post-recruit survey from simulated data with constant true M.

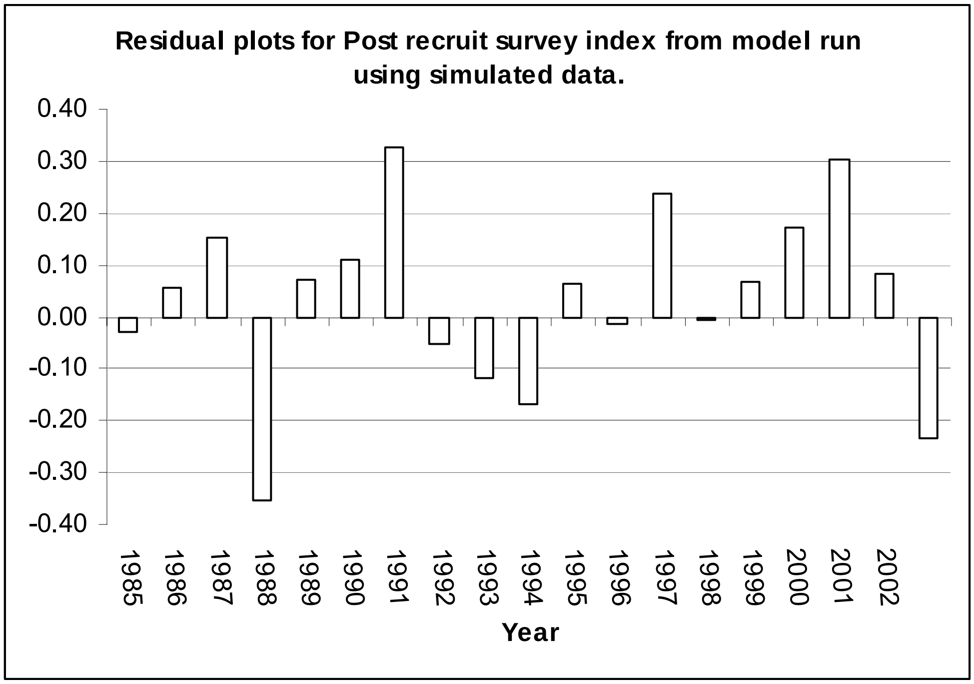


Figure 12. Plots of residual for recruit surveys from simulated data with M constant. Note increasing trend in residuals in the recruit survey from 1997-2002

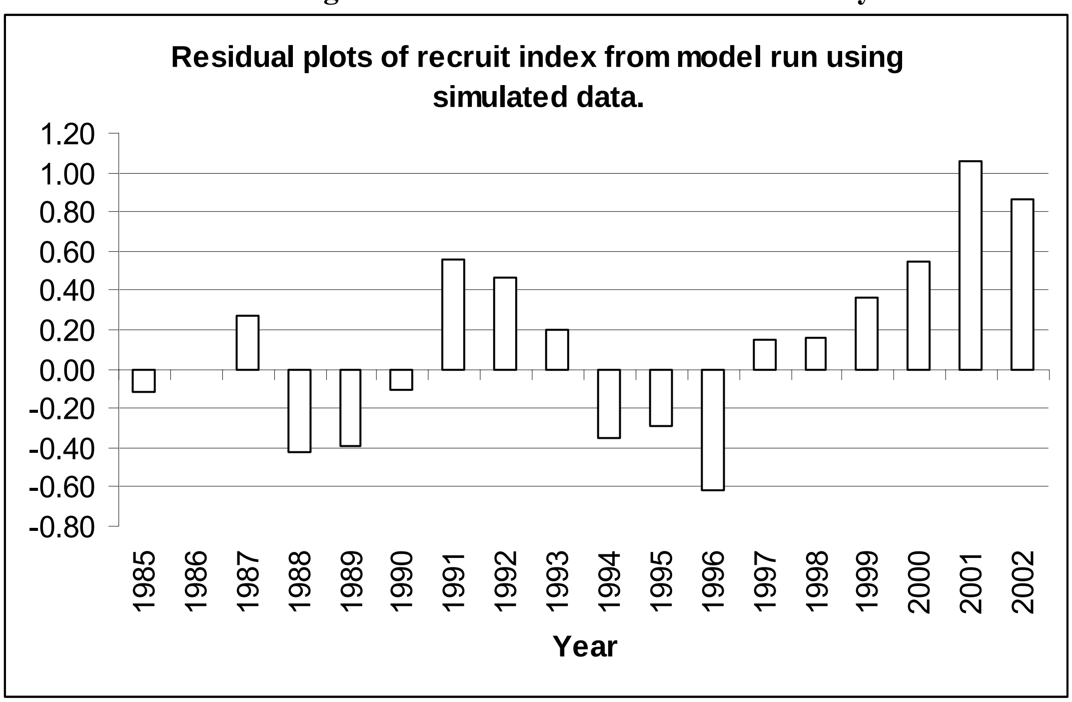


Figure 13. Plots of residual for total population surveys from simulated data with M constant. Note positive trend in residuals in the total survey from 1997-2002

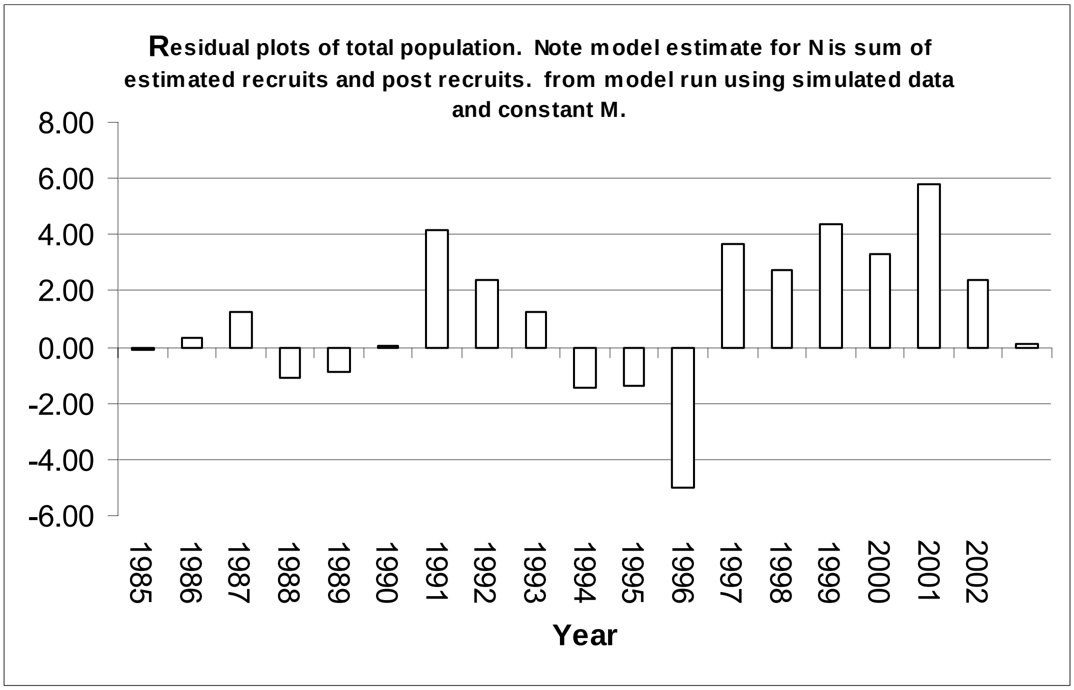


Figure 14. Trends in true M and estimated M in second simulation with M increasing in latter years.

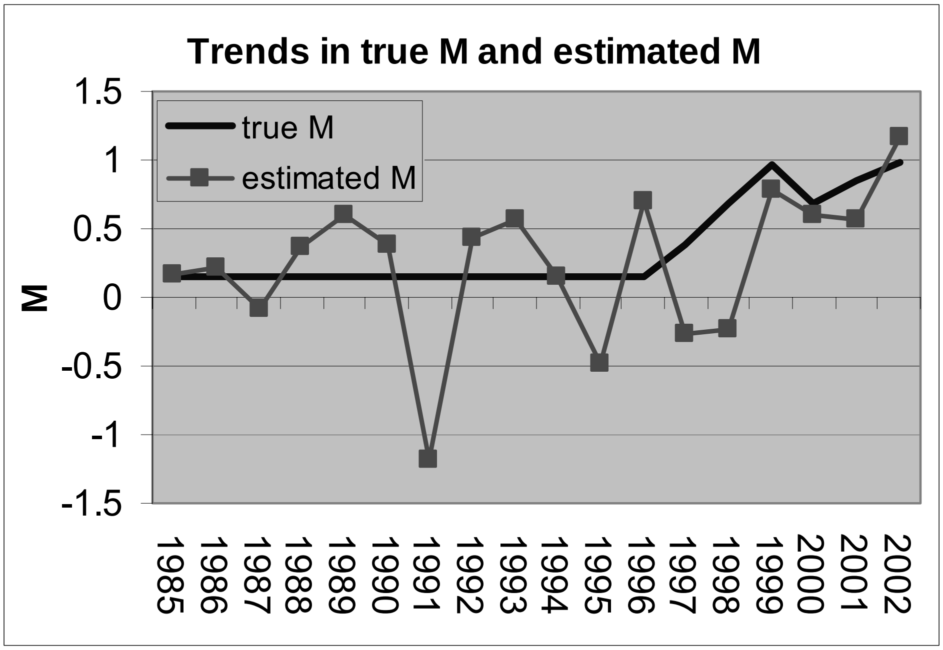


Figure 15. Scattter plot of M estimates and survey residuals (S_t/Q_t) – N_t from simulated population with M increasing in recent years.

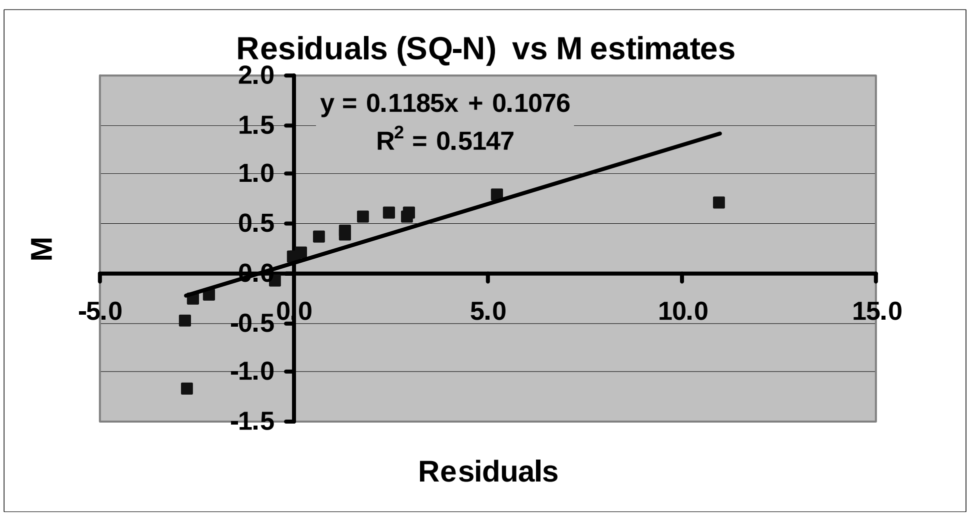


Figure 16. Scatter plot of Qt (ln $N_t/(S_t/Q)$) against M estimates from simulation with M increasing in recent years.

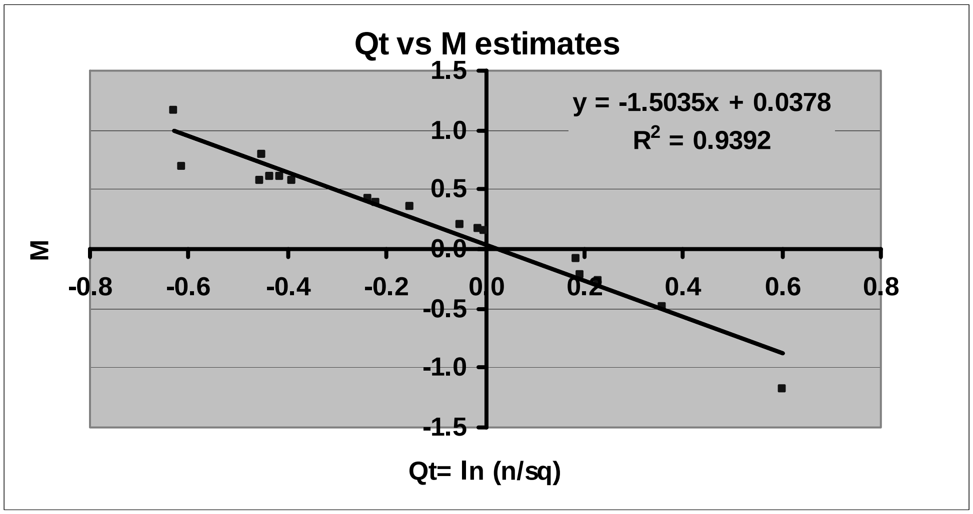


Figure 17. Residual plot of recruit index from long run, q constrained. From simulation with M increasing in recent years.

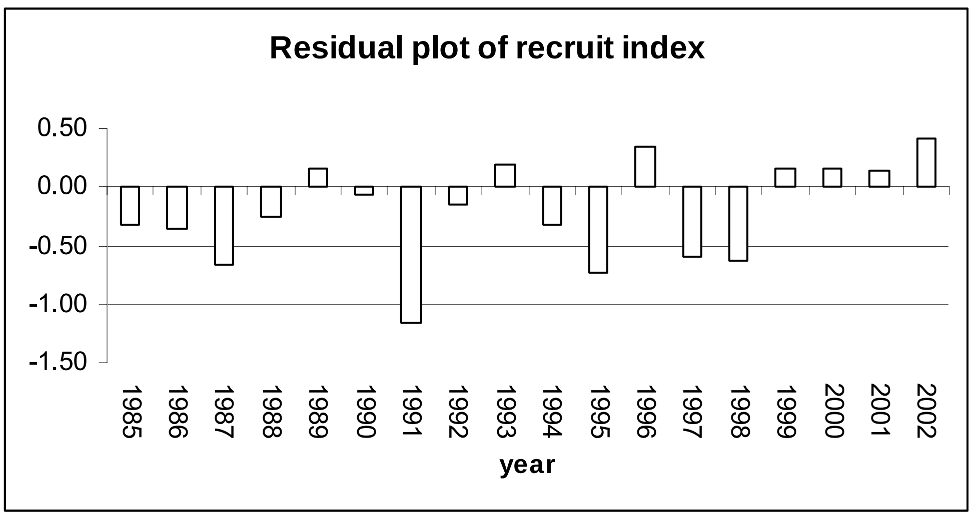


Figure 18. Residual plot of post recruit index from long run, q constrained. From simulation with M increasing in recent years.

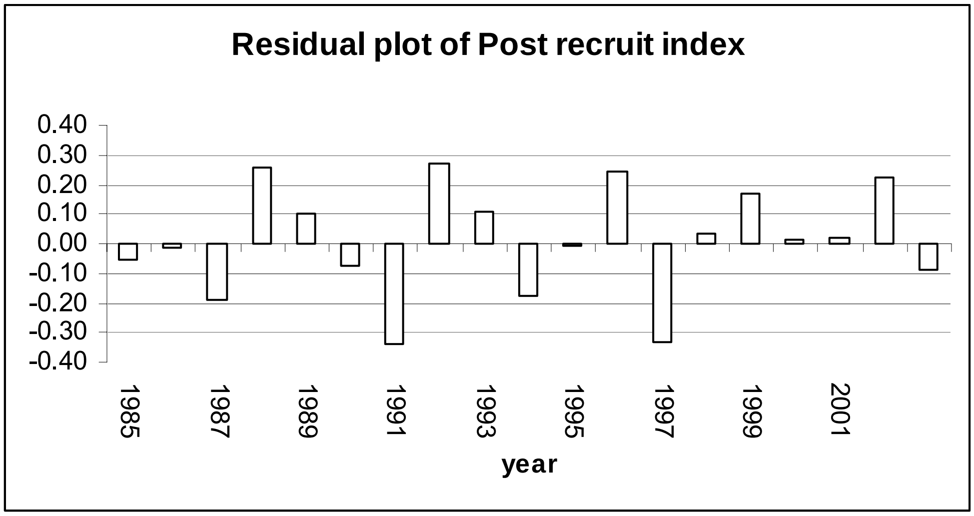


Figure 19. Residual plot of total index from long run, q constrained. Simulation with M increasing in recent years. Model results for Nt are sum of post recruits and recruits. Note run of positive residuals in 1999-2002, corresponding with high M estimates.

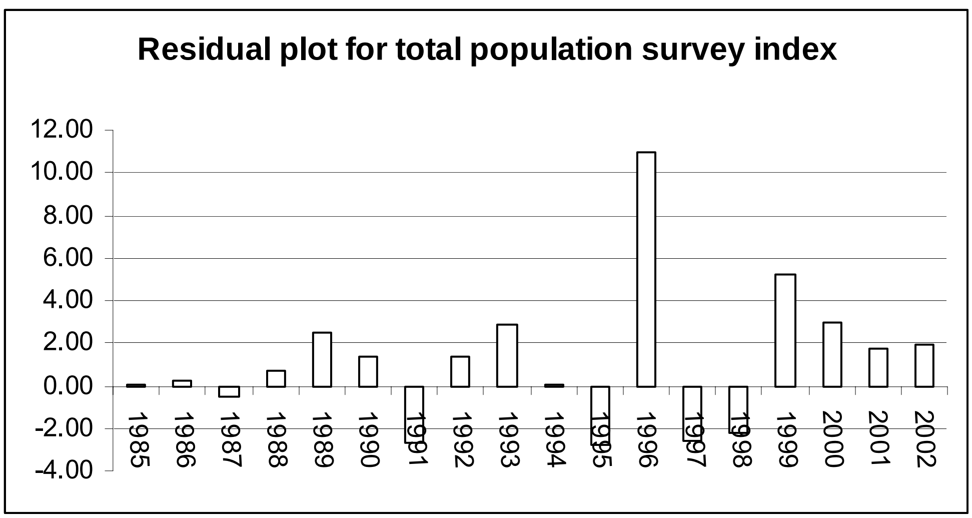
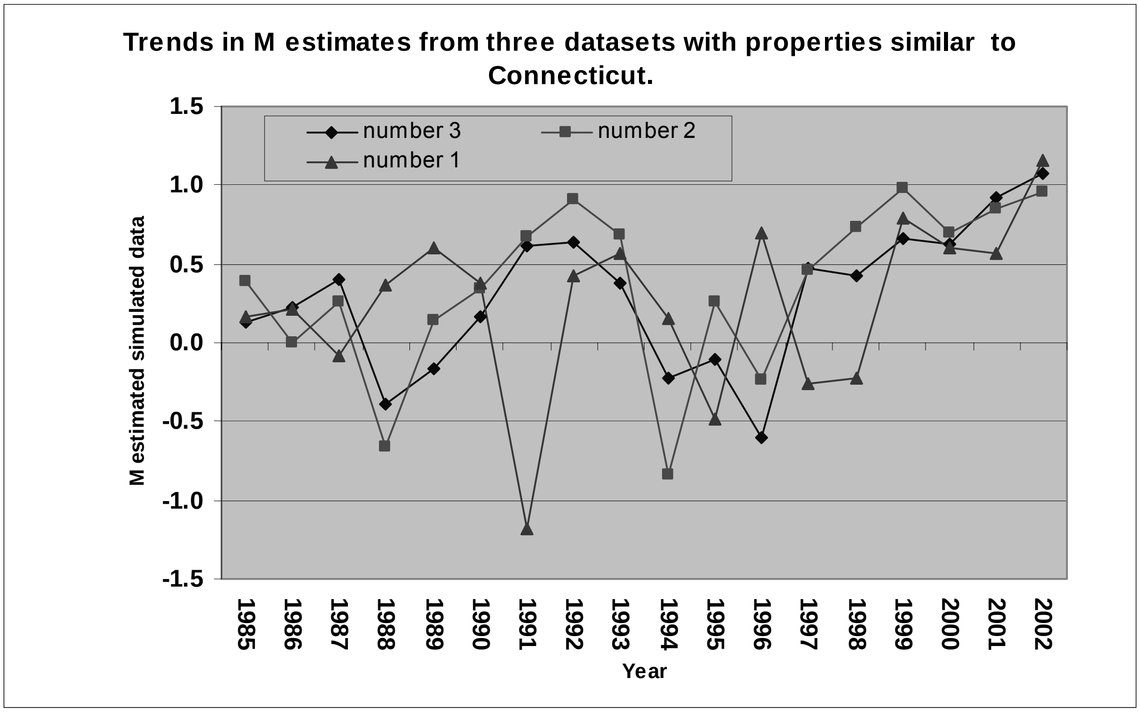


Figure 19. Estimates of M on three datasets with survey and catch properties similar to Long Island Sound data. In one dataset, true M is constant throughout, in one dataset M increases substantially after 1996, and in one dataset, true M is unknown.



Appendix V. Stock Indicator Tables

Table 1 Biological Stock indicators for the Southern Gulf of Maine-MA 514 sub-area during 1982-2003. The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

Stock Indicators MAGOM Stat Area 514	*Mortality Indicators*					*Abundance Indicators*				*Fishery Performance Indicators*			
	1. Exploitation Rate (catch/abundance)	2. Z (model)	3. A. Mean length Females (from MA survey 83 mm +)	3. B. Mean length Males (from MA survey 83 mm +)	4. % of the Exploitable Stock Comprised of Recruits (surveys)	5. Spawning Stock Abundance Index	6. Recruit Abundance (sexes combined Model)	7. Full Recruit Abundance (blended/sex combined	8. Settlement Index (Massachusetts Bay and Cape Cod Bay)	9. Effort (traps)	10. Landings (mt)	11. Mean Length (Landings)	12. Gross CPUE (pounds per trap fished)
1982	0.59	1.15	92.1	87.7	0.57	1.27	7.95	5.39		247,415	4,154	88.5	37.01
1983	0.56	1.05	89.8	88.7	0.71	1.15	11.11	4.24		259,642	3,984	88.4	33.83
1984	0.60	1.18	92.1	90.1	0.63	0.88	8.61	5.57		275,165	4,613	87.9	36.96
1985	0.71	1.54	89.6	87.4	0.64	0.82	8.86	4.50		313,758	4,152	88.2	29.17
1986	0.79	1.95	89.5	88.3	0.74	0.50	6.27	3.64		331,713	4,805	88.0	31.94
1987	0.86	2.48	88.7	87.1	0.85	0.38	9.01	1.08		356,169	4,422	87.8	27.37
1988	0.79	1.95	92.4	87.9	0.93	0.20	11.04	1.09		356,689	4,407	88.0	27.24
1989	0.70	1.49	90.5	87.6	0.90	0.38	14.43	1.91		351,584	4,313	88.0	27.04
1990	0.75	1.75	89.5	87.2	0.72	0.62	11.55	3.81		378,703	5,432	88.2	31.62
1991	0.70	1.51	88	87.1	0.79	0.33	7.96	4.05		399,010	5,722	88.0	31.62
1992	0.86	2.44	86.4	88	0.74	0.49	7.07	2.88		388,415	5,375	88.0	30.51
1993	0.71	1.53	89.3	87.8	0.93	0.18	11.48	1.03		370,641	4,844	88.0	28.81
1994	0.72	1.57	86.5	90.4	0.79	0.45	10.90	2.96		373,641	4,503	88.3	26.57
1995	0.75	1.71	87.6	87.2	0.79	0.39	9.30	3.27	0.63	377,305	5,329	88.4	31.14
1996	0.89	2.79	86.7	87.4	0.79	0.37	8.48	2.98	0.00	389,492	5,278	88.3	29.87
1997	0.82	2.11	87.9	86.7	0.94	0.17	7.70	1.87	0.23	383,506	5,037	88.0	28.96
1998	0.74	1.66	87.3	88	0.89	0.23	9.91	1.35	0.04	389,933	4,673	88.3	26.42
1999	0.75	1.72	86.7	84.8	0.85	0.41	10.52	2.37	0.49	379,970	3,869	88.6	22.45
2000	0.77	1.82	88.4	88	0.75	0.49	6.99	2.45	0.28	384,581	5,024	88.4	28.80
2001	0.80	2.01	89.8	87.7	0.84	0.50	7.22	1.64	0.53	375,807	5,094	88.3	29.88
2002	0.83	2.18	91.6	87.8	0.85	0.21	6.47	1.21	0.99	394,820	3,592	88.5	20.06
2003	0.90	3.00	87.9	85.8	0.87	0.32	5.64	1.04	0.88	383,055	4,022	88.3	23.15
2001-03 Avg.	0.84	2.40	89.77	87.10	0.85	0.34	6.44	1.30	0.80	384,560	4,236	88.4	24
Median	*0.75*	*1.75*	*89.30*	*87.70*	*0.79*	*0.39*	*8.61*	*2.45*	*0.51*	*377,305*	*4,613*	*88.30*	*29*
25th	*0.71*	*1.53*	*87.68*	*87.20*	*0.74*	*0.32*	*7.34*	*1.42*	*0.23*	*352,730*	*4,193*	*88.0*	*27*
75th	*0.81*	*2.08*	*89.80*	*88.00*	*0.86*	*0.50*	*10.81*	*3.77*	*0.63*	*384,312*	*5,079*	*88.4*	*31*

Table 1 Biological Stock indicators for the Southern New England-RI 539 sub-area during 1982-2003. The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Exploitation Rate (catch/ survey abundance)	Exploitation Rate (catch/model abundance)				Z (model)				v (expection of natural death)			
		M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90
1984	0.49	0.86	0.85	0.85	0.84	3.01	2.95	2.89	2.84	0.05	0.05	0.05	0.05
1985	0.67	0.80	0.79	0.78	0.78	2.28	2.23	2.17	2.12	0.06	0.06	0.06	0.06
1986	0.61	0.65	0.64	0.63	0.62	1.19	1.17	1.14	1.12	0.09	0.09	0.09	0.09
1987	0.33	0.51	0.50	0.48	0.47	0.83	0.80	0.78	0.76	0.10	0.10	0.10	0.11
1988	0.54	0.60	0.58	0.57	0.56	1.08	1.04	1.01	0.99	0.09	0.09	0.09	0.10
1989	0.36	0.65	0.64	0.63	0.62	1.41	1.36	1.32	1.27	0.08	0.08	0.08	0.08
1990	0.62	0.71	0.70	0.69	0.68	1.38	1.35	1.32	1.28	0.08	0.08	0.08	0.08
1991	0.44	0.66	0.65	0.64	0.63	1.19	1.15	1.12	1.09	0.09	0.09	0.09	0.09
1992	0.49	0.62	0.61	0.60	0.58	1.05	1.02	0.99	0.96	0.09	0.09	0.10	0.10
1993	0.38	0.62	0.62	0.61	0.60	1.12	1.10	1.08	1.05	0.09	0.09	0.09	0.09
1994	0.38	0.76	0.75	0.74	0.73	1.65	1.59	1.54	1.49	0.07	0.07	0.08	0.08
1995	0.39	0.68	0.66	0.65	0.64	1.33	1.28	1.23	1.18	0.08	0.08	0.09	0.09
1996	0.27	0.63	0.60	0.57	0.54	1.21	1.12	1.03	0.95	0.09	0.09	0.09	0.10
1997	0.24	0.79	0.69	0.60	0.52	1.86	1.86	1.89	1.96	0.07	0.18	0.29	0.39
1998	0.73	0.83	0.74	0.66	0.59	2.04	2.12	2.22	2.34	0.06	0.17	0.26	0.35
1999	1.12	0.84	0.75	0.68	0.60	2.06	2.14	2.24	2.36	0.06	0.16	0.26	0.35
2000	1.05	0.79	0.70	0.62	0.55	1.65	1.73	1.84	1.97	0.07	0.19	0.30	0.39
2001	0.47	0.57	0.47	0.38	0.30	0.81	0.93	1.08	1.24	0.10	0.26	0.40	0.51
2002	1.30	0.78	0.71	0.64	0.58	1.60	1.78	1.97	2.17	0.07	0.19	0.28	0.37
2003	1.03	0.79	0.71	0.63	0.56	1.71	1.82	1.95	2.08	0.07	0.18	0.29	0.38
2001 -2003	0.93	0.72	0.71	0.55	0.48	1.37	1.51	1.67	1.83	0.08	0.21	0.32	0.42
Median	*0.49*	*0.69*	*0.68*	*0.63*	*0.59*	*1.40*	*1.36*	*1.32*	*1.28*	*0.08*	*0.09*	*0.09*	*0.10*
25th	*0.38*	*0.63*	*0.61*	*0.60*	*0.56*	*1.17*	*1.12*	*1.08*	*1.08*	*0.07*	*0.08*	*0.09*	*0.09*
75th	*0.69*	*0.79*	*0.72*	*0.66*	*0.63*	*1.74*	*1.83*	*1.95*	*2.09*	*0.09*	*0.17*	*0.27*	*0.35*

Table 2 Fishery Performance Stock indicators for the Southern New England-RI 539 sub-area during 1982-2003. The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Fishery Performance Indicators			
	Effort	Landings (millions of pounds)	Mean Length (Landings) (no data)	Gross CPUE
1984	227,000	1.041		4.584
1985	211,625	0.946		4.472
1986	199,500	1.073		5.376
1987	215,925	0.909		4.211
1988	209,500	1.298		6.194
1989	183,450	1.479		8.061
1990	217,150	1.646		7.581
1991	243,900	1.332		5.461
1992	300,689	1.366		4.544
1993	241,066	1.795		7.445
1994	275,167	1.802		6.549
1995	274,385	1.745		6.359
1996	276,545	1.856		6.713
1997	295,359	1.887		6.390
1998	320,190	2.397		7.487
1999	321,065	2.363		7.361
2000	262,423	1.700		6.479
2001	254,470	1.278		5.022
2002	303,052	1.127		3.718
2003	244,606	1.300		5.316
2001 -2003 A	267,376	1.235		4.685
Median	*249538*	*1.42*		*6.28*
25th	*216844*	*1.24*		*4.91*
75th	*281248*	*1.80*		*6.87*

Table 3 Biological Stock indicators for the Southern New England-CT 611sub-area during 1982-2003. The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Exploitation Rate (catch/survey abundance)	Exploitation Rate (catch/model abundance)				Z (model)				v (expection of natural death)			
		M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90
1984	0.17	0.59	0.57	0.56	0.54	1.15	1.11	1.07	1.03	0.09	0.09	0.09	0.09
1985	0.31	0.50	0.49	0.48	0.47	0.92	0.89	0.87	0.84	0.10	0.10	0.10	0.10
1986	0.18	0.55	0.54	0.53	0.52	1.05	1.02	0.99	0.96	0.09	0.09	0.10	0.10
1987	0.21	0.60	0.59	0.57	0.56	1.18	1.15	1.11	1.08	0.09	0.09	0.09	0.09
1988	0.41	0.77	0.76	0.75	0.73	1.82	1.76	1.71	1.65	0.07	0.07	0.07	0.07
1989	0.44	0.68	0.67	0.66	0.66	1.44	1.41	1.37	1.34	0.08	0.08	0.08	0.08
1990	0.28	0.69	0.68	0.67	0.66	1.48	1.45	1.41	1.37	0.08	0.08	0.08	0.08
1991	0.20	0.60	0.59	0.58	0.57	1.17	1.14	1.11	1.08	0.09	0.09	0.09	0.09
1992	0.19	0.69	0.67	0.66	0.65	1.46	1.42	1.37	1.32	0.08	0.08	0.08	0.08
1993	0.21	0.59	0.58	0.56	0.55	1.15	1.12	1.08	1.05	0.09	0.09	0.09	0.09
1994	0.35	0.78	0.77	0.76	0.75	1.87	1.82	1.77	1.72	0.07	0.07	0.07	0.07
1995	0.51	0.79	0.78	0.77	0.76	1.96	1.92	1.87	1.83	0.07	0.07	0.07	0.07
1996	0.65	0.76	0.75	0.74		1.79	1.74	1.68	1.63	0.07	0.07	0.07	0.07
1997	0.25	0.85	0.76	0.68	0.60	2.37	2.43	2.49	2.58	0.06	0.15	0.24	0.32
1998	0.48	0.85	0.76	0.68	0.61	2.41	2.47	2.54	2.63	0.06	0.15	0.24	0.32
1999	0.20	0.78	0.68	0.59	0.51	1.97	2.03	2.10	2.19	0.07	0.17	0.27	0.36
2000	0.22	0.80	0.71	0.62	0.54	2.11	2.16	2.23	2.32	0.06	0.16	0.26	0.35
2001	0.20	0.91	0.83	0.76	0.68	3.15	3.16	3.18	3.21	0.05	0.12	0.20	0.27
2002	0.35	0.90	0.82	0.74	0.67	2.91	2.95	3.00	3.07	0.05	0.13	0.21	0.28
2003	0.31	0.79	0.70	0.61	0.54	1.97	2.06	2.16	2.27	0.07	0.17	0.27	0.36
2001 -2003	0.29	0.86	0.78	0.70	0.63	2.67	2.72	2.78	2.85	0.05	0.14	0.22	0.30
Median	*0.27*	*0.76*	*0.69*	*0.66*	*0.60*	*1.81*	*1.75*	*1.69*	*1.64*	*0.07*	*0.09*	*0.09*	*0.09*
25th	*0.20*	*0.60*	*0.59*	*0.58*	*0.54*	*1.18*	*1.15*	*1.11*	*1.08*	*0.06*	*0.08*	*0.08*	*0.08*
75th	*0.37*	*0.79*	*0.76*	*0.74*	*0.68*	*2.01*	*2.08*	*2.18*	*2.28*	*0.09*	*0.13*	*0.21*	*0.29*

Table 3 Biological Stock indicators for the Southern New England-CT 611sub-area during 1982-2003 (Con't). The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Mean Length (Survey - 83+ legals only)	% of the Exploitable Stock Comprised of Recruits (survey)	Spawning Stock Abundance Index				Recruit Abundance (sexes combined-model)				Full-recruit Abundance (sexes combined -model)				Settlement (no data)
			M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	
1984	89.8	0.66	1.344	1.386	1.429	1.472	2.092	2.139	2.189	2.239	1.402	1.446	1.490	1.535	
1985	89.6	0.75	1.243	1.301	1.361	1.421	2.438	2.446	2.456	2.468	1.133	1.211	1.291	1.372	
1986	88.0	0.61	1.351	1.403	1.458	1.514	2.554	2.570	2.587	2.605	1.422	1.495	1.572	1.652	
1987	88.0	0.75	1.427	1.480	1.535	1.592	2.779	2.789	2.799	2.809	1.402	1.478	1.558	1.641	
1988	89.0	0.69	1.316	1.360	1.406	1.455	2.603	2.584	2.567	2.554	1.312	1.385	1.462	1.541	
1989	86.9	0.77	1.068	1.102	1.138	1.178	4.327	4.347	4.365	4.379	0.637	0.682	0.732	0.787	
1990	87.4	0.72	1.545	1.584	1.626	1.669	4.116	4.138	4.162	4.187	1.180	1.234	1.292	1.351	
1991	87.8	0.83	1.226	1.270	1.317	1.365	4.159	4.193	4.228	4.265	1.212	1.277	1.345	1.416	
1992	87.3	0.74	1.386	1.444	1.505	1.568	3.635	3.651	3.671	3.695	1.666	1.749	1.838	1.930	
1993	86.2	0.86	1.585	1.649	1.719	1.791	5.666	5.729	5.793	5.854	1.239	1.323	1.414	1.512	
1994	87.6	0.76	2.202	2.279	2.360	2.444	6.502	6.475	6.449	6.427	2.221	2.347	2.478	2.613	
1995	85.9	0.77	2.293	2.349	2.411	2.477	9.772	9.799	9.825	9.850	1.353	1.435	1.523	1.617	
1996	86.8	0.79	3.020	3.104	3.194	3.287	11.150	11.248	11.355	11.470	1.622	1.712	1.807	1.905	
1997	86.7	0.83	3.099	3.400	3.747	4.145	9.248	10.418	11.812	13.468	2.150	2.306	2.474	2.652	
1998	86.8	0.85	2.118	2.322	2.556	2.821	8.437	9.455	10.664	12.089	1.092	1.154	1.209	1.252	
1999	86.5	0.85	0.935	1.074	1.236	1.424	4.336	5.054	5.936	6.997	0.882	0.924	0.959	0.983	
2000	85.7	0.84	0.904	1.020	1.150	1.292	2.579	2.970	3.461	4.073	0.809	0.873	0.927	0.966	
2001	85.0	0.90	0.616	0.675	0.741	0.814	1.940	2.127	2.356	2.633	0.447	0.479	0.507	0.530	
2002	83.8	0.93	0.229	0.251	0.277	0.307	1.196	1.311	1.446	1.603	0.112	0.120	0.129	0.138	
2003	84.4	0.94	0.251	0.287	0.328	0.377	1.338	1.521	1.737	1.992	0.073	0.076	0.079	0.082	
2001 -2003	84.4	0.92	0.37	0.40	0.45	0.50	1.49	1.65	1.85	2.08	0.21	0.23	0.24	0.25	
Median	*86.85*	*0.78*	*1.35*	*1.39*	*1.44*	*1.49*	*3.88*	*3.89*	*3.92*	*4.13*	*1.23*	*1.30*	*1.38*	*1.46*	
25th	*86.10*	*0.74*	*1.04*	*1.09*	*1.21*	*1.35*	*2.53*	*2.54*	*2.54*	*2.59*	*0.86*	*0.91*	*0.95*	*0.98*	
75th	*87.85*	*0.85*	*1.72*	*1.81*	*1.88*	*1.95*	*5.87*	*5.92*	*6.06*	*6.57*	*1.41*	*1.48*	*1.56*	*1.64*	

Table 4 Fishery Performance Stock indicators for the Southern New England-CT 611sub-area during 1982-2003. The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Fishery Performance Indicators			
	Effort	**Landings (millions of pounds)**	**Mean Length (Landings) (no data)**	**Gross CPUE**
1984	**157182**	**2.047**		**13.026**
1985	**178649**	**1.799**		**10.073**
1986	**156844**	**2.205**		**14.056**
1987	**155445**	**2.499**		**16.073**
1988	**205568**	**3.007**		**14.629**
1989	**288629**	**3.389**		**11.743**
1990	**276998**	**3.669**		**13.245**
1991	**312543**	**3.231**		**10.337**
1992	**377314**	**3.644**		**9.657**
1993	**476227**	**4.066**		**8.538**
1994	**540832**	**6.777**		**12.530**
1995	**507157**	**8.767**		**17.286**
1996	**630590**	**9.730**		**15.430**
1997	**673717**	**9.649**		**14.323**
1998	**742872**	**8.105**		**10.910**
1999	**762468**	**4.061**		**5.326**
2000	**491624**	**2.725**		**5.544**
2001	**502487**	**2.166**		**4.310**
2002	**362381**	**1.171**		**3.233**
2003	**250082**	**1.114**		**4.455**
2001 -2003 /	**371650**	**1.484**		**3.999**
Median	***369847***	***3.31***		***11.33***
25th	***238954***	***2.19***		***7.79***
75th	***515576***	***4.74***		***14.12***

Table 5 Biological Stock indicators for the Southern New England-NEFSC sub-area during 1982-2003 (Con't). The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Exploitation Rate (catch/survey abundance)	Exploitation Rate (catch/model abundance)				Z (model)				v (expection of natural death)			
		M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90
1984	4.17	0.49	0.45	0.43	0.41	0.90	0.83	0.78	0.75	0.10	0.10	0.10	0.11
1985	5.13	0.54	0.49		0.43	1.05	0.94	0.86	0.81	0.09	0.10	0.10	0.10
1986	7.18	0.43	0.41	0.39	0.38	0.78	0.74	0.71	0.68	0.10	0.11	0.11	0.11
1987	8.95	0.60	0.56	0.53	0.50	1.22	1.10	1.01	0.95	0.09	0.09	0.09	0.10
1988	9.54	0.61	0.57	0.54	0.52	1.21	1.11	1.03	0.97	0.09	0.09	0.09	0.10
1989	6.10	0.50	0.47	0.45	0.43	0.95	0.89	0.84	0.80	0.10	0.10	0.10	0.10
1990	7.50	0.51	0.48	0.46	0.44	0.98	0.91	0.86	0.83	0.10	0.10	0.10	0.10
1991	7.28	0.49	0.45	0.43	0.41	0.91	0.84	0.79	0.75	0.10	0.10	0.10	0.11
1992	4.81	0.44	0.42	0.41	0.40	0.86	0.81	0.78	0.75	0.10	0.10	0.10	0.11
1993	7.47	0.49	0.47	0.45	0.44	1.03	0.98	0.93	0.89	0.09	0.10	0.10	0.10
1994	23.49	0.68	0.65	0.62	0.60	1.45	1.34	1.25	1.18	0.08	0.08	0.09	0.09
1995	6.19	0.45	0.41	0.37	0.35	0.82	0.74	0.67	0.62	0.10	0.11	0.11	0.11
1996	2.46	0.46	0.38	0.32	0.28	0.83	0.68	0.58	0.52	0.10	0.11	0.11	0.12
1997	3.44	0.45	0.33	0.25	0.20	0.83	0.91	1.06	1.25	0.10	0.26	0.40	0.51
1998	4.97	0.54	0.42	0.34	0.30	1.04	1.11	1.27	1.48	0.09	0.24	0.37	0.47
1999	8.01	0.63	0.51	0.43	0.37	1.32	1.37	1.50	1.68	0.08	0.22	0.34	0.44
2000	3.79	0.46	0.34	0.26	0.20	0.86	0.94	1.09	1.27	0.10	0.26	0.40	0.51
2001	4.65	0.50	0.39	0.32	0.28	0.97	1.07	1.24	1.45	0.10	0.25	0.37	0.47
2002	7.68	0.46	0.38	0.33	0.29	0.89	1.05	1.25	1.47	0.10	0.25	0.37	0.47
2003	6.82	0.45	0.38	0.33	0.28	0.86	1.04	1.24	1.44	0.10	0.25	0.37	0.48
2001 -2003 Avg.	6.38	0.47	0.38	0.32	0.28	0.91	1.05	1.24	1.45	0.10	0.25	0.37	0.47
Median	*6.51*	*0.49*	*0.44*	*0.42*	*0.39*	*0.93*	*0.94*	*0.97*	*0.92*	*0.10*	*0.10*	*0.11*	*0.11*
25th	*4.77*	*0.46*	*0.39*	*0.33*	*0.29*	*0.86*	*0.84*	*0.79*	*0.75*	*0.09*	*0.10*	*0.10*	*0.10*
75th	*7.55*	*0.54*	*0.49*	*0.45*	*0.43*	*1.05*	*1.08*	*1.24*	*1.31*	*0.10*	*0.24*	*0.37*	*0.47*

Table 5 Biological Stock indicators for the Southern New England-NEFSC sub-area during 1982-2003 (Con't). The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Length (Survey - 83+ legals only)	Exploitable Stock Comprised of Recruits	Spawning Stock Abundance Index				Recruit Abundance (sexes combined-model)				Full-recruit Abundance (sexes combined - model)				Settlement (no data)
			M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	M=0- No Change	M=0.15/ M=0.40	M=0.15/ M=.65	M=0.15/ M=0.90	
1984	97.1	0.30	3.509	3.870	4.167	4.376	5.47	5.82	6.12	3.86	4.35	4.75	5.09	4.38	
1985	97.2	0.34	3.503	4.089	4.569	4.905	5.67	6.02	6.31	4.99	4.06	4.70	5.24	4.27	
1986	102.2	0.39	3.539	4.189	4.732	5.119	9.14	8.93	8.85	5.77	3.54	4.38	5.09	4.88	
1987	97.0	0.18	4.523	4.997	5.452	5.806	2.85	2.97	3.08	2.53	5.92	6.46	7.00	5.85	
1988	96.9	0.33	3.527	4.034	4.510	4.877	8.20	8.35	8.48	5.81	2.70	3.27	3.82	3.68	
1989	97.4	0.38	5.322	5.930	6.466	6.866	12.69	13.06	13.33	9.97	3.29	3.90	4.48	3.80	
1990	98.5	0.29	6.454	7.160	7.742	8.160	9.85	10.03	10.15	6.57	6.47	7.31	8.04	7.08	
1991	103.1	0.25	5.526	6.288	6.911	7.354	6.11	6.25	6.36	5.12	6.38	7.25	7.98	6.99	
1992	96.3	0.30	5.342	5.999	6.547	6.947	8.75	8.55	8.42	6.79	5.14	6.00	6.72	6.21	
1993	97.0	0.30	5.908	6.335	6.731	7.049	5.28	5.15	5.10	5.34	6.29	6.85	7.36	6.92	
1994	100.8	0.28	4.519	4.847	5.190	5.481	3.95	4.03	4.09	3.52	4.83	5.19	5.59	6.13	
1995	91.7	0.34	3.597	4.193	4.784	5.257	9.33	10.19	11.05	9.82	2.07	2.45	2.84	2.88	
1996	96.8	0.35	5.441	6.885	8.354	9.545	9.43	11.38	13.52	14.55	5.06	6.12	7.19	6.02	
1997	97.6	0.39	6.054	8.842	11.882	14.560	8.59	11.81	15.82	16.84	6.39	8.97	11.74	11.13	
1998	95.4	0.35	5.835	7.804	9.313	10.013	6.55	8.61	11.25	13.34	6.66	8.51	9.68	7.74	
1999	92.0	0.36	4.312	5.410	5.996	6.182	5.42	6.85	8.99	9.82	4.84	5.82	6.04	4.61	
2000	98.5	0.38	3.652	4.906	6.104	7.313	6.40	9.30	13.25	14.37	2.94	3.42	3.48	2.69	
2001	100.5	0.28	3.843	5.041	5.991	6.620	3.42	4.52	5.86	5.78	4.09	5.09	5.76	4.88	
2002	103.7	0.31	3.166	3.850	4.241	4.466	3.03	3.90	5.04	4.55	3.02	3.47	3.50	2.60	
2003	95.6	0.29	2.703	3.015	3.201	3.398	3.37	4.42	5.83	5.37	2.66	2.73	2.56	1.78	
2001 -2003 Avg.	99.92	0.29	3.24	3.97	4.48	4.83	3.27	4.28	5.58	5.23	3.26	3.77	3.94	3.09	
Median	*97.10*	*0.32*	*4.42*	*5.02*	*5.99*	*6.40*	*6.26*	*7.60*	*8.45*	*5.79*	*4.59*	*5.14*	*5.67*	*4.88*	
25th	*96.66*	*0.29*	*3.54*	*4.16*	*4.69*	*5.07*	*4.95*	*4.99*	*5.85*	*5.09*	*3.22*	*3.79*	*4.32*	*3.77*	
75th	*99.02*	*0.35*	*5.46*	*6.30*	*6.78*	*7.32*	*8.85*	*9.48*	*11.10*	*9.86*	*6.01*	*6.56*	*7.23*	*6.38*	

Table 6 Fishery Performance Stock indicators for the Southern New England-NEFSC sub-area during 1982-2003. The annual value of each stock indicator time series was categorized as positive (white), neutral (gray), or negative (black) based on its quartile ranking for the time series.

	Fishery Performance Indicators			
	Effort (no data)	**Landings (millions of pounds)**	**Mean Length (Landings)**	**Gross CPUE**
1984		**4.785**		
1985		**5.282**		
1986		**5.432**		
1987		**5.298**		
1988		**6.660**		
1989		**7.944**		
1990		**8.366**		
1991		**6.118**		
1992		**6.176**		
1993		**5.610**		
1994		**6.006**		
1995		**5.176**		
1996		**6.615**		
1997		**6.785**		
1998		**7.131**		
1999		**6.445**		
2000		**4.305**		
2001		**3.752**		
2002		**2.778**		
2003		**2.739**		
2001 -2003 Avg.		**3.090**		
Median		***5.81***		
25th		***5.08***		
75th		***6.63***		