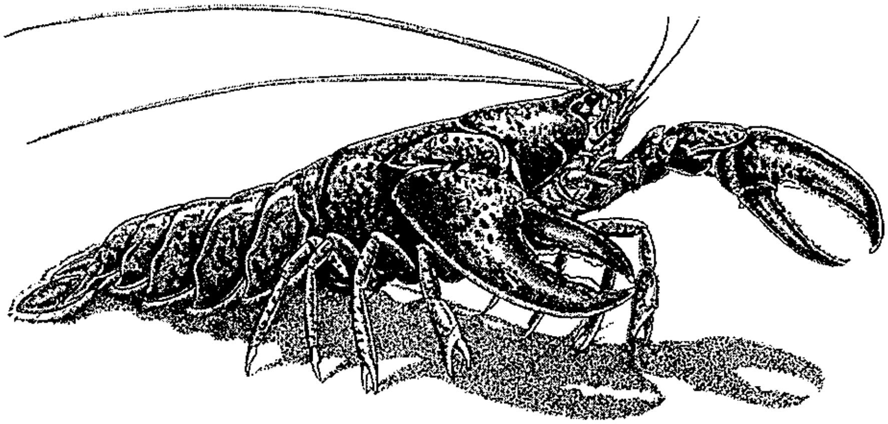
Stock Assessment Report No. 00-01(Supplement)
of the

# Atlantic States Marine Fisheries Commission

## *American Lobster Stock Assessment Report for Peer Review*



July 2000

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Conducted on
May 8-9, 2000
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# PREFACE

## Summary of the Commission Peer Review Process

The Stock Assessment Peer Review Process, adopted in October 1998 by the Atlantic States Marine Fisheries Commission, was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: (1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; (2) improve the quality of Commission stock assessments; (3) improve the credibility of the scientific basis for management; and (4) improve public understanding of fisheries stock assessments. The Commission stock assessment review process includes evaluation of input data, model development, model assumptions, scientific advice, and review of broad scientific issues, where appropriate.

The Stock Assessment Peer Review Process report outlines four options for conducting a peer review of Commission managed species. These options are, in order of priority:

1. The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).

2. A Commission stock assessment review panel composed of 3-4 stock assessment biologists (state, federal, university) will be formed for each review. The Commission review panel will include scientists from outside the range of the species to improve objectivity.

3. A formal review using the structure of existing organizations (i.e. American Fisheries Society, International Council for Exploration of the Sea, or the National Academy of Sciences).

4. An internal review of the stock assessment conducted through the Commission's existing structure (i.e. Technical Committee, Stock Assessment Committee).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes all Commission managed species based on species Management Board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In June 1998, the American lobster stock assessment was prioritized for an external peer review. An external review panel was formed of six stock assessment biologists with expertise in American lobster life history and stock assessment methods. The external peer review for the American lobster stock assessment was conducted May 8-9, 2000 in Providence, Rhode Island.

## Purpose of the Terms of Reference and Advisory Report

The Terms of Reference and Advisory Report provides summary information concerning the American lobster stock assessment and results of the external peer review to evaluate the accuracy of the data and assessment methods for this species. Specific details of the assessment are documented in a supplemental report entitled American Lobster Stock Assessment Report for Peer Review. To obtain a copy of the supplemental report please contact the Commission at (202) 289-6400.

# ACKNOWLEDGMENTS

Thanks are due to the many individuals who contributed to the Commission's American Lobster Stock Assessment Peer Review. Special thanks are extended to the American Lobster Peer Review Panel (Dr. Gerry Ennis, Canada Department of Fisheries and Oceans, Dr. John Hoenig, Virginia Institute of Marine Science, Dr. Peter Lawton, Canada Department of Fisheries and Oceans, Dr. Robert Muller, Florida Fish and Wildlife Conservation Commission, Dr. Saul Saila, University of Rhode Island, and Dr. David Sampson, Oregon State University) for their hard work in reviewing the meeting materials and providing advice on improvements to the Commission's American lobster stock assessment and fishery management. The Commission would like to extend its appreciation to the members of the American Lobster Technical Committee and Stock Assessment Subcommittee for development of the American Lobster Stock Assessment Report for Peer Review (Stock Assessment Peer Review Report 00-001 Supplement) and specifically to the following members for presenting this report at the Peer Review meeting: Josef Idoine (National Marine Fisheries Service, Northeast Fisheries Science Center), Dr. Larry Jacobson (National Marine Fisheries Service, Northeast Fisheries Science Center), Carl LoBue (New York State Department of Environmental Conservation), and Dr. David Stevenson (Maine Division of Marine Resources). Presentations of minority opinions were also provided by Dr. Victor Crecco (Connecticut Bureau of Marine Fisheries), Mark Gibson (Rhode Island Fish and Wildlife), and Josef Idoine.

The Commission would also like to thank the many people who attended the peer review and presented their individual viewpoints on the status of the American lobster assessment and fishery, including: Jim King (Mattituck, NY), Janice Plante (Commercial Fisheries News), Scott Olszewski (Rhode Island Fish and Wildlife), Matthew Mitro (ASMFC), Ernie Beckwith (Connecticut Bureau of Marine Fisheries, ASMFC Commissioner), Kurt Gottschall (Connecticut Bureau of Marine Fisheries), Harry Mears (National Marine Fisheries Service, Northeast Region), Pat White (ASMFC Commissioner), Patrice Farrey (York Beach, ME), John P. Davi, Jr. (Port Jeff, NY), Ed Rodman (Miller Place, NY), John German (Brookhaven, NY), David Borden (Rhode Island Fish and Wildlife, ASMFC Commissioner), David Spencer (Jamestown, RI), Paul Bennett (Middleton, RI), Bill Adler (Massachusetts), George Doll (Northpoint, NY), Linda Mercer (Maine Division of Marine Resources)Kevin Kelly (Maine Division of Marine Resources), Carl Wilson (Maine Division of Marine Resources), Clare McBane (New Hampshire Fish and Game), Kathy Castro (University of Rhode Island), Bruce Estrella (Massachusetts Division of Marine Fisheries), Don Landers (Northeast Utilities Environmental Laboratory), Thomas Angell (Rhode Island Fish and Wildlife), Jim Fair (Massachusetts Division of Marine Fisheries), Bill Andrews (New Jersey Fish and Wildlife), Richard Allen (Wakefield, RI), and George Lapointe (Maine Division of Marine Resources, ASMFC Commissioner).

Special appreciation is given to the staff dedicated to the performance of the Peer Review and finalization of peer review reports, specifically – Dr. Lisa Kline, Geoffrey White, Amy Schick, Tina Berger, and Vanessa Jones.

# EXECUTIVE SUMMARY

The American lobster (*Homarus americanus*) supports the most valuable commercial fishery in the Northeast United States (NMFS 1998). Landings have increased steadily since the early 1970s and fishing effort is intense and increasing throughout the range of the species. Previous stock assessments have warned that the stock is overfished and vulnerable to collapse. Such a collapse would have serious economic, social and ecological implications.

The U.S. lobster resource occurs in continental shelf waters from Maine to North Carolina. About 80% of the landings are caught in state waters (within 3 miles of the coast). As fishing effort has increased, the traditional inshore trap fishery has expanded to nearshore federal waters (3-20 miles from shore). There is also a deepwater fishery for lobster that occurs farther from shore. American lobsters are primarily harvested by traps, with 2% taken by bottom trawls.

This assessment report includes background information on life history, stock definitions, habitat, a description of historical and current fishery information, and a summary of data sources and assessment methodology. Primary data utilized for assessment purposes were derived from commercial landings, port and sea sampling information, and state and federal trawl surveys. Stock units were defined as in previous assessments: the Gulf of Maine (GOM), Georges Bank and the southern New England outer shelf (GBS), and South of Cape Cod to Long Island Sound (SCCLIS). Additional assessment information was developed for some sub-areas within the GOM and SCCLIS stock areas.

Many of the methods and approaches used in this assessment are improved versions of ones used in previous assessments along with some completely new analytical procedures. Trends in abundance and fishing mortality for male and female lobsters in individual stock areas were derived from DeLury models fit to sub-areas based on trawl surveys conducted by the U.S. National Marine Fisheries Service (NMFS) and the states of Massachusetts, Rhode Island, and Connecticut. Length cohort analysis (LCA) was used to estimate fishing mortality rates in recent years for the Georges Bank stock. The egg-per-recruit/yield-per-recruit (EPR) model was used to estimate egg production and yield per recruit as a function of fishing mortality for female lobsters in the three stock areas. In addition to results derived from assessment models, "common sense" indicators of stock and fishery status were evaluated by examining trends in twelve different fishery dependent and independent indices. Finally, a preliminary version of a new sex and size structured assessment model that can incorporate multiple stock status indices was developed, but not adopted because of unresolved technical issues (Appendix A).

The results of the stock assessment are broken down by stock area:

| **Stock Area** | **1995-97 F estimate** | | **$F_{10\%}$** | **Current EPR** |
|---|---|---|---|---|
| | *Male* | *Female* | | *Percent of Maximum* |
| **GOM** | 0.59 | 0.74 | 0.34 | 3.2 |
| **GBS** | 0.63 | 0.41 | 0.29 | 6.2 |
| **SCCLIS** | 1.41 | 1.25 | 0.84 | 8.3 |

**Gulf of Maine (GOM)**

Despite recent increases in landings and fishing effort, fishing mortality rates declined and abundance increased during the last ten years in the stock area as a whole, however a sub-area (Massachusetts Bay) showed very different conditions from the rest of the stock area. Total landings increased by 75% from 1982-1997, reaching a record high of 26,230 metric tons in 1997.

The average annual 1995-97 fishing mortality rates were 0.74 (49% annual exploitation rate) for females and 0.59 (42%) for males, with 80% confidence intervals of 0.54-0.88 and 0.30-0.70 respectively. Even though females are protected from fishing to a greater degree, female fishing mortality rates in the GOM were noticeably higher than male fishing mortality rates every year since 1987. Fishing mortality rates have remained relatively stable since 1993 for both males and females, but were higher in the late 1980s. There were no trends in exploitation indices calculated from NMFS fall survey data or in NMFS survey mass balance fishing mortality rates for either sex.

Average recruit abundance during 1994-97 was 50% above the long term mean and was particularly strong in 1994 and 1996. Fully-recruited (83+ mm) population abundance was 88% above the time series average during 1995-97. Total potential egg production, as indexed by the NMFS fall survey, increased during 1994-98 after varying without trend from 1976 to 1993.

Stock conditions in Area 514 (Massachusetts Bay) were different than the rest of the GOM: there was no change in recruitment over the past 16 years; full-recruit abundance (only 30% female) declined slightly in recent years; total potential egg production was higher during the early 1980s than during more recent years; fishing mortality rates are high and have increased in recent years; and fishing effort is shifting from inshore waters to fishing grounds located further offshore.

Coastal Maine and New Hampshire waters are not adequately surveyed by the NMFS fall trawl survey. A fisheries independent diver survey in four regions along the coast of Maine provided evidence of increasing abundance in eastern Maine and a downward trend in western Maine from 1989-1999, conforming with landings data. The downward trend in western Maine was similar to that observed in the Massachusetts inshore trawl survey in area 514. The GOM stock as a whole may be under-estimated since the majority of the NMFS survey data does not come from the more heavily exploited inshore area.

Egg production per recruit, based on 1995-1997 female fishing mortality, was 3.2% of maximum EPR. There was at least a 90% probability that female fishing mortality rates have exceeded the $F_{10\%}$ EPR reference point (0.34) for this stock every year since 1982. According to the Atlantic States Marine Fisheries Commission (ASMFC) overfishing definition this stock is overfished. However, recruitment into the fishery, total potential egg production, and stock abundance have increased in recent years, thus the majority of the Lobster Stock Assessment Subcommittee (LSASC) concluded that the stock is not currently recruitment overfished. Based on yield per recruit analysis for females, this stock is growth overfished.

## Georges Bank and South (GBS)

Unlike the other two stocks, landings, recruit abundance and full recruit population size remained relatively stable in the GBS stock area over the past 16 years. Total landings increased steadily from 2,444 mt in 1982 to a peak of 4,279 mt in 1990, and remained stable around 3,600 mt from 1992-1998. This stock is composed of a higher proportion of larger lobsters than the other two stocks. The fishery is less dependent on first molt group lobsters with 60-70% of the landings comprised of first molt group lobsters since the early 1990s compared to 90% in SCCLIS.

The average annual 1995-97 fishing mortality rates were 0.41 (31% annual exploitation rate) for females and 0.63 (44%) for males, with 80% confidence intervals of 0.32-0.46 and 0.59-0.69, respectively. Fishing mortality rates were higher for males, which only made up 30% of the average fully-recruited population but 53% of the landings during 1995-97. Patterns in DeLury model fishing mortality rates were confirmed by survey mass balance fishing mortality rates and exploitation indices. Average abundance weighted fishing mortality rate estimates for 1995-1997 calculated by length cohort analysis were 54% higher for females and 48% higher for males than estimates derived from DeLury model runs.

The abundance of recruits varied without trend over the time series. Abundance of fully recruited males dropped steadily from a high in 1988 to a low in 1995 while fishing mortality on males doubled between 1988 and 1994. Male abundance increased in the next two years as the fishing mortality rate dropped. The abundance of fully-recruited females was above average during the last four years, after varying without trend since 1982.

Total potential egg production changed very little since 1976 and is currently at average levels with 80-90% produced by lobsters at least one molt group above minimum legal size.

Egg production per recruit, based on 1995-1997 female fishing mortality, is 6.2% of maximum EPR. There is at least a 90% probability that female fishing mortality rates have exceeded the $F_{10\%}$ EPR reference point (0.29) for this stock in 8 out of the last 16 years. According to the ASMFC overfishing definition this stock is overfished. However, recruitment into the fishery, total potential egg production, and stock abundance have remained stable, thus the majority of the LSASC concluded that the stock is not currently recruitment overfished. Based on yield per recruit analysis for females, this stock is growth overfished.

## South of Cape Cod and Long Island Sound (SCCLIS)

Despite a steady increase in landings, and fishing mortality in recent years, the number of recruits in the SCCLIS stock area increased almost three-fold since the mid 1980s. Landings increased steadily from 2,352 mt in 1982 to a record high of 6,894 mt in 1997, nearly tripling over the time series.

Average 1995-97 fishing mortality rates were estimated from fall landings and survey data were 1.41 for males (71%) and 1.25 for females (67%) with 80% confidence intervals of 1.2-1.5 and 1.07-1.37, respectively. These fishing mortality rates were much higher than the average 1995-97 fishing mortality rates in the other two assessment areas. Fishing mortality rates for the SCCLIS stock as a whole fluctuated, but generally increased after the mid-1980s and remained above 1.0 (60% annual removal rate) during the past ten years. Recent fishing mortality estimates derived from CT fall survey data in LIS were even higher (80% removal rates) and increased steadily since the early 1980s. However, spring survey fishing mortality rates did not change over the time series and were not as high (60% removal rate). Area 539 fishing mortality rates have not changed to any notable degree since 1982, but were below average during the last four years.

Mass balance fishing mortality rates estimated from fall trawl survey data and exploitation indices estimated from landings and fall survey data corroborated the trends in fishing mortality rate derived from DeLury model runs.

Recruit abundance increased almost three-fold since the mid-1980s. The most notable gains in recruit abundance were in Long Island Sound. The individual trawl surveys indicate steadily increasing recruit abundance in inshore RI waters since 1982 and good recruit abundance in Block Island and Rhode Island Sound (area 539) in two of the last three years.

Despite increases in recruit abundance, abundance of legal-sized lobsters did not increase until 1996-97 with the largest relative gain in area 539. Fall and spring CT surveys produced contrasting full recruit abundance trends for LIS: an increasing trend based on spring survey data and constant abundance based on fall survey data. Full recruit abundance indices in area 538 during 1994-98 were 85% lower than during the previous five years.

Total potential egg production increased in recent years. Most of the egg production in inshore waters of this stock area is derived from sub-legal lobsters and about 90% of the landed lobsters are in the first molt group above minimum legal size.

Egg production per recruit, based on 1995-1997 female fishing mortality, is 8.3% of maximum EPR. There is at least a 90% probability that female fishing mortality rates exceeded the $F_{10\%}$ EPR reference point (0.84) for this stock in 11 out of the last 16 years and every year since 1991. According to the ASMFC overfishing definition this stock is overfished. However, recruitment into the fishery, total potential egg production, and stock abundance have increased in recent years, thus the majority of the LSASC concluded that the stock is not currently recruitment overfished. Based on yield per recruit analysis for females, this stock is growth overfished.

### General Comments and Recommendations:

The fact that lobster stock abundance has either remained stable or increased despite high and, in some cases, increasing fishing mortality rates, has led to a great deal of speculation concerning the resiliency of the lobster resource to high exploitation rates. Several possible explanations are presented in this report.

High priority recommendations for improvements in assessment methodology include:

- Develop a database to calculate lobster landings by area caught, time period, sex, and length in a timely and efficient manner (Section 11.3);
- Evaluation of additional stock assessment models and analyses that could provide the basis for alternative biological reference points for lobsters that would complement the current $F_{10\%}$ maximum egg production per recruit reference point, and account for prevailing spawning stock size, total egg production, or recruitment;
- Development of a yield per recruit analysis for male lobsters;
- Analysis of biological risk and economic costs and benefits associated with different management policies that rely on stock assessment models and reference points;
- Expanded use of annual trawl survey data for juvenile lobsters and development of surveys to monitor annual changes in abundance of pre-recruits and predict the effects of variable recruitment on stock abundance; and
- Expanded data collection efforts throughout the range of the resource to determine the spatial distribution of fishing effort and changes to the distribution of effort over time.

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## ACRONYMS

| | |
|---|---|
| ACFCMA | Atlantic Coastal Fisheries Cooperative Management Act |
| ASMFC | Atlantic States Marine Fisheries Commission |
| BRP | Biological Reference Point |
| CL | Carapace length |
| CPUE | Catch per unit effort |
| CT | Connecticut |
| CTH | Catch per trap haul |
| CTHSOD | Catch per trap haul set over days |
| DE | Delaware |
| DFO | Canadian Department of Fisheries and Oceans |
| EEZ | Exclusive Economic Zone |
| EPR | Egg per recruit |
| F | Fishing mortality rate |
| FMP | Fishery Management Plan |
| GBS | Georges Bank and South |
| GOM | Gulf of Maine |
| LCA | Length Cohort Analysis |
| LCMT | Lobster Conservation Management Team |
| LIS | Long Island Sound |
| LSASC | Lobster Stock Assessment Subcommittee |
| M | Natural mortality |
| MA | Massachusetts |
| MD | Maryland |
| ME | Maine |
| MSP | Maximum spawning potential |
| MSY | Maximum sustainable yield |
| mt | Metric tons |
| NC | North Carolina |
| NEFSC | Northeast Fisheries Science Center |
| NH | New Hampshire |
| NJ | New Jersey |
| NMFS | National Marine Fisheries Service |
| NOAA | National Organic and Atmospheric Administration |
| NUSCO | Northeast Utilities Company |
| NY | New York |
| RI | Rhode Island |
| SARC | Stock Assessment Review Committee |
| SASC | Stock Assessment Subcommittee |
| SAW | Stock Assessment Workshop |
| SCCLIS | South of Cape Cod and Long Island Sound |
| SNE | Southern New England |
| TITH | Total inshore trap hauls |
| URI | University of Rhode Island |
| VA | Virginia |
| YPR | Yield per recruit |
| Z | Total mortality |

## GLOSSARY

**Abundance Indices:** For lobsters, usually mean catch per tow in numbers or weight from bottom trawl surveys. Commercial and research trap catchabilities (e.g. lobsters per trap haul) are also used but believed less reliable. Abundance indices for lobster measure trends in abundance (e.g. percent increase or decrease) rather than exact number or weight of the stock.

**Abundance Weighted Fishing Mortality:** One way of calculating a single average fishing mortality rate for a stock with different fishing mortality rates on lobsters of different sizes. The weights used to calculate the average are model estimates of the number in each length group. Abundance weighted averages are easier to interpret than catch weighted averages because they are closer to the exact value calculated as total catch divided by total average abundance and more closely related to simple exploitation rates calculated as total catch divided by total abundance at the beginning of the year (Section 7.4.1).

**Availability:** A measure of how available lobsters of a particular size, sex, etc are for counting or capture in a particular area (e.g. small lobsters may be present, but less available to capture or observation than larger ones because they are better able to find refuge among rocks on the bottom).

**Biological Reference Point (BRP):** A biological statistic measuring some property of a lobster stock that is important to managers. Managers choose biological reference points with particular values to identify management targets and management thresholds.

**Bootstrap procedure:** Statistical technique for estimating uncertainty in estimates from stock assessment models.

**Catch per Unit Effort (CPUE):** Average catch in a commercial fishery or survey by one unit of fishing effort. Sometimes used as an abundance index (e.g. one trap haul, one trap haul per set over day, etc.).

**Catch Rates:** Same as catch per unit of effort.

**Catch Weighted Fishing Mortality:** Like abundance weighted averages (see above), a way of calculating a single average fishing mortality for a stock with different fishing mortality rates on lobsters of different size. The weights used to calculate the averages are actual catch at length data (Section 7.4.1).

**Catchability (q):** A term that relates an abundance index to actual abundance. For example, q times an abundance index converts the index (e.g. measured as number lobsters per tow) to units of population numbers.

**Cohort:** A group of animals born in the same year.

**DeLury Model:** This is the modeling method (Section 7.2) traditionally used to determine total abundance and fishing mortality rates (abundance weighted) for lobster. This method uses many years of information from research trawls, and groups lobsters from two classes - legal sized (full recruits) and those that will become legal (recruits) during the survey year. Results are sensitive to the Q-ratio specified (Section 7.2.4).

**Egg per recruit (EPR):** Expected egg production by a female in her lifetime. Usually expressed as a percentage of egg production in an unfished stock. For example, if a female lobster in an unfished stock produced 100 eggs over her life on average while a female in a fished stock produced 20 eggs over her lifetime on average, then egg per recruit in the fished stock would be 20/100 = 20% of the unfished stock.

**Exploitation Index:** Ratio of total catch and survey abundance data. For lobster, usually the total catch is divided by the survey abundance data.

**Federal waters Exclusive Economic Zone (EEZ):** Waters governed by federal regulations from 3-200 miles from shore.

**Fishing Mortality (F) Rate:** An instantaneous rate that measures how fast lobsters are caught and landed in the fishery.

**Full recruits or Fully-recruited:** All lobsters above the minimum legal size (i.e. 83+ mm CL).

**Immersion time (Soak time):** The amount of time (hours, days) that a trap remains on the bottom between hauls.

**Inshore:** Same as State waters.

**Intermolt Period** (Also called **intermolt duration** and **molt interval):** Number of years that a lobster of a given size will take to molt.

**Legal (Size):** All lobsters minimum legal size (greater than 82.5 mm CL) or greater.

**Length-Cohort Analysis (LCA):** Another method traditionally used for lobster to calculate abundance and fishing mortality rates based on length composition of landings data (Section 7.3).

**Natural Mortality:** Deaths from all causes except fishing.

**Nearshore:** Generally 3-40 miles from the coast (also called inshore or nearshore federal waters) but the definition depends on the context of the discussion.

**Offshore:** Generally more than 40 miles from the coast, but the definition depends on the context of the discussion.

**Ogive:** A curve that is "fit" to observed data for predictive purposes, e.g. a maturity ogive is used to predict the size at which 50% of the lobsters in an area reach maturity.

**Overfishing - ASMFC Definition ( Also called the legal definition):** (ASMFC Lobster FMP 1997) "The American lobster resource is overfished when it is harvested at a rate that results in egg production from the resource, on an egg-per-recruit basis, that is less than 10% of the level produced by an unfished population;"

**Overfishing - Growth** (NEFSC 1996): "The rate of fishing, as indicated by a yield-per-recruit curve, greater than that at which the loss in weight from total mortality equals the gain in weight due to growth. This point is defined as $F_{max}$ or $F_{0.1}$."

**Overfishing - Recruitment** (NEFSC 1996): "The rate of fishing above which recruitment to the exploitable stock becomes significantly reduced. This is characterized by a greatly reduced spawning stock, a decreasing proportion of older fish in the catch, and generally very low recruitment year after year;"

**Parameter:** A numerical description that measures some property of a population e.g. growth or natural mortality. Parameters are usually estimated and are often imprecise.

**Precautionary Approach** (FAO 1995): "States accept the principle of safeguarding the marine ecosystem by reducing dangerous fishing practices, by the use of the best technology available and other appropriate means. This applies especially when there is reason to assume that certain damage or harmful effects on the living resources are likely to be caused by such fishing practices and technologies, even where there is no scientific evidence to prove a causal link between practices and effects (the principle of precautionary action)."

**Pre-recruits:** Lobsters within two molts of minimum legal size (size range depends on stock area, e.g. 63-77 mm CL for 10 mm molt increment).

**Q-Ratio:** Catchability of recruit lobsters (one molt away from legal) relative to the catchability of fully recruited lobsters (legal) in bottom trawl surveys. If recruit lobsters are less catchable by the trawl than full recruits (because they are not present in the survey area, or the trawl does not retain them), then the Q-ratio is less than 1 (Sections 7.2 and 7.2.4).

**Recruit:** Lobsters within one molt of minimum size (depends on stock area) (e.g. 73-82 mm CL for 10 mm molt increments).

**Recruitment Indices:** Measures of abundance for young of the year lobsters often from data collected by divers or suction sampling .

**Regression:** A mathematical technique to fit a line to a set of observed data.

**Relative Abundance Indices:** Same as abundance indices.

**Selectivity:** Relative catchability of animals of different sizes or age.

**Sex Ratios:** Percent males or female.

**State waters:** Waters governed by State regulations from 0 - 3 miles from shore, including coastal embayments.

**Sub-legal:** Lobsters less than legal size (i.e. smaller than 82.5mm carapace length).

**Survey Mass Balance:** A relatively simple way to measure trends in mortality using abundance index data but without catch data.

**Survey year:** From October 1 of a given year to September 31 of the following year.

**Target Reference Point:** A biological reference point (e.g. a fishing mortality rate) used as a management goal.

**Threshold (also known as Limit) Reference Point:** A biological reference point that indicates serious undesirable conditions in a fishery and/or resource. Threshold reference points are often used to identify overfishing and overfished stocks.

**Total Potential Egg Production:** The relative total number of eggs potentially extruded by females present at the time a bottom trawl survey is conducted (Section 10.2). This is termed "potential" because high fishing mortality rates may reduce the chances that some eggs will actually be extruded.

## 1.0 INTRODUCTION

The American lobster (*Homarus americanus*) supports the most valuable commercial fishery in the Northeast United States (NEFSC 1998). Landings have increased steadily since the early 1970s and fishing effort is intense and increasing throughout the range of the species. Previous stock assessments have warned that the stock is overfished and vulnerable to collapse. Such a collapse would have serious economic, social, and ecological implications.

The U.S. lobster resource occurs in continental shelf waters from Maine to North Carolina. About 80% of the catch is from state waters (within 3 miles of the coast). As fishing effort has increased, the traditional inshore trap fishery has expanded to nearshore federal waters (3-20 miles from shore). There is also a deepwater fishery for lobster that occurs farther from shore. American lobsters are primarily harvested by traps with only 2% taken by bottom trawls.

The fishery in state waters is managed through the Atlantic States Marine Fisheries Commission's (ASMFC) American Lobster Management Board. The Board developed Amendment 3 to the Interstate Fishery Management Plan for American Lobster in December 1997, which is implemented through state regulations. The plan, when fully implemented, is designed to minimize the chance of a population collapse due to recruitment failure. The goal of Amendment 3 is to have a healthy American lobster resource and a 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 than 10% of the level produced by an unfished population." The current definition of overfishing was originally established by the New England Fishery Management Council (NEFMC 1991) in Amendment 4 to American Lobster Fishery Management Plan. There was further development in Amendment 5, which was only partially approved by the Secretary of Commerce. The NEFMC's original decision to use $F_{10\%}$ as an overfishing definition involved consideration of at least two options. Appendix A to Amendment 4 (NEFSC 1991) explains that:

> "A preliminary level of maximum egg per recruit of 10% was chosen as an overfishing definition goal to account for average long-term conditions. This value may be modified in light of further evidence and analyses, but at this time it seems to be a reasonable long-term reference point."

The most complete technical explanation of the $F_{10\%}$ overfishing definition policy is in the Review of the Population Dynamics of American Lobster in the Northeast (ASMFC 1996, Appendix H).

Amendment 3 outlines a rebuilding schedule to end overfishing by 2005. The primary management measures include a minimum size, protection on egg bearing females, and trap limits. The Board also recommends that the Secretary of Commerce implement consistent management measures in adjacent federal waters. The National Marine Fisheries Service (NMFS) is implementing federal lobster conservation management measures in federal waters of the Exclusive Economic Zone (EEZ) under the authority of the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA) as a part of state/federal cooperative management.

The intent is to establish management measures that are compatible with the implementation of Amendment 3, end overfishing, and rebuild the stocks.

Early in 1996, a Lobster Review Panel of internationally renowned scientists was convened by ASMFC and NMFS to provide advice on five broad subjects: stock structure, stock assessment, changes in abundance, management, and benthic ecology (ASMFC 1996). The Panel concurred with the 16th Stock Assessment Review Committee (NEFSC 1993) that the lobster resource was, by definition, overfished in all areas, and that a pragmatic first step would be to prevent further increases in fishing effort. The Panel also endorsed the stock assessment methods and stock definitions employed by the NMFS in conducting the 1993 assessment and made a number of recommendations for future research and development of improved assessment methodologies.

The most recent American lobster stock assessment was conducted by the 22nd Stock Assessment Review Committee (SARC) in 1996 (NEFSC 1996). For assessment purposes the lobster population is split into three stocks: Gulf of Maine (GOM), Georges Bank and South (GBS), and South of Cape Cod to Long Island Sound (SCCLIS). The results of SARC-22 indicated that all three stocks were overexploited. According to the last assessment, the GOM stock was at a high level of abundance, while the GBS and SCCLIS stocks were at medium levels of abundance. There was a 97-100% probability that average female fishing mortality rates during survey years 1991-1993 exceeded the overfishing definition. The 22nd SARC warned that when stock collapse has occurred in other lobster and crustacean stocks, it has been sudden, and stock rebuilding has required decades. It advised that fishing mortality be substantially reduced in the U.S. lobster fishery to decrease the possibility of stock collapse. Other conclusions were: 1) that a decrease in fishing mortality would also help restore population size structure, maximize long-term potential yield, and reduce dependence on recruitment; 2) additional yield and egg production would result from increasing the minimum legal size; and 3) management measures to protect mature females would be more effective if fishing mortality were reduced in the summer when females hatch their eggs.

A new assessment was commissioned in 1998 to provide up-to-date information on stock status for management purposes. The ASMFC Lobster Technical Committee was therefore charged with forming a Lobster Stock Assessment Subcommittee (LSASC) to carry out this task. The following people served on the LSASC:

Thomas Angell, Rhode Island Department of Environmental Management
Kathleen Castro, University of Rhode Island
Diane Cowan, Maine Department of Marine Resources
Victor Crecco, Connecticut Department of Environmental Protection
Bruce Estrella, Massachusetts Department of Marine Fisheries
Mark Gibson, Rhode Island Department of Environmental Management
Robert Glenn, Massachusetts Department of Marine Fisheries
Kurt Gottschall, Connecticut Department of Environmental Protection
Josef Idoine, National Marine Fisheries Service
Larry Jacobson, National Marine Fisheries Service
Kevin Kelly, Maine Department of Marine Resources

Don Landers, Northeast Utilities Environmental Laboratory
Carl LoBue, New York Department of Environmental Conservation
Clare McBane, New Hampshire Fish and Game
Amy Schick, Atlantic States Marine Fisheries Commission
Robert Steneck, University of Maine
David Stevenson, Chair, Maine Department of Marine Resources
Carl Wilson, Maine Department of Marine Resources

The Subcommittee was formed in January 1999 and carried out this assignment during the year, subject to the following terms of reference:

1. *Compile data needed for stock assessment purposes, updating databases to include most recent information available.*
2. *Retain the three stock assessment areas and for each area:*
    - *Estimate current levels of egg production, abundance and mortality rates;*
    - *Evaluate uncertainty associated with stock status indices;*
    - *Evaluate historical trends in population abundance, fishing mortality and recruitment, using population dynamics models and other indices;*
    - *Review and up-date biological reference points used to evaluate stock status.*
3. *Develop analyses that could explain why the abundance and recruitment of lobsters has continued to increase in spite of the overfished status of the resource.*
4. *Review reports made in 1996 by the Lobster Peer Review Panel and Stock Assessment Review Committee, evaluate the current status of each recommendation, and act on any remaining recommendations which the Assessment Subcommittee believes are appropriate and useful for resource assessment purposes, and for which there is sufficient time.*
5. *Evaluate any other appropriate stock assessment methods and approaches that the Assessment Subcommittee believes are needed and has time to develop and prepare analyses for review by the ASMFC Peer Review Panel.*

This report contains brief summaries of lobster life history and habitat, descriptions of the three unit stocks, historical and current characteristics of the fishery, sources of data, methods and models used in this assessment, a full accounting of all assessment model results and of twelve different stock and fishery status indices, and stock status summaries for each stock. A description of a new simulation model and some preliminary results are included in Appendix A and research progress and recommendations are summarized in Appendix B. Appendices C and D include detailed size frequency plots of survey and expanded landings data that were used in this assessment.

### 1.1 CONSENSUS

The LSASC strove to reach consensus on data, methods and results in this stock assessment. Most of the conclusions in this assessment are consensus opinions. However, it was not possible to reach consensus on some questions given the size of the LSASC, data limitations and biological uncertainties. In particular, there were differences of opinion about topics including gear saturation (Section 10.7), assumptions to the Egg Per Recruit (EPR) model (Section 9), and biological reference points (Sections 9 and 11). When consensus was incomplete, the LSASC tried to capture both sides of the question by asking presenters to describe the opposing view as minority reports contained in Section 11.4. Minority reports give the names of the authors and were included without change by the LSASC. Thus, this assessment endeavors to present the full range of technical uncertainty about the status of lobster stocks.

## 2.0 LIFE HISTORY

### 2.1 DISTRIBUTION AND ABUNDANCE

The American lobster, Homarus americanus, is distributed throughout the Northwest Atlantic from the Straight of Belle Isle, Newfoundland to Cape Hatteras, North Carolina from mean low water to depths of 700 m (Cooper and Uzmann 1980, Lawton and Lavalli 1995). Lobsters are most abundant in relatively shallow coastal zones. Population densities ranging from one to ten per square meter have been reported in Maine for areas west of Penobscot Bay in boulder and cobble substrates (Wahle and Steneck 1991, Steneck and Wilson 1998, Palma et al. 1999). Lobster densities are lower east of Penobscot Bay and in the far southwestern GOM.

Cooper et al. (1987) reported that deep-water population densities were one to two orders of magnitude lower than those found in coastal zones. Although they can not be directly compared because of differences in trawl design and capture efficiency, recent catch rates of sub-legal (one molt group below minimum legal size) lobsters in fall trawl surveys were higher in southern New England and Massachusetts Bay, and three times higher in Long Island Sound than anywhere else. With the exception of MA Bay, sub-legal catch rates were intermediate in the GOM and lowest on Georges Bank and offshore southern New England. Catch rates of legal-sized lobsters (83+ mm CL) were also higher in inshore southern New England waters (and highest in Long Island Sound), intermediate in the GOM (including MA Bay) and lowest on Georges Bank and in offshore southern New England waters. Lobsters are known to aggregate in offshore canyons on the southern edge of the continental shelf in much higher densities where they can not be caught in bottom trawls, thus the mean catch rates on Georges Bank and the outer shelf do not reflect the actual population densities.

Mean 1996-98 catch rates (number per tow) of lobsters one molt group below minimum legal size and of legal-sized lobsters in fall bottom trawl surveys in six different locations.

| Survey | Location | Sub-legals | Legals |
|---|---|---|---|
| NMFS | Gulf of Maine | 1.52 | 1.56 |
| NMFS | Georges Bank - offshore SNE | 0.33 | 0.55 |
| NMFS | Inshore SNE | 6.02 | 2.72 |
| MA | Massachusetts Bay | 7.89 | 1.55 |
| RI | RI coastal waters | 4.71 | 1.41 |
| CT | Long Island Sound | 23.27 | 4.27 |

Note: No adjustments made to account for differences in capture efficiency of gear used in each survey or for differences in availability of lobsters of different sizes due to substrate type.

### 2.2 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 lobsters 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 lobsters 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.

New research using lipofuscin pigment, has shown promise for aging in the blue crab (Ju et al. 1999), Western rock lobster, Panulirus cygnus (Sheehy et al. 1998), European lobster, H. gammarus (Sheehy et al. 1996; Uglem et al. 1997; Addison 1999) and the American lobster, H. americanus (Wahle et al. 1996). Significant correlations were found in blue crab, enabling an age class separation where length based techniques failed to find modes. Age information can be used for the development of better growth estimates, and to develop indices of recruitment that are based on age rather than length classes. Recent information from the European lobster, H. gammarus UK (Addison 1999) indicated a large variation in age at size with seven year classes making up the 85-95 mm carapace length (CL) size class. Predicted sizes at age were significantly below those estimated from tagging studies and large animals approached 70 years in age. This technique, although time intensive, may provide valuable information that is needed to understand the population dynamics of the American lobster.

### 2.3 MIGRATION

During their first year on the sea bottom, lobsters move little and can be found within a meter of where they settled (Wahle 1992; Palma et al. 1999). As they grow, their daily and annual range of movement increases. By the time lobsters approach harvestable size, their annual range of movement is about two to three kilometers (Krouse 1980, 1981). Upon reaching sexual maturity, the annual range of lobster averages just over 32 km (Campbell and Stasko 1985, Campbell 1986). This average reflects the majority of lobsters that move very little and a few that migrate hundreds of kilometers annually (Campbell 1986).

In general, mature legal-sized lobsters are proportionately more abundant offshore and in deeper water (Harding and Trites 1989 a&b). However large sexually mature lobsters are capable of traversing great distances, and show a variety of different migration behaviors. Pezzack and Duggan (1986) identified three behaviors: 1) ground keepers, that do not migrate; 2) seasonal migrators, females that move from deep to shallow to thermoregulate for optimal egg development; and 3) long-distance migrators. Among the seasonal migrating lobsters, some have been observed repeatedly returning to the same region (i.e., "homing") after moving several tens of kilometers (Pezzack and Duggan 1986).

Migratory behaviors differ geographically and may be under genetic control. The deep to shallow migrations of ovigerous lobsters in spring and early summer (e.g., Campbell 1986) has not been observed everywhere. When ovigerous lobsters from Newfoundland were tagged and released in the vicinity of Grand Manan in the GOM, they showed consistently different migratory behavior (Robichaud and Campbell 1995). They differed from mature Bay of Fundy females in having no apparent long distance, deep-shallow seasonal migration, but they had a similar reproductive cycle (Robichaud and Campbell 1995).

Migratory behavior affects size structure. Reproductive lobsters north and east of Grand Manan segregate distinctly from coastal populations of the Bay of Fundy and southwest Nova Scotia (Campbell and Pezzack 1986). Similar depth segregations have been described for the canyons of Georges Bank and the outer continental shelf (Skud 1969; Skud and Perkins 1969). Skud and Perkins (1969) concluded that shallow populations of prerecruit lobsters at Veatch Canyon move gradually to deeper water as they grow. Size segregation by depth was also reported for Oceanographer Canyon of Georges Bank.

There are varying hypotheses as to whether larger lobsters undergo directed migration, temperature-mediated movement, or no migration at all (Haakonsen and Anoruo 1994). Seasonal inshore-offshore movements of adult lobsters have been demonstrated by tagging studies conducted in the Gulf of Maine (Cooper et al. 1975), east of Cape Cod (Estrella and Morrissey 1997), and in southern New England (Saila and Flowers 1968, Cooper and Uzmann 1971, Uzmann et al. 1977, Briggs 1985, Cobb et al. 1989). In general, migrating lobsters move offshore in the fall and winter and inshore in the spring and summer. For ovigerous females, such behavior exposes eggs to warmer temperatures, thus enhancing egg development.

## 2.4 REPRODUCTION

### 2.4.1 Behavior

During mating, male lobsters deposit a spermatophore into the seminal receptacle of females. The lining of the female receptacle is shed during molting. Therefore, females must replenish their supply of sperm after each molt. Lobsters typically form a brief pair bond for mating. Female lobster can mate at any molt stage but their receptivity peaks immediately after molting (Dunham and Skinner-Jacobs 1978; Waddy and Aiken 1990). Mating takes place within 24 hours of molting and usually within 30 minutes (Talbot and Helluy 1995). Females can produce fertilized eggs if mating occurs sometime between molting and egg extrusion. However, if no mating occurs between the time of molting and egg extrusion, the female can extrude unfertilized eggs and broods them for several months. The eggs gradually die, turn bright orange and drop from her abdomen.

### 2.4.2 Spawning Times

Hatching and release of larvae occur after a 9 - 12 month period of development while the eggs are still attached to the female (Talbot and Helluy 1995). Seasonal timing of egg extrusion and larval hatching is somewhat variable among areas and can also vary inter-annually due to seasonal weather patterns. Overall, hatching tends to occur over a four month period from May through September, occurring earlier and over a longer period in the southern part of the range (Ennis 1995).

### 2.4.3 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 which defined geographic differences in size at maturity. Early maturation occurs in relatively warm water locations of the Gulf of St. Lawrence and inshore southern New England (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 is that once females reach minimum legal size, they are subject to fishing mortality. Thus, the proportions of mature legal-sized females are deflated below their actual values as they are harvested from the population. 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 southern New England 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 which 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, Massachusetts, Rhode Island, and New York 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 (Section 9.2).

The relationship between water temperature and size at onset of sexual maturity implies that significant climatic change may affect size at maturity. However, insufficient historical data are available for evaluating this hypothesis. Although speculation about the impact of exploitation in reducing size at maturity is a popular notion, a comparison of the smallest ovigerous females observed in southern Massachusetts waters across a 100-year period provided no evidence of change in the size at onset of sexual maturity (Estrella and Cadrin 1995).

### 2.4.4 Fecundity

Fecundity is an important parameter in assessment of the lobster resource, particularly when an egg per recruit (EPR) model is 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 1981), 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 lobsters 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 GOM, outer Cape Cod and Buzzards Bay). Southern GOM 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 other 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 lobsters (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.

Lobsters collected from three Maine coastal regions (western, central and eastern) in 1994-96 did not have significantly different size-fecundity relations (Kelly, in prep.). The combined fecundity vs. carapace length curve for all Maine areas was not significantly different (P>0.05) than that for the southern GOM reported by Estrella and Cadrin (1995) even though the Maine study was based on fall-caught females with recently extruded eggs, while the Massachusetts study used spring-caught lobsters with mature eggs. Average rates of egg loss between these two stages have been estimated to be 9% (Graulich 1991) and 36% (Perkins 1971). Fecundity estimates for all three stock areas in this assessment were based on Estrella and Cadrin's (1995) analysis of Herrick's data (Section 9.2).

## 2.5 EARLY LIFE HISTORY

### 2.5.1 Eggs and Larvae

Eggs are carried on the abdomen of the female for 9 to 12 months before hatching. Prelarvae are released by the female over the course of several days and molt into positively buoyant 1st stage zoeal larvae. The 1st, 2nd 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.

Fecundity and hatching success are influenced by the size of the ovigerous lobsters. Body size influences the timing of molting and spawning. Smaller females molt more often than larger ones and the ability to molt and spawn in the same season may allow some females <120 mm in Long Island Sound, where high incidences of ovigerous females have been observed in some size classes (Briggs and McGroaty 1985), to spawn in consecutive years (Waddy et al. 1995). Larger females molt less frequently, but can spawn twice between molts, a phenomenon called consecutive spawning. Because of consecutive spawning, 120-150 mm CL females may spawn more frequently than smaller lobsters, making their relative fecundity greater than often assumed (Waddy et al. 1995). Large lobsters (i.e., > 120 mm CL) produce eggs with a higher energy content (Attard and Hudon 1987) and thus may produce larvae with higher survival rates. Very large lobsters (> 200 mm CL) continue to spawn at least biennially and the viability of eggs and larvae produced by these very large females is similar to those produced by younger lobsters (Waddy and Aiken 1986).

### 2.5.2 Benthic Juveniles

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 lobsters 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 lobsters are rare or absent from sediment substrates and eel grass habitats although early benthic phase lobsters (sensu Steneck 1989; Wahle and Steneck 1991 for lobsters < 40 mm CL) are not.

Early benthic phase lobsters 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 lobsters 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 lobsters 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.

## 2.6 GROWTH

American lobsters, like all crustaceans, grow incrementally in distinct molting events called ecdysis. Although growth appears to entirely take place during molting, lobsters 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 lobsters or lobsters that molted and grew while held in captivity (including those in lobster traps). The frequency of molting is often reported as the probability of lobsters at a given size molting in a given year, but is sometimes reported as intermolt duration (the time spent between molts).

In earlier U.S. assessments of American lobsters, attempts were made to age lobsters using modal peaks in size frequency distributions (Cassie 1954; Thomas 1973; Halgren 1976; Fair 1976). However this method has been criticized because it is often difficult to replicate results (Anthony and Caddy 1980). In addition to difficulty identifying cohorts, data are usually not available for large lobsters in heavily exploited populations, particularly if growth rates are slow. Recent work on small juvenile lobsters in Maine has shown that the first three year classes can be seen fairly clearly in modal peaks of size frequency distributions (Wahle 1999).

Discussions about lobster growth rates occurred at a 1978 Canada-US lobster workshop, (Anthony and Caddy 1980; Ennis 1980). Ennis (1980) cautions that the growth parameters summarized at the 1978 workshop may not be "precise enough for practical purposes" beyond a limited size range. In general, lobsters in US waters lobsters grow more quickly and to larger sizes in northern and offshore populations than in southern inshore populations (Section 9.2). Fogarty (1995) summarized many of the parameter estimates used to model lobster growth in the US and Canada. More recent attempts have made use of molt frequency and molt increment information to develop more complex growth models (e.g. Caddy 1977; Fogarty and Idoine 1988).

The steady state nature of some 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 lobsters (Stewart and Squires 1968; Aiken and Waddy 1978; Van Olst et al. 1980; Ennis 1991), presence of larger more dominant lobsters (Cobb and Tamm,1974, 1975) or variations in temperature (Hughes et al. 1972; Aiken 1977). All of these variables have 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 lobsters 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 lobsters appear to be slower when they are in the presence of larger lobsters (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 (Cooper and Uzmann 1977, Fogarty and Idoine 1988) compared to those measured in warmer areas (NUSCO 1999) suggests this also is true of adult lobsters. In addition, summer seawater temperature appears to have confounding effects on growth by decreasing the size at which lobsters 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 effecting the frequency of molting and the size of molt increments in females is that growth is slower in warmer regions (Section 9.2).

### 2.6.1 Molt Probability

Many studies based on tag recaptures report information about intermolt duration in the form of molt probability functions (Cooper and Uzmann 1980; Campbell 1983a; Campbell 1983b 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 lobsters 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 lobsters. A problem encountered when using these functions for modeling growth in this assessment was that they provide little information about intermolt duration of lobsters 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 lobsters ever stop molting completely, as some other crustaceans do, this is unrealistic.

Growth estimates from laboratory studies may not be directly applicable in natural populations because of artificial laboratory conditions. These studies do, however, provide some useful information that can be compared to field studies. The lobster hatchery in St. Andrews, New Brunswick held several large mated female lobsters for relatively long periods of time (Waddy and Aiken 1986; Waddy 1995; Estrella 1997). Although these lobsters were collected in areas outside the range of the three US stock assessment areas, and were mostly held at ambient St. Andrews conditions, they provide some valuable insight to the intermolt duration of large females. These data suggest that immature females ($L_{50}$ = 96 mm) molt annually; 90% of the lobsters under 120 mm had a two year intermolt duration; between 120 mm and 160 mm females had a 2-3 year intermolt duration, and above 160 lobsters had a 3-4 year intermolt duration (based on only a few lobsters) (Waddy and Aiken 1986). This information suggests that setting the maximum average intermolt period at 3.2 years (Section 9.2) reasonably approximates the maximum average intermolt duration observed in the St. Andrews Laboratory (3-4 years). However, presumably because they mature at smaller sizes, lobsters in the three US assessment areas begin to exhibit longer intermolt durations at smaller sizes than in Canada. The intermolt durations used for females in GBS area are most similar to those observed in St. Andrews, while the rates used for females in inshore SCCLIS stock area are the least similar.

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

See Section 9.2 for additional details.

### 2.6.2 Molt Increments

Data on the size of molt increments are relatively easy to obtain by measuring lobsters in captivity before and after they molt, measuring cast shells and newly molted lobsters found in traps, or by measurement differences between lobsters when they are tagged and when they are recaptured (e.g. Cooper and Uzmann 1977; NUSCO. 1999). Increment measurements from cast shells are subject to bias because cast shells can shrink and newly molted lobsters may not have completely expanded their new shell (Estrella, perssonal communication). Increment measurements from tagging studies are usually limited to single molts. Although some studies report molt increments as the percent increase in carapace length (Wilder 1953; Andrews 1980), they are often derived from linear relationships between pre-molt and post-molt carapace lengths

(Wilder 1963; Ennis 1972; Ennis 1980; Campbell 1983a&b; Dube 1986; Miller et al. 1989a; Krouse 1981; Lawton et al. 1984; Briggs and Mustachacke 1984; NUSCO 1994) or simply as a frequency histogram of molt increments (as in Cooper and Uzmann 1977, Trembley and Eagles 1997). Fogarty (1995) summarizes many of these parameter estimates. The linear relationship of pre-molt to post-molt carapace length in many of the studies mentioned above describes a relatively constant absolute increment size over a lobster's life. A few studies suggest that there is a change in the pre-molt postmolt carapace length relationship between mature and immature lobsters (Ennis 1972; Campbell 1983a-b). The molt increments used in the models in this assessment are described in Section 9.2.

### 2.7 NATURAL MORTALITY

The models used in this assessment (LCA, DeLury, Mark and EPR) all require an estimate of the instantaneous rate of natural mortality (M). These models are usually sensitive to the values chosen for M and also to the interaction between M and other parameters (Vetter 1988; Bannister and Addison 1986). The natural mortality rate in post settlement American lobster is generally considered to be low because they are long-lived animals that produce fairly small egg clutches, carry their eggs for months until they hatch and are not very vulnerable to predation, particularly as they get bigger. A wide range of natural mortality estimates are available for H. americanus and close relatives, H. gammarus, Nephrops norvegicus and spiny lobsters (Table 1). A value of M = 0.1 has been assumed to apply to recruit and fully recruited lobsters in previous assessments (Fogarty and Idoine 1988; NEFSC 1993, 1996). In this assessment, natural mortality was 0.15 $yr^{-1}$ and was partitioned into a hardshell (0.10 $yr^{-1}$) and a softshell component (0.05 $yr^{-1}$) (Section 9.2).

Although it is difficult to estimate M directly, there are several methods currently used to generate values of M: (1) use of catch data (Ricker 1975) including sea sampling and tag/recapture methods; (2) life history models which correlate M with other parameters (Beverton 1964; Hoenig 1983); and (3) multispecies models which include predation interactions. Munro (1974) and Addison (1986) argue against the assumption of a constant M at all ages (sizes), implying density dependence. In addition, various authors (Wickens 1976; Fogarty 1986) suggest that many crustaceans experience higher natural mortality rates during molting and that the probability of a natural death is related to molting frequency. This would cause M to decrease as lobsters grow and reach maturity. However, higher hard shell mortalities have been observed in laboratory studies (D'Agostino, unpublished data from NYSDEC). There has been little field evidence to support these hypotheses (Cobb and Caddy 1989, Cobb 1995). Changes in behavior prior to and during molting (i.e., increased aggressiveness, increased shelter use, form and intensity of tail flipping behavior) may compensate for the increased vulnerability of the soft shell lobster to predation, etc. (Karnofsky et al. 1989; Cromarty et al. 1991; Cobb 1995).

The dominant sources of natural mortality of the clawed lobster include predation, disease and extreme environmental conditions (i.e., oil spills, anoxia, storms, etc). Predation risk is a strong selective force throughout an animal's life history (Bax 1998). Under threat of predation, individuals are known to change foraging tactics, shelter use and social behavior (Krebs and Davies 1993; McKenzie 1989). Predation pressures appear related to size and habitat. In tethered field trials, the smallest of early benthic phase lobsters suffered the highest predation rates

(Wahle and Steneck 1992). The presence of shelter greatly reduced predation mortality (Cobb et al. 1986; Richards 1992). Mortality due to predation is believed to decrease as the lobster grows (Wahle 1992).

There is evidence that 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 of cultured and wild lobsters (Bayer et al. 1993). Hatchery reared lobsters are susceptible to attack by the fungi Fusarium solani, Halephthorus milfordensis and Lagenidium spp. leading to significant mortalities in larval and juvenile stages. A number of animals parasitize lobsters, including protozoa, helmintha and copepods. Aiken and Waddy (1986) and Sherburne and Bean (1991) reported a cyclical infestation of the ciliate Mugardia spp. in the wild stock. Eggs are subject to high mortalities by the nemertean worm, Pseudocarcinonemertes homari. The best known disease, which leads to the development of gaffkemia, a fatal infection (Stewart 1980), is caused by the bacteria Aerococcus viridans.

The etiology of shell disease is less clear, involving many species of chitinoclastic organisms (Sinderman et al. 1989). Shell disease is believed to be the result of opportunistic microorganisms exploiting an injury or poor physiological state of the host (Getchell 1989). Ovigerous females display the highest rate of infection and carapace damage because they molt less frequently and therefore have older shells. Wilk et al. (1997) reported that less than 2% of all lobsters collected in NMFS sea sampling trips on the Atlantic coast during 1989-91 showed any signs of shell disease. There has been a recent increase in the incidence of shell diseased lobsters in the southern New England area (Castro 1999; Thatcher, personal communication). The consequences of shell disease on natural mortality are not known. Recent disease-related lobster mortalities in southern New England have raised questions concerning their impact on the natural mortality rates used in assessment models. The recent increase in shell disease, although not yet shown to lead to increase mortality, may also be an indication of stresses in the lobster populations.

Three recent studies using some of the best sources of information available have elaborated on natural mortality rates for clawed lobsters. Bannister (1998) summarized five years of experiments conducted in the United Kingdom evaluating the survival of tagged hatchery reared 10th stage lobsters, Homarus gammarus. Recaptures in the fishery were used to estimate survival rates of released lobsters. Overall, combined releases totaled 91,000, with recaptures of 1500. The average recovery rate was between 2.6-4.5%. Catch per unit effort of recaptures was converted into an estimate of local abundance that was then compared with numbers originally released near these locations. Recaptures indicated little migration from release sites, so migration was assumed to be minimal. Average survival rate ranged from 50-80% ($M = 0.04$-$0.11$) depending on assumptions made about tagging mortality and tag losses. The second approach used was to fit a mathematical model to the observed data making a range of assumptions on combinations of survival rate, fishing rate, and recovery rate. The resulting best estimate of survival was about 37% over five years from release to legal size ($M=0.13$). However, there is some concern that the recapture rate for hatchery reared animals may be biased low, therefore impacting the calculation of M.

Two other studies were associated with data obtained after an oil spill occurred off the coast of southern Rhode Island resulting in a large mortality event with beach strandings. Gibson et al.(1997) calculated stage-specific natural mortality rates as a parameter to be used in determining adult equivalents from the observed length frequency in the strandings. Estimates of mortality rates were taken from the literature or derived from available data for each stage - larval, early benthic and adult. Using data from the RIDFW trawl survey, they calculated an M of 0.21 for pre-recruits (60-80 mm); using a longevity model from Hoenig (1983) and a maximum age of 50 years, larger adults (83-185 mm) in RI had an M = 0.08; and using information on tagged legal sized lobsters in RI and MA (Anthony 1980) they found an M = 0.15. Saila (1996) calculated a lifetime Z from egg to pre-recruit size using data obtained from the oil spill strandings. After converting length to age, and applying catch curve analyses, he calculated a total Z from egg to 82.6 mm = 8.2 (total Z assumed to equal M because no F below legal size). A derived instantaneous mortality rate per mm of growth was calculated as 0.0683. This translates to values higher than those previously reported. However, this value is based on constant mortality over these size ranges which is not assumed to be true in the analysis done by Gibson et al. (1997).

## 2.8 ECOLOGICAL ROLE/INTERACTIONS

Lobsters interact with other organisms and with each other. They are very sensitive to capture and confinement and thus observations should be primarily taken in the field when possible. Interactions described in this Section involve the ecological role of lobsters as predators, as prey (interactions with predators of lobsters) and competitive interactions with other organisms and other lobsters.

### 2.8.1 Predation

The adult American lobster is the largest mobile benthic invertebrate in the North Atlantic. Its size and large claws make it an important predator (Elner and Campbell 1981; Moody and Steneck 1993). Adult lobsters are omnivorous, feeding largely on crabs, molluscs, polychaetes, sea urchins, and sea stars (Ennis 1973; Carter and Steele 1982a&b; Weiss 1970). Live fish and macroalgae are also part of the natural diet. Lobsters are opportunistic feeders so their diet varies regionally depending upon the abundance of different prey species. In areas where lobster traps are numerous, bait (mostly Atlantic herring) is a very important component of the diet.

Lobster larvae and postlarvae eat zooplankton during their first year (Lavalli 1988). In larval stomach analyses performed by Juinio and Cobb (1992), nine taxonomic prey groups were found. Copepods and decapod larvae are common prey items but cladocerans, fish eggs, nematodes and diatoms have been noted.

Lobster are preyed upon by a variety of bottom inhabiting species, including teleost fish, sharks, rays, skates, octopuses, and crabs (Phillips and Sastry 1980). Larvae are subject to predation in the water column and postlarvae are vulnerable to mud crabs, cunner, and an array of other bottom feeding finfish species after settlement. However, once post-larvae are established in shelter, they are thought to be relatively safe from fish predators (Wahle and Steneck 1992), but not necessarily invertebrates such as burrowing crabs (Lavalli and Barshaw 1986). Mud crabs are abundant throughout the northeast as are green crabs and rock crabs, which are also suspected predators on post-larvae. When not in their burrows, the foraging early benthic phase and larger juvenile lobsters are prey for sculpin, cunner, tautog, black sea bass, and sea raven (Cooper and Uzmann 1977). Atlantic cod, wolffish, goosefish, tilefish, and several species of sharks consume lobsters up to 100 mm CL (Cooper and Uzmann 1977; Herrick 1909).

In ongoing food habit studies in Massachusetts, striped bass are known to consume lobster up through minimum legal size (Stockwell, personal communication). In studies conducted in Maine, lobsters ranging in size from 7 mm to 110 mm CL were tethered and only very small lobsters were attacked (Steneck 1989, Wahle and Steneck 1992, Steneck 1997). Lobsters larger than 60 mm CL tethered for over 45 days were untouched (Steneck 1989). Settling lobsters suffer extraordinarily high rates of predation outside of refugia (Wahle and Steneck 1992). Small fish predators (primarily juvenile cunner, sculpins and shannys) are ubiquitous in shallow coastal zones where average densities of nearly one per meter squared have been recorded (Malpass 1992). Herrick (1909) suggested that large, hard-shelled lobster may be immune to predation.

### 2.8.2 Competition

Lobsters and crabs compete for space and food (Richards et al. 1983, Cobb et al. 1986, Richards and Cobb 1986). These studies showed that competition between lobsters and crabs caused a redistribution of individuals. Lobsters that lost space to their competitors also showed an increased mortality. There is no report of interspecific competition having a direct impact on the abundance of lobsters. Intraspecific competition among H. americanus individuals is well known. O'Neill and Cobb (1979) describe size-mediated shelter competition. Large body size and claw size is particularly important in determining competitive dominance among lobsters selecting shelters. There is some evidence that when local population densities increase, larger lobsters diffuse to habitats where total population densities are lower (Steneck 1989, Lawton and Lavalli 1995). Mortalities that result from aggression between lobsters may not represent predation, but do represent an additional source of natural mortality.

## 3.0 POPULATION STRUCTURE AND STOCK DEFINITIONS

To date, published genetic studies (summarized in Fogarty 1995) have not shown a clear differentiation of American lobster stocks. This includes recent work by Harding et al. (1996), using random amplified polymorphic DNA, which showed no significant difference between the populations of lobster from southern Gulf of St. Lawrence, Southwestern Nova Scotia and Georges Bank. They additionally concluded that so much anthropogenic interference has occurred through hatchery programs and transfer of adult animals that as few as five animals in each generation could obscure any genetic differentiation between stocks. New research is currently underway examining other biological characteristics of larvae and post-larvae that may provide relevant information (Clancy and Cobb, URI, personal communication). However, in the absence of genetic variability, differences in biological characteristics provide a justifiable basis for defining separate stocks of lobster for assessment and management purposes.

Information on migration, differences in growth and maturation rates, hydrography and its effect on larval supply, and morphometric characteristics have been used to differentiate lobster stocks. Stock identification information for American lobster in U.S. waters of the Northwest Atlantic was reviewed by the 14th Stock Assessment Review Committee (NEFSC 1991) which defined two separate lobster stocks: (1) the Gulf of Maine (inshore and offshore); and (2) Southern New England-Georges Bank. It was recognized that although growth and maturation rates may vary within these large areas, larval supply and interchange of older lobster through migration supported the combination of inshore and offshore areas in order to adequately define fishing mortality.

SARC 16 (NEFSC 1993) tentatively re-defined lobster stock units based on biological information from the inshore southern New England area, in particular the minimal movement (3-5 km) shown by inshore tagging studies (Templeman 1940; Templeman and Tibb 1945; Wilder and Murray 1958; Wilder 1963; Cooper 1970; Cooper et. al. 1975; Krouse 1980; Stasko 1980; Campbell 1982; Lawton et al. 1984). The Southern Cape Cod to Long Island Sound (SCCLIS) inshore area was identified as a third stock unit area, distinct from the offshore GBS stock. The evidence for a common larval supply was important in the decision to continue treating the GOM as a single stock unit.

SARC16 noted the lack of any definitive evidence for separate stocks based on differences in morphological characteristics, parasite infestation, and biochemical and genetic markers. Instead, the three stock units were defined on the basis of differences in life history parameters, particularly growth and size at maturity, which differ markedly between coastal populations in the GOM, offshore populations in the Georges Bank-southern New England area, and the warmer-water inshore populations south of Cape Cod. SARC16 also referred to coastwide differences in fishing patterns and regulations as practical reasons for dividing the resource into separate stock units for assessment purposes. It was noted that there is some exchange (owing to the migration of adults) between the SCCLIS and GBS areas and between the GOM and GBS stock units. Interchange of larvae, sub-adults, and adults between the SCCLIS and GBS stock areas was described in various studies (Saila and Flowers 1968; Cooper and Uzmann 1971; Uzmann et al. 1977; Briggs 1985; Cobb et al. 1989; NUSCO 1999). Previous assessments of these two areas assumed significant differences in biological characteristics even though interchange was recognized (NEFSC 1993). New information compiled for this assessment indicates that differences in size at maturity are similar between inshore and offshore locations in the GOM and southern New England and suggests that the combination of the GBS and SCCLIS stocks should be re-considered.

SARC 16 made no mention of larval transport or general circulation patterns as a basis for defining separate lobster stocks. However, any possible linkage between inshore and offshore can 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. More information is needed on larval transfer rates to identify linkages and possible metapopulation units.

The three stock units that are recognized in this assessment are the same ones that were defined by the 16th Stock Assessment Review Committee (NEFSC 1993). They are:

1) The GOM (inshore and offshore waters), or GOM area;
2) Georges Bank and South (offshore), or GBS area; and
3) South of Cape Cod and Long Island Sound (inshore), or SCCLIS area.

These three stock assessment areas and the NMFS statistical areas included in each one are shown in Figure 1.

Biological evidence that supports the division of the U.S. American lobster resource into three separate stock assessment units was reviewed by the 1996 Lobster Peer Review Panel (ASMFC 1996). The Panel engaged in a lengthy discussion of the North American (U.S. and Canada) lobster population as a metapopulation, i.e., a number of subpopulations with distinct biological characteristics that are linked by dispersal, and concluded that "*there* are *a number of problems associated with stock definitions and with the metapopulation question, but accepted that SAW16 scientists had a realistic perspective on the stock structure question, and had made justifiable decisions about how best to handle the data presently available*." Thus, it "*found no grounds for disputing this aspect of the 1993 assessment.*"

The Panel also identified the following descriptors of stock structure, which should be considered in any future re-examination of lobster stock structure:

1) The distribution of abundance, as indicated by trawl survey data, which shows lobsters to be more abundant near the coast, less dense across the shelf, then more abundant near the canyons associated with the shelf break;

2) The pattern of migration, based on tagging studies, which shows adults migrating seasonally between deep and shallow waters [and also laterally along the outer continental shelf between Georges Bank and southern New England, and in a southwesterly direction in the GOM, as noted in SARC16];

3) The location of spawners, based on the presence of egg-bearing females in sea sampling and survey data; and

4) The dispersal and transport of larvae, which are not well known but may be inferred from general patterns of circulation, e.g., in the case of larval dispersal from offshore banks to nearshore areas.

## 4.0 HABITAT

Lobsters of different ages and sizes inhabit different habitats and are affected by different environmental factors. Of the numerous oceanographic, geological and ecological components of lobster habitat only a few are generally believed or have been shown to be demographically important. In general, oceanographic factors such as water temperature and currents are important for reproduction, egg development and the dispersal of larvae and post-larvae, whereas substrate characteristics and depth affect juvenile and adult distribution and abundance. Environmental factors, as discussed by Mercaldo-Allen and Kuropat (1994), are summarized below relative to three life history stages of the lobster: eggs/embryos, larvae/postlarvae, and benthic juveniles/adults. While the potential effects of contaminants resulting from human activity cannot be overlooked, the focus here is primarily on the natural habitat of lobsters.

### 4.1 TEMPERATURE

The environment influences reproductive and developmental processes of lobster in a number of ways. Water 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 lobsters (Aiken and Waddy 1985). 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, which are important to survival during the pelagic larval stages.

The duration of the planktonic phase is dependent upon seawater temperature. Time from hatching to stage IV is approximately 10 days at 22-24°C and nearly two months at 10°C. At 5°C larvae generally die without reaching stage IV (Templeman 1936). Huntsman (1923, 1924) found that larvae developing in water less than 15°C developed much more slowly than those developing in warmer water. It is possible that temperature effects are nonlinear and that thermal thresholds exist.

The demographic impact of sea temperature on lobsters is best indicated by the cases in which lobster abundance or landings correspond with sea temperatures at the time of larval development or settlement. Flowers and Saila (1971) and Fogarty (1988) found landings corresponded with sea temperatures at about a six year lag. Acheson and Steneck (1997) found that as much as 60% of the variance in landings during 1946-86 could be explained by sea temperatures in August, seven years prior to harvest. Drinkwater et al. (1996) found a similar temperature relationship over that period of time but found no temperature relationship consistent with the population increase of the late 1980s and 1990s.

Temperature may also have a significant impact on benthic juvenile and adult lobster growth, survival and reproduction. Aiken and Waddy (1986) reported that juvenile and adult lobsters are found seasonally in waters ranging from 0°C to 25° C. Acclimation to the upper lethal limit depends on acclimation temperature, but tolerance to any temperature declines as optimal dissolved oxygen and salinity levels decrease.

### 4.2 CURRENTS

Larvae tend to concentrate in surface waters where currents converge and in windrows where floating debris may provide refuge (Cobb et al. 1983; Harding et al. 1983). Therefore, wind induced circulation patterns, such as prevailing southwesterly winds in the northeast US, may influence larval recruitment to coastal areas during the period of larval availability (Fogarty 1983; Incze and Wahle 1991; Watson and Miller 1991; Hudon and Fradette 1993; Katz et al. 1994; Incze et al. 1997, 1998). The swimming capability of Stage IV postlarvae may also affect distribution patterns (Cobb et al. 1989; Katz et al. 1994).

### 4.3 SALINITY

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 lobsters 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). In addition, 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

As juvenile and adult lobsters 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 lobsters appear twice as sensitive as juveniles and adults to reduced DO.

### 4.5 LIGHT INTENSITY

Larval lobsters are phototaxic. A minimum light intensity is required to attract larvae to the sea surface, but early stage larvae seek lower depths in bright sunlight (Templeman 1933). Juvenile and adult lobsters in Long Island Sound remained in burrows when ambient light exceeded 4 x $10^{-2}$ FW/$cm^2$ (Weiss 1970s). Emergence from burrows occurred 25 minutes after sunset when underwater light intensity was 2 x $10^{-2}$ FW/$cm^2$ from June November. During December and January they waited until 40 minutes after sunset (0.02 x $10^{-2}$ FW/$cm^2$).

### 4.6 SUBSTRATE

The pelagic larval period ends when stage IV postlarvae settle to the bottom. Postlarvae will actively seek suitable substrate with a series of descents and will delay molting to the fifth stage until successful settlement is completed. Lobster settlement is greatest in relatively shallow coastal zones (Wilson 1999; Cobb and Wahle 1994). Appropriate habitats protect postlarvae from predation and provide food and shelter thereby minimizing movement and exposure. Lobster may not leave their burrows until they reach a carapace length between 20 and 40 mm (Bryant-Rich and Barshaw 1988). However, a shift from this shelter-based existence to a wider ranging, foraging lifestyle occurs with greater energy needs and reduced vulnerability to predation associated with increasing body size.

Howard and Bennett (1979) and Pottle and Elner (1982) found that settling lobster tend to choose gravel rather than silt/clay substrates. However, when Botero and Atema (1982) included macroalgal-covered rock as an additional choice, it was preferred by settling lobster, followed by rocks on sand, mud, and sand. Cobb et al. (1983) found postlarvae settle rapidly into rock/gravel, macroalgal-covered rock, salt-marsh peat, eel grass, and seaweed substrates. Barshaw et al. (1985) and Barshaw and Bryant-Rich (1988) observed postlarval lobster to settle quickly into eelgrass, followed by rocks with algae in sand, then mud. Barshaw and Bryant-Rich (1988) emphasized the importance of macroalgal-covered rock habitat. Early benthic phase lobsters (5-40 mm CL) were found by Wahle and Steneck (1991), and Palma et al. (1999) to be most abundant in cobble and macroalgal-covered rock and rare in featureless mud, sand, or bedrock. Able et al. (1988) described the use of salt marsh peat reefs by juvenile lobsters on Cape Cod, MA.

Although mud habitat is the least preferred, the demonstrated ability of lobster to burrow (MacKay 1926; Cobb 1971; Berrill and Stewart 1973; Botero and Atema 1982) implies that mud habitat can be used when it is the only option. Under experimental conditions stage IV lobsters settled within 34 hours of searching on macroalgal-covered rocks, within 38 hours on scattered rocks in sand, and within 62 hours over mud bottom (Harding 1992). A classic example of the lobster's ability to settle in mud habitat can be found in Long Island Sound where a viable lobster resource and fishery exits, despite the area being devoid of cobble substrate.

The ability of postlarvae to successfully settle into non-optimal areas (as in Long Island Sound) implies that habitat is not lacking and makes it difficult to conclude that shelter-providing substrate, cobble in particular, represents a natural demographic bottleneck (Addison and Fogarty 1992; Miller et al. 1989b). Clearly, there is no evidence for a habitat-related bottleneck since recruitment and commercial landings have increased in most areas during the last two decades (Miller et al. 1989b). A review of the population dynamics of American lobster in the northeast (ASMFC 1996) concluded that no evidence for density-dependent compensatory mortality existed during the benthic phases of the life history prior to recruitment to the fishery.

## 5.0 FISHERY DESCRIPTION

### 5.1 HISTORICAL INFORMATION

American lobster is often mentioned in documents about colonial America as an abundant species and therefore a dependable source of bait and food. It helped to feed the early colonists and native populations in northwest Atlantic coastal regions of the U.S. Wood (1635), in referring to lobster abundance in coastal Massachusetts, indicated "their plenty makes them little esteemed and seldom eaten." Native Americans captured many every day at low tide for bait and for food.

Rathbun (1884), Goode (1887), and Herrick (1911) described the lobster fishery as beginning around 1800 along the coast of Massachusetts, in particular on Cape Cod and near Boston. Some fishing occurred as early as 1810 among the Elizabeth Islands at the entrance to Buzzards Bay and on the coast of Connecticut. This industry did not expand to the coast of Maine until about 1840. Similarly, the onset of the Provincetown, MA fishery at the tip of Cape Cod did not develop until about 1845. By the late 1800s, lobster fisheries existed off all states southward to Virginia. Lobsters that moved shoalward in the summer were fished at such shallow depths that traps were often exposed at low tide. Hoop nets were commonly used until wooden traps became popular in the mid 1800s.

By the 1880s there was widespread concern about declining lobster abundance and reduced size range. A formerly very active and profitable fishery in New York Bay and Hell Gate had collapsed, it was thought, due to overfishing and pollution. Although lobsters were thought to be moderately abundant along the shore of Connecticut, eastern Long Island Sound near Block Island, the outer Elizabeth Islands and Martha's Vineyard, MA, and coastal Maine. However, overfishing had nearly depleted the shallow water areas of coastal Massachusetts. Subsequently, Connecticut and Rhode Island also began to experience declines in abundance and average size of lobsters.

The New England lobster fishery expanded through the 1860's, after which there was a gradual decline in average size and a rapid decrease in annual catch. Total U.S. lobster landings were first reported in 1879 after the fishery had been underway for approximately 80 years (Figure 2). The total reported landings in the late 1800s were as high as 14,000 mt, which was approximately three times higher than reported landings in the 1920s and 1930s. The depletion of nearshore lobster populations forced range expansions and exploitation of deeper water areas (in some areas out to 35 fathoms). A thriving community fishery in Provincetown MA, which had supplied the bulk of the New York City market, was reduced to only eight fishermen by the year 1880. Ultimately, fishermen either abandoned this lifestyle or moved to more distant fishing grounds. The earlier transition from hoop nets to trap trawls was interrupted as fishermen began switching to single traps, which were more productive on the "more scattered" lobster resource.

The observed localized depletion of lobsters led early researchers to conclude that heavily exploited areas could not be immediately re-populated by lobsters emigrating from nearby areas. Declines in abundance \were documented in the Massachusetts, New Hampshire, Rhode Island, Connecticut, Maine, and Canada (catches were reduced by as much as 75% during a 20-year period in NH). Overfishing was considered to be the culprit and it was exacerbated by the harvest of small lobsters for canning. It is not known if unfavorable environmental conditions may have contributed to the decline in abundance in coastal areas during this era or if lobster stocks as a whole declined. However, the symptoms described in the literature, which included marked reduction in average size and near elimination of lobsters in shoal environments, strongly support the historical contention that removal rates were too high. Despite a lower number of lobstermen fishing significantly fewer traps, the average catch per trap haul was apparently higher in the early years of the fishery. Davis (1989) analyzed historical Buzzards Bay catch records in comparison to catch rates from the 1980s and concluded that historical abundance (during the early to mid 1800s) appeared to be higher by a factor of 2 to 4, even though traps were fished much less efficiently then.

It appears that lobsters were not only more plentiful historically, but also larger. Wood (1635) noted that lobsters captured by pilgrims in the shoal waters of Massachusetts were very large, some weighing 20 lbs. In the treatise "The Invertebrate of Massachusetts", Gould (1841) commented that 10 to 12 lb. lobster were commonly seen in the markets and the average weight was about 4 lbs. Martin and Lipfert (1985) note that 4 ft (45 lb.) specimens were common in colonial times and refer to a seventeenth century New York account which mentions lobsters 5-6 ft in length. They also refer to canneries in Canada in the mid 1860's where 4 to 5 lb. lobsters were considered small and described a record of a 37 lb. lobster at a Nova Scotian factory. Goode (1887) recalls the beginning of the Maine fishery in 1840 and describes the average weight of lobster marketed there in the 1850's as 3 lbs. In Massachusetts, he indicated that the average Buzzards Bay lobster weighed 3 lbs. in 1841 and 2 1/2 pounds by 1880. Today the average lobster in the Buzzards Bay fishery weighs 1.2 lbs. (Estrella and Glenn 1998).

A comparison of the size range of egg bearing female lobsters observed during May-June in the vicinity of Buzzards Bay, MA in the 1890s vs. 1997 is instructive (Figure 3). The population that was sampled in the 1890s was composed of a much higher percentage of larger animals than the 1997 population yet similar size at first maturity based on the smallest egg-bearing lobster in both data sets.

Wolff (1978) compiled data from 25 of the largest specimens of American lobster available in museums. Although data for each lobster may be incomplete, the treatise provides useful information on maximum size. The carapace length (CL) of these specimens ranged from 229 mm to 326 mm (9-12.8 inches). Weight ranged from 3.18 kg (7 lbs.) to 19.25 kg (42.4 lbs.). One 229 mm lobster (12.7 kg, 28 lbs.) was captured in only 6 meters of water at Belfast, ME in 1891. Approximately half of the specimens were captured at sites north of Cape Cod and the other half south of Cape Cod, including sites off the Virginia Capes, Atlantic Highlands and Bayonne, NJ, and RI. Wolff (1978) found two additional references to two 45 lb. lobsters but could not locate the specimens. One was taken by a dragger 125 miles off the eastern end of Long Island, NY on February 28, 1956 and the other off Nova Scotia in 1935.

Current levels of high exploitation, particularly in the coastal regions of the lobster's range, continue to minimize the number of lobsters, which can grow to the large sizes observed historically. Concerns which have been voiced by local fishermen about a declining size range in outer coastal areas of Massachusetts have been corroborated by Massachusetts Division of

Marine Fisheries coastwide sea sampling conducted since 1981. Catch rates of lobsters in four (10 mm) size groups >120 mm CL have trended downwards in the last two decades (Figure 4). Also, a comparison of available outer Cape Cod size frequencies from 1957 and 1998 MA commercial sea sampling demonstrate a dramatic change in size structure during this 41-year period (Figure 5) (Estrella and McKiernan 1989). Percent at size may be effected by recruitment changes. Comparable data from other states are unavailable.

## 5.2 FISHING ACTIVITY IN EACH STOCK UNIT

### 5.2.1 Landings

Total landings by state and catches by stock area are summarized in Tables 2 and 3 and Figure 6. Total landings were relatively constant at 14,000 mt through the late 1970s. Since then, landings have doubled, reaching 36-37,000 mt in 1997-98. During the last ten years, landings in Maine constituted about half of the total with 23% occurring in Massachusetts, 9% in Rhode Island and New York, 4% in Connecticut, and 2% in New Hampshire and New Jersey. Over the last decade, the relative proportions of landings among states have been relatively constant. On a relative basis, landings in the South of Cape Cod-Long Island Sound (SCCLIS) assessment area have increased faster than in the other two areas. Annual SCCLIS catches increased from <1,000 mt prior to 1982 to 4,000 mt in 1984 and are currently about 7,000 mt GOM catches started to increase slowly in the 1970s, then much faster during the late 1980s and 1990s. GOM catches are currently 26,000 mt and account for 71% of the total U.S. lobster harvest. Catches from Georges Bank and offshore southern New England waters (GBS stock area) increased slowly from <2,000 mt a year in the early 1960s (when bottom trawls were the principal gear used) to 4,300 mt in 1990 and have declined somewhat since then.

During the 1950s and 1960s non-trap catches were primarily from a developing offshore trawl fishery, however, the introduction of deep-water trap fishing around 1968 rapidly replaced trawls. Traps have accounted for well over 90% of the total catch since 1972 and >97% since 1979 (Figure 7).

Historical time series of catch and effort data from all states are lacking. However, available data from Massachusetts are enlightening. Figure 8 depicts Massachusetts lobster catch-per-unit-effort (CPUE) data (landings/traps fished) from 1888 to the present. CPUE was highest at the beginning of the time series, declined rapidly through 1906, then recovered somewhat and varied without trend until the 1960s as the number of traps fished increased to approximately 100,000. CPUE declined during the 1960s as fishing effort continued to increase, then recovered slightly before resuming its decline during the 1990s. A number of factors other than lobster abundance likely contribute to trends in CPUE, including increased competition for productive fishing grounds, gear saturation, and expansion to new fishing grounds.

### 5.2.2 Fishing Effort

The operational characteristics of the U.S. lobster fishery have changed significantly in recent decades. There have been very substantial increases in trap numbers and the areal extent of the fishery. Also, there has been a change from wood to wire gear and traps have become larger. Along with higher numbers of larger, more efficient traps, there has been an increase in soak time per trap. Fishing power has also been improved through changes in vessel and gear technology. Each of these factors affect catch rates and overall yield from the fishery.

Total traps fished in U.S. waters have increased over three fold since the late 1960s (Figure 9) and currently number more than four million. During this 30-year period, landings increased at a very similar rate.

In the Maine fishery, there was an approximately four-fold increase in total traps fished since 1967 and the average number of traps per boat increased from ≤250 in the late 1960s to ≥600 in 1998 (Figure 10). There has also been nearly a total changeover from wood to wire traps, and an increased use of the double, rather than single parlor type of trap (Figure 11). These traps are generally felt to be superior in fishing power and efficiency to wooden traps. Increases in escape vent openings have also enhanced trap efficiency by increasing the ratio of legal lobsters in the catch and reducing the number of culls. The average soak time per trap has nearly doubled during the last 30 years (Figure 12).

A five fold increase in total traps has been observed in the Massachusetts fishery since 1960 (Figure 13). Total traps fished increased to a time series high of over 500,000 in 1998. Nearshore traps increased through 1989, then subsequently declined, while offshore traps continued to increase indicating a spatial change in effort. The average number of traps per boat has increased steadily from 1967 through 1998 (Figure 14). Numbers of trap hauls per year in the inshore Massachusetts fishery have declined steadily since 1989, but increased offshore (Figure 15) while the average soak time has increased since 1985 (Figure 16). Longer soak times with larger numbers of traps offshore indicate a change in fishing strategy among Massachusetts harvesters. The proportion of landings from offshore has increased from <20% to >40% since 1980 (Figure 17). Unlike Massachusetts, the number of trap hauls have risen steadily in the Rhode Island inshore fishery since 1982 (Figure 18).

Examination of monthly effort statistics for the Connecticut fishery in Long Island Sound derived from logbook data indicated increases in the number of trap hauls, number of traps, and mean set over days since 1979 (Figure 19). A comparison of Connecticut and New York inshore traps and landings in Long Island Sound reveals that both fisheries tracked similarly through the late 1980s, but deviated after that, with NY landings and traps increasing 3-4 times compared to CT's two-fold increase (Figure 20). NY inshore traps have increased at a faster rate than either CT inshore or NY offshore traps (Figure 21).

The effects of technological changes are difficult to quantify for the fishing industry as a whole. Technological advances in marine electronics (color depth finders, GPS and LORAN, in particular), hydraulic pot haulers, and larger, faster boats allowed fishers to expand their fishing areas (they are now exploiting regions farther from shore which previously received little or no fishing pressure) and fish more traps more effectively. Color depth finders enable fishers to locate more productive lobster habitat and navigational instruments such as GPS and LORAN will allow fishers to relocate and return to productive areas.

Collectively, these observations on the operational features of the lobster fishery indicate an increase in fishing pressure on the resource mediated through technological change (gear technology). These changes have occurred gradually but consistently throughout the last three decades and have important implications for the fishing mortality rates exerted on the resource.

### 5.2.3 Background on traps

Many factors affect the catch rate 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). Encounter probability depends upon the lobster having the internal/external motivation to leave its shelter (i.e. state of hunger, gender, reproductive status, time of day, water temperature, odor cues from bait). In general, lobsters leave shelters when light intensity falls below $2 \times 10^{-2}$ $\mu W/cm^2$ (Weiss 1970). It is likely that in deeper or murkier waters, lobsters are active for greater proportions of the day (Cooper and Uzmann 1980). Temperature affects the encounter rate; walking rates increase linearly between 2 and 10° C, are constant between 10°-20° and increase again above 20 ° (McLeese and Wilder 1985). Koeller (1999) examined the relationship between temperature, effort and CPUE in Nova Scotia but was unable to distinguish between the effects of temperature alone. Odor plumes generated by bait are carried by currents in a plume, becoming more diffuse with distance. Lobsters are extremely sensitive to amino acids and amines and unusual compounds; chemoreceptive cells show preferential responses to brief stimuli, such as patches of odor in a turbulently dispersed odor plume (Atema and Voigt 1995). Miller (1990) found that traps are likely to have a diminishing probability of capturing animals according to the distance from the trap so that the effective fishing area is smaller than its area of attraction (Cobb, personal communication).

Catchability is lowest at time of ecdysis (Miller 1990) which is presumably related to hunger levels. Changes in serum protein have been noted over the molt cycle suggesting that a high level of feeding may be required to recover from molting (Ennis 1973). Many fishermen plan their maximum effort to correspond to the molt cycle.

Once in the vicinity of the trap, the lobster must locate the entrance. The number and design of the funnel entrance affects both entry and escapement. The diameter of the ring must be optimally sized; too small and larger animals will not enter; too large and escapement will increase. The addition of a parlor section has increased retainment since it is more difficult for the lobster to pass through the separation funnel. Some of the more recent trap designs have multiple parlor sections. Soak time may affect escape rate. Skud (1979) found that catch per day declined with increasing soak time in the offshore fishery and that catch per haul is not a reliable measure of abundance unless it is standardized for length of soak. .

However, many lobsters are observed not to enter traps and may violate the assumption of equal catchability. Karnofsky and Price (1989) examined lobsters in a semi-natural environment and found that there was considerable individual variation in responsiveness to traps. Watson (1999) using a trap with a mounted low light camera indicated that not all lobsters will enter traps and that trap saturation may only affect larger lobsters. Sex and size also are factors that affect the catch. Ennis (1978) and Miller (1989, 1990) compared sex ratios in traps to simultaneous surveys conducted by divers and found a 1:1 male/female sex ratio in the field compared to a 3:1 in traps. Larger lobsters were more catchable than smaller ones - 41% of the trap catches, but only 4% of the diver samples were lobsters with a carapace length greater than 80 mm. Ovigerous females were caught at lower rates than expected. Addison and Bannister (1998) quantified the potential behavioral factors that would influence the outcome of the cohort analysis noting that an asymptotic relationship between fishing effort and fishing mortality may reduce the likelihood of stock collapse and such a combination might explain the apparent resilience of highly exploited lobster fisheries.

Trap saturation (decreasing catch rates with increasing catch) occurs as a result of the interaction between the animal and the gear (Auster 1985; Miller 1989; Fogarty and Addison 1992). Behavioral interactions resulting in reduced entry contributes to the saturation effect (Richards et al. 1983). Escapement has been greater increased with the use of escape vents. Selectivity ogives for different escape vent sizes have been calculated (Nulk 1978; Krouse, unpublished). Addison and Bell (1997) modelled the capture process involved in catch rates of clawed lobster. Noting that the variance: mean ratio for the catch of lobsters in individual traps was less than or close to unity, implying a random or even distribution of lobsters among traps, they hypothesized that behavioral interactions reduced the incidence of high numbers of lobsters per trap. In the simulation model, the effectiveness of bait and local depletion around the trap had less influence than behavioral interactions on catch rates and the distribution of catch among traps. All of the results were sensitive to the assumptions made about random movement of lobsters.

Since catchability is influenced by so many factors, assumptions about linear relationships between fishing effort and fishing mortality and assumptions that the population indices such as sex ratio and size distribution are unbiased, are questionable. For instance, including a non-linear relationship between catchability and YPR model shifts the YPR curve upwards and to the right, increasing the estimated fishing effort at which optimum yield is reached (Addison and Bannister 1998). Other simulation models that incorporate behavior in the capture process also suggest that more research is needed before trap catches can be used as an indication of abundance or fishing mortality.

### 5.3 RESOURCE MANAGEMENT

The American lobster fishery has a long history of management, with some state regulations enacted as early as the 1870s (Table 4). Historic regulations, like recent measures, focused primarily on size limits and protection of egg bearing females.

The lobster fishery occurs primarily in state waters (approximately 80% of total landings). Lobster regulations historically were implemented by the states. Since the 1970s, the lobster fishery has been managed cooperatively by the states and the federal government. Regulatory authority for the American lobster fishery is vested in the coastal states for fishing within three miles of shore and the NMFS for fishing in the EEZ (3-200 miles). Cooperative management began under the auspices of the Northeast Fisheries Management Board, which developed the first American Lobster Interstate Fishery Management Plan for state waters in 1978. The New England Fishery Management Council developed its first American Lobster Fishery Management Plan in 1983 to implement regulations in federal waters that were compatible with state regulations. Both plans were amended several times to refine and modify the management of the lobster fishery. Currently, the Atlantic States Marine Fisheries Commission has taken the lead on management of the American lobster fishery under Amendment 3 to the Interstate Fishery Management Plan (FMP) for American Lobster (ASMFC 1997) under the Atlantic Coastal Fisheries Cooperative Management Act (ACFCMA). The Final Rule for American lobster management (Federal Register 1999) established compatible regulations in Federal Waters.

The goal of the ASMFC plan is "to have a healthy American lobster resource and a management regime which provides for sustained harvest, maintains appropriate opportunities for participation, and provides for cooperative development of conservation measures by all stakeholders". The plan objectives include protection of brood stock abundance; control of effort and regulation of fishing mortality rates; collection, analysis and dissemination of biological and economic information; maintenance of social and cultural features of the industry; minimization of lobster injury and discard mortality; increasing understanding of the biology of American lobster and improvement of stock assessment models; insurance that changes in exploitation patterns do not undermine the success of the management program; optimization of yield from the fishery while maintaining harvest; and maintenance of stewardship relationship between fishermen and the resource.

Amendment 3, when fully implemented, is designed to minimize the chance of a population collapse due to recruitment failure. The ASMFC Interstate Fishery Management Program (ISFMP) Charter requires all FMPs to include an overfishing definition and rebuilding schedule (if necessary). To this end, the Plan defines overfishing as the rate of removal that results in less than 10% egg production, on a per-recruit basis, of an unfished population, and establishes a schedule to rebuild egg production by 2005 (below). According to the last stock assessment (NEFSC 1996), lobsters are overfished throughout their range.

| **Percent Maximum Egg Production Per Recruit** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **1998*** | **1999*** | **2000** | **2001** | **2002** | **2003** | **2004** | **2005** |
| **GOM** | 3.25 | 3.25 | 4.375 | 5.5 | 6.625 | 7.75 | 8.875 | 10+ |
| **GBS** | 1.68 | 1.68 | 3.07 | 4.46 | 5.85 | 7.24 | 8.63 | 10+ |
| **SCCLIS** | 2.21 | 2.21 | 3.51 | 4.81 | 6.11 | 7.41 | 8.71 | 10+ |

* Values reflect baseline information available at the time Amendment 3 was developed (1997).

Amendment 3 provides a flexible management process to modify management measures in response to changes in the condition of the stocks and fishery through an adaptive management process. Following this process, the ASMFC American Lobster Management Board approved Addendum I to Amendment 3 in August 1999. Amendment 3 and Addendum I include coastwide and area specific management measures that are specific to the seven lobster conservation management areas (Figure 22). The coastwide measures are:

- Prohibition on possession of egg bearing or scrubbed lobsters
- Prohibition on possession of lobster parts
- Prohibition on spearing lobsters
- Requirement for biodegradable ghost panels
- Minimum gauge size of 3-1/4 inches carapace length
- Limits on landing by non-trap gear to 100 lobsters per day up to a maximum of 500 lobsters per trip for trips 5 days and longer
- Prohibition on possession of v-notched female lobsters
- Maximum trap size
- Requirement for escape vents (1-15/16 inches by 5-3/4 inches rectangular)

The area specific measures include the following:

| Management Area | Trap Limit* | Other Measures |
|---|---|---|
| *Area 1* | 800 | 5-inch maximum size |
| *Area 2* | 1000 in 2000, 800 in 2001 | |
| *Area 3* | Cap set at individual historical levels, then decreasing by 20% | Limit on vessel upgrade |
| *Area 4* | Cap set at individual historical levels | Four sub-areas, representing 11% of Area 4, closed to trap fishing |
| *Area 5* | Cap set at individual historical levels | |
| *Area 6* | Cap set at individual historical levels | |
| *Outer Cape* | 800 | |

*The trap limit in Federal waters is 800, except in Area 3 which has an 1800 trap limit. Presently there is no Federal limit on vessel upgrades in Area 3, nor closed areas in Area 4. These measures will be considered during the next Federal regulatory cycle.

The American lobster management program under the ASMFC functions under the Interstate Fishery Management Program, with direction provided by the American Lobster Management Board (Board). The Board is composed of three Commissioners (State Director, State Legislator, Governor's Appointee) from each state, Maine through North Carolina, and a representative from the NMFS. The Board has several supporting committees including the Lobster Technical Committee, which conducts the analytical activities for the program, seven industry-based Lobster Conservation Management Teams (LCMT), which provide recommendations on management in each of the seven management areas, and an industry-based Advisory Panel, which provide advice and recommendations from a coastwide perspective.

The LCMTs in each area have developed recommendations on future management measures that will meet the egg production targets in Amendment 3, while considering the needs of the fishery in that area. Some of the LCMTs have recommended an increase in the minimum gauge size to 3-3/8 inches, and a vent size increase to 2-inches. The Board has tabled any further discussion and action on these items until the completion of a peer-reviewed stock assessment.

The LSASC was convened by the Technical Committee and was composed of Committee members and outside experts. Its purpose was to complete a stock assessment under the terms of reference given in Section 1.

# 6.0 DATA SOURCES

## 6.1 FISHERIES DEPENDENT

### 6.1.1 Landings

Maine

Lobster landings information from dealers is compiled in the NMFS weighout and canvass database by county and month. The state of Maine does not collect any landings data for lobster. County landings were converted to statistical area landings as follows:

Area 511: Washington and Hancock counties
Area 512: Knox and Waldo counties
Area 513: Sagadahoc, Lincoln, Cumberland, and York counties

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 (Figure 23); principal ports of landing; and information relative to the vessels and traps used in the fishery. Recreational fishermen are asked to report on their license renewal application form the number of lobsters taken during the previous year and the maximum number of traps fished.

Rhode Island

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 was 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.

### 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 which was first implemented in the mid-1970s to provide catch and effort information from all commercial license holders. This mandatory monthly logbook system provides a detailed daily catch by species, area (Figure 24), and gear as well as port landed, traps hauled, set over days, and hours trawled (for draggers). In addition, it 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. This includes 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 the NOAA form *Purchases from Fishing Vessels*. Since several dealers buy only lobster from commercial fishermen, a *Connecticut Seafood Dealer Report, Abbreviated Form for Lobster Transactions Only* has been created. A quality assurance program has also been established to verify the accuracy of reported statistics through law enforcement coverage and electronic cross-checking of fisherman catch reports, law enforcement boarding reports, and seafood dealer reports.

### New York

Catch and effort information is collected from resident commercial lobster fishermen through an annual 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. Data requested from lobstermen include: number of days fished, pounds of lobster caught, number of pots used, average number of vents per pot, size and shape of vents, percent of catch taken by gear type, and areas fished (percent of time). 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 or which would be otherwise unreported.

Staffing shortages have limited the state's ability to enforce a mandatory survey system. Thus, fishermen have not been required to complete the survey before obtaining a new commercial permit for the subsequent year. In addition, not all fishermen responding to the survey provide legible and/or complete responses. Data provided are reviewed prior to data entry, and when possible, attempts are made to contact respondents by telephone to clarify and/or complete insufficient information. However, lack of staff and incomplete contact information has made it impossible to contact all license holders to verify and/or complete responses. Contact efforts have been concentrated, in order of priority, on responses which represent potential outlier data followed by missing catch, gear, area, pot number, bycatch, days fished and/or vent data, respectively.

Survey responses are entered into a customized SAS® data entry program using SAS/FSP® software. This program was developed to include quality control measures such as protection against outliers. Project staff conduct further quality assurance checks by randomly selecting a subset of original survey data cards and matching information with the observations in the dataset. The largest potential for error includes misinformation from fishermen and interpreting responses on handwritten cards.

In 1995, there were improvements to the survey and analytical methods used by NY to estimate lobster landings and fishing effort. In particular, estimates of lobster landings to NY ports in 1995 and later years were expanded to account for non-response to the survey:

$$L=R/p$$

where L was estimated total estimated landings (weight) during one year, for one gear type and area, R was total landings reported in the survey (for the same year, gear type and area), and p was the proportion of license holders (by gear type) that responded to the survey and returned useable data. The expansion was particularly important for 1995 when the proportion of respondents was low (26.7%, see below) due to printing and distribution problems.

Estimates of NY lobster landings prior to 1994 used by NEFSC (1996) were expanded for use in this assessment. However, the expansion was based on the proportion of active license holders in 1997 (88%), rather than the proportion of license holders that responded in each year. Proportion of active license holders, rather than proportion respondents, was used because of concerns about the proportion of respondents who were active in catching lobster. Data for 1997 were used because it was the most recent year with complete information.

The expansion procedure improved estimates of recent and historical NY landings but there are several possible sources of bias. The proportion of "active" license holders (those that actually fish for lobster) may differ between respondents and non-respondents. If the proportion active is less for non-respondents, then estimates of landings would be biased high. Second, biologists familiar with the data suggest that the mean response rate was likely less than 88% prior to 1995. If the true mean response rate was less than 88%, then estimates of total landings prior to 1995 would be biased low. Techniques for expanding historical and recent NY landings are an important area for future research that should be addressed in the next assessment and in development of databases for lobster fishery data.

The proportion of fishermen responding to the survey varied over time (see below) with the lowest response rate occurring the first year of the survey. Low response rates may affect the accuracy of the expansions. Response rates to individual questions within the survey were also variable. Expansions of catch and effort by area have been based on the proportion of fishermen who responded fully to questions on poundage, area fished, gear type and, when appropriate, the number of pots fished.

| **Year** | **1995** | **1996** | **1997** |
|---|---|---|---|
| ***Total Survey Responses*** | 266 (26.7%) | 790 (84.8%) | 656 (73.9%) |
| ***Total Licenses Issued*** | 995 | 932 | 888 |

Areas of analysis include: 1) Long Island Sound; 2) the east end of Long Island, (Block Island Sound, Gardiners Bay, Peconic Bays, Fishers Island Sound, inshore north shore Montauk, etc).; and 3) the south shore of Long Island. In most analyses, the south shore fishery was further subdivided into the inshore fishery (within three miles of shore) and the offshore fishery (more than three miles from shore). This subdivision was necessary in order to assess differences between the inshore and offshore fisheries and to provide state managers with a more accurate view of the fishery that exists within their jurisdiction.

### 6.1.2 Port and Sea Sampling

Maine

Since 1966, port sampling has occurred during ten randomly-selected days each month from April through December from lobster dealers along the entire coast who buy from at least five commercial lobstermen. This survey is designed to produce unbiased estimates of catch and effort and 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, number of traps hauled, total weight of catch, number of lobsters caught, and hydrographic information. Ten lobsters from each boat are randomly selected to provide individual length and weight data, as well as sex, claw and shell condition. A summary of 1994-98 port sampling coverage (number of boats sampled and number of marketable sized lobsters measured in statistical areas 511-513) can be found in Table 5.

A sea sampling program was also started in 1985 during the months of May through November aboard commercial lobster vessels using observers to record data. Data include carapace length (mm), cull status, sex, egg development stage, second abdominal width, v-notch/mutilation condition, presence of eggs, numbers of legal and sub-legal lobsters, trap type and dimensions, immersion time, traps per string, geographical distribution of traps, trip duration, amount and type of bait used, total weight of catch and ex-vessel price per pound. This program was expanded in 1998 to include more trips aboard a larger number of boats in more ports. Prior to 1998, sea sampling was limited to only three locations, with repeated trips made aboard the same vessels. Port sampling has been used in this assessment, as well as past assessments, to estimate size distribution of landings by area rather than sea sampling because data comes from a wider range of fishing vessels and areas and are more representative of the total landed catch.

New Hampshire

New Hampshire conducts a monthly sea sampling program during June-October, aboard commercial fishing vessels in the lower Piscataqua River, state coastal waters, and around the Isles of Shoals. Data collected since 1991 include CPUE , bait and trap type, carapace length, sex, molt stage, cull status, female second abdominal width, V-notch condition and the presence of eggs. A summary of 1994-98 sea sampling coverage (number of trips and number of marketable sized lobsters measured in statistical area 513) can be found in Table 5.

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 (Figure 25) 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 (LORAN), and water depth (from chart plots) for legal and sub-legal lobsters. A summary of 1994-98 sea sampling coverage (number of trips and number of marketable sized lobsters measured by statistical area) can be found in Tables 5 (GOM), 6 (GBS), and 7 (SCCLIS).

### 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. A summary of 1994-98 sea sampling coverage (number of trips and number of marketable sized lobsters measured by statistical areas 537, 539, and 616) can be found in Tables 6 (GBS) and 7 (SCCLIS).

### Connecticut

Sea sampling trips have been conducted with commercial trap fisherman since 1982 within two areas of Long Island Sound. The western basin from Bridgeport to Norwalk accounts for 50-60% of the total annual catch and New York waters of eastern LIS known as the "the Race" account for 10-15%. Therefore, it is felt that sampling from these two areas adequately represents the LIS lobster fishery as a whole. Biological information is recorded for all lobsters 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. A summary of 1994-98 sea sampling coverage (number of trips and number of marketable sized lobsters measured in statistical area 611) can be found in Table 7.

### 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, shell disease, and soak time and water quality for some or all years. 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 (Section 6.1.1). Fishing effort data can be calculated from this information. Sampling in areas 612 and 613 has always been sporadic and was very poor in area 611 during 1995-98 (Table 7).

### National Marine Fisheries Service/Canadian Department of Fisheries and Oceans

NMFS sea sampling data were also utilized to estimate total landings (in numbers by sex and size) from the GBS and GOM stock areas and DFO sea sampling data were used in offshore areas of the GOM (Tables 5 and 6).

### 6.2 FISHERIES INDEPENDENT - TRAWL SURVEYS

Data used in this assessment were obtained from bottom trawl surveys conducted by the U.S. NMFS, Northeast Fisheries Science Center (NEFSC), on the continental shelf between Cape Hatteras and Nova Scotia and from inshore bottom trawl surveys conducted by the states of Massachusetts, Rhode Island, Connecticut and, to a lesser extent, by New Jersey and Maine. Trawl surveys are conducted by NMFS, MA, RI, and CT during the spring and fall, but the only spring survey data that were utilized in this assessment were from RI and CT. In order to be consistent with previous assessments, DeLury model analyses (Section 8) for all stock areas and for all sub-areas except one were based on fall survey data only. DeLury model analyses for Long Island Sound were conducted using both spring and fall CT trawl survey data.

Trawl survey data for lobster collected by NMFS, Connecticut, Massachusetts and Rhode Island are routinely tabulated using delta distribution techniques (Pennington 1986) to avoid problems due to "zero" tows (e.g. survey tows containing no lobsters). More detailed information on survey area and timing, years surveyed, sampling design, gear and methods for each survey is presented below.

National Marine Fisheries Service

Currently the Northeast Fisheries Science Center, Woods Hole Laboratory, conducts four bottom trawl surveys a year, one during each of the four seasons. The summer and winter surveys are relatively new, having started in 1991 and 1992. The spring survey and autumn surveys represent the longest and most important time series. The spring survey was initiated in 1967 and the fall survey in 1963. Spring surveys are generally conducted during March and April and fall surveys in September and October.

The NMFS bottom trawl survey utilizes a stratified random sampling design which provides estimates of sampling error or variance. The study area, which now extends from the Scotian shelf to Cape Hatteras including the GOM and Georges Bank was stratified by depth (Figure 26). 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.

Before 1972, sampling was limited to depths > 27 m. In the 1970s and early 1980s, the surveys were extended south of Cape Hatteras to Cape Fear, and (primarily in the mid-Atlantic) coverage was extended inshore to depths of less than 9 m whenever possible. 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$^2$. In the late 1970s and early 1980s as many as 450 stations were occupied on a survey, with more extensive sampling being conducted in important resource areas such as Georges Bank. In recent years sampling south of Cape Hatteras, on Browns Bank (near Nova Scotia), and in the Bay of Fundy were eliminated and coverage reduced in the most inshore (<18 m) and offshore (>110 m) strata, as a means of saving costs and time.

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 standardized, roller rigged #36 Yankee otter trawl was used. From 1972 until 1981, a larger #41 Yankee trawl was used on spring surveys, and from 1972 until 1975, a ¾ Yankee trawl was used on some of the inshore (<27 m) surveys. 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

Two groundfish trawl surveys were conducted by the Maine Department of Marine Resources in Maine coastal waters during 1992-1998. 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 (Figure 27). 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 (Figure 28). 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, lobsters 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 lobsters 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 lobsters. This survey was discontinued in 1999. Results of these surveys are presented for the first time in this report; they were not used in any of the assessment models owing to the short time duration of the surveys and the absence of data for individual lobsters.

### Massachusetts

Massachusetts Division of Marine Fisheries has conducted a biannual trawl survey since 1978 in state waters (out to 3 nautical miles) from the New Hampshire to the Rhode Island borders, including Cape Cod Bay and Nantucket Sound (Figure 29). Pre-determined trawl sites are allocated randomly in proportion to stratum area, although some sites are relocated because of concentrations of fixed gear or untowable bottom. Sampling occurred in May and September each year aboard either the vessel R/V Francis Elizabeth (1978-81) or the vessel R/V Gloria Michelle (1982-97). Each tow was made at 2.5 knots for twenty minutes 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. Total weight and length-frequency, surface and bottom water temperatures, and salinity data were recorded, and 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 (Figure 30). Collected data include carapace length, sex, shell hardness, presence of extruded ova, bottom and surface water temperature, sea conditions, and wind speed/direction.

The University of Rhode Island (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 lobsters. 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 data was difficult to compare to other sources because of 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 (Figure 31).

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

New Jersey

The New Jersey Division of Fish, Game and Wildlife has conducted a groundfish survey along the New Jersey coast since 1988. The survey area is about 1800 square miles of coastal waters between the entrance to New York harbor to Cape May and from a depth of 18 to 90 ft and is divided into 15 strata which are bounded by the 30, 60 and 90 ft isobaths (Figure 32). The survey design is stratified random. Since 1991, 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. The trawl gear is a two seam three-in-one trawl (so named because all the tapers are three to one) with 12 cm (4.7 inch) mesh in the wings and belly and 7.6 cm (3 inch) in the codend with a 6.4 mm (0.25 inch) liner. The headrope measures 25 m (82 ft) and the footrope 30.5 m (100 ft). Rubber cookies measuring 2 3/8 inch in diameter are used on the trawl bridles and groundwires, but not on the footrope of the net opening. The same vessel has been used to do these surveys since 1991. Data from this survey were not utilized in this assessment owing to the small area represented by the survey.

## 7.0 ASSESSMENT METHODS - DATA AND MODELS

### 7.1 LANDINGS DATA

Monthly landings (pounds) for lobster from each state during calendar years 1994-1998 were allocated to statistical areas within each stock area (Figure 1) as described in Section 6.1.1. For analysis in stock assessment models, monthly lobster landings for October 1994 through September 1998 were aggregated by "survey years" (October in year t through September in year t+1) for individual statistical areas and stock areas. Survey years are traditionally used in stock assessment models for lobster because the beginning of a survey year corresponds to the approximate date of the fall bottom trawl surveys. Landings in pounds were converted to numbers landed by sex, survey year and 1 mm CL size groups using biological data from sea and port samples (Tables 5, 6, and 7). Methods used to compute landings in numbers by sex, size group, and month were similar to those used in previous assessments (see detailed description in NEFSC 1996).

Initial calculations of landings by sex and size group from the SCCLIS stock area during the 1994-1997 survey years had erratic sex ratios, probably due to inadequate sampling effort in Long Island Sound (Table 7). Numbers of male and female lobsters in recent years were therefore adjusted based on sex ratios in preceding years. The total number of lobsters (males + females) was not changed by the adjustment. Another chronic problem was inadequate sample coverage in GBS during winter months when weather was inclement and sea sampling difficult. In cases with missing information, sea sample data were "borrowed" from other months or from the same month in other years, increasing the likelihood of error.

Based simply on the ratio of numbers of lobsters sampled to total estimated numbers of lobsters landed, sample coverage in recent years has been highest in the GBS area, intermediate in the SCCLIS, and lowest in the GOM (Tables 5, 6, and 7). The percentage of lobsters landed in survey year 1997 that were measured in the GOM during 1998 was 0.04% (or 4 lobsters out of every 10,000 landed), with 0.09% in the SCCLIS area and 0.24% in the GBS area. In the SCCLIS area, sample coverage was poor in Long Island Sound (0.03%) compared to areas 538 and 539 (0.3%). Sampling in the GBS area in recent years has been patchy, with a higher sampling percentage in Block and Hudson Canyons (0.37% in 1998) than in the rest of the stock area (0.15%). Areas 537 and 616, where these two canyons are located, accounted for 38% of the 1997 survey year landings from this stock area and 60% of the measured lobsters. Statistical areas on the outer portion of Georges Bank are very poorly sampled, in some years (e.g., 1997) not at all due to a reduction in NMFS sea sampling trips (Table 6).

Sampling coverage should also be evaluated in terms of the fraction of all trips made by commercial vessels which are sampled during discrete time periods (e.g., years) and areas (e.g., stock areas or statistical areas). On this basis, sample coverage was higher in the GOM stock area owing to the large number of port samples in areas 511, 512 and 513 and extensive sea sampling in areas 513 and 514 (Table 5). Even though only 10 lobsters are measured from each catch during port sampling, sampled trips are distributed over much broader temporal and spatial ranges than is possible during sea sampling trips which produce large numbers of measurements, but which only represent individual fishing trips. Non-random spatial and temporal distributions of male and female lobsters and lobsters of different sizes confound this problem.

After adjustments to recent (see above) and historical (see below) data for the SCCLIS stock area, numbers of lobsters landed by sex and 1 mm CL intervals during survey years 1994-1997 were appended to data files used in the last assessment for survey years 1982-1993 (SCCLIS and GOM stock areas) or 1981-1993 (GBS stock area). Fishery data for the GBS and GOM stock areas during survey years 1981-1993 were the same as in the last assessment (NEFSC 1996).

Annual New York landings data were broken down into monthly landings using the proportion of Connecticut landings by month from Connecticut logbook data. Length frequencies by sex and cull status from sea sample data collected by New York and Connecticut were combined and broken down by quarter. If a quarter was not sampled, biological data from the most appropriate adjacent quarter was used as a proxy. Combined monthly New York and Connecticut landings for statistical area 611 in pounds were then converted to numbers of lobsters by sex and length group using combined CT/NY seasonal sea-sampling length frequencies for the landed (legal) catch. Different length weight formulas were used for males and females, and culls (lobsters with one claw or no claws) were removed from the calculation of landed length composition.

Annual New York landings from the south shore of Long Island were also distributed by month using the methods described above, except that the biological data were collected by Rhode Island during fishing trips to Block and Hudson Canyons. Monthly New York landings from the south shore of Long Island during 1995-1998 were split evenly between statistical areas 612 and 613. For the SCCLIS stock area, landings data for survey years 1982-1994 were adjusted up to account for non-response to the annual survey used by New York to estimate catch (Section 6.1). When landings data for 1982-1994 were updated, additional landings from the south shore of Long Island Sound were split evenly between statistical areas 612 and 613 and length frequency data were adjusted proportionally.

## 7.2 MODIFIED DELURY MODEL

The DeLury stock assessment model was introduced by NMFS (1992) and Conser and Idoine (1992) and has been used for lobster since that time. The general modeling approach was developed by Collie and Sissenwine (1983) and the "modified" version by Conser (1991, 1995).

The DeLury model divides the lobster population in each stock area into "recruit" and "fully-recruited" size groups. Recruits are lobsters that will molt and grow into legal size during the current survey year. Fully-recruited lobsters have been legal size for at least one survey year. Research vessel bottom trawl survey indices and annual landings in numbers of lobster are stratified into recruit and fully recruited size groups and used in the model to estimate stock sizes and fishing mortality rates.

The DeLury model assumes that the number of fully recruited individuals at time t is equal to the number of full recruits in the previous time step plus the number of new recruits less the number removed by fishing and losses due to natural mortality:

$$N_t = (N_{t-1} + R_{t-1})e^{-M} - C_{t-1}e^{(t_c-1)M}$$

where: $N_t$ is the fully recruited stock size in number at the beginning of survey year t,
$R_t$ is the recruit stock size in numbers at the beginning of survey year t,
$C_t$ is the catch in number during survey year t,
$M$ is the annual instantaneous natural mortality rate (=0.15 ),
$t_c$ is the point during the survey year when the catch is assumed taken (for lobster, $t_c$=0.8 and catch is assumed to be taken during June).

The model assumes that trawl research survey indices are proportional to true abundance

$$n_t = q_n N_t$$
$$r_t = q_r R_t$$

where $n_t$ is the survey abundance index for the fully recruited stock in year t,
$r_t$ is the survey abundance index of the recruited stock in year t,
$q_n$ is the survey catchability coefficient for full recruits,
$q_r$ is the survey catchability coefficient for recruits.

Substituting equations for survey index observations into the model and inserting terms for multiplicate random process errors ($\varepsilon_t$) gives an equation that relates abundance indices for recruits and full recruits in subsequent years:

$$n_t = \{(n_{t-1} + s_r r_{t-1})e^{-M} - q_n C_{t-1}\, e^{(t_c-1)M}\}e^{\varepsilon_t}$$

where the "Q-ratio" is $s_r = q_r / q_n$. Process errors are a way to change one of the key parameters (M) to a limited degree in each year to account for natural variability in the underlying biological processes.

Catchability estimates for full recruits and recruits cannot be estimated separately in the DeLury model based on the data available for lobster. It is necessary to specify a constraint such as one based on the Q-ratio (for lobster $s_r$ =1.0 for state surveys or $s_r$ =0.5 for the NMFS fall bottom trawl survey, see Section 7.5) before the model is run (see Appendix A for a detailed discussion). The Q-ratio constraint is typically used in DeLury model calculations (Conser 1991 1995)

The catchability coefficients ($q_n$) in the DeLury model implicitly include a gear efficiency term (i.e., probability of capture given encounter $P_{C|E}$) and a scaling factor to convert between average area (a) swept by the survey gear and the total area of the stock (A):

$$q = P_{C|E} \frac{a}{A}$$

The model for lobster assumes that survey abundance indices are measured with error. Let $n'_t$ and $r'_t$ be observations of population abundance indices $n_t$ and $r_t$, then:

$$n_t^{'} = n_t e^{\eta_t}$$
$$r_t^{'} = r_t e^{\delta_t}$$

where $\eta_t$ and $\delta_t$ are the random measurement errors.

The parameters vector $\Theta = \{(n_t| \, t=1,...T), (r_t| \, t=1,...T-1), q_n\}$ was estimated by weighted least squares:

$$SS(\Theta) = \lambda_\varepsilon \sum_{t=2}^{T} \varepsilon_t^2 + \lambda_\eta \sum_{t=1}^{T} \eta_t^2 + \lambda_\delta \sum_{t=1}^{T-1} \delta_t^2$$

where $_{\varepsilon}$ is the weighting factor for process errors and $_{\eta}$ and $_{\delta}$ are weighting factors for survey measurement errors. The weighting factors traditionally used for lobster ( $_{\eta}$ = $_{\delta}$=1 and $_{\varepsilon}$=4; NMFS 1992; NEFSC 1996) were used in all DeLury model runs for this assessment. These weighting factors tend to give model fits that allow for more measurement than process error. The emphasis on measurement errors for lobster is similar to most other stock assessment models that accommodate measurement errors but assume no process errors (e.g. Collie and Kruse 1998).

After the DeLury model is fit, recruited and fully recruited stock sizes are calculated:

$$\hat{N}_t = \frac{\hat{n}_t}{\hat{q}_n}$$

$$\hat{R}_t = s_r \frac{\hat{r}_t}{\hat{q}_n}$$

Total mortality and fishing mortality rates in year t for the entire population are calculated:

$$Z_{R+N_t} = -\ln\left(\frac{\hat{N}_{t+1}}{\hat{N}_t + \hat{R}_t}\right)$$

$$F_{R+N_t} = Z_{R+N_t} - M$$

### 7.2.1 Survey Data for Recruits and Fully Recruits in the DeLury Model

As described above, fully recruited lobsters in each annual time step are minimum legal size or larger. Recruits are lobsters that will molt, grow to legal size and recruit to the fishery during the current year. At the outset of the year, recruits are within one molt increment of legal size. Information about the distribution of molt increments for each stock area were used to define the probability that lobsters less than minimum size will molt and grow into the fishery. Molt increments were distributed normally with means of 11 mm CL (5 to 95% probability range 6-16 mm) for the SSCLIS and GOM stocks and 14 mm CL (5 to 95% probability range 7-21 mm) for the GBS stock.

For a given minimum legal size, the probability of recruiting to the fishery is:

$$RP_{CL} = \begin{cases} 1.0 \; if \; (CL_{crit} - CL) < moltinc_{\min} \\ \\ \displaystyle\sum_{i = CL_{crit} - moltinc_{\min} - CL + 1}^{moltinc_{\max}} P(moltinc_i) \end{cases}$$

where CL is the carapace length (in mm), $CL_{crit}$ is the minimum legal size, $moltinc_{min}$ is the minimum molt increment, $moltinc_{max}$ is the maximum molt increment, and $P(moltinc_i)$ is the probability of a molt increment equal to i mm (CL) . The recruit index ($R_{tot}$) for the DeLury calculations is:

$$R_{tot} = \sum_{j = CL_{crit} - moltinc_{\max}}^{CL_{crit}} Nj * RP_j$$

where $N_j$ is the survey index (number per tow) of lobsters length j. For this assessment, the minimum legal size was assumed to be 81 mm CL from 1982 to 1987, 82 mm in 1988 and 83 mm from 1984 to present (1998).

### 7.2.2 Blending Procedure for Stock Areas Not Covered by One Survey

In past assessments (NEFSC 1996), the NMFS fall bottom trawl survey was assumed to measure trends in abundance of lobster in entire stock areas and used in a DeLury model for each sex to estimate abundance and fishing mortality rates for the stock area as a whole. A problem with this approach for the SCCLIS and GOM stock areas was that trends measured by the NMFS survey in offshore areas were not the same as trends in nearshore areas where most of the fishing occurs. For this reason, fishing mortality rate estimates were likely biased. A better approach that blends results for subareas covered by individual surveys was developed for this assessment.

The GBS stock area is completely covered by the NMFS (fall and spring) bottom trawl surveys (Section 6.2). There are no state sponsored bottom trawl survey programs in the GBS stock area. Thus, data from a single survey (NFMS fall bottom trawl) can be used to track lobster abundance in the entire GBS stock area.

In contrast to the GBS area, no single bottom trawl survey covers the entire SCCLIS and GOM stock areas. NMFS (fall and spring), Connecticut (fall and spring), Rhode Island (spring and fall) and Massachusetts (spring and fall) bottom trawl surveys taken together cover most of the SCCLIS stock area (Section 6.2). Similarly, NMFS (fall and spring) and Massachusetts (fall and spring) bottom trawl surveys, cover most of the GOM stock area (with the exception of inshore areas along the coast of Maine). There is little overlap between the subareas covered by different bottom trawl survey programs in the SCCLIS and GOM stock areas.

As in previous assessments, estimates of abundance and fishing mortality were derived primarily from DeLury model analyses of fall trawl survey data (CT spring survey data from Long Island Sound were also analyzed). Blended abundance and fishing mortality estimates for the GOM and SCCLIS stock areas were derived from individual sub-area DeLury model runs using fall survey data.

The blending approach is based on separate DeLury models run for each of the subareas covered by state and federal surveys. Subarea model runs used state or federal survey data and fishery catch data from the same subarea. Biomass estimates for entire stock areas were calculated by summing estimates for subareas. Fishing mortality rate estimates for entire stock areas were obtained as abundance weighted averages of the fishing mortality rate estimates for subareas.

The blending approach is a major advance in stock assessment of American lobster because it makes fuller use of survey data, reduces bias in fishing mortality and abundance estimates, and provides information about fishing mortality rates and abundance trends in subareas (which are of considerable interest). 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 subarea.

Three subareas of the SCCLIS lobster stock area were defined based on fall surveys conducted by Connecticut, Rhode Island and NMFS. The fall survey conducted by Massachusetts was not used because lobster were seldom taken in recent years, there were numerous zero observations and the DeLury model is not configured to handle zeroes. NMFS survey data were used in DeLury model analyses for the subarea (statistical area 538) covered by the MA survey. Since the Connecticut survey started in 1984, rather than 1982, SCCLIS stock area abundance and fishing mortality estimates for 1982-1983 were based on Rhode Island and NMFS surveys only and reflect conditions in statistical areas 538 and 539 for those two years .

The GOM assessment area was divided into two subareas, represented by the Massachusetts and NMFS surveys. DeLury model runs for statistical area 514 (Massachusetts Bay) were performed using MA trawl survey data. In the absence of survey data for the Maine coast, NMFS survey data from statistical areas 511-513 and 515 were used in DeLury analyses for the remainder of the GOM stock area. Catch data from the GOM and SCCLIS stock areas were assigned to subareas as follows:

| Stock Area | Fall Trawl Survey | Statistical Area(s) for Landings | Years |
|---|---|---|---|
| SCCLIS | Connecticut | 611 | 1984 – 1998 |
| | NMFS | 538 & 50% of 539 | 1982 – 1998 |
| | Rhode Island | 50% of 539 | 1982 – 1998 |
| GOM | NMFS | 511, 512, 513 & 515 | 1982 – 1998 |
| | Massachusetts | 514 | 1982 – 1998 |

Bootstrap procedures was used to compute probability distributions for abundance and fishing mortality rate estimates. Probability distributions for the GBS stock area and individual subareas in the SCCLIS and GOM stock areas were calculated based on standard methods (e.g. NEFSC 1996) and 200 bootstrap runs per original DeLury 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 were more complicated. A new exhaustive (all possible combinations) bootstrap procedure was used. The new procedure was based on bootstrap iterations for individual subareas described above. Every possible combination of one bootstrap iteration for each sex and subarea was used to generate up to $200^3$=8 million combined bootstrap estimates for male and female lobsters in the SCCLIS stock area and $200^2$=40 thousand bootstrap estimates for each sex in the GOM stock area. For females, the Rhode Island survey run converged in 197 out of 200 runs and the total number of blended bootstrap combinations was 200 x 200 x 197 = 7,880,000. Probability distributions for original estimates of blended abundance and fishing mortality were based on distributions of the blended bootstrap estimates (see below).

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 ($F_c$), and three-year average fishing mortality ($\overline{Fc}$) were calculated.

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

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

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

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

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

where t is the survey year, k is one of the blended bootstrap estimates (formed from all unique combinations of converged bootstrap results for each subarea), and $\forall\, k$ means for all k unique combinations. All of the blended bootstrap estimates for a stock area were sorted so that the median and 80 percent confidence intervals (with bounds at the lower 10 and upper 90 percentile) were easy to calculate.

### 7.2.3 DeLury Model Diagnostics

Methods

Residual analysis, including plots of observed and fitted values vs. survey year and log scale residuals vs. predicted survey abundance, were used to identify lack of fit in DeLury model results. Ideally, model results have residuals that show no serial correlation (pattern over time) and no pattern in relationship to predicted survey values (a proxy for lobster abundance). Patterns in residuals over time indicate that some underlying factor (e.g. survey catchability) changed over time and biased abundance and mortality estimates. Patterns in relationship to abundance indicate that model performance, and possibly bias, depend on whether lobster abundance is low or high.

Results

Residual analysis (Figure 33, 34, and 35) showed some residual patterns and possible lack of fit, especially for the GOM and SCCLIS stock areas. The most important pattern in plots of residuals vs. survey year was a tendency for models to under predict survey data for recruits in recent years (GOM: female recruits in the NMFS survey and male recruits in the NMFS and Massachusetts surveys; SCCLIS: male and female recruits in the NMFS and Rhode Island surveys). This means that abundance of recruits may have been underestimated for some sexes and subregions or that survey catchabilities (or some other factor) for recruit lobsters changed during recent years. Large positive residuals (with observed values greater than predicted values) were associated with high abundance levels for the same combinations of survey data (subregion) and sex. Patterns in residual plots were related because highest abundance (and survey data) levels were generally in the most recent years. The Subcommittee was not able to resolve questions about goodness of fit to recruit indices for lobster during recent years in some of the model runs.

### 7.2.4 Basis for Selection of Q-ratios Used in DeLury Models

DeLury model analyses are very sensitive to the relative catchability (or survey selectivity) of recruits and fully recruited lobsters in trawl survey gear (NEFSC 1993, 1996; Conser 1995; ASMFC 1996). Since neither of these coefficients can be estimated directly, the DeLury model (Section 7.2) includes a Q-ratio term that measures the trawl survey selectivity of recruits relative to full recruits. In other words, the Q-ratio measures the relative degree to which a trawl survey "indexes" the two size groups of lobster. If recruits are less available to the survey gear (either because the survey takes place in an area where there are fewer small lobsters or because the trawl gear is less effective at catching them), then the Q ratio will be less than one. The Q-ratio cannot be estimated in the DeLury model, so it must be specified before the model is run. Thus, the question that must be answered before performing any DeLury model analysis is "how well are the recruits (the first molt group below minimum legal size) indexed by the survey, relative to the full recruits (83+ mm CL)?"

Because DeLury model results are so sensitive to Q-ratio values, the LSASC examined all available information about trawl survey estimates of abundance for recruits and full recruits and the characteristics of the trawl gear used in each survey area. Decisions about Q-ratio's were taken before final models were run for stock status evaluations. Available information included length frequency plots (all years combined) for individual surveys and a review of data collected during a comparative tow study done in Cape Cod Bay by the Massachusetts Division of Marine Fisheries and NMFS using two different bottom trawls (memo from Bruce Estrella to ASMFC Lobster Technical Committee, Feb. 23 1995). The Subcommittee also performed a series of test model runs at different Q-ratio values using different survey data to determine how model fit was affected by Q-ratio assumptions and to compare terminal fishing mortality estimates. These test runs were performed on preliminary data sets and not used for status determination purposes. Results are presented here merely to show the effects of different Q-ratio assumptions on fishing mortality estimates and goodness of fit.

Trends in residual variance in DeLury models run with five different surveys and a range of Q-ratio values (Figures 42, 43, and 44) were generally curvilinear with higher values (poorer fit) at small Q-ratios of 0.2-0.4 improving to relatively constant residual variance at Q-ratios between 0.5 and 1.0. Based purely on model performance one would conclude that Q-ratio values between 0.5 and 1.0 are almost equally probable. Predictably, fishing mortality rates were highest at low Q-ratio values and decreased as the Q-ratio increased (Figures 45, 46, and 47).

In the comparative gear study, side by side tows were made using the Massachusetts survey bottom trawl (39/51 ft whiting trawl with a 3.5 inch rubber disc chain sweep) from the R/V Gloria Michelle and the NMFS bottom trawl (16 inch roller rigged Yankee-36 bottom trawl) on the R/V Delaware II. The NMFS trawl is a larger net designed to roll over obstructions on the bottom. All 25 tows were made in Cape Cod Bay during September 1994 on smooth bottom at depths mostly between 9.4 and 54.9 meters. Fifteen tows met comparability criteria (adherence to intended depth range, spatial separation of tows on site, and absence of net damage). Three tows were eliminated from analysis (for this report) because of missing or problematic data. Results, in terms of numbers of pre-recruits and full recruits caught in each survey (sexes combined) for comparable tows only and for all tows are given below.

| | **Number Recruits in MA Trawl** | **Number Full Recruits in MA Trawl** | **Number Recruits in NMFS Trawl** | **Number Full recruits in NMFS Trawl** | **Recruits/Full Recruits in MA Trawl** | **Recruits/Full Recruits in NMFS Trawl** |
|---|---|---|---|---|---|---|
| *Comparable tows* | 106 | 37 | 176 | 124 | 2.86 | 1.42 |
| *All tows* | 259 | 68 | 264 | 152 | 3.81 | 1.74 |

Results show that the net used in the Massachusetts survey caught roughly twice as many pre-recruit lobsters (73-82 mm CL) per fully recruited lobster compared to the NMFS net. These results are the only available information regarding differences in survey selectivity between NMFS bottom trawl gear and smaller bottom trawl gear used in state surveys. It is probably also applicable, in at least a qualitative sense, to trawl gear used in the Connecticut and Rhode Island surveys.

All of the available information suggest that selectivities of recruit and fully recruited lobster are similar in state surveys. The information also suggests that the selectivity of recruit lobster in the NMFS survey is less than for fully recruited individuals. Based on the above information, the LSASC decided to use a Q-ratio of 1.0 for all state surveys conducted in nearshore areas with relatively small bottom trawls and a Q-ratio of 0.5 for all NMFS surveys conducted in offshore areas with the standard NMFS trawl. These Q-ratio values were the same as used in previous DeLury model analyses for lobster (DeLury runs were carried out with state surveys in previous assessments but not used for stock status determinations).

### 7.3 LENGTH COHORT ANALYSIS

Length cohort analysis (LCA) was used to estimate instantaneous fishing mortality for male and female lobster in each stock area based on fishery length composition data. The model is based on Jones' (1974) modification of Pope's (1972) age-based cohort analysis and is similar to the familiar VPA (virtual population analysis) approach often used for finfish stock assessment. LCA is often used for stocks with at least one year of fishery length data but no age composition information. The spreadsheet program used for LCA in this assessment is from Cadrin and Estrella (1996).

The LCA model for lobster landed during one survey year is:

$$N_L = N_{L+1}e^{M\Delta t} + C_L e^{0.8M\Delta t}$$

where $N_L$ is the number of lobsters alive at the beginning of length interval L, M=0.15 is the natural mortality rate, $C_L$ is catch from length group L, and $t$ is the "delta-t" value. In the LCA for lobster, fishery length composition data were divided into 5 mm length groups. Delta-t values measure how long a lobster spends, on average, in each 5 mm length group (see below). The constant 0.8 adjusts removals in the model for a fishery that is assumed to start after 80% of the year has elapsed (Cadrin and Estrella 1996). The LCA equation is applied iteratively, beginning with the largest length group and working backward until fishing mortality rates and abundance for each length group in the catch at length data set for one survey year are calculated. Recruitment is estimated by abundance of the smallest length group or groups (see below). Delta-t values for females in all stock areas and males in the SCCLIS stock were calculated using a new "distance divided by velocity" algorithm and the set of assumptions about growth used in the egg per recruit (EPR) model:

$$\Delta t_L = \frac{5}{{}^{k}\!/_{d_L}}$$

where 5 mm was distance equal to the size of the length groups used in LCA and velocity ($k/d_L$) was the average speed with which lobsters moved through each length group. Velocity for each length group was calculated as the ratio of average molt increments (k=10 mm $\text{molt}^{-1}$ for SSCLIS, 11 mm $\text{molt}^{-1}$ for GOM and 14 mm $\text{molt}^{-1}$ for GBS) and length- and stock-area specific mean molt intervals ($d_L$). Mean molt intervals were estimated for female lobsters in egg per recruit (EPR) model runs. The distance divided by velocity algorithm is an improvement over the regression approach used previously (Cadrin and Estrella 1996; NEFSC 1996) because implied ages near assumed maximum sizes (assumed to be about 280 mm CL) were younger and more reasonable. In addition, it is consistent with assumptions made in EPR and DeLury model runs (Sections 7.2.1 and 9.2).

For lack of better information, delta-t values for males in the GOM and GBS stock areas were estimated in a similar manner except that mean molt intervals were computed $d'_L=(d_L+1)/2$ for lengths with $d_L<1$, where $d_L$ was the mean molt interval for females. This ad-hoc adjustment was made to accommodate the observation that mature males molt more frequently than mature females.

In practice, LCA fishing mortality rate estimates tend to decline for larger size lobsters (Cadrin and Estrella 1996 and see below). For ease of presentation, average fishing mortality rates are usually reported. Catch-weighted averages of fishing mortality rates are traditional in LCA for lobster but abundance weighted averages are useful and can also be computed (Section 7.4.1).

### 7.3.1 Assumptions for LCA

The most important assumptions in LCA are: i) constant recruitment; ii) constant fishing mortality; iii) accurate characterization of growth; iv) accurate estimates of natural mortality; vi) accurate catch-at-length data (see below); and vii) accurate specification of "terminal F" (the assumed fishing mortality rate on the largest length group). The first two of these are "equilibrium" assumptions that are particularly important for lobster.

LCA makes equilibrium assumptions because it uses fishery catch at length data from landings (composed of many cohorts) in a single year as a proxy for catch at length data for each cohort over a larger number of years. Under equilibrium conditions (constant recruitment and fishing mortality), current and previous conditions are the same so length composition data from one year is sufficient. In interpreting real data sets with variation in recruitment and fishing mortality, it is important to remember that LCA fishing mortality and recruitment estimates are "average" values because the catch at length in any single year is influenced by changes in fishing mortality over the lifetime of each cohort and by variation in recruitment among cohorts.

Equilibrium assumptions make interpretation of LCA recruitment estimates particularly difficult. Small lobsters molt more often than once a year and mean molt increments are 2-3 times larger than the 5 mm CL groups used to aggregate catch data for LCA. Three length groups were used because 15 mm is approximately equal to one molt increment. In no way does it represent one "cohort" it covers many year classes. In this analysis, annual recruitment was estimated from LCA results as the sum of abundance in the first three length groups. The first three length groups (covering 3 x 5 =15 mm CL) were used because 15 mm is near the assumed mean molt increment for lobster in the GBS stock area and may be a crude approximation of the number of lobster recruiting to the first legal molt group each year.

LCA results are very sensitive to assumptions about growth (i.e. delta-t values) and the natural mortality rate (Cadrin and Estrella 1996). However, LCA and reference point calculations are consistent for females because delta-t values in LCA are based on the same information as the EPR model.

All of the models used for lobster including LCA are sensitive to assumptions about natural mortality. Management advice may be robust, however, as long as assumptions about natural mortality are reasonable and consistent. For LCA the natural mortality rate was $M=0.15$ (the same as used in the DeLury model and approximately equal to average natural mortality in the EPR model).

A number of assumptions in LCA can be relaxed without biasing estimates but at the expense of precision. Assumptions of constant recruitment and constant fishing mortality can be relaxed to allow random variation (but not trends) in recruitment and fishing mortality. It is important, however, to avoid using LCA in situations when there are trends in recruitment or fishing mortality because fishing mortality rate estimates will be biased. In particular, bias in LCA fishing mortality rate estimates is positive when recruitment increases in trend and negative when recruitment decreases in trend. Bias is negative when fishing mortality trends up and positive when fishing mortality trends down. The terminal F assumption can be relaxed when fishing mortality rates are high (Pope and Shephard 1985) and is probably not important for lobster because fishing mortality rates are probably high and because runs with a range of terminal F values gave similar results (Cadrin and Estrella 1996).

The assumption of accurate catch-at-length data can be relaxed because fishing mortality rate estimates depend only on accurate estimates of proportional catch at length. They are not affected by errors in the total number of lobster caught. For example, fishing mortality rate estimates will not change if total catch is halved or doubled. In contrast, recruitment estimates are very sensitive to errors in total catch and will change proportionally if total catch is halved or doubled. Some random errors in proportional catch at length can probably be accommodated. Aggregation by 5 mm size intervals reduces the importance of errors in catch at length data.

### 7.3.2 LCA Uncertainties

The LSASC computed LCA fishing mortality rate and recruitment estimates for each stock area but it was agreed that estimates for the SCCLIS and GOM stock areas were difficult to interpret because of obvious trends in recruitment as measured by trawl survey data and DeLury model results. However, the LSASC could not agree on whether LCA estimates for the GBS stock area during recent years were meaningful and decided to put the question to reviewers. Although there was disagreement about this technical point, it was primarily academic and not pivotal in interpreting assessment results.

Arguments for using LCA results for the GBS stock area in recent years are that survey data show abundance of pre-recruit lobsters (73-82 mm CL) varied but without trend after 1990 (Figure 36). In addition, catch divided by survey abundance (a crude measure of trends in exploitation rates and fishing mortality rates) varied but without trend after 1990 (Figure 36). Thus, it appears the most important equilibrium assumptions were met for lobster in this stock area.

One factor that undermines use of LCA results for the GBS area in recent years is the fact that catch at length data for the GBS area are based primarily on sea samples from two small areas (Section 6.1.2). In addition, delta-t estimates are uncertain. Some idea of the uncertainty in estimates of growth for lobster can be gleaned from comparing delta-t estimates from the previous and current assessments ( NEFSC 1996; Figure 37). Changes made in the current assessment were particularly striking for females in the GOM and SCCLIS stock areas but estimates for the Georges Bank stock area also changed substantially.

If valid for the GBS stock area in recent years, LCA provides the only alternative in this assessment to DeLury estimates of average fishing mortality and recruitment, which depend on "Q-ratio" assumptions (Section 7.5). In addition, if valid, length specific fishing mortality estimates from LCA provide the only available information about fishery selectivity patterns (relationships between lobster size and fishing mortality). Fishery selectivity may be important in understanding population dynamics of lobster and their apparent ability to resist high exploitation rates (Section 7.4.2).

The LSASC could not agree whether catch weighted or catch and abundance weighted average fishing mortality rates should be reported for LCA and decided to put the question to reviewers. The question and disagreement were primarily academic and do not effect interpretation of the assessment as a whole. For presentation to reviewers, catch weighted values are reported for each year (Tables 8 to 10) while both catch and abundance weighted estimates are reported for recent years. Estimates for recent years were based on LCA runs with average catch at length during 1995-1997 (Tables 11 to 13). Catch at length was similar during 1995-1997 and combining years may reduce errors in the data.

If units agree (Section 7.4) and abundance weighted fishing mortality estimates for the GBS stock area during recent years are valid, then it should be possible to compare them to biological reference points (e.g. $F_{10\%}$) estimated using the EPR model (and similar assumptions about growth) and average fishing mortality rates estimated with the DeLury model.

If units agree (Section 7.4) and abundance weighted estimates of average recruitment for lobster in the GBS stock area are valid, it should be possible to compare them to average recruitment estimates from the DeLury model. Length composition data from the fishery (analogous to length composition from LCA) are compared to predicted length composition from the EPR model in Section 9 (Figure 94).

### 7.3.3 LCA Results

Results from LCA analysis for male and female lobster in the GBS stock area during 1995-1997 (summarized in Table 13) suggest that fishing mortality rates are higher in males than females. Abundance and catch weighted mean annual fishing mortality rates for all length groups were 0.94 and 1.10 for males and 0.63 and 0.74 for females. As expected, catch weighted averages were higher than abundance weighted averages (Section 7.4.2) because catches give more weight to length groups with highest catch and highest fishing mortality.

LCA suggests that fishing mortality rates decline rapidly by about 50% as male lobsters grow larger than 102 mm CL and females grow larger than 97 mm CL (Table 13). Simple average annual fishing mortality rates for lobster 83-97 mm CL were 1.09 for males and 0.65 for females. For larger lobsters (98+ mm CL), simple average fishing mortality rates were 0.51 for males and 0.31 for females.

## 7.4 ASSUMPTIONS AND CONVENTIONS IMPORTANT IN COMPARING FISHING MORTALITY RATE ESTIMATES FROM EPR, LCA AND DELURY MODELS

### 7.4.1 Catch versus Abundance Weighted Fishing Mortality Rates

It is important to use consistent methods for weighting average fishing mortality rates when comparing results from lobster stock assessment models. At issue is whether catch or abundance weighted fishing mortality rates are (or should be) compared to reference point values. Ways in which average fishing mortality rates are (or can be) weighted in each of the three models used in this assessment are shown below.

| | |
|---|---|
| ***Egg per recruit (EPR) model*** | Abundance weighted averages are traditionally reported but catch weighted averages can be calculated. |
| ***Modified DeLury Model*** | Abundance weighted averages |
| ***Length Cohort Analysis (LCA) Model*** | Catch weighted averages are traditionally reported but abundance weighted averages can be calculated. |

Catch weighted average fishing mortality rates are computed:

$$F_{Catch} = \frac{\sum C_L F_L}{\sum C_L}$$

where $C_L$ and $F_L$ are catch data (numbers of lobsters) and model estimates of fishing mortality rates for lobster in length group L. Abundance weighted average fishing mortality rates are computed:

$$F_{Abun} = \frac{\sum N_L F_L}{\sum N_L}$$

where $N_L$ is the model's estimate of abundance (number of lobster) in the stock. In computing catch and abundance weighted averages, the weights (catch or abundance) are implicitly converted to proportions. Thus, the averages don't depend on accurate estimates of total catch or abundance, only on accurate estimates of the proportion of total catch and abundance in each length group.

Length specific fishing mortality rates $F_L$ used to compute abundance and catch weighted average fishing mortality rates are the same but the two types of averages may be quite different. In general, catch weighted averages are higher than abundance weighted averages because catch weights emphasize size groups with the highest catch and fishing mortality.

The primary advantage of catch weighted averages is that the weights (proportional to observed catch at length) are relatively precise so that variance in $F_{Catch}$ is reduced. Weights based on abundance estimates from LCA may be less precise than catch at length data so that $F_{Abun}$ estimates are less precise.

The primary advantage of abundance weighted averages is that they are easier to interpret as measures of fishing impacts on the population as a whole in models like the DeLury and LCA that measure abundance in numbers of lobster (rather than as biomass). This is evident in the example (see below) where the abundance weighted average (0.77) is closer than the catch weighted average (0.88) to the fishing mortality rate for the whole population (0.71).

**Example fishing mortality rate calculations (M=0.15)**

| *Age* | *Fishing Mortality* | *Abundance Number* | *Catch Number* |
|---|---|---|---|
| *1* | 1.00 | 200 | 119 |
| *2* | 0.30 | 100 | 24 |
| *Total* | 0.71 | 300 | 143 |
| | | | |
| *Catch Weighted Average* | | | 0.88 |
| *Abundance Weighted Average* | | | 0.77 |

Either convention is fine for comparisons, but it is important to use one consistently. Otherwise, as in the example above, one might mistakenly compare the catch weighted average (0.88), instead of the abundance weighted average (0.77), with the reference F at 10% maximum egg per recruit (in abundance weighted units) from the EPR model.

### 7.4.2 Fishery Selectivity

Fishery selectivity parameters measure the relative vulnerability of different size lobsters to commercial fishing. As such, they relate the length distributions of lobsters in landings (not in the catch because catch includes individuals returned to the water) and the length distribution in the population. Fishery selectivity is the net effect of size specific differences in how often lobsters encounter, enter and leave traps, sex (e.g. because of management measures that protect females), and discard in the fishery (lobsters may be returned to the water because they are too large, too small, v-notched or ovigerous).

Fishery selectivity is not very important in estimating abundance weighted fishing mortality rates or reference points for lobster stocks. Sensitivity analysis using the EPR model shows that biological reference points ($F_{10\%}$) are the same in model runs with much different selectivities (Section 9.4.2). The DeLury model is not sensitive to assumptions about fishery selectivity because fishing mortality rates are implicitly estimated from the ratio $N_{t+1} / (N_t + R_t/s)$ where $N_t$ and $R_t$ are survey indices for fully recruited and recruit lobsters and s is the Q-ratio (a survey, rather than fishery, selectivity parameter). In effect, the DeLury model for lobster makes strong assumptions about survey selectivity (for which there is some information) in lieu of any assumptions about fishery selectivity (which is very uncertain).

For calculations in this section, selectivity parameters for each length group ($s_L$) are defined relative to the selectivity of lobster in the smallest legal size group:

$$s_L = \frac{F_L}{F_1}$$

where $F_1$ is the fishing mortality rate for the smallest legal length group.

Estimates of fishery selectivity from LCA and EPR models depend on many assumptions (Section 7.2) and, in particular, imprecise estimates of growth. In addition, both the LCA and EPR (see below) models make equilibrium assumptions that probably effect selectivity estimates. Selectivity calculations based on LCA and EPR model results are meant only to show possible trends.

LCA model results (like results from the experimental Mark model, Appendix A), invariably show selectivity patterns that decline with size (Cadrin and Estrella 1996). Declines may be steep or modest, depending on stock area, sex and assumptions about growth. For this analysis, selectivity patterns were calculated from LCA model runs for lobster in the GBS stock area based on average catch at length data for 1995-1997 (Table 13). LCA runs for other stock areas were judged to be unreliable (Section 7.2). The model run for GBS indicates that fishery selectivity (and fishing mortality rates) increase and then drop rapidly by about 50% as male lobster grow larger than 102 mm CL and female lobster grow larger than 97 mm CL (Figure 38). Fishery selectivity appears relatively constant once lobsters in the GBS stock area grow larger than about 100 mm CL.

Crude estimates of fishery selectivity patterns from egg per recruit model runs can be obtained from tables in output files that show deaths from natural causes ($D_L$) and deaths from fishing ($C_L$) over the lifespan of a cohort, by 1 mm length groups. The ratio of length specific fishing mortality rates ($F_L$) and natural mortality ($M_L$) rates is the same as the ratio of deaths from fishing and deaths from natural causes:

$$\frac{F_L}{M_L} = \frac{C_L}{D_L}$$

Solving for length specific fishing mortality rates gives:

$$F_L = \frac{M_L C_L}{D_L}$$

Fishery selectivities from the EPR model can then be computed $s_L = F_L / F_1$ (as above).

Natural mortality ($M_L$) changes with length in the EPR model because soft-shell (newly molted) lobsters are usually assumed to be more vulnerable to predators and disease and because the frequency of molting changes with size. However, for inferring general trends in fishery selectivity, it is sufficient to assume $M_L$=0.15 for all length groups.

Selectivity patterns implied by the EPR model depend on the overall level of fishing mortality (specified by the $F_{nominal}$ or "encounter rate" parameter in the EPR model). At high fishing mortality rates, only ovigerous females remain and fishery selectivity for ovigerous females declines towards zero. To avoid problems, we used EPR runs with abundance weighted fishing mortality rates near best estimates of $F_{10\%}$ (see below).

**Egg per recruit model runs used in selectivity calculations.**

| *Stock Area* | *Encounter Rate (Nominal F Multiplier)* | *Mean F (Abundance Weighted)* |
|---|---|---|
| *SCCLIS* | 1.35 | 0.81 |
| *GBS* | 0.46 | 0.30 |
| *GOM* | 0.66 | 0.35 |

The EPR model is for female lobsters only, so selectivity calculations were for females only. Selectivities of males and females likely differ in lobster because of various management measures that protect females (i.e. v-notching and protection of ovigerous females) and behavioral patterns.

Selectivity patterns implied by the EPR model differ among stock areas (Figure 38). Selectivities implied by the EPR model for the GOM stock area are flat over the entire range of length groups. In contrast, fishery selectivities implied by the EPR model for the SCCLIS and GBS stock area increase with size.

Fishery and bottom trawl survey length composition suggest that fishery selectivity declines rapidly with size in the GBS (Figure 39) stock area because there are proportionally more small (83-92 mm CL) and less larger lobster in fishery catches than there are in survey catches. Fishery length composition data were average values during the fall (October-November) of 1995-1997. Survey data were averages from the NMFS fall bottom trawl survey during 1995-1997, which was mostly during October-November. In these comparisons, NMFS bottom trawl survey data were assumed to measure population length composition for lobster larger than 83 mm CL (the same assumption made in tuning the DeLury model).

Comparisons of length composition data from the fishery and NMFS fall trawl survey in the GOM and SCCLIS stock areas are not shown because the survey and fishery do not overlap completely. In particular, the fishery operates mainly in shallow near shore areas where the survey is not carried out. If small lobster are most common near shore and poorly sampled by the NMFS fall trawl survey, then fishery catch data might show higher proportions of small lobster even if fishery selectivity was constant for lobsters of different size.

In contrast to other areas, fishery and survey data for Long Island Sound in the SCCLIS stock area suggest that fishery selectivity increases with size because there are more lobster larger than 88 mm CL in fishery than in survey catches (Figures 40 and 41). Fishery length composition data were average values for Long Island Sound during the fall (September-October) or spring (April-June) of 1995-1997. Survey data were averages from the Connecticut fall or spring bottom trawl surveys during 1995-1997, during September-October or April-June. In these comparisons, Connecticut bottom trawl survey data were assumed to measure population length composition for lobster larger than 83 mm CL (the same assumption made in tuning the DeLury model).

In summary, the various models used for lobster stock assessments imply (or assume) a wide range of fishery selectivity patterns. LCA model results imply that fishery selectivity declines with size. EPR model runs imply that fishery selectivities are constant or increase with size. Fortunately, assumptions about fishery selectivity had little effect on assessment results.

Information about fishery selectivity for lobster may be important in the context of policy and management. If fishery selectivities decline with size, persistence of lobster populations in the face of fishing may be due, at least partly, to egg production by large female lobsters that are not completely vulnerable to commercial traps. This is only a hypothesis, however, because large lobsters were more common in fishery catches historically (Section 5.1). Reduced selectivity of large lobster, if it has occurred, may be due to distribution of large lobsters in offshore areas that are not typically fished, reluctance of large lobsters to enter traps, or other factors. In any case, the hypothesis points to important areas for future research, particularly as the fishery expands offshore and the number and efficiency of traps increases (Section 5.2).

## 8.0 ASSESSMENT RESULTS

### 8.1 GULF OF MAINE (GOM) - OVERVIEW

For DeLury model analyses, the GOM was broken down into two subareas (Figure 1). The first subarea (statistical area 514, Massachusetts Bay) is covered by fall trawl survey data collected by the state of Massachusetts. The second much larger subarea contains the rest of the GOM (statistical areas 511, 512, 513 and 515). The NMFS fall trawl survey covers most of the second subarea, but nearshore waters along the Maine and NH coast (<56 meters depth, see Figure 26) are not adequately surveyed. In effect, DeLury model runs for the second subarea assumed that the NMFS fall trawl survey measured trends in lobster abundance for the entire subarea. This assumption was unavoidable. The main problem is that fishing activity is most intense in nearshore coastal waters and recruits are most abundant there. The Subcommittee considered applying the MA inshore trawl survey data to NH and ME coastal waters and the NMFS survey to the offshore portions of statistical areas 511-513. This approach was not used because: 1) landings from statistical areas 511-513 could not be partitioned into inshore and offshore components; and 2) temporal trends in landings and CPUE (Figure 48 and Section 10.6) indicate that production and abundance are declining in southern coastal areas (e.g., area 514), but not in northern areas (e.g., area 512).

Fishing mortality rates were also estimated from length cohort analysis, but not used for evaluating stock status in the GOM stock area because of probable biases (Section 7.3)

#### 8.1.1 GOM - Area 514 (Massachusetts Bay)

Males

Landings of male lobsters in area 514 have varied without trend since 1982 (Figure 48). DeLury analysis for the whole time series showed that the abundance of recruits varied without trend from 1982 to 1997 but has declined from a peak 1994 to 1997 (Figure 49). There was no clear trend in the abundance of fully recruited male lobsters during the 16-year time period. Fishing mortality also varied without trend with several peaks in 1986, 1992, and 1997. It fell below 0.8 in only one year (1983) and exceeded 1.35 in seven years (Table 14). The average 1995-97 male F was 1.57, equivalent to an annual removal rate of 75%, and exceeded the 16 year average F of 1.45. Male fishing mortality rates in area 514 have been higher than in the rest of the GOM ever since 1982 (Table 14 and Figure 51).

Females

Landings of female lobsters from area 514 varied without trend after 1982, but increased between 1994 and 1997 (Figure 50). Recent (1995-97) landings were almost equally divided between males (47%) and females (53%), but females made up only 38% of the estimated fully recruited population. Female recruit abundance varied without trend. Full recruit (legal-sized) females were most abundant at the beginning of the time series, declined between 1984 and 1988, increased until 1994, then declined again. The 1997 estimate of fully recruited female abundance was the lowest in the entire time series. Fishing mortality on females was high throughout the time period peaking in 1996. Fishing mortality in Area 514 is considerably higher than in the rest of the stock area (Figure 51 and Table 14). The average 1995-97 female F of 2.1 was equivalent to an annual exploitation rate of 84%, a value higher than average fishing mortality rates during 1995-97 for male or female lobster in any other stock area or statistical area.

Both Sexes

The estimated abundance of male and female recruits and full recruits in area 514 (MA survey) was much lower than their abundance in the rest of the GOM stock area and remained relatively constant during the time series (Figure 52). This area only accounted for 14% of the total population of recruits in 1995-97 and 4% of the fully recruited lobsters in the GOM stock area (Table 14).

### 8.1.2 GOM - Areas 511-513 and 515

Males

Landings of male lobsters harvested from statistical areas 511-513 and 515 doubled after 1988 after remaining constant between 1982 and 1987 (Figure 53). Recent landings from these four areas consisted of 52.4% males and 47.6% females. DeLury analysis estimates a greater abundance of males (56% of the recruits and 60% of the full recruits in 1995-97). Abundance of recruits and full recruits varied without trend during the 1980's and then increased after 1993. Legal-sized males were nearly as abundant as male recruits, with fully recruited males actually exceeding recruits in abundance in some years. Recruit abundance doubled between 1991 and 1994 and remained above the long-term average during the last four years (Table 14). Similarly, the population of legal sized males almost doubled between 1994 and 1995, and continued to increase slightly in 1996 and 1997 (Figure 53). Fully recruited males were almost three times more abundant in 1997 than they were between 1982 and 1994. Fishing mortality declined from an average of 0.77 during 1982-1992 to 0.5 in 1995-97. This was equivalent to a drop in annual exploitation rates from 50% to 37%.

Females

Trends in landings, abundance, and fishing mortality of females closely resembled trends for males (Figure 54). Landings nearly doubled during the 1990's. Estimated abundance of both recruits and full recruits remained constant during the 1980's and early 1990's, but both increased in recent years. Recruit abundance was particularly strong in 1994, 1996, and 1997. Fishing mortality rates were higher for females than for males throughout the time series, declining from an average of 0.74 during 1982-1992 to 0.58 during 1995-97. These F values are equivalent to annual removal rates of 55% and 41%.

Both Sexes

On average, for all 16 years in the time series of DeLury model results, recruits in this larger subarea accounted for 80% of all the recruits in the GOM stock area and 90% of the fully recruited lobsters. The discrepancy was much greater (85% for recruits and 96% for full recruits) during 1995-97 due to the steady growth in population size in areas 511-513 and 515 and the lack of population growth in area 514 (Figure 52).

### 8.1.3 Gulf of Maine - Entire Area

A blending procedure (described in detail in Section 7.2.2) was used to obtain a single, complete assessment of trends in abundance and mortality for the entire GOM stock area.

Males

Total landings of male lobsters harvested in the GOM increased by 72% between survey years 1982 and 1997 (Figure 48). Male landings exceeded female landings in the GOM every year between 1982 and 1994 by 10%, on average. During the last three years, males and females have been landed in almost equal numbers. There was a slight upward trend in the number of recruits between 1982 and 1993, followed by higher abundance during 1994-97 (Figure 55). Fully recruited males were also more abundant in recent years. Recruits were, on average, 90% more abundant during 1994-97 than during 1982-93 and fully recruited males were 150% more abundant during 1995-97 than during 1982-94. Annual male fishing mortality rates declined from a peak value of 1.06 (61% removal rate) in 1987 to a low of 0.53 in 1995, then increased slightly in 1996 and 1997 (Table 14 and Figure 55). The average male F was 0.59 (42% removal rate) during 1995-97 and the 80% confidence interval ranged from 0.39 to 0.70 (Figure 57).

Females

Landings of female lobsters from the GOM increased by 70% over the 16-year time period (Figure 48). Estimated abundance of recruits remained nearly constant between 1982 and 1993, but was 72% higher during 1994-97 (Figure 56). Fully recruited female population size has followed the same trend as for males but did not increase as sharply in recent years. Legal sized females were 54% more abundant during 1995-97 than during 1982-1994. Female fishing mortality rates declined from 1.09 in 1987 to a low of 0.65 in 1994, then increased in 1996 and 1997 (Table 14 and Figure 56). The average 1995-97 female F was 0.74, equivalent to a 49% annual exploitation rate. The 80% confidence interval ranged from 0.54 to 0.85 (Figure 57).

Even though females in the GOM are protected from fishing to a greater degree than in the other two stock areas because of the v-notching program, estimated female fishing mortality rates in the GOM were higher than male fishing mortality rates every year since 1987 (Figure 58). This was particularly true in 1989 and 1990 and during 1995-97 when the average female F was 27% higher than the average male F. Prior to 1987, female F was higher than male F only twice. Males have recruited to the exploited portion of the stock in greater numbers than females during 7 of the last 9 years (Figure 58), producing a population of legal-sized lobsters that is 60% male.

Both Sexes

The GOM accounts for 71% of the total US landings. Landings remained stable and averaged 10,000 mt/year between 1962 and 1976, reached 20,000 mt in 1991 and exceeded 25,000 mt in 1997/8. The catch was evenly divided between males and females. For the entire stock area, female and male fishing mortality rates peaked in 1987 and declined since then, with a secondary peak in 1990. Average annual 1995-97 Fs were 0.74 for females and 0.59 for males (Figure 59). Since 1987, females have been subjected to consistently higher removal rates than males.

There has been an increase in abundance of recruits beginning in 1991 with strong peaks in 1994 and 1996 (Figure 60). Abundance of legal sized lobsters varied without trend during the 1980s, increased slightly and leveled off in the early 1990s. Stimulated by the recent increase in recruits, fully recruited population size increased by 88% during 1995-97 compared to the long term mean.

### 8.2 GEORGES BANK AND SOUTH (GBS)

Stock status information for Georges Bank and offshore waters of southern New England (Figure 1) is based on results of single male and female DeLury model analyses of landings and NMFS fall trawl survey data for survey years 1982-1997. The NMFS survey covers the entire GBS stock area. LCA results were also utilized to characterize fishing mortality rates in recent years for this stock area (Section 7.3).

Males

Landings of male lobsters caught in this stock area increased by 50% between 1982 and 1992, then declined by almost the same amount in more recent years (Figure 61). During the last three years, males accounted for 47% of the landings and 50% of the recruit size group, but only 32% of the fully recruited population. Abundance of recruits varied without trend over time but there has been a recent upward period from 1994-1997 (Figure 63). Fully recruited male abundance declined by 70% between 1988 and 1995 before increasing in 1996 and 1997. Fishing mortality increased steadily from 0.71 to 1.16 between 1990 and 1994 (Figure 63) as the abundance of full recruits declined, then dropped to an average of 0.63 (equivalent to an annual removal rate of 44%) during 1995-97. The 80% confidence interval was 0.59 to 0.69 (Figure 65).

The average 1995-97 abundance weighted fishing mortality rate derived from length cohort analysis was 0.94 (Table 11), a value that was 48% higher than the corresponding DeLury male F estimate. The catch weighted 1995-97 LCA male F estimate was 1.10.

Females

Landings of females generally increased from 1982 to 1984, then remained relatively constant except for a large harvest in 1990 (Figure 62). Female recruits varied widely in abundance without following any trend. Fully recruited females were generally more abundant than recruits. There was a decrease in fully recruited females in 1995 and 1996, which reversed in 1997 (Figure 64). Female fishing mortality rates during the last four years were almost as high (0.38-0.46) as the record high (0.49) in 1990. Overall, female mortality rates were lower than male mortality rates and much more constant (Figure 64). Female fishing mortality rates during 1995-97 averaged 0.41 (31% annual removal rate). The 80% confidence interval was 0.32 to 0.46 (Figure 65). The average abundance weighted female LCA F of 0.63 during 1995-97 (Table 12) was 54% higher than the average DeLury F for the last three years. (The catch weighted 1995-97 F was 0.74). Females and males recruit to the exploited portion of the GBS stock in equal numbers, but fully recruited females are about twice as numerous as males (Figure 63 and 64).

Both Sexes

Landings, abundance of recruits and full recruits have remained relatively constant since 1982 (Figure 66). Total landings increased steadily from 2,444 mt in 1982 to a peak of 4,279 mt in 1990 and remained constant around 3,600 mt from 1992 to 1997. The average annual 1995-97 GBS Fs were 0.41 for females and 0.63 for males. Fishing mortality rates were higher for males, which only made up 40% of the average fully-recruited population but 53% of the landings during 1995-97. The abundance of recruits varied without trend over the time series. The abundance of fully recruited males dropped steadily from 1988 to 1995 while fishing mortality doubled between 1988 and 1994. Abundance increased during the next two years as F dropped.

### 8.3 SOUTH OF CAPE COD AND LONG ISLAND SOUND (SCCLIS) - OVERVIEW

The relatively small SCCLIS stock area (Figure 1) is almost completely covered by several bottom trawl surveys (Figures 29, 30, and 31). The MA surveys are conducted in state waters south of Cape Cod. The RI surveys are conducted in Narragansett Bay and in nearshore coastal waters of the state and CT trawl surveys are confined entirely to Long Island Sound (Section 6.2). The NMFS surveys are conducted further offshore and the number of tows made within the SCCLIS stock area during the NMFS survey is much smaller compared to the inshore state surveys.

Individual DeLury model runs were conducted for males and females using data from three fall trawl surveys and one spring survey and their respective fall and spring survey year landings (October 1 - September 31 and April 1- March 30) for statistical areas 538, 539 and 611. Since the NMFS fall survey is conducted in areas 538 and 539, it was used in a combined area model run for each sex with 50% of area 539 fall survey year landings and 100% of 538 fall survey year landings. The MA fall survey in area 538 could not be used because there were a number of years when no legal sized lobsters were caught. Fall RI survey data were also used to estimate abundance and mortality in area 539, with the remaining 50% of area 539 fall survey year landings. Model runs for Long Island Sound (area 611) utilized fall and spring CT survey data and area 611 landings for the appropriate survey year. DeLury runs based on spring survey data in LIS were carried out for comparison with results based on fall survey data but were not used for stock status determination. Spring trawl survey data collected by NMFS, RI and MA were not used (Section 7.2.2).

For the entire SCCLIS area, stock status was evaluated by blending fishing mortality rate and abundance estimates from DeLury model runs based on fall survey data (Section 7.2.2). As in the GOM stock area, fishing mortality estimates based on length cohort analysis were not used.

### 8.3.1 SCCLIS - Southern New England (Areas 538 and 539)

Together, areas 538 and 539 accounted for 24% of total SCCLIS area landings during 1995-97 (Figure 67). They accounted for a higher percentage of total landings during the mid 1980's, before landings from Long Island Sound (area 611) started to increase. Landings of male lobsters in areas 538 and 539 increased between 1985 and 1990 and declined steadily after 1993 (Figure 68). Females made up 58% of the combined area 538 and 539 landings during 1995-97, 67% of the estimated recruit abundance and 64% of the estimated fully recruited lobsters in the population. Landings of females in areas 538 and 539 varied without trend, with peaks in 1989 and 1993.

### Area 538 + 539 (NMFS Survey)

#### Males

DeLury analysis of NMFS survey data produced male abundance estimates that remained fairly constant until recently (Figure 69). Recruits were more abundant in 1996 and 1997, and full recruits in 1997, than at any other point since 1982. The combination of high abundance and reduced landings during 1995-97 caused fishing mortality rates to drop below 0.60 for the first time since 1987 (Table 15). The average 1995-97 fishing mortality rate was 0.50 (37% annual removal rate). During the last four years, male fishing mortality rates estimated from NMFS survey data were lower than estimates derived from either the RI or CT survey data (Figure 71).

#### Females

The abundance of recruits and fully recruited females varied without trend until recently (Figure 70). The highest values in the time series were in 1996 and 1997. The recent increase in abundance reduced mortality rates during the last three years to the lowest values in the 16 year time series (Table 15). The average 1995-97 female mortality rate (0.41) was lower than the average male F and equivalent to a 31% annual removal rate. With one exception, female fishing mortality rates estimated from NMFS survey data since 1989 remained well below estimates for more nearshore areas derived from either the RI or CT survey data (Figure 71).

#### Both Sexes

Recruitment of male and female lobsters varied without trend until 1996 and 1997 when it doubled relative to the long term 1982-97 average (Figure 74). Legal sized lobsters also increased in abundance during the 1996 and 1997 survey years to values higher than in any previous year in the time series.

### Area 539 (RI Survey)

#### Males

DeLury analysis of the RI survey data (Figure 72) showed recruit abundance doubling between 1985 and 1989, then remaining relatively constant until 1996 and dropping in 1997. Full recruit abundance changed very little between 1982 and 1995, then increased to the highest values in the time series in 1996 and 1997. Fishing mortality estimates were lower in 1995 and 1996 than in the previous 13 years of the time series, but still remained near 1.0 (Table 15). The average 1995-97 fishing mortality was 1.11 (annual removal rate of 63%).

#### Females

DeLury analysis based on RI survey data produced no obvious trends in either recruit or full recruit abundance and no evidence of higher abundance in recent years (Figure 73). Except for the high mortality rates in 1984 and 1985 (which may be unrealistic), there was no trend during the 16 year time period. Female fishing mortality rates were very high (all but two years were > 1.0) and, unlike the males, remained high during recent years, averaging 1.45 in 1995-97 (72% annual removal rate).

Both Sexes

The RI survey, which is conducted much closer to shore, did not produce the same trends in recruit or full recruit abundance as the NMFS survey. In fact, instead of increasing, DeLury estimates of recruit abundance in area 539 dropped in 1997 to the lowest value in the 16 year time series (Figure 74). Fully recruited lobsters increased in abundance with higher values in 1996 and 1997.

### 8.3.2 SCCLIS - Long Island Sound (Statistical Area 611)

DeLury model analyses for Long Island Sound were conducted using CT fall and spring survey data and their respective fall and spring survey year landings. Area 611 landings have increased from less than 50% of the total SCCLIS harvest to 76% during the period from 1995-1997.

Fall Survey Males

Area 611 landings of male lobsters increased four-fold between 1984 and 1997 (Figure 75). Males made up 38% of the combined 1995-97 fall survey year landings, 37% of the estimated number of recruits in the population, and 35% of the legal-sized population.

DeLury model results show that abundance of male recruits in Long Island Sound started to increase at about the same time (1990) that landings started to increase reaching a population size in 1996-97 that was 3-4 times larger than in the mid 1980's (Figure 75). In contrast, the fully recruited male population remained fairly constant. Male fishing mortality rates kept pace with the increased supply of recruits, rising steadily from 0.6 in 1985-86 to values >2.0 in 1995 and 1997 (Table 15). The average 1995-97 fishing mortality rate was 2.0 (82% annual removal rate). Male fishing mortality rates estimated from fall CT survey data in recent years were higher than those estimated from either NMFS or RI survey data (Figure 71) and were higher than the female fishing mortality rates in LIS (see below).

Fall Survey Females

Fall survey year landings of female lobsters from Long Island Sound also increased four fold between 1984 and 1997 (Figure 76). Lobsters landed from area 611 during 1995-97 were 62% females.

Trends in annual estimates of recruit and full recruit female abundance diverged over time (Figure 76). Recruit abundance increased almost three fold in 14 years while fully-recruited females declined in abundance between 1984 and 1990 and increased since then. DeLury model estimates of female fishing mortality increased in the early part of the time series (1984-1989), then varied without trend until 1995 after which they increased, reaching a record high of 2.4 in. The average 1995-97 F was 1.80 (annual exploitation rate of 79%). Female fishing mortality rates estimated from fall CT survey data were higher than those estimated from RI survey data and much higher than those estimated from NMFS survey data in recent years (Figure 71).

Fall Survey, Both Sexes

Recruitment of male and female lobsters increased three fold between 1988 and 1996-97 (Figure 83). At the same time, the abundance of fully-recruited lobsters in Long Island Sound declined by about 50% between 1984 and 1989, but varied without trend since then. On average, 61% of the total estimated recruit population in the SCCLIS stock area during 1995-97 was in Long Island Sound during the fall, but only 38% of the fully-recruited population.

Spring Survey Males

DeLury model runs with CT spring trawl survey data produced similar trends in recruit abundance as the fall survey analysis, but the abundance of fully recruited males increased in recent years, rather than remaining stable (Figure 77). Fishing mortality rates were high and varied without trend (between 0.7 - 2.6), as opposed to the increasing trend evident in the analysis of fall survey data (Figure 79). After 1993, F declined markedly to 0.77 in 1996 and 0.89 in 1997. Average 1995-97 male F was 0.98 (annual exploitation rate of 59%).

Spring Survey Females

DeLury model results based on spring survey year landings and spring trawl survey data produced upward trends in the estimated abundance of recruits and fully recruited females in Long Island Sound (Figure 78). The trend for fully recruited females was different than the trend from fall survey data (Figure 79). Recruits increased dramatically in abundance in both the fall and spring survey year analyses. Using the spring survey data, fully recruited female abundance increased four fold between 1986 and 1997 while fishing mortality rates declined in recent years, from 1.84 in 1993 to 1.06 in 1997. Female F estimates were not as variable as male F estimates. The average 1995-97 spring survey female F was 1.26 (68% exploitation rate).

### 8.3.3 SCCLIS - Entire Area

Blended abundance and F estimates in this stock area were derived from fall survey year analyses, and did not include results of the spring survey year DeLury model. Results of the blended fall survey analyses provided the most complete and reliable stock assessment information for the entire stock area and were used to evaluate stock status relative to the biological reference point.

Total landings (both sexes) from the SCCLIS stock area increased from <6 million lobsters in the mid 1980's to 14 million in 1997 (Figure 67). Landings from the SCCLIS stock area in 1997 were 18% of total U.S. lobster landings. On average, females accounted for 61% of all the lobsters landed from the SCCLIS stock area between 1984 and 1997 (range 55-70%).

Males

Landings of male lobsters from the SCCLIS stock area increased from about 2 million in the mid 1980's to 5.4 million in 1997 (Figure 67). Recruit abundance increased steadily after 1988, rising nearly three fold through 1996, while fully recruited males showed no change in abundance for most of the 16 year time series before increasing in 1997 (Figure 80). Total abundance, influenced by the more numerous recruits, remained constant increasing during the recent period. Fishing mortality doubled from a low of 0.69 (47% annual removal rate) in 1985 to sustained high levels of 1.24-1.55 (67-75% annual removal rates) between 1992 and 1997 (Figure 80). The weighted average 1995-97 male F estimates was 1.41 (80% confidence interval 1.2 to 1.5) and the annual removal rate averaged 75% (Table 15, Figure 82).

Females

Landings of female lobsters from this stock area have increased from <4 million in the mid 1980's to >8 million in 1996-97 and have always exceeded male landings (Figure 67). Recruit abundance varied without trend before increasing in 1996. Full recruits varied without trend before increasing in 1996 (Figure 81). There was an upward trend in female fishing mortality from 0.9 to 1.5 (annual removal rates of 56-73%) (Figure 81). The average 1995-97 female F estimate was 1.25 (67% annual removal rate) (Table 15). The 80% confidence interval was 1.07 to 1.37 (Figure 82).

Female lobsters in the SCCLIS stock area were more abundant and experienced similar fishing mortality rates as males (Figure 84). Female recruits and full recruits were 75 and 80% more abundant, respectively, than males in 1997 (Figure 83). Blended male F estimates were higher in 1991-93 and in 1995, but males and females were exploited at similar rates during 1987-90 and in 1996 and 1997.

Both Sexes

Landings account for 18% of the total US harvest and have increased steadily from 2,352 mt in 1982 to a record high of 6,894 mt in 1997. The majority of the increase was from Long Island Sound (area 611). Males made up 39% of the 1995-97 catch. Average 1995-97 Fs were 1.41 for males and 1.25 for females. Abundance of recruits tripled between the mid 1980's and 1997 (Figure 85). The increase in recruit abundance was particularly strong in LIS in 1996 and 1997. Female recruits have consistently outnumbered males; the sex ratio in 1995-97 was 63% female. There was no trend in the abundance of legal-sized lobsters until 1996 and 1997 when they nearly doubled in numbers.

## 9.0 BIOLOGICAL REFERENCE POINTS

A growth model, incorporating calculations for eggs per recruit (EPR) and yield per recruit (YPR) for female lobsters (NEFSC 1996) was used to calculate $F_{10\%}$ and other biological reference points ($F_{MAX}$ and $F_{0.1}$, see below). $F_{10\%}$ is the fishing mortality rate that results in egg production per recruit to 10% of the value in an unexploited stock. $F_{10\%}$ is particularly important because lobster are considered overfished (ASMFC 1997) when fishing mortality rates exceed $F_{10\%}$. The overfishing definition applies to the resource throughout its range, but is applied on a stock by stock basis to lobsters in the GOM, GBS and SCCLIS stock areas.

Yield per recruit calculations were for females only because a suitable growth model for male lobsters was not available. Biological reference points ($F_{MAX}$ and $F_{0.1}$) from yield per recruit analysis for females are useful but not applicable to entire lobster stocks.

## 9.1 EGG PER RECRUIT MODEL

Conventional egg production 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 assessment incorporates 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) and size specific management measures for female lobster (e.g. maximum and minimum size regulations).

In these models 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 lobster encounter and enter traps. In baseline runs, nominal encounter rates were assumed equal for female lobsters of all sizes. 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 though escape vents. 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 are removed from the model population. Encounter and retention parameters in the model can be changed to simulate management measures.

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 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.

Each model run was based on a cohort of female lobsters. Growth is modeled using 1 mm size groups starting at 55 mm CL (female lobster in warm water areas begin to mature at 55 mm CL). The initial input (cohort) was based on a normal distribution (defined by a minimum 5% value, maximum 95% value and mean molt increment at that size range). 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 size group in each time step over the lifetime of the cohort.

Quarter years are the basic time steps in the model (previous versions used annual time steps). The first quarter is when the majority of molting, mating and egg extrusion occurs. The third quarter is when the second (minor) molt by immature lobsters occurs. Fishing occurs in all quarters at rates specified by the user (see below). The quarter year cycle assumed in the EPR model is described below.

| |
|---|
| **Quarter 1** (July-September for GOM and GBS; June-August for SCCLIS): First (major) molt; newly molted females become berried (egg bearing); a portion of berried females caught in the fishery are V-notched prior to release (GOM only) |
| **Quarter 2**: No growth; V-notching as in Quarter 1 |
| **Quarter 3**: Second (minor) molt (for size classes that may molt twice a year); newly molted females become berried; V-notching as in Quarter 1 |
| **Quarter 4**: Eggs hatch, protections on berried females disappear, no growth or V-notching |

Biological reference points (e.g. $F_{10\%}$) for lobster were calculated in the EPR and YPR models as abundance weighted averages of fishing mortality over the lifetime of the cohort. Abundance weighted averages are comparable (Section 7.4.1) to estimates of fishing mortality for lobster stocks from the DeLury model.

### 9.2 MODEL PARAMETERS

Model calculations used stock-specific estimates of growth, reproduction and mortality and included current fishery practice and management practices.

**Maturity**

This assessment used maturity ogives (NEFSC 1996) based on ova diameter (lobsters with ova >0.8 mm are mature, Skud and Perkins 1969; Squires 1970; Krouse 1973; Briggs and Mustacke 1979; Briggs and Mustacke 1980) where available. Other measures such as ova color (by dissection and direct observation) or cement gland stage (with adjustments for ova diameter) are also indicators of maturity and yield similar results (Briggs and Mustacke 1980).

There were at least two maturity ogives for each stock area associated with different subareas. For these cases, the previously calculated ogives were defined by logistic functions:

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

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 (Figure 86). Parameter estimates for the final, average maturity ogives and details for the ogives from each subarea are given below.

| Stock Area | $\alpha$ | $\beta$ |
|---|---|---|
| GOM | 21.210 | -0.2320 |
| GBS | 11.145 | -0.1197 |
| SCCLIS | 18.145 | -0.2490 |

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, personal communication) and represents the offshore section of the GOM. The three ogives indicate that female lobsters 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.

Maturity ogives were available from four regions within the GBS assessment area. One was based on ova diameters of lobsters collected off the south shore of Long Island, NY (Briggs and Mushacke 1980). The second was based on ova color (Aiken and Waddy 1982), determined by external observation (without dissection, nor direct observation) from lobsters collected in Block and Hudson Canyons by the state of RI. The third was based on cement gland and ova diameter data from lobsters collected off outer Cape Cod, by the state of MA. The fourth (Cooper and Uzmann 1977; Fogarty and Idoine 1988), was based on ovigerous condition (adjusted for the interaction between growth and extrusion) in lobsters from northern Georges Bank. The four ogives indicate that lobsters mature at smaller sizes in the southern areas and larger sizes in the northern areas of the GBS assessment area.

Maturity ogives were available from two regions within the SCCLIS assessment area. The first ogive was based on a reanalysis of Long Island Sound ova diameter data from Briggs (1979). The second was based on ova diameter adjusted cement gland data collected in Buzzards Bay by the state of MA. The ogives indicate that female lobsters mature at a smaller size in the Long Island Sound than in inshore RI and Buzzards Bay.

**Escape Vent Retention Rates**

Size specific encounter rate parameters were used to account for escape of smaller lobsters from traps through escape vents. Retention rates (see below) were estimated in a field study by the Maine Department of Marine Resources. Lobsters larger than 86 mm CL in the EPR model were assumed too large to escape through vents.

| | **Retention In Traps With Different Proportions Of 1 7/8" And 1 15/16" Escape Vents** | | | | | | |
|---|---|---|---|---|---|---|---|
| **CL** | **100% 1-7/8"** | **100% 1-15/16"** | **5% 1-15/16"** | **10% 1-15/16"** | **25% 1-15/16"** | **50% 1-15/16"** | **2" vent** |
| **82** | 0.21 | 0.035 | 0.201 | 0.193 | 0.166 | 0.123 | 0.047 |
| **83** | 0.48 | 0.286 | 0.470 | 0.461 | 0.432 | 0.383 | 0.143 |
| **84** | 0.89 | 0.414 | 0.866 | 0.842 | 0.771 | 0.652 | 0.207 |
| **85** | 1 | 0.517 | 0.976 | 0.952 | 0.879 | 0.759 | 0.286 |
| **86** | 1 | 0.758 | 0.988 | 0.976 | 0.940 | 0.879 | 0.444 |
| **87** | 1 | 1 | 1 | 1 | 1 | 1 | 0.647 |
| **88** | 1 | 1 | 1 | 1 | 1 | 1 | 0.8 |
| **89** | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

During 1995-1997, some lobstermen in all three stock areas used 1 15/16 inch vents while others used 1 7/8 inch vents (the minimum vent size allowed by regulations). It is important to account for the proportions of the two vent sizes in EPR calculations because the $F_{10\%}$ biological reference point is compared to estimates of average fishing mortality during the survey years 1995 through 1997. The proportions (50% in each stock area) were estimated from sea sampling data and by calling lobster vent dealers and inquiring about sales.

### V-Notching

The model for the GOM assumes that berried females that are captured are v-notched and sometimes 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 might 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). For baseline model runs (based on conditions during 1995-1997), the proportion of lobstermen who might v-notch was 71% and estimated from the proportion of lobsters captured from the GOM stock assessment area that were landed in the state of Maine (where v-notching is most common). The conditional probability of being v-notched was assumed to be 50%. Only the GOM stock unit is assumed to have significant v-notching.

### Maximum Size Limit

Regulations limited the maximum size of lobsters landed in Maine only to 5" CL (127 mm) during the time period evaluated in this assessment. As described above, 71% of landings from the GOM stock area were landed in the state of Maine. Therefore, 71% of lobsters >=127 mm CL captured in the model for the GOM stock area were returned to the water. There are currently no maximum size restrictions for the GBS or SCCLIS stock areas.

### Fecundity

In previous assessments, separate fecundity curves were used for the three assessment areas but differences between curves were likely due to sampling methodology, sample size and length of lobsters sampled (Section 2.4.4). For this assessment, Estrella and Cadrin's (1995) fecundity relationship (Figure 88) based on Herrick's (1896) data was used:

$$\text{Fecundity} = (0.000605 * CL^{3.7227})$$

The EPR model requires fecundity estimates for lobsters up to 280 mm CL. Herrick's data cover the widest range of sizes but EPR calculations require extrapolation well beyond the range of sizes that he actually sampled. The most fecund lobster in Herrick's study had less than 100,000 eggs but the curve extrapolated to 280 mm CL predicts 780,000 eggs.

### Length-Weight Relationship

Three stock area specific, but similar, length-weight relationships were used in this assessment for female lobsters.

| Stock Area | Formula | Source |
|---|---|---|
| GOM | $W = 0.001167*CL^{2.9194}$ | Estrella and Cadrin (1995) |
| GBS | $W = 0.000833998*CL^{2.972}$ | Burns et al. (1979) |
| SCCLIS | $W = 0 .001365*CL^{2.88726}$ | SARC 22 |

### Quarterly Distribution Of Capture Rate

The model requires the user to partition annual nominal encounter rates (roughly proportional to annual fishing effort) by quarter. Proportions of landings by quarter during 1994-1998 were used to estimate the seasonal distribution of fishing effort in the GOM and GBS stock areas. Landings estimates from CT logbooks, NMFS landings data and landings data from MA annual lobster surveys for 1994 were used for the SCCLIS stock area.

| Quarter/Season | GOM | GBS | SCCLIS |
|---|---|---|---|
| 1 | 0.32 | 0.400 | 0.525 |
| 2 | 0.58 | 0.319 | 0.264 |
| 3 | 0.02 | 0.124 | 0.110 |
| 4 | 0.08 | 0.157 | 0.101 |

### Natural Mortality

Natural Mortality (M, see Section 2.7) for lobsters in the model is partitioned into hard shell (0.10 $y^{-1}$) and soft shell (0.05 $y^{-1}$) components. Soft-shell natural mortality is applied only during the quarter when a lobster molts. Lobsters that do not molt in a particular year have $M=0.10\ y^{-1}$. Lobsters that molt once have $M=0.15\ y^{-1}$ during the year of molting and lobsters that molt twice have $M= 0.20\ y^{-1}$ during the year of molting. 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 for a cohort of lobsters in the model ranged from 0.13-0.15 $y^{-1}$, depending on stock areas and fishing mortality rate, and were close to the 0.15 $y^{-1}$ value assumed in the DeLury and LCA assessment models.

### Growth-Molt Increments

Based on NEFSC (1996), molt increments for female lobsters in the GOM stock area (all length groups) were assumed to follow a normal distribution with a mean value of 11 mm CL (range 6 – 16mm CL). Based on Uzmann's (1977) offshore tag recovery data analyzed by Fogarty and Idoine (1988), molt increments for the GBS stock area (all size groups) were assumed to follow a normal distribution with a mean of 14 mm CL (range 7 – 20 mm CL, values listed in NEFSC 1996 are incorrect). Molt increments and associated probabilities for the SCCLIS area were based on analysis of tag recaptures in a University of Rhode Island tagging study and sea sampling from RI cast shell measurements (see below).

| Molt Increment (mm) | Probability for lobsters 55 – 69 mm CL | Probability for lobsters 70 – 80 mm CL | Probability for lobsters > 80 mm CL |
|---|---|---|---|
| **6*** | 0.0718 | 0.0695 | 0.0963 |
| **7** | 0.0589 | 0.0696 | 0.0781 |
| **8** | 0.085 | 0.1056 | 0.1086 |
| **9** | 0.1099 | 0.1379 | 0.1329 |
| **10** | 0.1273 | 0.1547 | 0.1431 |
| **11** | 0.1322 | 0.1491 | 0.1355 |
| **12** | 0.1231 | 0.1235 | 0.113 |
| **13** | 0.1028 | 0.088 | 0.0829 |
| **14** | 0.0769 | 0.0538 | 0.0535 |
| **15** | 0.0516 | 0.0283 | 0.0304 |
| **16** | 0.031 | 0.0128 | 0.0152 |
| **17** | 0.0167 | 0.005 | 0.0067 |
| **18** | 0.0081 | 0.0017 | 0.0026 |
| **19** | 0.0035 | 0.0005 | 0.0012 |
| **20** | 0.0012 | | |

* The probabilities for molt incremented listed for the 6 mm molt includes the sum of molt increments for 4, 5, and 6 mm.

### Molting Frequency for Female 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 (> 55 mm CL), it is assumed that there is a maximum of two molts per year (see "proportion of double molting lobsters" 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. 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.

Another factor affecting molt frequency is the maximum intermolt period, the longest amount of time a lobster of a given size will take to molt. Determining size-specific maximum intermolt periods is difficult. In-situ estimates of intermolt durations of large lobsters have been hard to obtain especially for the southern New England area. Data from existing laboratory studies are difficult to interpret because lobsters are frequently isolated and the effects of mating and reproduction on molt frequency cannot be identified. Data were available for 32 large Bay of

Fundy female lobsters from the St. Andrews Laboratory. However, details on the holding conditions and size distributions were not available and the committee did not feel comfortable extrapolating these estimates to the entire range of the resource given evidence of area specific growth rates estimated from tagging studies.

Research presented (NEFSC 1996) from Canadian stocks (D. Pezzack, Department of Fisheries and Oceans, Canada, personal communication) 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. Based on the assumption that at the onset of maturity lobsters take two years to molt, the minimum intermolt period is 2 years. It is not realistic that the transition from two to seven years is instantaneous.

Current data for estimating intermolt durations between the minimum and maximum values are sparse. It is reasonable to assume, however, that the maximum duration increases with size up to the absolute (7 years). Tagging experiments have been analyzed to estimate intermolt durations. Fogarty and Idoine (1988) applied a modification of the anniversary method (Hancock and Edwards 1967) to estimate size specific probabilities of annual molting for offshore lobsters on the northeast continental shelf. Results are described by the logistic function:

$$Pam_{CL} = \frac{1}{1+e^{\alpha+\beta CL}}$$

While biases exist with this approach, reasonable estimates of size-specific maximum intermolt periods can be derived from the inverse of the annual molt probability (in model notation $rk_{CL} = 1/Pam_{CL}$).

The maximum molt interval, in integer form (rounded up to the next integer), defines the size-specific whole number of years required for all lobsters to molt in the model, i.e., the longest number of years (model notation is $k_{CL}$). An example of the relationship between annual molt probabilities ($Pam_{CL}$) and real and integer maximum molt interval values ($rk_{CL}$, $k_{CL}$) for female lobsters of increasing size is shown here:

| $Pam_{CL}$ | $rk_{CL}$ | $k_{CL}$ |
|---|---|---|
| 0.250 | 4.000 | 4 |
| 0.240 | 4.167 | 5 |
| 0.225 | 4.444 | 5 |
| 0.210 | 4.761 | 5 |
| 0.200 | 5.000 | 5 |

The function $1/Pam_{CL}$ approaches zero (0) as lobsters become large implying that the maximum intermolt duration approaches infinity. This unrealistic situation is avoided, as described above, by truncating this value at a maximum of seven years. The size (when $Pam_{CL} = 0.143$) at which the seven year maximum occurs is 130 mm for the GOM, 150 mm for the GBS, and 112 mm for the SCCLIS assessment areas.

The size specific annual molt probabilities for the three areas are the same as those used in the previous 1996 stock assessment (Blake 1996, NEFSC 1966), and were calculated from logistic functions with the following parameters:

| Stock Area | $\alpha$ | $\beta$ |
|---|---|---|
| GOM | -8.08127 | 0.076535 |
| GBS | -6.86700 | 0.058000 |
| SCCLIS | -9.72000 | 0.103200 |

The minimum and maximum intermolt durations for mature females can be justified biologically as 2 and 7 years respectively. For individuals with predicted intermolt durations exceeding 2 years, an important challenge in modeling lobster growth is to define the distribution of molt duration as a function of the time spent in the size class (1 mm CL). As described above, data to resolve this issue are limited. For the purposes of this model, the model was modified to accommodate any hypotheses related to size and duration within size groups.

The approach used in NEFSC (1966) was to estimate year at size annual molting probabilities ($Pmolt_{yas(CL)}$) as:

$$P_{molt\,yas(CL)} = \frac{yas}{k_{CL}}$$

where

$$yas = \begin{cases} 1,\ldots,k_{CL} & if\,immature \\ 2,\ldots,k_{CL} & if\;mature \end{cases}$$

where yas is the year at size (number of years the lobster has spent at a given size, CL), and $k_{CL}$ is the integer value of maximum molt interval in years. Under the assumption that immature lobsters molt at least annually, the $k_{CL}$ for immature females is defined as equal to 1.

A modified approach used in this assessment is to use the real value of molt interval $rk_{CL}$ instead of the integer representation in the denominator. This allows a smoother progression, with animals at the beginning of an integer range molting, on average, more rapidly than those nearing the next integer value. When $yas/rk_{CL} > 1.0$, $Pmolt_{yas(CL)}$ is set to 1.0, and the value for molting probability in the final year at is always 1.0 to insure all animals molt into a new size.

The growth and mortality rates predicted through the combination of all parameters in the EPR models are plotted in figures 89 and 90. When fishing mortality equals zero the predicted percent of female lobsters still alive at 180 mm CL is; GBS = 6.1%, GOM = 2.5%, SCCLIS = 1.2%.

**Proportion of Double Molting Lobsters**

Immature female lobsters are assumed to molt at least once a year and at small sizes, generally less than 85mm CL, may molt twice during the first and third quarters. Estimates from Cooper and Uzmann's (1977) tag recapture data from the offshore section of the GBS stock area suggest that proportions of female double molters are: 0.33 (55-64 mm CL), 0.17 (65 – 73 mm CL), 0.08 (74 – 82 mm CL), and zero (> 83 mm CL). For lack of better information, these estimates were used for the GOM stock area also (Figure 87).

Proportions of female lobsters double molting in the SCCLIS area were estimated from a polynomial regression model fit to NUSCO tag recapture data for 430 female lobsters between 56 and 83 mm (Figure 87). For a detailed explanation of the original dataset and the polynomial equation coefficients, see LoBue (1999).

| CL (mm) | Predicted proportion of female double molters | CL (mm) | Predicted proportion of female double molters |
|---|---|---|---|
| 55 | 0.38 | 66 | 0.07 |
| 56 | 0.33 | 67 | 0.06 |
| 57 | 0.28 | 68 | 0.05 |
| 58 | 0.24 | 69 | 0.04 |
| 59 | 0.21 | 70 | 0.03 |
| 60 | 0.18 | 71 | 0.03 |
| 61 | 0.16 | 71 | 0.02 |
| 62 | 0.13 | 73 | 0.01 |
| 63 | 0.11 | 74 | 0.01 |
| 64 | 0.01 | 75 | 0.002 |
| 65 | 0.08 | >76 | 0.0 |

### 9.3 $F_{10\%}$ REFERENCE POINT ESTIMATES BY STOCK AREA

Estimates of $F_{10\%}$, nominal encounter rates and annual exploitation rates from baseline EPR model runs are listed below for the three assessment areas.

| Area | $F_{10\%}$ | Nominal Encounter Rate | Annual Exploitation Rate |
|---|---|---|---|
| *GOM* | 0.34 | 0.63 | 0.27 |
| *GBS* | 0.29 | 0.44 | 0.23 |
| *SCCLIS* | 0.84 | 1.40 | 0.53 |

As described above, nominal encounter rates are proportional to effective fishing effort. The annual exploitation rate is the fraction of the total fishable stock alive at the beginning of the year that dies (is landed) in the fishery.

### 9.4 YIELD PER RECRUIT

As described above, $F_{MAX}$ and $F_{0.1}$ were calculated based on a yield per recruit (YPR) model for female lobsters (but not for males). $F_{0.1}$ is the fishing mortality rate corresponding to the point on the yield per recruit curve where the slope is one-tenth of the slope at the origin. $F_{MAX}$ is the fishing mortality rate that gives maximum yield (in weight) per recruit. $F_{0.1}$ usually gives near maximum levels of yield per recruit but at fishing mortality levels less than $F_{MAX}$. Fogarty and Idoine (1988) indicate that in offshore lobsters YPR curves are more convex and that $F_{MAX}$ is lower for males then for females.

| Stock Area | $F_{MAX}$ (Female Lobsters) | $F_{0.1}$ (Female Lobsters) |
|---|---|---|
| *GOM* | 0.55 | 0.14 |
| *GBS* | 0.26 | 0.10 |
| *SCCLIS* | not defined | 0.13 |

Yield per recruit for female lobster in the GOM changed very little over a wide range of F values because of additional protections for female lobsters in this area (maximum size and v-notching). Lobsters in the GOM stock area had the highest $F_{0.1}$ value (Figures 91, 92, and 93), probably due to the additional protections. The absence of a maximum value for YPR (Fmax) for SCCLIS could be the result of poorly defined growth for this area since the protections are the same as GBS.

### 9.5 COMPARISON OF OBSERVED AND PREDICTED LENGTH COMPOSITION

The EPR model calculates the size distribution of lobsters caught in a theoretical fishery under equilibrium conditions. In this context, "equilibrium" means constant fishing effort and fishing mortality, constant natural mortality, constant recruitment, no changes in the fishery and no changes in management over a time period at least as long as the life of a lobster (i.e. more than 20 years).

Average size distributions for actual catches during the 1997-1998 survey years were compared (Figures 94, 95, and 96) to size distributions for theoretical catches from the EPR model. Catches from the EPR model were calculated with fishing mortality rates similar to those estimated for each stock area during 1997-1998. In all three cases, the proportion of small lobsters in EPR model catches was smaller than the actual proportion and the proportion of large lobsters was larger.

It was not possible to determine if discrepancies between actual and predicted EPR catches were due to conditions in the fishery or problems in EPR calculations. There are many explanations for the discrepancies that seem plausible. For the GOM and GBS stock areas, actual catches of small lobsters may be higher than predicted by the EPR model because of increasing recruitment trends in recent years (Section 8). Fishing mortality rates have varied widely over the last twenty years in all three stock areas (Section 8) and probably affect comparisons. The actual catch of large lobsters may be lower than predicted by the EPR model because recent estimates of fishing mortality for lobster in all three stock areas are too low. It is possible that numbers of small lobster taken in the actual fishery are higher than expected because growth is slower than assumed in the EPR model. Another possible explanation involves assumptions about fishery selectivity in the EPR model (Section 7.4.2). Results from analyses using two stock assessment models (LCA, Section 8 and MARK, Appendix A), as well as a simple comparison of commercial catch versus trawl survey catch (Section 7.2.4), suggest that the fishery harvests small lobsters more efficiently than large lobsters.

## 9.6 SENSITIVITY ANALYSES

Parameter estimates used in the EPR model for this assessment were based on the best available information. However, sensitivity analyses were used to evaluate uncertainty because there is currently no way to calculate confidence intervals for $F_{10\%}$ estimates. In addition, growth, maturity, and natural mortality parameter estimates for lobsters are uncertain. Uncertainties are greatest for describing an unfished, virgin stock because all studies were carried out under conditions of relatively heavy fishing. Sensitivity analyses were not meant to suggest alternative parameter values or $F_{10\%}$ values. Effects of simultaneous changes to two or more parameters are not additive and it is therefore difficult to predict their combined effect without knowing more about how they interact.

Results (see below) show that the estimates of the $F_{10\%}$ reference point for female lobster in the GOM and GBS stock areas are moderately sensitive to small changes in input parameters. In contrast, the $F_{10\%}$ reference point for SCCLIS is very sensitive to small changes in input parameters. This appears to be a consequence of lobsters maturing at smaller sizes and having significantly slower growth rates than those estimated for the other two stock areas.

| Run | Parameter | GOM | GBS | SCCLIS |
|---|---|---|---|---|
| A | Increase molt increment by 1 mm | -3.8% | -2.6% | -23.2% |
| B | Decrease molt increment by 1 mm | +2.2% | +3.6% | +50.2% |
| C | Change mean intermolt period from 3.2 to 4 years<br>(7 year maximum intermolt duration) | +8.6% | +10.7% | +40.1% |
| D | Change mean intermolt period from 3.2 to 2.5 years<br>(4 year maximum intermolt duration) | -10.9% | -13.7% | -34% |
| E | Change M: hardshell = 0.075, soft shell=0.075 | -7.5% | -7.4% | -16.4% |
| F | Change M: hardshell = 0.125, soft shell=0.025 | +6.2% | +7.1% | +19.3% |
| G | Change M: hardshell = 0.15, soft shell=0.0 | +12.4% | +13.6% | +40.3% |
| H | Substitute Perkins (1971) fecundity curve | +11.4% | +17.1% | +84.2% |

### 9.6.1 Explanation for Sensitivity Analysis Runs

*Runs A-B*: Several studies suggest that molt increment is related to carapace length in lobster (Landers 1999, Andrews 1980), but molt increments were assumed the same for all size groups in EPR calculations for the GOM and GBS assessment areas. EPR calculations for the SCCLIS area used slightly different increments for different sized lobsters but these were estimated from small samples with few legal lobsters. NUSCO (1999) reported female molt increments 2 mm smaller than those used in baseline runs. For sensitivity analysis runs, the mean size of the molt increments was changed by plus or minus 1 mm by simply shifting the input distributions of increments by one mm to the left or right. One mm changes do not represent the same percentage in the molt increments for each area because different increments were used in the baseline calculations for each area.

*Runs C-D*: Intermolt duration was tested because it was one of the most difficult parameters to estimate and experience suggested that the EPR model was sensitive to changes in intermolt duration for lobsters smaller than 150 mm CL. As described above, intermolt durations were calculated from molt probability curves subject to a constraint on the maximum and average intermolt duration. In baseline runs, the average intermolt duration is 3.2 years. Maximum intermolt periods (and averages) are assumptions, loosely based on empirical data. Sensitivity run C allowed intermolt duration to increase to an average of 4 years, which is the same value found for female Bay of Fundy lobsters over 160 mm CL, held at a laboratory in St Andrews, Canada. Run D held intermolt duration constant once the average reached 2.5 years, corresponding to a maximum intermolt duration of 4 years which was the maximum intermolt duration of female lobsters held at in St. Andrew's laboratory.

Once the average intermolt duration reaches it's assumed maximum, the frequency of molting followed distributions given below (recall that mature females have a minimum intermolt duration of two years).

| Year | Baseline % molting (mean = 3.2 years)* | Run C % molting (mean = 4 years)* | Run D % molting (mean = 2.5 years)* |
|---|---|---|---|
| 1 | 0.00% | 0.00% | 0.00% |
| 2 | 25.85% | 15.08% | 49.19% |
| 3 | 25.06% | 17.06% | 30.47% |
| 4 | 17.28% | 15.43% | 6.24% |
| 5 | 8.38% | 11.64% | 0.00% |
| 6 | 2.60% | 7.37% | 0.00% |
| 7 | 0.39% | 6.67% | 0.00% |

* The percent of lobsters molting does not add to 100% because some ovigerous lobsters die of natural mortality (the hard shell natural mortality rate is M=0.1 resulting in natural mortality of 9.5% each year).

Different molt probability curves are used in EPR model runs for each stock area. Thus the size at which lobster reach stable molt frequency distributions differs. The following table shows the size at which lobsters reach stable molt frequency distributions.

| Area | Baseline (3.2 year mean) | Run C (4 year mean) | Run D (2.5 year mean) |
|---|---|---|---|
| GOM | 130 mm | 137 mm | 119 mm |
| GBS | 150 mm | 160 mm | 135 mm |
| SCCLIS | 112 mm | 118 mm | 104 mm |

*Runs E–G*: Sensitivity analyses to determine effects of partitioning natural mortality between hard and softshell lifestages were requested by reviewers in NEFSC (1996). When the partitioning of natural mortality is changed, the total M at size also changes depending on the frequency of molting at size.

*Run H*: Perkins (1971) fecundity ogive was originally used for the GBS assessment area but rejected in favor of an ogive based on Herrick's (1895) data. However as mentioned in Section 9.2, the ogive based on Herrick's data predicts fecundity 10 times higher than the most fecund individual in his sample. Perkins' ogive was used because it predicts that lobsters would be about half as fecund at very large (>230 mm) sizes, but have similar fecundity at smaller (<120 mm) sizes.

## 9.7 SENSITIVITY TO FISHERY SELECTIVITY PATTERNS

There is some evidence, based on LCA results and comparison of fishery and survey length composition data for lobster in the GBS stock area (Section 38), that fishery selectivity and fishing mortality rates decline with size in lobster. In contrast, EPR model runs used to estimate $F_{10\%}$ for lobster imply fishery selectivity patterns (Figure 38) that are relatively flat (GBS) or increasing with size (SCCLIS and GOM).

We evaluated the sensitivity of $F_{10\%}$ estimates to fishery selectivity patterns in the EPR model by changing assumptions about the size specific encounter rates. Encounter rates are a good proxy for fishery selectivity parameters because in an ideal fishery, a change in the rate at which lobsters encounter traps changes the fishing mortality rate by the same amount.

LCA fishing mortality estimates for female lobsters in the GBS stock area suggest that fishery selectivities rise from about 100% at 83mm to about 200% at 93mm, fall to about 30% at 103 mm, and then rise gradually to about 100% at 208 mm. For sensitivity runs, we used the trend in LCA fishing mortality estimates from Georges Bank (scaled to a maximum value of one) as encounter rates for female lobster in all three stock areas. The selectivity patterns implied by EPR runs in sensitivity analyses were much different than in runs used to estimate $F_{10\%}$, but very similar to the assumed size-specific encounter probabilities. Results (see below) showed that $F_{10\%}$ estimates were robust to assumptions about selectivity. However, the amount of fishing effort (f-nom) required to generate fishing mortality rates equal to $F_{10\%}$ was much greater in sensitivity analysis runs because the selectivity of some length groups was reduced.

| | **GOM** | **GBS** | **SCCLIS** |
|---|---|---|---|
| *$F_{10\%}$-Baseline Runs* | 0.34 | 0.29 | 0.84 |
| *$F_{10\%}$-Fishery Selectivity Sensitivity Run* | 0.35 | 0.28 | 0.79 |
| *Relative Effort (f-nom) at $F_{10\%}$-Baseline Run* | 0.63 | 0.44 | 1.40 |
| *Relative Effort (f-nom) at $F_{10\%}$-Fishery Selectivity Sensitivity Run* | 1.40 | 1.10 | 2.00 |

## 9.8 UNCERTAINTY ASSOCIATED WITH $F_{10\%}$ REFERENCE POINTS

There are aspects of uncertainty about reference point estimates for lobster that are difficult to quantify, but possibly important. Fishing mortality rates that achieve 10% of the maximum egg production per female recruit ($F_{10\%}$) in an unexploited population were calculated for each stock unit based on growth, maturity, natural mortality, and fecundity rates that were imprecisely estimated in some cases. Fecundity of large lobsters, which may account for most of the egg production in a virgin population, is very uncertain (Section 2.3.2). Estimates of growth, natural mortality, and maturity rates were all based on data collected from populations that have been heavily exploited for many years and may not accurately represent conditions in a virgin population. Density dependent shifts in any one of these parameters - or some combination of them - could cause the $F_{10\%}$ values currently being used to manage lobsters stocks to change. If the average female lobster in an unexploited population grows more slowly and produces fewer eggs over its lifetime than a female that is vulnerable to capture in a heavily exploited population, the $F_{10\%}$ values currently used to manage lobster in U.S. waters might be too small. On the other hand, reduced natural mortality rates in older size groups, a strong possibility not considered in the current calculations, might cause the current $F_{10\%}$ values to be too large.

One reason to suspect that the $F_{10\%}$ values used in this assessment may be under-estimated is that female fishing mortality rates for the three stocks have exceeded $F_{10\%}$ levels since 1982, yet abundance (in the GOM and SCCLIS stock areas) is increasing. The persistence of lobster stocks at fishing mortality rates greater than $F_{10\%}$ suggests a number of possible hypotheses. It is possible, for the reasons stated above, that estimates of $F_{10\%}$ are too low. It is also possible that recruitment has remained above a long term average due to favorable environmental conditions, allowing enough female lobsters to survive high exploitation rates and produce enough eggs to compensate for high harvest levels even though egg production per recruit is below the $F_{10\%}$ value

The LSASC noted that density dependent effects on life history parameters have been documented for some finfish stocks and for exploited and unexploited populations of crayfish in the Dock and Shallow Lakes, Ontario Canada (Momet 1998), but not for lobster. Some laboratory studies (Aiken and Waddy 1986) indicate that growth of lobsters is reduced and mortality rates are increased at higher densities, but these results cannot be extrapolated to wild populations in open ocean environments. Sensitivity analyses performed for this assessment (section 9.6) showed that $F_{10\%}$ values increase when growth slows (but maximum size remains the same), when natural mortality for all age groups increases, or if the fecundity of large lobsters is reduced. For the GOM and GBS stocks, however, these effects were minimal, but for the SCCLIS stock, the changes were large. The uncertainty associated with $F_{10\%}$ is further complicated because growth, maturity and natural mortality are inter-related. In the absence of information on how growth or natural mortality might change as F approaches zero, and how they are related, and without any evidence that fecundity is incorrectly parameterized in the EPR model, it was impossible to be certain about the direction and magnitude of potential bias in the $F_{10\%}$ values used in this assessment.

# 10.0 STOCK AND FISHERY STATUS INDICES

## 10.1 ABUNDANCE INDICES

### 10.1.1 Trawl Surveys

Trawl surveys are conducted by the NMFS and the states of Massachusetts, Rhode Island, Connecticut, and New Jersey (Section 6.2 for more details). Maine also conducted a limited series of trawl surveys during the 1990s which were discontinued in 1999. Fall trawl survey data collected by NMFS, MA, and RI and fall and spring survey data collected by CT were used for DeLury model analyses (Section 8). Abundance indices derived from these surveys, and from the ME, RI spring, and NJ surveys are presented in this section of the report. The complete list of surveys that are included, by stock and statistical area (Figure 1) is the following:

- NMFS fall survey for GOM (all areas), GBS (all areas), and SCCLIS (SA538 and 539) stock areas
- ME surveys for GOM stock area (SA511-514)
- MA fall survey for GOM (SA514) and SCCLIS (SA538) stock areas
- RI fall and spring survey for SCCLIS stock area (SA539)
- CT fall and spring survey for SCCLIS stock area (SA611)
- NJ surveys for GBS stock area (SA612/614/615)

As explained in Section 6.2.1, spring catch rates are low and extremely variable, especially for surveys that are conducted early in the spring when lobsters are not very vulnerable to capture because of low bottom water temperatures. Spring surveys in RI and CT nearshore waters are conducted later in the spring when bottom temperatures are not as low. Abundance indices from these two surveys were included in this section. The ME and NJ survey data are presented here, but were not used for assessment purposes because individual lobsters were not sexed or measured (ME) or because of the limited geographical coverage (NJ). The RI spring survey data were not available by sex. Spring surveys are also conducted by NMFS and MA but were not included in this report.

Relative abundance indices derived from bottom trawl surveys can be expected to index actual changes in population size as long as catch rates are proportional to the numbers of lobsters in the survey area. Thus, downward trends indicate declining population size and upward trends indicate increasing population size as long as the survey methods (area surveyed, fishing practices, gear used and statistical design) remain the same every year and lobsters in any given size group are equally available to the survey over time. (This is less likely to be true in the spring). Care should be taken in comparing the magnitude of catch rates between surveys that utilize different gears or are conducted at different times of year and even between size groups in the same survey since lobsters of different sizes may be differentially vulnerable to capture (Section 7.5). Trawl survey data by themselves can not be used to determine whether or not a stock is over-exploited, only whether lobsters are more or less abundant in the survey area from one year to the next or from one time period to the next.

Relative abundance indices were calculated as the mean number caught per tow for both sexes combined for lobsters one molt group below minimum size (recruits) and for all legal (83+ mm) sized lobsters and shown as annual means and as moving three year averages. All trawl survey data were calculated on a survey year basis. For the NMFS survey data, recruits included all sub-legal size lobsters that were expected to reach minimum legal size during the year, based on the range and distribution of molt increments in 1 mm CL intervals in each stock area (Section 7.3 for details). Adjustments were made for changes in minimum size. Catch rates for recruits in the state surveys were simply calculated over the 72-82 mm size range for all years (i.e., with no adjustment for annual changes in minimum size or allowance for molt probabilities by size). Mean catch rates in the NMFS, RI, CT and MA surveys were calculated as delta transformed means and stratified according to stratum size. The delta mean is the preferred statistic to estimate the population mean when the data contains many zeros (Pennington 1986).

### Gulf of Maine (GOM)

There is some evidence that recruits in the NMFS fall survey increased in abundance during the 1980s and 1990s (Figure 97). They were more abundant in 1994 and 1996. Fully-recruited lobsters were also more abundant in recent years. Recruit and full recruit abundance indices declined in 1997 and 1998 compared to the preceding 2-3 years, but remained above the long term average. Recruit abundance increased by an order of magnitude between 1978 and 1998 while 83+ mm lobsters increased three-fold.

Catch rates of legal sized lobsters in the inshore MA survey area (Figure 97) varied without trend between 1983 and 1998. There was a slight upward trend in the recruit time series, but it is obscured by the large scale fluctuations in abundance. The increased recruitment of sub-legal lobsters to the MA survey during 1994-1996 corresponds with the NMFS survey data for recruits in 1994 and 1996, indicating that recruitment increased in nearshore as well as offshore waters of the GOM in those years. Similarly, recruits were less abundant in 1997 and 1998 in both surveys. Legal-sized lobsters are less abundant relative to recruits in inshore MA waters than they are in more offshore waters of the GOM.

Catch rates of lobsters caught along the Maine coast were much higher in 1996 and 1998 than in 1992-1994 or 1997 and in shallower water (0-35 fathoms vs. 36-55 fathoms) in all years (Figure 98). The increased abundance in 1996 and 1998 was not affected by the reduction in the survey area (compare Figures 27 and 28 since the catch rates in these two years were also higher for just the mid-coast stations. These results indicate that the abundance of lobsters in the mid-coast region of Maine has increased in the last three years compared to 1992-1994.

### Georges Bank and South (GBS)

Results from the NMFS fall survey in this stock area showed no trend in the abundance of either pre-recruits or fully-recruited lobsters since 1976 (Figure 99). Unlike the two other stock areas, fully-recruited lobsters on Georges Bank are consistently caught in greater numbers than sub-legals.

Catch rates for lobster (all sizes, both sexes combined) caught in the NJ trawl survey were calculated as stratified mean numbers per tow for the six northernmost strata (12-17, see Figure 32) because 96% of the lobsters caught in the ten year time period came from these six strata. There has been no trend in abundance of recruits or full recruits since 1989 (Figure 100).

**South Shore of Cape Cod and Long Island Sound**

Catch rates of recruits in the NMFS fall survey varied without trend from 1976 to 1995, then increased sharply in 1996 and 1997 and dropped in 1998 (Figure 101). Legal-sized lobsters also increased in abundance in recent years. This increase in abundance was very similar to what was observed in the GOM NMFS fall survey, but it occurred two years later in the SCCLIS stock area. Despite the decline from the record high 1996 value, fully-recruited lobsters remained more abundant in 1998 than at any other time prior to 1996.

Temporal abundance patterns in the three state fall surveys (CT, RI and MA) were very different. There was a gradual increase in recruit abundance in area 538 (MA survey) in the late 1980s, followed by even higher catch rates during 1991 and 1994, and then a severe downward trend with very low 1995, 1997 and 1998 indices (Figure 101). The fully-recruited size group followed a very similar pattern.

The RI and CT fall surveys also showed low abundance of recruits in nearshore waters of area 539 and in Long Island Sound in the 1980s. Recruit abundance increased about three-fold in RI waters between 1987 and 1991 and again after 1992, reaching values about five times the 1980 values. Recruits in the CT survey were twice as abundant between 1993 and 1998 as they were in the 1980s, with an extremely high catch rate in 1997. Three-year averaged indices leveled off in both surveys in recent years with no convincing evidence of a downward trend as was revealed by the MA survey. The 1998 RI recruit catch rate was, however, the lowest it has been in the last six years and legal-sized lobsters reached their lowest point since 1986.

The two spring surveys (RI and CT) also showed very different trends. As was the case in the fall surveys, abundance was low during the 1980s and higher during the 1990s (Figure 102). In area 539, catch rates of both recruits and fully-recruited lobsters were 2-3 times above the 1980 values throughout the 1990s. In area 611, however, recruit abundance did not increase until 1996 when it tripled in three years time following a six year period of fairly constant catch rates. RI catch rates also tripled over a three year time period (1989-1991). Abundance indices for legal-sized lobsters followed the changes in recruits fairly closely in the spring RI survey and to some degree in the spring CT survey, showing (in contrast to the fall CT survey) about a ten fold increase in abundance since 1986. The increase in the abundance of fully-recruited lobsters in the spring RI survey was similar.

### 10.1.2 SCUBA Diver Survey In Boulder Habitat

**Methods**

Divers from the University of Maine, under the direction of Dr. Robert Steneck, sampled lobster abundance in four outer coastal regions in Maine 1989 – 1999 (York 513, Pemaquid 513, Mount Desert 512 and Jonesport 511). Each region is separated by 50 km, and 4 to 6 sites were surveyed within each region. All sites were selected a priori without knowledge or reference to lobster distribution or abundance. Selection criteria were outer coastal, away from estuarine influence, had unimpeded exposure to the southwest, and a variety of substrates (boulder, ledge and sediment).

To quantify each site, divers haphazardly tossed forty 1-$m^2$ quadrats within each habitat at 10 m depth. All individuals therein were counted and measured *in situ*, then released. See Palma et al. 1999, for additional sampling procedures. Trends in abundance of adolescent phase lobsters (40-90 mm CL) in boulder habitats are reported.

**Results**

During the period of 1989 – 1999 lobster abundance increased significantly at the Pemaquid (513 East), Mount Desert I. (512) and Jonesport (511) regions, while York (513 west) trended downward (Figure 174). This region is the southern most in Maine and may reflect a generally reduced abundance of lobsters in the southwestern corner of the GOM (e.g., similar to Area 514). These trends in lobster abundance (40-90 mm CL) conform with landings data from the same regions.

### 10.2 TRAWL SURVEYS AS AN INDEX OF EGG PRODUCTION

An analysis was done to compare the potential number of eggs produced (i.e. egg production that includes females lost to fishing mortality) by female lobsters captured in the trawl surveys over time and among size groups. If a population has been recruitment overfished for a significant period of time it should be expected that the total potential egg production of the population would decline over time. For populations that are also growth overfished it would also be expected that the proportion of potential egg production coming from large lobsters would be small relative to lobsters that have matured for the first time.

A complete evaluation of recruitment overfishing requires information on total egg production or spawning stock size. This analysis provides information on changes in total potential egg production for each stock that is derived from trawl survey catch at size data as opposed to estimating egg production per recruit relative to a theoretical unfished population using the EPR model. It is therefore a direct measure of reproductive capacity that accounts for the number and size (fecundity) of female lobsters in the population.

Results are presented in terms of average potential egg production because they are calculated from mean stratified catch rates which only provide a "snapshot" of abundance and size distribution at the time of the survey. Not all the mature females captured during the survey will survive to actually produce eggs to hatching during the year, thus the estimated egg production is "potential," not actual and is expressed on a per tow, not an absolute basis. The utility of this index is therefore realized on a relative basis by comparing trends in potential egg production and proportions of egg production that are derived from individual molt (size) groups between surveys and areas.

These calculations do not account for differences in fishery selectivity at size (Section 7.3) which suggest that lobsters in the first molt group are subjected to higher mortality rates than lobsters in subsequent size groups. This could result in an overestimate of the egg production potential of the first legal sized molt group if more of these lobsters are killed before hatching eggs. However, this would only effect trends in egg production if fishery selectivity patterns changed over time, which seems unlikely.

## Methods

Average total potential egg production (eggs per tow) was estimated for seven different trawl surveys: 1) the NMFS and MA fall surveys in the GOM; 2) the NMFS fall survey in the GBS stock area, 3) the NMFS, RI and CT fall surveys in the SCCLIS stock area, and 4) the RI and CT spring surveys in the SCCLIS stock areas. For each survey the annual survey index of female lobsters was compiled for each 1 mm size group. The index was multiplied by the proportion of females at that size which are mature using the maturity ogives generated for the EPR model (Section 9.2). This value was divided by the average intermolt duration of a female lobster for each 1 mm size group using the intermolt durations generated for the EPR model. This was done to account for the fact that a lobster will only produce eggs once while at a particular size and that the frequency of egg extrusion is assumed to be the same as the frequency of molting. Finally, this value was multiplied by the number of eggs that each female at size is expected to carry to the hatching stage using Herrick's fecundity curve, which is utilized in the EPR model for all three assessment areas. For ease of presenting the results, years were combined and lobsters were collated into 5 mm size groups.

Total potential egg production by year for the first molt group was calculated for the 83-93 mm size group for the GOM and SCCLIS stock areas and for the 83-96 mm size group for GBS for all years. Absolute values are comparable among years but not necessarily among surveys. Although extensive consideration was given to Q ratios in this assessment (Section 7.5), no attempt was made in this analysis to adjust the survey indices to reflect differential catchability of recruits and full recruits.

## Results

The NMFS GOM trawl survey (Figure 103) shows that potential egg production varied without trend until 1994. After that, it increased to the highest level in the time series in 1996 and remained above average in 1997 and 1998. The proportion of potential egg production coming from small lobsters was higher after 1982, however this appears to be a result of an increased abundance of small lobsters rather than a decrease in the production coming from large lobsters. In recent years about 75% of the potential egg production comes from lobsters that have survived at least one molt above the legal size. The NMFS survey data from the GOM indicates that sexually mature females are more numerous in recent years and that most of the egg production is derived from larger females. These results are consistent with the recent decline in female DeLury model fishing mortality estimates derived from the GOM NMFS survey data. The only other survey area that showed a higher proportion of egg production from 2+ molt group females was GBS.

Results derived from the MA inshore trawl survey are very different. The potential egg production was above average in the first five years of this survey and below average during 1995-98 (Figure 104). Egg production varied without trend after 1985 with the lowest value in 1988 and with peaks in 1990 and 1994. There was a downward trend in potential egg production coming from lobsters 2+ molts above legal size and a corresponding upward trend in egg production by sub-legal lobsters. Lobsters >110 mm CL made up a greater proportion of trawl catches in the 1980s than during the 1990s. The reduction in larger lobsters is consistent with DeLury model estimates of fishing mortality that increased during this time period (Section 8.1.1). Currently only a small percentage (0-30%) of the total egg production in the survey area (statistical area 514, see Figure 1) is produced by 2+ molt group females.

Analysis of the GBS NMFS trawl survey data (Figure 105) indicates that potential egg production generally decreased from 1977 to 1987 and then maintained average values in the late 1980s and early 1990s. The peak in potential egg production apparently shifted to lobsters of 130 mm CL as compared to 120 mm CL in the previous years. Overall 80-90% of the total potential egg production in this area comes from lobsters which have survived at least one molt above the minimum legal size. These results are consistent with the comparatively low female fishing mortality rates estimated for this stock area (Section 8.2).

The NMFS SCCLIS trawl survey (Figure 106) shows a slight increase in potential egg production from 1976 to 1992, a decline in 1993 and 1994, and above average values during recent years, especially in 1996 and 1997. The proportion of potential egg production that is derived from sub-legal sized lobsters in the NMFS southern New England survey area (50-70% in recent years) is much higher than in either of the other two NMFS surveys in the GBS and GOM assessment areas. Larger 2+ molt group females currently only account for about 10% of potential egg production.

Data from the RI inshore trawl survey were only available through 1995 (Figure 107). Average potential egg production was much lower during 1979-1986 than between 1987 and 1995. Sub-legal females accounted for the same proportion of total egg production over the entire time period (60-100%), but were more abundant after 1986. The increased contribution of sub-legal females in this survey area is a result of the lower size at maturity that prevails in inshore waters of southern New England (Section 9.2). Females that survived at least one molt group were only represented in three years of survey data.

CT spring trawl survey data from Long Island Sound (Figure 108) show that potential egg production increased during the 1990s (except for 1994), particularly in 1997 and 1998. Most of the spring egg production (80-90%) in LIS comes from sub-legal sized lobsters with the remainder from females in the first molt group. Although the contribution of 2+ molt lobsters decreased from <10% in the late 1980s to almost none in the mid and late 1990s (numbers and proportions were too small to show up in the figure), the absolute egg production potential from this group has remained constant or increased.

CT fall trawl survey data from Long Island Sound (Figure 109) produced results that were very similar to the fall survey results. Average potential egg production was higher in the 1990s than in the 1980s with a peak value in 1997 and was dominated by sub-legal lobsters. CT fall survey data also show a decrease in total egg production from lobsters 2+ molts above the minimum legal size early in the time series. There was a small decrease in the potential egg production of legal sized lobsters from 30-40% between 1984 and 1988 to 10-20% in recent years.

GOM

Estimates of potential egg production vary between the two GOM surveys. Total potential egg production estimates derived from the NMFS survey during the last five years were well above the 1976-1998 average. Although the proportion of potential egg production coming from first molt group lobsters increased since the beginning of the time series, larger females are producing more eggs (potentially) in recent years than previously. The MA inshore survey does show a loss of larger lobsters, however. It also indicates that potential egg production was higher during the early 1980s than during the last 13 years. The size structure of lobsters in the MA inshore survey and the inshore surveys in the SCCLIS stock area is similar. However, because females mature at larger sizes in the GOM, the potential egg production coming from sub-legal lobsters is not as high as it is in southern New England. The contrast in the conclusions reached for these two survey areas is entirely consistent with DeLury abundance and fishing mortality estimates (Section 8.1) which show that female F is much higher in Massachusetts Bay than in the rest of the GOM and increased in recent years whereas neither abundance nor fishing mortality estimates derived from NMFS survey data changed over time.

GBS

The GBS assessment area showed a declining trend in total potential egg production from 1977 to 1987, but stable values since then. This survey shows that absolute egg production potential from lobsters >180 mm has declined in the last few years of the time series, however the size at which maximum egg production occurs has increased slightly in the last few years.

SCCLIS

For an overall view of the SCCLIS stock one needs to review the four surveys simultaneously. There is an overall stable to increasing trend in average potential egg production estimates derived from all four surveys. In addition, because females mature at smaller sizes in this stock area, sub-legal sized females account for most of the egg production in this area. The proportion of potential sub-legal egg production is exacerbated by the virtual absence of large lobsters in the population. Potential egg production coming from the 2+ molt group was virtually lost from Long Island Sound in the late 1980s, but not in the NMFS survey area further offshore. The RI survey sporadically collects a few larger lobsters and therefore no trend could be identified in this time series.

### 10.3 EXPLOITATION INDICES

The ratio between catch (landings) and abundance was used as an index of exploitation for each stock area. Abundance was defined as the yearly index of abundance (stratified mean number per tow) for all legal-sized lobsters obtained from trawl surveys. This index provided information on the portion of the resource removed by fishing in relation to stock abundance.

**Methods**

Total catch (millions of lobsters landed as estimated from expanded landings at size data, see Section 7.1) for each sex was divided by survey abundance for fully-recruited lobsters for each stock area to obtain the exploitation index. NMFS fall trawl survey indices of abundance were used for the GOM stock area in statistical areas 511-513 and 515, for all of the GBS stock area, and for statistical areas 538 and 50% of 539 in the SCCLIS stock area (Figure 1). The RI fall trawl survey was used to represent the other 50% of area 539, the MA fall trawl survey was used for area 514 in the GOM, and the CT spring and fall trawl survey data were used for area 611 (Long Island Sound). For survey data, the year was the calendar year of the survey. Years were defined as fall survey years, i.e., October 1 - September 30 of the following year. Time periods varied according to the year in which each survey started, but in no case began earlier than survey year 1982.

Exploitation indices were scaled relative to the mean because the magnitude of each index was directly affected by survey catch rates which in turn depended on the design and fishing performance of the trawl gear used in each survey. For this reason, exploitation indices between surveys could only be compared in terms of temporal trends. The same was true of any comparison of exploitation indices with fishing mortality or abundance estimates derived from DeLury model analysis.

**Results**

Gulf of Maine

Exploitation indices based on the NMFS fall survey showed no clear trend over the time series, especially if the high values early in the two time series are ignored (Figure 110). During the last six years the exploitation indices based on this survey trended downward despite a 50% increase in landings of males and a 60% increase in the landings of females from the survey area.

Exploitation indices based on MA trawl survey data for statistical area 514 were more variable than the NMFS indices for the rest of the GOM assessment area (Figure 110). Male values produced no clear trend over the time series and, like the NMFS survey, showed little change during 1994-97. The overall trend for males was very similar between the two surveys. Female exploitation indices based on the MA survey showed an increasing trend, primarily due to high values in 1988, 1993 and 1997. The 1997 MA survey abundance index was the lowest of the time series and produced a high exploitation estimate.

There is some agreement between the recent downward trend in male and female fishing mortality (Section 8.1) and the reduced exploitation indices in the NMFS survey area, but the exploitation indices for the MA survey area provide no confirmation (except for the single 1997 female index) of the recent increase in male and female F in statistical area 514 (Figure 51).

Georges Bank and South

Exploitation indices for males and females trended upward over the time series (Figure 111). Trends in exploitation were nearly identical for both sexes. Values in recent years were relatively high but variable, especially for males. These indices followed almost an identical trend as the male DeLury fishing mortality rate estimates which increased steadily between 1987 and 1994 and then declined sharply in 1995-97 (Figure 63), but not the female DeLury fishing mortality rates which showed no evidence of an upward trend (Figure 64).

South of Cape Cod and Long Island Sound

Exploitation indices for the SCCLIS stock area were quite variable, particularly for females (Figure 112). The CT fall survey indicated a clear increase in exploitation of males and females during 1984-97 in area 611 (Long Island Sound). Female exploitation indices based on the RI fall survey were highly variable during 1982-87 but since then they have remained low and virtually flat in trend. Male exploitation indices derived from the RI survey were quite stable until 1996 and 1997 when they declined to their lowest point in the time series. NMFS survey data indicated female exploitation has been variable in areas 538 and 539 since 1982, but was also relatively low in 1995-97. NMFS survey data for males were variable and showed no clear trend, but 1995-97 indices were the lowest of the time series.

The exploitation indices for the SCCLIS stock area corroborate the trends in DeLury model fishing mortality rates estimated from individual fall surveys (Section 8.3). The trends in F estimated from CT survey data were upwards, RI survey data produced fishing mortality rates that did not vary (but were low during 1995-97 for males), and NMFS survey data produced variable fishing mortality rates that showed no trend, but were low in recent years (Figure 71).

Exploitation indices calculated from spring survey year catch and spring CT trawl survey data in Long Island Sound failed to show a temporal trend for either sex (Figure 113). Based on the spring indices, one would conclude that lobsters in Long Island Sound are not being harvested at an increasing rate relative to survey abundance indices. The fall exploitation indices, in contrast, indicated increasing trends in the removal rates of both sexes. DeLury model analyses of fall and spring survey data and landings from LIS revealed the same difference, i.e., no change in spring male and female fishing mortality rates and an upward trend in fall F values (Figure 79).

## 10.4 SURVEY MASS BALANCE MORTALITY ESTIMATES

Survey mass balance mortality estimates provide a relatively simple way to observe trends in mortality which, unlike the DeLury model, do not require information on landings. In addition, the DeLury model could not be run for the early years of the surveys because expanded landings in numbers were not available prior to 1981-82. Because this analysis does not require landings data it was possible to compute mortality rates back to the beginning of the surveys.

**Methods**

The calculation can be summarized as:

$$Z_t = -\ln\left[N_{t+1} / \left( N_t + (p\,R)_t / q\right)\right]$$

Where: $Z$ = total annual mortality rate

$N$ = survey index of legal lobsters

$R$ = survey index of lobsters in an 11 mm bin below the legal minimum gauge size

$p$ = proportion of recruits that molt to legal size

$t$ = year

$q$ = ratio of the catchability of $R$ to the catchability of $N$

The parameter *p* was assumed to be one for males. For females *p* was assumed to be 0.5 for mature lobsters and 1.0 for immature lobsters. For females in the size range that included mature and immature individuals, *p* estimates were calculated for each 1 mm size group using the EPR model maturity input parameters for each stock (Section 9.2). Probabilities of recruiting to the fishery during the year were calculated the same way in DeLury model analyses (Section 7.2.1). This simplification could cause Z to be overestimated if *p* is actually less than the values used in the calculation, but it would not effect the trends over time. The parameter q was assumed to be 0.5 for the NMFS trawl surveys and 1.0 for the state trawl surveys (Section 7.5). Once Z is calculated, the annual fishing mortality rate (F) was simply calculated as Z – M, where M is the natural mortality rate. M was assumed to be 0.15.

Mass balance male and female fishing mortality rates were calculated from individual survey data and as blended fishing mortality rates for each stock area by adding recruit and full recruit abundance indices from the appropriate surveys. With the exception of the RI trawl surveys, all the recruit and full recruit abundance indices were calculated directly from raw survey data (stratified mean number per tow), adjusting for changes in the minimum legal size in 1989 and 1990. Estimates of recruit and full recruit abundance for the combined sex RI spring and fall surveys were taken directly from Gibson (1999). Data for recruit and full recruit indices for each of the other fall surveys used in this analysis were taken directly from DeLury input parameters (Section 8). The DeLury model abundance indices for recruits were slightly different because they included a portion of the lobsters smaller than 11 m below the gauge size.

Annual mass balance fishing mortality rates for each survey and sex (when available) were plotted as point estimates and as a three year running average (years t, t-1 and t+1) to better show trends. Because the DeLury model is used to estimate F for survey years and these analyses estimate F for calendar years, comparing three year averages of both helps to reduce the differences between the two. A two year average was used for years at the beginning and end of each time series. Some of the conventions that were established for running the DeLury model (e.g., replacement of zero values) were adopted for this analysis.

Three year running averages of mass balance male and female fishing mortality rates for each stock unit were compared with three year averages of blended stock unit point estimates of male and female fishing mortality rates from individual DeLury model runs that were calculated as weighted averages based on total recruit plus full recruit abundance from each run (Section 7.2.2).

For each stock area, three year running averages of mass balance male and female fishing mortality rates were compared with three year averages of male and female fishing mortality rates derived from DeLury model runs. Combined stock mass balance F estimates were calculated by weighting annual mass balance F estimates derived from individual surveys according to DeLury model abundance estimates (recruits plus full recruits) for the same survey area. For example, the combined GOM mass balance female F for any year n was calculated as follows:

$$\text{Fbar GOM}_{(\text{year n})} = \frac{F_{(\text{MA year n})} * \text{Abun}_{(\text{MA year n})} + F_{(\text{NMFS year n})} * \text{Abun}_{(\text{NMFS year n})}}{\text{Abun}_{(\text{MA year n})} + \text{Abun}_{(\text{NMFS year n})}}$$

where MA refers to the MA survey in area 514 and NMFS to the NMFS survey in areas 511-513 and 515.

**Results**

GOM

Analysis of NMFS GOM fall trawl survey data produced more improbable F estimates than any other survey (Figure 114). Because they occur more frequently in the earlier years, the three year running average is lower in those years and the mortality rates are not reliable. Averaged mass balance F estimates for both sexes were fairly constant during the late 1980s, declined in the early 1990s, and increased in recent years. DeLury F estimates from NMFS survey data in the GOM declined during the 1990s (Figure 51) and were about half the value of the mass balance F's.

The MA GOM survey produced higher values of F than the NMFS survey. There was an upward trend in male and female F estimates that was more apparent for females (Figure 114). Male fishing mortality rates remained fairly stable during the 1990s, but female fishing mortality rates increased in recent years. Average values of 2.5 for females and 1.8 for males were very similar to DeLury F estimates (Figure 51).

Combined mass balance F estimates for the GOM were more variable than for the other two stocks and did not follow the same trend as the blended DeLury model F estimates (Figure 116). Despite their variability, mass balance fishing mortality rates trended upward for both sexes while DeLury fishing mortality rates declined during the last ten years. It is somewhat unclear why the DeLury and mass balance mortality estimates don't track more closely. The high interannual variability in GOM mass balance F values suggest that they are unreliable. Averaged mass balance estimates during 1995-97 were >1.0 compared to DeLury estimates of 0.59 (males) and 0.74 (females).

GBS

Analysis of NMFS survey data from the GBS stock area produced three year average fishing mortality rates that varied between 0.2 and 0.8 for males and 0.2 to 0.6 for females (Figure 114) and did not show any obvious trends. Averaged male F estimates did increase, however, during the late 1980s and early 1990s and then declined in the late 1990s. DeLury estimates of male F and male exploitation indices followed the same trends (Figure 63 and 111). Female DeLury F estimates and exploitation indices were less variable, as were the averaged mass balance F's.

Averaged GBS mass balance F estimates compared fairly well with averaged DeLury model F estimates (Figure 116). Mass balance male fishing mortality rates were consistently lower than the DeLury estimates but followed the same general trend. Mass balance female fishing mortality rates were similar in magnitude and trend to DeLury F's.

Because the trends observed in DeLury and mass balance F estimates are similar, it seems reasonable to utilize this information to estimate mortality rates in the GBS stock area prior to 1982. Even discounting the improbable values in 1976, it appears that fishing mortality rates were lower during the late 1970s (0.1-0.3 for females and 0.2-0.4 for males) and increased in the early 1980s to levels that have been sustained for the last 15 years or so.

SCCLIS

The NMFS fall survey started in 1976, however the catches of males were sparse prior to 1980 and thus there are several missing values. Averaged mass balance male fishing mortality rates remained constant at 1.5 from the mid 1980s to the early 1990s and varied thereafter (Figure 115). The averaged mass balance female fishing mortality rates increased from 0.5 in the late 1970s to values >1.0 in the mid 1980s, then declined before reaching even higher values in recent years (Figure 112).

Annual estimates derived from CT surveys were much less variable than estimates based on the NMFS and RI surveys (Figure 115) and showed similar trends between sexes within each season. However, fall and spring trends were quite different. Fishing mortality rates for both sexes and both seasons gradually increased until the early 1990s. After that the spring survey fishing mortality rates declined (both sexes) while the fall survey fishing mortality rates leveled off (males) or continued to increase (females). The contrasting trends in spring and fall fishing mortality rates was also shown by DeLury model F estimates and exploitation indices that were based on the same survey data (Figures 79 and 113).

The combined sex mass balance analyses of RI spring and fall survey data (Figure 115) both showed F varying without trend from 1979 to about 1990 and then increasing to over 2.0 in 1994 before decreasing in the last few years (particularly in the fall). The magnitudes of the F estimates in the RI, NMFS and CT survey areas in recent years were similar. Averaged male F estimates derived from RI fall survey data followed a similar trend to the spring combined sex estimates (Figure 115). Female fishing mortality rates increased from 1.5 to 2.5 between 1992 and 1997 (Figure 115). Fall mass balance fishing mortality rates were higher than spring fishing mortality rates in recent years.

Comparison of averaged DeLury and mass balance fishing mortality rates for the entire stock SCCLIS area was reminiscent of the GBS comparisons except that the mass balance male fishing mortality rates were generally higher, rather than lower, than the DeLury fishing mortality rates (Figure 116). Averaged female fishing mortality rates estimated using the two methods were almost identical (Figure 116).

## 10.5 PERCENT LANDED LOBSTERS IN FIRST MOLT GROUP

Fishing mortality can strongly affect size structure in a population. In particular, heavily fished populations often have truncated size distributions and increasing proportions of smaller animals in the catch as survival to larger sizes is diminished. For lobsters, a fishery which is highly dependent on newly-recruited animals is at higher risk of failure should environmental factors cause a disruption of the molting process, or worse, a decrease in survival between egg and adult stages (Idoine 1998). Increasing proportions of lobsters one molt above legal size can also be indicative of increased recruitment or increased selectivity of small lobsters.

### Methods

Proportions of newly-recruited lobsters in the landings were obtained from expanded catch-at-length estimates (Section 7.1). Newly-recruited lobsters were defined as those within one molt increment of minimum legal size (MLS). In the GOM stock area the first molt group was 81-91 mm CL in survey years 1981-86, in survey year 1987 it was 82-92 mm CL, and in survey years 1988-97 it was 83-93 mm CL. For the GBS and SCCLIS areas, new recruits were defined as 83-92 mm CL lobsters. These size intervals do not correspond exactly to those used to define molt groups in other sections of this report.

### Results

#### Gulf of Maine

The proportion of male and female lobsters landed in the first molt group increased during the 1980s, from 72 to 85% for males and from 77 to 90% for females (Figure 117). The trend reversed during the early 1990s to lows of 77% (males) and 85% (females). During the last three years these percentages increased slightly, averaging 80% for males and 88% for females. The proportions of females in the first molt group were higher than males in all years. A longer time series from the coastal Maine fishery (Figure 118) indicates that the proportion of lobsters (sexes combined) within one molt of minimum legal size (MLS) was >80% in the late 1960s and declined to a low of 70% in 1973 (Figure 118). The steady increase to the current values of 85-90% took place over a period of about 25 years.

Despite the reduction in the proportion of first molt group lobsters during the early 1990s, the numbers of landed males and females in the first molt group have trended upward since the early 1980s (Figure 117). The increased abundance of recruits in the GOM was particularly strong during 1994-97, as shown by NMFS trawl survey data (Section 10.1) and DeLury model estimates of abundance (Section 8.1). The increase in numbers of lobsters within one molt of MLS in conjunction with the slight decline in the proportion of lobsters within one molt of MLS in recent years demonstrates that the dependence on newly recruited lobster in the GOM lobster fishery is declining. Despite this decline, the relative proportion of newly recruited lobster in the landings remains high. This could have potentially negative impacts on the resource since less than 10 % of females are sexually mature at minimum legal size in this stock unit (Figure 86).

Georges Bank and South

The proportion of new recruit male lobsters in the landings from the GBS stock area increased slightly over the time series (Figure 119). In general, the proportion of new recruit male lobsters was lower in the 1980s (50-60%) than in the 1990s (60-65%). (In the absence of data for earlier years, the 1983 estimates -about 40% for both sexes - were discounted). The proportion of new recruit females increased to 72% in 1997. Female values have been higher than males since 1992. The proportion of lobsters within one molt of MLS is lower in the GBS stock area than in the other two assessment areas where intense nearshore fisheries produce more truncated size distributions. Trends in numbers are similar to trends in proportions, indicating that there has been little change in population size structure during the past 15 years.

Despite the fact that female lobsters in the first molt group are being harvested more intensively than males, the abundance of legal sized (83+ mm) females in the GBS stock area is about twice as high as the abundance of males. This results in females being harvested at lower exploitation rates than males (Section 8.2).

Sea sampling data from Block and Hudson Canyons indicate an increasing trend in the proportion of first molt group lobsters in the catch during 1991-98 (Figure 121). These values ranged between 61% in 1991 and 87% in 1997. These data suggest that new recruits in certain discrete areas in the GBS stock area are being subjected to increasing fishing pressure. Increasing removals of new recruit females is of concern since approximately 52-76% of GBS females are sexually immature at 83-92 mm CL (Figure 86).

South of Cape Cod to Long Island Sound

Landings in the SCCLIS area contain the highest proportions of lobsters within one molt of MLS (Figure 120). New recruit males declined from 93% in the mid 1980s to 83% in 1994 and increased to about 90% in the last three years. New recruit females remained between 90% and 96% during the entire time series. Female values were higher than males in all years except 1985-86. There has been a steady rise in the number of both males and females landed in the first molt group since 1985. This increase corresponds with recent increases in recruitment demonstrated by fall trawl surveys in this stock area and DeLury model estimates of abundance (sections 10.1 and 8.3). The percentage of new recruits of both sexes in landings from the RI inshore fishery is very high (>95%) and has remained high since 1991 (Figure 121).

The fishery in this stock area is strongly dependent on newly recruited animals. Approximately 90% of female lobsters in the SCCLIS stock area are sexually mature by the time they reach minimum legal size (Figure 86). The early age at maturity in this stock unit moderates the potential negative impacts on egg production associated with heavy exploitation of newly recruited animals.

### 10.6 CATCH PER UNIT EFFORT

Catch per unit effort (CPUE) has been historically used as an index of relative abundance for lobster in different locations and over time. Comparisons are confounded, however, by the fact that sampling methods and months sampled vary between states and, most importantly, because effort is not estimated in a consistent manner. There is also evidence that trends in CPUE are not reliable indicators of changes in abundance because, as heavily fished areas become saturated with traps, the relationship between fishing mortality and fishing effort degrades (Section 10.7). Despite these shortcomings, CPUE data from different locations were examined for temporal trends. In some cases where effort was estimated consistently between areas, geographic comparisons were also made.

**Methods**

CPUE data presented in this report were compiled from port sampling and sea sampling of commercial catches conducted by the states of Maine, New Hampshire, Massachusetts, and Rhode Island and from monthly log books collected in Connecticut and annual surveys conducted in New York (Table 16). Research data comes from studies carried out at the Seabrook Nuclear Power Station, Seabrook, NH and the Millstone Nuclear Power Station, Waterford, CT. CPUE estimates from these studies only apply to the respective study areas and are not comparable to CPUE estimates derived from the commercial fishery since the traps that are used do not have escape vents.

Estimates of CPUE for lobster traditionally include catch per trap and catch per trap haul. Catch per trap is the simplest of the three and the least reliable since no attempt is made to account for the number of times a given trap is hauled during a period of time. Catch per trap haul is calculated as total numbers or pounds of lobsters caught or landed divided by the total number of trap hauls. This calculation, though straightforward and easy to do, does not account for immersion (or soak) time. Catch is known to vary with soak time, but not linearly (i.e., there is an optimum soak time beyond which the catch per day declines). If soak time does not vary greatly from one trap haul to the next, catch per trap haul is a reasonable index.

Catch per trap haul (CTH) and catch per trap haul set-over-day (CTHSOD) are used by the states of Maine, New Hampshire and Massachusetts to estimate CPUE (Table 16). Rhode Island estimates catch per trap haul. Connecticut collects information on numbers of trap hauls and average soak time from which CTH and CTHSOD can easily be calculated. New York only compiles data on trap numbers. CPUE data collected by the two power stations are in CTH (Millstone) and CTHSOD (Seabrook). Most of the CPUE data from the commercial fishery are obtained from sea sampling. Maine is the only state with a port sampling program (Section 6.1.2).

Since catch does not increase linearly with soak time, CTHSOD varies depending on how soak time is treated in the calculation. Massachusetts standardizes to three set over days in order to adjust for variable soak time, using the approach described by Sinoda and Kobayasi (1969) (Table 17). Seabrook Nuclear Power Station also follows this method and standardizes CTHSOD as catch per 15 traps adjusted to two set-over-days (Table 18). Maine does not standardize to any particular soak time, but instead factors in soak time (or, average soak time when the information is collected at the dock for a trip when many different traps were hauled that soaked for various time periods) with the number of trap hauls to get CTHSOD.

CPUE data compiled for this assessment were the following:

- Numbers of marketable lobsters per trap haul and per trap haul set over days for three statistical areas along the Maine coast (511-513) from Maine port sampling data, 1989-1996;
- Numbers of marketable lobsters per trap haul and per trap haul set over days for area 513 from NH sea sampling data, 1992-1998;
- Total numbers of lobsters above and below 3.25" CL (the approximate minimum legal size) caught in 15 traps per two day soak from two sampling sites off the NH coast from Seabrook Power Station study, 1975-1998;
- Numbers of marketable lobsters per trap haul per three day soak for three areas off the MA coast (514, 521, and 538) from MA sea sampling data, 1981-1997;
- Numbers of marketable lobsters per trap haul for inshore RI waters (area 539) and for two canyons on the southern New England continental shelf (located in areas 537 and 616) from RI sea sampling data, 1991-1998;
- Numbers of legal-sized and all lobsters per trap haul from three sampling sites in eastern Long Island (area 611) near the Millstone Power Plant, 1978-1998;
- Numbers of marketable lobsters per trap haul and per trap haul set over days estimated from CT landings and effort data compiled from logbooks filled out by CT fishermen, 1984-1997.

**Results**

Maine CPUE increased slightly in area 511 during the last ten years, doubled in area 512, and did not change in area 513 (Figures 122 and 123). Current CPUE estimates are approximately twice as high in area 512 as in area 511, with intermediate values in area 513. A decrease in area 513 is evident in recent New Hampshire sea sampling data (Figure 124). Seabrook CPUE data for lobster above 3.25 inches CL declined by 75% during the 1980s and then leveled off during the last ten years (Figure 125). Catch rates for undersized lobsters at these two nearshore stations remained fairly stable until 1995-1998.

CPUE in Massachusetts Bay (area 514, GOM) fluctuated without trend between 1981 and 1997 (Figure 126), although there was a downward trend during the last four years from a peak in 1994. In area 521 (east of Cape Cod) there was a clearly defined upward trend between 1986 and 1992, followed by decreasing CPUE during the last few years. CPUE in area 538 (Buzzard Bay) has varied widely and without trend since 1981, but rose sharply in 1997 after five years of very stable values. CPUE in area 538 was higher than the other two areas during the 1980s, but area 521 CPUE was highest during the 1990s. Area 514 CPUE was consistently lower than in the other two areas. These results reinforce the conclusion that catch rates along the southern GOM coast (southern Maine, NH, and Massachusetts Bay) are lower than in other areas.

There was no discernible trend in CPUE of marketable lobsters in inshore RI waters during the last eight years (Figure 127). The offshore areas showed an increase between 1995 and 1997 followed by a drop in 1998. Offshore catch rates were higher than inshore catch rates.

In eastern Long Island Sound (area 611), the Millstone Power Station data indicate a slight increasing trend in total lobster CPUE, but catches were comprised mostly of sublegal lobsters (Figure 128). CPUE for legal sized lobsters declined during the 1980s and leveled off during the 1990s, but increased in 1997 and 1998. In contrast, scaled CPUE estimates based on CT landings and effort data (Figure 129) increased steadily during the 1980s and early 1990s and abruptly during 1994-97.

### 10.7 GEAR SATURATION

Many factors in the lobster trap fishery influence catchability (q) (Miller 1989, 1990; Karnofsky and Price 1989; Addison and Bell 1997; Addison and Bannister 1998). As a passive gear, catches are dependent upon animals encountering, entering, and remaining in the gear. Individual trap saturation (maximum number of animals inside a trap at a given time) occurs as a result of the interaction between the animal and the gear (Auster 1985; Miller 1989; Fogarty and Addison 1992). Each trap is assumed to have an effective area of influence that changes with many factors as well (Eggers et al. 1982).

Catch efficiency may be affected by local effort level or gear density (Angelsen and Olsen 1987; Rugolo et al. 1998). This is termed gear saturation or gear competition (not to be confused with trap saturation) and is defined by Ricker (1975) as a type 3 competition where the setting of an additional unit of gear interferes directly with other units of gear. In this case, instead of a direct linear relationship between fishing mortality and effort, the efficiency of each unit of fishing gear decreases as the total amount of gear increases (see below). In a simple fishery with no gear saturation, a 10% change in fishing effort would produce a 10% change in fishing mortality. With gear saturation, the change in fishing mortality would be less than 10%. In addition catch rates (e.g., numbers of lobster caught per trap haul) would not change in proportion to changes in population size. Management measures aimed at controlling fishing mortality by regulating fishing effort must account for gear competition in order to be fully effective.

If gear saturation exists in the lobster fishery, it should be more likely in areas with high trap densities and/or low lobster abundance. Available estimates of trap densities are summarized below. They suggest that there are large differences in trap density between different areas on the Maine coast and also between larger areas (e.g., Maine and Long Island Sound) within the range of the resource. Trap densities in the Mt. Desert Island region of the Maine coast were considerably lower than in Boothbay and Penobscot Bay. Trap densities increased during 1997-1999 in Mt. Desert Island and Boothbay. Also, there are currently more traps per unit area along the Maine coast than in Long Island Sound.

## Methods

Hypotheses about gear saturation in the lobster fishery were tested statistically using catch data, fishing effort data and estimates of fishing mortality. In theoretical fisheries with mobile trawl gear and a fish stock that is well mixed and distributed randomly, fishing mortality rate (F) changes with fishing effort (f):

$$F = q\,f$$

where q is the catchability coefficient that measures the impact of one unit of fishing effort on fishing mortality rates (Hilborn and Walters 1993). In theoretical fisheries, catchability (q) is constant and the relationship between effort (f) and mortality (F) is simple and proportional. In real fisheries, catchability may change as a function of the type of fishing gear used, resource abundance and other factors.

| Year | Region | Traps/km$^2$ | Source | Method |
|---|---|---|---|---|
| 1988 | GOM, Boothbay | 438 | Kelly (1993) | Aerial Photos |
| 1989 | | 555 | Kelly (1993) | Aerial Photos |
| 1990 | | 559 | Kelly (1993) | Aerial Photos |
| 1996 | | 576 | Steneck (Sea Grant) | Visual |
| 1997 | | 660 | Steneck (Sea Grant) | Visual |
| 1999 | | 768 | Steneck (NOAA) | Visual |
| | | | | |
| 1996 | GOM, Mt. Desert I. | 159 | Steneck (Sea Grant) | Visual |
| 1997 | | 145 | Steneck (Sea Grant) | Visual |
| 1998 | | 292 | Steneck (NOAA) | Visual |
| | | | | |
| 1998 | GOM, Penobscot Bay | 778 | Steneck (NOAA) | Visual |
| 1999 | | 908 | Steneck (NOAA) | Visual |
| | | | | |
| 1998 | Gulf of Maine * | 206 | This report | Estimation |
| 1998 | Long Island Sound ** | 110 | This report | Estimation |

* Total # traps tags sold in 1998 (2.8 million) divided by total area inside 3 miles (13,742 km$^2$). This density may be overestimated since not all 2.8 million traps are fished in state waters.

** Total # CT+NY traps (585,000) divided by total area of LIS (5,300 km$^2$). This density may under-represent density in nearshore waters if most traps are fished there.

Because of gear saturation, the catchability coefficient for lobster may vary in relation to fishing effort. Hypotheses were tested statistically ($p=0.05$) by fitting a model with $q=A\,f^{B-1}$ so that:

$$F = Af^{B}$$

The model is easy to fit by linear regression because:

$$\log(F) = \log(A) + B\log(f)$$

where log (A) and B are the intercept and slope parameters from the log-log regression model. All effort data used in this analysis were compiled on a calendar year basis whereas fishing mortality was estimated on a survey year basis, i.e., from October 1 through September 30 of the following year.

Statistical tests on the estimate for B may provide useful information about saturation in the lobster fishery. In particular, if the slope parameter B is not significantly different from zero, then fishing mortality might not be related to fishing effort, at least not over the range of estimates available for the analysis. However, in a practical sense, a regression analysis with a non-significant slope is inconclusive because the negative result might be due to using crude estimates of fishing effort (e.g., total trap numbers or trap hauls not adjusted for soak time), low statistical power caused by small data sets, limited range in fishing effort and mortality estimates, measurement errors, and autocorrelation in statistical errors. An inconclusive test (B not significantly different from zero) does suggest, however, that changes in fishing effort as measured in the analysis would result in changes in fishing mortality that would be too small to be readily measured.

If a log-log regression is statistically significant ($B \neq 0$) then a second statistical test can be performed to see if the slope equals one. If B is not significantly different from one, then the statistical evidence suggests constant catchability (q) and the relationship between fishing effort and fishing mortality is a simple, proportional one (i.e., no saturation). If B is significantly less than one, then the statistical evidence supports the hypothesis of gear saturation because fishing mortality and fishing effort are related such that increases in effort cause fishing mortality to increase, but not proportionally.

Regression results, even when statistically significant, can be implausible. For example, if B is significantly greater than one, then the statistical evidence supports the hypothesis that traps become more efficient (increasing q) as fishing effort increases. This is probably impossible in the lobster fishery. Another possibility is that regressions have significant negative slopes (i.e., $B<0$), in which case q and trap efficiency decline as fishing mortality decreases. In this impossible case fishing mortality apparently would decrease as effort increased.

Likelihood distributions are similar to confidence intervals and give additional information about results from log-log regression analyses. They complement hypothesis tests described above by measuring the likelihood of the data over a wider range of possible parameter values. Unlike hypothesis tests, likelihood distributions are not affected by choice of null or alternative hypotheses.

Based on regression results and assuming normality, the likelihood of the regression data (D) given a parameter value B, can be approximated:

$$L(D \mid B) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left[\frac{(B-\hat{B})}{\hat{\sigma}}\right]^2}$$

where $\hat{B}$ is the regression (maximum likelihood) estimate and $\hat{\sigma}$ is its estimated standard error. For each regression analysis, likelihoods L(D|B) were calculated for B values between –3 and 3 and plotted. In addition, likelihoods for average values of $\hat{B}$ (and standard errors) were calculated and plotted for the GOM, SCCLIS (fall surveys only) and SCCLIS (spring surveys only). Finally, the likelihood distribution for the grand mean $\hat{B}$ from all data sets was calculated and plotted.

**Data Sources**

Gulf of Maine Stock (GOM)

The 1982-97 fishing mortality estimates for GOM male and female lobsters were derived from DeLury model analyses for two subareas of the GOM: Massachusetts Bay (statistical area 514) and the remaining portion of the stock area (statistical areas 511-513 and 515) (Table 19 and 20). All effort data used for this stock area were in units of trap hauls, although ME, NH, and MA also compile effort statistics in trap haul set over days (Section 10.6).

The number of trap hauls (TH) in Massachusetts Bay (area 514) were only available from 1990 to 1998, but total inshore trap haul data for the whole state were available from 1985 to 1998. To estimate TH levels in MA waters of the GOM (area 514) between 1985 and 1989, a linear regression was developed between total inshore trap hauls (TITH) and area 514 trap hauls (TH) from 1990 to 1998:

$$TH = -5.24 + 1.214 * TITH \ (r^2 = 1.0)$$

Area 514 trap hauls (TH) during 1985-89 were estimated by substituting TITH values from 1985 to 1989 into the linear regression equation (Table 20).

To test for gear saturation in these two subareas of the GOM, the two sets of DeLury-based male and female F estimates from 1982-97 were fitted to the corresponding Maine and Massachusetts fishing effort (f) data using the log-log regression.

Spatial correspondence between Area 514 fishing mortality estimates and MA effort data was better than for the rest of the GOM which included all of the Maine and offshore waters. Fishing mortality rates derived from the DeLury analysis of the NMFS trawl survey data may not represent fishing mortality in nearshore waters along the Maine coast where the effort data were collected. For this reason, MA effort data and Area 514 mortality estimates may provide more reliable tests for gear saturation.

South Cape Cod Long Island Sound (SCCLIS)

The 1982-97 fishing mortality estimates for SCCLIS male and female lobsters (Tables 21 and 22) were derived from DeLury model analyses for two subareas of the SCCLIS stock area, the inshore portion of the RI coast (statistical area 539) and Long Island Sound (area 611). F estimates for area 539 were from DeLury model runs based on RI trawl survey data and 50% of the area 539 landings (Section 8.3). The RI trawl survey is conducted in Narragansett Bay and within a few miles of the RI coast (Section 6.2), therefore the fishing mortality rates for this area reflect stock conditions in nearshore waters. Fishing mortality estimates for Long Island Sound (area 611) were based on DeLury model runs using fall and spring CT trawl survey data.

Fishing effort for area 539 was expressed in terms of trap hauls (Gibson 1999). For Long Island Sound, effort was estimated as both total number of traps used by NY and resident CT fishermen and as trap hauls by resident CT fishermen (Section 6.1.1). Attempts were made to derive a trap haul effort index between 1985-97 for the south shore of Massachusetts (statistical area 538) using the linear regression approach described above for the GOM. However, the regression of total inshore trap hauls and area 538 trap hauls for 1990-97 was not significant ($P>0.05$) and therefore not used to estimate trap hauls in area 538 during 1985-89.

Georges Bank and South (GBS)

The only effort data available from this stock area were from two fairly localized nearshore fishing grounds, the area east of Cape Cod (area 521) and the south shore of Long Island (areas 612 and 613). These effort estimates were not considered by the Subcommittee to be representative of fishing effort for the entire stock area, even on a relative basis. Furthermore, the fishing mortality estimates for this area were derived from the NMFS trawl survey, which covers the entire area. Therefore, no tests for gear saturation in this area are reported in this assessment.

**Results**

As described above, care is required in interpreting results of hypotheses tests for gear saturation in lobster due to factors including lack of statistical power and small sample size and limited range in fishing effort and fishing mortality data. This type of skepticism is good practice even when all theoretical assumptions are met in the regression analyses. In addition, the "errors in variables" problem often encountered in spawner-recruit analyses is potentially important because it bias estimates of the slope parameter in a regression analysis towards zero. For lobster, errors in variables may make estimates of the saturation parameter B from log-log regressions tend towards zero (implying gear saturation), even if the true value is one (no saturation exists).

Gulf of Maine (GOM)

Fishing effort (f) expressed as Maine trap hauls did not show any obvious trend between 1982 and 1997, but MA trap hauls declined almost 100% between 1989 and 1997 (Figure 130). Fishing mortality rates in MA coastal waters (area 514) were very high and variable (for both sexes) throughout the 1985-97 time period and increased during the last five years (Section 8.1.1). Fishing mortality rates in the much larger portion of the GOM that is indexed by the NMFS trawl survey were much lower and declined during the last ten years (Section 8.1.2).

The slope (B) estimates for the log-log regressions between fishing mortality and Maine TH estimates were not significantly different from zero for either male or female lobsters (Table 23, Figure 131). The same was true for the regressions using MA TH data (Figure 131). Likelihood distributions for the GOM stock area (Figure 136) are grouped nearer $B=0$ than $B=1$. Three out of five distributions (ME females, MA females and GOM average) had implausible negative estimates of B with the bulk of their mass over implausible negative B values. The average saturation parameter for the GOM was –0.208 (SE 0.142).

### South Cape Cod Long Island Sound (SCCLIS)

Fishing effort (f) in area 539 (RI coastal waters) increased four-fold between 1982 and 1997 (Figure 132). Similar increases occurred in Long Island Sound, but more notably in terms of traps fished, not trap hauls, meaning that trap numbers increased faster than trap hauls. The number of traps fished by CT and NY fishermen increased by about the same amount (3.5 times) as RI trap hauls. The estimated number of trap hauls by CT residents in LIS increased by about two-thirds between 1984 and 1997 and remained fairly steady between 1990 and 1995. Comparing trap hauls in the two locations, there was clearly a larger increase in area 539. As described in Section 8.3, fishing mortality rates for male and female lobsters in area 539 (RI survey) were high, and varied without trend during the last 16 years. In Long Island Sound, F estimates based on fall trawl survey data increased whereas F estimates based on spring trawl survey data did not change (Figure 79). The fall F estimates also had a larger range than the spring estimates.

The slope (B) estimates for the log-log regressions between area 539 fishing mortality (F) and RI TH were not significantly different from zero for either sex (Figure 133 and Table 23).

Tests for gear saturation in Long Island Sound that were based on fishing mortality rates that were estimated from fall CT survey data (Figure 134, Table 23) produced very different results than results based on F estimates from spring CT survey data (Figure 135, Table 24). Regressions based on spring trawl survey data were similar to the RI results. Three out of four regressions using fall estimates were significantly different from zero. All four slopes were also different from one, but regressions based on trap hauls (Figure 134) had slopes that were nearly equal to two and were implausible. Slopes of regressions based on trap numbers were not as steep. Even these results are equivocal, however, since trap numbers are a poor estimate of fishing effort.

Results of regression analyses for Long Island Sound show how sensitive these tests are to ranges and trends in fishing mortality. It is difficult to reach any definitive conclusions regarding gear saturation in Long Island Sound.

Likelihood distributions based on fall survey data show that estimates were erratic and usually implausible (Figure 136). Two out of seven distributions (males and females, RI trap hauls) were centered over implausible negative B values. Two distributions (fall males and females, CT trap hauls) were centered over implausibly high B values (B>1). Two distributions (fall males and females, CT+NY traps) and the distribution for average parameters were centered and had the bulk of their likelihood over plausible B values between zero and one. The average saturation parameter for the SCCLIS area based on fall survey data was 0.785 (SE 0.085).

Likelihood distributions based on spring survey data (Figure 136) were grouped closer to B=0 than B=1. However, the bulk of the distributions was over implausible negative B values and maximum likelihood estimates from the regression analyses were often negative. The average saturation parameter for the SCCLIS area based on spring survey data was –0.106 (SE 0.22).

**Conclusions**

It was difficult to reach any solid conclusions about relationships between fishing mortality and fishing effort as measured by the data currently available. Definite conclusions were impossible because effort data were crude, likelihood distributions were broad, and because most of the individual regression analyses produced implausible parameter values. The average of the maximum likelihood estimates from all data sets was 0.252 (SE 0.158) with the bulk of the likelihood over plausible values (Figure 136). Some members of the LSASC felt that the results, as a whole, suggest that gear saturation may occur in the lobster fishery. Others felt, in view of the many problems and uncertainties, that no conclusion could be reached.

A very important practical problem in interpreting relationships between fishing effort and mortality data for lobster is lack of understanding about how lobster traps and fishing effort work. Estimates of the saturation parameter B=0 may imply that traps become less and less efficient as the number of traps increases so that fishing mortality tends to be limited.

A competing hypothesis predicts that traps may work like shovels in a sand pile, individually catching a fairly constant quantity of lobster over a wide range of abundance levels. If this were true recent fishing mortality rates would have remained fairly steady while effort increased because abundance of the stock kept going up. This hypothesis implies that fishing mortality may increase dramatically if recruitment and abundance declines while fishing effort remains high (because catch will remain high as abundance declines).

We have experience with fishing mortality in the lobster fishery at low effort and abundance levels, and at high effort and high abundance levels, but no experience with high effort and low abundance levels. It was therefore not possible to predict whether fishing mortality rates would remain stable or increase when recruitment and abundance begin to decline.

While compiling the effort data available from different jurisdictions it became obvious that the number of licensed traps was a relatively poor measure of effort. Trap numbers do not measure how efficiently the traps are being fished. The number of times a trap is hauled, the length of time it fishes between sets, as well as the area fished, bait used, time of year fished, and proximity to other gear will all effect how efficiently it catches lobsters. This has management implications when attempting to control effort through controls on the total number of licensed traps.

## 10.8 SEX RATIOS

**Introduction**

Interpreting trends in mortality rates or evaluating the status of lobster stocks using sex ratio data is not very straightforward. In unexploited lobster stocks the sex ratio would be expected to vary by size group. Assuming lobsters hatch at a 50-50 sex ratio, and assuming there is no differential mortality between sexes, the sex ratio would begin to shift more heavily towards females around the size that females become sexually mature due to differential growth rates between mature males and females (Skud 1969). This happens because mature female lobsters molt less frequently than males of the same size (Section 2.6). In addition, the molt increments of males may also be larger than for females of the same size (Templeman 1936; Skud 1969). As a result, mature females of different ages accumulate in discrete size groups while males continue to grow from one size group to the next, thus producing higher proportions of females in each size group. However, as long as male and female mortality rates are the same, differential growth will result in males eventually outnumbering females at very large sizes because fewer females survive long enough to attain these large sizes (Skud 1969).

Assuming that their biological characteristics (growth and maturity rates) remain the same, and assuming no differential mortality between sexes, size-specific sex ratios in exploited and unexploited lobster populations should be the same. However, as the size structure of the exploited stock changes, due to the increasing removal of animals by the fishery, the sex ratio of the exploited population will change. As larger lobsters are removed and the population size structure shifts toward the minimum legal size, the overall sex ratio of the stock should more closely resemble the sex ratio of the dominant size group. Since most of the commercial catch in all three stock areas is derived from lobsters within one molt of legal minimum size, the sex ratio of the total catch and of the legal-sized portion of the population should be correlated with the average size of female maturity in each stock unit and to the sex ratio of the first molt group. In stocks with a higher proportion of smaller maturing females (e.g., the SCCLIS stock), females should make up a higher proportion of the legal sized population and the landings. As long as growth and maturity rates remain the same over time, there is no reason to expect changes in fishing mortality to produce any trends in size-specific sex ratios.

Several realities complicate this scenario, however. First, it has been shown that in some areas there may be different migration patterns between sexes (e.g., inshore-offshore migrations of females in southern New England) and also that the sex ratio of the catch can be dependent upon small-scale changes in depth or differential behavior of males and females of different sizes which affect how many lobsters of each sex enter or remain in traps. Second, as discussed in sections 2.4.3 and 9.2 of this report, maturity ogives as well as growth rates not only vary among stock units, they vary within stock units. Thus, even within stock units, assuming no migration, no exploitation, and no differential mortality, one would still expect spatial or habitat-related differences in the sex ratio of lobsters in different size groups (see, for example, Section 4.6). This is then further complicated by management regulations that protect females, but not males (Section 5.3).

Despite these complications, data from several sources were evaluated to try and identify trends in size specific sex ratios of lobster stocks or landings in the three stock areas which might be related to temporal or spatial differences in male and female fishing mortality rates. It is possible that sex ratio data could provide an independent source of stock assessment information that could be compared with the output from models like the DeLury model in much the same way as they are used as a tuning index in the simulation model (Appendix A). The examination of sex ratio data in this report represents the first attempt to explore this possibility for U.S. American lobster stocks.

### Methods

Sex ratio data that were examined for each stock unit are summarized below (P and L signify whether data were collected from Populations or Landed lobsters; unless otherwise noted, molt groups were defined by 10, 11 and 14 mm CL intervals for the SCCLIS, GOM, and GBS stocks, respectively). Sex ratios were calculated as percent female in all cases. All data except the Maine sea and port sampling data were smoothed using a three or five year running average. Thus, references to specific years (year t) in the text, tables, and graphs are, in fact, references to three or five year averages (years t, t-1, t-2, etc.). Data available on sex ratios comes from small sample sizes and sex ratios are highly variable.

| *Stock* | **Data source** | | **Data resolution** |
|---|---|---|---|
| *GOM (11 mm)* | NMFS fall trawl survey | P | 4 groups: one molt below and 1, 2, and 3 molts above legal size |
| | Maine port sampling | L | 4 10 mm size groups above legal size |
| | Maine sea-sampling | P/L | 5 10 mm size groups: one below and 4 above legal size |
| | MA fall trawl survey | P | 2 groups: one molt below legal size, and all lobsters above legal size |
| | MA sea-sampling | L | legal lobsters (>83 mm, no egg bearing females) |
| *GBS (14 mm)* | NMFS fall trawl survey | P | 4 groups: one molt below and 1, 2, and 3 molts above legal size |
| | NJ trawl surveys (4/yr) | P | 4 groups: <73 mm, 73-82, 83-92 and 93+ mm CL |
| | RI sea-sampling (Block and Hudson Canyons) | P/L | 3 groups: two molts below 83 mm and all marketable lobsters >83 mm |
| *SCCLIS (10 mm)* | NMFS fall trawl survey | P | 4 groups: one molt below and 1, 2, and 3 molts above legal size |
| | MA fall trawl survey | P | 2 groups: one molt below legal size, and all lobsters above legal size |
| | RI fall trawl survey | P | 3 groups: one molt below, one above and two above legal size |
| | CT fall trawl survey | P | 2 groups: one molt below legal size and all lobsters above legal size |
| | CT spring trawl survey | P | 2 groups: one molt below legal size and all lobsters above legal size |
| | MA sea-sampling | L | legal lobsters (>83 mm, no egg bearing females) |
| | RI sea-sampling | P/L | 3 groups: two molts below 83 mm and all marketable lobsters >83 mm |

Trawl survey data for lobster and other species in the northeast are routinely tabulated using delta distribution techniques (Pennington1986) to avoid problems due to "zero" tows (e.g. survey tows containing no lobsters). Delta distribution techniques may make sex ratio information for lobster harder to interpret because the sum of delta means for male lobsters and delta means for female lobsters does not, in at least some cases, exactly equal the delta mean calculated for male and female lobsters combined. This potential problem was trivial in this assessment because of other uncertainties about interpreting sex ratio data for lobster. It may, however, deserve attention in the future if sex ratio data for lobster are used for assessment purposes.

## Results

### Gulf of Maine

Recruits collected in the NMFS and MA bottom trawl surveys in the GOM are almost equally divided between males and females (Table 25). The sex ratio has remained fairly stable in both surveys over the past 15-20 years, although the proportion of females in the NMFS survey increased by 10% in the last three years (and Figure 137 and 139). In contrast, females accounted for 63% of all the recruits caught in Maine sea sampling trips between 1985 and 1997 and there was evidence of a slight increase in the proportion of females in recent years (Figure 140).

Fully recruited (83+ mm CL) female lobsters also make up about half of the catch in the NMFS survey, but considerably less than half of the catch in Massachusetts coastal waters (Table 25). The percentage of 83+ mm females in the MA survey varied from year to year, but declined from >40% in the mid 1980s to an average of 31% during 1996-98 (Figure 139). On the other hand, Massachusetts sea sampling data show an increasing trend since the late 1980s in the percent females (Figure 143).

There was a general decline in the percentage of legal-sized females in the earlier years of the NMFS survey, particularly between 1985 and 1992 (Figure 138). Since then females have been making up an increasing proportion of the fully recruited population in the large area of the GOM covered by this survey (Figure 26). The individual molt groups above the minimum legal size have averaged 48-54% female for the entire 21 year time series (Table 25) with downward trends in the first two molt groups between the late 1970s and the early 1990s. The percentages of females has increased in all three groups for approximately the last six years (Figure 138).

Analysis of Maine port sampling data showed a 50-50 sex ratio of landed lobsters in the 83-92 mm size group that did not change over time and declines in percent females in the 93-102 size group which only made up 37% of the landed catch during 1996-98 and the largest size group (113+ mm) which included <20% females in 1998 (Figure 141). Both of these size groups included >50% females in the late 1960s. On the other hand, there was no trend in the sex ratio of the third molt group which included 45% females during 1996-98 (Table 25). Maine sea sampling data (marketable lobsters only) also failed to show a trend in the sex ratio of the first molt group above the minimum size, but the next size group again followed a downward trend, this time from 52% to 35% (Figure 142).

The fact that females made up a diminishing percentage of second molt group lobsters in the population and in the landings (Table 25) seems contradictory. If it were a result of increasing exploitation rates on females (relative to males), landings would include an increasing, not a decreasing, percentage of females in this molt group. The only possible explanation is that more males are recruiting to the exploited population (as is indicated by DeLury model abundance estimates for the GOM stock area, see Figure 50) and surviving capture in the first molt group, (52% females during 1996-98) but not in the second (37% female). The implication is that an increasing proportion of male lobsters are avoiding capture in the first molt group, as their abundance increases.

In both the Maine port and sea sampling data, 52% of the landed lobsters in the first molt group in recent years were females, with a lower percentage (37%) in the second molt group and an intermediate percentage (44-45%) in the third group (Table 25). As would be expected, the total catch in each of these size groups (legals plus protected females) included higher percentages females, especially molt groups 2-4 which include most of the mature females.

### Georges Bank and South

The sex ratio of lobsters one molt group below minimum legal size in this stock area has varied between 40 and 55% female over the past 20 years (Figure 144). Female recruits were more numerous in the NMFS trawl survey as recently as 1992, but made up a decreasing percentage of the catch between 1992 and 1995. Males also outnumbered females between 1987 and 1989. The percentage of female recruits has increased from 40 to 45% during the last four years. Females made up 44% of the recruits and 55% of the legal-sized lobsters (83+ mm) caught in the NJ trawl surveys between 1989 and 1998. No trends were discernible.

Additional information on the sex ratio of lobsters in Block and Hudson Canyons, on the southern flank of the southern New England continental shelf, is available from RI sea sampling data (Figure 147 and Table 26). Pre-recruits (55-68 mm) averaged 55% female and recruits (69-82 mm) 69%between 1993 and 1998. Neither size group showed a trend.

Sex ratio data for fully recruited lobsters in this stock area show substantial temporal shifts that are consistent with male and female abundance and mortality estimates derived from the DeLury model analyses of trawl survey abundance indices and landings (Section 8.2). The percentage of 83+ mm females in the NMFS trawl survey declined steadily from >60% in the late 1970s to 50% in 1989, increased sharply to 70% in 1995 and then dropped just as abruptly to 55% in 1998 (Figure 144). DeLury model estimates of fully recruited male abundance and male fishing mortality follow very similar trends, with male abundance decreasing and male F increasing during the same time period when females were making up a larger and larger proportion of the trawl catches (Figure 61 and 62). Unlike males, female abundance and fishing mortality have remained fairly stable over the past 16 years (Figure 64). DeLury model estimates of the sex ratio of fully recruited lobsters in the GBS stock area during 1995-97 (32%) were lower than the ratio derived from trawl survey catches alone (40%).

The sex ratio of the first fully-recruited size group also declined from >50% females at the beginning of the time series to <40% in the early 1990s, then increased after 1992 (Figure 145). The two larger fully recruited size groups were predominantly female throughout the time series. The sex ratio of the second group averaged 61% and declined from more than 70% in 1993 to 50% in 1998. The largest size group averaged 69% female and also declined in recent years, from 86% in 1995 to 73% in 1998.

The increasing percentage of females in the larger size groups (not males, as would be expected if the mortality rates of the two sexes were the same) is consistent with DeLury model results which show that males are exposed to higher fishing mortality rates than females. Even though females accounted for 52% of the 1993-98 catch of marketable lobsters in the RI sea sampling data and 56% in the MA sea sampling data during 1996-98 (Table 26), legal-sized females are about twice as abundant in this stock area as males (Section 8.2). The percentage of landed females in area 521 (east of Cape Cod) has been increasing slowly over the past ten years whereas there has been no change in the two canyons sampled in areas 537 and 616 (Figure 146 and 147).

### Southern Cape Cod/Long Island Sound

Sex ratios for recruits calculated from NMFS trawl survey data collected mostly in statistical area 539 were extremely variable even after smoothing (Figure 148) owing to the small number of tows made each year and the small numbers of lobsters captured, but averaged 62% female in recent years, higher than the recent averages in any of the other trawl surveys conducted in more inshore waters (Table 27). On average, females accounted for <40% of all the recruits captured by trawl in coastal RI waters and 49% in Long Island Sound in the fall and 59% in the spring. Females dominated trap catches sampled during sea sampling trips in areas 539. Pre-recruits averaged 49% female in area 539. The higher proportion of female recruits (higher than the pre-recruits) in these two data sets can be attributed to the increased maturation of females in the larger size group.

Of the seven different time series of recruit sex ratio data, three showed upward trends (i.e., an increasing proportion of females), one showed a downward trend, and three failed to show any overall trend (Table 27). The most obvious shift occurred on the south shore of Massachusetts (Figure 149) where females accounted for about 30% in the mid 1980s and >50% in recent years. The percentage of female recruits caught in LIS in the fall CT survey declined between 1986 and 1992, then increased through 1998 (Figure 151) while the spring survey data showed a slight upward trend overall, but not since 1992 (Figure 152). The high percentage (75%) of female recruits in the RI sea sampling trips did not change over a six year time period; similarly, pre-recruits remained at 50% female (Figure 153). However, females only accounted for 30% of the recruits captured in the inshore RI trawl survey in 1998 (Figure 150).

As was true of the recruits, the sex ratio of fully recruited (83+ mm CL) lobsters in the NMFS survey data was also skewed more highly towards females than in any of the other trawl surveys (Table 27 and Figure 148). Three of the other survey data sets (RI fall, CT fall and spring) produced sex ratios of 83+ mm lobsters for 1996-98 that were <50% female. Legal-sized lobsters in area 538 have only recently become predominantly female, following the same upward trend as the recruits (Figure 149). On the other hand, according to the RI trawl survey, legal-sized females are currently outnumbered by males 3 to 1 (as they also were in the early 1980s), but were caught in nearly equal numbers only a few years ago (Figure 150).

In Long Island Sound, fully recruited lobsters caught in the fall survey were predominantly males (61%), but in the spring the sex ratio fluctuated above and below 50% female (Figure 151 and 152), averaging 49% (Table 27). Recent trends in the proportion of fully recruited females in the two CT surveys were also opposite, up in the fall and down in the spring. Currently they are about the same (Figure 151 and 152), about 45%.

Fully recruited lobsters captured during sea sampling trips in area 539 have remained at or just below 60% female since the early 1990s (Figure 153) and between 57 and 65% in area 538 since the mid 1980s (Figure 154).

Owing to the scarcity of lobsters larger than one molt group above minimum legal size in this stock area, sex ratios were only computed for individual molt groups in one instance, the RI trawl survey in area 539 (Table 27). In this case, annual sex ratios for the first and second molt groups were nearly identical, so they were combined into a single 83+ mm group and not displayed graphically.

Caution should be used when considering sex ratio data. Although the trawl surveys have consistent methodologies over time, timing, location, and sample size of sea and port sampling data could bias sex ratios toward one sex or the other.

Sex ratios of lobsters in all three stock areas vary widely. There are a number of factors that are likely to contribute to the fluctuations in sex ratios observed in these data. They include: differential growth rates relative to size at sexual maturity, differences in catch rates due to behavioral segregation, management regulations that are specific to females, differential exploitation rates between sexes, and survey noise. After a thorough review of all the available sex ratio data, it was not possible to draw any conclusions on how changes in sex ratio affect the overall status of the lobster resource in each stock unit.

### 10.9 PROPORTION HARDSHELL/SOFTSHELL

An analysis was done to compare the annual proportion of recently molted softshell lobsters in the landed catch over time. Increased proportions of softshell lobsters would be indicative of changes in fishing strategy which target recently molted animals, but don't necessarily increase fishing mortality. Thus, there is no reason to expect that changes in the percentage of softshell lobsters in the catch would follow trends in fishing mortality. It is likely that they would be related to shifts in the seasonal pattern of landings and effort (Section 10.10).

Molting in legal-sized American lobster generally occurs during warm-water months, typically late June-November with peaks in July and September-October. Also, as lobsters get larger (older), the intermolt duration increases (Section 2.6.1). Additionally, egg-bearing female lobster exhibit a delayed molting cycle. Therefore, the proportion molting is dependent on the time of year, size (age), and sexual maturity (females only). Proportion molting may also be influenced by population density.

This evaluation of hardshell/softshell proportion was exploratory in nature. Shell hardness can be evaluated in different ways. Caution should be taken when interpreting data on shell condition without a standardized approach to monitor shell harness. A change in sampling personnel can cause broad fluctuations in data that appear illogical.

#### Methods

A limited amount of information on the proportion of softshell male and female marketable lobster (i.e., excludes egg bearing females) was available from Massachusetts sea sampling trips in areas 514, 521, and 538 and from Rhode Island offshore sea sampling trips to Block and Hudson Canyons (areas 537 and 616) and inshore trips (area 539) in southern New England (Figure 1). Proportions were calculated for all legal sized marketable lobsters from Massachusetts sea sampling data, and for three size groups of marketable lobsters (first, second and third fully-recruited molt groups) from Rhode Island sea sampling data. Softshell lobsters were defined as lobsters with new shells or lobsters with "soft" shells that had not yet hardened. Designation of softshell lobsters was somewhat subjective since it depended on the judgement of the sea sampler. Definitions of size groups were based on molt increment data for each area, i.e., 10 mm CL in the SCCLIS stock area (areas 539 and 538), 14 mm CL in the GBS stock area (areas 521, 537 and 616) and 11 mm CL in the GOM (area 514).

## Results

### Gulf of Maine

Massachusetts sea sampling data in area 514 (Figure 1) showed an increase in the proportion of softshell lobsters in the landed catch from almost zero in 1981-82 to 28% in 1990 followed by a decline to <10% in 1995-96 (Figure 155). The percentage increased to 20% in 1997. No data were available from Maine or NH.

### Georges Bank and South/Offshore

Massachusetts sea sampling data from area 521, east of Cape Cod, show a steady increase in the percentage of 83+ mm landed softshell lobsters from <10% during the 1980s to 32% in 1995 (Figure 155). After 1995 the percentage dropped to very low percentages in a single year and remained below 10% through 1998. Without additional information on the location and timing of fishing during 1993-95 and 1996-98, it is impossible to speculate on what caused such a sudden shift in the harvest of recently molted lobsters in this area.

Rhode Island sea sampling data from Block and Hudson Canyons (Figure 156) show similar trends in the first two fully recruited size groups of males and females. Softshell lobsters made up 25%-50% of the landings in 1991 and 70%-87% two years later and for the rest of the time series. Male landings were composed of higher percentages of softshell lobsters than female landings, with the second size group of males reaching the highest percentage (90%). The third fully recruited size groups of males and females also showed increasing percentages of softshell lobsters between 1991 and 1993, but the percentages declined after that to values that were intermediate between the low in 1991 and the high in 1993. The percentage of landed softshell lobsters in 1998 (both sexes, first two size groups) varied from 69% to 82%. Recently molted lobsters in these two locations are clearly being targeted by the fishery.

### Southern Cape Cod/Long Island Sound

Massachusetts sea sampling data from area 538 followed a similar pattern to the area 521 data except that higher percentages were reached during the 1990s and the initial estimate for 1981 was high (Figure 155). Discounting 1981, the percentage of softshell lobsters in the landed catch remained below 10% until 1988, then increased to 40% in five years and 50% in eight years before dropping suddenly in 1996-97. The increasing harvest of recently molted lobsters in this area may be related to an expansion of the fishery into federal waters that occurred east of Cape Cod during the 1990s (Section 10.11). Whatever caused the abrupt drop off in 1996 and 1997 in this area also occurred south of Cape Cod in area 538, but not north of Cape Cod in area 514. This drop off appears to coincide with a new sampler taking over both Areas 521 and 538 in 1996.

Rhode Island sea sampling data for the first two fully recruited size groups of males and females from inshore waters in area 539 (Figure 157) show a similar trend to the offshore RI data. (So few larger lobsters were encountered that the data were not reliable). Percentage softshell increased sharply between 1991 and 1993 then declined somewhat through the end of the time series. The percentage of softshell lobsters in the 1998 landings (both sexes, first two size groups) varied from 58% to 68%. Recently molted lobsters in this location are clearly being targeted by the fishery as well.

## 10.10 SEASONAL TRENDS IN LANDINGS AND EFFORT

Trends in the seasonal distribution of lobster landings (numbers) were examined for each stock unit (Section 7.1). Reported landings were collated into survey year quarters and the proportion of landings by quarter were calculated. Survey year quarters were partitioned as 1st quarter (fall) = October – December, 2nd quarter (winter) = January – March, 3rd quarter (spring) = April – June, and 4th quarter (summer) = July – September.

The proportion of lobster landings by quarter remained relatively constant in the GOM (Figure 158) and George's Bank & South (Figure 159) stock units. The fourth quarter consistently accounted for the largest proportion of lobster landings, followed by the first, third, and second quarters, respectively. Proportionally more lobsters are landed from the GOM during the summer and from the GBS stock area in the winter and spring.

The proportion of SCCLIS landings from the fourth quarter declined between 1982 and 1997 (Figure 160). In survey year 1997 the proportion of summer landings was 6.6% below the time series mean. Despite this declining trend the fourth quarter still accounted for the largest proportion of total lobster landings in this stock area. Conversely, the proportion of landings in the first quarter increased over the time series (1997 was 13.7% above the time series mean). These trends reflect a change in fishing practices in recent years in which lobsters are targeted during the fall molt. There was no change in the proportion of lobsters landed in the second and third quarters. Even though the fall landings are increasing in importance in this area, they still do not account for as high a percentage of the annual landings as in the GOM stock area.

More detailed information available from Long Island Sound showed somewhat different results. Data collected from CT residents fishing in central and western Long Island Sound were examined for evidence of changes in the seasonal patterns of landings and effort over the 19-year time series from 1979 to 1997. The proportion of annual landings from each month was plotted for seven different groups of years (Figure 161 and 163). These data show that the proportion of landings coming from April, May and June has steadily declined, while the proportion of landings coming from November and December has steadily increased. Figure 162 shows the same information plotted a bit differently. Here the spring, summer and fall seasons are represented by the months of April and May, July and August, and November and December respectively. June, September and October were omitted because they are transition months when the availability of lobsters is affected by weather conditions which could distort any trends in landings. Figure 162 shows that the proportion of landings coming from July and August varied without trend between 40% and 50 % throughout the time series, while the proportion of landings from April and May steadily declined and the proportion of landings from November and December steadily increased.

The proportion of trap hauls by season was examined in the same way (Figure 163 and 164). This was done to see if the trend in the proportion of landings among seasons was due to changes in the availability of lobsters among seasons, or changes in the distribution of effort among seasons. Distribution of effort among seasons shows the same trend as landings. The proportion of effort in the summer has varied without trend since 1979 with a slight increase in the last few years. Similarly the proportion of effort in the fall has steadily increased while the proportion of effort in the spring has steadily decreased.

This information suggests that there has been a shift in fishing strategies, with fishermen targeting lobsters in the fall rather then in the spring. Although Long Island Sound does represent a significant portion of the SCCLIS stock unit, the patterns observed in the proportion of landings for the entire stock unit (Figure 160) do not match those shown here. This must be the result of a different seasonal distribution in fishing effort or differences in the availability of lobsters in other portions of the SCCLIS stock area.

There is a potential economic loss or gain to fishermen if the price they receive for lobsters differs between the spring and fall seasons. Shifts in fishing effort that result in the targeting of newly molted lobsters are symptomatic of increased competition in a fishery that already relies on lobsters in the first molt group above minimum size for >90% of the annual harvest (Section 10.5).

One possible biological consequence of shifting effort to target new shedders is that they have not had an opportunity to extrude eggs before they are caught. This would have an impact on potential egg production and calculated eggs per recruit. The egg production is never realized because lobsters are caught prior to egg extrusion, which affords females additional protection.

### 10.11 TRENDS IN SPATIAL DISTRIBUTION OF EFFORT

There has been a substantial increase in fishing effort in the GOM over the past 5-10 years. The traditional nearshore trap fishery has expanded into many areas approximately 5-15 miles from shore. The estimated number of traps in Maine increased from around 2.0 million in 1988 to 2.8 million in 1998. The average number of traps fished per boat increased from around 400 in 1985 to over 600 in 1998. Average soak time went from 3.6 days to 4.4 days during the same period (Section 5.2).

A significant amount of new effort has come from harvesters displaced from the groundfish and urchin fisheries. Many of these fishers transferred into lobstering because of declining finfish and urchin stocks, more restrictive management in these fisheries and higher profitability in lobsters. Increased density of traps in nearshore fishing grounds has resulted in gear conflicts and reduced production in some areas (i.e., declining catch per trap haul). This has forced many fishers to seek lobstering areas further from shore. Advances in technology (e.g., wire traps, improved electronics) as well as faster and larger boats have resulted in greater fishing power and efficiency. This has allowed fishers to haul more traps and to make day trips to areas rarely fished only 5-10 years ago (Terry Stockwell, ME DMR, personal communication).

The offshore expansion has also been facilitated by the reduced amount of trawling by groundfish vessels in areas including Jeffrey's Ledge and Platts Bank where traps could previously not be set without being damaged or lost. Displaced groundfishers who had knowledge of areas where lobsters were located but were not being trapped moved into these areas. In order to support the higher overheads of larger vessels and crews, these harvesters fished more traps and longer days. This effort often resulted in much higher landings than the traditional nearshore fishery produced. High landings at the docks resulted in increased inter-boat competition, with

many traditional lobster fishers gearing up and heading offshore (Terry Stockwell, ME DMR, personal communication). The expansion of effort into these areas could potentially add to removal rates from the stock as a whole and possibly increase the harvest of larger reproductively active lobsters that are more abundant in deeper water, thus reducing spawning stock biomass.

Recent areal expansion of the fishery has been documented off Washington County in eastern Maine. Interviews were conducted with 20-30 lobster fishers in fishing communities between Jonesport and West Quoddy Head for several years in the mid-1980s and again in the winter of 1998-99 for the purpose of determining when and where herring eggs were deposited on lobster traps (Stevenson et al. 1999). The traditional lobster fishery along the shore east of Cutler is conducted within a mile or less from shore. A few fishermen have had traps on offshore banks in the vicinity of Machias Seal Island (eight miles offshore) since the late 1970s, but no traps were set in the intervening 6-7 miles of the Grand Manan Channel until the last 4-5 years. Now, there are so many traps in the channel that trap trawls are laid on mud bottom within a tenth of a mile or less from each other. Also, catch rates have declined in local nearshore waters to the point where traps are sometimes left for a week between hauls (as opposed to being hauled every 3-4 days).

In Massachusetts, total fishing effort measured as the total number of trap hauls (number of trips x average number hauls reported) has steadily declined since 1990. There has also been a shift in fishing effort from inshore to offshore areas (Figure 23). For the entire state, trap hauls decreased by 33% between 1990 and 1998 (Figure 165). Inshore trap hauls (areas 1-14) declined by 28% while offshore trap hauls increased by 53%. The decline in inshore trap hauls was more pronounced (50%) north of Cape Cod (Figure 166) and most of the increased "offshore" fishing effort occurred outside of state waters east of Cape Cod. As the total number of trap hauls declined the total number of traps increased (Figure 166). This trend (more traps, fewer trap hauls) is correlated with increased soak times (Figure 167). Another possible factor that could reduce trap hauls and increase soak time is reduced catch rates. There is, however, no evidence that CPUE in Massachusetts has declined in recent years (Figure 168).

The number of traps fished in both NY state and federal waters south of Long Island did not change much from 1979-1988 (Figure 169). Since 1988 the number of traps has increased three-fold, but traps were not moved out of state waters into federal waters (Figure 170). In fact, the proportion of traps fished in state waters (within three miles) increased from about 35% in the late 1970s and early 1980s to >50% in the early 1990s. In the last three years there has been a slight increase (5%) in the proportion of traps fished in federal waters compared to state waters.

### 10.12 RECRUITMENT INDICES

The Lobster Assessment Subcommittee examined two time series of density estimates of newly settled lobsters for evidence of variability in year class strength and of temporal trends that could possibly be used at some point in the future 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. Settlement data were provided by Rick Wahle, Bigelow Laboratory for Ocean Sciences, W. Boothbay Harbor, ME.

Settlement was measured by taking suction samples of natural cobble substrates. Settlement strength was defined as the abundance of newly settled lobsters (0+ year class: <10 mm CL in ME, <13 mm CL in RI) in cobble nurseries after the end of the settlement season. Settlers have been measured identically at the same eight sites every year since 1989 in mid-coast Maine (Boothbay Harbor region), and since 1990 at six sites in Rhode Island (Narragansett Bay). This is the longest settlement time series available for the species. Data are also available from other sites in Maine, from New Hampshire and from four regions (16 sites) in Massachusetts, but only for the past four years.

The Maine data suggest that settlement has declined since 1989-91 (Figures 171 and 172). Densities at the Maine sites were low in 1993 and between 1995 and 1998, then increased somewhat in 1999. Densities at the RI sites were low in 1992-93 and again in 1995-96, but moderate in 1997-99. Settlement was strong in 1994 at all sites. Overall, densities in ME and RI correlated fairly well (Figure 173). The downward trend was most apparent for the ME data: in fact, a t-test for slope deviating from zero was significant for the ME data, but not for the RI data. Settlement densities at several sites in Massachusetts were also mostly below 0.5 per square meter during 1995-1998 (Bob Glenn, MA Division of Marine Fisheries, personal communication), but without any data prior to 1995 it is not known whether these observations indicate reduced settlement or not.

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 because 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 ME and RI, suggests that settlement varies similarly on a regional basis and enhances the possibility that annual sampling at a relatively few selected sites could provide sufficient data for documenting temporal changes in year class size and, possibly, for forecasting changes in the abundance of recruits prior to their entry into the fishery.

The extent to which trends in settlement will eventually affect landings in any given year depends on the survival of juvenile lobsters 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 information on growth, lobsters in mid-coast Maine are likely to enter the fishery at the age of 6-8 years. Year class size ranges are currently estimated by modal analysis of size-frequency distributions. Uncertainty remains in defining size at age, however.

# 11.0 RECOMMENDATIONS AND FINDINGS

## 11.1 STOCK STATUS SUMMARY

### 11.1.1 Gulf of Maine (GOM)

State of the Stock: Despite recent increases in landings and fishing effort, fishing mortality rates declined and abundance increased during the last ten years in the stock area as a whole, however a sub-area (Massachusetts Bay) showed very different conditions from the rest of the stock area. Total landings increased by 75% from 1982-1997, reaching a record high of 26,230 metric tons in 1997.

The average annual 1995-97 fishing mortality rates were 0.74 (49% annual exploitation rate) for females and 0.59 (42%) for males, with 80% confidence intervals of 0.54-0.88 and 0.30-0.70 respectively. Even though females are protected from fishing to a greater degree, female fishing mortality rates in the GOM were noticeably higher than male fishing mortality rates every year since 1987. Fishing mortality rates have remained relatively stable since 1993 for both males and females, but were higher in the late 1980s. There were no trends in exploitation indices calculated from NMFS fall survey data or in NMFS survey mass balance fishing mortality rates for either sex.

Average recruit abundance during 1994-97 was 50% above the long term mean and was particularly strong in 1994 and 1996. Fully-recruited (83+ mm) population abundance was 88% above the time series average during 1995-97. Total potential egg production, as indexed by the NMFS fall survey, increased during 1994-98 after varying without trend from 1976 to 1993.

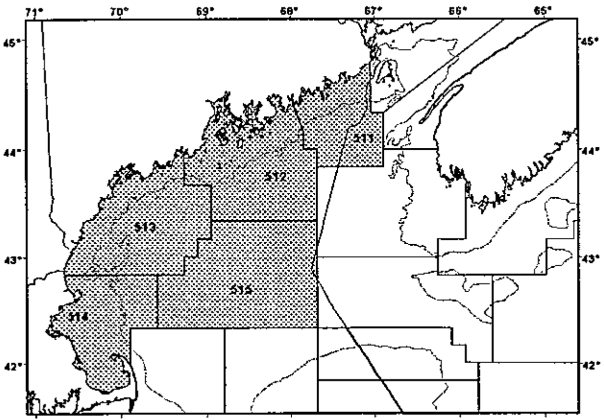
Stock conditions in Area 514 (Massachusetts Bay) were different than the rest of the GOM: there was no change in recruitment over the past 16 years; full-recruit abundance (only 30% female) declined slightly in recent years; total potential egg production was higher during the early 1980s than during more recent years; fishing mortality rates are high and have increased in recent years; and fishing effort is shifting from inshore waters to fishing grounds located further offshore.

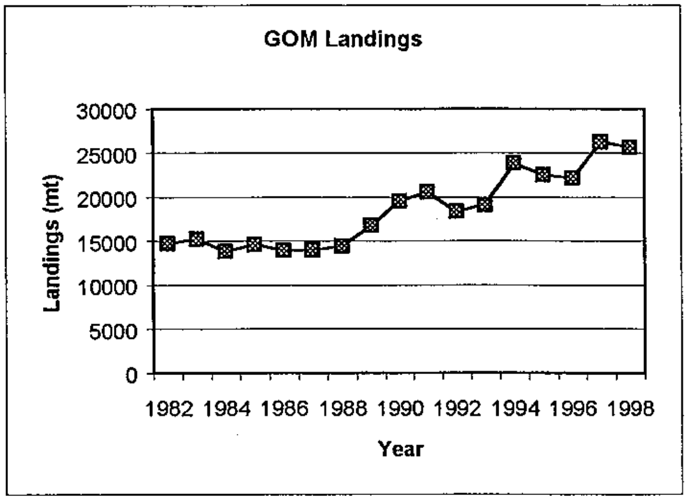
Coastal Maine and New Hampshire waters are not adequately surveyed by the NMFS fall trawl survey. A fisheries independent diver survey in four regions along the coast of Maine provided evidence of increasing abundance in eastern Maine and a downward trend in western Maine from 1989-1999, conforming with landings data. The downward trend in western Maine was similar to that observed in the Massachusetts inshore trawl survey in area 514. Fishing mortality rates for the GOM stock as a whole may be under-estimated since the majority of the NMFS survey data does not come from the more heavily exploited inshore area.

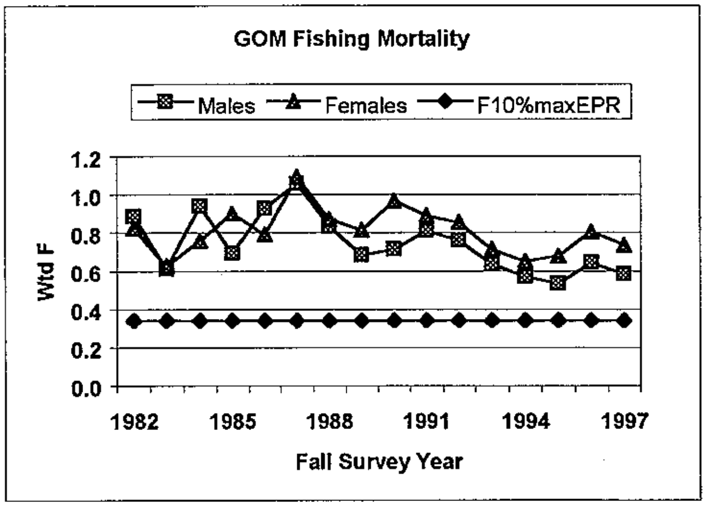
Egg production per recruit, based on 1995-1997 female fishing mortality, was 3.2% of maximum EPR. There was at least a 90% probability that female fishing mortality rates have exceeded the $F_{10\%}$ EPR reference point (0.34) for this stock every year since 1982. According to the ASMFC overfishing definition this stock is overfished. However, recruitment into the

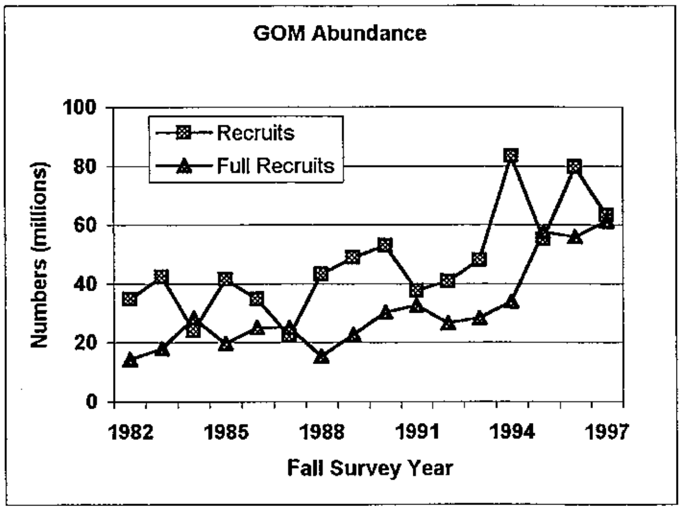
# Gulf of Maine – Stock Status Summary Figures and Tables

**Gulf of Maine Stock Area and Statistical Areas**




GOM Landings


GOM Fishing Mortality


GOM Abundance

| *Year*[1] | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | Max[5] | Min[5] | Mean[5] |
|---|---|---|---|---|---|---|---|---|---|---|
| *Total landings (1000s of mt)* | 18.3 | 19.1 | 23.8 | 22.5 | 22.1 | 26.2 | 25.6 | 26.2 | 13.8 | 19.7 |
| *Female landings (numbers in millions)* | 14.54 | 16.31 | 18.97 | 18.94 | 21.83 | 22.13 | | 22.13 | 11.73 | 15.61 |
| *Male landings (numbers in millions)* | 16.85 | 19.13 | 21.86 | 18.27 | 22.32 | 23.04 | | 23.04 | 12.86 | 16.80 |
| *Abundance female recruits*[2] | 17.75 | 21.54 | 36.42 | 22.48 | 36.47 | 31.13 | | 36.48 | 9.75 | 21.69 |
| *Abundance male recruits*[2] | 23.01 | 26.34 | 47.01 | 32.66 | 43.28 | 32.07 | | 47.01 | 9.74 | 25.32 |
| *Abundance female fully recruited*[3] | 11.40 | 11.80 | 14.19 | 23.83 | 21.45 | 25.11 | | 25.11 | 5.15 | 13.17 |
| *Abundance male fully recruited*[3] | 15.10 | 16.58 | 19.79 | 33.70 | 34.41 | 36.12 | | 36.12 | 8.36 | 17.74 |
| *Female F*[4] | 0.85 | 0.71 | 0.65 | 0.68 | 0.80 | 0.73 | | 1.09 | 0.62 | 0.81 |
| *Female exploitation rate* | 54% | 48% | 45% | 46% | 52% | 49% | | 62% | 43% | 52% |
| *Male F*[4] | 0.76 | 0.63 | 0.57 | 0.53 | 0.64 | 0.58 | | 1.06 | 0.53 | 0.74 |
| *Male exploitation rate* | 50% | 44% | 41% | 38% | 44% | 41% | | 61% | 38% | 52% |

[1] Total landings by calendar year, male and female landings by survey year (Oct 1 year t to Sept 30 year t+1). [2] Sum of abundance estimates from DeLury analyses of MA and NMFS fall trawl survey data for last molt group below minimum legal size at time of survey. [3] Sum of abundance estimates from DeLury analyses for two subareas based on MA and NMFS fall trawl survey data for all lobsters >83 mm CL. [4] Abundance weighted averages of DeLury F estimates for two subareas. [5] Maximum, minimum and mean landings for 1982-1997 survey years and 1982-1998 calendar years.

fishery, total potential egg production, and stock abundance have increased in recent years, thus the majority of the LSASC concluded that the stock is not currently recruitment overfished. Based on yield per recruit analysis for females, this stock is growth overfished.

### Landings

The GOM accounts for 71% of the current U.S. lobster harvest. Landings were stable and averaged 10,000 mt a year between 1962 and 1976, reached 20,000 mt in 1991, and exceeded 25,000 mt in 1997/98. Eighty-three percent of the GOM harvest is landed in Maine ports. The catch is evenly divided between males and females. The fishery became increasingly dependent on recently-molted lobsters during the 1970s and 1980s (70% of the Maine landings in 1973 compared to 90% in 1989), but since the late 1980s first molt group lobsters have accounted for a declining proportion of the catch as older lobsters have become more abundant. Summer (July-September) landings make up more than 50% of the harvest and there were no trends in the seasonal distribution of landings over the past 16 years. Not all areas are experiencing increasing production, however. Landings in MA ports north of Cape Cod dropped by 18% between 1997 and 1998.

### Fishing effort and CPUE

Fishing effort has been increasing in GOM in recent years, but not in all areas. The number of traps used in Maine increased from around 2.2 million during 1990-95 to 2.7 million during 1996-98 at the same time that the number of traps fished per boat, the total number of trap hauls, and the average soak time per trap were also increasing. There is evidence of a shift in fishing effort from heavily exploited inshore fishing grounds to new grounds located 10-15 miles offshore during the past 5-10 years. In Massachusetts Bay, for example, the number of inshore trap hauls declined by 50% since 1990 while offshore they have increased by about 50%. Catch per trap haul and per trap haul set over days of marketable sized lobsters increased in mid-coast ME (area 512) during the past ten years, but not in eastern ME, western ME, NH and MA waters.

### Data and Assessment Methods

Fall survey year landings (in numbers) and landed size frequencies were estimated from ME port sampling data, and NH, MA, NMFS and Canadian Department of Fisheries and Oceans (DFO) sea sampling data for 1994-1997. Population size and mortality estimates were based on DeLury model analyses of male and female annual landings and NMFS fall trawl survey abundance indices in areas 511-513 and 515 and on DeLury model analyses of annual male and female landings and MA fall trawl survey data from area 514. Weighted average estimates of male and female fishing mortality for the entire stock area were calculated from individual DeLury analyses. Fishing mortality estimates based on length cohort analysis were not used because they were biased by steadily increasing recruitment. For this assessment, changes were made to female maturity and fecundity parameters used in the egg-per-recruit model, but not to molt probability and molt increment estimates. The quarterly time steps used in the model were changed to start in July-September, the quarter when 60% of the landings occur. In addition to DeLury model results, a series of other indices based on surveys, landings, and catch sample data were examined for evidence of trends in the fishery or stock status.

### Fishing Mortality and Exploitation Rates

For the entire stock area, female and male fishing mortality rates peaked in 1987 (F = 1.1, both sexes) and then declined, with secondary peaks in 1990 (females, F = 0.97) and 1991 (males, F = 0.81). Average annual 1995-97 fishing mortality rates were 0.74 (49% annual exploitation rate) for females and 0.59 (42%) for males. Eighty percent confidence intervals for average 1995-97 fishing mortality rates were 0.54-0.85 for females and 0.39-0.70 for males. Fishing mortality rates remained relatively stable after 1993 for both males and females. Male fishing mortality rates exceeded female fishing mortality rates in some years prior to 1989, but since 1989 females have been subjected to consistently higher removal rates than males.

Fishing mortality rates derived from the inshore MA survey (area 514) were much higher than fishing mortality rate estimates derived from the NMFS survey. MA survey fishing mortality rate estimates increased during the last four years whereas NMFS survey fishing mortality rate estimates in recent years did not change. Fishing mortality estimates for the GOM stock as a whole are probably under-estimated since the majority of the survey data does not come from the more heavily exploited inshore area. There was no clear trend in exploitation indices calculated from landings and NMFS survey data, but high values in 1988, 1993, and 1997 produced an upward trend for females in area 514 (MA survey). Mass balance fishing mortality rate estimates based on NMFS and MA survey abundance indices had improbable values and no clear trends.

### Recruit Abundance

Combined DeLury model results for the entire stock show a 50% increase in recruit abundance (males and females combined) during 1994-97 compared to the mean, with a general increasing trend since the late 1980s and peaks in 1994 and 1996. The MA survey showed no clear trend in recruitment while the NMFS survey shows a clear upward trend since the late 1980s. NMFS and MA trawl catches of recruits were equally divided between males and females throughout the time series.

Total potential egg production estimated from MA trawl survey catch rates in area 514 was higher in the early 1980s and then varied without trend. NMFS trawl survey data indicate that potential egg production varied without trend until 1994 and has increased during the last four years, with a peak in 1996. According to this survey, about 75% of the potential egg production in the GOM is currently derived from lobsters larger than 93 mm (one molt after recruitment) compared to about 15% in Area 514 where large lobster became increasingly scarce in the 1990s. Juvenile lobster settlement indices for the Boothbay Harbor region of the Maine coast declined since 1989.

### Fully-Recruited Abundance

Estimated abundance of legal-sized lobsters in the entire stock area varied without trend during the 1980s, then increased slightly and leveled off in the early 1990s. Stimulated by increased recruit abundance in the last four years, fully-recruited population size increased by 88% during 1995-97 compared to the long term mean. Increased population size for the stock as a whole is based on the NMFS survey DeLury model runs; estimated population sizes in Area 514 (MA survey) declined slightly.

For the whole stock, increased recruit abundance of males relative to females after 1989 has produced a fully-exploited population that is currently only 40% female. Fully-recruited females are less abundant in area 514 now than the average during the last 16 years (males have not changed) and currently make up only 30% of the fully exploited population.

Biological Reference Points

The egg-per-recruit model indicates that the female fishing mortality rate which achieves 10% of the maximum egg production per recruit for this stock is 0.34 (29% annual exploitation rate). The $F_{10\%}$ reference point was slightly sensitive to changes in growth, natural mortality, and fecundity, but not to reduced fishing mortality rates for larger lobsters. Yield per recruit increased over the range of fishing mortality rates examined and $F_{0.1}$ was equal to 0.17.

### 11.1.2 Georges Bank and South (GBS)

State of Stock

Unlike the other two stocks, landings, recruit abundance and full recruit population size remained relatively stable in the GBS stock area over the past 16 years. Total landings increased steadily from 2,444 mt in 1982 to a peak of 4,279 mt in 1990, and remained stable around 3,600 mt from 1992-1998. This stock is composed of a higher proportion of larger lobsters than the other two stocks. The fishery is less dependent on first molt group lobsters with 60-70% of the landings comprised of first molt group lobsters since the early 1990s compared to 90% in SCCLIS.

The average annual 1995-97 fishing mortality rates were 0.41 (31% annual exploitation rate) for females and 0.63 (44%) for males, with 80% confidence intervals of 0.32-0.46 and 0.59-0.69, respectively. Fishing mortality rates were higher for males, which only made up 30% of the average fully-recruited population but 53% of the landings during 1995-97. Patterns in DeLury model fishing mortality rates were confirmed by survey mass balance fishing mortality rates and exploitation indices. Average abundance weighted fishing mortality rate estimates for 1995-1997 calculated by length cohort analysis were 54% higher for females and 48% higher for males than estimates derived from DeLury model runs.

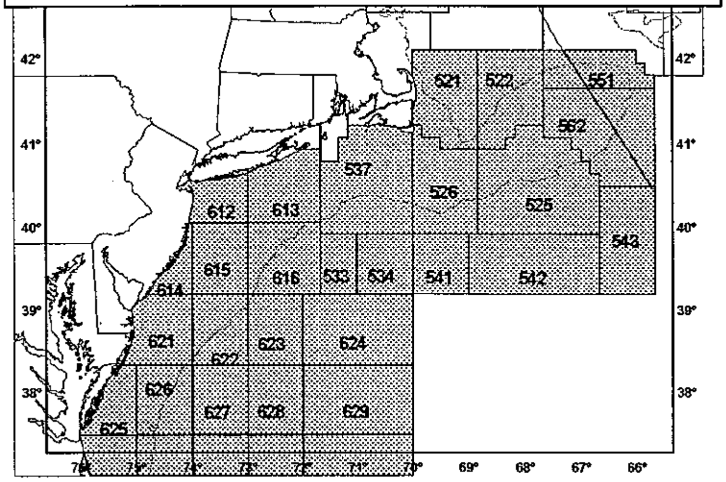
The abundance of recruits varied without trend over the time series. Abundance of fully recruited males dropped steadily from a high in 1988 to a low in 1995 while fishing mortality on males doubled between 1988 and 1994. Male abundance increased in the next two years as the fishing mortality rate dropped. The abundance of fully-recruited females was above average during the last four years, after varying without trend since 1982.

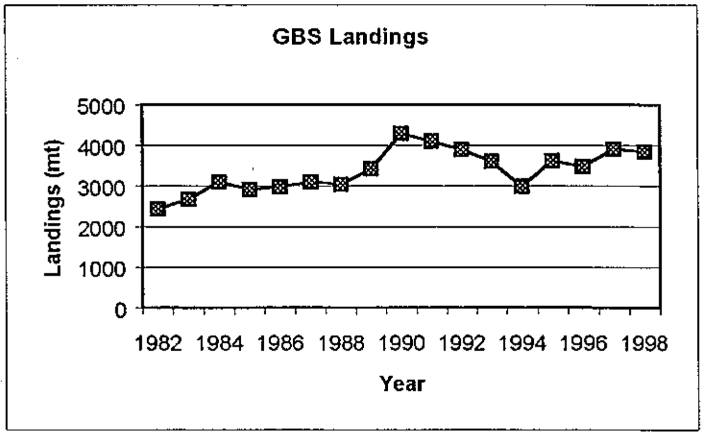
Total potential egg production changed very little since 1976 and is currently at average levels with 80-90% produced by lobsters at least one molt group above minimum legal size.

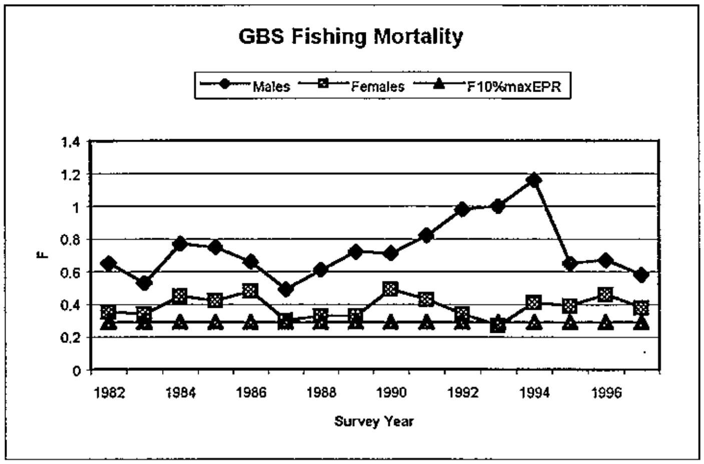
Egg production per recruit, based on 1995-1997 female fishing mortality, is 6.2% of maximum EPR. There is at least a 90% probability that female fishing mortality rates have exceeded the $F_{10\%}$ EPR reference point (0.29) for this stock in 8 out of the last 16 years.

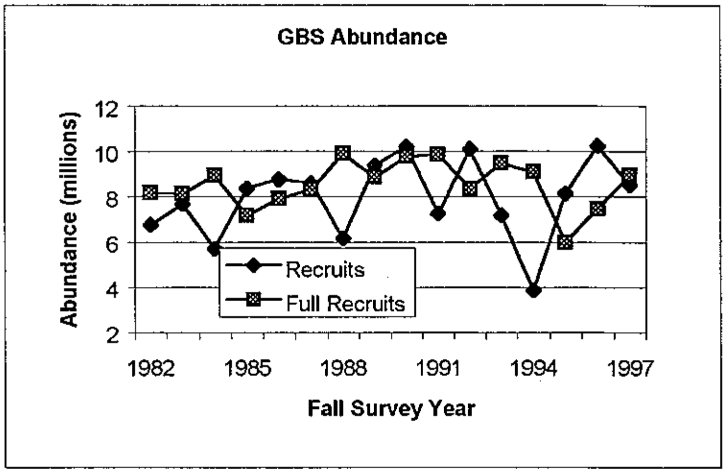
# Georges Bank and South – Stock Status Summary Figures and Table

**Georges Bank and South Stock Area Map with Statistical Areas**









| Year[1] | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | Max[3] | Min[3] | Mean[3] |
|---|---|---|---|---|---|---|---|---|---|---|
| Total landings (1000s of mt) | 3.9 | 3.6 | 3.0 | 3.6 | 3.5 | 3.9 | 3.8 | 4.3 | 2.4 | 3.4 |
| Female landings (numbers in millions) | 2.95 | 3.02 | 3.19 | 2.63 | 3.41 | 3.08 |  | 4.70 | 1.58 | 2.68 |
| Male landings (numbers in millions) | 3.53 | 3.11 | 2.91 | 2.51 | 2.79 | 2.78 |  | 3.53 | 2.34 | 2.87 |
| Abundance female recruits[2] | 6.23 | 3.79 | 0.84 | 3.72 | 6.19 | 3.73 |  | 6.23 | 0.84 | 4.18 |
| Abundance male recruits[2] | 3.87 | 3.38 | 3.01 | 4.44 | 4.05 | 4.78 |  | 5.15 | 2.27 | 3.76 |
| Abundance female fully recruited[2] | 5.82 | 7.42 | 7.35 | 4.70 | 4.90 | 6.03 |  | 7.42 | 4.70 | 5.83 |
| Abundance male fully recruited[2] | 2.55 | 2.07 | 1.73 | 1.28 | 2.58 | 2.92 |  | 4.24 | 1.28 | 2.69 |
| Female F[2] | 0.34 | 0.27 | 0.41 | 0.39 | 0.46 | 0.38 |  | 0.49 | 0.27 | 0.39 |
| Female exploitation rate | 27% | 22% | 31% | 30% | 34% | 29% |  | 36% | 22% | 30% |
| Male F[2] | 0.98 | 1.00 | 1.16 | 0.65 | 0.67 | 0.58 |  | 1.16 | 0.49 | 0.73 |
| Male exploitation rate | 59% | 59% | 65% | 45% | 46% | 41% |  | 65% | 36% | 49% |

[1] Total landings by calendar year, male and female landings by survey year (Oct 1 year t to Sept 30 year t+1). [2] Estimates from DeLury analysis of NMFS trawl survey data. [3] Maximum, minimum and mean landings for 1982-1997 survey years and 1982-1998 calendar years.

According to the ASMFC overfishing definition this stock is overfished. However, recruitment into the fishery, total potential egg production, and stock abundance have remained stable, thus the majority of the LSASC concluded that the stock is not currently recruitment overfished. Based on yield per recruit analysis for females, this stock is growth overfished.

## Landings

Landings increased slowly from less than 2,000 mt a year in the early 1960s (when bottom trawls were the principal gear type) to 4,300 mt in 1990, and then declined to a 1992-1998 average of 3,400 mt. The 1998 catch from this stock area represented 11% of the total U.S. lobster catch and 1995-97 landings were 53% female.

The proportion of landed lobsters in the first molt group above minimum legal size increased steadily from the mid-1980s to the early 1990s, but leveled off at 60% (males) and 70% (females) afterwards. The catch from the GBS stock area is not dominated by first molt group lobsters to the same extent as catch from the other two more heavily exploited stocks.

Most lobsters (45%) are harvested in the summer (July-September), but fishing in the winter and spring (January-June) accounts for a larger percentage of the landings from this stock area than in the other two areas. There were no trends in the seasonal distribution of landings since 1982.

## Fishing Effort and CPUE

Catch per trap haul set over days of marketable lobsters in inshore federal waters east of Cape Cod increased by about 50% from the mid 1980s until 1992, but declined during the past five years. Catch per trap haul of marketable lobsters from Block and Hudson Canyons was higher in 1996/97 then during 1991-1995, but dropped in 1998. No historical effort or CPUE data were available from Georges Bank itself.

## Data and Assessment Methods

Fall survey year landings (in numbers) and landed size frequencies were estimated from RI and MA sea sampling data from Block and Hudson Canyons and east of Cape Cod, and on NMFS sea sampling trips in other parts of the GBS stock area during 1994-1997. Population size and mortality estimates were based primarily on DeLury model analyses of male and female annual landings and NMFS fall trawl survey abundance indices for the entire area. Fishing mortality rate estimates were also derived from length cohort analysis of landed size frequencies in recent years. Changes were made to female maturity and fecundity parameters used in the egg-per-recruit model, but not to molt probability and molt increment estimates. In addition to DeLury model results, a series of other indices that relied on information from surveys, landings, and catch sample data were examined for evidence of trends in the fishery or stock status.

## Fishing Mortality and Exploitation Rates

DeLury male fishing mortality rate estimates increased from 0.47 in 1987 to a peak of 1.16 in 1994, then dropped abruptly to average 0.63 (44% annual exploitation rate) during 1995-97. Female DeLury fishing mortality rate estimates showed no trend over the 16-year time series, but were above the long term average during the last four years. The 1995-97 average female fishing mortality rate was 0.41 (31% annual exploitation rate). The 80% confidence intervals for average 1995-97 fishing mortality rates were 0.59-0.69 for males and 0.32-0.46 for females. Trends in exploitation indices were similar to trends in fishing mortality, showing no change for females after 1985 and an upward trend for males during the 1990s with a return to lower values in 1996-97. Abundance weighted LCA estimates of 1995-97 fishing mortality were 48% (males) and 54% (females) higher than DeLury estimates.

Trends in DeLury male and female fishing mortality rates since 1982 were corroborated by mass balance estimates of fishing mortality rates (which rely on survey abundance but not catch data) and exploitation indices derived from annual catch and survey abundance indices.

Recruit Abundance

Recruit abundance in GBS showed no trend after 1980, in contrast to the increasing trends of the GOM and SCCLIS. Female recruits in the NMFS survey varied throughout the time series, falling below 45% of lobsters caught in 1987-1988 and 1994-1998.

Total potential egg production declined from above average values between the late 1970s and the mid 1980s, then increased to average long term values in the late 1980s and early 1990s and remained average through the end of the time series. Eighty to ninety percent of the potential egg production in this stock area since 1976 was produced by females greater than 96 mm CL (one molt after recruitment). Large (>180 mm) females were less abundant during 1994-98 than in earlier years.

Fully-Recruited Abundance

There was no change in the total abundance of fully recruited lobsters in the GBS stock area during the past 16 years. However, there were changes in sex ratios. The percentage of fully recruited females in the NMFS trawl survey declined steadily from more than 60% of lobsters caught in the late 1970s to 50% in 1989, increased sharply to 70% in 1995 and then dropped just as abruptly to 55% in 1998. DeLury model estimates of sex ratio of fully recruited lobsters during 1995-1997 (32% female) were lower than the ratio derived from trawl survey catches alone (40% female).

Larger lobsters were predominantly female throughout the time series (>60% of the 125+ mm size group), but were less so in recent years. A small proportion of total egg production between 1976 and the early 1990s was derived from females as large as 200 mm CL, but since 1994 the largest females caught in the survey were 180 mm CL.

Biological Reference Points

The egg-per-recruit model indicates that the female fishing mortality rate which achieves 10% of the maximum egg production per recruit for this stock is 0.29 (23% annual exploitation rate). The $F_{10\%}$ reference point was slightly sensitive to changes in growth, natural mortality, and fecundity, but not to reduced fishing mortality rates for larger lobsters. The female yield per recruit curve for this stock peaked at $F_{max} = 0.28$ with a $F_{0.1}$ value of 0.10.

### 11.1.3 South of Cape Cod and Long Island Sound (SCCLIS)

State of the Stock

Despite a steady increase in landings, and fishing mortality in recent years, the number of recruits in the SCCLIS stock area increased almost three-fold since the mid 1980s. Landings increased steadily from 2,352 mt in 1982 to a record high of 6,894 mt in 1997, nearly tripling over the time series.

Average 1995-97 fishing mortality rates were estimated from fall landings and survey data were 1.41 for males (71%) and 1.25 for females (67%) with 80% confidence intervals of 1.2-1.5 and 1.07-1.37, respectively. These fishing mortality rates were much higher than the average 1995-97 fishing mortality rates in the other two assessment areas. Fishing mortality rates for the SCCLIS stock as a whole fluctuated, but generally increased after the mid-1980s and remained above 1.0 (60% annual removal rate) during the past ten years. Recent fishing mortality estimates derived from CT fall survey data in LIS were even higher (80% removal rates) and increased steadily since the early 1980s. However, spring survey fishing mortality rates did not change over the time series and were not as high (60% removal rate). Area 539 fishing mortality rates have not changed to any notable degree since 1982, but were below average during the last four years.

Mass balance fishing mortality rates estimated from fall trawl survey data and exploitation indices estimated from landings and fall survey data corroborated the trends in fishing mortality rate derived from DeLury model runs based on fall survey data.

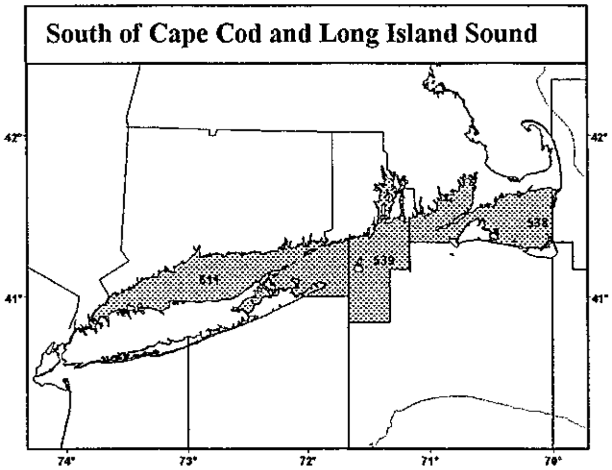
Recruit abundance increased almost three-fold since the mid-1980s. The most notable gains in recruit abundance were in Long Island Sound. The individual trawl surveys indicate steadily increasing recruit abundance in inshore RI waters since 1982 and good recruit abundance in Block Island and Rhode Island Sound (area 539) in two of the last three years.

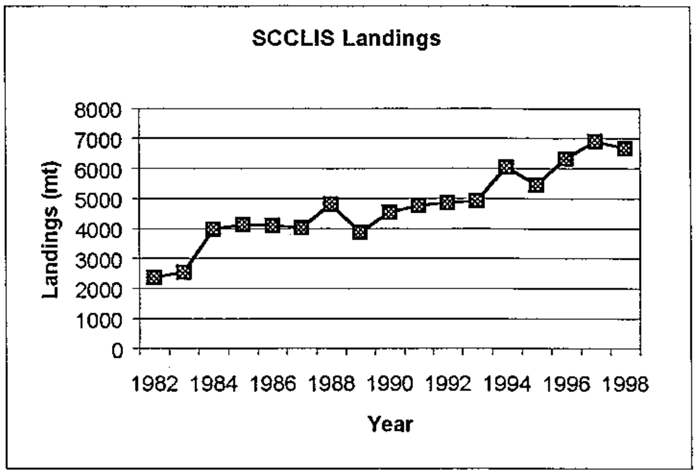
Despite increases in recruit abundance, abundance of legal-sized lobsters did not increase until 1996-97 with the largest relative gain in area 539. Fall and spring CT surveys produced contrasting full recruit abundance trends for LIS: an increasing trend based on spring survey data and constant abundance based on fall survey data. Full recruit abundance indices in area 538 during 1994-98 were 85% lower than during the previous five years.

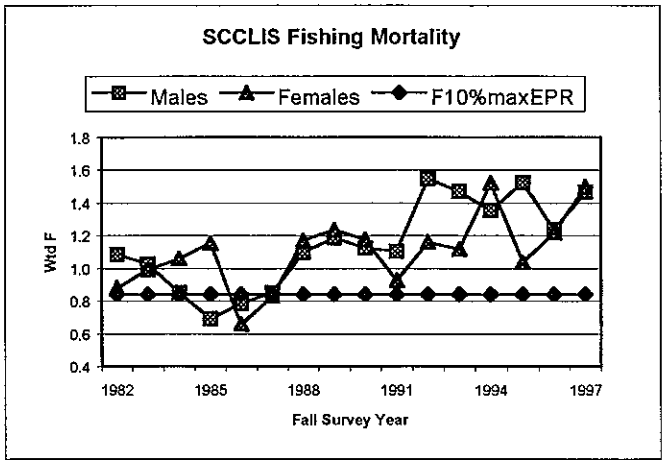
Total potential egg production increased in recent years. Most of the egg production in inshore waters of this stock area is derived from sub-legal lobsters and about 90% of the landed lobsters are in the first molt group above minimum legal size.

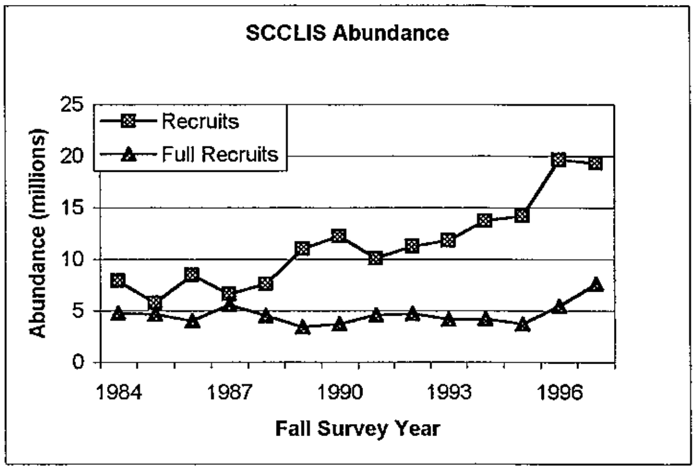
Egg production per recruit, based on 1995-1997 female fishing mortality, is 8.3% of maximum EPR. There is at least a 90% probability that female fishing mortality rates exceeded the $F_{10\%}$ EPR reference point (0.84) for this stock in 11 out of the last 16 years and every year since 1991. According to the ASMFC overfishing definition this stock is overfished. However, recruitment into the fishery, total potential egg production, and stock abundance have increased in recent years, thus the majority of the LSASC concluded that the stock is not currently recruitment overfished. Based on yield per recruit analysis for females, this stock is growth overfished.

## South of Cape Cod and Long Island Sound – Stock Status Summary Figures and Table









| Year[1] | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | Max[5] | Min[5] | Mean[5] |
|---|---|---|---|---|---|---|---|---|---|---|
| Total landings (1000s of mt) | 4.8 | 4.9 | 6.0 | 5.4 | 6.3 | 6.9 | 6.7 | 6.9 | 3.9 | 5.0 |
| Female landings (numbers in millions) | 5.5 | 5.8 | 6.4 | 6.3 | 8.4 | 8.6 |  | 8.6 | 3.6 | 5.4 |
| Male landings (numbers in millions) | 4.3 | 4.4 | 5.2 | 4.5 | 5.2 | 5.3 |  | 5.3 | 1.5 | 3.5 |
| Abundance female recruits[2] | 6.8 | 6.8 | 6.5 | 9.6 | 12.1 | 12.0 |  | 12.0 | 3.5 | 6.9 |
| Abundance male recruits[2] | 4.7 | 5.3 | 6.4 | 4.9 | 7.6 | 6.7 |  | 7.6 | 2.1 | 4.4 |
| Abundance female fully recruited[3] | 3.0 | 2.9 | 2.7 | 1.9 | 3.8 | 4.8 |  | 4.8 | 1.9 | 3.0 |
| Abundance male fully recruited[3] | 1.7 | 1.2 | 1.4 | 1.8 | 1.6 | 2.6 |  | 2.6 | 1.2 | 1.6 |
| Female F[4] | 1.17 | 1.13 | 1.53 | 1.05 | 1.22 | 1.49 |  | 1.53 | 0.66 | 1.19 |
| Female exploitation rate | 65% | 64% | 74% | 61% | 66% | 73% |  | 74% | 45% | 66% |
| Male F[4] | 1.55 | 1.47 | 1.35 | 1.52 | 1.24 | 1.47 |  | 1.55 | 0.69 | 1.16 |
| Male exploitation rate | 75% | 73% | 70% | 74% | 67% | 73% |  | 75% | 47% | 65% |

[1] Total landings by calendar year, male and female landings by survey year (Oct 1 year t to Sept 30 year t+1). [2] Sum of abundance estimates from DeLury analyses of CT, RI and NMFS fall trawl survey data for last molt group below minimum legal size at time of survey. [3] Sum of abundance estimates from DeLury analyses for two subareas based on CT, RI and NMFS fall trawl survey data for all lobsters >83 mm CL. [4] Abundance weighted averages of DeLury F estimates for two subareas. [5]Maximum, minimum and mean landings for 1982-1997 survey years and 1982-1998 calendar years.

### Landings

Landings from this small stock area account for 18% of the total U.S. lobster harvest and have tripled since 1982. The majority of the harvest (78% in 1997) is in Long Island Sound (area 611) where landings increased more than four fold since 1984. Catches from areas 538 and 539 did not change. Males only made up 39% of the 1995-97 landings. About 90% of the lobsters harvested in the SCCLIS stock area are in the first molt group, a higher percentage than in the other two stock areas.

The fishery is predominantly a summer and fall fishery. In the entire stock area, the proportion of the fall landings increased slightly while the proportion of landings from the summer decreased slightly. In Long Island Sound, the proportion of lobsters landed in the fall (October-December) increased over the past 16 years and the proportion of lobsters landed in the spring decreased.

### Fishing Effort and CPUE

Fishing effort in this stock area increased dramatically during the last 15-20 years. The number of traps fished by CT and NY fishermen in Long Island Sound has increased ten-fold since the early 1980s. Trap hauls by CT residents and non-residents increased 3.5 times in LIS between 1979 and 1997 and by the same amount in RI inshore waters between 1982 and 1997. Average soak time in LIS doubled during the same time period. Catch per trap haul set over days (CTHSOD) of marketable lobsters varied without trend since 1981 in MA (area 538). The same was shown for catch per trap haul (CTH) in RI (area 539) since 1991. In contrast, CTHSOD and CTH increased by 100% between 1984 and 1997 in Long Island Sound (area 611).

### Data and Assessment Methods

Fall survey year landings (in numbers) and landed size frequencies were estimated from NY, CT, RI and MA sea sampling data for male and female lobsters during years 1994-97. Population size and mortality estimates were based on DeLury model analyses of annual male and female landings and trawl survey abundance indices from spring and fall CT surveys in area 611, the fall RI survey in area 539, and the NMFS fall survey in areas 539. Blended male and female fishing mortality rates for the entire stock were estimated from each of the three fall survey DeLury model runs. Fishing mortality estimates based on length cohort analysis were not used because they were biased by increasing recruitment. Changes were made to the maturity and fecundity parameters used in the egg per recruit model, but not to the female growth parameters. In addition to DeLury model results, a series of other indices that relied on information from surveys, landings, and catch sample data were examined for evidence of trends in the fishery or stock status.

### Fishing Mortality and Exploitation Rates

Fishing mortality rates for both sexes increased during the last 16 years, but not consistently. The lowest values occurred in 1985-86 and the highest in 1992, 1995, and 1997 (males) and 1994 and 1997 (females). Average 1995-97 fishing mortality rates were 1.41 (71% annual exploitation rate) for males and 1.25 (67%) for females with 80% confidence intervals of 1.2-1.5 and 1.1-1.4.

Individual DeLury model analyses of fall survey data show that fishing mortality rate estimates for both sexes are currently higher in Long Island Sound than they are in the areas indexed by the RI and NMFS surveys. Fishing mortality in LIS increased steadily since the early 1980s, reaching 2.0 for males and 1.8 for females during 1995-97. Fishing mortality estimates in area 539, on the other hand, remained fairly flat (discounting two very high estimates derived from RI survey data in 1984 and 1985), and were lower during the last three to four years. Analysis of spring CT survey data for LIS indicates that male and female fishing mortality rates did not increase, but results based on spring survey data may not be directly comparable to results based on fall survey data. Exploitation indices followed the same trends as fishing mortality rate estimates derived from DeLury model runs. Trends in three year averaged mass balance fishing mortality rates also corroborated the trend in the blended DeLury model results.

### Recruit Abundance

Blended DeLury model results for the entire stock showed a steady increase in recruit abundance since the mid-1980s. Recruit abundance was particularly high during the last two years. Female recruits have consistently outnumbered male recruits: the sex ratio during 1995-97 was 63% female. Gains in recruit abundance were most notable in Long Island Sound, which accounted for about 60% of all recruits in the entire stock area between 1995-1997.

Abundance indices based on the NMFS and RI fall trawl surveys in Area 539 show different trends. The abundance index from the NMFS survey, which is conducted further from shore, varied without trend until it sharply increased in 1996-97. On the other hand, the abundance index from the fall RI survey generally increased since the late 1980s. Abundance indices were also higher during the last ten years of the RI spring survey. The trend in area 538 is the reverse of the other two sub-areas: the MA fall trawl survey indicates that recruits were 80% less abundant there during 1995-98 than during 1991-94.

Estimates of total potential egg production derived from four different surveys have generally increased in recent years. Sub-legal sized lobsters in this stock area contribute much more to total egg production than in the other two stocks since females mature at smaller sizes. There has been an increasing trend in the percentage of sub-legal egg production in LIS (from 60-70% in the late 1980s to almost 90% in 1998), but not in coastal RI waters where sub-legal egg production has been high since the beginning of the RI survey. Sub-legal lobster account for more than 80% of the egg production in inshore waters of the SCCLIS stock area and 30-80% in more offshore waters of area 539 that are indexed by the NMFS survey.

### Fully-Recruited Abundance

Steady gains in recruit abundance since the mid-1980s did not affect the fully-recruited abundance portion of the SCCLIS stock until 1996-97. DeLury estimates of full recruit abundance (both sexes) increased by 40% after varying without trend for 12 years. The full recruit sex ratio in recent years was the same as the recruits (63% female).

The largest relative gains in abundance in recent years occurred in the NMFS survey area (offshore area 539) where legal sized abundance estimates in 1995-97 increased by 62% compared to the 1982-97 average. Growth of the small fully-recruited population in the inshore portion of area 539 indexed by the RI fall survey waters was more modest (37%). According to DeLury model analyses of fall survey data, fully recruited lobsters in Long Island Sound declined in abundance by 30% between 1984-87 and 1995-97 despite the large gains in recruit abundance. The analysis of spring survey data shows increasing trends in full recruit abundance for both sexes. Analysis of NMFS and RI trawl survey data indicated increasing numbers of legal-sized lobsters in area 539.

The percentage of legal-sized males in the inshore RI survey increased from 50% in the late 1980s to 80% in 1997-98, but there were no long term trends in either of the two CT surveys, in the NMFS survey, or in RI sea sampling data from area 539.

Biological Reference Points

The female fishing mortality rate which achieves 10% of the maximum egg production per recruit for this stock is much higher (0.84) than for the other two stocks owing to the reduced growth rate and smaller size at maturity that characterizes this population. EPR model results for this stock were much more sensitive to small changes in input parameters than they were for the other two stocks. Female yield per recruit for this stock increased over the range of fishing mortality rates examined and $F_{0.1}$ was equal to 0.13.

### 11.2 PRIORITIES FOR FUTURE ASSESSMENTS

Lobsters in the GOM and SCCLIS stock areas increased in abundance in recent years despite that fact that egg production per recruit at current fishing mortality rates were well below the threshold (10% maximum EPR) values which have been established (ASMFC 1996) to prevent overfishing. For all three stock areas, female fishing mortality rates since 1982 have exceeded $F_{10\%}$ values in 35 out of 48 instances, or 73% of the time. However, estimates of potential egg production derived from five out of seven trawl surveys indicate that reproductive capacity in most areas increased in recent years.

Based on this information, plus other information included in this report, the majority of the LSASC concluded that all three stocks of American lobster are overfished according to the established legal definition, but are not recruitment overfished. The $F_{0.1}$ values generated from the yield per recruit analyses in this report showed that lobsters are growth overfished in all three stock areas.

Yield per recruit analyses were based on the egg per recruit model and were therefore for females only. Furthermore, $F_{max}$ was not defined in the GOM and SCCLIS stock areas over the range of fishing mortality rates examined. However, it seems obvious by comparing landed size distributions, which are dominated by new recruits, to the potential size and life expectancy of lobsters, that yield per recruit would increase if fishing mortality were reduced and lobsters were allowed to grow larger before being harvested. Yield per recruit would also increase if the minimum size were increased. Inclusion of yield per recruit analyses for male lobsters in future assessments would provide a firmer basis for evaluating growth overfishing for entire stocks. Such analyses would also reveal the optimum size distributions necessary to maximize yield in all three stock areas.

U.S. lobster stocks are currently managed relative to only one reference point, the fishing mortality that achieves 10% of the maximum egg production per recruit. Without an alternative reference point that is associated with prevailing total egg production, spawning stock size, or recruitment to the exploitable portion of the population, managers are required to take action to reduce female fishing mortality rates below the $F_{10\%}$ reference. Preliminary analyses were conducted by the LSASC to determine the feasibility of using spawner-recruit, yield and spawner biomass per recruit, and surplus production models as the basis for developing alternative reference points for lobsters. It is critical that this work be continued. Also, any new reference points or changes to the overfishing definition for lobsters should be linked to clearly defined management objectives and policies. It is also important that management decisions be considered according to the biological and economic risks associated with using a particular reference point.

Reliance on lobsters that have recently reached legal size is a concern in all three stock areas. Heavy reliance on new recruits puts the fishery at risk should recruitment decline, as it is bound to do at some point in the future. Although egg bearing females are protected coast wide, most females in the GBS and GOM stock areas do not mature and extrude eggs until they reach about 90 mm CL and are thus exposed to heavy fishing pressure before they are protected. Thus, at high fishing mortality rates only a small proportion of females in these two stock areas will survive to produce eggs. The situation is somewhat better in the SCCLIS stock area where a greater proportion of the reproductively active females are below the minimum legal size.

Although there is some information available for recently settled juvenile lobsters over the past ten years, the only fishery independent information that is currently being collected on a regular basis over large areas is for sizes >50 mm CL from trawl surveys. These data are only evaluated at irregular intervals when stock assessments are conducted and even then most of the attention is devoted to lobsters in the molt group just below minimum legal size. More frequent (annual) examination of trawl survey data might provide early warning of declining recruitment and allow for more flexible management strategies.

Relative abundance estimates of pre-recruit lobsters are compiled every year from bottom trawl survey data collected twice a year by the U.S. National Marine Fisheries Service and the states of MA, RI and CT. However, these data are only examined when stock assessments are carried out (every 3-4 years). All trawl survey data, including spring surveys, for pre-recruit sizes should be examined annually for evidence of declining recruitment that might require management action. Some additional time series information on densities of recently settled and adolescent phase (40-90 mm CL) lobsters is available from coastal waters in the GOM and southern New England. Surveys that target the full range of juvenile sizes and benthic habitats should be designed and conducted on a regular basis.

Much concern has been expressed in past assessments about the expansion of fishing effort to new fishing grounds that have not traditionally been fished. An expansion of effort into offshore areas that are populated by a higher proportion of larger, sexually mature lobsters than nearshore waters could further reduce the spawning potential of the GOM and SCCLIS stocks. Evidence of such an offshore expansion of effort is not well documented and should be improved. At present, the only good evidence for this offshore expansion of effort is in Massachusetts.

Assessment work for lobster requires and is currently hindered by lack of a database containing landings reports from states, sea sampling data and port sampling data that could be used to calculate numbers of lobsters landed by time period, area caught, length group and sex. The requisite data are available. The programming and calculations required are fairly simple. Once a database is constructed, landings by time/area caught/sex and length group could be calculated quickly on a personal computer. In contrast, calculation of landings data for this assessment involved many months of largely wasted time by a large number of people over a time span of about a year. Excessive time and expense were required for this fundamental task because efforts were replicated in each state and carried out in isolation, because the spreadsheet approach was inefficient, and because data errors (which are always encountered in assessment work) required several recalculations. The time and effort required to recalculate landings data delayed modeling work and prevents development of new or improved models for lobster that might require landings data by different time periods (e.g. quarters instead of survey years) or length groups. The importance and value of the lobster fishery are more than sufficient to justify development of a simple database, like those used in many other fisheries, to make produce basic data required for stock assessment work.

### 11.2.1 Lobster Information/Research Needs

Stock Identification

- Determine feasibility/benefits of applying metapopulation theory to stock definitions.
- Review/evaluate existing information on larval transport, benthic-pelagic coupling, etc. needed to apply metapopulation theory to stock definition for lobster in NW Atlantic.
- Re-evaluate biological basis for stock definitions/boundaries, especially SCCLIS/GBS.

Life History Parameters

- Molting frequency/mean and maximum intermolt periods/molt increments, especially for larger lobsters.
- Area specific maximum size (historically and currently)
- Egg extrusion schedule (annual/biannual)
- Natural mortality estimates on hard and soft shell lobster
- Effects of density-dependence on life history parameters
- Effects of predation and changing ecological communities on life history parameters
- Age determination
- Effect of high and low fishing mortality rates on life history parameters

Fishery - Dependent Information

- Expand studies of sex and size selectivity of traps
- Additional analysis of relationship between fishing mortality (F) and effort (f) in trap fishery, i.e. field studies, improved effort estimates.
- Enhanced sea sampling and/or port sampling for biological characteristics of catches and landings

Fishery -Independent Information

- Comparative studies to determine selectivity of pre-recruits and recruits (all sizes) to capture in trawl gear
- Conduct spatial mapping of survey abundance indices by size and projected egg production per tow
- Develop methods for monitoring recruitment variability at various pre-recruit life history stages and for forecasting catch

Stock Assessment Models

- Develop and maintain a regional standardized data base for assessments
- DeLury should be expanded to include males
- Examine all available spring survey trawl data and evaluate their use in DeLury model
- Conduct field and lab studies of male and female growth (molt transition probabilities and molt increments) in each stock area
- Evaluate bias in LCA fishing mortality estimates and determine if it can be removed
- Determine whether LCS should be discontinued
- Validate predictions of EPR models with respect to data from fishery dependent and fishery independent sources including: projected growth trajectory, size specific sex ratios, fraction egg-bearing, fraction soft shell and fraction v-notched
- Investigate geographic and seasonal patterns of growth, reproductive events, and fishing intensity from catch and sea sampling data. Explore alternatives timing of events in the EPR model.
- Develop YPR analysis for males and females that is independent of EPR model
- Further development of the MARK model
- Evaluate possibility/utility of using alternative reference points (Spawner-recruit analysis, surplus production model) that account for spawning stock biomass and/or recruitment
- Develop new overfishing definition that combines a long-term egg per recruit reference point with an assessment of current recruitment and/or egg production in each stock area. Needs to be clear if this is to be applied as a threshold, target or on a precautionary basis, and whether it is designed to prevent recruitment or growth overfishing
- Develop appropriate yield per recruit reference point that can be defined and incorporated into future assessments
- Develop a risk analysis to determine the probability of defined reductions in landings and abundance and of stock collapse, given a range of possible management actions.

## 11.3 MINORITY OPINIONS

### 11.3.1 Minority Report, By J.S. Idoine (primary author)

This report includes comments and thoughts of the following: R.P. Glenn[1], B.T. Estrella[1], M.J. Fogarty[2], P.J. Rago[2], and S.X. Cadrin[2].

1) Overfishing and Overfishing Definitions:

An overfishing definition should allow managers and industry time to adjust the rate of removals before the stock has collapsed. Arguing that this stock is not overfished because it has not yet collapsed (the "majority opinion" of this assessment) is dangerous. Evidence for resiliency in American lobsters (discussed in this assessment) would indicate a very steep slope at the origin of whatever stock-recruit relationship exists. Current monitoring methods are insufficient to characterize recruitment failure. Should it occur, the first signs would be a rapid decline in landings. Spawning stock biomass would drop off rapidly and the potential for recovery would be reduced. The inability of the fishery to respond to such changes, and the latent ability of the fishery to increase mortality, pose substantial risk to the resource. Therefore, it would be difficult to measure, with a great deal of precision, the signals just before the decline. The life history of lobsters suggests that recovery from a collapse would be a long term process. Given this, a precautionary approach would reverse the direction before a decline, rather than wait to be certain a catastrophic decline was occurring.

Adoption of a precautionary approach to management has been broadly recommended and adopted by international and national fishery management agencies. Such an approach defines reference points that account explicitly for uncertainty in our understanding of population dynamics and provides a buffer for changing environmental conditions. It appears that environmental conditions have been favorable for lobster survival during the last two decades. During this period, fishing effort has been allowed to increase. If the physical and/or biotic environment reverts to less favorable conditions, the stock could be placed at serious risk. Declines in landings in the U.S. Lobster fishery from previous high levels have in fact been observed at the turn of the century, during the 1930's and again in the late 1960's. The overfishing definition adopted by the New England Fishery Management Council and subsequently by the Atlantic States Marine Fishery Commission [the $F_{10\%\,EPR}$ reference point] was intended to provide such a buffer against recruitment overfishing. This definition was further reviewed and discussed in detail in an ASMFC review (ASMFC 1996). The review panel offered the following in defense of such a position:

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[1] Massachusetts Division of Marine Fisheries

[2] National Marine Fisheries Service

**"THE OVERFISHING DEFINITION"**

*The previous paragraphs illustrate just why an overfishing definition is necessary. For the lobster, it is likely that the threshold where egg production falls so low as to affect recruitment, can only be investigated with real data by allowing the level of exploitation to reach very high levels near the collapse point. Even then a collapse would only be detectable five or six years later because of the time taken for lobsters to reach legal size. Further, detection in real data will be masked by natural fluctuations in recruitment resulting from environmental variation. The justification for an overfishing definition is that it is just too dangerous and costly to wait until recruitment collapses, then try to reduce effort and rebuild the stock. It is much more prudent to estimate a safe level of fishing mortality on a pragmatic basis, and then avoid going below that level. Although there is a well developed theory underlying the setting of overfishing thresholds, the essential basis for these thresholds is comparison with other fisheries or similar stocks. Comparisons among similar species have shown that an F level that results in 30-40% EPR (i.e. egg production per recruit which is 30-40% of that at zero fishing mortality) is an appropriate level for finfish, and that F values corresponding to 5% or 10% EPR* ($F_{5\%}$*EPR, or* $F_{10\%}$*EPR) are appropriate for many crustaceans. Such definitions are widely applied in the management of fisheries in the U.S., and the Panel supports the adoption of such an overfishing definition for the lobster.*

*We stress that the overfishing F threshold is not the target level at which a fishery should be managed. It is specifically identified as the 'danger' level which, when approached or reached, should give rise to management action to move the fishery away from the danger area. The benefit of taking such action is not necessarily any overt benefit in yield, particularly in the lobster fishery, where the mortality rate is so far in excess of the maximum on the yield per recruit curve. The benefit is the reduction or avoidance of the risk of collapse, and the preservation of the existing social and economic order."*

Accordingly, arguments that this reference point is not valid because the stock(s) have not yet collapsed are entirely inappropriate. Precedents for setting precautionary levels are clear in other aspects of public policy and are routinely accepted for the common good. Further, it is now widely accepted in areas of environmental policy that the burden of proof should be on those who would permit higher levels of exploitation or impacts on natural resources to show that a conservative or precautionary approach is not appropriate. This issue is particularly relevant with respect to arguments that the EPR/YPR model should account for density-dependent effects in the post-recruit component of the population. No evidence is presented for density-dependence in growth, reproduction, or survival. Accordingly, the burden of proof is not met and the risk-averse position of no density dependence is appropriate.

The drastic truncation in the size composition of the lobster resource relative to historical levels is fully documented in the assessment report. We argue that the erosion of the size and age structure in lobster stocks, and its implications for reduction in the number of lifetime reproductive opportunities, is a principal source of concern. The reduction in life expectancy and lifetime egg production degrades a primary evolutionary mechanism for coping with variable environmental conditions and leaves the stock vulnerable to serious declines.

The section in this assessment on defining overfishing is incomplete because reference points are ill defined. Three definitions were offered. The current ASMFC definition, with some degree of measurability (i.e., $F_{10\%\,EPR}$), is presented as a "legal" one, with no description of its relationship to stock status consequence of exceeding the threshold F's. The second definition, referencing NEFSC (1996), and referred to as a "recruitment overfishing" definition is actually a description of a stock that is severely depressed due to a period of overfishing. The third, a definition of growth overfishing, while adequate, is only applied to females in this assessment, and therefore is not comprehensive. Given these choices, the committee's "votes" on defining these stocks, based on this choice of definitions, give little insight as to the status of this resource. In fact, this assessment is left without any reference points for comparison (since there is a statement that the "a majority of the Subcommittee members ... agreed that conceptually the $F_{10\%}$ maximum EPR definition is not a sufficient measure of recruitment overfishing"). To rule out the only quantitative reference point without replacing it (or amending it) leaves a major gap in the process. The only statement reported is a majority view that all three areas are "legally" overfished (F's greater than $F_{10\%\,EPR}$), and that all three areas are growth overfished in terms of females.

In terms of recruitment considerations there are differences between a) recruitment overfishing a stock, b) a stock being recruitment overfished and c) a collapsed stock. The report seems to lump all these as if they were one condition, and defines overfishing as a state in which all three conditions must be true.

An overfishing definition should distinguish between probability and outcome. Unless it can be shown that some underlying biological mechanism is the basis for continued resilience, the current F's should be judged as risky, with a high probability of inducing recruitment failure. If the only criteria of recruitment overfishing is the absence of recruits, recruitment overfishing cannot be defined yet.

Just because a stock has not collapsed is no assurance that recruitment overfishing is not occurring. Georges Bank cod is an example. For most of the 1980's good year classes masked non-sustainable harvest rates. When recruitment survival returned to more normal rates, the stock declined to low levels.

The lobster resource, as described in the current assessment document, is being subjected to recruitment overfishing as well, and at high risk of serious decline. Over the series presented (1982-1997 SY) F is rather flat when viewed over the entire Gulf. Evidence in the report (Section 8.1.1 , Figure 51) indicates that there are portions of the GOM where F is increasing (and over $F_{10\%}$) and fully recruited abundance is decreasing (Figure 52). The conclusion in the report that there are no signs of recruitment overfishing ignores the evidence of significant localized fishery depletions (SA's 514 and 611), "recent" reduction in average size (SA 515), decreases in CPUE , etc. These conditions are masked by the overall apparent "health" of the GOM stock, but represent a stock status that should raise concerns. Orensanz et al (1998) describe similar conditions, and stock responses for other crustacean stocks. Specifically, in the 1990's the Southern GOM segment's level of landings fell to a~1980 level. This was followed by an attrition of Boston area lobster businesses of up to 50% . Almost all of these businesses, and accompanying effort, were relocated to the Cape Cod area.

When signs of being recruitment overfished are apparent it is too late to correct the process. Signs of stress on this stock are apparent. Abundance is increasing, but this occurs primarily in the recruiting molt group. Size groups above this (representing at least ten or more molt groups) are increasing at a much lower rate, if at all. This indicates that the removals are tracking the increased recruitment, but few, if any, benefits of the increase are being realized in terms of larger animals (in either yield or egg production). To rely on a fishery composed of mainly first time spawners and the continuation of favorable conditions for survival is risk prone. These conditions are not signs of a healthy stock. This new interpretation is not counter to the view presented in the assessment that landings and abundance are high, in fact it is only an additional perspective of the conditions presented. We are presented with an ideal time to curb the excess in this fishery, and by doing so offer the opportunity to address the overfishing, but choose not to due to an inability to define the status of the stocks.

The intention of developing overfishing definitions was to provide a quantitative approach to determining the status of the stock. To have to vote on a determination, because the only existing definitions were rejected without replacement, suggests there are no clear definitions.

2) Growth Rates in SCCLIS:

The female growth rates used in this assessment for the warm-water, early-maturing stock are poorly defined. Accelerated pre-recruit growth rates followed by the sudden retardation of growth (around 90mm CL) has not been seen in other groups of lobsters (e.g., Prince Edward Island, in Canada). Extremely slow growth beyond 90 mm CL is the major contributor to the lack of an estimate for $F_{max}$ (see YPR, Section 9.4) and for an abnormally high $F_{10\%\ EPR}$ ($F = 0.84$ vs. 0.30 – 0.34 for the other US areas). While this does not change advice (even this level is currently exceeded) it is of concern when trying to compare results across stock regions.

### 3) Stock Structure:

It is clear, to some on the committee, that the current stock designations need reevaluation. Specifically, the GBS and SCCLIS stocks may be better defined as a Georges Bank and a SCCLIS and southern offshore grouping. The latter would be similar to the current ideas on the GOM (inshore and offshore combined) stock. Examination of this was not done, but would most likely moderate the mortality estimates of the SCCLIS stock, and perhaps provide more realistic growth estimates as well (both by incorporating some of the larger animals in the area).

### 4) Uncertainty:

A general note of concern is that a large amount of this report refers to uncertainty. With no clear definition of what the term means when invoked, it leads this reader to the overall conclusion that the LSASC could come to few or no conclusions about the status of this resource (or at least none that couldn't be discounted by "uncertainty"). The purpose of an assessment should be to make a case for what we do know, and admit to uncertainty, but not come to the conclusion that the assessment has nothing to offer. The uncertainty associated with this assessment is commensurate with other resources. In any case, under the precautionary approach, uncertainty would be met by more conservative management – not less (Section on overfishing above).

### 5) Fishery Selectivity:

The "evidence" that suggests a declining selectivity as lobsters increase in size is based on two models that were rejected by the committee for various reasons. To extend results from these models to defend such a hypothesis has little merit, especially since the selectivity component is, at best, a minor focus of the models. Length cohort analysis of lobsters indicated decreasing partial recruitment with size (Cadrin and Estrella 1996). However, several important caveats were expressed in the interpretation of the results:

> *"male partial recruitment patterns with size and sensitivity analyses illustrate the dependence on accurate growth models to estimate F with LCA. Unless males are less vulnerable to the fishery at large sizes, F should be constant over all size classes (except in the GOM where there is a 5" maximum size in Maine). Decreasing partial recruitment at size may be the result of systematic bias in t estimates. If growth is underestimated at larger size, F will decrease as an artifact of the growth model."*
>
> and
>
> *"It is evident that better growth information is necessary for more accurate length-based estimates of F for lobsters. Growth information can be improved through stochastic growth models, more powerful statistical analyses, and more field observations of molt probability over a broad range of sizes."*

Unfortunately, most information on intermolt period or molt increment are from a narrow range around the minimum legal size. Extrapolating those observations to larger sizes may lead to inaccurate estimates of growth and mortality.

This is also true for the application presented in Figure 38 referring to the YPR model (this report) used for defining reference points. As stated in the text of this assessment (p. 56, Section 7.4.2) these analyses were "crude estimates", and, in fact show a flat or increasing selectivity with increase in size for females.

Evidence to contradict the notion that selectivity decreases with size can be found in the observation that the large lobsters that used to inhabit inshore regions from Nova Scotia to New York (at the least) have been fished out. They were removed at rates great enough to essentially eliminate them from the population. If selectivity declines as proposed, this would not be the case. Additionally, the offshore lobsters at the beginning of that fishery (e.g., in the canyon regions) in the 1960's had much larger animals at higher proportions and abundance than now. These too have been removed by fishing, not some aspect of natural mortality. While one could make the argument that some lobsters are too large to fit in a trap, this assumes traps are constant in design, and that traps are the only gear used to capture lobsters. These are clearly not true. To infer size selectivity based on landings also ignores market considerations.

We do not argue that size selectivity is not an important consideration, however there has been no evidence presented in this report to draw the conclusions made in Sections 7.4.2 and 11.2.

6) <u>Economics</u>:

It is unfortunate that there is no section in this report on the economics of this industry, since it is an integral part of the picture and any management options that might be available.

### 11.3.2 Alternative Assessment and Biological Reference Points for the RI Inshore Lobster Stock with Estimations of Unfished Stock Size, by Mark Gibson (full report can be found in Appendix E)

The current approaches for assessing US lobster stocks and estimating biological reference points are decoupled. By convention, a modified DeLury model is used to estimate prevailing stock sizes and fishing mortality rates while an egg per recruit model is used to estimate the rate of fishing allowing for 10% of unfused egg production on a per recruit basis. The decoupled, dynamic assessment and equilibrium reference point models lead to a logical inconsistency in that lobster biomass has increased over several decades under fishing mortality rates exceeding the over fishing rate. An alternate, biomass dynamic model was developed and applied to landings-abundance data for the Rhode Island inshore area. The biomass dynamic model estimates both fishing mortality and biomass based reference points. The model is based on a logistic population dynamics process and allows for both process and measurement error. Auxiliary estimates of fishing mortality rate from trawl survey size composition were used to "tune" the model. Model results indicate that stock biomass has increased over the past three decades and is close to biomass for maximum sustainable yield. Fishing mortality rate has declined in recent years and is near Fmsy. If Fmsy is an over fishing definition, then 0.8*Fmsy is a reasonable target. A 12% reduction in fishing mortality rate is needed to reach the target. This assessment is at odds with the SCCLIS assessment, which indicates the need for a much larger reduction in fishing mortality. The production model indicates that current stock biomass is considerably higher than that implied by EPR model results. Sensitivity runs indicated that results were sensitive to the weight assigned to auxiliary fishing mortality rate rates and the balance between process and measurement error. Residual diagnostics indicated that stock productivity increased over time.

### 11.3.3 Examination of Assumptions to the Egg = Per = Recruit Model (EPR)and Development of Alternative Stock Biomass and Fishing Mortality (F) Thresholds, By Victor Crecco (entire report can be found in Appendix F)

Under the previous management regime in 1993, the two near shore lobster stock units (GOM and South Cape Cod Long Island Sound (SCCLIS)) were considered to be over fished if the magnitude of current fishing mortality rate (average 1995-97 F) on female lobsters had exceeded the over fishing definitions ($F_{10\%}$) for each stock unit. The $F_{10\%}$ levels, derived from a steady-state egg-per-recruit (EPR) model (Fogarty and Idoine 1986), is the fishing mortality (F) rate that generated an egg/recruit value that corresponds to 10% of virgin (F = 0) egg/recruit. Another relative measure of stock status is the percentage of maximum egg production (MEP). MEP estimates were derived as the ratio of egg-per-recruit at current fishing mortality rate levels to virgin (F = 0) egg-per-recruit. In the 1998 assessment, current estimates of $F_{10\%}$ for the GOM ($F_{10\%} = 0.32$) and SCCLIS ($F_{10\%} = 0.84$) stocks were far below current female fishing mortality rate estimates for these stock units (Appendix F, Table 1). Current MEP levels range from 3.5% to 8%, suggesting that current egg production and stock biomass levels are about 15 to 20 times below the expected levels at F = 0. Taken alone, these low MEP levels suggest that the GOM and SCCLIS lobster stocks are at high risk of recruitment failure since recruitment levels have been sustained by only about 3-9% of maximum egg production from 1982 to 1998. Yet growing skepticism concerning the usefulness of $F_{10\%}$ and MEP levels as recruitment over fishing thresholds exists for clawed lobsters among some scientists (Addison 1986), particularly over the two principal predictions of the EPR model: 1) that lobster stocks have been maintained for at least 20 years by only 3-9% MEP; and 2) that lobster egg production would escalate about 15-20 fold over current levels if fishing mortality rate was reduced to zero. These two predictions underlying the EPR model were examined here based on historic lobster size frequency data taken from lobster traps in 1894 (Appendix F, Figure 2 females only taken from Appendix F, Table 9, Herrick 1909) and USA landings data in 1894 (Appendix F, Figure 1). Specifically, average stock biomass (mt) and abundance (millions of lobsters) of newly recruited lobsters (75-85 mm CL) from 1995 to 1998 were estimated when size was severely truncated and fishing mortality rate was high. These current stock data were then compared to stock biomass (mt) and recruitment levels in 1894 when there was an extended size structure (Appendix F, Figure 2), relatively high landings (Appendix F, Figure 1), and very low (F<0.20) fishing mortality (F) levels. Since fishing rates were low in 1894, these early data were used to back calculate the carrying capacity (virgin (F = 0) stock biomass). If the predictions underlying the MEP calculations are correct estimated virgin stock biomass (mt) should be about 15-20 times greater than the 1995-98 average stock biomass level. Secondly, since recruitment levels are assumed to be constant in the EPR model, the magnitude of newly recruited (75-85 mm CL) lobster abundance in 1894 should be similar to average recruitment levels from 1995-98.

Based on the 1894 length frequency (Appendix F, Table 2) and corresponding mean length (mm, CL) data (Appendix F, Table 4), the fishing mortality (F) rate in 1894 based on the Hoenig model (equation 1) was about 0.09 (Appendix F, Table 4). This was about ten times lower than the current (1995-98) average (F = 1.00) fishing mortality rate based on DeLury in the GOM and SCCLIS stock units (Appendix F, Tables 1 and 4). The resulting standing stock biomass (STSSB, mt) in 1894 was 156,250 mt as compared to an average STSSB of 51,634 mt from 1995-98 (Appendix F, Table 5). Available spawning stock biomass (ASSB) in the combined GOM and SCCLIS was about four times higher in 1894 (150,00 mt) than the current average (36,402 mt). However, based on a virgin (F=0) stock biomass of 161,235 mt (Appendix F, Table 5), current (1995-98) MSP was 22.6% (from equation 5) of virgin biomass (Appendix F, Table 5). This MSP level is about four times greater than the predicted average MEP level (MEP=5.6%) from the EPR model for the combined GOM and SCCLIS stocks (Appendix F, Table 1). That current MSP approaches 23% not 5.6% is consistent with recent results of Gibson (Appenix E), who reported that current (1997-99) MSP levels for lobsters within Rhode Island waters approached 38% using a Discrete Biomass Dynamic model based on the 1962 to 1999 landings. Moreover, Jensen (1986) used landings (mt) and fishing effort data on the Maine lobster fishery from 1928-72 to estimate effort at maximum sustainable yield and the carrying capacity (Binf) using stock production models Jensen (1986) reported that Binf for the Maine lobster fishery was estimated to be 80,000 mt. The current (1995-98) ASSB estimate for the Maine fishery was about 30,974 mt from equation 3 (mean landings = 18,504 mt, F = 0.67). This indicated a current MSP level of 39% (i.e. 30,974mt/80,000mt), which was 10 times greater than the predicted MEP of 3.5% for the GOM (Appendix F, Table 1) based on the EPR model. Unlike the expected 20 fold rise in egg production and stock biomass at F = 0 predicted by the EPR model, these findings and those of Gibson (Appendix E) and Jensen (1986) strongly suggest that current stock biomass in the GOM and SCCLIS would rise about three to four-fold if fishing mortality rate dropped to zero.

The comparison between length frequencies in 1894 to those from 1997 (Appendix F, Figure 2) revealed that about 8.5% (Appendix F, Table 2) of the lobsters sampled in 1894 were newly recruited (size: 75-85 mm CL) to the fishery. This was in sharp contrast to the 1997 data (Appendix F, Figure 2) in which about 90% of the lobsters were new recruits to the fishery. As a result, estimated recruitment (REC = 93.0 million lobsters)) during recent years (1995-98) (from equation 4) was about ten times higher than new recruit abundance (REC = 8.9 million lobsters) in 1894 (Appendix F, Table 5). Given the striking disparity between recruitment levels (REC = 93.0 million lobsters), these findings strongly suggest that the EPR assumption of constant recruitment has been violated. Due to increases in recruitment during the mid-1990's, maximum spawning potential (MSP = 22.6%) in 1998 (Appendix F, Table 5) was much greater than the predicted MEP level (MEP = 5.6% (Appendix F, Table 1) based on the EPR model. Violation of the constant recruitment assumption is the major reason why current MSP levels (MSP = 22.6%) (Appendix F, Table 5) are so much higher than the EPR predicted mean MEP levels (MEP = 5.6%) (Appendix F, Table 1). Record high recruitment after 1995 has largely compensated for the loss in biomass and egg production from larger (>140 mmCL) lobsters.

Two spawning stock biomass thresholds (SSB10% and SSB20%) which corresponds to 10% and 20% MSP, respectively, were derived by multiplying the virgin biomass level (161,235 mt) for the combined GOM and SCCLIS stocks by 0.10 and 0.20. The resulting spawning biomass thresholds (ASSB10% = 16,124 mt, SSB20% = 32,247 mt) were below the average 1995-98 ASSB level of 36,402 mt (Appendix F, Table 5), indicating that lobsters spawning stock sizes within near shore management units (GOM and SCCLIS) are high enough to ensure good recruitment when environmental conditions are favorable.

The MSP estimates in 1894 (MSP = 96.9%) and from 1995-98 (MSP = 22.6%)( Appendix F, Table 5) were used in conjunction to generated adjusted fishing mortality thresholds (i.e. adj$F_{10\%}$, adj$F_{20\%}$) for recruitment over fishing. These thresholds ($F_{10\%}$, $F_{20\%}$) correspond to MSP levels of 10% and 20%, respectively, and can be easily calculated by direct proportion. The resulting adj$F_{10\%}$ estimate of 1.16 exceeded the average near shore fishing mortality rate of 1.00 (Appendix F, Table 1) by about 14% (Appendix F, Table 5), although the adj$F_{20\%}$ threshold of 1.04 was only slightly above the current fishing mortality rate of 1.00. Based on these analyses, I would recommend that the near shore lobster stocks be assessed for recruitment over fishing based on a dual threshold approach. Specifically, the near shore lobster stocks (GOM, SCCLIS) would be regarded as recruitment over fished if they satisfy two criteria: 1) current average (mean F 1995-97) fishing mortality rate must exceed the adj$F_{10\%}$ threshold of 1.16; and 2) current spawning stock biomass (mt) levels must fall below the 10% spawning stock biomass threshold (SSB10% = 16,124 mt). Neither of these preconditions are currently met for the combined near shore lobster fisheries.

### 11.3.4 The Effects of Intense Gear Saturation on the Assessment and Management of American lobster (*Homarus americanus*), by Victor Crecco (full report can be found in Appendix G)

Because the overall scope and management significance of gear saturation in the USA lobster trap fishery are poorly developed in the main body of the stock assessment, I believe that a more comprehensive synthesis of gear saturation was needed in this minority report. Since 1980, USA commercial lobster (*Hommarus americanus*) landings have increased steadily from about 21.0 thousand metric tons (mt) in 1986 to over 36.0 thousand mt in 1998. These historic high landings have recently occurred, despite a persistent rise in lobster fishing effort (trap hauls, number of licensed traps) within most inshore areas from Maine to New York. By contrast, fishing mortality estimates (F) on American lobster from 1982 to 1997 for the SCCLIS, GOM and GBS stocks have remained relatively stable in the face of a sharp rise in landings and fishing effort (f). This lack of linearity between F and f may have resulted from gear saturation in the commercial trap fishery. Gear saturation has been widely reported for a variety of crustaceans commercial trap fisheries, including American lobsters in Maine waters (Waltz 1989), European lobster off the United Kingdom (*Hommarus gammerus*) (Addison and Bannister 1998), Chesapeake Bay blue crab (Callinectes sapidus) and the northern crayfish (*Oronectes virilus*) (Momot 1998). The test of gear saturation and its implications on the usefulness of trap reduction strategies was examined for the SCCLIS, GOM and GBS lobster stock units using updated fishing effort (f) and fishing mortality (F) rates from 1982 to 1997.

The results of this analysis indicate widespread and persistent evidence of gear saturation in the USA lobster commercial fishery at least since 1982 (note the exception for GOM males with Massachusetts fishing effort). As a result of gear saturation, fishing mortality rates (F) on the USA lobster fishery would not be expected to rise further in concert with greater expansion of the trap fishery. Short-term fluctuations in lobster commercial landings would be expected via changes in recruitment. Since trends in F and fishing effort (f) are largely independent from 1982 to 1997 for all three stocks (Appendix G, Table 22 and 23), a strategy to significantly (20-40%) reduce F on USA lobsters via reductions in licensed traps or trap hauls will probably fail unless fishing effort is drastically reduced to levels that occurred well before 1982. Recent attempts at effort reductions (40% reduction in traps between 1991 and 1995) in the spiny lobster fishery (*Panulirus argus*) off the Florida Keys (Muller et al 1997) resulted in only a 5-19% reduction in fishing mortality (F)

The implications of gear saturation in lobster management extend far beyond their impact on the usefulness of trap reductions. Addison and Bannister (1998) reported that nonlinearity between F and fishing effort (f) in exploited crustacean stocks can greatly alter the relationship between egg-per-recruit (E/R) and changes in the current fishing effort patterns. They found, for example, that Fmax and $F_{10\%}$ levels, when F and f are nonlinear, could be much higher than Fmax and $F_{10\%}$ levels under the conventional assumption that F is linearly related to f. Perhaps their (Addison and Bannister 1998) most interesting finding was that the magnitude of Fmsy and the overall resiliency of lobster stocks were greatly improved in stock-recruit models if the catchability coefficient (q) was inversely related to lobster stock size. An inverse relationship between q and stock size (N) has been reported for many heavily exploited finfish stocks harvested with pursuit gear (i.e. otter trawl, purse seines and drift gill nets) (Winters and Wheeler 1985; Crecco and Savoy 1985; Crecco and Overholtz 1990). However, for exploited crustacean stocks harvested by stationary traps, this phenomenon has not yet been reported (Addison and Bannister 1998).

Although lobster fishing mortality rates (F) on the SCCLIS stock that exceed 1.0 would place most finfish stocks at high risk of recruitment failure, the relative risk of fisheries-induced stock collapse for the SCCLIS lobsters may be minimized by several factors related to lobster behavior and how this interacts with stationary gear. Firstly, severe discard mortality among finfish species is a real problem with mobile gear such as trawls and purse seines, but there is little or no discard mortality among sublegal lobsters taken from stationary traps. Secondly, the occurrence of intensive gear saturation shown here, within LIS (Crecco and Gottschall 1999), within Rhode Island waters (Gibson 1999) and for Chesapeake Bay blue crabs (Rugolo et al 1997) is more likely to occur for stationary gear fisheries, where the crab and lobster voluntarily enter baited traps in order to be harvested. This mode of capture is in sharp contrast to those for most finfish fisheries, which employ mobile gear (i.e. trawls and purse seines). In these modern fisheries, the mechanism of capture involves search (with the aid of sonar), pursuit and, ultimately, entrapment of finfish that attempt to escape. In contrast to the observed decoupling between F and f arising from gear saturation in decapod trap fisheries, the use of mobile or pursuit gear in finfish fisheries can be highly destabilizing. This is particularly so at low stock sizes, where search and pursuit by mobile gear often causes the catchability coefficient (q) and fishing mortality (F) rates to rise in concert at alarmingly high rates as stock size declines (Crecco and Overholtz 1990).

## 12.0 UNRESOLVED ISSUES: Possible Explanations For Resilience To High Exploitation Rates

The ASMFC Lobster Stock Assessment Committee was tasked with addressing several terms of reference in conducting the stock assessment during 1999-2000. Term of Reference #3 charged the committee to develop analyses that could explain why the abundance and recruitment of lobsters have continued to increase in spite of the overfished status of the resource. Section 11.2 was reserved for inclusion of the consensus of the American Lobster Technical Committee on this issue. A report to the Technical Committee was drafted by Kathleen Castro and Robert Steneck, however, the committee was unable to develop a consensus opinion. In order to provide information to the American Lobster Peer Review Panel to address this issue, the Castro and Steneck report to the Technical Committee and several alternative viewpoints of members of the Technical and Stock Assessment Committees are included in this section.

### Report to the American Lobster Technical Committee
### Drafted by Kathleen Castro and Robert Steneck

The fact that lobster stock abundance has either remained stable or increased despite high, and in some cases increasing fishing mortality rates, has led to a great deal of speculation concerning the resiliency of the lobster resource to high exploitation rates. Possible reasons for increased abundance were summarized in the previous ASMFC (1996, pages 18-22) report. This assessment shows that lobster abundance has increased or remained constant in the three stock areas as a whole (although landings have decreased in some of the heaviest fished areas of GOM and SCCLIS), despite long term high exploitation rates due to recent high levels of new fishery recruits.

Understanding the principal factors and mechanisms contributing to population fluctuations remains one of the largest challenges facing ecologists and fisheries scientists. Here we address some possible hypotheses for this persistence despite the high fishing effort on this species. There are at least two important components to this question: 1). Why aren't stocks reproductively limited? and, 2). What mechanisms contribute to population increase? There are many components that are involved in recruitment to a population and a fishery: mature female abundance, larval release, transport of larvae, larval/post-larval mortality, settlement and post-settlement survival and growth. The Subcommittee was not been able to conclude which factors contribute to the persistence of the American lobster stocks, however felt that some of the theories were important areas for future exploration.

Recent increases in abundance suggest that stocks are not reproductively limited. Reasons for this may vary regionally. As described in this report, the reproductive characteristics of lobster stocks vary greatly along its range (Section 2.4.3). The smaller size at maturity for lobsters in the SCCLIS may allow females to reproduce 1-2 times before they grow to legal size. Unless there is larval exchange from the offshore stock area, the primary source of egg production in SCCLIS may come from these sub-legal lobsters. There is also a likely bias towards females in the sex ratio (Section 10.8) of the population. These characters might help explain why the SCCLIS population is not reproductively limited.

Different mechanisms might operate in other stock areas where sexual maturity in females occurs primarily above harvestable size. In the GOM, the majority of egg production comes from legal animals. It is possible that two factors contribute to female survival - persistence and growth of reproductive lobsters. One is intrinsic (i.e., a behavioral change in lobsters making them less trapable) and one is extrinsic (i.e., they spend considerable time in habitats under lower fishing pressure). In the GBS stock area, results of the LCA showed a decrease in catchability with increasing size for lobsters between 83-180 mm CL (Figure 38). In contrast, field studies conducted using SCUBA and trap sampling (Miller 1989) showed an increasing catchability with size for smaller lobsters between 50-89 mm CL Miller (1995) found that catchability coefficients for males increased with size between 70-109 mm CL, and was higher than that for females. Templemann and Tibbo (1945) reported that ovigerous females trapped less than expected and attributed it to feeding behavior.

Larger lobsters may be less available to the fishery because there is evidence that mature lobsters segregate from inshore juvenile populations and move to offshore habitats (Lawton and Lavalli 1995). Numerous tagging studies have documented significant migration capabilities of mature lobsters (Campbell 1986). The offshore segregation of reproductive lobsters from juvenile populations is well-documented (Campbell and Pezzack 1986). Since fishing effort is greatest in nearshore areas, the reproductive lobsters are effectively migrating to habitats where fishing mortality rates may be lower. Their survival may be facilitated by migrating to refugia where fishing mortality rates may be reduced.

The relationship between broodstock and recruitment to the fishery (i.e., landings) has not been directly examined for any population of American lobster (Fogarty 1995). However, the relationship between post-larval production and subsequent stock size (landings) has been examined in the southern Gulf of St. Lawrence (Fogarty and Idoine 1986) and in Arnold's Cove, Newfoundland (Ennis and Fogarty 1997). In both cases, the data was fitted with a Beverton-Holt asymptotic stock-recruitment model with a very steep ascending limb at the lowest range of egg production. However, once the asymptote is reached, there is no effect of increased post-larval production on the resulting stock size. This steep slope of the curve at the origin is consistent with the apparent resilience of the stock to exploitation and reinforces the need to understand these relationships. The ASMFC peer review (1996) examined evidence for this and suggested that a stock collapse could occur if recruitment were to fall below the asymptotic value and proposed a risk-averse management strategy. However, we have no precise estimates on what recruitment levels produce these descending values. Since abundance and egg production has increased over the past decade in most areas, larval abundances must have been high and increasing over that period. There is no satisfying explanation based on the published post-larval to recruitment curves (Fogarty and Idoine 1986 and Ennis and Fogarty 1997) why recruitment has apparently increased from the asymptote.

This asymptotic relationship also suggests that there is strong density dependence operating at some life history stage. Evidence of density-related effects on survival, molting frequency and molt increment have been seen for American lobster in culture systems (Aiken and Waddy 1978; Van Olst et al. 1980), and for molting frequency and egg production in one natural system (Ennis 1991) and in spiny lobsters (Polovina 1989; Chubb 1994).

In contrast, other studies at smaller scales did not find an asymptotic relationship between lobster larvae and abundance. Incze et al. 1997 found a strong correlation between stage IV post-larvae and young of the year, suggesting that habitat was not limiting and the relationship between larval abundance and settlement success is density independent. Miller (1997) evaluated the relationship between the spatial trends in the abundance of ovigerous females, planktonic fourth stage lobsters, and fishery recruits/km$^2$ along a spatial scale in Nova Scotia. He found no relationship between the number of ovigerous females and any other stage, but found a significant correlation between the post-larval production and new recruits to the fishery. Further correlation showed that egg to postlarval survival and not egg abundance was related to fishery recruits. This suggests stock recruitment relationships may be weak or nonexistent because they are masked by the stronger patterns of larval mortality.

Stock recruitment relationships as defined by Beverton and Holt (1957) require that broodstock and subsequent life history phases to recruitment to the fishery live sufficiently close together to be considered a "closed system". The differences in scale between patterns of larval settlement within a small cove (Incze et al 1997) and larger fisheries-based relationships (Fogarty and Idoine 1986) may result in the different patterns of larval to recruit abundances. As a general application to lobster management, stock recruitment relationships must encompass areas large enough to be considered a closed system. That has not been demonstrated to date for any American lobster study.

Variable growth rates also obscure the recruit-stock relationship since cohorts are believed to overlap, possibly obscuring good or poor year classes. This process could mask the inter-annual variability in cohort strength. Specifically, the draws into question using a specific number of years to indicate the period of time between post larval appearance and the recruitment to the fishery (a major assumption in all published stock-recruitment studies). Recent information on the European lobster, *Homarus gammarus* (Addison 1999; Sheehy et al. 1999) indicates a large variation in age at size with seven year classes making up the 85-95 mm size class. Because of the extreme variation in growth rates, their data suggests that lobsters between the age of 3-20 have only partially recruited to the fishery. The minimum legal size therefore protects a substantial age range distribution even in the more heavily fished regions. This variability in growth may help maintain supplies of legal sized lobsters even under heavy fishing pressure because strong and weak year classes are averaged out in the catch. However, it does not ensure the protection of the stock, nor does it explain increasing populations.

It is possible that a relatively high proportion of larvae survive to settle compared to other managed species (particularly finfish). Successful settlement of larvae depends on larval delivery, propensity to settle and availability of suitable nursery grounds (Palma et al 1999). The American lobster possesses several unique characteristics that distinguish them from other invertebrates and finfish. They are relatively large, have high parental investment (carrying their eggs for 9 to 11 months), and produce relatively large eggs that hatch into larvae that have a relatively short larval life. Lobster larvae and post-larvae are relatively large (compared to other decapods in the western North Atlantic or other lobsters of the world). Settling postlarvae select their habitats (Wahle and Steneck 1991) and a high proportion of post-larvae have been reported to settle in coastal zones with relatively low mortality (Incze et al 1998). Palma et al. (1998, 1999) examined settlement patterns in several species in the GOM to examine temporal and spatial scales of settlement. Lobsters settled only in specific rocky habitats contrary to rock crabs that settled indiscriminately on sand or rocky bottoms resulting in higher post-settlement crab mortality. These are all characteristics of organisms with high per egg survival rates (Todd 1986).

Recent research (Steneck and Wilson 1998) suggests that there is a larval production source/sink relationship between the eastern and western portions of the GOM. This is also suggested by the distribution of small and large females collected by the NMFS trawl survey. Reproductive linkage between areas can have potential effects on the persistence in an area 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 system resilience under this scenario, even with modest larval subsidies. Any notable reproductive exchange between stock areas could affect the current egg production values estimated and the $F_{10\%}$ values calculated in each stock area, especially if biological parameters (e.g., growth, maturity, etc.) are different between stock areas. Without quantified estimates of the immigration and emigration of reproductive sized lobsters and rates of larval exchange among areas, it is not possible to quantify changes to the current calculations. This emphasizes the importance of accurately identifying stock areas.

Large geographic areas experienced an increase in abundance in recent years (Miller 1994). These increases may be the result of increased settlement, since most studies have shown lobsters to have a strong coupling between the pelagic post-larval and benthic phases (Incze, et al. 1997) and very low post-settlement mortality (Wahle and Steneck 1992, Cobb and Wahle 1994, Palma et al 1998). Settlement is driven by larval abundance and delivery (i.e., the ocean currents that link hatching larvae with nursery grounds). Increases in larval delivery to nursery grounds could be the result of higher egg production because of higher abundance of females, a change in fecundity or oceanographic conditions. Since there is no evidence of a strong increase in egg production prior to the population increase, it is less likely than oceanographic changes to explain differences in larval delivery. Large demographic impacts on myriad marine organisms has been shown to result from changes in larval delivery (reviewed by Underwood and Fairweather 1989, reef fish, Doherty and Fowler 1994, barnacles, Gaines and Roughgarden 1985, crabs and the American lobster Palma et al 1999).

Currently, considerable research is being conducted on how ocean currents deliver larvae from their source (hatching ovigerous lobsters) to their sink (nursery grounds). It is not known if larvae travel considerable distances, or retained within the general region of hatching (Miller 1997). However, it is possible that oceanographic regime shifts such as those observed in the North Pacific (i.e., affecting abundance of *Panulirus marginatus*, Polovina et al 1999) have occurred in the western North Atlantic. There is some evidence to show that patterns of lobster settlement along the coast of Maine correlate with those of Rhode Island (Figure 173 in this assessment, Incze et al. 1997). There is not thought to be a larval linkage between these portions of the two stock areas. Larger oceanographic forcing functions could explain these large-scale, temporally correlated, changes in settlement. Since the pattern of increased recruitment occurred from Newfoundland to New Jersey, factors operating at scales transcending biogeographic and ocean basins should be considered as possible causal mechanisms in recent recruitment trends.

Since temporal trends in landings and sea surface temperature are large scale events along the Atlantic coast, temperature has long been considered to be a key environmental variable affecting lobster recruitment (Huntsman 1924; McLeese and Wilder 1985; Flowers and Saila 1971, Aiken and Waddy 1986; Fogarty 1988, Campbell et al. 1991; Koeller 1999). However, there is no consensus on how temperature affects survival and landings. Temperature may affect abundance and landings by changing catchability, growth rates and/or settlement success (Fogarty 1988, 1995, Addison and Fogarty 1992; Acheson and Steneck 1997). Effects of temperature on catchability should be immediately evident (McLeese and Wilder 1985). Temperature effects on growth may occur quickly but may not be evident for one or two years. Temperature effects on recruitment may occur within a year but may not be evident in the landings for 5-7 years.

Acheson and Steneck (1997) found a significant correlation between temperature and landings 7 years later in the GOM (For years 1946-1986) implicating settlement as a strong signal. A similar time-lag correlation was reported by Flowers and Saila (1971). However, Koeller (1999) examined a 50-year time series in Nova Scotia fisheries and found a significant correlation between catches and temperatures at short time lags (0-3 years) prior to 1974. He was unable to conclude if temperature or increases in effort caused this correlation since weather (and hence fishable days) may be associated with temperature. Longer lags (6-8 yr) after 1974 were consistent with increased larval survival. Several studies found no relationship between the recent increase in lobster abundance and temperature (Drinkwater et al. 1996).

There is no correlation between Maine and Rhode Island lobster densities after settlement. Densities of juvenile lobsters in cobble habitat in Rhode Island are only about one third that in Maine (Wahle1999; Incze et al. 1997). It is not known if differences in densities of older lobster are attributable to differing growth, mortality or emigration rates. Pollock (1993) examined the role of density-dependent processes in heavily exploited spiny lobster populations and their effects on resilience. He suggested that the major determinant of size at maturity for spiny and clawed lobsters is food availability for juveniles. He concluded that when juvenile densities are high relative to food supply, growth increments are reduced, leading to a smaller size at maturity. However, it would be difficult to explain recent increases in American lobster abundance if they have density-dependent declines in growth rates.

Changes in growth, size at maturity and natural mortality resulting from density dependent processes, may contribute to increased abundance and landings. Momet (1998) found that after 15 years of comparison between an exploited and an unexploited population of northern crayfish, *Orconectes virilis*, that the exploited population increased pre-recruitment survival rates. The removal of mature males allowed the overall population size to increase by increasing growth rates and depressing natural mortality. However, examples based on a freshwater crayfish in a closed environment may not be applicable to American lobster. Both growth and natural mortality parameters for exploited American lobster populations are still poorly understood.

It is unlikely that reductions in predation could have caused the large-scale population increases over the past decade because there has not been significant decline in predators over this period in coastal zones (Witman and Sebens 1992) where juvenile lobsters live and grow to harvestable size (Steneck 1997).

Fishermen have long believed that the escalation in the number of traps has markedly increased the availability of food, habitat and ultimately, the survival of lobsters. Traps could be habitat for adolescent phase lobsters (greater than 40 mm CL) but not for settling individuals because the required shelter sizes are much smaller. Lobsters near legal size have relatively low mortality rates in the absence of fishing so added shelter is not likely to reduce their mortality. The several million lobster traps currently in use may provide additional food and thus increase growth rates but there is no evidence demonstrating this. It is likely that traps may simply attract and concentrate lobsters approaching harvestable sizes but since neither food nor shelter is known to limit populations, their demographic impact is not likely to be great.

## Alternative Viewpoints

### Alternative Viewpoint by Robert Steneck

The ASMFC Lobster Stock Assessment Committee was given the following charge: Term of Reference 3: Develop analyses that could explain why the abundance and recruitment of lobsters has continued to increase in spite of the overfished status of the resource. Section 11.2 was written to address these questions. The section was written from more of an ecological than a population-dynamics perspective. This is a different approach from that used in the assessment. The differences between ecological approaches and more traditional fisheries modeling approaches is the source of some of the confusion that led to this section being labeled "unresolved issues". Some of the confusion is semantic and some conceptual. Here, I'd like to clarify a few important points.

A. Lobster abundance has increased despite intense fishing pressure

The term of reference above asserts that lobster abundance and recruitment has increased despite the overfished status of the resource. That lobster population densities have increased is well documented in the assessment (see executive summary). Over the past two decades the abundance of lobsters as indicated by landings (given that there have been no recent increases in fishing mortality rates), NMFS trawl data, most state trawl surveys (except MA) and coastal scuba surveys in Maine all show population increases. The record of increased abundance has also been documented for Canadian waters (e.g., and Campbell 1991 and Miller 1994). Those papers and analysis of temporal patterns shows that the timing of the population increases and in some places subsequent decreases varies regionally. Overall, stocks have increased in the past two decades.

B. Two important ecological points: populations are not reproductively limited and increases in abundance may relate to post-reproduction processes.

1) Lobster are not evidently reproductively limited

There is an important distinction between populations that are reproductively limited vs those that are limited by later mortality (i.e., recruitment or post-recruitment limited populations). Thus, a reproductively limited population is one that is limited by the number of fertile zygotes a population can produce. If a population=s reproductive potential is significantly reduced, the population cannot increase until the broodstock is restored. There are many fisheries examples of this. If a population has more than sufficient broodstock, it does not mean that recruits to the population or to the fishery will increase. There can be, and often is, significant mortality in the larval and post-larval stages and at the time of settlement or later.

The fact that lobster populations increased means they cannot have been reproductively limited. This is further supported in the assessment that shows total potential egg production, as indexed by the NMFS fall survey and other data showed increases in the GOM and South of Cape Cod and Long Island Sound and no trend in GBS. Speculation as to why broodstock lobsters have survived such high fishing pressure is given in Section 11.2.

2) Recent population increases suggests increased settlement success of lobster larvae.

In this assessment, in past assessments and in other comments related to Section 11.2 there is wide recognition that conditions good for developing larvae or settling post-larvae could be the root cause of the population increase. This is supported from several lines of research articulated in Section 11.2 and elsewhere. There is a sizable literature on this point now called the "recruitment limitation hypothesis" (Doherty and Fowler 1994, Science 263: 935 - 939). Studies of reef fish, barnacles, sea urchins and other lobsters (referenced in the Assessment and in Section 11.2) have shown large demographic changes due to oceanographic control of larval delivery.

It is possible that large scale oceanographic differences have caused the observed population increases. Evidence for this is found in the positive correlation between lobster settlement in Rhode Island and in Maine (Figure 173) despite these two areas being in different biogeographic provinces, ocean systems and not thought to receive larvae from the same broodstock population.

The ecological perspective to Term of Reference 3 is that patterns of recruitment can be rather independent of patterns of reproductive individuals as long as populations are not reproductively limited. Further information of this ecological perspective can be found in: Caley et al. 1996. Recruitment and the local dynamics of open marine populations. Annu. Rev. Ecol. Syst. 27: 477 - 500.

The points I've raised are to reduce some of the confusion that lead to Section 11.2 being left as an unresolved issue. These points are not intended to resolve the issue but to clarify the intent of the message contained in that section.

**Alternative Viewpoint by David Stevenson**

Statements made in this section of the report to the effect that American lobster stocks in U.S. and Canadian waters have been increasing in abundance over the past decade are incorrect. This report contains no information on trends in abundance in Canadian lobster stocks. Results presented for the three U.S. stocks in this report (Section 8) show that significant increases in the abundance of recruits and fully-recruited lobsters in the GOM and SCCLIS stock areas only occurred during the last 3-4 years (or less) and that lobsters are currently no more abundant in the GBS stock area than they were 16 years ago. Furthermore, there are subareas within the GOM (e.g., Massachusetts Bay) where abundance has not increased at all during the last 16 years. Inaccurate characterization of abundance trends may not really be a problem, however, given the fact that exploitation rates have remained well above $F_{10\%}$ reference points for the entire time period in the GOM and for the last ten years in the SCCLIS stock area and abundance has not declined. Attempts to identify factors that account for resilience to high removal rates might best focus on areas and time periods that clearly show increased abundance and high exploitation rates. For that matter, the question could be turned around: why haven't lobsters on Georges Bank increased in abundance in the same way as lobsters in coastal waters?

Depiction of lobster stocks as not being reproductively limited, even when offered as a possibility, is misleading in the absence of a more complete explanation of exactly what this means or implies and whether it is applied to current conditions or is meant as a general comment about lobster populations. Without more explanation, the reader is left to make his or her own inferences, one of which could be that lobsters produce enough eggs regardless of how many females are removed by the fishery, therefore management to achieve some minimum egg production per female is pointless. It is one thing to say that lobster stocks are currently producing more than enough eggs to offset the effects of fishing and natural mortality, it is quite another thing to say that for some reason (or reasons) the survival of eggs, larvae, or juvenile lobsters has improved in recent years or that more larvae are settling into favorable habitat because of some change in circulation patterns that deliver larvae to coastal nursery areas. It is hard to believe that current levels of egg production per recruit in the GOM (3.5% of maximum) are more than enough to sustain the stock in the face of a 50% annual exploitation rate. What is much more likely is that favorable environmental factors during the last few years are promoting high survival and/or settlement rates. This could easily change at some point in the future, in which case 3.5% of maximum egg production per recruit would no longer be sufficient and the stock would be "reproductively limited."

**Alternative Viewpoint by Bob Glenn**

Section 11.2 does not account for the possibility that American lobster stocks do not seem reproductively limited because of increased larval and post-larval survival caused by favorable environmental conditions. It is possible that under different environmental regimes larval and post-larval survival would decrease. In this situation the current protracted size distributions of lobster in the GOM and GBS stock units would not likely be capable of providing a significant egg production buffer against down turns in recruitment. This is apparent when you compare the size at 100% maturity with the size distributions of female lobsters in each of these stock units. The size at 100% maturity is 113 mm and 132 mm for the GOM and GBS respectively. When compared to the trawl survey size distributions (Appendix C2 and C4) and the commercial catch size distributions (Appendix D3 and D5) it becomes apparent that very few adult reproductive lobsters exist in either stock unit. Currently the largest proportion of egg production from each stock comes from lobsters that have not reached 100% sexual maturity.

Section 11.2 compares density dependent processes of Northern crayfish (Momet 1998) to American lobster to demonstrate reasons for the resiliency of American lobster stocks. Northern crayfish live in small, closed, freshwater systems. These small, closed systems provide favorable conditions for density dependent, compensatory changes in life history. This section also cites two studies on spiney lobster (Chubbs 1999 and Polovina 1989) to provide evidence of density dependent shifts in life history parameters. Spiney lobsters are obligate reef dwellers. Density dependent effects are common in species that have restricted habitat requirements.

To the contrary, American lobster live in large, open marine systems and are not restricted to specific habitat types. Significant abundances of American lobster are found in shallow estuarine, rocky coastal, mud, sand, deep water ledge, and deep offshore canyons. Furthermore, the American lobster inhabits an extremely large geographic range making it unlikely that population densities are any where near carrying capacity. Historical accounts (Wood,1635) (though anecdotal and possibly prone to exaggeration) provide evidence that American lobsters once existed at abundance levels greater than what they are today.

The comparisons made using Northern crayfish and Spiney lobster as examples are not applicable to American lobster and therefore are not appropriate. Neither comparison provide sufficient evidence that density dependent processes are occurring in American lobster stocks. Providing these comparisons are misleading to the reader.

In general the explanations for stock resilience presented in Section 11.2 are speculative, and stop just short of suggesting to the reader that it is impossible to over-exploit American lobster. For this reason, it is my opinion that section 11.2 not be included as a section with "consensus", unless significant revisions are made.

**Alternative Viewpoint by Josef Idoine**

1) The argument that large lobsters are less available to the fishery may be, in some sense true, but the fact that the report begins by stating that the mean size in the catch in the mid-1800's in Maine was over 4 lbs sure doesn't lend a lot of support to the idea that large lobsters are not catchable and are safe from harvesting. Also a look at the size composition from Herrick's work in the 1890's (for example, see Crecco's minority report) shows that there are lots of large

lobsters in the catch B up to over 160 mm CL. So at best, the section is not consistent with other parts of the report. Even if it were true, the fishing rates inshore are high enough to severely affect the chances of a lobster reaching a refuge in larger size.

2) The recruitment analysis of Ennis and Fogarty (1997) was in fact based on egg production estimated recruitment and not stage IV abundance and landings as stated in Section 11.2. So it differed from the what Fogarty and Idoine (1986) had to work with for the Northumberland Strait series.

3) The fact that lobster landings have increased by a factor of 2 in the last two decades does not mean that they are not potentially reproductively limited if the physical and/or biological environment shifts to conditions unfavorable for lobsters. An alternate theory , presented in the former ASMFC (1996) review, is that the survival rates approximately doubled (for the prerecruit stages) and therefore despite low egg production levels, the recruiting population size doubled. This does not invoke an increase in egg production or imply that egg production was not limiting. Ironically, the section does list the 'many components' that affect recruitment B including mortality during the pre-recruit stage but then seems to ignore this and claim that the increase tells us something about adequacy of egg production. A change in survival from 0.00001 to 0.00002 during the larval stages could account for a doubling in recruitment. In the report of the last review panel (ASMFC 1996), there is an example (Figure 3) that shows how a change in survival could result in an increase in recruitment without a change in egg production. The danger is that if conditions deteriorate and fishing pressure is allowed to increase, we could push the stock over the edge. The statement that Athere is no satisfactory explanation based on the published curves ... "is not meaningful – an explanation was given to the review committee last time and they accepted it to the point of incorporating it in their report.

4) It is stated that stock-recruitment relationships must encompass areas large enough to be considered a closed system and that this has not been demonstrated to date for any American lobster study. In Fogarty and Idoine (1986) this issue was examined and provided all the information available on this point for the Northumberland Straight. Citing Caddy's work, we noted that the larvae were retained in the area and it did not seem to be a flow through system.

5) The text in Section 11.2 states that a 'specific number of years' is used to indicate the period of time between spawning and recruitment and, by doing so, ignores the effects of variable growth (a major assumption of all stock-recruitment studies). At least in the case of Fogarty and Idoine (1986) used weighted moving averages specifically to account for the fact that a cohort would recruit over a number (3) of years.

6) The only actual data that anyone has shown that suggests why lobsters are resilient is in Fogarty and Idoine (1986) and Ennis and Fogarty (1997) B showing recruitment curves with a steep slope at the origin. This alone is sufficient to explain the resilience of lobster stocks. This is noted in the report but it then goes on to say that we don't know the level of recruitment (should be egg production) when this occurs and this is presented as a problem. This statement follows a quote from the last review committee saying that we need a risk averse approach because of the uncertainty over where the threshold level lies B yet this section doesn't seem to make the connection. This exemplifies a major point of misunderstanding about why a precautionary approach was advocated in setting the overfishing level in the first place.

Analysis shows that you can rapidly drop off the edge once the threshold level is reached. If the committee don't believe this, they should look at the Northumberland Strait situation again. In the last 3 years of the series, Fogarty and Idoine (1986) showed the recruitment declining at low Stage IV density. This fishery collapsed shortly thereafter. It's only too bad that the sampling wasn't continued a bit longer and we would have had the anatomy of a stock failure as a case study.

7) The section on the supposed beneficial effects of traps should be deleted since it is very inconclusive (like so much else of the rest of this section).

Some of the "answers" to the section question are weakly defined and confusing. The major concern has little to do with the hypotheses (a.k.a., theories), rather, how one addresses the concept of resilience interms of dealing with a population. As mentioned above, and in Section 11.2 itself, the more resilient a population is, the steeper the cliff leading to a serious decline (i.e., a steep slope at the origin of a S/R relationship). With this in mind, the question becomes how far should we test such resilience? If one chooses to fish a population to collapse, and then wait for rebuilding, the answer is "as far as it can go" on the other hand, if we feel there are some undesirable costs associated with such a strategy, then we may view resilience as a process to cover our lack of precision on predicting the "edge", and continue attempts to avoid such a region (once again, my precautionary thinking). Since Section 11.2 offer only reasons for resilience, without some advice on how to treat such a concept, it does not offer the best scientific information/advice available.

**Alternative Viewpoint by Kevin Kelly**

I am concerned with the use of the term "reproductively limited", since it is a term which has major implications as far as a conclusion about stock status. I don't believe this term appears in any of the stock status findings and summaries in the report. I am not willing to say that lobsters are not reproductively limited, when F's are currently high enough to cause major concern if natural conditions favorable to the species were to change significantly. We can control management practices in an effort to sustain the resource but will not be able to change what is happening in the environment.

Although this section presents several interesting ecological hypotheses, primarily on larval and postlarval dynamics, I'm not certain it really gets at why certain stocks have increased despite escalating effort and in some cases, escalating F. The authors presented several possible ways in which lobsters can sustain themselves while being heavily exploited, but at this point are we willing to risk seeing how much more resilient they can be?

**Alternative Viewpoint by James Wilson**

It is important that the science advisors to the process publicly recognize divergences between their theories/models and the real world behavior of the stocks. Not to do so is bad science and, as we have found out over the years, seriously reduces the credibility of science and of the management process.

**Alternative Viewpoint by Bruce Estrella**

The Castro and Steneck report fails to address all available literature on the subject of lobster migration. Their statement that "Larger lobsters may be less available to the fishery because there is evidence that mature lobsters segregate ...to off shore habitats" does not accurately reflect the current state of knowledge. A number of tagging studies (Canadian and American) define the inshore, return movement of large mature females (many of them egg bearing females) and males into the shoal waters throughout the range of the species for reasons of reproduction and molting (Pezzack and Dugan 1986, Estrella and Morrissey 1997). Pezzack and Dugan (1986) describe the homing tendencies of offshore lobsters. These lobsters were observed through commercial lobstering operations; consequently, it cannot be concluded that mature lobsters migrate beyond the effective range of commercial fishing.

In addition, the reference to Miller (1997) (page 153) is used to support a statement of unsurety about whether larval movement occurs over considerable distance. This paragraph fails to recognize that one of the principal conclusions of Miller (1997) was that "that lobster productivity is area specific". This implies that any geographically broad-based similarities in larval production are likely only an artifact of similar environmental influence. Miller (1997) also indicated that his work suggested that mortality form eggs to larvae and from post-larvae to fishery recruits was density independent and stated that this indicated that measures designed to increase egg production will, on average, increase the number of recruits. This was not noted anywhere in the Castro/Stenneck report where discussions of density dependence occurred.

Finally, the text also refers to a Momet (1998) study based on a freshwater crayfish in a closed environment, which may not be applicable to American lobster. There is no evidence that density dependent response of a crayfish to high density and size structure manipulation in an enclosed environment would be applicable to American lobster in an open-water existence where lobsters can relocate from undesirable conditions. Video studies of lobster competition showed that subordinants (those who lost competitive bouts) just wandered to low quality habitats. They appear to suffer little from that relocation (R. Stenneck, personal communication).

**Alternative Viewpoint by Larry Jacobson:**

An important technical question not addressed in the unresolved issue section, is how long the current period of high lobster recruitment and productivity will last. Some of the hypotheses about resilience and persistence described below relate to biological characteristics of lobster that are unlikely to change (e.g. growth rates, maturity schedules, etc.). Other hypotheses relate to environmental conditions (recently favorable for reproduction) and fishing procedures (e.g. the distribution of fishing effort relative to the distribution of large lobsters, numbers of traps) that may change, possibly quickly and dramatically. The distinction is important to the extent that persistence, resiliency and recent conditions of high abundance and productivity depend on temporary factors. This topic is another important area for future research and analysis.

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Table 1. Estimates of natural mortality rates for clawed lobsters

| AUTHOR | M | METHOD | SPECIES |
|---|---|---|---|
| Scarrett (1964) | 3.00(98.9%) | Mean survival | First larval stage-fourth stage *H. americanus* |
| Thomas (1973) | 0.04-0.08<br>0.11 Canadian | Catch and effort<br>Silliman (1943) | Juvenile and adult *H. americanus* |
| Anthony and Cooper (1977) | 0.05-0.2 | | *Homarus americanus* |
| Hepper (1978) | 0.15-0.25 | | *Homarus gammarus* |
| Ennis (1979) | 0.02 (2.2%) males | Catch/effort<br>Tag/recapture | *H. americanus* |
| Anthony, 1980 | 0.02-0.35<br>Average: 0.15 | Tagging studies | *H. americanus* |
| Campbell, 1980 | 4.6 (99.9%) | | *H. americanus* (larval stages) |
| Fogarty and Idoine (1988) | 0.1 Hardshell<br>0.05- 0.1 Softshell | literature | *H. americanus* |
| Saila (1996) | Z estimates for several stages<br>$M_{average}$=0.25 | Catch curves<br>Oil spill strandings | *H. americanus*<br>7 mm-82.6 mm |
| Bannister (1998) | $M_{average}$ 0.04-0.11<br>$M_{average}$ 0.13 | Tag/Recapture - Catch rates<br>Biological Survival Model | *H. gammarus (10th stage through legal size)* |

Table 2. American lobster landings (mt) by state, 1962-1998.

| Calendar Year | ME | NH | MA | RI | CT | NY | NJ | DE,MA,VA,NC | Total |
|---|---|---|---|---|---|---|---|---|---|
| 62 | 10013 | 329 | 1923 | 261 | 285 | 143 | 395 | 11 | 13360 |
| 63 | 10344 | 339 | 2020 | 269 | 214 | 172 | 340 | 11 | 13709 |
| 64 | 8586 | 386 | 2489 | 452 | 132 | 248 | 481 | 14 | 12788 |
| 65 | 8556 | 347 | 2885 | 816 | 337 | 294 | 462 | 21 | 13719 |
| 66 | 9034 | 366 | 2190 | 759 | 355 | 331 | 347 | 18 | 13400 |
| 67 | 7479 | 326 | 2134 | 885 | 409 | 399 | 399 | 98 | 12129 |
| 68 | 9299 | 342 | 2185 | 1394 | 402 | 529 | 549 | 53 | 14755 |
| 69 | 8997 | 332 | 2248 | 1926 | 423 | 642 | 650 | 94 | 15313 |
| 70 | 8243 | 312 | 2579 | 2357 | 305 | 747 | 833 | 114 | 15489 |
| 71 | 7964 | 303 | 2788 | 2444 | 237 | 812 | 600 | 132 | 15281 |
| 72 | 7374 | 305 | 3643 | 1516 | 245 | 519 | 593 | 421 | 14617 |
| 73 | 7731 | 226 | 2549 | 1258 | 247 | 405 | 618 | 115 | 13149 |
| 74 | 7465 | 226 | 2387 | 1550 | 294 | 331 | 540 | 153 | 12947 |
| 75 | 7714 | 218 | 3054 | 1670 | 269 | 304 | 386 | 80 | 13696 |
| 76 | 8619 | 216 | 2982 | 1548 | 217 | 269 | 293 | 130 | 14275 |
| 77 | 8386 | 215 | 3270 | 1584 | 290 | 241 | 362 | 54 | 14400 |
| 78 | 8677 | 213 | 4323 | 1280 | 362 | 264 | 420 | 91 | 15630 |
| 79 | 10039 | 354 | 4333 | 1038 | 366 | 318 | 365 | 97 | 16912 |
| 80 | 9970 | 328 | 4502 | 1087 | 374 | 333 | 232 | 54 | 16880 |
| 81 | 10266 | 360 | 5090 | 849 | 458 | 404 | 269 | 55 | 17750 |
| 82 | 10310 | 366 | 5965 | 1440 | 472 | 455 | 384 | 73 | 19465 |
| 83 | 9968 | 594 | 5635 | 2320 | 812 | 661 | 349 | 74 | 20413 |
| 84 | 8866 | 712 | 6669 | 2386 | 853 | 856 | 421 | 109 | 20872 |
| 85 | 9129 | 538 | 7391 | 2332 | 726 | 875 | 490 | 111 | 21592 |
| 86 | 8938 | 515 | 6830 | 2571 | 711 | 787 | 509 | 118 | 20979 |
| 87 | 8957 | 570 | 6857 | 2412 | 747 | 809 | 634 | 88 | 21074 |
| 88 | 9861 | 508 | 7198 | 2159 | 907 | 1138 | 706 | 66 | 22262 |
| 89 | 10600 | 649 | 6997 | 2597 | 917 | 1241 | 934 | 63 | 23998 |
| 90 | 12732 | 752 | 7736 | 3292 | 1053 | 1703 | 997 | 69 | 28334 |
| 91 | 13965 | 817 | 7497 | 3377 | 1091 | 1839 | 759 | 40 | 29385 |
| 92 | 12170 | 694 | 7177 | 3068 | 1025 | 2336 | 550 | 22 | 27042 |
| 93 | 13574 | 768 | 6503 | 2825 | 967 | 2501 | 411 | 33 | 27582 |
| 94 | 17667 | 749 | 7303 | 2937 | 978 | 2915 | 264 | 8 | 32821 |
| 95 | 16557 | 832 | 7234 | 2433 | 1132 | 3116 | 275 | 25 | 31605 |
| 96 | 16427 | 741 | 6966 | 2531 | 1285 | 3656 | 290 | 23 | 31919 |
| 97 | 21015 | 641 | 6844 | 2534 | 1547 | 4027 | 389 | 17 | 37015 |
| 98 | 21329 | 567 | 5976 | 2372 | 1659 | 3867 | 316 | 51 | 36137 |
|  |  |  |  |  |  |  |  |  |  |
| Overall Ave. % | 53.4 | 2.3 | 23.7 | 9.2 | 3.1 | 5.5 | 2.4 | 0.4 |  |
| Ave % 1989-98 | 51.0 | 2.4 | 23.0 | 9.1 | 3.8 | 8.9 | 1.7 | 0.1 |  |

Table 3. Total American lobster landings by stock unit.

| Calendar Year | Georges Bank | Gulf of Maine | S. Cape Cod & Long Isl. Sound | Total |
|---|---|---|---|---|
| 62 | 1322 | 11549 | 489 | 13360 |
| 63 | 1302 | 12023 | 385 | 13709 |
| 64 | 1780 | 10639 | 369 | 12788 |
| 65 | 2422 | 10612 | 686 | 13719 |
| 66 | 854 | 10858 | 688 | 12400 |
| 67 | 2197 | 8161 | 772 | 11129 |
| 68 | 2452 | 11211 | 1092 | 14755 |
| 69 | 3283 | 10802 | 1229 | 15313 |
| 70 | 3827 | 10332 | 1331 | 15489 |
| 71 | 3535 | 10436 | 1310 | 15281 |
| 72 | 3485 | 10318 | 814 | 14617 |
| 73 | 2292 | 10110 | 746 | 13149 |
| 74 | 2819 | 9233 | 894 | 12947 |
| 75 | 2792 | 9933 | 971 | 13696 |
| 76 | 2702 | 10889 | 701 | 14293 |
| 77 | 2391 | 11205 | 805 | 14400 |
| 78 | 2908 | 11845 | 876 | 15630 |
| 79 | 2572 | 13444 | 896 | 16912 |
| 80 | 1860 | 13962 | 1059 | 16880 |
| 81 | 2119 | 14777 | 854 | 17750 |
| 82 | 2444 | 14669 | 2352 | 19465 |
| 83 | 2678 | 15201 | 2534 | 20413 |
| 84 | 3105 | 13797 | 3969 | 20871 |
| 85 | 2912 | 14554 | 4123 | 21589 |
| 86 | 2979 | 13905 | 4095 | 20979 |
| 87 | 3108 | 13952 | 4013 | 21073 |
| 88 | 3045 | 14415 | 4802 | 22262 |
| 89 | 3424 | 16708 | 3867 | 23999 |
| 90 | 4279 | 19535 | 4520 | 28334 |
| 91 | 4091 | 20532 | 4763 | 29386 |
| 92 | 3884 | 18309 | 4849 | 27042 |
| 93 | 3604 | 19079 | 4901 | 27584 |
| 94 | 2993 | 23789 | 6038 | 32819 |
| 95 | 3627 | 22536 | 5447 | 31610 |
| 96 | 3485 | 22118 | 6317 | 31920 |
| 97 | 3906 | 26230 | 6894 | 37030 |
| 98 | 3838 | 25644 | 6671 | 36153 |

**Table 4. Timeline Of Lobster Regulations By State***

| Year | Maine | Massachusetts | Rhode Island** | Connecticut | k |
|---|---|---|---|---|---|
| 1874 | 10.5 inch total length minimum (10/15 –4/1) | 10.5 inch total length minimum | | | |
| 1879 | | | 10.5 inch total length minimum | | |
| 1880 | | Illegal to take berried females | | | |
| 1883 | 9 inch total length minimum (4/1 –8/1) | | | | |
| 1889 | Illegal to catch berried females | | | | |
| 1893 | | | | | tal length minimum |
| 1895 | 10.5 inch total length minimum size | | | | |
| 1904 | | | 9 inch total length minimum | | |
| 1907 | 4-3/4 inch total back shell length minimum | 9 inch total length minimum | | | |
| 1912 | | | | | h carapace length (including rostrum); take or scrub berried first lath must be 1-1/2 ove trap bottom |
| 1919 | 3-1/2 inch (eye socket to rear of shell) minimum | | | | |
| 1921 | 3-1/2 inch carapace length minimum | | | | |
| 1933 | 3-1/16 inch carapace length minimum;<br>4-3/4 inch carapace length maximum | 3-1/16 inch carapace length minimum | | | |
| 1935 | 5 inch carapace length maximum | | | | ch carapace length |
| 1938 | | | 4-1/8 inch carapace length minimum | | |
| 1941 | | 3-1/8 inch carapace length minimum; illegal to take V-notched females; spearing, dipping, dragging illegal | | | |

Table 4 (cont.). Timeline Of Lobster Regulations By State*

| Year | Maine | Massachusetts | Rhode Island* | Connecticut | New York |
|---|---|---|---|---|---|
| 1942 | 3-1/8 inch carapace length minimum | | | | 3-1/8 inch carapace length minimum |
| 1948 | V-notch program instituted; illegal to harvest v-notched lobster | | | | |
| 1949 | | DMF staff required to V-notch hatchery spent females | | | |
| 1950 | | 3-3/16 carapace length minimum | | | |
| 1953 | | | | | 3-3/16 inch carapace length minimum |
| 1958 | 3-3/16 inch carapace length minimum; 5-3/16 inch carapace length maximum | | | | |
| 1959 | | Licensed fishers allowed to V-notch | | | Lath spacing requirement repealed |
| 1960 | 5 inch carapace length maximum | | | | |
| 1961 | Illegal to take lobsters by any means except traps | | | | |
| 1967 | | | | | Buoy and ID requirements for all traps |
| 1968 | Buoy colors consistent, displayed on boat | | 3-1/16 inch carapace length minimum | | |
| 1973 | | V-notch statute repealed | | | |
| 1975 | | Lobster license moratorium | | | |
| 1976 | | 1-3/4 by 6 inch escape vent or (2) 2.28" circular | | 3-3/16 inch carapace length minimum; illegal to take berried or stripped female lobster; more than 10 requires commercial license; illegal to possess parts; no hauling pots at night | |
| 1977 | | | | | No spearing; detached tail must have 1" sixth segment |
| 1978 | | | 3-3/16 inch carapace length minimum | | |

Table 4 (cont.). **Timeline Of Lobster Regulations By State***

| Year | Maine | Massachusetts | Rhode Island* | Connecticut | New York |
|---|---|---|---|---|---|
| 1979 | 1-3/4 by 6 inch oblong or rectangular vents, or (2) 2-1/4 inch circular vents; lath spacing 1-3/4 inch; Illegal to strip a lobster of eggs | | | | |
| 1981 | | License limiting program | | | Detached tail must have 1-1/16 inch 6th segment |
| 1983 | | 100 count allowed for draggers | 1-7/8 inch by 5-3/4 inch rectangular escape vent; 2-3/8 inch diameter circular escape vent | No pots in USCG- marked navigation channels | Trawlers limited to 100 lobsters |
| 1984 | | | | 1-3/4 inch by 6 inch rectangular escape vent; or (2) 2-1/4 inch circular vents; Trawl bycatch limit of 100 pieces west of 73° W | |
| 1985 | | | | No pots on oysterbeds | |
| 1986 | | | | 100 piece limit west of 14810 | No trawling in Long Is. Sound |
| 1987 | 1-3/4 by 5-3/4 inch rectangular vent | | | No pots in mooring areas 5/1 – 10/15 | |
| 1988 | 3-7/32 inch carapace length minimum | 3-7/32 inch carapace length; V-notch statute reinstated to protect ME lobsters; New license moratorium | 3-7/32 inch carapace length minimum | 3-7/32 minimum carapace length for federal permit holders only; 3/38 inch lath escape panel on wood pots; other pots must have 3-3/4 inch square panel attached with 3/32" wire | |
| 1989 | 3-8/32 inch carapace length minimum | 3-1/4 inch carapace length minimum | 3-1/4 inch carapace length minimum | 3-7/32 minimum carapace length for all; Buoys must be uniform color | 3-7/32 inch carapace length minimum |
| 1990 | Ghost panels required | | | 3-1/4 inch carapace length minimum | 3-1/4 inch carapace length minimum |
| 1991 | | V-notch statute repealed again | | No NY residents can take lobster by trawl | |

Table 4 (cont.). Timeline Of Lobster Regulations By State*

| Year | Maine | Massachusetts | Rhode Island | Connecticut | New York |
|---|---|---|---|---|---|
| 1992 | 1-7/8 by 5-3/4 inch rectangular vent, or (2) 2-3/8 inch circular vents; lath spacing 1-7/8 inches | 1-7/8 inch rect. or (2) 2-3/8 inch circular vents; ghost panel required (3-3/4 square); 800 trap limit | | 1-7/8 by 6 inch rectangular or (2) 2-3/8 circular vents for federal permit holders only | 1-7/8 inch by 6 inch rectangular or (2) 2-3/8 inch circular vents;<br>Escape panels required on all non-biodegradable pots |
| 1993 | | New license limiting and reduction plan | | | |
| 1995 | | | | 1/7/8 by 6 inch rectangular or (2) 2-3/8 circular vents for all<br>April 1: 1-7/8 by 5-3/4 rect. or (2) 2-3/8 inch circular; commercial fishing vessel permit required and moratorium on new ones | |
| 1996 | | Illegal to possess stripped females | | | |
| 1997 | | | | | Commercial license moratorium |
| 1998 | 1-15/16 inch by 5-3/4 inch rectangular escape vent; 2-7/16 inch diameter circular escape vent; trap size limited to 22,950 cubic inches. | | 22,950 cu in. max trap size; trap limit reduction schedule passed (first limit 1200 as of 6/1/99); 100/day or 500/trip limit with non-trap gear; illegal to use spear, gig, gaff to harvest lobster; illegal to take V-notched females | 1-15/16 inch rectangular or (2) 2-7/16 inch circular; Illegal to take V-notched lobsters; no pots over 22,950 cubic inches; no spearing lobsters; non-trap gear limited to 100 pieces in state waters; 100 pieces a day, not more than 500 in federal waters | Rectangular vent requirements changed to 1-15/16 inch; Illegal to take V-notched lobsters; 22,950 cubic inches maximum pot size; prohibition on landing parts; non-trap gear limited to 100 lobsters/day, 500 per trip |
| 1999 | 1000 trap limit per license holder; trap limit = boat limit; 2-7/16" circular escape vent required | 1-15/16 inch by 5-3/4 inch rectangular escape vent; 2-7/16 inch diameter circular escape vent; illegal to take V-notched females; 5 inch max. CL in area 1; trap size limited to 22,950 cubic inches; trap tags required. | 1-15/16 inch by 5-3/4 inch rectangular escape vent or space between lathes; 2-7/16 inch diameter circular escape vent;1200 maximum traps; limits on non-trap fishers | | |

* New Hampshire, New Jersey, Delaware, Maryland, Virginia, and North Carolina all have regulations in place for American lobster. New Hampshire and New Jersey have implemented all measures contained in Amendment 3 and Addendum I. Delaware, Maryland, Virginia, and North Carolina are only required to implement, at a minimum, the first five coastwide measures listed in Section 5.3 due to low landings in each of these states.

** It is currently illegal to harvest berried females in Rhode Island, but the enactment date of the law is unknown.

Table 5. American lobster biological sampling coverage in the Gulf of Maine stock area, 1994-98.

| Calendar year | Statistical area | Data source | No. samples (i.e., boats or trips) | No. lobsters measured ** (marketable catch) | Landings ($X10^6$ lbs.) |
|---|---|---|---|---|---|
| 1994 | 511 | ME DMR port sampling | 34 | 338 | 2.73 |
| | 512 | ME DMR port sampling | 147 | 1,470 | 20.25 |
| | 513 | ME DMR port sampling | 157 | 1,566 | 16.68 |
| | | NH F&G sea sampling | 13 | 1,999 | |
| | 514 | MA DMF sea sampling | 54 | 13,865 | 11.75 |
| | 464* | Canada DFO sampling | NA | 4,286 | NA |
| | 465* | Canada DFO sampling | NA | 2,819 | NA |
| | 515 | NMFS sea sampling | NA | 1,971 | 0.69 |
| | Total | | | 28,314 | 52.10 |
| 1995 | 511 | ME DMR port sampling | 67 | 669 | 2.54 |
| | 512 | ME DMR port sampling | 127 | 1,267 | 20.84 |
| | 513 | ME DMR port sampling | 118 | 1,173 | 13.82 |
| | | NH F&G sea sampling | 13 | 2,403 | |
| | 514 | MA DMF sea-sampling | 54 | 14,104 | 11.62 |
| | 464* | Canada DFO sampling | NA | 2,160 | NA |
| | 465* | Canada DFO sampling | NA | 483 | NA |
| | 515 | NMFS sea sampling | NA | 1,096 | 0.85 |
| | Total | | | 23,355 | 49.67 |
| 1996 | 511 | ME DMR port sampling | 28 | 280 | 3.99 |
| | 512 | ME DMR port sampling | 203 | 2,024 | 19.09 |
| | 513 | ME DMR port sampling | 87 | 870 | 14.24 |
| | | NH F&G sea sampling | 14 | 2,547 | |
| | 514 | MA DMF sea-sampling | 52 | 13,210 | 11.1 |
| | 464* | Canada DFO sampling | NA | 3,880 | NA |
| | 465* | Canada DFO sampling | NA | 283 | NA |
| | 515 | NMFS sea sampling | NA | 2,312 | 0.91 |
| | Total | | | 25,406 | 49.33 |

Table 5 (cont.). American lobster biological sampling coverage in the Gulf of Maine stock area, 1994-98.

| Calendar year | Statistical area | Data source | No. samples (i.e., boats or trips) | No. lobsters measured ** (marketable catch) | Landings ($X10^6$ lbs.) |
|---|---|---|---|---|---|
| 1997 | 511 | ME DMR port sampling | 69 | 683 | 3.57 |
| | 512 | ME DMR port sampling | 256 | 2,553 | 26.23 |
| | 513 | ME DMR port sampling<br>NH F&G sea sampling | 138<br>8 | 1,380<br>1,333 | 16.91 |
| | 514 | MA DMF sea-sampling | 86 | 21,339 | 10.35 |
| | 464* | Canada DFO sampling | NA | 491 | NA |
| | 465* | Canada DFO sampling | NA | 49 | NA |
| | 515 | NMFS sea-sampling | NA | 92 | 0.75 |
| | Total | | | 27,920 | 57.81 |
| 1998 | 511 | ME DMR port sampling | 31 | 310 | 4.40 |
| | 512 | ME DMR port sampling | 260 | 2,600 | 26.98 |
| | 513 | ME DMR port sampling<br>NH F&G sea sampling | 156<br>10 | 1,552<br>1,274 | 15.97 |
| | 514 | MA DMF sea-sampling | 53 | 12,322 | 8.66 |
| | 515 | none | 0 | 0 | 0.52 |
| | Total | | | 18,058 | 56.53 |

* data from these areas were used for SA 515

** not certain if all lobsters measured in NMFS and DFO sea sampling trips were marketable size

Table 6. American lobster biological sampling coverage in the Georges Bank and South stock area, 1994-98.

| Calendar year | Statistical area | Data source | No. samples (i.e., boats or trips) | No. lobsters measured * (marketable catch) | Landings ($X10^6$ lbs.) |
|---|---|---|---|---|---|
| 1994 | 521 | MA DMF sea sampling | 13 | 3,369 | 0.82 |
| | 522 | NMFS sea sampling | NA | 632 | 0.05 |
| | 523 | none | 0 | 0 | 0.01 |
| | 524 | none | 0 | 0 | 0.35 |
| | 525 | NMFS sea sampling | NA | 1,232 | 0.74 |
| | 526 | NMFS sea sampling | NA | 608 | 1.15 |
| | 537 + | RI DEM sea sampling | 4 | 7,746 | 3.11 |
| | 616 | | | | 0.56 |
| | 561 | none | 0 | 0 | <0.01 |
| | 562 | NMFS sea sampling | NA | 105 | <0.01 |
| | 612 | none | 0 | 0 | 0.64 |
| | 613 | | | | 0.48 |
| | 614 | | | | <0.01 |
| | 621 | | | | 0.01 |
| | 622 | | | | 0.06 |
| | 623 | | | | 0.08 |
| | 625 | | | | <0.01 |
| | 626 | | | | 0.01 |
| | 631 | | | | <0.01 |
| | Total | | | 13,692 | 8.07 |
| 1995 | 521 | MA DMF sea sampling | 14 | 3,297 | 1.07 |
| | 522 | none | 0 | 0 | 0.11 |
| | 523 | none | 0 | 0 | <0.01 |
| | 524 | none | 0 | 0 | 0.28 |
| | 525 | NMFS sea sampling | NA | 180 | 0.47 |
| | 526 | none | 0 | 0 | 0.93 |
| | 534 | none | 0 | 0 | <0.01 |
| | 537 + | RI DEM sea sampling | 4 | 6,668 | 2.76 |
| | 616 | | | | 0.46 |
| | 561 | none | 0 | 0 | <0.01 |
| | 562 | none | 0 | 0 | <0.01 |
| | 612 | none | 0 | 0 | 0.59 |
| | 613 | | | | 0.40 |
| | 614 | | | | <0.01 |
| | 621 | | | | 0.03 |
| | 622 | | | | 0.03 |
| | 623 | | | | 0.06 |
| | 625 | | | | <0.01 |
| | 626 | | | | 0.01 |
| | Total | | | 10,145 | 7.21 |

Table 6 (cont.). American lobster biological sampling coverage in the Georges Bank and South stock area, 1994-98.

| Calendar year | Statistical area | Data source | No. samples (i.e., boats or trips) | No. lobsters measured * (marketable catch) | Landings ($X10^6$ lbs.) |
|---|---|---|---|---|---|
| 1996 | 521 | MA DMF sea sampling | 14 | 3,407 | 0.85 |
| | 522 | NMFS sea sampling | NA | 444 | 0.09 |
| | 523 | none | 0 | 0 | 0.02 |
| | 524 | none | 0 | 0 | 0.44 |
| | 525 | NMFS sea sampling | NA | 1,045 | 0.55 |
| | 526 | none | 0 | 0 | 0.90 |
| | 534 | none | 0 | 0 | <0.01 |
| | 537 +<br>616 | RI DEM sea sampling | 4 | 8,177 | 2.80<br>0.47 |
| | 561 | NMFS sea sampling | NA | 158 | <0.01 |
| | 562 | NMFS sea sampling | NA | 1,945 | <0.01 |
| | 612 | none | 0 | 0 | 0.36 |
| | 613 | | | | 0.27 |
| | 614 | | | | <0.01 |
| | 615 | | | | <0.01 |
| | 621 | | | | 0.03 |
| | 622 | | | | 0.07 |
| | 623 | | | | 0.12 |
| | 625 | | | | <0.01 |
| | 626 | | | | 0.01 |
| | Total | | | 15,176 | 6.99 |

Table 6 (cont.). American lobster biological sampling coverage in the Georges Bank and South stock area, 1994-98.

| Calendar year | Statistical area | Data source | No. samples (i.e., boats or trips) | No. lobsters measured * (marketable catch) | Landings ($X10^6$ lbs.) |
|---|---|---|---|---|---|
| 1997 | 521 | MA DMF sea sampling | 14 | 2,547 | 0.85 |
| | 522 | none | 0 | 0 | 0.14 |
| | 523 | none | 0 | 0 | 0.01 |
| | 524 | none | 0 | 0 | 0.61 |
| | 525 | none | 0 | 0 | 0.48 |
| | 526 | none | 0 | 0 | 0.92 |
| | 534 | none | 0 | 0 | <0.01 |
| | 537 +<br>616 | RI DEM sea sampling | 4 | 9,965 | 3.16<br>0.48 |
| | 542 | none | 0 | 0 | <0.01 |
| | 561 | NMFS sea sampling | NA | 158 | <0.01 |
| | 562 | none | 0 | 0 | <0.01 |
| | 612<br>613<br>615<br>621<br>622<br>623<br>625<br>626 | none | 0 | 0 | 0.36<br>0.35<br><0.01<br><0.01<br>0.08<br>0.13<br><0.01<br>0.02 |
| | Total | | | 12,670 | 7.60 |
| 1998 | 521 | MA DMF sea sampling | 14 | 2,379 | 0.87 |
| | 522 | none | 0 | 0 | 0.19 |
| | 525 | none | 0 | 0 | 0.54 |
| | 526 | NMFS sea sampling | NA | 3,257 | 0.81 |
| | 533 | none | 0 | 0 | <0.01 |
| | 534 | none | 0 | 0 | <0.01 |
| | 537 +<br>616 | RI DEM + NMFS sea sampling | NA | 8,173 (combined) | 2.72<br>0.45 |
| | 561 | none | 0 | 0 | 0.03 |
| | 562 | none | 0 | 0 | 0.51 |
| | 612<br>613<br>614<br>615<br>621<br>622<br>626<br>635 | none | 0 | 0 | 0.50<br>0.51<br><0.01<br><0.01<br>0.09<br>0.01<br><0.01<br><0.01 |
| | Total | | | 13,809 | 7.24 |

* not certain if all lobsters measured in NMFS and DFO sea sampling trips were marketable size

Table 7. American lobster biological sampling coverage in the South of Cape Cod and Long Island Sound stock area, 1994-98.

| Calendar year | Statistical area | Data source | No. samples (i.e., boats or trips) | No. lobsters measured (marketable catch) | Landings ($X10^6$ lbs.) |
|---|---|---|---|---|---|
| 1994 | 538 | MA DMF sea sampling | 10 | 2,592 | 0.61 |
| | 539 | RI DEM sea sampling | 24 | 5,304 | 3.30 |
| | 611 | CT DEP sea sampling<br>NYSDEC sea sampling | 10<br>32 | 7,114 (combined) | 7.90 |
| | Total | | | 15,010 | 11.81 |
| 1995 | 538 | MA DMF sea sampling | 11 | 1,921 | 0.65 |
| | 539 | RI DEM sea sampling | 25 | 6,770 | 2.76 |
| | 611 | CT DEP sea sampling<br>NYSDEC sea sampling | 8<br>4 | 825 (combined) | 8.60 |
| | Total | | | 9,516 | 12.01 |
| 1996 | 538 | MA DMF sea sampling | 11 | 2,635 | 0.63 |
| | 539 | RI DEM sea sampling | 26 | 7,263 | 2.93 |
| | 611 | CT DEP sea sampling<br>NYSDEC sea sampling | 26<br>2 | 2,463 (combined) | 10.37 |
| | Total | | | 12,361 | 13.93 |
| 1997 | 538 | MA DMF sea sampling | 10 | 1,792 | 0.66 |
| | 539 | RI DEM sea sampling* | 24 | 5,690 | 2.98 |
| | 611** | CT DEP sea sampling<br>NYSDEC sea sampling | 13<br>0 | 1,936 (combined) | 11.56 |
| | Total | | | 9,418 | 15.20 |
| 1998 | 538 | MA DMF sea sampling | 15 | 3,400 | 0.81 |
| | 539 | RI DEM sea sampling* | 24 | 5,636 | 2.76 |
| | 611** | CT DEP sea sampling<br>NYSDEC sea sampling | 19<br>2 | 3,311 (combined) | 11.13 |
| | Total | | | 12,347 | 14.70 |

* these data also used for Area 611 size frequencies in this year

** also used CT DEP trawl survey data for this statistical area in this year

Table 8. Catch weighted estimates of fishing mortality rates for male and female lobsters in the SCCLIS stock assessment area from LCA analysis. Estimates are not reliable (see text). Annual values give results based on fishery length composition for each survey year but should not be interpreted as time series of independent estimates because LCA estimates average or equilibrium fishing mortality rates.

| Survey Year | Males | Females |
|---|---|---|
| 1982 | 1.526 | 0.643 |
| 1983 | 1.441 | 0.650 |
| 1984 | 1.493 | 0.660 |
| 1985 | 1.597 | 0.748 |
| 1986 | 1.655 | 0.733 |
| 1987 | 1.521 | 0.723 |
| 1988 | 1.559 | 0.748 |
| 1989 | 1.489 | 0.724 |
| 1990 | 1.471 | 0.715 |
| 1991 | 1.533 | 0.803 |
| 1992 | 1.542 | 0.858 |
| 1993 | 1.495 | 0.866 |
| 1994 | 1.429 | 0.840 |
| 1995 | 1.620 | 0.803 |
| 1996 | 1.575 | 0.842 |
| 1997 | 1.601 | 0.805 |

Table 9. Catch weighted estimates of fishing mortality rates for male and female lobsters in the Gulf of Maine (GOM) stock assessment area from LCA analysis.

Estimates are not reliable (see text). Annual values give results based on fishery length composition for each survey year but should not be interpreted as time series of independent estimates because LCA estimates average or equilibrium fishing mortality rates.

| Survey Year | MALES | FEMALES |
|---|---|---|
| 1981 | 1.006 | 0.918 |
| 1982 | 0.998 | 0.926 |
| 1983 | 0.970 | 0.950 |
| 1984 | 1.102 | 0.986 |
| 1985 | 0.924 | 1.011 |
| 1986 | 1.075 | 0.991 |
| 1987 | 1.122 | 1.134 |
| 1988 | 1.085 | 1.071 |
| 1989 | 1.049 | 1.087 |
| 1990 | 1.083 | 1.104 |
| 1991 | 1.096 | 1.069 |
| 1992 | 1.068 | 1.011 |
| 1993 | 1.038 | 1.044 |
| 1994 | 0.997 | 0.984 |
| 1995 | 1.043 | 0.961 |
| 1996 | 1.089 | 1.061 |
| 1997 | 1.103 | 1.043 |

Table 10. Catch weighted estimates of fishing mortality rates for male and female lobster in the Georges Bank & South stock assessment area from LCA analysis.

Estimates for recent years may be reliable but estimates for earlier years are not (see text). Annual values give results based on fishery length composition for each survey year but should not be interpreted as time series of independent estimates because LCA estimates average or equilibrium fishing mortality rates. Estimates from data for recent years are summarized in tables 7.3.2-4 and 7.3.2-5.

| Survey Year | Females | Males |
|---|---|---|
| 1981 | 0.431 | 0.764 |
| 1982 | 0.410 | 0.629 |
| 1983 | 0.376 | 0.527 |
| 1984 | 0.514 | 0.720 |
| 1985 | 0.453 | 0.737 |
| 1986 | 0.568 | 0.935 |
| 1987 | 0.592 | 0.731 |
| 1988 | 0.447 | 0.835 |
| 1989 | 0.571 | 0.895 |
| 1990 | 0.740 | 1.165 |
| 1991 | 0.734 | 1.242 |
| 1992 | 0.752 | 1.234 |
| 1993 | 0.762 | 1.131 |
| 1994 | 0.831 | 1.057 |
| 1995 | 0.734 | 0.977 |
| 1996 | 0.751 | 1.184 |
| 1997 | 0.726 | 1.155 |

Table 11. LCA data, calculations and results for male lobsters in the Georges Bank & South stock area during 1995-1997.

Results include recruitment estimates (stock number at 83 mm), fishing mortality by length group, and average (catch and abundance weighted) fishing mortality for legal size lobster. Data were average catch in number by length group for 1996-1998. Recruitment and fishing mortality rates are average estimates for recent years that may or may not be reliable (see text). $F_t$ is the terminal fishing mortality rate. $T_c$ is the proportion of the year elapsed when fishing is assumed to take place.

| LENGTH-BASED COHORT ANALYSIS | | | | | | Ft = | 0.7 |
|---|---|---|---|---|---|---|---|
| American lobster | | | | | | M = | 0.15 |
| GBS Males | | | 1995-1997 Mean Males | | | Tc = | 0.8 |
| | | | | | | | |
| Length (mm) | | Catch (numbers) | Delta-t (y) | Stock Numbers | F/Z | Z | F |
| 203 | 207 | 22 | 0.601 | 67 | | | 0.7 |
| 198 | 202 | 133 | 0.601 | 216 | 0.891 | 1.373 | 1.223 |
| 193 | 197 | 152 | 0.601 | 400 | 0.827 | 0.867 | 0.717 |
| 188 | 192 | 53 | 0.601 | 495 | 0.560 | 0.341 | 0.191 |
| 183 | 187 | 140 | 0.601 | 692 | 0.710 | 0.516 | 0.366 |
| 178 | 182 | 872 | 0.601 | 1,695 | 0.870 | 1.152 | 1.002 |
| 173 | 177 | 1,010 | 0.601 | 2,940 | 0.811 | 0.793 | 0.643 |
| 168 | 172 | 1,602 | 0.601 | 4,939 | 0.801 | 0.755 | 0.605 |
| 163 | 167 | 3,678 | 0.601 | 9,358 | 0.832 | 0.894 | 0.744 |
| 158 | 162 | 4,515 | 0.601 | 15,094 | 0.787 | 0.705 | 0.555 |
| 153 | 157 | 4,812 | 0.601 | 21,692 | 0.729 | 0.554 | 0.404 |
| 148 | 152 | 6,502 | 0.599 | 30,717 | 0.720 | 0.536 | 0.386 |
| 143 | 147 | 11,269 | 0.570 | 45,523 | 0.761 | 0.628 | 0.478 |
| 138 | 142 | 16,147 | 0.537 | 66,565 | 0.767 | 0.645 | 0.495 |
| 133 | 137 | 14,757 | 0.510 | 87,544 | 0.703 | 0.506 | 0.356 |
| 128 | 132 | 19,854 | 0.486 | 115,207 | 0.718 | 0.531 | 0.381 |
| 123 | 127 | 20,260 | 0.467 | 144,997 | 0.680 | 0.469 | 0.319 |
| 118 | 122 | 26,060 | 0.448 | 182,579 | 0.693 | 0.489 | 0.339 |
| 113 | 117 | 23,365 | 0.438 | 219,616 | 0.631 | 0.406 | 0.256 |
| 108 | 112 | 33,913 | 0.432 | 270,022 | 0.673 | 0.458 | 0.308 |
| 103 | 107 | 37,289 | 0.420 | 326,801 | 0.657 | 0.437 | 0.287 |
| 98 | 102 | 127,247 | 0.404 | 480,775 | 0.826 | 0.864 | 0.714 |
| 93 | 97 | 686,616 | 0.385 | 1,228,462 | 0.918 | 1.836 | 1.686 |
| 88 | 92 | 827,057 | 0.367 | 2,162,369 | 0.886 | 1.311 | 1.161 |
| 83 | 87 | 826,360 | 0.350 | 3,140,532 | 0.845 | 0.967 | 0.817 |
| Sum | | 2,693,684 | | 8,559,294 | | | |
| | | | | | | | |
| | | | | Catch weighted mean | | | 1.101 |
| | | | | Abundance weighted mean | | | 0.935 |

Table 12. LCA data, calculations and results for female lobsters in the Georges Bank & South stock area during 1995-1997.

Results include recruitment estimates (stock number at 83 mm), fishing mortality by length group, and average (catch and abundance weighted) fishing mortality for legal size lobster. Data were average catch in number by length group for 1996-1998. Recruitment and fishing mortality rates are average estimates for recent years that may or may not be reliable (see text). $F_t$ is the terminal fishing mortality rate. $T_c$ is the proportion of the year elapsed when fishing is assumed to take place.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LENGTH-BASED COHORT ANALYSIS | | | | | | $F_t$ = | 0.4 |
| American lobster | | | | | | M = | 0.15 |
| GBS Females | | | 1995 to 1997 mean females | | | $T_c$ = | 0.8 |
| | | | | | | | |
| Length | | Catch | Delta-t | Stock | | | |
| (mm) | | (numbers) | (y) | Numbers | F/Z | Z | F |
| 193 | 197 | 49 | 1.0174 | 156 | | | 0.4 |
| 188 | 192 | 31 | 1.0174 | 216 | 0.508 | 0.305 | 0.155 |
| 183 | 187 | 248 | 1.0174 | 532 | 0.785 | 0.699 | 0.549 |
| 178 | 182 | 133 | 1.0174 | 770 | 0.558 | 0.340 | 0.190 |
| 173 | 177 | 758 | 1.0174 | 1,752 | 0.771 | 0.654 | 0.504 |
| 168 | 172 | 1,217 | 1.0174 | 3,416 | 0.731 | 0.558 | 0.408 |
| 163 | 167 | 2,107 | 1.0174 | 6,360 | 0.716 | 0.528 | 0.378 |
| 158 | 162 | 3,989 | 1.0174 | 11,916 | 0.718 | 0.532 | 0.382 |
| 153 | 157 | 5,470 | 1.0174 | 20,061 | 0.672 | 0.457 | 0.307 |
| 148 | 152 | 6,574 | 1.0118 | 30,771 | 0.614 | 0.388 | 0.238 |
| 143 | 147 | 11,667 | 0.9449 | 48,525 | 0.657 | 0.438 | 0.288 |
| 138 | 142 | 16,867 | 0.8707 | 74,019 | 0.662 | 0.443 | 0.293 |
| 133 | 137 | 21,537 | 0.8084 | 107,292 | 0.647 | 0.425 | 0.275 |
| 128 | 132 | 31,085 | 0.7531 | 154,148 | 0.663 | 0.446 | 0.296 |
| 123 | 127 | 38,336 | 0.7106 | 213,235 | 0.649 | 0.427 | 0.277 |
| 118 | 122 | 49,929 | 0.6672 | 289,772 | 0.652 | 0.431 | 0.281 |
| 113 | 117 | 54,169 | 0.6449 | 377,729 | 0.616 | 0.390 | 0.240 |
| 108 | 112 | 64,867 | 0.6295 | 485,090 | 0.604 | 0.379 | 0.229 |
| 103 | 107 | 93,065 | 0.6031 | 631,066 | 0.638 | 0.414 | 0.264 |
| 98 | 102 | 94,504 | 0.5659 | 788,121 | 0.602 | 0.377 | 0.227 |
| 93 | 97 | 386,018 | 0.5232 | 1,263,491 | 0.812 | 0.798 | 0.648 |
| 88 | 92 | 1,089,571 | 0.4824 | 2,512,816 | 0.872 | 1.173 | 1.023 |
| 83 | 87 | 1,067,649 | 0.4418 | 3,810,773 | 0.823 | 0.845 | 0.695 |
| Sum | | 3,039,838 | | 10,832,028 | | | |
| | | | | | | | |
| | | | | Catch weighted mean | | | 0.736 |
| | | | | Abundance weighted mean | | | 0.633 |

Table 13. Summary of LCA results for lobster in the Georges Bank & South stock area during 1995-1997.

| | Males | Females |
|---|---|---|
| Average Total Catch in Number | 2,693,684 | 3,039,838 |
| Average Total Abundance | 8,559,294 | 10,832,028 |
| Average Recruitment (Numbers at 83-97 mm CL) | 7,587,080 | 6,531,363 |
| Catch Weighted Mean F-All Length Groups | 1.10 | 0.74 |
| Abundance Weighted Mean F-All Length Groups | 0.94 | 0.63 |
| Simple Mean F | 0.61 | 0.37 |
| Simple Mean F 93-97mm CL | 1.09 | 0.65 |
| Simple Mean F 98+ mm CL | 0.51 | 0.31 |
| Maximum Average F at Length | 1.69 | 1.02 |
| F on 83-87 mm CL (smallest length group) | 0.82 | 0.70 |
| Relative Fishing Mortality at Length (Scaled to 1 at 83-87 mm CL): | | |
| *83 -87 mm CL* | 1.00 | 1.00 |
| *88 -92 mm CL* | 1.42 | 1.47 |
| *93 -97 mm CL* | 2.07 | 0.93 |
| *98 -102 mm CL* | 0.87 | 0.33 |
| *103 -107 mm CL* | 0.35 | 0.38 |
| *108 -112 mm CL* | 0.38 | 0.33 |
| *113 -117 mm CL* | 0.31 | 0.35 |
| *118 -122 mm CL* | 0.42 | 0.40 |
| *123 -127 mm CL* | 0.39 | 0.40 |
| *128 -132 mm CL* | 0.47 | 0.43 |
| *133 -137 mm CL* | 0.44 | 0.40 |
| *138 -142 mm CL* | 0.61 | 0.42 |
| *143 -147 mm CL* | 0.59 | 0.41 |
| *148 -152 mm CL* | 0.47 | 0.34 |
| *153 -157 mm CL* | 0.50 | 0.44 |
| *158 -162 mm CL* | 0.68 | 0.55 |
| *163 -167 mm CL* | 0.91 | 0.54 |
| *168 -172 mm CL* | 0.74 | 0.59 |
| *173 -177 mm CL* | 0.79 | 0.73 |
| *178 -182 mm CL* | 1.23 | 0.27 |
| *183 -187 mm CL* | 0.45 | 0.79 |
| *188 -192 mm CL* | 0.23 | 0.22 |
| *193 -197 mm CL* | 0.88 | 0.58 |
| *198 -202 mm CL* | 1.50 | NA |
| *203 -207 mm CL* | 0.86 | NA |

Table 14. Estimates of male and female recruit and fully-recruited (FR) abundance (millions), total abundance (recruits + full recruits) and fishing mortality (F) from DeLury model analyses using NMFS and MA trawl survey data, and average weighted F estimates for entire Gulf of Maine stock area, with 1982-97 and 1995-97 averages.

| Females | NMFS | NMFS | NMFS | NMFS | MA | MA | MA | MA | |
|---|---|---|---|---|---|---|---|---|---|
| | Recruits | FR | Total Pop | F | Recruits | FR | Total Pop | F | Wtd F |
| 1982 | 16.33 | 2.27 | 18.59 | 0.83 | 3.35 | 2.89 | 6.24 | 0.8 | 0.82 |
| 1983 | 14.66 | 6.99 | 21.65 | 0.60 | 4.89 | 2.42 | 7.31 | 0.7 | 0.63 |
| 1984 | 10.07 | 10.28 | 20.35 | 0.65 | 4.07 | 3.13 | 7.19 | 1.06 | 0.76 |
| 1985 | 12.75 | 9.12 | 21.87 | 0.67 | 4.00 | 2.14 | 6.13 | 1.72 | 0.90 |
| 1986 | 13.84 | 9.61 | 23.44 | 0.58 | 4.10 | 0.95 | 5.05 | 1.76 | 0.79 |
| 1987 | 6.18 | 11.27 | 17.45 | 0.82 | 3.58 | 0.75 | 4.32 | 2.19 | 1.09 |
| 1988 | 16.84 | 6.63 | 23.46 | 0.70 | 4.76 | 0.42 | 5.17 | 1.64 | 0.87 |
| 1989 | 13.88 | 10.04 | 23.92 | 0.74 | 5.59 | 0.86 | 6.45 | 1.08 | 0.81 |
| 1990 | 17.57 | 9.84 | 27.41 | 0.83 | 4.53 | 1.89 | 6.42 | 1.55 | 0.97 |
| 1991 | 16.26 | 10.31 | 26.57 | 0.81 | 4.03 | 1.18 | 5.21 | 1.29 | 0.89 |
| 1992 | 14.67 | 10.17 | 24.84 | 0.63 | 3.08 | 1.23 | 4.31 | 2.13 | 0.85 |
| 1993 | 16.90 | 11.35 | 28.26 | 0.64 | 4.64 | 0.44 | 5.08 | 1.12 | 0.71 |
| 1994 | 30.93 | 12.76 | 43.70 | 0.52 | 5.49 | 1.43 | 6.92 | 1.47 | 0.65 |
| 1995 | 17.15 | 22.46 | 39.61 | 0.52 | 5.33 | 1.37 | 6.70 | 1.61 | 0.68 |
| 1996 | 31.97 | 20.29 | 52.26 | 0.60 | 4.51 | 1.15 | 5.66 | 2.69 | 0.80 |
| 1997 | 25.69 | 24.78 | 50.47 | 0.59 | 5.44 | 0.33 | 5.77 | 1.99 | 0.73 |
| | | | | | | | | | |
| 82-97 | 17.23 | 11.76 | 28.99 | 0.67 | 4.46 | 1.41 | 5.87 | 1.55 | 0.81 |
| 95-97 | 24.94 | 22.51 | 47.45 | 0.57 | 5.09 | 0.95 | 6.04 | 2.10 | 0.74 |
| | | | | | | | | | |
| | | | | | | | | | |
| Males | NMFS | NMFS | NMFS | NMFS | MA | MA | MA | MA | |
| | Recruits | FR | Total Pop | F | Recruits | FR | Total Pop | F | Wtd F |
| 1982 | 11.24 | 6.92 | 18.16 | 0.82 | 3.80 | 2.10 | 5.90 | 1.09 | 0.89 |
| 1983 | 17.62 | 6.87 | 24.49 | 0.56 | 5.25 | 1.71 | 6.97 | 0.79 | 0.61 |
| 1984 | 5.17 | 12.09 | 17.26 | 0.85 | 4.57 | 2.71 | 7.28 | 1.15 | 0.94 |
| 1985 | 19.14 | 6.38 | 25.52 | 0.57 | 5.50 | 1.98 | 7.49 | 1.11 | 0.69 |
| 1986 | 13.87 | 12.45 | 26.32 | 0.58 | 2.93 | 2.13 | 5.06 | 2.73 | 0.93 |
| 1987 | 7.83 | 12.72 | 20.56 | 0.84 | 4.70 | 0.28 | 4.98 | 1.95 | 1.06 |
| 1988 | 16.67 | 7.62 | 24.29 | 0.65 | 4.94 | 0.61 | 5.56 | 1.64 | 0.83 |
| 1989 | 23.16 | 10.94 | 34.10 | 0.57 | 6.12 | 0.93 | 7.05 | 1.23 | 0.68 |
| 1990 | 24.10 | 16.66 | 40.77 | 0.63 | 6.78 | 1.78 | 8.56 | 1.1 | 0.71 |
| 1991 | 13.92 | 18.71 | 32.63 | 0.72 | 3.38 | 2.46 | 5.85 | 1.31 | 0.81 |
| 1992 | 19.66 | 13.74 | 33.40 | 0.58 | 3.35 | 1.36 | 4.71 | 2.03 | 0.76 |
| 1993 | 21.86 | 16.05 | 37.91 | 0.58 | 4.48 | 0.53 | 5.01 | 1.04 | 0.63 |
| 1994 | 40.62 | 18.26 | 58.89 | 0.46 | 6.39 | 1.53 | 7.92 | 1.38 | 0.57 |
| 1995 | 27.70 | 31.99 | 59.70 | 0.45 | 4.96 | 1.71 | 6.67 | 1.28 | 0.53 |
| 1996 | 38.26 | 32.82 | 71.07 | 0.57 | 5.02 | 1.59 | 6.61 | 1.43 | 0.64 |
| 1997 | 28.80 | 34.76 | 63.56 | 0.48 | 3.27 | 1.36 | 4.63 | 1.99 | 0.58 |
| | | | | | | | | | |
| 82-97 | 20.60 | 16.19 | 36.79 | 0.62 | 4.72 | 1.55 | 6.26 | 1.45 | 0.74 |
| 95-97 | 31.59 | 33.19 | 64.78 | 0.50 | 4.42 | 1.55 | 5.97 | 1.57 | 0.59 |

Table 15. Estimates of male and female recruit and fully-recruited (FR) abundance (millions), total abundance (recruits + full recruits) and fishing mortality (F) from DeLury model analyses using NMFS, RI, and CT trawl survey data, and average weighted F estimates for entire South of Cape Cod and Long Island Sound stock area, with 1982-97 and 1995-97 averages.

| | NMFS | | | | RI | | | | CT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Males | Recruits | FR | Total | F | Recruits | FR | Total | F | Recruits | FR | Total | F | Wtd F |
| 1982 | 0.245 | 1.077 | 1.322 | 0.8 | 0.576 | 0.061 | 0.637 | 1.67 | | | | | 1.08 |
| 1983 | 0.635 | 0.509 | 1.144 | 0.69 | 0.339 | 0.103 | 0.442 | 1.89 | | | | | 1.02 |
| 1984 | 1.317 | 0.492 | 1.809 | 0.65 | 0.56 | 0.058 | 0.618 | 1.76 | 1.274 | 0.873 | 2.147 | 0.76 | 0.85 |
| 1985 | 0.66 | 0.813 | 1.473 | 0.59 | 0.379 | 0.091 | 0.47 | 1.35 | 1.058 | 0.862 | 1.92 | 0.61 | 0.69 |
| 1986 | 0.833 | 0.701 | 1.534 | 0.73 | 0.442 | 0.105 | 0.547 | 1.71 | 1.224 | 0.901 | 2.125 | 0.59 | 0.79 |
| 1987 | 1.026 | 0.638 | 1.664 | 0.55 | 0.508 | 0.085 | 0.593 | 1.62 | 1.407 | 1.011 | 2.418 | 0.87 | 0.85 |
| 1988 | 0.501 | 0.825 | 1.326 | 0.88 | 0.621 | 0.101 | 0.722 | 1.24 | 1.678 | 0.873 | 2.551 | 1.17 | 1.10 |
| 1989 | 1.096 | 0.475 | 1.571 | 1.15 | 0.833 | 0.179 | 1.012 | 1.2 | 1.934 | 0.681 | 2.615 | 1.2 | 1.18 |
| 1990 | 1.849 | 0.43 | 2.279 | 0.77 | 0.774 | 0.263 | 1.037 | 2.03 | 1.818 | 0.676 | 2.494 | 1.07 | 1.12 |
| 1991 | 0.429 | 0.907 | 1.336 | 1.16 | 0.698 | 0.117 | 0.815 | 1.54 | 3.044 | 0.735 | 3.779 | 0.99 | 1.10 |
| 1992 | 1.45 | 0.361 | 1.811 | 1.01 | 0.819 | 0.15 | 0.969 | 1.54 | 2.392 | 1.212 | 3.604 | 1.82 | 1.55 |
| 1993 | 0.909 | 0.567 | 1.476 | 1.91 | 0.781 | 0.179 | 0.96 | 2.23 | 3.668 | 0.501 | 4.169 | 1.14 | 1.47 |
| 1994 | 1.593 | 0.188 | 1.781 | 0.77 | 0.774 | 0.089 | 0.863 | 1.74 | 4.065 | 1.147 | 5.212 | 1.49 | 1.35 |
| 1995 | 1.018 | 0.706 | 1.724 | 0.56 | 0.941 | 0.13 | 1.071 | 0.99 | 2.995 | 1.011 | 4.006 | 2.08 | 1.52 |
| 1996 | 2.286 | 0.849 | 3.135 | 0.51 | 0.79 | 0.342 | 1.132 | 1.02 | 4.667 | 0.431 | 5.098 | 1.73 | 1.24 |
| 1997 | 1.961 | 1.614 | 3.575 | 0.44 | 0.465 | 0.35 | 0.815 | 1.33 | 4.529 | 0.775 | 5.304 | 2.18 | 1.47 |
| **82-97** | **1.113** | **0.697** | **1.81** | **0.82** | **0.644** | **0.150** | **0.794** | **1.55** | **2.554** | **0.835** | **3.389** | **1.26** | **1.15** |
| **95-97** | **1.755** | **1.056** | **2.811** | **0.50** | **0.732** | **0.274** | **1.006** | **1.11** | **4.064** | **0.739** | **4.803** | **2.00** | **1.41** |
| **Females** | | | | | | | | | | | | | |
| 1982 | 1.335 | 0.921 | 2.256 | 0.63 | 0.766 | 0.016 | 0.782 | 1.72 | | | | | 0.88 |
| 1983 | 1.061 | 1.038 | 2.099 | 0.79 | 0.911 | 0.120 | 1.031 | 1.41 | | | | | 0.99 |
| 1984 | 1.223 | 0.817 | 2.040 | 1.03 | 0.651 | 0.216 | 0.867 | 3.59 | 2.599 | 2.324 | 4.923 | 0.64 | 1.06 |
| 1985 | 1.021 | 0.624 | 1.645 | 1.67 | 0.940 | 0.021 | 0.961 | 2.8 | 1.976 | 2.225 | 4.201 | 0.6 | 1.15 |
| 1986 | 2.648 | 0.268 | 2.916 | 0.42 | 1.067 | 0.050 | 1.117 | 1.23 | 2.365 | 1.988 | 4.353 | 0.68 | 0.66 |
| 1987 | 0.196 | 1.644 | 1.840 | 0.84 | 0.940 | 0.280 | 1.220 | 0.98 | 2.393 | 1.896 | 4.289 | 0.82 | 0.83 |
| 1988 | 1.354 | 0.686 | 2.040 | 1.54 | 1.095 | 0.393 | 1.488 | 1.27 | 2.470 | 1.626 | 4.096 | 0.99 | 1.17 |
| 1989 | 2.832 | 0.375 | 3.207 | 0.92 | 1.187 | 0.359 | 1.546 | 1.77 | 3.178 | 1.310 | 4.488 | 1.32 | 1.23 |
| 1990 | 2.065 | 1.106 | 3.171 | 0.68 | 1.135 | 0.226 | 1.361 | 1.55 | 4.552 | 1.033 | 5.585 | 1.39 | 1.18 |
| 1991 | 1.026 | 1.376 | 2.402 | 0.4 | 0.685 | 0.248 | 0.933 | 0.94 | 3.735 | 1.195 | 4.930 | 1.2 | 0.93 |
| 1992 | 1.933 | 1.382 | 3.315 | 0.55 | 0.891 | 0.315 | 1.206 | 1.25 | 3.942 | 1.274 | 5.216 | 1.54 | 1.16 |
| 1993 | 0.557 | 1.650 | 2.207 | 1.37 | 1.275 | 0.297 | 1.572 | 1.3 | 4.997 | 0.962 | 5.959 | 1 | 1.12 |
| 1994 | 1.198 | 0.484 | 1.682 | 0.75 | 0.565 | 0.367 | 0.932 | 1.64 | 4.786 | 1.895 | 6.681 | 1.71 | 1.52 |
| 1995 | 2.433 | 0.681 | 3.114 | 0.36 | 0.892 | 0.156 | 1.048 | 1.22 | 6.256 | 1.041 | 7.297 | 1.32 | 1.04 |
| 1996 | 3.885 | 1.870 | 5.755 | 0.44 | 1.046 | 0.266 | 1.312 | 1.31 | 7.120 | 1.678 | 8.798 | 1.72 | 1.22 |
| 1997 | 4.219 | 3.175 | 7.394 | 0.44 | 0.610 | 0.305 | 0.915 | 1.83 | 7.130 | 1.352 | 8.482 | 2.36 | 1.50 |
| **82-97** | **1.812** | **1.131** | **2.943** | **0.80** | **0.916** | **0.227** | **1.143** | **1.61** | **4.107** | **1.557** | **5.664** | **1.24** | **1.10** |
| **95-97** | **3.512** | **1.909** | **5.421** | **0.41** | **0.849** | **0.242** | **1.092** | **1.45** | **6.835** | **1.357** | **8.192** | **1.80** | **1.25** |

Table 16. Description of Sampling Programs to Estimate Catch Per Unit Effort (CPUE) for Lobster in the U.S. Northwest Atlantic.

| STATE/ STUDY | MONTHS SAMPLED | AREAS SAMPLED | SAMPLING PROGRAM | INDEX OF RELATIVE ABUNDANCE | SEGMENT OF POPULATION MEASURED |
|---|---|---|---|---|---|
| ME | Apr. - Dec. | 511<br>512<br>513 | Port sampling and Sea sampling | CTH[1] (# lobsters/# traps hauled)<br>CTHSOD[2] (# lobsters/#traps hauled X average days set) [days set = soak time] | # marketable and total lobsters |
| NH | Jun. - Oct. | 513 | Sea sampling | CTH (# lobsters/# traps hauled)<br>CTHSOD (# lobsters/# traps hauled X days set) | # marketable and total lobsters |
| Seabrook Nuclear Power Station | Jun. - Nov. | 513 | Experimental[3] | CTHSOD standardized to 2 set-over-days ($CPUE_2$)[4] | # legal and sub-legal sized lobsters |
| MA | May - Nov. | 514<br>521<br>538 | Sea sampling | CTHSOD standardized to 3 set-over-days ($CTH'_3$)[5] | # marketable and total lobsters |
| RI | Jan. - Dec. for area 539<br>Quarterly (Feb., Mar., Apr., Nov.) for areas 537 & 616 | 539<br>537<br>616 | Sea sampling | CTHAUL (# lobsters/# traps hauled) | # marketable and total lobsters |
| CT | Jan. - Dec. | 611 | Log books, monthly filing | Total lbs. of marketable lobster and total # of traps owned | Lbs. of marketable lobster |
| Millstone Nuclear Power Station | May - Oct. | 611 | Experimental[6] | CTH[7]<br>Geometric mean used for total CTH<br>Delta mean used for legal sized CTH (including ovigerous females) | # legal sized (including ovigerous females) and total lobsters |
| NY | One time for entire year | 611<br>612<br>613 | Annual survey (requested with license application) | Total lbs. of marketable lobsters and total # of traps owned | Lbs. of marketable lobster |

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[1] Catch per trap haul

[2] Catch per trap haul set-over-day

[3] Fifteen 25.4 mm (1 inch) mesh lobster traps without escape vents are retrieved at 2-day intervals, approximately three times per week.

[4] Lobster $CPUE_2$ was calculated (similar to Estrella & McKiernan, 1989) as catch per 15 traps adjusted to two days soak time using Adjustment factor = $1-(C_s-C_2)/C_s$ where $C_s$ = Mean catch (lobsters per 15 traps) for all samples with soak time s and $C_2$ = Mean catch for samples with soak time of 2 days (75 lobsters per 15 traps). Table 18 illustrates the adjustment factor used. Samples with soak times of more than 5 days were excluded from the analysis (~3% of total samples collected), (Normandeau Associates [NAI] 1997).

[5] In order to correct variable immersion time (days set = soak time), MA uses the nonlinear regression as an estimate of fishing where the ratio serves as a correction factor for set-over-days, $C'_s = C_s\,(1-e^{-Rs^*}/1-e^{-Rs})$ where $C'_s$ is the adjusted catch at day s, $C_s$ is the empirical catch/trap haul on day s, R is the capture rate, and s* is the standard immersion time (modal or mean immersion time). Effort is standardized to MA's survey modal value of 3. Immersion times greater than or less than 3 days are adjusted, while catches of traps hauled following a 3-day immersion are assigned the immersion correction factor of 1.0. (Table 17).

[6] Sixty unvented pots with 2.5 $cm^2$ mesh are used. These are hauled 3 days per week if possible (Monday, Wednesday, and Friday).

[7] Number of lobsters caught per pothaul (# lobsters/traps), (NUSCO, Northeast Utilities Service Company, 1999).

Table 17. Seasonal Estimates of Regression Model Coefficients, Predicted CTH (Catch/trap haul in numbers of lobster), and Soak-time Correction Factors for Massachusetts Commercial Lobster Data (Taken from Estrella & McKiernan, 1989).

| | Spring | | Summer | | Fall | |
|---|---|---|---|---|---|---|
| *C* | 0.54602 | | 0.83002 | | 0.73470 | |
| (SE) | (0.05424) | | (0.04406) | | (0.04646 | |
| *R* | 0.60831 | | 0.88977 | | 1.11799 | |
| (SE) | (0.15038) | | (0.19040) | | (0.30781) | |
| Day | Predicted CTH | Corr. Factors | Predicted CTH | Corr. Factors | Predicted CTH | Corr. Factors |
| 1 | 0.24883 | 0.54333 | 0.49809 | 0.63313 | 0.49450 | 0.69744 |
| 2 | 0.38427 | 0.83905 | 0.68998 | 0.89318 | 0.65617 | 0.92545 |
| 3 | 0.45798 | 1.00000 | 0.77250 | 1.00000 | 0.70903 | 1.00000 |
| 4 | 0.49810 | 1.08760 | 0.80639 | 1.04388 | 0.72630 | 1.02437 |
| 5 | 0.51994 | 1.13528 | 0.82032 | 1.06190 | 0.73196 | 1.03243 |
| 6 | 0.53182 | 1.16123 | 0.82603 | 1.06930 | 0.73380 | 1.03495 |
| 7 | 0.53829 | 1.17536 | 0.82838 | 1.07234 | 0.73441 | 1.03580 |

Table 18. Mean catch of lobsters, and Adjustment Factors for Soak Times from 1 to 5 Days (Taken from Normandeau Associate, Inc. 1997).

| Soak Time (days) | Mean Catch (lobsters/15 traps) | Adjustment Factor |
|---|---|---|
| 1 | 46.5 | 1.613 |
| 2 | 75.0 | 1.000 |
| 3 | 90.1 | 0.832 |
| 4 | 95.1 | 0.789 |
| 5 | 107.1 | 0.700 |

Table 19. Male and female fishing mortality rates (F) and effort data (Maine trap hauls) for areas 511-513+515 in the Gulf of Maine.

| Year | Maine Trap Hauls (millions) | Female F | Male F |
|---|---|---|---|
| 1982 | 138.3 | 0.84 | 0.82 |
| 1983 | 141.8 | 0.61 | 0.56 |
| 1984 | 128.7 | 0.67 | 0.85 |
| 1985 | 98.7 | 0.69 | 0.57 |
| 1986 | 83.3 | 0.6 | 0.58 |
| 1987 | 113.6 | 0.84 | 0.84 |
| 1988 | 109.8 | 0.71 | 0.65 |
| 1989 | 102.6 | 0.75 | 0.57 |
| 1990 | 112.4 | 0.85 | 0.63 |
| 1991 | 114.5 | 0.83 | 0.72 |
| 1992 | 97.4 | 0.65 | 0.58 |
| 1993 | 83 | 0.66 | 0.58 |
| 1994 | 149 | 0.53 | 0.46 |
| 1995 | 145.5 | 0.53 | 0.45 |
| 1996 | 118.1 | 0.61 | 0.57 |
| 1997 | 117.9 | 0.61 | 0.48 |
|  |  |  |  |

Note: F estimates are for fall survey years starting in October and effort data are for calendar years. Trap hauls were estimated by multiplying the annual number of traps times the estimated number of hauls per trap using annual estimates of mean soak time from port sampling data and assuming a 200 day fishing season.

Table 20. Male and female fishing mortality rates (F) and effort data (MA trap hauls) for area 514 (Massachusetts Bay) in the Gulf of Maine.

| Year | MA Trap Hauls (millions) | Female F | Male F |
|---|---|---|---|
| 1982 | | 0.8 | 1.09 |
| 1983 | | 0.71 | 0.79 |
| 1984 | | 1.07 | 1.15 |
| 1985 | 16.3 | 1.74 | 1.11 |
| 1986 | 18.1 | 1.78 | 2.73 |
| 1987 | 17.5 | 2.2 | 1.95 |
| 1988 | 19.3 | 1.66 | 1.64 |
| 1989 | 19.4 | 1.09 | 1.23 |
| 1990 | 17.4 | 1.56 | 1.1 |
| 1991 | 16.3 | 1.3 | 1.31 |
| 1992 | 16.3 | 2.14 | 2.03 |
| 1993 | 15.1 | 1.13 | 1.04 |
| 1994 | 14.9 | 1.48 | 1.38 |
| 1995 | 13.8 | 1.62 | 1.28 |
| 1996 | 12.4 | 2.7 | 1.43 |
| 1997 | 11.3 | 2 | 1.99 |

Note: F estimates are for fall survey years starting in October and effort data are for calendar years. 1985-89 trap hauls were estimated based on a linear regression of total inshore traps hauls and Area 514 trap hauls from 1990 to 1998.

Table 21. Male and female fishing mortality rates (F) and effort data (RI trap hauls) for area 539 in the SCCLIS stock area.

| Year | RI Trap Hauls x 1000 | Female F | Male F |
|---|---|---|---|
| 1982 | 147.4 | 1.97 | 1.67 |
| 1983 | 164.2 | 1.52 | 1.89 |
| 1984 | 246.4 | 3.85 | 1.76 |
| 1985 | 251.6 | 3.06 | 1.35 |
| 1986 | 269.8 | 1.38 | 1.71 |
| 1987 | 318 | 1.13 | 1.62 |
| 1988 | 330.3 | 1.46 | 1.24 |
| 1989 | 351.1 | 2.01 | 1.2 |
| 1990 | 373.1 | 1.75 | 2.03 |
| 1991 | 383.9 | 1.11 | 1.54 |
| 1992 | 460.9 | 1.42 | 1.54 |
| 1993 | 489.5 | 1.44 | 2.23 |
| 1994 | 550.2 | 1.86 | 1.74 |
| 1995 | 475.4 | 1.4 | 0.99 |
| 1996 | 540.4 | 1.45 | 1.02 |
| 1997 | 651.9 | 2.11 | 1.33 |

Note: F estimates are for fall survey years starting in October and effort data are for calendar years.

Table 22. Male and female fishing mortality rates (F) and effort data (CT + NY traps) for area 611 in the SCCLIS stock area (Long Island Sound).

| Year | CT + NY Traps x 1000 | CT Trap Hauls x 1000 | Fall Female F | Fall Male F | Spring Female F | Spring Male F |
|---|---|---|---|---|---|---|
| 1984 | 87 | 1,477 | 0.83 | 0.76 | | |
| 1985 | 103 | 1,475 | 0.79 | 0.61 | | |
| 1986 | 117 | 1,380 | 0.89 | 0.59 | 1.36 | 0.96 |
| 1987 | 111 | 1,525 | 1.08 | 0.87 | 1.25 | 1.38 |
| 1988 | 123 | 1,688 | 1.3 | 1.17 | 1.55 | 1.35 |
| 1989 | 137 | 1,749 | 1.63 | 1.2 | 1.17 | 1.7 |
| 1990 | 164 | 2,079 | 1.67 | 1.07 | 1.53 | 0.7 |
| 1991 | 180 | 2,058 | 1.52 | 0.99 | 1.21 | 1.06 |
| 1992 | 198 | 2,236 | 1.87 | 1.82 | 1.28 | 1.31 |
| 1993 | 227 | 2,197 | 1.24 | 1.14 | 1.84 | 2.57 |
| 1994 | 268 | 2,029 | 2.08 | 1.49 | 1.53 | 1.56 |
| 1995 | 301 | 1,981 | 1.64 | 2.08 | 1.38 | 1.27 |
| 1996 | 297 | 2,296 | 2.02 | 1.73 | 1.34 | 0.77 |
| 1997 | 352 | 2,552 | 2.75 | 2.18 | 1.06 | 0.89 |

Note: F estimates are for fall survey years starting in October and effort data are for calendar years. CT traps and trap hauls are for CT residents only.

Table 23. Tests for gear saturation for the GOM and SCCLIS stocks using the slope (B) estimates and standard errors (SE) for the log-log regression between fall fishing mortality (F) rates for male and female lobsters and fishing effort (f). The null hypothesis is that changes in F are directly proportional to changes in fishing effort (ie B = 1.0), or that the slope (B) differs significantly from zero. The t-statistics ($t_{b=1.0}$, $t_{B>0}$) refer to the statistical tests between the estimated B level and expected B = 1.0 and B = 0.0. NA = not applicable.

| Data Set | Sex | $B^{1/}$ | SE | $t_{B=0.0}$ | $t_{B=1.0}$ |
|---|---|---|---|---|---|
| | | | GOM Stock | | |
| Maine<br>TH, 1982-97 | male | -0.057 | 0.293 | 0.19 | NA |
| | female | -0.165 | 0.228 | 0.72 | NA |
| MA<br>TH, 1985-97 | male | 0.035 | 0.540 | 0.06 | NA |
| | female | -0.645 | 0.445 | 1.45 | NA |
| | | | SCCLIS Stock | | |
| RI<br>TH, 1982-97 | male | -0.170 | 0.140 | 1.21 | NA |
| | female | -0.191 | 0.204 | 0.94 | NA |
| CT + NY<br>Traps, 1984-97 | male | 0.812 | 0.135 | 6.02* | 1.39 |
| | female | 0.707 | 0.123 | 5.75* | 2.38* |
| CT<br>TH, 1984-97 | male | 1.845 | 0.338 | 5.46* | -2.50* |
| | female | 1.705 | 0.257 | 6.63* | -2.74* |

1/ $F = A * \text{Effort}^{B}$

Log Transformed: $\text{Log } F = \text{Log } A + B * \text{Log Effort}$.

* statistically ($P < 0.05$) different from B = 1.0 or B = 0.

Table 24. Tests for gear saturation for the SCCLIS stock using the slope (B) estimates and standard errors (SE) for the log-log regression between spring fishing mortality (F) rates for male and female lobsters and fishing effort (f). The null hypothesis is that changes in F are directly proportional to changes in fishing effort (ie B = 1.0), or that the slope (B) differs significantly from zero. The t-statistics ($t_{b=1.0}$, $t_{B>0}$) refer to the statistical tests between the estimated B level and expected B = 1.0 and B = 0.0. NA = not applicable.

| Data Set | Sex | B[1/] | SE | $t_{B=0.0}$ | $t_{B=1.0}$ |
|---|---|---|---|---|---|
| CT + NY Traps, 1986-97 | male | -0.098 | 0.284 | 0.34 | NA |
| | female | -0.020 | 0.117 | 0.17 | NA |
| CT TH, 1986-97 | male | -0.261 | 0.636 | 0.41 | NA |
| | female | -0.045 | 0.263 | 0.17 | NA |

1/ $F = A * \text{Effort}^{B}$
Log Transformed: Log F = Log A + B * Log Effort.

* statistically ($P < 0.05$) different from B = 1.0 or B = 0.

Table 25. Summary of lobster sex ratio data (percent females) for Gulf of Maine stock area, from fall trawl survey, port sampling and sea sampling data bases, by size group, based on three year running averages. (P = population data, L = landings of marketable size lobsters only, REC = recruits (one molt group below 83 mm CL), FR1 = full recruits in first molt group above 83 mm CL, FR2 = full recruits in second molt group, FR3 = full recruits in third molt group, FR4 = full recruits in fourth molt group and above, and 83+ = all lobsters above 83 mm CL).

| Data Source (Location) | P or L | Size | Min | Max | Long Term Mean | Years | 96-98 Mean | Long Term Trend | 96-98 Trend |
|---|---|---|---|---|---|---|---|---|---|
| NMFS Fall Trawl | P | REC | 36 | 58 | 49 | 78-98 | 48 | No | Up |
| (All areas) | | FR1 | 38 | 64 | 50 | | 48 | Down | Up |
| | | FR2 | 27 | 76 | 48 | | 48 | Down | Up |
| | | FR3 | 37 | 82 | 54 | | 54 | Up | Up |
| | | 83+ | 41 | 62 | 46 | | 48 | Down | Up |
| | | | | | | | | | |
| MA Fall Trawl | P | REC | 43 | 52 | 47 | 83-98 | 49 | No | Up |
| (SA 514) | | 83+ | 28 | 47 | 37 | | 31 | Down | Down |
| | | | | | | | | | |
| ME Sea Sampling | P | REC | 60 | 69 | 63 | 85-97 | 65 | Up | Up |
| (Maine coast) | | FR1 | 54 | 61 | 58 | | 57 | No | No |
| | | FR2 | 46 | 67 | 57 | | 50 | Down | No |
| | | FR3 | 56 | 94 | 76 | | 73 | No | No |
| | | FR4 | 57 | 94 | 76 | | 80 | Up | No |
| | | | | | | | | | |
| ME Port Sampling | L | FR1 | 47 | 53 | -- | 66-98 | 52 | No | Down |
| (Maine coast) | | FR2 | 32 | 53 | -- | | 37 | Down | No |
| | | FR3 | 32 | 53 | -- | | 45 | No | No |
| | | FR4 | 0 | 58 | -- | | 27 | Down | No |
| | | | | | | | | | |
| ME Sea Sampling | L | FR1 | 48 | 58 | 54 | 85-97 | 52 | No | Down |
| (Maine coast) | | FR2 | 35 | 52 | 44 | | 37 | Down | Down |
| | | FR3 | 19 | 84 | 50 | | 44 | No | No |
| | | FR4 | 14 | 100 | 41 | | 38 | Up | No |
| | | | | | | | | | |
| MA Sea Sampling (SA 514) | L | 83+ | 48 | 58 | 52 | 83-97 | 57 | Up | No |

Table 26. Summary of lobster sex ratio data (percent females) for the Georges Bank and South stock area, from fall trawl survey and sea sampling data bases, by size group, based on three year running averages. (P = population data, L = landings of marketable size lobsters only, PR = pre-recruits two molt groups below 83 mm CL, REC = recruits one molt group below 83 mm CL, FR1 = full recruits in first molt group above 83 mm CL, FR2 = full recruits in second molt group, FR3 = full recruits in third molt group and above, and 83+ = all lobsters above 83 mm CL).

| Data Source (Location) | P or L | Size | Min | Max | Long Term Mean | Years | 96-98 Mean | Long Term Trend | 96-98 Trend |
|---|---|---|---|---|---|---|---|---|---|
| NMFS Fall Trawl | P | REC | 40 | 56 | 49 | 78-98 | 43 | Down | Up |
| (All areas) | | FR1 | 36 | 57 | 46 | | 44 | Down | Down |
| | | FR2 | 48 | 73 | 61 | | 52 | No | Down |
| | | FR3 | 61 | 86 | 69 | | 77 | Up | Down |
| | | 83+ | 50 | 70 | 54 | | 60 | No | Down |
| | | | | | | | | | |
| RI Sea Sampling | P | PR | 53 | 57 | 55 | 93-98 | -- | No | No |
| (SA 537/616) | | REC | 68 | 70 | 69 | | -- | No | No |
| | L | 83+ | 51 | 54 | 52 | | -- | No | No |
| | | | | | | | | | |
| MA Sea Sampling (SA 521) | L | 83+ | 50 | 58 | 52 | 83-97 | 56 | Up | Up |

Table 27. Summary of lobster sex ratio data (percent females) for the South of Cape Cod and Long Island Sound stock area, from fall and spring trawl survey and sea sampling data bases, by size group, based on three and five year running averages. (P = population data, L = landings of marketable size lobsters only, PR = pre-recruits two molt groups below 83 mm CL, REC = recruits one molt group below 83 mm CL, FR1 = full recruits in first molt group above 83 mm CL, FR2 = full recruits in second molt group and above, and 83+ = all lobsters above 83 mm CL).

| Data Source (Location) | P or L | Size | Min | Max | Long Term Mean | Years | 96-98 Mean | Long Term Trend | 96-98 Trend |
|---|---|---|---|---|---|---|---|---|---|
| NMFS Fall Trawl | P | REC | 33 | 85 | 57 | 78-98 | 62 | Up | No |
| (SA 539) | | 83+ | 59 | 82 | 64 | | 65 | No | No |
| | | | | | | | | | |
| MA Fall Trawl | P | REC | 24 | 59 | 36 | 85-98 | 56 | Up | No |
| (SA 538) | | 83+ | 13 | 66 | 38 | | 59 | Up | Up |
| | | | | | | | | | |
| RI Fall Trawl | P | REC | 31 | 44 | 38 | 81-98 | 34 | No | Down |
| (SA 539) | | FR1 | 21 | 50 | 33 | | 26 | No | Down |
| | | FR2 | 11 | 50 | 32 | | 26 | No | Down |
| | | 83+ | 21 | 50 | 33 | | 26 | No | Down |
| | | | | | | | | | |
| CT Fall Trawl | P | REC | 42 | 52 | 48 | 86-98 | 49 | No | Up |
| (SA 611) | | 83+ | 34 | 47 | 39 | | 42 | No | Up |
| | | | | | | | | | |
| CT Spring Trawl | P | REC | 53 | 63 | 58 | 88-98 | 59 | Up | No |
| (SA 611) | | 83+ | 40 | 60 | 49 | | 47 | No | Down |
| | | | | | | | | | |
| MA Sea Sampling | L | 83+ | 59 | 48 | 53 | 83-97 | 65 | No | No |
| (SA 538) | | | | | | | | | |
| | | | | | | | | | |
| RI Sea Sampling | P | PR | -- | -- | 49 | 93-98 | -- | No | No |
| (SA 539) | | REC | -- | -- | 74 | | -- | No | No |
| | L | 83+ | -- | -- | 58 | | -- | No | No |
| | | | | | | | | | |
| NY Sea Sampling | P | PR | 44 | 76 | 61 | 85-98 | 51 | Down | No |
| (SA 612/613) | | REC | 50 | 84 | 74 | | 59 | Down | Down |

Figure 1. NMFS Statistical Areas and US Lobster Stock Areas.

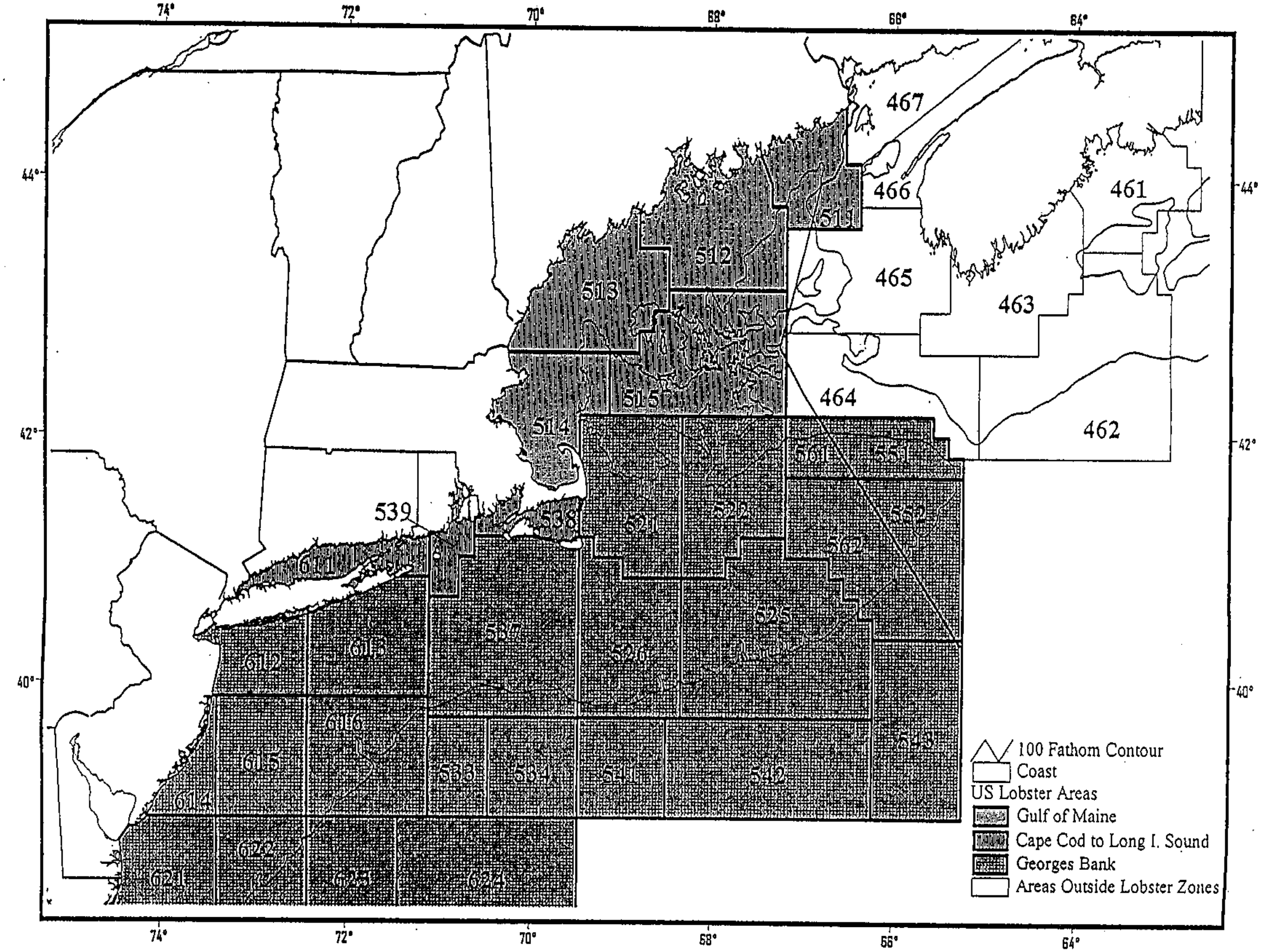
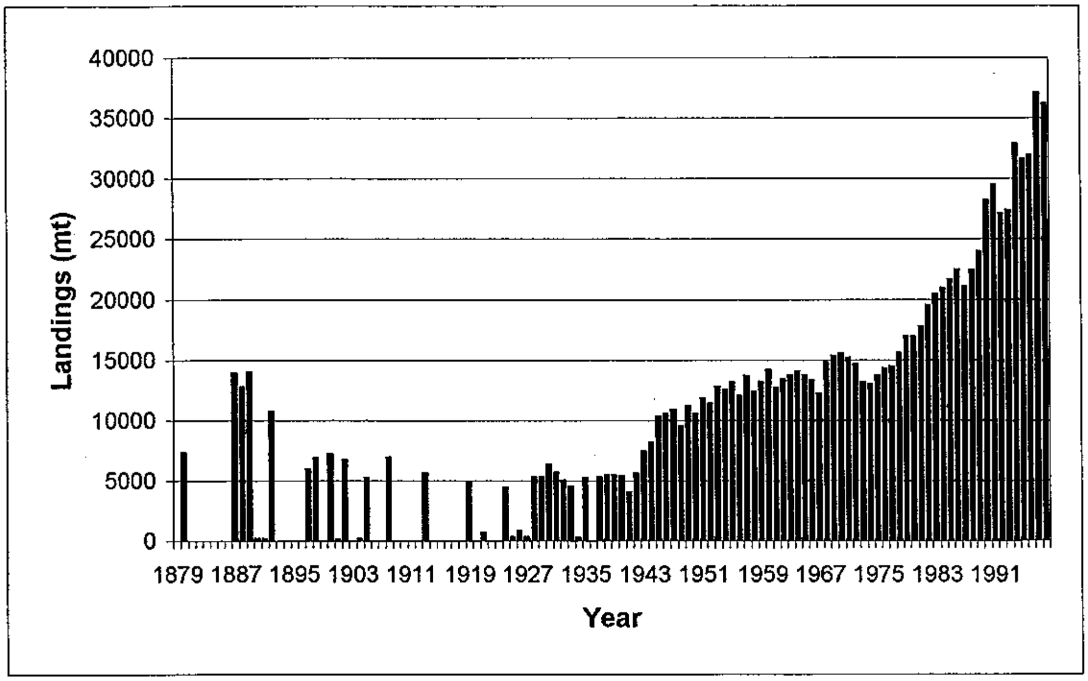


Figure 2. Reported total US lobster landings, 1880-1998 (metric tons).



Note: Only years with complete information for all states are plotted.

Figure 3. Comparison of size frequiencies of female lobsters from Buzzards Bay, MA (May-June) in 1890s and 1997.

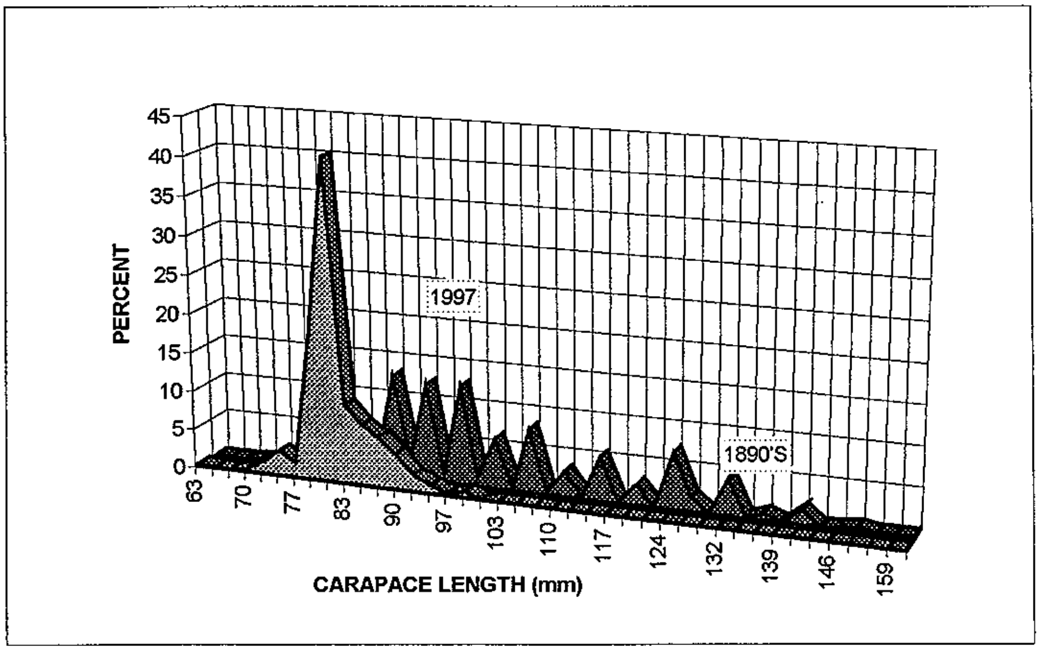


Figure 4. Catch per unit effort (number of marketable lobsters per trap haul set over days, standardized to a 3 day soak) of large lobsters in four 10 mm size groups, 1981-1997, as estimated from MA sea sampling data.

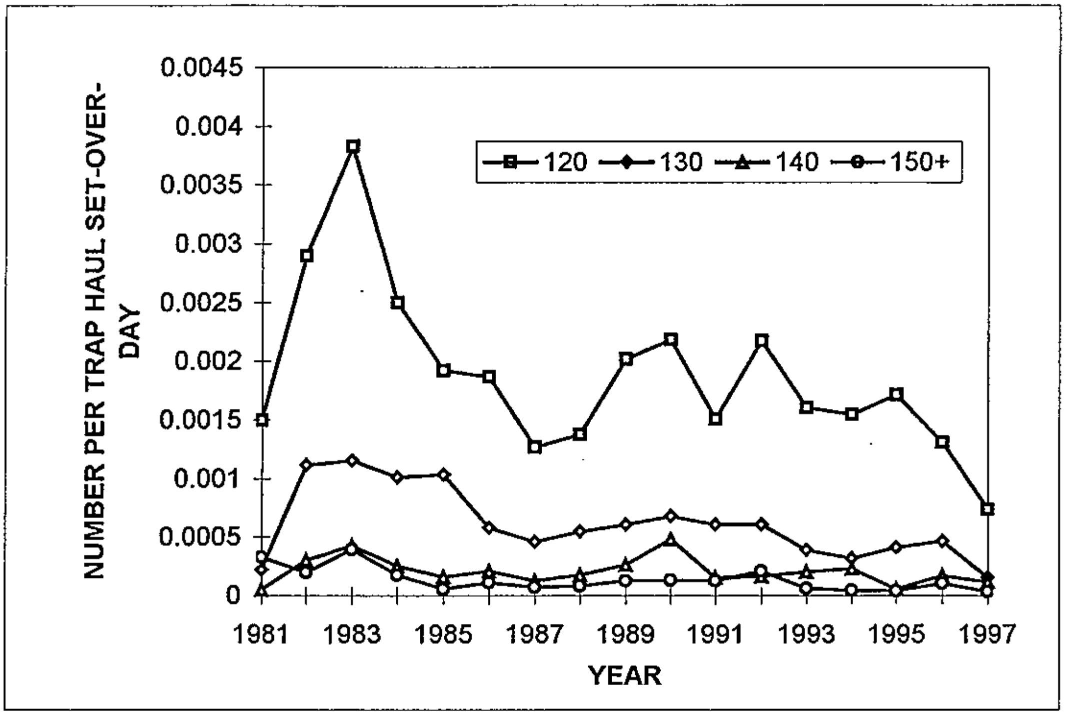
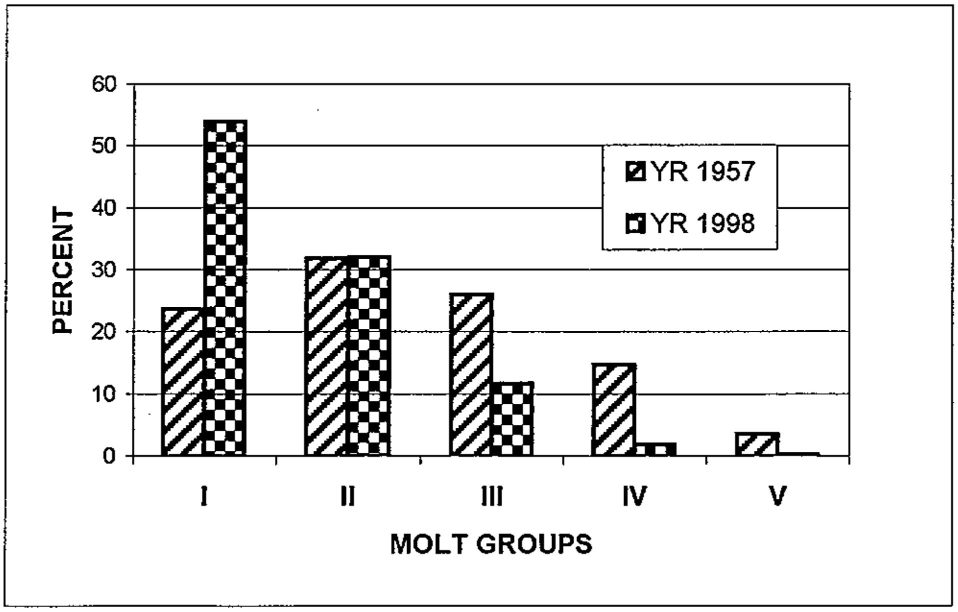


Figure 5. Percentage of 1957 and 1998 lobster landings from area 521 (east of Cape Cod outside 3 miles) composed of five 14 mm molt groups above minimum legal size.



Percent at size may be effected by changes in recruitment

Figure 6. US lobster landings (metric tons) by stock area, 1962-1998

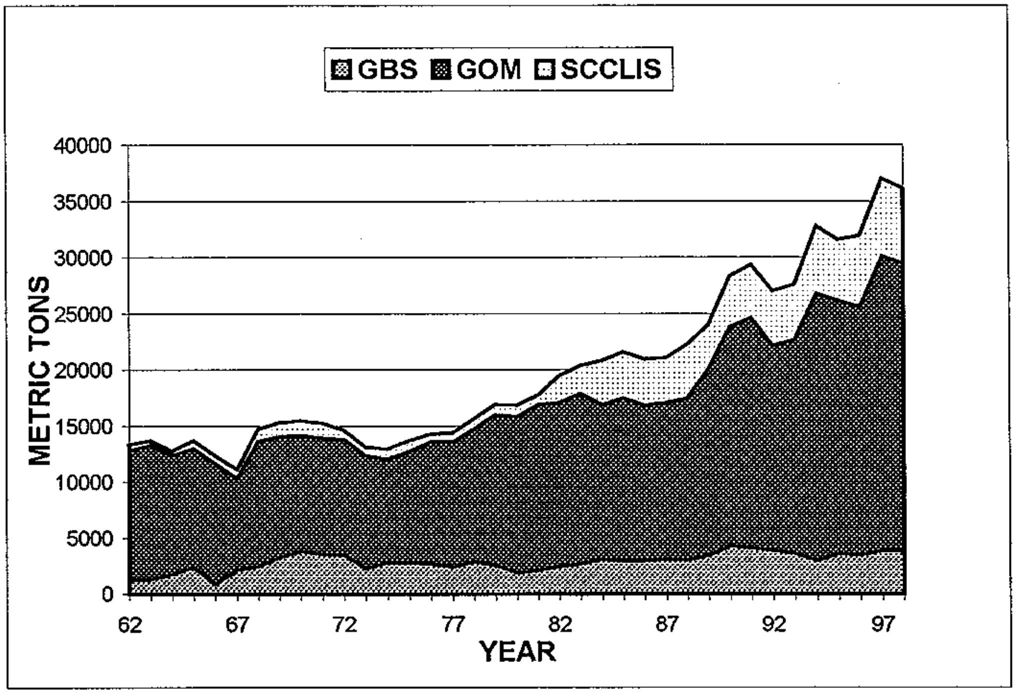


Figure 7. Percentage of US lobster landings by gear type (trap and non-trap), 1964-1998

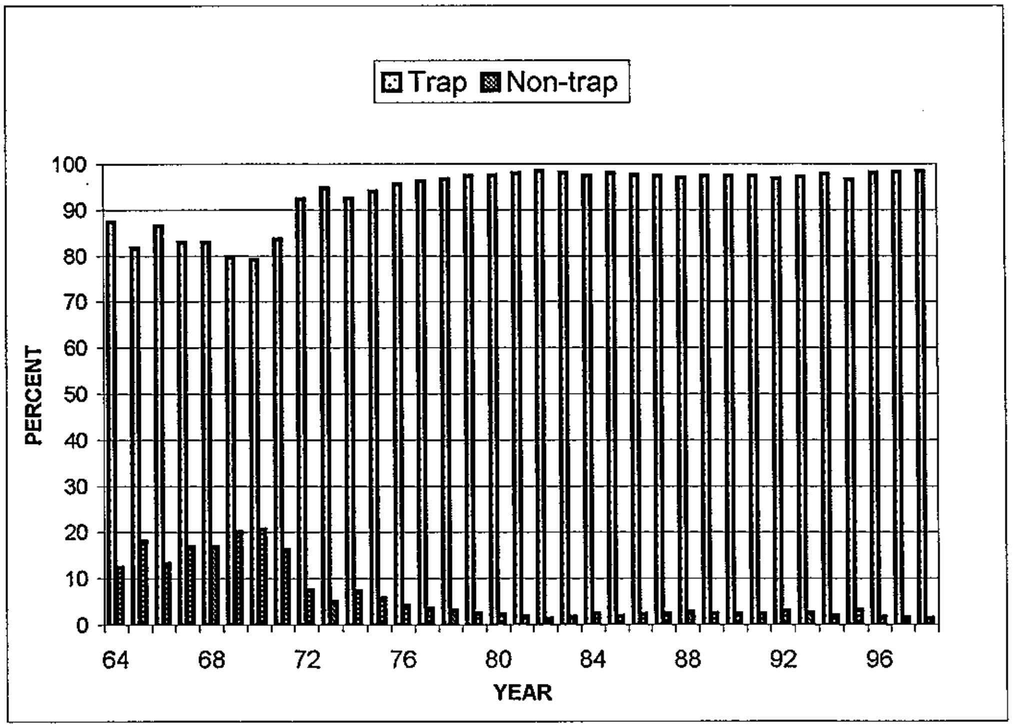


Figure 8. Number of traps and catch per trap (numbers) in MA lobster fishery, 1888-1997

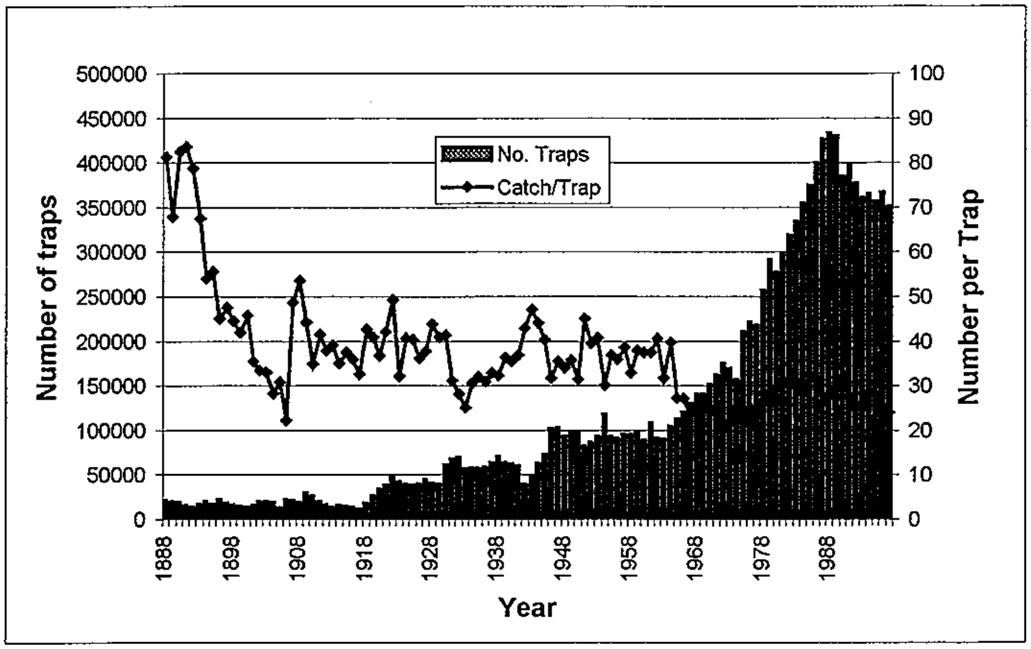


Figure 9. Total number of traps and total landings (metric tons) in US lobster fishery , 1970-1998

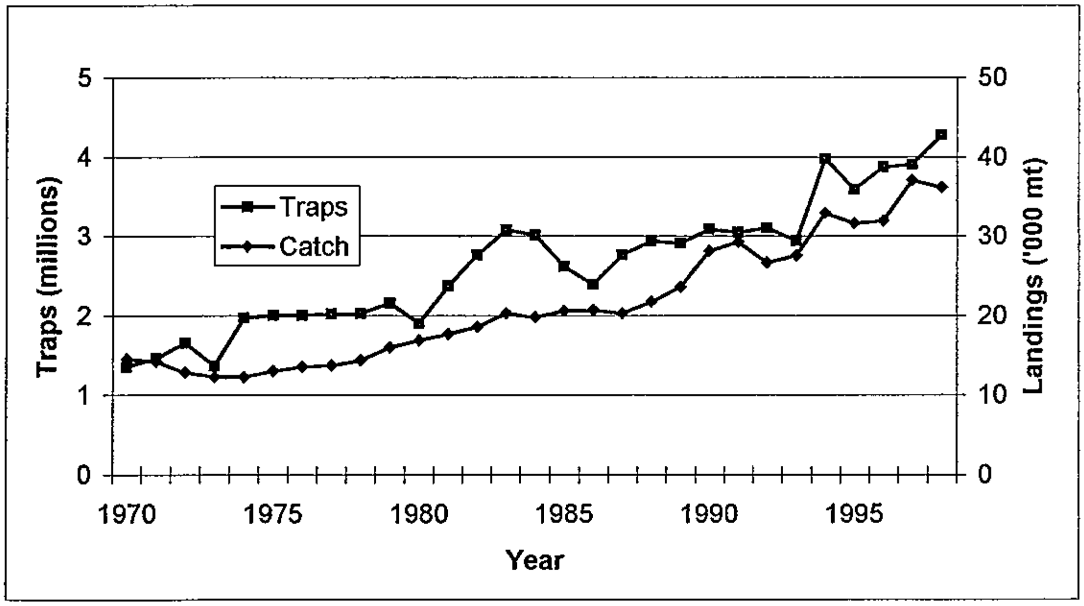


Figure 10. Total traps and mean number of traps per boat in the Maine lobster fishery, 1967-1998

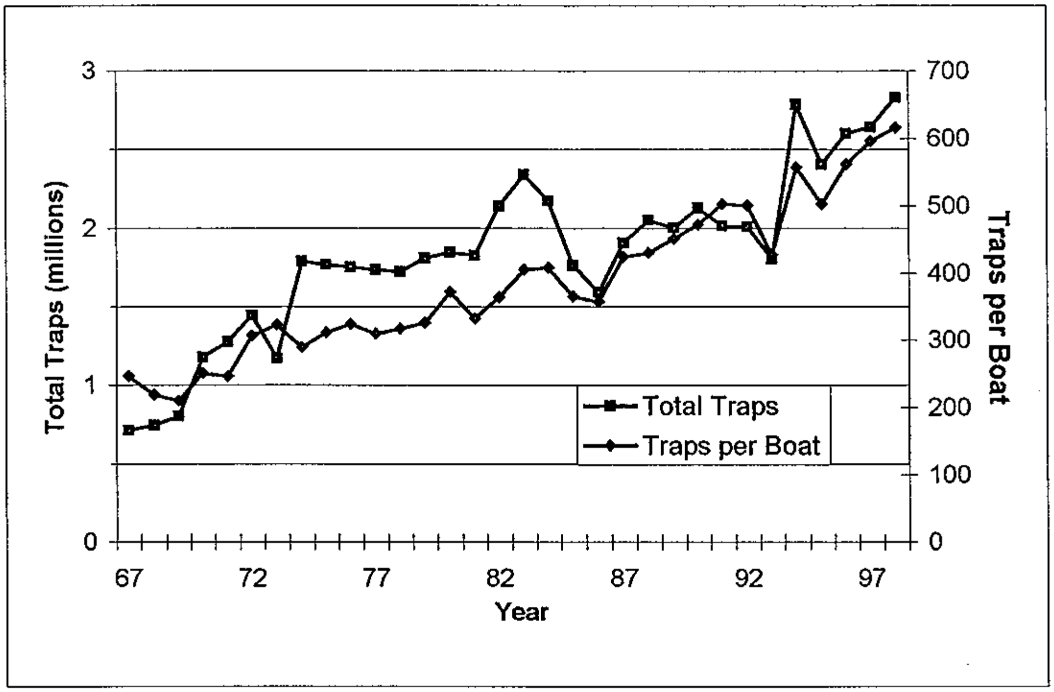


Figure 11. Proportions of wire and two-parlor traps in the Maine lobster fishery, 1978-1998

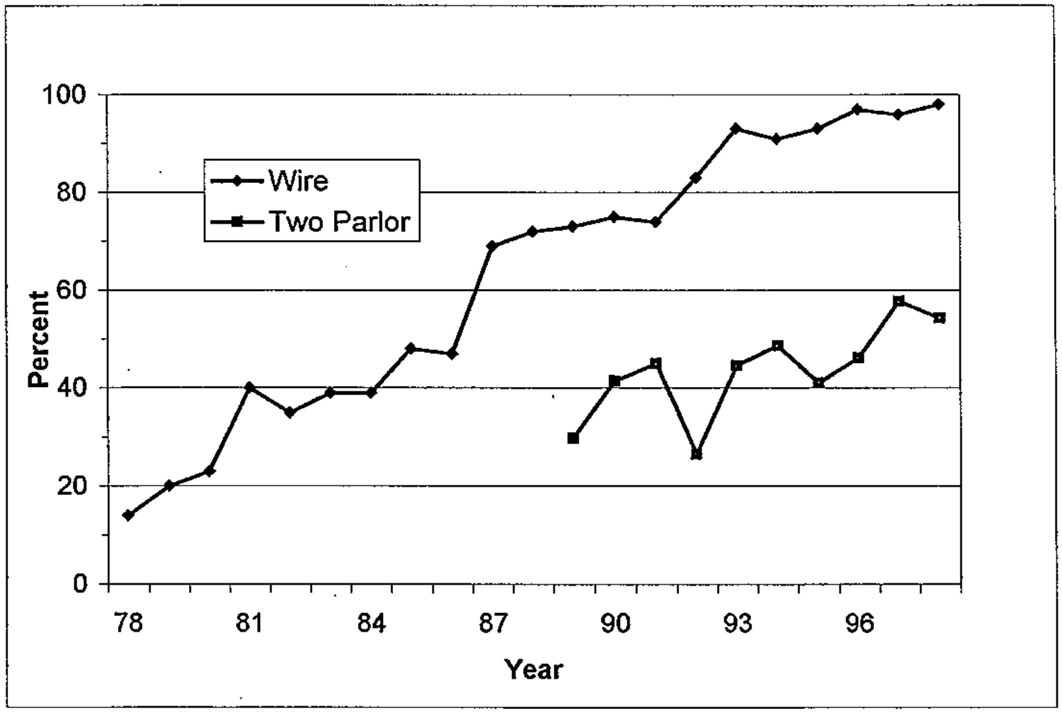


Figure 12. Mean soak time (days) in the Maine lobster fishery, 1968-1998

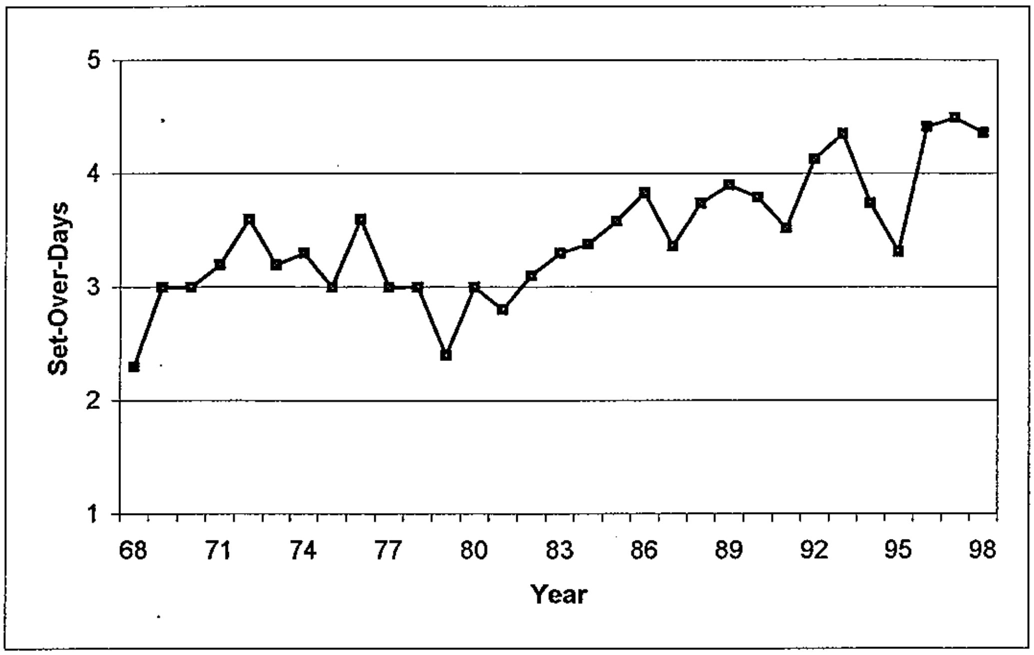
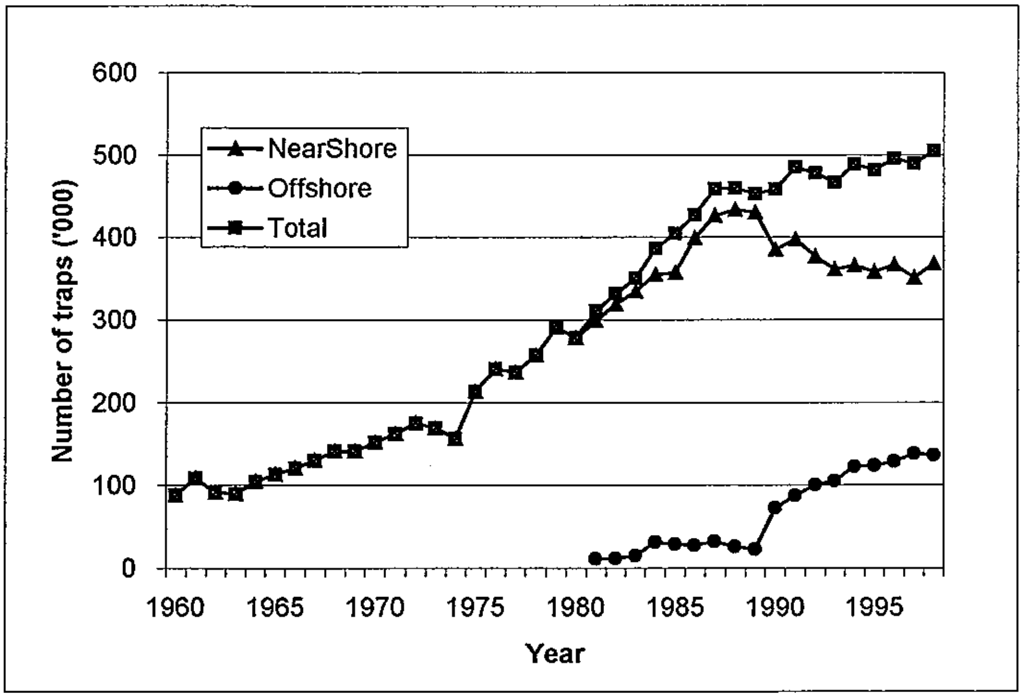


Figure 13. Total number of traps and number of traps fished in the inshore and offshore MA lobster fishery, 1960-1998 (inshore areas 1-7,9 and 10-14, see Figure 23)



In 1990, the MA reporting map was revised to improve the territorial/non-territorial breakdown

Figure 14. Average number of traps fished per boat in the MA lobster fishery, 1967-1998

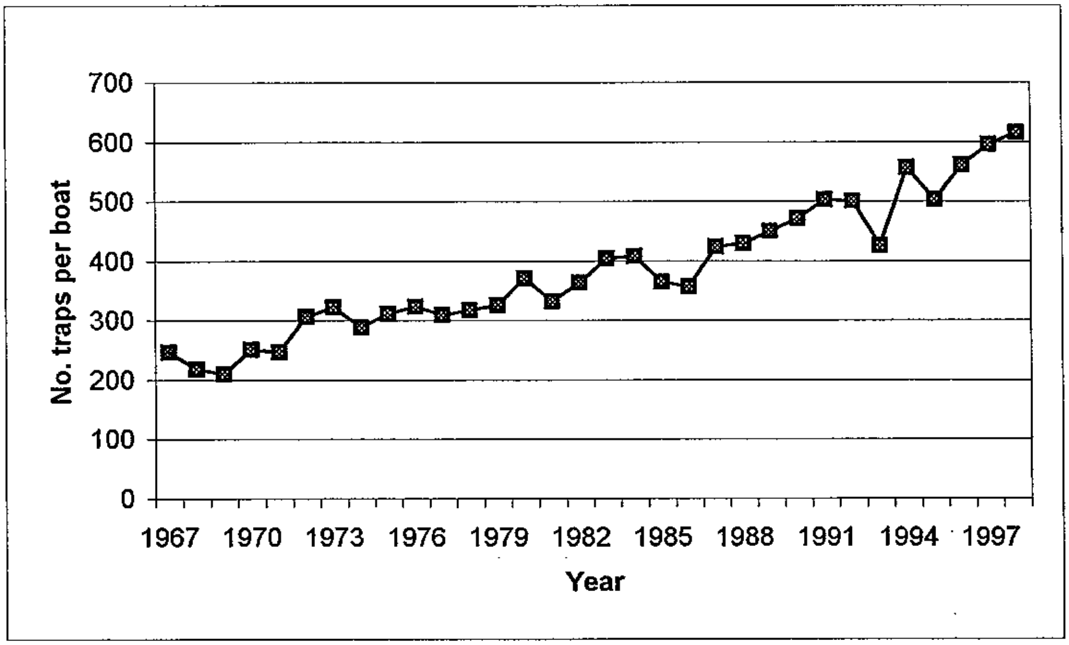
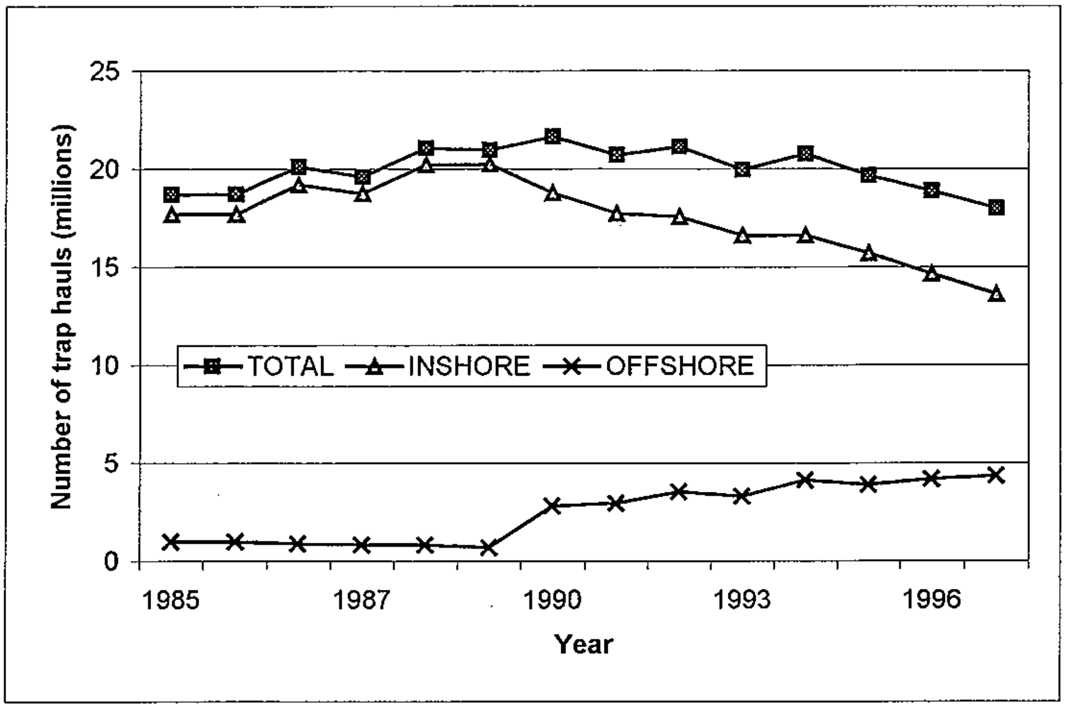


Figure 15. Total trap hauls in the MA lobster fishery, 1985-1998 (inshore areas 1-7, 9 and 10-14, see Figure 23)



In 1990, the MA reporting map was revised to improve the territorial/non-territorial breakdown

Figure 16. Mean soak time (days) in the MA lobster fishery, 1985-1998

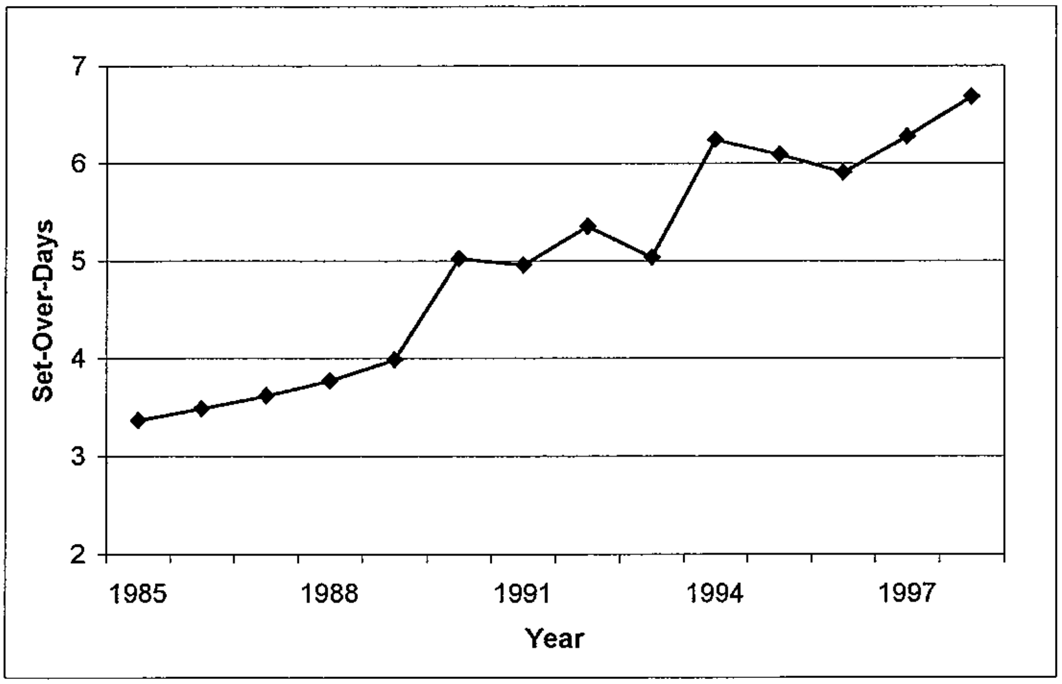


Figure 17. Percent offshore (areas 8, 15-19, see Figure 23) landings and wire traps in MA lobster fishery, 1980-1998

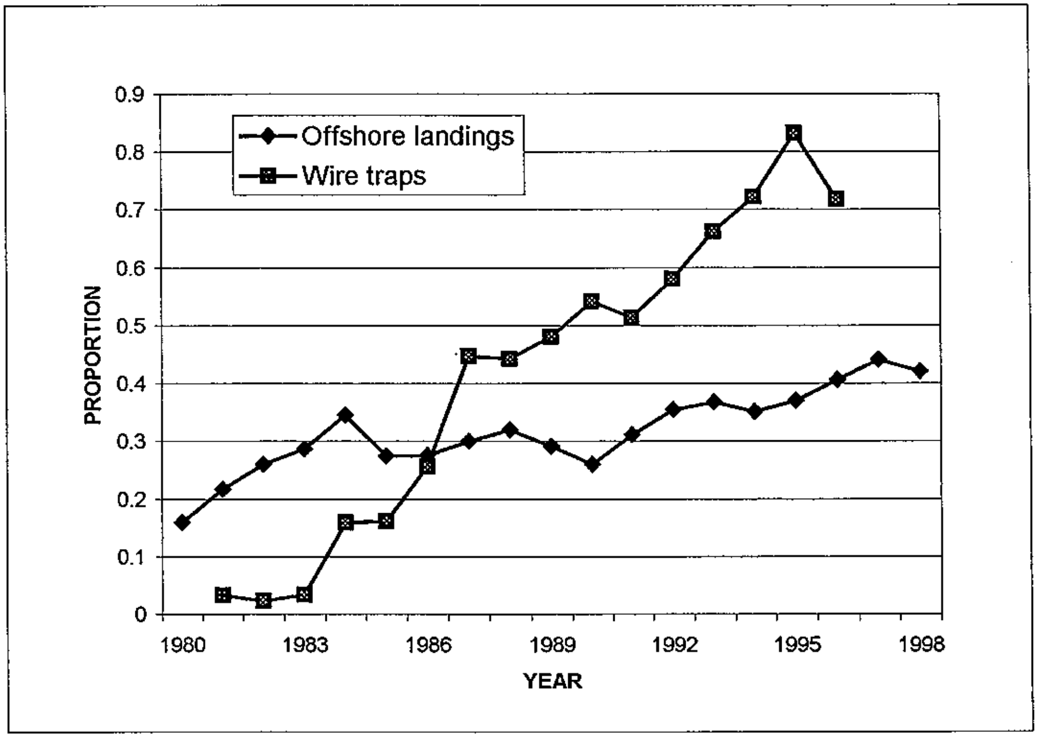


Figure 18. Trap hauls in the RI inshore lobster fishery, 1982-1997

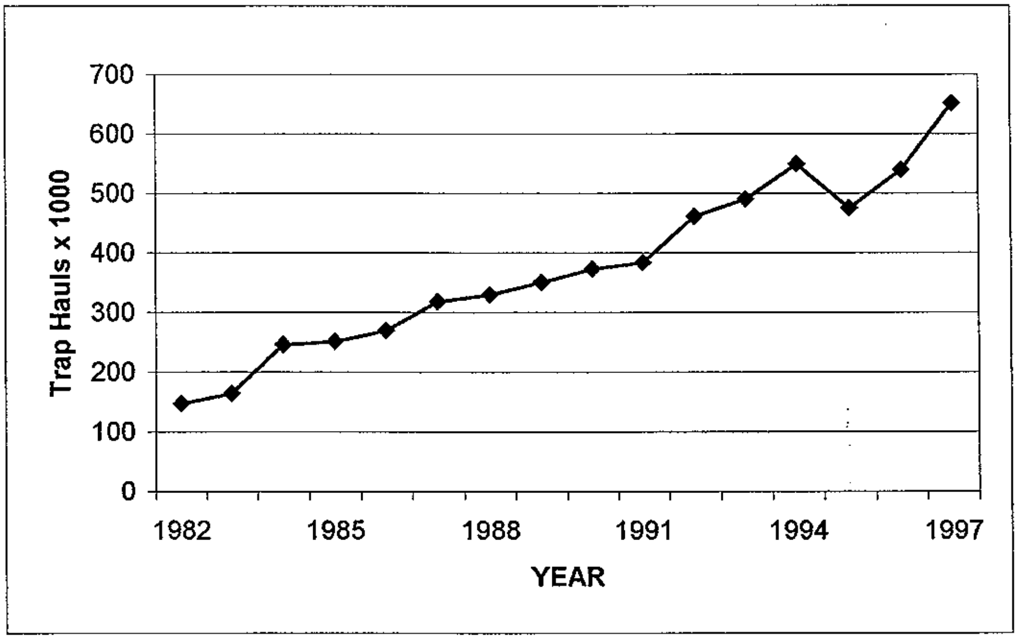


Figure 19. Effort and catch per unit effort in CT lobster fishery, 1979-1998

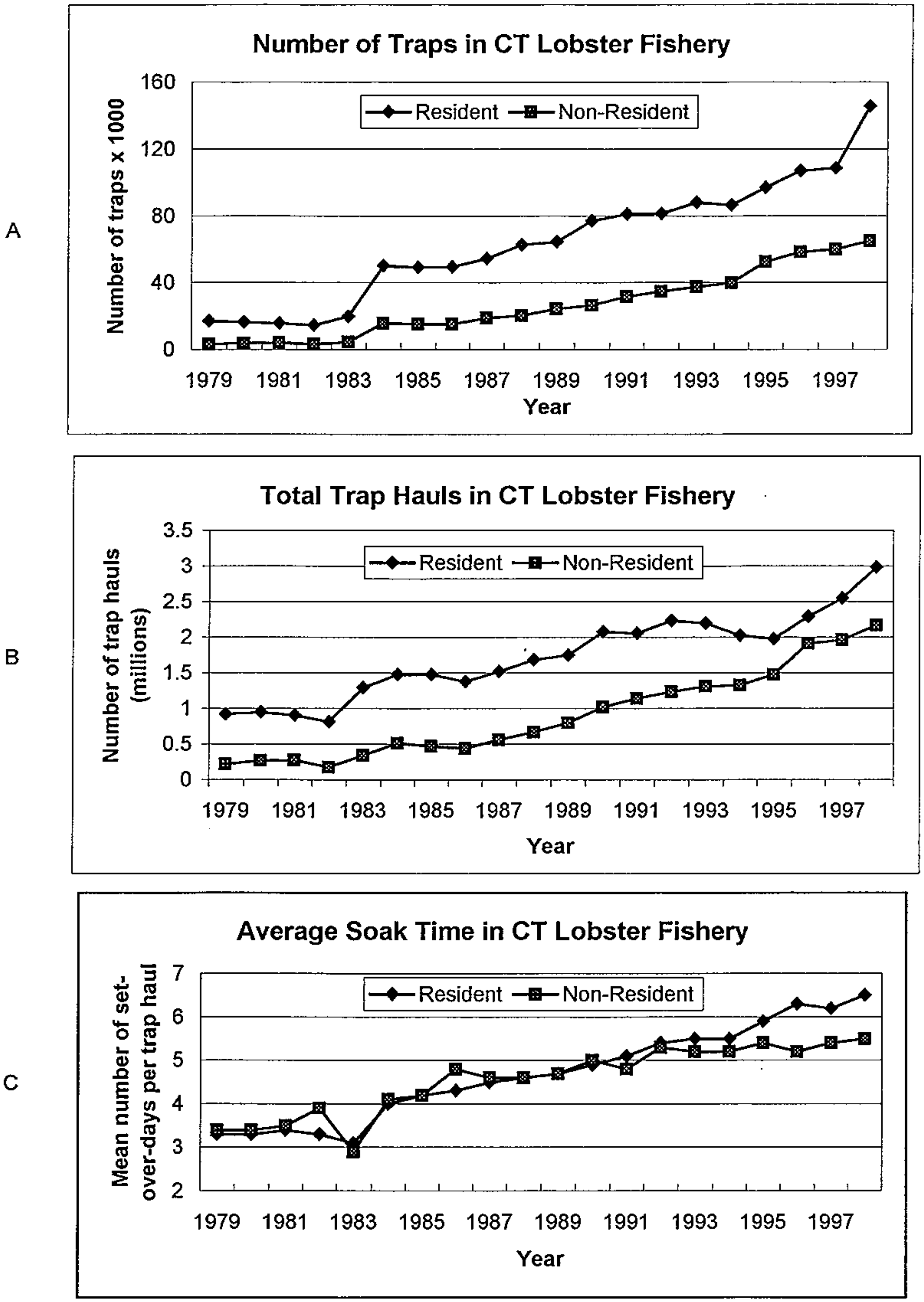
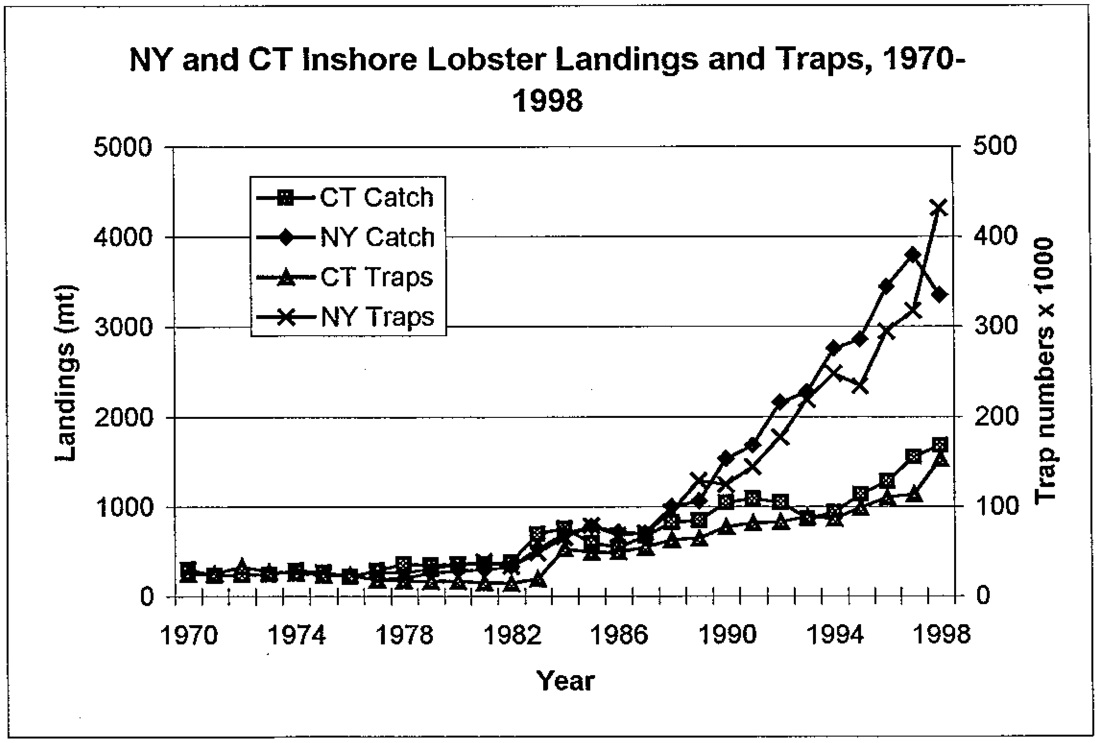


Figure 20



Note: NY catch and trap numbers for inshore waters (<3 miles) in Long Island Sound and south shore of Long Island; CT data for Long Island only.

Figure 21. Number of traps fished in inshore (<3 miles) and offshore (>3 miles) NY lobster fishery, 1970-1998

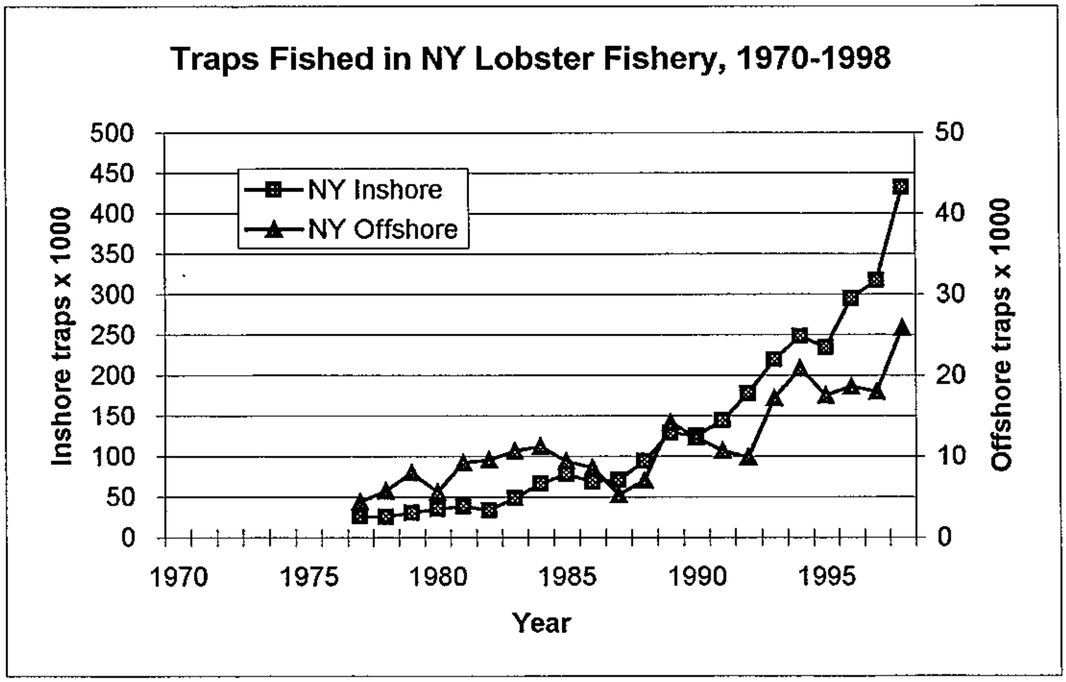


Figure 22. American Lobster Management Areas established for the purpose of regional lobster management.

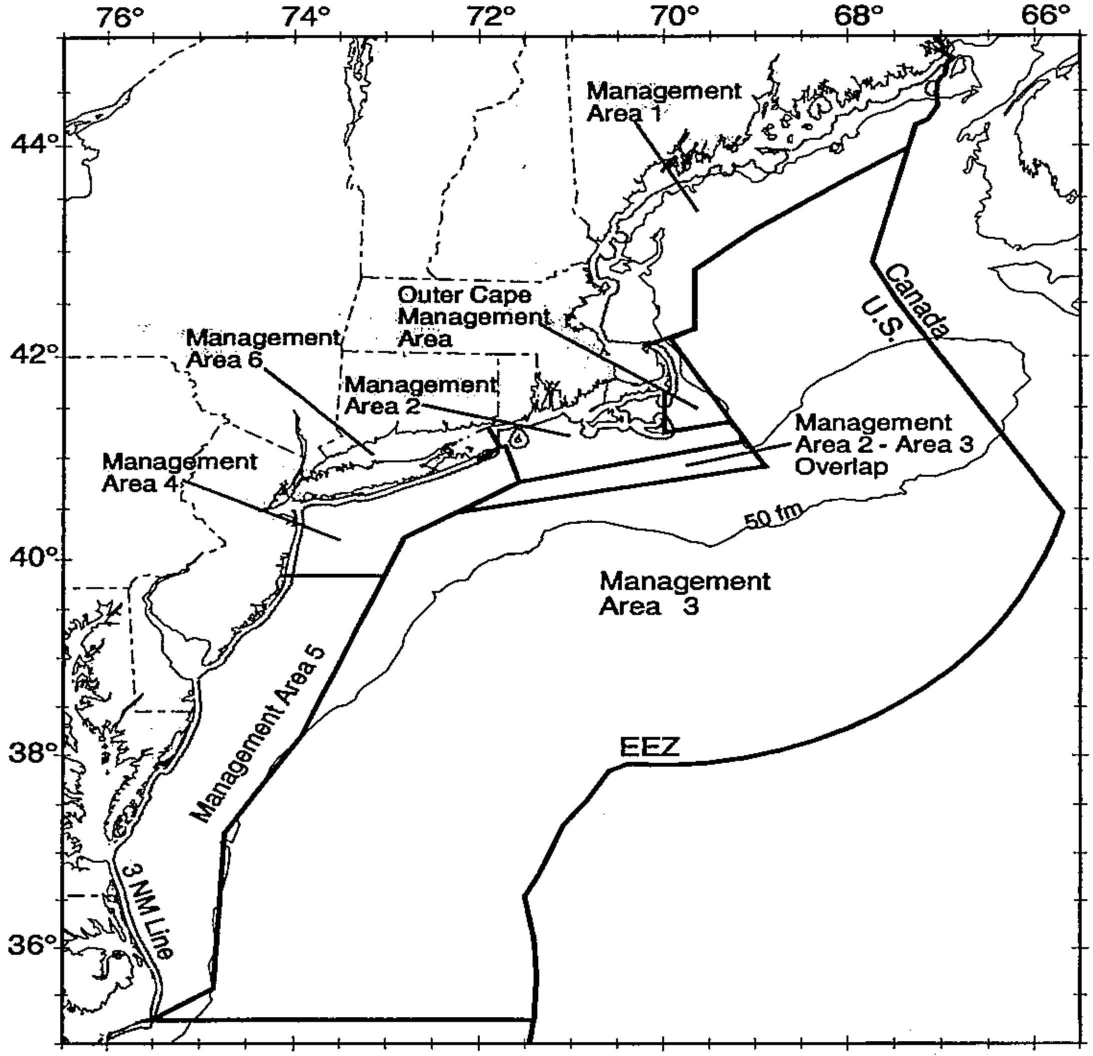
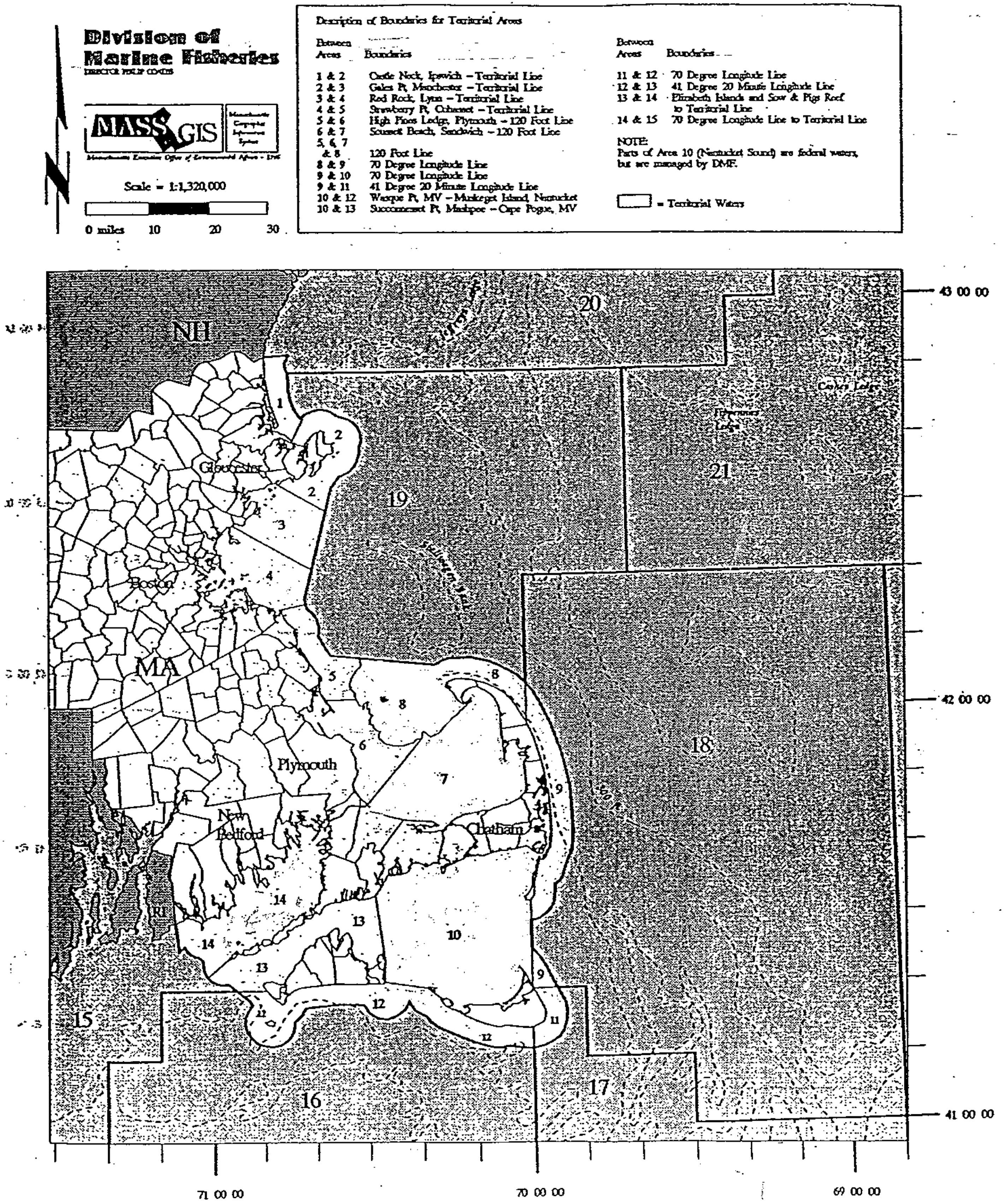


Figure 23. Massachusetts Lobster Fishery; Statistical Reporting Map Showing Territorial Waters and Outlying Areas.



Description of Boundaries for Territorial Areas

| Between Areas | Boundaries |
|---|---|
| 1 & 2 | Castle Neck, Ipswich – Territorial Line |
| 2 & 3 | Gales Pt, Manchester – Territorial Line |
| 3 & 4 | Red Rock, Lynn – Territorial Line |
| 4 & 5 | Strawberry Pt, Cohasset – Territorial Line |
| 5 & 6 | High Pines Ledge, Plymouth – 120 Foot Line |
| 6 & 7 | Scusset Beach, Sandwich – 120 Foot Line |
| 5, 6, 7 & 8 | 120 Foot Line |
| 8 & 9 | 70 Degree Longitude Line |
| 9 & 10 | 70 Degree Longitude Line |
| 9 & 11 | 41 Degree 20 Minute Longitude Line |
| 10 & 12 | Wasque Pt, MV – Muskeget Island, Nantucket |
| 10 & 13 | Succonnesset Pt, Mashpee – Cape Pogue, MV |
| 11 & 12 | 70 Degree Longitude Line |
| 12 & 13 | 41 Degree 20 Minute Longitude Line |
| 13 & 14 | Elizabeth Islands and Sow & Pigs Reef to Territorial Line |
| 14 & 15 | 70 Degree Longitude Line to Territorial Line |

NOTE:
Parts of Area 10 (Nantucket Sound) are federal waters, but are managed by DMF.

▭ = Territorial Waters

**Figure 24. Fishing areas used in the CT DEP Marine Fisheries Information System.**

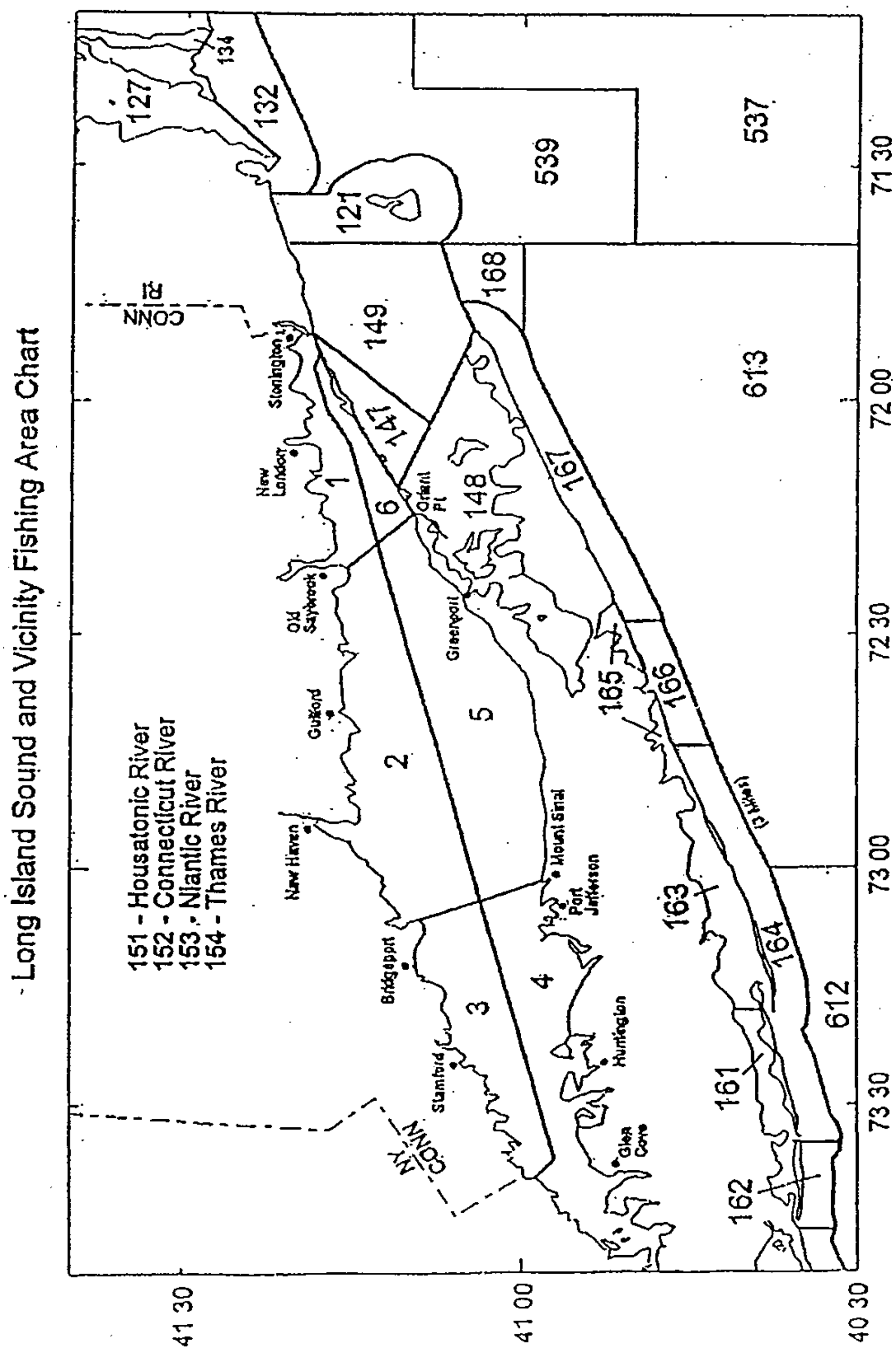


Figure 25. Map of Massachusetts with six sampling regions (hatch-marked) and territorial sea boundary (dotted line) indicated.

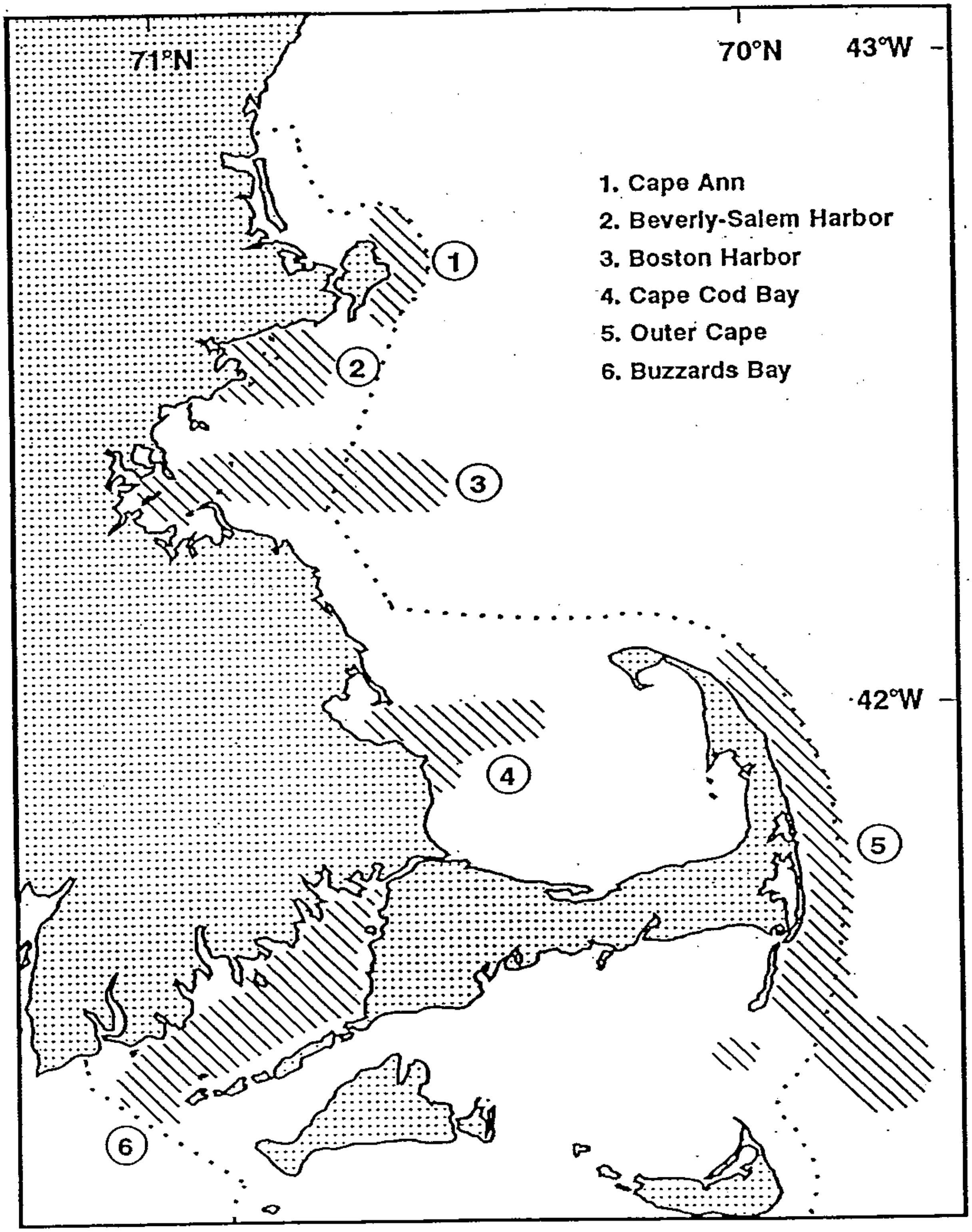


Figure 26. Sampling strata used in NMFS/NEFSC bottom trawl survey.

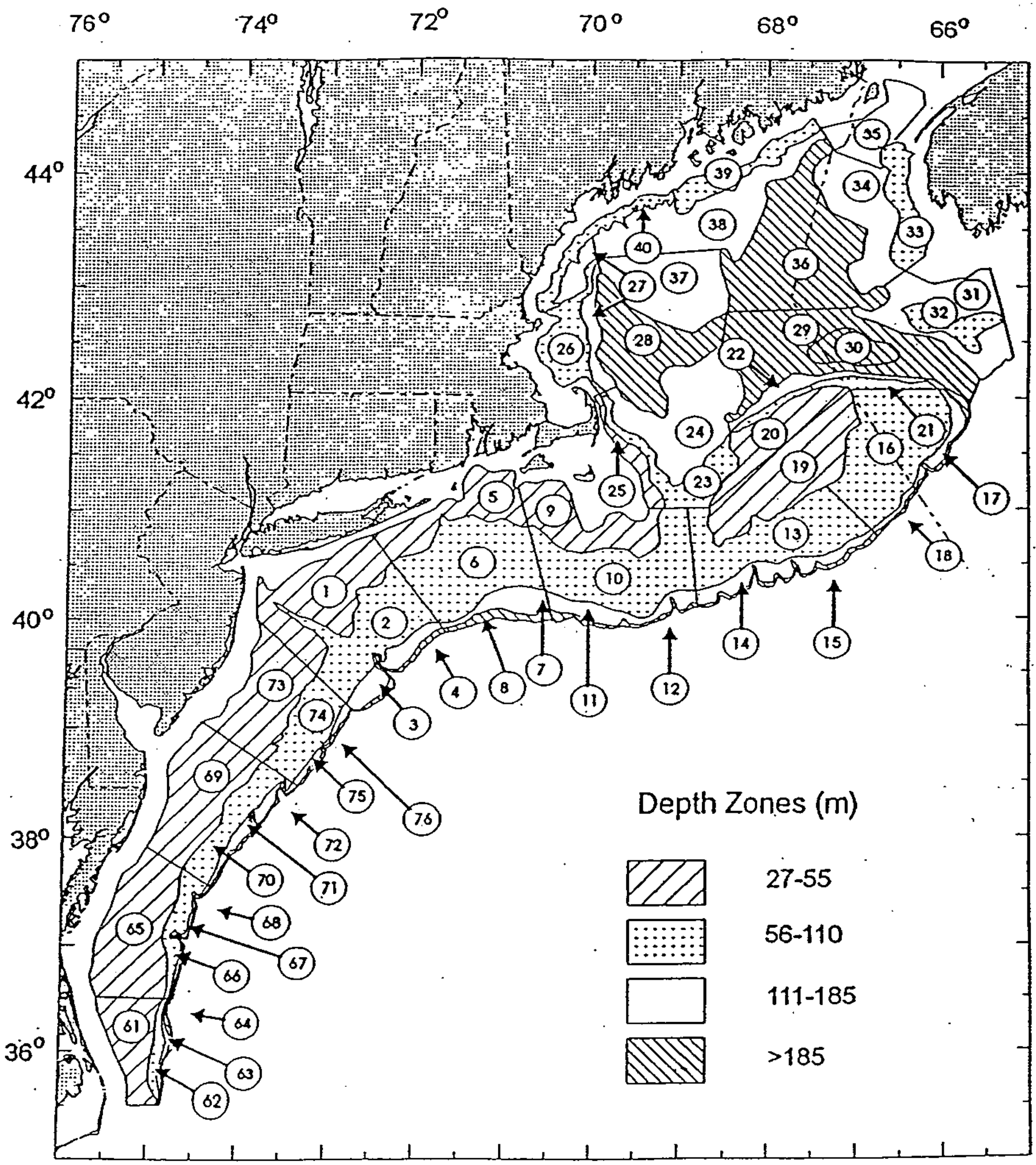
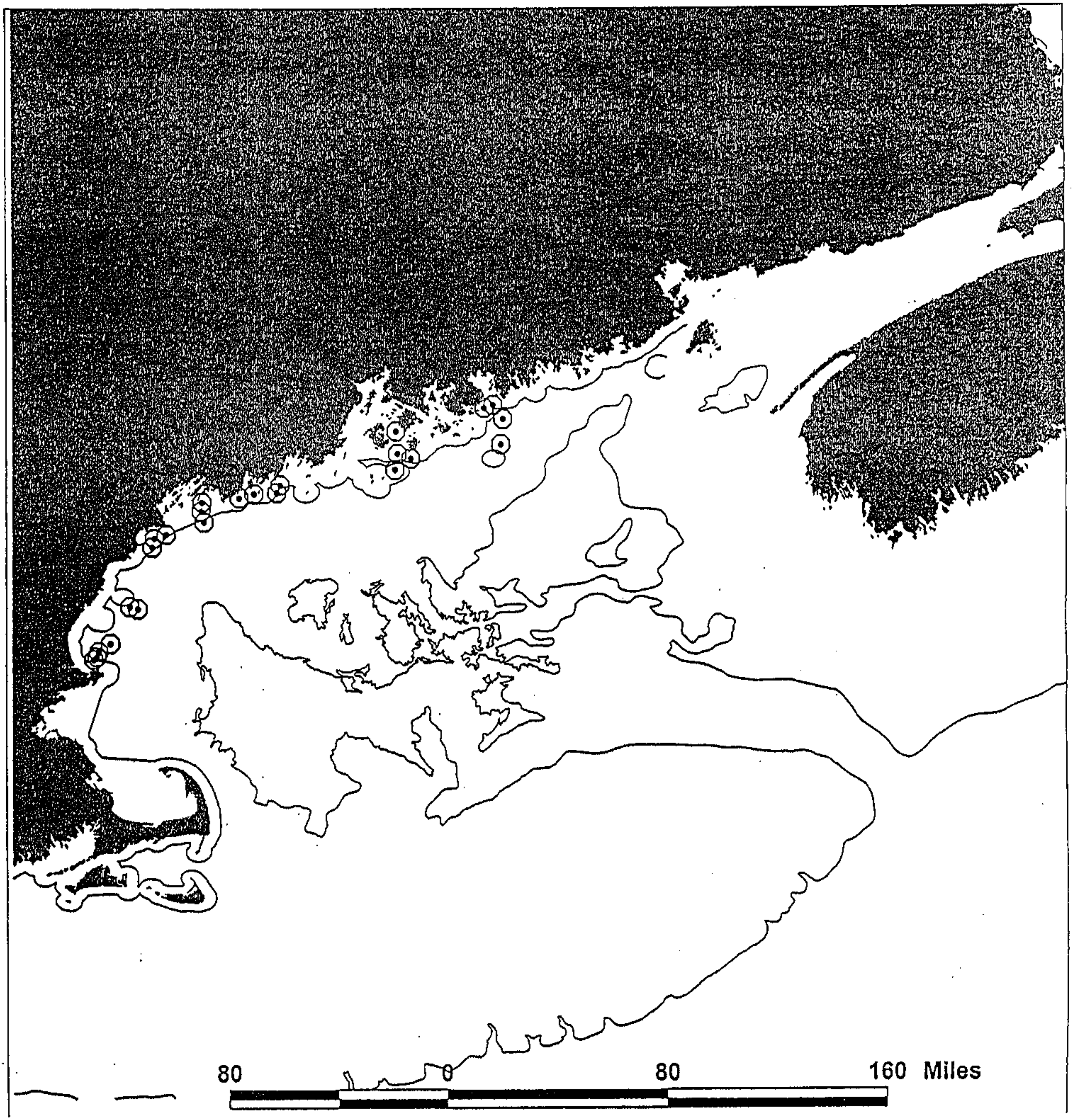


Figure 27.

# Maine DMR Trawl Survey 1992 - 1994



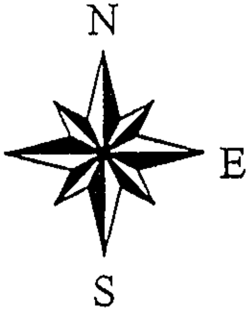


Figure 28. Maine DMR Trawl Survey, 1996–1998

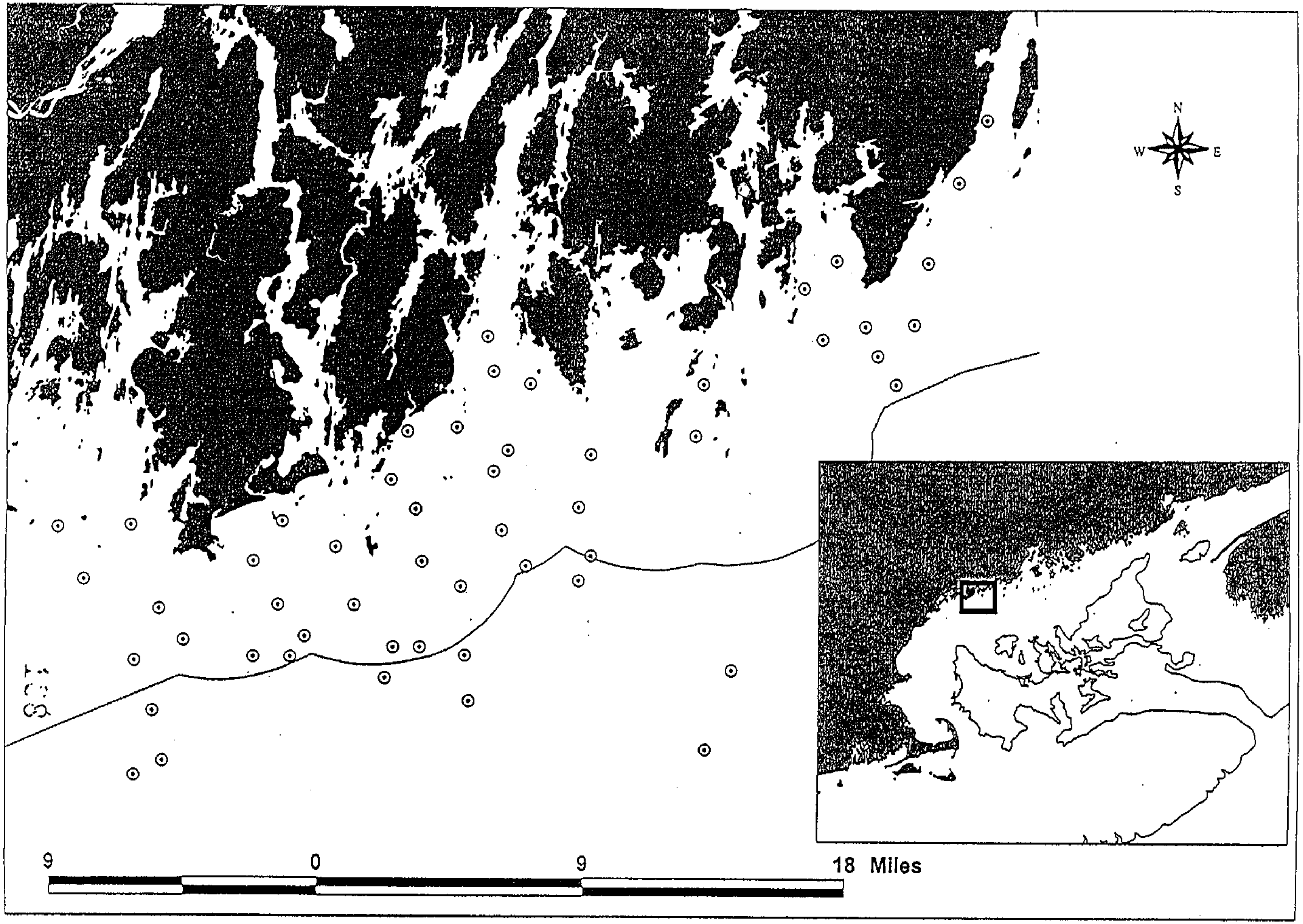


Figure 29. Sampling strata used in Massachusetts DMF inshore bottom trawl survey.

| Region | Stratum | Area (sq n mi) |
|---|---|---|
| Buzzards Bay | 11 | 102 |
| Vineyard Sound & coastal water south of Martha's Vineyard | 12 | 160 |
| | 13 | 88 |
| | 14 | 16 |
| Nantucket Sound | 15 | 190 |
| | 16 | 212 |
| East of Cape Cod, Race Pt. to Muskeget Isl. | 17 | 85 |
| | 18 | 88 |
| | 19 | 39 |
| | 20 | 24 |
| | 21 | 40 |
| Cape Cod Bay | 25 | 47 |
| | 26 | 87 |
| | 27 | 94 |
| | 28 | 93 |
| | 29 | 103 |
| | 30 | 32 |
| Massachusetts Bay north to N.H. border | 31 | 41 |
| | 32 | 49 |
| | 33 | 78 |
| | 34 | 38 |
| | 35 | 174 |
| | 36 | 33 |

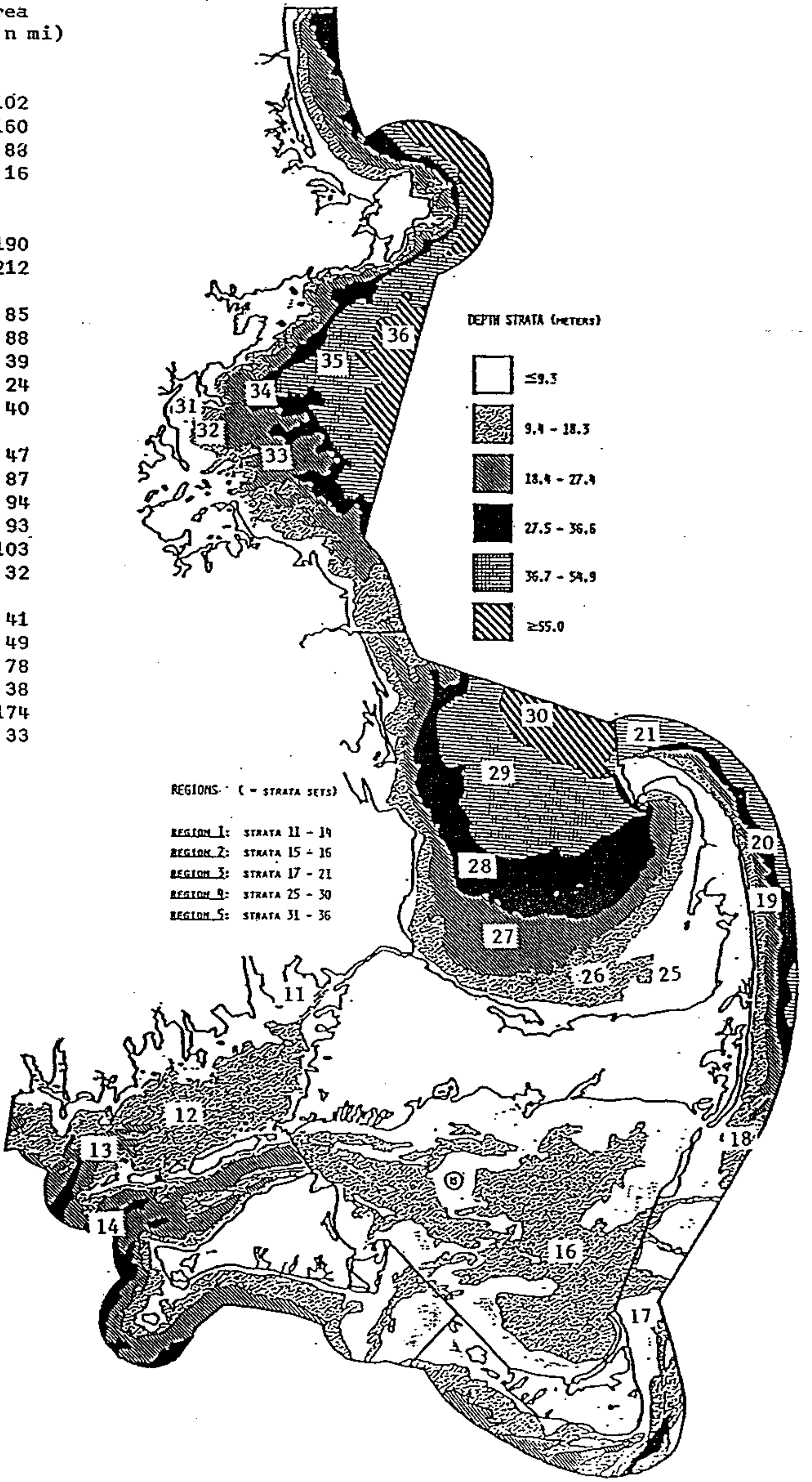


Figure 30. Trawl Survey Areas for Massachusetts, Rhode Island, and Connecticut.

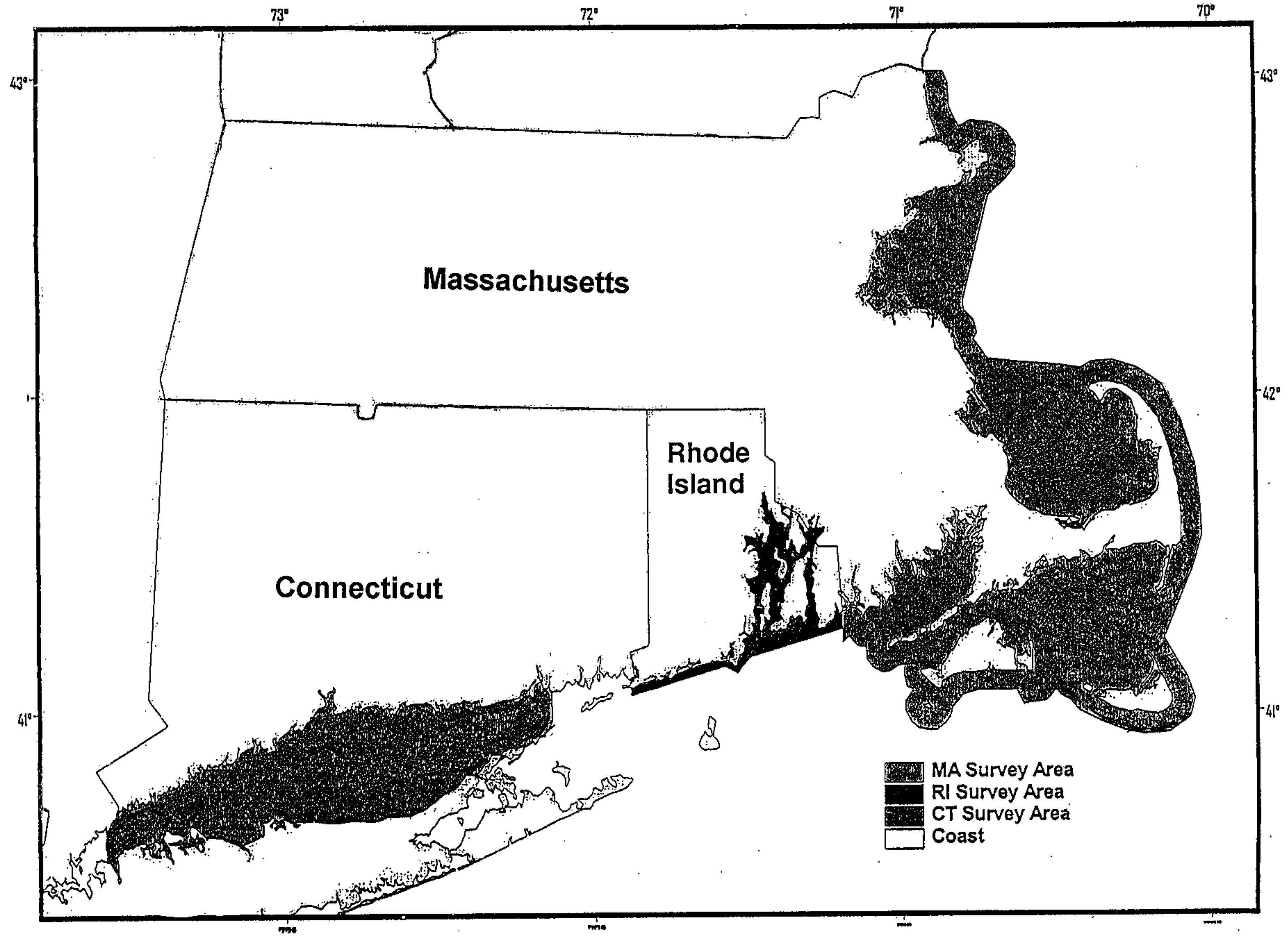


Figure 31. Marine Finfish Survey sampling area with site grid overlay. Each sampling site is 1x2 nmi (nautical miles). A four-digit number identifies the site: the first two digits are the row numbers (corresponding to minutes of latitude) and the last two digits are the column numbers (corresponding to two nautical miles in length on the longitudinal axis). Examples: site 1428 near Guilford and 0028 near Mattituck. (Note: The sites in column 16 are approximately 2x1 nmi. The grid was drawn on the Eastern and Western Long Island Sound 80,000: 1 nautical charts, which overlap by the area in column 16.)

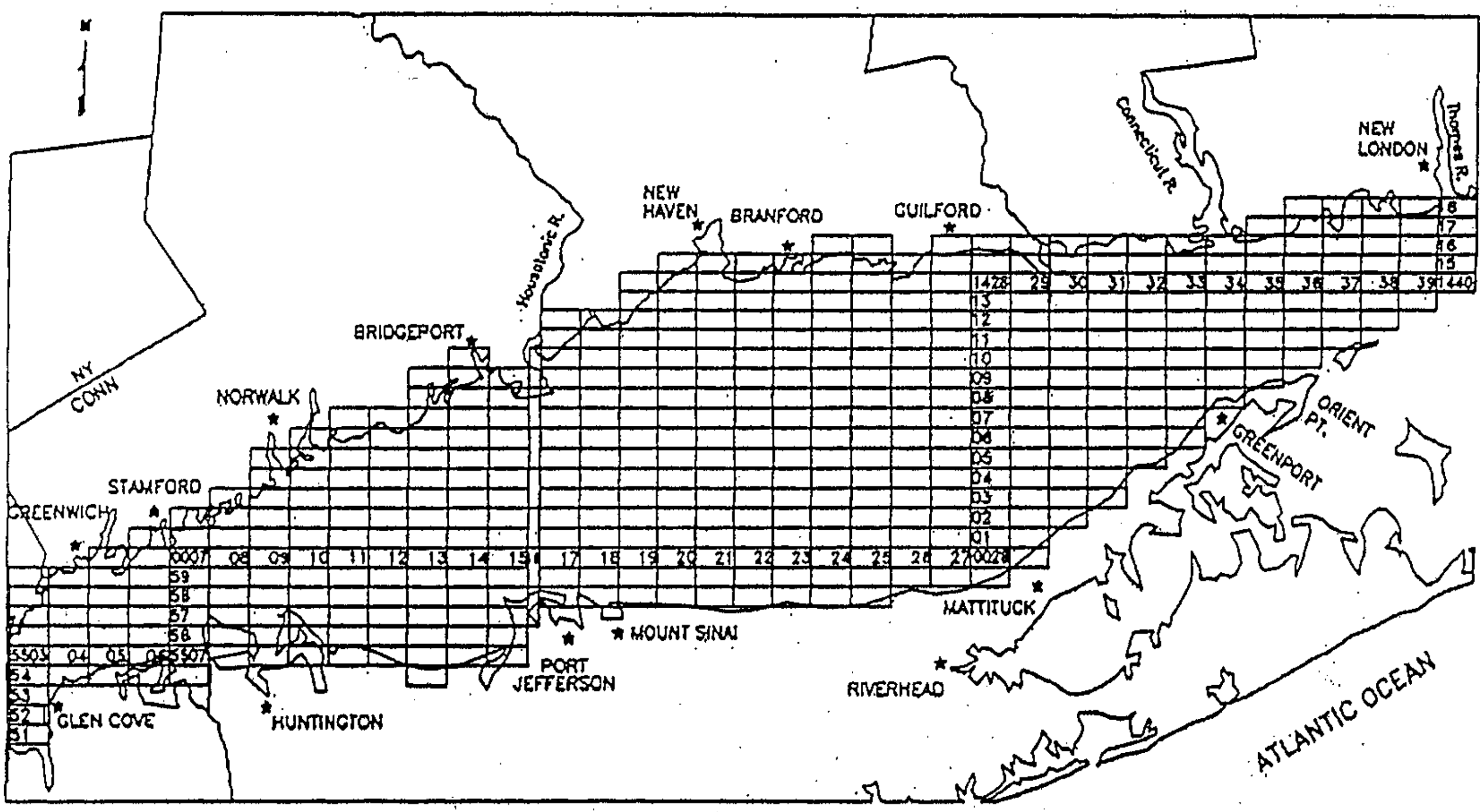


Figure 32. New Jersey nearshore recreational fisheries resources stock assessment sampling locations (New Jersey Division of Fish, Game and Wildlife, 1998).

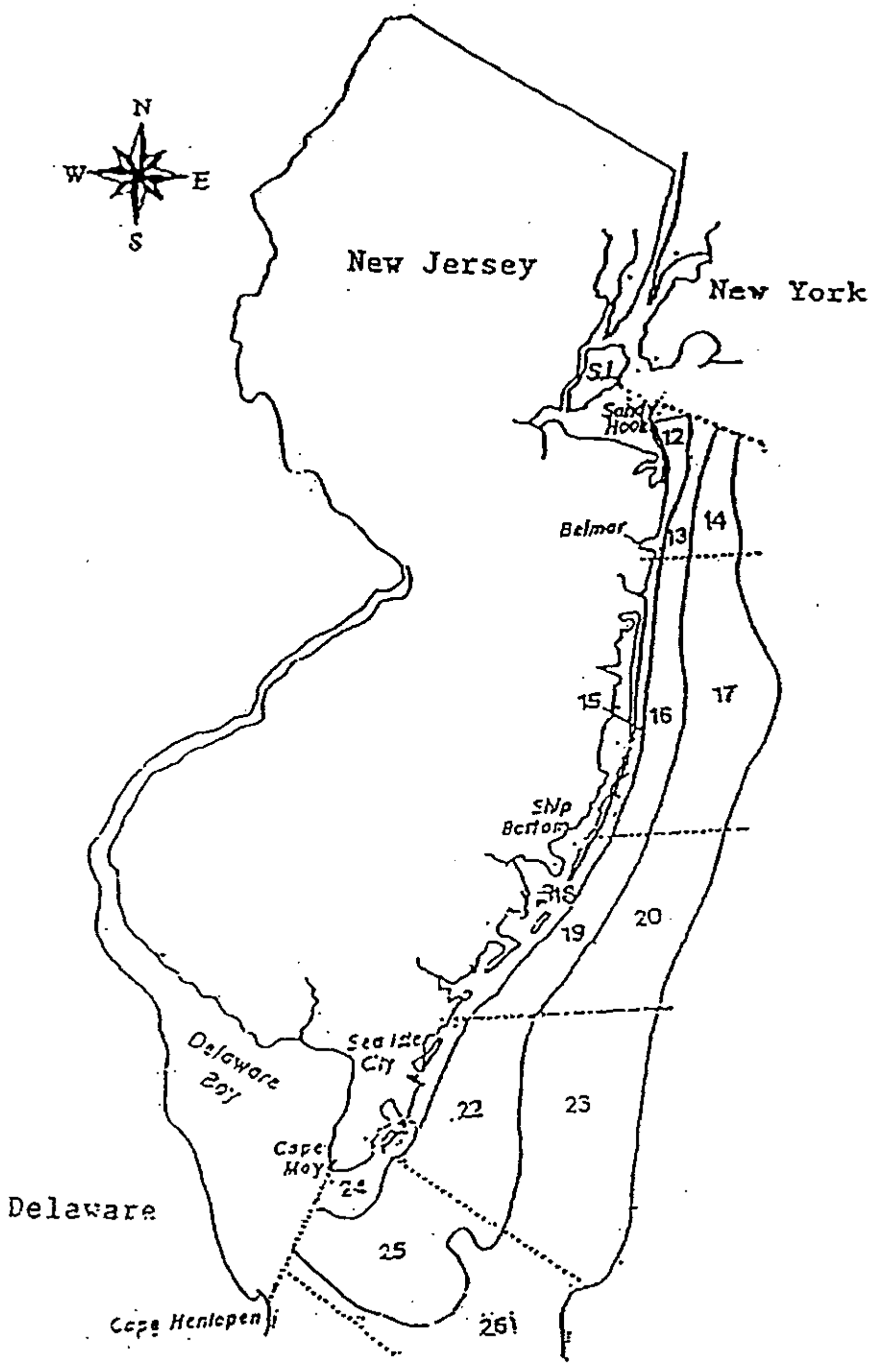
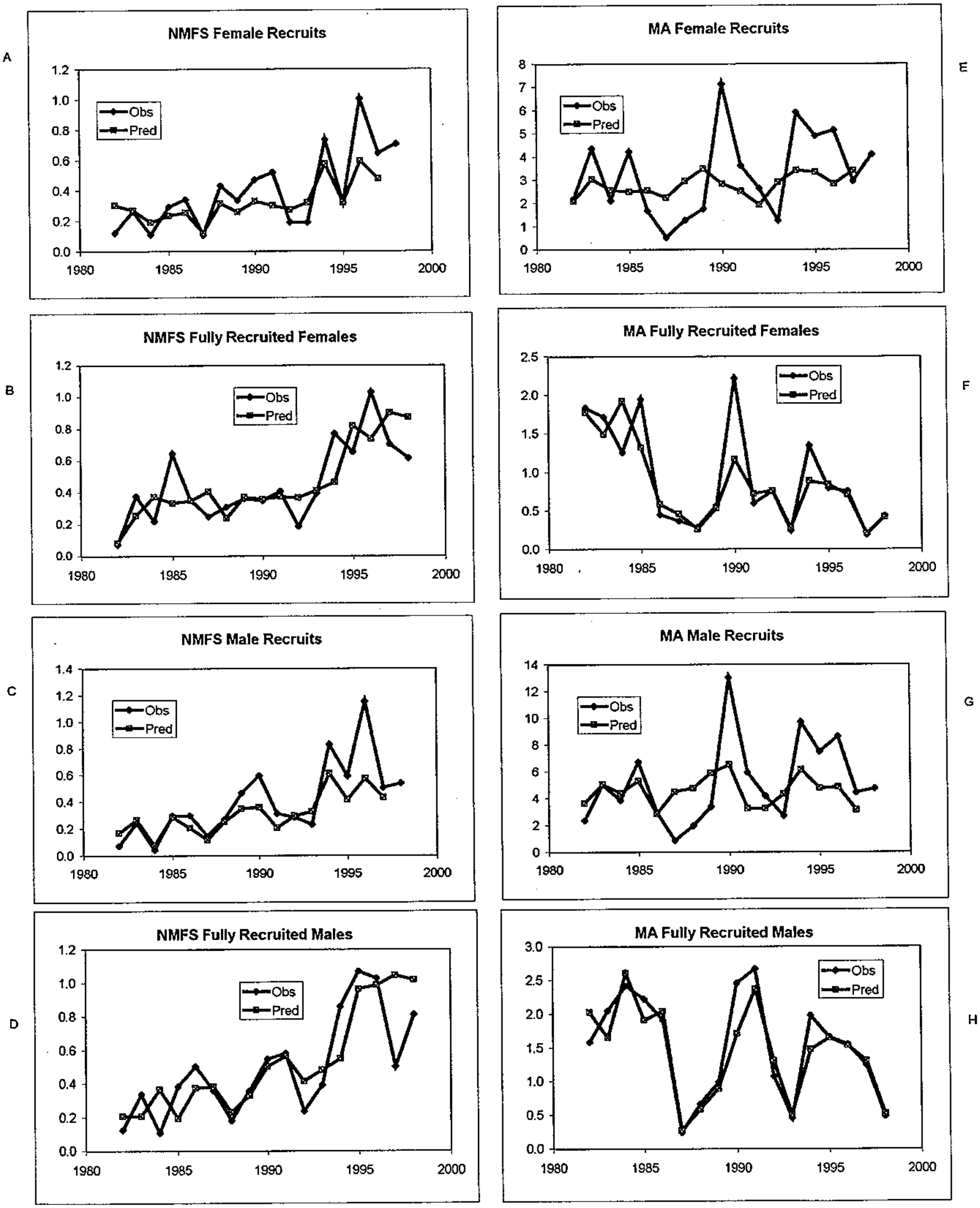


Figure 33. Observed and DeLury model predictions of survey abundance (mean number per tow) for male and female recruits and full recruits in the NMFS and MA fall trawl surveys, Gulf of Maine stock area, 1982-1997 fall survey years.



NMFS Female Recruits

MA Female Recruits

NMFS Fully Recruited Females

MA Fully Recruited Females

NMFS Male Recruits

MA Male Recruits

NMFS Fully Recruited Males

MA Fully Recruited Males

Figure 34. Observed and DeLury model predictions of survey abundance (mean number per tow) for male and female recruits and full recruits in the NMFS fall trawl survey, Georges Bank and South stock area, 1982-1997 fall survey years.

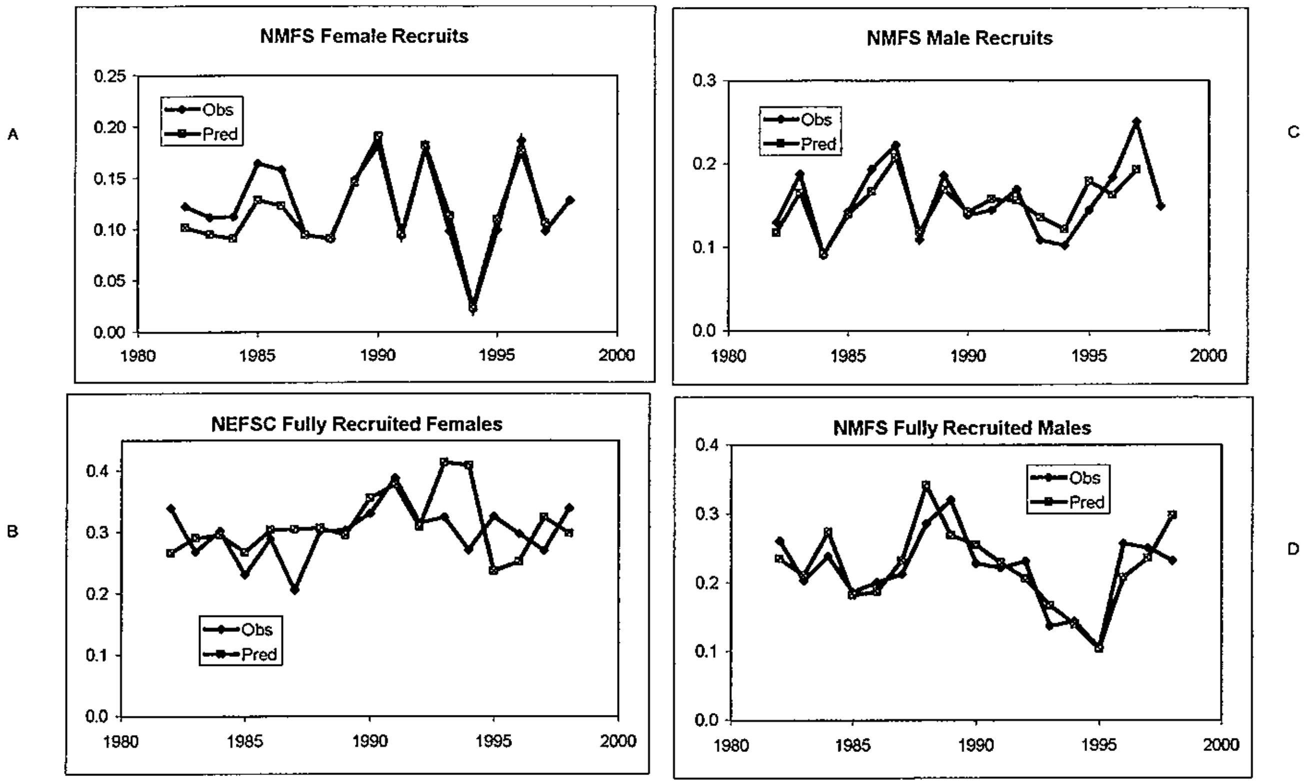


Figure 35. Observed and DeLury model predictions of survey abundance (mean number per tow) for male and female recruits and full recruits in the NMFS, CT, and RI fall trawl surveys, South of Cape Cod and Long Island Sound stock area, 1982-1997 fall survey years.

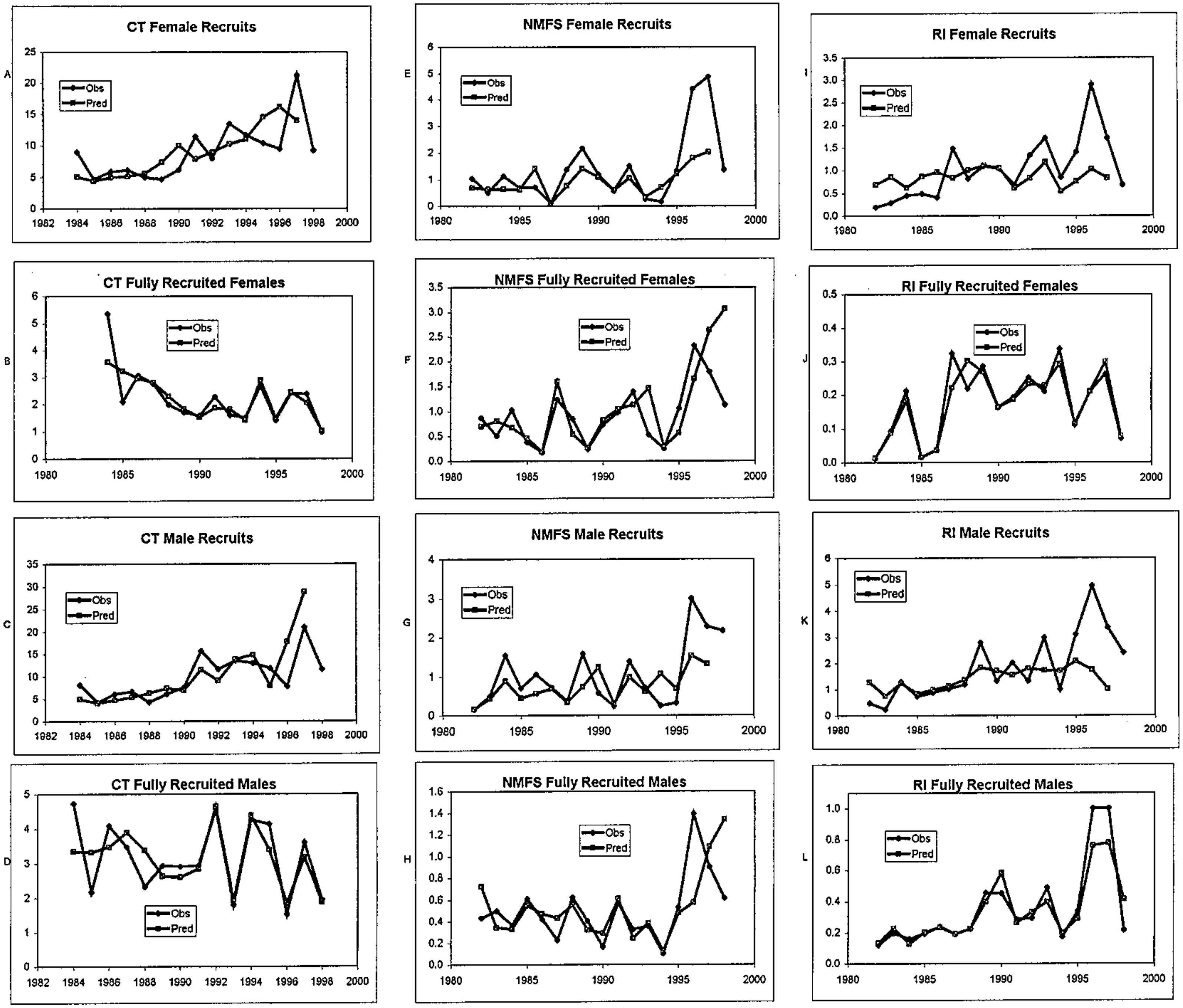


FIGURE 36. Recruitment (abundance of 73-82 mm CL lobster, sexes combined, in the NMFS fall trawl survey) and a simple exploitation index (catch in number divided by NMFS fall trawl survey abundance, 83+ mm CL, sexes combined) for lobster in the GBS stock area.

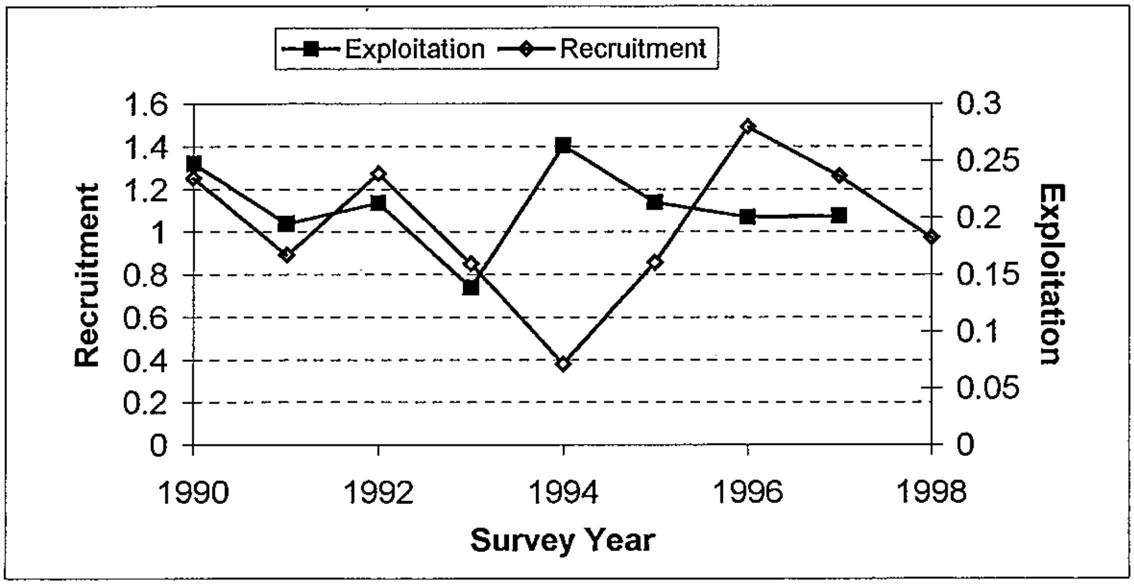
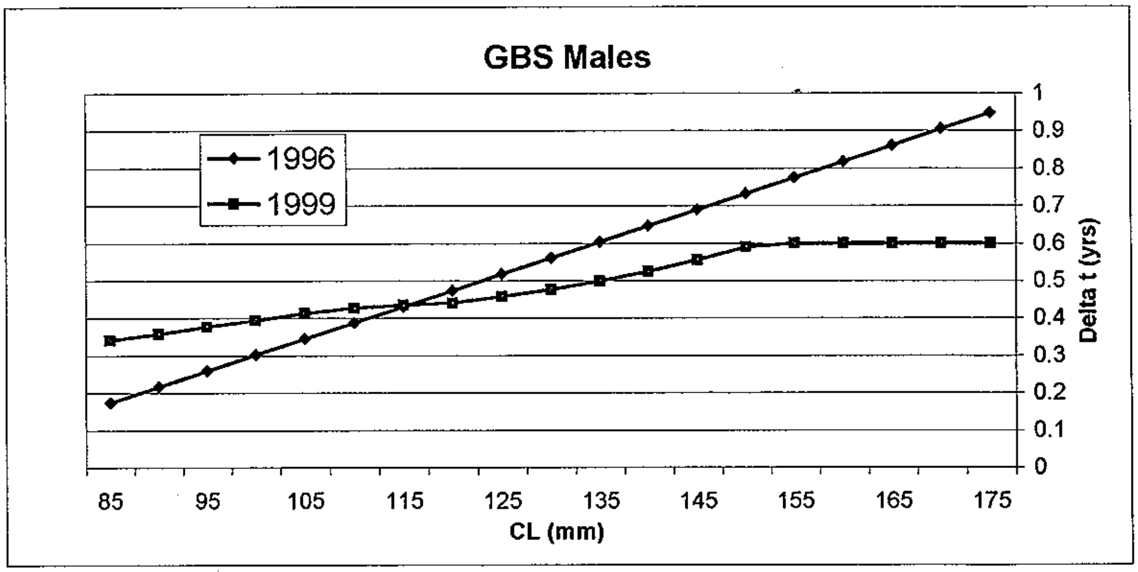


Figure 37. Delta-t estimates (time spent in each 5 mm length interval) used in LCA analyses for female and male lobsters in GBS in this and previous assessment.



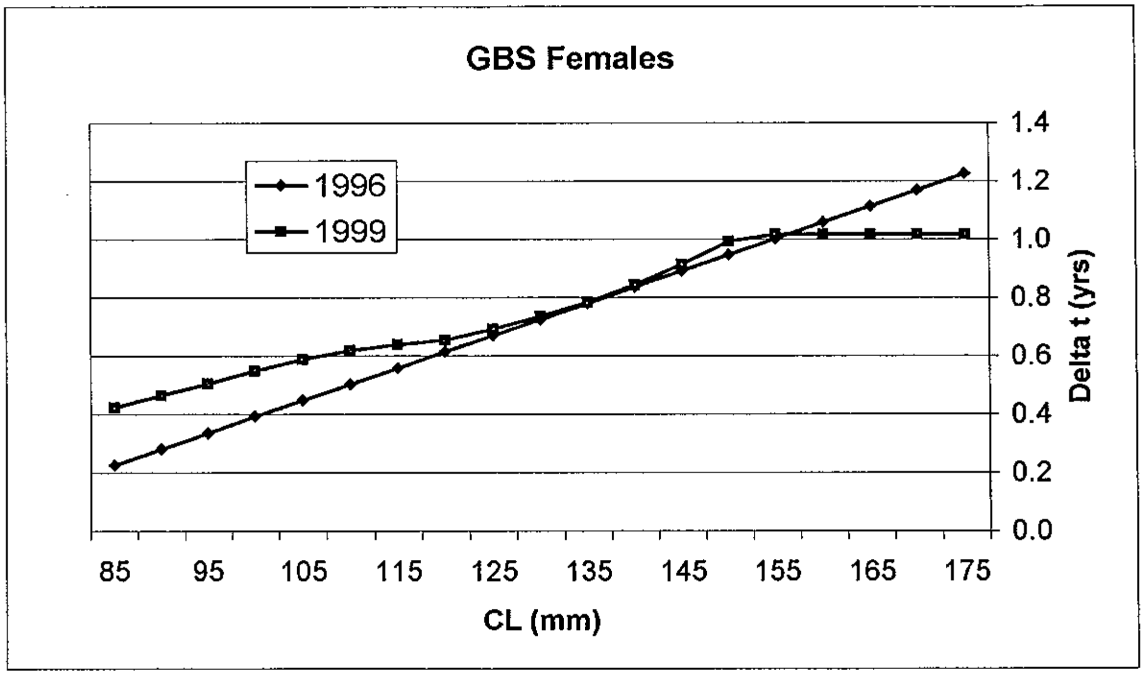


Figure 38. Fishery Selectivities Assumed or Implied by Lobster Stock Assessment Models

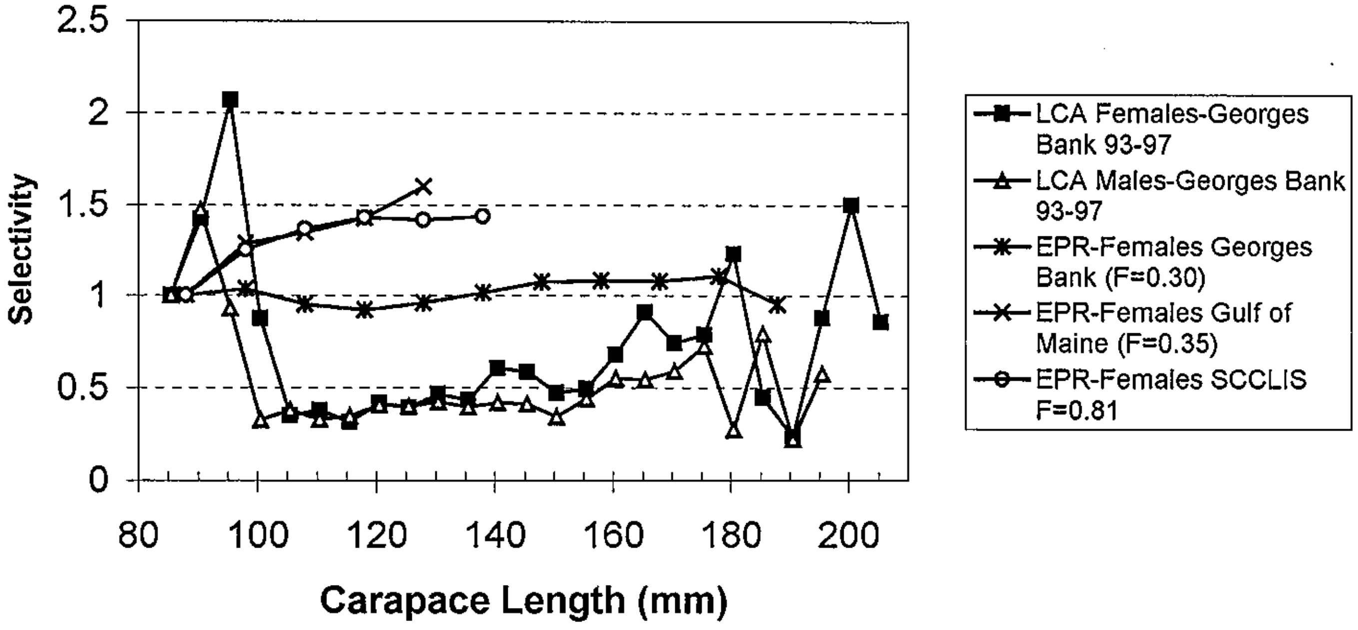


**Figure 39. Mean Fishery (Oct-Nov) and NMFS Fall Survey Length Composition Data for Lobster during 1995-1997 in the Georges Bank & South Stock Area**

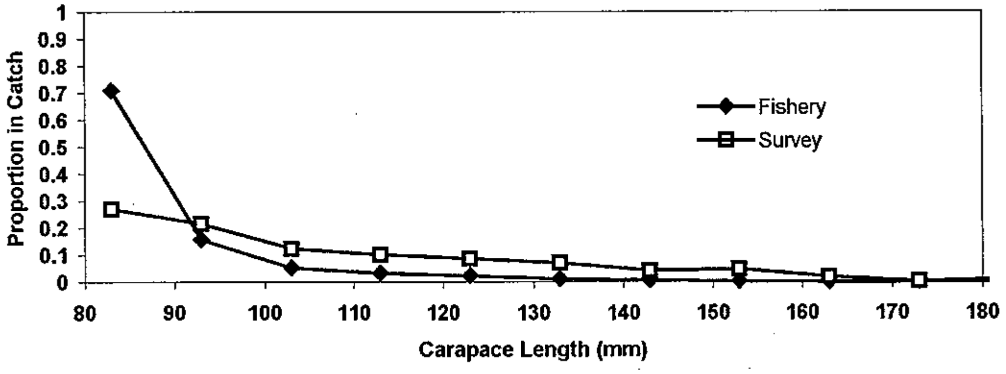


**Figure 40. Mean Fishery (Apr-Jun) and Connecticut Spring Survey Length Composition Data for Lobster during 1995-1997 in Long Island Sound**

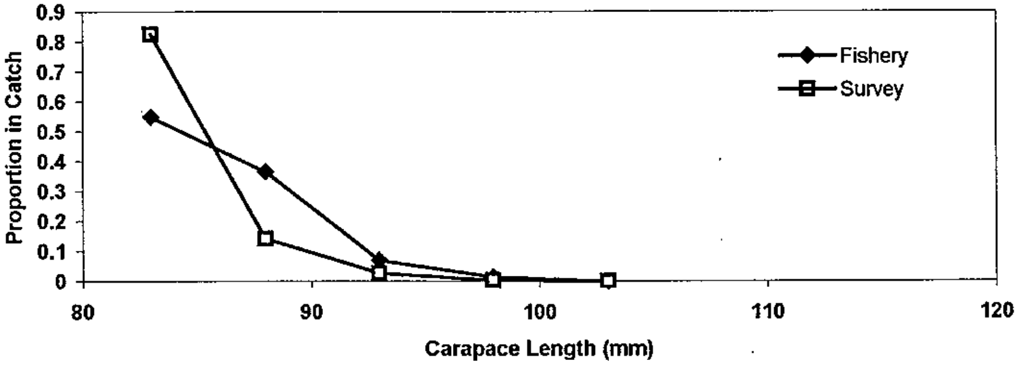
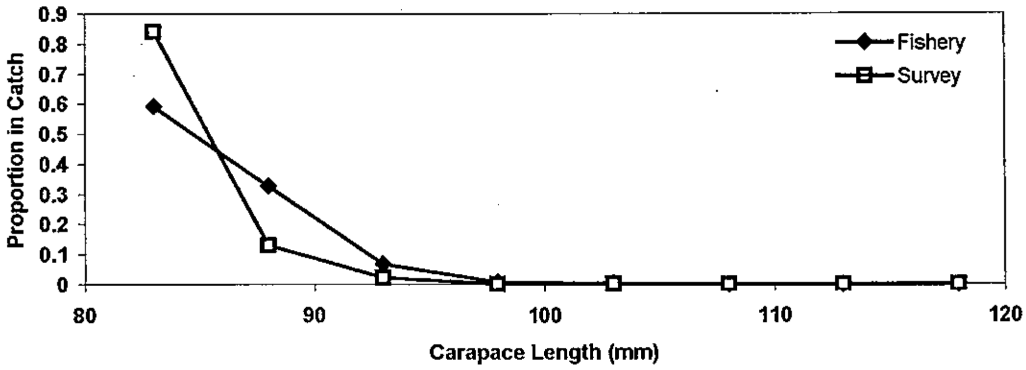


**Figure 41. Mean Fishery (Sep-Oct) and Connecticut Fall Survey Length Composition Data for Lobster during 1995-1997 in Long Island Sound**



Figures 42-47. Variance of DeLury model fits and median 1995-1997 DeLury model female fishing mortality rate estimates with a Q ration of 0.2-1.0

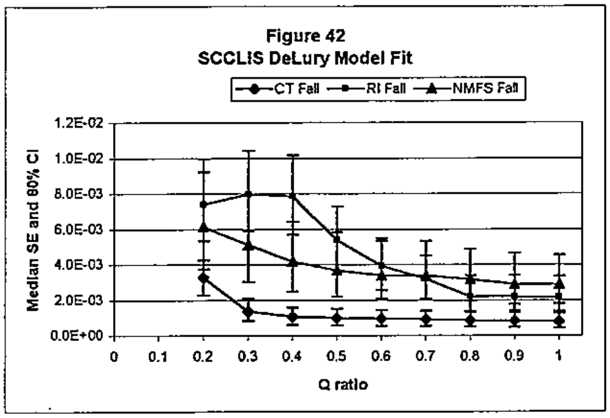


Figure 42
SCCLIS DeLury Model Fit

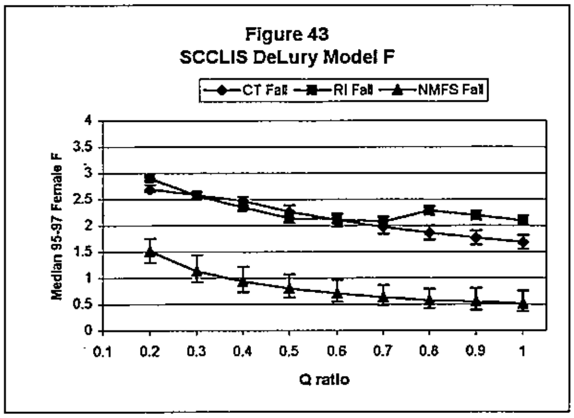


Figure 43
SCCLIS DeLury Model F

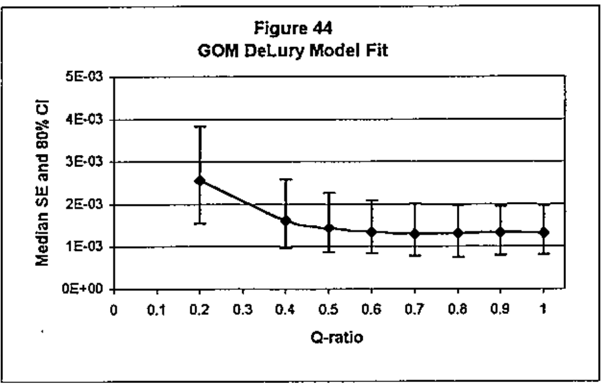


Figure 44
GOM DeLury Model Fit

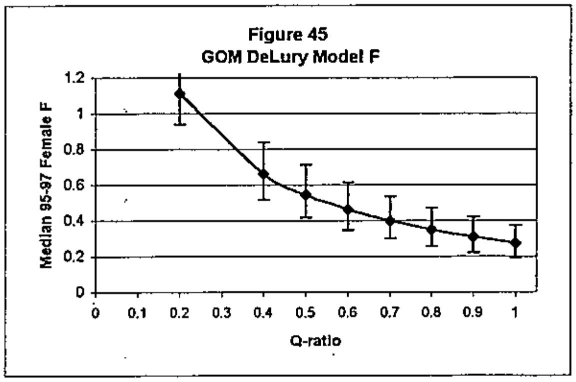


Figure 45
GOM DeLury Model F

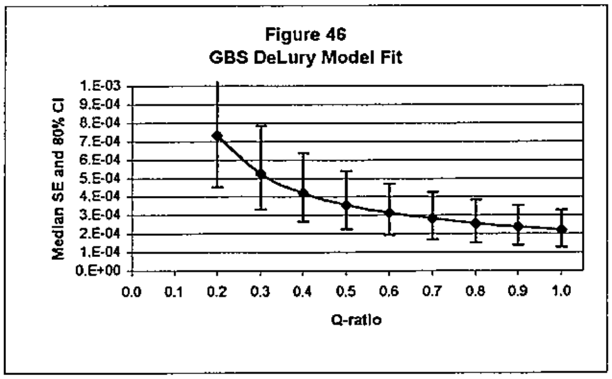


Figure 46
GBS DeLury Model Fit

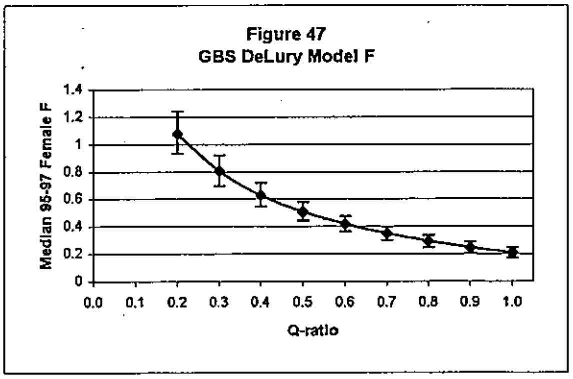
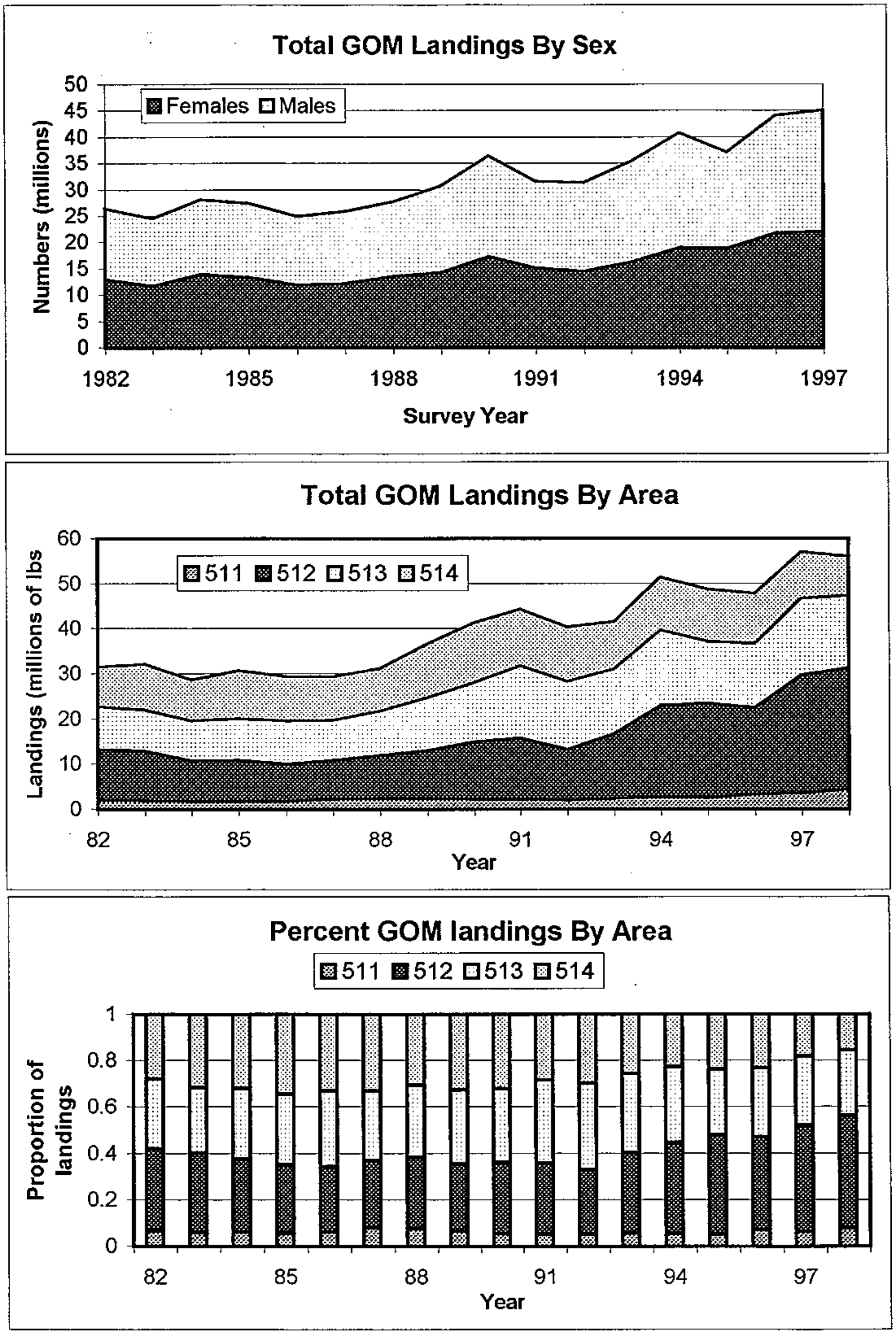


Figure 47
GBS DeLury Model F

Figure 48. Gulf of Maine stock area landings by sex (in numbers) and statistical area (in pounds), 1982-1997 fall survey years.



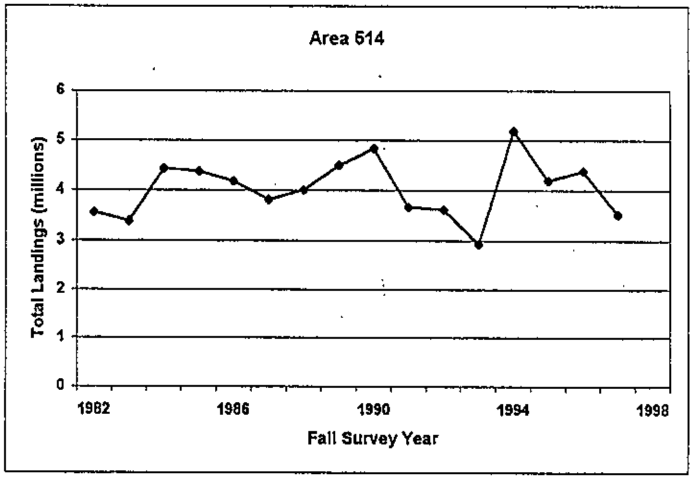
Note: Area 515 landings are <1 million lbs a year and are not shown.

Figure 49. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for GOM male lobsters in statistical area 514 for fall survey years 1982-1997 estimated from MA fall survey (Q ratio =1.0).

**GOM [MA] Male Lobsters**
Using Fall SY Landings from SA 514

s_r =1.0

| Survey Year | Indices of Abundance: Recruits | Indices of Abundance: Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 2.3550 | 1.5840 | 3.5644 |
| 1983 | 5.0261 | 2.0460 | 3.3875 |
| 1984 | 3.8671 | 2.4220 | 4.44998 |
| 1985 | 6.7426 | 2.2210 | 4.38655 |
| 1986 | 2.9973 | 1.9090 | 4.19309 |
| 1987 | 0.8875 | 0.2450 | 3.82475 |
| 1988 | 1.9813 | 0.6690 | 4.01500 |
| 1989 | 3.3773 | 0.9850 | 4.50162 |
| 1990 | 13.0362 | 2.4570 | 4.84123 |
| 1991 | 5.9192 | 2.6640 | 3.67207 |
| 1992 | 4.1892 | 1.0760 | 3.62331 |
| 1993 | 2.6737 | 0.4580 | 2.93710 |
| 1994 | 9.7083 | 1.9770 | 5.19565 |
| 1995 | 7.4855 | 1.6560 | 4.20032 |
| 1996 | 8.6313 | 1.5440 | 4.39370 |
| 1997 | 4.4282 | 1.2450 | 3.52914 |
| 1998 | 4.7165 | 0.4900 | |



| | |
|---|---|
| Input File Name | R10.dat |
| Tuning Dataset | MA Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 1.0 |
| Average F_all sizes (1995-97) | 1.57 |

| Survey Year | Stock Size Estimates millions at time of Survey: Recruits | Stock Size Estimates millions at time of Survey: Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 3.798 | 2.104 | 1.09 |
| 1983 | 5.254 | 1.712 | 0.79 |
| 1984 | 4.574 | 2.710 | 1.15 |
| 1985 | 5.502 | 1.983 | 1.11 |
| 1986 | 2.934 | 2.125 | 2.73 |
| 1987 | 4.698 | 0.284 | 1.95 |
| 1988 | 4.943 | 0.612 | 1.64 |
| 1989 | 6.121 | 0.926 | 1.23 |
| 1990 | 6.780 | 1.775 | 1.1 |
| 1991 | 3.383 | 2.462 | 1.31 |
| 1992 | 3.350 | 1.359 | 2.03 |
| 1993 | 4.482 | 0.530 | 1.04 |
| 1994 | 6.387 | 1.532 | 1.38 |
| 1995 | 4.959 | 1.709 | 1.28 |
| 1996 | 5.020 | 1.591 | 1.43 |
| 1997 | 3.266 | 1.359 | 1.99 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

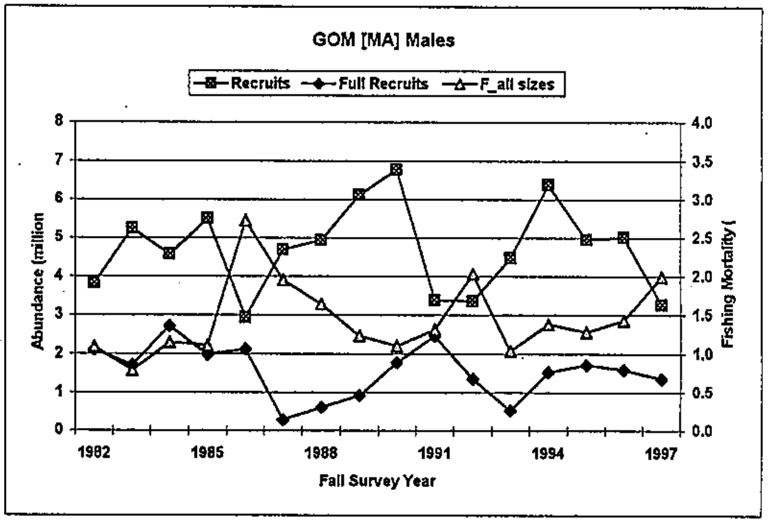


Figure 50. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for GOM female lobsters in statistical area 514 for fall survey years 1982-1997 estimated from MA fall survey (Q ratio =1.0).

**GOM [MA] Female Lobsters**
Using Fall SY Landings from SA 514

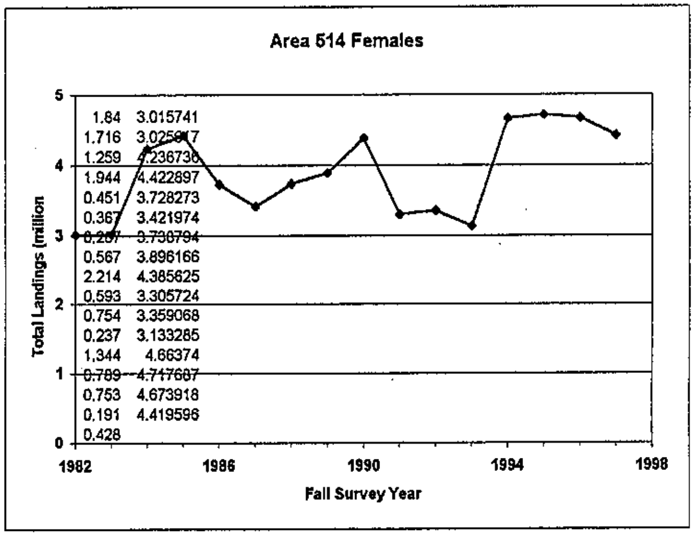
s_r =1.0

| Survey Year | Indices of Abundance: Recruits | Indices of Abundance: Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 2.1497 | 1.8400 | 3.0157 |
| 1983 | 4.2892 | 1.7160 | 3.0256 |
| 1984 | 2.0925 | 1.2590 | 4.23674 |
| 1985 | 4.1782 | 1.9440 | 4.42290 |
| 1986 | 1.6426 | 0.4510 | 3.72827 |
| 1987 | 0.5198 | 0.3670 | 3.42197 |
| 1988 | 1.2410 | 0.2870 | 3.73879 |
| 1989 | 1.7250 | 0.5670 | 3.89617 |
| 1990 | 7.0012 | 2.2140 | 4.38563 |
| 1991 | 3.5359 | 0.5930 | 3.30572 |
| 1992 | 2.5905 | 0.7540 | 3.35907 |
| 1993 | 1.2288 | 0.2370 | 3.13329 |
| 1994 | 5.7911 | 1.3440 | 4.66374 |
| 1995 | 4.8101 | 0.7890 | 4.71769 |
| 1996 | 5.0639 | 0.7530 | 4.67392 |
| 1997 | 2.8926 | 0.1910 | 4.41960 |
| 1998 | 4.0283 | 0.4280 | |

| | |
|---|---|
| Input File Name | R105.dat |
| Tuning Dataset | MA Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits (s_r) | 1.0 |
| Average F_all sizes (1995-97) | 2.10 |

| Survey Year | Stock Size Estimates millions at time of Survey: Recruits | Stock Size Estimates millions at time of Survey: Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 3.354 | 2.887 | 0.8 |
| 1983 | 4.886 | 2.423 | 0.7 |
| 1984 | 4.069 | 3.125 | 1.06 |
| 1985 | 3.995 | 2.136 | 1.72 |
| 1986 | 4.102 | 0.947 | 1.76 |
| 1987 | 3.575 | 0.745 | 2.19 |
| 1988 | 4.757 | 0.416 | 1.64 |
| 1989 | 5.592 | 0.861 | 1.08 |
| 1990 | 4.530 | 1.890 | 1.55 |
| 1991 | 4.029 | 1.177 | 1.29 |
| 1992 | 3.076 | 1.231 | 2.13 |
| 1993 | 4.637 | 0.442 | 1.12 |
| 1994 | 5.488 | 1.429 | 1.47 |
| 1995 | 5.325 | 1.370 | 1.61 |
| 1996 | 4.507 | 1.154 | 2.69 |
| 1997 | 5.439 | 0.331 | 1.99 |

Note that the DeLury model estimates total mortality (all sizes); fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates



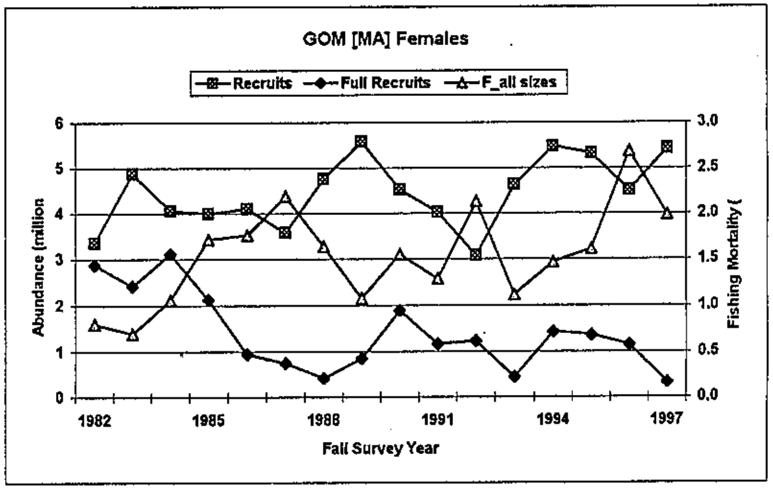
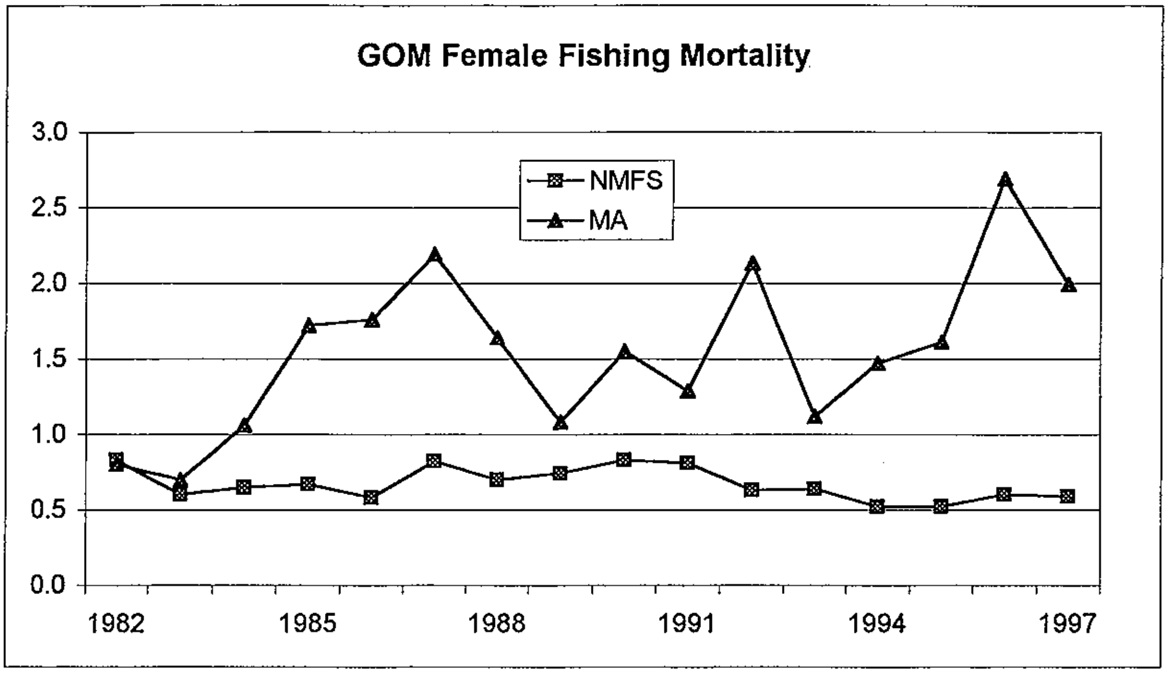


Figure 51. Male and female fishing mortality rates estimated from DeLury model runs for GOM stock ar using NMFS and MA fall survey data, 1982-1997 survey years.

A



B

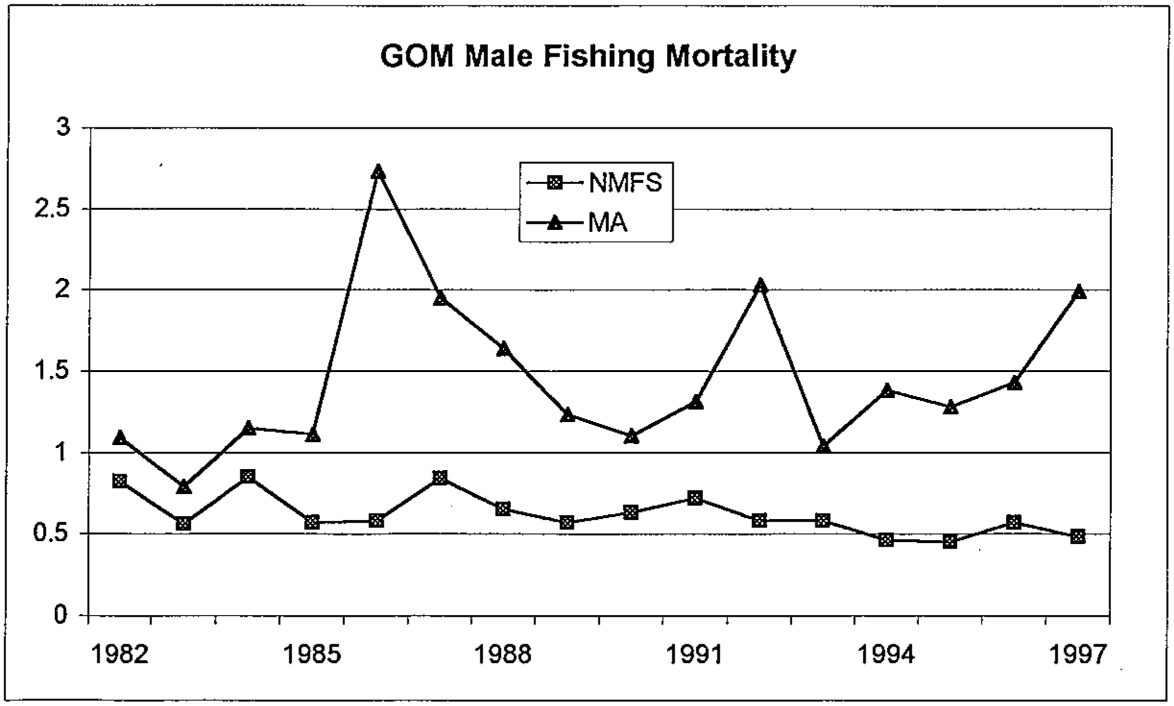
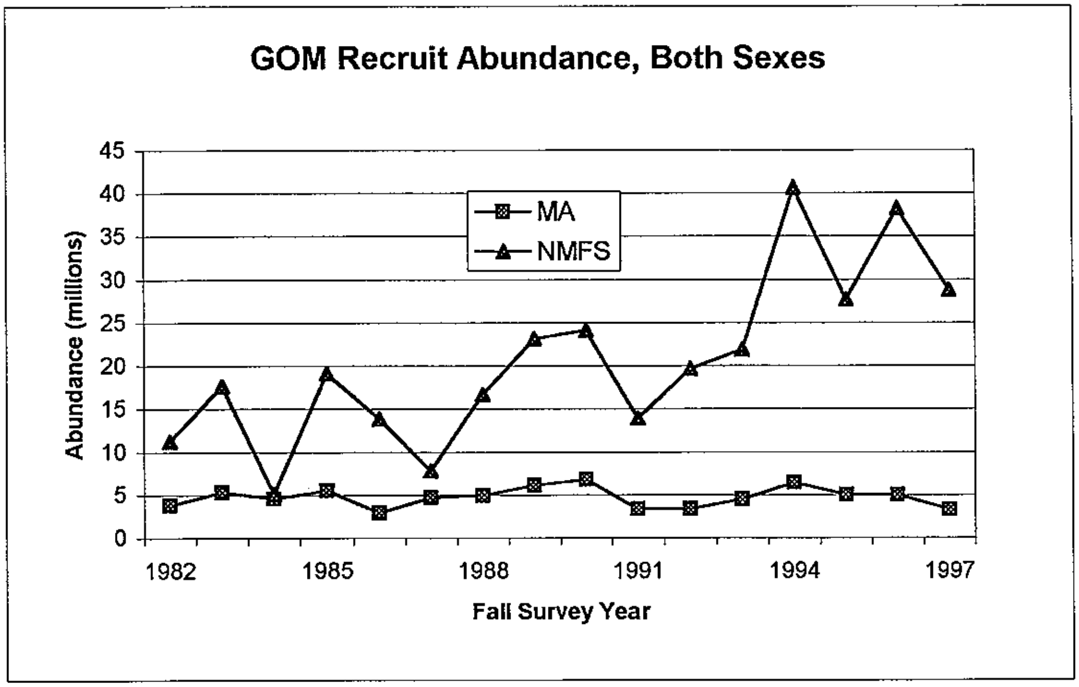


Figure 52. DeLury model estimates of recruit and full recruit abundance (millions of lobsters, both sexes combined) for GOM stock area using NMFS and MA fall survey data, 1982-1997 survey years.

A



B

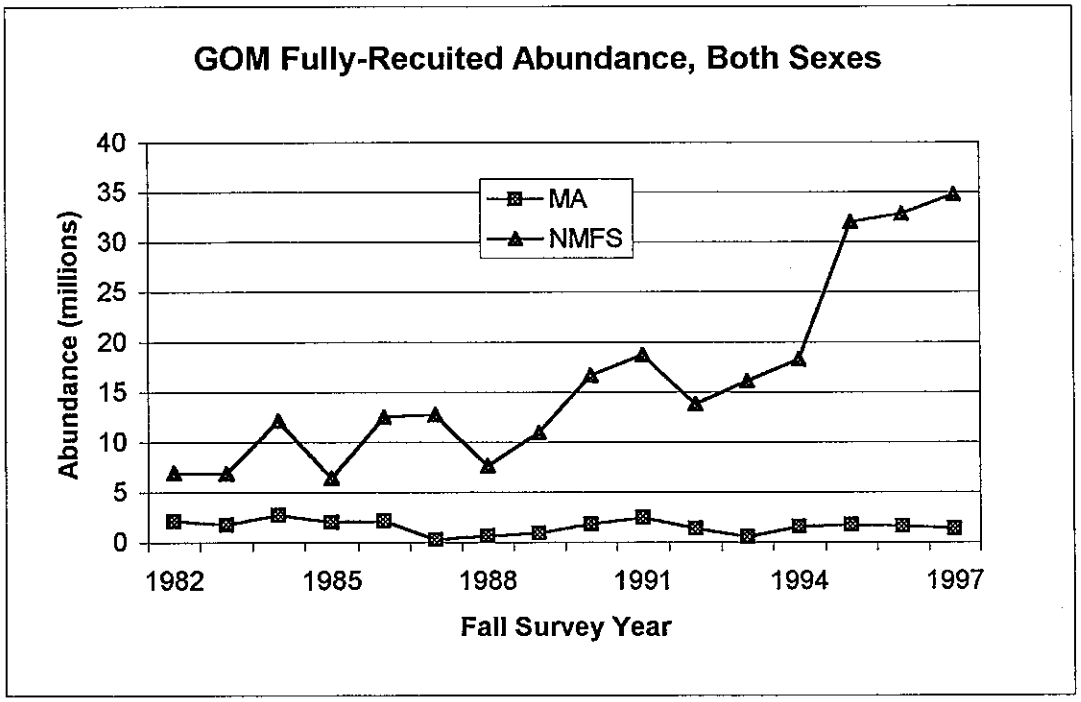
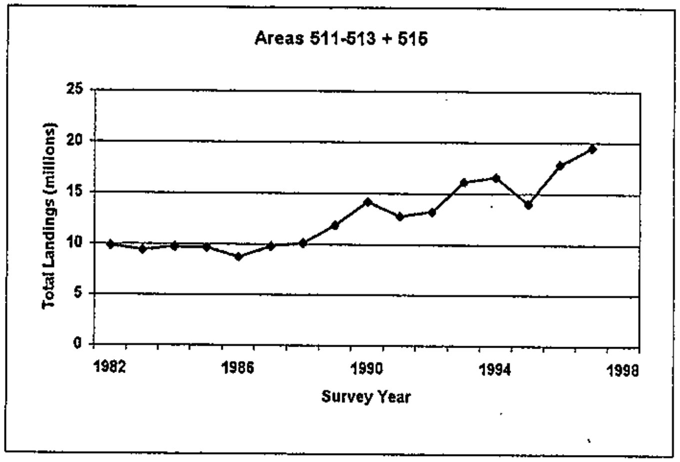


Figure 53. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for GOM male lobsters in statistical areas 511-513 + 515 and fall survey years 1982-1997 estimated from NMFS fall survey (Q ratio = 0.5).

**GOM [NMFS] Male Lobsters**
**Using Fall SY Landings from SA 511-513 + 515**

s_r = 0.5

| Survey Year | Indices of Abundance Recruits | Indices of Abundance Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 0.0743 | 0.1247 | 9.8843 |
| 1983 | 0.2430 | 0.3351 | 9.4706 |
| 1984 | 0.0443 | 0.1066 | 9.7577 |
| 1985 | 0.2990 | 0.3821 | 9.7128 |
| 1986 | 0.2988 | 0.5028 | 8.7655 |
| 1987 | 0.1472 | 0.3588 | 9.8332 |
| 1988 | 0.2681 | 0.1808 | 10.1227 |
| 1989 | 0.4677 | 0.3594 | 11.9076 |
| 1990 | 0.5984 | 0.5454 | 14.2285 |
| 1991 | 0.3146 | 0.5820 | 12.7686 |
| 1992 | 0.2847 | 0.2361 | 13.2291 |
| 1993 | 0.2343 | 0.3902 | 16.1910 |
| 1994 | 0.8316 | 0.8570 | 16.6600 |
| 1995 | 0.5931 | 1.0672 | 14.0746 |
| 1996 | 1.1527 | 1.0284 | 17.9257 |
| 1997 | 0.5065 | 0.5015 | 19.5088 |
| 1998 | 0.5395 | 0.8130 | |



| | |
|---|---|
| Input File Name | R5.dat |
| Tuning Dataset | NMFS Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 0.5 |
| Average F_all sizes (1995-97) | 0.50 |

| Survey Year | Stock Size millions at time of Survey Estimates Recruits | Stock Size millions at time of Survey Estimates Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 11.240 | 6.921 | 0.82 |
| 1983 | 17.619 | 6.872 | 0.56 |
| 1984 | 5.168 | 12.094 | 0.85 |
| 1985 | 19.143 | 6.380 | 0.57 |
| 1986 | 13.869 | 12.453 | 0.58 |
| 1987 | 7.833 | 12.723 | 0.84 |
| 1988 | 16.666 | 7.621 | 0.65 |
| 1989 | 23.161 | 10.938 | 0.57 |
| 1990 | 24.102 | 16.663 | 0.63 |
| 1991 | 13.918 | 18.713 | 0.72 |
| 1992 | 19.663 | 13.736 | 0.58 |
| 1993 | 21.857 | 16.053 | 0.58 |
| 1994 | 40.624 | 18.261 | 0.46 |
| 1995 | 27.704 | 31.991 | 0.45 |
| 1996 | 38.255 | 32.819 | 0.57 |
| 1997 | 28.800 | 34.756 | 0.48 |

Note that the DeLury model estimates total mortality (all sizes); fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

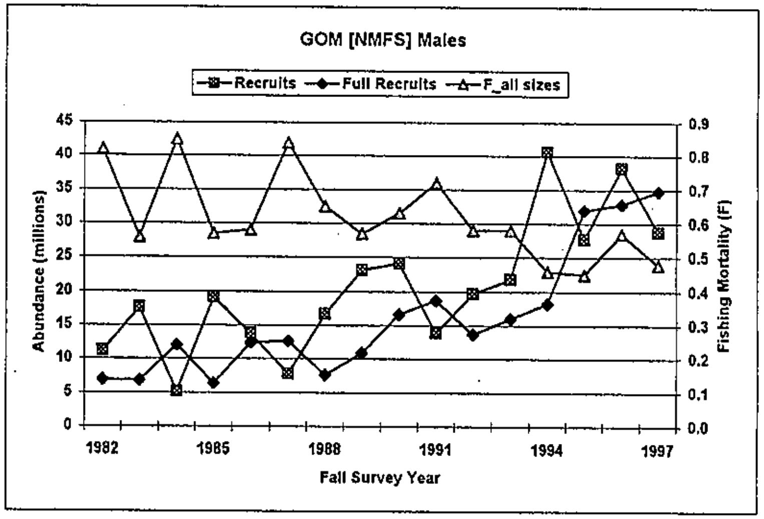
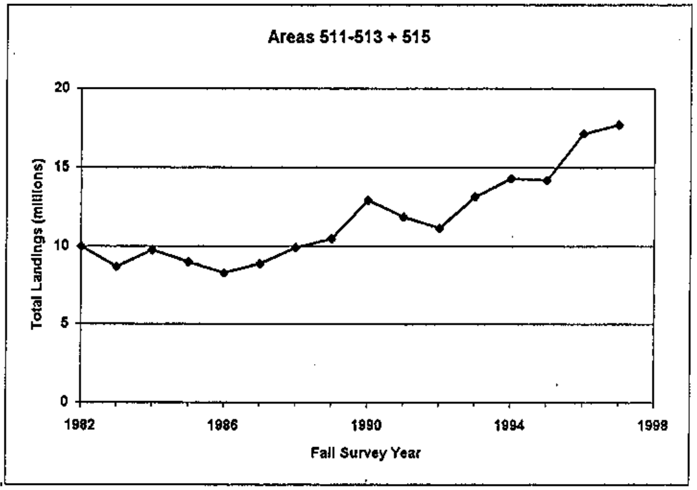


Figure 54. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for GOM female lobsters, statistical areas 511-513 + 515 and fall survey years 1982-1997 estimated from NMFS fall survey (Q ratio = 0.5).

GOM [NMFS] Female Lobsters
Using Landings from SA 511-513 + 515

s_r = 0.5

| Survey Year | Indices of Abundance Recruits | Abundance Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 0.1206 | 0.0727 | 9.98434 |
| 1983 | 0.2564 | 0.3756 | 8.70313 |
| 1984 | 0.1064 | 0.2211 | 9.76649 |
| 1985 | 0.2895 | 0.6463 | 8.98563 |
| 1986 | 0.3387 | 0.3507 | 8.27273 |
| 1987 | 0.1006 | 0.2475 | 8.87341 |
| 1988 | 0.4065 | 0.3089 | 9.91511 |
| 1989 | 0.3287 | 0.3600 | 10.47052 |
| 1990 | 0.4587 | 0.3486 | 12.96672 |
| 1991 | 0.5063 | 0.4062 | 11.87925 |
| 1992 | 0.1864 | 0.1860 | 11.18085 |
| 1993 | 0.1847 | 0.3959 | 13.17969 |
| 1994 | 0.7206 | 0.7729 | 14.30519 |
| 1995 | 0.3122 | 0.6563 | 14.22669 |
| 1996 | 0.9792 | 1.0305 | 17.15526 |
| 1997 | 0.6303 | 0.7041 | 17.70716 |
| 1998 | 0.6893 | 0.6142 | |



| | |
|---|---|
| Input File Name | R55.dat |
| Tuning Dataset | NMFS Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits (s_r) | 0.5 |
| Average F_all sizes (1995-97) | 0.57 |

| Survey Year | Stock Size millions at Recruits | Estimates time of Survey Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 16.325 | 2.265 | 0.83 |
| 1983 | 14.664 | 6.989 | 0.6 |
| 1984 | 10.073 | 10.276 | 0.65 |
| 1985 | 12.749 | 9.123 | 0.67 |
| 1986 | 13.839 | 9.605 | 0.58 |
| 1987 | 6.179 | 11.267 | 0.82 |
| 1988 | 16.835 | 6.625 | 0.7 |
| 1989 | 13.876 | 10.039 | 0.74 |
| 1990 | 17.572 | 9.840 | 0.83 |
| 1991 | 16.263 | 10.308 | 0.81 |
| 1992 | 14.670 | 10.168 | 0.63 |
| 1993 | 16.904 | 11.353 | 0.64 |
| 1994 | 30.933 | 12.764 | 0.52 |
| 1995 | 17.153 | 22.461 | 0.52 |
| 1996 | 31.967 | 20.294 | 0.6 |
| 1997 | 25.688 | 24.779 | 0.59 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

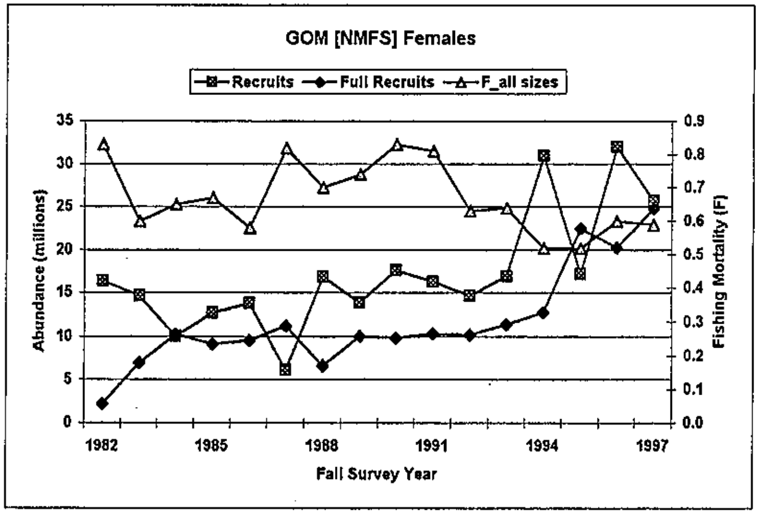


Figure 55. Combined DeLury model abundance and fishing mortality estimates for male lobsters in the GOM stock area, fall survey years 1982-1997. (Lines connect 10, 50 and 90 percentile estimates from bootstrapped model runs, triangles indicate point estimates, see text for details).

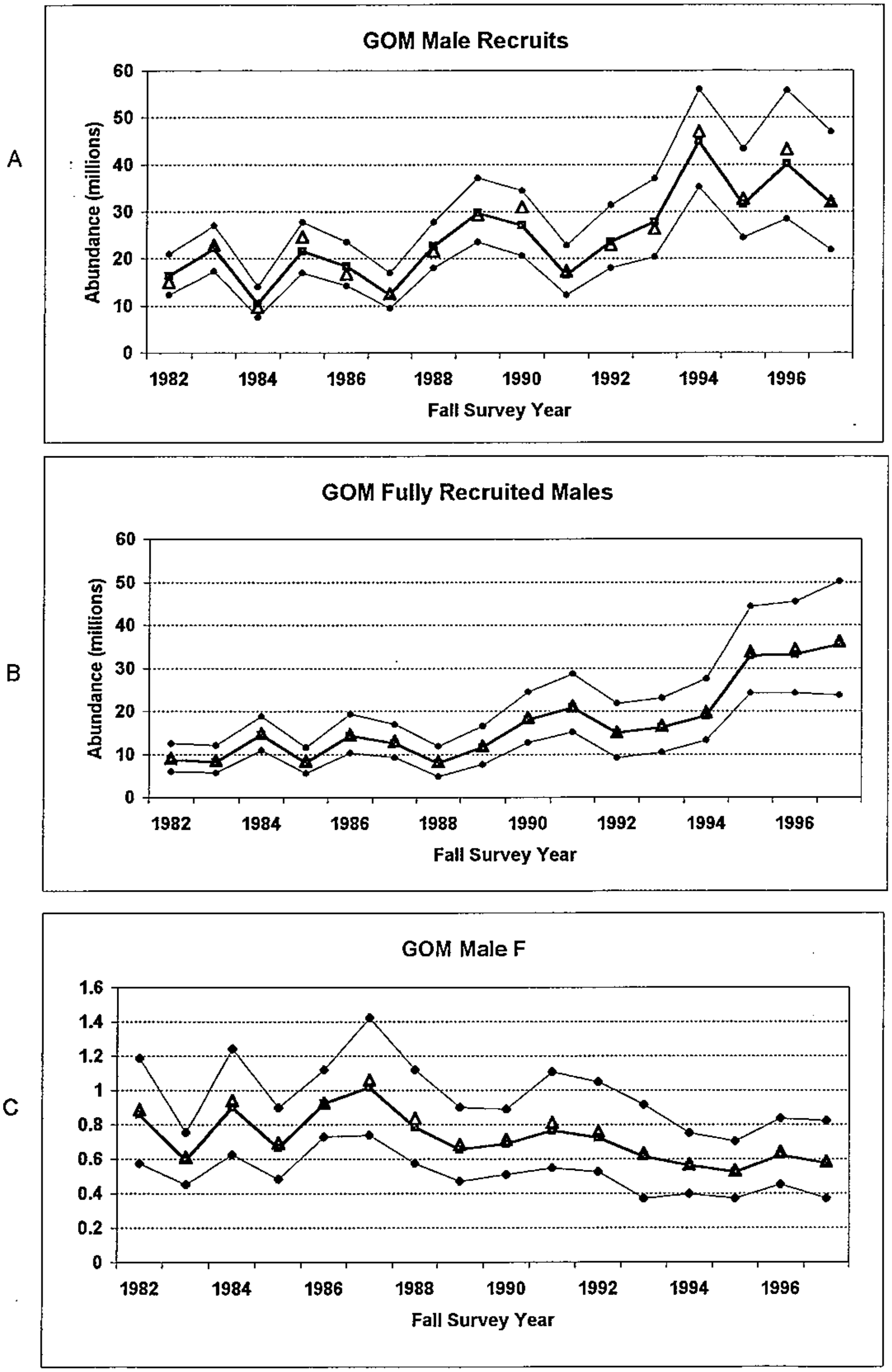
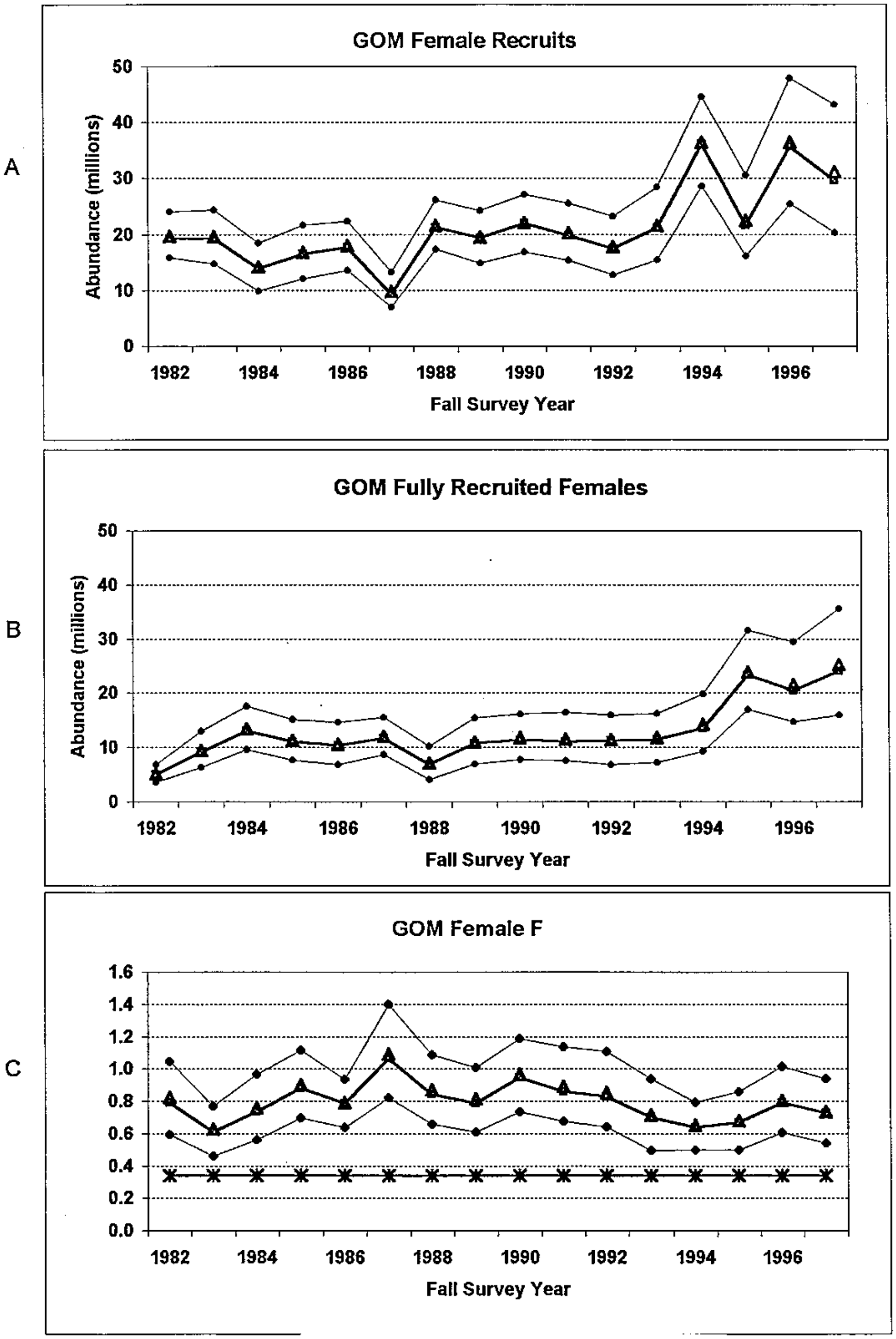


Figure 56. Combined DeLury model abundance and fishing mortality estimates for female lobsters in the GOM stock area, fall survey years 1982-1997. (Lines connect 10, 50 and 90 percentile estimates from bootstrapped model runs, triangles indicate point estimates, and straight line shows F10% maximum EPR reference point, see text for details).

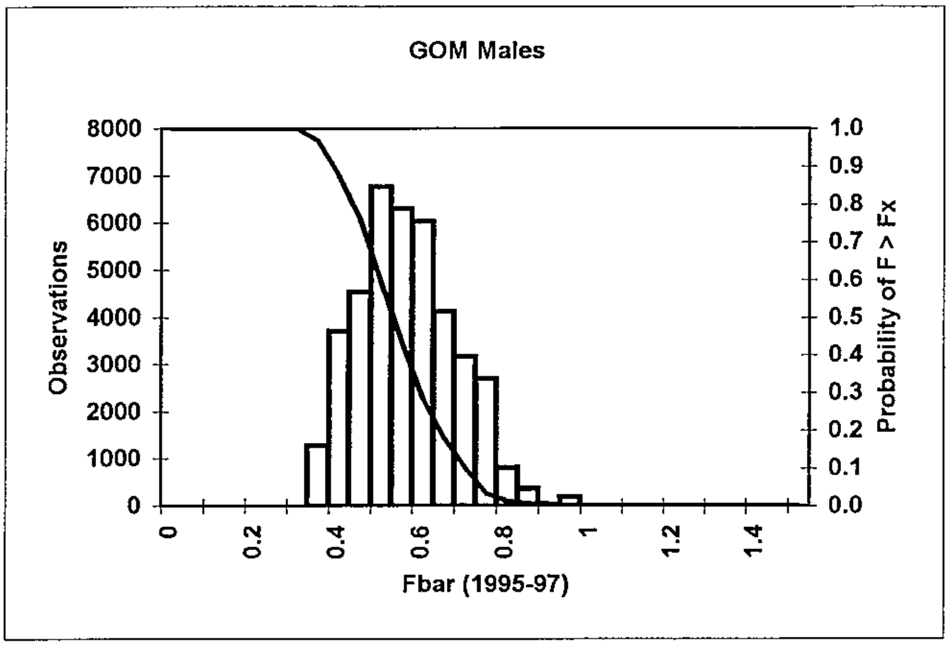

GOM Female Recruits

GOM Fully Recruited Females

GOM Female F

Figure 57. Probability distributions of average GOM male and female 1995-1997 fishing mortality rates estimated from bootstrapped DeLury model runs (see text for details).

A



B

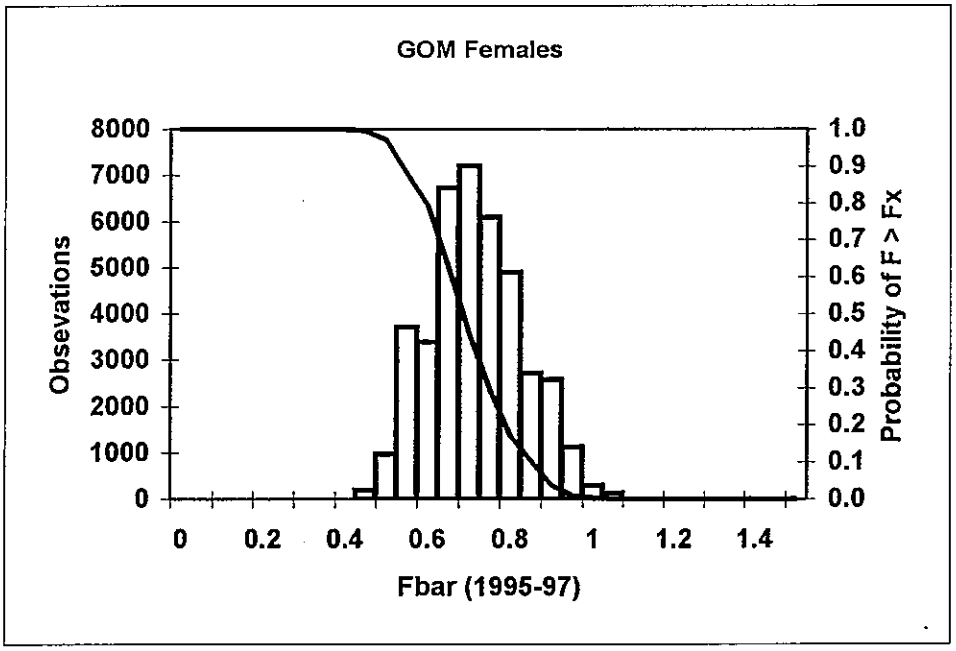


Figure 58. DeLury model point estimates of abundance for recruits and full recruits (by sex) for GOM stock area, fall survey years 1982-1997.

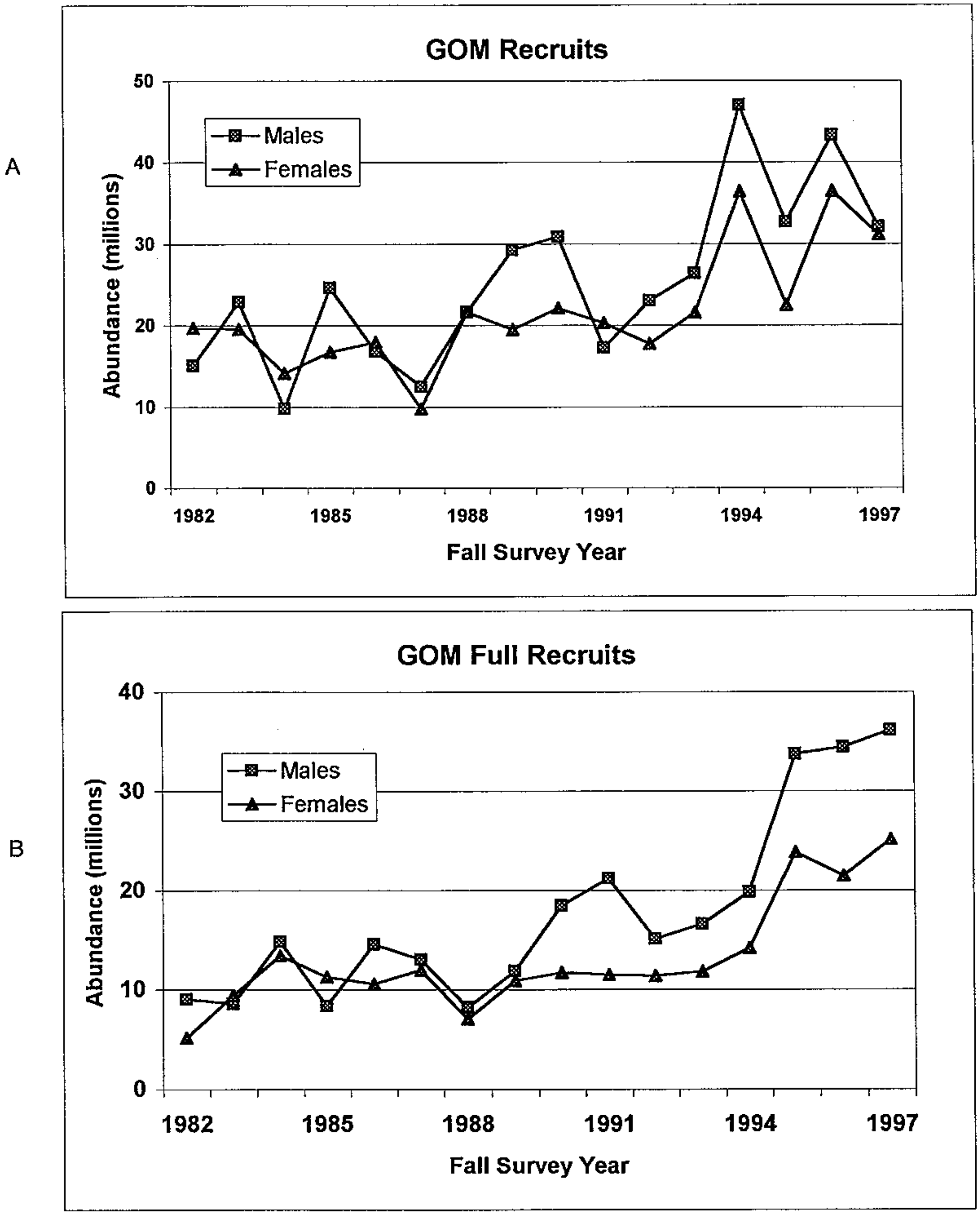


Figure 59. DeLury model point estimates of male and female fishing mortality rates for GOM stock area, fall survey years 1982-1997.

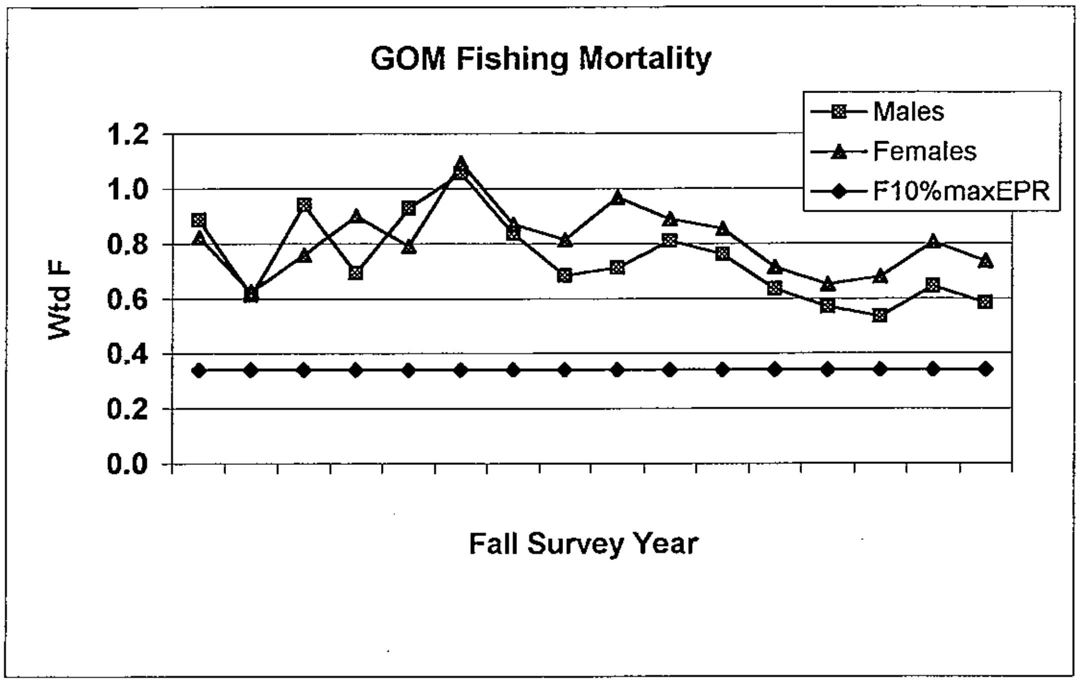


Figure 60. DeLury model point estimates of recruit and full recruit abundance (both sexes combined) GOM stock area, fall survey years 1982-1997.

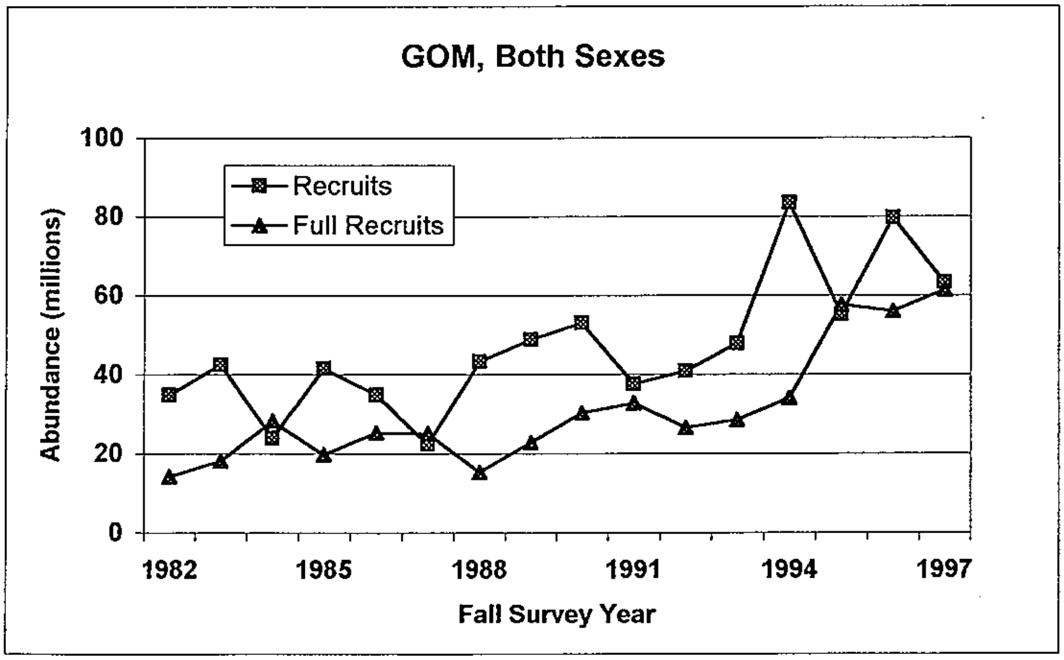


Figure 61. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for GBS male lobsters in fall survey years 1982-1997 estimated from NMFS fall survey (Q ratio =0.5).

**GBS [NMFS] Male Lobsters**
Using Fall SY Landings from all SA

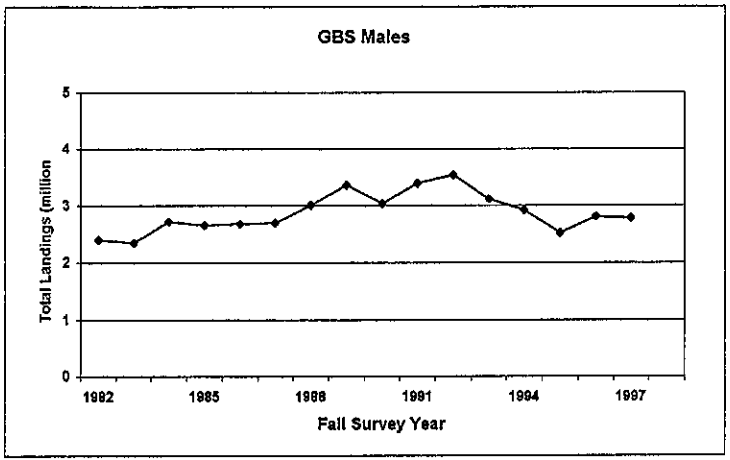
s_r = 0.5

| Survey Year | Indices of Abundance: Recults | Indices of Abundance: Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 0.1303 | 0.2605 | 2.3967 |
| 1983 | 0.1874 | 0.2034 | 2.3415 |
| 1984 | 0.0906 | 0.2389 | 2.7128 |
| 1985 | 0.1426 | 0.1867 | 2.6510 |
| 1986 | 0.1940 | 0.2003 | 2.6747 |
| 1987 | 0.2225 | 0.2127 | 2.6875 |
| 1988 | 0.1094 | 0.2861 | 3.0008 |
| 1989 | 0.1860 | 0.3201 | 3.3626 |
| 1990 | 0.1381 | 0.2286 | 3.0263 |
| 1991 | 0.1450 | 0.2216 | 3.3948 |
| 1992 | 0.1694 | 0.2308 | 3.5341 |
| 1993 | 0.1086 | 0.1378 | 3.1073 |
| 1994 | 0.1020 | 0.1439 | 2.9080 |
| 1995 | 0.1444 | 0.1060 | 2.5111 |
| 1996 | 0.1835 | 0.2572 | 2.7919 |
| 1997 | 0.2510 | 0.2503 | 2.7780 |
| 1998 | 0.1491 | 0.2316 | |

| | |
|---|---|
| Input File Name | gbkmlR5.dat |
| Tuning Dataset | NMFS Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 0.5 |
| Average F_all sizes (1995-97) | 0.63 |

| Survey Year | Stock Size Estimates millions at time of Survey: Recruits | Stock Size Estimates millions at time of Survey: Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 2.909 | 2.908 | 0.65 |
| 1983 | 4.105 | 2.607 | 0.53 |
| 1984 | 2.269 | 3.399 | 0.77 |
| 1985 | 3.451 | 2.253 | 0.75 |
| 1986 | 4.140 | 2.326 | 0.66 |
| 1987 | 5.155 | 2.878 | 0.49 |
| 1988 | 2.930 | 4.235 | 0.61 |
| 1989 | 4.204 | 3.337 | 0.72 |
| 1990 | 3.527 | 3.161 | 0.71 |
| 1991 | 3.905 | 2.839 | 0.82 |
| 1992 | 3.870 | 2.549 | 0.98 |
| 1993 | 3.380 | 2.068 | 1.00 |
| 1994 | 3.010 | 1.730 | 1.16 |
| 1995 | 4.435 | 1.285 | 0.65 |
| 1996 | 4.050 | 2.575 | 0.67 |
| 1997 | 4.783 | 2.919 | 0.58 |

Note that the DeLury model estimates total mortality (all sizes); fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates



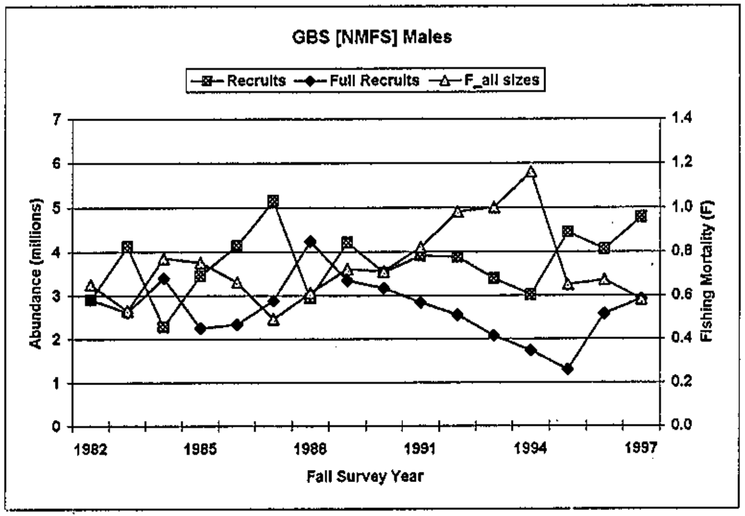
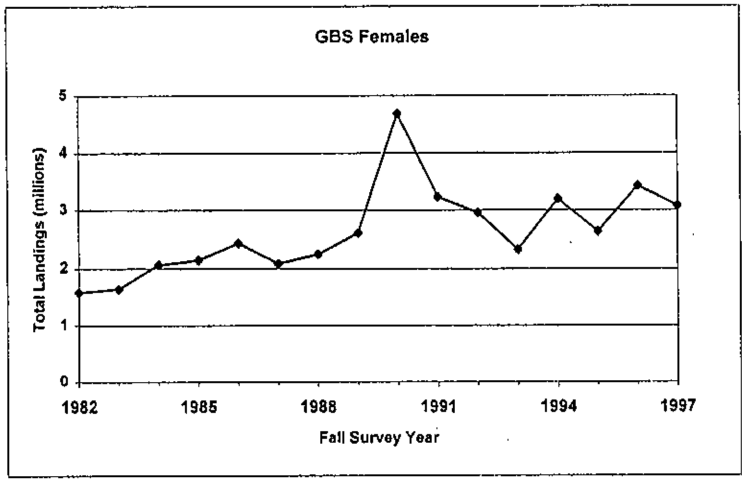


Figure 62. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for GBS female lobsters in fall survey years 1982-1997 estimated from NMFS fall survey (Q ratio =0.5).

**GBS [NMFS] Female Lobsters**
Using Fall SY Landings from all SA

s_r = 0.5

| Survey Year | Indices of Abundance: Reculits | Indices of Abundance: Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 0.1175 | 0.3398 | 1.5808 |
| 1983 | 0.1069 | 0.2688 | 1.6445 |
| 1984 | 0.1071 | 0.3019 | 2.0629 |
| 1985 | 0.1570 | 0.2311 | 2.1377 |
| 1986 | 0.1513 | 0.2891 | 2.4296 |
| 1987 | 0.0908 | 0.2061 | 2.0829 |
| 1988 | 0.0855 | 0.3019 | 2.2380 |
| 1989 | 0.1403 | 0.3038 | 2.6028 |
| 1990 | 0.1721 | 0.3310 | 4.6899 |
| 1991 | 0.0893 | 0.3882 | 3.2262 |
| 1992 | 0.1687 | 0.3157 | 2.9528 |
| 1993 | 0.0924 | 0.3249 | 2.3186 |
| 1994 | 0.0211 | 0.2714 | 3.1917 |
| 1995 | 0.0931 | 0.3262 | 2.6309 |
| 1996 | 0.1743 | 0.2975 | 3.4104 |
| 1997 | 0.0929 | 0.2705 | 3.0781 |
| 1998 | 0.1198 | 0.3399 | |



| | |
|---|---|
| Input File Name | R51.dat |
| Tuning Dataset | NMFS Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 0.5 |
| Average F_all sizes (1995-97) | 0.41 |

| Survey Year | Stock Size Estimates millions at time of Survey: Recruits | Stock Size Estimates millions at time of Survey: Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 3.839 | 5.269 | 0.35 |
| 1983 | 3.579 | 5.519 | 0.34 |
| 1984 | 3.436 | 5.548 | 0.45 |
| 1985 | 4.921 | 4.918 | 0.42 |
| 1986 | 4.631 | 5.576 | 0.48 |
| 1987 | 3.437 | 5.449 | 0.30 |
| 1988 | 3.235 | 5.665 | 0.33 |
| 1989 | 5.180 | 5.526 | 0.33 |
| 1990 | 6.689 | 6.602 | 0.49 |
| 1991 | 3.361 | 7.029 | 0.43 |
| 1992 | 6.233 | 5.821 | 0.34 |
| 1993 | 3.791 | 7.421 | 0.27 |
| 1994 | 0.845 | 7.353 | 0.41 |
| 1995 | 3.715 | 4.697 | 0.39 |
| 1996 | 6.191 | 4.898 | 0.46 |
| 1997 | 3.727 | 6.033 | 0.38 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by subtracting M (=0.15) from DeLury total mortality estimates

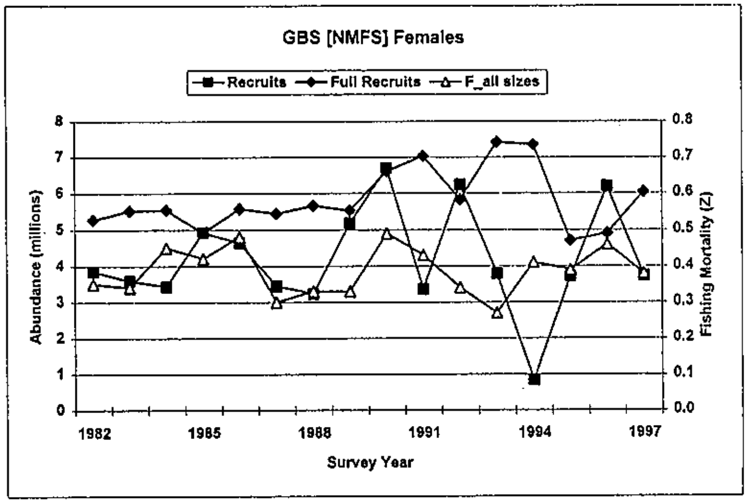


Figure 63. DeLury model abundance and fishing mortality estimates for male lobsters in the GBS stock area, fall survey years 1982-1997. (Lines connect 10, 50 and 90 percentile estimates from bootstrapped model runs, triangles indicate point estimates, see text for details).

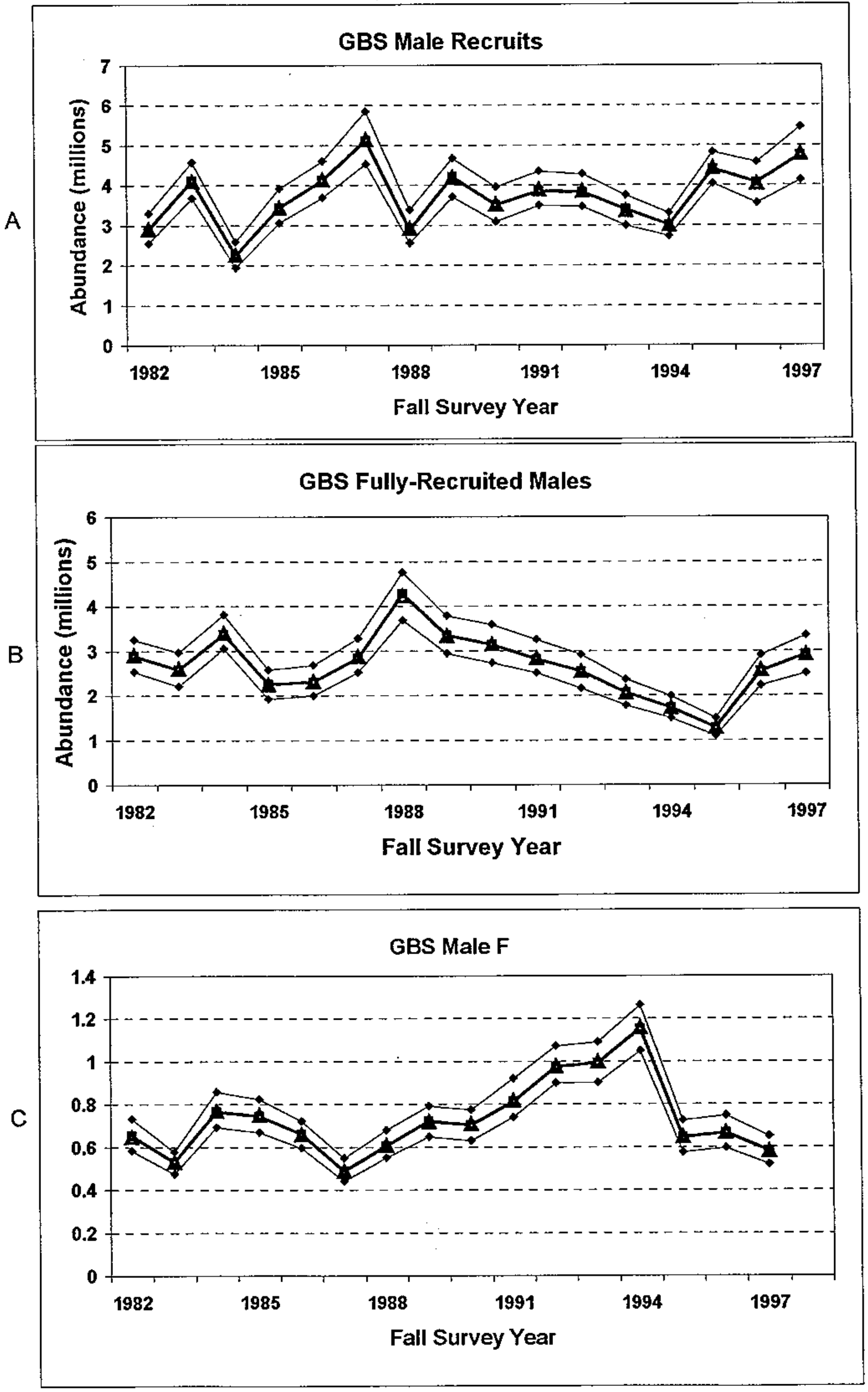


Figure 64. DeLury model abundance and fishing mortality estimates for female lobsters in the GBS stock area, fall survey years 1982-1997. (Lines connect 10, 50 and 90 percentile estimates from bootstrapped model runs, triangles indicate point estimates, and straight line shows F10% maximum EPR reference point, see text for details).

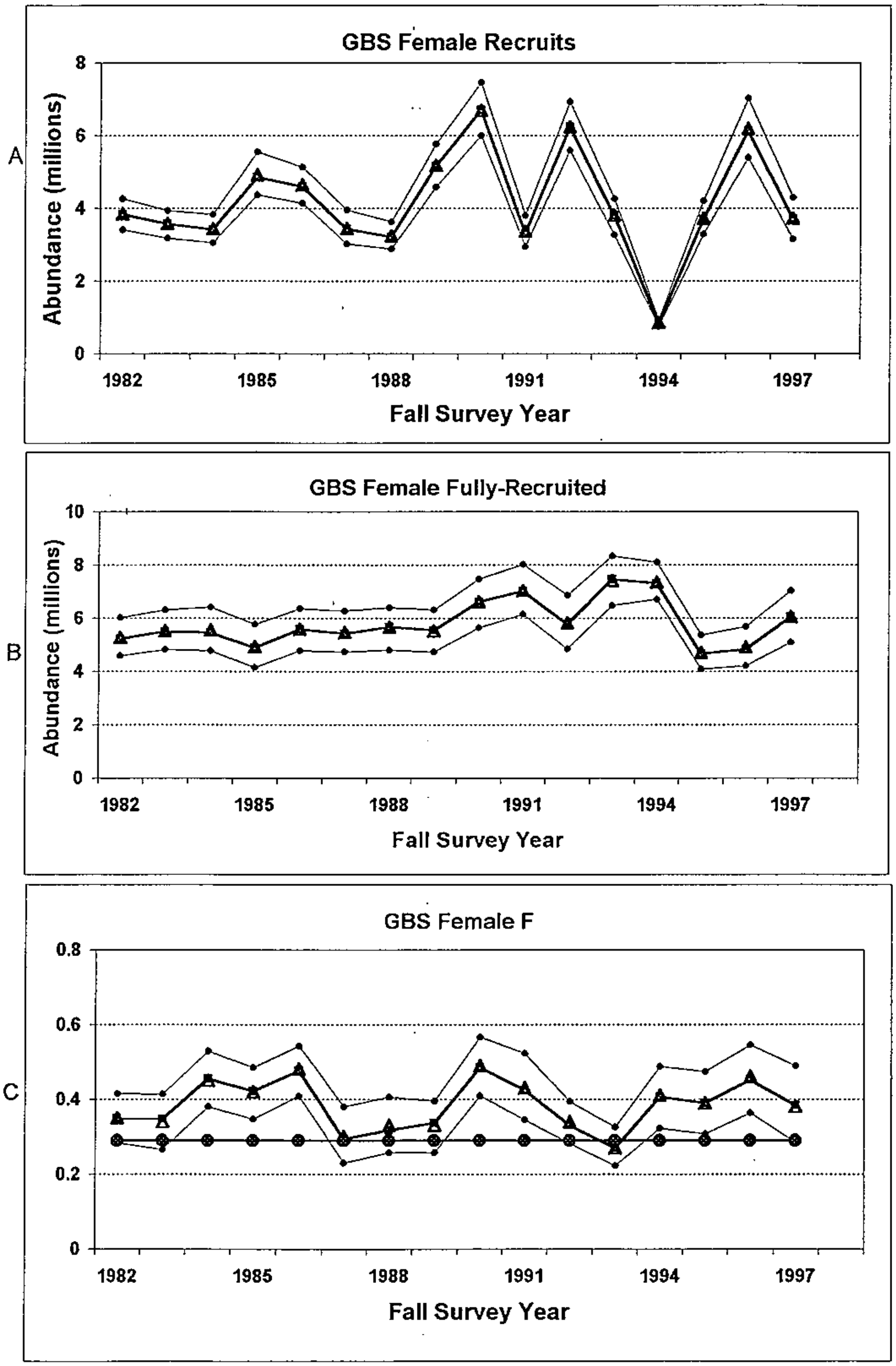


Figure 65. Probability distributions of average GBS male and female 1995-1997 fishing mortality rate estimated from bootstrapped DeLury model runs (see text for details).

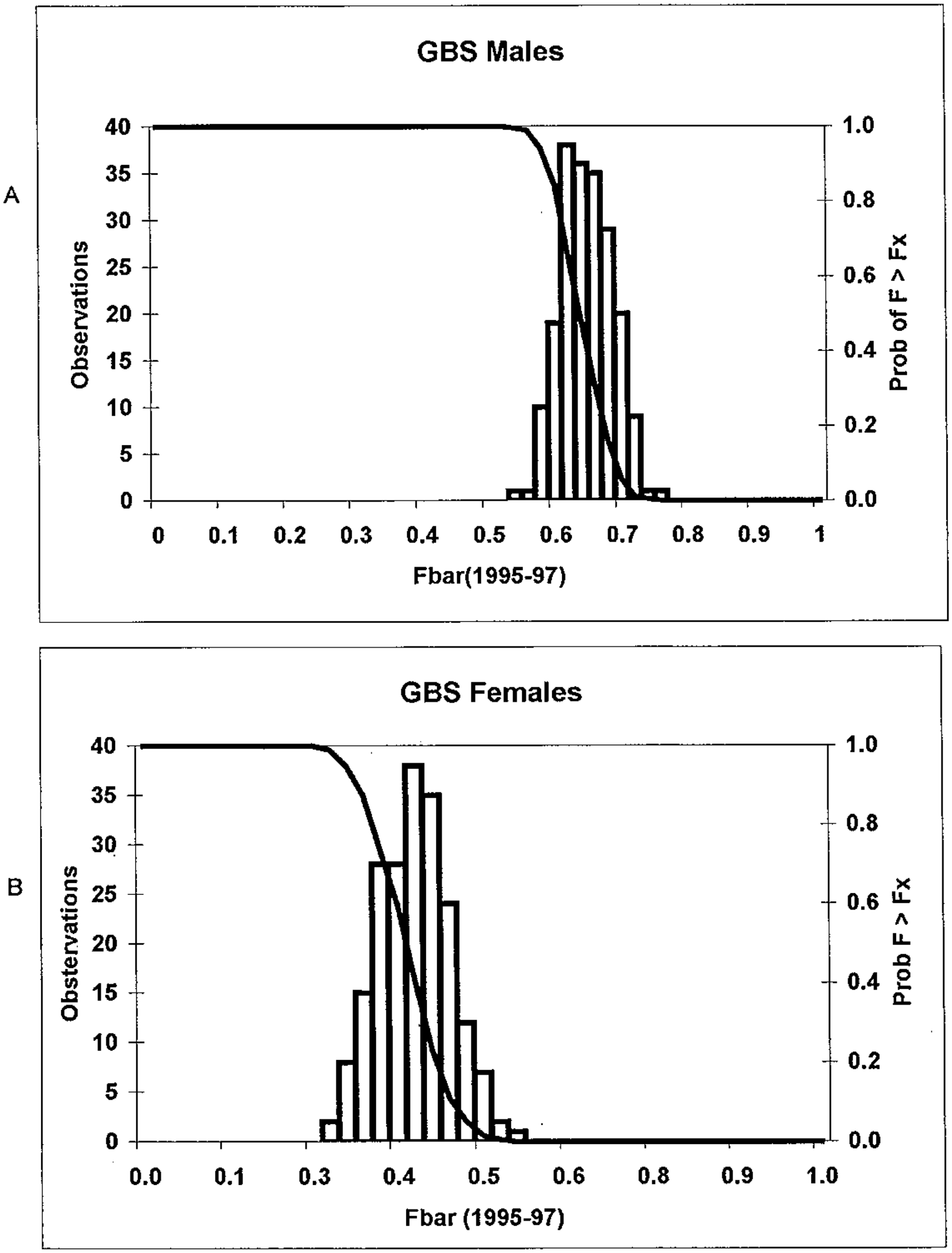


Figure 66. DeLury model point estimates of recruit and full recruit abundance (both sexes combined) GBS stock area, fall survey years 1982-1997.

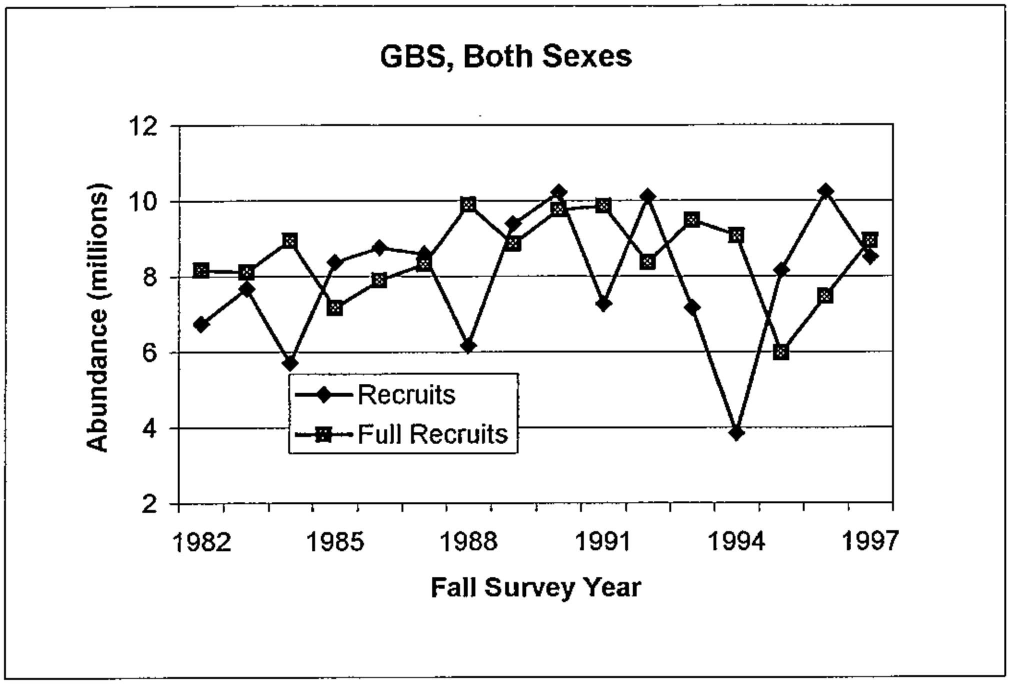
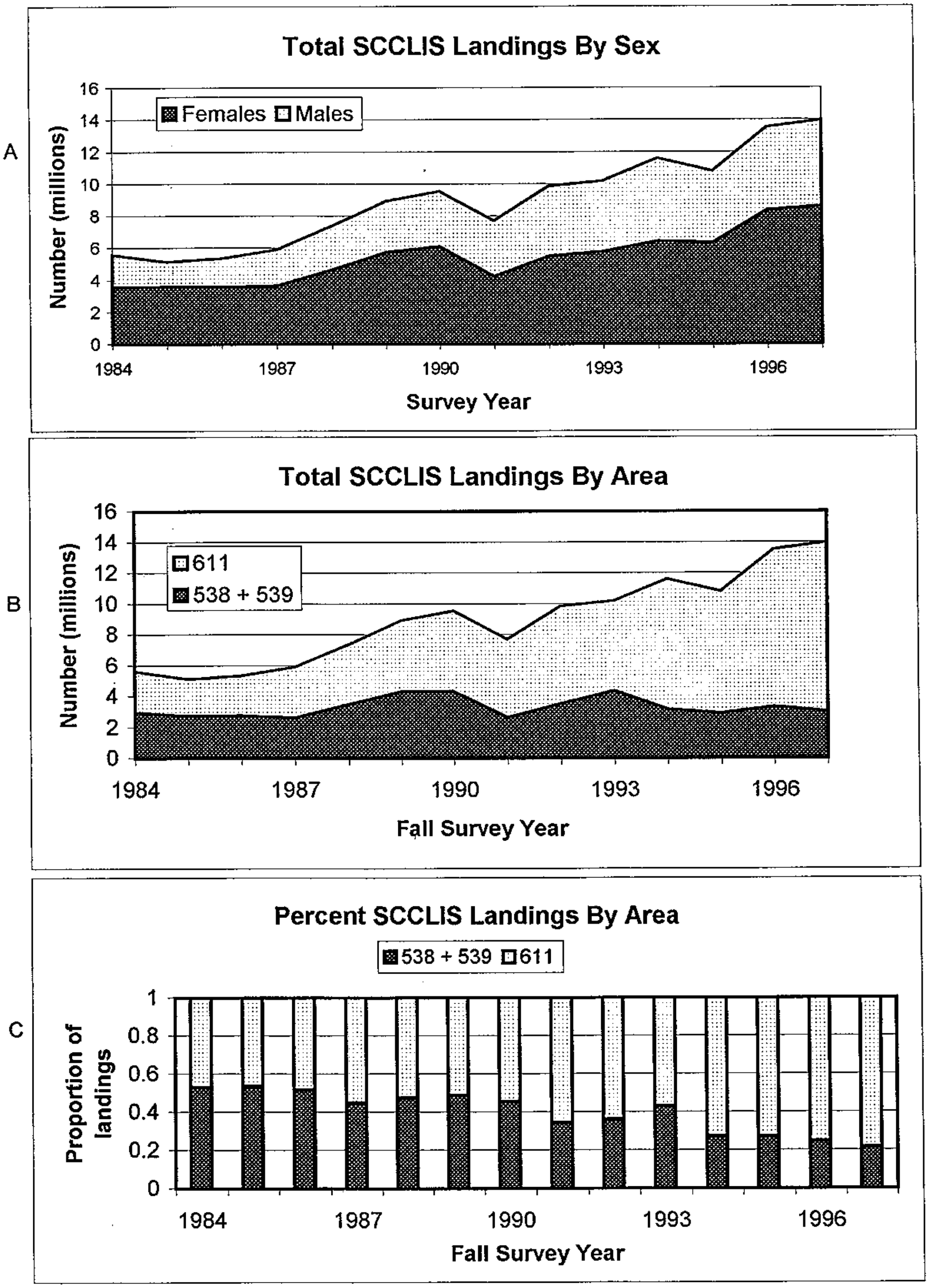


Figure 67. South of Cape Cod and Long Island Sound stock area landings by sex and statistical area numbers), 1982-1997 fall survey years.

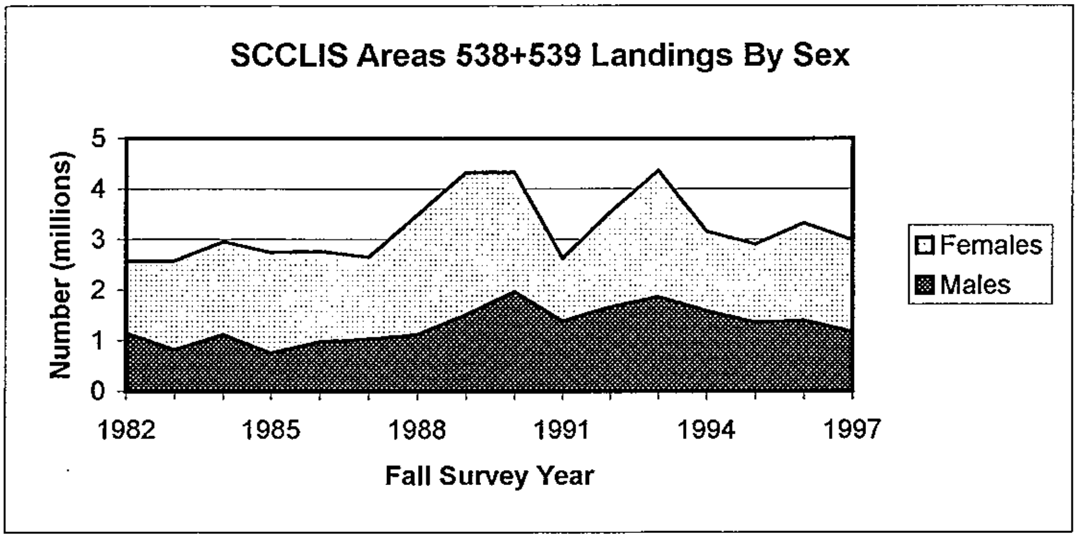

Total SCCLIS Landings By Sex

Total SCCLIS Landings By Area

Percent SCCLIS Landings By Area

Figure 68. SCCLIS male and female landings for statistical areas 538+539 and area 611 (in numbers 1982-1997 fall survey years.

A



B

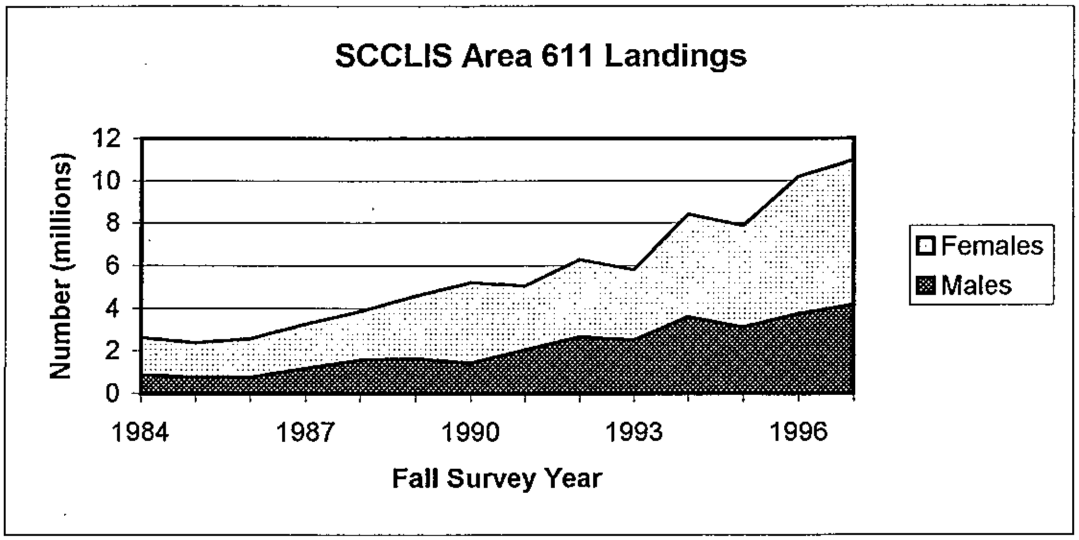
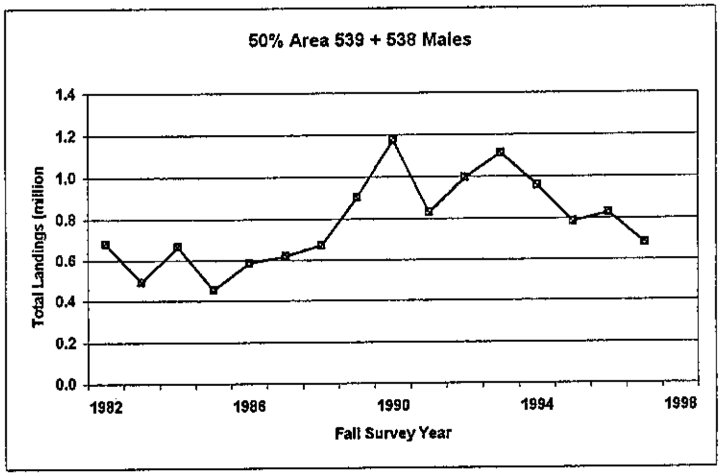


Figure 69. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS male lobsters in statistical areas 538 and 539 for fall survey years 1982-1997 estimated from NMFS fall survey (Q ratio = 0.5) using 100% of area 538 and 50% of area 539 landings.

**SCCLIS [NMFS] Male Lobsters**
Using Fall SY Landings from SA 538 and 50%SA539

s_r = 0.5

| Survey Year | Indices of Abundance<br>Recruits | <br>Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 0.1463 | 0.4291 | 0.6822 |
| 1983 | 0.4849 | 0.4971 | 0.4932 |
| 1984 | 1.5495 | 0.3626 | 0.6666 |
| 1985 | 0.6978 | 0.6091 | 0.4555 |
| 1986 | 1.0544 | 0.4169 | 0.5844 |
| 1987 | 0.7107 | 0.2248 | 0.6204 |
| 1988 | 0.3669 | 0.6208 | 0.6739 |
| 1989 | 1.5838 | 0.4054 | 0.9057 |
| 1990 | 0.5728 | 0.1630 | 1.1756 |
| 1991 | 0.2309 | 0.5719 | 0.8316 |
| 1992 | 1.3873 | 0.3266 | 0.9963 |
| 1993 | 0.7153 | 0.3560 | 1.1141 |
| 1994 | 0.2452 | 0.1019 | 0.9607 |
| 1995 | 0.3142 | 0.5306 | 0.7841 |
| 1996 | 2.9889 | 1.3918 | 0.8288 |
| 1997 | 2.2778 | 0.8989 | 0.6820 |
| 1998 | 2.1666 | 0.6125 | |



| | |
|---|---|
| Input File Name | R2.dat |
| Tuning Dataset | NEFSC AutumnSurvey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 0.5 |
| Average F_all sizes (1995-97) | 0.50 |

| Survey Year | Stock Size millions at<br>Recruits | Estimates time of Survey<br>Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 0.245 | 1.077 | 0.80 |
| 1983 | 0.635 | 0.509 | 0.69 |
| 1984 | 1.317 | 0.492 | 0.65 |
| 1985 | 0.660 | 0.813 | 0.59 |
| 1986 | 0.833 | 0.701 | 0.73 |
| 1987 | 1.026 | 0.638 | 0.55 |
| 1988 | 0.501 | 0.825 | 0.88 |
| 1989 | 1.096 | 0.475 | 1.15 |
| 1990 | 1.849 | 0.430 | 0.77 |
| 1991 | 0.429 | 0.907 | 1.16 |
| 1992 | 1.450 | 0.361 | 1.01 |
| 1993 | 0.909 | 0.567 | 1.91 |
| 1994 | 1.593 | 0.188 | 0.77 |
| 1995 | 1.018 | 0.706 | 0.56 |
| 1996 | 2.286 | 0.849 | 0.51 |
| 1997 | 1.961 | 1.614 | 0.44 |

Note that the DeLury model estimates total mortality (all sizes); fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

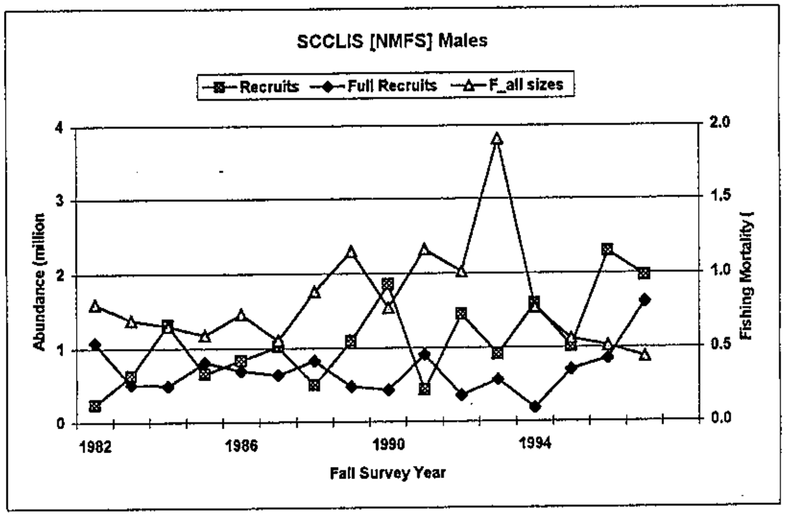


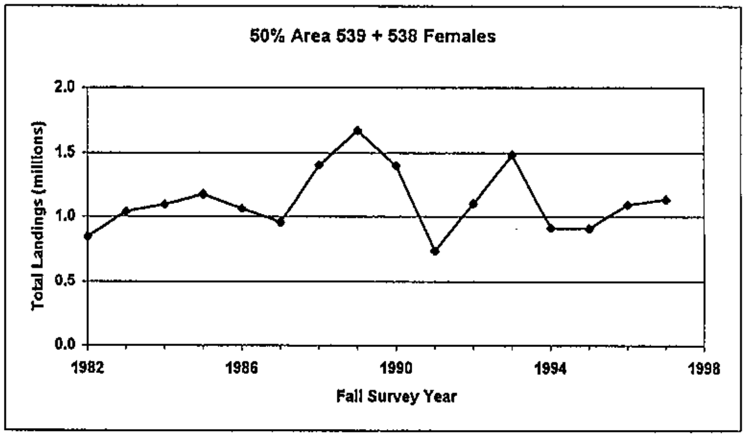
Figure 70. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS female lobsters in statistical areas 538 and 539 for fall survey years 1982-1997 estimated from NMFS fall survey (Q ratio = 0.5) using 100% of area 538 and 50% of area 539 landings.

**SCCLIS [NMFS] Female Lobsters**

**Using Fall SY Landings from SA 538 and 50% SA539**

s_r = 0.5

| Survey Year | Indices of Abundance Recruits | Indices of Abundance Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | 0.6872 | 0.8614 | 0.8463 |
| 1983 | 0.3543 | 0.5128 | 1.0424 |
| 1984 | 0.8472 | 1.0306 | 1.0986 |
| 1985 | 0.5071 | 0.3738 | 1.1766 |
| 1986 | 0.5171 | 0.1730 | 1.0638 |
| 1987 | 0.0703 | 1.2389 | 0.9598 |
| 1988 | 0.9082 | 0.8470 | 1.4027 |
| 1989 | 1.3674 | 0.2404 | 1.6718 |
| 1990 | 0.7604 | 0.7330 | 1.4009 |
| 1991 | 0.3651 | 0.9781 | 0.7372 |
| 1992 | 0.9605 | 1.3891 | 1.1097 |
| 1993 | 0.1732 | 0.5251 | 1.4819 |
| 1994 | 0.1110 | 0.2462 | 0.9134 |
| 1995 | 0.7626 | 1.0568 | 0.9105 |
| 1996 | 2.9427 | 2.3161 | 1.0975 |
| 1997 | 3.1820 | 1.7952 | 1.1430 |
| 1998 | 0.8805 | 1.1330 | |


50% Area 539 + 538 Females

| | |
|---|---|
| Input File Name | R2.dat |
| Tuning Dataset | NMFS Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 0.5 |
| Average F_all sizes (1995-97) | 0.41 |

| Survey Year | Stock Size Estimates millions at time of Survey Recruits | Stock Size Estimates millions at time of Survey Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | 1.335 | 0.921 | 0.63 |
| 1983 | 1.061 | 1.038 | 0.79 |
| 1984 | 1.223 | 0.817 | 1.03 |
| 1985 | 1.021 | 0.624 | 1.67 |
| 1986 | 2.648 | 0.268 | 0.42 |
| 1987 | 0.196 | 1.644 | 0.84 |
| 1988 | 1.354 | 0.686 | 1.54 |
| 1989 | 2.832 | 0.375 | 0.92 |
| 1990 | 2.065 | 1.106 | 0.68 |
| 1991 | 1.026 | 1.376 | 0.4 |
| 1992 | 1.933 | 1.382 | 0.55 |
| 1993 | 0.557 | 1.650 | 1.37 |
| 1994 | 1.198 | 0.484 | 0.75 |
| 1995 | 2.433 | 0.681 | 0.36 |
| 1996 | 3.885 | 1.870 | 0.44 |
| 1997 | 4.219 | 3.175 | 0.44 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

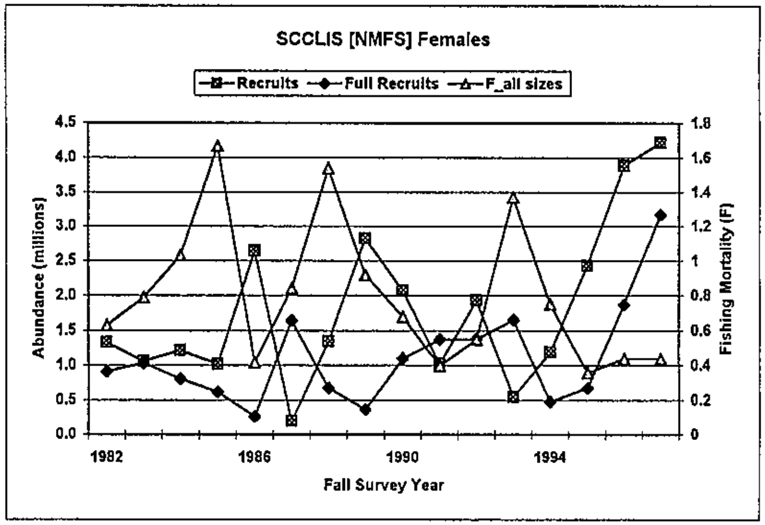
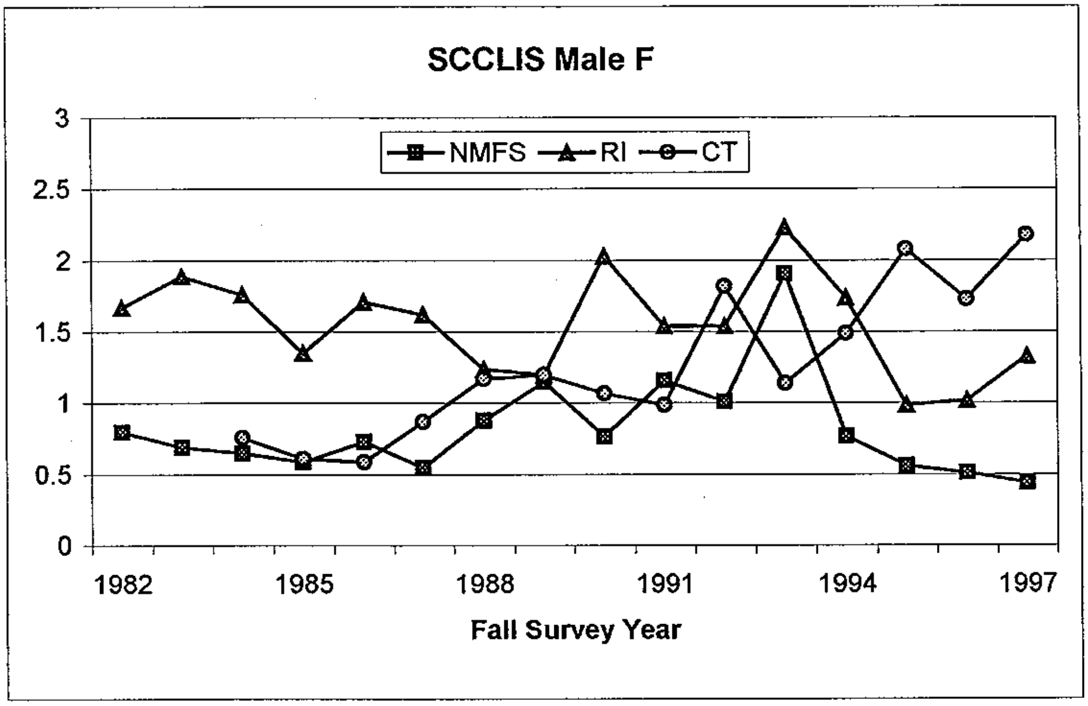

SCCLIS [NMFS] Females

Figure 71. Male and female fishing mortality rates estimated from DeLury model runs for statistical areas 538+539, 539, and 611 using NMFS, RI and CT fall survey data, 1982-1997 survey years.

A



B

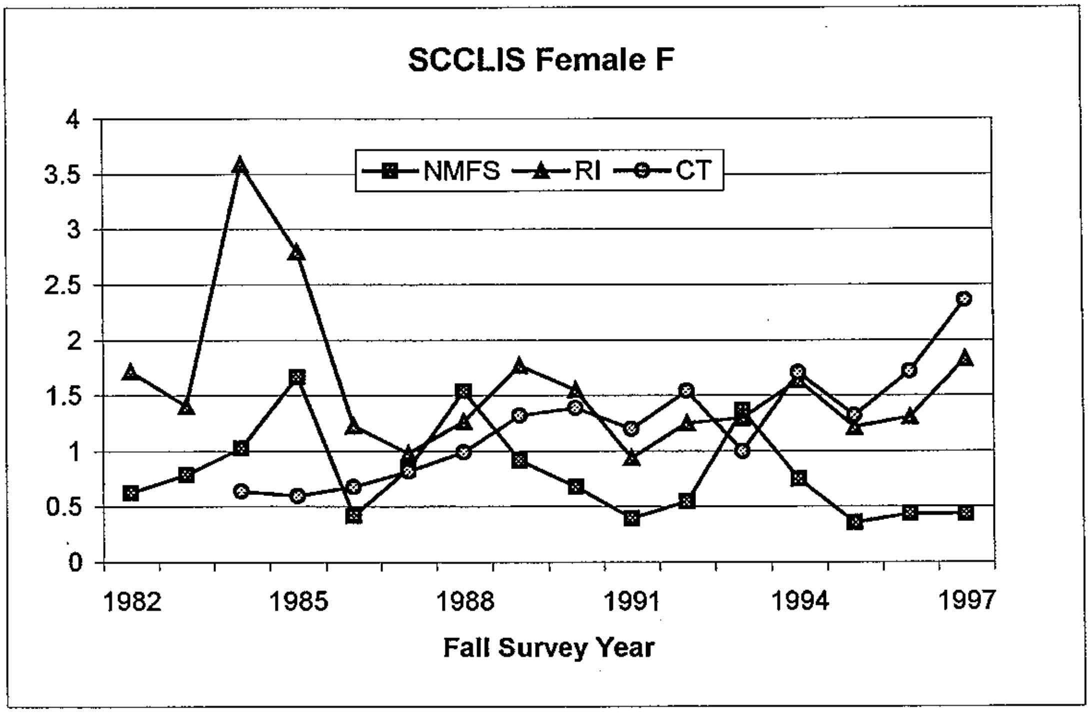
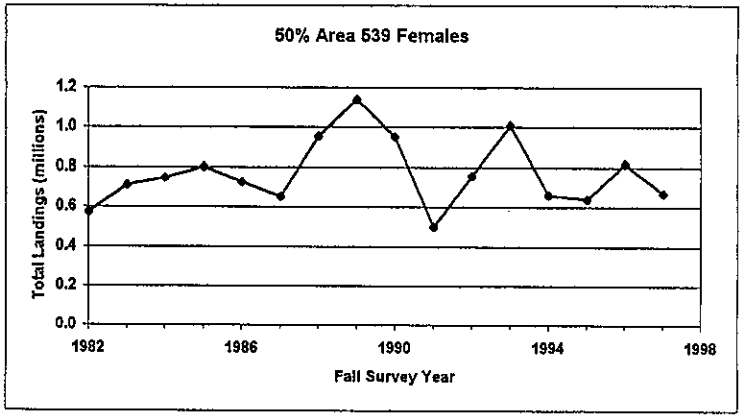


Figure 72. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS female lobsters in statistical area 539 for fall survey years 1982-1997 estimated from NMFS fall survey (Q ratio = 1.0) using 50% of area 539 landings.

**SCCLIS [RI] Female Lobsters**
Using Fall SY Landings from 50% SA539

s_r = 1.0

| Survey Year | Indices of Abundance | | Total Catch Millions |
|---|---|---|---|
| | Recruits | Full Recruits | |
| 1982 | 0.1657 | 0.0118 | 0.5761 |
| 1983 | 0.1889 | 0.0937 | 0.7095 |
| 1984 | 0.4189 | 0.2116 | 0.7478 |
| 1985 | 0.4235 | 0.0153 | 0.8009 |
| 1986 | 0.2694 | 0.0368 | 0.7241 |
| 1987 | 1.0868 | 0.3234 | 0.6533 |
| 1988 | 0.6924 | 0.2192 | 0.9548 |
| 1989 | 0.8950 | 0.2851 | 1.1379 |
| 1990 | 0.7513 | 0.1640 | 0.9536 |
| 1991 | 0.5286 | 0.1928 | 0.5018 |
| 1992 | 0.8528 | 0.2508 | 0.7553 |
| 1993 | 1.1685 | 0.2098 | 1.0087 |
| 1994 | 0.6452 | 0.3362 | 0.6597 |
| 1995 | 1.1619 | 0.1110 | 0.6407 |
| 1996 | 2.2301 | 0.2110 | 0.8159 |
| 1997 | 1.3204 | 0.2620 | 0.6716 |
| 1998 | 0.5315 | 0.0710 | |



| | |
|---|---|
| Input File Name | R3.dat |
| Tuning Dataset | RI Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 1.0 |
| Average F_all sizes (1995-97) | 1.45 |

| Survey Year | Stock Size Estimates millions at time of Survey | | Fishing Mortality |
|---|---|---|---|
| | Recruits | Full Recruits | F_all sizes |
| 1982 | 0.7660 | 0.0160 | 1.72 |
| 1983 | 0.9110 | 0.1200 | 1.41 |
| 1984 | 0.6510 | 0.2160 | 3.59 |
| 1985 | 0.9400 | 0.0210 | 2.8 |
| 1986 | 1.0670 | 0.0500 | 1.23 |
| 1987 | 0.9400 | 0.2800 | 0.98 |
| 1988 | 1.0950 | 0.3930 | 1.27 |
| 1989 | 1.1870 | 0.3590 | 1.77 |
| 1990 | 1.1350 | 0.2260 | 1.55 |
| 1991 | 0.6850 | 0.2480 | 0.94 |
| 1992 | 0.8910 | 0.3150 | 1.25 |
| 1993 | 1.2750 | 0.2970 | 1.3 |
| 1994 | 0.5650 | 0.3670 | 1.64 |
| 1995 | 0.8920 | 0.1560 | 1.22 |
| 1996 | 1.0460 | 0.2660 | 1.31 |
| 1997 | 0.6100 | 0.3050 | 1.83 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

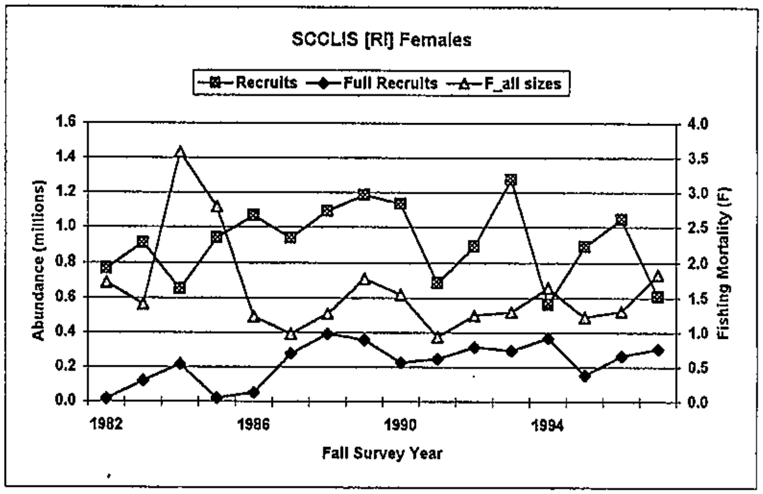


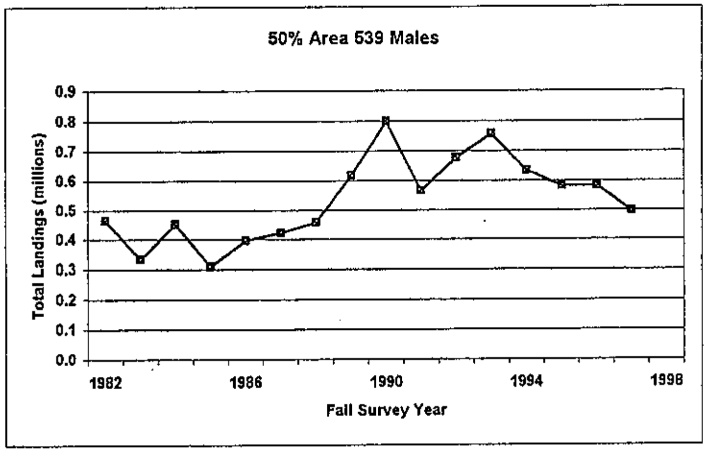
Figure 73. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS male lobsters in statistical area 539 for fall survey years 1982-1997 estimated from RI fall survey (Q ratio = 1.0) using 50% of area 539 landings.

**SCCLIS [RI] Male Lobsters**

**Using Fall SY Landings from 50% SA539**

s_r = 1.0

| Survey Year | Indices of Abundance | | Total Catch Millions |
|---|---|---|---|
| | Recruits | Full Recruits | |
| 1982 | 0.4728 | 0.1213 | 0.4643 |
| 1983 | 0.2391 | 0.1949 | 0.3357 |
| 1984 | 1.2937 | 0.1597 | 0.4537 |
| 1985 | 0.7303 | 0.1941 | 0.3100 |
| 1986 | 0.8818 | 0.2366 | 0.3978 |
| 1987 | 1.0192 | 0.1900 | 0.4223 |
| 1988 | 1.1847 | 0.2242 | 0.4587 |
| 1989 | 2.7849 | 0.4558 | 0.6165 |
| 1990 | 1.3297 | 0.4544 | 0.8002 |
| 1991 | 2.0268 | 0.2846 | 0.5661 |
| 1992 | 1.3347 | 0.2926 | 0.6782 |
| 1993 | 2.9682 | 0.4874 | 0.7583 |
| 1994 | 1.0044 | 0.1707 | 0.6342 |
| 1995 | 3.0926 | 0.3375 | 0.5815 |
| 1996 | 4.9470 | 1.0000 | 0.5808 |
| 1997 | 3.3570 | 1.0000 | 0.4967 |
| 1998 | 2.4050 | 0.2140 | |



| | |
|---|---|
| Input File Name | R3.dat |
| Tuning Dataset | RI Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 1.0 |
| Average F_all sizes (1995-97) | 1.11 |

| Survey Year | Stock Size Estimates millions at time of Survey | | Fishing Mortality |
|---|---|---|---|
| | Recruits | Full Recruits | F_all sizes |
| 1982 | 0.5760 | 0.0610 | 1.67 |
| 1983 | 0.3390 | 0.1030 | 1.89 |
| 1984 | 0.5600 | 0.0580 | 1.76 |
| 1985 | 0.3790 | 0.0910 | 1.35 |
| 1986 | 0.4420 | 0.1050 | 1.71 |
| 1987 | 0.5080 | 0.0850 | 1.62 |
| 1988 | 0.6210 | 0.1010 | 1.24 |
| 1989 | 0.8330 | 0.1790 | 1.2 |
| 1990 | 0.7740 | 0.2630 | 2.03 |
| 1991 | 0.6980 | 0.1170 | 1.54 |
| 1992 | 0.8190 | 0.1500 | 1.54 |
| 1993 | 0.7810 | 0.1790 | 2.23 |
| 1994 | 0.7740 | 0.0890 | 1.74 |
| 1995 | 0.9410 | 0.1300 | 0.99 |
| 1996 | 0.7900 | 0.3420 | 1.02 |
| 1997 | 0.4650 | 0.3500 | 1.33 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

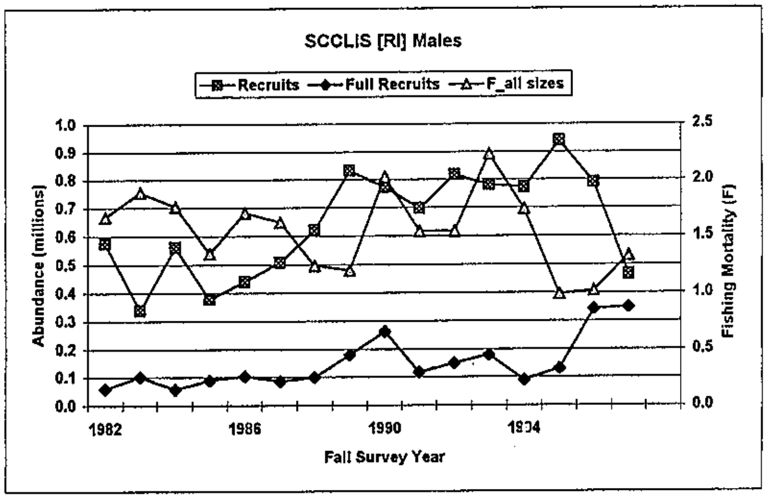
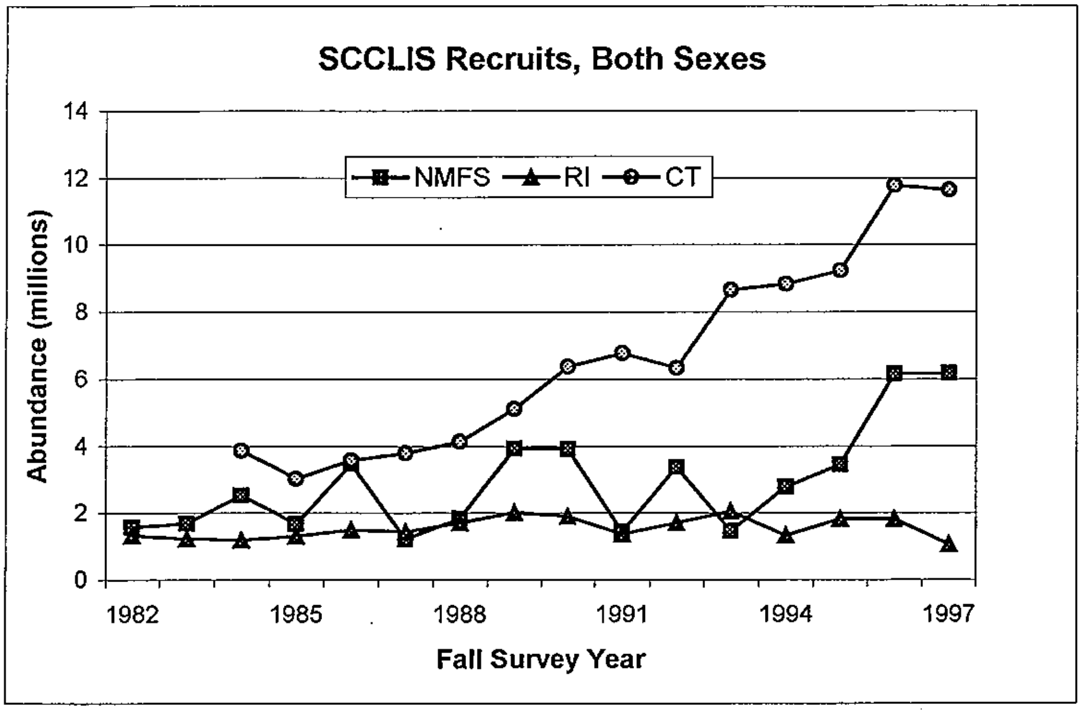


Figure 74. DeLury model estimates of recruit and full recruit abundance for statistical areas 538-539, 539 and 611 using NMFS, RI, CT, fall survey data, 1982-1997 survey years.



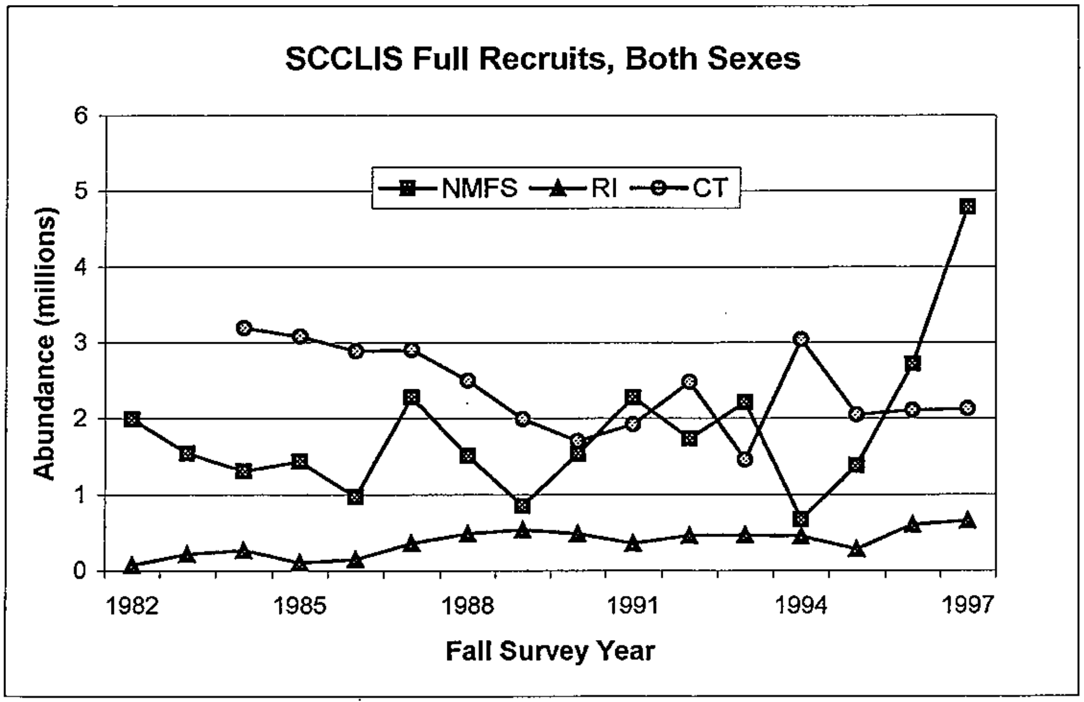
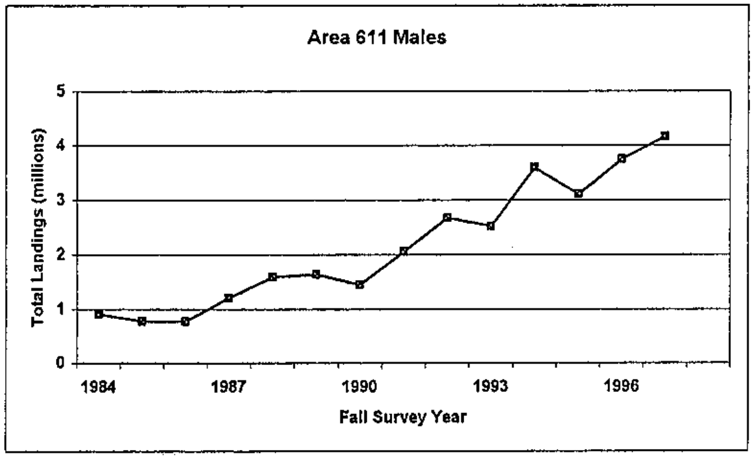


Figure 75. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS male lobsters in statistical area 611 for fall survey years 1984-1997 estimated from CT fall survey (Q ratio = 1.0).

SCCLIS [CT] Male Lobsters
Using Fall SY Landings from SA 611

s_r =1.0

| Survey Year | Indices of Abundance |  | Total Catch Millions |
|---|---|---|---|
|  | Recuits | Full Recruits |  |
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | 8.0746 | 4.7240 | 0.91187 |
| 1985 | 4.1441 | 2.1664 | 0.77084 |
| 1986 | 6.0511 | 4.0851 | 0.77298 |
| 1987 | 6.6218 | 3.4685 | 1.21037 |
| 1988 | 4.3050 | 2.3274 | 1.59126 |
| 1989 | 6.0974 | 2.9281 | 1.63584 |
| 1990 | 7.5346 | 2.8912 | 1.44797 |
| 1991 | 15.6373 | 2.9192 | 2.05830 |
| 1992 | 11.5820 | 4.5533 | 2.67259 |
| 1993 | 13.5101 | 1.8027 | 2.51998 |
| 1994 | 13.0308 | 4.2444 | 3.59349 |
| 1995 | 11.8035 | 4.1274 | 3.10864 |
| 1996 | 7.7791 | 1.5214 | 3.75336 |
| 1997 | 20.9238 | 3.5997 | 4.16899 |
| 1998 | 11.6158 | 1.9313 |  |



|  |  |
|---|---|
| Input File Name | R1.dat |
| Tuning Dataset | CT Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 1.0 |
| Average F_all sizes (1995-97) | 2.00 |

| Survey Year | Stock Size millions at time of Survey Recruits | Estimates Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | 1.274 | 0.873 | 0.76 |
| 1985 | 1.058 | 0.862 | 0.61 |
| 1986 | 1.224 | 0.901 | 0.59 |
| 1987 | 1.407 | 1.011 | 0.87 |
| 1988 | 1.678 | 0.873 | 1.17 |
| 1989 | 1.934 | 0.681 | 1.2 |
| 1990 | 1.818 | 0.676 | 1.07 |
| 1991 | 3.044 | 0.735 | 0.99 |
| 1992 | 2.392 | 1.212 | 1.82 |
| 1993 | 3.668 | 0.501 | 1.14 |
| 1994 | 4.065 | 1.147 | 1.49 |
| 1995 | 2.995 | 1.011 | 2.08 |
| 1996 | 4.667 | 0.431 | 1.73 |
| 1997 | 4.529 | 0.775 | 2.18 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

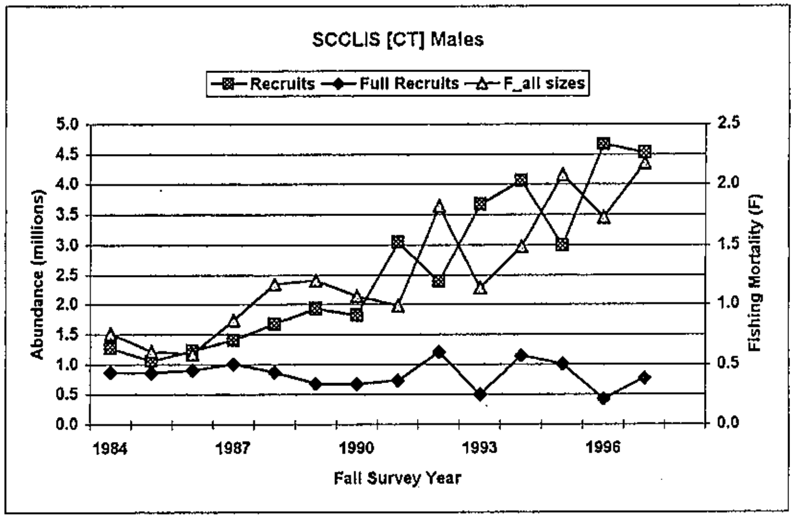
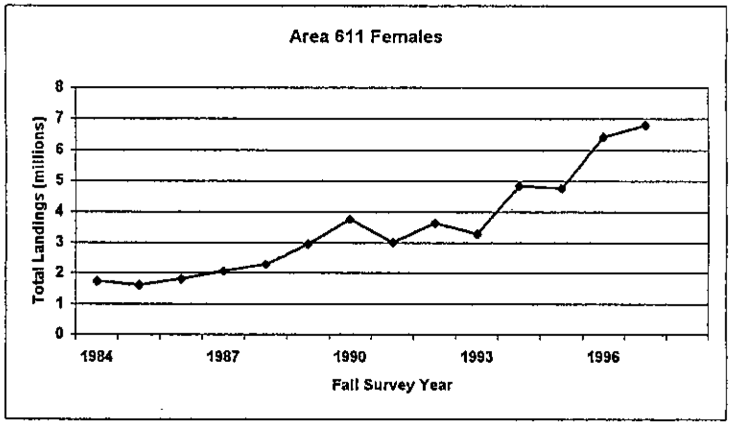


Figure 76. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS female lobsters in statistical area 611 for fall survey years 1984-1997 estimated from CT fall survey (Q ratio = 1.0).

**SCCLIS [CT] Female Lobsters**
Using Fall SY Landings from SA 611

s_r =1.0

| Survey Year | Indices of Abundance | | Total Catch Millions |
|---|---|---|---|
| | Recruits | Full Recruits | |
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | 6.3113 | 5.3556 | 1.72570 |
| 1985 | 3.2226 | 2.0880 | 1.61858 |
| 1986 | 4.2123 | 3.0677 | 1.81755 |
| 1987 | 4.3460 | 2.7636 | 2.05691 |
| 1988 | 3.5059 | 1.9819 | 2.29263 |
| 1989 | 3.2041 | 1.6995 | 2.95241 |
| 1990 | 4.2639 | 1.5895 | 3.76420 |
| 1991 | 7.7854 | 2.2678 | 3.01257 |
| 1992 | 5.4129 | 1.6000 | 3.64013 |
| 1993 | 9.0532 | 1.5162 | 3.28735 |
| 1994 | 7.8831 | 2.6767 | 4.84588 |
| 1995 | 7.0370 | 1.4337 | 4.77842 |
| 1996 | 6.3802 | 2.4021 | 6.44727 |
| 1997 | 14.3837 | 2.3786 | 6.80834 |
| 1998 | 6.1907 | 0.9823 | |



| | |
|---|---|
| Input File Name | R1.dat |
| Tuning Dataset | CT Fall Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.8 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 1.0 |
| Average F_all sizes (1995-97) | 1.80 |

| Survey Year | Stock Size millions at time of Survey Recruits | Estimates Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | 2.599 | 2.324 | 0.64 |
| 1985 | 1.976 | 2.225 | 0.60 |
| 1986 | 2.365 | 1.988 | 0.68 |
| 1987 | 2.393 | 1.896 | 0.82 |
| 1988 | 2.470 | 1.626 | 0.99 |
| 1989 | 3.178 | 1.310 | 1.32 |
| 1990 | 4.552 | 1.033 | 1.39 |
| 1991 | 3.735 | 1.195 | 1.20 |
| 1992 | 3.942 | 1.274 | 1.54 |
| 1993 | 4.997 | 0.962 | 1.00 |
| 1994 | 4.786 | 1.895 | 1.71 |
| 1995 | 6.256 | 1.041 | 1.32 |
| 1996 | 7.120 | 1.678 | 1.72 |
| 1997 | 7.130 | 1.352 | 2.36 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

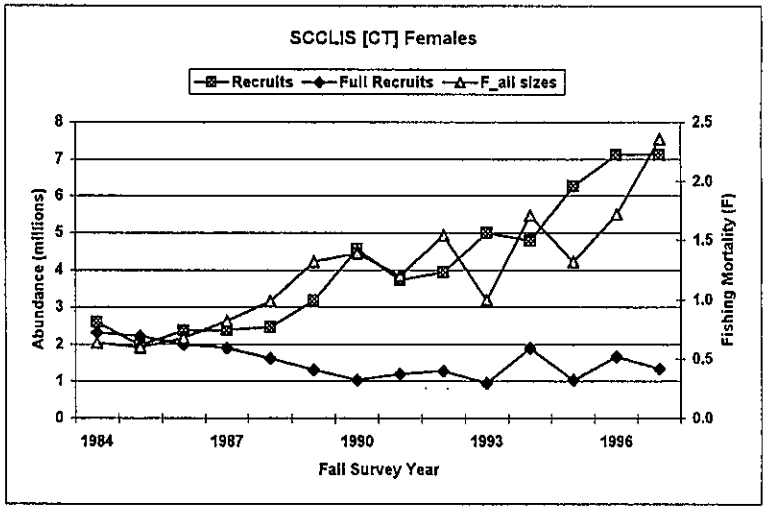
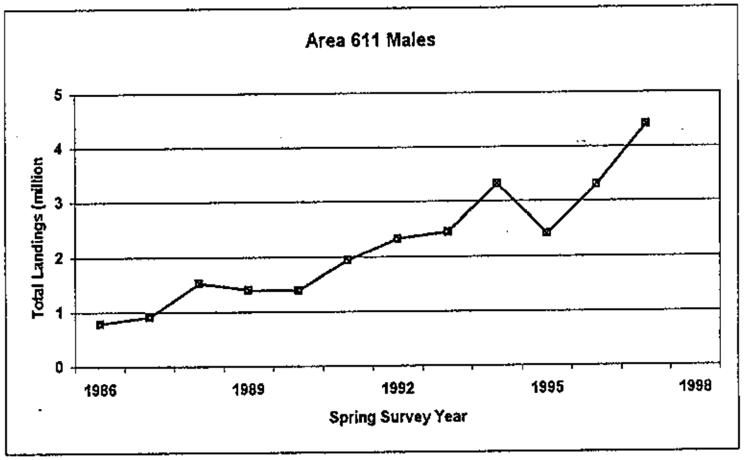


Figure 77. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS male lobsters in statistical area 611 for spring survey years 1986-1997 estimated from CT spring survey (Q ratio = 1.0).

**SCCLIS [CT] Male Lobsters**
**Using Spring SY Landings from SA 611**

s_r = 1.0

| Survey Year | Indices of Abundance Recuits | Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | n/a | n/a | n/a |
| 1985 | n/a | n/a | n/a |
| 1986 | 1.8497 | 0.5554 | 0.7855 |
| 1987 | 2.0987 | 1.0857 | 0.9134 |
| 1988 | 1.1841 | 0.4659 | 1.5295 |
| 1989 | 3.2106 | 1.4645 | 1.4002 |
| 1990 | 4.5068 | 0.5693 | 1.3924 |
| 1991 | 9.5220 | 4.4160 | 1.9441 |
| 1992 | 8.1983 | 1.5984 | 2.3299 |
| 1993 | 5.3228 | 1.5403 | 2.4401 |
| 1994 | 3.4368 | 0.3626 | 3.3262 |
| 1995 | 7.8142 | 2.2319 | 2.4133 |
| 1996 | 8.7284 | 1.5625 | 3.2962 |
| 1997 | 14.4594 | 6.6734 | 4.4183 |
| 1998 | 26.8015 | 5.2938 | |



| | |
|---|---|
| Input File Name | R100.dat |
| Tuning Dataset | CT Spring Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.333 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 1.0 |
| Average F_all sizes (1995-97) | 0.98 |

| Survey Year | Stock Size Estimates millions at time of Survey Recruits | Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | n/a | n/a | n/a |
| 1985 | n/a | n/a | n/a |
| 1986 | 1.046 | 0.275 | 0.96 |
| 1987 | 0.855 | 0.436 | 1.38 |
| 1988 | 1.832 | 0.281 | 1.35 |
| 1989 | 1.330 | 0.473 | 1.70 |
| 1990 | 2.561 | 0.284 | 0.70 |
| 1991 | 2.115 | 1.219 | 1.06 |
| 1992 | 2.428 | 0.990 | 1.31 |
| 1993 | 1.983 | 0.796 | 2.57 |
| 1994 | 4.187 | 0.184 | 1.56 |
| 1995 | 2.768 | 0.793 | 1.27 |
| 1996 | 5.403 | 0.858 | 0.77 |
| 1997 | 5.554 | 2.494 | 0.89 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

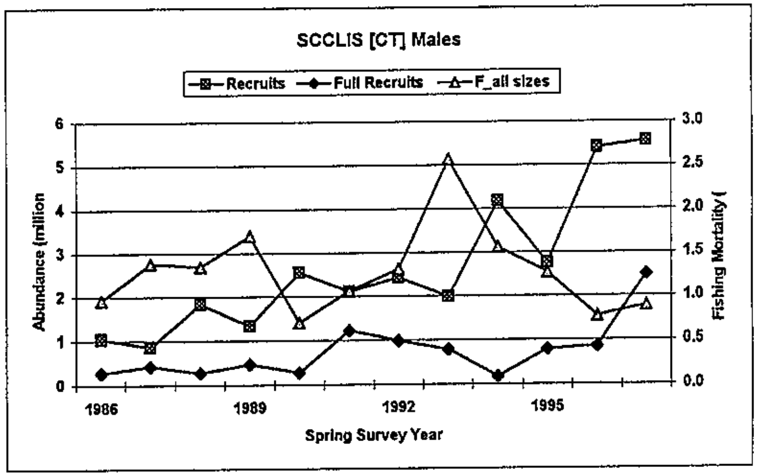
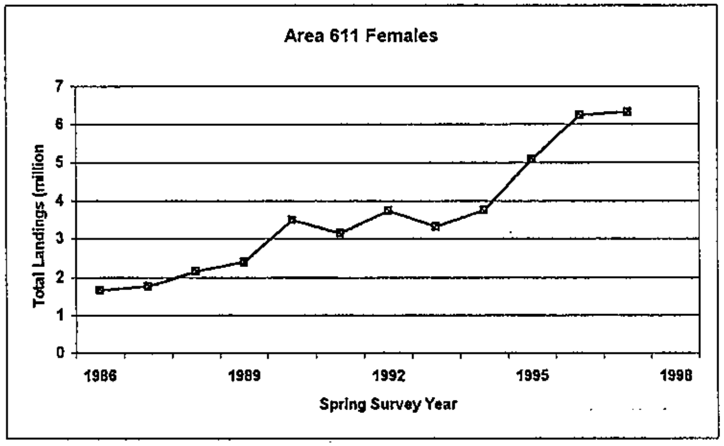


Figure 78. DeLury model input parameters, estimated abundance of recruits and full recruits at time of survey, and annual fishing mortality rates for SCCLIS female lobsters in statistical area 611 for spring survey years 1986-1997 estimated from CT spring survey (Q ratio = 1.0).

**SCCLIS [CT] Female Lobsters**
Using Spring SY Landings from SA 611

s_r =1.0

| Survey Year | Indices of Abundance Recruits | Indices of Abundance Full Recruits | Total Catch Millions |
|---|---|---|---|
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | n/a | n/a | n/a |
| 1985 | n/a | n/a | n/a |
| 1986 | 2.0733 | 0.6330 | 1.66653 |
| 1987 | 2.5910 | 0.8937 | 1.77409 |
| 1988 | 1.1539 | 0.8166 | 2.15883 |
| 1989 | 3.8158 | 1.0738 | 2.39762 |
| 1990 | 6.6127 | 1.7732 | 3.49021 |
| 1991 | 11.1094 | 1.5747 | 3.14222 |
| 1992 | 14.8688 | 2.0265 | 3.74259 |
| 1993 | 10.4407 | 2.4080 | 3.31899 |
| 1994 | 3.9943 | 0.7045 | 3.76954 |
| 1995 | 11.4383 | 1.7908 | 5.09479 |
| 1996 | 10.5899 | 2.3893 | 6.24365 |
| 1997 | 22.1405 | 3.8055 | 6.31159 |
| 1998 | 37.5874 | 4.0968 | |



| | |
|---|---|
| Input File Name | R1.dat |
| Tuning Dataset | CT Spring Survey |
| Time of Survey (yr) | 0 |
| Time of Catch (yr) | 0.333 |
| Natural Mortality Rate | 0.15 |
| Relative Catchability: Recruits to Full Recruits s_r | 1.0 |
| Average F_all sizes (1995-97) | 1.26 |

| Survey Year | Stock Size Estimates millions at time of Survey Recruits | Stock Size Estimates millions at time of Survey Full Recruits | Fishing Mortality F_all sizes |
|---|---|---|---|
| 1982 | n/a | n/a | n/a |
| 1983 | n/a | n/a | n/a |
| 1984 | n/a | n/a | n/a |
| 1985 | n/a | n/a | n/a |
| 1986 | 1.907 | 0.425 | 1.36 |
| 1987 | 2.070 | 0.516 | 1.25 |
| 1988 | 2.188 | 0.637 | 1.55 |
| 1989 | 3.094 | 0.515 | 1.17 |
| 1990 | 3.727 | 0.962 | 1.53 |
| 1991 | 3.948 | 0.874 | 1.21 |
| 1992 | 4.359 | 1.241 | 1.28 |
| 1993 | 2.849 | 1.336 | 1.84 |
| 1994 | 4.437 | 0.571 | 1.53 |
| 1995 | 6.240 | 0.934 | 1.38 |
| 1996 | 7.312 | 1.554 | 1.34 |
| 1997 | 8.446 | 2.003 | 1.06 |

Note that the DeLury model estimates total mortality (all sizes): fishing mortality rates shown here are derived by substracting M (=0.15) from DeLury total mortality estimates

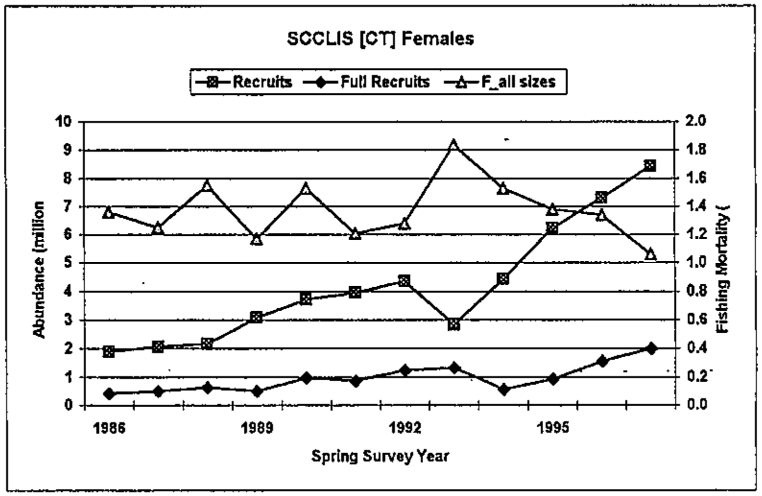
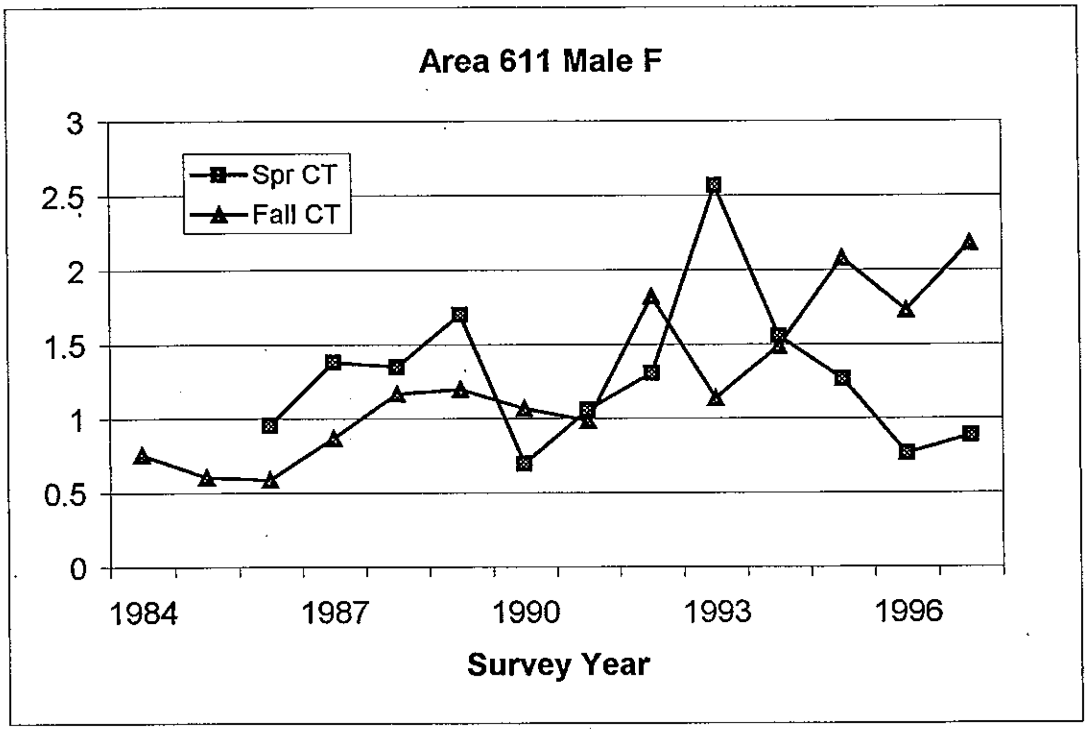


Figure 79. Male and female fishing mortality rates estimated from DeLury model runs for statistical area 611 using spring and fall CT survey data, 1984/86-1997 survey years.

A



B

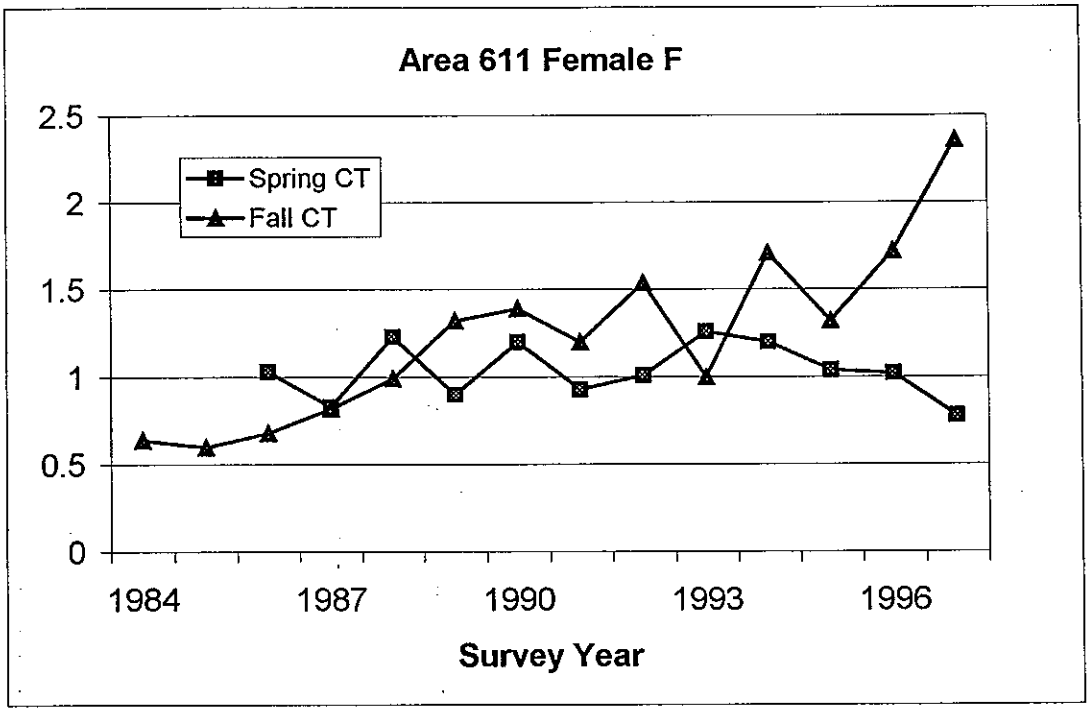


Figure 80. Combined DeLury model abundance and fishing mortality estimates for male lobsters in the SCCLIS stock area for fall survey years 1982-1997. (Lines connect 10, 50 and 90 percentile estimates from bootstrapped model runs, triangles indicate point estimates, see text for details).

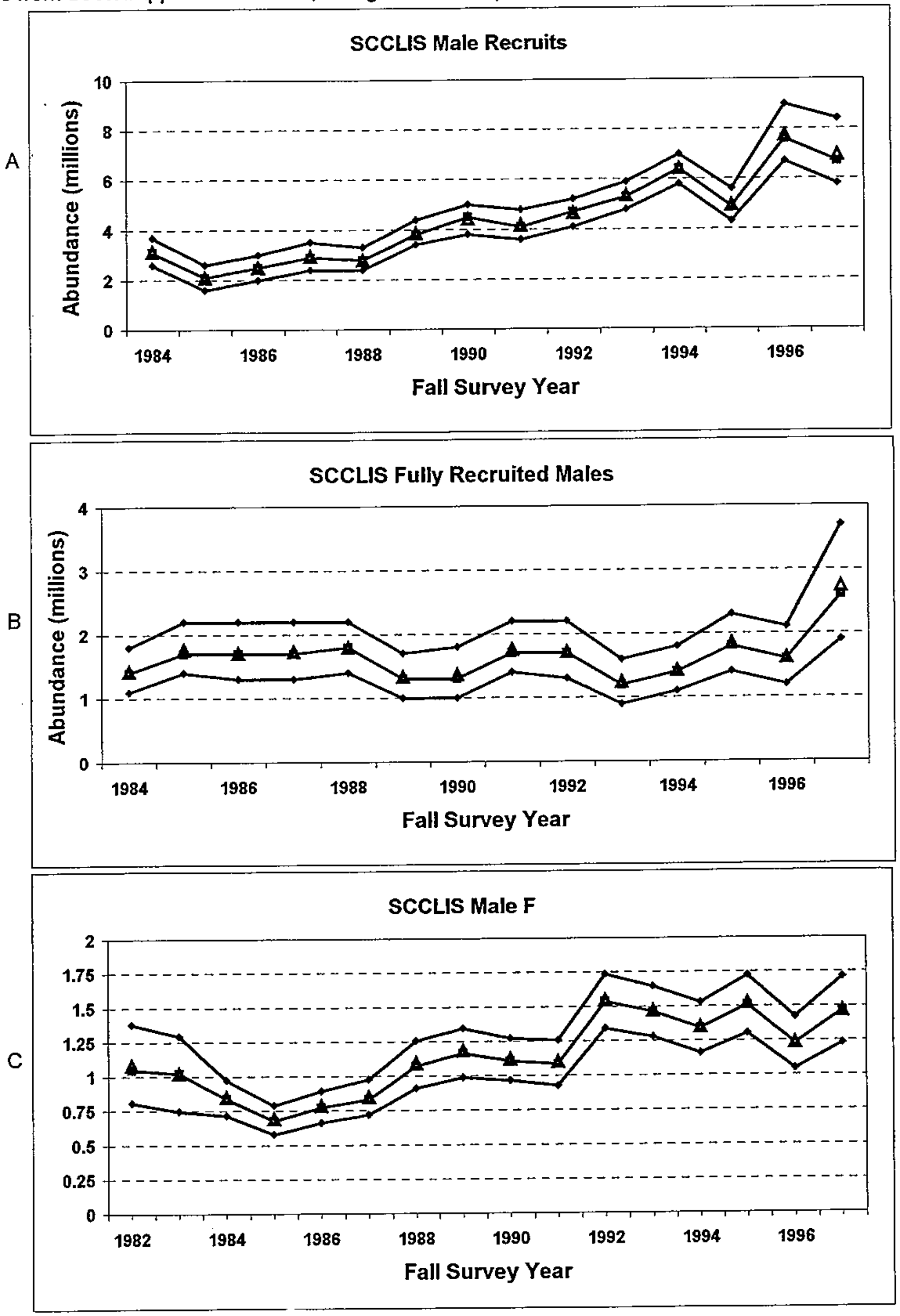


Figure 81. Combined DeLury model abundance and fishing mortality estimates for female lobsters in the SCCLIS stock area for fall survey years 1982-1997. (Lines connect 10, 50 and 90 percentile estimates from bootstrapped model runs, triangles indicate point estimates, and straight line shows F10% maximum EPR reference point, see text for details).

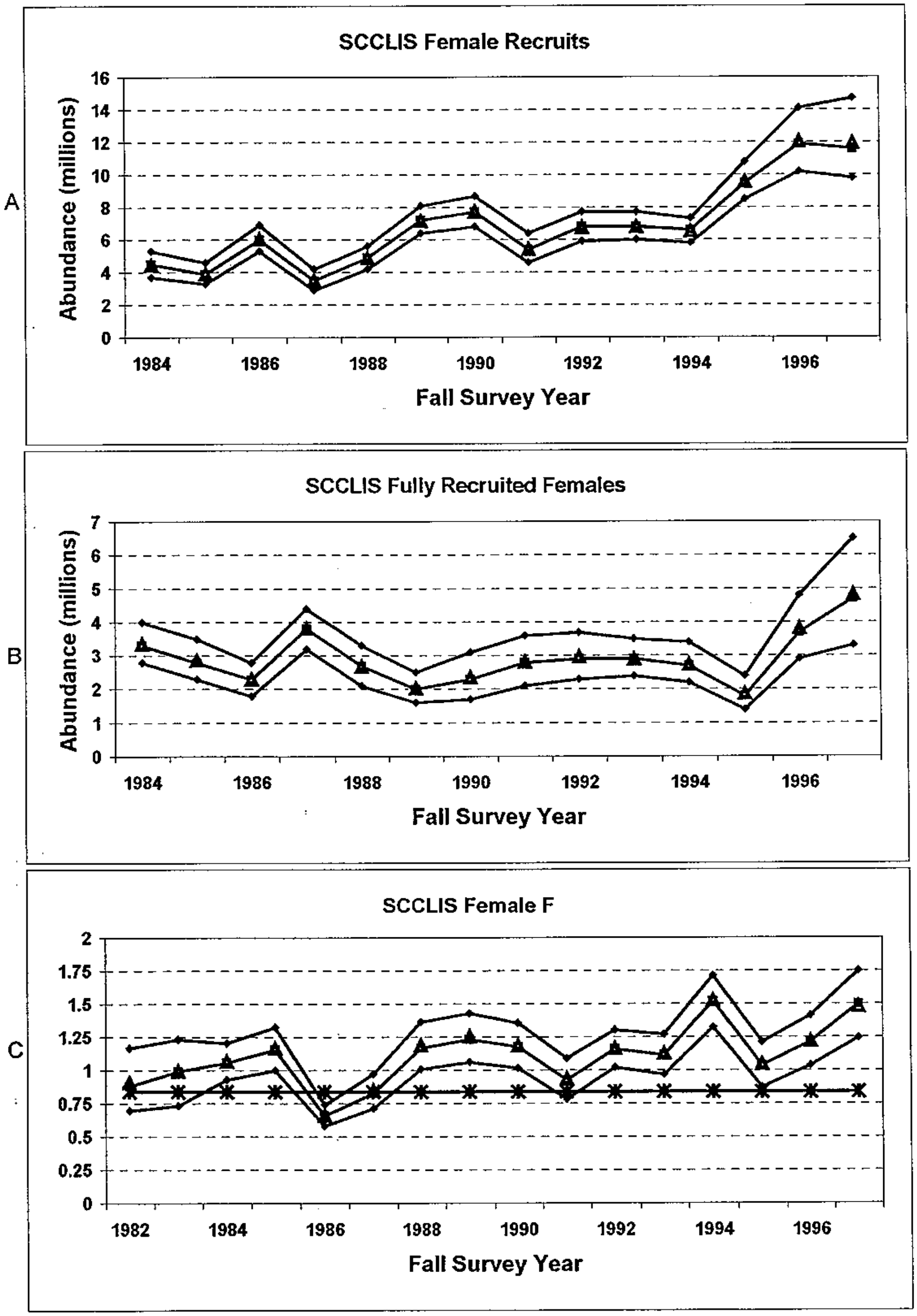


Figure 82. Probability distributions of average SCCLIS male and female 1995-1997 fishing mortality rates estimated from bootstrapped DeLury model runs (see text for details).

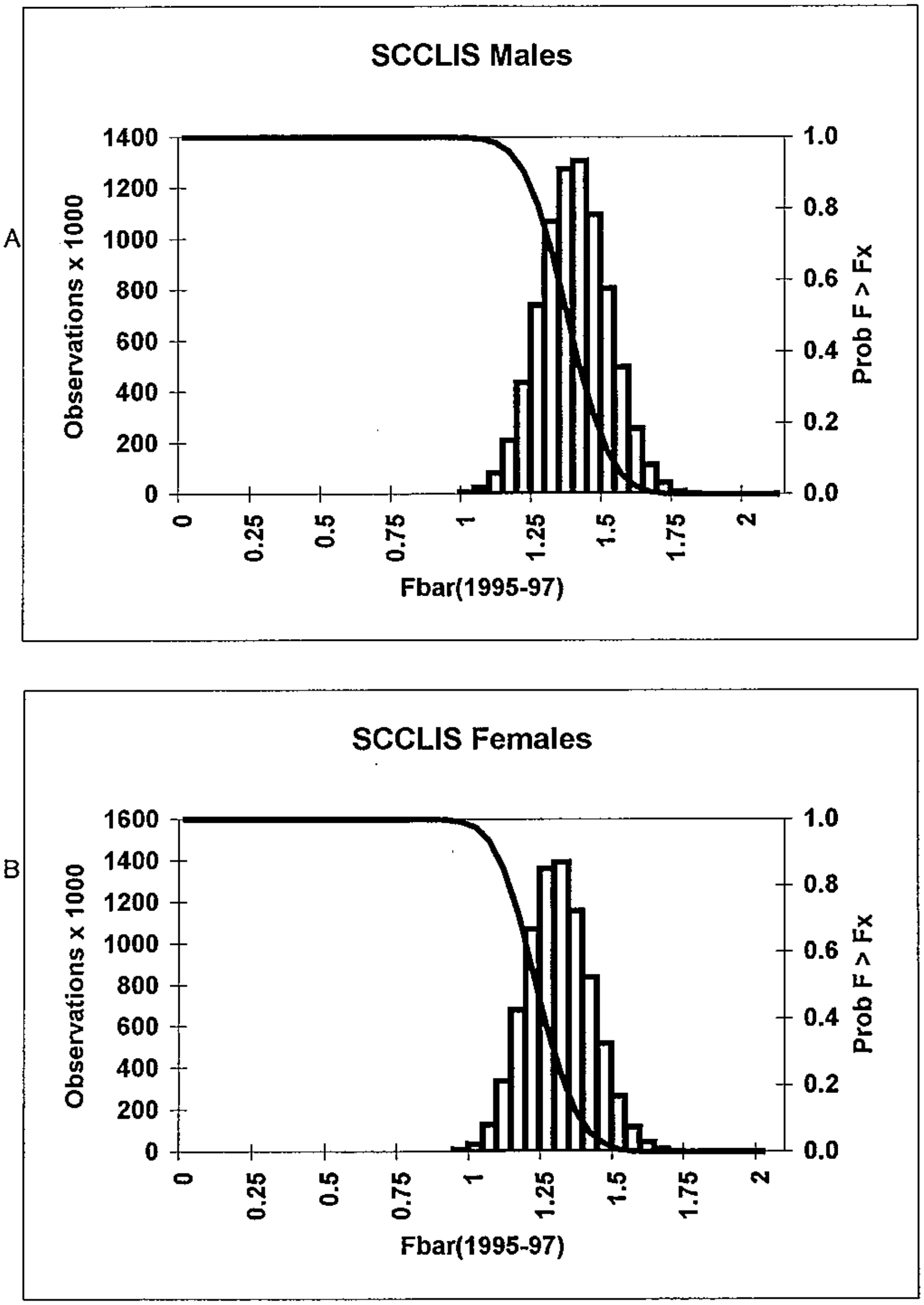


Figure 83. DeLury model point estimates of abundance for recruits and full recruits (by sex) for SCCLIS stock area for fall survey years 1982-1997.

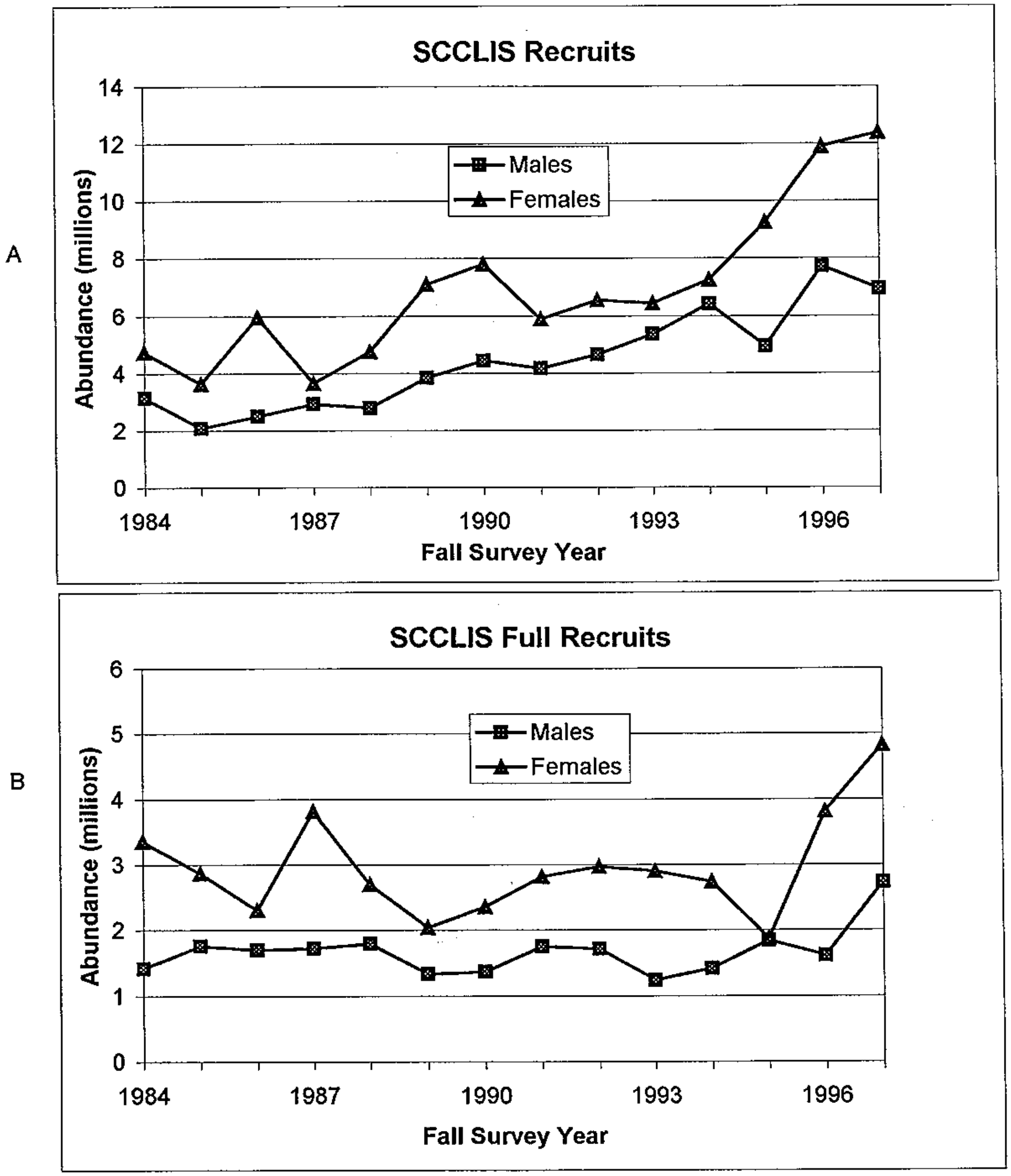


Figure 84. DeLury model point estimates of male and female fishing mortality rates for SCCLIS stock area for fall survey years 1982-1997.

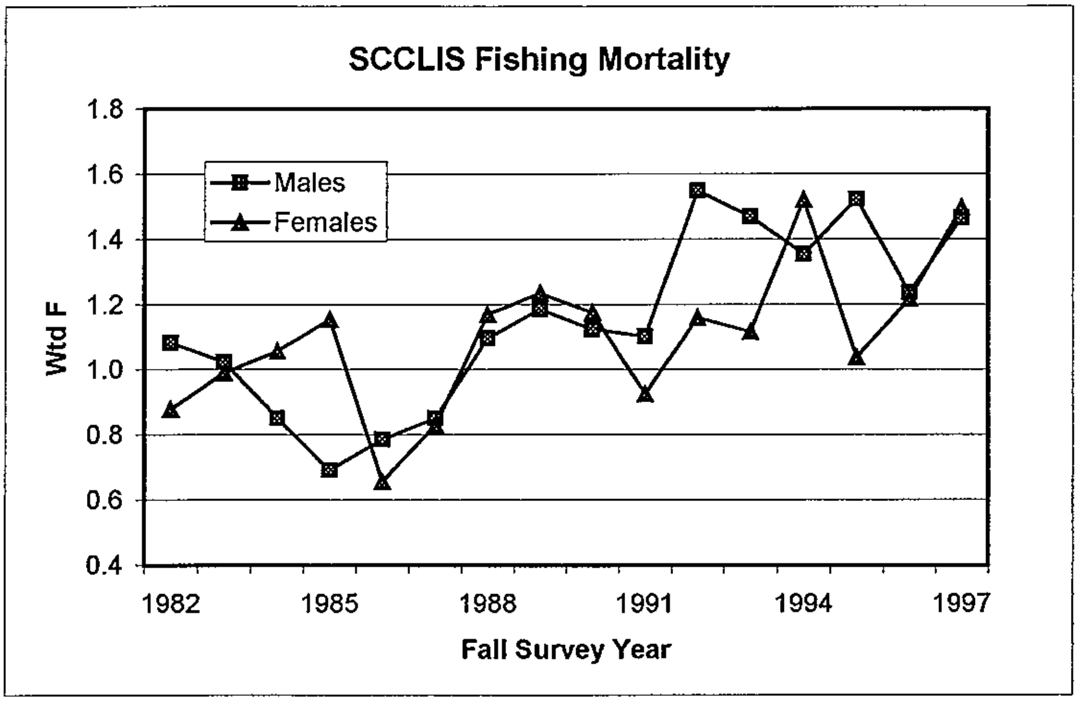


Figure 85. DeLury model point estimates of recruit and full recruit abundance (both sexes combined) SCCLIS stock area for fall survey years 1982-1997.

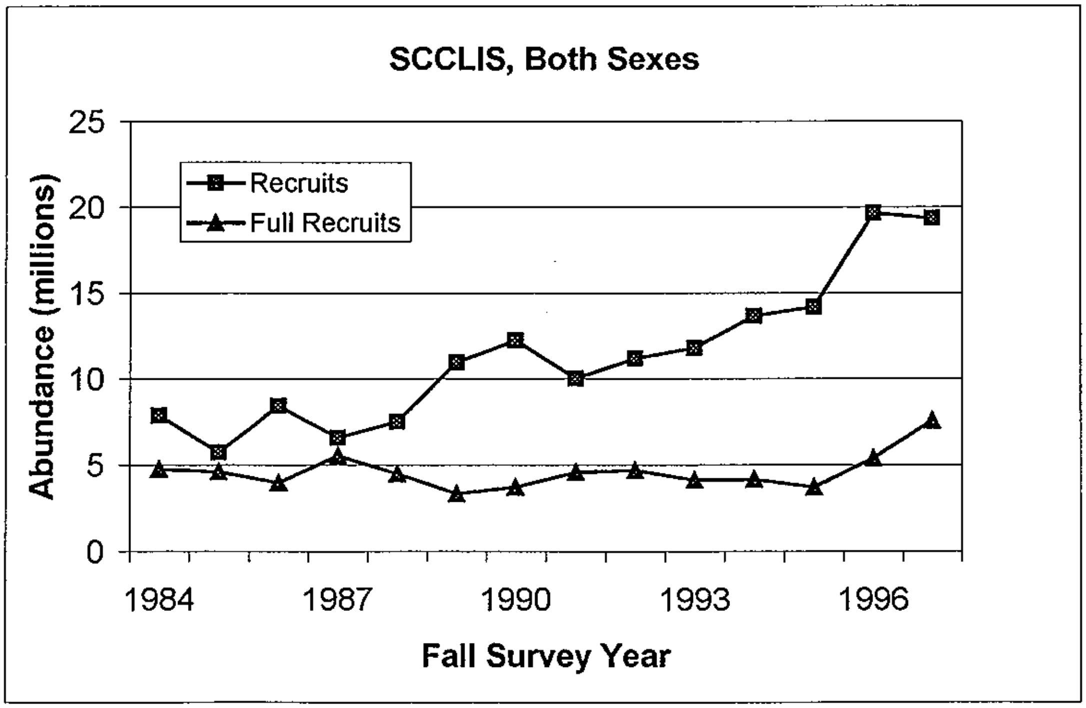


Figure 86

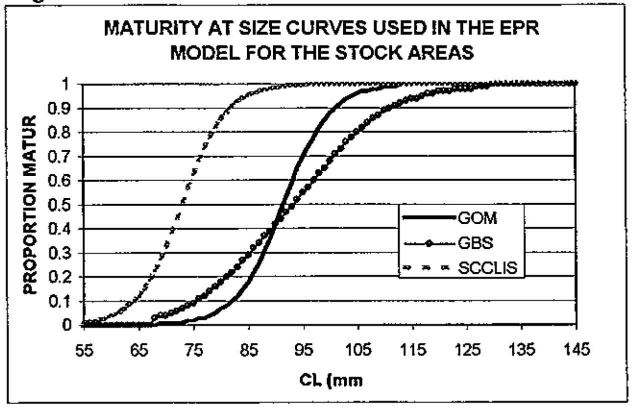

MATURITY AT SIZE CURVES USED IN THE EPR MODEL FOR THE STOCK AREAS

Figure 87

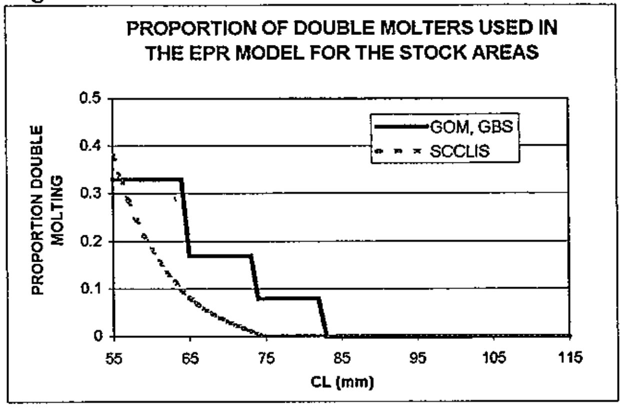

PROPORTION OF DOUBLE MOLTERS USED IN THE EPR MODEL FOR THE STOCK AREAS

Figure 88

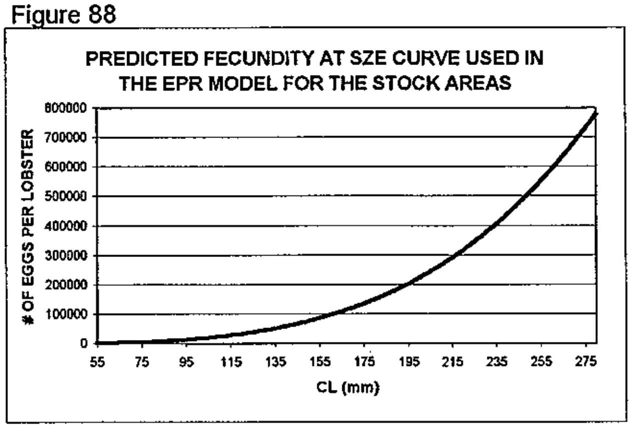

PREDICTED FECUNDITY AT SZE CURVE USED IN THE EPR MODEL FOR THE STOCK AREAS

Figure 89

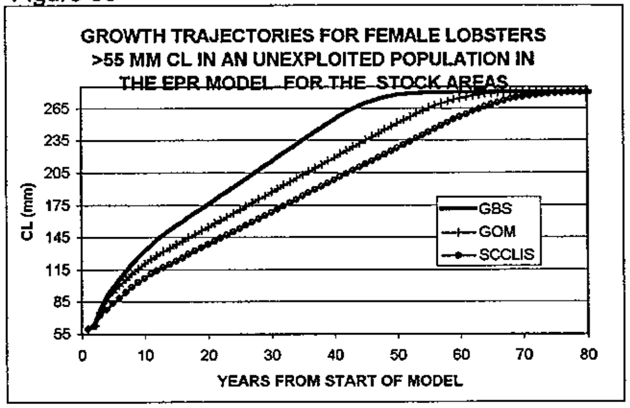
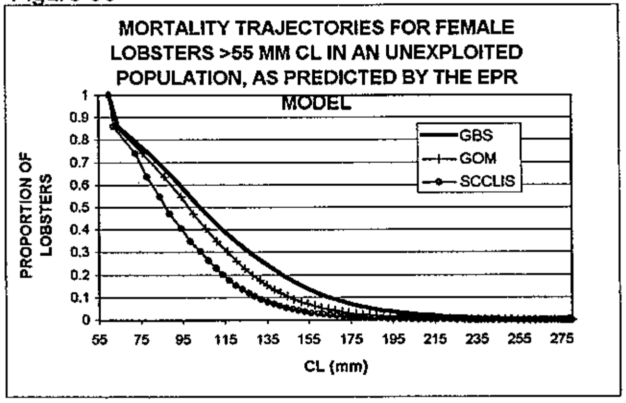
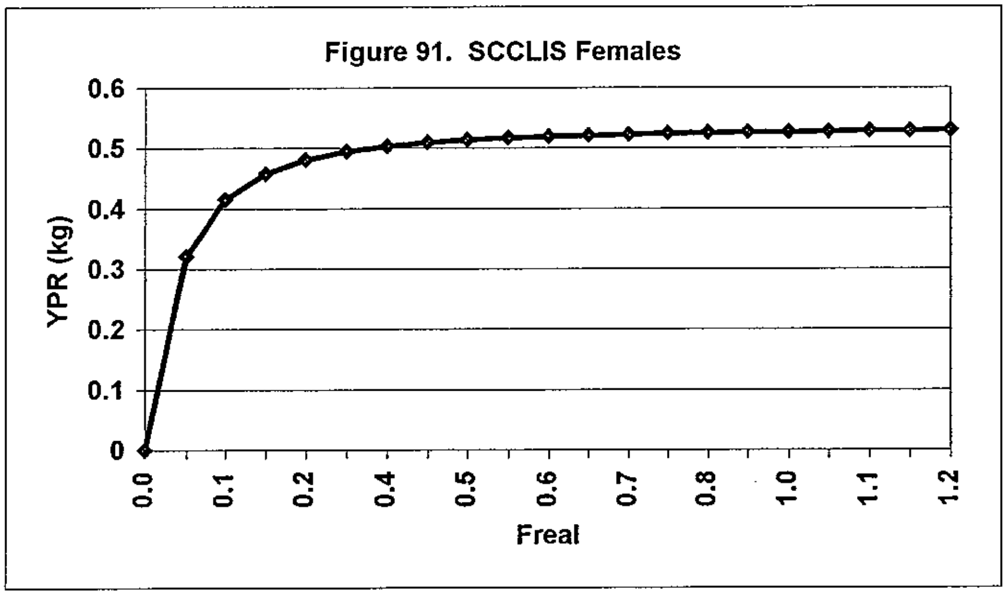
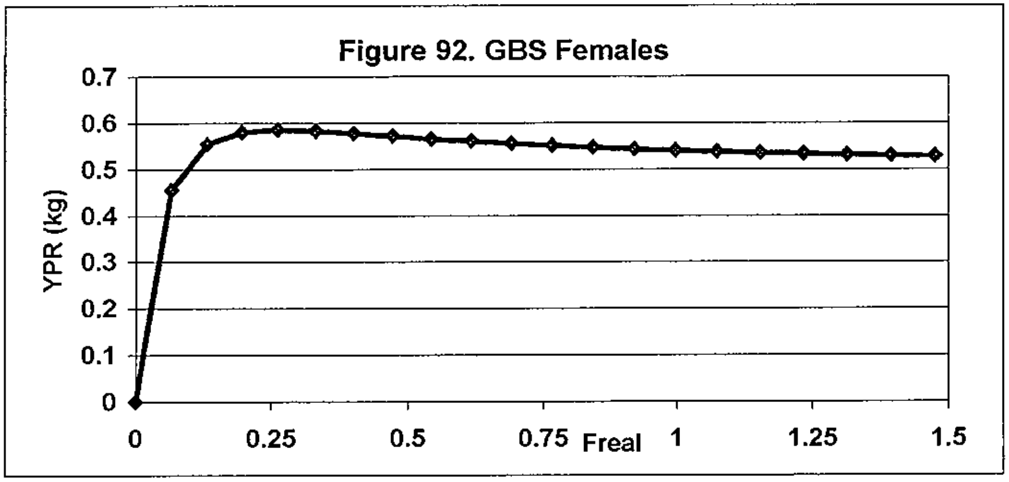

GROWTH TRAJECTORIES FOR FEMALE LOBSTERS >55 MM CL IN AN UNEXPLOITED POPULATION IN THE EPR MODEL FOR THE STOCK AREAS

Figure 90


MORTALITY TRAJECTORIES FOR FEMALE LOBSTERS >55 MM CL IN AN UNEXPLOITED POPULATION, AS PREDICTED BY THE EPR MODEL

Figures 91, 92, and 93. Yield Per Recruit (YPR) curve over a range of fishing mortality values for each stock area.





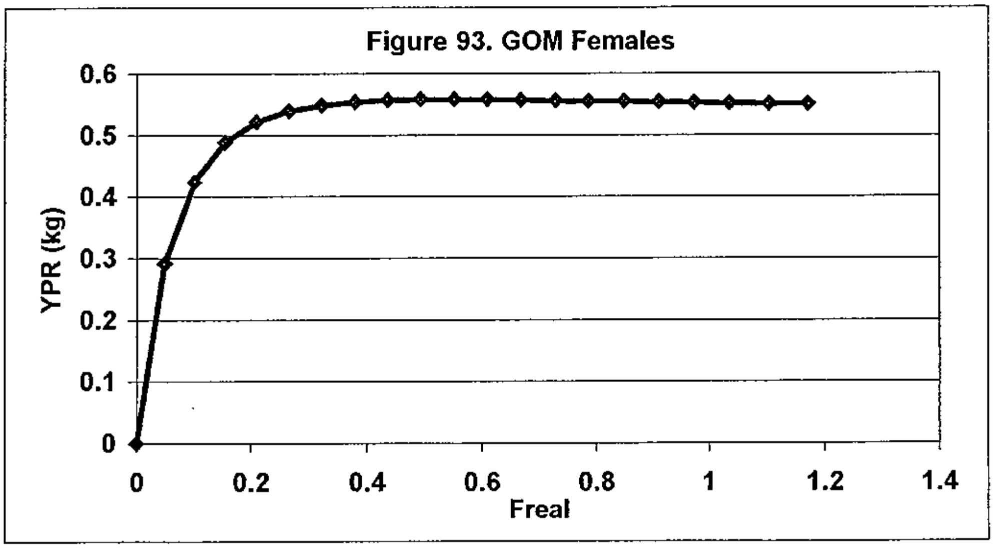


Figure 94. Size distributions of expanded 1995-97 landings, of expected landings at female fishing mortality rate (F) that achieves 10% of the maximum egg production per recruit, and of expected landings of females at prevailing average 1995-1997 female fishing mortality rate in the GOM stock area. Expected size distributions are based on output from EPR model runs.

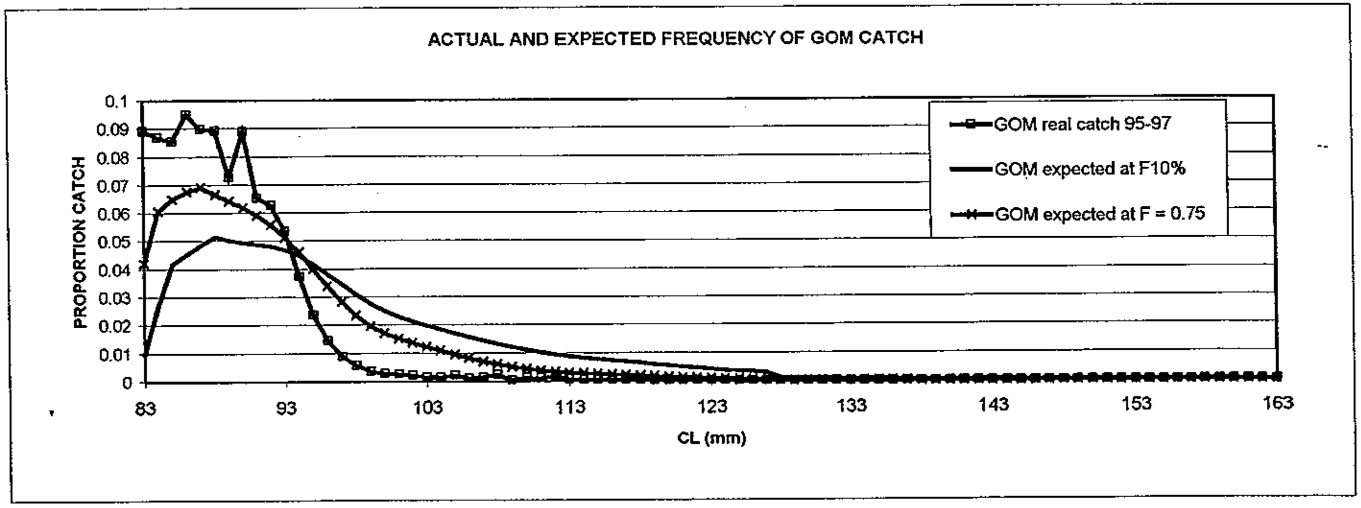


Figure 95. Size distributions of expanded 1995-97 landings, of expected landings at female fishing mortality rate (F) that achieves 10% of the maximum egg production per recruit, and of expected landings of females at prevailing average 1995-1997 female fishing mortality rate in the GBS stock area. Expected size distributions are based on output from EPR model runs.

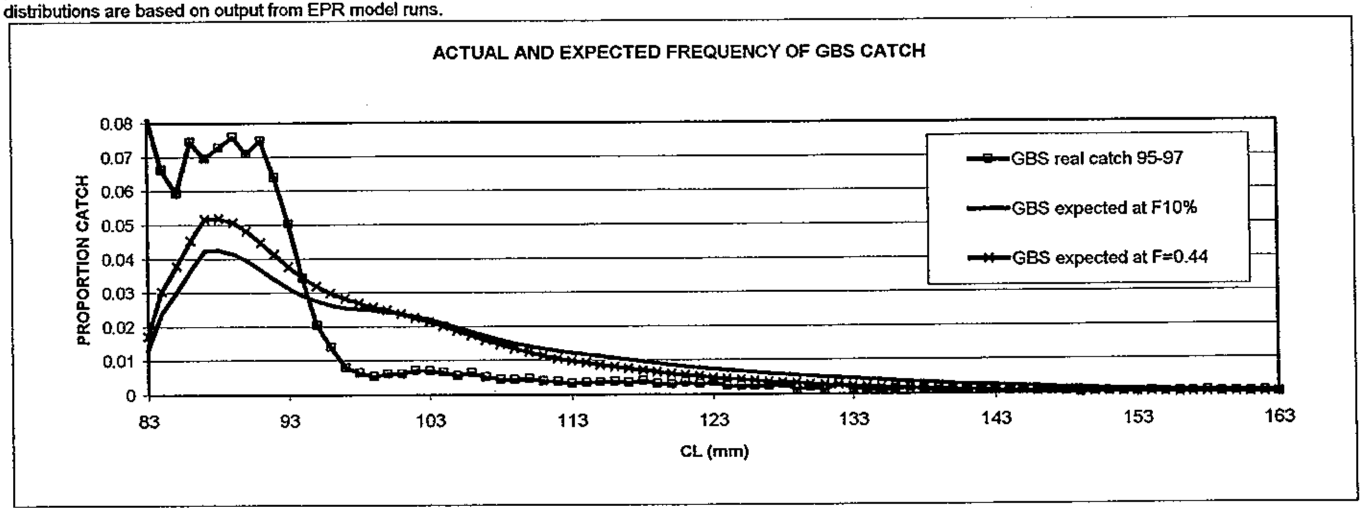


Figure 96. Size distributions of expanded 1995-97 landings, of expected landings at female fishing mortality rate (F) that achieves 10% of the maximum egg production per recruit, and of expected landings of females at prevailing average 1995-1997 female fishing mortality rate in the SCCLIS stock area. Expected size distributions are based on output from EPR model runs.

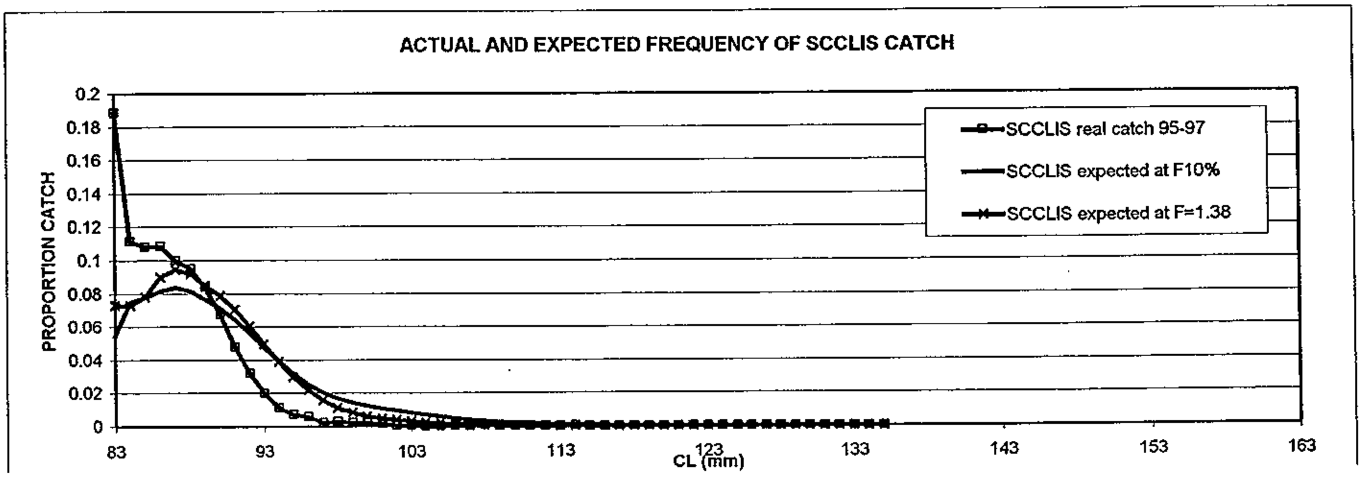


Figure 97. Relative Abundance Indices for Recruits and Fully-Recruited Lobster in Fall NMFS and MA Trawl Surveys in GOM Stock Area

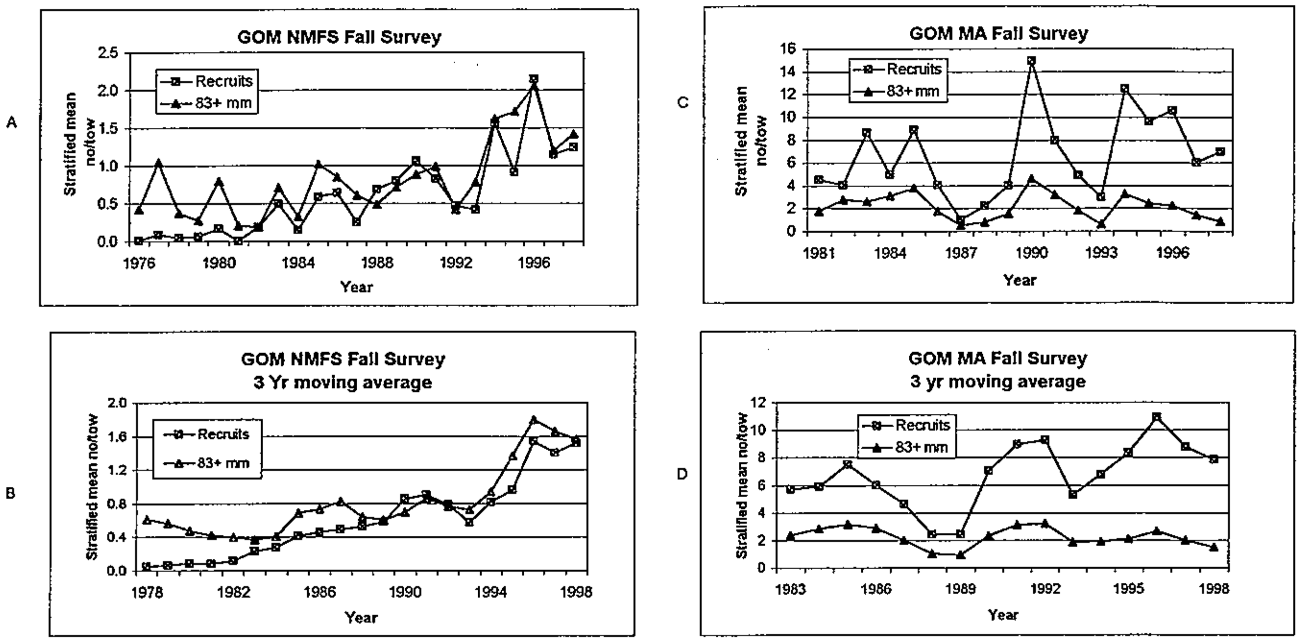
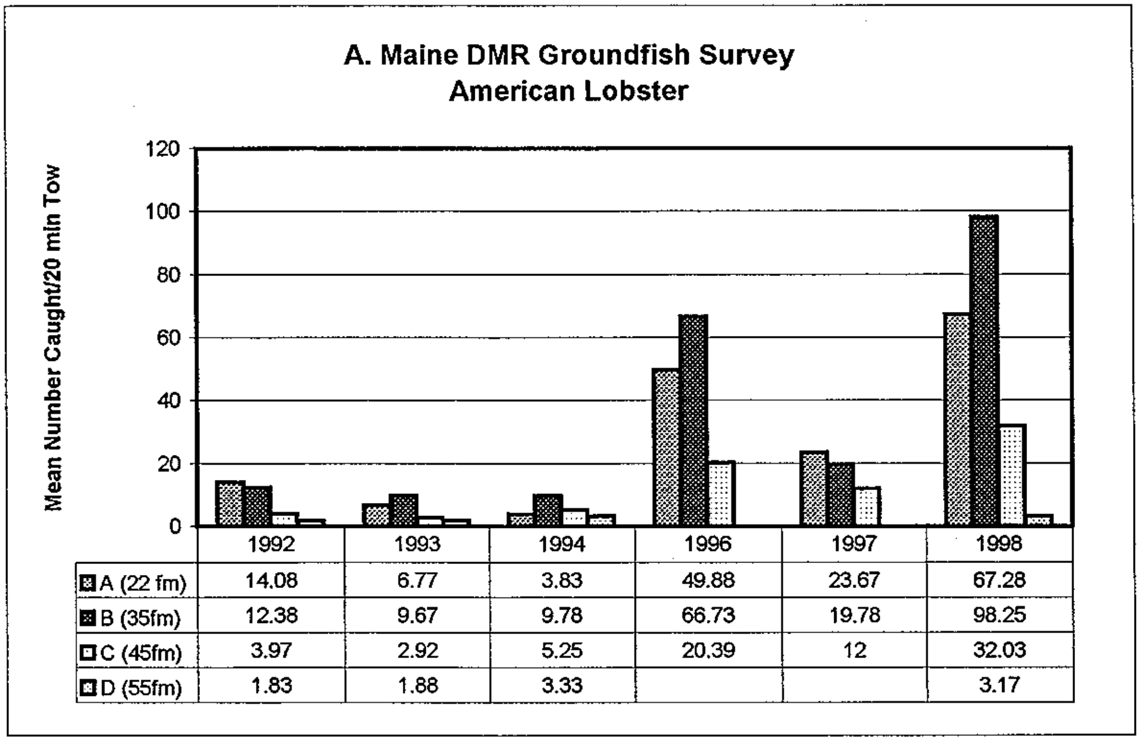
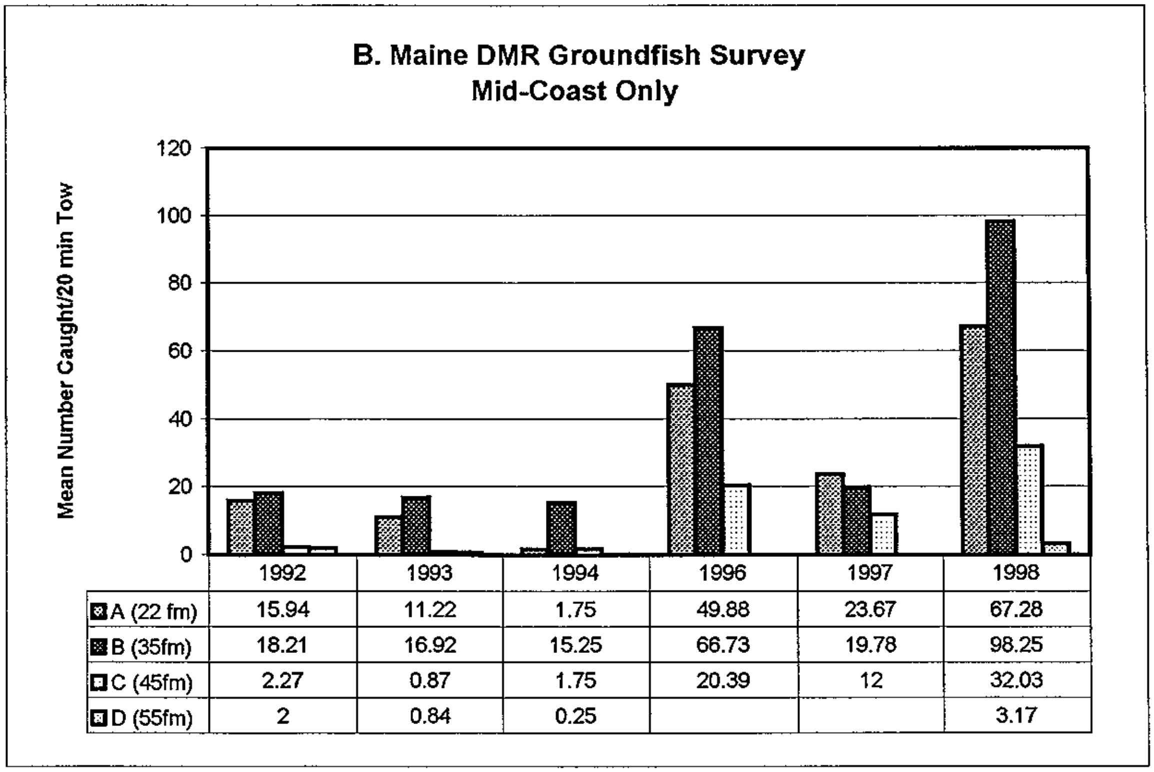


Figure 98. Mean catch rates (number per 20 minute tow) for lobsters of all sizes by depth strata in Maine DMR trawl survey in the Gulf of Maine during 1992-1994 and 1996-1998: (A) all survey station tows (see Figs. 6.1.2-2 and 3); and (B) mid-coast stations only.



| | 1992 | 1993 | 1994 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|
| ▨ A (22 fm) | 14.08 | 6.77 | 3.83 | 49.88 | 23.67 | 67.28 |
| ■ B (35fm) | 12.38 | 9.67 | 9.78 | 66.73 | 19.78 | 98.25 |
| □ C (45fm) | 3.97 | 2.92 | 5.25 | 20.39 | 12 | 32.03 |
| ▨ D (55fm) | 1.83 | 1.88 | 3.33 | | | 3.17 |



| | 1992 | 1993 | 1994 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|---|
| ▨ A (22 fm) | 15.94 | 11.22 | 1.75 | 49.88 | 23.67 | 67.28 |
| ■ B (35fm) | 18.21 | 16.92 | 15.25 | 66.73 | 19.78 | 98.25 |
| □ C (45fm) | 2.27 | 0.87 | 1.75 | 20.39 | 12 | 32.03 |
| ▨ D (55fm) | 2 | 0.84 | 0.25 | | | 3.17 |

Figure 99. Relative abundance indices (stratified mean number per tow) for recruits and fully-recruited (83+ mm CL) lobster in fall NMFS trawl survey in GBS stock area during 1976-1998. Indices in bottom figure are three year running averages.

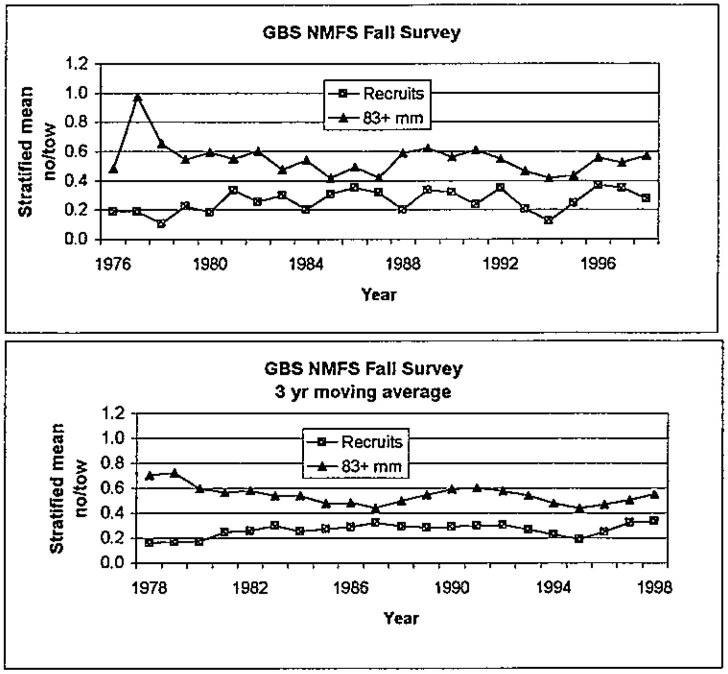


Figure 100. Relative abundance indices (stratified mean number per tow) for recruits (73-82 mm CL) and fully-recruited (83+ mm CL) lobster in NJ trawl survey during 1989-1998.

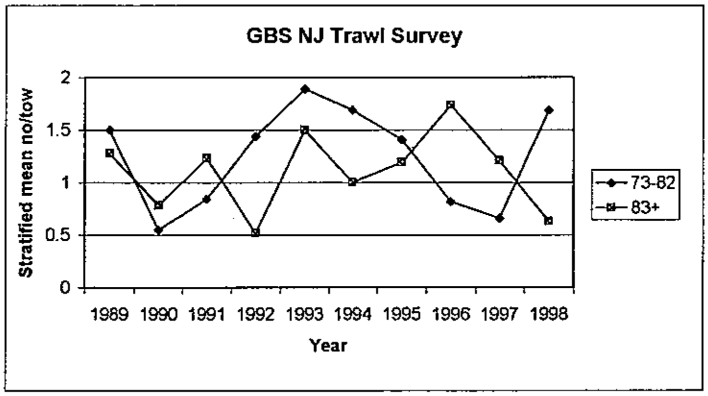


Figure 101. Relative Abundance Indices for Recruits and Fully-Recruited Lobster in Fall NMFS, MA, RI and CT Trawl Surveys in SCCLIS Stock Area

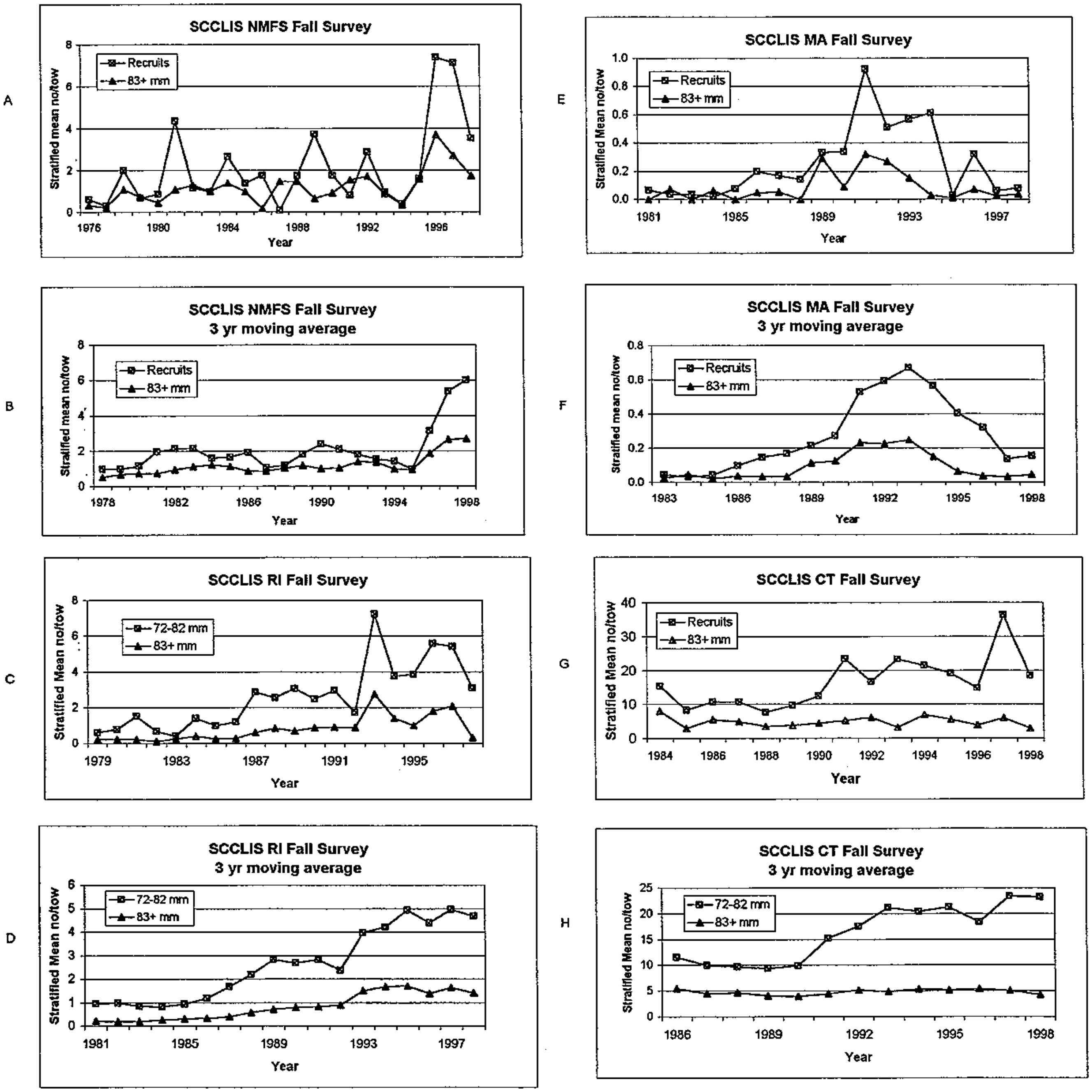


Figure 102. Relative Abundance Indices for Recruits and Fully-Recruited Lobster in Spring RI and CT Trawl Surveys in SCCLIS Stock Area

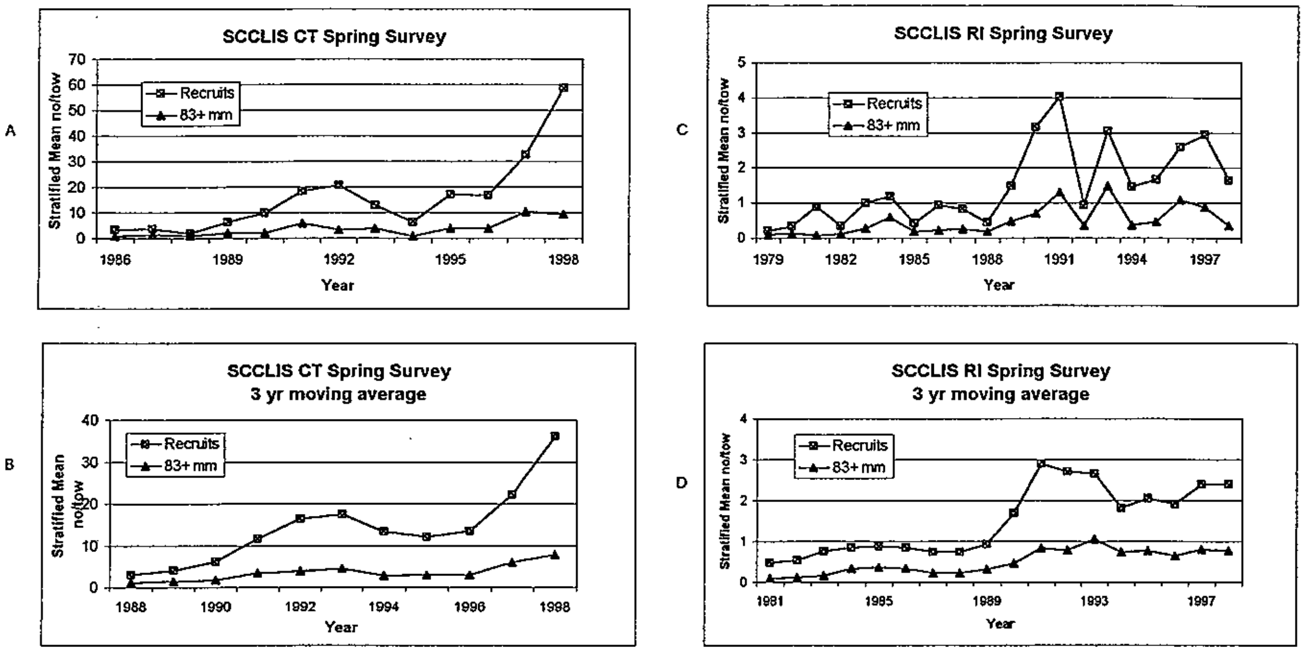


Figure 103. Average potential egg production per tow by size group and year derived from NMFS fall survey in the Gulf of Maine stock area: (A) potential number of eggs produced per tow by sub-legals, females in first molt group above minimum legal size, and females in second molt group and subsequent molt groups; (B) proportion of average potential egg production per tow derived from sub-legals, first molt group and 2+ molt groups; (C-G) average potential egg production per tow and proportion average potential egg production per tow by 5 mm size groups for selected combinations of years.

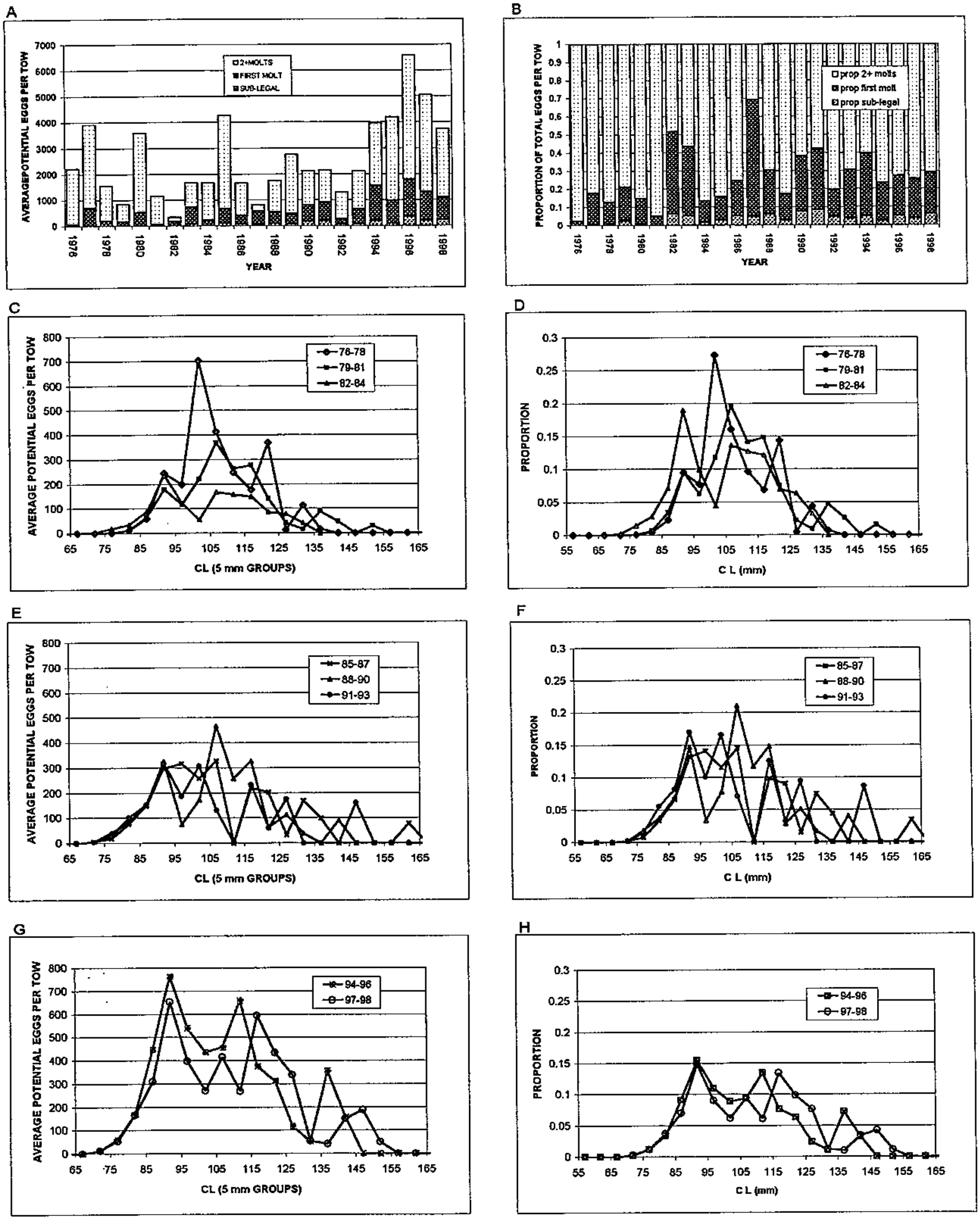


Figure 104. Average potential egg production per tow by size group and year derived from MA fall survey in the GOM stock area (514): (A) potential number of eggs produced per tow by sub-legals, females in first molt group above minimum legal size, and females in second molt group and subsequent molt groups; (B) proportion of average potential egg production per tow derived from sub-legals, first molt group and 2+ molt groups; (C-G) average potential egg production per tow and proportion average potential egg production per tow by 5 mm size groups for selected combinations of years.

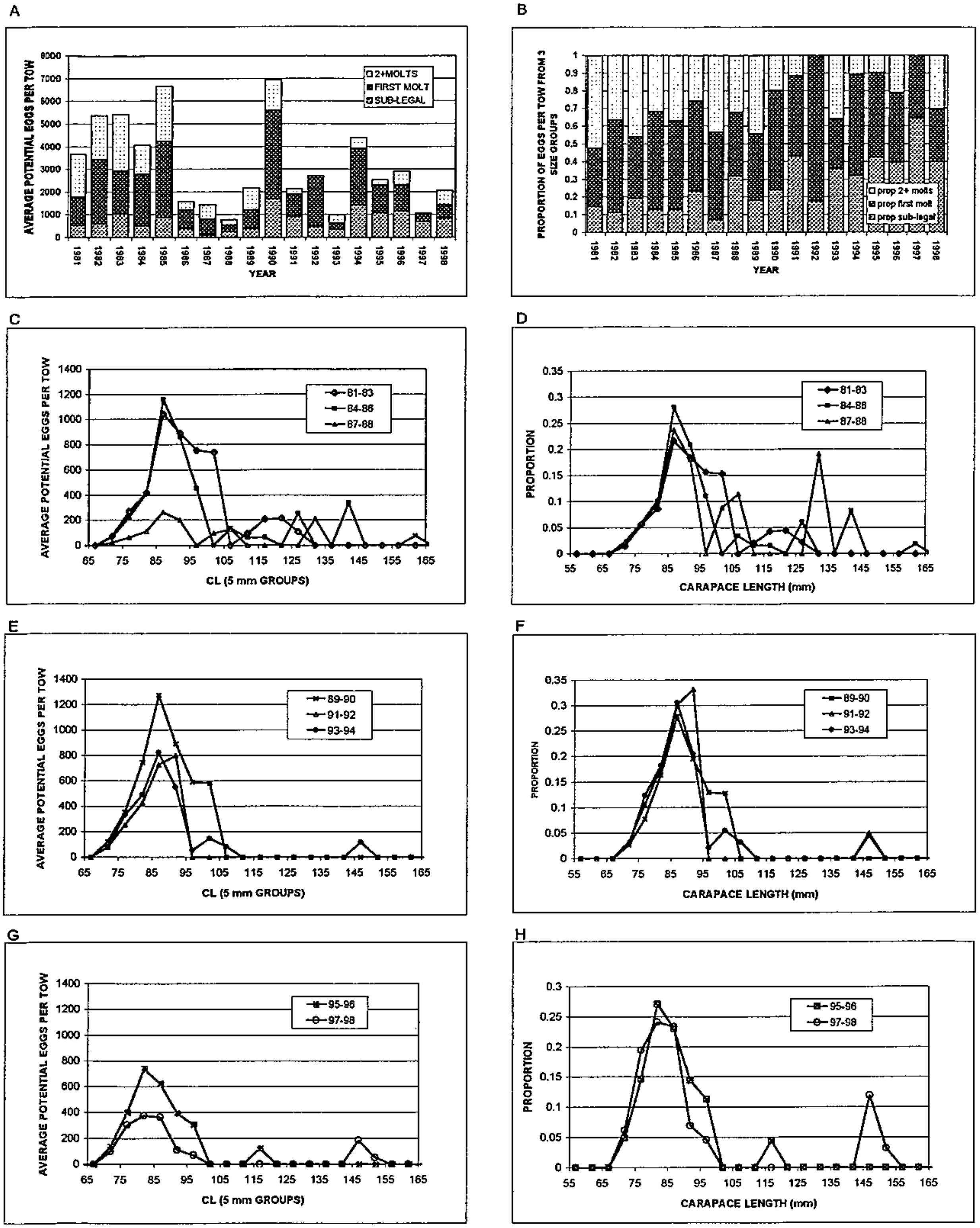


Figure 105. Average potential egg production per tow by size group and year derived from NMFS fall survey in the GBS stock area: (A) potential number of eggs produced per tow by sub-legals, females in first molt group above minimum legal size, and females in second molt group and subsequent molt groups; (B) proportion of average potential egg production per tow derived from sub-legals, first molt group and 2+ molt groups; (C-G) average potential egg production per tow and proportion average potential egg production per tow by 5 mm size groups for selected combinations of years.

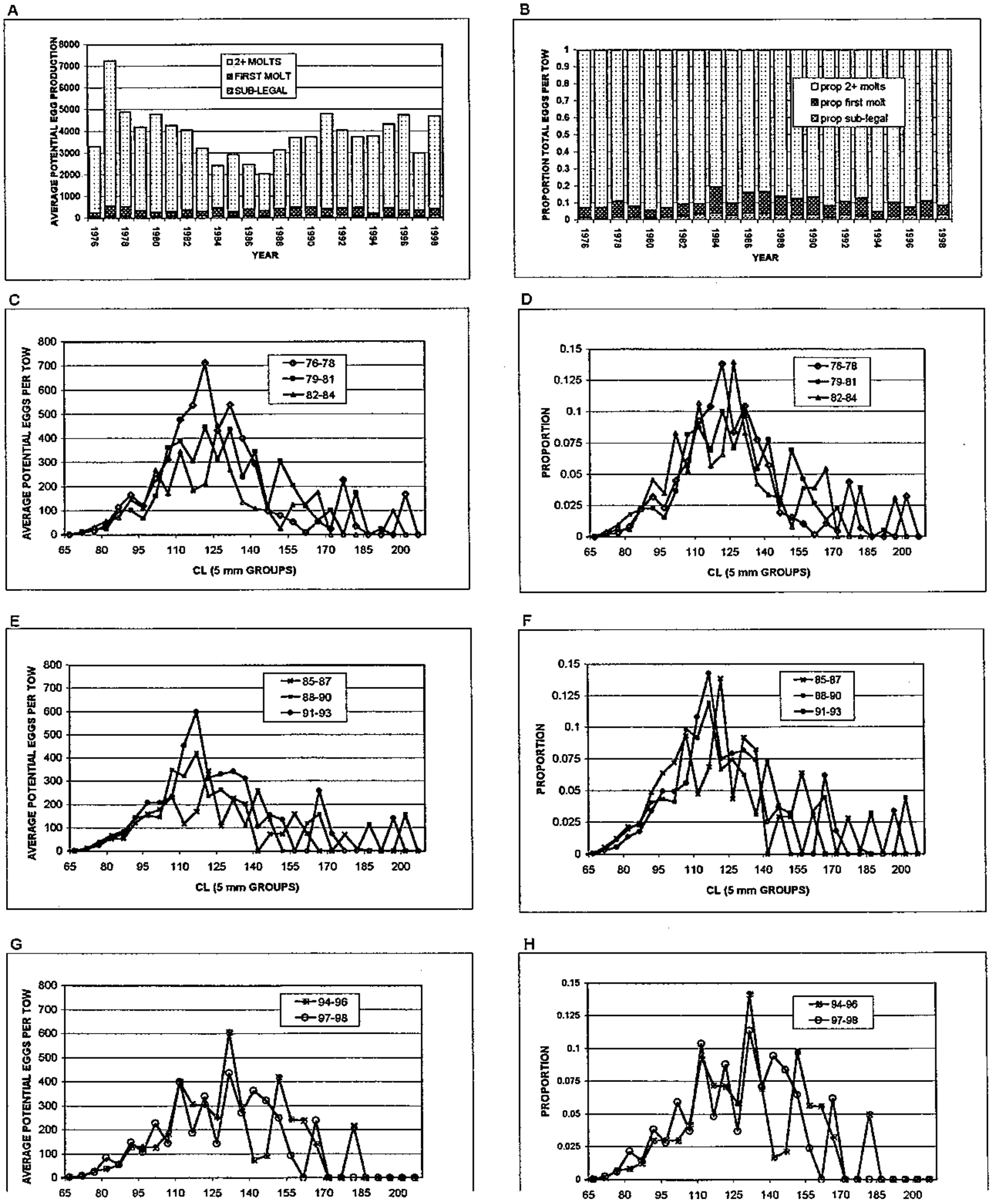


Figure 106. Average potential egg production per tow by size group and year derived from NMFS fall survey in the SCCLIS stock area (offshore waters of statistical area 539): (A) potential number of eggs produced per tow by sub-legals, females in first molt group above minimum legal size, and females in second molt group and subsequent molt groups; (B) proportion of average potential egg production per tow derived from sub-legals, first molt group and 2+ molt groups; (C-G) average potential egg production per tow and proportion average potential egg production per tow by 5 mm size groups for selected combinations of years.

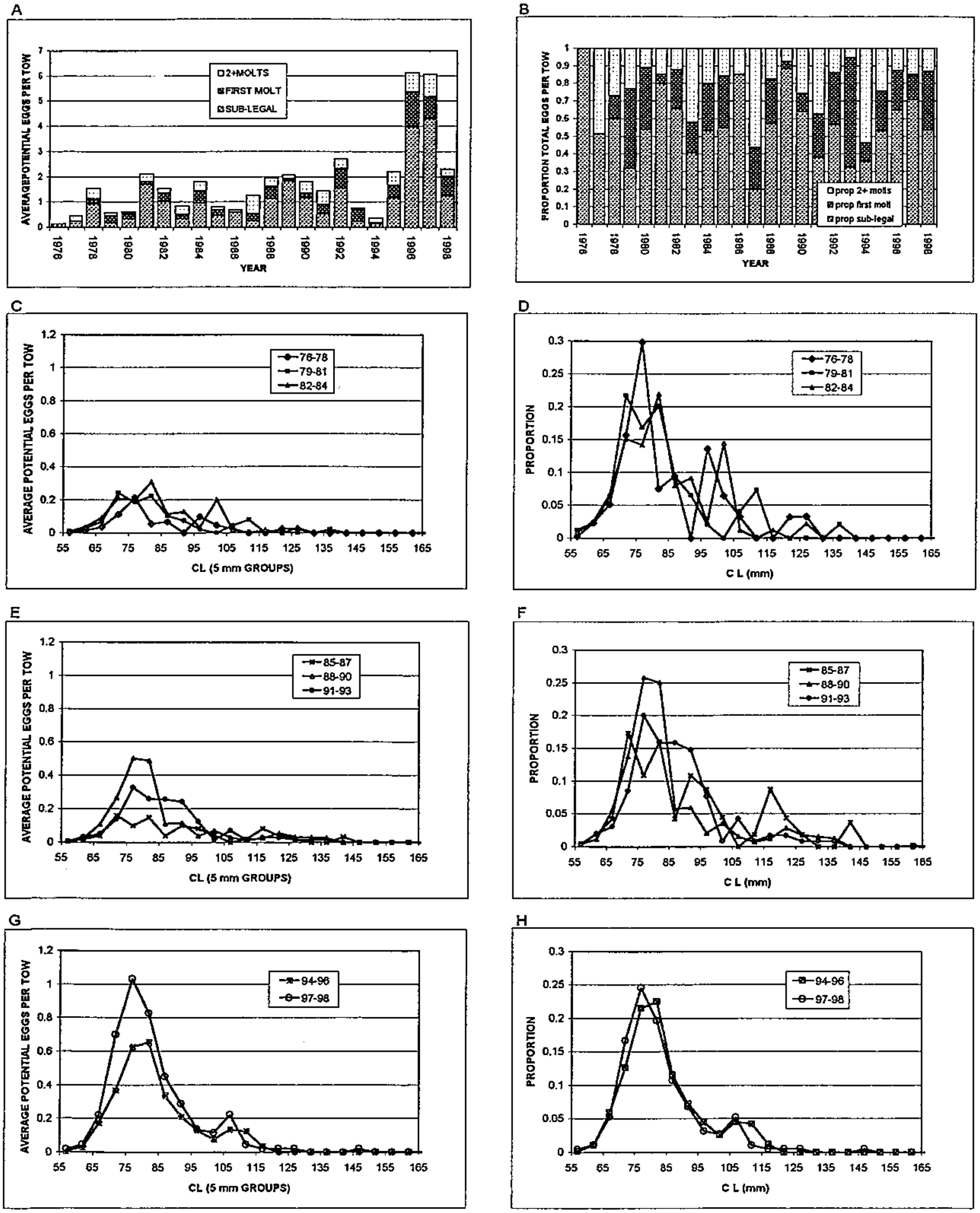


Figure 107. Average potential egg production per tow by size group and year derived from RI fall survey in the SCCLIS stock area (inshore waters of statistical area 539): (A) potential number of eggs produced per tow by sub-legals, females in first molt group above minimum legal size, and females in second molt group and subsequent molt groups; (B) proportion of average potential egg production per tow derived from sub-legals, first molt group and 2+ molt groups; (C-G) average potential egg production per tow and proportion average potential egg production per tow by 5 mm size groups for selected combinations of year

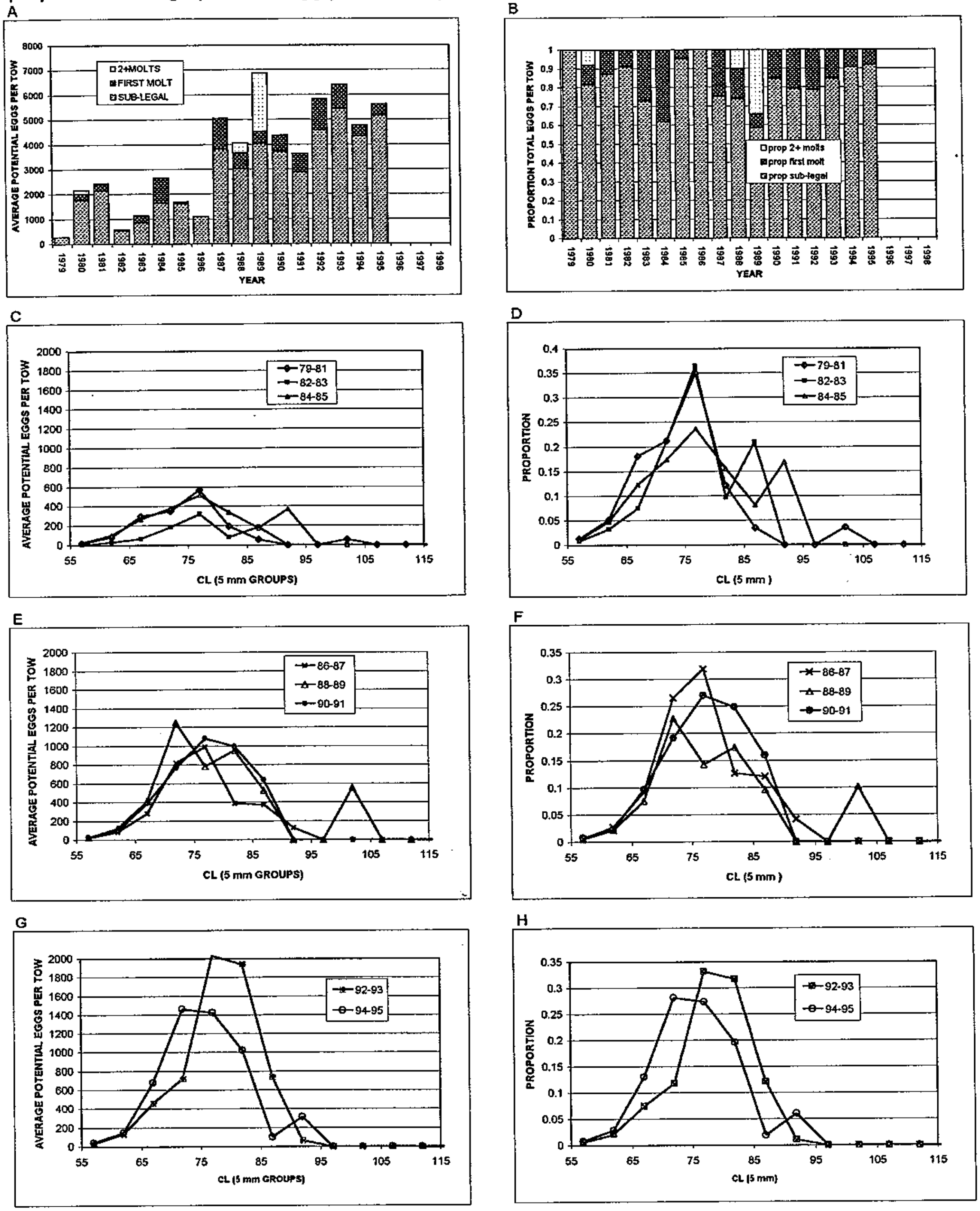


Figure 108. Average potential egg production per tow by size group and year derived from CT fall surv in the SCCLIS stock area (Long Island Sound): (A) potential number of eggs produced per tow by sub-legals, females in first molt group above minimum legal size, and females in second molt group and subsequent molt groups; (B) proportion of average potential egg production per tow derived from sub-legals, first molt group and 2+ molt groups; (C-G) average potential egg production per tow and proporti average potential egg production per tow by 5 mm size groups for selected combinations of years.

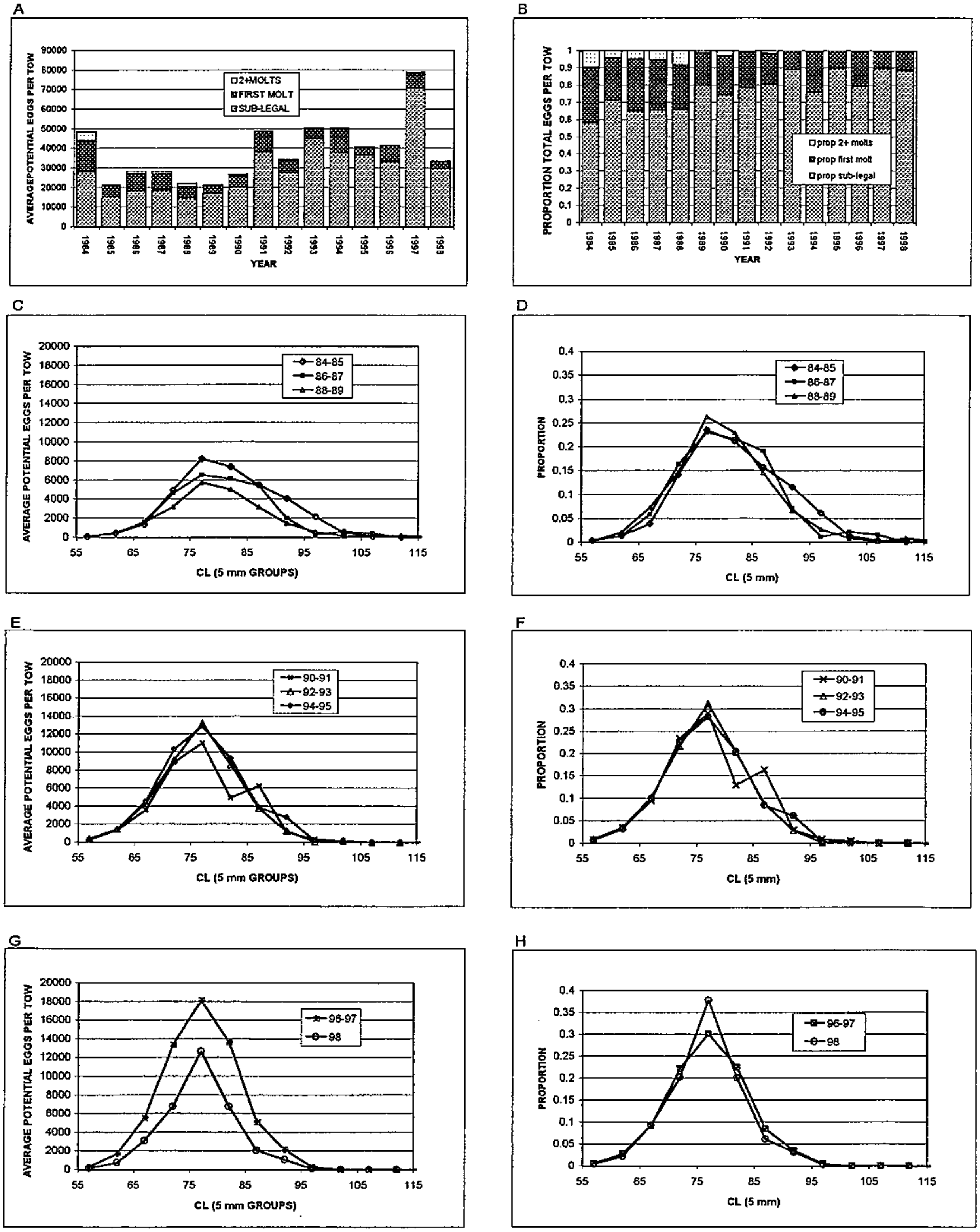


Figure 109. Average potential egg production per tow by size group and year derived from CT spring survey in the SCCLIS stock area (Long Island Sound): (A) potential number of eggs produced per tow by sub-legals, females in first molt group above minimum legal size, and females in second molt group and subsequent molt groups; (B) proportion of average potential egg production per tow derived from sub-legals, first molt group and 2+ molt groups; (C-G) average potential egg production per tow and proportion average potential egg production per tow by 5 mm size groups for selected combinations of years.

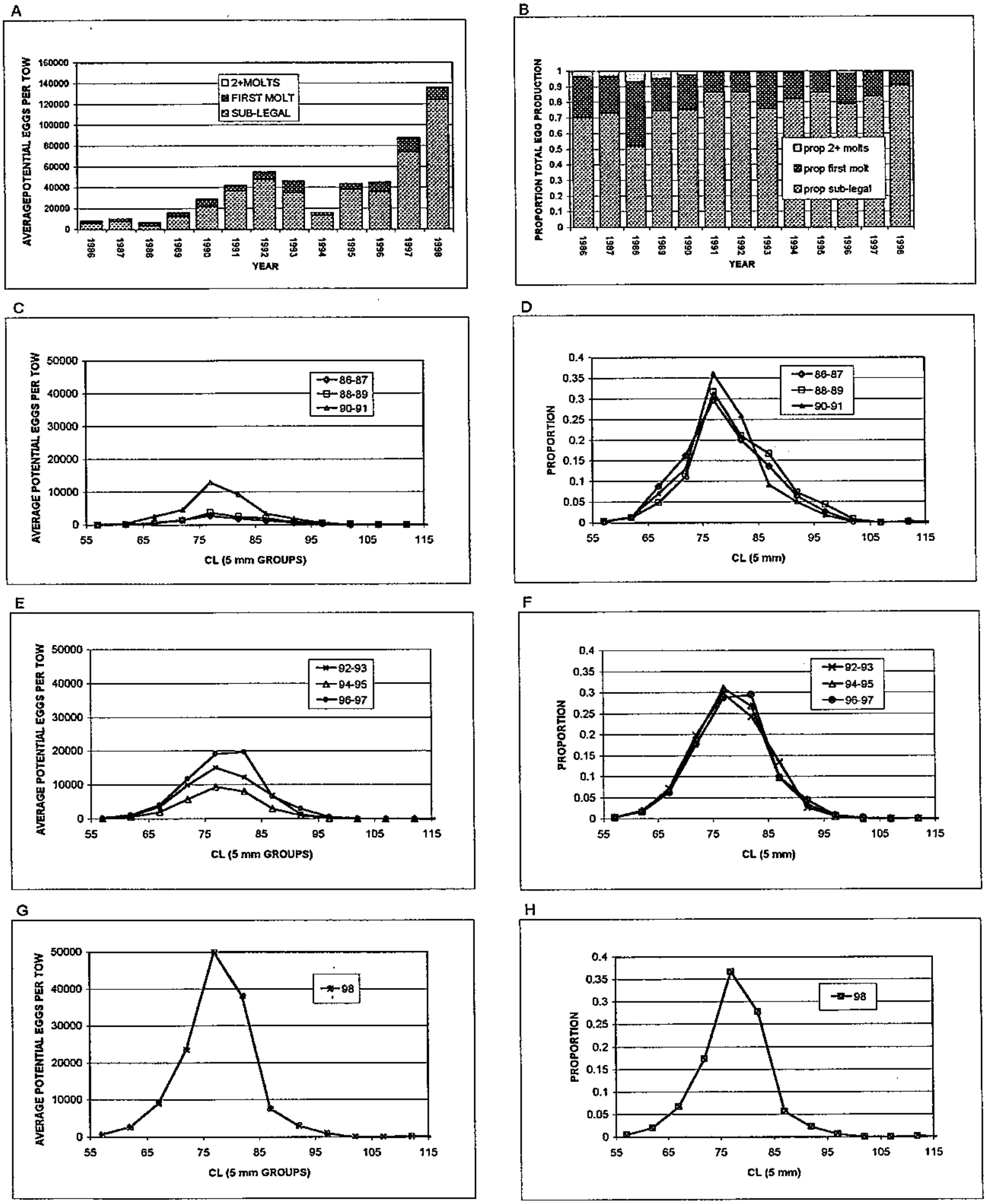
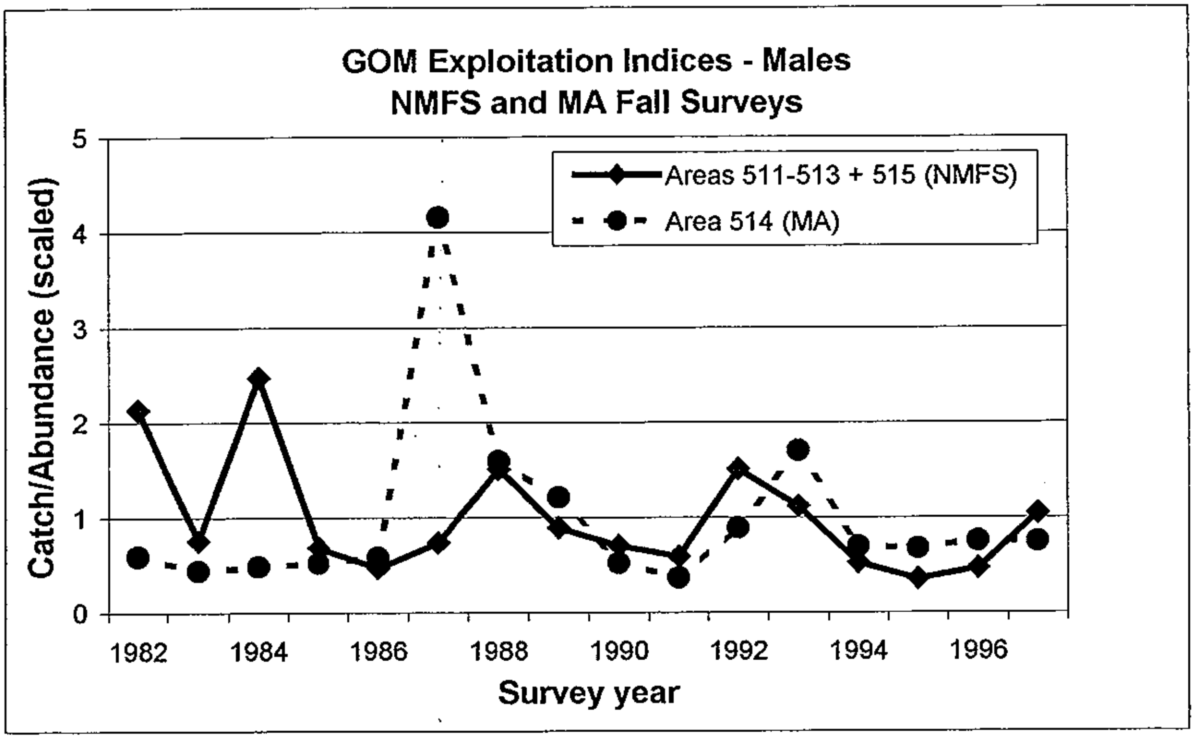


Figure 110. Exploitation indices for male and female lobsters in the GOM stock area derived from NMFS fall survey in statistical areas 511-513 + 515 and from MA fall survey in statistical area 514 for survey years 1982-1997.



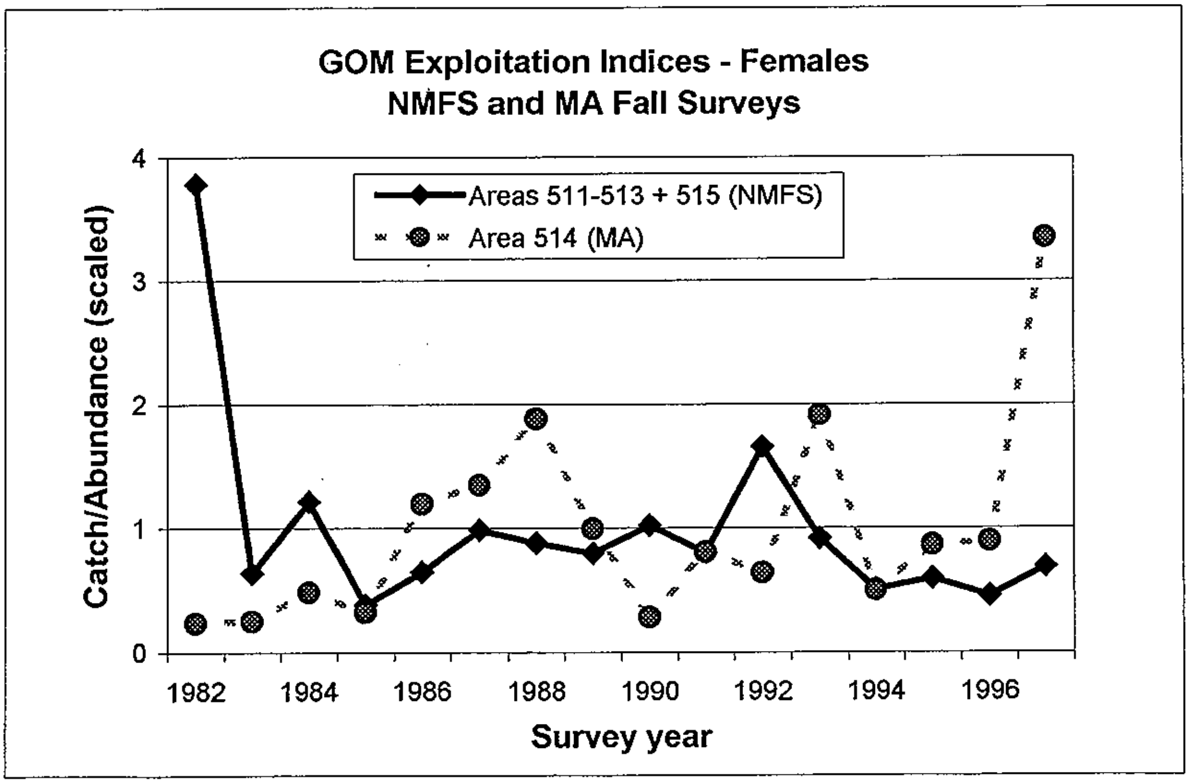


Figure 111. Exploitation indices for male and female lobsters in the GBS stock area derived from NMFS fall survey for survey years 1982-1997.

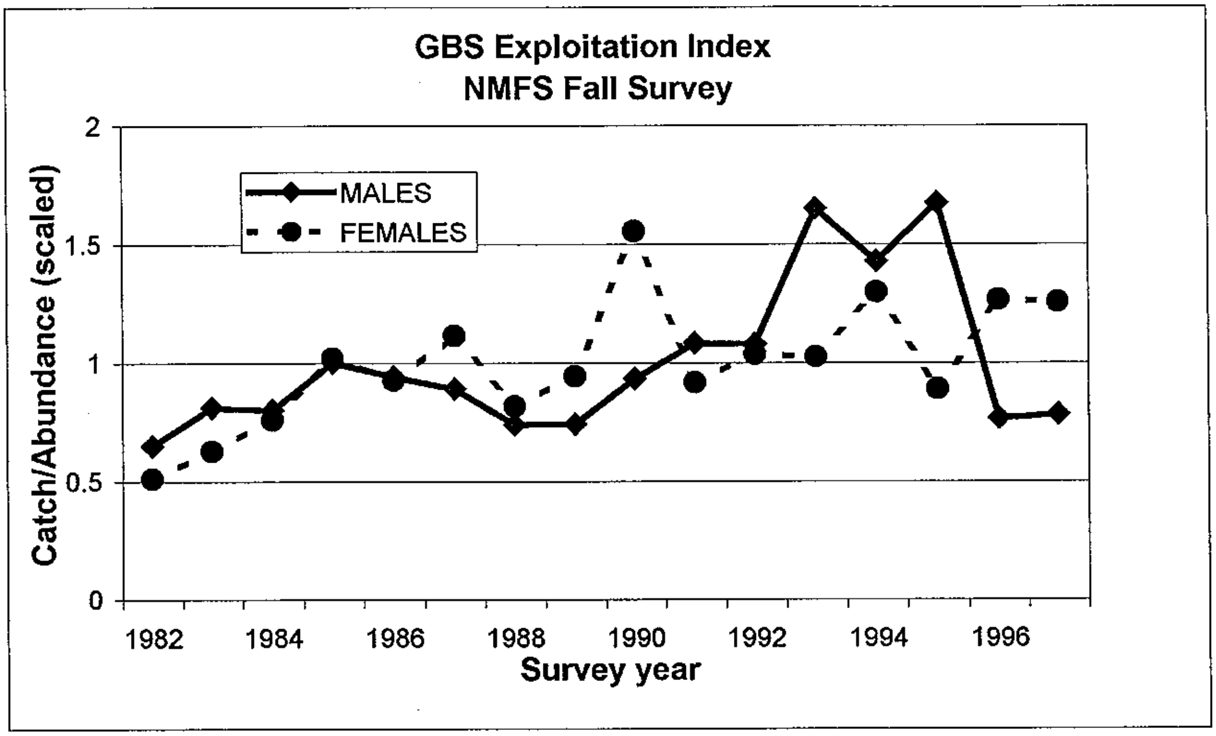
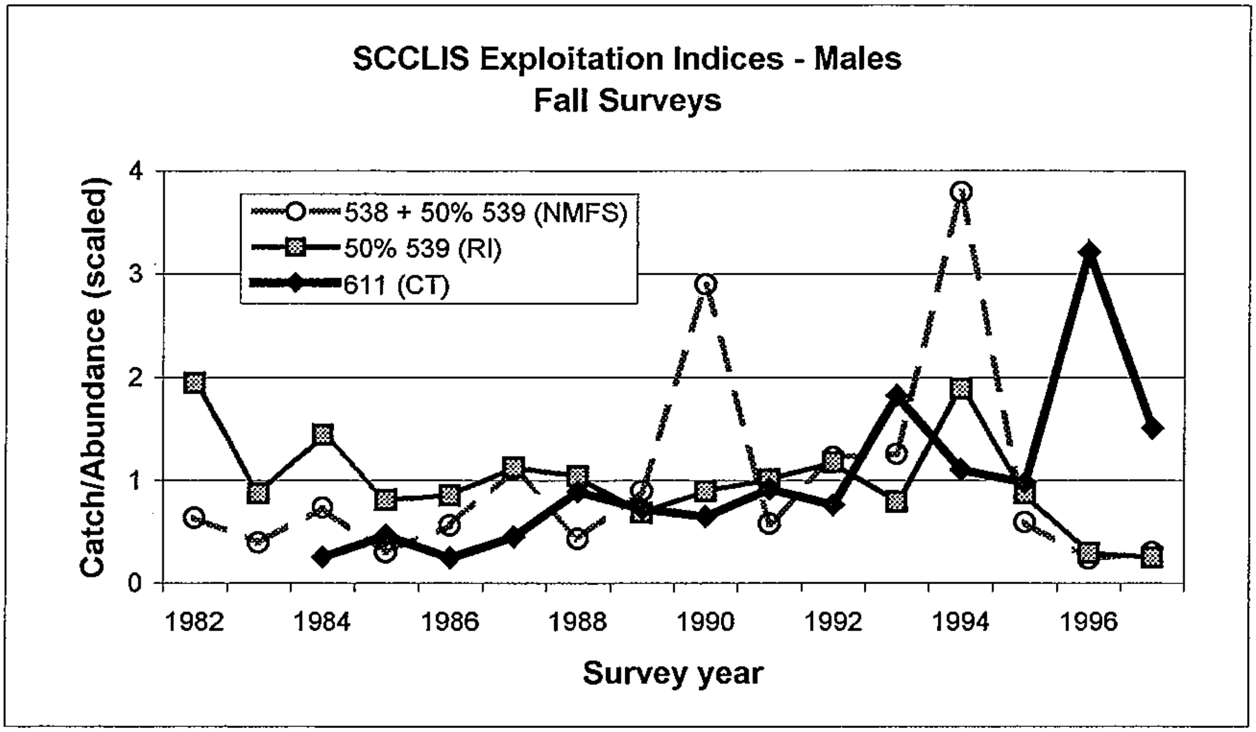


Figure 112. Exploitation indices for male and female lobsters in the SCCLIS stock area derived from NMFS fall survey in statistical areas 538 and 539, RI fall survey in area 539 and from CT fall survey in statistical area 611 for survey years 1982-1997.



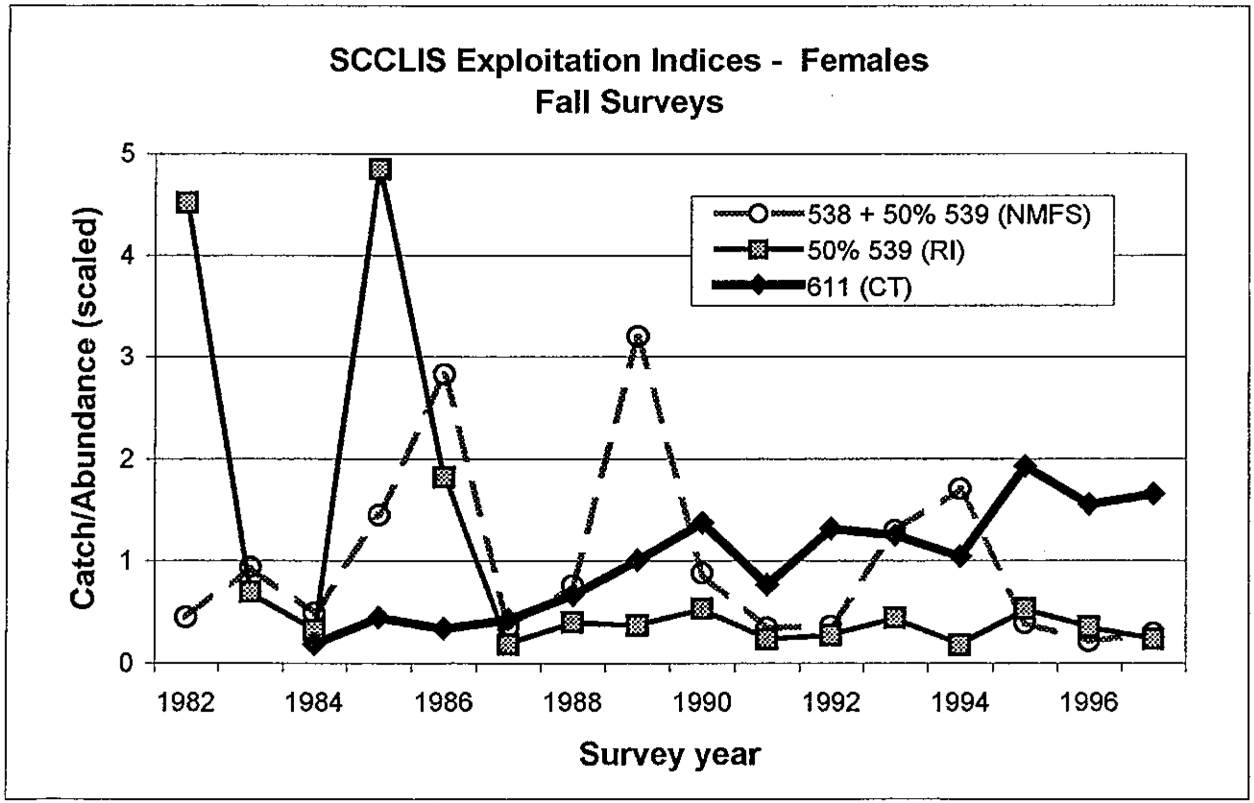
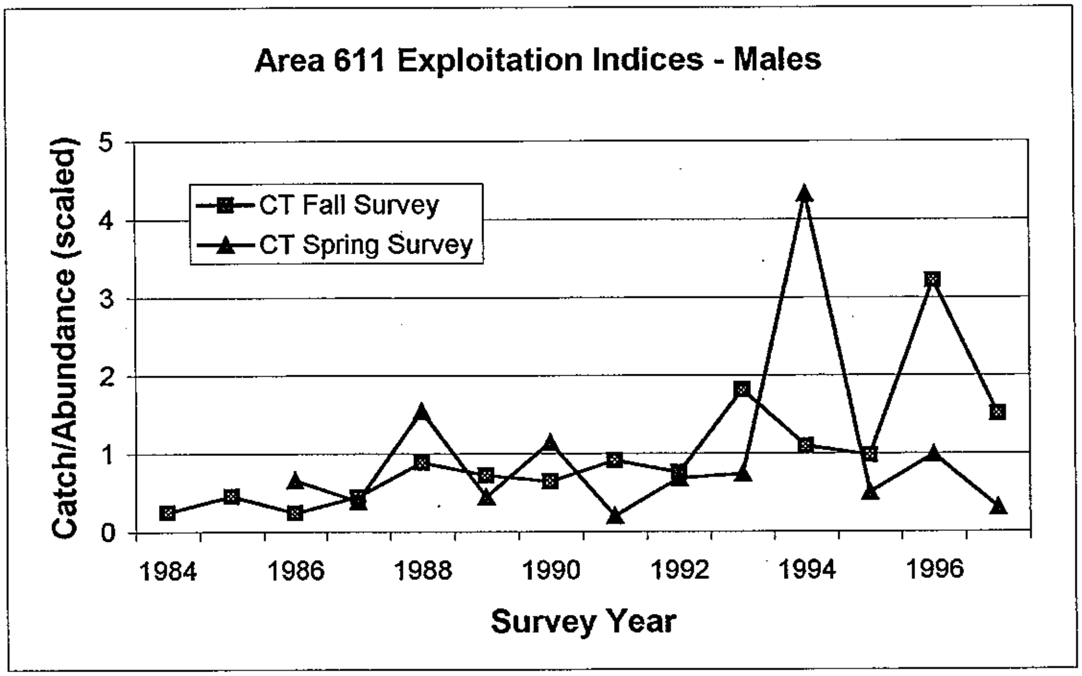


Figure 113. Exploitation indices for male and female lobsters in Long Island Sound derived from fall spring CT surveys



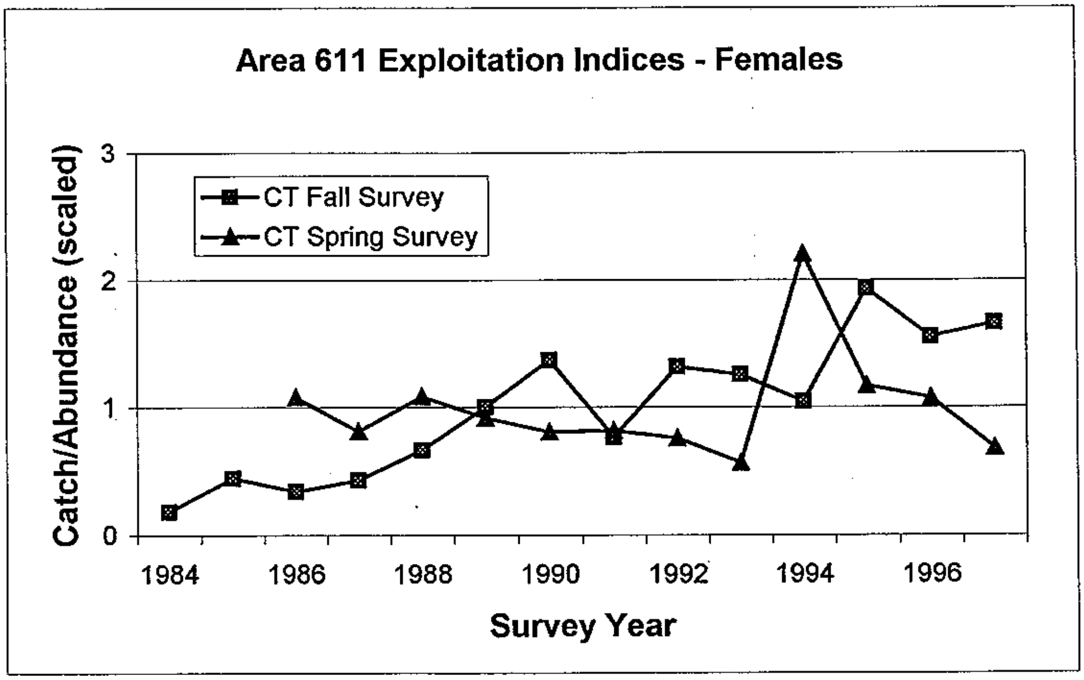


Figure 114. GOM and GBS survey mass balance fishing mortality rates from federal and MA inshore trawl surveys

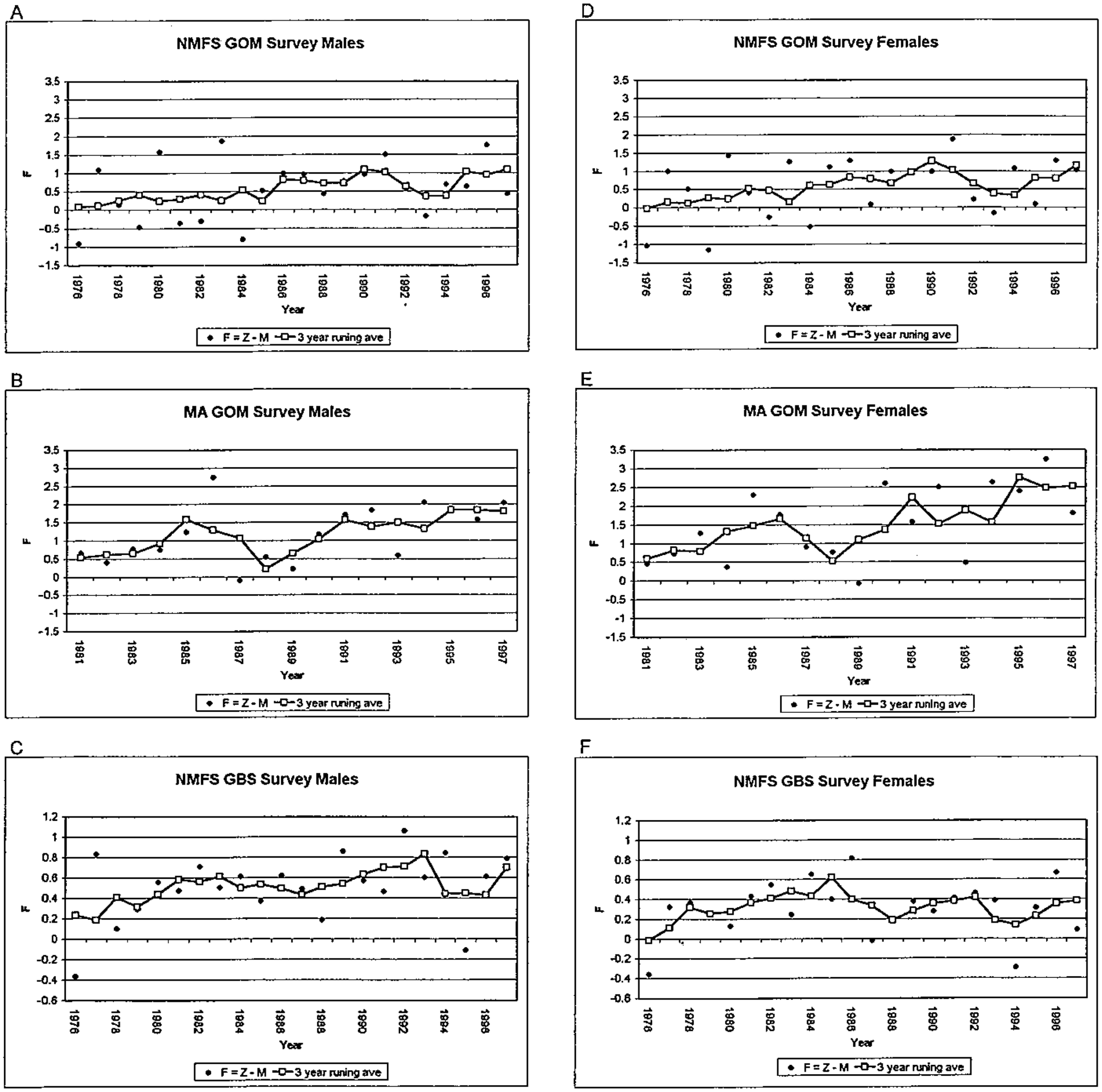


Figure 115. SCCLIS survey mass balance fishing mortality rates from several state and federal trawl surveys

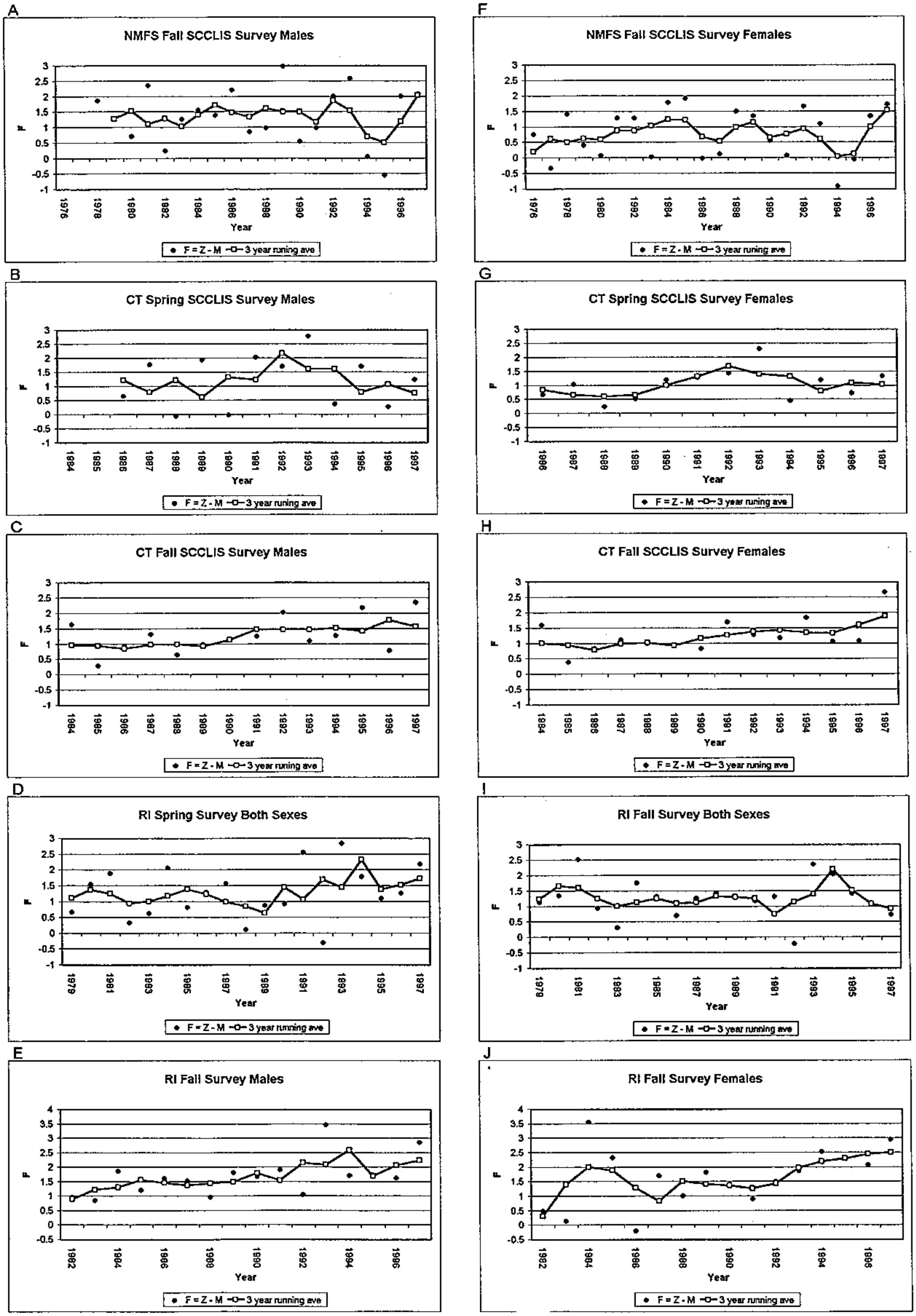


Figure 116. Comparison of Fishing Mortality Estimates from DeLury and Survey Mass Balance for the Three Stock Areas

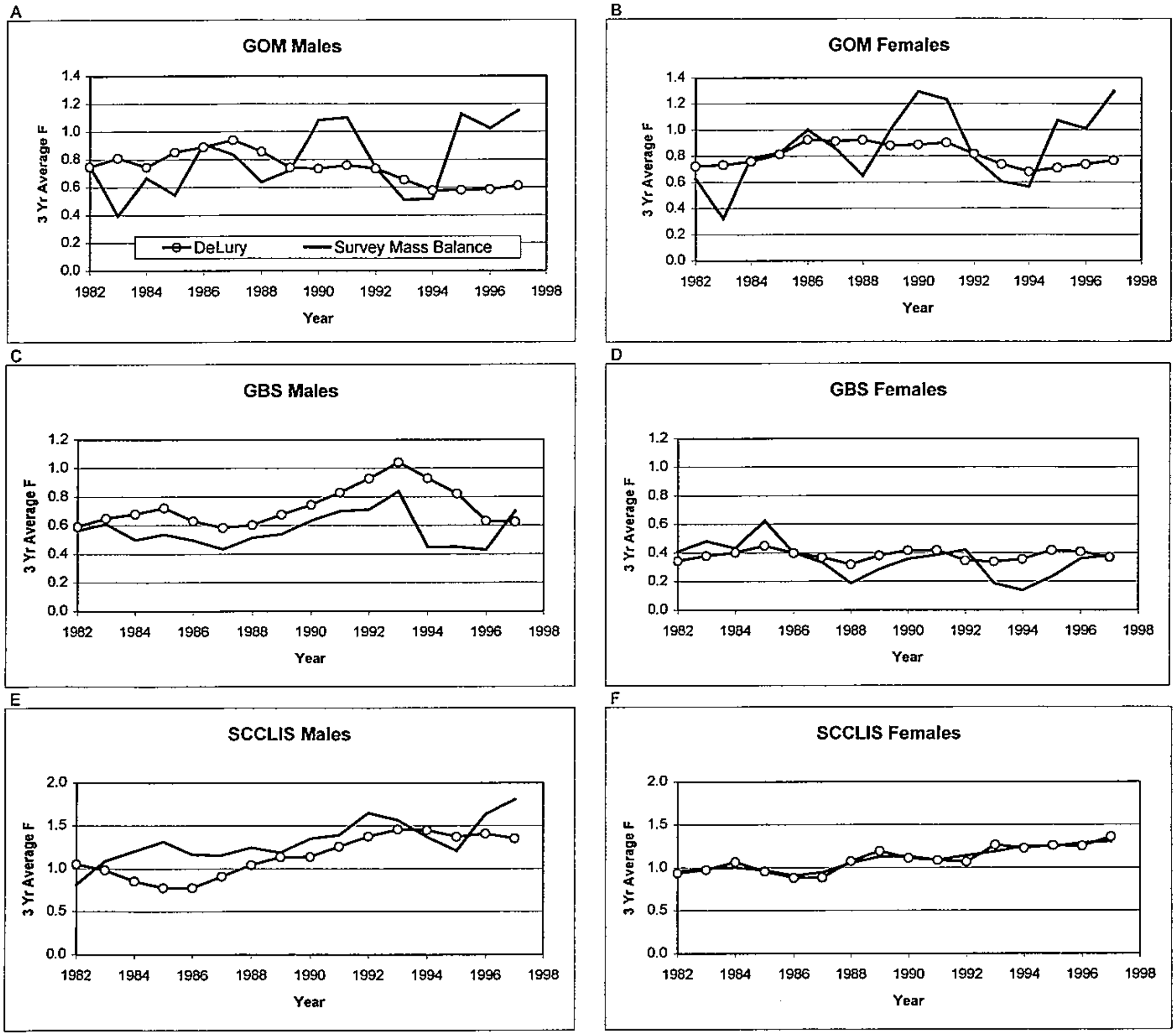
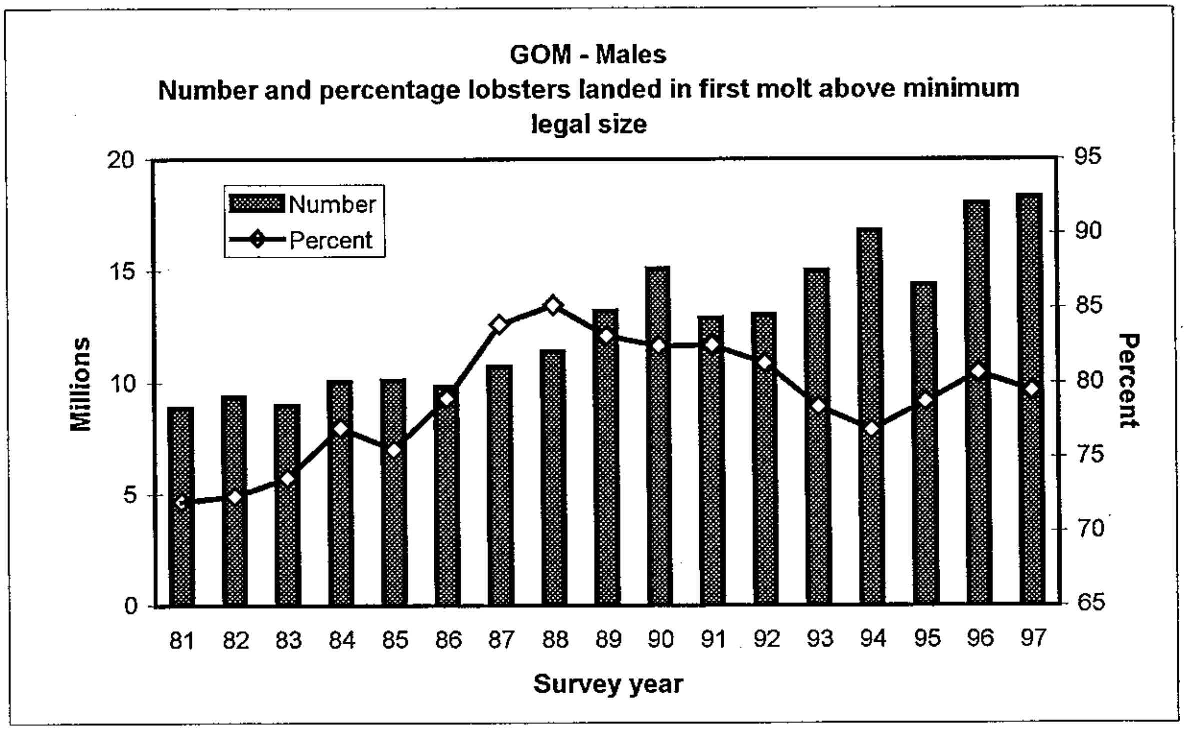


Figure 117

A



B

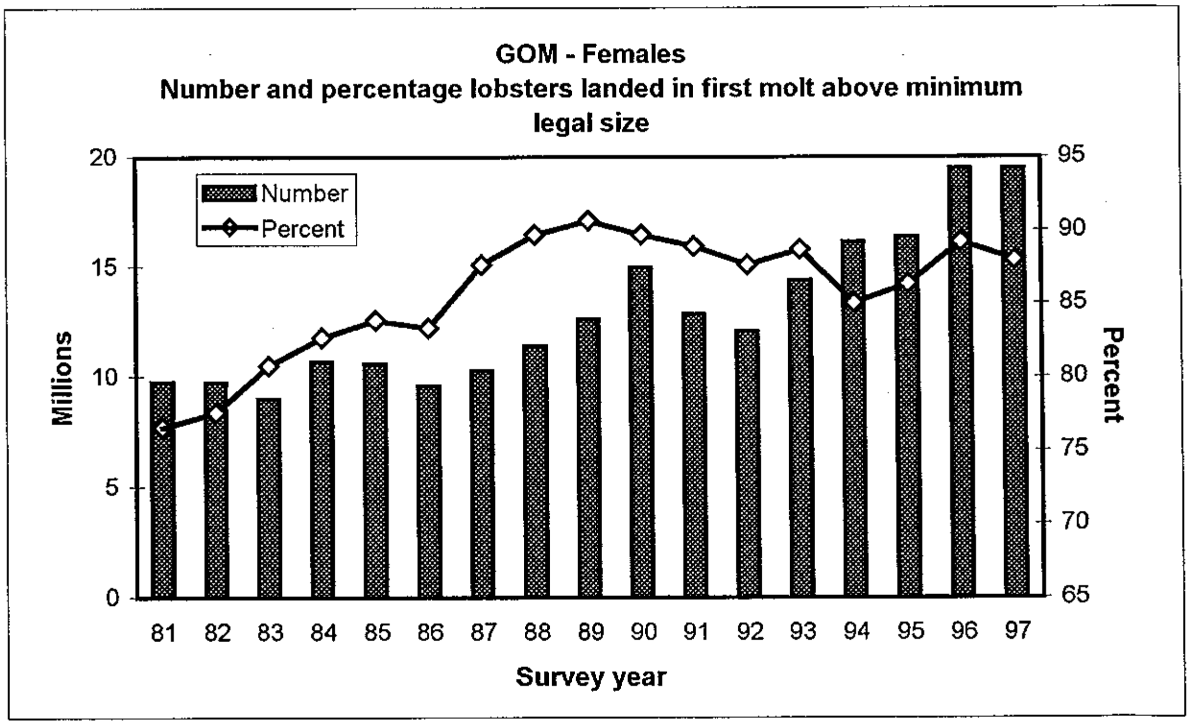


Figure 118

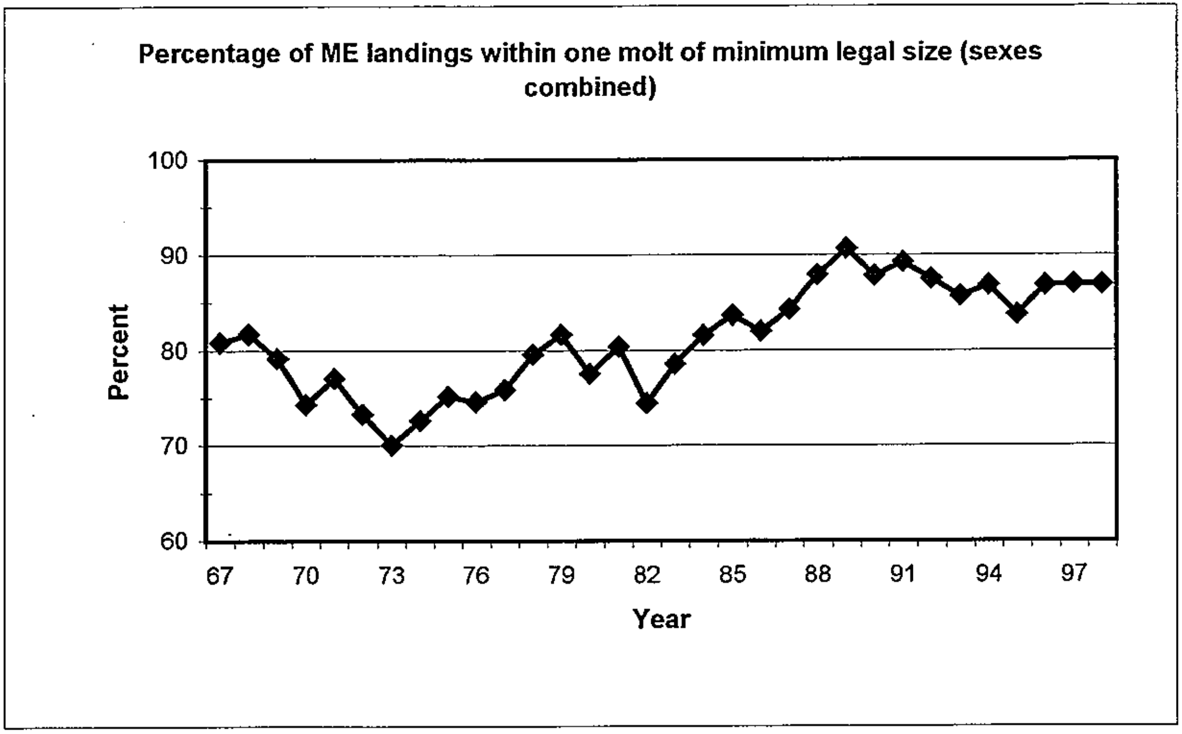
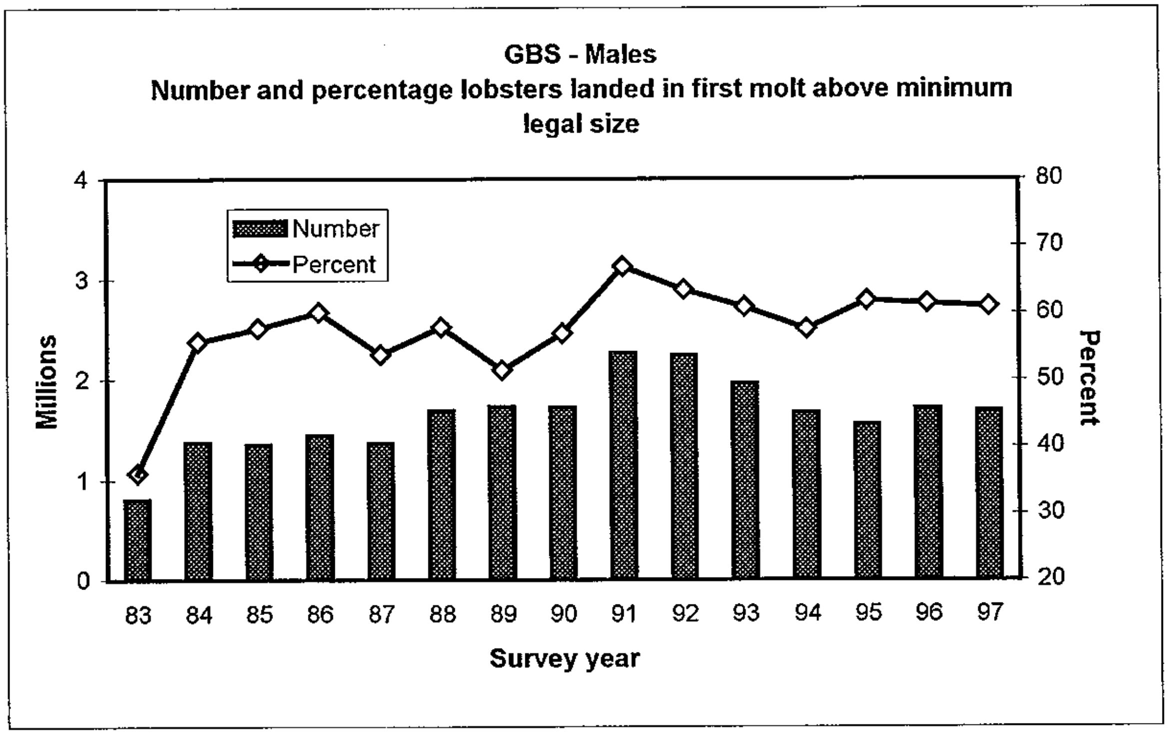

Percentage of ME landings within one molt of minimum legal size (sexes combined)
100
90
80
70
60
Percent
67
70
73
76
79
82
85
88
91
94
97
Year

Figure 119


GBS - Males
Number and percentage lobsters landed in first molt above minimum legal size
Number
Percent
Millions
Percent
0
1
2
3
4
20
30
40
50
60
70
80
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
Survey year

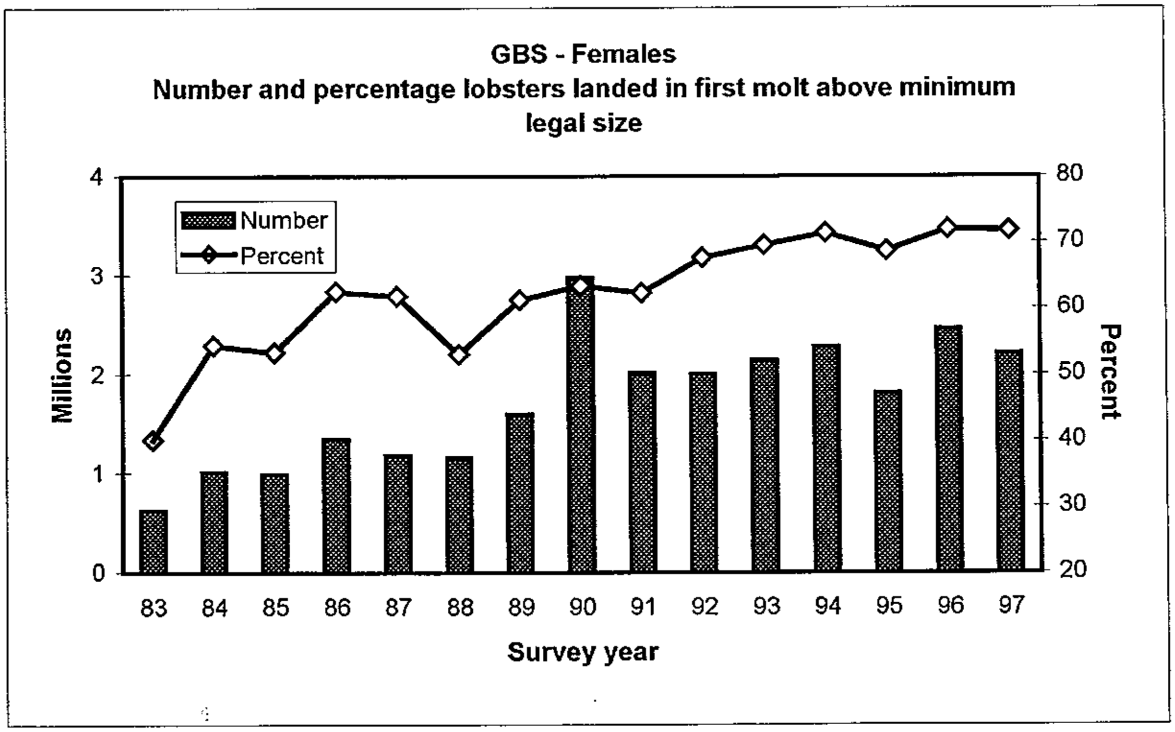
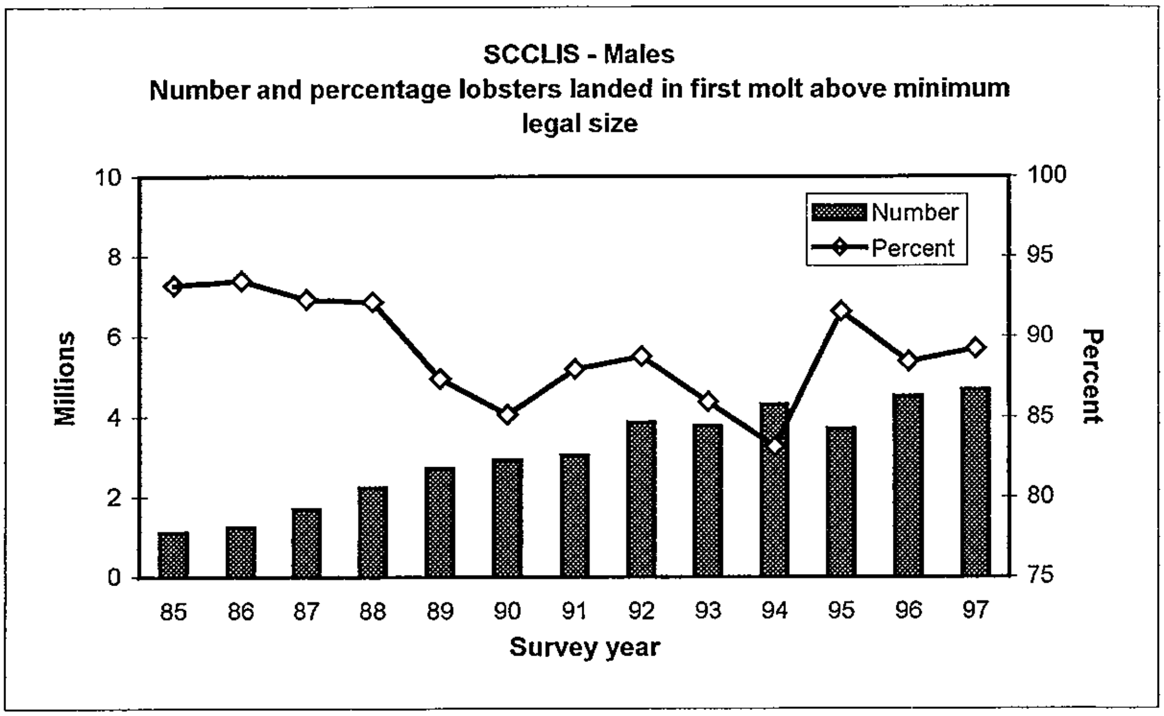

GBS - Females
Number and percentage lobsters landed in first molt above minimum legal size
Number
Percent
Millions
Percent
0
1
2
3
4
20
30
40
50
60
70
80
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
Survey year

Figure 120


SCCLIS - Males
Number and percentage lobsters landed in first molt above minimum legal size
Millions
Percent
10
8
6
4
2
0
100
95
90
85
80
75
Number
Percent
85
86
87
88
89
90
91
92
93
94
95
96
97
Survey year

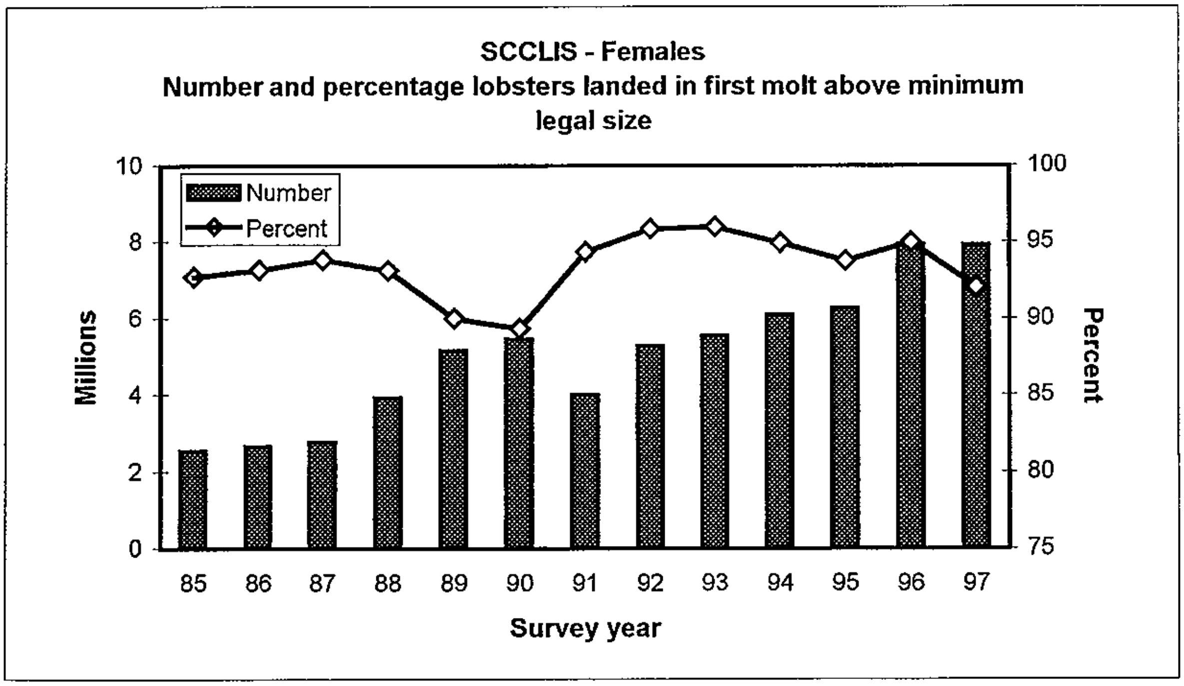
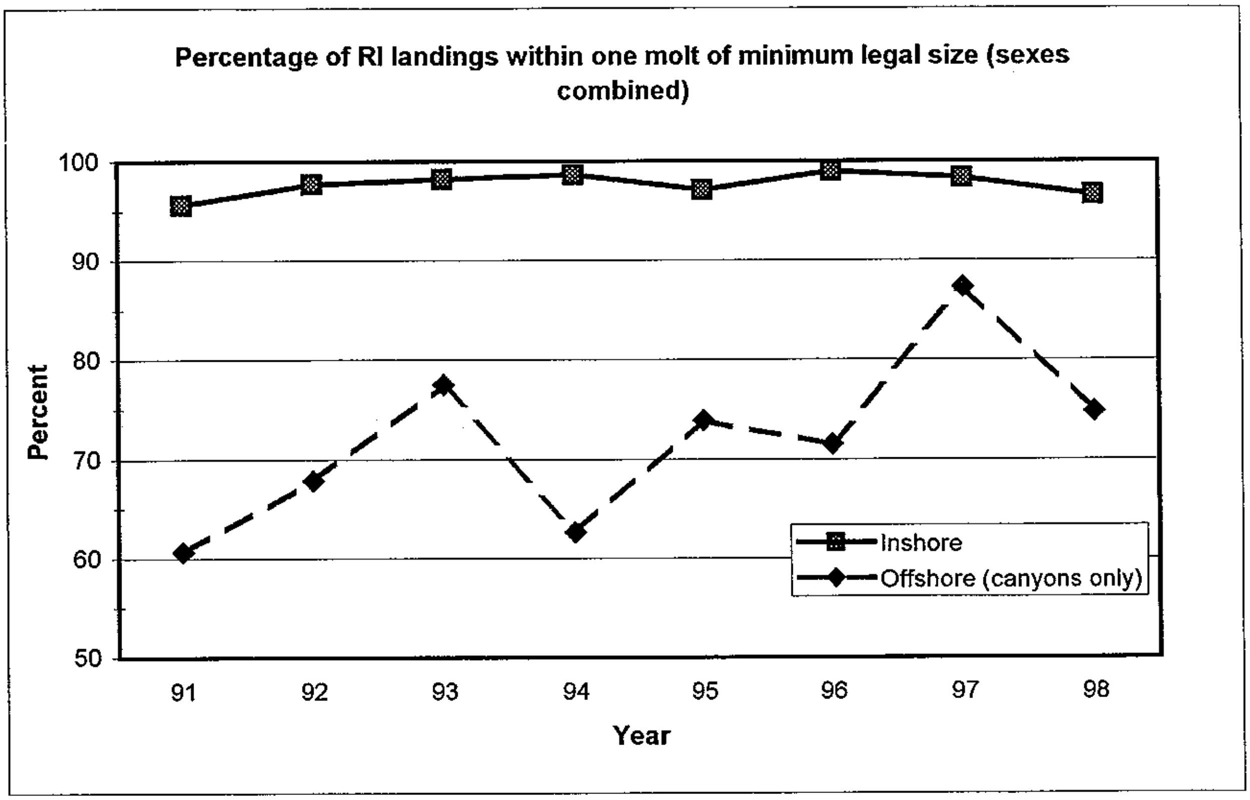

SCCLIS - Females
Number and percentage lobsters landed in first molt above minimum legal size
Millions
Percent
10
8
6
4
2
0
100
95
90
85
80
75
Number
Percent
85
86
87
88
89
90
91
92
93
94
95
96
97
Survey year

Figure 121



Percentage of RI landings within one molt of minimum legal size (sexes combined)

Figure 122. Commercial catch-per-unit-effort for three statistical areas along the eastern (511), central (512), and western (513) Maine coast derived from Maine Dept. Marine Resources port sampling data in numbers of marketable lobsters per trap haul.

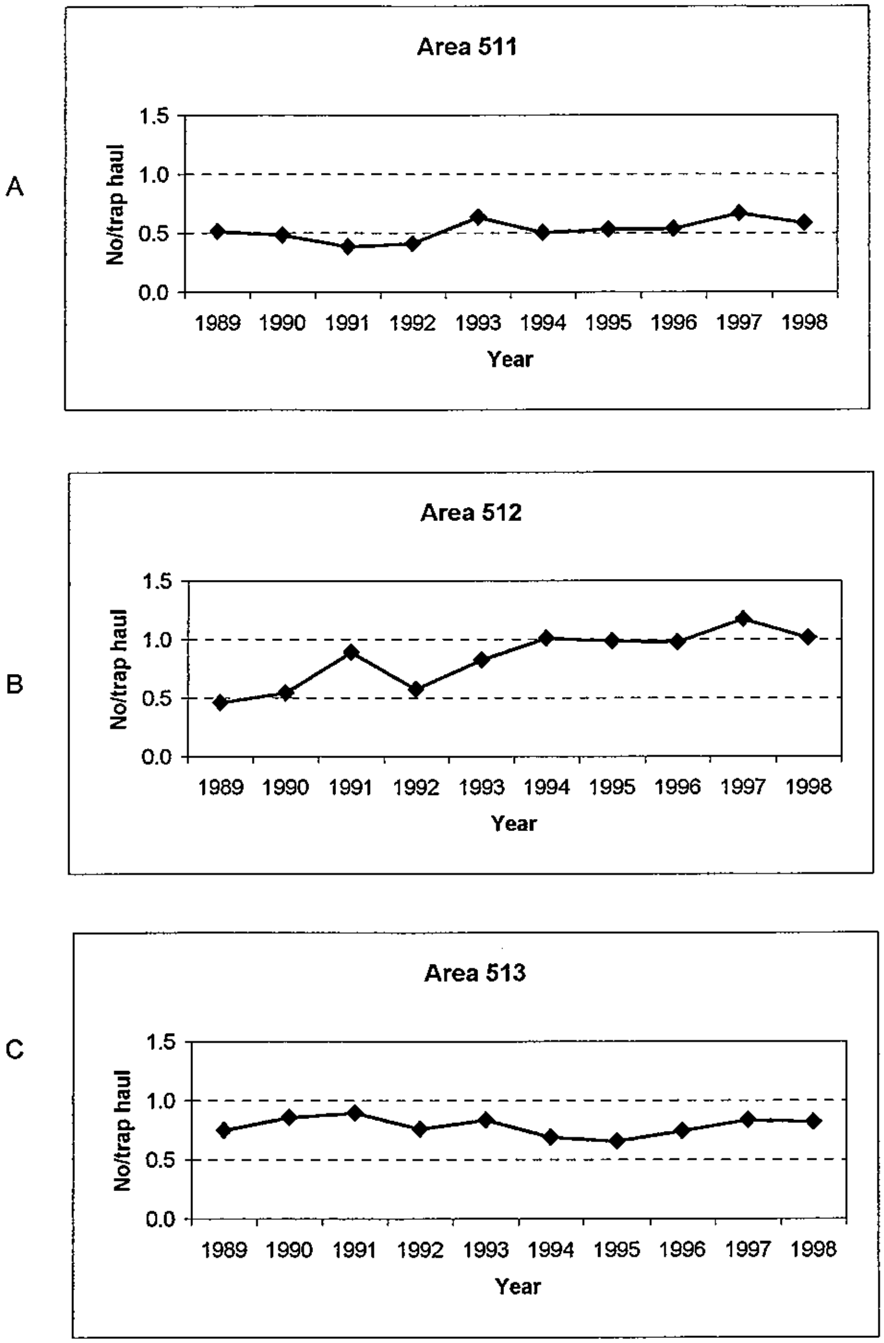


Figure 123. Commercial catch-per-unit-effort for three statistical areas along the eastern (511), central (512), and western (513) Maine coast derived from Maine Dept. Marine Resources port sampling data in numbers of marketable lobsters per trap haul set-over-days.

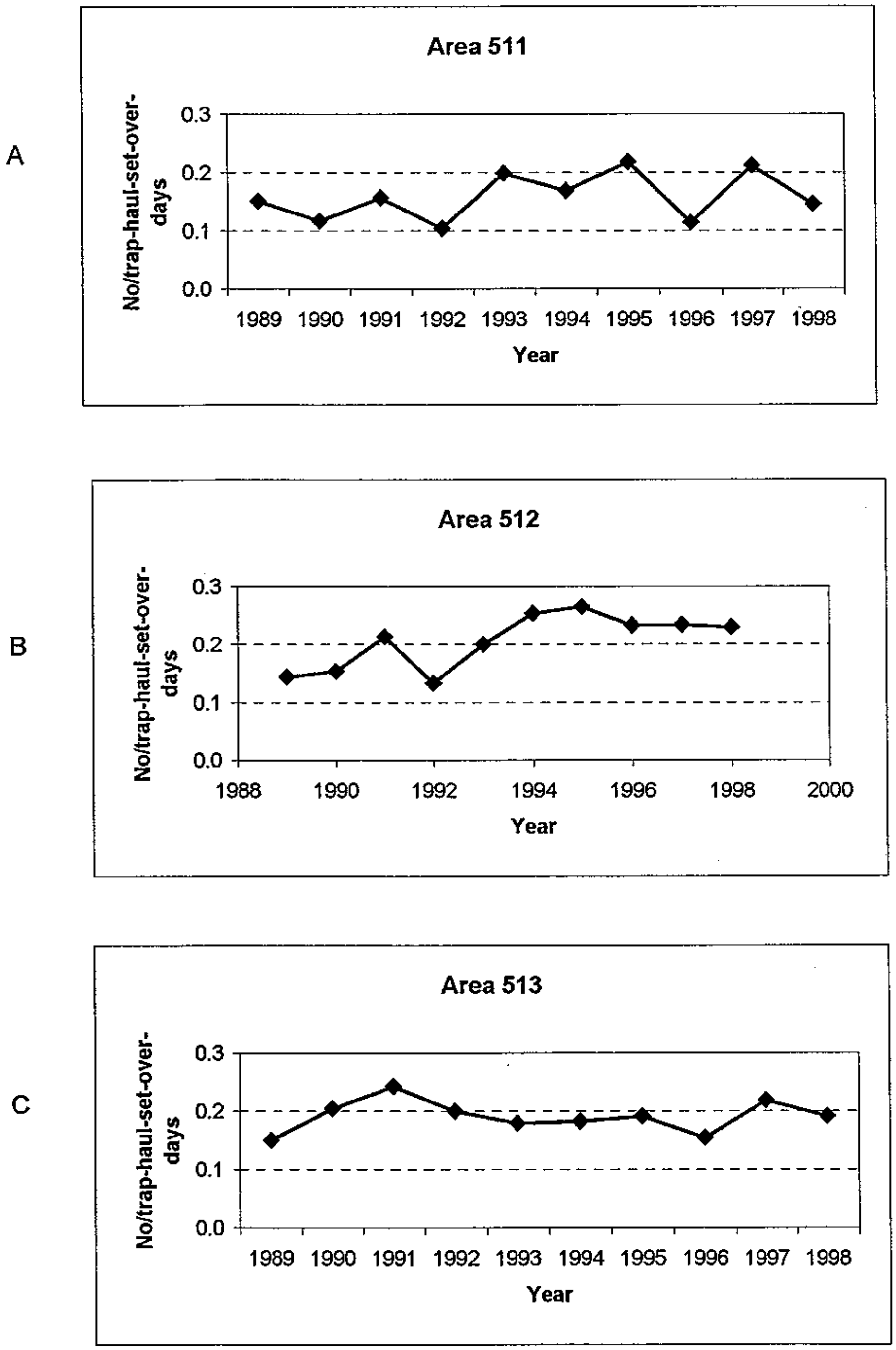


Figure 124. Commercial catch-per-unit-effort for area 513 derived from NH Fish & Game sea sampling data in numbers of marketable lobsters per trap haul (CTH) and per trap haul-set-over-days (CTHSOD).

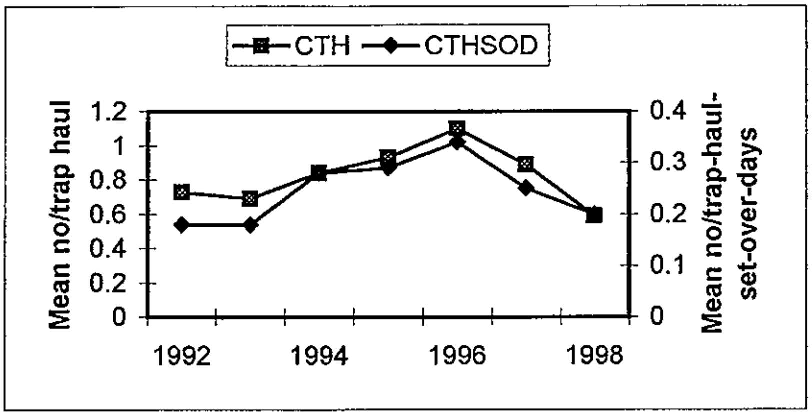
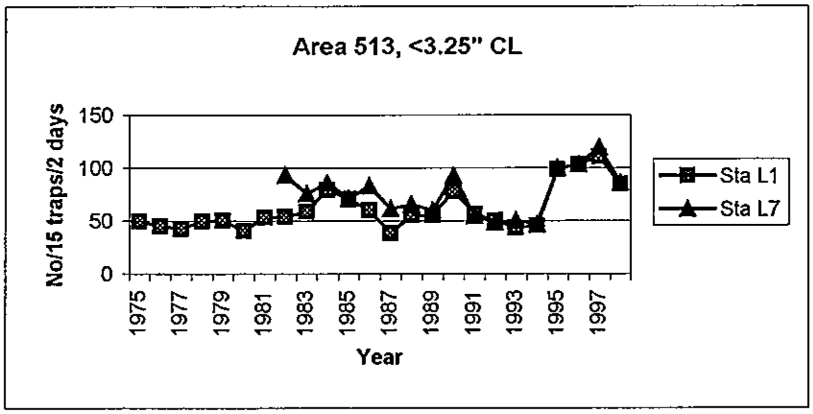


Figure 125. Catch-per-unit-effort for lobsters below and above 3.25 inches CL from two locations off the Seabrook power plant (area 513) taken in ventless traps, with effort standardized to catch per 15 traps for a two day soak time. (Data provided as part of Seabrook Station Environmental Monitoring Program).

A



B

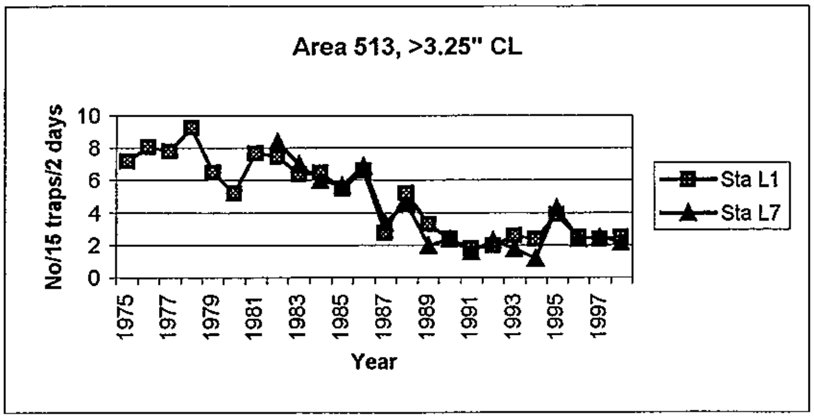


Figure 126. Commercial catch-per-unit-effort for three statistical areas off the MA coast, SW GOM (area 514), east of Cape Cod (521), and south of Cape Cod (538), derived from sea sampling data and standardized to a three day soak time.

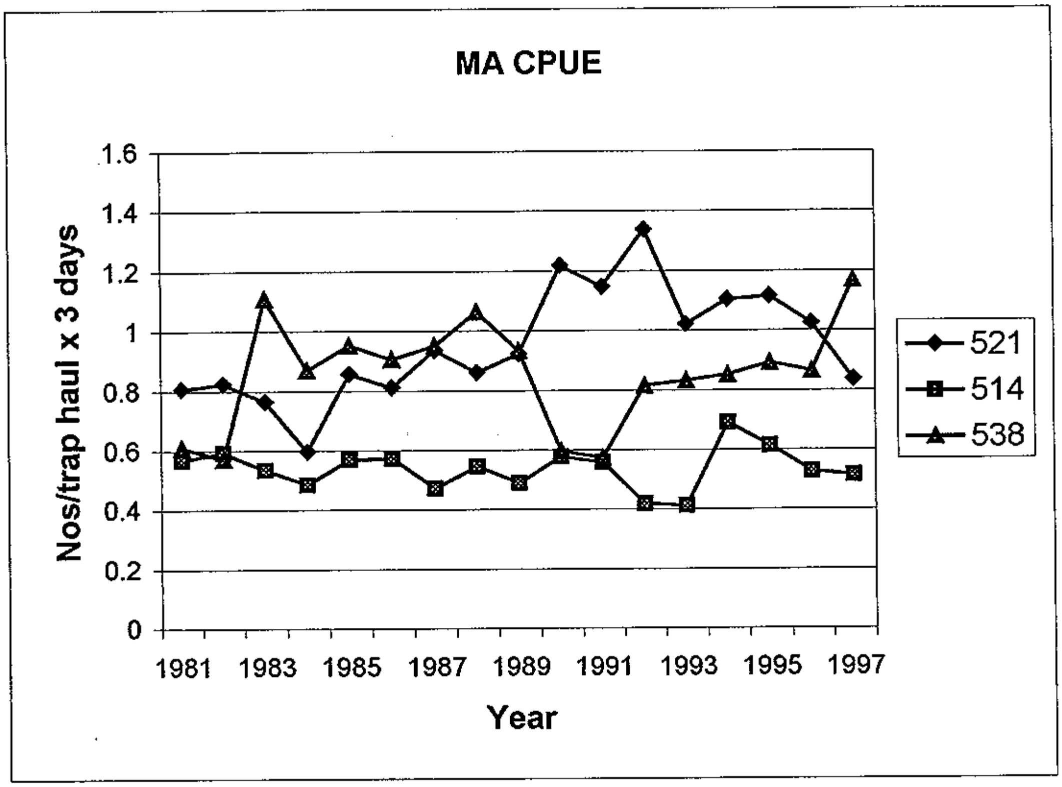
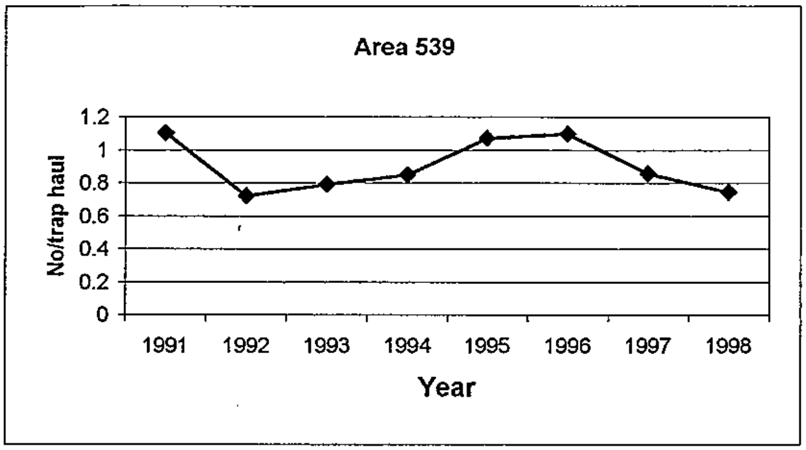


Figure 127. Commercial catch-per-unit-effort for statistical areas 539 (RI inshore) and 537+616 (Block and Hudson Canyons) derived from RI Dept. Environmental Management sea sampling data for marketable lobsters.



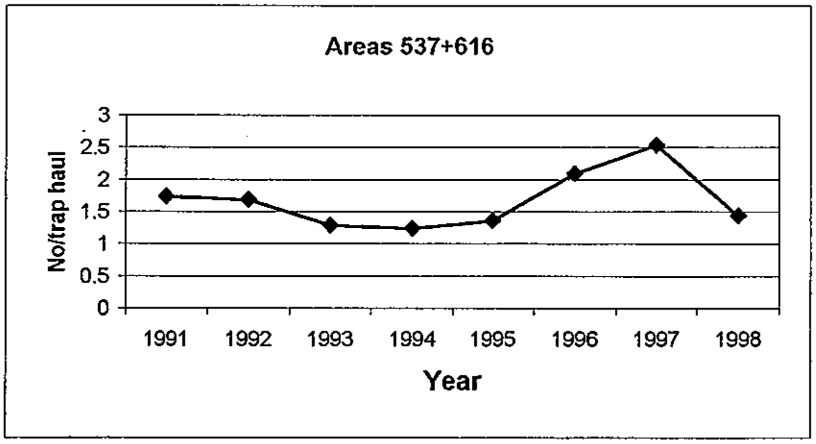
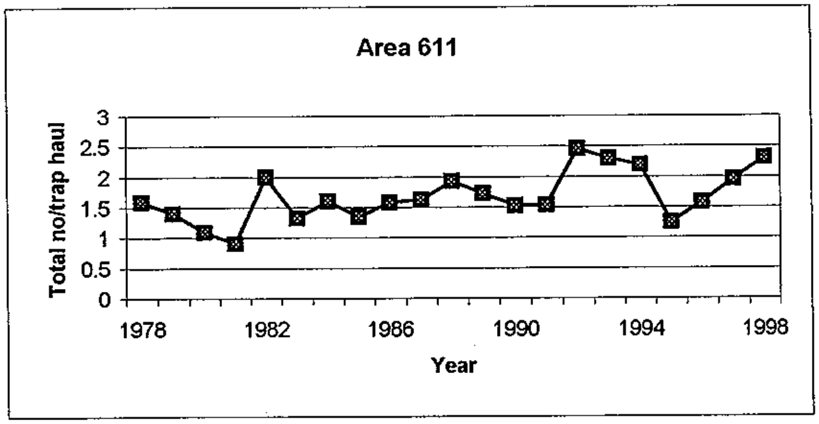


Figure 128. Catch-per-unit effort for all lobsters (top) and legal-sized lobsters (bottom) caught at three stations in eastern Long Island Sound near Millstone Power Plant (area 611) in 10 traps per station in 1978-81 and 20 traps per station after 1982 calculated as geometric mean (top) and delta mean (bottom) CPUE.



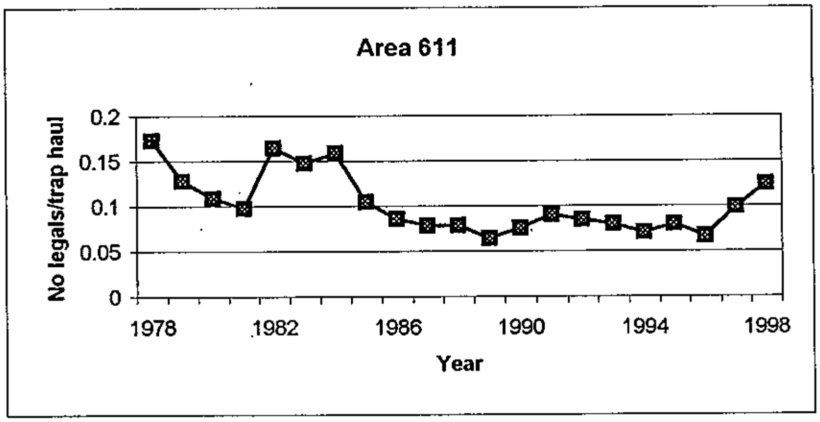


Figure 129. Scaled catch-per-unit-effort for marketable lobsters in Long Island Sound in numbers per trap haul and per trap-haul-set-over-days as estimated from area 611 landings and effort data for CT residents from logbooks.

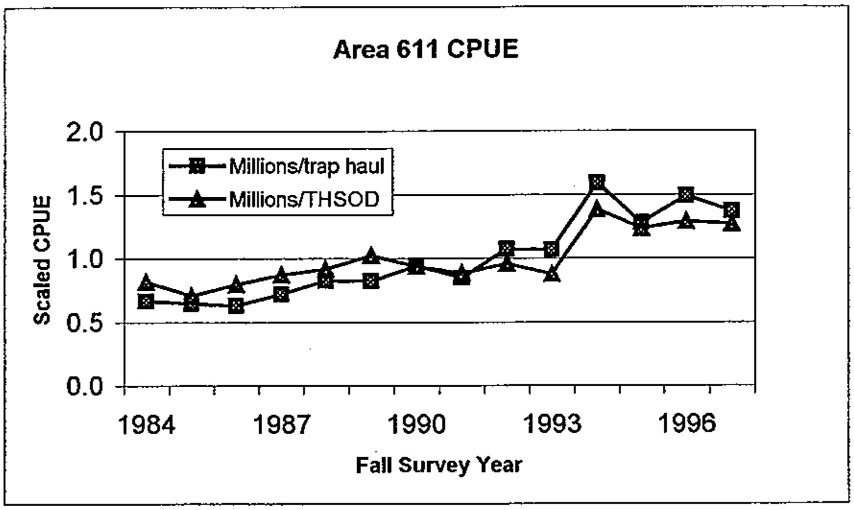


Figure 130. Fishing effort in Maine and Massachusetts lobster fisheries in GOM stock area expressed millions of trap hauls during 1982/1984-1997.

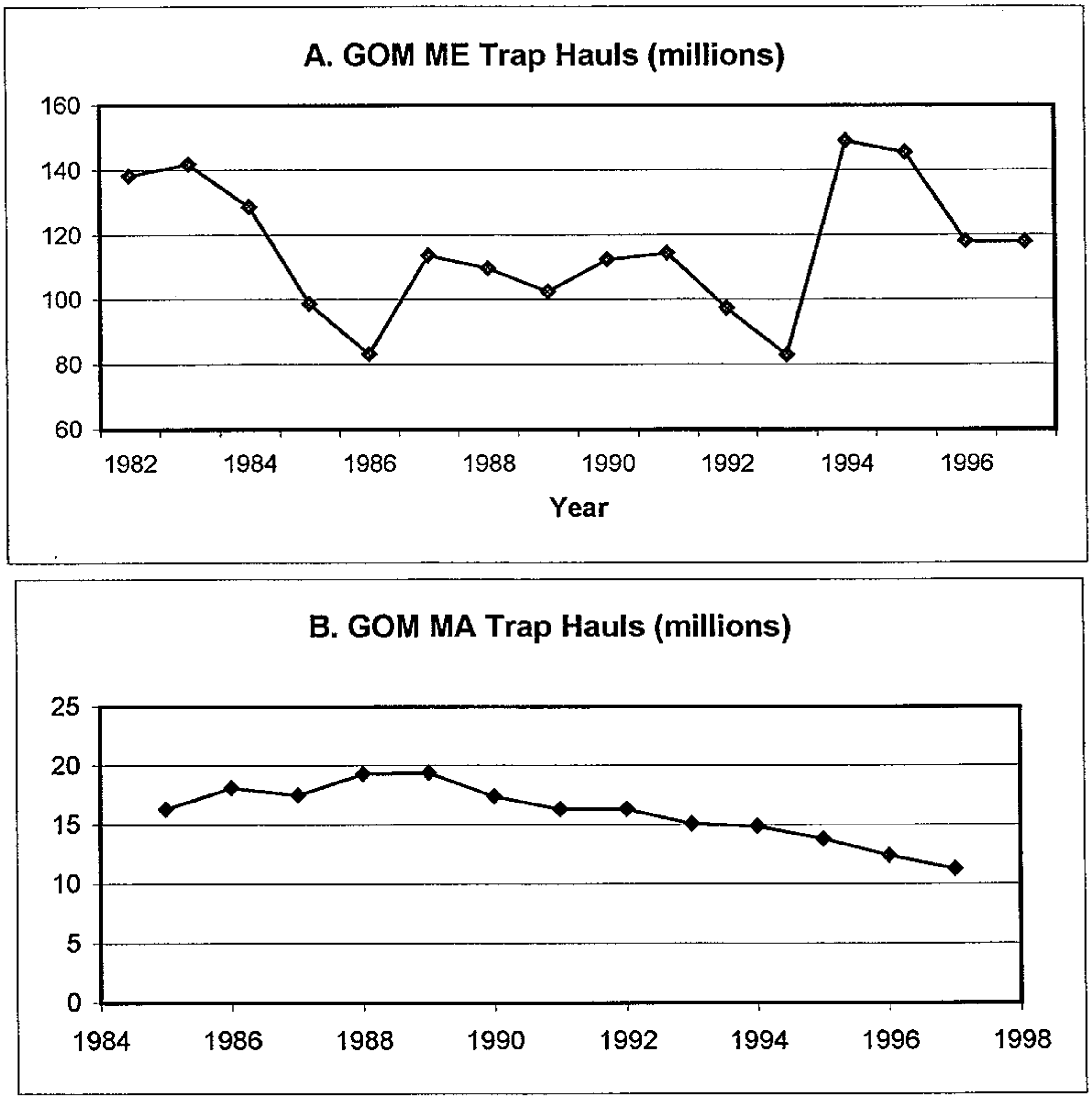


Figure 131. Linear regressions of log fishing mortality versus log fishing effort (ME and MA trap hauls) for female lobsters in statistical areas 511-513 + 515 and area 514 in the GOM stock area.

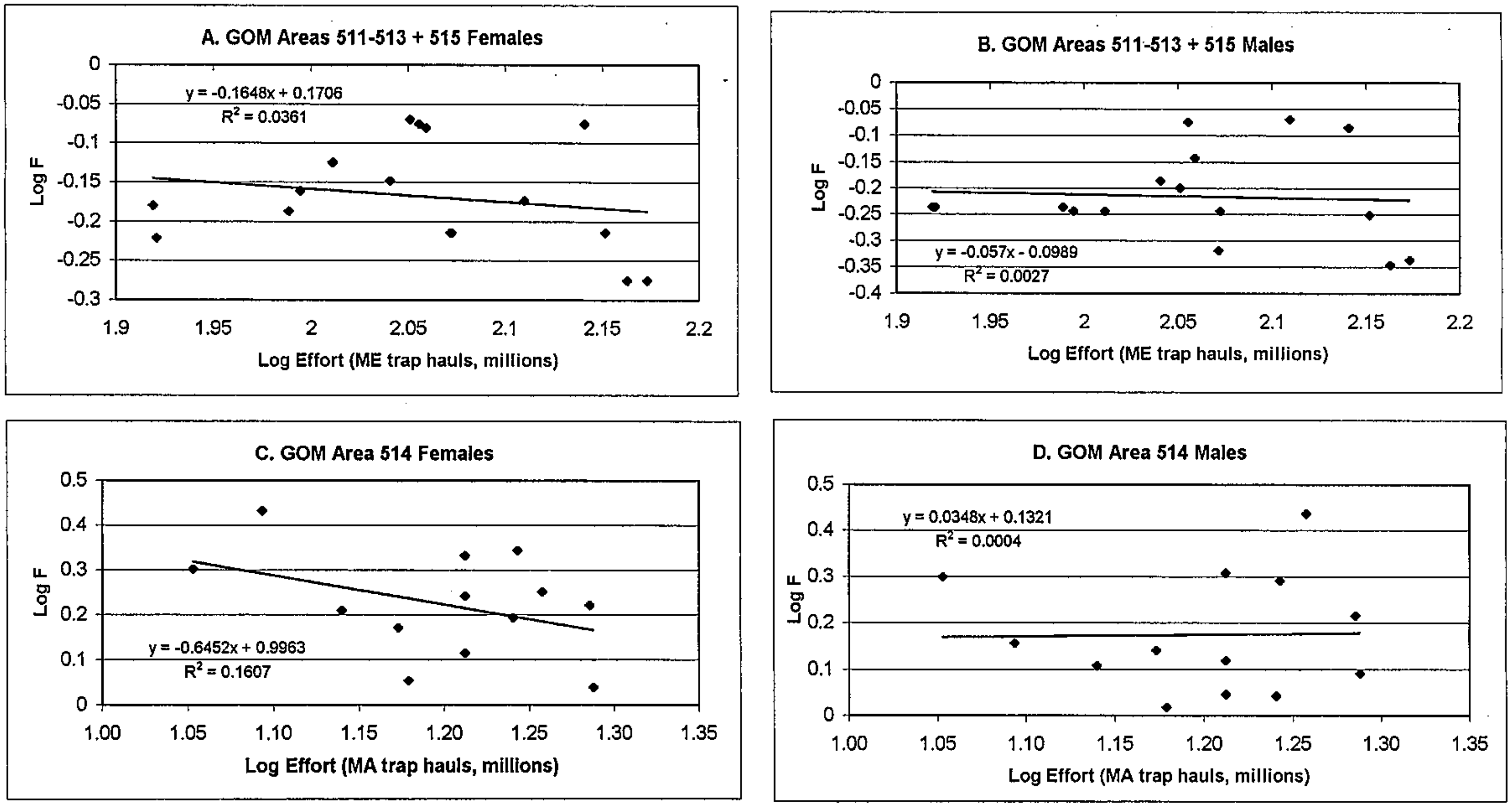
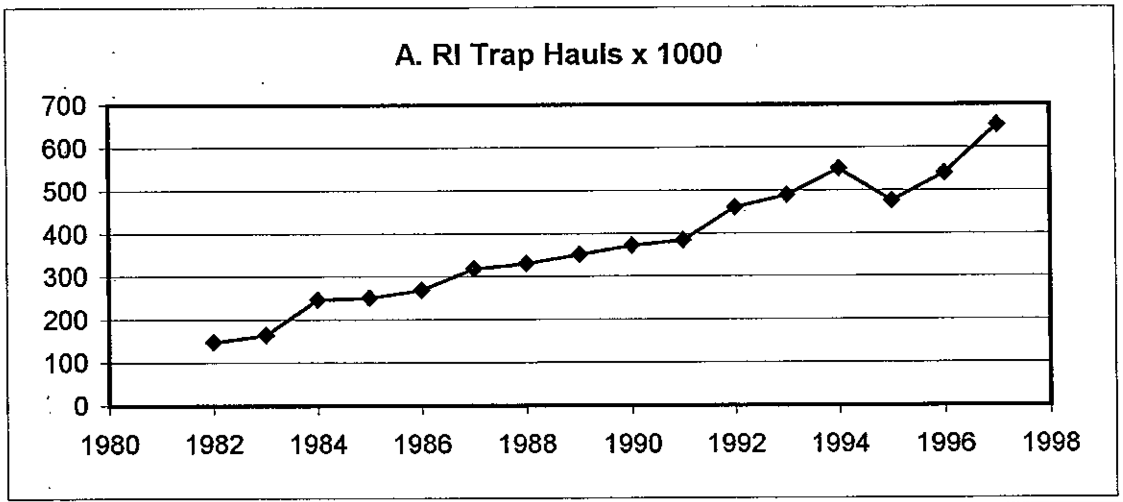
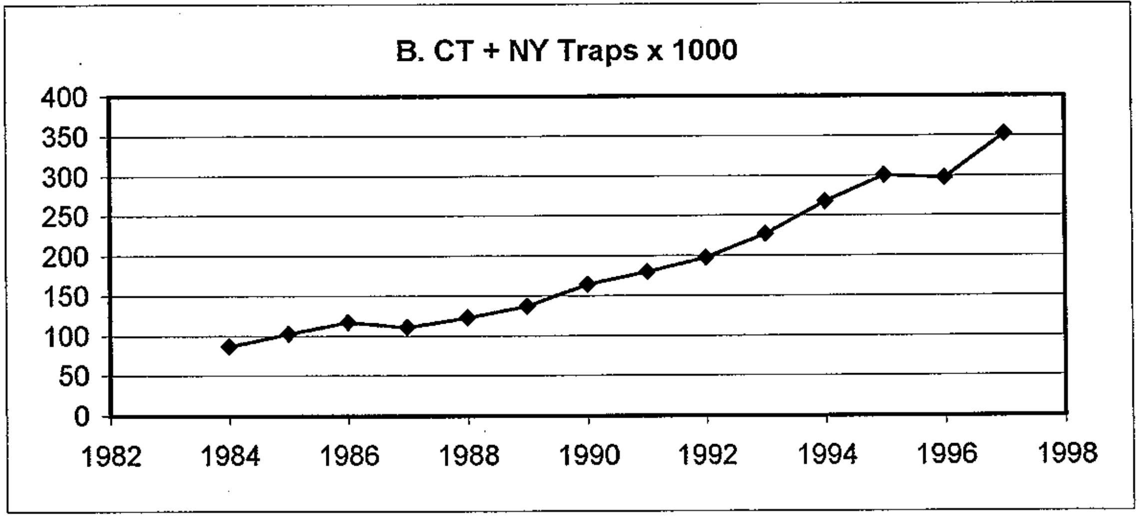


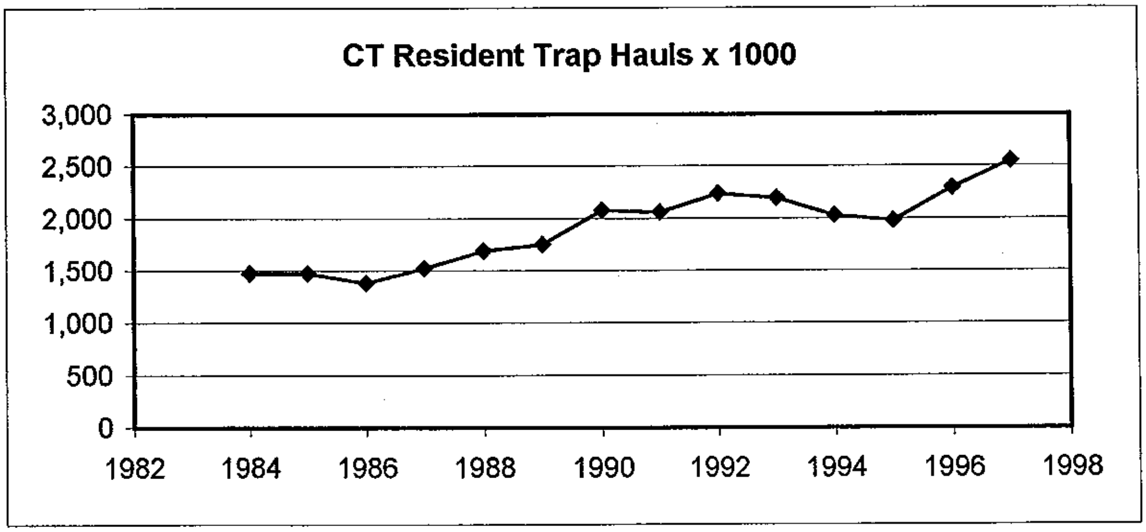
Figure 132. . Fishing effort in Rhode Island inshore fishery (trap hauls) and Long Island Sound (num traps fished by NY and CT fishermen and number of trap hauls by CT residents).



A. RI Trap Hauls x 1000



B. CT + NY Traps x 1000



CT Resident Trap Hauls x 1000

Figure 133. Linear regressions of log fishing mortality versus log fishing effort (RI trap hauls) for female lobsters in statistical area 539 in the SCCLIS stock area.

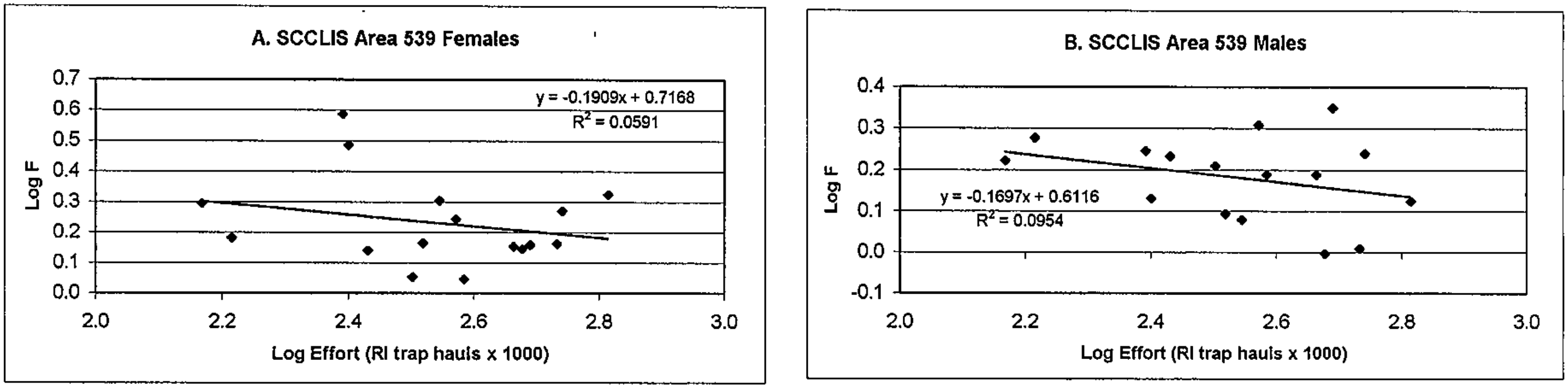


Figure 134. Linear regressions of log fishing mortality derived from fall CT survey data versus log fishing effort (CT+NY traps and CT trap hauls) for female lobsters in statistical area 611 in the SCCLIS stock area.

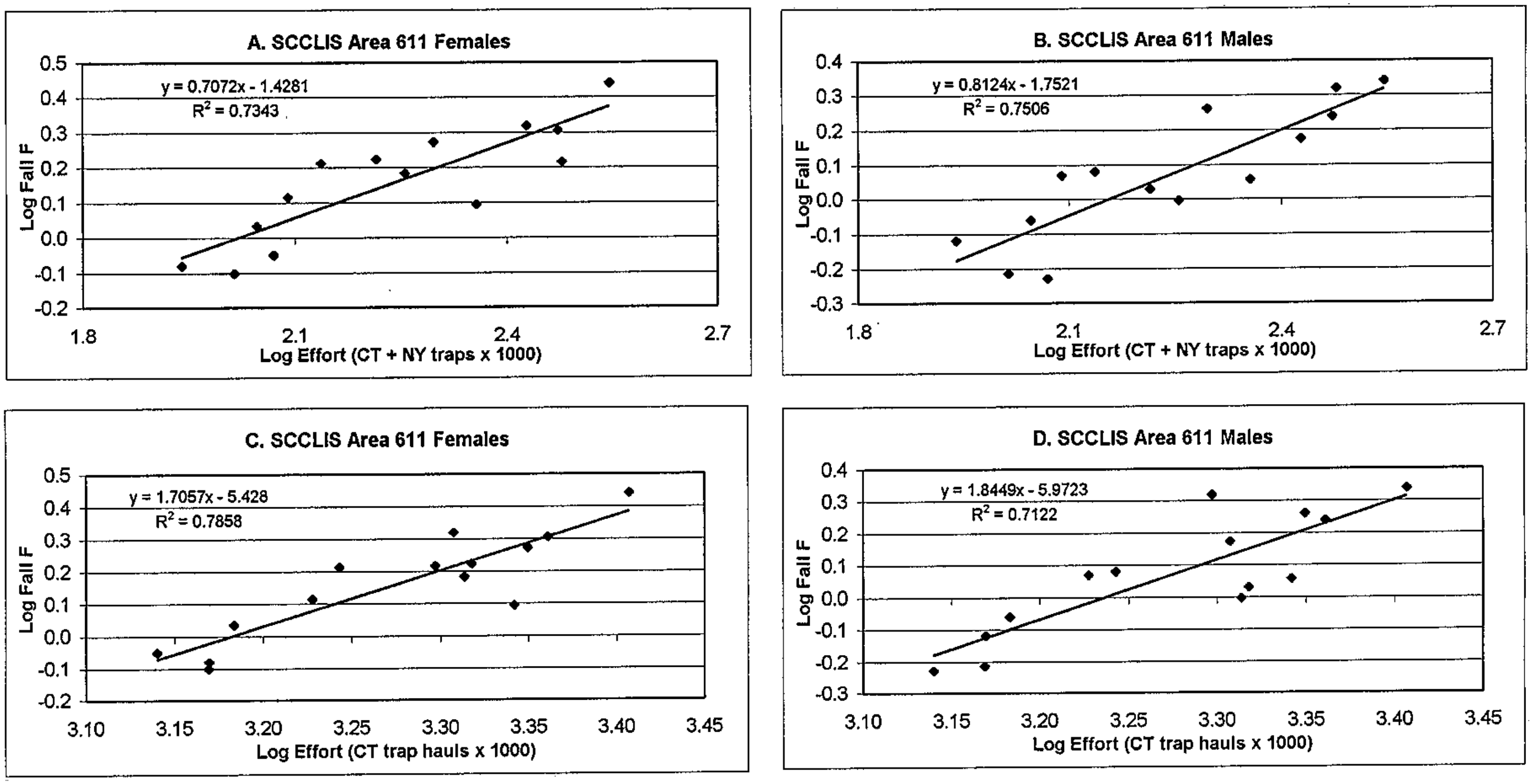


Figure 135. Linear regressions of log fishing mortality derived from spring CT survey data versus log fishing effort (CT+NY traps and CT trap hauls) for female lobsters in statistical area 611 in the SCCLIS stock area.

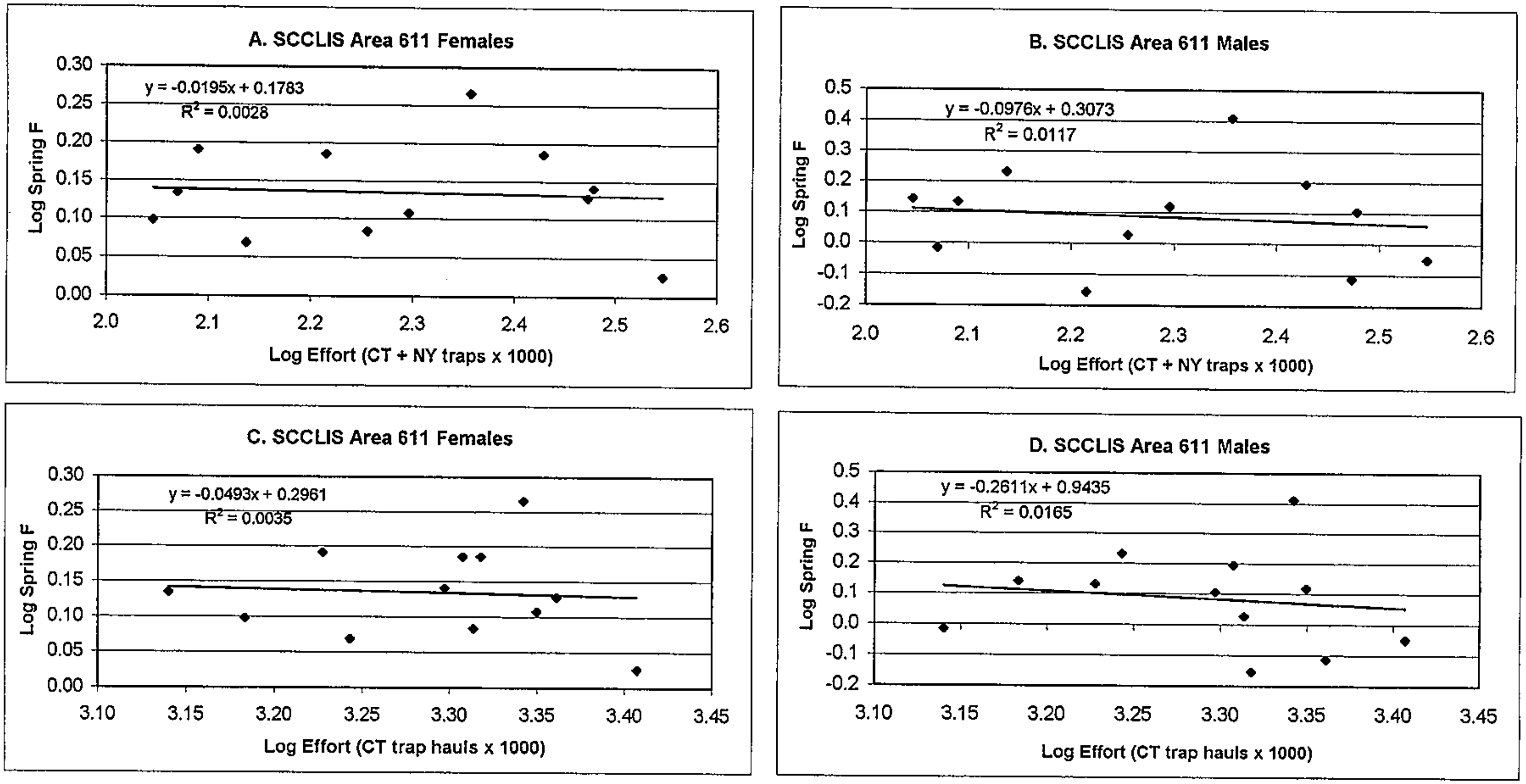
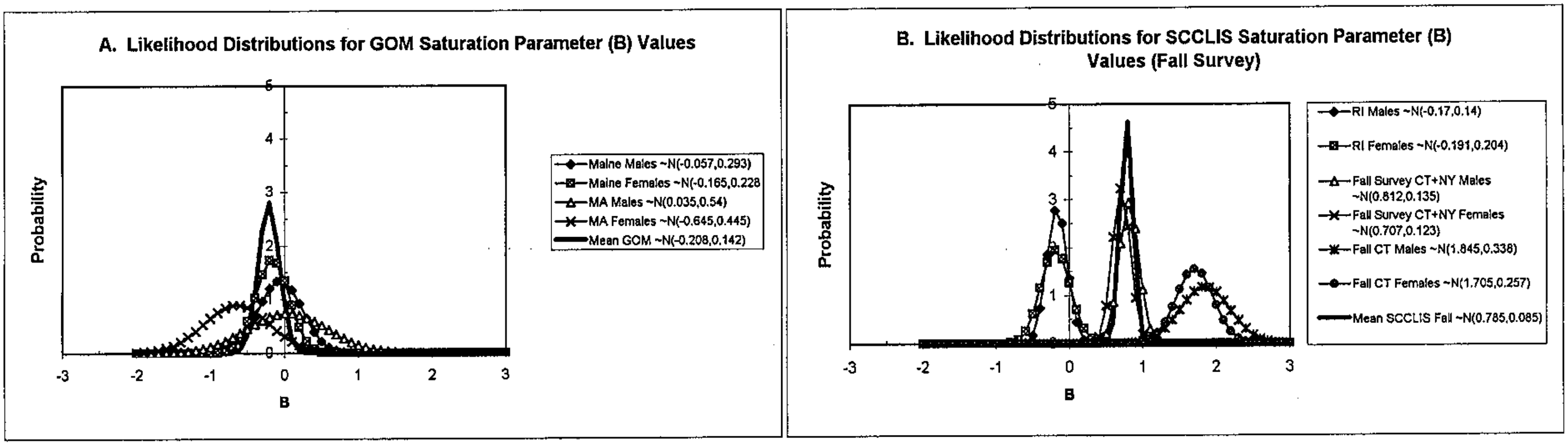
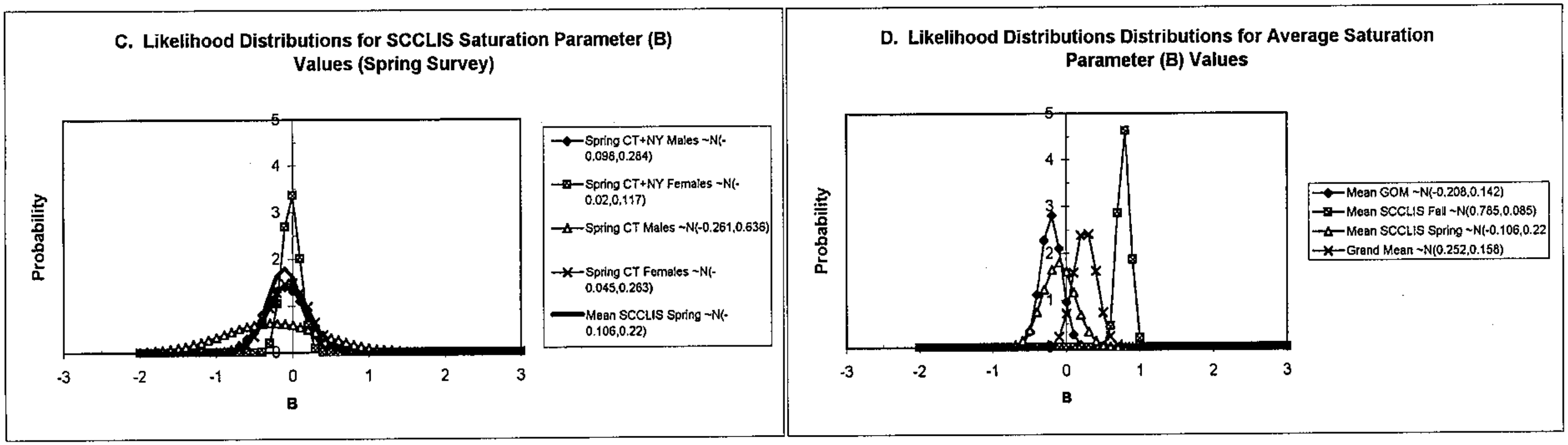


Figure 136. Likelihood distributions for gear saturation parameter B values from (A) GOM, (B) SCCLIS, fall survey, (C) SCCLIS, spring survey, and (D) average B values for each stock area and for all stock areas combined.



A. Likelihood Distributions for GOM Saturation Parameter (B) Values

B. Likelihood Distributions for SCCLIS Saturation Parameter (B) Values (Fall Survey)



C. Likelihood Distributions for SCCLIS Saturation Parameter (B) Values (Spring Survey)

D. Likelihood Distributions Distributions for Average Saturation Parameter (B) Values

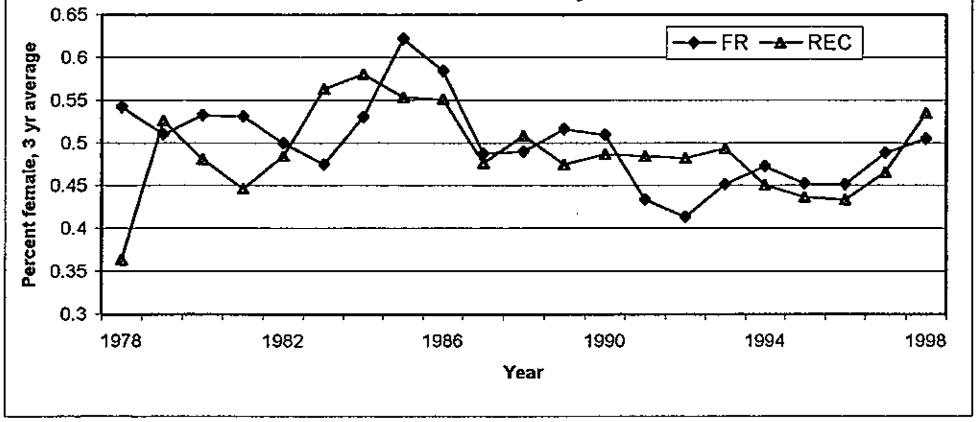


**Figure 137**
**GOM NMFS Fall Trawl Survey Sex Ratio**

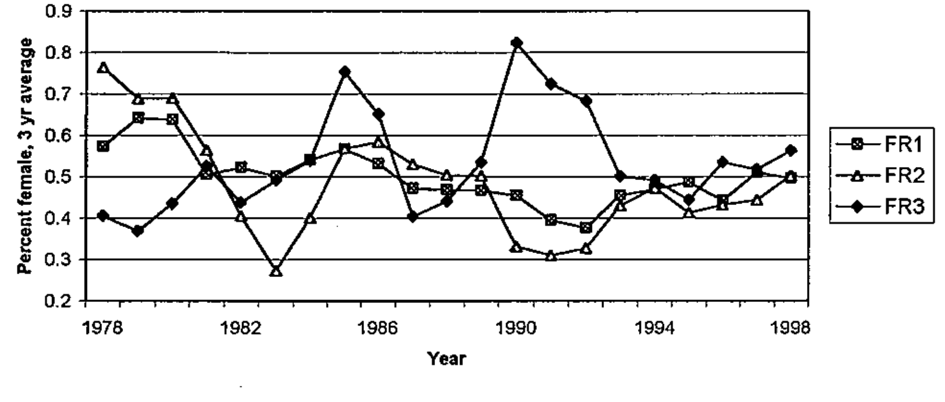


**Figure 138**
**GOM NMFS Fall Trawl Survey Sex Ratio**

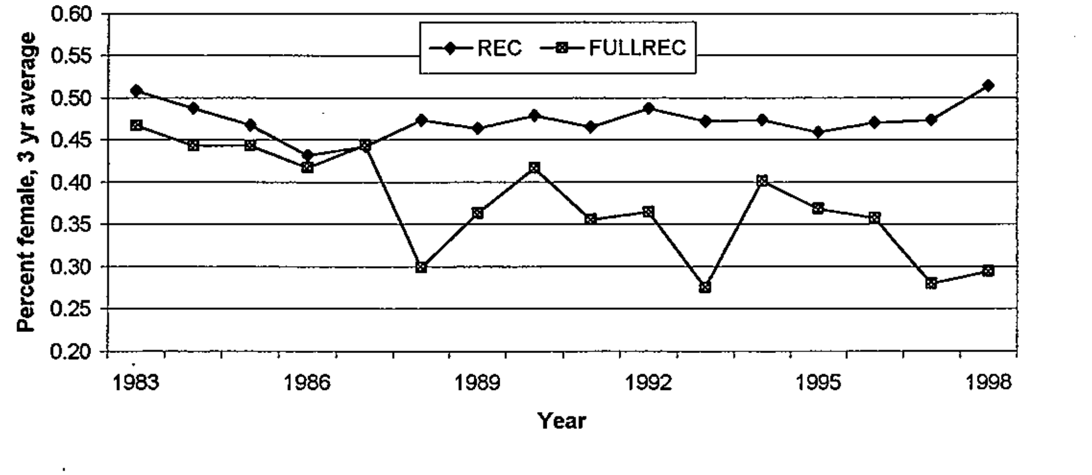
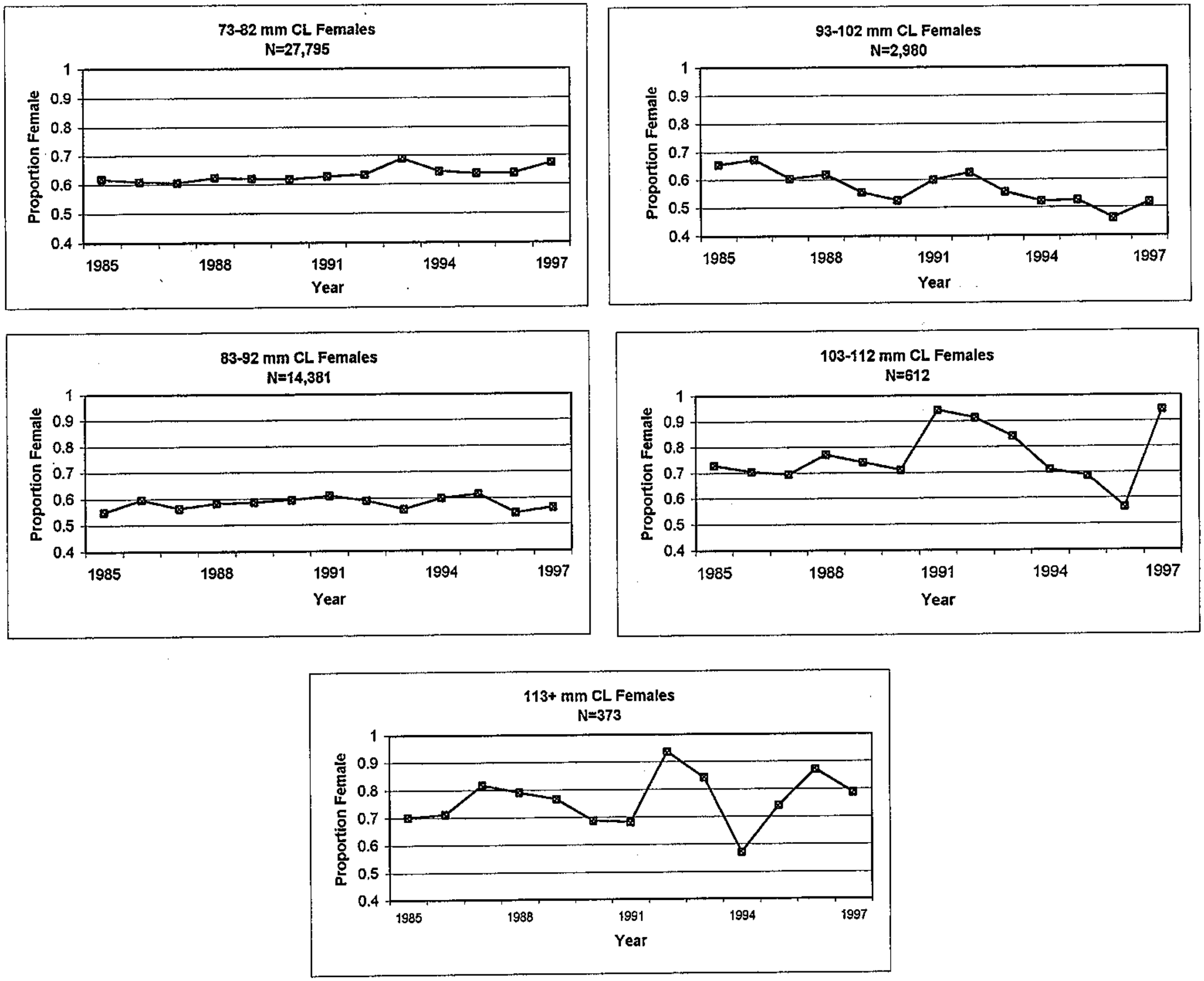


**Figure 139**
**GOM MA Fall Trawl Survey Sex Ratio**
**(SA 514)**

FIGURE 140. MAINE SEA SAMPLING DATA, PERCENT FEMALE BY SIZE GROUP (ALL LOBSTERS)



73-82 mm CL Females
N=27,795

93-102 mm CL Females
N=2,980

83-92 mm CL Females
N=14,381

103-112 mm CL Females
N=612

113+ mm CL Females
N=373

Figure 141. Percent female lobsters in Maine port sampling data by size group during 1966-1998

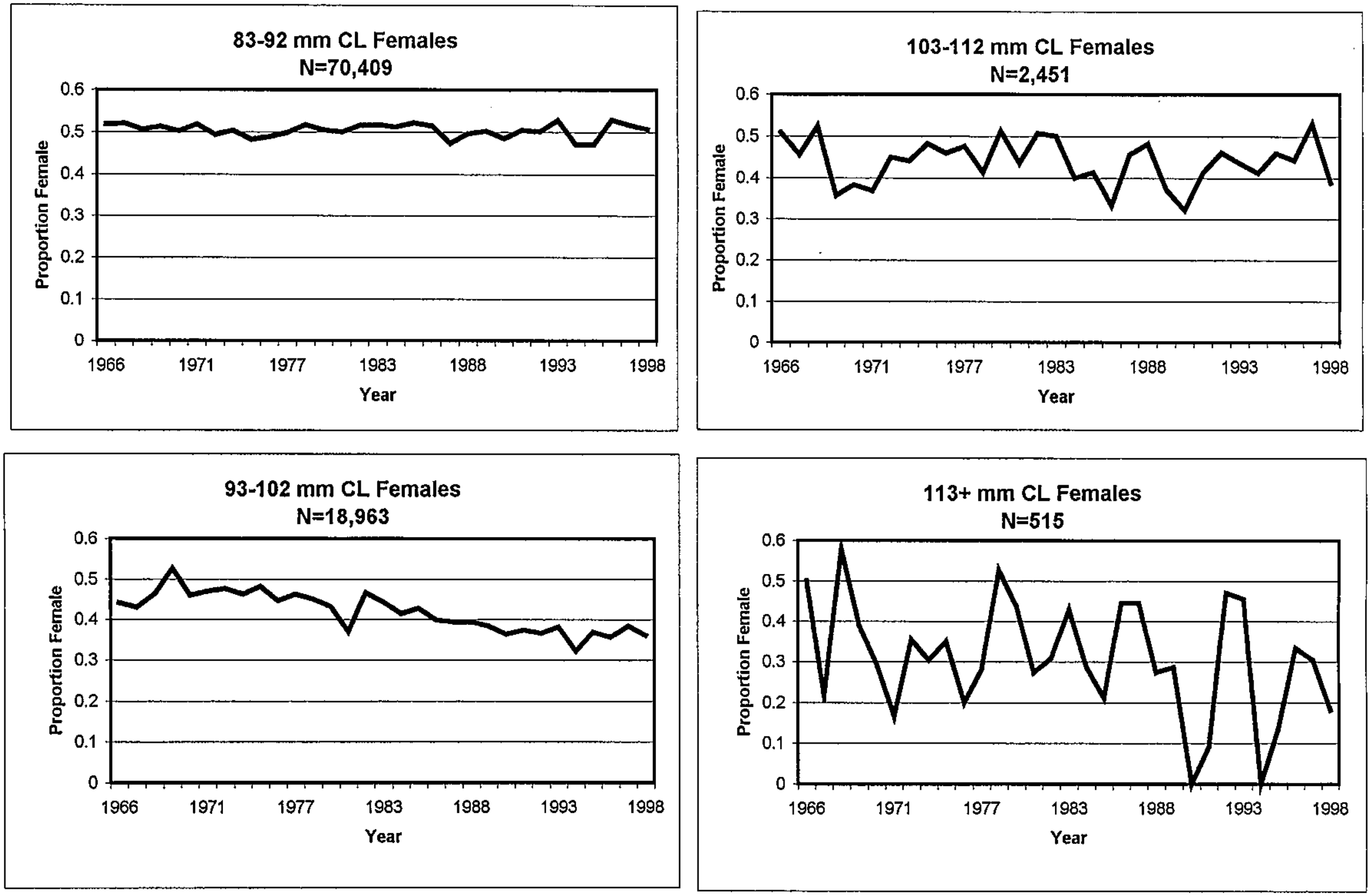
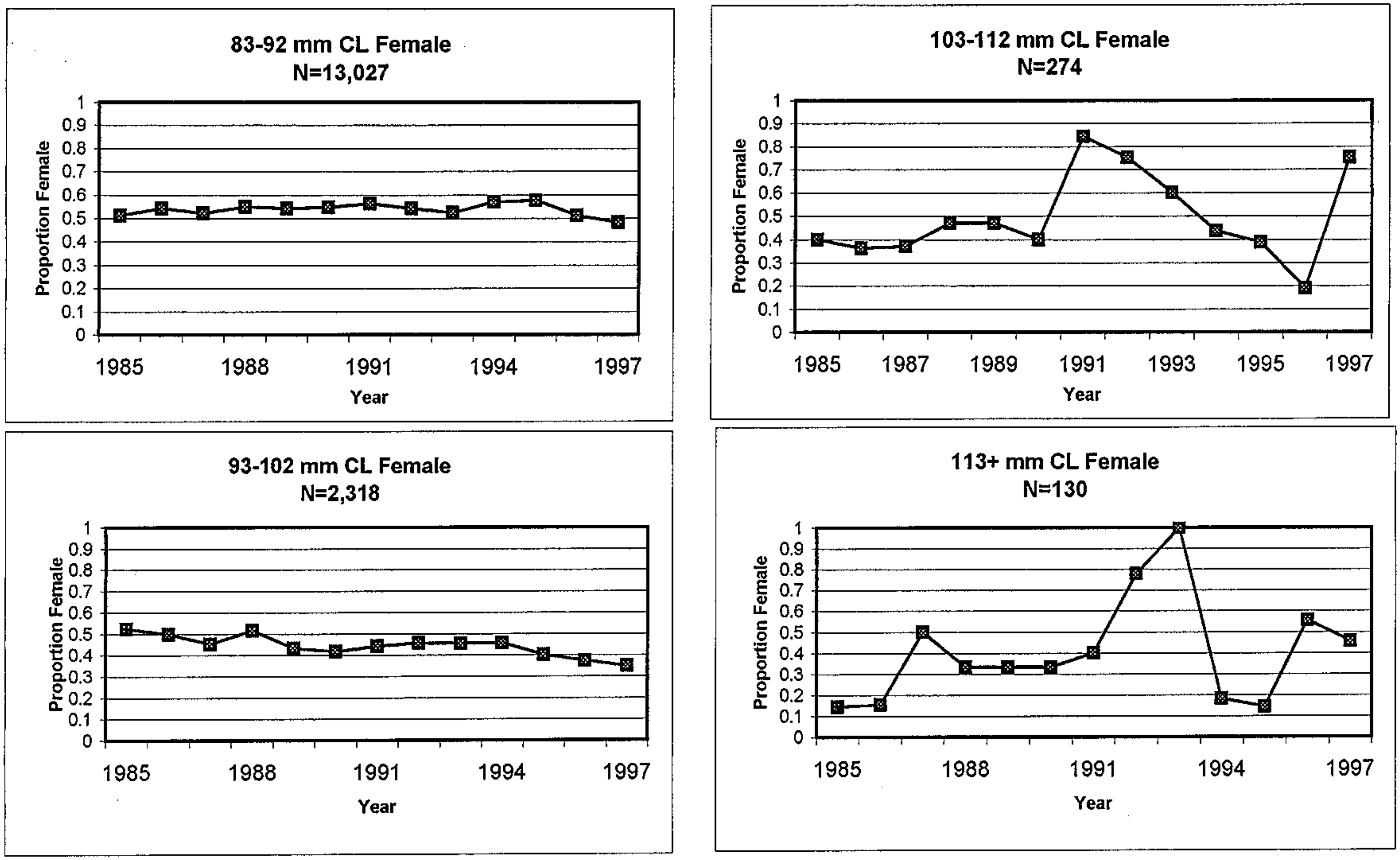


FIGURE 142. MAINE SEA-SAMPLING DATA, PERCENT FEMALES BY SIZE GROUP (MARKETED ONLY)



83-92 mm CL Female
N=13,027

103-112 mm CL Female
N=274

93-102 mm CL Female
N=2,318

113+ mm CL Female
N=130

## Figure 143
## GOM MA Sea Sample Sex Ratio
## (Marketable 83+ mm CL, SA514)

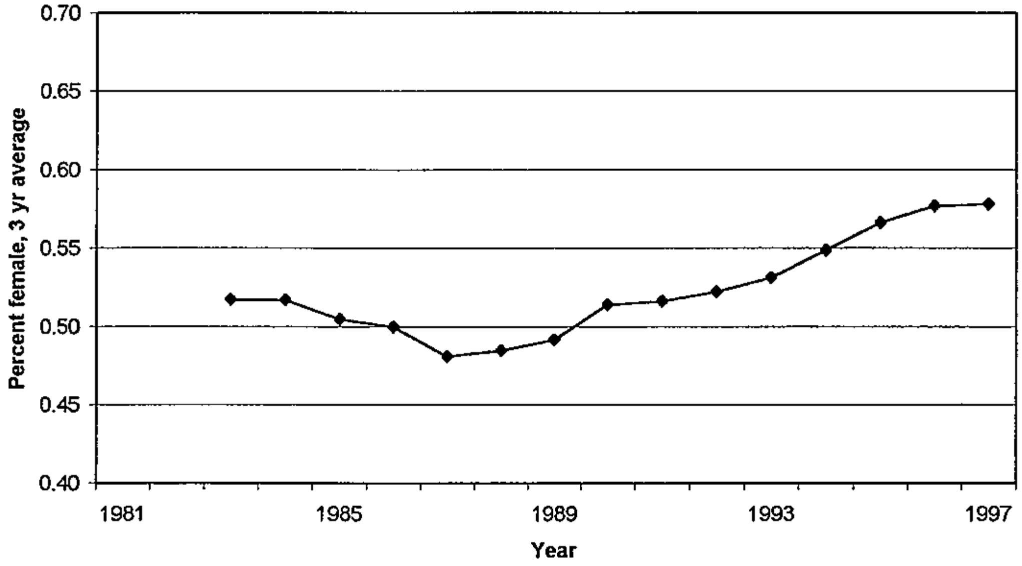


Figure 144
GBS NMFS Trawl Survey Sex Ratio

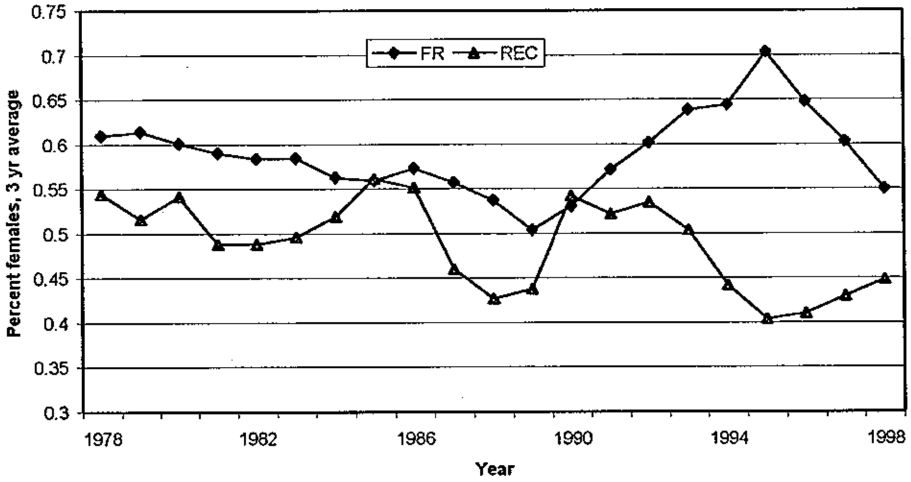


Figure 145
GBS NMFS Trawl Survey Sex Ratio

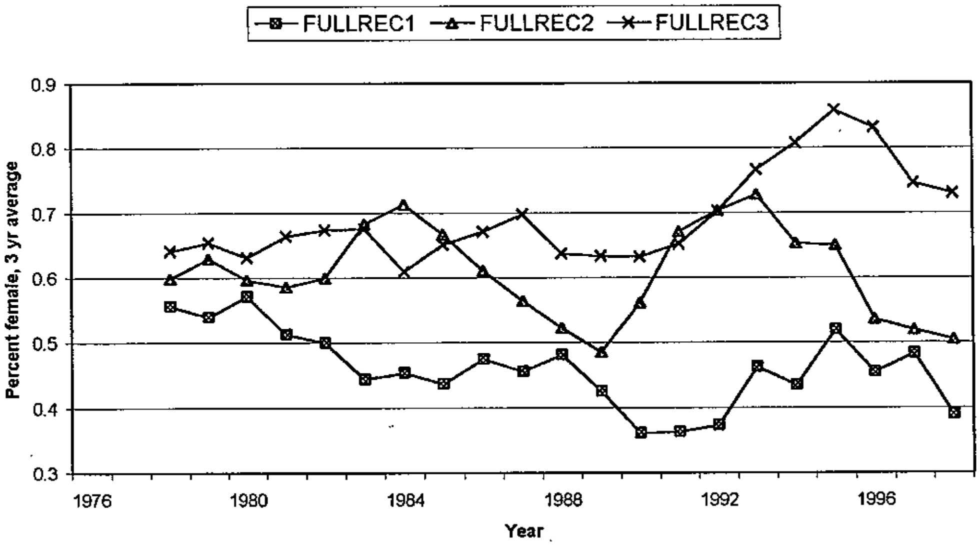


Figure 146
GBS MA Sea Sample Sex Ratio
(Marketable 83+ mm, SA521)

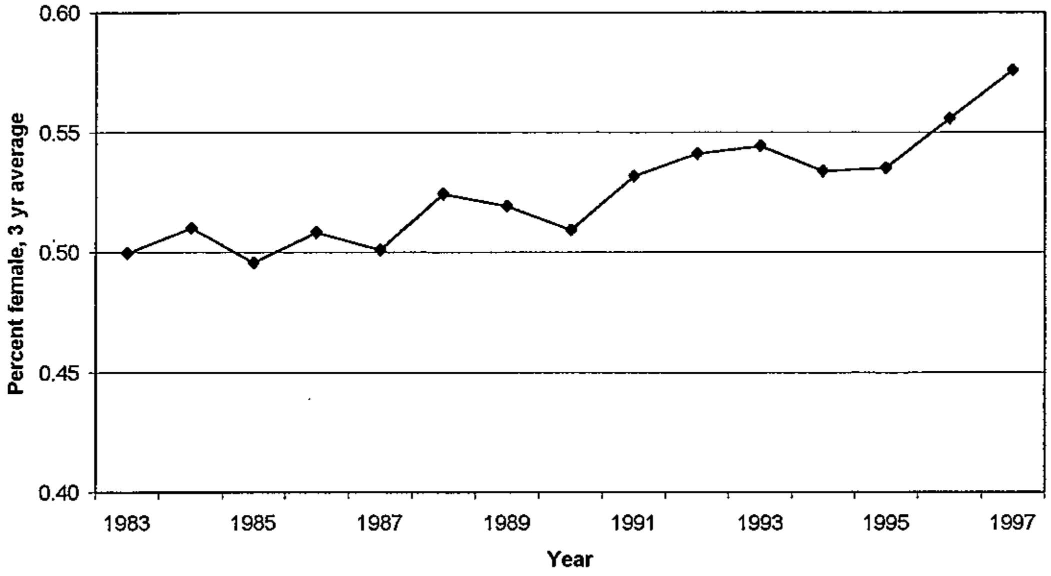


Figure 147
GBS RI Sea Sample Sex Ratio
(SA 537 + 616)

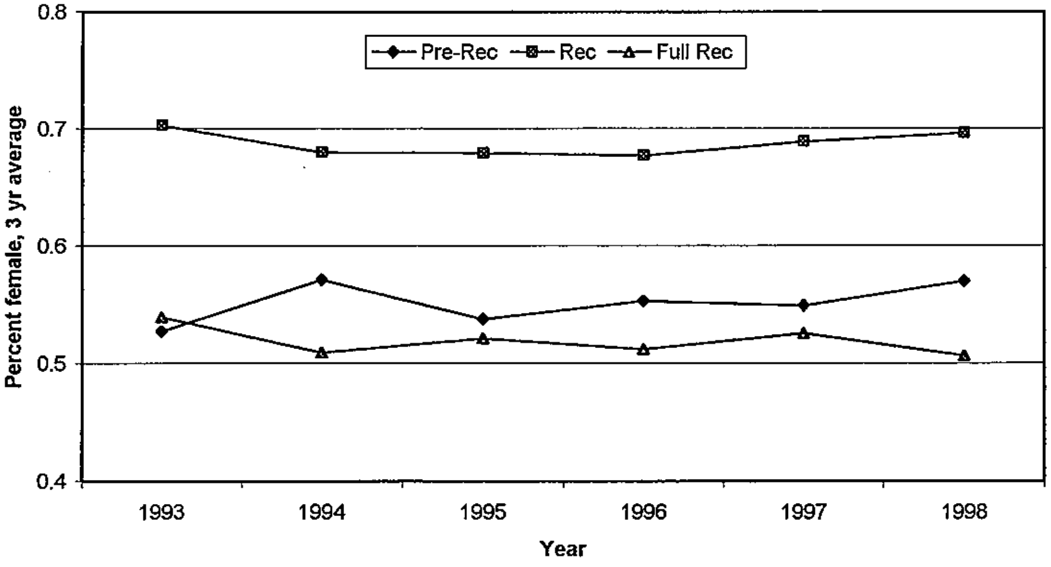


Figure 148
SCCLIS NMFS Trawl Survey Sex Ratio

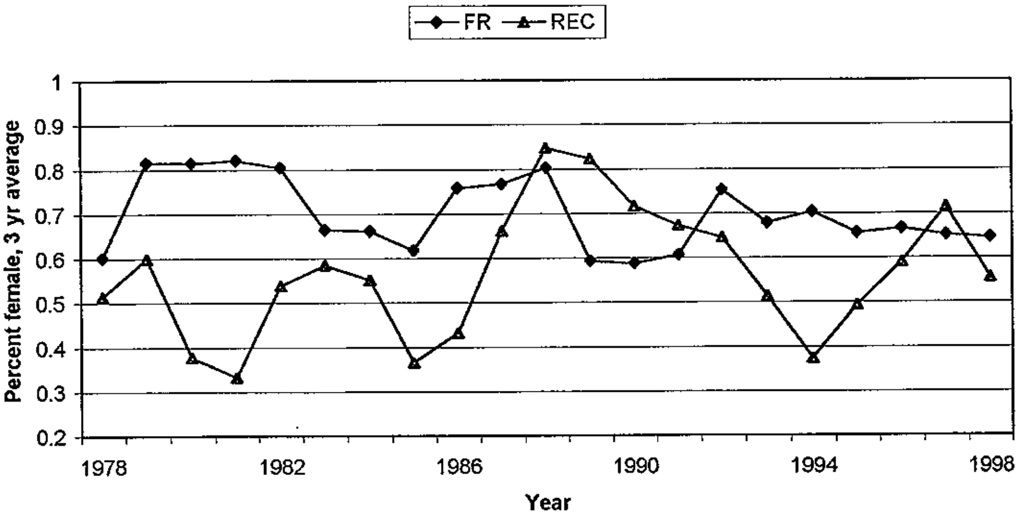


Figure 149
SCCLIS MA Trawl Survey Sex Ratio
(SA 538)

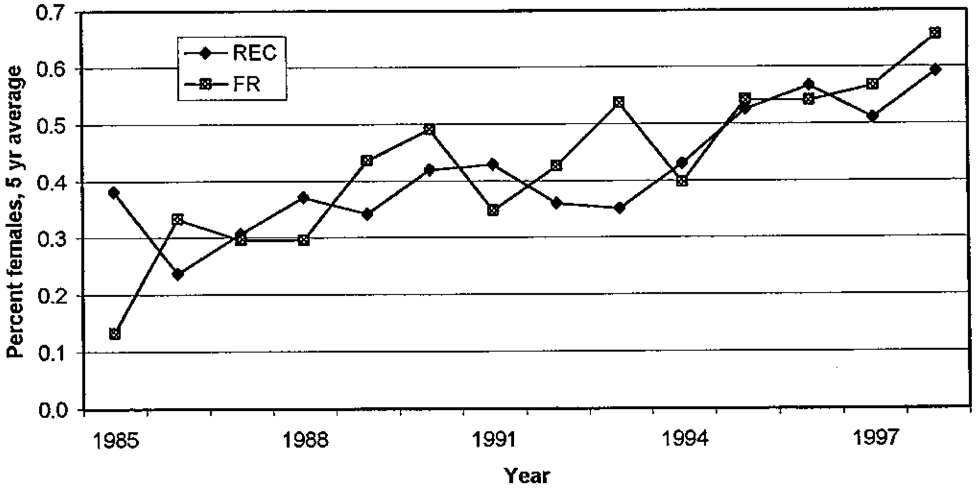


Figure 150
SCCLIS RI Fall Trawl Survey Sex Ratio
(SA 539)

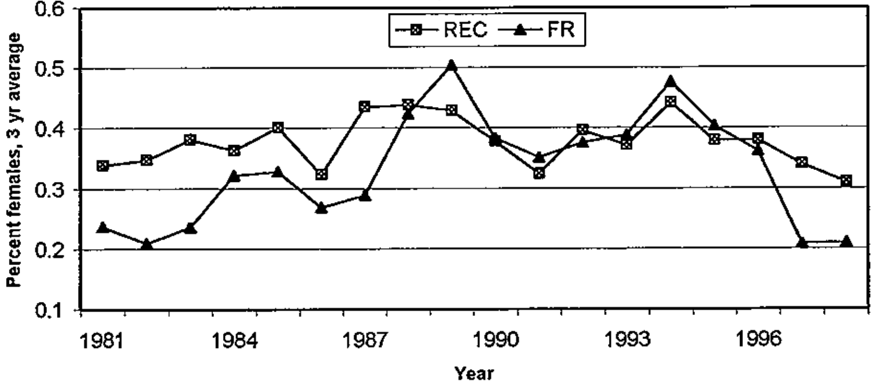


Figure 151
SCCLIS CT Fall Trawl Survey Sex Ratio
(SA 611)

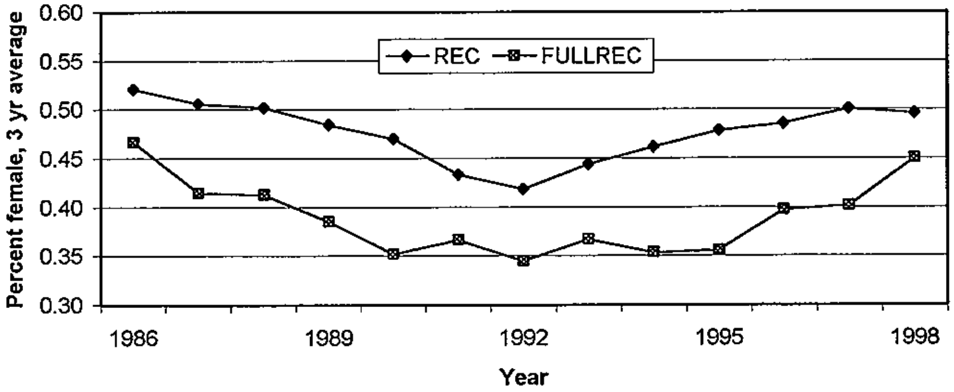


Figure 152
SCCLIS CT Spring Trawl Survey Sex Ratio
(SA 611)

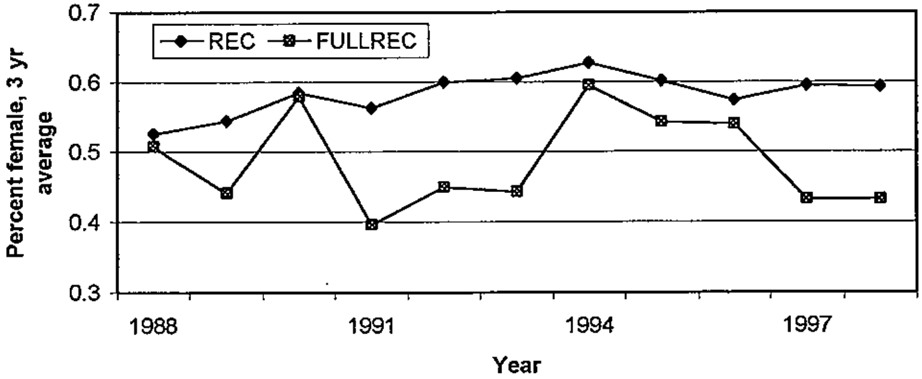


**Figure 153**
**SCCLIS RI Sea Sampling Sex Ratio**
**(SA 539)**

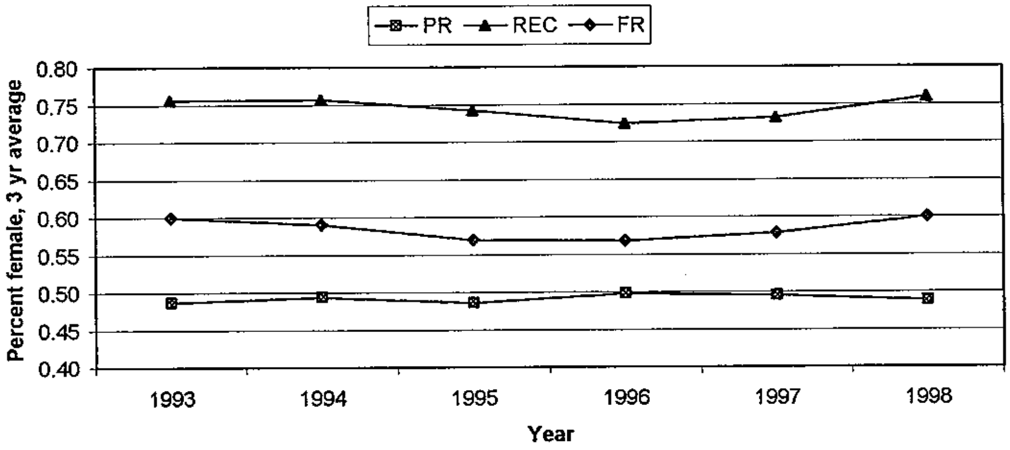


**Figure 154**
**SCCLIS MA Sea Sample Sex Ratio**
**(Marketable 83 + mm CL, SA538)**

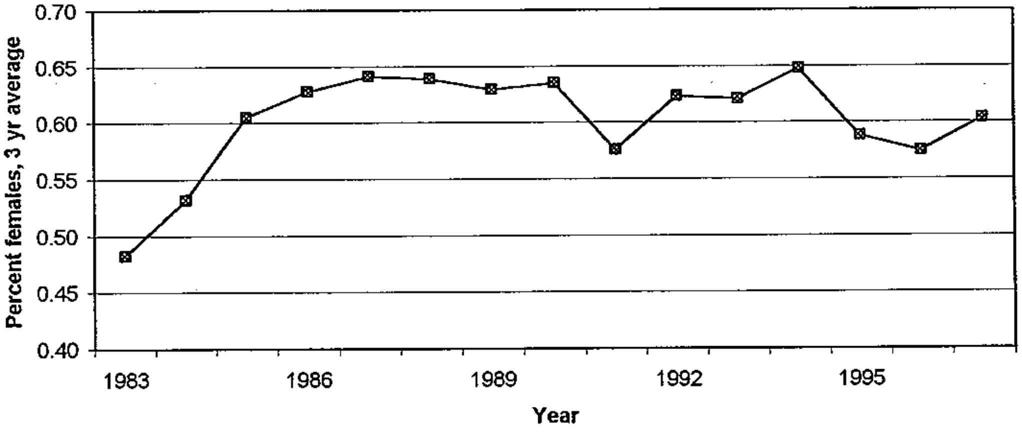


Figure 155. Percent softshell marketable lobsters in Massachusetts sea sampling data from statistical areas 514, 521, and 538 during 1981-1997.

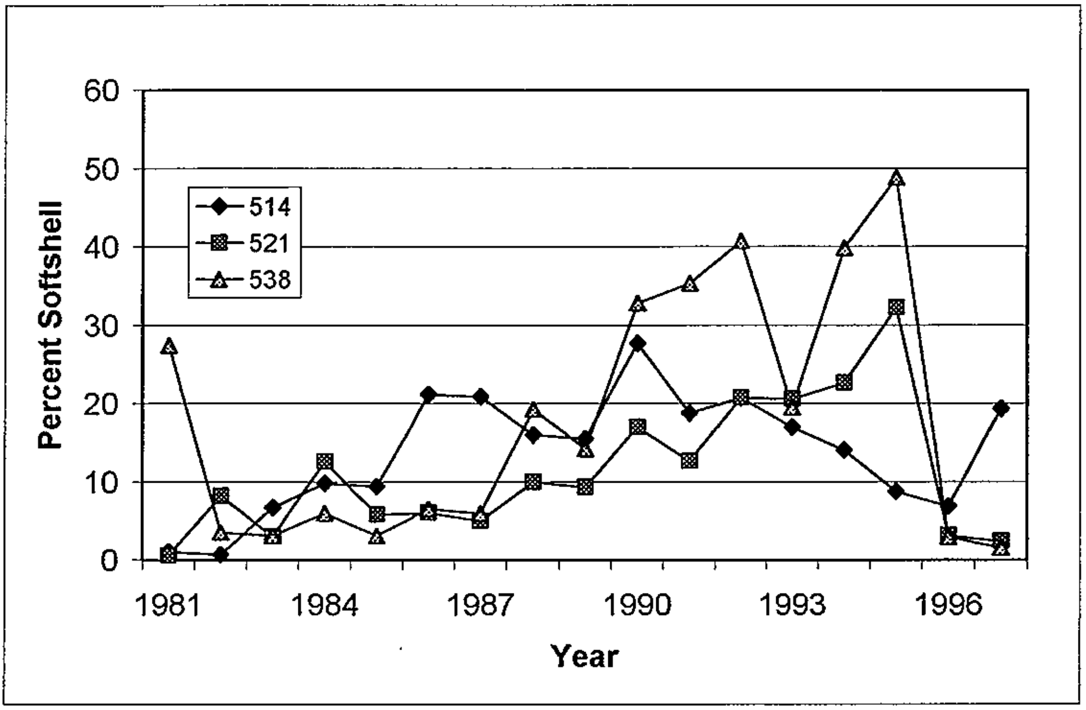


Figure 156
GBS RI Sea Sample Percent Softshell in Marketable Catch
Block and Hudson Canyons (Areas 537 and 616)

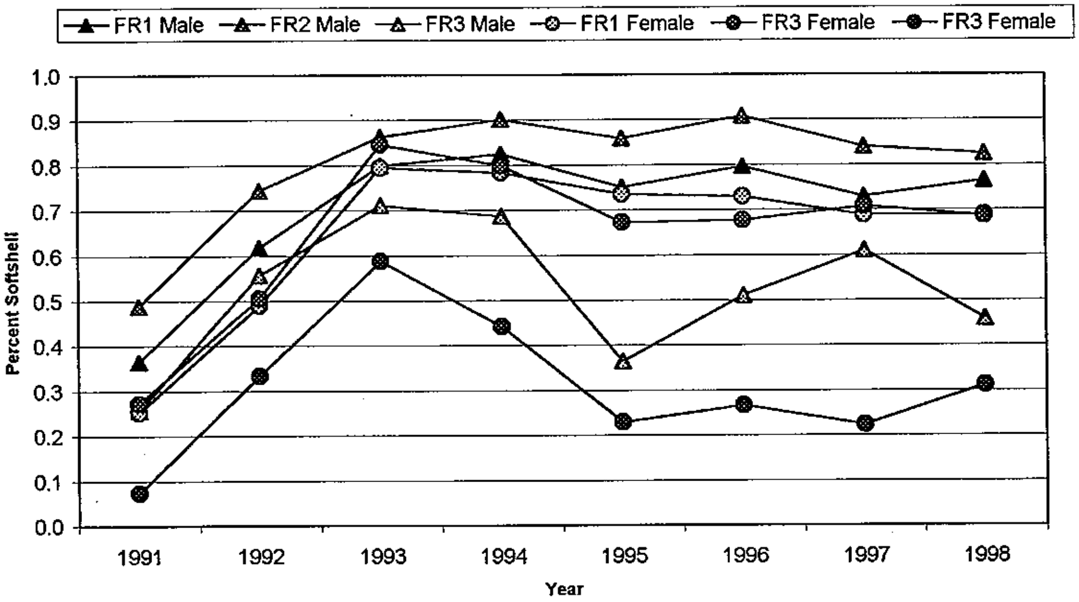


Figure 157
SCCLIS RI Sea Sample Percent Softshell in Marketable Catch
RI Coastal Waters, Area 539

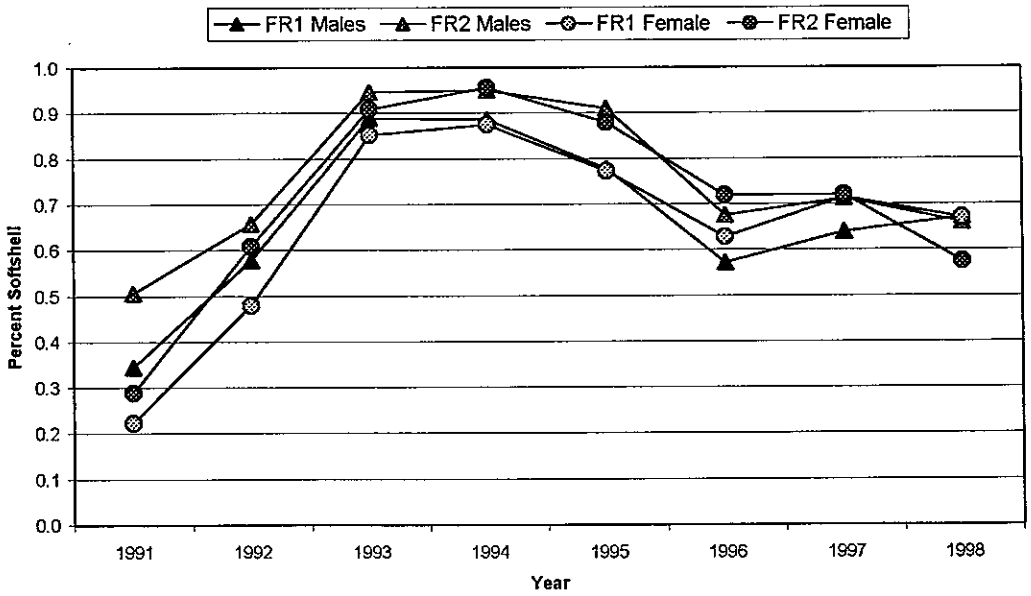


Figure 158. Proportion of lobster landings in the GOM stock area by quarter during fall survey years 1982-1997

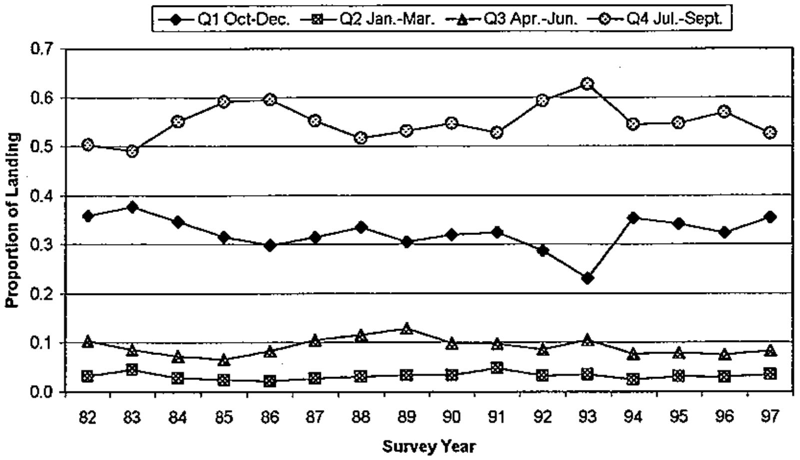


Figure 159. Proportion of lobster landings in the GBS stock area by quarter during fall survey years 1982-1997

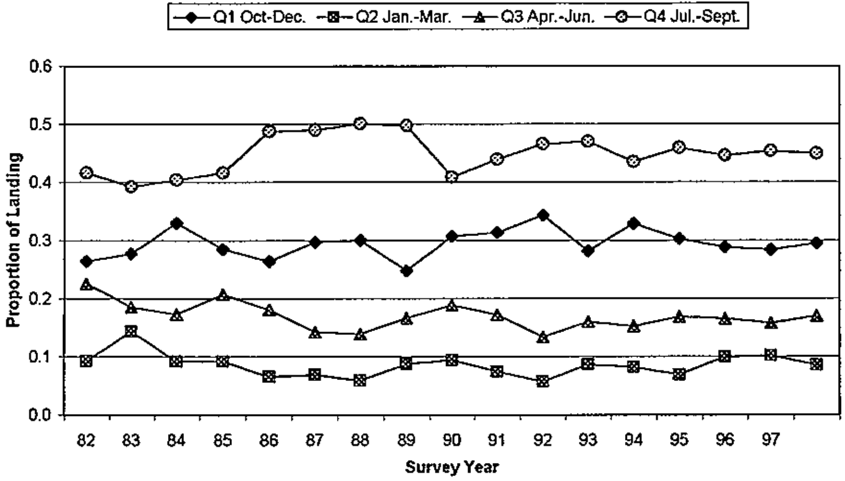


Figure 160. Proportion of lobster landings in the SCCLIS stock area by quarter during fall survey years 1982-1997

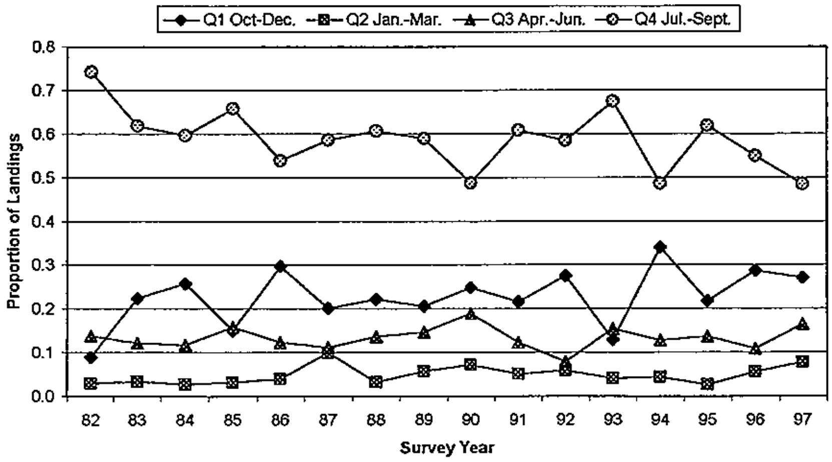


Figure 161. Proportion of lobster landings made by CT residents in Central and Western Long Island Sound by month during 1979-1997

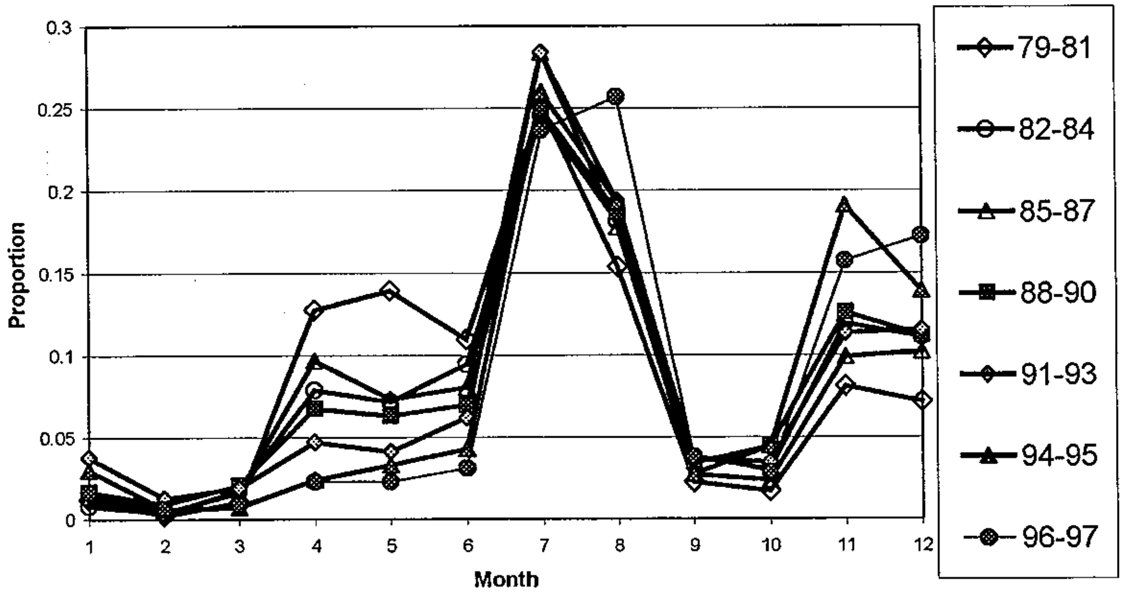


Figure 162. Proportion of lobster landings made by CT residents in central and western Long Island Sound during April-May, July-August, and November-December, 1979-1997.

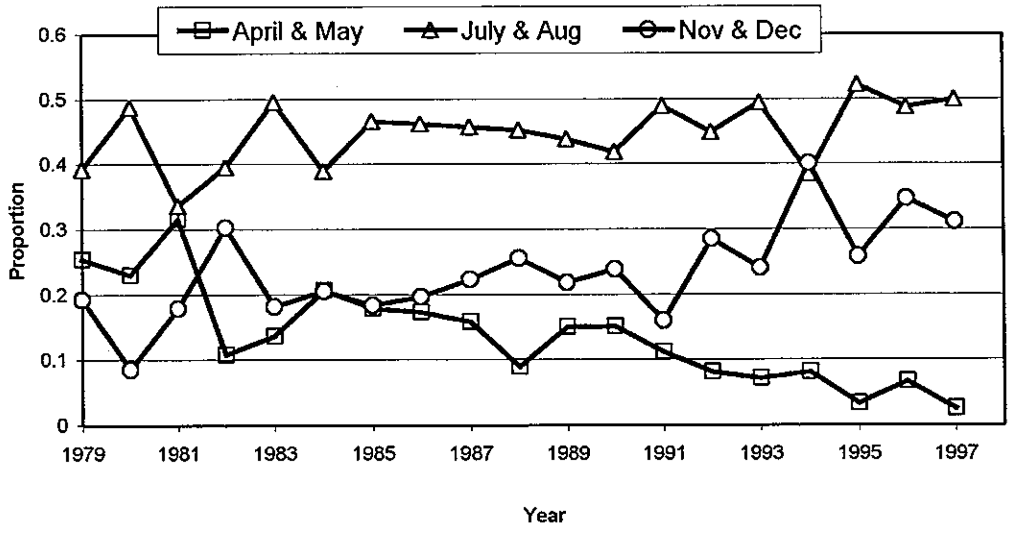


**Figure 163. Proportion of trap hauls made by CT residents in central and western Long Island Sound by month for selected two or three year periods during 1979-1997.**

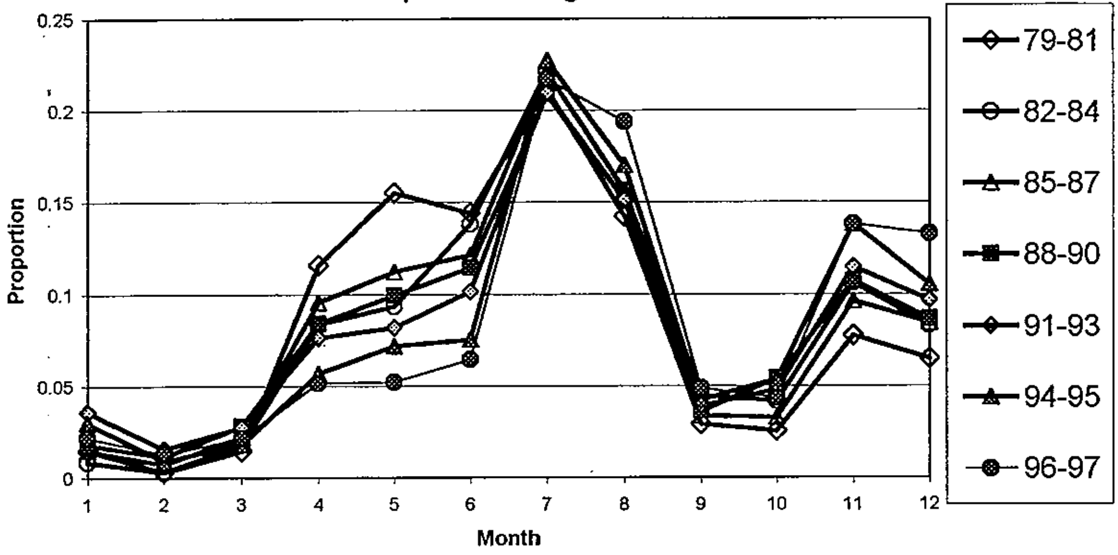


**Figure164. Proportion of trap hauls made by CT residents in central and western Long Island Sound during April-May, July-August, and November-December, 1979-1997.**

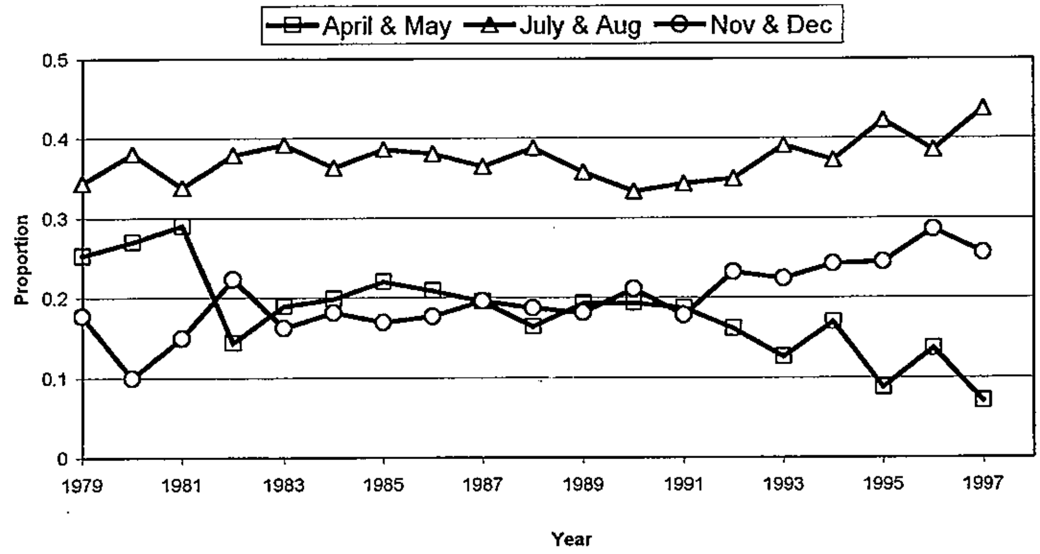
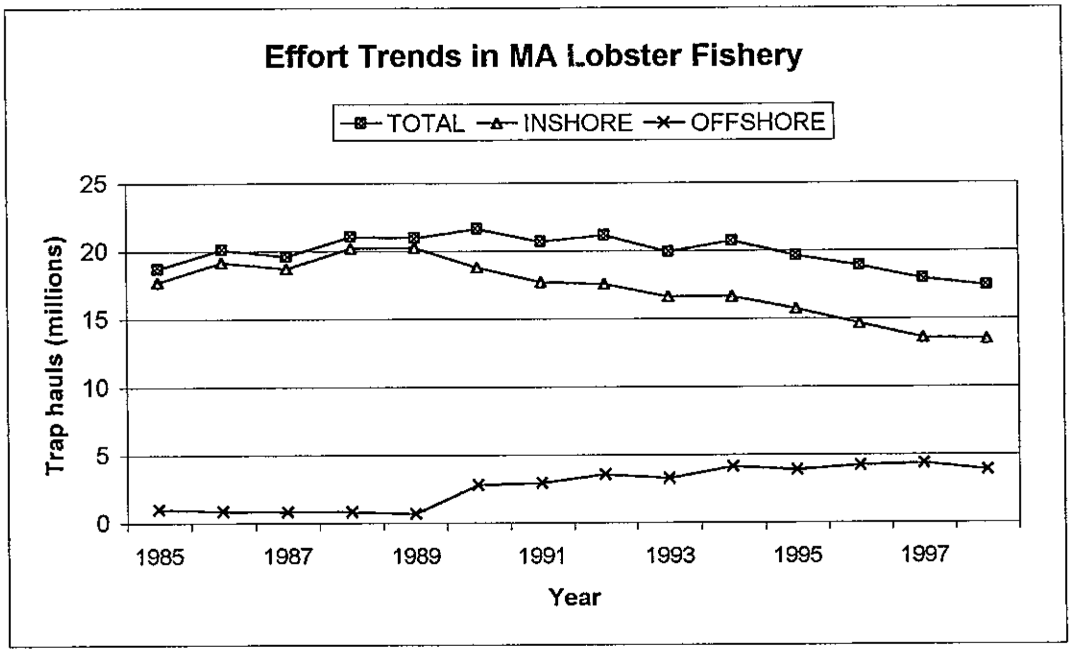


Figure 165. Trends in total, inshore and offshore trap hauls in Massachusetts lobster fishery during 1985-1998.



In 1990, the MA reporting map was revised to improve the territorial/non-territorial break down.

Figure 166. Trends in total, inshore and offshore trap hauls in Massachusetts Gulf of Maine lobster fishery during 1990-1998.

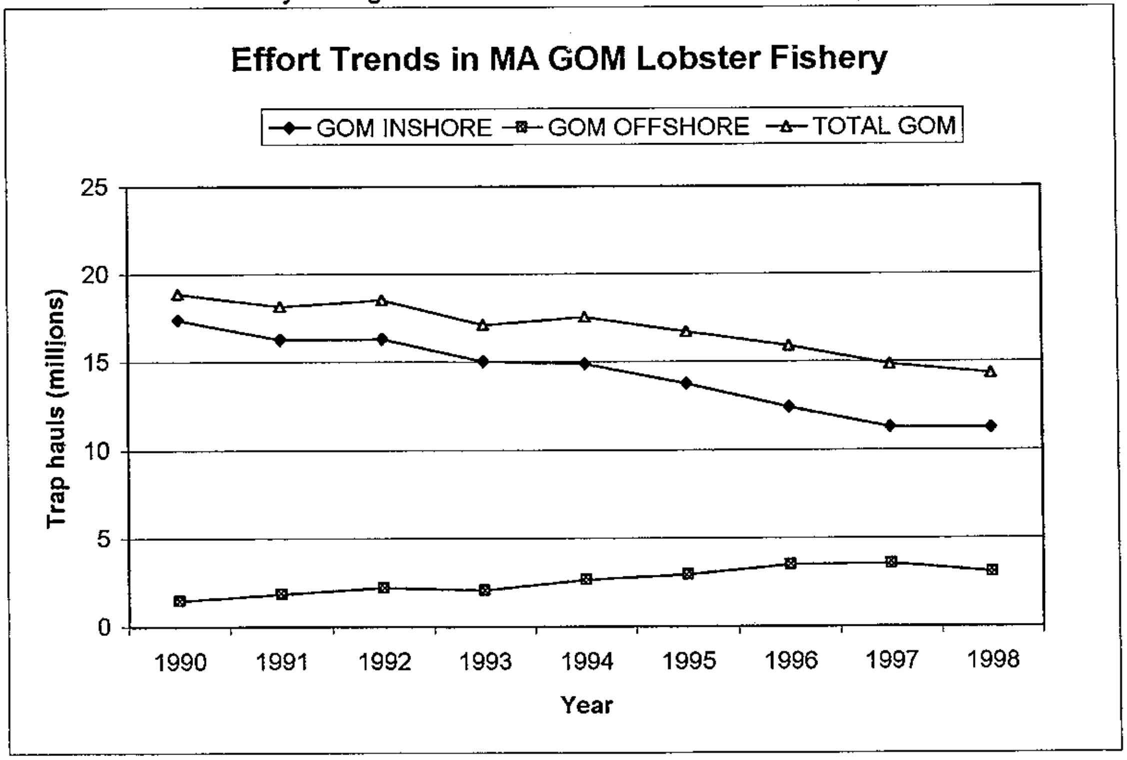


Figure 167. Trends in total, inshore and offshore traps fished in Massachusetts lobster fishery during 1990-1997.

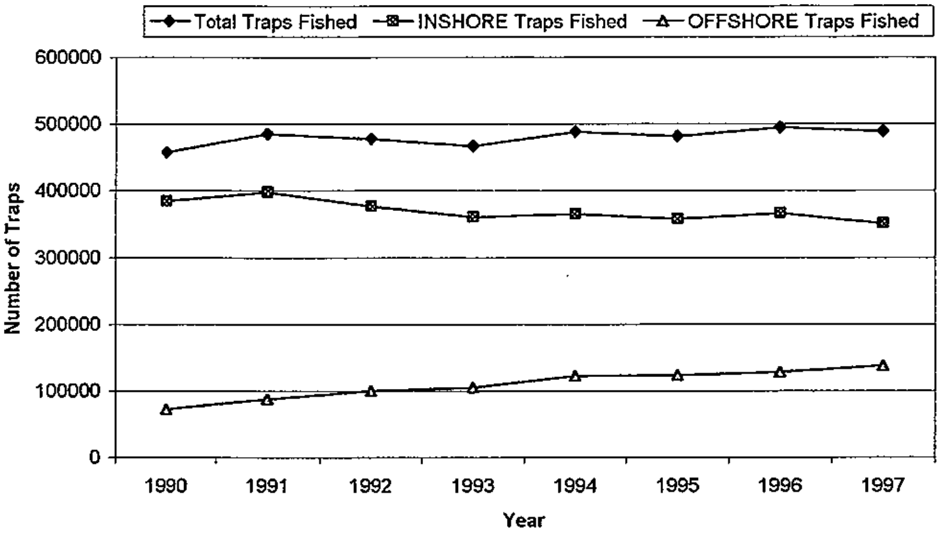


Figure 168. Trends in average soak time for all areas, inshore, and offshore areas in MA lobster fishery during 1990-1998.

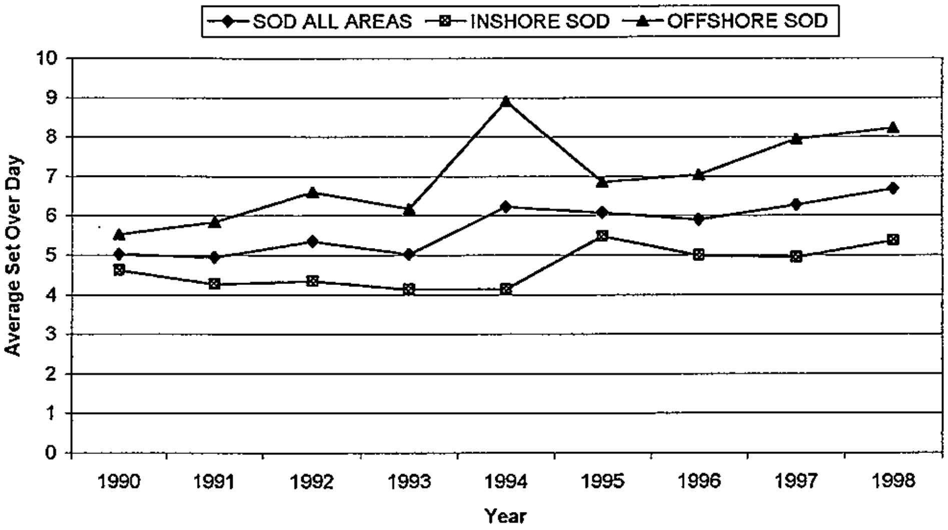


Figure 169. Number of traps reported by NY fishermen in state and federal waters off the south shore of Long Island

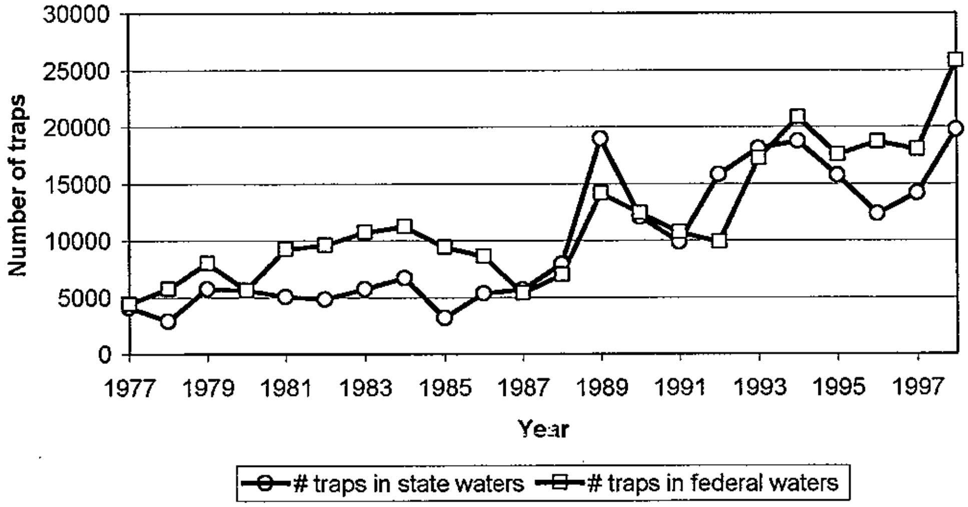


Figure 170. Proportion of traps reported by NY fishermen in state and federal waters off the south shore of Long Island

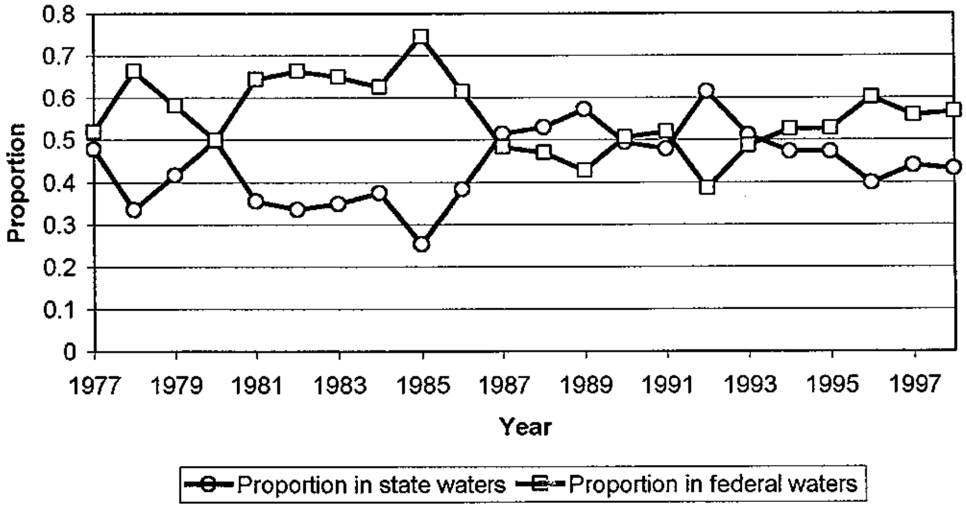


Figure 171. Mean densities of recently settled young of the year lobsters (mean numbers per square meter + - standard error) on the Maine coast during 1989-1999. (Data provided by Rick Wahle, Bigelow Laboratory for Ocean Sciences).

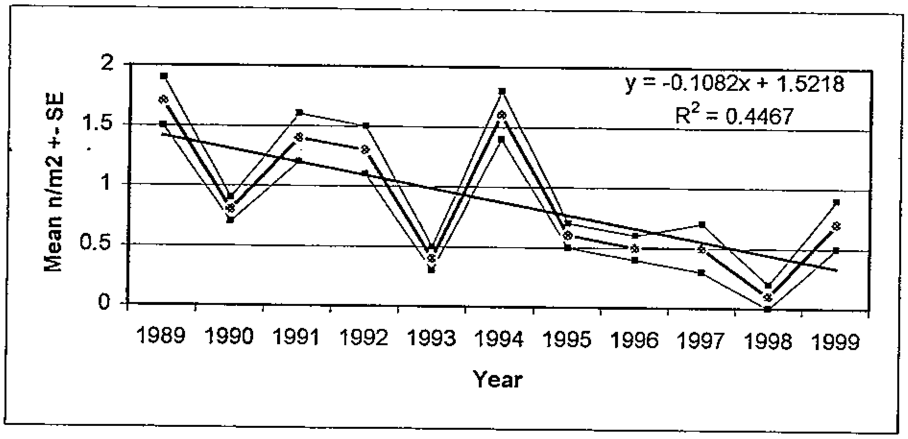


Figure 172. Mean densities of recently settled young of the year lobsters (mean numbers per square meter + - standard error) on the RI coast during 1990-1999. (Data provided by Rick Wahle, Bigelow Laboratory for Ocean Sciences).

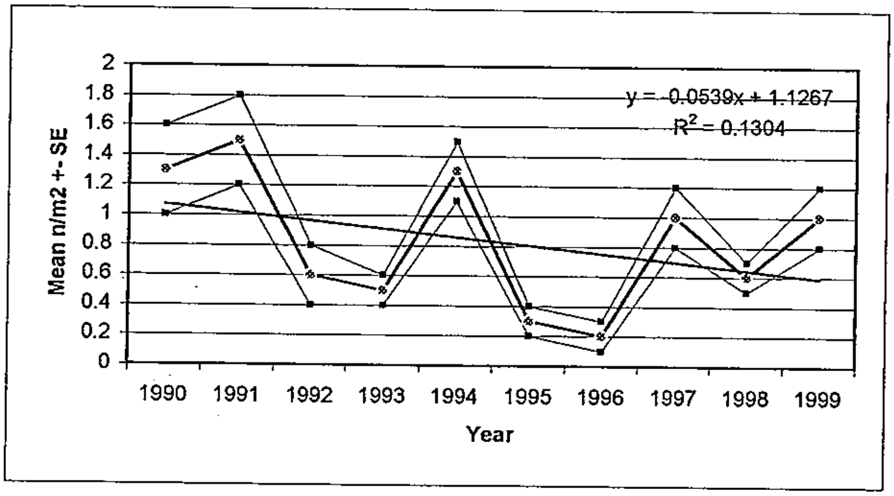
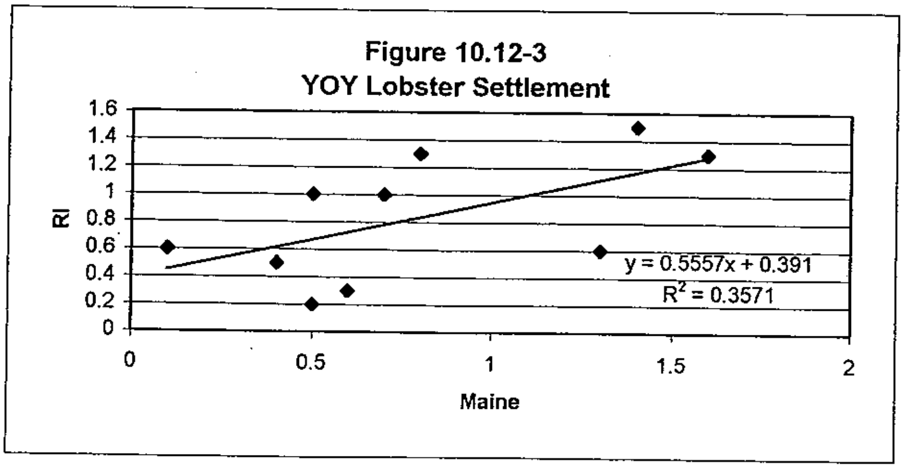


Figure 173. Correlation of RI and Maine lobster settlement density estimates, 1990-1999.



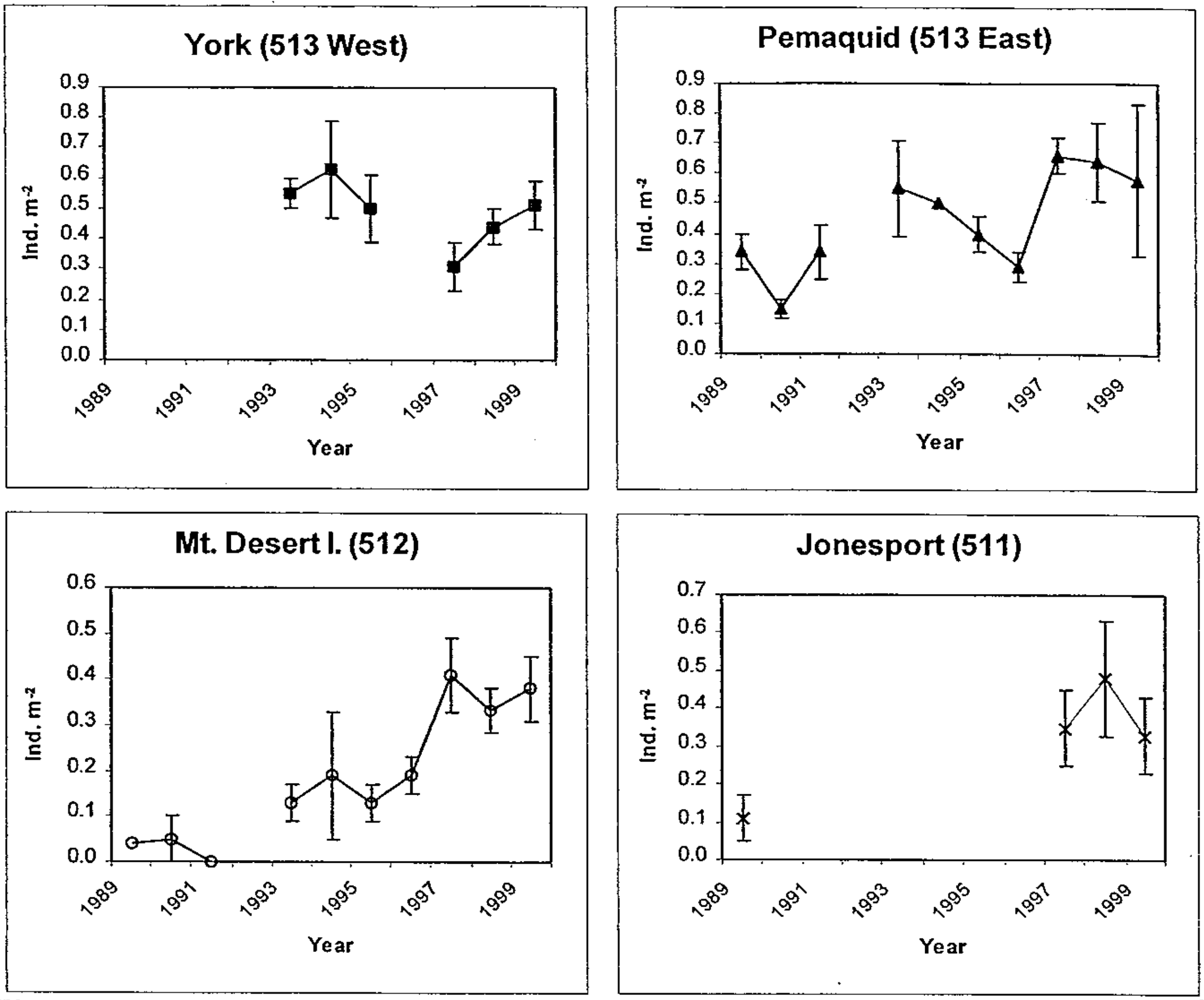


Figure 174. Abundance of Adolescent Phase lobsters (40-90 mm CL) in boulder habitat, in four outer coastal regions (separated by 50 km) along the coast of Maine, from diver surveys at 10 m depth.

# APPENDIX A

## Mark: A New Assessment Model and Preliminary Assessment Results for American Lobster in the Gulf of Maine, Georges Bank and South, and South of Cape Cod & Long Island Sound Stock Areas

**The Mark Model is a work in progress and was not used in the main body of the stock assessment report due to known technical problems.**

## **Appendix A** - Mark: A New Assessment Model and Preliminary Assessment Results for American Lobster in the Gulf of Maine, Georges Bank & Offshore, and South of Cape Cod & Long Island Sound Stock Areas

This appendix describes work in progress towards developing a new stock assessment model for lobster (*Homerus americanus*) called "Mark." Mark was developed by Larry Jacobson (National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA) and the Atlantic States Marine Fisheries Commission's (ASMFC) Lobster Stock Assessment Subcommittee. The effort to develop a new model for lobster was motivated by Gibson (1999) and Crecco and Gottschall (1999). Mark is part of the Lobster stock Assessment Subcommittee's effort to implement research recommendations (Attachment A-1) from the last Stock Assessment Review Committee (NEFSC 1996) review and the Review of the Population Dynamics of American Lobster in the Northeast (ASMFC 1996).

This analyses described below based on Mark supplements the stock assessment prepared by the Atlantic States Marine Fisheries Commission's (ASMFC) Lobster Stock Assessment Subcommittee which gives more complete information about the fishery, data and lobster biology. This analysis based on Mark does not represent a minority view. In general, results from the Subcommittee's assessment and Mark were similar.

Catch or other data used in Mark may differ from data used in the Subcommittee's assessment. In case of discrepancies, the data in the Subcommittee's assessment should be regarded as the best available information. Basically, there was insufficient time to update catch at length and other data used in Mark to include revisions made late in the assessment process. Results from Mark were preliminary, due to technical problems, so there was little reason to make changes in data at the last minute.

Preliminary assessment results from Mark are given for three stock areas: Southern Cape Cod and Long Island Sound (SCCLIS), Georges Bank & South (GNK) and the Gulf of Maine (GOM). Results are preliminary because preliminary data were used and because Mark is not yet fully evaluated or tested (see below). The three stock areas were specified by the ASMFC in terms of reference for this assessment.

The central task for the lobster assessment, as described in the terms of reference, was to estimate recent fishing mortality rates. Recent fishing mortality rates are important to managers because they are used to determine if lobster stocks are legally overfished according to a threshold fishing mortality rate criterion (ASMFC 1997).

The main problem in lobster assessment work is uncertainty about the absolute level of fishing mortality and abundance due to lack of synoptic survey coverage in most stock areas, uncertainty about growth, size specific selectivity of commercial fishing gear, size specific selectivity of research trawl survey gear, and uninformative catch/abundance histories. Neither Mark nor the modified DeLury model (used in the Subcommittee's assessment) for lobster converged to "best estimates" of fishing mortality and abundance based on abundance index and fishery data alone. Both required constraints to identify feasible solutions. A traditional q-ratio constraint (see below) was used in the DeLury model but there were unresolved problems with q-ratios (i.e. infeasible values) in Mark. In addition, the Subcommittee's assessment was carried out by sub-regions that were defined based on areas covered by state and federal trawl surveys. In Mark, the surveys in sub-regions were assumed to cover entire stock areas. The Subcommittee's approach is better technically because trends in abundance and fishing mortality differed among sub-regions within stock areas. The next version of Mark should accommodate surveys for lobster in heterogenous subareas.

Abundance and fishing mortality rate estimates from Mark are less reliable than estimates from the DeLury model for lobster but Mark does provide useful information about trends and other factors. Preliminary results are summarized below.

## Summary

- Data and preliminary model results indicate that lobster abundance increased (GOM and SCCLIS) or fluctuated without trend since 1982 (GBK). Increased lobster abundance in GOM and SCCLIS was due to recruitment that increased steadily since 1982, probably in response to environmental conditions favorable for lobster reproduction.
- In GOM and SCCLIS where abundance increased, catch increased proportionally and fishing mortality rates were relatively constant after 1990. In the GBK area, abundance was flat and fishing mortality rates increased with increases in catch.
- Based on abundance index data from bottom trawl surveys and commercial CPUE, there is evidence of localized depletion of lobster in sections of all three stock areas where fishing is heaviest.
- Mark model results for GOM and GBK implied q-ratios larger than one that are probably not feasible. Model results for SCCLIS have feasible q-ratio values but may depend on assumptions about growth.
- Catch weighted average fishing mortality rates are higher (usually about double) for lobster stocks than abundance weighted averages. Mark calculates both catch and abundance weighted averages (catch weighted averages are generally used in this report). Either convention is fine, but using both causes confusion unless differences are understood. It is probably better to use the same convention for all models so that results are easily comparable.
- Length cohort analysis and preliminary results from Mark both indicate that fishing mortality rates decline with size for lobster.
- Mark was implemented in Excel because spreadsheets are understood by all lobster biologists, it was easy to build prototype models quickly, data and calculations are clear to all users, and graphs are easy to make. Mark should be rewritten in a more efficient language if faster run times are more important than transparent calculations.
- The current version of Mark does not include uncertainty calculations (other than manual likelihood profiles, see below). Bootstrap capabilities should be included in the next version. Bootstrap calculations are feasible in spreadsheet models (e.g. Atlantic surfclam assessment in NEFSC 2000) but are more efficient and faster in other languages.
- Future versions of Mark should also include tuning to surveys data with zeroes because trawl survey data for large lobsters in inshore areas are often zeroes (Butler et al. 1999). Survey zeroes for large lobster may be due to movement of large individuals to deep water, or high mortality rates, or both. In some cases, the frequency of zeroes appears to have increased over time. However, hypotheses are difficult to investigate if the survey data are not included in the assessment model for lobster.

*GOM Assessment Results*

- Catches of lobster in GOM during 1996-1997 (1998 data incomplete) were the highest since 1982 and almost evenly divided between males and females.

- The bulk of the catch comes from the first legal size group (83-92 mm CL). Catch of males in the second legal size group (93-102 mm) is proportionally higher for males than for females in GOM.
- NMFS and Massachusetts fall bottom survey data indicate that recruitment increased across GOM during 1982-1998.
- NMFS fall trawl survey data indicate that abundance of larger lobster increased also during 1982-1998.
- Massachusetts fall trawl survey data, in contrast, show flat or declining trends in abundance for larger lobster in Massachusetts waters of the GOM.
- Commercial catch rates for lobster fishing in Maine increased steadily during 1982-1996 (the last year with data). A short time series of catch rates based on federal logbook data, which is probably less reliable and measures abundance trends in a relatively small part of GOM, declined markedly during 1994-1998.
- Simple exploitation rate indices (catch / survey abundance) data for lobster in GOM indicate increasing exploitation rates in Massachusetts waters, where fishing is heaviest, and relatively constant exploitation rates for the stock area as a whole.
- NMFS and Massachusetts fall trawl survey data were used to tune Mark for lobster in GOM. A wider range of data including commercial CPUE and sex ratio information were included in the model and assessment but not used for tuning.
- All Mark model runs suggest that female lobster fishing mortality rates for the stock as a whole varied without trend during 1982-1998 while catch and recruitment increased and abundance nearly doubled. Increases in catch appear to have been offset by increased recruitment.
- Based on preliminary model runs, relative abundance (proportion of total stock) of large female lobster (113 mm CL and larger) increased in the GOM during 1982-1998.
- Estimated fishing mortality rates for male lobsters were usually higher than for female lobsters in GOM. Catch weighted estimates of average fishing mortality rates were about twice as large as abundance weighted estimates

*GBK Assessment Results*

- Catches of lobster in GBK increased during 1982-1993 and were relatively stable at near record levels afterwards. Sex ratio of the catch declined from about 60% male in 1982 to about 48% male in 1997. The reasons for changes in sex ratio of landings are unknown.
- The bulk of the catch comes from the first legal size group (83-92 mm). Catch of males in the second legal size group (93-102 mm) is proportionally higher for males than for females in GBK.
- NMFS fall bottom survey data indicate that recruitment fluctuated without trend for lobster in GBK during 1982-1998.
- NMFS fall trawl survey data indicate that abundance of legal size lobster (the sum of abundance for all legal size groups) in GBK also fluctuated without trend during 1982-1998. The same data show, however, that abundance of females in the largest length group (113+ CL) increased by about 50% as the sex ratio for the largest length group declined from about 35% male to about 20% male.
- Commercial catch rates for lobster fishing in canyons collected by Rhode Island during 1990-1997 suggest increasing trends in recruitment and variable abundance of larger lobster. However, Rhode Island CPUE data were collected from a small part of the stock area and do not measure trends in abundance for GBK as a whole.
- Commercial catch rates from federal logbook (VTR) data indicate a decline in lobster abundance during 1994-1998. The data were collected from a small part of the stock area and likely reflect trends in a local area. VTR catch rates probably do not measure trends in abundance of legal size lobster for GBK as a whole.

- A simple exploitation rate index (catch / survey abundance) for lobster in GBK indicates that exploitation rates in GBK as a whole increased during 1982-1990 and fluctuated without trend afterwards.
- Rhode Island sea sampling data for lobsters taken in canyons indicate that the proportion of soft shell lobster increased during 1991-1993 and fluctuated without trend afterwards. Proportion soft shell lobster in traps from sea samples may be an index of the intensity of or seasonal distribution of exploitation. This is a topic for future research.
- NMFS fall trawl survey data and all commercial CPUE data were used to tune Mark for lobster in GBK. CPUE is likely not as useful as trawl data for tracking trends in lobster abundance but CPUE indices were the only information (other than NMFS trawl data) available (we wanted to avoid tuning Mark to only one type of index data). Trends in trawl survey and CPUE data (except from federal logbooks) were similar. Estimated trends in fishing mortality rates and abundance did not change substantially when CPUE data were added or removed. Sex ratio information were included in the model and assessment but not used for tuning.
- All Mark model runs suggest that fishing mortality rates for lobster in the GBK stock increased during 1982-1989, fluctuated without trend during 1990-1994 and declined afterwards. Abundance and recruitment fluctuated without trend during 1982-1998.
- Estimated fishing mortality rates for males were usually higher than for female lobsters in GBK.

*SCCLIS Assessment Results*

- Catches in 1996-1997 (1998 data incomplete) were the highest since 1982. Unlike other stock areas, lobster landings from SCCLIS were predominantly female (62% female, on average during 1982-1997).
- The bulk of lobster catch of both sexes in SCCLIS comes from the first legal size group (83-92 mm) with small amounts from the second legal length group (93-102 mm).
- A large number of trawl survey abundance indices were available for lobster in SCCLIS but none covered all or most of the stock area. However, nearly the entire SCCLIS stock area was surveyed by the surveys as a group. None of the surveys provide reliable indices of abundance for large lobsters because they are relatively uncommon in SCCLIS and difficult to survey.
- Crude exploitation rate indices (catch divided by survey abundance for legal size lobsters) based on NMFS and Rhode Island trawl survey data fluctuated without trend. The index based on Connecticut spring data declined after 1993 while the index based on fall data continued to increase.
- Estimates of catch weighted average female fishing mortality rates differed in runs with alternative growth assumptions. This suggests that estimates from Mark are sensitive to assumptions about growth.
- Sex ratio at recruitment is likely skewed towards females in SCCLIS because landings are mostly female and prohibitions on landing ovigerous females are believed to protect female lobsters. Lower fishing mortality rates for females (due to management measures) and higher female catch (62% of total landings) would be impossible without a sex ratio skewed towards females.
- All runs suggest that fishing mortality increased after 1987 and remained relatively constant afterwards (except for a drop in 1991 likely due to errors in the catch data). All runs depict increasing recruitment and abundance levels.
- Fishing mortality rates were often higher for males than females (contrary to results for other areas). This pattern may be real or due to inaccurate partitioning of total landings to sex groups.

## Model Structure

The main new features in Mark in comparison to the DeLury model are: 1) spreadsheet (rather than APL) implementation; 2) calculations for both sexes (instead of one) in the same model, 3) length- (rather than age-based) calculations based on estimates of intermolt duration and molt increments from the Subcommittee's assessment; 4) five length groups (instead of two age groups); 5) ability to use either exact solutions for fishing mortality in the conventional catch equation or an approximation like Pope's (1972); 6) inclusion of all available data (up to forty indices of abundance, sex ratio, exploitation or any other type of information); 7) ability to tune to index data as measures of trend, trend and scale, or scale only; 8) changes to assumptions about process error; and 9) flexible implementation of ad-hoc constraints. Ability to calculate a scaling parameter for an index (e.g. an abundance index) and to compare data and model predictions without tuning were new and very useful features (see below).

Like the modified DeLury model, Mark is a member of the family of models based on forward simulation calculations (Fournier and Archibald 1982). In terms of model structure and complexity, Mark lies between the very simple production and biomass dynamic models (with one or two age or size classes, e.g. Deriso et al. 1985) and the most complex age- and size-structured models (e.g. Methot 1989). Mark is more complex than the DeLury framework because growth is modeled in greater detail, males and females are included in the same model run, and because more data are used. Mark assumes discontinuous growth based on a stochastic molting process (a lobster may or may not molt and grow during a particular year).

Mark has two parts. The first part is a population simulation model. The second part "tunes" the simulation model and estimates parameters by statistical comparison (based on maximum likelihood) of observed and predicted data.

As described above, Mark was implemented as an Excel spreadsheet. Tuning and parameter estimation are carried out using the Solver function in Excel. Excel, rather than a more powerful optimization language (e.g. AD-Model Builder), was used because spreadsheets are understood by all lobster biologists, it was easy to build prototype models quickly, data and calculations are clear to all users, and graphs are easy to make. The costs in using Excel were long model run times because Solver is relatively slow and inefficient. Bootstrap calculations for Mark (as a spreadsheet program) are technically feasible (see Atlantic surfclam in NEFSC 2000) but may be impractical due to long run times. Mark should probably be rewritten in a more efficient language (e.g. AD-Model Builder, Otter Software Ltd.) in future if faster run times are more important than transparent calculations.

### *Simulating the Population*

Length groups used for lobster in Mark were chosen for convenience and to correspond to typical growth increments in lobster (about 10 mm) and management regulations (i.e. legal size limit). There were five length groups in the model: 73-82 mm CL (length group –1), 83-92 mm (length group 0), 93-102 (length group 1), 103-112 (length group 2) and 113+ mm (length group 3+). The first length group (group –1) includes small/young lobster recruited to the biological stock but not to the fishery. The second group, group 0, starts at 83 mm which is the current minimum legal size and includes new recruits to the fishery. Groups 1 and 2 are one and two length groups after recruitment to the fishery, etc. Group 3+ is a "plus group" that includes all lobster 113 mm and larger. There is no direct correspondence between size and age in Mark or in lobsters in general (see below) although the very smallest length group may approximate a year class. In particular, larger size groups include lobsters of many different ages. Unless otherwise stated, "recruits" in this report means lobsters in length group –1 (73-82 mm) that are newly recruited to the biological stock (and not yet recruited to the fishery because the legal size limit is 83 mm). In some contexts and following tradition (e.g. NEFSC 1996), the first length group is sometimes referred to as "pre-recruits" (the author apologizes for any confusion).

"Number of length groups at least five" is a rule of thumb coined for this assessment based on analogy to estimating mortality rates from a catch curve and linear regression. The first and last length groups for lobster (groups -1 and 3+) are not useful for catch curve analysis because the first has not recruited to the fishery and the last is a plus group (Ricker 1975). Eliminating the first and last leaves only three length groups (groups 0, 1 and 2), the minimum number for linear regression that does not interpolate between two points. The modified DeLury model is well not suited for estimating fishing mortality rates without constraints (see below) because there are too few length groups to track changes in abundance used to measure fishing mortality.

Mark was configured with 10 mm length groups for lobster in this analysis. Length group definitions are flexible, however, and any combination of even or uneven size length groups can be used.

Mark uses October-September "survey years" as annual time steps because fishery data are traditionally compiled by survey year and it was not practical to recompile historical catch data by other annual periods. For example, the 1984 survey year started 1 October 1984 and ended 30 September 1985. In the what follows, "year" means survey year unless otherwise indicated. A different annual period corresponding to the beginning of the peak molting period may have been better and this is a topic for future research.

Model runs for all areas included survey years 1982-1998. Fishery data were complete for 1982-1997 but preliminary for 1998. For this reason, estimates from Mark for 1997 were the best recent estimates of recent fishing mortality.

Abundance of lobster in length groups 0 to 3+ at the beginning of the first year (1982) were calculated either as the product of sex ratio and length specific initial abundance parameters (SCCLIS) or from sex- and length group-specific abundance parameters (GOM and GNK). In what follows, "parameters" (symbolized with capital letters) are quantities estimated in the model. For example, numbers of females in length group 2 at the beginning of 1982 (the initial year) in SCCLIS was:

$$n_{F,82,2} = (1-x)\,e^{P_{82,2}}$$

where x was the sex ratio [defined as proportion male at recruitment and calculated $x=e^K/(1+e^K)$ where K was a parameter estimated in the model] and $P_{y,g}$ was log abundance for lobsters in length group g at the beginning of survey year y (also a parameter). The equivalent calculation for lobster in GOM and GNK was:

$$n_{F,82,2} = e^{P_{F,82,2}}$$

The configuration used for GOM and GBK was more flexible and allowed the model to better match sex ratio and abundance data for the first few years (at the cost of four extra parameters).

Recruitment to the stock in each year was calculated based on the sex ratio and annual recruitment parameters. Recruitment of males to the stock in each year was:

$$r_{M,y} = x\, e^{P_y}$$

and recruitment of females was:

$$r_{M,y} = (1-x)\, e^{P_y}$$

Population dynamics of males and females were independent after recruitment and, for SCCLIS, after the beginning of the first year in the model.

It is important to distinguish between the number of new recruits $r_{s,y}$ and abundance of the smallest length group $n_{s,y,-1}$. They are not the same because all lobsters do not molt every year. In general, the number of lobster in the smallest length group will be larger than or equal to the number of recruits.

Lobster population dynamic calculations in Mark for lobster in this assessment used Baranov's (Ricker 1975) catch equation (instead of a Pope-type approximation, see below) with length groups and annual time steps:

$$c_{s,y,g} = u_{s,y,g}\, n_{s,y,g}$$

where $c_{s,y,g}$ was catch in number for sex s, during year y and for length group g (catch at length by sex were data supplied to the model). The exploitation rate $u_{s,y,g}$ was calculated:

$$u_{s,y,g} = \frac{f_{s,y,g}}{m + f_{s,y,g}}\left(1 - e^{-m-f_{s,y,g}}\right)$$

The instantaneous natural mortality rate for lobster was assumed to be m=0.15 $y^{-1}$ (NEFSC 1996).

Instantaneous fishing mortality rates ($f_{s,y,g}$ in units of $y^{-1}$) in the catch equation were calculated using Sims (1982) algorithm usually to a precision of at least $10^{-6}$. Sims' algorithm was implemented as a C++ function in a Windows DLL file that could be called directly from Excel (DLL file and code available from the author). The total instantaneous mortality rate was $z_{s,y,g} = m + f_{s,y,g}$.

As described above, the assessment for lobster used exact solutions for fishing mortality rates and the catch equation but the spreadsheet for Mark was programmed to use either the exact solution or a generalized Pope-type approximation (Pope 1972), as specified by the user. The exact solution works well when fishing mortality is continuous or distributed symmetrically through the year. The approximation works well for pulse fisheries that occur early or late in the year. Ignoring subscripts for sex and length group, the generalized version of Pope's approximation was:

$$n'_y = \left[\left(n_y e^{-\delta m}\right) - c_y\right] e^{-(1-\delta)m}$$

where $n'_y$ was abundance at the very end of the year and $\delta$ was the elapsed fraction of the year when fishing takes place. For the Pope-type approximation, fishing mortality rates were calculated:

$$f_{s,y,g} = \ln\left(\frac{n'_{s,y,g}}{n_{s,y,g}}\right) - m$$

Mark included a spreadsheet page with a simple simulation program designed to help the user choose an approach and make good choices for δ.

The lobster fishery is seasonal with peaks in the fall (at the beginning of the survey year after the main molting season) and spring (at the end of the survey year). Lobster catches are highest in the fall at the beginning of the survey year and lower in the spring at the end of the survey year. However, CPUE and spring/fall survey data show that abundance is lower in the fall at the beginning of the survey year after the peak molt and lower in the spring near the end of the survey year after a year of fishing. Simulation calculations in Mark showed that the lower spring catches were offset by lower abundance in all three stock areas so that fishing mortality was symmetrically distributed through the year and the exact solution to the catch equation was sufficiently accurate. The Pope-type approximation with suitable choice of δ would have been just as accurate.

Similar to VPA (virtual population analysis) and like the DeLury model and LCA, Mark assumed that catches in number by length group and sex ($c_{s,y,g}$) were known without error. This assumption is not valid for lobster because lobster catch data are imprecise (even by fishery standards). More realistic approaches require estimation of fishing mortality rates as parameters and would not have practical in a spreadsheet.

Mark (like VPA and LCA) did not assume "separability" (Megrey 1983) or a particular pattern in fishing mortality rates for lobster of various sizes. In contrast, the DeLury model makes no assumptions about fishery selectivity (this is one of its main advantages, see explanation in the Subcommittee's assessment). The approach in Mark is more interesting for lobster because LCA results (Cadrin and Estrella 1996) show fishing mortality rates that decline with size and selectivity patterns may be important in understanding the resilience of lobster stocks.

Numbers of lobsters in each size group change over time as individuals die from fishing and natural mortality and molt out of their current length group. For example, numbers in the smallest length group after the initial year would be calculated:

$$n_{s,y,-1} = r_{s,y} + n_{s,y-1,-1} e^{-Z_{s,y-1,-1}} (1 - p_{s,-1})$$

where $p_{s,g}$ was the sex- and length group-specific annual transition probability (see below).

*It is important to distinguish between transition probabilities in Mark and molting probabilities.* The transition probability $p_{s,g}$ is the combined probability of molting and the conditional probability of molting with an increment large enough to grow into the next length interval. Transition probabilities must be smaller than or equal to molting probabilities because some lobsters may molt without growing into the next length group. Transition probabilities were estimated as described below.

In addition to transition probabilities, Mark included conditional probabilities of skipping the next length group. These probabilities are conditional because they apply only under the condition that a lobster molts out of its current length group. As described above, Mark used 10 mm length groups but the molt increment for some stock areas is larger than 10 mm (i.e. 11 mm in GOM, 14 mm in GBK and 10 mm in SCCLIS). A lobster in length group –1 with a molt increment of 14 mm, for example, would skip length group 0 and molt directly into length group 1. By definition in Mark, the conditional probability of molting into the next length group is $o_{s,g}$ and the probability of skipping the next group is $(1- o_{s,g})$. For simplicity and for lack of information, we assumed the conditional probability of skipping two or more length groups was zero. Estimates of conditional probabililities for lobster are described below.

Calculations involving growth and mortality for lobster in the largest (plus) length group are a special case because the probability of molting out of the plus length group is zero by definition:

$$n_{s,y,3+} = n_{s,y-1,2} e^{-z_{s,y-1,2}} p_{s,2} + n_{s,y-1,1} e^{-z_{s,y-1,1}} p_{s,1} (1 - o_{s,1}) + \\ n_{s,y-1,3+} e^{-z_{s,y-1,3+}}$$

Abundance of intermediate length groups was calculated:

$$n_{s,y,g} = n_{s,y-1,g-1} e^{-z_{s,y-1,g-1}} p_{s,g-1} o_{s,g-1} + \\ n_{s,y-1,g-2} e^{-z_{s,y-1,g-2}} p_{s,g-2} (1 - o_{s,g-2}) + \\ n_{s,y-1,g} e^{-z_{s,y-1,g}} (1 - p_{s,g})$$

Transition probabilities were calculated from sex- and length group-specific estimates of mean time in length group using a "distance divided by velocity" approximation suggested (but not endorsed!) by J. Idoine (National Marine Fisheries Service, Northeast Fisheries Science Center). Mean time in length group ($t_g$) was:

$$t_{s,g} = \frac{d_{s,g}}{i/x_{s,g}}$$

where $d_{s,g}$=10 mm was the size of the length group in the model, i was the stock area-specific average molt increment (i.e. 11 mm in GOM, 14 mm in GBK and 10 mm in SCCLIS, as used in LCA and EPR calculations), and $x_{s,g}$ was the length group-specific average molt interval (y $\text{molt}^{-1}$, also as used in LCA and EPR calculations). In effect, mean time in length group was calculated as distance (d in mm) divided by velocity (i/z in mm $y^{-1}$).

The annual transition probability was approximated:

$$p_{s,g} = \min\left(1, \frac{1}{t_{s,g}}\right)$$

One mm estimates of inter-molt durations (provided by J. Idoine, Northeast Fisheries Science Center, National Marine Fisheries Service, Woods Hole, MA) were averaged to calculate stock area- and sex-specific average $x_{s,g}$ values for 10 mm length groups in Mark. For the plus group, one mm molt average durations for all lobster larger than 113 mm were calculated with weights based on average numbers at length in the NMFS trawl survey. The weighted average eliminated problems in calculations based on long inter-molt durations for relatively large and rare lobsters.

Conditional probabilities of molting to the next length group or skipping a length group were calculated based on an approximation suggested by D. Hart (National Marine

Fisheries Service, Northeast Fisheries Science Center). If lobsters are distributed evenly across their length group and the molt increment is larger than the length group used in the Mark, then:

$$o_{s,g} = \frac{d_{s,g}}{i_{s,g}}$$

Estimation of transition and conditional probabilities for lobster were crude but based on the best available data and common approximations.

*Objective Function*

Mark estimated parameters that minimized the weighted sum of squares (negative log-likelihood):

$$\Xi = 0.5\left(\sum_{j=1}^{n_\Gamma} \lambda_j \Gamma_j + \sum_{k=1}^{n_\Theta} \lambda_k \Theta_k + \sum_{L}^{n_\Omega} \lambda_L \Omega_L\right)$$

where the sums of squares $\Gamma_j$ was for fit to trends in one of the $n_\Gamma$ indices (usually an index of abundance, exploitation, or sex ratio), $\Theta_k$ was the sum of squares for fit to one of the $n_\Theta$ other types of data (e.g. estimates of sex ratio at recruitment), $\Omega_j$ was the sum of squares for one of the $n_\Omega$ constraints, and $\lambda_j$, $\lambda_k$, and $\lambda_L$ were component-specific weighting factors (see below). The number of parameters in Mark estimated by Solver was usually 23-27 (e.g. 18 recruitments, the sex ratio at recruitment, and four to eight initial abundance values; survey scaling parameters were not estimated using Solver, see below).

In addition to likelihood component-specific weights ($\lambda$), the objective function in Mark for each component included weights ($\nu$, generally set to one, see below) applied to each observation in an index time series or each instance of a constraint (see below). Component specific weights effect goodness of fit for the entire index data set but observation/instance weights have a smaller scope. The product ($\lambda\nu$) determines the importance of an individual observation or instance of a constraint in tuning the model (Conser and Powers 1989).

Mark was an "all measurement error" model that did not include objective function terms for process errors as in the traditional DeLury model. Process errors were omitted for simplicity, because they are implicitly included in recruitment parameters that change from year to year (Jacobson et al. 1994), because measurement errors in lobster data were substantial and likely dominant, and because process error terms complicate parameter estimation, usually with few benefits (Collie and Kruse 1998). Process errors can be accommodated in a state-space modeling framework (e.g. Meyer and Millar 1999) and this is an area for future research.

*Tuning to Indices*

Mark made effective use of a very wide range of index data (up to forty time series). Types of index data that could be included in the stock assessment were anything that could be measured on the real stock and calculated in the model. For lobster, these types of data include indices of: 1) abundance (usually sex and length group-specific), 2) sex ratio (length group-specific) from trawl surveys, 3) instantaneous mortality rate (usually based on Von Bertalanffy growth models and length composition data, e.g. LCA), and 4) exploitation rate (from mark-recapture data). The only constraint on indices was the assumption that measurement errors were log normal or symmetrical in log scale. Fortunately, the log normal assumption works well for most types of fishery data which are inherently positive.

In Mark, predicted values for indices were calculated:

$$\hat{w}_{v,s,y} = q_v a_{v,s,y}$$

where hats "^" denote model estimates, $w_{v,s,y}$ was index type v for year y, $q_v$ was an index-specific scaling coefficient, and $a_{v,s,y}$ was abundance (or mortality, sex ratio, exploitation rate, etc.) of lobster "available" to the index. For example, lobster available to an abundance index were calculated:

$$a_{v,s,y} = \sum_{g=-1}^{3+} s_{v,s,g} n_{s,y,g}$$

where $s_{v,s,g}$ were survey-, sex-, and length group-specific selectivity parameters specified by the user.

Scaling parameters for abundance indices were calculated based on the analytical maximum likelihood estimator (MLE):

$$q_{v,s} = e^{b_{v,s}}$$

where:

$$b_{v,s} = \frac{\sum_{j=1}^{n_v} \ln\left(\frac{w_{v,s,j}}{a_{v,s,j}}\right)}{n_v}$$

and $n_v$ was the number of observations for index v. Years with missing index data were omitted from the summation and did not effect calculations. Note that the MLE for survey scaling parameters in the preliminary Mark model does not include observations specific weights ($\upsilon$). This shortcoming means that the MLE holds only if the weights are either zero (out of the model) or one (completely in the model). In all model runs, the observation weights were therefore either zero or one. A closed form MLE that accommodates observation weights of any value is given in NEFSC (2000).

As described above, the MLE used to calculate scaling factors in Mark assumes log normally distributed errors or symmetrical log scale errors in the relationship between observed and predicted values of an index. This means that the MLE automatically calculates the scaling parameter $q_k$ to minimize the sum of squares:

$$\Gamma_k = \sum_{j=1}^{n_j} \upsilon_{k,j} \left[\ln\left(w_{k,s,j}\right) - \ln\left(q_k a_{k,s,j}\right)\right]^2 = \sum_{j=1}^{n_j} \upsilon_{k,j} \left[\ln\left(w_{k,s,j}\right) - \ln\left(\hat{w}_{k,s,j}\right)\right]^2$$

for the data and values of $a_{k,s,y}$ already calculated in the simulation (as long as $\upsilon_{k,j}$=zero or one, see above). Advantages in using the MLE instead of Solver to estimate scaling parameters (in addition to including indices without tuning, described above) include speed of calculation and limits in Solver to the number of parameters that can be estimated. It would have been impossible to use Solver because the number of scaling factors (up to 40) was potentially large. Another important advantage related to modeling flexibility is described below under "tuning to ad-hoc constraints."

The selectivity terms $s_{v,s,g}$ used in tuning (e.g. to an abundance index) were one for an index and length group if changes in abundance of lobsters in the length group were expected to be reflected proportionally in the index, zero if abundance of the length group did not effect the index, or some value between zero and one if part of the length group was available to the index. Selectivity parameters for lobster in Mark were simpler than in many other length- or age-stratified models because indices for lobster are usually length specific (e.g. Methot 1989). For example, the NMFS bottom trawl survey stratified for female pre-recruits was assumed to measure relative abundance of female lobsters 73-82 mm CL so $s_{v,s,g}$ was one for length group –1 (73-82 mm) and zero for all other length groups.

Calculations for indices of instantaneous mortality (e.g. LCA estimates of catch weighted f) were similar except that available abundance $a_{v,s,y}$ was replaced in calculations by selectivity filtered, catch weighted mean mortality rates ($u_{v,s,y}$):

$$u_{v,s,y} = \frac{\sum_{g=-1}^{3+} s_{v,s,g} c_{s,y,g} f_{s,y,g}}{\sum_{g=-1}^{3+} s_{v,s,g} c_{s,y,g}}$$

Catch, rather than abundance, weights were used in calculating average fishing mortality rates because catch weighting is traditional in LCA for lobster (Cadrin and Estrella 1996).

Calculations involving indices of exploitation rates (rather than instantaneous mortality rates) substituted model estimates of selectivity filtered, abundance weighted mean exploitation rates for available abundance. Specifically, $f_{s,y,g}$ in the equation above was replaced with $f_{s,y,g} / z_{s,y,g} \, [1-\exp(_{s,y,g})]$ and catch $c_{s,y,g}$ was replaced with abundance $n_{s,y,g}$ .

For sex ratio indices, we used selectivity filtered, abundance weighted model estimates of sex ratio instead of available abundance (i.e. replace $f_{s,y,g}$ with $x_{y,g}=n_{M,y,g} / [n_{M,y,g} + n_{F,y,g}]$). Sex ratio indices may be particularly useful because changes in sex ratio are a form of change-in-ratio estimator that might measure sex-specific differences in mortality or growth rates.

*Tuning to Other Types of Data*

A variety of data describing the sex ratio of recruits was available from sea samples, port samples and surveys from all three stock areas. These were used to estimate sex ratios at recruitment in the stock. Recruitment parameters in the model (which determine numbers of males, females and the sex ratio) were adjusted by Solver to minimize:

$$\Theta = \ln\left(\frac{x}{\hat{x}}\right)^2$$

where $\hat{x}$ was an abundance weighted sex ratio calculated in the model and x was the mean sex ratio calculated over all observations from each data set (or an assumed value).

### *Tuning to Constraints*

Ad-hoc constraints are an important in many stock assessment models, particularly those based on forward simulation calculations like Mark and the DeLury model (Methot 1989; Jacobson et al. 1994). The DeLury model for lobster, for example, does not converge to feasible estimates unless the ratio of scaling factors for length group –1 (73-82 mm) and larger (83+ mm) lobsters are constrained to a pre-specified value (NEFSC 1996). A model for northern anchovy (*Engraulis mordax*) gave recruitment estimates that were too variable unless a constraint on recruitment variability was applied (Jacobson et al. 1994).

Constraints in Mark requiring "equality to target" penalized model fits with estimates that did not match a target value. These constraints were calculated:

$$\Omega_k = \sum_{j=1}^{n_j} \nu_{k,j} \ln\left[\frac{\tau_{k,j}}{\mathrm{T}_{k,j}}\right]^2$$

where $\tau_{i,j}$ was the current model estimate, $n_i$ was the number of instances for the constraint, and $T_{i,j}$ was a target for the constraint calculated in the model or specified by the user. The associated weight $\lambda_i$ in the objective function (see above) determined the strength of the constraint as a whole and the weights $\gamma_{i,j}$ (usually zero or one) determined the importance of each instance. A zero weight for $\lambda$ or $\gamma_{i,j}$ removed the constraint or instance from the model completely while a weight of one gave the constraint or instance the same importance as one index datum. A large weight (e.g. 1000) makes the constraint binding so that the model's estimate $\tau_{i,j}$ and target $T_{i,j}$ are almost identical. Constraints requiring equality to target are mathematically the same as a Bayesian prior for the estimate $\tau$ because the negative log likelihood minimized in the model is the same as the Bayesian posterior distribution.

Constraints in Mark requiring "directional inequality" penalized model fits with estimates that were either larger than or smaller than a target. For example, a constraint requiring $\tau_{i,j} \geq T_{i,j}$ (model estimate larger than or equal to the target) would be calculated:

$$\Omega_j = \sum_{j=1}^{n_j} \left[ \begin{array}{c} 0 \; if \; \tau \geq T \\ \nu_{k,j} \ln\left(\dfrac{\tau_{k,j}}{\mathrm{T}_{k,j}}\right)^2 \; if \; \tau < T \end{array} \right]$$

The most important feature in constraints for directional inequality is that they be differentiable with no abrupt changes in derivatives that hinder parameter estimation.

### *Tune to Trend, Trend & Scale or Scale Only*

Mark provides a very useful and powerful opportunity for using constraints with index data. For example, assume a model with index data $\theta$, scaling parameter $q_\theta$, the equality constraint $q_\theta=1$, objective function weight $\lambda_\theta$ on the fit to index trends, and objective function weight $\lambda_k$ on the constraint. With the trend "turned on" ($\lambda_\theta > 0$) and the constraint "turned off" $\lambda_k=0$, Mark treats the index as a measure of trend but not scale. With both the trend and the constraint turned on, Mark treats the index as a measure of trend and scale (i.e. as an absolute index). With the trend turned off and the constraint turned on, Mark treats the index of a measure of scale but not trend (i.e. the model tends towards solutions that match the geometric mean of index data and geometric mean of predicted values) without penalizing the fit for lack of agreement in trend. As shown below, all of these combinations were useful for lobster.

*Useful Constraints for Lobster*

The "first difference" constraint for lobster was based on an idea and constraint developed by D. Fournier and J. Ianelli. The first difference constraint requires positive first derivatives in selectivity curves (increasing selectivity parameter estimates for lobster of increasing size). It penalized model fits when scaling decreases with size. This constraint can be applied only when abundance index data for different length groups are rescaled to a mean of one (see below). Therefore, all size structured survey data including NMFS and state bottom trawl survey data were normalized to mean one before use in Mark to estimate trends.

To understand the need to rescale survey data with the first difference constraint, assume an index ($\Pi$) for length group -1 and an index ($\varsigma$) for length group 0 with scaling factors $q_{-1}$ and $q_0$. As long as transition probabilities are similar, it is probably safe to assume that lobster abundance for length group -1 is larger than average abundance for length group 0 (i.e. $n_{-1} > n_0$). By definition, abundance is $n_{-1}= \Pi/q_{-1}$ for length group –1 and $n_0= \varsigma/q_0$ for length group 0. If indices are rescaled to a common mean, $\Pi=\varsigma$ (on average) and $q_0 < q_{-1}$ (scaling factors decline with size). Constraints on successive differences in scaling factors were implemented with weights for each length group and not applied to the largest (plus) length group because there was no guarantee that $n_{3+} < n_2$.

The "swept-area" constraint penalized model runs with estimates of abundance lower than the swept-area abundance implied by a trawl survey (an idea borrowed from P. Rago, Northeast Fisheries Science Center, National Marine Fisheries Service, Woods Hole, MA). Swept-area abundance was calculated as the average density of lobster per tow (estimated from a trawl survey) multiplied times area of the stock and divided by average area swept per tow (NEFSC 1996). Swept area abundance was expected to be less than actual abundance in the stock area because trawls probably don't catch all of the lobsters in their path. The swept area abundance estimates were included in Mark and scaling parameters were calculated but without tuning to either scale or trend. Model fits with scaling parameters less than one were penalized.

The "protect females" constraint penalized model fits with fishing mortality rate estimates larger for females than males in any year and for any length group. The lobster fishery is managed with a variety of measures designed to protect females (i.e. v-notching and regulations that prohibit landing ovigerous females). Management measures that protect females make it reasonable to expect fishing mortality rates for females to be lower than for males (although this was not always the case, see results). This constraint can also effect estimates of sex ratio at recruitment. For example, more female than male lobsters are caught and landed in SCCLIS. If there are no differences in mortality rate between the sexes and female catch exceeds male catch, then the number of females in the population would have to be greater than the number of males. Lower fishing mortality rates for females would mean an even more skewed sex ratio.

The "q-ratio" constraint was used to run Mark in a modified DeLury-type mode. The q-ratio constraint requires solutions in which the ratio of scaling parameters for female lobsters in length groups –1 (73-82 mm) and 0+ (83+ mm) in the NMFS fall trawl survey are equal to some specified value (e.g. 0.5 as in the conventional DeLury).

The "SCCLIS tag" constraint penalized fits with exploitation rates for males and females combined that were lower than exploitation rates estimated by mark-recapture studies. The Subcommittee believed that tag study estimates were miminum exploitation rate estimates because tag loss with molting and emmigration from the study area likely reduced recapture rates. This notion was implemented by entering the time series of mark-recapture exploitation rate indices and with the directional constraint $q_{tag}>1$.

The "LCA F" constraint penalized model fits with average catch weighted fishing mortality rates that were different than average catch weighted fishing mortality rate estimates from LCA. The LCA F constraint was implemented by entering the time series of LCA fishing mortality rate estimates and penalizing fits with the scaling parameter $q_{LCA}\neq 1$ without tuning to trend in LCA fishing mortality rates. Tuning to trends was avoided because LCA mortality rate estimates are smooth, long term average estimates of mortality (Cadrin and Estrella 1996).

The "low abundance" constraint penalized fits in Mark with absurdly small abundance estimates (abundance smaller than catch). This constraint did not effect results but was useful in fitting models because unreasonable solutions were avoided during the parameter estimation process. The user specified a maximum allowed value for fishing mortality rate (e.g. $f_{toobig}=4$) and the model calculated the corresponding exploitation rate $\{u_{toobig}=f_{toobig}/(f_{toobig}+m)(1-\exp(f_{toobig}+m)]\}$. Next, the model calculated a minimum allowed abundance level for each sex, year and length group with catch data $b_{toosmall}=c/u_{toobig}$. In the course of fitting the model, if an abundance estimate dropped below $b_{toosmall}$, the model applied the penalty:

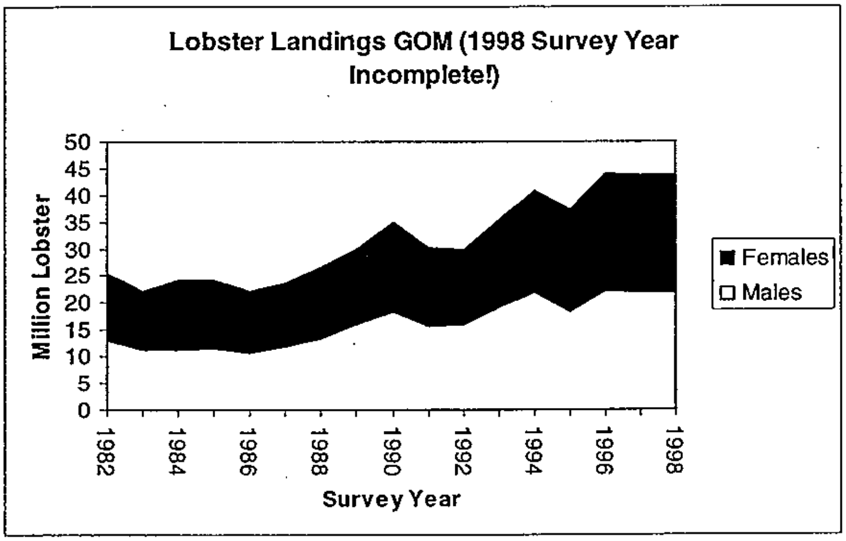
$$\Omega_L = \lambda_L \ln\left[\frac{n_{s,y,g}}{n_{toosmall_{n,s,g}}}\right]^2$$

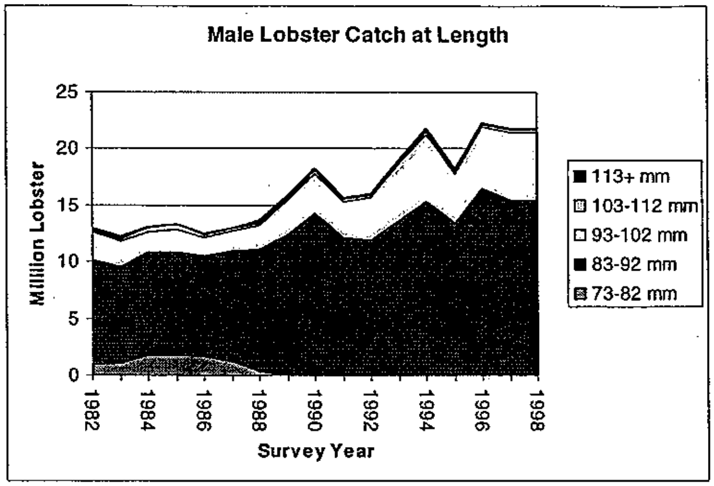
where the weight $\lambda_L=1000$ was large so that the model would avoid solutions with absurdly small abundance estimates.

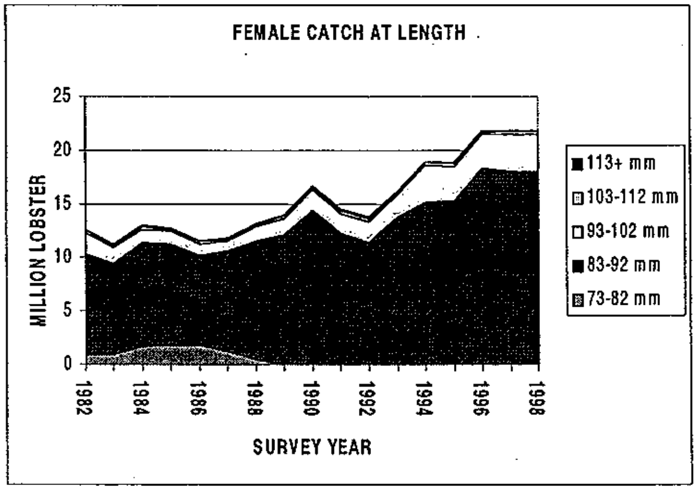
## Assessment Data

### *GOM-Assessment Data*

Catches in 1996-1997 (1998 data incomplete) were the highest since 1982 and, for the stock area as a whole, almost evenly divided between males and females. The bulk of the catch of both sexes comes from the first legal size group (83-92 mm). Catch of males in the second legal size group is proportionally higher for males than females in GOM. Percent male lobsters in landings was 45-55% but averaged about 50%.


Lobster Landings GOM (1998 Survey Year Incomplete!)
Million Lobster
50
45
40
35
30
25
20
15
10
5
0
1982
1984
1986
1988
1990
1992
1994
1996
1998
Survey Year
■ Females
□ Males





Massachusetts fall trawl survey and NMFS fall trawl survey data were available for lobster in GOM. Massachusetts trawl survey data cover only the southern most and inshore part of the stock area, a region of relatively heavy fishing, and catches mostly small lobster. Knowledgeable biologists assert, however, that the Massachusetts trawl survey data likely provide information about trends in a larger area that extends farther to the north into Maine where fishing is relatively heavy. The NMFS trawl survey covers most of the stock area and catches large lobster but does not extend into near shore coastal areas.

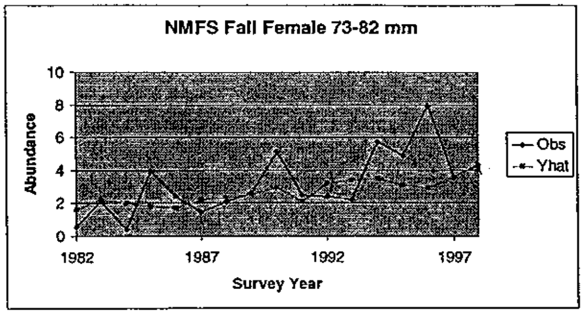
In plots shown below for index data, observed values are labeled "Obs" and predictions from Mark are labeled "Yhat". Predictions are not necessarily from the "best" model but are probably characteristic of a wide range of model fits. Predictions for survey years with missing data are plotted as zeroes.

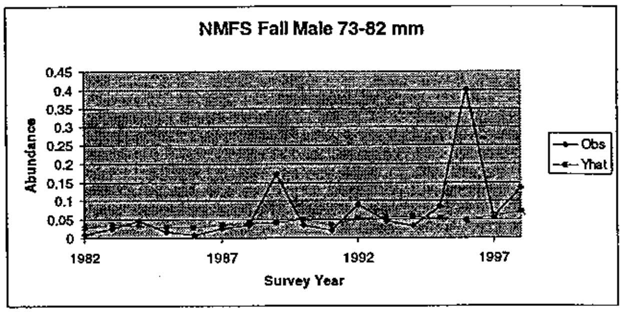
NMFS trawl survey data show that lobster recruitment and abundance of larger lobster in GOM as a whole increased steadily after 1982. Massachusetts data also show increasing recruitment trends but abundance of larger lobster in near shore waters varied without trend or declined, probably due to fishing mortality rates that were locally high.

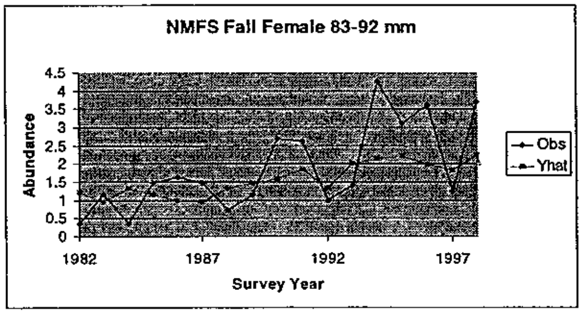
There were three indices of commercial catch rats for lobster in the GOM (see below). Catch in number per trap haul and catch per trap haul set over day from Maine increased throughout the time series. A short time series based on federal logbooks for fishing in a small area (VTR data) declined sharply.

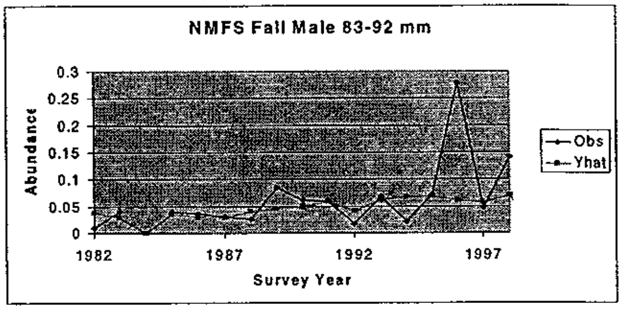
There were five sources of information about sex ratio of recruits from trawl surveys, sea sampling and diver surveys (see below). Sex ratios for GOM lobster in length group –1 (73-82 mm) averaged 48% male overall.

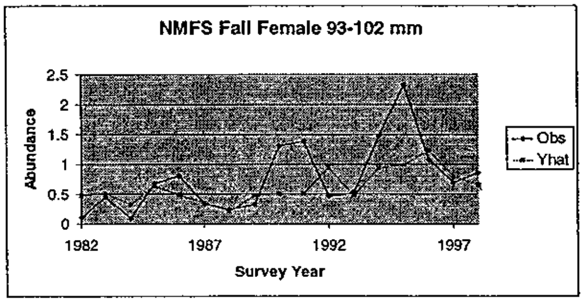
Crude exploitation rate indices (calculated as male+female catch divided by male+female survey abundance for legal size lobsters) based on NMFS survey data indicate declining exploitation rates for the stock as a whole. Exploitation rate indices based on Massachusetts survey data indicate and increasing exploitation rates in near shore areas (see below).

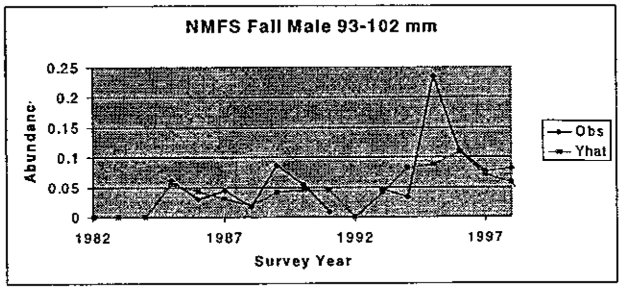

NMFS Fall Female 73-82 mm

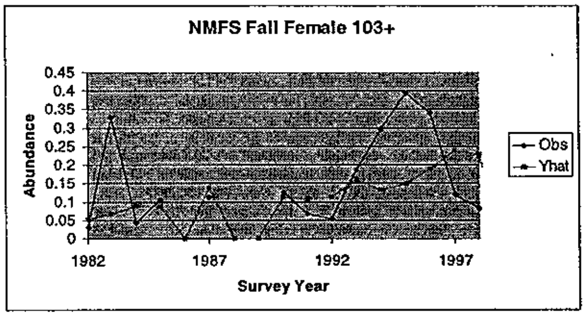

NMFS Fall Male 73-82 mm

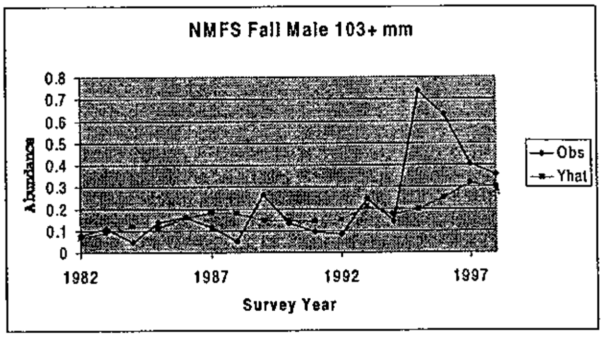

NMFS Fall Female 83-92 mm

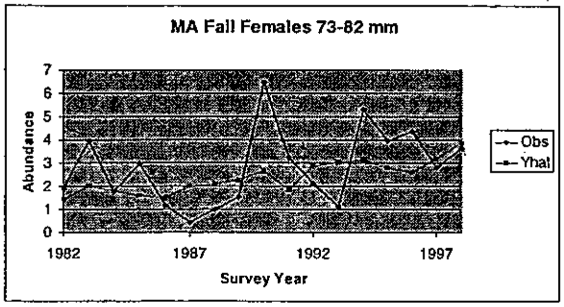

NMFS Fall Male 83-92 mm

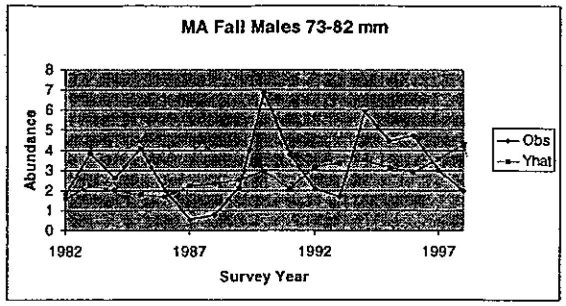

NMFS Fall Female 93-102 mm

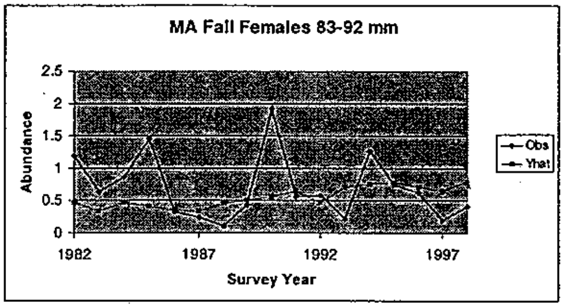

NMFS Fall Male 93-102 mm

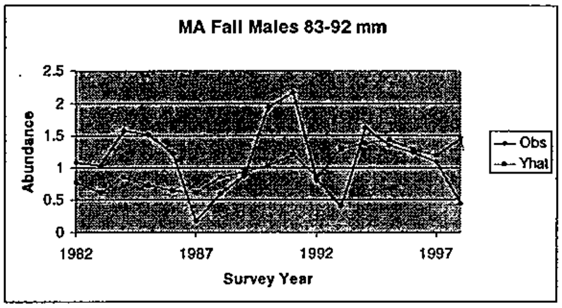

NMFS Fall Female 103+

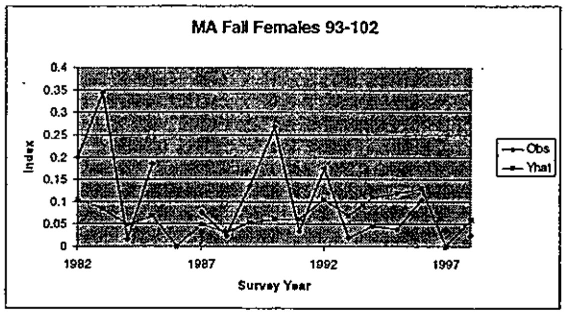

NMFS Fall Male 103+ mm

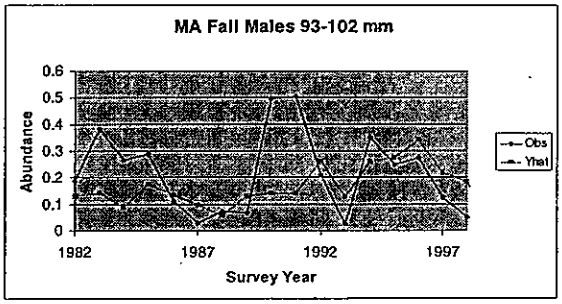

MA Fall Females 73-82 mm

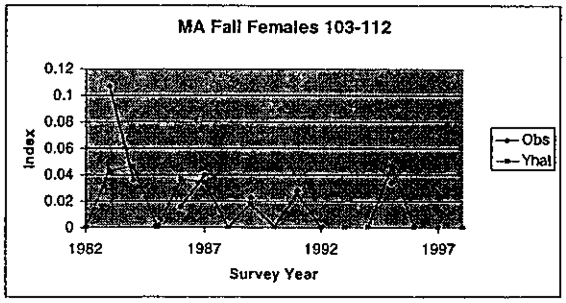

MA Fall Males 73-82 mm

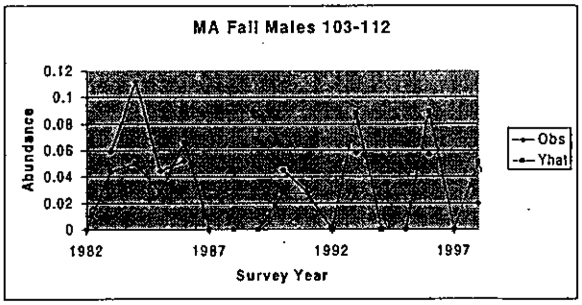

MA Fall Females 83-92 mm

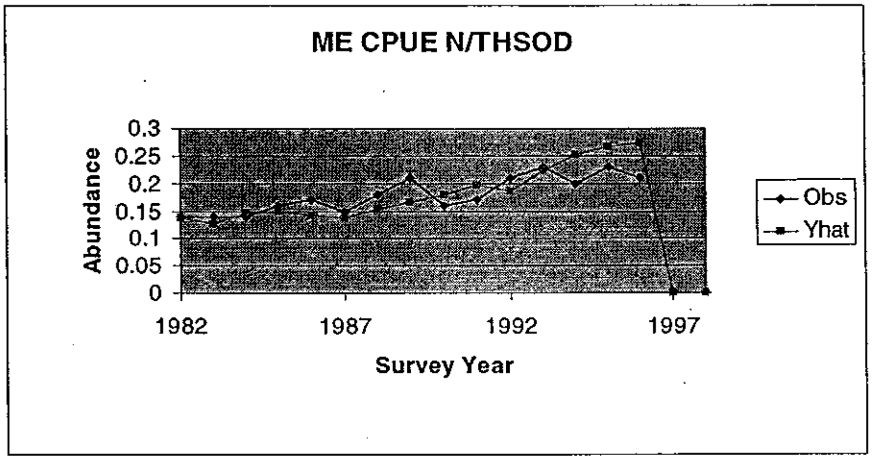

MA Fall Males 83-92 mm

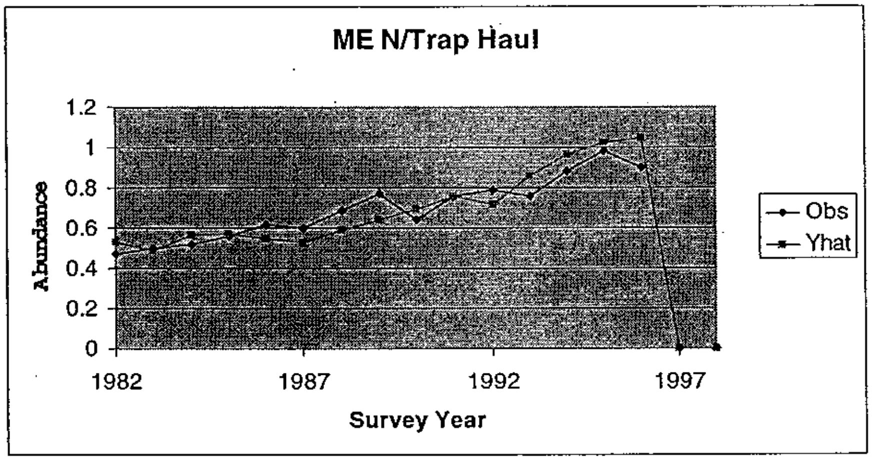

MA Fall Females 93-102

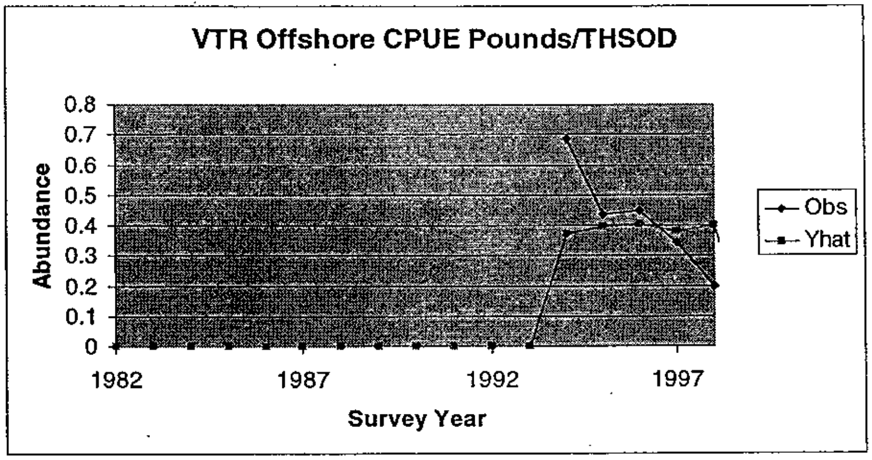

MA Fall Males 93-102 mm

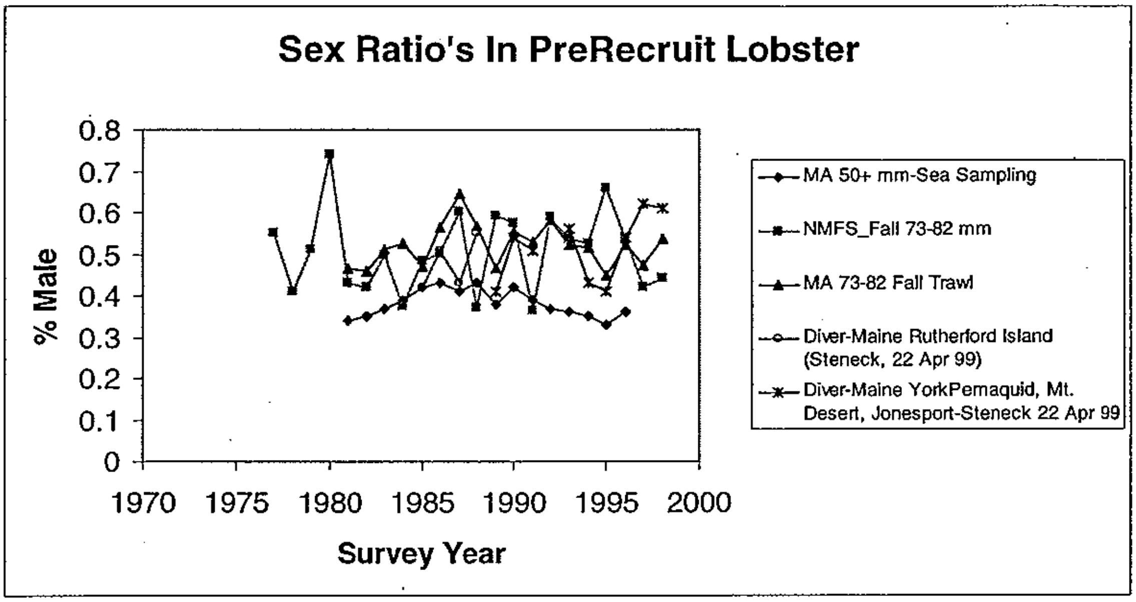

MA Fall Females 103-112

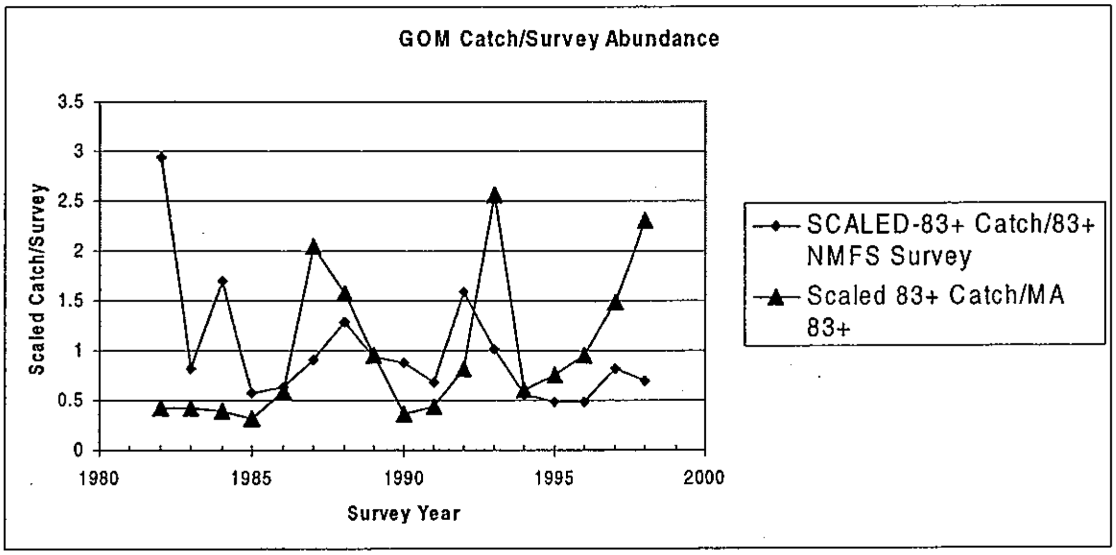

MA Fall Males 103-112


ME CPUE N/THSOD


ME N/Trap Haul


VTR Offshore CPUE Pounds/THSOD

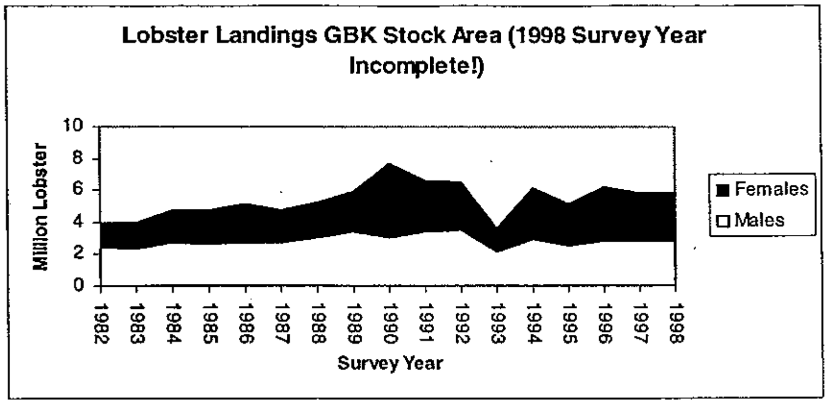


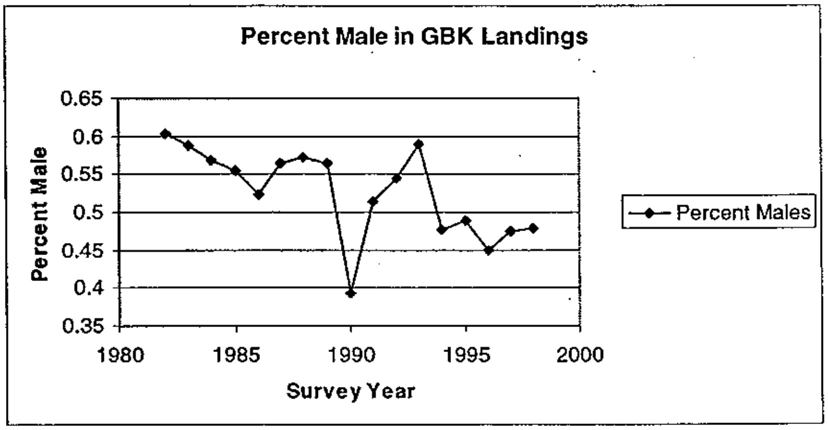


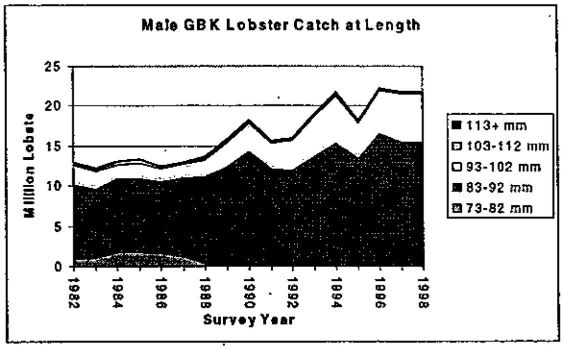
*GBK-Assessment Data*

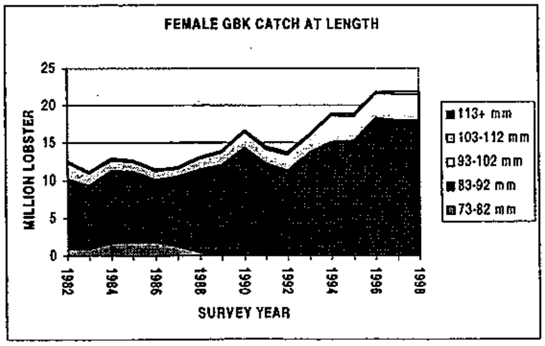
Landings (data for 1998 incomplete) for the GBK stock area have been steady at about 6 million lobster per year since 1994. Landings during the early 1980's were mostly male. However, percent males in the landings decreased steadily and lobster landings are now mostly female. The apparent decline in landings during 1993 was an error not corrected until late in the stock assessment process.

As in GOM, the bulk of the catch of both sexes comes from the first legal size group (83-92 mm). Catch of males in the second legal size group (93-102 mm) is proportionally higher for males than females.


Lobster Landings GBK Stock Area (1998 Survey Year Incomplete!)
Million Lobster
0
2
4
6
8
10
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Survey Year
■ Females
□ Males


Percent Male in GBK Landings
Percent Male
0.35
0.4
0.45
0.5
0.55
0.6
0.65
1980
1985
1990
1995
2000
Survey Year
—◆— Percent Males


Male GBK Lobster Catch at Length
Million Lobste
0
5
10
15
20
25
1982
1984
1986
1988
1990
1992
1994
1996
1998
Survey Year
■ 113+ mm
□ 103-112 mm
□ 93-102 mm
■ 83-92 mm
▨ 73-82 mm


FEMALE GBK CATCH AT LENGTH
MILLION LOBSTER
0
5
10
15
20
25
1982
1984
1986
1988
1990
1992
1994
1996
1998
SURVEY YEAR
■ 113+ mm
□ 103-112 mm
□ 93-102 mm
■ 83-92 mm
▨ 73-82 mm

NMFS trawl survey data show flat or variable trends in abundance trends for lobster in most length groups including recruits in GBK. GBK is unique in this respect because recruitment increased steadily in both the GOM and SCCLIS stock areas.

Another interesting aspect of the NMFS survey data for GBK is the increase in abundance of large female lobsters (length group 3, 113+ mm). The data seem to indicate a roughly 50% increase in abundance of the largest female lobsters since the early 1980's. Sex ratios in NMFS survey data for most length groups were consistent over time but percent male declined abruptly for the largest lobsters (113+ mm) after 1992 due to increases in abundance of large females.

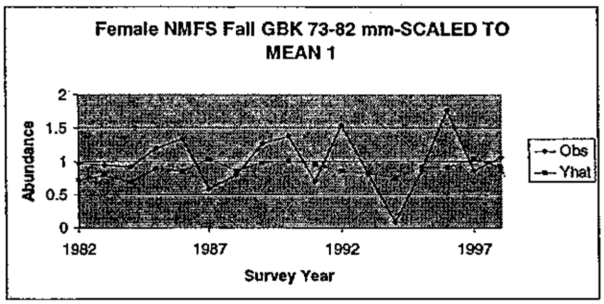
There were fourteen sets of commercial CPUE indices for lobster in GBK. Ten of the indices (sex and length stratified) were from Rhode Island sea sample trips based on a small number of trips and boats but a large number of trap hauls and lobsters sampled, one index was based on annual reports of lobster catch and numbers of traps from New York state, one based on Massachusetts sea sampling data, and one based on federal logbooks (VTR data).

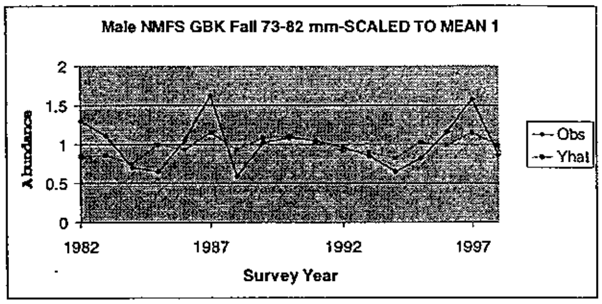
Rhode Island CPUE data were collected along the inshore edge of GBK near the border with SCCLIS. They show increasing trends in recruitment and flat or decreasing trends in abundance of larger lobsters. The patterns in Rhode Island CPUE are similar to abundance trends for SCCLIS and may not be typical of the GBK area as a whole. The short time series of VTR data shows a steeply declining trend in CPUE for legal sized lobster. The trend in New York catch per trap was flat.

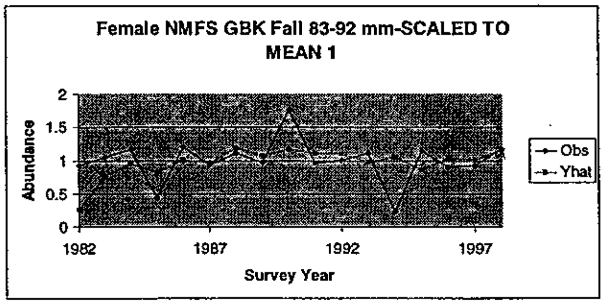
The simple exploitation index calculated as catch divided by NMFS survey abundance for legal size lobsters increased after 1982 but varied without trend after 1990 (see below).

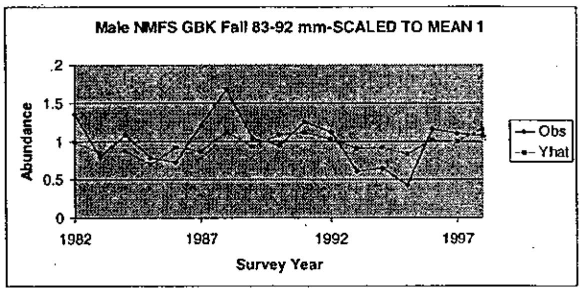
There were three sources of data regarding sex ratio of recruits for GBK. Average sex ratios varied 30-52% and averaged 41%. Sex ratios from Rhode Island and Masasachusetts sea sampling were from relatively near shore areas and may reflect conditions in SCCLIS. Sex ratio data from the NMFS trawl survey, which may best reflect conditions in the GBK area as a whole, averaged 52% male.

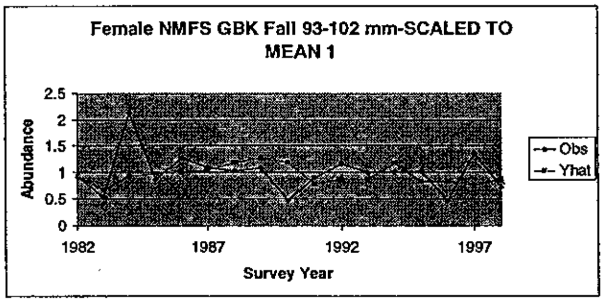
We examined trends in percent of recently molted lobsters with "soft" shells in length group 0 (83-92 mm) because percent soft shell may (or may not) be useful as an index of exploitation rate or fishing intensity (P. Rago, Northeast Fisheries Science Center, National Marine Fisheries Service, Woods Hole, MA). Three data sets based on Rhode Island and Massachusetts sea sampling data were available (see below). All three data sets showed increased percent soft shell lobster in sea samples after 1990. Trends in the Rhode Island data were stable after 1992 but percent soft shell lobster declined dramatically in Massachusetts samples after 1992.

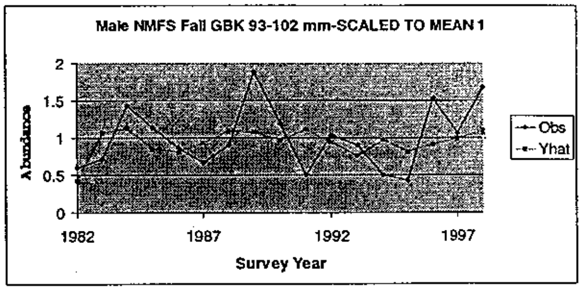

Female NMFS Fall GBK 73-82 mm-SCALED TO MEAN 1

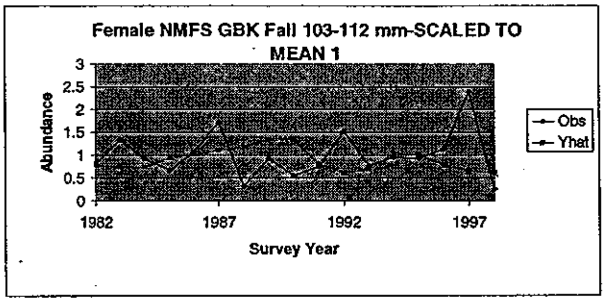

Male NMFS Fall GBK 73-82 mm-SCALED TO MEAN 1

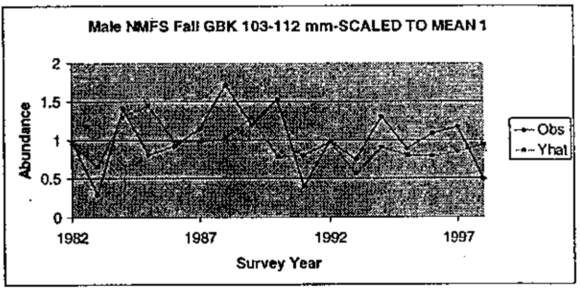

Female NMFS GBK Fall 83-92 mm-SCALED TO MEAN 1

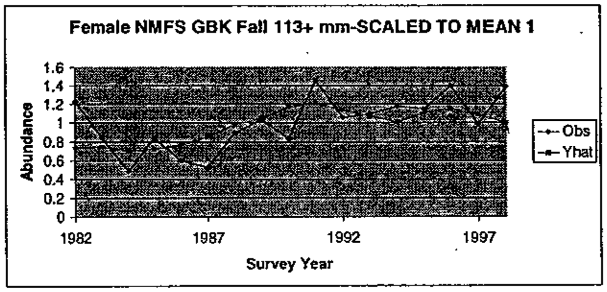

Male NMFS GBK Fall 83-92 mm-SCALED TO MEAN 1

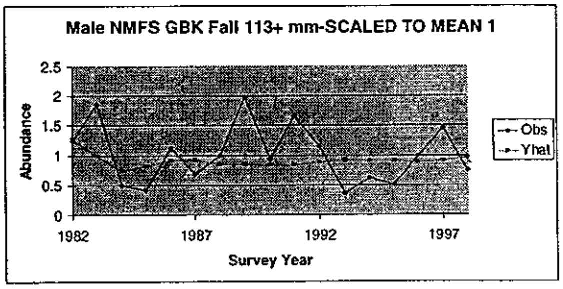

Female NMFS GBK Fall 93-102 mm-SCALED TO MEAN 1

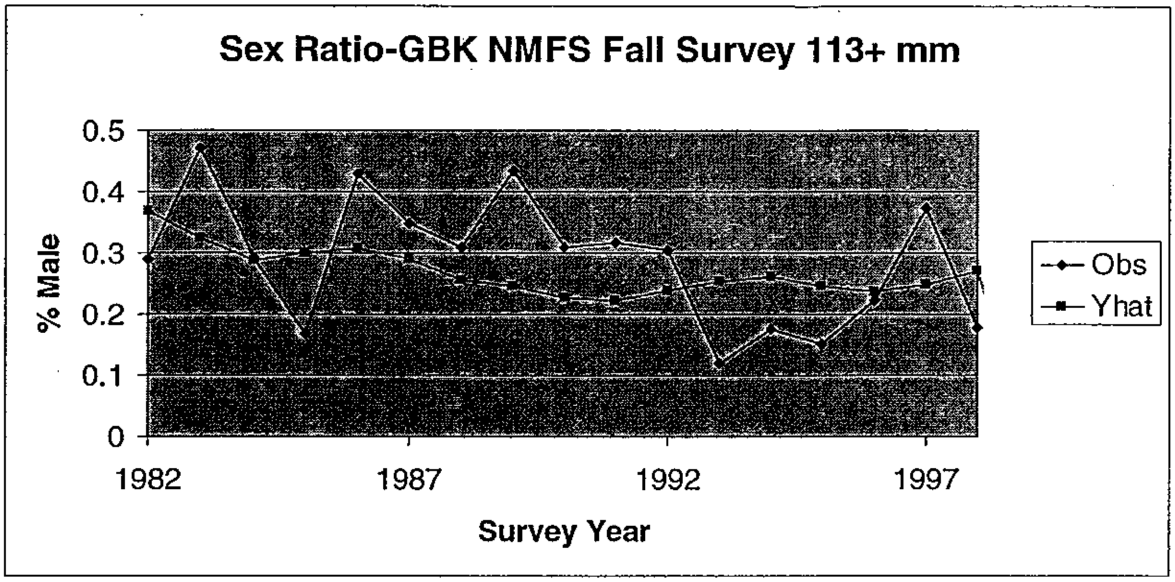

Male NMFS Fall GBK 93-102 mm-SCALED TO MEAN 1

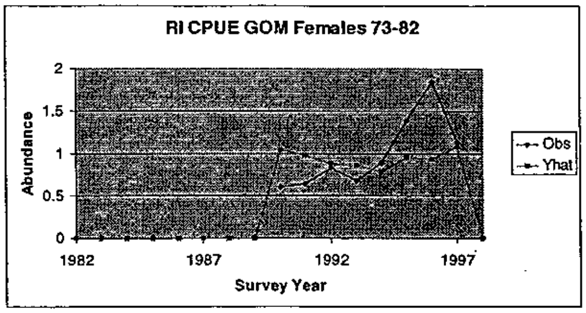

Female NMFS GBK Fall 103-112 mm-SCALED TO MEAN 1

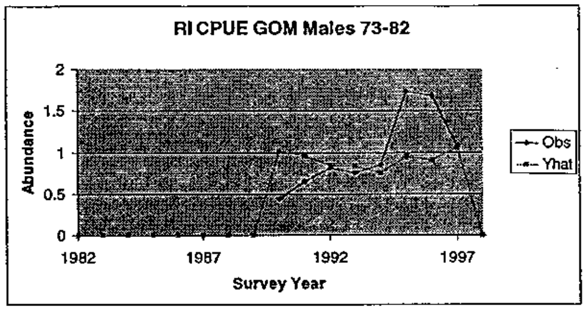

Male NMFS Fall GBK 103-112 mm-SCALED TO MEAN 1

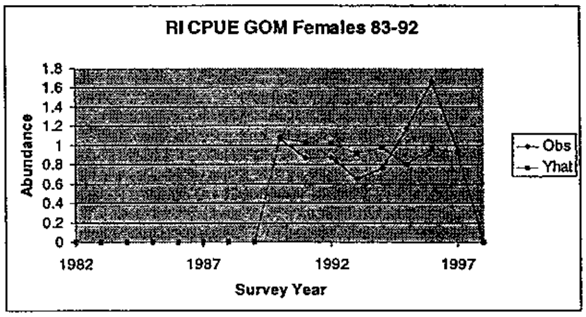

Female NMFS GBK Fall 113+ mm-SCALED TO MEAN 1

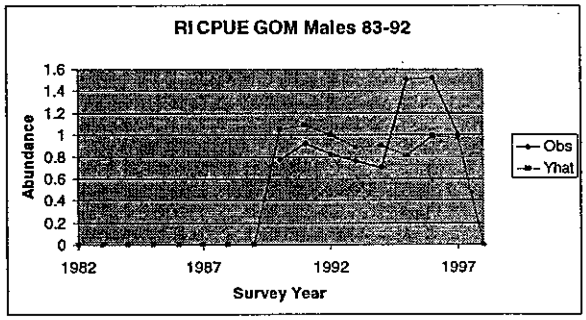

Male NMFS GBK Fall 113+ mm-SCALED TO MEAN 1

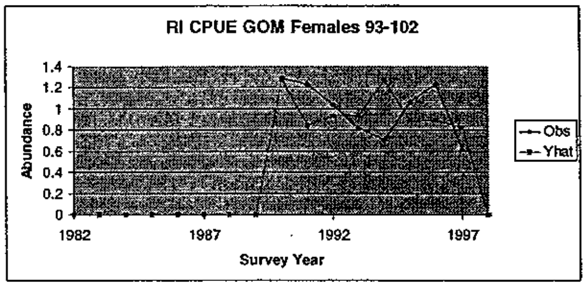

Sex Ratio-GBK NMFS Fall Survey 113+ mm
0.5
0.4
0.3
0.2
0.1
0
% Male
1982
1987
1992
1997
Survey Year
Obs
Yhat

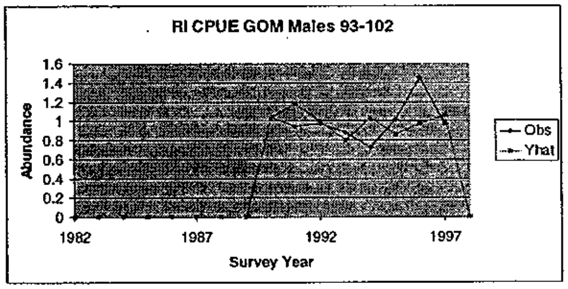

RI CPUE GOM Females 73-82

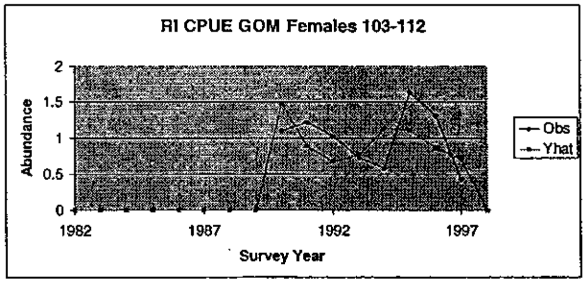

RI CPUE GOM Males 73-82

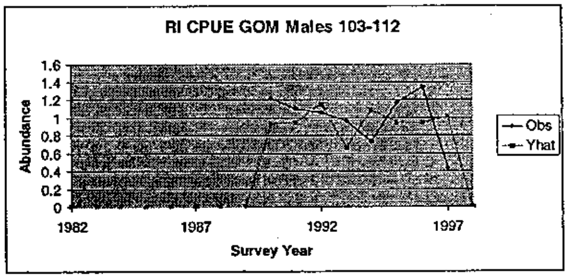

RI CPUE GOM Females 83-92

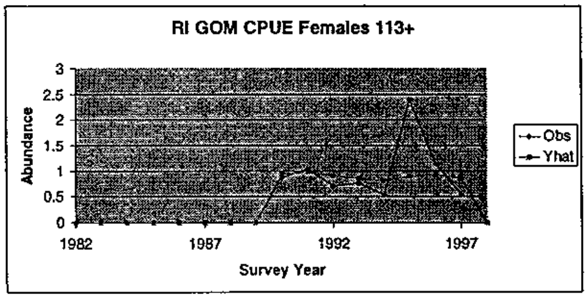

RI CPUE GOM Males 83-92

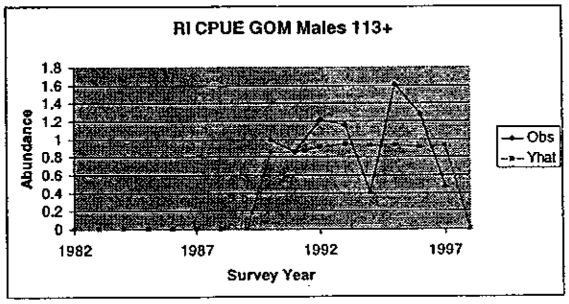

RI CPUE GOM Females 93-102

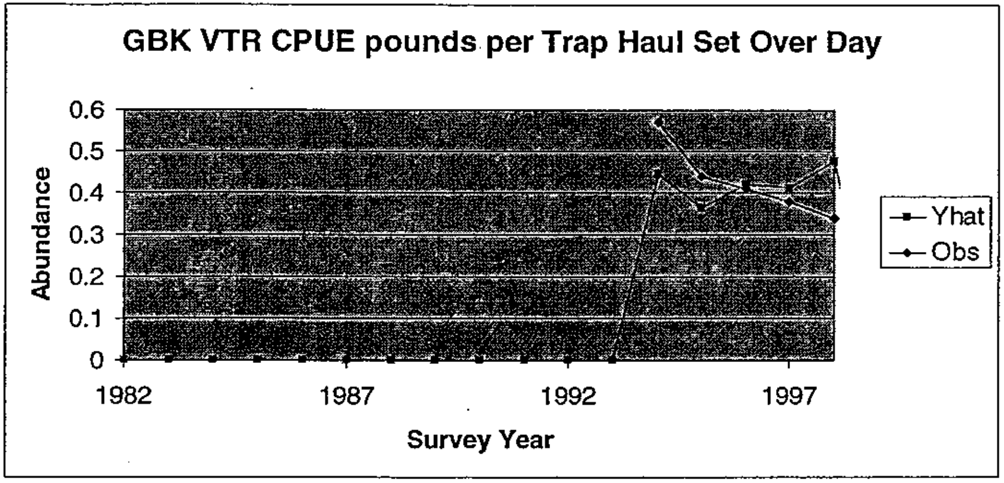

RI CPUE GOM Males 93-102

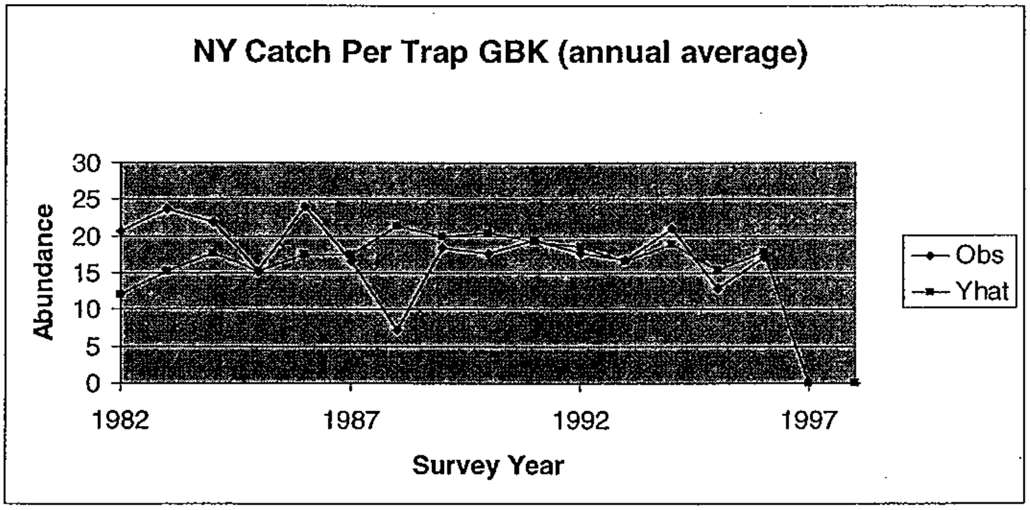

RI CPUE GOM Females 103-112

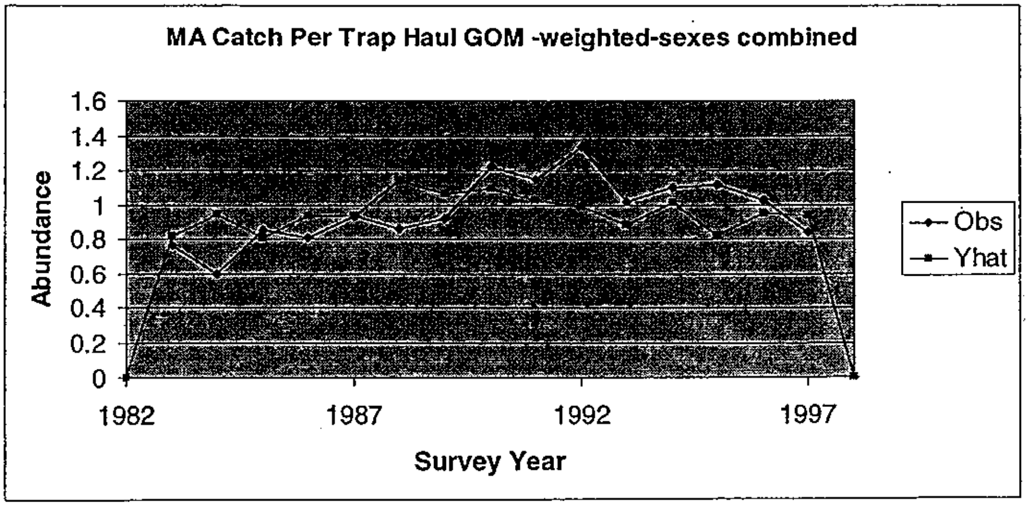

RI CPUE GOM Males 103-112

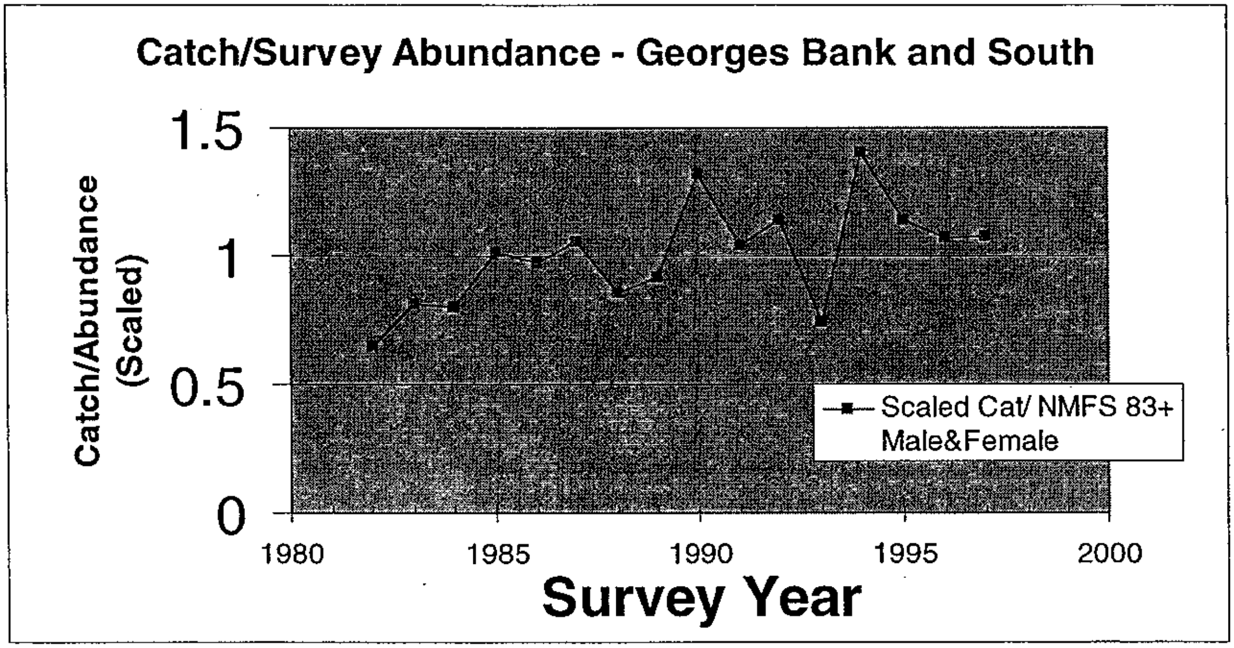

RI GOM CPUE Females 113+

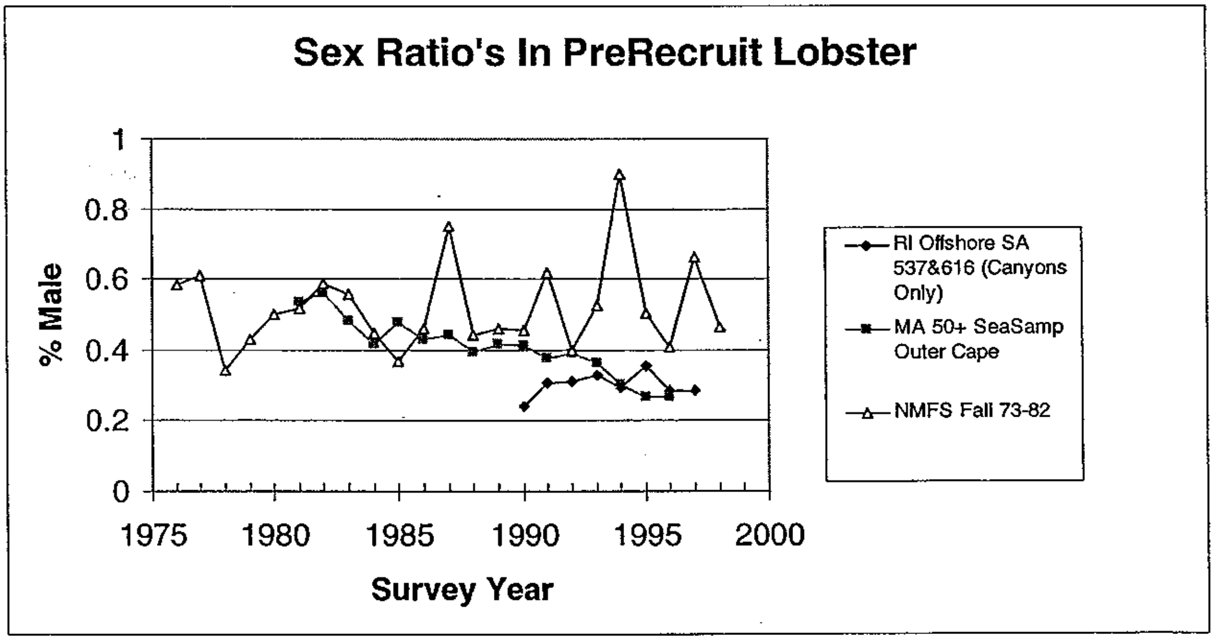

RI CPUE GOM Males 113+

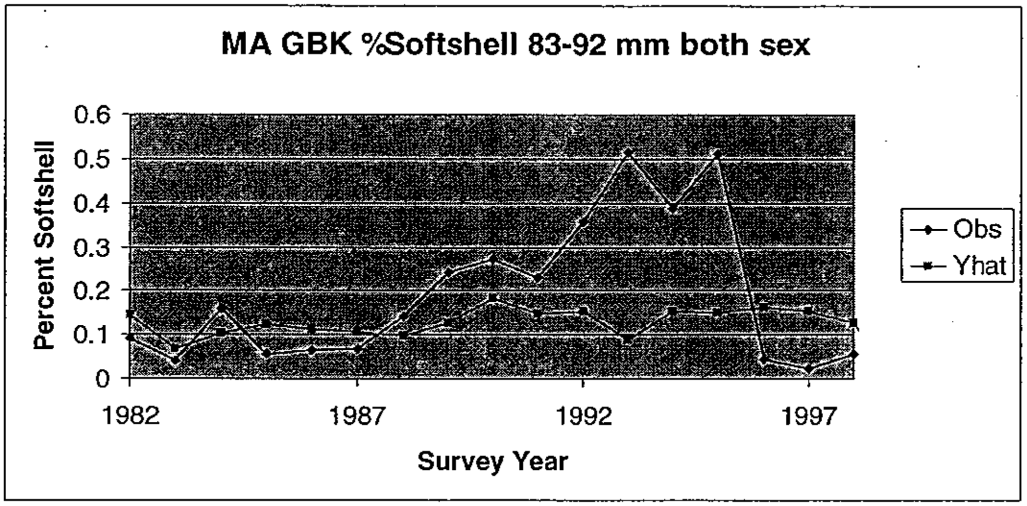

GBK VTR CPUE pounds per Trap Haul Set Over Day
Abundance
0.6
0.5
0.4
0.3
0.2
0.1
0
1982
1987
1992
1997
Survey Year
Yhat
Obs

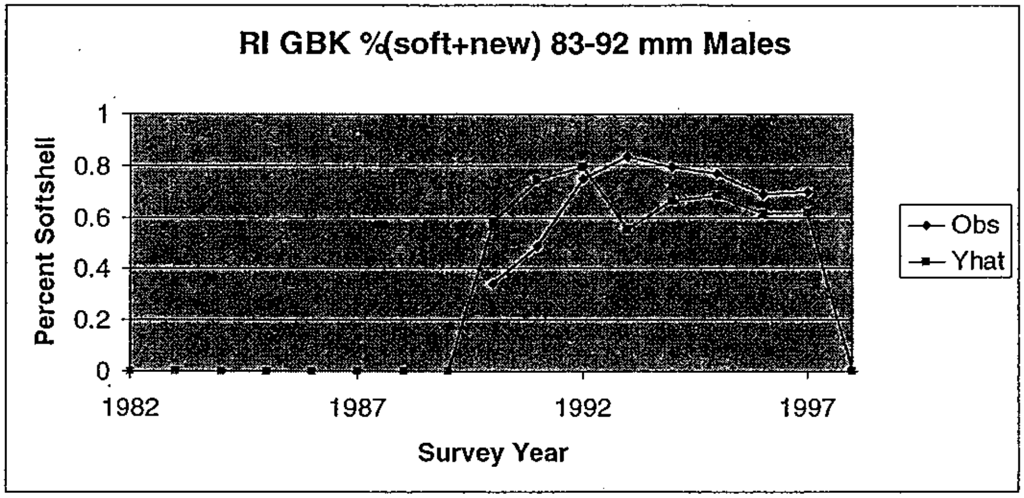

NY Catch Per Trap GBK (annual average)
Abundance
30
25
20
15
10
5
0
1982
1987
1992
1997
Survey Year
Obs
Yhat

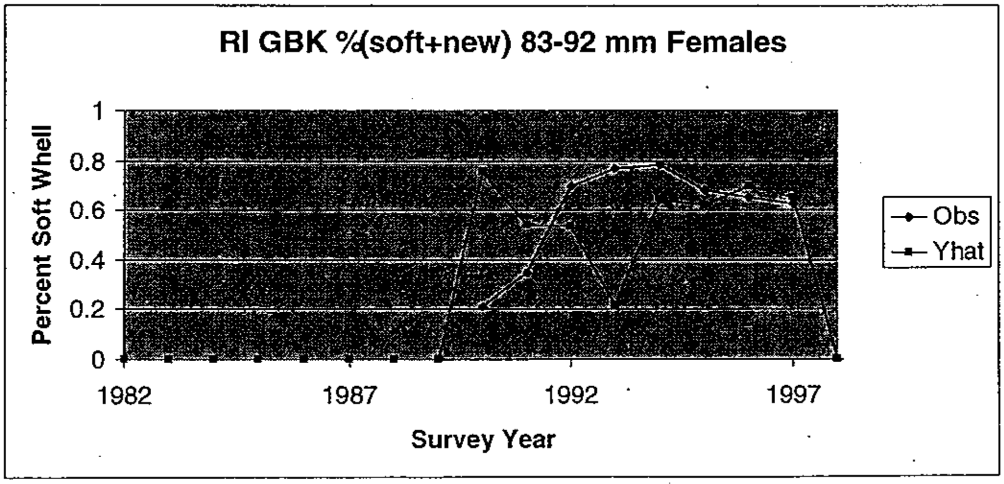

MA Catch Per Trap Haul GOM -weighted-sexes combined
Abundance
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1982
1987
1992
1997
Survey Year
Obs
Yhat


Catch/Survey Abundance - Georges Bank and South
Catch/Abundance (Scaled)
1.5
1
0.5
0
1980
1985
1990
1995
2000
Survey Year
Scaled Cat/ NMFS 83+ Male&Female


Sex Ratio's In PreRecruit Lobster
% Male
1
0.8
0.6
0.4
0.2
0
1975
1980
1985
1990
1995
2000
Survey Year
RI Offshore SA 537&616 (Canyons Only)
MA 50+ SeaSamp Outer Cape
NMFS Fall 73-82


MA GBK %Softshell 83-92 mm both sex
Percent Softshell
0.6
0.5
0.4
0.3
0.2
0.1
0
1982
1987
1992
1997
Survey Year
Obs
Yhat

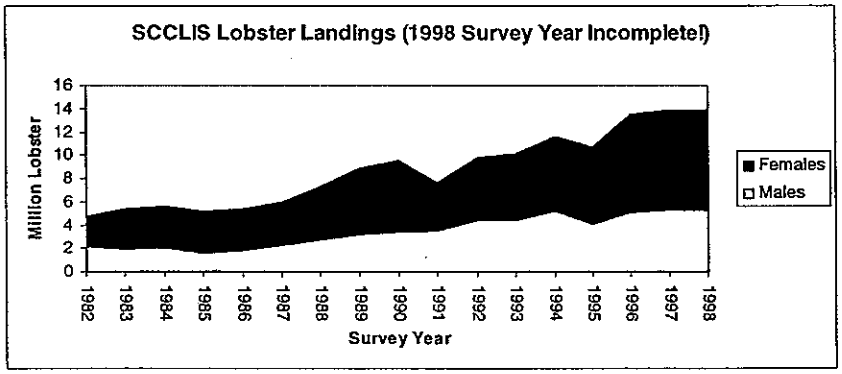

RI GBK %(soft+new) 83-92 mm Males
Percent Softshell
1
0.8
0.6
0.4
0.2
0
1982
1987
1992
1997
Survey Year
Obs
Yhat

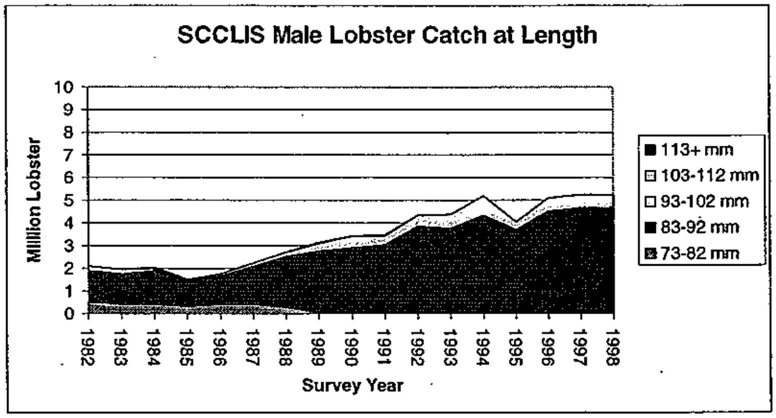

RI GBK %(soft+new) 83-92 mm Females
Percent Soft Whell
1
0.8
0.6
0.4
0.2
0
1982
1987
1992
1997
Survey Year
Obs
Yhat

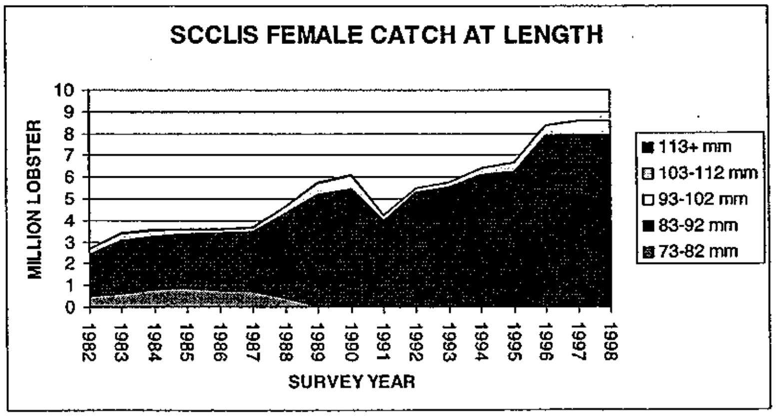
*SCCLIS-Assessment Data*

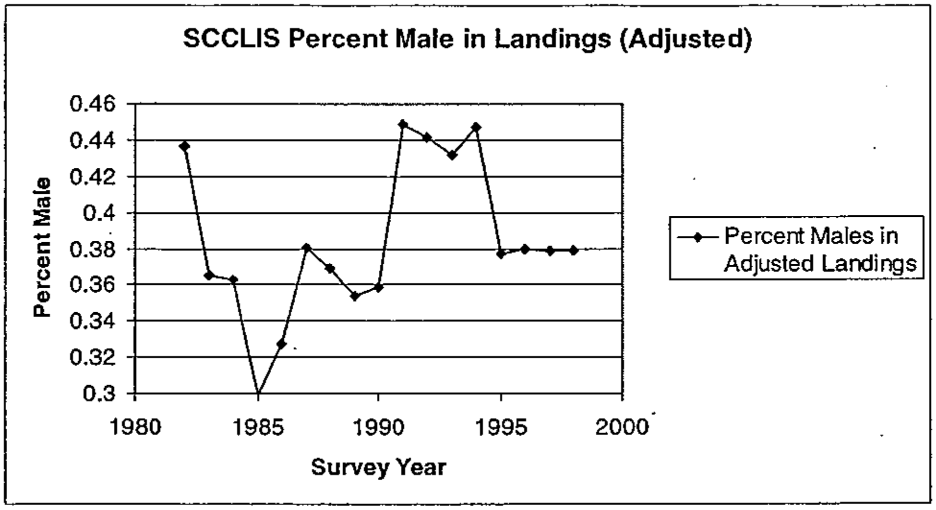
Catches in 1996-1997 (1998 data incomplete) were the highest since 1982. In contrast to other areas, lobster landings from SCCLIS were predominantly female (62% female, on average during 1982-1997). The bulk of the catch of both sexes was from the first legal size group (length ghoup 0, 83-92 mm) with small amounts from the second legal length group (length group 1, 93-102 mm).

Sex ratios in the lobster catch data for 1995 and 1997-1998 fluctuated erratically due to low sample size. Catch data for these years were therefore adjusted to have the same sex ratio as the average during 1982-1993.









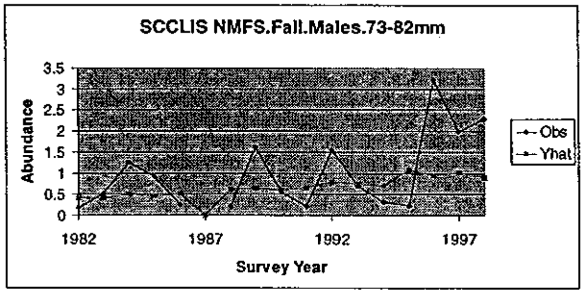
A large number of trawl survey abundance indices were available for lobster in SCCLIS (see below). None, however, covered all or most of the stock area although the entire SCCLIS was surveyed (in parts) by the surveys as a group. None provide reliable indices of abundance for large lobster (103+ mm for most surveys) because large lobster are not common in SCCLIS and difficult to survey. Large lobster were most common in the NMFS survey (less than ten tows per year) which is conducted furthest offshore and away from Long Island Sound. Spring and fall surveys by both Connecticut and Rhode Island and a fall survey by Massachusetts provide abundance information for state waters in Long Island Sound and south of Cape Cod. The University of Rhode Island Graduate School of Oceanography (URIGSO) abundance index is a long time series but was broken into two short time series for recent years that shows sex-specific abundance trends at two sampling sites in Rhode Island waters. Data for earlier years were not sex-specific.

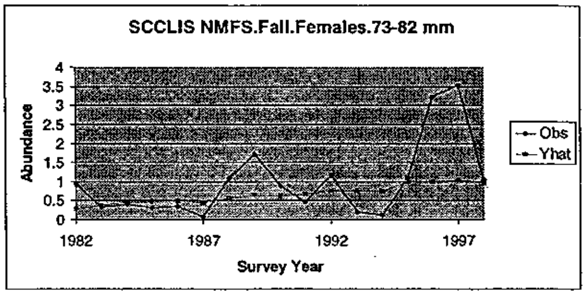
In addition to abundance indices, two time series of exploitation rate indices were available based on recapture rates from Northeast Utilities Service Company (NUSCo) tag studies near Millstone Nuclear Power Plant in Waterford, Connecticut (NUSCO 1998. The NUSCo index is an index of minimum exploitation rates because tag loss, emmigration and unreported tags were not included in calculations.

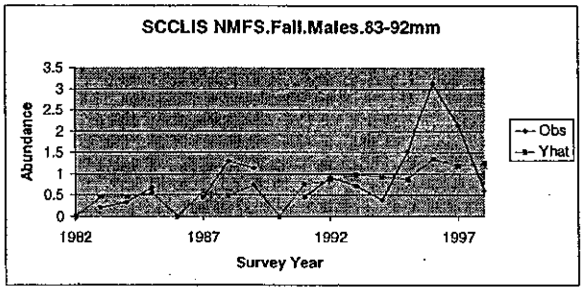
As a whole, Rhode Island and Conncecticut survey data for lobster in SCCLIS indicate recruitment increased after 1982 to record levels in recent years. NMFS survey data show record high recent recruitment also, but with a flatter trend in recent years. According to the Massachusetts survey, lobster recruitment increased steadily after 1982 but fell to low levels after 1994.

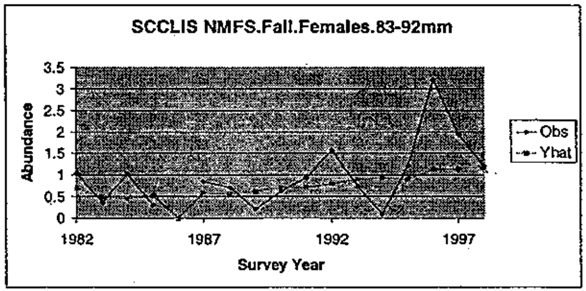
Although recruitment apparently increased, survey data for lobster in SCCLIS suggest that abundance of legal size (83+ mm) lobster fluctuated without trend or declined, with a tendency for flatter or more steeply declining trends in the largest size groups. As mentioned above, lobster larger than 103 mm are rare in bottom trawl surveys in SCCLIS.

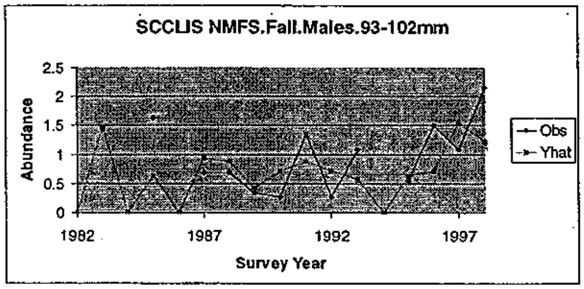
Crude exploitation rate indices (male+female catch for the whole stock area divided by male+female survey abundance for legal size lobsters) were calculated based on all five surveys. Exploitation indices based on NMFS and Rhode Island survey data fluctuated without trend. The index based on Connecticut spring data declined after 1993 while the index based on fall data continued to increase.

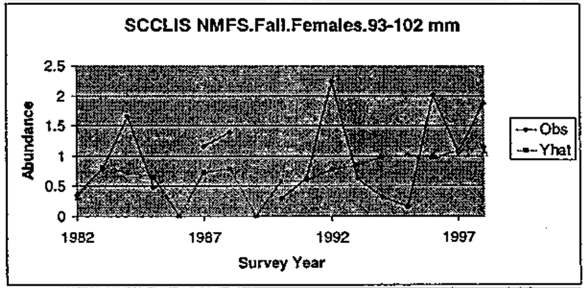

SCCLIS NMFS.Fall.Males.73-82mm

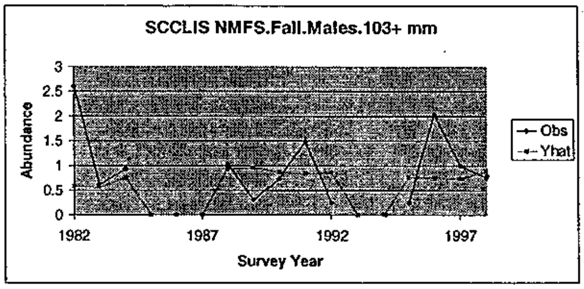

SCCLIS NMFS.Fall.Females.73-82 mm

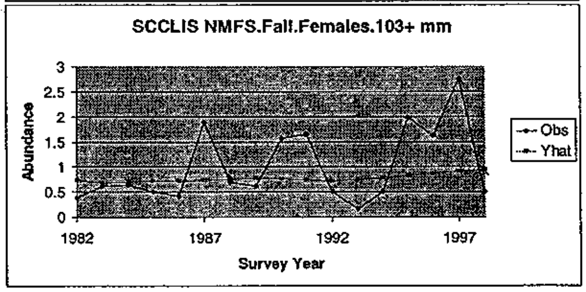

SCCLIS NMFS.Fall.Males.83-92mm

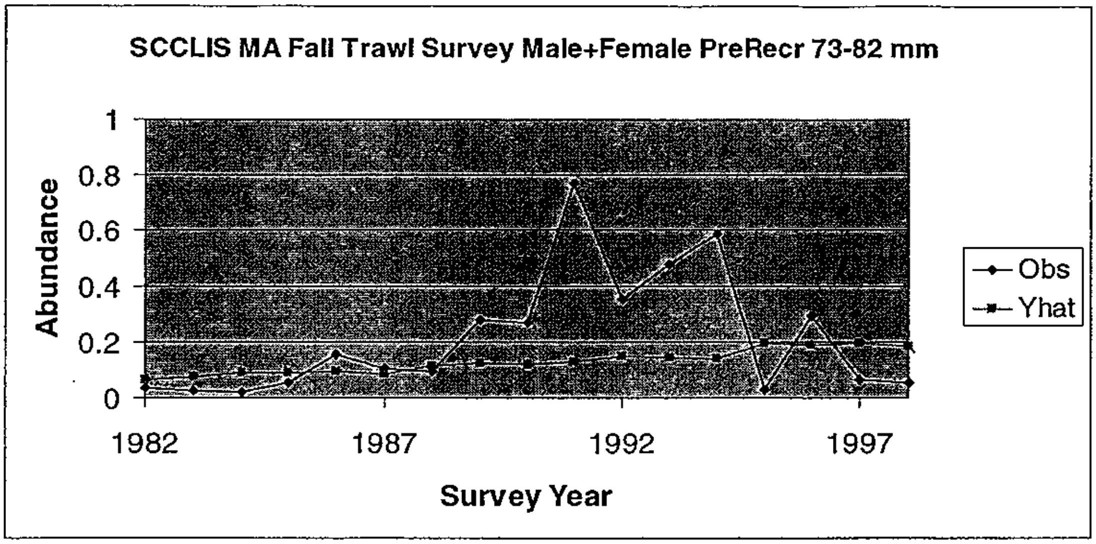

SCCLIS NMFS.Fall.Females.83-92mm

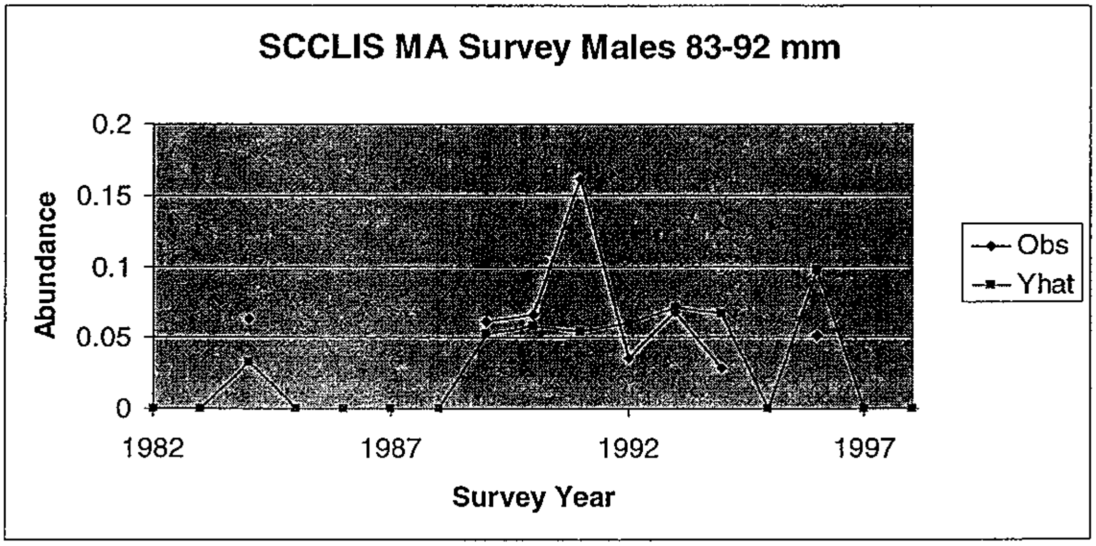

SCCLIS NMFS.Fall.Males.93-102mm

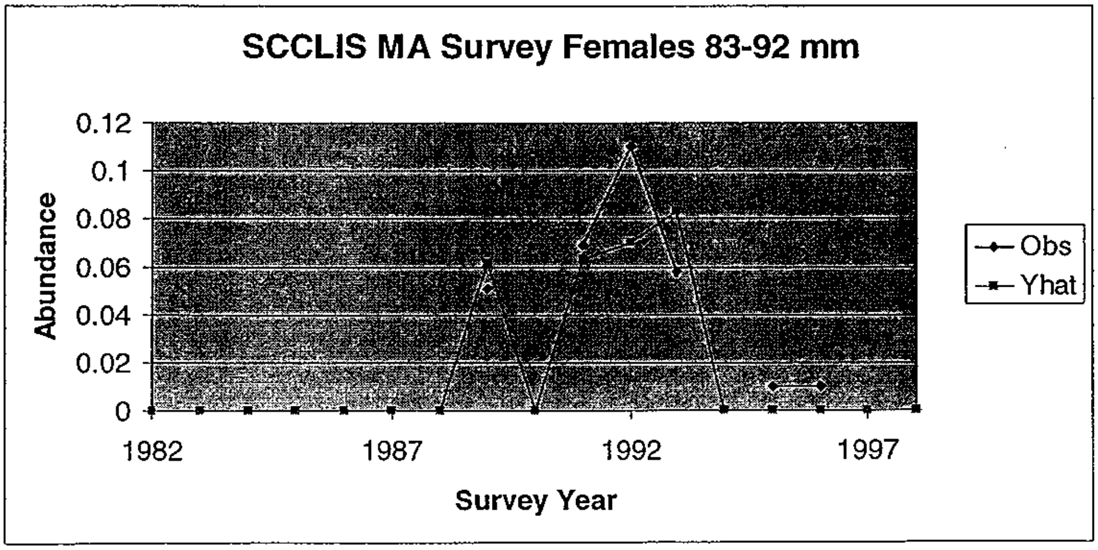

SCCLIS NMFS.Fall.Females.93-102 mm

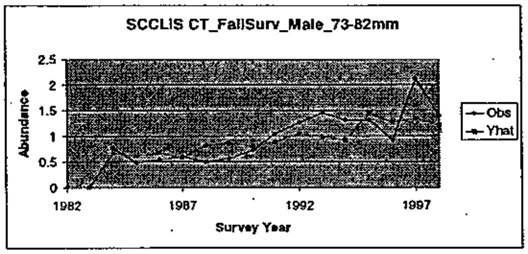

SCCLIS NMFS.Fall.Males.103+ mm

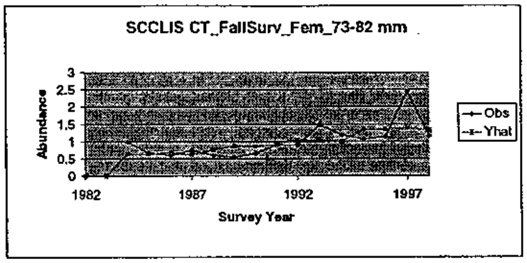

SCCLIS NMFS.Fall.Females.103+ mm

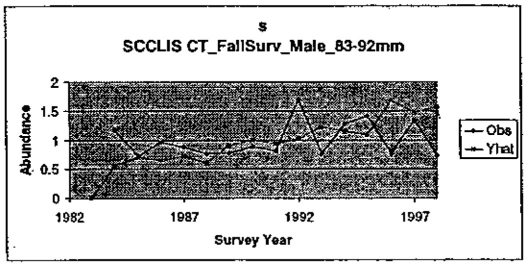

SCCLIS MA Fall Trawl Survey Male+Female PreRecr 73-82 mm
Abundance
1
0.8
0.6
0.4
0.2
0
1982
1987
1992
1997
Survey Year
Obs
Yhat

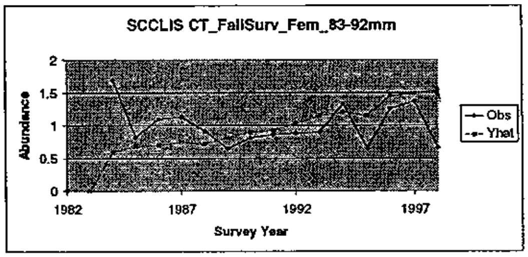

SCCLIS MA Survey Males 83-92 mm
Abundance
0.2
0.15
0.1
0.05
0
1982
1987
1992
1997
Survey Year
Obs
Yhat

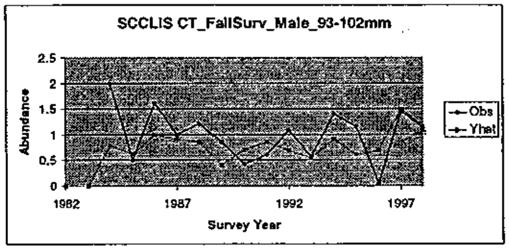

SCCLIS MA Survey Females 83-92 mm
Abundance
0.12
0.1
0.08
0.06
0.04
0.02
0
1982
1987
1992
1997
Survey Year
Obs
Yhat

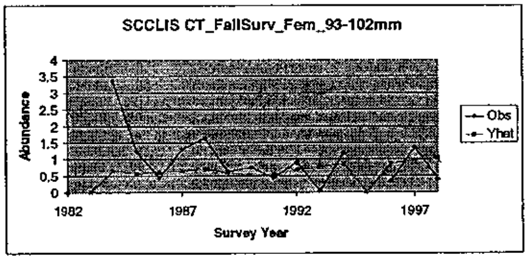

SCCLIS CT_FallSurv_Male_73-82mm

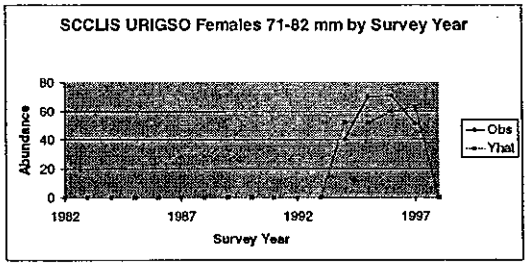

SCCLIS CT_FallSurv_Fem_73-82 mm

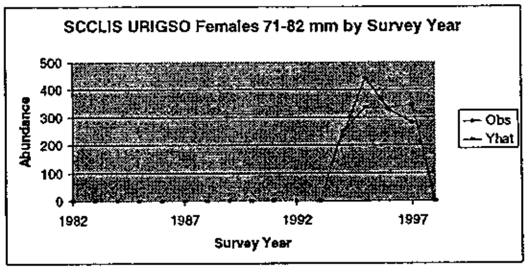

s
SCCLIS CT_FallSurv_Male_83-92mm

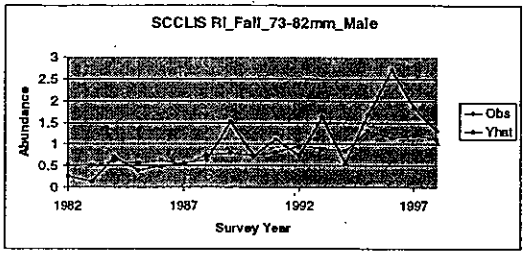

SCCLIS CT_FallSurv_Fem_83-92mm

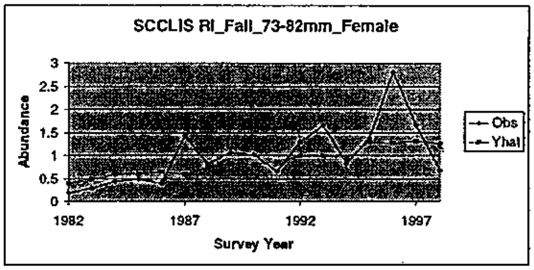

SCCLIS CT_FallSurv_Male_93-102mm

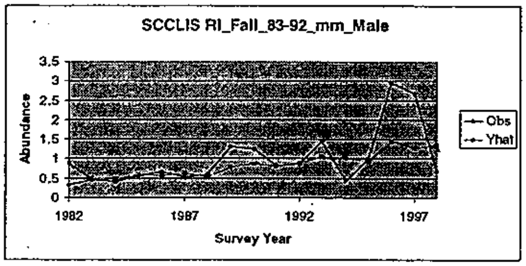

SCCLIS CT_FallSurv_Fem_93-102mm

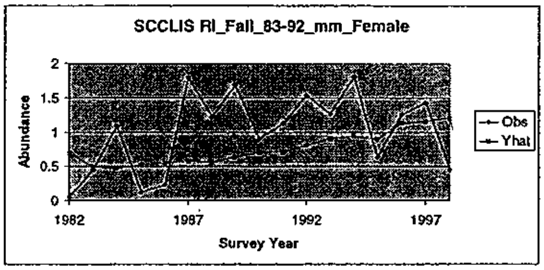

SCCLIS URIGSO Females 71-82 mm by Survey Year

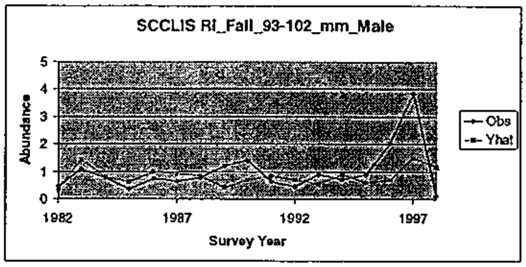

SCCLIS URIGSO Females 71-82 mm by Survey Year

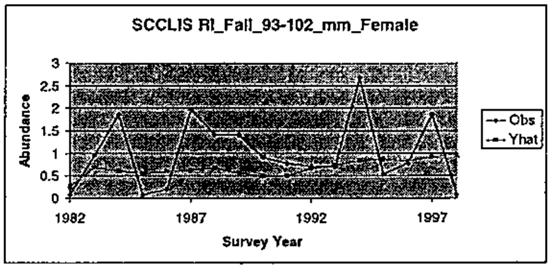

SCCLIS RI_Fall_73-82mm_Male

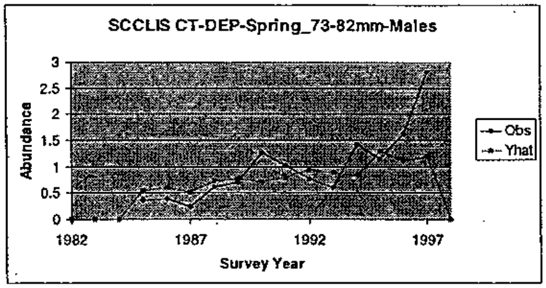

SCCLIS RI_Fall_73-82mm_Female

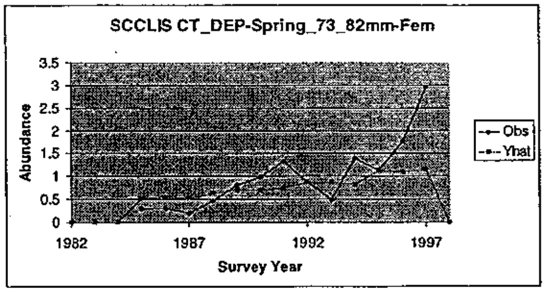

SCCLIS RI_Fall_83-92_mm_Male

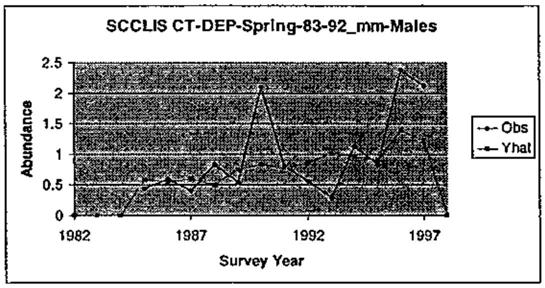

SCCLIS RI_Fall_83-92_mm_Female

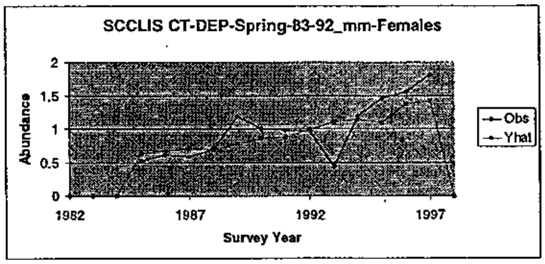

SCCLIS RI_Fall_93-102_mm_Male


SCCLIS RI_Fall_93-102_mm_Female


SCCLIS CT-DEP-Spring_73-82mm-Males


SCCLIS CT_DEP-Spring_73_82mm-Fem


SCCLIS CT-DEP-Spring-83-92_mm-Males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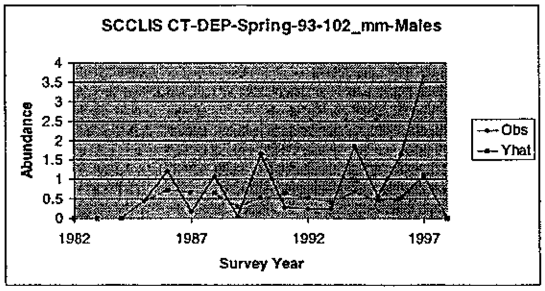
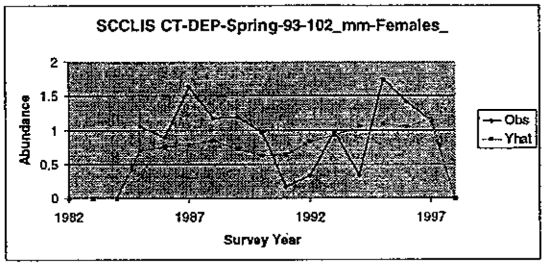
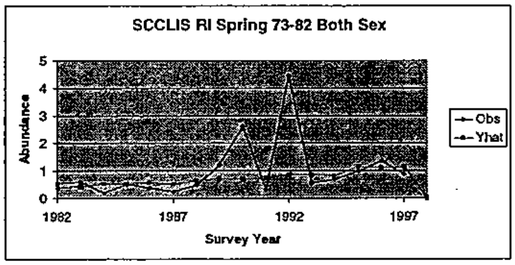
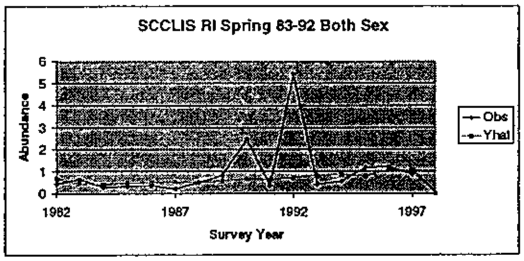
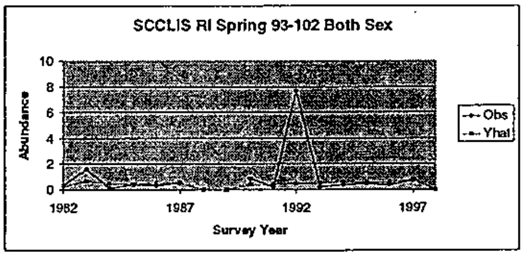
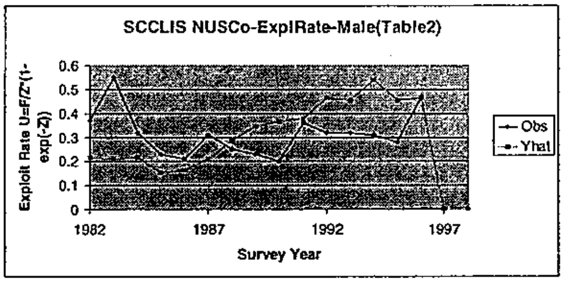

SCCLIS CT-DEP-Spring-93-102_mm-Males

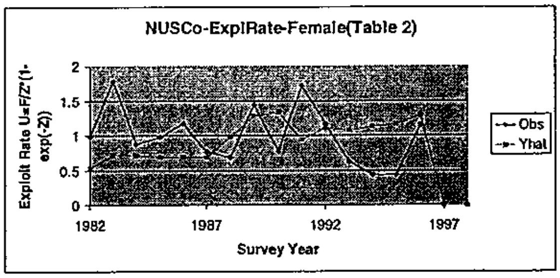

SCCLIS CT-DEP-Spring-93-102_mm-Females_


SCCLIS RI Spring 73-82 Both Sex
Abundance
0
1
2
3
4
5
1982
1987
1992
1997
Survey Year
Obs
Yhat


SCCLIS RI Spring 83-92 Both Sex
Abundance
0
1
2
3
4
5
6
1982
1987
1992
1997
Survey Year
Obs
Yhat


SCCLIS RI Spring 93-102 Both Sex
Abundance
0
2
4
6
8
10
1982
1987
1992
1997
Survey Year
Obs
Yhat


SCCLIS NUSCo-ExplRate-Male(Table2)
Exploit Rate U=F/Z*(1-exp(-Z))
0
0.1
0.2
0.3
0.4
0.5
0.6
1982
1987
1992
1997
Survey Year
Obs
Yhat


NUSCo-ExplRate-Female(Table 2)
Exploit Rate U=F/Z*(1-exp(-Z))
0
0.5
1
1.5
2
1982
1987
1992
1997
Survey Year
Obs
Yhat

## Preliminary Model Results

As described in the introduction, Mark did not converge to well defined solutions based on the available index and catch data unless constrained in some fashion. In plain terms, this means that a wide range of hypotheses about abundance and fishing mortality rates fit the index data almost equally well and that there was uncertainty about current abundance and fishing mortality rates for lobster. This problem occurs routinely in stock assessment work, particularly with models based on forward simulation. The art and science of stock assessment, under these conditions, is to use model results, tools, tricks, and information not already in the model (including simple fisheries biology and common sense) to identify feasible solutions and provide useful management advice.

Problems with convergence and precision are best viewed as a shortage of information, rather than a problem with a particular model. They are particularly acute for stocks like lobster with that show flat abundance trends or abundance trends that are "one way trips" (Hilborn and Walters 1992). One way trips are trends either always increasing or decreasing. In plain terms, it is difficult for any model to estimate effects of fishing if abundance did not appear to change (i.e. lobster in GBK) or was continuously increasing (i.e. lobster in GOM and SCCLIS) while data were collected. Without a strong response to fishing in the population, there is little a model can measure.

Although there is often uncertainty about the "scale" or level in absolute terms of abundance and fishing mortality rates, trends in relative abundance and mortality are usually better estimated. As shown below, scenarios with a wide range of current abundance and fishing mortality rates show the same relative trends for lobster in all three stock areas. Managers may remain uncertain about recent levels of fishing mortality but can be more confident about trends.

### *Profiles Analysis-General*

Uncertainty in assessment results for lobster was summarized using likelihood profiles that covered a range of hypotheses ("scenarios") about lobster abundance and fishing mortality rate levels. Profiles were constructed with scenarios in columns and assessment results in rows. Assessment results for each scenario include likelihood components for each type of data and constraint. Measures of goodness of fit were useful for determining how indices, other data, and constraints supported different scenarios.

The most important likelihood profile for each stock used a range of scenarios based on different $q_{NMFS,-1}$ values, the scaling parameter for female lobster 73-82 mm CL (length group -1) in the NMFS fall trawl survey (referred to below as "q"). Low values of q imply high abundance and low fishing mortality rates. High values of q imply low abundance and high fishing mortality rates.

Other useful likelihood profiles were based on "q-ratios" (the ratio of scaling parameters for 73-82 mm and 83+ mm female lobster in the NMFS fall survey). Q-ratios in likelihood tables are similar to q-ratio's for small and large lobster used to constrain the conventional DeLury model.

For q-ratio calculations, NMFS survey data were tabulated according to the required length groups (73-82 mm or 83+ mm) and included in the model (without transformation to unit mean), but not tuned to either scale or trend. As explained above, Mark calculates scaling factors in model runs for data sets not used in tuning. This means that the scaling parameters and q-ratios could be calculated but used only in the constraint and without otherwise effecting tuning to other data.

*Plausible Values and Problems With Q-ratios*

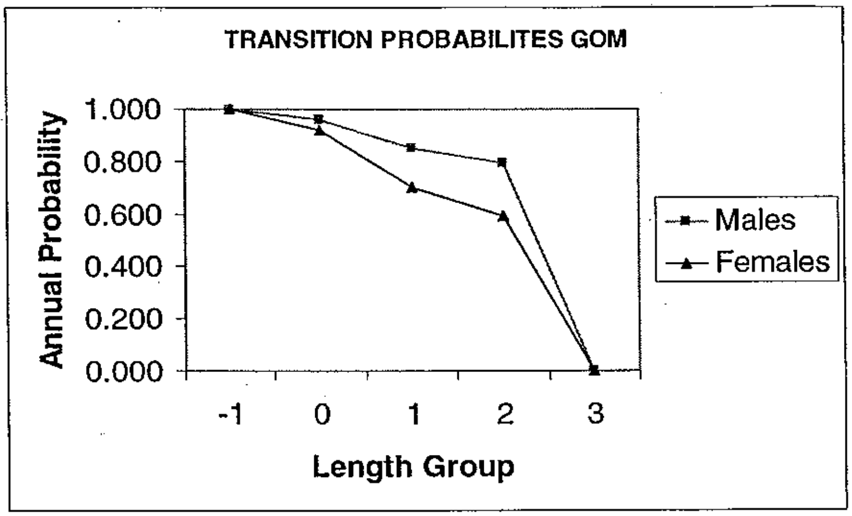
The Subcommittee decided, by consensus, that the range of plausible values for q-ratios (defined above) was 0.5-1.0. The Subcommittee's decision means that feasible solutions (plausible model fits) should have q-ratios in the range 0.5-1.0. As shown below, results from Mark tends to fit best with q-ratios greater than one. Colleagues suggested that growth assumptions (which were similar to assumptions about growth in the LCA and EPR models) may not invalid. More work is required to resolve differences in q-ratio results from the DeLury model and Mark.

*GOM-Preliminary Results*

Index data (NMFS and Massachusetts fall trawl survey data) used to tune Mark for trends in likelihood profile runs are listed below with assumed selectivity values for each length groups and objective function weights. A wider range of data were included in the model but not used for tuning to trend. CPUE data, in particular, were not used in tuning because the Subcommittee felt CPUE data from commercial lobster traps were less reliable in measuring trends than bottom trawl survey data. Moreover, it was not necessary to use CPUE information because two sets of bottom trawl survey data (NMFS and Massachusetts) were available.

| | | *Selx by group ->* | | | | |
|---|---|---|---|---|---|---|
| **Survey_Name** | **OBJFunctionWts** | **-1** | **0** | **1** | **2** | **3** |
| NMFS Fall Female 73-82 mm - SCALED TO MEAN 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| NMFS Fall Female 83-92 mm-SCALED TO MEAN 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| NMFS Fall Female 93-102 mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| NMFS Fall Female 103+ mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| NMFS Fall Male 73-82 mm-SCALED TO MEAN 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| NMFS Fall Male 83-92 mm-SCALED TO MEAN 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| NMFS Fall Male 93-102 mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| NMFS Fall Male 103+ mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| MA Fall Males 103-112 (scaled to mean 1) | 1 | 0 | 0 | 0 | 1 | 0 |
| MA Fall Males 73-82 mm (scaled to mean 1) | 1 | 1 | 0 | 0 | 0 | 0 |
| MA Fall Males 83-92 mm (scaled to mean 1) | 1 | 0 | 1 | 0 | 0 | 0 |
| MA Fall Males 93-102 mm (scaled to mean 1) | 1 | 0 | 0 | 1 | 0 | 0 |
| MA Fall Females 73-82 mm (scaled to mean 1) | 1 | 1 | 0 | 0 | 0 | 0 |
| MA Fall Females 83-92 mm (scaled to mean 1) | 1 | 0 | 1 | 0 | 0 | 0 |
| MA Fall Females 93-102 (scaled to mean 1) | 1 | 0 | 0 | 1 | 0 | 0 |

A set of sex-specific transition probabilities for lobster in GOM were calculated from the Subcommittee's best estimates for one mm molt intervals and mean molt increments used in LCA and egg per recruit (EPR) model runs. Little information was available for males in GOM, so the Subcommittee decided to choose values for males $p_{m,g}=(p_{f,g}+1)/2$ that were midway between values for females (a lower bound) and one (the upper bound, see below). The average molt increment in the GOM is the same size as the size of length groups in Mark (10 mm) so the conditional probabilities of skipping the next length group were zero for lobster in GOM.

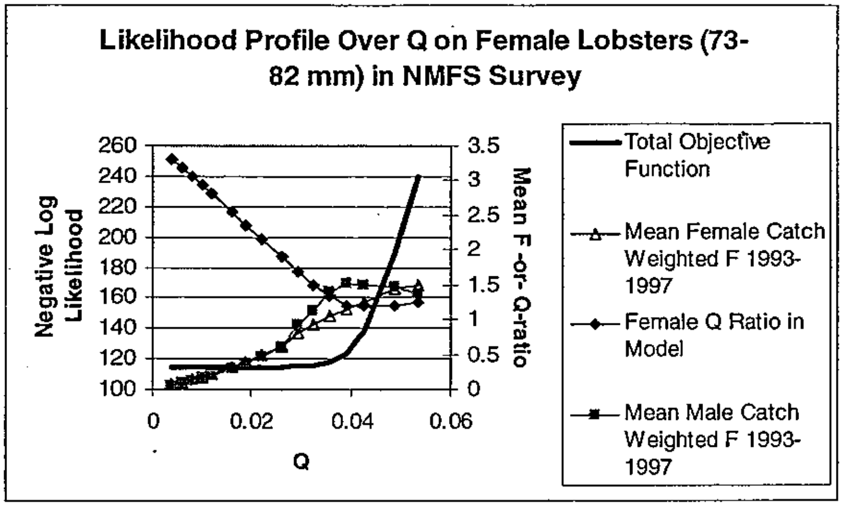


The average sex ratio for lobster in the first length group (measured in five data sets described above) was 48%. The Subcommittee decided to fix the parameter for sex ratio of new recruits at 0.5 in the Mark runs for lobster in GOM.

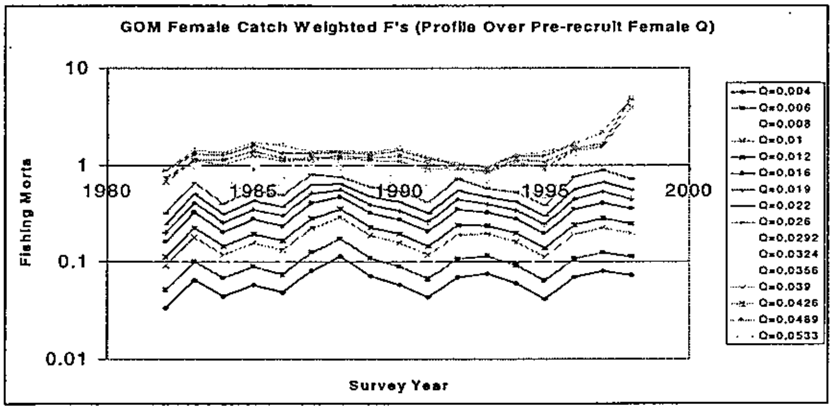
Active constraints in Mark during likelihood profile runs for GOM lobster were: the first difference constraint for the NMFS trawl survey (likelihood weight one), the first difference constraint for the Massachusetts trawl survey (weight one), the protect females constraint (weight one), the swept area constraint (weight one), and the constraint on q for pre-recruit females in the NMFS survey (weight 10000). A very high weight was used for the latter constraint because it was used to drive the profile runs (i.e. I wanted the model to match the target q level ).

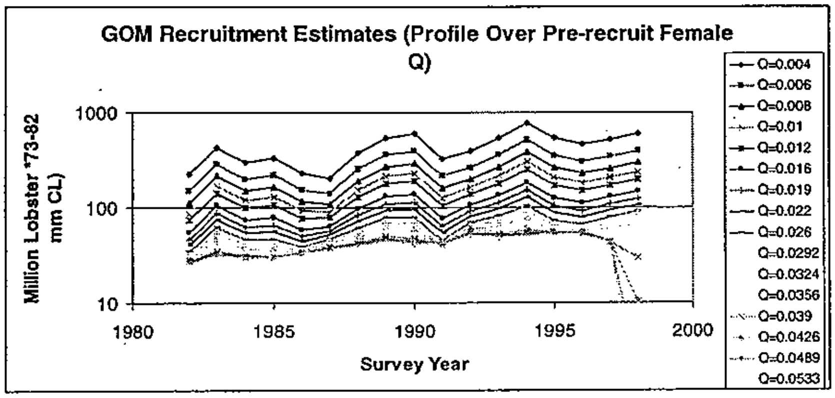
As shown below, penalties imposed by the first difference constraint were non-zero in many runs because the estimated scaling parameters for male and female lobsters in length group 2 (103-112 mm) had a tendency to be less than the scaling parameters for the adjacent, smaller length groups. This result was likely due to noise in the survey data. Likelihood components for other active constraints were zero in most cases.

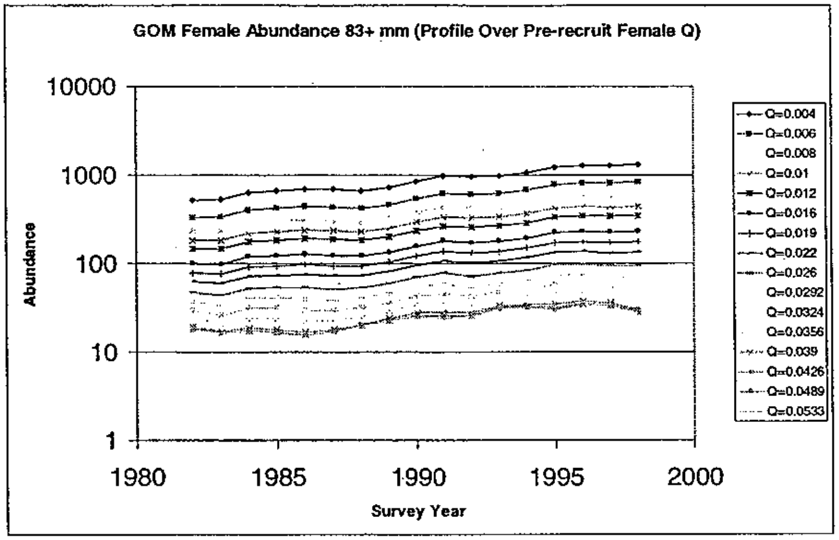
Likelibood profile results (see below) show that the total negative log likelihood was flat over a broad range of scenarios but increased sharply at q=0.0356 as the fit to most of the survey indices began to degrade. At q=0.0356, the average recent (1993-1997) catch weighted fishing mortality rates for females was about 1.0 and the q-ratio was about 1.3. This might mean that catch weighted fishing mortality rates on female lobsters were probably not greater than 1.0 during 1993-1997. However, this point estimate of an upper bound is uncertain because the q-ratio (1.3) implied by the solution with recent fishing mortality rates of one was larger than one and not feasible.


Likelihood Profile Over Q on Female Lobsters (73-82 mm) in NMFS Survey

Trends in fishing mortality rates, recruitment and abundance of females were similar in all scenarios. All suggest that female lobster fishing mortality rates varied without trend and abundance increased steadily in the GOM after 1982 (see below). Higher catches in GOM were apparently offset by higher recruitment.

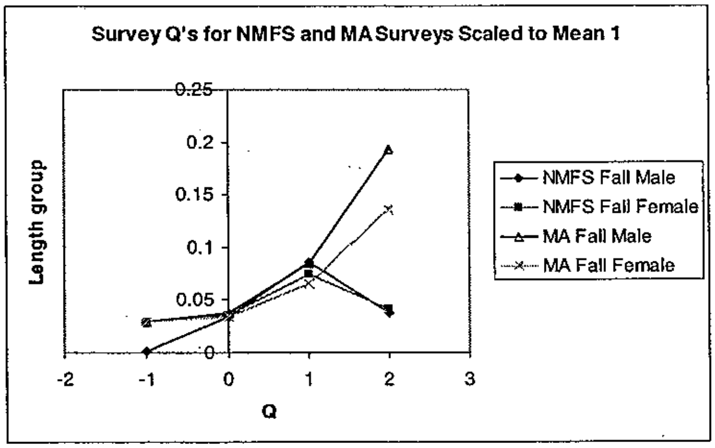

GOM Female Catch Weighted F's (Profile Over Pre-recruit Female Q)


GOM Recruitment Estimates (Profile Over Pre-recruit Female Q)



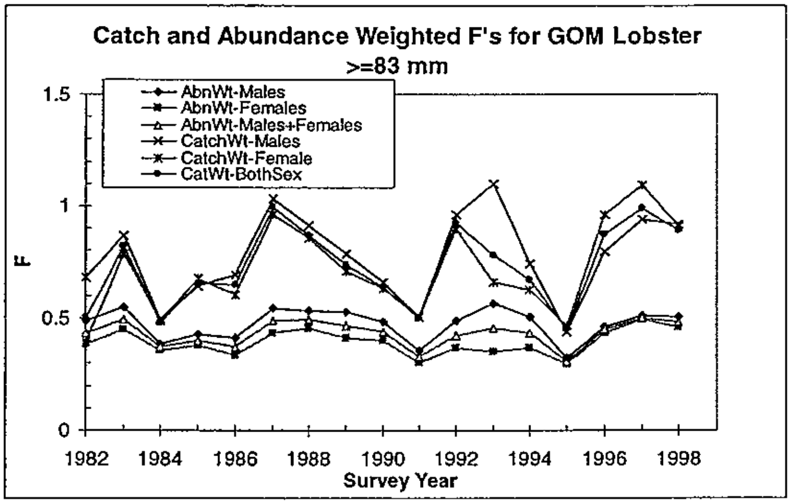
Patterns in estimated selectivity and other results were similar in most scenarios. The model fit all of index data GOM well for a wide range of model scenarios and there was little evidence of lack of fit in residual plots. The run with q=0.0292 and mean recent fishing mortality of 0.81 for females is used below for display purposes.

Most scenarios showed the expected pattern of increasing scaling parameters for NMFS and Massachusetts trawl survey data (see below) although scaling parameter estimates for males and females 103-112 mm (length group 2) were often smaller than for the smaller lobster.

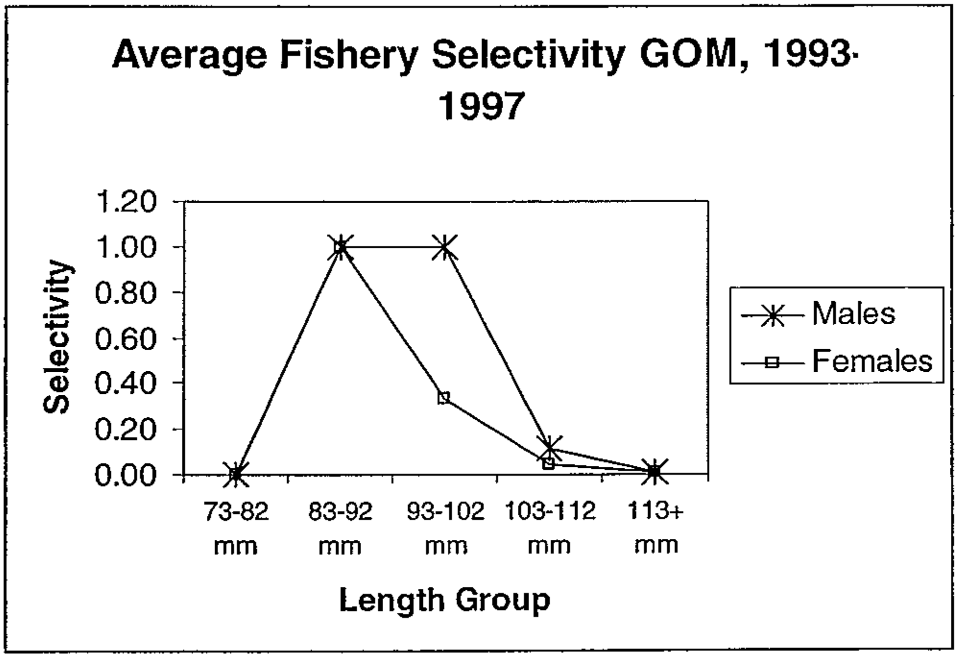


Fishing mortality rates for males were usually higher than for females (see below), particularly in scenarios with low fishing mortality rates overall. Catch weighted fishing mortality rates were higher than abundance weighted or mean fishing mortality rates (see below).

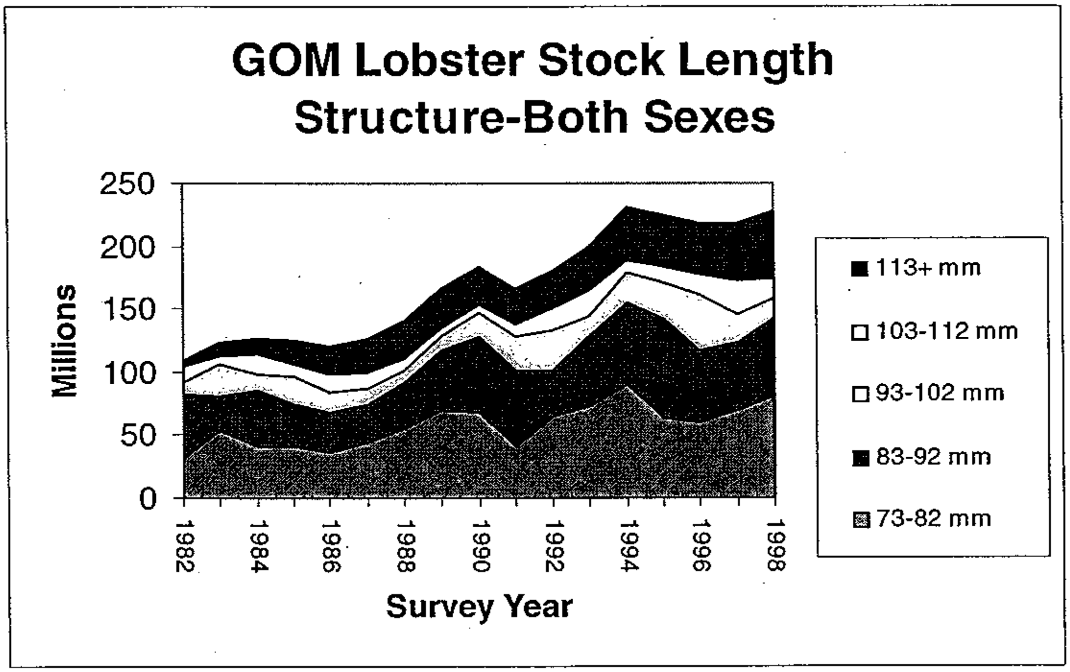
In addition to being higher, catch weighted estimates of fishing mortality rates were more variable than abundance weighted estimates (see below), particularly when calculated separately by sex, because catch weighted averages are calculated from imprecise landings estimates while abundance weighted averages are calculated from smoother model based estimates of proportions of the population in each length group. Differences in fishing mortality rate between males and females are much clearer in abundance weighted estimates.



Fishery selectivity estimates (fishing mortality rates for lobster of different size in the same year scaled to a maximum value of one) from Mark, like those from LCA (Cadrin and Estella 1996, figures 2), decline rapidly with size in GOM lobsters for male lobsters larger than 102 mm and for female lobsters larger than 93 mm (see below).



Preliminary estimates from Mark indicate that the GOM lobster stock includes increasing numbers of lobsters in the largest size group (113+ mm). This may be due to the maximum size limit restriction in Maine which protects large individuals.



*Likelihood profile over a range of values for the scaling parameter q for pre-recruit female lobsters taken in the NMFS fall trawl survey from the Gulf of Maine. Results for different scenarios are given in different columns. Rows give the total log likelihood (sum of individual likelihoods times their weights), unweighted log likelihoods for each component, and assessment results. The smallest log likelihood (i.e. best fit) identifies the run with best fit for a likelihood component.*

| | Q=0.004 | Q=0.006 | Q=0.008 | Q=0.01 | Q=0.012 | Q=0.016 | Q=0.019 | Q=0.022 | Q=0.026 | Q=0.0292 | Q=0.0324 | Q=0.0356 | Q=0.039 | Q=0.0426 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Profile Control Variables: | | | | | | | | | | | | | | |
| Weight Constraint on Female Prerecruit Q in NMFS | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 | 10000.00 |
| Female Prerecruit Q Model | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 |
| Female Prerecruit Q Target | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 |
| | | | | | | | | | | | | | | |
| Weight Penalty for Q-Ratio Constraint (DeLury Run: | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Female Q Ratio in Model | 3.31 | 3.19 | 3.06 | 2.93 | 2.80 | 2.55 | 2.35 | 2.16 | 1.90 | 1.68 | 1.49 | 1.34 | 1.21 | 1.20 |
| Female Q Ratio Target | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| | | | | | | | | | | | | | | |
| Mean Female Catch Weighted F 1993-1997 | 0.07 | 0.10 | 0.14 | 0.18 | 0.22 | 0.31 | 0.39 | 0.48 | 0.62 | 0.81 | 0.93 | 1.06 | 1.16 | 1.25 |
| Mean Male Catch Weighted F 1993-1997 | 0.06 | 0.09 | 0.13 | 0.17 | 0.21 | 0.29 | 0.37 | 0.46 | 0.61 | 0.93 | 1.13 | 1.40 | 1.53 | 1.48 |
| | | | | | | | | | | | | | | |
| Sex Ratio at Recruitment | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.51 |
| | | | | | | | | | | | | | | |
| Total Objective Function | 114.38 | 114.45 | 114.54 | 114.63 | 114.72 | 114.87 | 114.96 | 115.01 | 115.04 | 115.54 | 115.41 | 117.38 | 123.66 | 138.57 |
| | | | | | | | | | | | | | | |
| Goodness of Fit for Major Likelihood Components: | | | | | | | | | | | | | | |
| From Indices | **112.56** | 112.68 | 112.80 | 112.93 | 113.05 | 113.30 | 113.48 | 113.64 | 113.88 | 114.57 | 114.85 | 117.02 | 122.65 | 134.65 |
| Catch/F Penalties-Males | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Catch/F Penalties-Females | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Weight Sex Ratio Data or Constraint | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Weight First Difference Constraint-NMFS Survey | 1.79 | 1.76 | 1.73 | 1.70 | 1.66 | 1.57 | 1.48 | 1.37 | 1.16 | 0.95 | 0.55 | 0.18 | 0.04 | 0.00 |
| Weight First Difference Constraint-MA Survey | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Weight Protect Females Constraint | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.17 |
| Weight Swept Area Constraint | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Weight Constraint on Female Prerecruit Q in NMFS | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | | | | | | | | | | | | | |
| Goodness of Fit for Individual Indices: | | | | | | | | | | | | | | |
| NMFS Fall Female 73-82 mm - SCALED TO MEAN | **4.56** | 4.61 | 4.67 | 4.74 | 4.82 | 4.98 | 5.11 | 5.24 | 5.41 | 5.81 | 5.58 | 5.87 | 6.80 | 10.19 |
| NMFS Fall Female 83-92 mm-SCALED TO MEAN | 7.34 | 7.29 | 7.23 | 7.16 | 7.10 | 6.96 | 6.85 | 6.73 | 6.55 | 6.29 | 6.29 | 6.27 | 6.13 | 6.03 |
| NMFS Fall Female 93-102 mm-SCALED TO MEAN | **8.47** | 8.54 | 8.54 | 8.54 | 8.54 | 8.56 | 8.59 | 8.67 | 8.88 | 9.49 | 9.68 | 10.19 | 11.58 | 12.50 |
| NMFS Fall Female 103+ mm-SCALED TO MEAN 1 | 5.36 | **5.34** | 5.34 | 5.34 | 5.35 | 5.37 | 5.38 | 5.40 | 5.44 | 5.54 | 5.41 | 5.22 | 4.77 | 4.43 |
| NMFS Fall Male 73-82 mm-SCALED TO MEAN 1 | **5.08** | 5.11 | 5.15 | 5.21 | 5.26 | 5.39 | 5.50 | 5.62 | 5.77 | 6.19 | 6.01 | 6.19 | 6.87 | 9.87 |
| NMFS Fall Male 83-92 mm-SCALED TO MEAN 1 | **6.96** | 6.98 | 7.00 | 7.03 | 7.05 | 7.11 | 7.14 | 7.18 | 7.20 | 7.03 | 7.22 | 7.31 | 7.15 | 7.15 |
| NMFS Fall Male 93-102 mm-SCALED TO MEAN 1 | 9.07 | 9.00 | 8.95 | 8.88 | 8.81 | 8.64 | 8.50 | 8.36 | **8.22** | 8.70 | 8.29 | 8.44 | 9.49 | 9.87 |
| NMFS Fall Male 103+ mm-SCALED TO MEAN 1 | 8.54 | 8.54 | **8.55** | 8.56 | 8.57 | 8.59 | 8.62 | 8.66 | 8.72 | 8.82 | 8.68 | 8.39 | 6.40 | 6.28 |
| MA Fall Males 103-112 (scaled to mean 1) | 3.63 | 3.64 | 3.63 | 3.62 | 3.60 | 3.57 | 3.52 | 3.46 | 3.30 | 3.21 | 2.62 | 2.17 | 2.01 | 1.21 |
| MA Fall Males 73-82 mm (scaled to mean 1) | **5.06** | 5.16 | 5.29 | 5.43 | 5.58 | 5.89 | 6.14 | 6.40 | 6.73 | 7.31 | 7.01 | 6.80 | 6.82 | 8.08 |
| MA Fall Males 83-92 mm (scaled to mean 1) | **4.95** | 5.00 | 5.03 | 5.07 | 5.11 | 5.24 | 5.36 | 5.51 | 5.76 | 6.07 | 6.23 | 6.41 | 6.99 | 7.22 |
| MA Fall Males 93-102 mm (scaled to mean 1) | 13.99 | 13.89 | 13.73 | 13.56 | 13.37 | 12.94 | 12.56 | 12.13 | 11.48 | **9.96** | 10.88 | 11.72 | 13.12 | 14.05 |
| MA Fall Females 73-82 mm (scaled to mean 1) | **4.82** | 4.94 | 5.07 | 5.21 | 5.36 | 5.69 | 5.95 | 6.22 | 6.57 | 7.05 | 7.01 | 7.21 | 7.90 | 10.68 |
| MA Fall Females 83-92 mm (scaled to mean 1) | **7.54** | 7.63 | 7.70 | 7.78 | 7.88 | 8.10 | 8.29 | 8.51 | 8.85 | 9.03 | 9.47 | 9.82 | 10.50 | 10.81 |
| MA Fall Females 93-102 (scaled to mean 1) | 17.18 | 17.04 | 16.92 | 16.80 | 16.65 | 16.29 | 15.95 | 15.57 | 15.00 | **14.07** | 14.47 | 15.00 | 16.12 | 16.29 |

*Bounds for Q-ratio Assumptions in GOM*

Simple algebraic assumptions and trawl survey data can be used to infer lower bounds on the range of feasible q-ratio values. Assume that average values of NMFS trawl survey density estimates for lobster during 1976-1998 are $\eta$ for length group –1 (73-82 mm) and $\mu$ for any other length group (other than the plus group). The corresponding stock abundance values are H and M, and the corresponding index scaling parameters are $s_\eta$ and $s_\mu$.

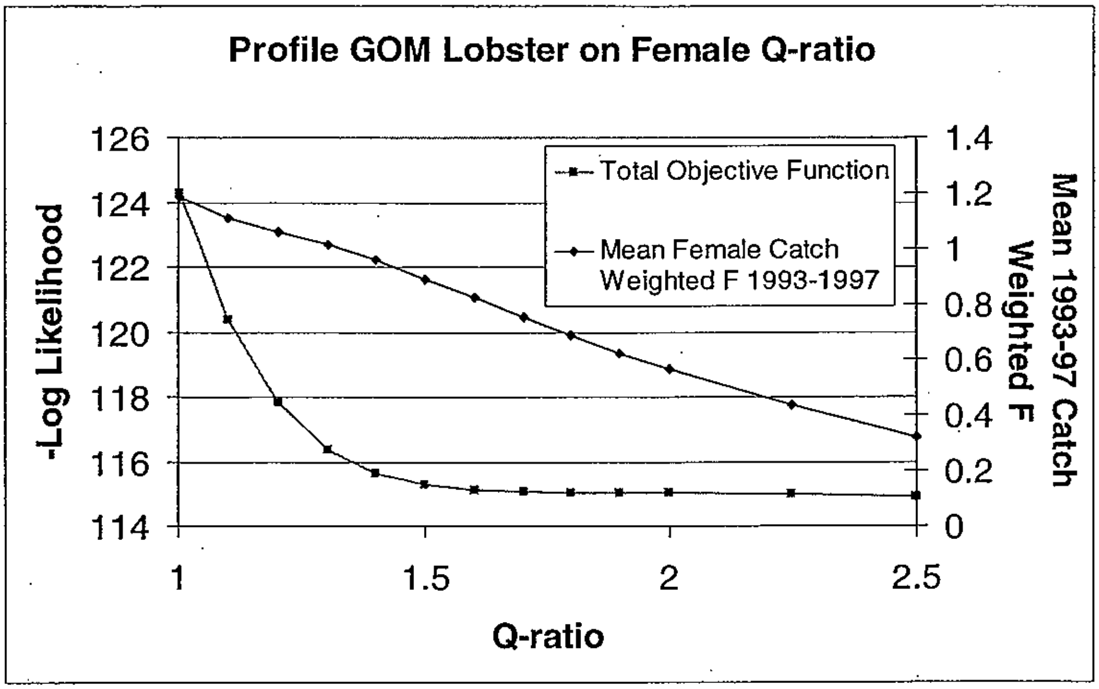
On average $M < H$ so $\mu s_\mu < \eta s_\eta$ and $s_\mu / s_\eta < \eta/\mu$. Thus the ratio of average densities are estimates of the lower bound on feasible q-ratios (see below) for use in the lobster stock assessment models.

The lower bound can be refined at the expense of a more speculative calculation. If the instantaneous natural mortality rate for lobster is m, then $Me^{2m} < H$, $\mu s_\mu e^{2m} < \eta s_\eta$ and $s_\mu / s_\eta < \eta/(\mu e^{2m})$. Inequalities with $e^{2m}$ hold because fishing mortality rates in lobster are thought to be at least as high as natural mortality. The assumed natural mortality rate is $m=0.15$ for lobster so $s_\mu / s_\eta < 0.74\eta/\mu$. Thus, $0.74\eta/\mu$ is another, more speculative bound on q-ratios for lobster (see below).

| Length Group | Mean Density Females in NMFS Survey | $\eta/\mu$ Ratio | $0.74\eta/\mu$ Ratio | Mean Density Males in NMFS Trawl Survey | $\eta/\mu$ Ratio | $0.74\eta/\mu$ Ratio |
|---|---|---|---|---|---|---|
| 73-82 | 0.29 | | | 0.30 | | |
| 83-92 | 0.18 | 0.6 | 0.5 | 0.20 | 0.7 | 0.5 |
| 93-102 | 0.09 | 0.3 | 0.2 | 0.10 | 0.3 | 0.2 |
| 103-112 | 0.06 | 0.2 | 0.2 | 0.027 | 0.09 | 0.07 |

Ratios of $\eta/\mu$ and 0. $0.74\eta/\mu$ were 0.2-0.6 and 0.2-0.5 for female lobsters. For male lobsters, ratios were 0.09-0.7 and 0.07-0.5. Abundance weighted average ratio values for male and female lobster in GOM would likely be about 0.5, a value intermediate between the $s_\mu / s_\eta$ and $0.74\ s_\mu / s_\eta$ ratios for the smallest length group. An average of 0.5 is likely because the weighted averages would be similar to ratios for the smallest size groups (abundance used as a weight in calculating averages is highest for small lobster). These calculations all seem to suggest that the traditional q-ratio=0.5 assumption is at the lower end of the feasible range.

Likelihood profiles were carried out over a range of scenarios with different q-ratios for lobster in the GOM. For these runs, the q-ratio was held constant and all other parameters were estimated to provide the best fit to the data given the specified q-ratio. Results (see below), demonstrate the direct, almost functional relationship between the choice of a q-ratio and estimates of fishing mortality rate from a stock assessment model. As expected, many scenarios, with much different q-ratios and fishing mortality rate levels, fit the index data and constraints in Mark equally well. However, goodness of fit to abundance indices degrades and negative log likelihood increases once q-ratios drop below about 1.5. As described above, Mark fit the index data as a whole best with q-ratio values greater than one that were not feasible.


Profile GOM Lobster on Female Q-ratio
-Log Likelihood
126
124
122
120
118
116
114
Total Objective Function
Mean Female Catch Weighted F 1993-1997
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Mean 1993-97 Catch Weighted F
1
1.5
2
2.5
Q-ratio

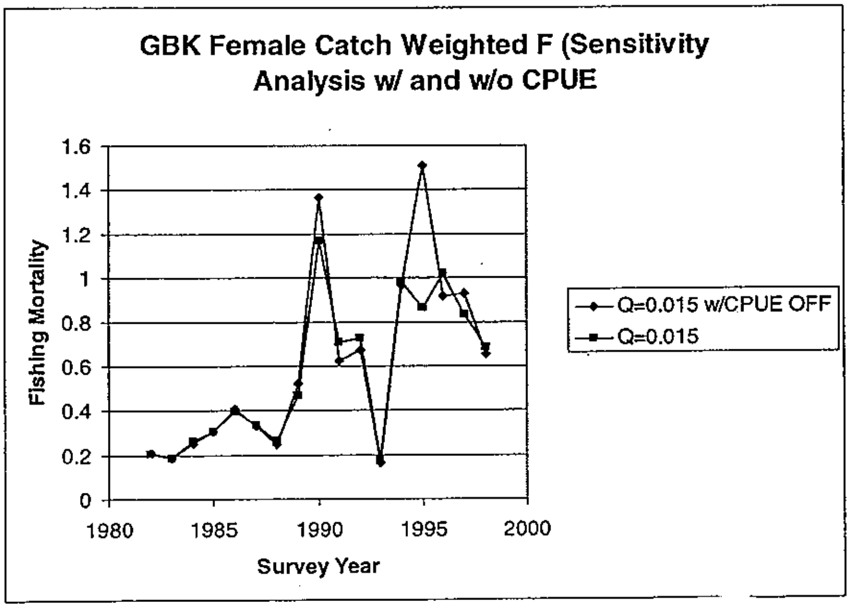
## *Likelihood profile over a range of female q-ratio values for GOM lobster.*

| | Q-ratio=1 | Q-ratio=1.1 | Q-ratio=1.2 | Q-ratio=1.3 | Q-ratio=1.4 | Q-ratio=1.5 | Q-ratio=1.6 | Q-ratio=1.6 | Q-ratio=1.7 | Q-ratio=1.8 | Q-ratio=1.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Profile Control Variables: | | | | | | | | | | | |
| Weight Constraint on Female Prerecruit Q in NMFS S | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Female Prerecruit Q Model | 0.036 | 0.035 | 0.034 | 0.034 | 0.033 | 0.031 | 0.030 | 0.030 | 0.029 | 0.027 | 0.026 |
| Female Prerecruit Q Target | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 |
| Weight Penalty for Q-Ratio Constraint (DeLury Runs) | 10000.000 | 10000.000 | 10000.000 | 10000.000 | 10000.000 | 10000.000 | 10000.000 | 10000.000 | 10000.000 | 10000.000 | 10000.000 |
| Female Q Ratio in Model | 1.003 | 1.102 | 1.201 | 1.301 | 1.401 | 1.500 | 1.600 | 1.600 | 1.700 | 1.800 | 1.900 |
| Female Q Ratio Target | 1.000 | 1.100 | 1.200 | 1.300 | 1.400 | 1.500 | 1.600 | 1.600 | 1.700 | 1.800 | 1.900 |
| Mean Female Catch Weighted F 1993-1997 | 1.183 | 1.108 | 1.060 | 1.014 | 0.958 | 0.887 | 0.822 | 0.822 | 0.752 | 0.685 | 0.623 |
| Mean Male Catch Weighted F 1993-1997 | 1.466 | 1.469 | 1.398 | 1.277 | 1.175 | 1.084 | 1.013 | 1.013 | 0.786 | 0.688 | 0.612 |
| Sex Ratio at Recruitment | 0.505 | 0.503 | 0.502 | 0.501 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 | 0.500 |
| Total Objective Function | 124.283 | 120.385 | 117.823 | 116.369 | 115.653 | 115.271 | 115.108 | 115.108 | 115.072 | 115.049 | 115.038 |
| Goodness of Fit for Major Likelihood Components: | | | | | | | | | | | |
| From Indices | 123.381 | 120.005 | 117.604 | 116.111 | 115.232 | 114.665 | 114.335 | 114.335 | 114.149 | 114.000 | 113.882 |
| Catch/F Penalties-Males | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Catch/F Penalties-Females | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Weight Sex Ratio Data or Constraint | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Weight First Difference Constraint-NMFS Survey | 0.000 | 0.011 | 0.069 | 0.219 | 0.412 | 0.604 | 0.773 | 0.773 | 0.922 | 1.049 | 1.156 |
| Weight First Difference Constraint-MA Survey | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Weight Protect Females Constraint | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Weight Swept Area Constraint | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Weight Penalty for Q-Ratio Constraint (DeLury Runs) | 0.062 | 0.029 | 0.014 | 0.004 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Goodness of Fit for Individual Indices: | | | | | | | | | | | |
| NMFS Fall Female 73-82 mm - SCALED TO MEAN 1 | 5.117 | 5.132 | 5.188 | 5.312 | 5.414 | 5.479 | 5.557 | 5.557 | 5.514 | 5.462 | 5.405 |
| NMFS Fall Female 83-92 mm-SCALED TO MEAN 1 | 5.162 | 5.331 | 5.540 | 5.793 | 5.991 | 6.115 | 6.239 | 6.239 | 6.353 | 6.452 | 6.538 |
| NMFS Fall Female 93-102 mm-SCALED TO MEAN 1 | 11.785 | 10.616 | 10.010 | 9.760 | 9.613 | 9.454 | 9.364 | 9.364 | 9.160 | 9.000 | 8.873 |
| NMFS Fall Female 103+ mm-SCALED TO MEAN 1 | 5.583 | 5.735 | 5.737 | 5.609 | 5.548 | 5.528 | 5.499 | 5.499 | 5.476 | 5.455 | 5.439 |
| NMFS Fall Male 73-82 mm-SCALED TO MEAN 1 | 5.997 | 5.891 | 5.888 | 5.937 | 5.963 | 5.946 | 5.940 | 5.940 | 5.888 | 5.831 | 5.773 |
| NMFS Fall Male 83-92 mm-SCALED TO MEAN 1 | 6.641 | 6.780 | 6.931 | 7.048 | 7.116 | 7.146 | 7.163 | 7.163 | 7.185 | 7.196 | 7.198 |
| NMFS Fall Male 93-102 mm-SCALED TO MEAN 1 | 9.778 | 9.002 | 8.567 | 8.421 | 8.342 | 8.270 | 8.259 | 8.259 | 8.209 | 8.198 | 8.219 |
| NMFS Fall Male 103+ mm-SCALED TO MEAN 1 | 5.921 | 7.498 | 8.288 | 8.499 | 8.628 | 8.737 | 8.807 | 8.807 | 8.788 | 8.754 | 8.722 |
| MA Fall Males 103-112 (scaled to mean 1) | 1.675 | 2.013 | 2.116 | 2.284 | 2.507 | 2.740 | 2.937 | 2.937 | 3.095 | 3.214 | 3.305 |
| MA Fall Males 73-82 mm (scaled to mean 1) | 7.967 | 7.642 | 7.415 | 7.276 | 7.195 | 7.132 | 7.088 | 7.088 | 6.976 | 6.857 | 6.735 |
| MA Fall Males 83-92 mm (scaled to mean 1) | 7.803 | 7.374 | 6.948 | 6.640 | 6.425 | 6.264 | 6.131 | 6.131 | 5.998 | 5.875 | 5.762 |
| MA Fall Males 93-102 mm (scaled to mean 1) | 13.959 | 12.528 | 11.857 | 11.386 | 11.017 | 10.803 | 10.635 | 10.635 | 10.917 | 11.205 | 11.480 |
| MA Fall Females 73-82 mm (scaled to mean 1) | 7.309 | 7.172 | 7.066 | 7.027 | 7.004 | 6.968 | 6.945 | 6.945 | 6.828 | 6.701 | 6.570 |
| MA Fall Females 83-92 mm (scaled to mean 1) | 11.446 | 10.889 | 10.420 | 10.034 | 9.735 | 9.527 | 9.344 | 9.344 | 9.166 | 9.003 | 8.855 |
| MA Fall Females 93-102 (scaled to mean 1) | 17.238 | 16.403 | 15.634 | 15.085 | 14.735 | 14.555 | 14.426 | 14.426 | 14.595 | 14.794 | 15.008 |

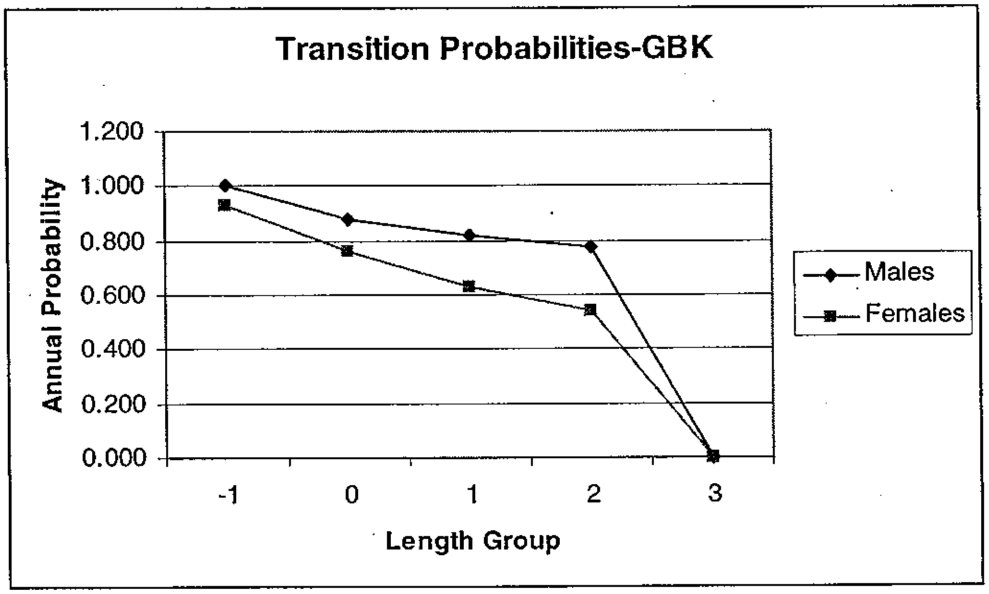
*GBK-Preliminary Results*

Index data (NMFS fall trawl survey and all commercial CPUE data) used to tune Mark are given below with assumed selectivity values and objective function weights. CPUE data were included in runs for GBK, but not for GOM or SCCLIS, because they were the only abundance index information other than the NMFS fall trawl survey available and fits based on at least two types of data were desired. The Subcommittee does not believe catch rates from commercial traps were as reliable as catch rates from trawl surveys but trends in the two types of data for lobster in GBK were similar. Runs with and without commercial catch rate data gave similar results (see below). CPUE data were tuned to abundance of length groups 0 and 1 only (83-102 mm) because lobster larger than 103 mm are seldom taken in the commercial fishery.

| | | Selx by group -> | | | | |
|---|---|---|---|---|---|---|
| **Survey Name** | **OBJ Func** | **-1** | **0** | **1** | **2** | **3+** |
| Male NMFS Fall 73-82 mm-SCALED TO MEAN 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Male NMFS Fall 83-92 mm-SCALED TO MEAN 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| Male NMFS Fall 93-102 mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| Male NMFS Fall 103-112 mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| Male NMFS Fall 113+ mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| Female NMFS Fall 73-82 mm-SCALED TO MEAN 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Female NMFS Fall 83-92 mm-SCALED TO MEAN 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| Female NMFS Fall 93-102 mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| Female NMFS Fall 103-112 mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| Female NMFS Fall 113+ mm-SCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| MA Catch Per Trap Haul-weighted-sexes combined | 1 | 0 | 1 | 1 | 0 | 0 |
| NY Catch Per Trap (annual average) | 1 | 0 | 1 | 1 | 0 | 0 |
| RI CPUE Males 73-82 | 1 | 1 | 0 | 0 | 0 | 0 |
| RI CPUE Males 83-92 | 1 | 0 | 1 | 0 | 0 | 0 |
| RI CPUE Males 93-102 | 1 | 0 | 0 | 1 | 0 | 0 |
| RI CPUE Males 103-112 | 1 | 0 | 0 | 0 | 1 | 0 |
| RI CPUE Males 113+ | 1 | 0 | 0 | 0 | 0 | 1 |
| RI CPUE Females 73-82 | 1 | 1 | 0 | 0 | 0 | 0 |
| RI CPUE Females 83-92 | 1 | 0 | 1 | 0 | 0 | 0 |
| RI CPUE Females 93-102 | 1 | 0 | 0 | 1 | 0 | 0 |
| RI CPUE Females 103-112 | 1 | 0 | 0 | 0 | 1 | 0 |
| RI CPUE Females 113+ | 1 | 0 | 0 | 0 | 0 | 1 |
| VTR CPUE pounds per Trap Haul Set Over Day | 1 | 0 | 1 | 1 | 0 | 0 |

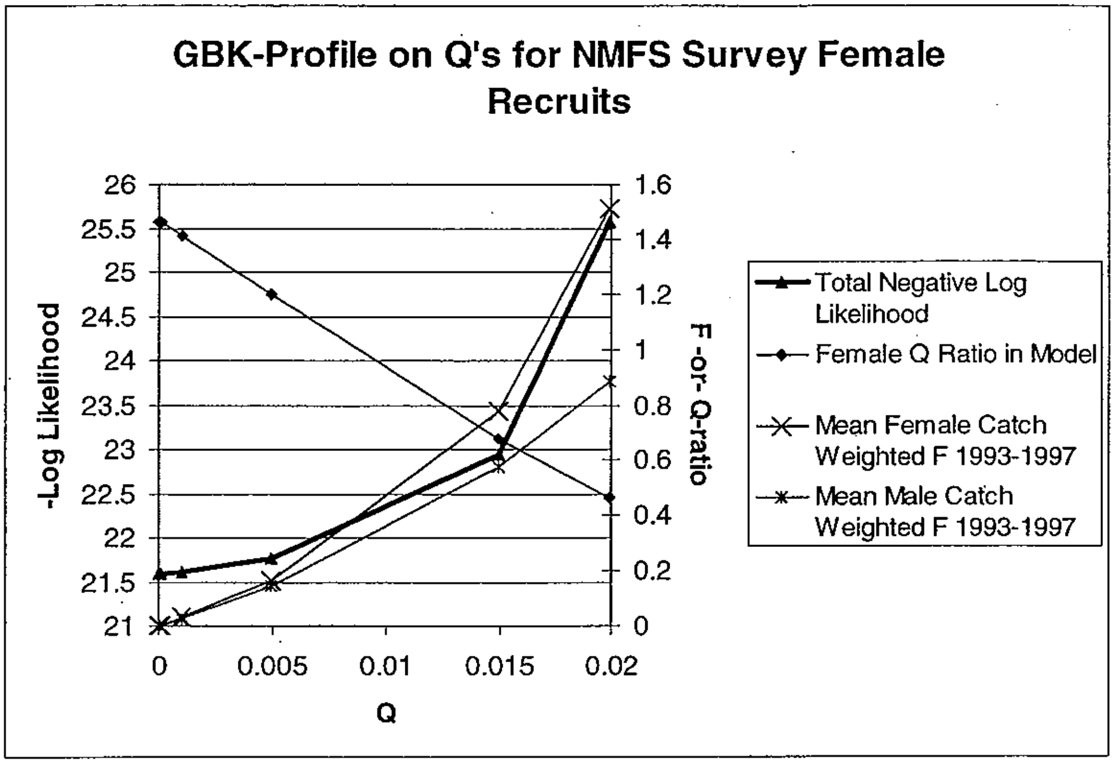


A set of sex-specific transition probabilities for lobster in GBK were calculated from the Subcommittee's best estimates of one mm molt intervals and mean molt increments used in LCA and EPR model runs. Little information was available for males in GBK, so males values were set midway between female values and one (see discussion for GOM). The average molt increment in the GBK is 14 mm so conditional probabilities of skipping the next length group were 1-(14-10)/14=0.29 for length groups –1 to 1.



The average sex ratio for lobster in the first length group (measured in three data sets) was 41%. Two of the data sets were from sea sampling data and had relatively low average percent male (Rhode Island offshore sea sampling in canyons, 30% and Massachusetts sea sampling 41% male). The third data set was from the NMFS trawl survey (52% female). The NMFS trawl survey probably gives better information for the stock as a whole. We therefore assumed a 50% sex ratio (likelihood weight 10000) in the first length group, which is close to the value from the NMFS trawl survey.

Active constraints in Mark during likelihood profile runs for GNK lobster were: the first difference constraint for the NMFS trawl survey (likelihood weight one), the protect females constraint (weight one), the swept area constraint (weight one), and the constraint on q for pre-recruit females in the NMFS survey (weight 10000). A very high weight was used for the latter constraint because it was used to drive the profile runs (i.e. I wanted the model to match the target q level ). In profile analysis, penalties were usually zero for all constraints with the exception of the protect females constraint. The protect females constraint was non-zero in all years except 1990-1991 and 1994-1997 when the sex ratio of the aggregate catch declined to less than 50% male (see data section). The decline in 1990-1991 was likely due to measurement error. The decline in 1994-1997 was part of a long term decline in percent male in landings.



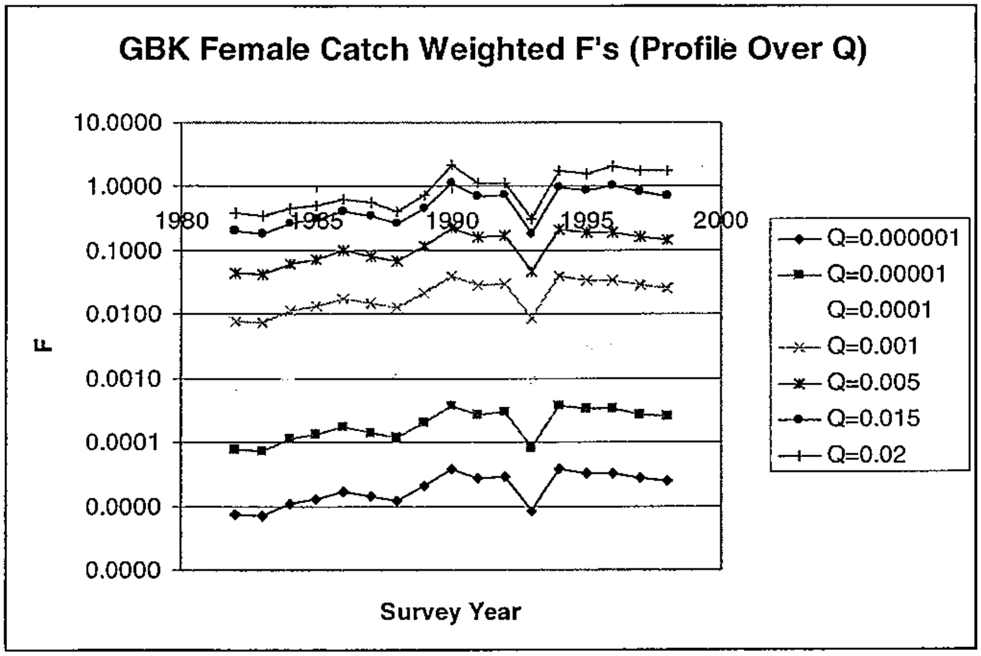
The negative log likelihood trend in profile analysis for GBK was not as flat as in GOM. Instead, it increased continuously across the whole range of survey q values in the profile. The lowest log likelihood in the profile was at the edge of the profile run (-log likelihood about 21.5) with low levels of survey q, high (infeasible) q-ratio values, and low (near zero) levels of recent fishing mortality rates.

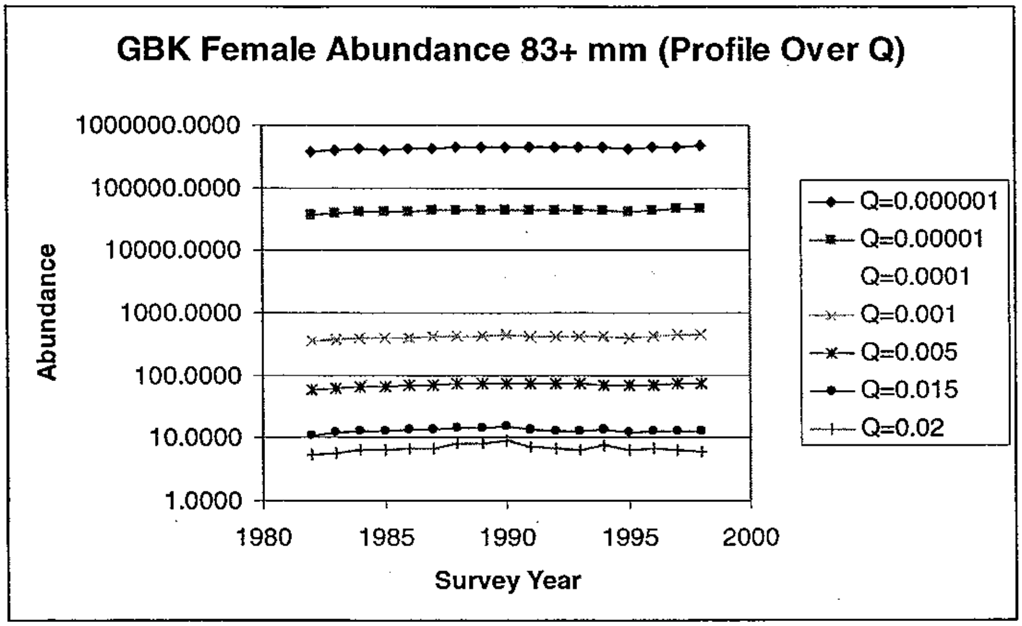
*Likelihood profile over a range of values over the scaling parameter q for female lobsters in length group –1 (the first length group, 73-82 mm CL) and the NMFS fall trawl survey for the Georges Bank stock area. Results for different scenarios show the total log likelihood (sum of likelihood components times their likelihood weights), unweighted log likelihoods for each component, and assessment results. The smallest log likelihood (i.e. best fit) identifies the run with best fit for a likelihood component.*

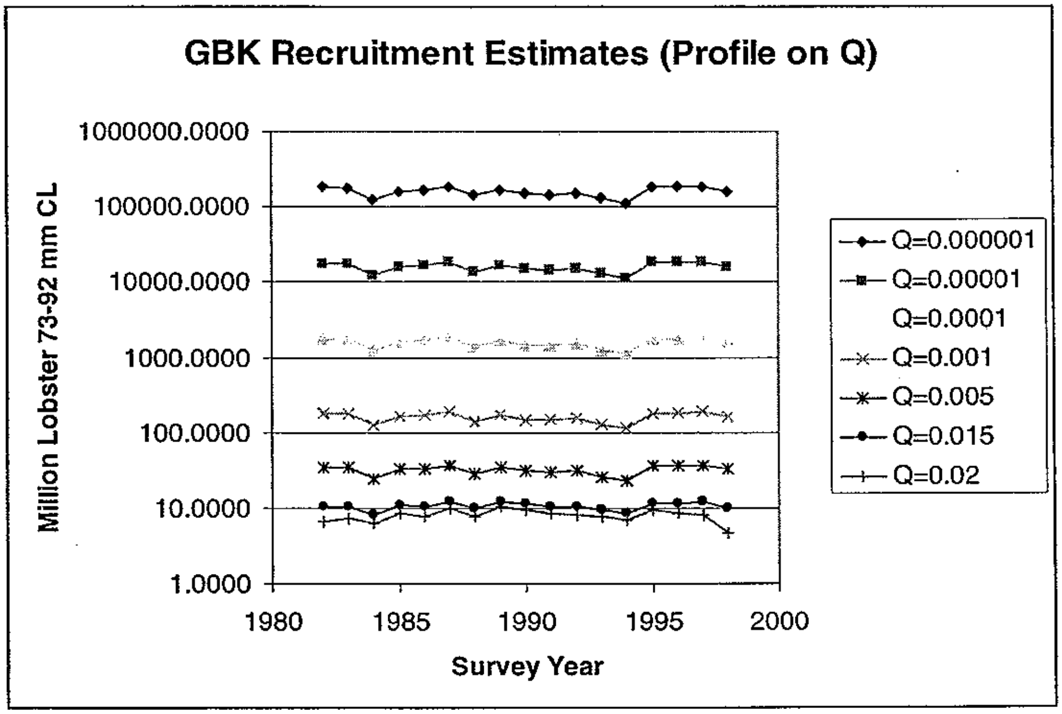
| | Q=0.000001 | Q=0.00001 | Q=0.0001 | Q=0.001 | Q=0.005 | Q=0.015 | Q=0.02 |
|---|---|---|---|---|---|---|---|
| **Profile Control Variables:** | | | | | | | |
| Weight Constraint on Female Prerecruit Q in NMFS Survey | 10000.0000 | 10000.0000 | 10000.0000 | 10000.0000 | 10000.0000 | 10000.0000 | 10000.0000 |
| Female Prerecruit Q Model | 0.0000 | 0.0000 | 0.0001 | 0.0010 | 0.0050 | 0.0150 | 0.0200 |
| Female Prerecruit Q Target | 0.0000 | 0.0000 | 0.0001 | 0.0010 | 0.0050 | 0.0150 | 0.0200 |
| | | | | | | | |
| Weight Penalty for Q-Ratio Constraint (DeLury Runs) | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Female Q Ratio in Model | 1.4644 | 1.4639 | 1.4591 | 1.4106 | 1.1961 | 0.6760 | 0.4670 |
| Female Q Ratio Target | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| | | | | | | | |
| Mean Female Catch Weighted F 1993-1997 | 0.0000 | 0.0003 | 0.0028 | 0.0284 | 0.1613 | 0.7766 | 1.5095 |
| Mean Male Catch Weighted F 1993-1997 | 0.0000 | 0.0003 | 0.0025 | 0.0258 | 0.1418 | 0.5754 | 0.8876 |
| | | | | | | | |
| Sex Ratio at Recruitment | 0.5150 | 0.5150 | 0.5150 | 0.5150 | 0.5148 | 0.5142 | 0.5142 |
| | | | | | | | |
| Total Negative Log Likelihood | 21.5836 | 21.5838 | 21.5859 | 21.6088 | 21.7600 | 22.9457 | 25.5684 |
| | | | | | | | |
| **Goodness of Fit for Major Likelihood Components:** | | | | | | | |
| From Indices | 21.3194 | 21.3196 | 21.3217 | 21.3442 | 21.4816 | 22.4589 | 24.4872 |
| Catch/F Penalties-Males | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Catch/F Penalties-Females | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Weight for first difference constraint NMFS Q | 0.0096 | 0.0096 | 0.0093 | 0.0066 | 0.0004 | 0.0000 | 0.0000 |
| Weight Sex Ratio Data | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Weight Protect Females Constraint | 0.2542 | 0.2542 | 0.2545 | 0.2574 | 0.2770 | 0.4796 | 1.0429 |
| Weight Constraint on Female Prerecruit Q in NMFS Survey | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Weight Swept Area Constraint | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | | | | | | |
| **Goodness of Fit for Individual Indices:** | | | | | | | |
| Male NMFS Fall 73-82 mm-SCALED TO MEAN 1 | 0.3929 | 0.3929 | 0.3928 | 0.3926 | 0.3944 | 0.4560 | 0.7190 |
| Male NMFS Fall 83-92 mm-SCALED TO MEAN 1 | 0.5739 | 0.5739 | 0.5743 | 0.5777 | 0.5971 | 0.6982 | 0.7323 |
| Male NMFS Fall 93-102 mm-SCALED TO MEAN 1 | 1.2513 | 1.2513 | 1.2514 | 1.2526 | 1.2642 | 1.3762 | 1.5616 |
| Male NMFS Fall 103-112 mm-SCALED TO MEAN 1 | 1.5952 | 1.5952 | 1.5946 | 1.5885 | 1.5561 | 1.4305 | 1.6093 |
| Male NMFS Fall 113+ mm-SCALED TO MEAN 1 | 2.1184 | 2.1184 | 2.1182 | 2.1159 | 2.1043 | 2.0749 | 2.2208 |
| Female NMFS Fall 73-82 mm-SCALED TO MEAN 1 | 3.0738 | 3.0739 | 3.0750 | 3.0869 | 3.1470 | 3.3969 | 3.7685 |
| Female NMFS Fall 83-92 mm-SCALED TO MEAN 1 | 1.3463 | 1.3463 | 1.3466 | 1.3496 | 1.3635 | 1.4238 | 1.5441 |
| Female NMFS Fall 93-102 mm-SCALED TO MEAN 1 | 1.1466 | 1.1465 | 1.1463 | 1.1437 | 1.1378 | 1.2107 | 1.3407 |
| Female NMFS Fall 103-112 mm-SCALED TO MEAN 1 | 2.7554 | 2.7554 | 2.7562 | 2.7641 | 2.8096 | 3.0866 | 3.4133 |
| Female NMFS Fall 113+ mm-SCALED TO MEAN 1 | 0.7082 | 0.7082 | 0.7084 | 0.7099 | 0.7181 | 0.7487 | 0.6959 |
| MA Catch Per Trap Haul-weighted-sexes combined | 0.5031 | 0.5031 | 0.5030 | 0.5017 | 0.4893 | 0.3760 | 0.2857 |
| NY Catch Per Trap (annual average) | 0.7180 | 0.7180 | 0.7182 | 0.7193 | 0.7260 | 0.7805 | 0.8847 |
| RI CPUE Males 73-82 | 0.5132 | 0.5132 | 0.5139 | 0.5208 | 0.5568 | 0.7005 | 0.7583 |
| RI CPUE Males 83-92 | 0.4189 | 0.4188 | 0.4186 | 0.4166 | 0.4081 | 0.4037 | 0.4299 |
| RI CPUE Males 93-102 | 0.1799 | 0.1799 | 0.1799 | 0.1799 | 0.1801 | 0.1868 | 0.2046 |
| RI CPUE Males 103-112 | 0.5016 | 0.5016 | 0.5017 | 0.5031 | 0.5100 | 0.5448 | 0.6680 |
| RI CPUE Males 113+ | 0.8274 | 0.8274 | 0.8274 | 0.8272 | 0.8267 | 0.8368 | 0.8684 |
| RI CPUE Females 73-82 | 0.3371 | 0.3371 | 0.3376 | 0.3428 | 0.3703 | 0.4859 | 0.5568 |
| RI CPUE Females 83-92 | 0.3064 | 0.3064 | 0.3065 | 0.3068 | 0.3091 | 0.3231 | 0.3193 |
| RI CPUE Females 93-102 | 0.3054 | 0.3054 | 0.3055 | 0.3061 | 0.3111 | 0.3405 | 0.3575 |
| RI CPUE Females 103-112 | 0.7281 | 0.7281 | 0.7277 | 0.7239 | 0.7052 | 0.6625 | 0.7038 |
| RI CPUE Females 113+ | 0.8053 | 0.8053 | 0.8052 | 0.8047 | 0.8019 | 0.7842 | 0.7487 |
| VTR CPUE pounds per Trap Haul Set Over Day | 0.2131 | 0.2131 | 0.2128 | 0.2100 | 0.1950 | 0.1311 | 0.0760 |

There were 23 abundance indices for lobster in GBK (ten from the NMFS trawl survey and twelve from commercial CPUE). As a whole, the survey data fit best at high values of survey q and low values of fishing mortality rates. Thirteen indices (six trawl survey and seven CPUE indices) fit best (lowest negative log likelihood) at low values of survey q and high values of recent fishing mortality rate. Ten indices fit best at high values of survey q and low estimates of average fishing mortality rate.

As with GOM, trends in fishing mortality rates, abundance and recruitment estimates were similar over a wide range of model runs even though there was a great deal of uncertainty about scale (see below). All runs suggest that fishing mortality increased during 1982-1990 and remained relatively constant afterwards (except for a drop in 1993 likely due to errors in the catch data). All runs depict flat or slightly declining abundance and recruitment levels.

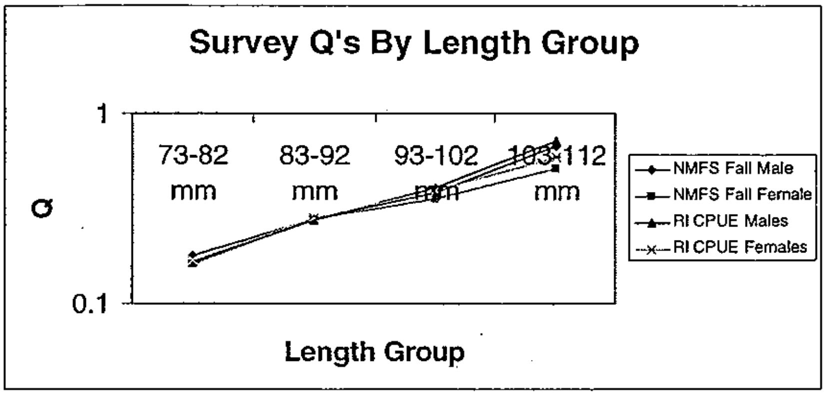


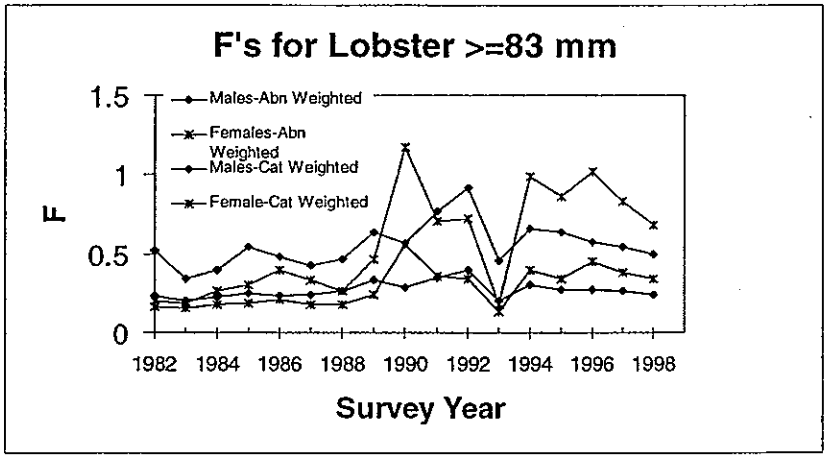


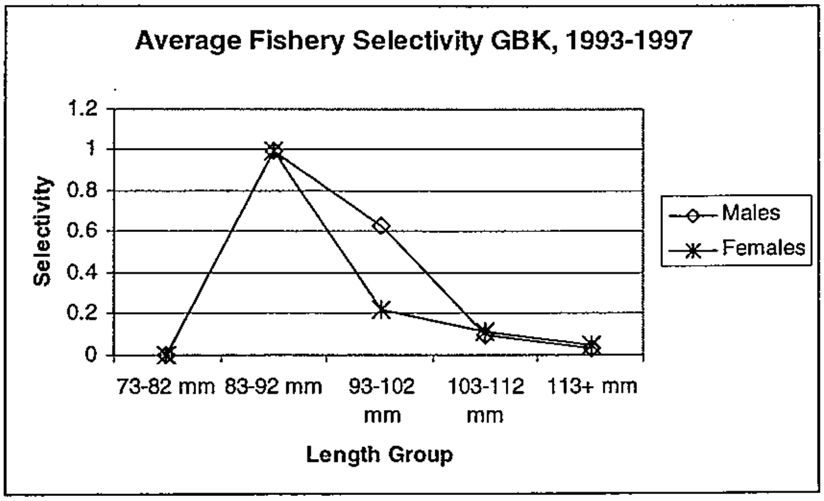


Mark fit all of the index data for GBK reasonably well for a wide range of model scenarios and there was little evidence of lack of fit in residual plots. A run with mean recent fishing mortality of 0.78 for females (q=0.015 and q-ratio=0.68) is used below for display purposes..

Fishing mortality rates were usually higher for males than for females (see below). Catch weighted estimates of average fishing mortality rates were than abundance weighted estimates (see below). As with lobster in GOM, results indicate that fishing mortality rates decline with size of lobster in GBK (see below).







Algebraic calculations of the lower bound on feasible q-ratios based on survey data for all available years are given below.

| Length Group | Mean Density Females in NMFS Trawl Survey | $s_\mu / s_\eta$ Ratio | Mean Density Males in NMFS Trawl Survey | $s_\mu / s_\eta$ Ratio |
|---|---|---|---|---|
| 73-82 | 0.086 | | 0.090 | |
| 83-92 | 0.068 | 0.79 | 0.076 | 0.84 |
| 93-102 | 0.052 | 0.60 | 0.054 | 0.60 |
| 103-112 | 0.056 | 0.65 | 0.026 | 0.29 |

Ratios of $s_\mu/s_\eta$ were 0.65-0.79 for female lobsters and 0.29-0.84 for male lobsters. Abundance weighted averages would probably be in the range 0.60-0.79 for females and 0.60-0.84 for males. The estimates of a feasible lower bound of q-ratios of lobster in the NMFS fall trawl survey are all larger than the conventional 0.5 value conventionally assumed.

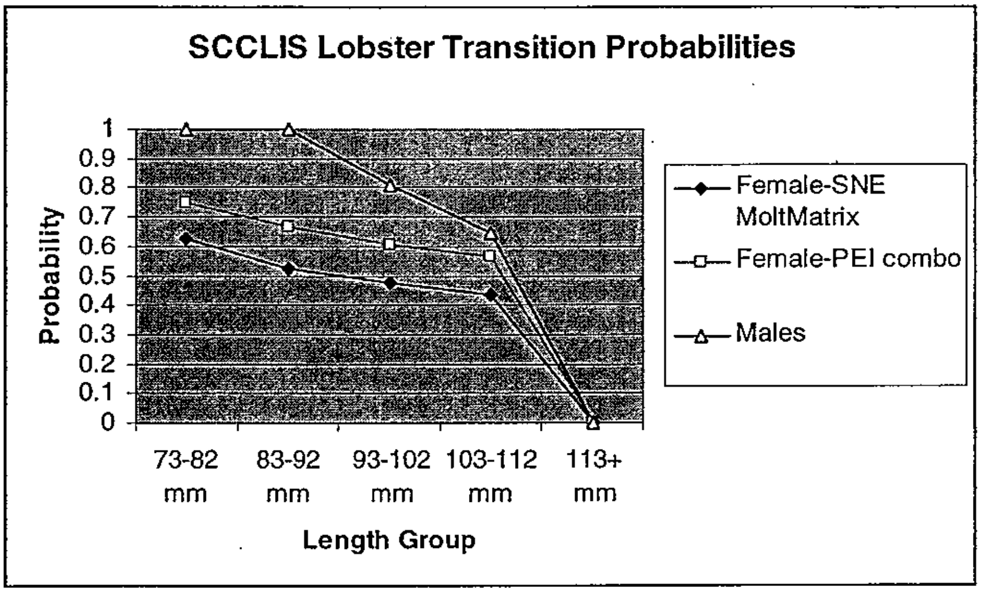
*SCCLIS-Preliminary Results*

Index data used to tune Mark for lobster in SCCLIS are given below with assumed selectivity values and objective function weights.

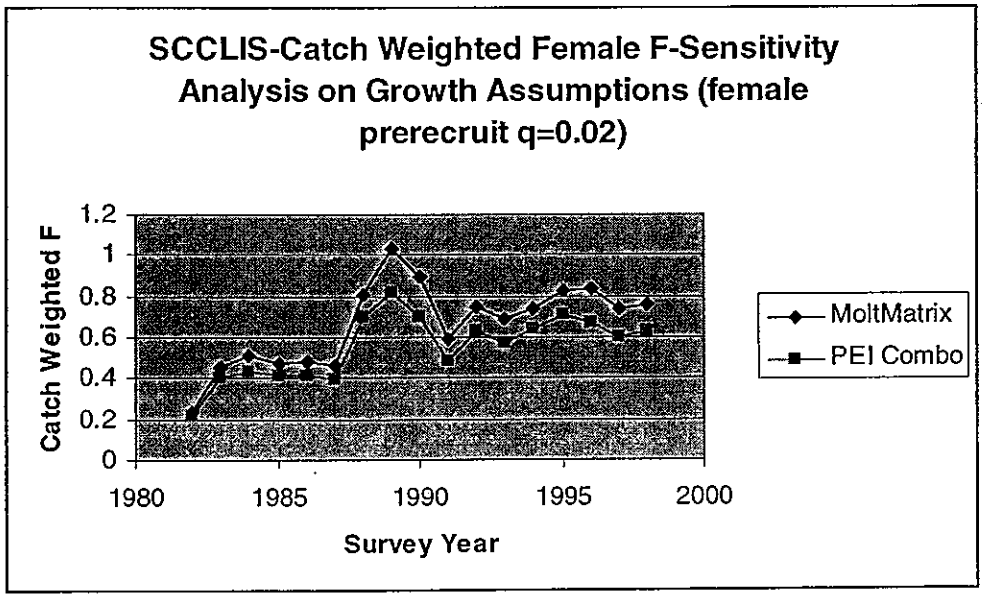
| | | *Selx by group ->* | | | | |
|---|---|---|---|---|---|---|
| **Survey_Name** | **OBJ Wts** | **-1** | **0** | **1** | **2** | **3** |
| NMFS.Fall.Males.73-82mm-RESCALED TO MEAN 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| NMFS.Fall.Males.83-92mm-RESCALED TO MEAN 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| NMFS.Fall.Males.93-102mm-RESCALED TO MEAN 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| NMFS.Fall.Males.103+-RESCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| NMFS.Fall.Females.73-82mm-RESCALED TO MEAN 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| NMFS.Fall.Females.83-92mm-RESCALED TO MEAN 1 | 1 | 0 | 1 | 0 | 0 | 0 |
| NMFS.Fall.Females.93-102mm-RESCALED TO MEAN 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| NMFS.Fall.Females.103+-RESCALED TO MEAN 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| MA Survey Males 83-92 mm | 1 | 0 | 1 | 0 | 0 | 0 |
| CT_FallSurv_Fem_73-82 mm (rev 5/11/99) | 1 | 1 | 0 | 0 | 0 | 0 |
| CT_FallSurv_Male_73-82mm_(rev 5/11/99) | 1 | 1 | 0 | 0 | 0 | 0 |
| CT_FallSurv_Fem_83-92mm (rev 5/11/98) | 1 | 0 | 1 | 0 | 0 | 0 |
| CT_FallSurv_Male_83-92mm_(rev 5/11/99) | 1 | 0 | 1 | 0 | 0 | 0 |
| MA Survey Females 83-92 mm | 1 | 0 | 1 | 0 | 0 | 0 |
| RI_Fall_73-82mm_Female_(rev_5/11/98) | 1 | 1 | 0 | 0 | 0 | 0 |
| RI_Fall_73-82mm_Male_(rev_5/11/98) | 1 | 1 | 0 | 0 | 0 | 0 |
| RI_Fall_83-92_mm_Female_(rev_5/11/99) | 1 | 0 | 1 | 0 | 0 | 0 |
| RI_Fall_83-92_mm_Male_(rev_5/11/99) | 1 | 0 | 1 | 0 | 0 | 0 |
| MA Fall Trawl Survey Male+Female PreRecr 73-82 mm | 1 | 1 | 0 | 0 | 0 | 0 |
| CT_FallSurv_Fem_93-102mm_(rev 5/11/99) | 1 | 0 | 0 | 1 | 0 | 0 |
| RI Spring 73-82 Both Sex_(rev_5/11/99) | 1 | 1 | 0 | 0 | 0 | 0 |
| RI Spring 83-92 Both Sex_(rev_5/11/99) | 1 | 0 | 1 | 0 | 0 | 0 |
| CT-DEP-Spring_73-82mm-Males_(rev_5/11/99) | 1 | 1 | 0 | 0 | 0 | 0 |
| CT-DEP-Spring-83-92_mm-Males_(rev_5/11/99) | 1 | 0 | 1 | 0 | 0 | 0 |
| CT_DEP-Spring_73_82mm-Females_(rev_5/11/99) | 1 | 1 | 0 | 0 | 0 | 0 |
| CT-DEP-Spring-93-102_mm-Males_(rev_5/11/99) | 1 | 0 | 0 | 1 | 0 | 0 |
| CT-DEP-Spring-93-102_mm-Females_(rev_5/11/99) | 1 | 0 | 0 | 1 | 0 | 0 |
| RI_Fall_93-102_mm_Female_(rev_5/11/99) | 1 | 0 | 0 | 1 | 0 | 0 |
| RI_Fall_93-102_mm_Male_(rev_5/11/99) | 1 | 0 | 0 | 1 | 0 | 0 |
| CT_FallSurv_Male_93-102mm_(rev 5/11/99) | 1 | 0 | 0 | 1 | 0 | 0 |
| RI Spring 93-102 Both Sex_(rev_5/11/99) | 1 | 0 | 0 | 1 | 0 | 0 |
| CT-DEP-Spring-83-92_mm-Females_(rev_5/11/99) | 1 | 0 | 1 | 0 | 0 | 0 |

Two sets of sex-specific transition probabilities for lobster in SCCLIS were calculated from the Subcommittee's preliminary estimates of one mm molt intervals and mean molt increments. The two sets of preliminary estimates for one mm molt intervals and increments were later replaced but the preliminary estimates are used here for sensitivity analysis and comparison. Male transition probabilities were set at a single set of values suggested by the Subcommittee. The average molt increment in the SCCLIS is

11 mm so conditional probabilities of skipping the next length group were 1-(11-10)/11=0.09 for length groups –1 to 1.



Estimates of catch weighted female fishing mortality rates differed in runs with alternative growth assumptions. For these runs, the scaling parameter for 73-82 mm females in NMFS fall survey fixed was fixed at 0.02 (see below). Although the scale of fishing mortality rates differed, trends over time were the same. The rest of this analysis uses the "PEI Combo" growth assumptions by convention. This convention is arbitrary and no preference for one set of growth parameters over the other is implied.

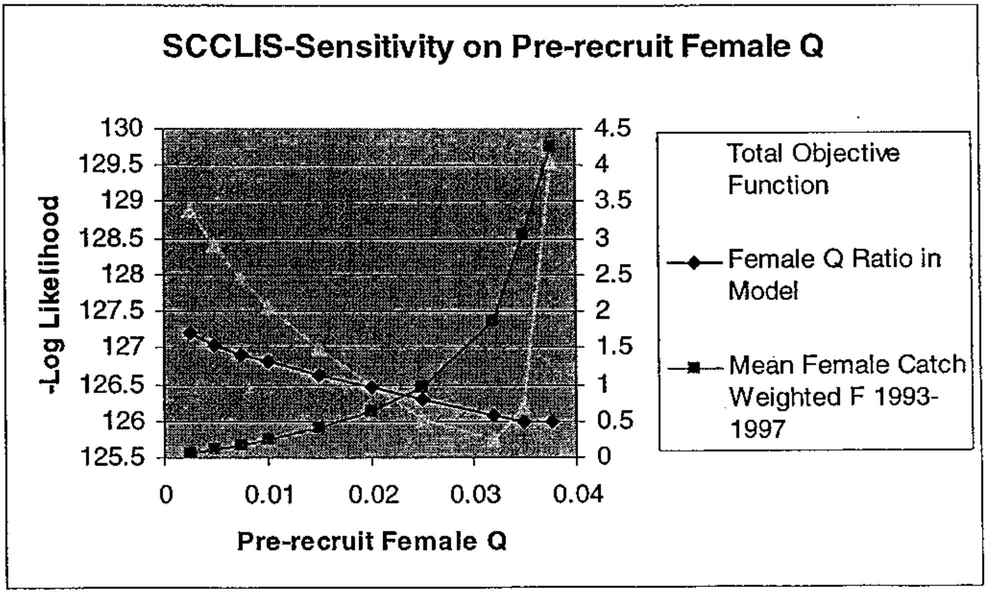


Likelihood profile analysis for lobster in SCCLIS showed different patterns in goodness of fit than in other stock areas. In general, model fit improved (rather than worsened) as q increased, q-ratio decreased and catch weighted fishing mortality rates for recent years increased. The pattern was interrupted at q values above 0.032 because fit to the survey data began to degrade. The model fit best at a q value 0.032, q-ratio of 0.58 and recent catch weighted female fishing mortality rate of about 1.86 $y^{-1}$. Unlike the models for GOM and GNK, there was a clear minimum in the negative log likelihood surface corresponding to a set of best estimates with a feasible q-ratio. These estimates for lobster in SCCLIS should probably not be taken seriously, however, until problems with q-ratios in other stock areas are completely understood.

There were five sources of information about sex ratio of recruits from trawl surveys (NMFS fall, Connecticut spring and fall, and Rhode Island spring and fall trawl surveys), two sources from sea sampling (Massachusetts and Rhode Island) and one from port sampling (New York). Average sex ratio from each source averaged 24% (New York port samples) to 53% (Connecticut fall trawl survey) male. The mean of the average from each source was 38% male.

Sex ratio at recruitment is likely skewed towards females in SCCLIS because landings are mostly female (see above) and management measures (prohibition on landing ovigerous females) are believed to protect female lobsters. Lower fishing mortality rates for females (due to management measures) and higher female catch (62% of total landings) would be impossible without a sex ratio skewed towards females. Even if fishing mortality rates for males and females were the same, higher catch of females would be impossible without a skewed sex ratio.

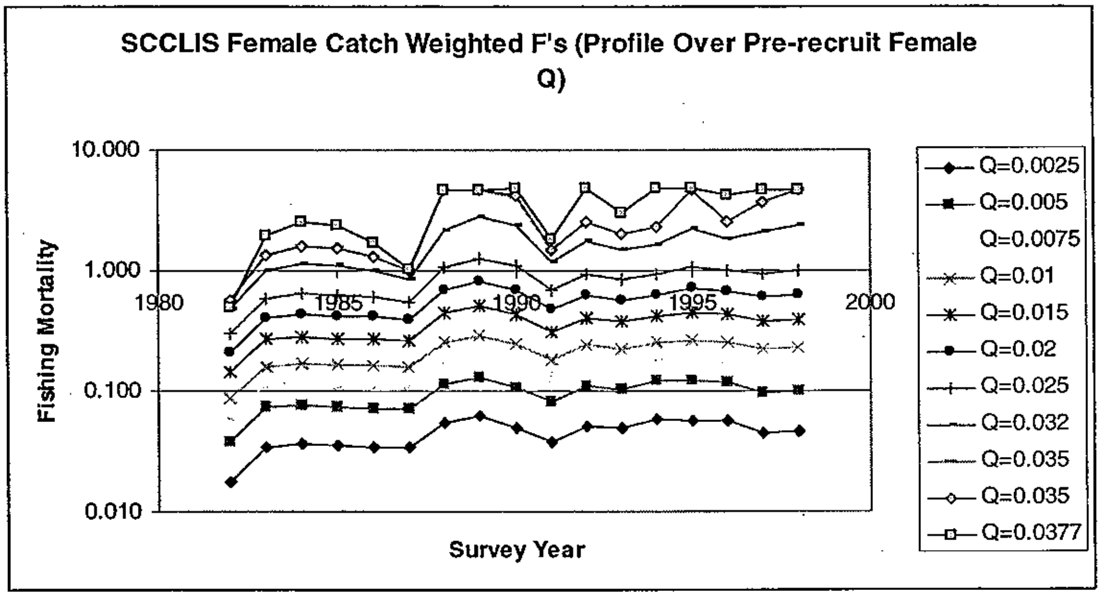
Mark was set up to tune sex ratio at recruitment estimates to the mean of average sex ratios (38%) observed in lobster 73-82 mm (see above). Under these conditions, the primary factors used to estimate sex ratio would be the sex ratio data, index data and the protect females constraint. Depending on the q value used in likelihood profile runs (and the resulting fishing mortality rate), the estimated sex ratio was 31%-45% male (see below).

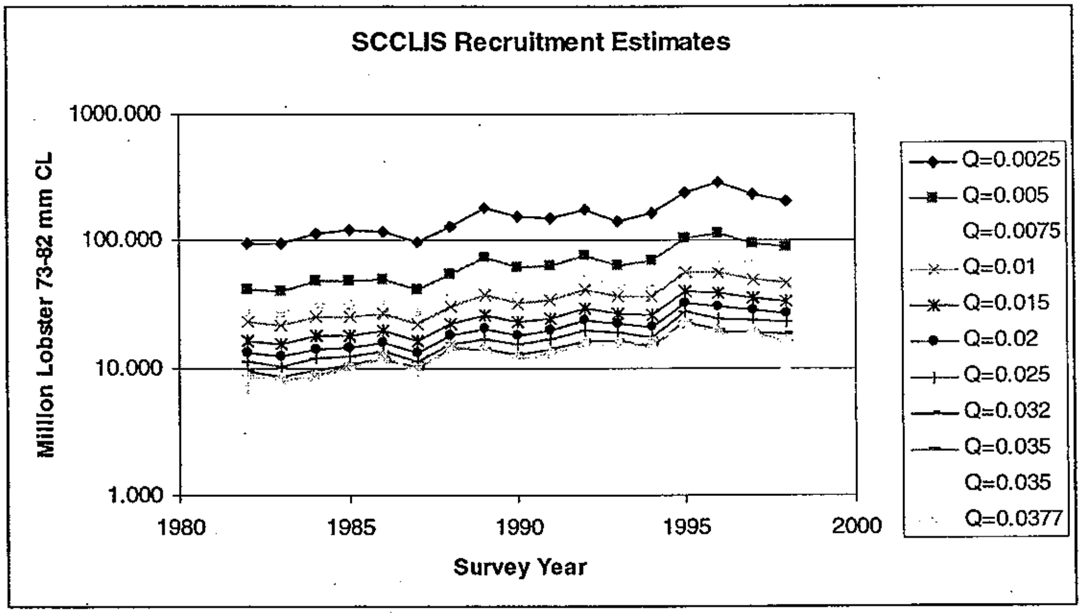


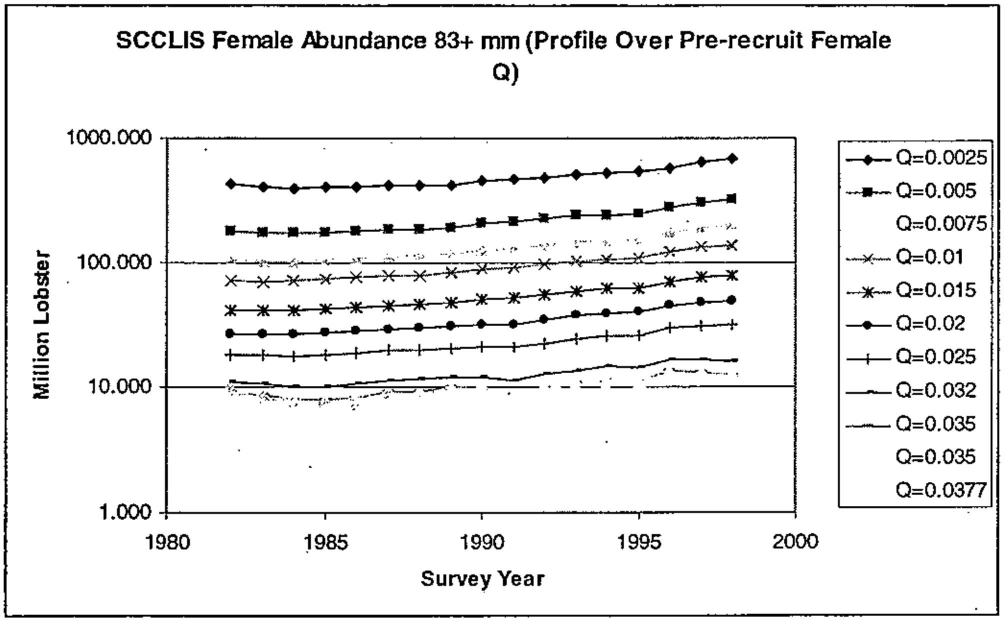
*Likelihood profile over a range of values over the scaling parameter q for female lobsters in length group –1 (the first length group, 73-82 mm CL) and the NMFS fall trawl survey for the Southern Cape Cod and Long Island Sound stock area. Results for different scenarios show the total log likelihood (sum of likelihood components times their likelihood weights), unweighted log likelihoods for each component, and assessment results. The smallest log likelihood (i.e. best fit) identifies the run with best fit for a likelihood component.*

| ***Profile Control Variables:*** | | Q=0.0025 | Q=0.005 | Q=0.0075 | Q=0.01 | Q=0.015 | Q=0.02 | Q=0.025 | Q=0.032 | Q=0.035 | Q=0.035 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Weight Constraint on Female Prerecruit Q in NMFS Survey** | Active | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 |
| **Female Prerecruit Q Model** | Active | 0.0025 | 0.005001 | 0.007501 | 0.010001 | 0.015002 | 0.020004 | 0.025005 | 0.03199529 | 0.034953 | 0.034955 |
| **Female Prerecruit Q Target** | Active | 0.003 | 0.005 | 0.008 | 0.010 | 0.015 | 0.020 | 0.025 | 0.032 | 0.035 | 0.035 |
| | Active | | | | | | | | | | |
| **Weight Penalty for Q-Ratio Constraint (DeLury Runs)** | Active | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Female Q Ratio in Model** | Active | 1.710 | 1.538 | 1.411 | 1.312 | 1.134 | 0.964 | 0.798 | 0.579 | 0.500 | 0.497 |
| **Female Q Ratio Target** | Active | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 | 0.750 |
| | Active | | | | | | | | | | |
| **Mean Female Catch Weighted F 1993-1997** | Active | 0.053 | 0.112 | 0.175 | 0.245 | 0.414 | 0.637 | 0.959 | 1.860 | 3.043 | 3.054 |
| **Mean Male Catch Weighted F 1993-1997** | Active | 0.053 | 0.112 | 0.175 | 0.245 | 0.414 | 0.637 | 0.959 | 1.860 | 3.043 | 3.054 |
| | Active | | | | | | | | | | |
| **Sex Ratio at Recruitment** | Active | 0.313 | 0.179 | 0.193 | 0.222 | 0.275 | 0.319 | 0.356 | 0.399 | 0.417 | 0.415 |
| | Active | | | | | | | | | | |
| **Total Objective Function** | Active | 128.883 | 128.407 | 127.929 | 127.565 | 126.990 | 126.488 | 126.028 | 125.749 | 126.191 | 126.175 |
| | Active | | | | | | | | | | |
| ***Goodness of Fit for Major Likelihood Components:*** | Active | | | | | | | | | | |
| **From Indices** | Active | 254.655 | 253.120 | 252.359 | 251.897 | 251.090 | 250.299 | 249.548 | *249.245* | 250.271 | 250.253 |
| **Catch/F Penalties-Males** | Active | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Catch/F Penalties-Females** | Active | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Weight First Difference Constraint-NMFS/CT/RI Surveys** | Active | 2.990 | 2.824 | 2.773 | 2.735 | 2.660 | 2.574 | 2.466 | 2.247 | 2.090 | 2.075 |
| **Weight Sex Ratio Data** | Active | 0.121 | 0.870 | 0.727 | 0.499 | 0.229 | 0.103 | 0.041 | 0.007 | 0.001 | 0.001 |
| **Weight Constraint on Female Prerecruit Q in NMFS Survey** | Active | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **Weight Swept Area Constraint** | Active | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Active | | | | | | | | | | |
| ***Goodness of Fit for Individual Indices:*** | Active | | | | | | | | | | |
| **NMFS.Fall.Males.73-82mm-RESCALED TO MEAN 1** | Active | *11.005* | 11.263 | 11.502 | 11.656 | 11.900 | 12.132 | 12.396 | 12.949 | 13.334 | 13.336 |
| **NMFS.Fall.Males.83-92mm-RESCALED TO MEAN 1** | Active | 4.667 | 4.743 | 4.818 | 4.860 | 4.915 | 4.952 | 4.966 | 4.877 | 4.830 | 4.837 |
| **NMFS.Fall.Males.93-102mm-RESCALED TO MEAN 1** | Active | 4.538 | 4.166 | 4.030 | *4.015* | 4.095 | 4.293 | 4.663 | 5.675 | 6.224 | 6.266 |
| **NMFS.Fall.Males.103+-RESCALED TO MEAN 1** | Active | 7.104 | 6.873 | *6.809* | 6.834 | 6.961 | 7.169 | 7.497 | 8.388 | 9.098 | 9.084 |
| **NMFS.Fall.Females.73-82mm-RESCALED TO MEAN 1** | Active | *12.941* | 13.047 | 13.220 | 13.347 | 13.562 | 13.771 | 14.001 | 14.406 | 14.384 | 14.391 |
| **NMFS.Fall.Females.83-92mm-RESCALED TO MEAN 1** | Active | *9.160* | 9.349 | 9.515 | 9.603 | 9.724 | 9.830 | 9.952 | 10.185 | 10.297 | 10.319 |
| **NMFS.Fall.Females.93-102mm-RESCALED TO MEAN 1** | Active | 8.653 | 8.757 | 8.846 | 8.839 | 8.728 | 8.551 | 8.351 | 8.261 | 8.309 | 8.358 |
| **NMFS.Fall.Females.103+-RESCALED TO MEAN 1** | Active | 8.769 | 8.541 | 8.431 | 8.386 | 8.335 | *8.308* | 8.326 | 8.677 | 9.314 | 9.257 |
| **MA Survey Males 83-92 mm** | Active | *2.418* | 2.632 | 2.790 | 2.869 | 2.965 | 3.031 | 3.086 | 3.171 | 3.212 | 3.228 |
| **CT_FallSurv_Fem_73-82 mm (rev 5/11/99)** | Active | 1.566 | 1.484 | 1.422 | 1.392 | 1.356 | *1.338* | 1.339 | 1.427 | 1.480 | 1.473 |
| **CT_FallSurv_Male_73-82mm_(rev 5/11/99)** | Active | 1.840 | 1.695 | 1.584 | 1.529 | 1.465 | 1.428 | *1.420* | 1.525 | 1.653 | 1.639 |
| **CT_FallSurv_Fem_83-92mm (rev 5/11/98)** | Active | 2.816 | 2.752 | 2.740 | *2.740* | 2.748 | 2.764 | 2.793 | 2.903 | 3.108 | 3.115 |
| **CT_FallSurv_Male_83-92mm_(rev 5/11/99)** | Active | *2.423* | 2.510 | 2.532 | 2.528 | 2.507 | 2.481 | 2.456 | 2.435 | 2.544 | 2.546 |
| **MA Survey Females 83-92 mm** | Active | *0.344* | 0.367 | 0.374 | 0.375 | 0.376 | 0.376 | 0.379 | 0.404 | 0.446 | 0.443 |
| **RI_Fall_73-82mm_Female_(rev_5/11/98)** | Active | 3.817 | 3.901 | 3.917 | 3.925 | 3.945 | 3.967 | 3.982 | 3.928 | 3.775 | 3.776 |
| **RI_Fall_73-82mm_Male_(rev_5/11/98)** | Active | *4.390* | 4.462 | 4.490 | 4.517 | 4.579 | 4.651 | 4.736 | 4.880 | 4.904 | 4.895 |
| **RI_Fall_83-92_mm_Female_(rev_5/11/99)** | Active | 16.637 | 16.249 | 15.974 | 15.830 | 15.620 | 15.402 | 15.107 | 14.464 | 14.315 | *14.286* |
| **RI_Fall_83-92_mm_Male_(rev_5/11/99)** | Active | 3.904 | 3.782 | 3.737 | 3.712 | 3.664 | 3.609 | 3.540 | 3.381 | 3.329 | 3.333 |
| **MA Fall Trawl Survey Male+Female PreRecr 73-82 mm** | Active | 19.636 | 19.740 | 19.704 | 19.670 | 19.621 | 19.576 | 19.509 | 19.251 | 19.080 | 19.077 |
| **CT_FallSurv_Fem_93-102mm_(rev 5/11/99)** | Active | 17.053 | 16.921 | 16.836 | 16.714 | 16.384 | 15.932 | 15.322 | 14.075 | 13.358 | 13.419 |
| **RI Spring 73-82 Both Sex_(rev_5/11/99)** | Active | *7.340* | 7.427 | 7.476 | 7.509 | 7.568 | 7.631 | 7.708 | 7.849 | 7.917 | 7.930 |
| **RI Spring 83-92 Both Sex_(rev_5/11/99)** | Active | 8.959 | 8.927 | 8.881 | 8.845 | 8.784 | 8.727 | 8.663 | 8.521 | 8.478 | *8.461* |
| **CT-DEP-Spring_73-82mm-Males_(rev_5/11/99)** | Active | *2.499* | 2.595 | 2.666 | 2.716 | 2.804 | 2.898 | 3.016 | 3.287 | 3.304 | 3.305 |
| **CT-DEP-Spring-83-92_mm-Males_(rev_5/11/99)** | Active | *3.329* | 3.403 | 3.475 | 3.520 | 3.588 | 3.648 | 3.709 | 3.769 | 3.811 | 3.812 |
| **CT_DEP-Spring_73_82mm-Females_(rev_5/11/99)** | Active | *3.624* | 3.735 | 3.810 | 3.862 | 3.958 | 4.063 | 4.196 | 4.477 | 4.500 | 4.499 |
| **CT-DEP-Spring-93-102_mm-Males_(rev_5/11/99)** | Active | 16.961 | 16.307 | 15.838 | 15.615 | 15.378 | *15.280* | 15.295 | 15.537 | 15.343 | 15.353 |
| **CT-DEP-Spring-93-102_mm-Females_(rev_5/11/99)** | Active | 7.330 | 7.188 | 7.077 | 6.976 | 6.747 | 6.447 | 6.049 | 5.379 | 5.219 | *5.204* |
| **RI_Fall_93-102_mm_Female_(rev_5/11/99)** | Active | 19.888 | 19.720 | 19.588 | 19.487 | 19.285 | 19.045 | 18.701 | 17.655 | 17.240 | 16.984 |
| **RI_Fall_93-102_mm_Male_(rev_5/11/99)** | Active | 10.681 | 10.783 | 10.870 | 10.867 | 10.754 | 10.539 | 10.193 | 9.429 | *9.353* | 9.451 |
| **CT_FallSurv_Male_93-102mm_(rev 5/11/99)** | Active | 15.597 | 14.819 | 14.354 | 14.115 | 13.791 | 13.549 | *13.394* | 13.661 | 14.202 | 14.157 |
| **RI Spring 93-102 Both Sex_(rev_5/11/99)** | Active | 13.434 | 13.662 | 13.742 | 13.734 | 13.676 | 13.608 | 13.516 | 13.193 | 12.736 | 12.847 |
| **CT-DEP-Spring-83-92_mm-Females_(rev_5/11/99)** | Active | 1.328 | 1.321 | 1.313 | 1.309 | 1.305 | 1.300 | 1.287 | 1.229 | 1.172 | 1.172 |

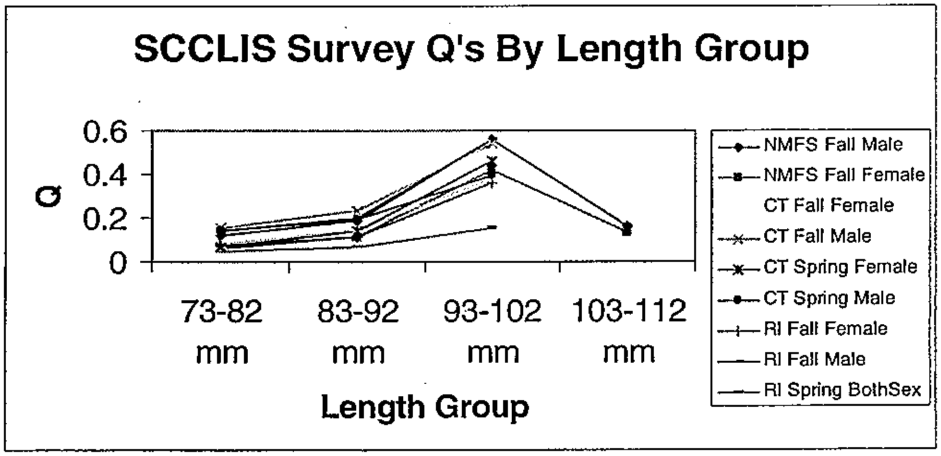
As with other stock areas, trends in fishing mortality rates, abundance and recruitment estimates were similar over a wide range of model runs (see below). All runs suggest that fishing mortality increased after 1987 and remained relatively constant afterwards (except for a drop in 1991 likely due to errors in the catch data). All runs depict increasing recruitment and abundance levels.







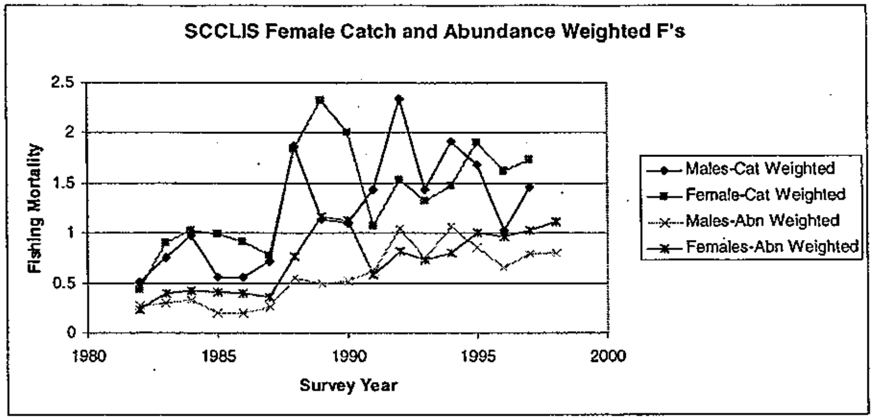
Patterns in estimated selectivities and other results were similar for most scenarios. The model fit the index data reasonably well. The run with best fit estimates of q=0.031 and q-ratio=0.62 was used for display purposes.

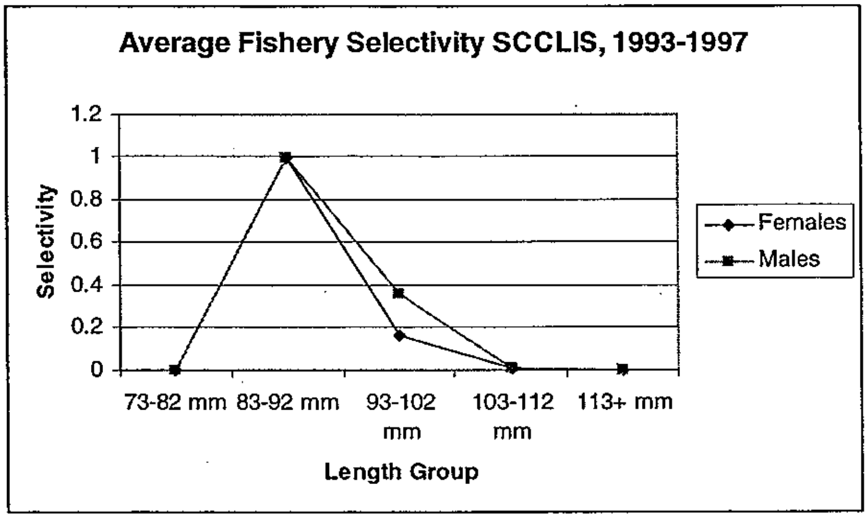


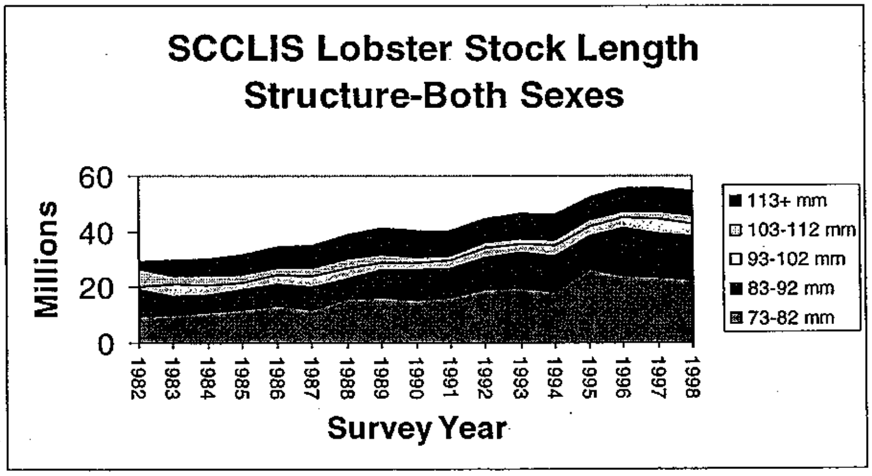
Scenarios showed the expected pattern of increasing scaling parameters except that scaling parameters for the largest males and females in the NMFS survey declined (see above). Fishing mortality rates (see below) often higher for males than females (contrary to expectation and results for other areas). This pattern may be real or due to inaccurate partitioning of total landings into sex groups.

Abundance weighted fishing mortality rates were lower than catch weighted estimates. Fishery selectivities for lobster declined with size in both sexes but were lower for females than males in length group 1 (93-102 mm).

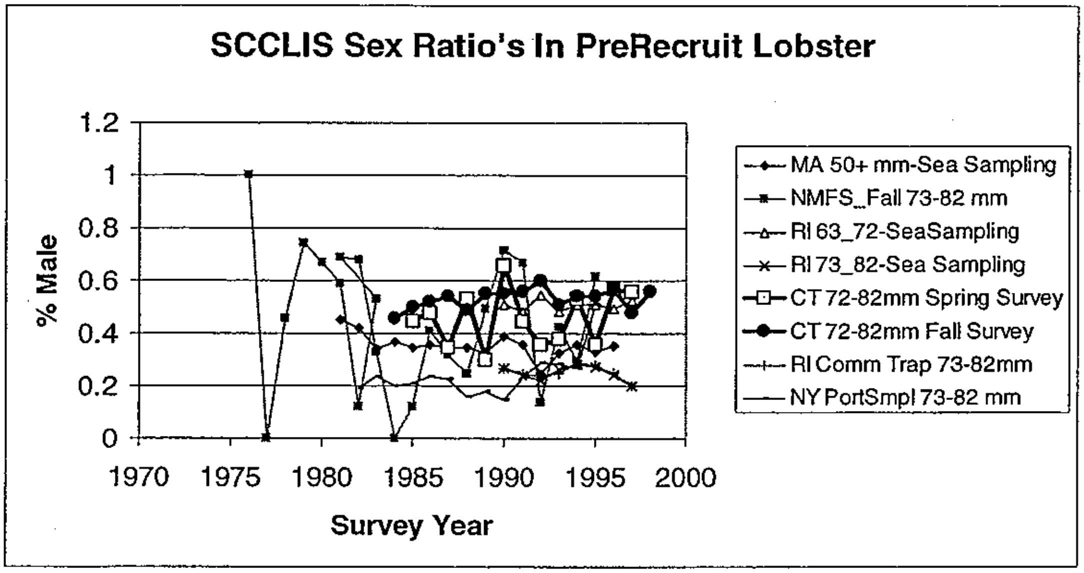
Increased abundance of lobster in SCCLIS appears to be mostly in the first and second legal length groups (83-92 and 93-102 mm CL, length groups 0 and 1).


SCCLIS Female Catch and Abundance Weighted F's
Fishing Mortality
2.5
2
1.5
1
0.5
0
1980
1985
1990
1995
2000
Survey Year
Males-Cat Weighted
Female-Cat Weighted
Males-Abn Weighted
Females-Abn Weighted


Average Fishery Selectivity SCCLIS, 1993-1997
Selectivity
1.2
1
0.8
0.6
0.4
0.2
0
73-82 mm
83-92 mm
93-102 mm
103-112 mm
113+ mm
Length Group
Females
Males


SCCLIS Lobster Stock Length Structure-Both Sexes
Millions
60
40
20
0
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Survey Year
113+ mm
103-112 mm
93-102 mm
83-92 mm
73-82 mm

Sex ratio at recruitment was estimated in the model based on the index data and average sex ratio for length group –1 (73-82 mm) in survey, sea sampling and port sample data (described above). In estimation, the average of the sex ratios from the eight data sets was given a weight of one (the same weight as one survey observation). The sex ratio data, abundance index data and the constraint that male fishing mortality rates exceed female fishing mortality rates, were likely the basis for the model's estimate.



Active constraints in Mark during likelihood profile runs for SCCLIS lobster were: the first difference constraint for trawl surveys (likelihood weight one), the swept area constraint (weight one), and the constraint on q for pre-recruit females in the NMFS survey (weight 10000). A very high weight was used for the latter constraint because it was used to drive the profile runs (i.e. I wanted the model to match the target q level ). The protect females constraint (weight zero) was turned off because the catch at length data were noisy, the constraint was encountered too frequently and interferred with model fits. In future assessments, catch at length data for SCCLIS should probably be adjusted based on estimates of average sex ratio.

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## **Attachment A-1**. Research recommendations relevant to lobster stock assessment models.

**From NEFSC (1996):**

### 7.7 Future Assessment Methods

The DeLury model is not capable of tracking changes in abundance by length-age stages. Traditional age or length structured fisheries models would be inappropriate because of the life history characteristics of lobsters and the regulations in place to manage them. The opportunity exists for a new, state-of-the-art assessment model to be used for American lobster (and other crustacea), since the egg-per-recruit model is also set up as a population projection matrix. In principle, it should be simple (in the short term) to embed this projection model within a non-linear minimisation algorithm to estimated recruitment and fishing mortality rates given data on catches and relative indices of abundance. An even more fruitful approach would be to generalize this into a maximum likelihood estimation procedure (see Fournier and Archibald 1982) that would incorporate multiple sets of information: landings, length frequencies in the catches, relative abundance, tagging, and environmental data. The Panel strongly recommends that such a model be developed and implemented in the near future. However, considering the importance of continuity and model testing, the Panel also recommends that the DeLury and LCA models continue to be used in parallel, at least for several assessments.

Research Recommendations

- Sensitivity to the assumed ratio of pre-recruit and fully-recruited survey catchability needs to be further investigated. Field studies are needed to support assumptions concerning the trawl selectivity ratio. The best way to estimate $s_r$ would be with *insitu* observations in surveyed areas.
- Revisions to the structure of the DeLury model should be explored, such as including multiple surveys, CPUE indices, a "sex-lined" run which estimates a single catchability coefficient for both sexes, and using length-cohort results for tuning.
- More accurate information on lobster growth is needed for length-cohort analysis and EPR models. Growth information can be improved through stochastic growth models, more powerful statistical analyses of tagging and biological catch samples, and more field observations of molt probability over a broad range of sizes.
- The Massachusetts survey should be investigated for inclusion in the Gulf of Maine DeLury analyses.
- The SARC Assessment Methods Subcommittee should determine the appropriate error structure in the DeLury model so that bias corrections can be applied which are not influenced by assumptions about how errors are distributed.
- Additional analyses of biological attributes of the catch and survey data are needed to corroborate patterns and trends in F estimates. Such analyses may provide guidance for assumption of model parameters such as seasonal molting patterns.

From Review of the Population Dynamics of American Lobster in the Northeast (ASMFC 1996):

### 7.3 DeLury Assessments

7.3.1 Evaluate whether DeLury estimates are biased by poor representation of the rocky and inshore stations in the bottom trawl survey data.

7.3.2 Complete analysis of the effect of different spatial combinations of survey stations.

7.3.3 Extend the use of sensitivity analysis to evaluate the robustness of the DeLury results to departures from both implicit and explicit assumptions, including M.

7.3.4 Introduce routine estimates of the degree of uncertainty.

7.3.5 Verify assumptions about the selectivity of the survey gear for the pre-recruit and recruit groups.

7.3.6 Investigate the effect of
  1. Uneven lobster and effort distribution within a stock unit (inshore-offshore) over time;
  2. Changes in the distribution of the bottom trawl survey with time;
  3. The movement of lobsters in and out of stock units;

7.3.7 Examine the pros and cons of random sampling versus fixed stations in the bottom trawl survey

7.3.8 Investigate how the DeLury model can be modified to take into account multiple survey indices, and whether there is bias in the use of lumped recruit and post-recruit groups.

# APPENDIX B

## Research Progress since 1996

Appendix B. Summary of progress made since 1996 in addressing research needs identified by 1996 Peer Review Panel, including this assessment.

| Research Recommendations | | Progress/Comments |
|---|---|---|
| A | STOCK STRUCTURE | |
| 1 | Compile existing tagging studies to establish transfer rates | Haakonsen, H.O. and A.O. Anoruo. 1994. Tagging and migration of the American lobster, *Homarus americanus.* Reviews in Fisheries Science 2(1):79-93.<br>Estrella, B.T. and T. D. Morrissey. 1997. Seasonal movement of offshore American lobster, *H. americanus*, tagged along the eastern shore of Cape Cod, Massachusetts. Fishery Bulletin 95: 466-476. |
| 2 | Genetic studies | Tam, Y.K., and I. Kornfield. 1996. Characterization of microsatellite markers in *Homarus*. Molecular Biol. And Biotech. 5(3):230-238.<br>Harding, G.C., Kenchington, E.L., Bird, C.J., Pezzack, D.S., and D.C. Landry. 1996. Genetic relationships among sub-populations of the American lobster as revealed by random amplified polymorphic DNA. Can. J. Fish. Aquat. Sci. 54:1762-1771. |
| 3 | Assess regional contribution to total egg production | Miller, R.J. 1997. Spatial differences in the productivity of American lobster in Nova Scotia. Can. J. Fish. Aquat. Sci. 54:1613-1618.<br>This assessment, section 10.2. |
| 4 | Compile existing larval data transfer rates | Wahle, R. and Incze, L. 1997. Pre- and post-settlement processes in recruiment of the American lobster. J. Exp. Mar.Biol. Ecol. 217: 179-207.<br>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. |
| 5 | Investigate spatial differences in demography | Lawton, P. 1999. Update on lobster research in the Canadian portion of the Gulf of Maine *In* US Canadian Summit III. Lobster Stock assessment: towards greater understanding, collaboration and improvement. Pgs 61-67. Edited by: Farrey, |

| | | |
|---|---|---|
| | | P.M.,Mooney-Sues, M.L., and H.C. Tausig. Report 99-2. New England Aquarium, Boston, MA. |
| **B** | **LANDINGS/EFFORT/LPUE/CPUE** | |
| 1 | Develop time series of standardized LPUE -Index Fishers | Some of the existing effort data (MA, ME, CT) are standardized for variable soak time, but not changes in gear effieciency that have occurred over time (see section 10.6, this assessment). |
| 2 | Quantify changes in spatial distribution of effort | This assessment (Section 10.11). |
| 3 | Develop area specific data/effort/LPUE | Crecco, V.A. and K. Gottschall. 1999. Stock assessment of American lobster in the Connecticut portion of LIS 1978-1998.<br>Gibson, M. 1999. Stock assessment of American lobster in Rhode Island waters.<br>This assessment (Sections 10.6 and 10.7). |
| 4 | Increase coverage of offshore fishery | NMFS-declining coverage; also a problem in some inshore areas like Long Island Sound (see section 6.2.1, this assessment). |
| 5 | Conduct cooperative studies with fishermen (gear efficiency) | Sea Grant funded projects in ME, NH, RI, and MA cited in SARC 22. |
| **C** | **DELURY ANALYSIS** | |
| 1 | Evaluate potential biases due to incomplete coverage in different substrates | Partially resolved by expanded use of DeLury model in individual statistical areas, with individual surveys (This assessment, sections 7.2.2 and 8). |
| 2 | Analyze effect of different spatial combinations of survey stations | No progress. |
| 3 | Undertake sensitivity analysis | See SARC 22. |

|  |  |  |
|---|---|---|
| 4 | Introduce routine measures of uncertainty | See SARC 22 and this assessment, section 7.3.3; new method applied to blend DeLury estimates of fishing mortality for each stock area. |
| 5 | Examine selectivity for prerecruit and recruit lobsters. | Crecco, V.A. and K. Gottschall. 1999. Stock assessment of American lobster in the Connecticut portion of LIS 1978-1998. Pg 13.<br>Gibson, M. 1999.<br>Somerton, D., Ianelli, J., Walsh, S. Smith, S., Godo, O.R. and D. Ramm. 1999. Incorporating experimentally derived estimates of survey trawl efficiency into the stock assessment process: a discussion. ICES J. Mar. Sci. 56:299-302.<br>This assessment, section 7.5. |
| 6 | Investigate effects of spatial distribution/movements/selectivity | This assessment (Patterns of fishery selectivity at size, section 7.4.2). |
| 7 | Examine fixed vs random sampling | No progress. |
| 8 | Examine use of multiple surveys | This assessment: Appendix A and blended DeLury analyses for each stock area (Section 7.2.2). |
| **D** | **LENGTH COHORT ANALYSIS** |  |
| 1 | Continue development of LCA and compare with DeLury Analysis | This assessment (Section 7.3). |
| 2 | Compare fishery dependent and fishery independent length frequencies | Data presented in this assessment, but only landings length frequencies were analyzed. |
| 3 | Include spatial component | No progress. |
| **E** | **FISHING MORTALITY AND FISHING EFFORT** |  |
| 1. | Develop time series of standardized fishing effort - compare with F | Available fishing mortality estimates and effort data (numbers of traps and trap hauls) for individual statistical areas analyzed for evidence of gear saturation (this assessment, section 10.7). |

| F | EGG PRODUCTION PER RECRUIT | |
|---|---|---|
| 1 | Examine sensitivity of F(10%) to input parameters | This assessment (Section 9.7) |
| 2 | Examine effects of measurement errors | ? |
| 3 | Define acceptable level of risk | Recommendations of this assessment. |
| 4 | Examine spatial differences in F (10%) via life history studies | Requires additional life-history information - see research recommendations this assessment. |
| 5 | Include reproductive output of sub-legal lobster where needed | Done- SARC 22; new size at maturity information incorporated into the EPR model for this assessment for all three stock areas (Section 9.2). |
| 6 | Include process error in growth, reproduction, etc. | Included in molt increment only. This assessment (Section 9.2). |
| 7 | Evaluate effects of mating behavior, sex ratios, size structure, sexual maturity | Bianchini, M.L., Di Stefano, L., and S. Ragonese. 1997. Size and age at onset of sexual maturity of female Norway lobster, *Nephrops norvegecus* in the Strait of Sicily. Sci. Mar., 62(1-2):151-159.<br>Hankin, D.G., and Q.L. Xue. 1996. Preliminary report on interannual variation in size specific molting probabilities of adult female Dungeness crabs *(Cancer magister)* in Northern California. In High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant College Program. AK-SG 96-02.<br>Juanes, F. and L.D. Smith. 1995. The ecological consequences of limb damage and loss in decapod crustaceans: a review and prospectus. J. Exp.Mar. Biol. And Ecol. 197-223<br>Punt, A.E., Kennedy, R.B., and S.D. Frusher. 1997. Estimating the size transition matrix for Tasmanian rock lobster, *Jasus edwardsii*. Mar. Freshwater Res. 48:981-992. Special Issue: Lobster Biology and Management. |

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| | | Saila, S.B. 1996. Lobster modeling - long term recovery and related methods. Report on North Cape oil spill. 74 pps.<br>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. |
| **G** | **FUTURE ASSESSMENT METHODS** | |
| 1 | Develop models with enhanced size/stage structure | ? |
| 2 | Include multiple input series | This assessment: Mark Model (Appendix A). |
| 3 | Continue use of DeLury and LCA | Use of LCA questioned (This assessment, section 7.3) |
| **H** | **CHANGES IN ABUNDANCE AND RECRUITMENT** | |
| 1 | Examine temperature, effort and abundance effects on catch | Drinkwater, K.F., Harding, G.C., Mann, K. H., and N. Tanner. 1996. Temperature as a possible factor in the increased abundance of American lobster during the 1980s and early 90s. Fisheries Oceanography 5:176-193. |
| 2 | Undertake regional examinations of temperature-yield relationships | Koeller, P. 1998. Influence of temperature and effort on lobster catches at different temporal and spatial scales and the implications for stock assessments. Fish. Bull 97:62-70. |
| 3 | Use comparative approach (temperature, larval drift, etc) | |
| 4 | Examine trap effects on catch | Addison, J.T. 1995. Influence of behavioral interactions on lobster distribution and abundance as inferred from pot-caught samples. ICES Marine Science Symposia 199:294-300.<br>Addison, J.T. and R.C.A. Bannister. 1998. Quantifying potential impacts of behavioral factors on crustacean stock monitoring and assessment: modelling and experimental approaches. In Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Edited by G.S. Jamieson and A. |

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| | | Campbell. Canb/. Spec. Publ. Fish. Aquat. Sci. 125:167-177.<br>Addison, J.T. and M.C. Bell. 1997. Simulation modelling of capture process in trap fisheries for clawed lobsters. Marine Freshwater Research 48(8):1035-1044. Special Issue: Lobster Biology and Management.<br>Fogarty, M.J. and J.T. Addison. 1997. Modeling capture processes of individual traps: entry, escapement and soak time. ICES J. Mar. Sci. 54:193-205.<br>Karnofsky, E.B. and H.J Price. 1989. Behavioral response of the lobster to traps. Can. J. Fish. Aquat. Sci. 46: 1625-1632.<br>Miller, R.J. 1989. Catchability of American lobster and rock crabs by traps. Can. J. Fish. Aquat. Sci. 46: 1652-1657.<br>Miller, R.J. 1995. Catchability coefficients for American lobster. ICES Marine Science Symposia 199:349-356.<br>Watson, W. 1999. Lobster trapability and saturation study. US/Canadian Lobster Summit III, Lobster Stock Assessment: Towards greater understanding, collaboration and improvement. Draft Report. Maine. |
| 5 | Examine temperature effects on growth, reproduction, etc. | ? |
| 6 | Examine effects of predation, regime shifts, etc. | Steneck, R.S. 1997. Fisheries-induced biological changes in the structure and function of the Gulf of Maine Ecosystem. Plenary paper. In Proceedings of the Gulf of Maine Ecosystem Dynamics Scientific Symposium and Workshop. RARGOM Report-91-1. Edited by: G.T. Wallace and E.F. Braasch. Pgs. 151-165. |
| 7 | Develop monitoring plan to detect recruitment decline | Incze, L.S., Wahle, R.A, and J.S. Cobb. 1997. Quantitative relationships between postlarval production and benthic recruitment in lobster, Homarus americanus. Marine Freshwater Research 48(8):729-744. Special Issue: Lobster Biology and Management<br>This assessment, section 10.12. |
| 8 | Promote Canada/USA coordinated studies | Upcoming joint workshop. |

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| **I** | **BENTHIC ECOLOGY** | |
| 1 | Establish field studies of density dependent processes | Wahle, R.A. and L.S. Incze. 1997. Pre and post settlement processes in recruitment of the American lobster. J. Exp. Mar. Biol. And Ecol. 217:179-207. |
| 2 | Test thermal limit hypothesis (temperature affecting settlement) | ? |
| 3 | Establish wide-scale collector program | On-going |
| **J** | **OTHER RELEVANT PUBLICATIONS** | |
| | **RESEARCH** | Moriyasu, M., Landsburg, W., Wade, E. and D.R. Maynard. 1999. The role of an estuary environment for regeneration of claws in the American lobster, *Homarus americanus*. Crustaceana 72(4):415-433.<br>Watson III, W.H., Vetrovs, A., and W.H. Howell. 1999. Lobster movements in an estuary. Marine Biology 134:65-75.<br>Cobb, J.S. , Booth, J.D., and M. Clancy. 1997. Recruitment strategies in lobsters and crabs: a comparison. Mar. Freshwater Res. 48:797-806.<br>Palma, A.T., Wahle, R.A., and R.S. Steneck. 1998. Different early post-settlement strategies between American lobsters *Homarus americanus*,and rock crabs, *Cancer irroratus* in the Gulf of Maine. Mar. Ecol. Prog. Ser. 162:215-225.<br>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. Mar. Ecol. Prog. Ser., 138: 117-123. |
| | **MANAGEMENT** | Caddy, J.F. and R. McGarvey. 1996. Targets or limits for management of fisheries. North American J. Fish. Manage. 16(3):479-486. |

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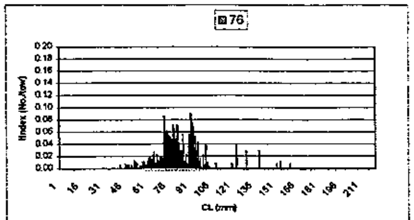
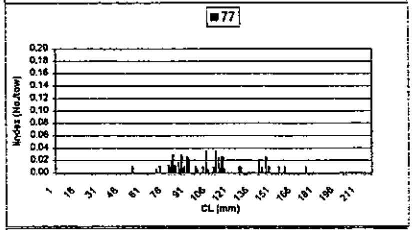
| | | Caddy, J. 1997. Checks and balances in the management of marine fish stocks: organizational requirements for a limit reference point approach. Fisheries Research 30:1-15.<br>Gates, J.M. and J.G. Sutinen. 1995. SIMLOB: The resource and harvest sector components of the North American lobster Market Model. Final Report. Technical Publication from the University of Rhode Island. Department of Environmental and Natural Resource Economics. Kingston RI 71 pps.<br>Herrmann, M., Greenberg, J., and K. Criddle. 1998. An economic analysis of pot limits for the Adak Brown King crab fishery: a distinction between open access and common property. Alaska Fishery Research Bulletin 5(1): 25-38.<br>McGarvey, R., Gaertner, P., and J. Matthews. (1998). South Australian rock lobster fishery management model. User guide. SARLMOD. 39 pps.<br>Punt, A.E. and T. I. Walker. 1998. Stock assessment and risk analysis for the school shark (Galeorhinus galeus) off Southern Australia. Mar. Freshwater Res. 49:719-731. |

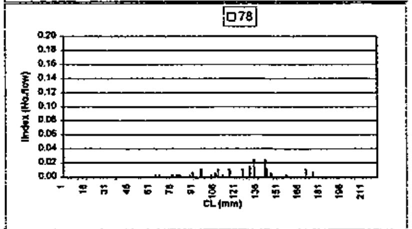
# APPENDIX C

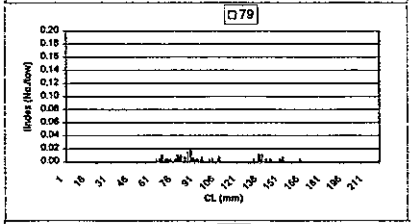
## Trawl Survey Length Frequencies

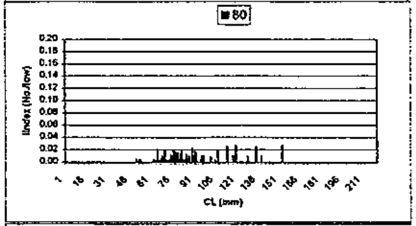
NMFS fall trawl survey indices GOM males

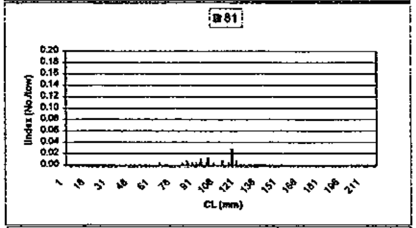


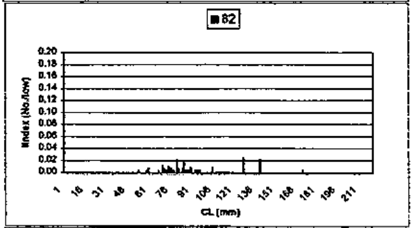


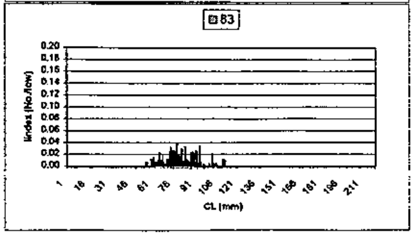


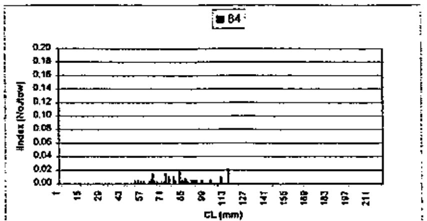


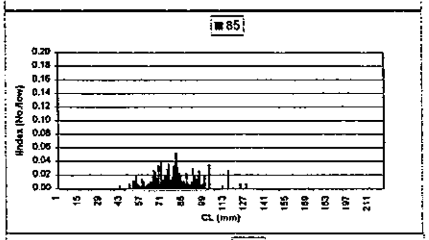


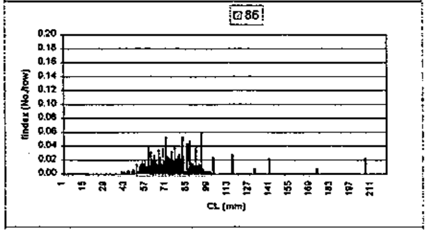


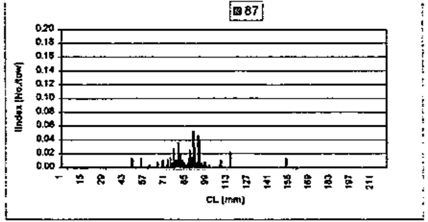


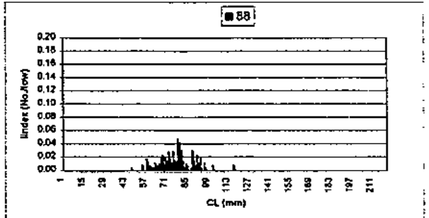


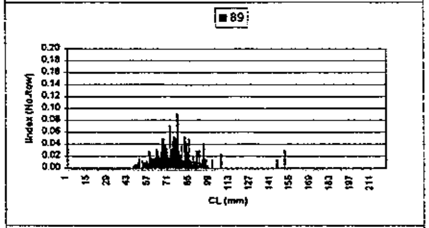


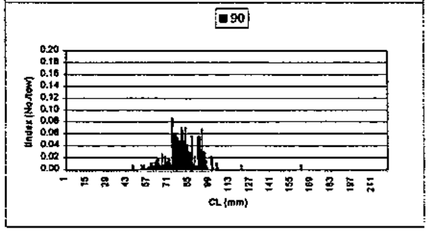


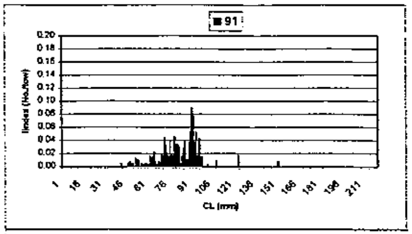


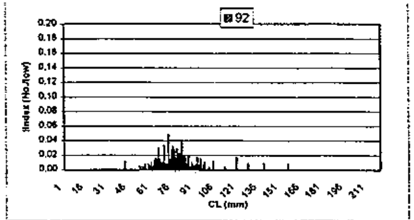


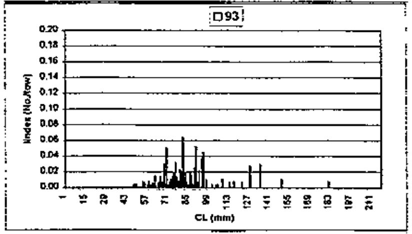


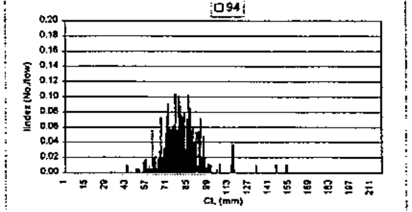


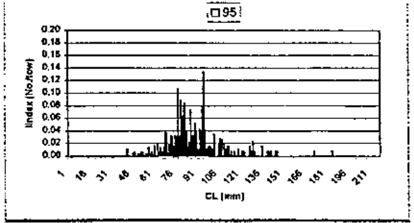


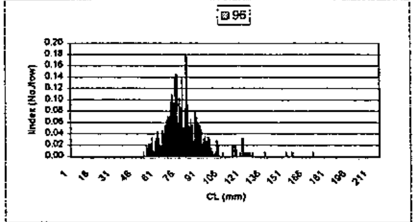


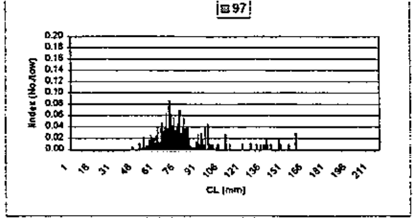


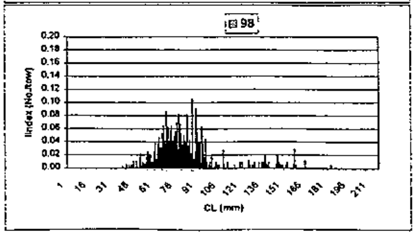




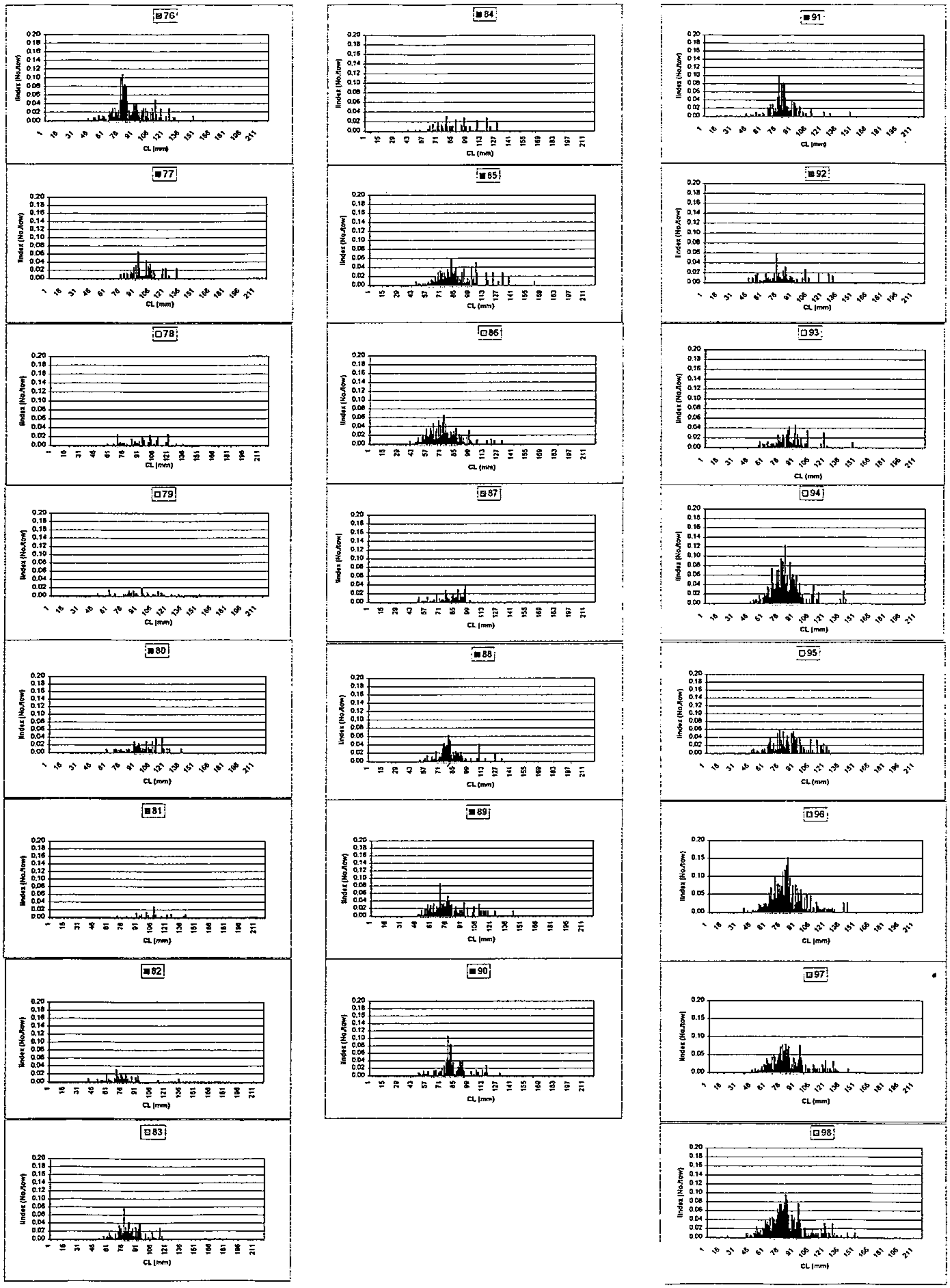




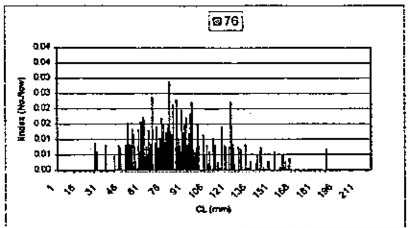


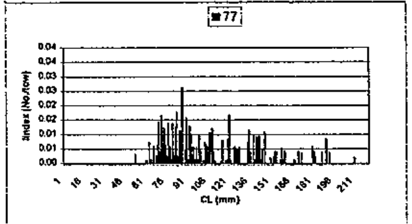


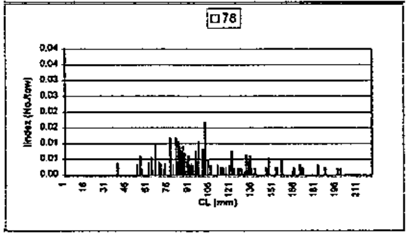
# NMFS fall trawl survey indices GOM females

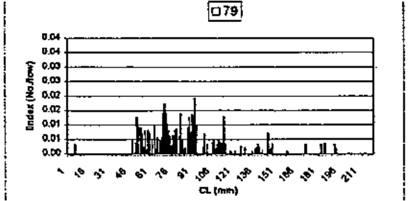


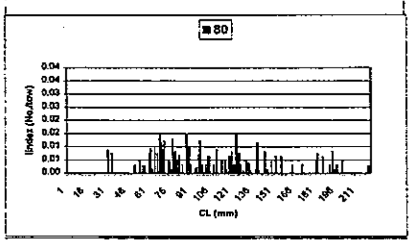
NMFS fall trawl survey indicies GBS males

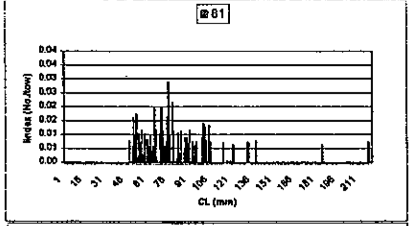


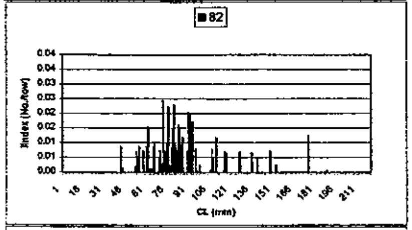


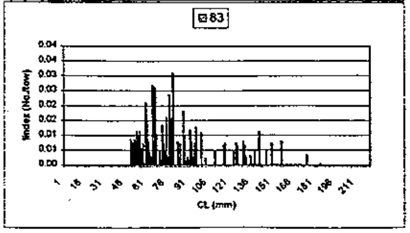


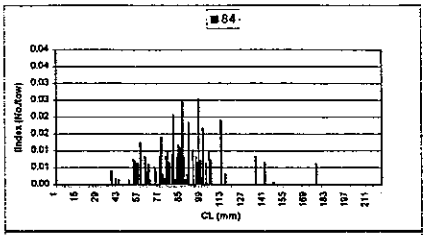


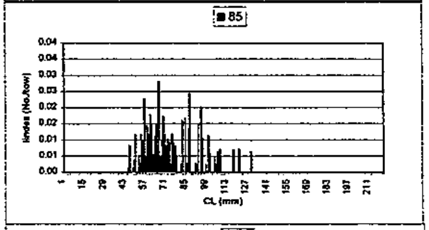


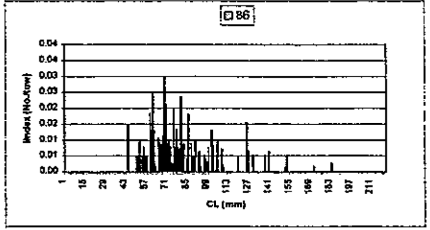


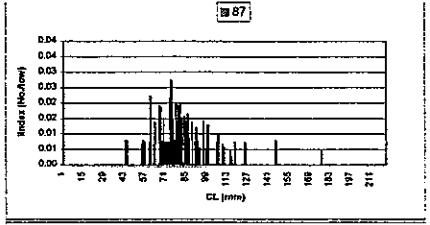


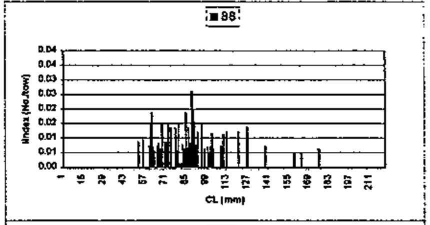


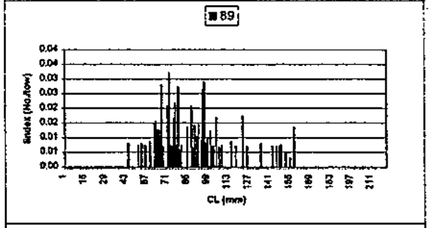


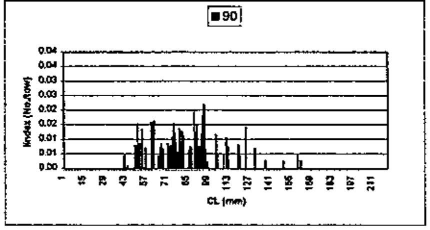


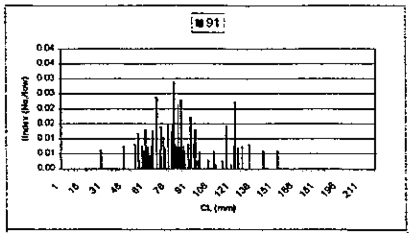


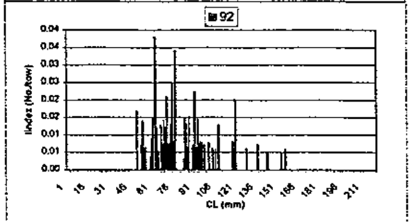


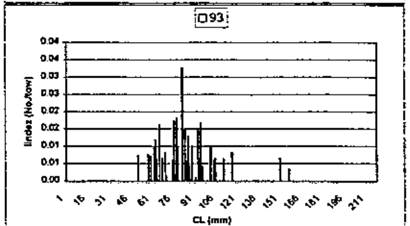


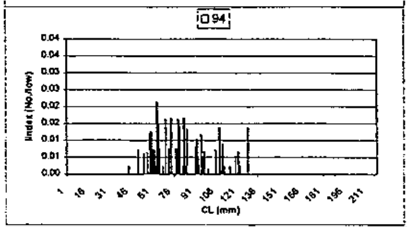


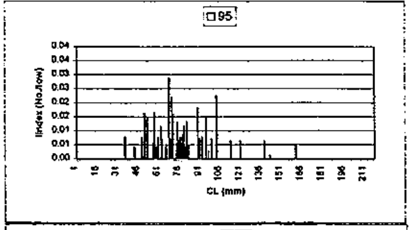


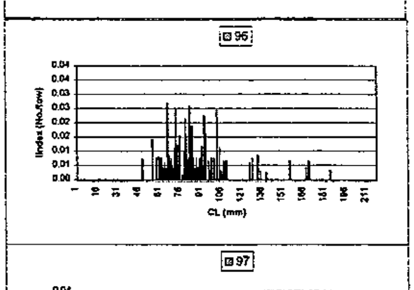


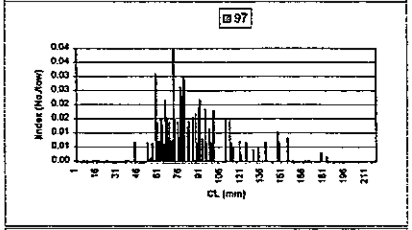


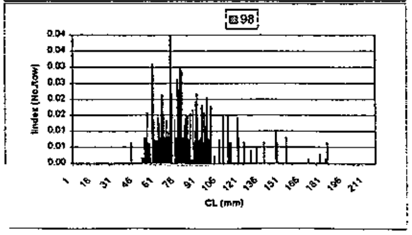




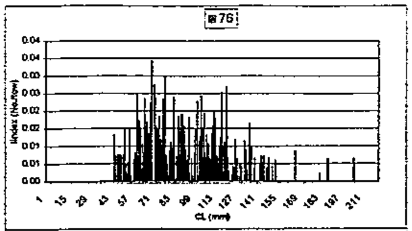


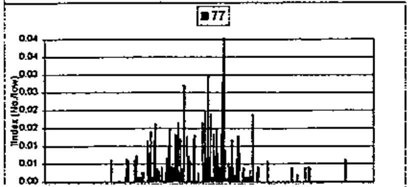


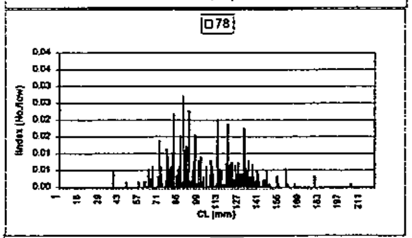


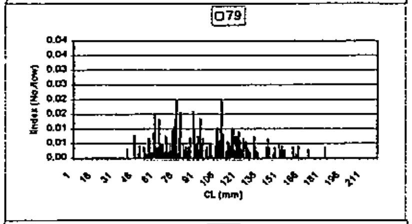


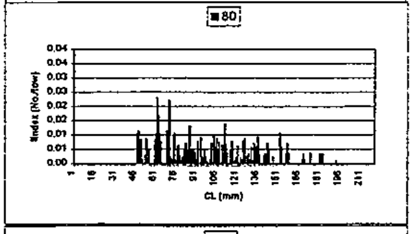
NMFS fall trawl survey indicies GBS females

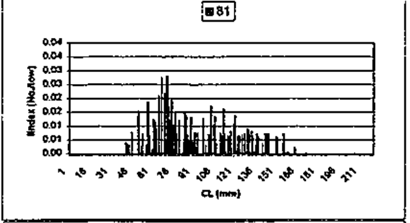


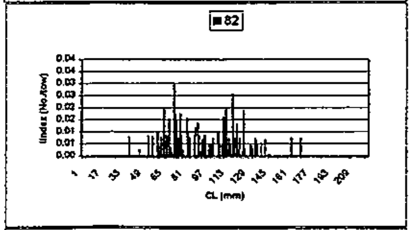


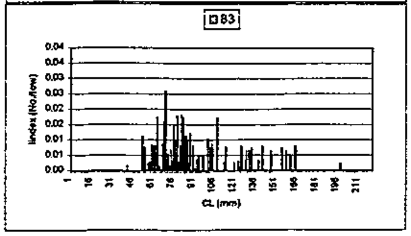


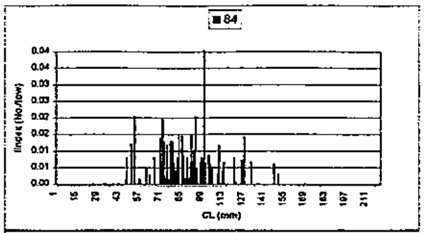


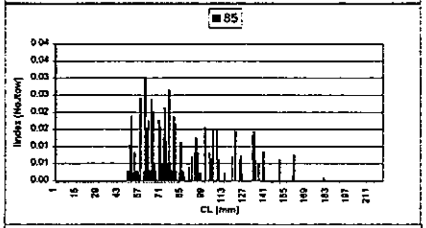


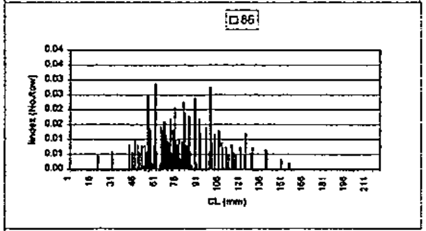


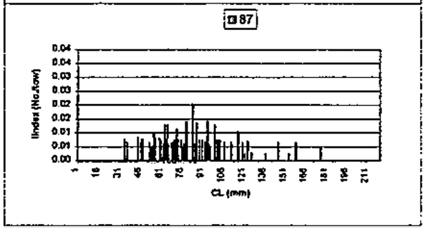


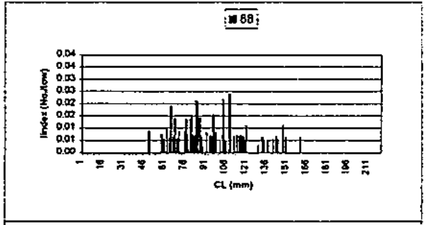


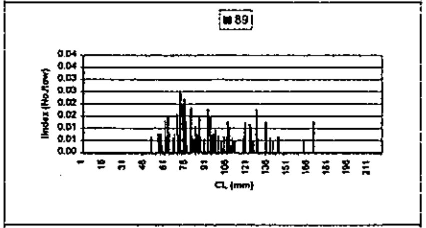


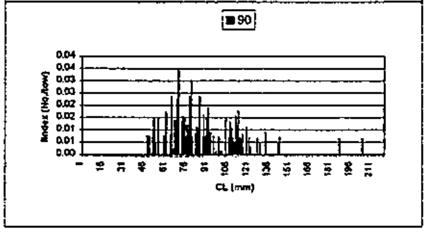


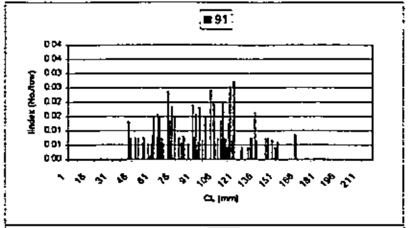


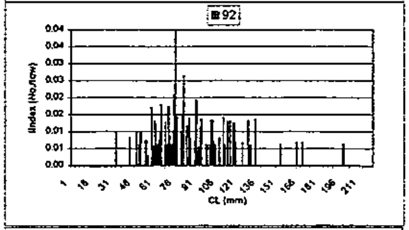


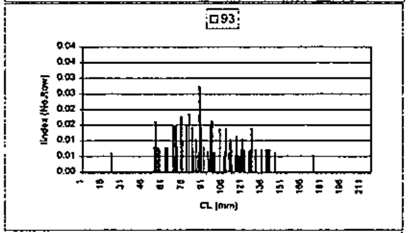


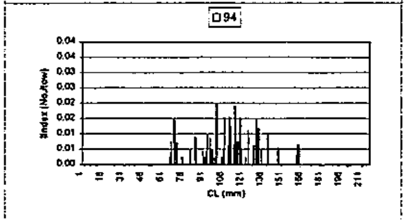


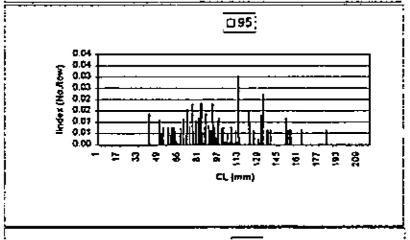


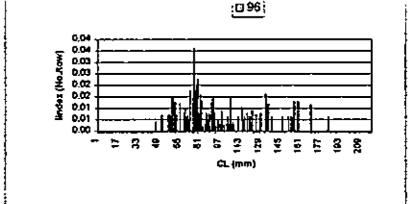


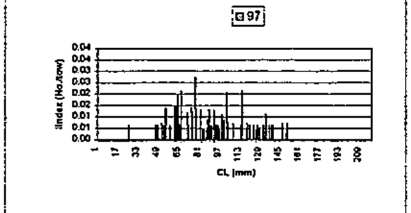


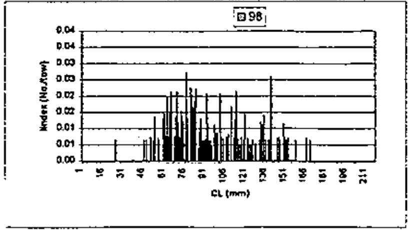




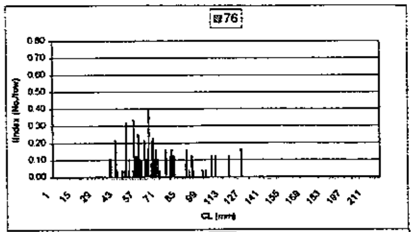


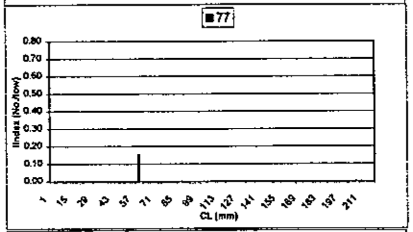


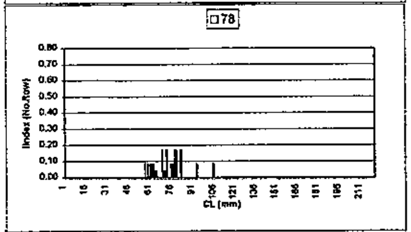


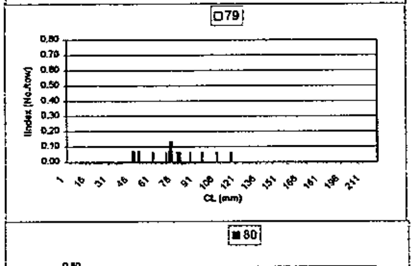


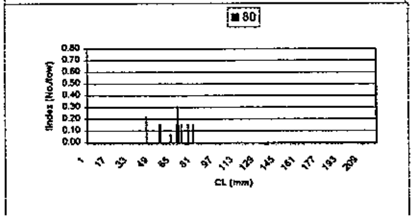
NMFS fall trawl survey indicies SCCLIS males

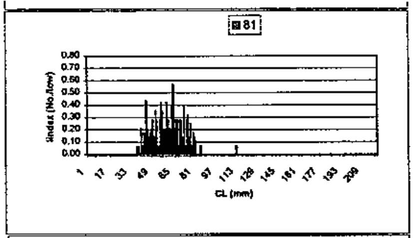


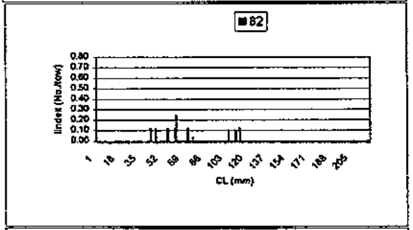


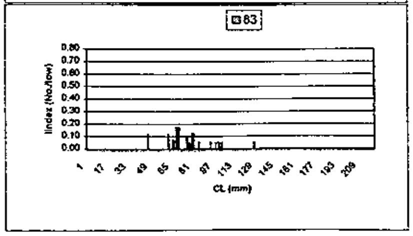


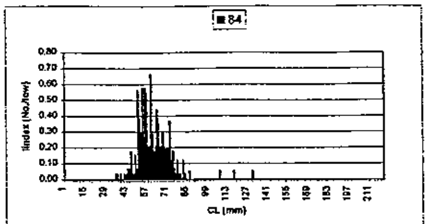


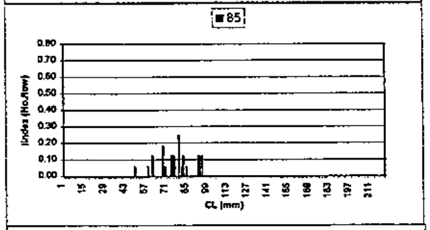


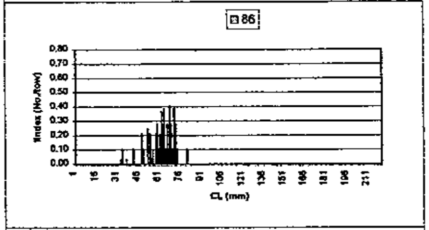


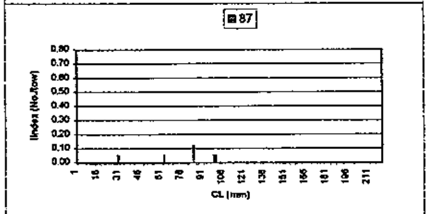


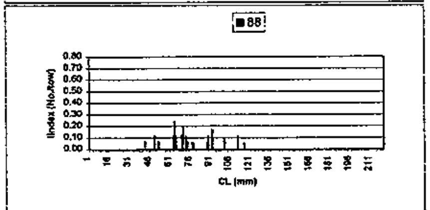


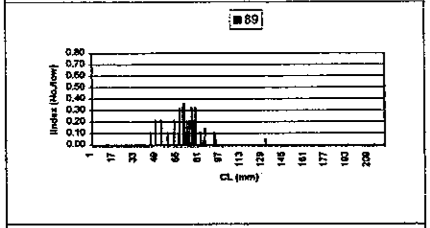


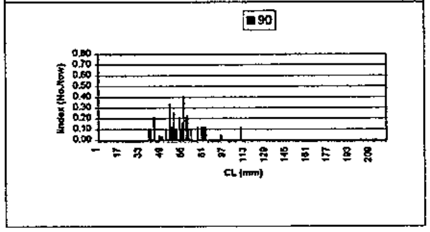


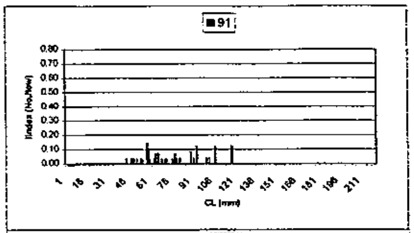


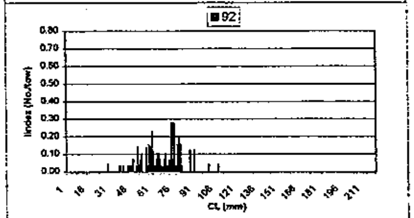


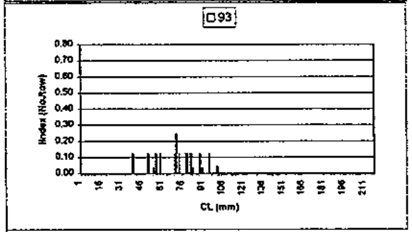


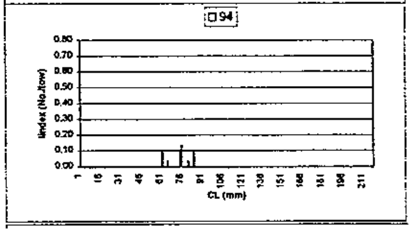


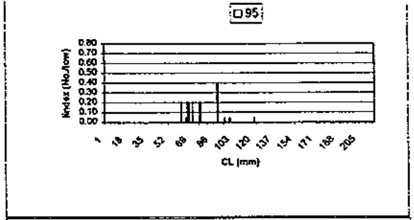


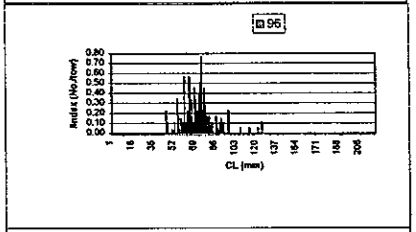


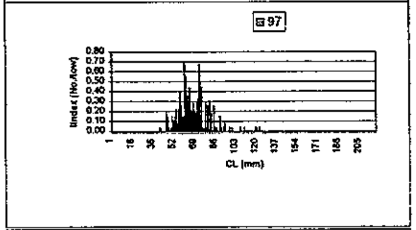


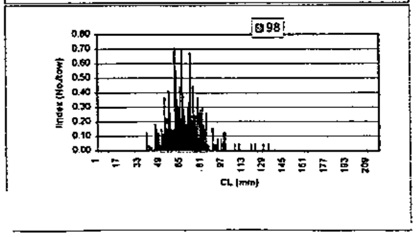




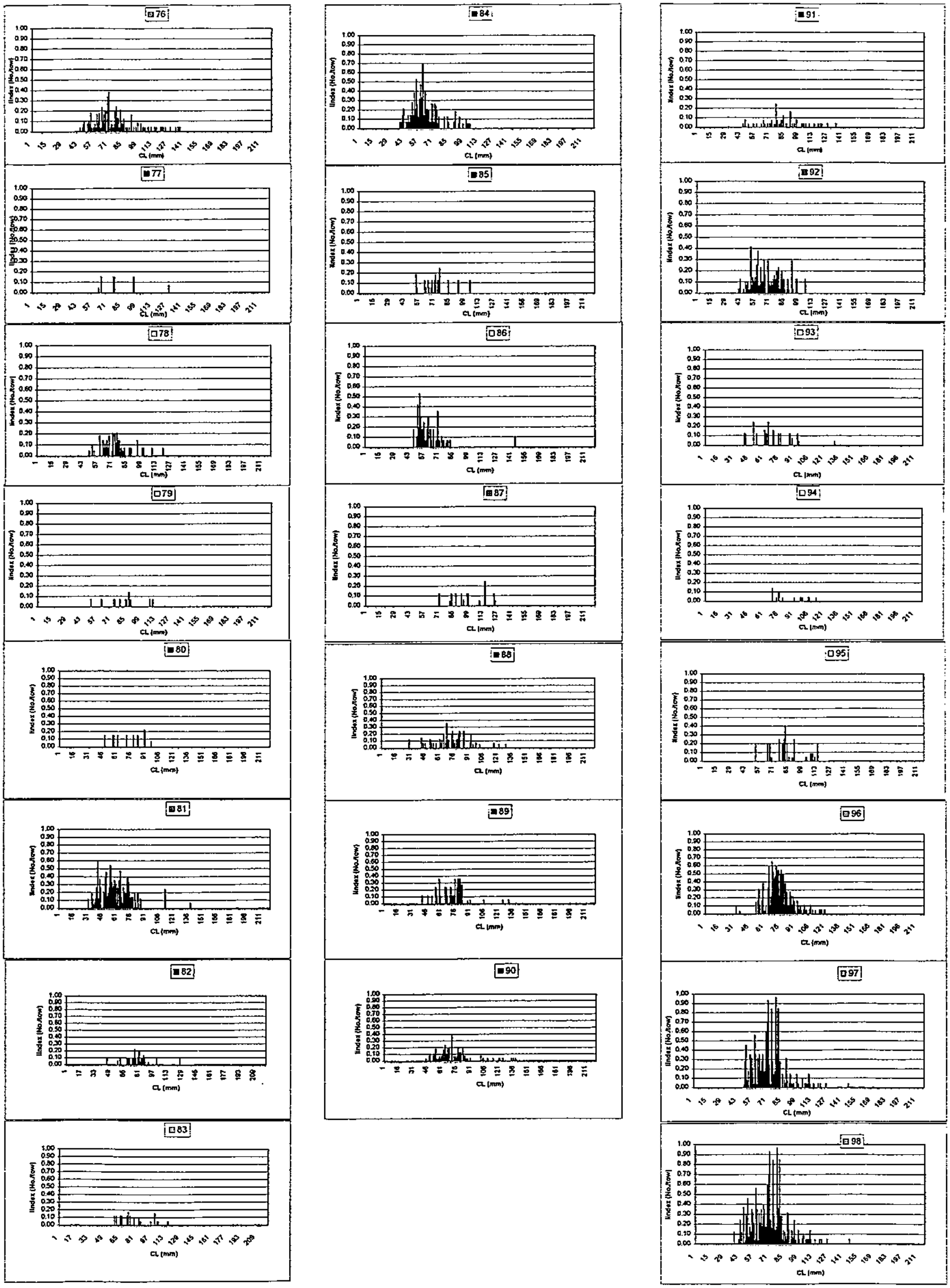








# NMFS fall trawl survey indicies SCCLIS females



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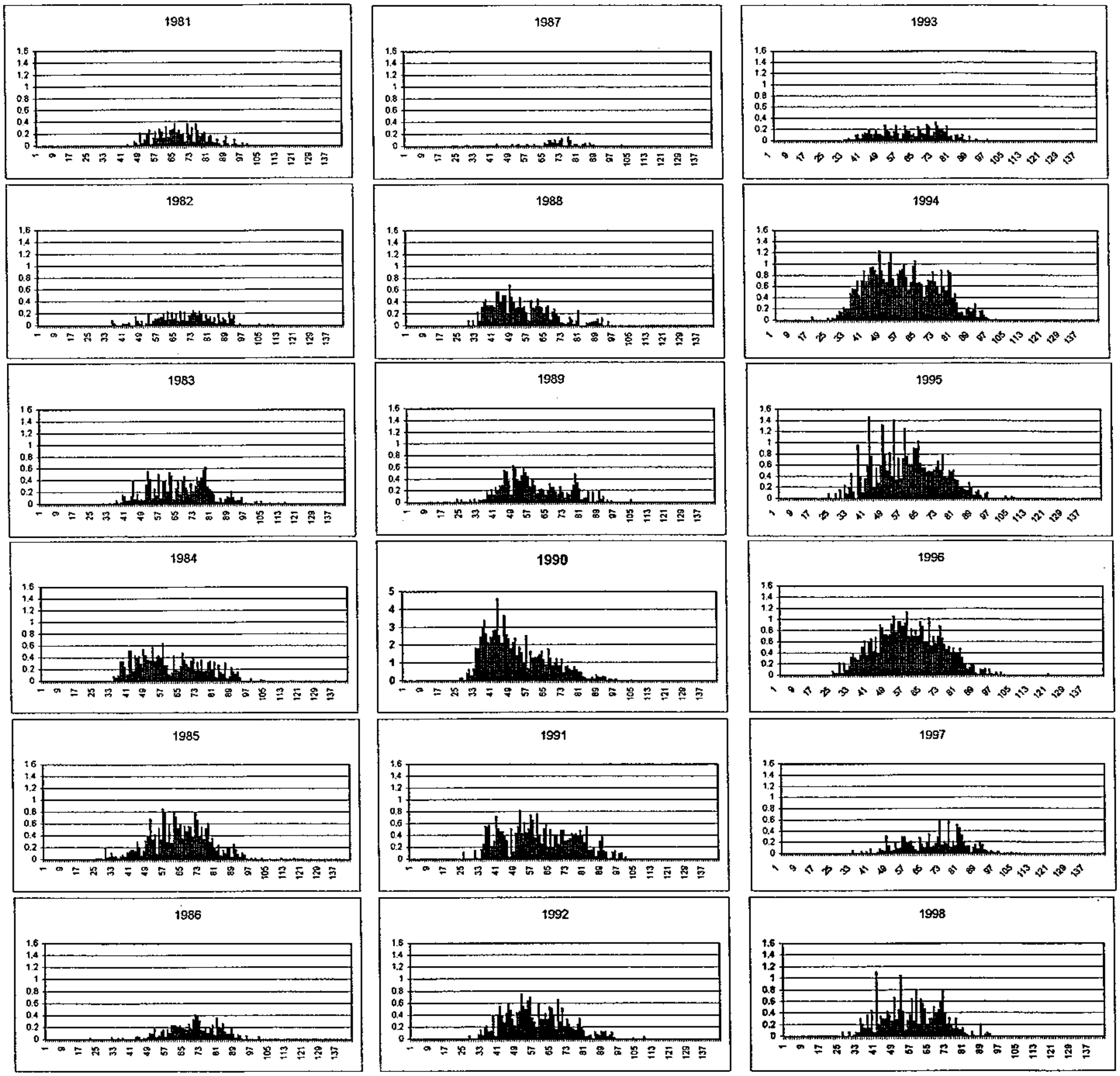
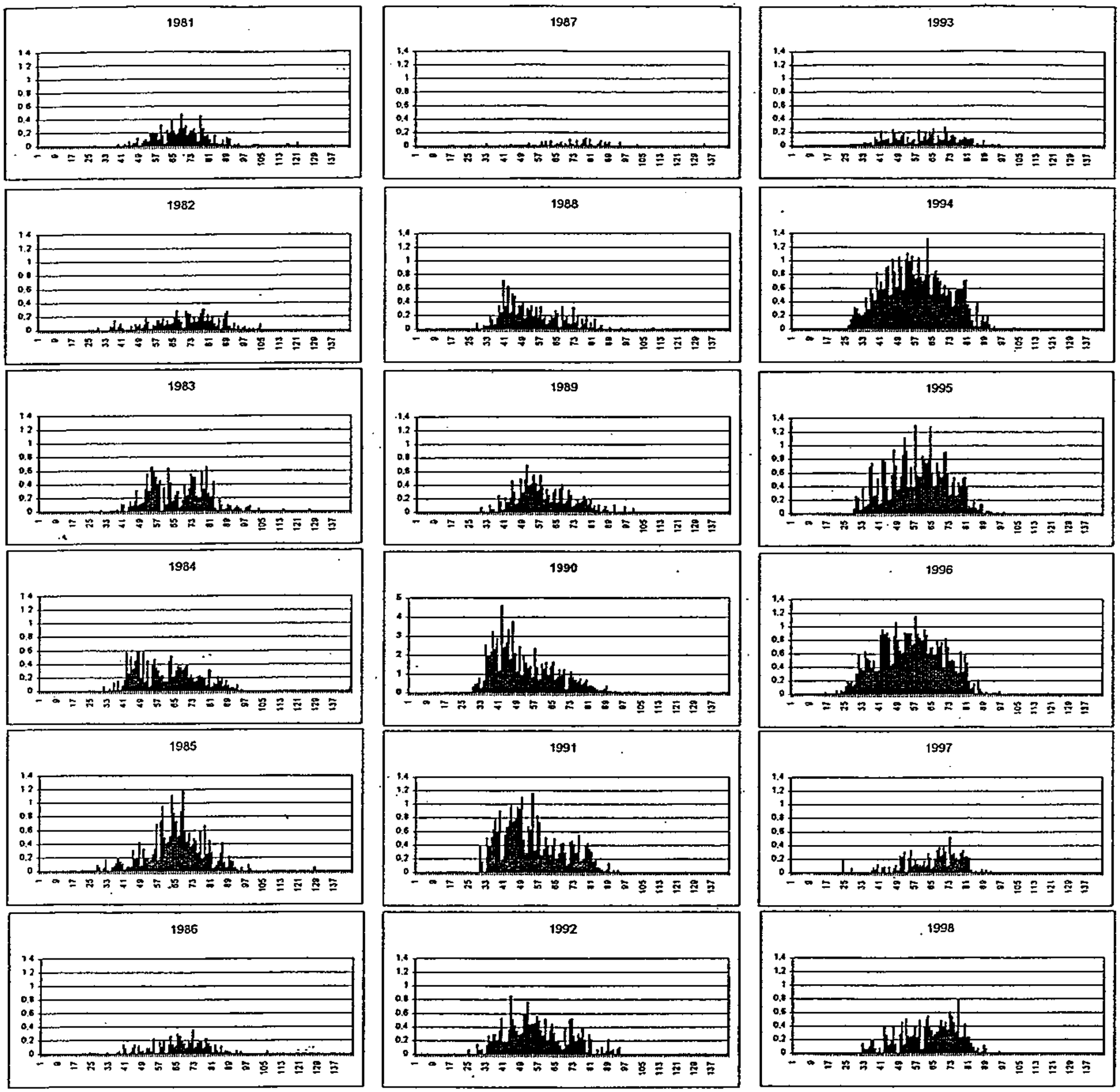
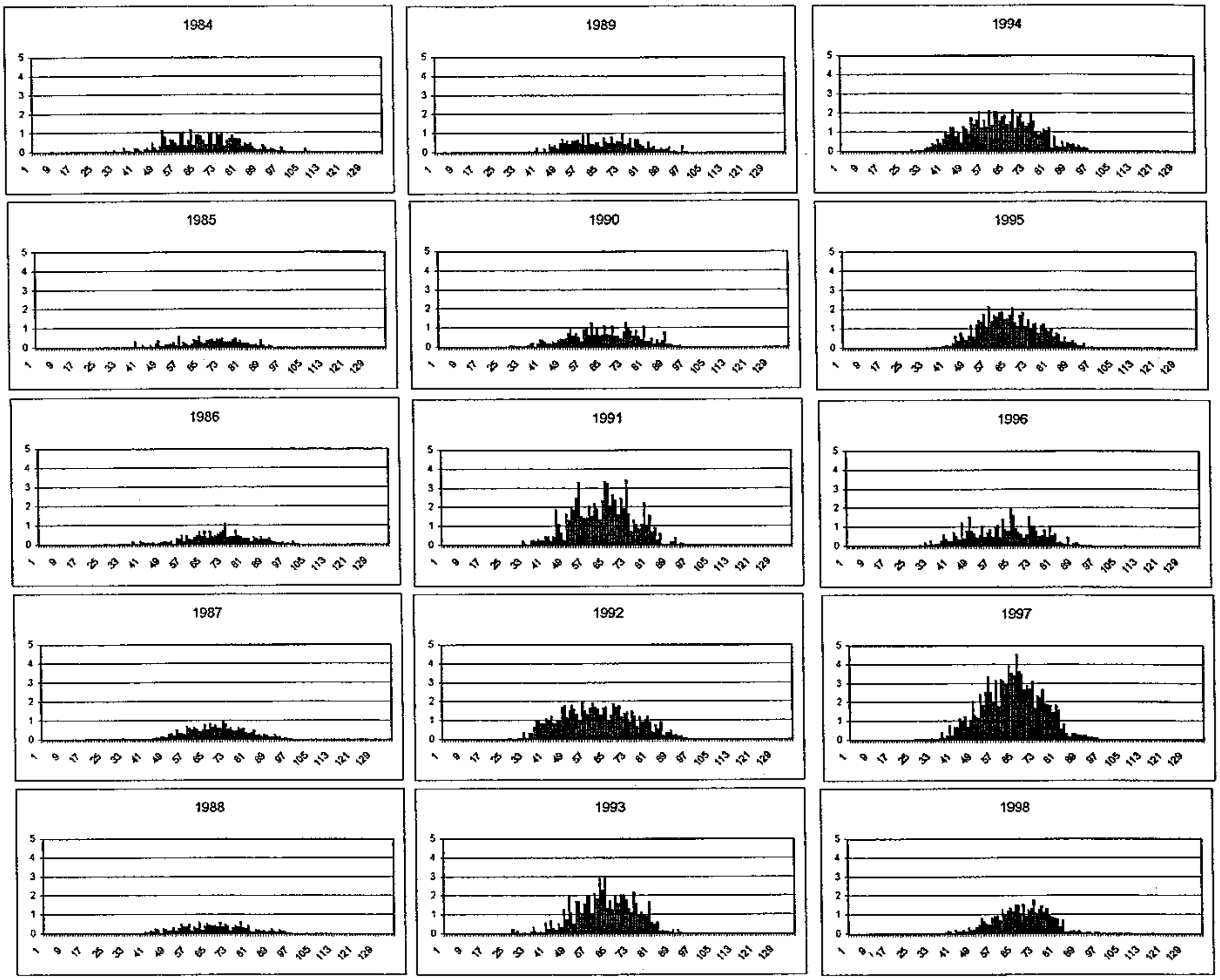


## MA FALL SURVEY INDICES GOM FEMALES



CT Fall Survey Indices - SCCLIS Males



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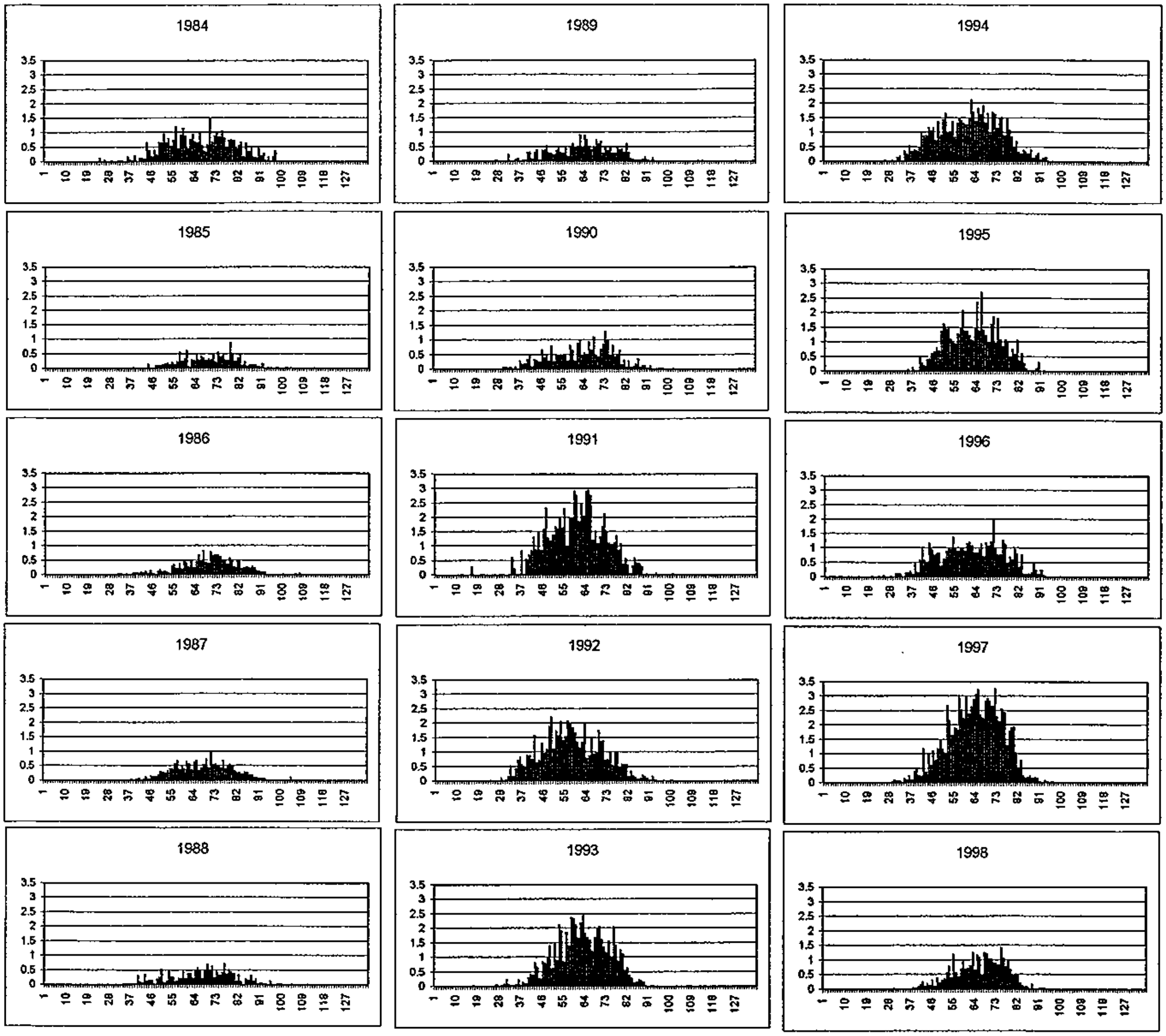
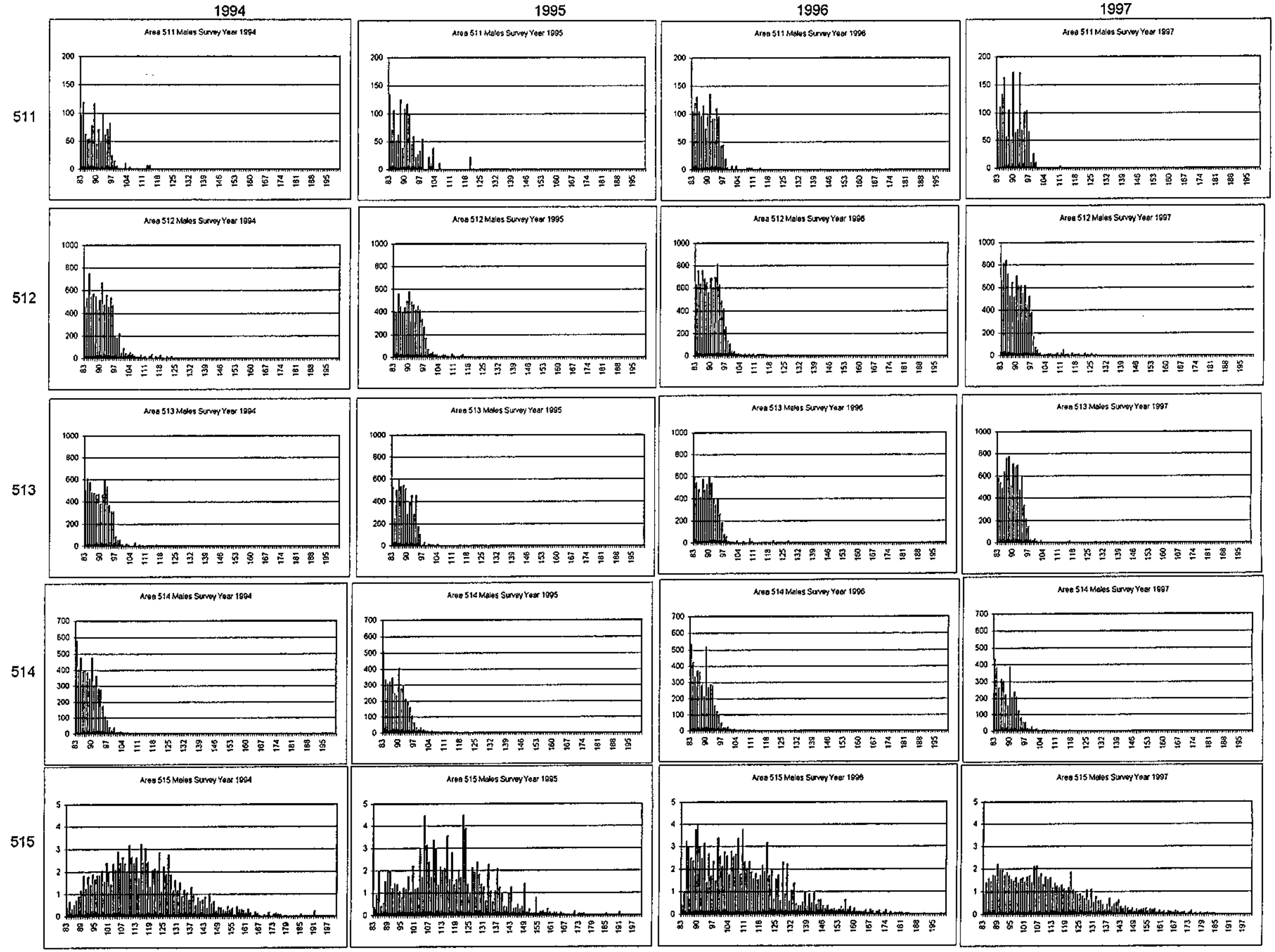


# APPENDIX D

## Expanded Length Frequencies of Landings

# GOM Expanded Male Landings at Size by Area and Survey Year



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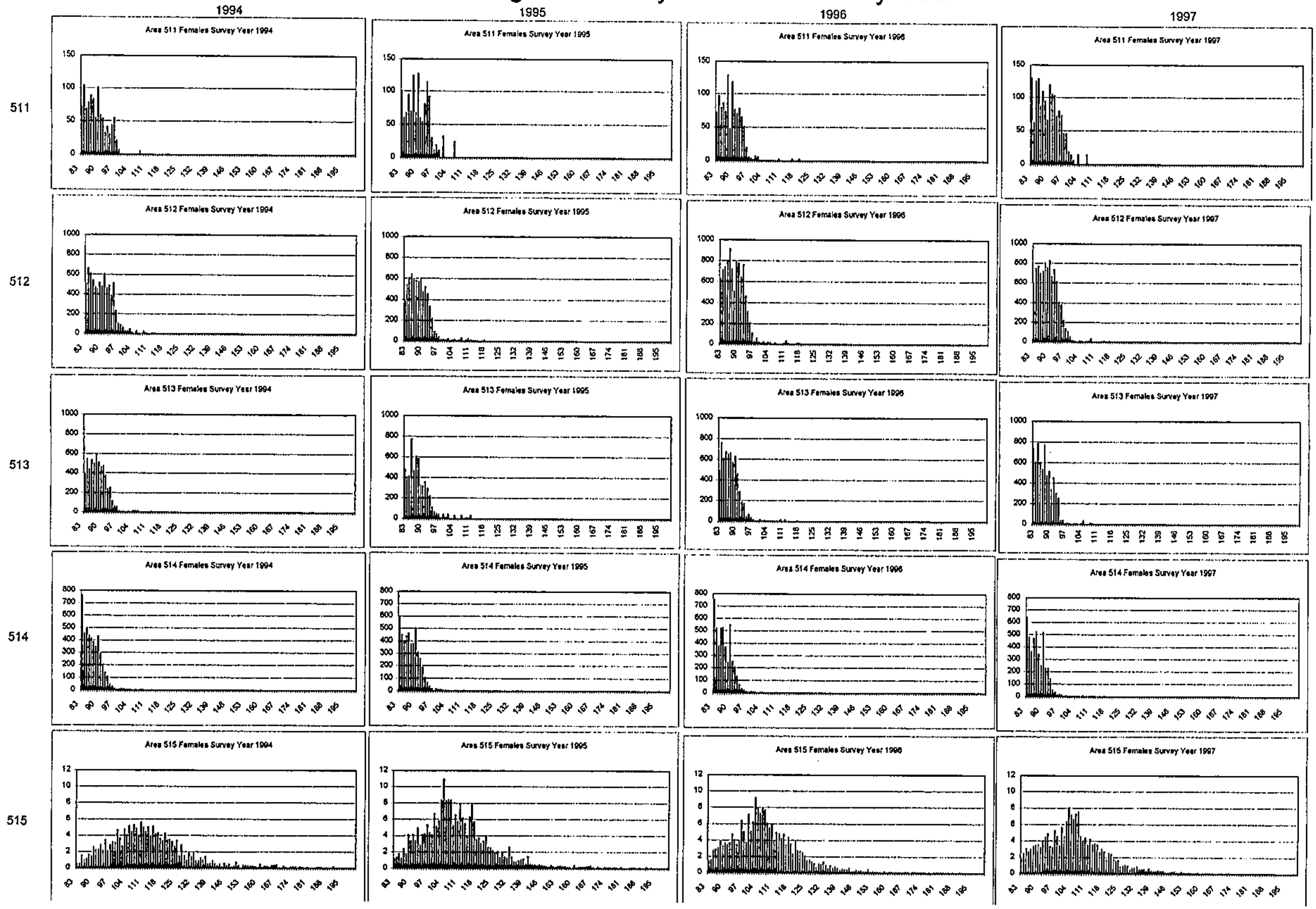

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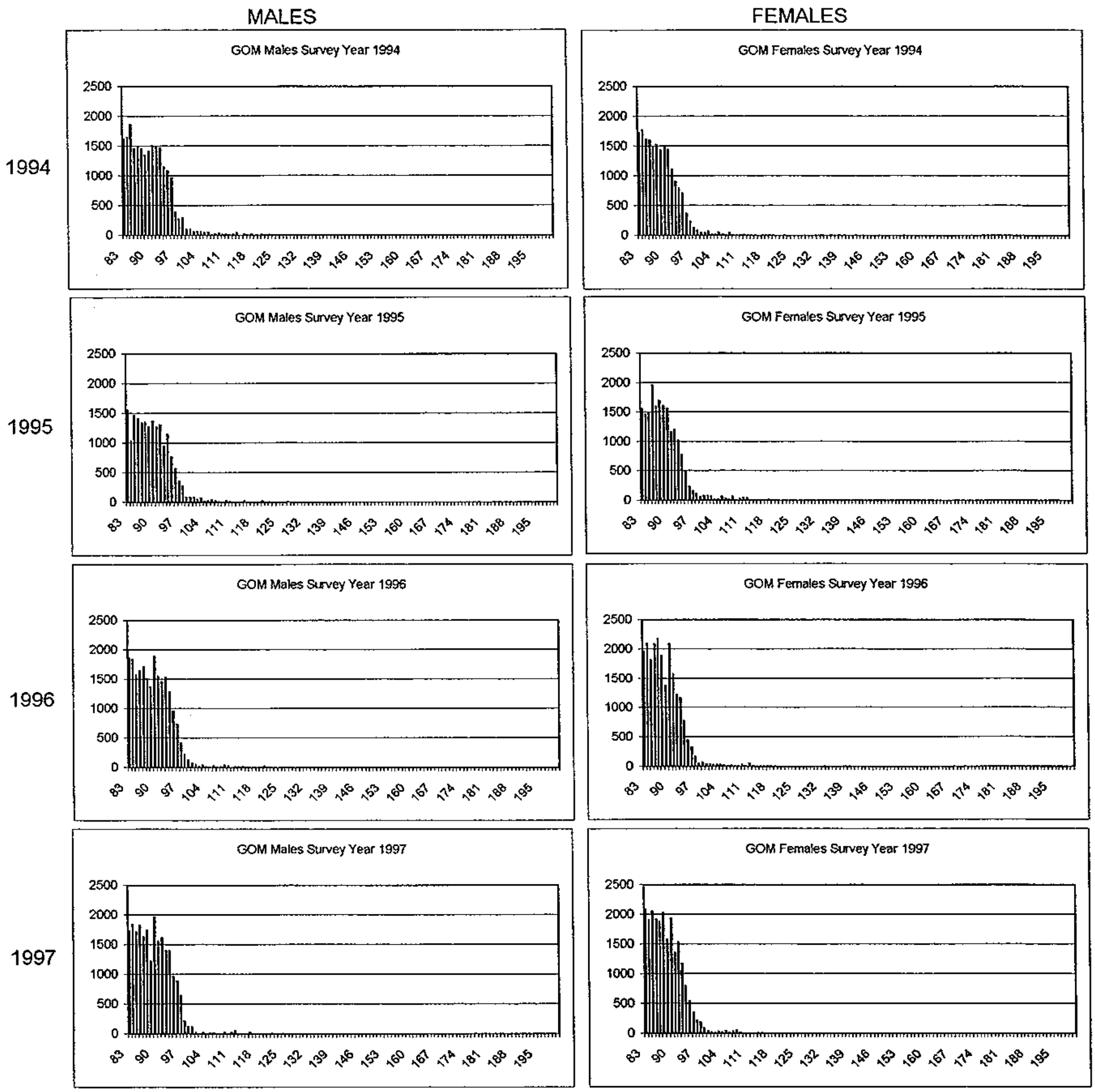

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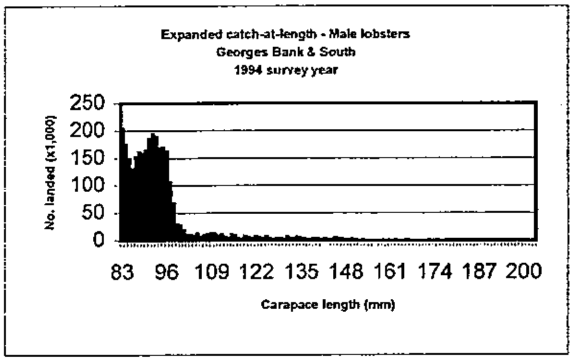
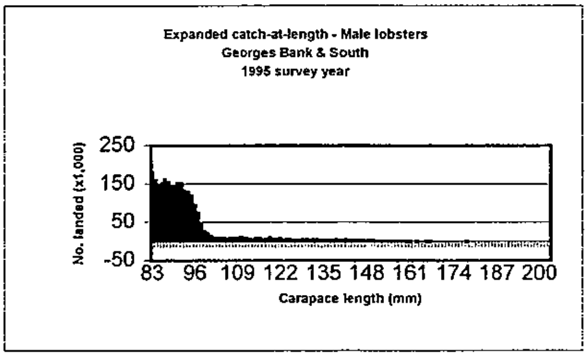
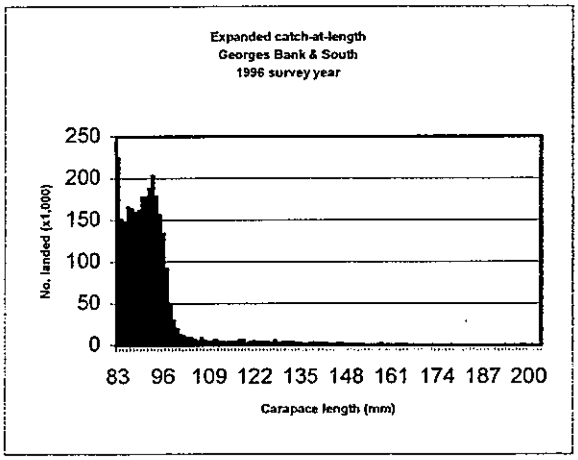
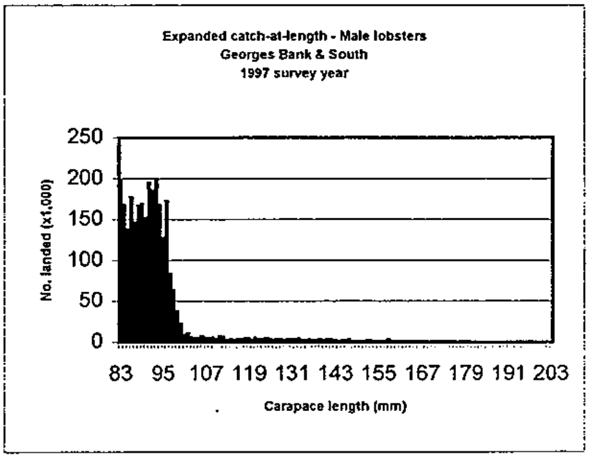
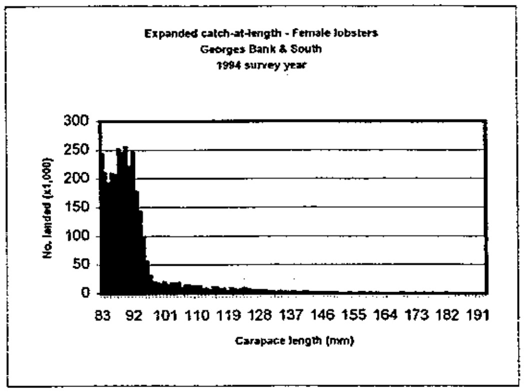


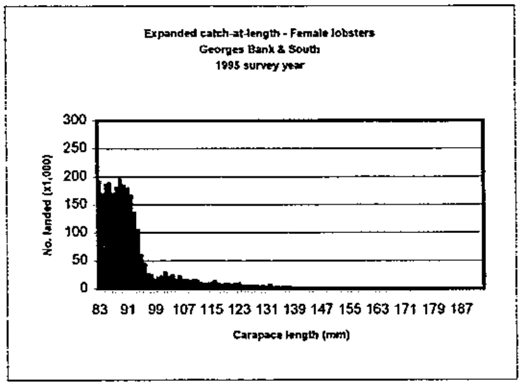


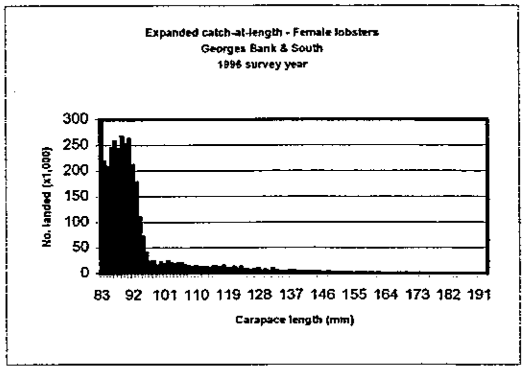


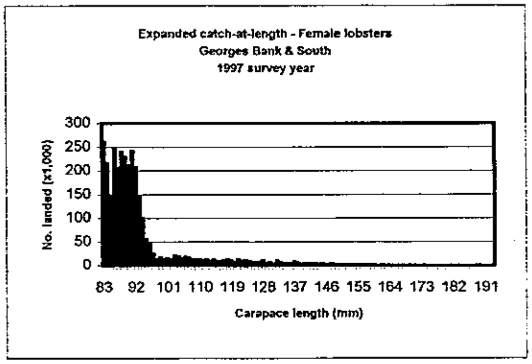


# GBS Expanded Female Landings at Size by Survey Year

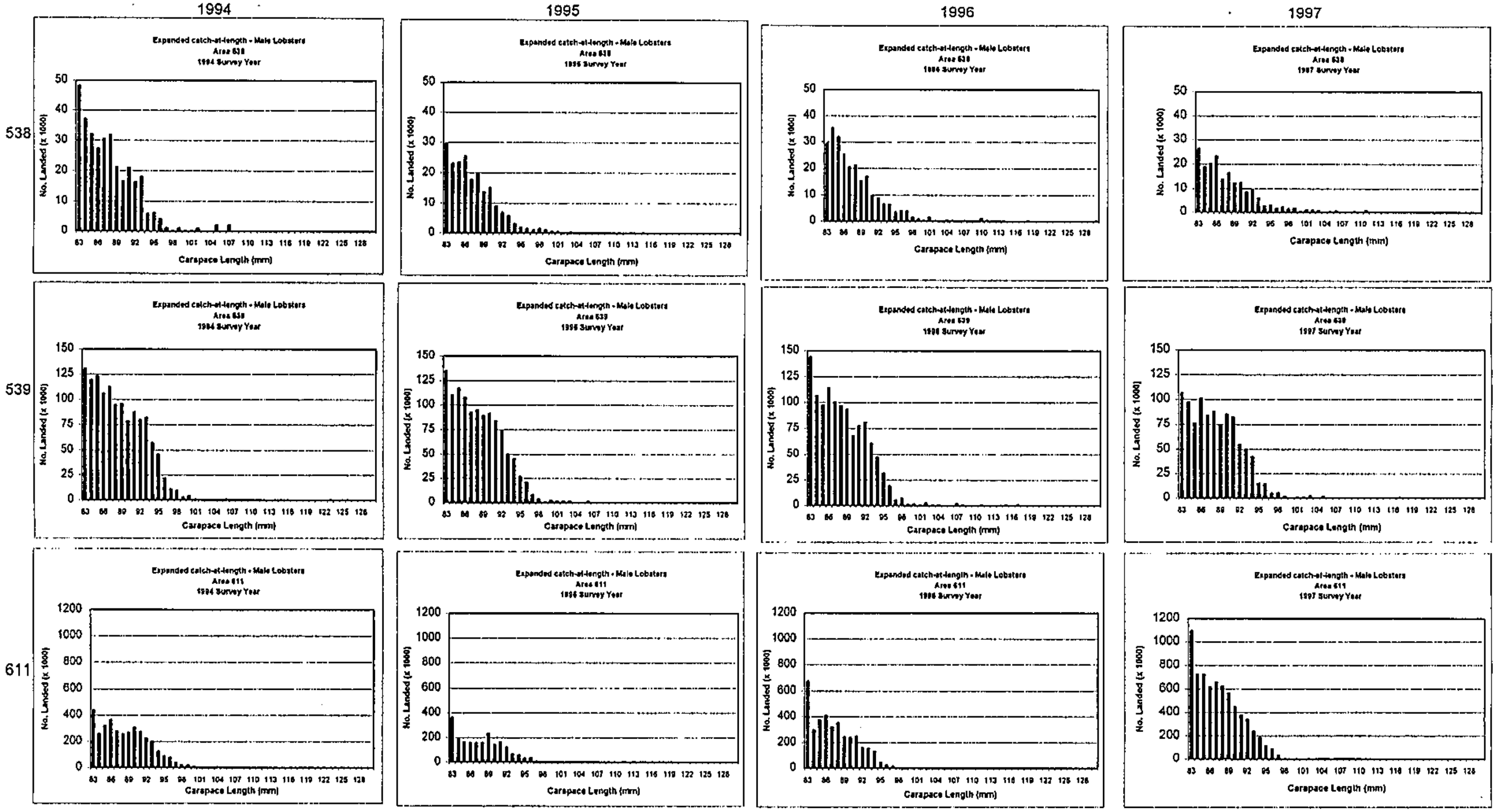

Expanded catch-at-length - Female lobsters
Georges Bank & South
1994 survey year


Expanded catch-at-length - Female lobsters
Georges Bank & South
1995 survey year

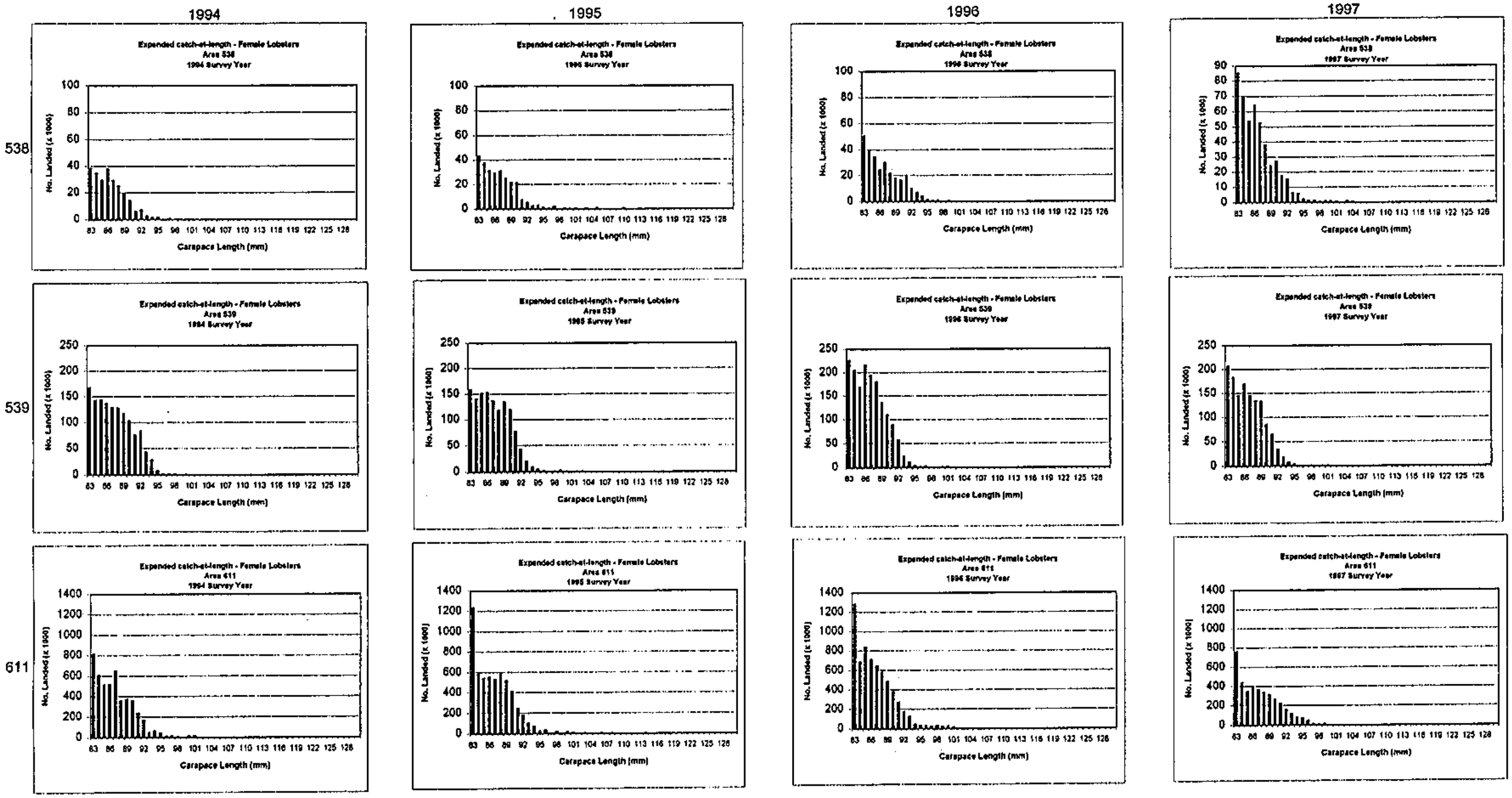

Expanded catch-at-length - Female lobsters
Georges Bank & South
1996 survey year


Expanded catch-at-length - Female lobsters
Georges Bank & South
1997 survey year

# SCCLIS Expanded Male Landings at Size by Area and Survey Year



# SCCLIS Expanded Female Landings at Size by Area and Survey Year

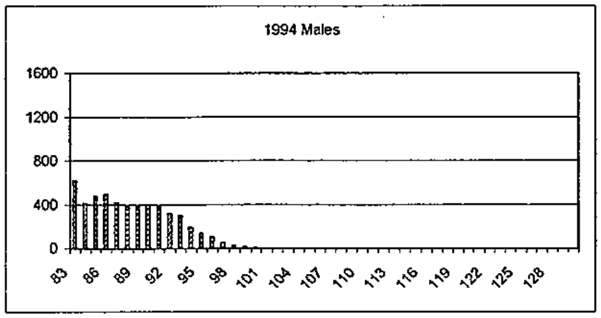


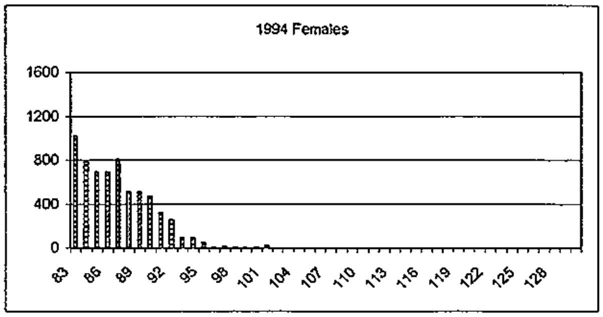
# SCCLIS Expanded Landings at Size by Sex and Survey Year, All Areas

MALES

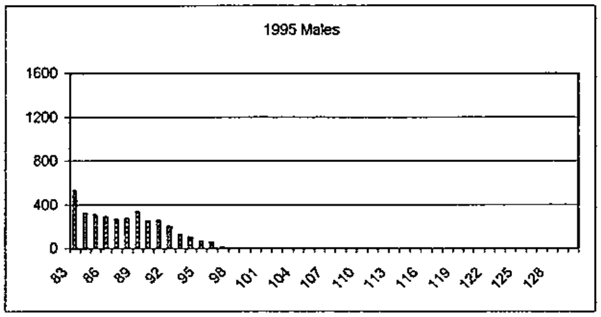
FEMALES

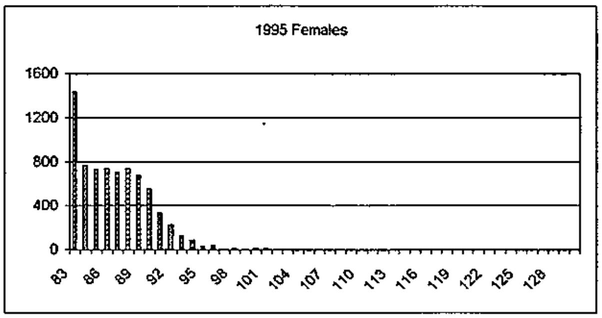
1994


1994 Males

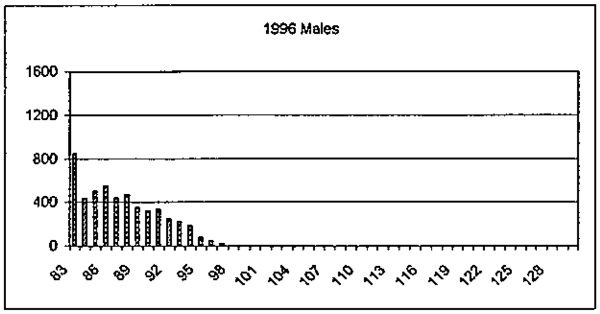

1994 Females

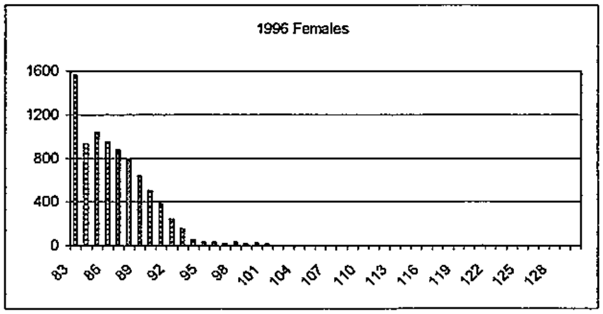
1995


1995 Males

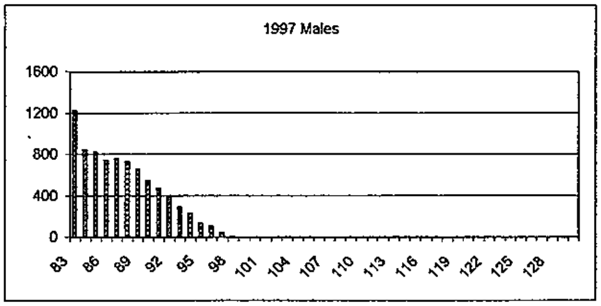

1995 Females

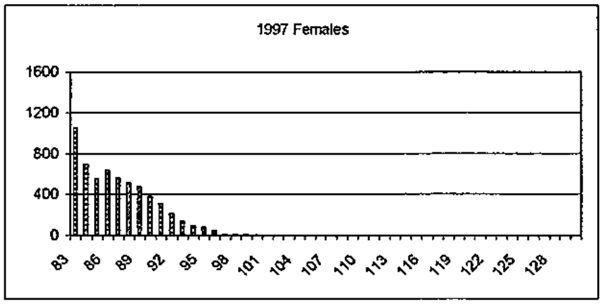
1996


1996 Males


1996 Females

1997


1997 Males


1997 Females

# APPENDIX E

## MINORITY REPORT

## Alternative Assessment and Biological Reference Points for the RI Inshore Lobster Stock with Estimations of Unfished Stock Size

**By Mark Gibson**

# Alternative Assessment and Biological Reference Points for the RI Inshore Lobster Stock with Estimations of Unfished Stock Size

By
Mark Gibson
RI Division Fish and Wildlife
150 Fowler St., Wickford RI 02852
February 2000

**A Report to the Atlantic States Marine Fisheries Commission and Lobster Assessment Peer Review Panel**

## Introduction-

The most recent peer reviewed lobster stock assessment indicated that the resource was over fished throughout the US Atlantic coast range (NEFCS 1996, ASMFC 1996). This conclusion was based on the results of independent size structured assessment and biological reference point (BRP) models. A two size bin DeLury model (Conser and Idoine 1992) was used to estimate prevailing fishing mortality rates and stock sizes. An egg per recruit (EPR) model (Fogarty and Idoine 1988) was used to estimate the fishing mortality rate allowing for 10% of virgin egg production to persist. The fishing mortality rate associated with 10% EPR defines over fishing in the Atlantic States Marine Fisheries Commission (ASMFC) fishery management plan for lobster (ASMFC 1997). The plan outlines an eight year schedule for rebuilding egg production. A set of plan addenda are under development to identify area specific measures which will raise egg production above the 10% level. Of critical consideration is the reliability of the F10% calculation and the magnitude of the gap between prevailing F and F10%.

The assessment update now being prepared by the ASMFC technical committee uses the same approaches, refined to reflect new information. Although the DeLury and EPR models are accepted methods, they are lacking in several areas. First, the analyses are independent and although attempts are made to conform inputs and model structure, there remains and issue of comparability of outputs. The first peer review panel recognized this and recommended development of an advanced assessment-BRP model which merged the approaches (ASMFC 1996). Second, because the EPR model is a per recruit model, it cannot be used to draw reliable conclusions about sustainable yield and stock biomass levels supporting MSY. That would require merging EPR models with stock-recruit curves (Bannister and Addison 1986).

The EPR model contains no compensatory elements to adjust vital rates in accordance with stock biomass levels. Lacking a stock regenerating function, the EPR model can only track the fate of a cohort of lobsters through their fishable life span under the assumption of constant vital rates. The 1996 assessment found that fishing mortality rates were quite high and that egg production was very low on a per recruit basis (<10% of maximum). It is generally accepted that the stock-recruitment relationship in lobster is asymptotic with a steep slope at the origin (Fogarty and Idoine 1986, Ennis and Fogarty 1997). EPR models predict that a large reduction in fishing mortality rate would result in a great increase in stock abundance for a constant level of recruitment, i.e. the stock should move from left to right along the asymptote of the S-R curve. Unfortunately, there are no S-R data points corresponding to unfished conditions so there is no empirical basis for the EPR predictions. Crecco (2000), gives a more thorough analysis of the limitations of the EPR model.

Lobster abundance has generally increased throughout the region over the past decade although the reasons are not completely clear (ASMFC 1996, Drinkwater 1996). Record landings have been achieved, supported by high recruitment as evidenced by research trawl surveys. It is difficult to see how another large increase in biomass could be supported if fishing mortality rate were reduced substantially as indicated by the SARC 22 findings. It seems more likely that there would be adjustments in vital rates so that biomass would be constrained to more realistic levels (Addison 1986). Lobster habitat has been viewed by Caddy (1986) as a fractal surface which imposes ever growing constraints on the numbers of aging lobsters. Peters (1983) has summarized the information supporting a general inverse relationship between body size and density in animal populations. Behavioral interactions between older male lobsters and younger subordinates (Lawton and Lavalli 1995) may be a mechanism limiting recruitment in senile populations and may explain the lack of recruit size lobster in Herrick's (1909) sample data as compared to modern data. Such a mechanism has been demonstrated for crayfish (Momot 1998). Strong density dependence in lobster would mean that current egg production may not be as low as indicated by the EPR results and that virgin stock size may not greatly exceed that existing today. That lobster may not have been fished to as low a level as heretofore thought, is a simple if not obvious explanation for their great resiliency. To evaluate this possibility, a biomass dynamic model was applied to landings and abundance data for the RI inshore lobster resource. Although the area is small relative to conventional assessment areas for the species, there is a long time series of abundance data for the area. The biomass dynamic model estimates among other things, unfished stock size which may be compared to current biomass levels and the fishing mortality rate for maximum sustainable yield ($F_{msy}$).

## Stock Structure-

The lobster stock in National Marine Fisheries Service (NMFS) statistical reporting area 539 was assessed using fishery landings and independent survey abundance data. Statistical area 539 covers Narragansett Bay and the adjacent waters of Rhode Island and Block Island Sounds (Figure 1). It is part of the south of Cape Cod to Long Island Sound inshore area (SCCLIS) currently assessed by NMFS (NEFSC 1996). Lobster populations are distributed from Labrador to Cape Hatteras out to depths of 700 m (Fogarty et al. 1982). A study of genetic variation in the species found some difference between distant inshore populations and between inshore and offshore populations (Tracey et al. 1975). Ennis (1986) reviewed the genetic data, tagging results, and landings patterns and concluded that several stocks exist but their boundaries were indistinct. Fogarty (1995) in a later review, concluded that evidence of genetic differences between inshore and offshore stocks was equivocal. Assessment scientists currently recognize three US stock areas based on biological attributes; Gulf of Maine, Georges Bank and south, and SCCLIS (NEFSC 1996). The peer review panel considered this separation reasonable but recommended conducting assessments on a finer scale if possible. This assessment addresses that recommendation. The SCCLIS stock area corresponds approximately with ASMFC management area 2. Population closure is not achieved within area 539 nor within SCCLIS in general as there is tagging evidence that some inshore lobsters disperse from Eastern Long Island Sound through Block Island Sound toward the submarine canyons (NUSCo. 1998). Fogarty et al. (1980) also documented movements between the inshore and offshore area. Offshore stocks undertake seasonal onshore migrations, mixing with inshore stocks (Uzmann et al. 1977). Long distance movements are size related and associated with sexual maturity (Krouse 1980). Under heavy exploitation however, most movements are localized so that the area 539 stock boundary is sufficient for local assessment purposes. Long distance movements of inshore tagged lobsters toward the submarine canyons of the continental shelf could cause underestimation of lobster population size based on area 539 data alone. Lobster stocks likely exist as a metapopulation with as yet unknown topology between patches (Fogarty 1995, 1998, ASMFC 1996). Katz et al. (1994) have shown that larvae hatched along the continental shelf in southern New England could recruit to coastal areas. This, along with migrations of mature adults, is sufficient to maintain gene flow between inshore and offshore stocks (Cobb 1995). If a larval subsidy accrues to inshore stocks from offshore spawning, the spawner biomass supporting inshore yield and recruitment could be underestimated. Also, resilience of the inshore stock to fishing would be overestimated and contingent on maintenance of the offshore sanctuary (Fogarty 1998).

**Methods and Data Sources-**

Abundance Indices- Two trawl surveys are conducted in the assessment area which estimate lobster abundance. The Rhode Island Division of Fish and Wildlife (RIDFW) conducts a seasonal trawl survey in Narragansett Bay and the adjacent sounds. The survey makes 42 tows during each spring and fall cruise employing a random stratified design (Lynch 1998). For the purposes of this work, spring and fall cruise data were combined. Data were available from 1979 to 1999. Mean catch per tow was computed for all lobster 72 mm carapace length and larger as this size defines legal lobster and those which recruit to legal the next molt. The University of Rhode Island Graduate School of Oceanography (URIGSO) has conducted a trawl survey in Narragansett Bay since 1959 (Jeffries et al. 1989). The survey samples two fixed stations in the lower West passage on a weekly basis. Abundance estimates between the two surveys were highly correlated allowing them to be inter-calibrated into a single long term abundance index in RIDFW units. This was done by fitting a log-log regression model to the 1979-1998 overlap period. Abundance estimates in RIDFW survey units for years 1962-1978 were hindcast from the URIGSO indices using the regression results.

Landings Data- Commercial lobster landings for the state were obtained from NMFS sources for years 1962 to 1998. The RI inshore area is characterized by landings from NMFS statistical area 539. Area 539 specific landings were available from NMFS sources through 1994. With implementation of the VTR system, area specific landings have been difficult to estimate since state licensed fishers are not required to report. Total Rhode Island and area 539 specific landings were highly correlated ($r=0.93$, $P<0.01$). Estimates for area 539 in 1995-1998 were made from total Rhode Island landings and the fitted regression equation. No attempt was made to dissagregate landings or abundance data by sex. No sea sample data is available prior to 1991 to estimate sex ratio in the catch. Total mortality rates are about 25% higher in male lobster in the SCCLIS region because of the protection offered to ovigerous females (NEFSC 1996). Combining sexes may overestimate female rates but is conservative in terms of resource assessment. It also limits problems caused by differential trends in sex-specific, recruit abundance indices.

The reported landings data exhibit an anomalous and abrupt increase occurring midway through the time series. Between 1982 and 1983, landings increased by over 200% and remained high. Baranov's catch equation requires a large increase in abundance and/or fishing effort when landings increase. Abundance indices and trap count data show no such increase suggesting a reporting change. Interviews with RIDFW staff formerly employed as NMFS port agents indicate that large amounts of landings were unreported prior to 1983 (A. Valliere- pers. comm.). The amount of "new" landings discovered by the expanded canvas procedure was reported to be about 450 tons. It was concluded that landings prior to 1983 were under reported and an adjustment was needed. A categorical regression was used to estimate the correction factor. To adjust the 1962-1982 landings, the estimated intercept was added to the observed values.

Fishery Sea Sampling- RIDFW staff scientists have sampled catch aboard inshore lobster fishing vessels since 1991. Details of the program may be found in Angell and Olszewski (1999). Briefly, two trips are made each month aboard RI inshore lobster vessels and catch is processed for biological data. The number of pots hauled is enumerated. Lobster catch is separated by sex, ovigerous condition, and measured for carapace length. An annual legal CPUE index is computed by averaging the 24 trips within a year. Legal CPUE consist of all non-ovigerous lobster above 82.6 mm. An estimate of total effort (pot hauls) in the fishery can be made by dividing landings by mean CPUE. Catch rates of sublegal lobster are also routinely calculated.

Auxiliary Mortality Rates- Biomass dynamic models can be "tuned" to external data on fishing mortality rate. Calibrating model F to independent F estimates constrains the estimation and reduces the scaling problem, i.e. information on the catchability parameter is provided. Independent estimates of F may come from tagging studies or size composition analyses. Gibson (1999) estimated fishing mortality rates from trawl survey size composition data using catch curve methods. RIDFW spring and fall survey data were combined and CPUE by molt group was calculated. Total mortality rate was estimated as:

$$Z_t = -log[(N_{t+1}/(N_t+pR_t)] \qquad (1)$$

*where:* $Z$ = *total mortality rate*
$N$ = *cpue legal lobsters 83+ mm*

$R$ = cpue lobsters 72-82 mm
$p$ = proportion of recruits that molt into legal size
$t$ = year.

The parameter p was estimated from a long term tagging study in Connecticut (D. Landers, NUSCo.- pers. comm.) and RIDFW sea sample data on maturity rates. Tag data give direct estimates of molt probability while the maturity status excludes a percentage of females from the recruit pool since molting and reproduction are generally staggered in females (Waddy and Aiken 1995). Estimates of Z were made for years 1979-1998 and reduced by M=0.10 to estimate F on legal lobster. A lowess smoothing algorithm (tension =0.5) was applied to the time series of F estimates to reduce the influence of survey availability. The estimates of F were used calibrate the biomass dynamic model.

The URI Department of Fisheries (URIDOF) has tagged lobster caught during research trawl surveys in the west passage of Narragansett Bay since 1994 (Castro 1998). Legal and recruit lobster are tagged with T-bar anchor tags at Whale Rock and Fox Island in the lower west passage. Recoveries are made by commercial gear and several scientific surveys in the area. If mortality rate, recovery effort, and tag return rates have been relatively constant in recent years, an estimate of total mortality rate can be made assuming an exponential depletion model. Given assumed rates of natural mortality and tag loss, total mortality can be reduced to fishing mortality. Tag return data from the URI study were obtained (K. Castro- pers. comm.), pooled across release year, and summed by 100 day at large time intervals. Mortality rate was modeled as a declining exponential over time:

$$R_t = R_0 e^{-Zt} \qquad (2)$$

where:

$R$ = number of tag recoveries
$R_0$ = initial abundance parameter
$Z$ = instantaneous mortality rate
$t$ = time interval (100 days).

An estimate of Z was made as the slope of a regression of $\log_e$ tag returns vs. days at large:

$$\ln(R_t) = \ln(R_0) - Z^*t. \qquad (3)$$

Fishing mortality rate was estimated as Z minus 0.20 to account for natural mortality and tag loss.

Estimates of Fishing Mortality and Stock Sizes- The preferred method to assess an age uncertain stock and estimate MSY based BRPs is a non-equilibrium stock production model also known as a biomass dynamic model. This type of model was recently used to assess rock lobster stocks in Australia (Chen and Montgomery 1999). In addition to estimation of MSY type reference points, production modeling may allow for examination of trends in lobster productivity if a sufficiently long data base is available. Biomass dynamic models differ from the DeLury model in that a stock regenerating function is substituted for the empirical recruitment index. In most applications, logistic type population growth is assumed. Data required are a time series of landings and a biomass index along with any auxiliary estimates of F or stock biomass to tune the model. Biomass dynamic models are a mass balance approach in which stock biomass in a new year is the sum of last years biomass plus new production minus the catch removed (Hilborn and Walters 1992). New production is the net balance between additions from growth and recruitment and natural losses. If stock growth is assumed to follow the familiar logistic curve, a simple biomass model in discrete form is:

$$B_t = B_{t-1} + rB_{t-1}(1-(B_{t-1}/k)) - C_{t-1} + e_p \qquad (4)$$

*where:*

$B$= *population biomass*
$C$= *catch*
$r$= *per capita rate of increase*
$k$= *unfished population biomass.*
$t$= *year*
$e_p$= *process error term.*

The r parameter is a measure of the population growth rate in the absence of density dependent factors, that is at low abundance. The term in parenthesis in eq. 4 is the density dependent feedback mechanism which reduces stock growth when abundance is high. The discrete form of the production model is a simplification over the differential equation which forms the basis for example of Prager's (1994) ASPIC application. Hilborn and Walters (1992) note that the discrete and differential forms are essentially equivalent unless extreme values of r and fishing mortality (F) occur. Biomass in eq.4 is not total stock weight but that vulnerable to the fishery.

Since the actual biomass levels are not known, an observation model is needed in the form of survey or fishery catch per unit effort:

$$B_t = (U_t)/q + e_m \qquad (5)$$

*where:*

$B$= *biomass*
$U$= *survey abundance*
$q$= *catchability coefficient*
$t$= *year*
$e_m$= *measurement error term.*

Survey abundance is used in this work and is preferred since it avoids the problems of standardizing fishing effort. The q parameter is a scaler which relates survey abundance to absolute stock abundance. Substitution of eq.5 into eq.4 and combining error terms gives the final biomass dynamic model form:

$$U_t = U_{t-1} + rU_{t-1}(1 - U_{t-1}/kq) - qC_{t-1} + e \qquad (6)$$

Parameters in eq. 5 (r,k,q) were estimated by minimizing the sum of squares deviations between observed and predicted log catch per unit effort or:

$$\text{minimize} \sum_{t=1}^{n} (\ln U_t - \ln \hat{U}_t)^2 \qquad (7)$$

A mixed error model was assumed so that the residual sum of squared (RSSQ) was composed of process error in the population dynamics model and measurement error in the CPUE indices (Polachek et al. 1993, Chen and Andrew 1998). This procedure involves estimation of additional parameters in the form of process errors and a starting biomass level ($U_0$). Weighting in the minimization was adjusted until the proportion of RSSQ was uniformly distributed amongst error components. Solutions were found with the EXCEL problem solver employing a quasi-Newton search method with quadratic approximation. The EXCEL production model was modified from a catch-survey application provided by J. Collie from the University of Rhode Island Graduate School of Oceanography. As suggested by Hilborn and Walters (1992) and Prager (1994), the objective function (eq. 7) was expanded to consider auxiliary data.

$$\text{minimize} \sum_{t=1}^{n} (\ln U_t - \ln \hat{U}_t)^2 + \alpha \sum_{t=1}^{n} (\ln F_t - \ln \hat{F}_t)^2 \qquad (8)$$

Auxiliary F data can be given various weights depending on the level of confidence in the data. In this assessment, auxiliary F data was weighted so that it made a similar contribution to the RSSQ as the abundance data. Model F was calculated by solving exploitation rate (catch/biomass) for F assuming M=0.10 with a maximum F constraint of 3.0 applied. Uncertainty in estimated quantities was evaluated with bootstrapping (Efron 1982). Residuals from the original model fit were randomly resampled and added to the estimated abundance indices and auxiliary F estimates. The model was then successively refit to the alternate input data series and output quantities accumulated over 500 replications. Means and variances for parameters and calculated quantities were estimated directly from the bootstrap results. Uncertainty was expressed as a coefficient of variation (CV) or as an empirical 80% confidence range. Management quantities of interest were included in the bootstrap exercise and are defined from the population dynamics process as:

| | |
|---|---|
| Maximum Sustainable Yield | $MSY = rk/4$ |
| Biomass for MSY | $B_{msy} = k/2$ |
| Fishing Rate at MSY | $F_{msy} = r/2$ |

Sensitivity runs were made to examine the influence of process error and auxiliary F weights on relative F and biomass levels. Prager (1994) suggested focusing on relative parameter levels, i.e. the estimate divided by the MSY counterpart, since they are more robust to model structure. Process weights were varied so that process error as a proportion of the RSSQ varied from 5% to 70%. Auxiliary F weights were varied so that the survey based F's had virtually no influence or nearly completely determined model F rates. Trial runs were also made using only the first or second half of the time series to evaluate stationarity of the production parameters (Hilborn and Walters 1992).

**Results-**

Trawl Survey Abundance- Abundance of lobster in the RIDFW and URIGSO trawl surveys from 1979 to 1999 is plotted in Figure 2. Both surveys show strong increases in abundance over the past two decades with evidence of a decline in recent years. In the log scale, the series were significantly correlated ($r=0.86$, $P<0.001$) and exhibited good linearity (Figure 3). Regression residuals were well behaved (Figure 4). Long term abundance from the inter-calibrated surveys in RIDFW units is found in Figure 5. Two peaks in abundance, 1967 to 1977 and 1990 to 1997 are evident. Very recent abundance has declined somewhat but remains at above average levels.

Fishery Landings- The regression of reported landings on period variable (1962-1982=0, 1983-1998=1) was highly significant ($F=134.9$, $P<0.001$). The intercept of the regression (323.0 metric tons SE=53.8), estimates the intervention effect of improved reporting. Reported and adjusted landings are plotted in Figure 6. As noted earlier, reported landings exhibited an abrupt increase from 1982 to 1983 which is not reflected in the trawl abundance data. It is worthwhile noting that biomass dynamic model runs using landings without adjustment exhibited serious diagnostic problems including a massive increase in fishing mortality rate between 1982 and 1983. We are not aware of any reason for increased fishing effort in 1983. The most parsimonious explanation is that offered by former port agents, namely that considerable under reporting occurred prior to 1983. All analyses that follow use the adjusted series from Figure 6. The adjusted series closely tracks the independent abundance data with two periods of higher abundance (1968-1974, 1989-1994) and a recent moderation from very high levels.

Sea Sampling Results- Legal catch per pot haul has varied between 0.8 and 1.3 pounds per haul since 1991 (Figure 7a). Although the trend has a slight negative slope, the regression was not significant. Landings significantly declined from nearly 2000 tons to less than 1200 over the same time period. The estimated number of trap hauls deployed in making the catch fell from about 3.5 million to about 2.8 million, a decline of 19%. The sea sample data indicate that while there may have been some decline in abundance, landings have clearly declined. If catchability per pot haul is constant, the decline in estimated effort should be reflected in a reduction in fishing mortality. Sublegal CPUE has been stable over time, ranging from 1.7 to 2.9 animals per tow (Figure 7b).

Survey and Tag Based Estimates of Fishing Mortality- Estimates of molt probability (p in eq.1) for recruit lobster (72-82 mm) were similar. NUSCo. data on time at large and growth increment estimated that 80% of lobsters (sexes combined) in this size class would molt at least once over the course of a year. Of the 9234 recruit females examined by RIDFW during sea sampling, 56.6% (SE=0.26) had maturing ovaries. Only 43.4% would be available to molt. If a 50:50 sex ratio exists and all male recruits molt, the total proportion molting would be 72%. To estimate F by eq. 15, a mean proportion of 76% was used. Survey based estimates of F are plotted in Figure 8. The lowess algorithm smoothed extreme values of F which are likely due to anomalies in survey availability, particularly in 1992-1993. Fishing mortality rate has fluctuated without trend around a mean of F=1.05. The estimate for 1998-1999 was 1.51.

Tag returns from the URI study in Narragansett Bay are plotted against days at large in Figure 9 along with the fitted regression curve. The exponential model explained 76% of the variation in log recaptures. Residuals properties were adequate with respect to time (Figure 10). The estimated slope was -0.0048 per day (SE=0.0008). This corresponds to an annual Z of 1.76. If natural mortality and tag loss are both 0.1 per year, then F in recent years has been 1.56. This estimate is very close to that from analysis of size composition in the trawl surveys. The exponential depletion estimator would be sensitive to any dispersion of the tagged population outside of the area where recovery effort is expended.

Biomass Dynamic Model Results- A summary of biomass dynamic model results is given in Table 1 and complete output is given in the Appendix. The observed and model estimated trawl abundance trend is given in Figure 11. The model estimated trend conforms closely with the observed data except in recent years when the survey becomes erratic. Large deviations in 1992-1993 and 1996-1997 were treated by the model as measurement errors. The large survey index in 1993 is likely related to a delay in starting the survey due to vessel problems. This resulted in the spring survey being conducted in warmer water with correspondingly higher catch rates. Absolute abundance and landings are plotted in Figure 12 relative to $B_{msy}$. Absolute abundance is the estimated survey index, divided by the estimated catchability coefficient. Abundance in recent years is very near the $B_{msy}$ level after a series of years above it. Biomass in 1999 was estimated at 2202 metric tons with an 80% confidence interval of 1550-3450. Mean 1996-1999 stock size was 3205 metric tons (80% CI: 2850-4220). Fishing mortality was quite high in the mid-1960's before dropping to lower levels by 1974 (Figure 13). This was followed by a period of F over 1.0 from 1978 to 1986. Recent F estimates have moderated and fluctuated around the $F_{msy}$ level since 1994. The decline in F occurs because landings drop while abundance remains relatively high. F in 1998 was estimated at 0.76 with an 80% confidence interval of 0.45 to 1.05. Mean F during 1996-1998 was 0.51 (80% CI: 0.37-0.63).

Precision on model parameters and derived management quantities was generally good with CV's ranging from 0.065 to 0.350. Precision was lowest on terminal F and biomass estimates and highest on derived management quantities. Bootstrap distributions for 500 model replications are plotted in Figures 14-23. MSY was estimated at 1287 metric tons with an 80% confidence bound of 1275-1520. Biomass for MSY was 2296 tons (80% CI: 2075-2750). The fishing mortality rate at MSY was estimated at 0.56 (80% CI: 0.53-0.63). Logistic model parameters were well estimated with CV's less than 10%. The per capita rate of increase was estimated at 1.12 with an

80% confidence bound of 1.06-1.30. Unfished stock size was estimated at 4593 tons (80% CI: 4150-5550). The catchability parameter was estimated at $1.07*10^{-3}$ ($9.1*10^{-4}$-$1.13*10^{-3}$). Bootstrap estimates of r and k were significantly correlated in an inverse manner ($P<0.001$), emphasizing the difficulty in estimating parameters when the exploitation history has not been experimentally controlled. Because of the correlation, uncertainty remains over whether the stock is large and of low productivity or small with high productivity.

Residual plots are found in Figures 24-26. They were generally acceptable but some patterns are worth mentioning. Process errors displayed a block of negatives in the late 1970's and early 1980's which shifted to predominately positive residuals 10 years later. This suggests increasing stock productivity that the constant logistic parameters could not accommodate. This was confirmed by fitting the model to partial time series. The 1962-1980 series estimated the per capita rate parameter at 0.89 while the 1981-1999 series estimated it at 1.36. Carrying capacity (k) did not change between time periods. Observation errors tend to grow larger over time despite estimation in the log scale. This suggests that abundance has become more variable, albeit higher over time, perhaps as a results of high F which makes the stock more dependent on incoming recruitment. A general increase in water temperature in the area may also be affecting survey catchability. There is a trend in auxiliary F residuals, changing from negative to positive. Survey based estimates of F are high and without trend from 1979 to 1998 whereas biomass dynamic model F declines with falling landings. Survey F rates were computed directly from the size composition and require an estimate of molt probability. Biomass dynamic model F is calculated essentially from catch divided by estimated biomass. Both approaches have weaknesses and further research is warranted to investigate the effect of trends in molt probability (survey based F) and changes in the seasonality of the fishery (biomass dynamic F).

Terminal estimates of fishing mortality rate relative to $F_{msy}$ were sensitive to the proportion of process error allowed in the model (Figure 27). At low levels of process error, estimates of relative F were consistently above 1.0 indicating fishing in excess of $F_{msy}$. When process error increased to over 40% of the RSSQ, F was below $F_{msy}$. Conser and Idoine set process error at 10-20% of the RSSQ to smooth F trajectories. This assessment used a somewhat higher level of 33% which provided the most consistent residual properties. Relative biomass level was sensitive to process error weighting as well (Figure 27). With low levels of process error, biomass was above $B_{msy}$ and vice versa. The weight assigned the auxiliary F data had considerable influence on terminal year estimates (Figure 28). At very low weights, i.e low influence, the stock condition was more optimistic. F was below $F_{msy}$ and biomass above $B_{msy}$. With increasing influence of the external F rates, terminal F rises rapidly above $F_{msy}$ and biomass falls below $B_{msy}$. High F rates based on survey size composition are corroborated by the tagging study in the area. Forcing the model to closely match the survey F however triggered observation error problems. It is not known why the biomass dynamic model using only catch and abundance data estimates lower F. More research is warranted, particularly in the area of comparability of biomass and size structured F estimates.

## Stock Summary and Discussion-

The Rhode Island inshore lobster stock has increased in abundance over the past three decades. Peak abundance was reached in 1990-1997. Abundance has fallen somewhat in recent years but remains above the long term average. The 1999 estimated abundance of 2202 metric tons (80% CI: 1550-3450) is very close to the estimated $B_{msy}$ level of 2296 tons (2075-2750). The biomass estimates suggest that lobster abundance in the RI inshore area approached carrying capacity in the mid-1990's and that the recent reduction may be a response to density. Fishing mortality rates moderated in the 1990's and have fluctuated around $F_{msy}$. The recent decline in F is corroborated by sea sample estimates of effort in the fishery which also decline. Mean F in 1996-1998 was 0.51 (80% CI: 0.37-0.63) compared to an $F_{msy}$ estimate of 0.56 (0.53-0.63). If $F_{msy}$ is considered an over fishing definition then target F should be somewhat below $F_{msy}$ considering uncertainty in the estimate. The lower 80% confidence bound on $F_{msy}$ was 0.53. A useful target might be 80% of $F_{msy}$ or 0.45. Mean F from 1996-1998 (F=0.51, 80% CI: 0.37-0.63) is above $0.8F_{msy}$ and the uncertain 1998 terminal estimate of 0.76 (0.45-1.05) is a concern. In terms of biomass, stock size in 1999 was very close to $B_{msy}$ =2296 tons and the three year mean exceeded it (3205 80% CI: 2850-4220). Collectively, the results indicate that a 12% reduction in F (0.51 to 0.45) is warranted to maintain stock biomass above the $B_{msy}$ level with reasonable certainty.

These results are at odds with past assessments which indicated large deficits between prevailing F and BRP's (NEFSC 1996, ASMFC 1996). Those conclusions however were as noted earlier, derived from assessment models and BRP models which were not linked and included no compensatory elements. The SARC 22 assessment indicated that mean F on SCC-LIS females was 1.3 compared to an F10% estimate of 0.44. The prevailing rate of fishing was associated with only about 6% of unfished egg production and a 66% reduction in F was needed. Similarly, the Gulf of Maine (GOM) had a mean F=0.62 vs. an F10% estimate of 0.32. The GOM was at about 4% of unfished egg production and needed a 48% reduction in F. This new work has shown that lobster have a considerable compensatory reserve. The estimate of r from the production model is in the upper range reported for finfish stocks in the summary of Myers et al. (1999) and consistent with the steep stock-recruit slope estimated by Fogarty and Idoine (1986). This work also indicates that egg production in the SCCLIS area is not as low as indicated by SARC 22. Abundance is currently near $B_{msy}$ or one-half capacity. If unfished, exploitable biomass is 4593 metric tons, unfished mean weight is about 2.2 kilograms (Fogarty 1995, Gibson 1999), sex ratio is 50:50, and Herrick's (1909) fecundity schedule applies; egg production would be about 30 million per year for a two year cycle. The mean size of females in the catch is now about 87 mm or 0.52 kgs (Angell and Olszewski 1999). If biomass is now 2202 tons, egg production is about 12 million or 38% of an unfished stock. Jensen (1986) showed that the Maine lobster stock declined from about 70,000 metric tons in 1935 to about 20,000 tons in 1972. He estimated the carrying capacity at 80,000 tons suggesting that the stock was about 25% of maximum during the low levels of the 1970's. The SARC 22 assessment indicates that the same stock increased from about 24,000 tons in 1981 to 50,000 by 1993 (NEFSC 1996) or about 63% of Jensen's estimate of virgin biomass. His analysis is no doubt flawed by equilibrium estimation methods but even if virgin biomass was double his estimate, the stock was higher than 10% during the 1970's low point and was about 30% in recent years. As with the RI inshore area, the GOM data do not support the conclusion that egg production is very low in lobster stocks. Similarly, the rock lobster stock in New South Wales was recently assessed at about 25% of maximum after 100 years of steady exploitation (Chen and Montgomery 1999). Finally, Addison (1986) noted the lack of realism in per recruit models which predict order of magnitude increases in large lobster at low F. He states that for the heavily exploited European lobster fishery off the east coast of England, dive surveys indicate that the habitat could only support a 2-3 fold increase in large lobster abundance which would mean the stock is at 33-50% of maximum. Although size composition would be greatly extended under no fishing and individual fecundity would be high, the carrying capacity limit on overall biomass would constrain egg production which is roughly proportional to weight. These observations underscore the difference between non-equilibrium conditions and equilibrium, per recruit projections. This assessment and information from other studies indicate that EPR analysis alone provides an overly pessimistic appraisal of lobster reproductive output. It is essential that stock biomass levels be considered in addition to fishing mortality rates (Crecco 2000). A formal control rule should be developed for lobster incorporating both.

**Key Uncertainties-**

<u>Discrepancies Between Model and External F Estimates</u>- Size composition in surveys and recent tagging results indicate higher fishing mortality than the biomass dynamic model in recent years. Independent sea sample data indicate a recent drop in effort as pot hauls, corroborating the model. The gap can be closed by increasing the influence of the external F estimates but this causes positive residuals between observed and estimated abundance indices. The discrepancy manifests itself in an inverse correlation between the intrinsic rate of increase and carrying capacity parameters of the logistic population model. There is a continuum of plausible solutions ranging from large stocks with low productivity to smaller stocks with higher productivity. It is likely that the production dynamics have changed over time in relation to environmental or biological factors. If identified, these could be used as covariates in a generalized production model. Management of stocks fluctuating between high and low productivity regimes needs to be precautionary when the regime shifts are not predictable.

<u>Potential Linkages with Other Stock Areas</u>- This assessment assumes that the Rhode Island inshore area is closed. Emigration of lobster from the inshore to offshore area and larval subsidy from offshore to inshore area are possible (Fogarty 1998). The impact on the assessment depends on the relative rates. Referring to eq. 2, emigration would function as a drain on the inshore stock much like catch. Larval subsidy would inflate the productivity parameter r. If the rates offset one another, the assessment is unaffected. If larval subsidy exceeds emigration losses, the resiliency of the inshore stock is overstated. Linked production models should be explored between the inshore and offshore areas.

<u>Size Structured Effects</u>- The lumped, biomass dynamic model does not take into account the effect of size structure on lobster population dynamics. Because of the 100 plus year exploitation history, there are no stock production data for unexploited stocks. The implications to growth, recruitment, and natural mortality of a greatly expanded size structure in the inshore area are not known. The complicated life history and behavioral repertoire of lobster may result in deviations from the logistic growth curve in the form of time lags, asymmetries, or multiple equilibria. It

also may be possible to refine the abundance index to reflect a series of gauge size which occurred since 1967.

Spatial Effects- The fishery in the RI inshore area may have expanded even within area 539. The trawl surveys are conducted in near shore areas. There may be a progressive mismatch developing between the area surveyed and area fished. Additional abundance data from the NEFSC/NMFS surveys in federal waters of area 539 should be examined and included in the assessment. Exploratory biomass dynamic model runs with a combined RI-NMFS survey index showed qualitatively similar results but the model needs to be generalized to handle multiple indices.

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**Table 1- Summary of Results for Biomass Dynamic Model Applied to the Rhode Island Inshore Lobster Stock.**

| Parameter or Mgt. Quantity | Estimate | Bootstrap CV | Lower 80% | Upper 80% |
|---|---|---|---|---|
| Stock Biomass in 1999 | 2202 | 0.350 | 1550 | 3450 |
| Mean 1996-1999 Biomass | 3205 | 0.082 | 2850 | 4220 |
| Fishing Mortality in 1998 | 0.757 | 0.326 | 0.450 | 1.050 |
| Mean 1996-1998 F | 0.509 | 0.197 | 0.370 | 0.630 |
| r parameter | 1.121 | 0.084 | 1.060 | 1.300 |
| k parameter | 4593 | 0.111 | 4150 | 5550 |
| q parameter | 0.00107 | 0.078 | 0.00091 | 0.00113 |
| MSY | 1287 | 0.065 | 1275 | 1520 |
| Fmsy | 0.561 | 0.084 | 0.530 | 0.630 |
| Bmsy | 2296 | 0.111 | 2075 | 2750 |

## Figure 3-1
## NMFS Statistical Areas and US Lobster Stock Areas

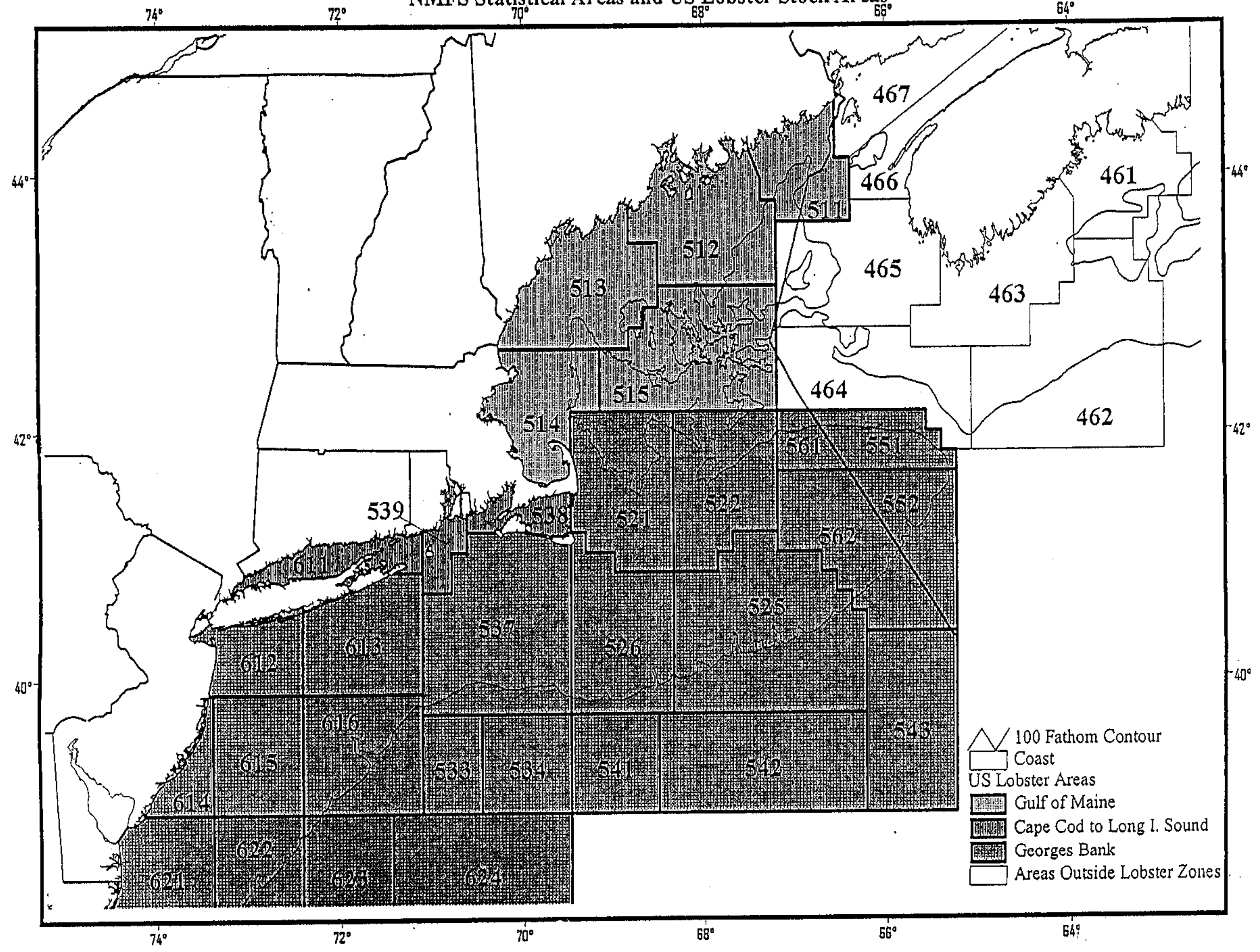


Fig.2- Abundance of Legal and Recruit Lobster in the RIDFW and URIGSO Trawl Surveys in Narragansett Bay and Coastal RI Waters

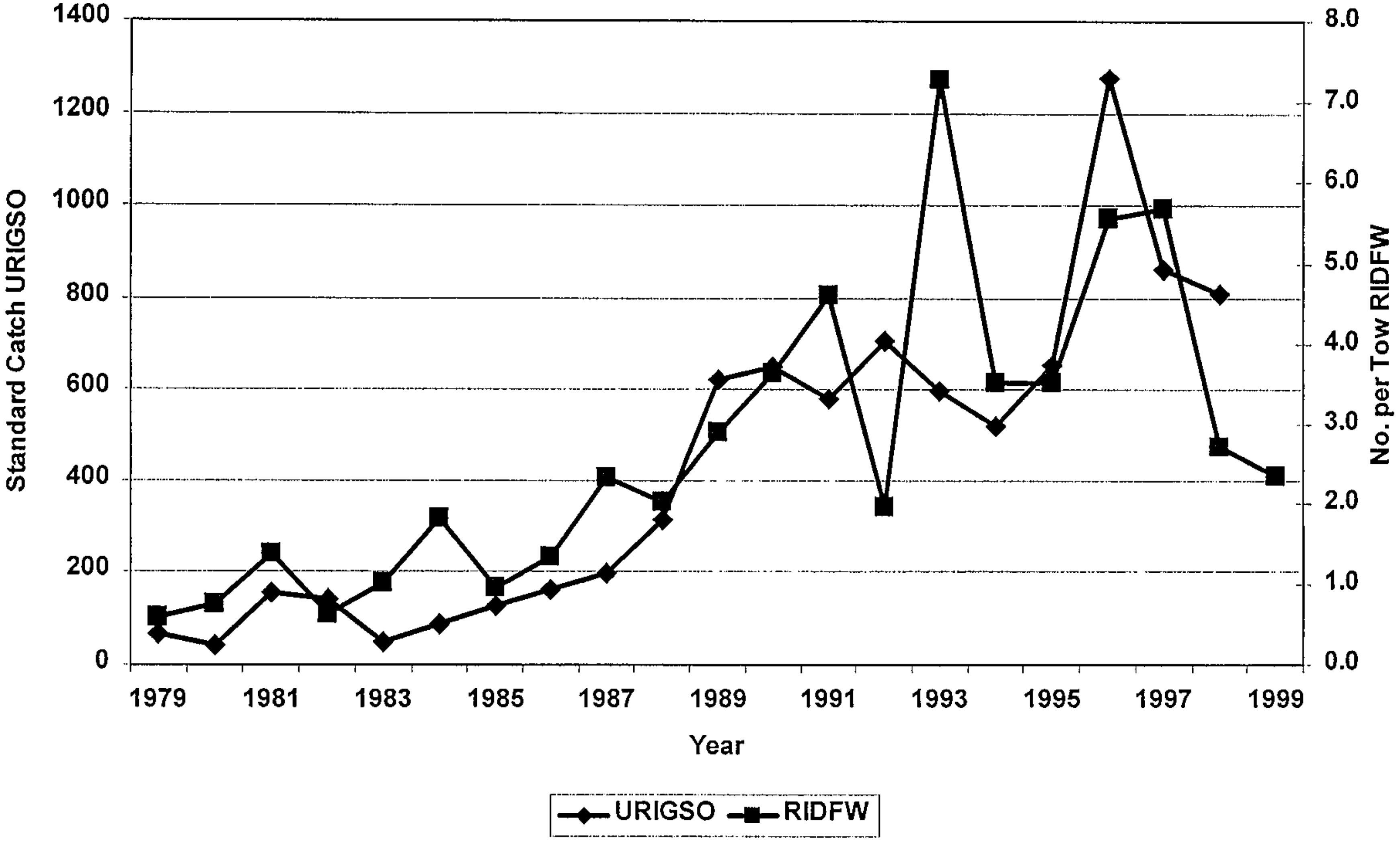


Fig.3- Regression of RIDFW Legal and Recruit Lobster Trawl Abundance on URIGSO Trawl Abundance

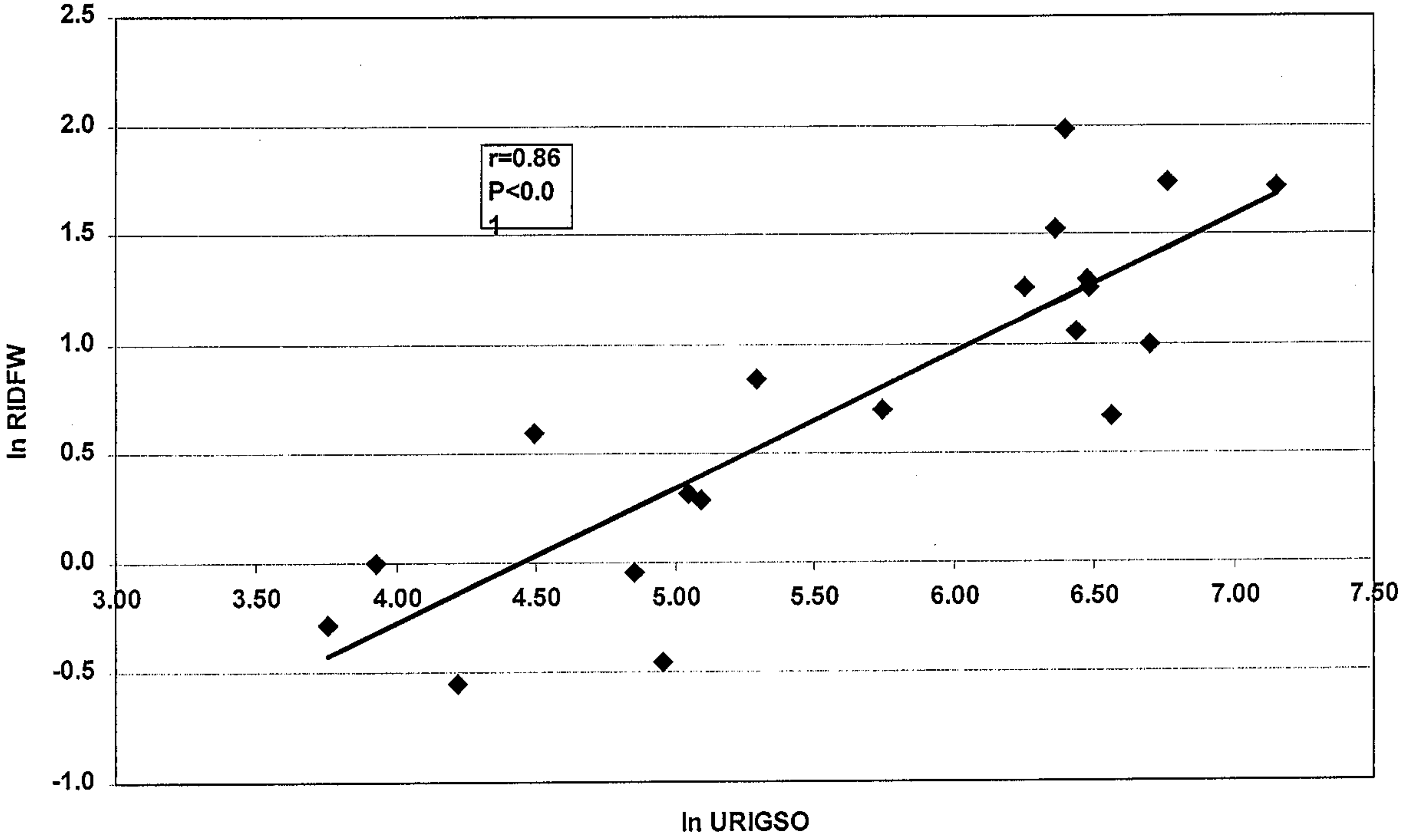
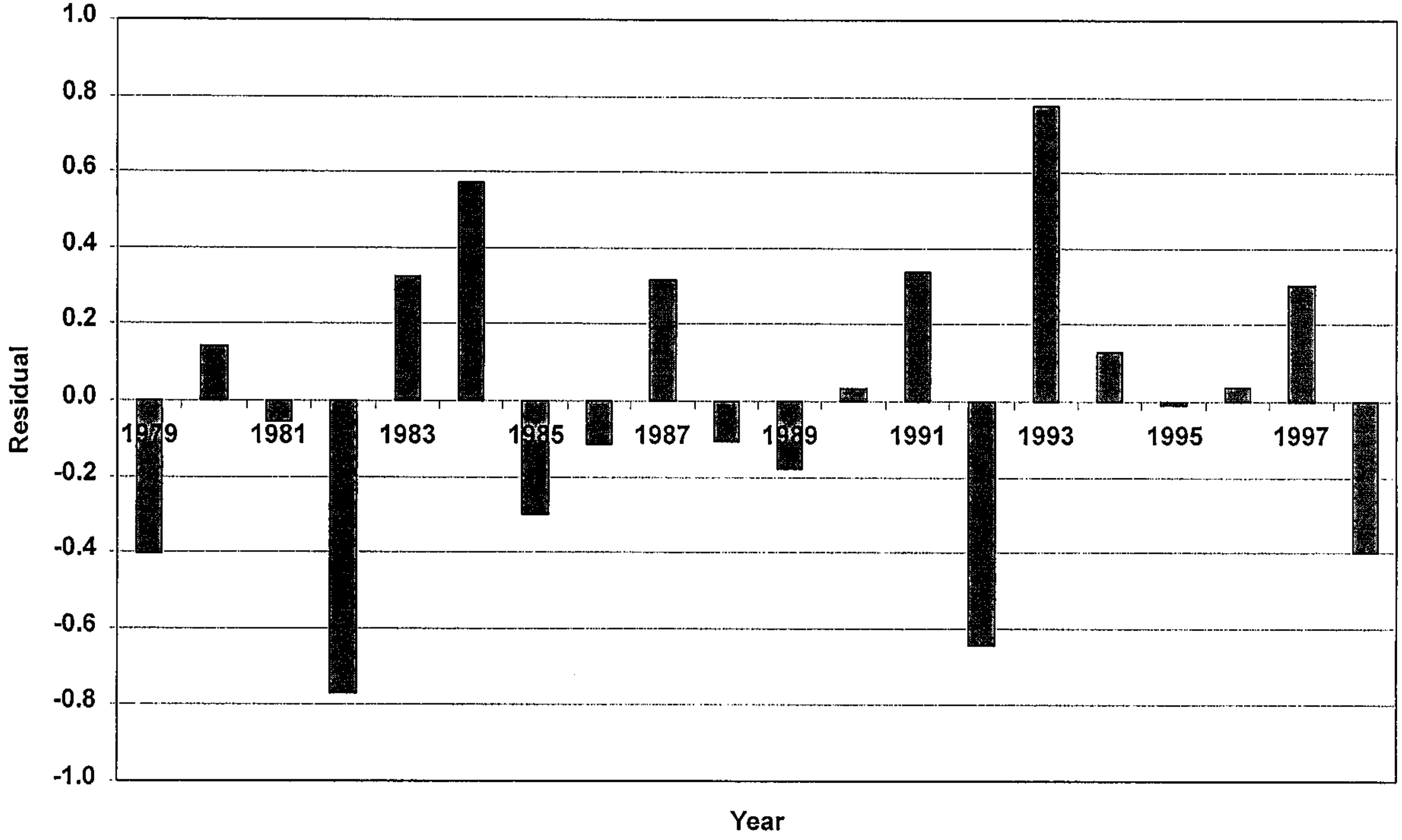


Fig.4- Residual Time Plot for Legal and Recruit Lobster Abundance Index Calibration Regression



## Fig.5- Long Term Legal and Recruit Lobster Abundance in the Narragansett Bay Area from the RIDFW and URIGSO Trawl Surveys

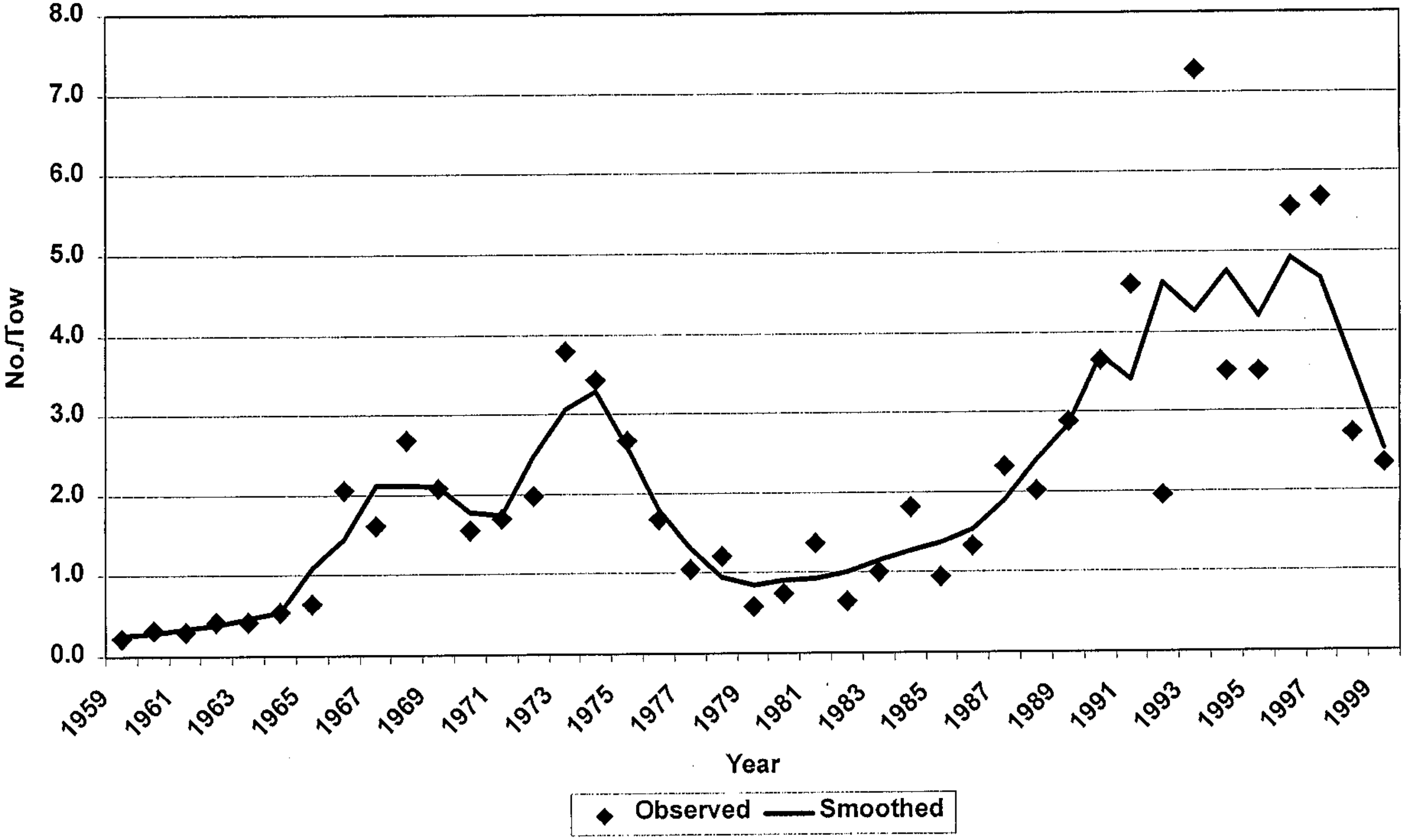


Figure 6- Rhode Island Inshore Lobster Landings, 1962-1998

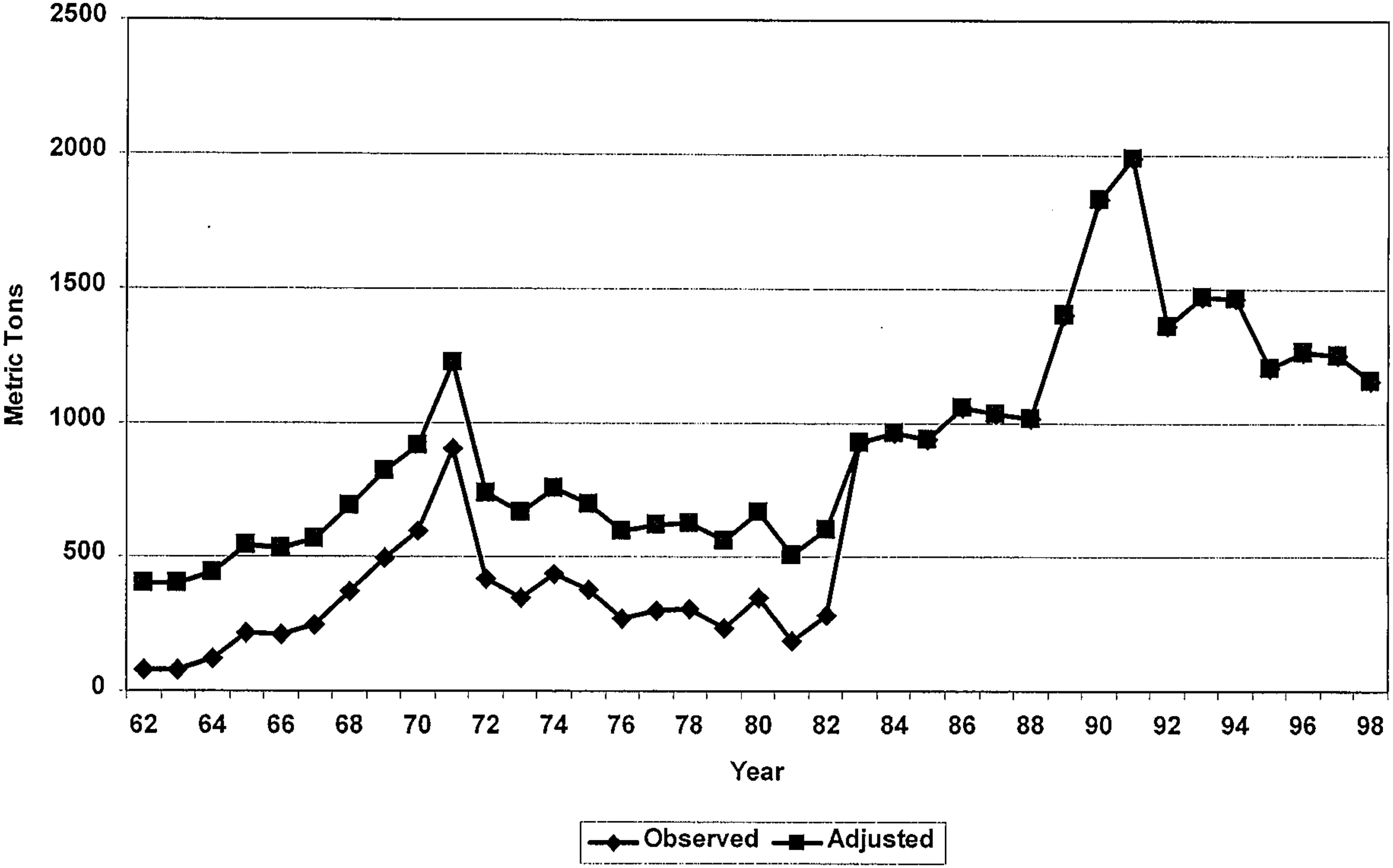


Fig.7a- Landings, Catch per Pot Haul, and Total Trap Hauls in the RI Inshore Lobster Fishery

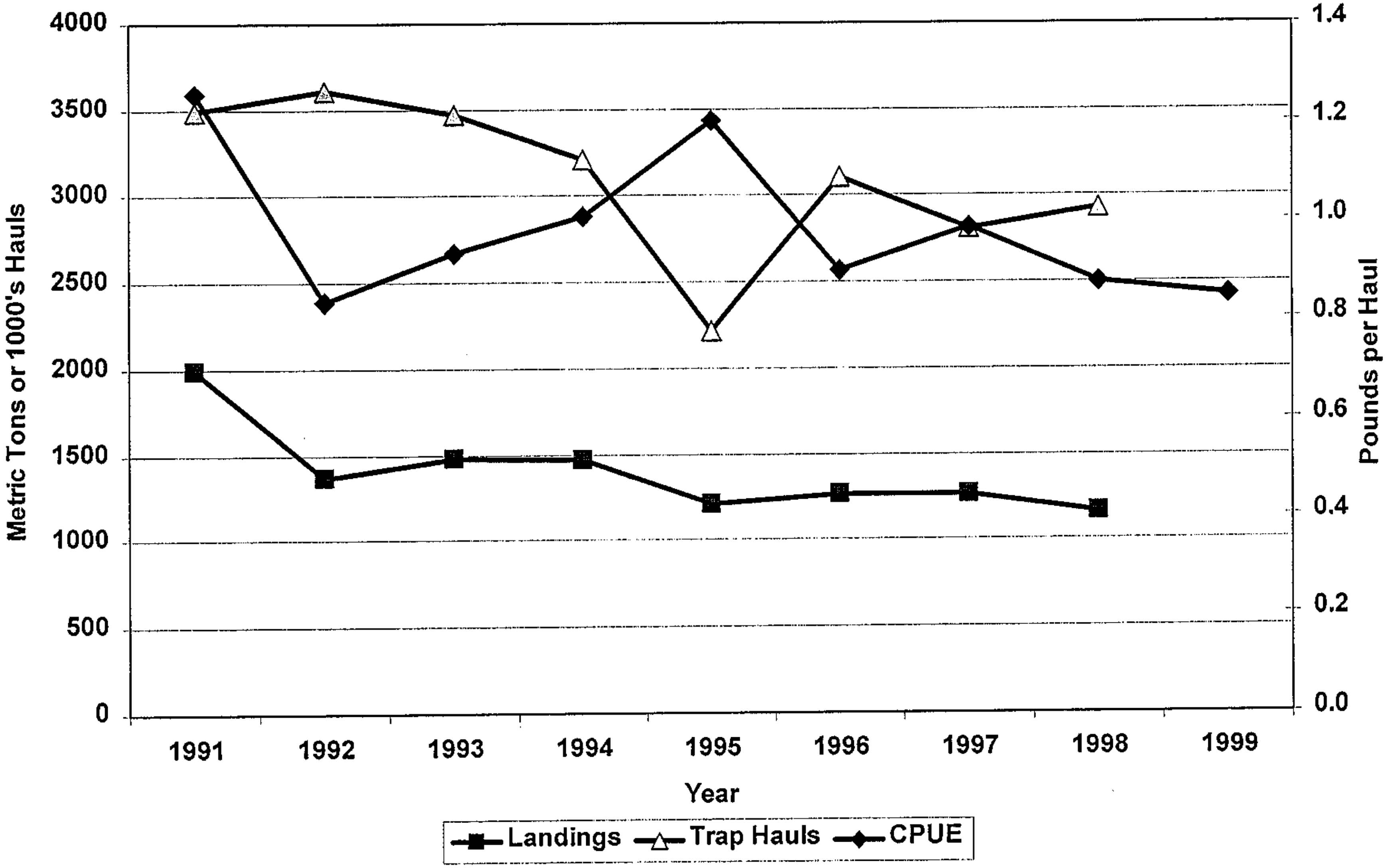


Fig.7b- Catch per Pot Haul of Sublegal Lobster in the RI Inshore Fishery

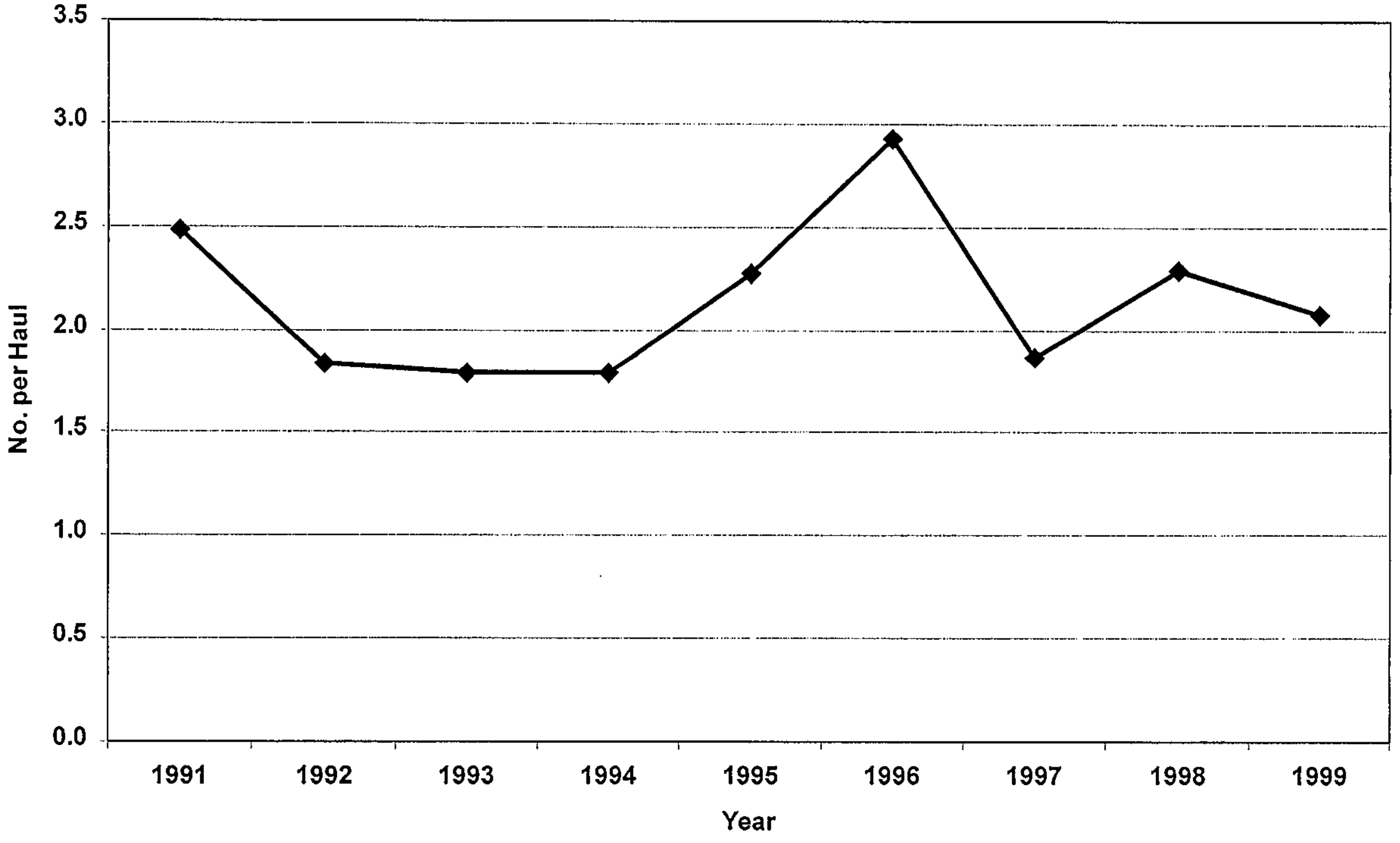


Fig.8- Trawl Survey Based Estimates of RI Inshore Lobster Fishing Mortality

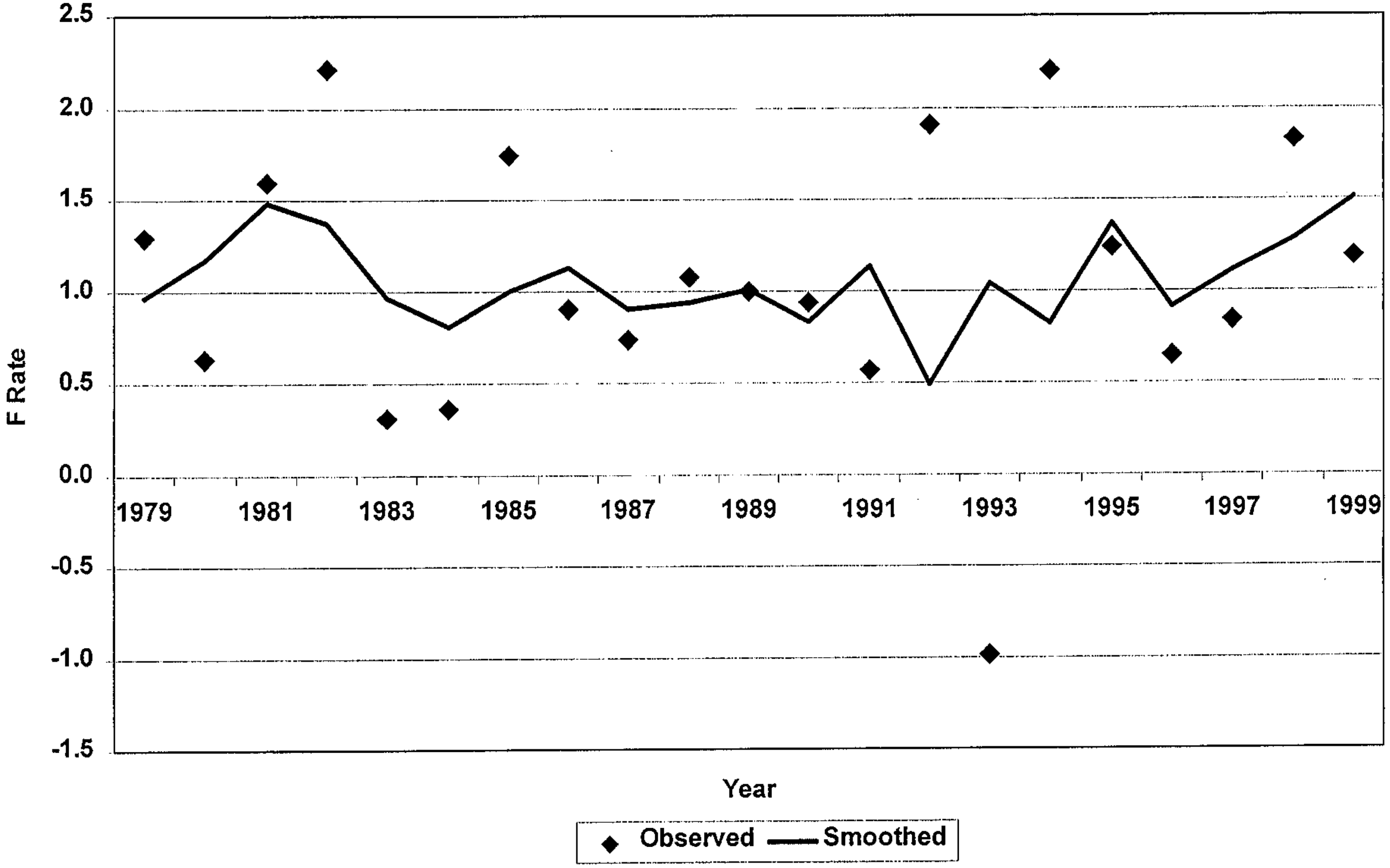


Fig.9- Longevity of Tagged Lobster in the Inshore Area From the URI Fisheries Tagging Study and Depletion Model Fit

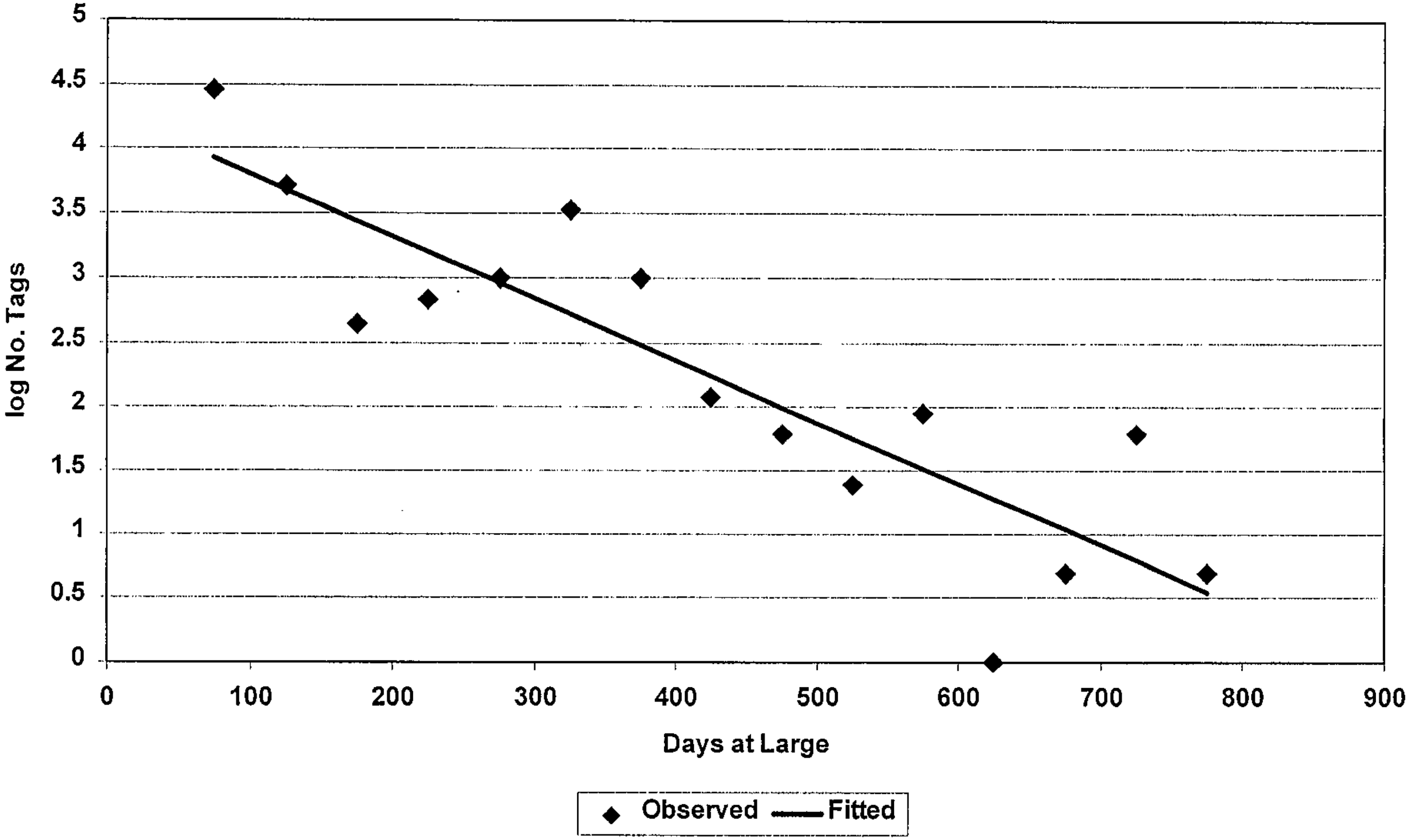


Fig.10- Residual Plot for URI Lobster Tagging Study Depletion Model

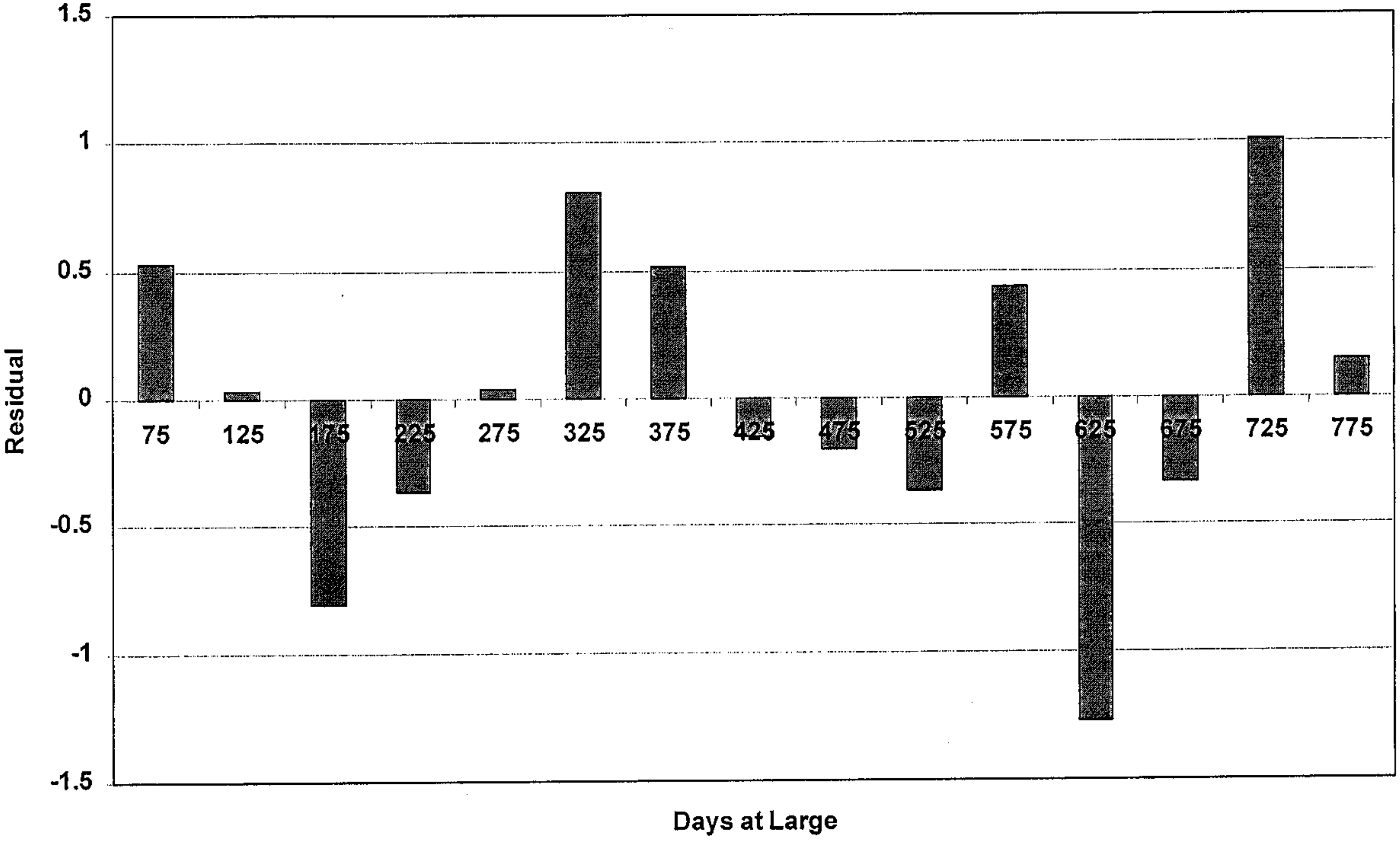
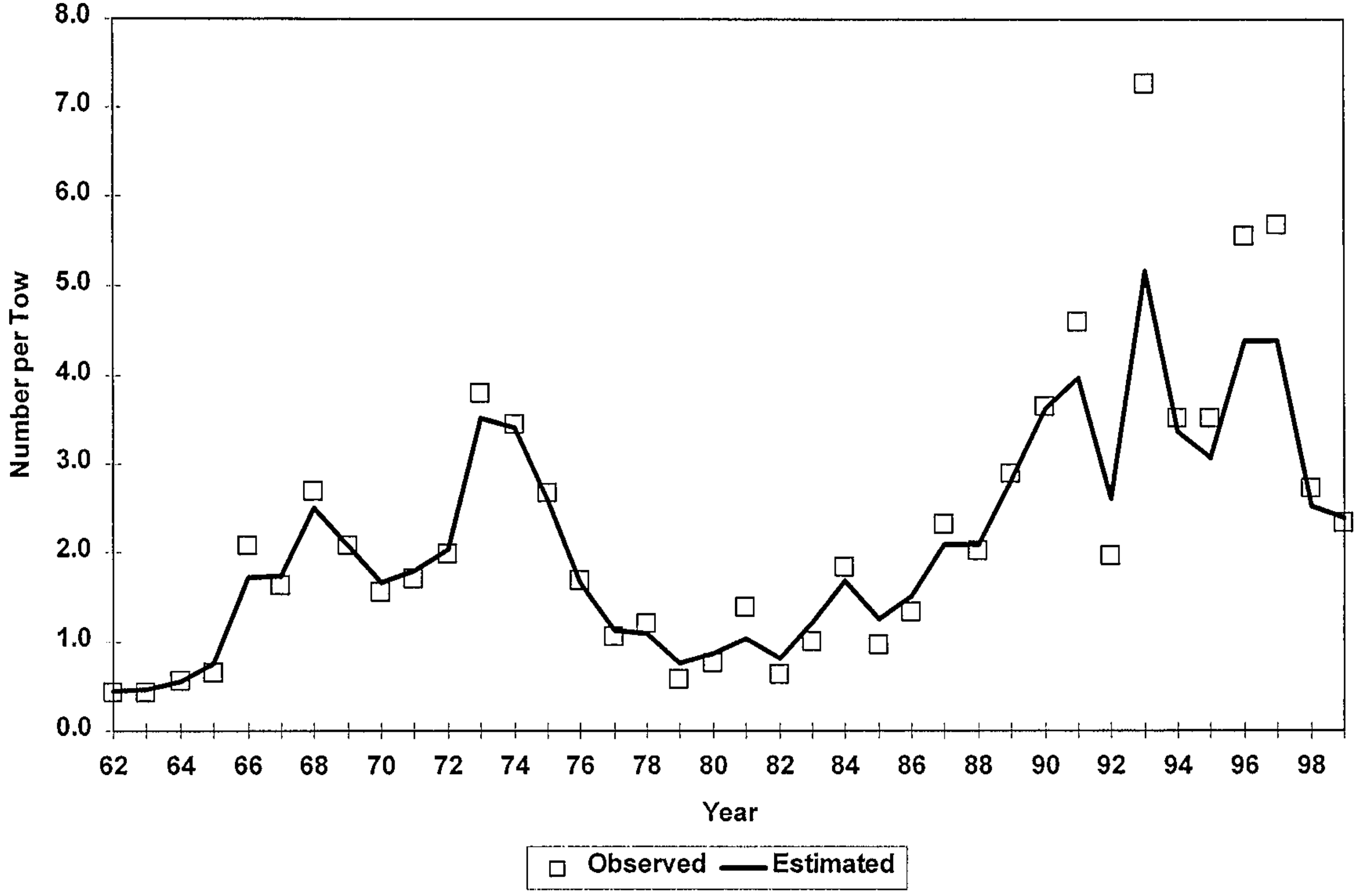


Fig.11- RI Inshore Lobster Trawl Abundance Index and Biomass Dynamic Model Fitted Trend



## Fig.12- RI Inshore Lobster Landings and Absolute Abundance Relative to Bmsy Level

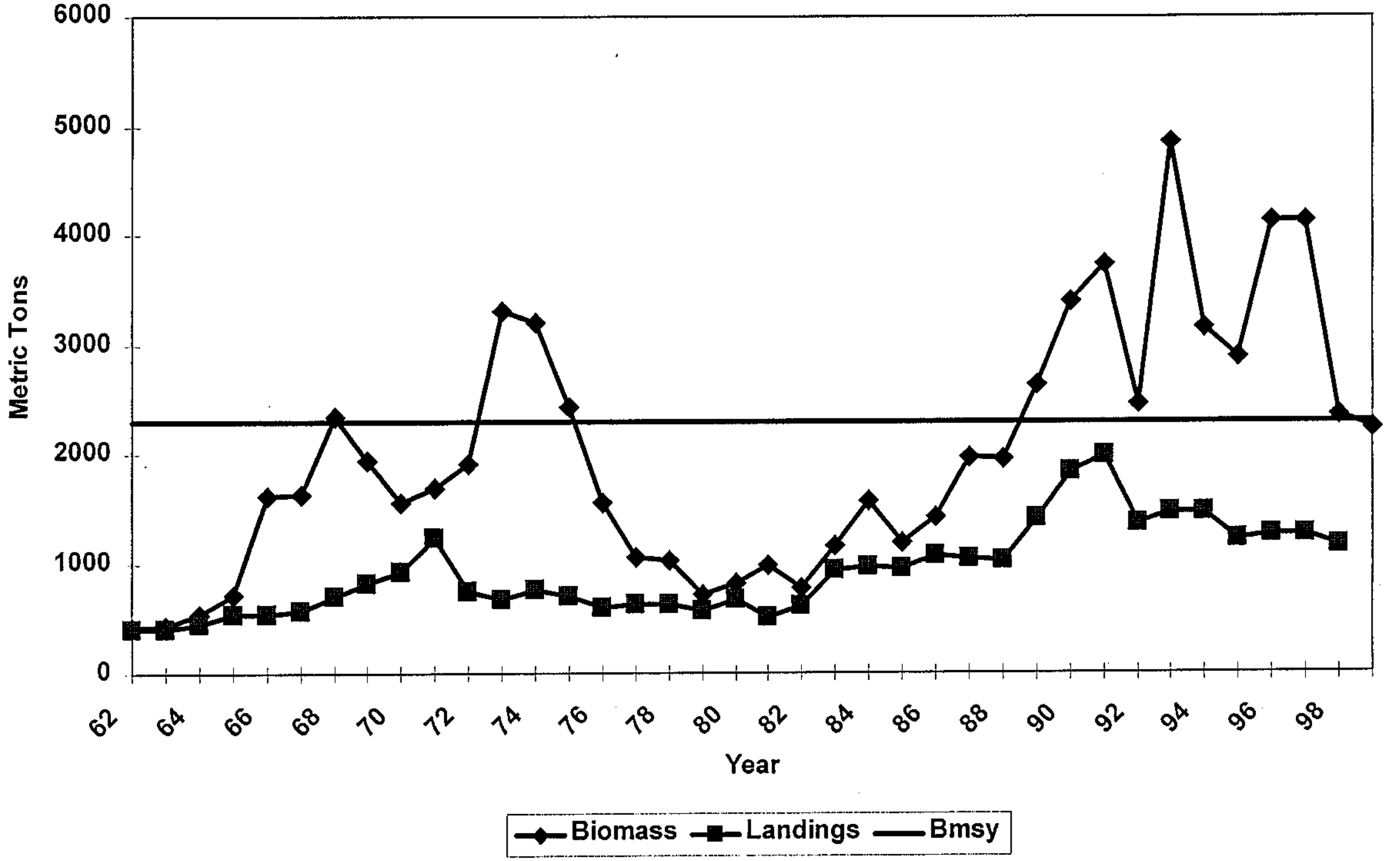
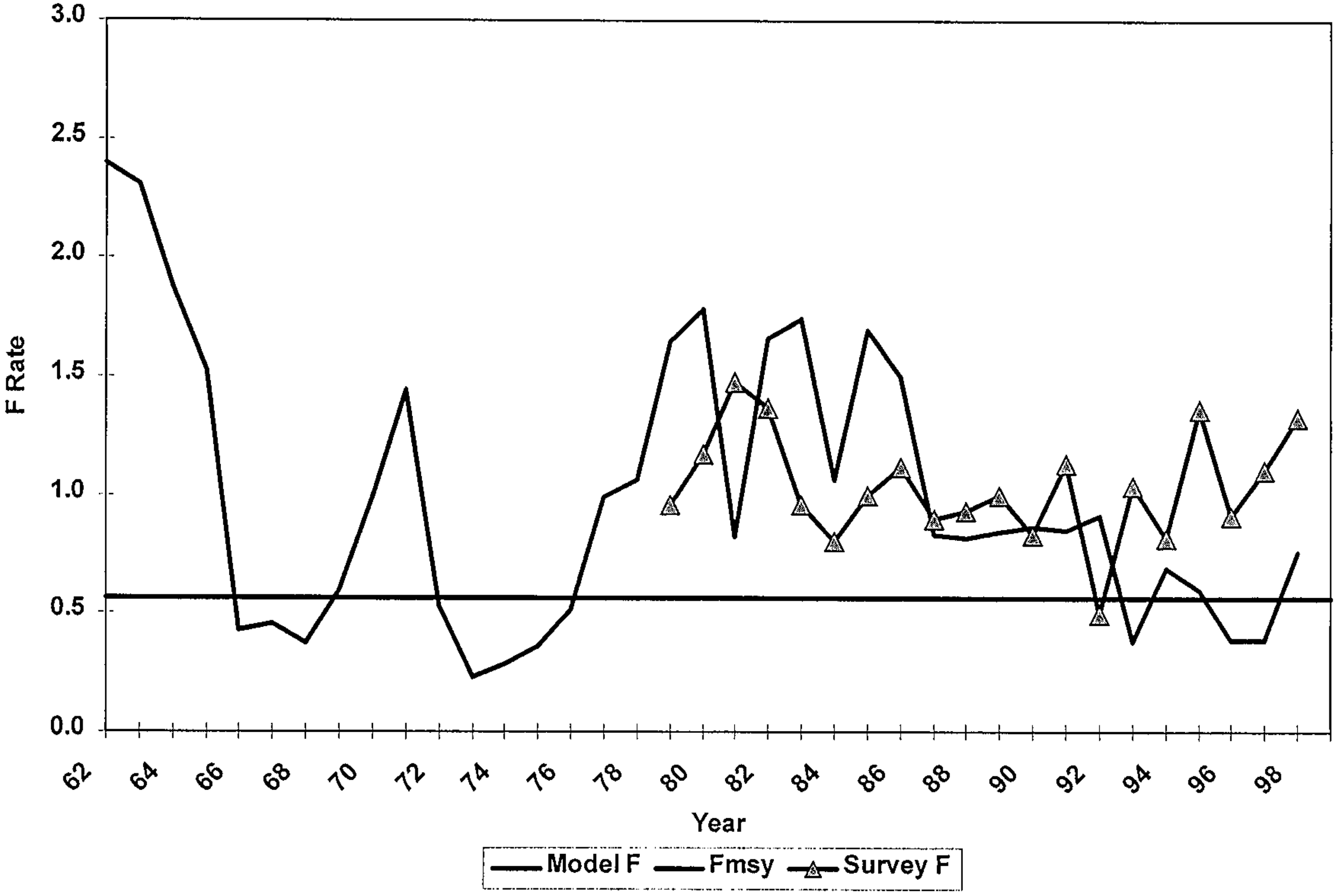
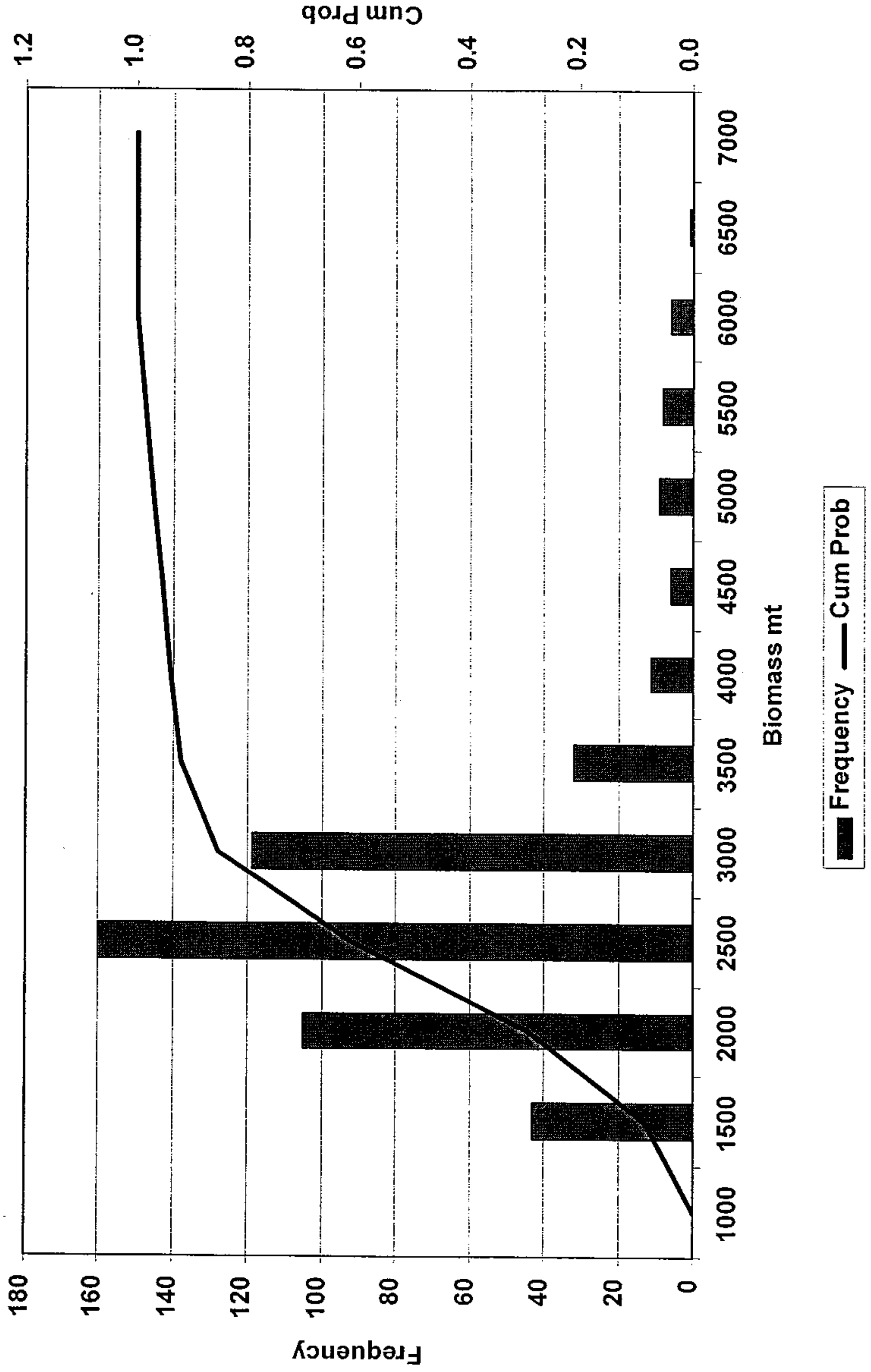


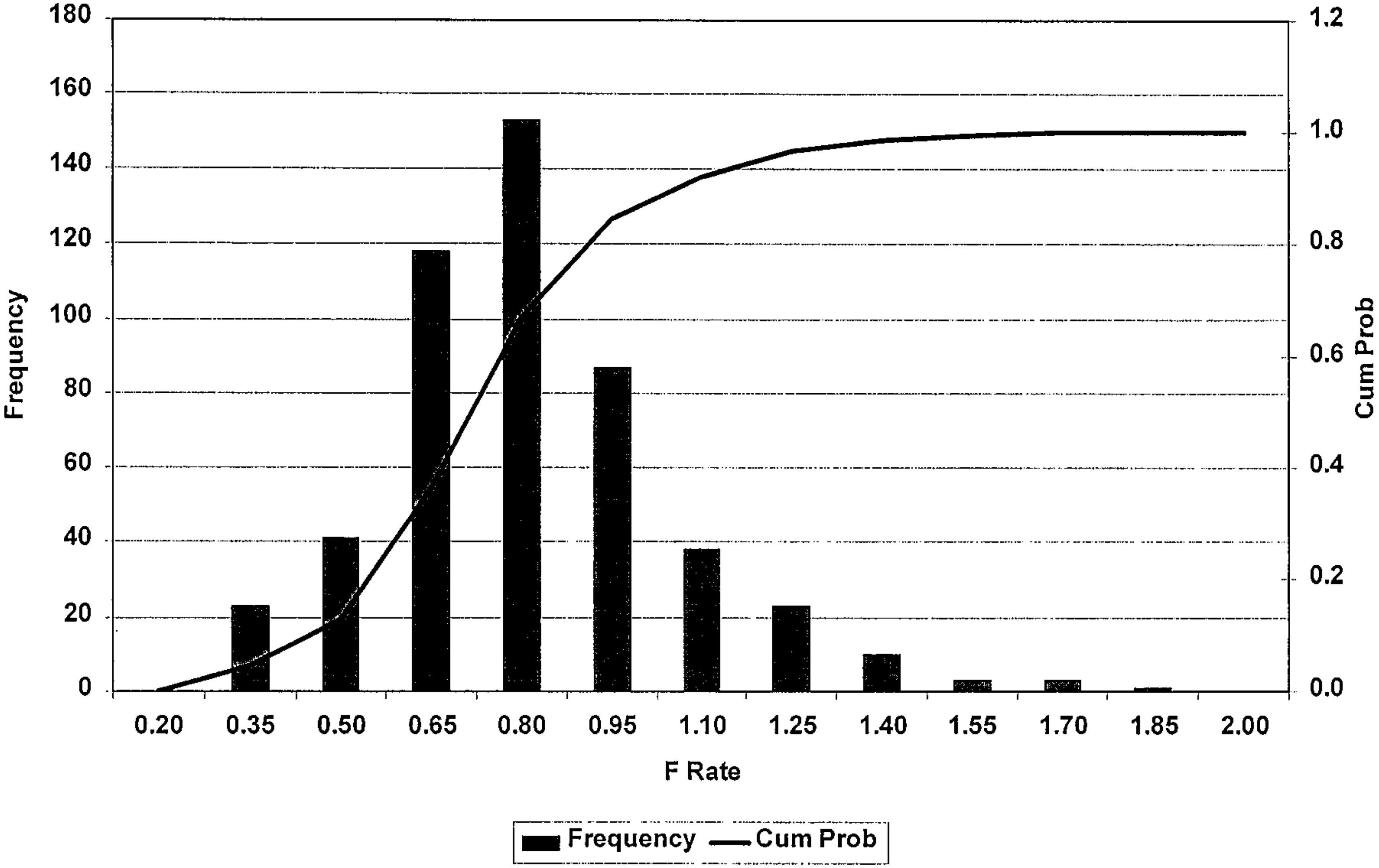
Fig.13- RI Inshore Lobster Fishing Mortality Rate Relative to Fmsy Level



## Fig.14- Bootstrap Distribution for RI Inshore Lobster 1999 Stock Size



## Fig.15- Bootstrap Distribution for RI Inshore Lobster 1998 F Rate



## Fig.16- Bootstrap Distribution for RI Inshore Lobster Mean 1996-1999 Stock Size

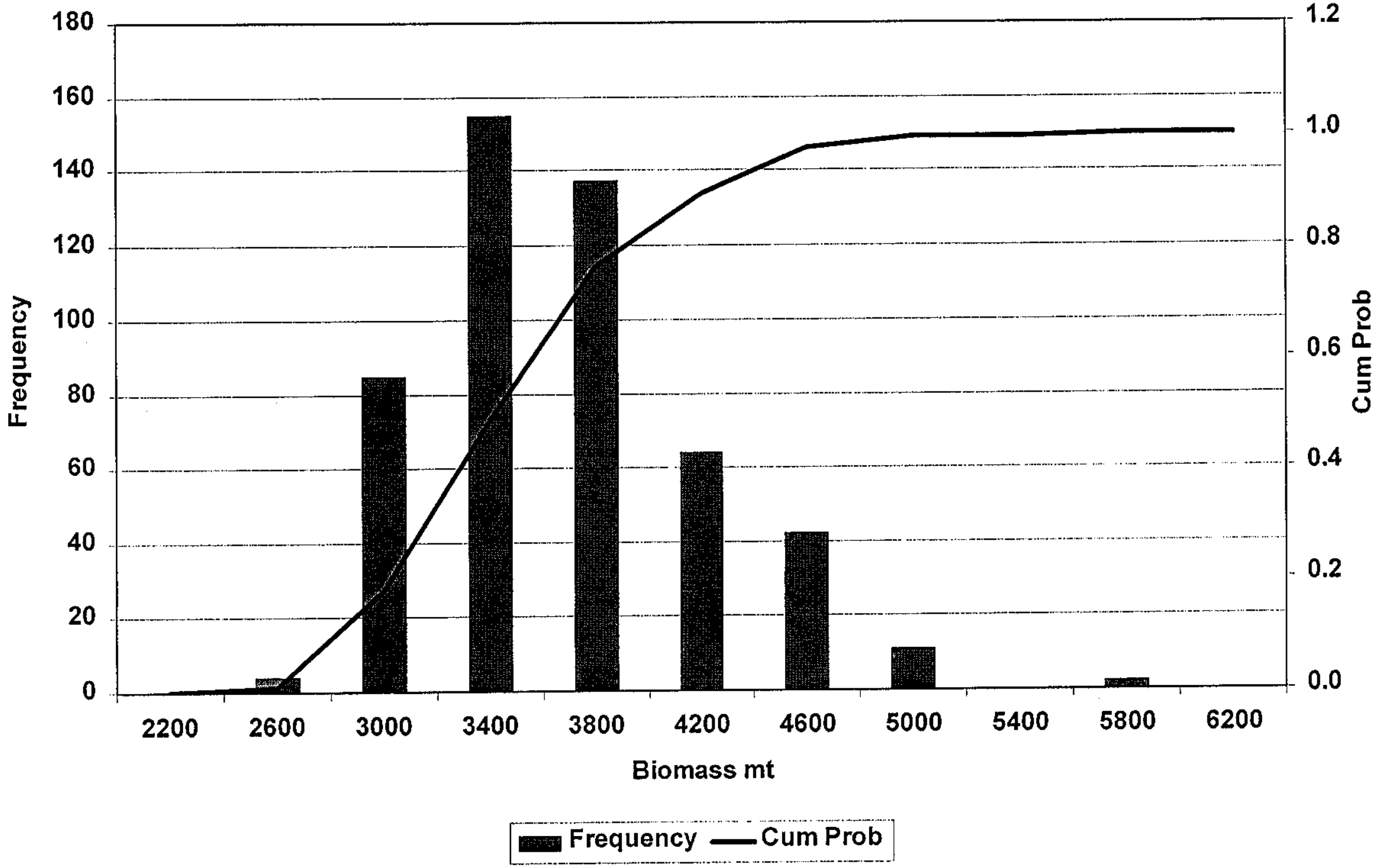


Fig.17- Bootstrap Distribution for RI Inshore Lobster Mean 1996-1998 F Rate

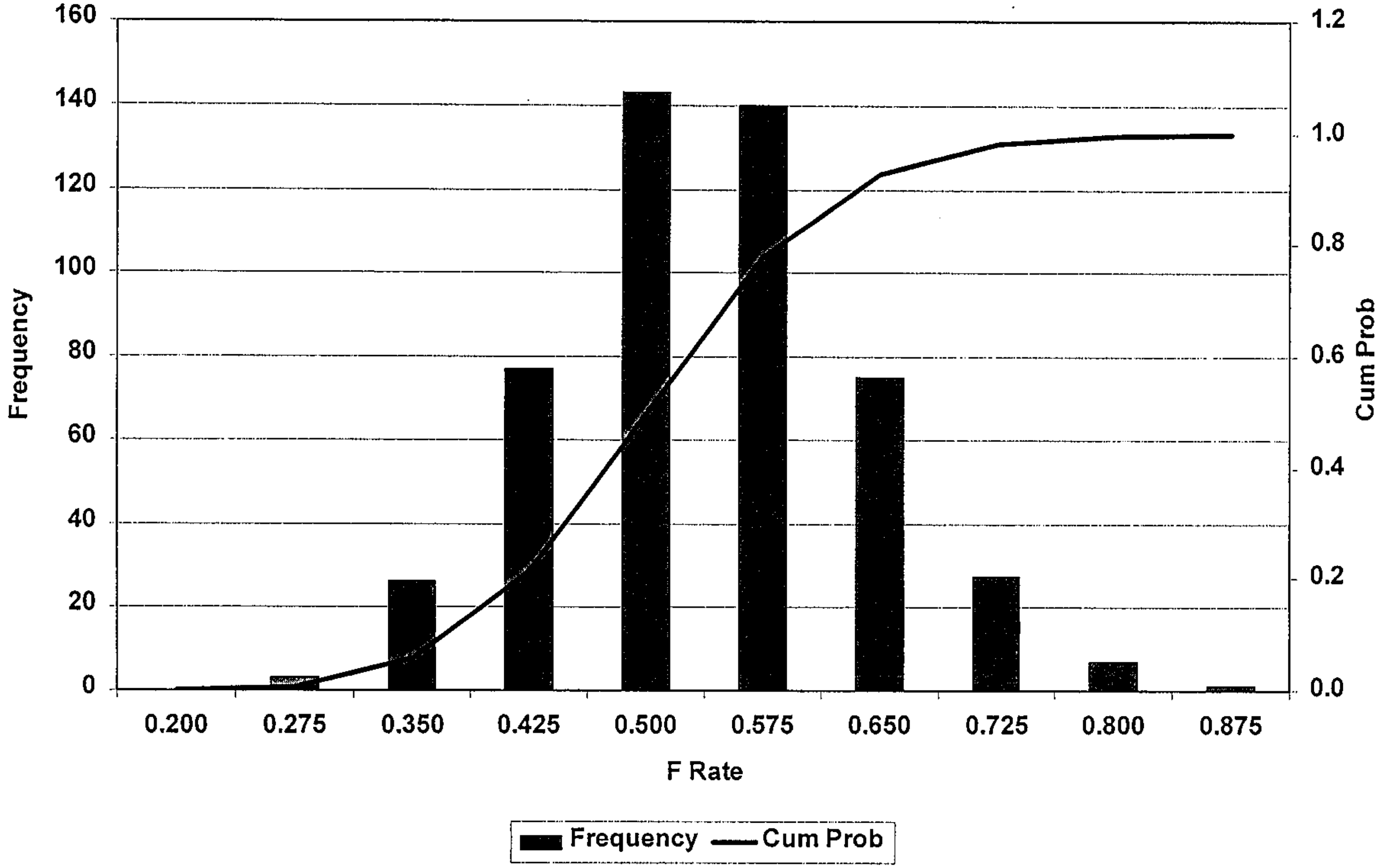
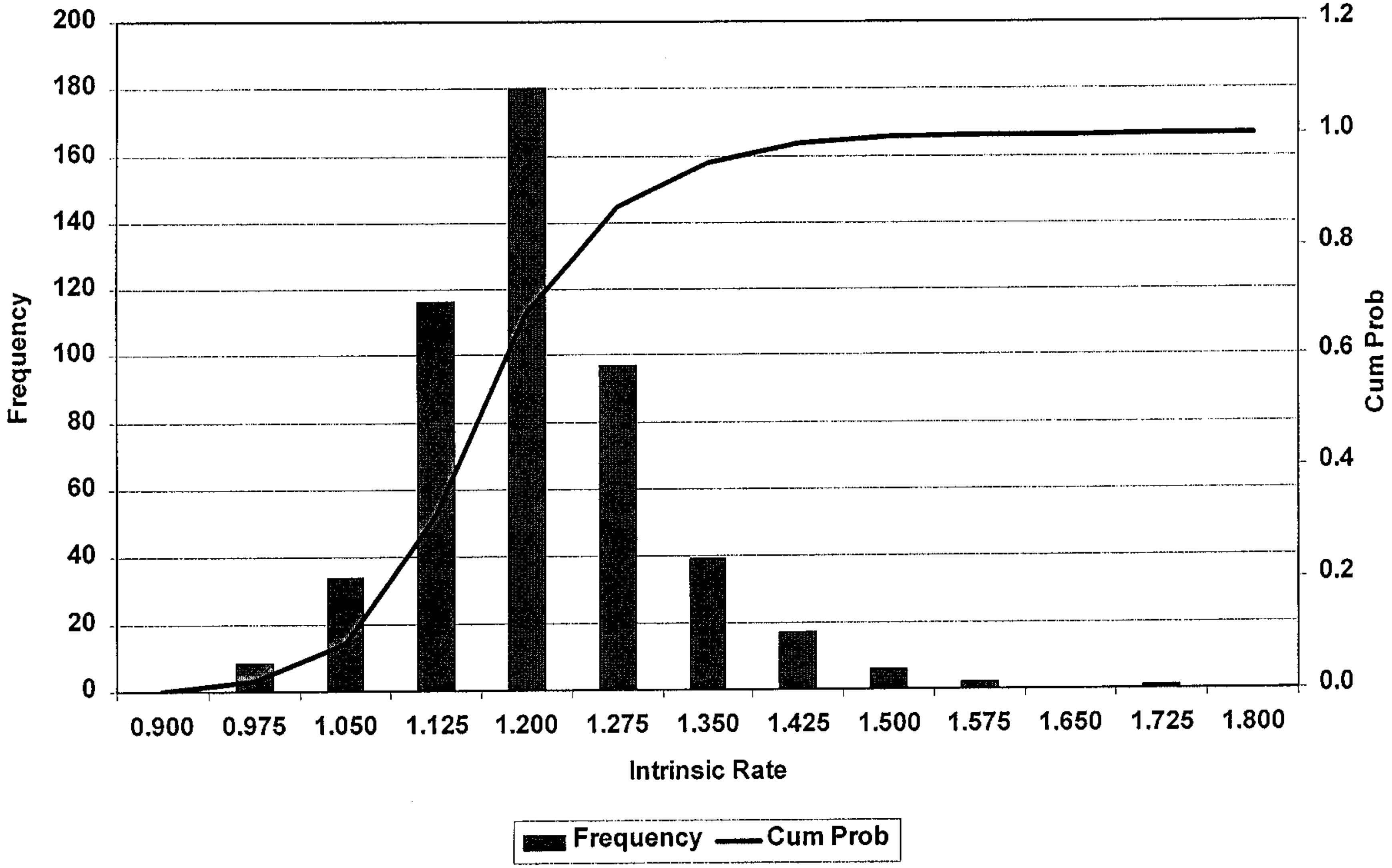


Fig.18- Bootstrap Distribution for RI Inshore Lobster Logistic Production Parameter



## Fig.19- Bootstrap Distribution for RI Inshore Lobster Logistic Asymptotic Stock Size

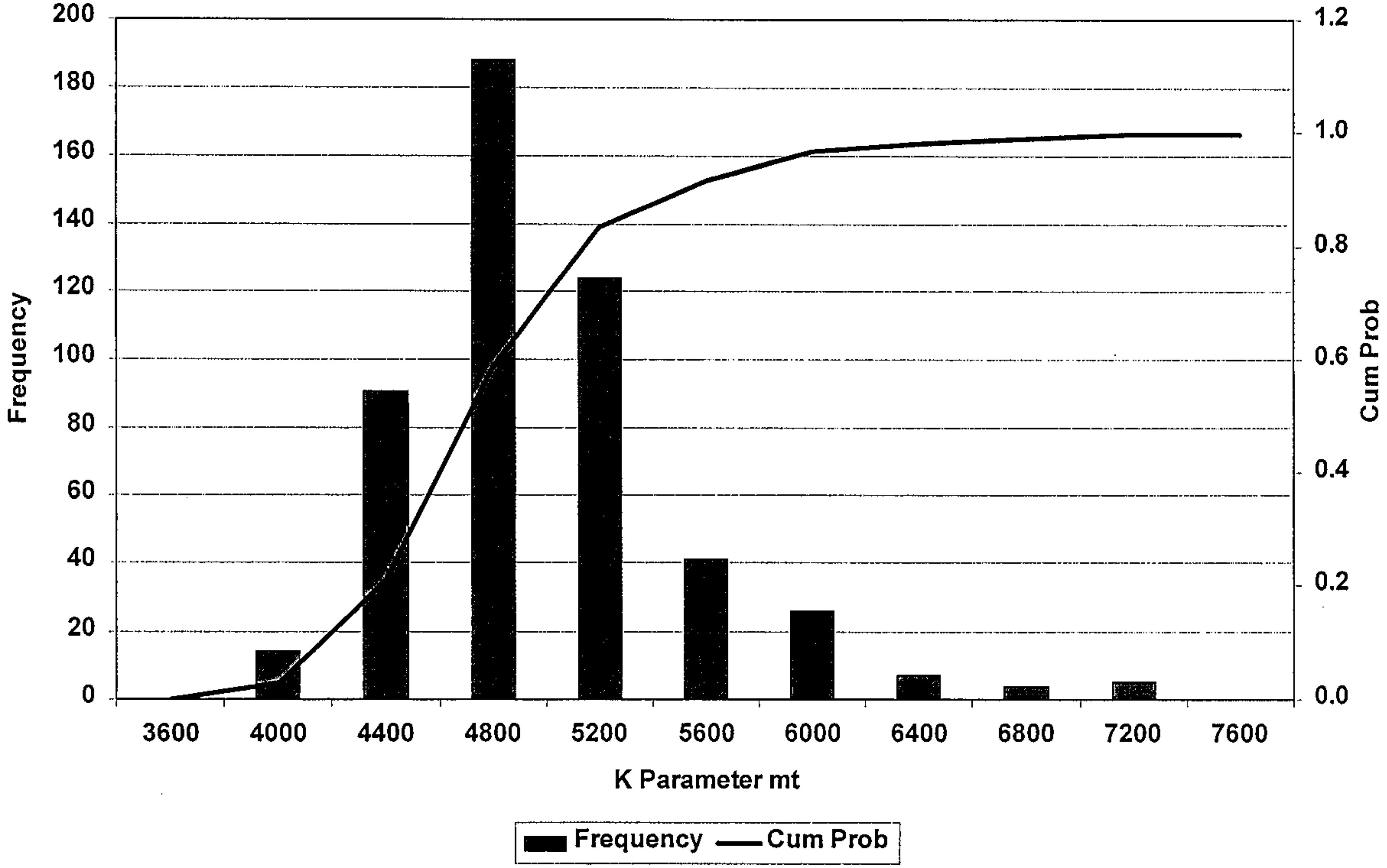


Fig.20- Bootstrap Distribution for RI Inshore Lobster Catchability Parameter

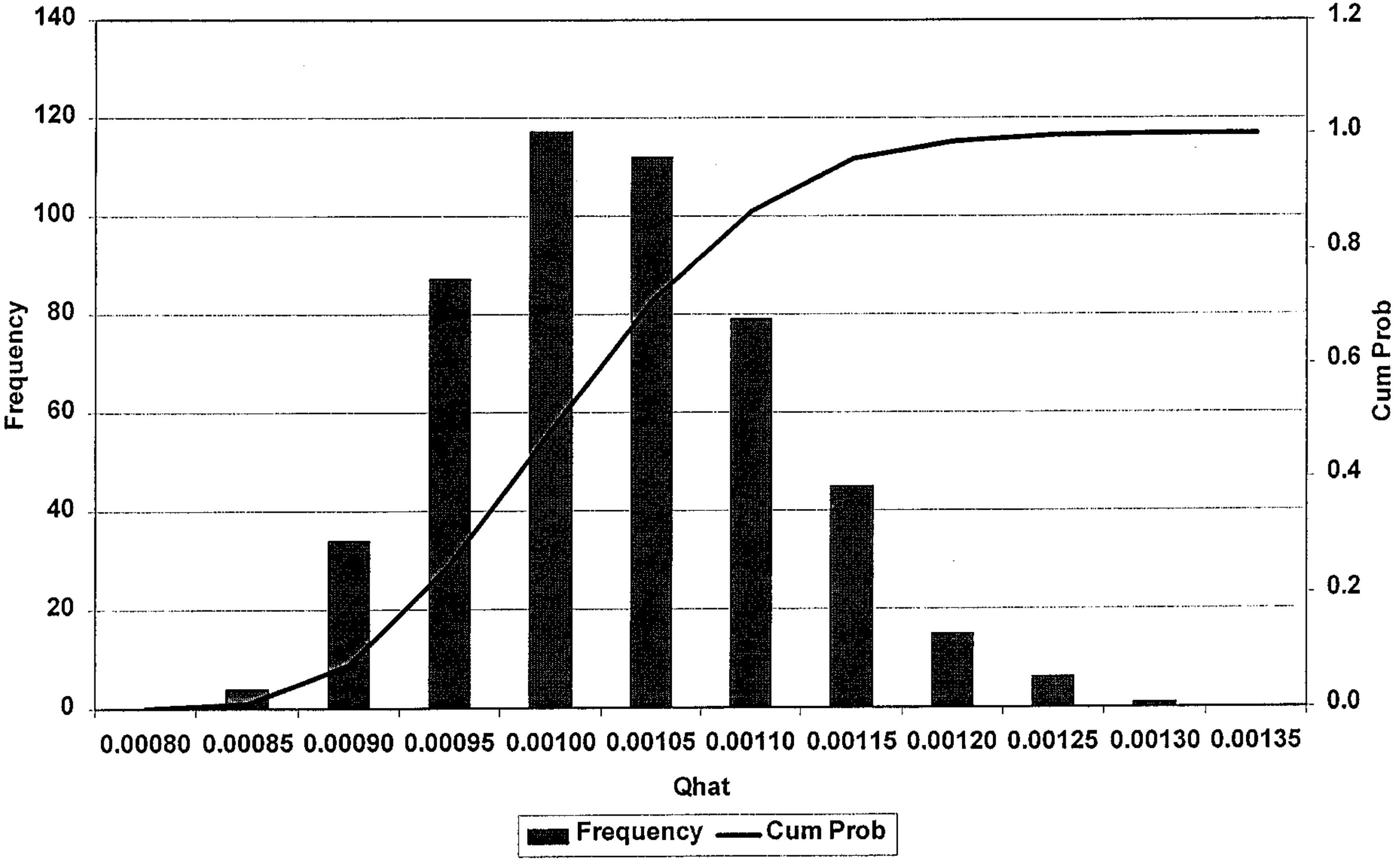


Fig.21- Bootstrap Distribution for RI Inshore Lobster Fishing Mortality at MSY

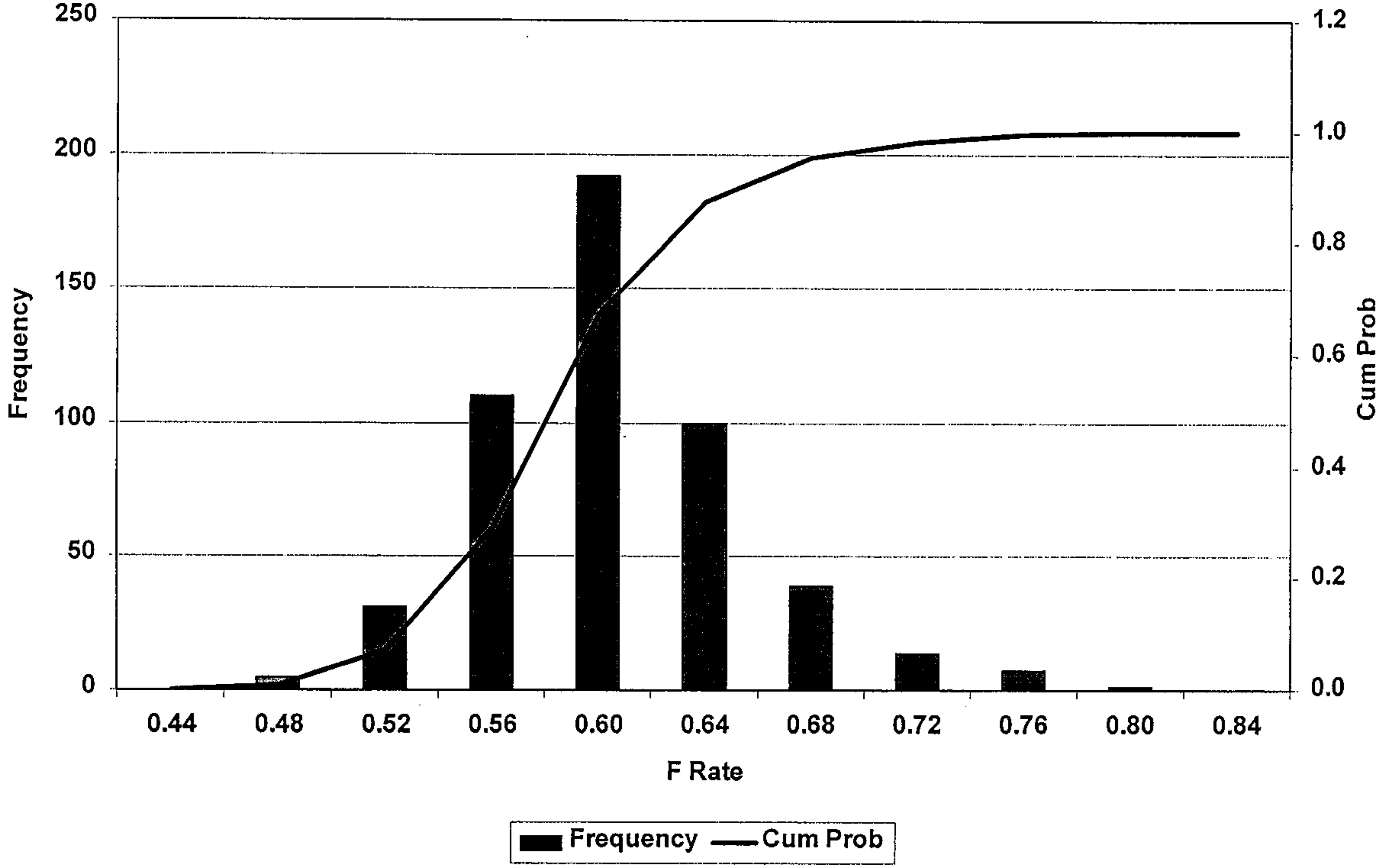


Fig.22- Bootstrap Distribution for RI Inshore Lobster MSY

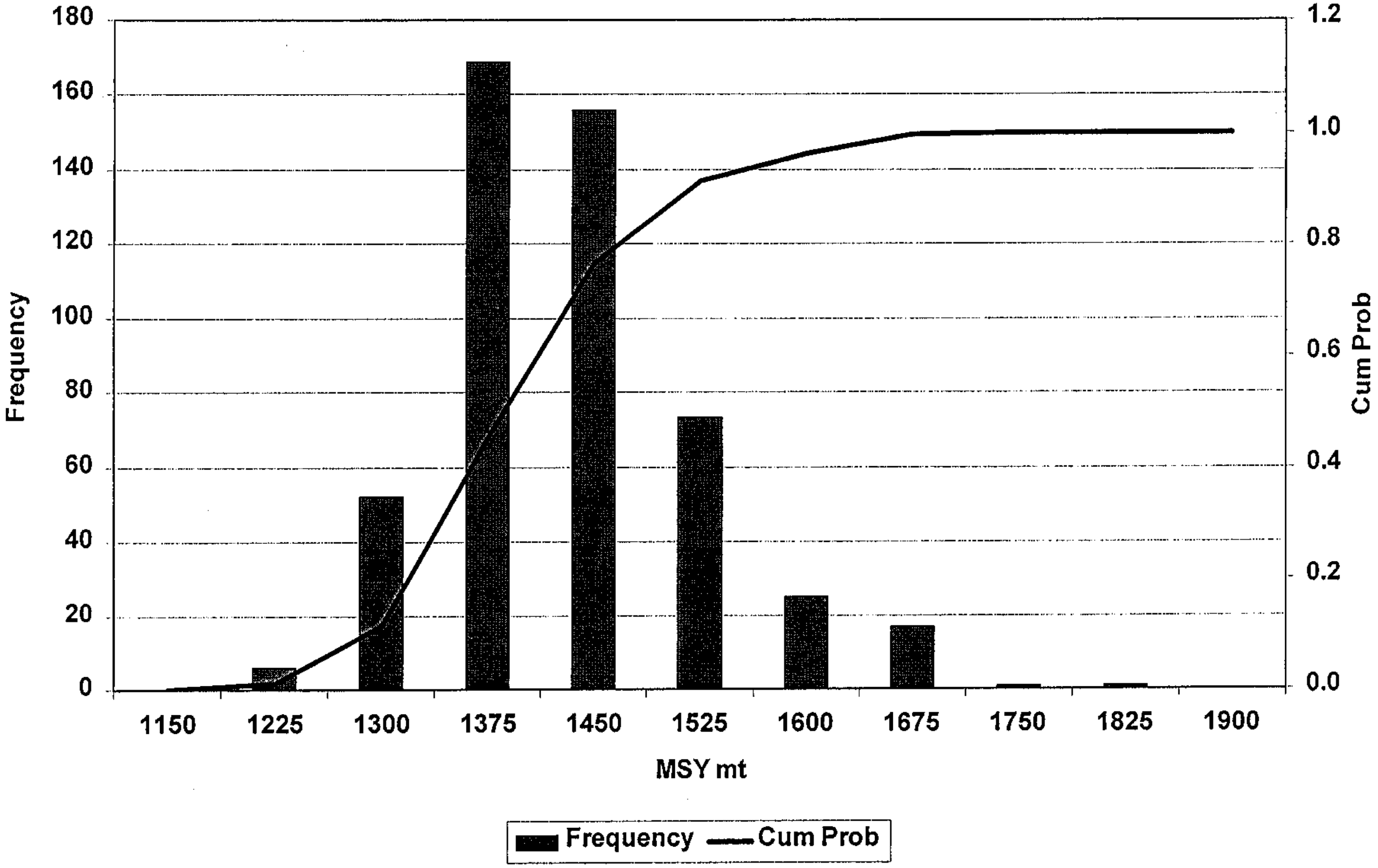


Fig.23- Bootstrap Distribution for RI Inshore Lobster Biomass at MSY

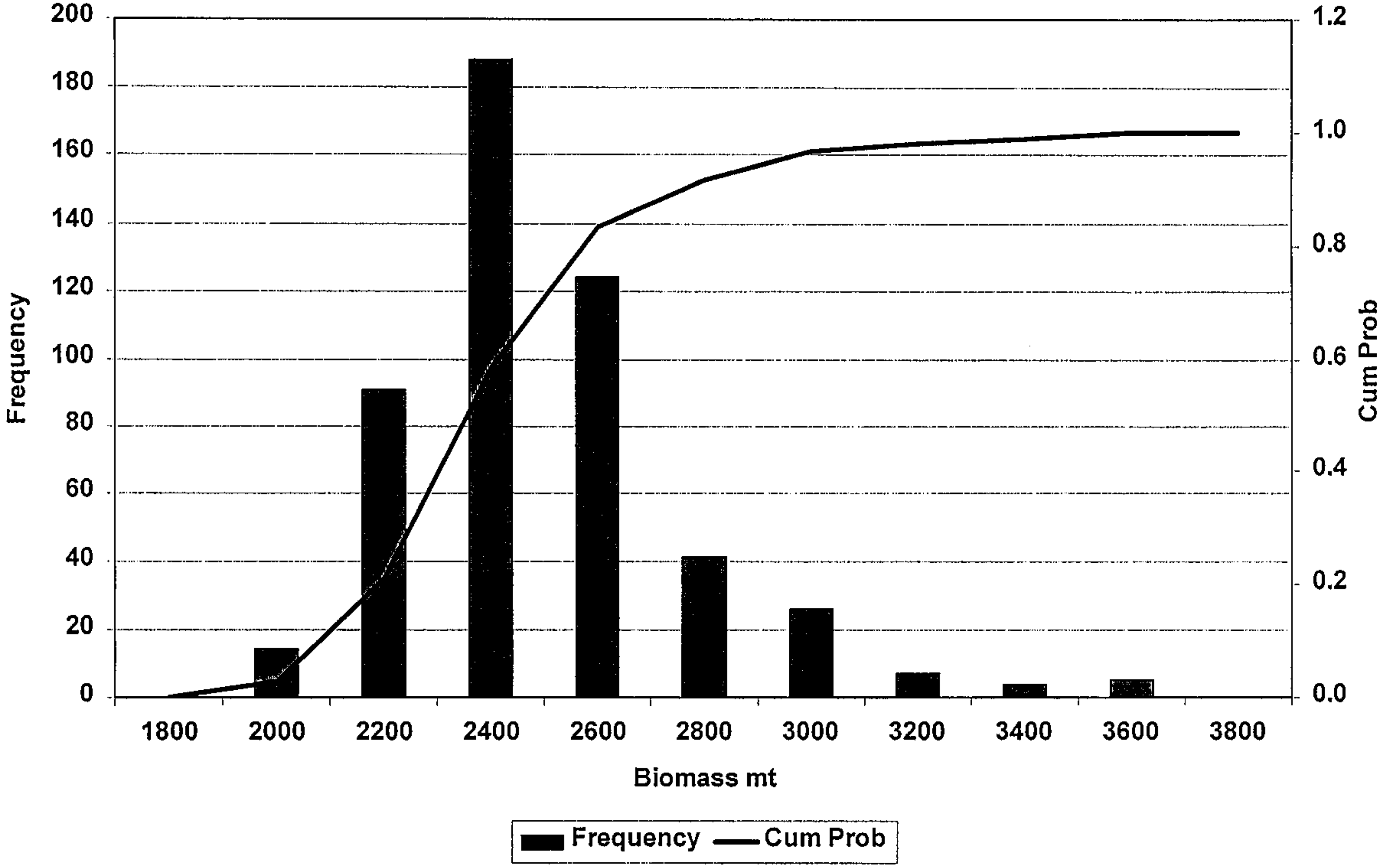
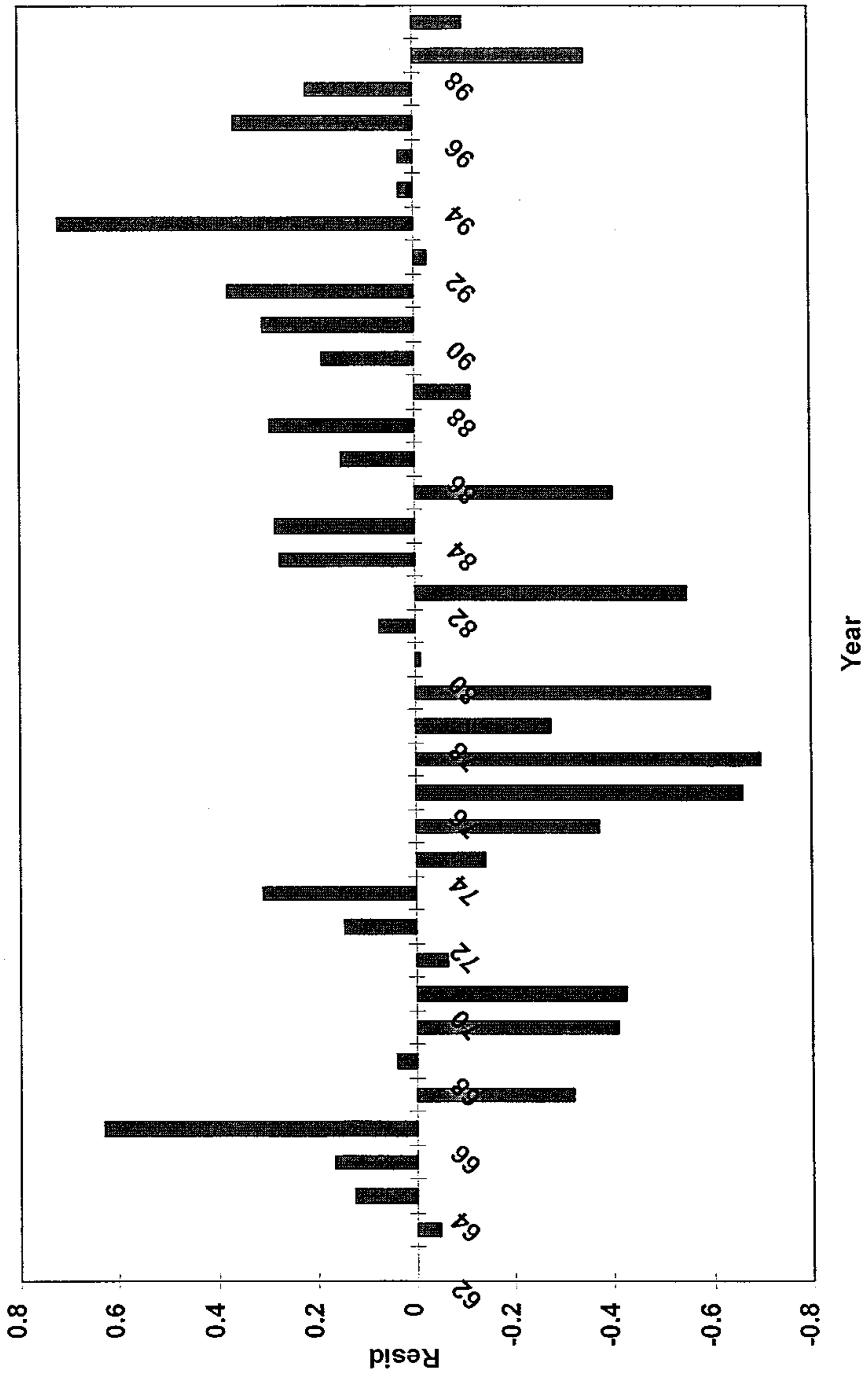


Fig.24- RI Inshore Lobster Biomass Dynamic Model Process Errors



## Fig.25- RI Inshore Lobster Biomass Dynamic Model Observation Errors

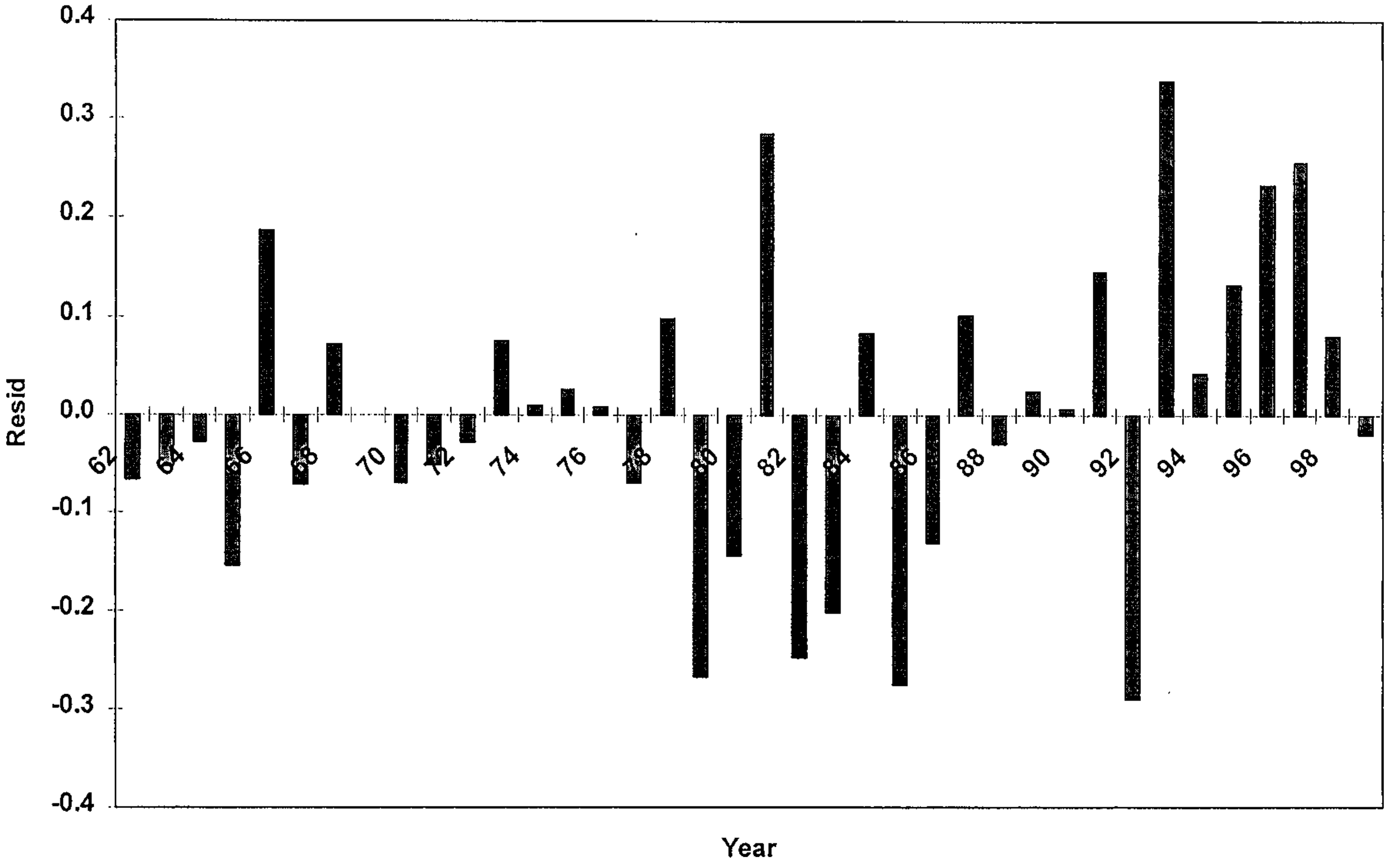


Fig.26- RI Inshore Lobster Biomass Dynamic Model Auxiliary F Rate Residuals

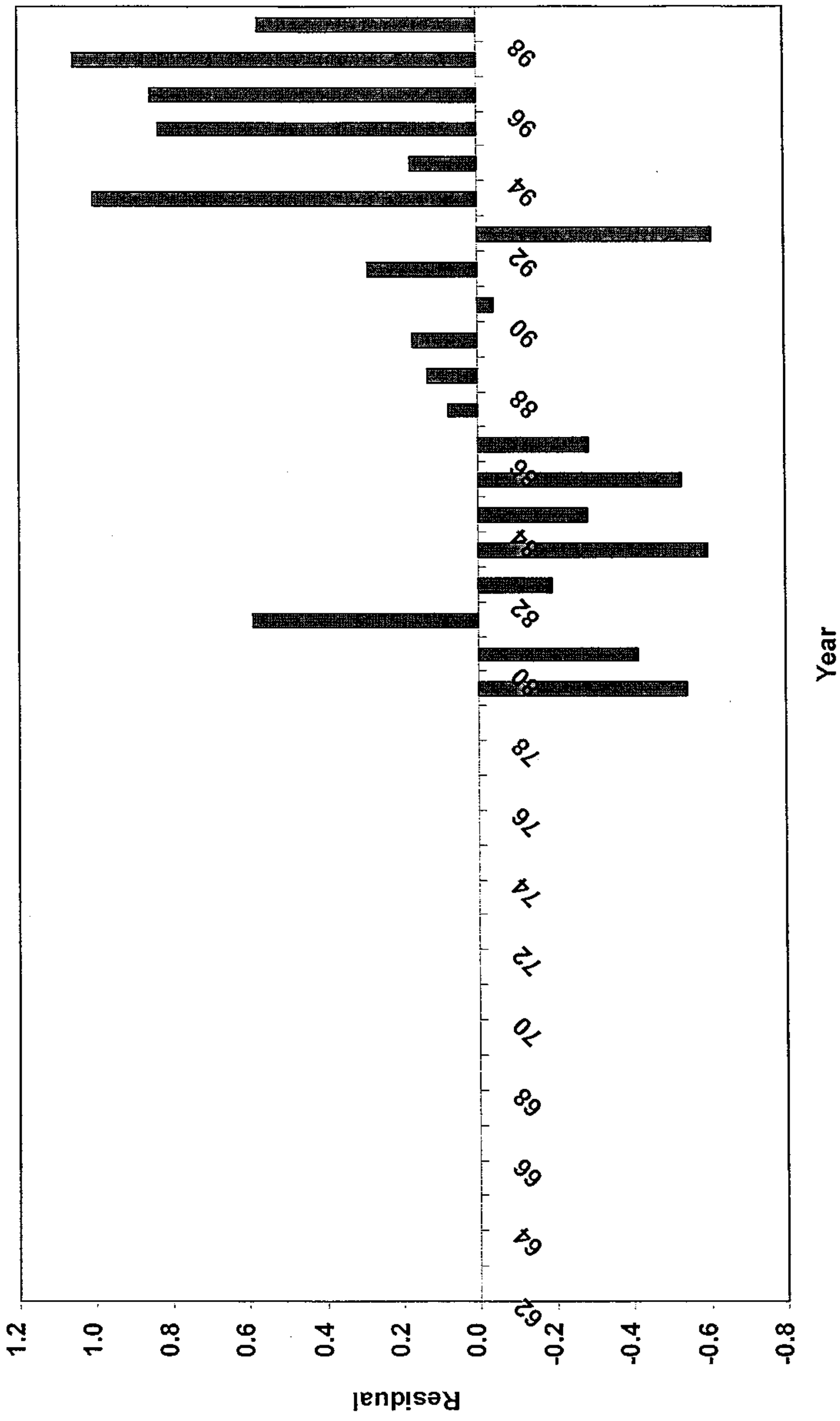


Fig.27- Sensitivity of Lobster Fishing Mortality and Biomass Ratios to Process Error Level

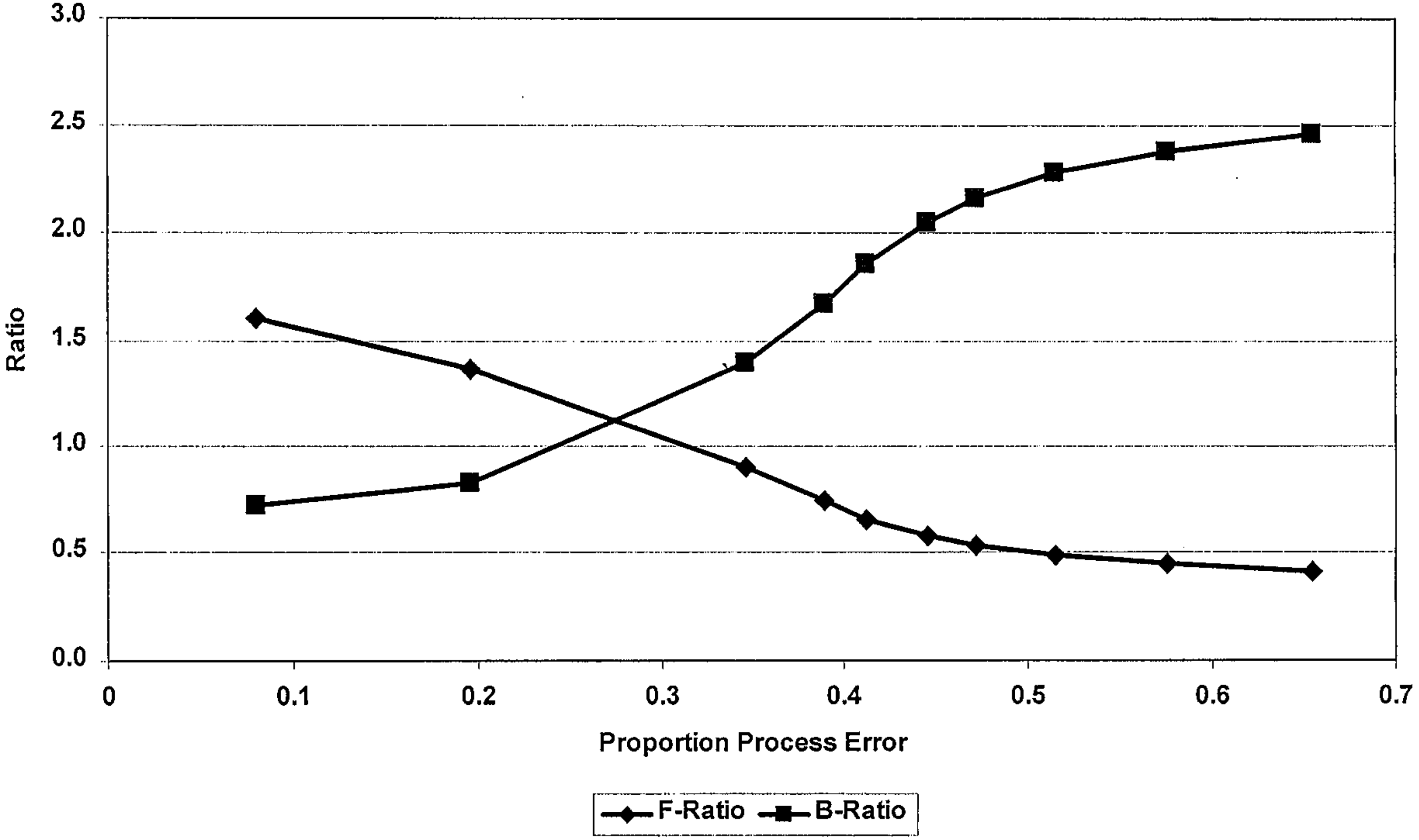
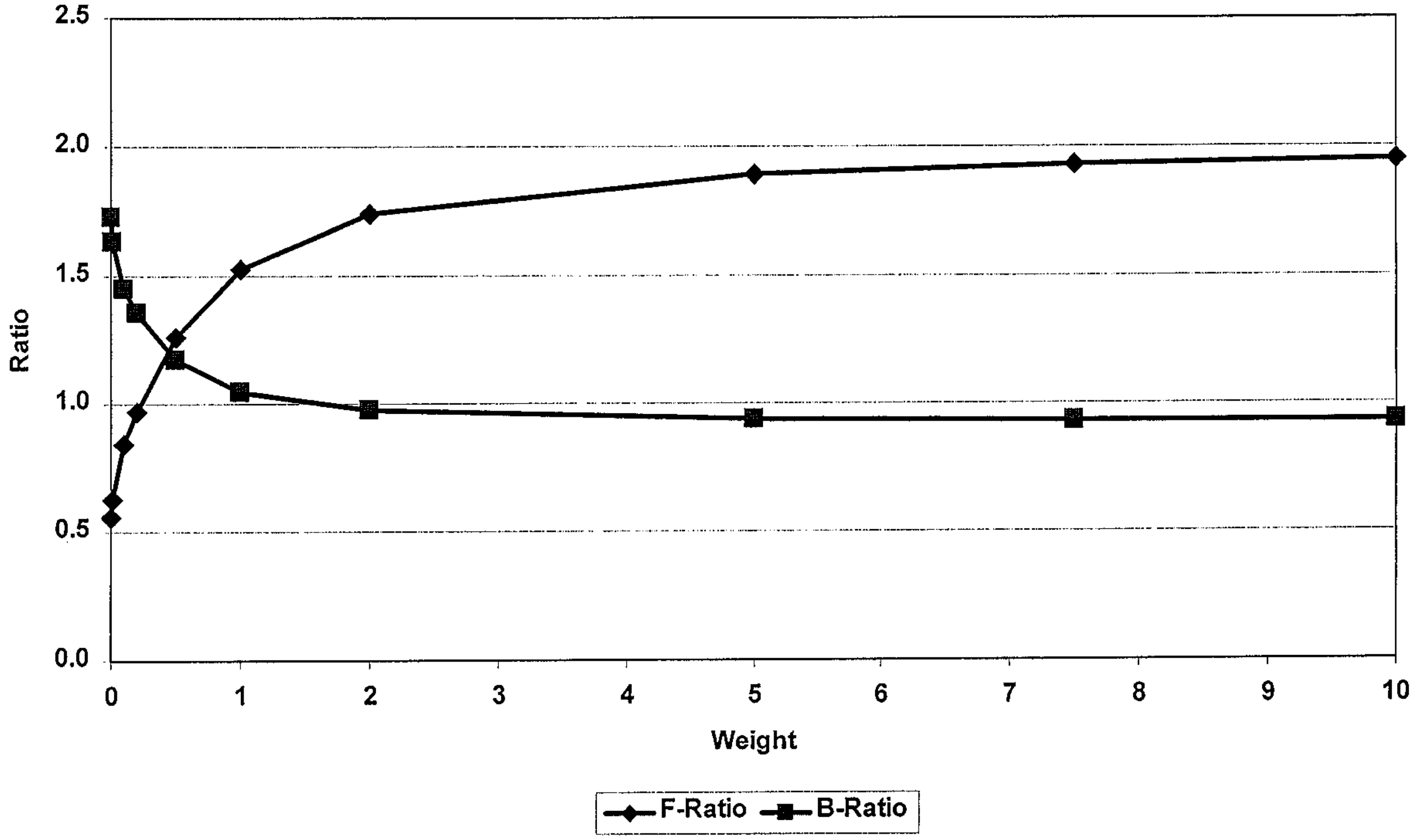


Fig.28- Sensitivity of Lobster Fishing Mortality and Biomass Ratios to Auxiliary F Weight



**Appendix- RI Inshore Lobster Biomass Dynamic Ru**Baseline
Uses Area 539 Comm and RIDFW-URIGSO Composite Index
1962-1981 landings adjusted w/ intervention model

| | Estimated Absolute Abundances and Catch in MT | | | | | Fishing Rate |
|---|---|---|---|---|---|---|
| Year | Prod(t) | B(t) | C(t) | Exp Rate | | F Rate |
| 62 | 407 | 421 | 400.3 | 0.950 | 2297.5 | 2.399 |
| 63 | 498 | 429 | 399.4 | 0.932 | 2297.5 | 2.308 |
| 64 | 632 | 527 | 441.8 | 0.839 | 2297.5 | 1.873 |
| 65 | 1430 | 717 | 539.7 | 0.752 | 2297.5 | 1.528 |
| 66 | 556 | 1608 | 529.8 | 0.330 | 2297.5 | 0.426 |
| 67 | 1270 | 1633 | 565.2 | 0.346 | 2297.5 | 0.455 |
| 68 | 299 | 2338 | 690.9 | 0.296 | 2297.5 | 0.370 |
| 69 | 433 | 1946 | 819.6 | 0.421 | 2297.5 | 0.597 |
| 70 | 1041 | 1559 | 916.7 | 0.588 | 2297.5 | 0.996 |
| 71 | 1452 | 1683 | 1227.6 | 0.729 | 2297.5 | 1.443 |
| 72 | 2132 | 1908 | 738.8 | 0.387 | 2297.5 | 0.530 |
| 73 | 556 | 3302 | 665.3 | 0.201 | 2297.5 | 0.233 |
| 74 | -3 | 3193 | 758.9 | 0.238 | 2297.5 | 0.283 |
| 75 | -172 | 2430 | 698.7 | 0.287 | 2297.5 | 0.357 |
| 76 | 91 | 1559 | 592.6 | 0.380 | 2297.5 | 0.517 |
| 77 | 588 | 1058 | 621.5 | 0.588 | 2297.5 | 0.995 |
| 78 | 313 | 1024 | 626.9 | 0.612 | 2297.5 | 1.065 |
| 79 | 664 | 710 | 557.0 | 0.784 | 2297.5 | 1.650 |
| 80 | 822 | 817 | 667.5 | 0.817 | 2297.5 | 1.780 |
| 81 | 299 | 972 | 506.8 | 0.522 | 2297.5 | 0.822 |
| 82 | 988 | 764 | 601.7 | 0.788 | 2297.5 | 1.663 |
| 83 | 1356 | 1150 | 929.8 | 0.808 | 2297.5 | 1.747 |
| 84 | 572 | 1576 | 965.8 | 0.613 | 2297.5 | 1.066 |
| 85 | 1184 | 1183 | 941.6 | 0.796 | 2297.5 | 1.696 |
| 86 | 1603 | 1425 | 1061.6 | 0.745 | 2297.5 | 1.500 |
| 87 | 1024 | 1966 | 1034.7 | 0.526 | 2297.5 | 0.834 |
| 88 | 1707 | 1955 | 1018.2 | 0.521 | 2297.5 | 0.821 |
| 89 | 2156 | 2644 | 1401.8 | 0.530 | 2297.5 | 0.844 |
| 90 | 2163 | 3399 | 1830.5 | 0.539 | 2297.5 | 0.865 |
| 91 | 713 | 3731 | 1989.1 | 0.533 | 2297.5 | 0.851 |
| 92 | 3775 | 2455 | 1365.1 | 0.556 | 2297.5 | 0.910 |
| 93 | -233 | 4864 | 1472.1 | 0.303 | 2297.5 | 0.381 |
| 94 | 1188 | 3160 | 1465.4 | 0.464 | 2297.5 | 0.688 |
| 95 | 2463 | 2883 | 1209.2 | 0.419 | 2297.5 | 0.594 |
| 96 | 1260 | 4136 | 1265.5 | 0.306 | 2297.5 | 0.387 |
| 97 | -518 | 4131 | 1257.1 | 0.304 | 2297.5 | 0.384 |
| 98 | 1047 | 2355 | 1161.9 | 0.493 | 2297.5 | 0.755 |
| 99 | | 2240 | | | 2297.5 | |
| Mean 96-98 | | 3216 | 1223 | 0.381 | | 0.509 |

Implied Life Span at 1% Resid Pop
#DIV/0! yrs

17 parameters

| Residual error weights | |
|---|---|
| Aux F Rat | 0.15 |
| Measure | 1 |
| Process | 0.2 |

Total SS =
***2.64324*** <=obj fcn

| | Frac RSSE |
|---|---|
| Process | 0.331 |
| Measure | 0.325 |
| Aux F | 0.344 |

Baseline

| | | | | |
|---|---|---|---|---|
| rmax | 1.121419 | F msy | 0.561 | ***AFTER OPTIMIZATION*** |
| K | 4594.912 | f msy | 526.6007 | Biomass Dynamic model based estimates |
| qhat1 | 0.001065 | MSY | 1288.205 | Process Error Calculations |
| | | Bmsy | 2297.456 | |

| b'(t) | C(t+1) | | n(t) | n_calc(t) | Resid^2 | Resid |
|---|---|---|---|---|---|---|
| | 400.3 | | estimated | | | |
| 0.42 | 399.4 | 0.561 | 0.449 | | | |
| 0.43 | 441.8 | 0.561 | 0.456 | 0.479 | 0.002461 | -0.050 |
| 0.55 | 539.7 | 0.561 | 0.561 | 0.495 | 0.015665 | 0.125 |
| 0.65 | 529.8 | 0.561 | 0.764 | 0.647 | 0.027273 | 0.165 |
| 2.06 | 565.2 | 0.561 | 1.712 | 0.912 | 0.396633 | 0.630 |
| 1.62 | 690.9 | 0.561 | 1.739 | 2.396 | 0.102561 | -0.320 |
| 2.68 | 819.6 | 0.561 | 2.489 | 2.394 | 0.001517 | 0.039 |
| 2.07 | 916.7 | 0.561 | 2.072 | 3.125 | 0.16874 | -0.411 |
| 1.55 | 1227.6 | 0.561 | 1.660 | 2.539 | 0.180601 | -0.425 |
| 1.70 | 738.8 | 0.561 | 1.792 | 1.914 | 0.004311 | -0.066 |
| 1.97 | 665.3 | 0.561 | 2.032 | 1.759 | 0.020802 | 0.144 |
| 3.79 | 758.9 | 0.561 | 3.516 | 2.577 | 0.0964 | 0.310 |
| 3.43 | 698.7 | 0.561 | 3.399 | 3.917 | 0.020068 | -0.142 |
| 2.65 | 592.6 | 0.561 | 2.588 | 3.755 | 0.138531 | -0.372 |
| 1.67 | 621.5 | 0.561 | 1.660 | 3.211 | 0.435047 | -0.660 |
| 1.05 | 626.9 | 0.561 | 1.126 | 2.259 | 0.485007 | -0.696 |
| 1.20 | 557.0 | 0.561 | 1.090 | 1.436 | 0.075994 | -0.276 |
| 0.58 | 667.5 | 0.561 | 0.756 | 1.373 | 0.355766 | -0.596 |
| 0.75 | 506.8 | 0.561 | 0.870 | 0.880 | 0.000124 | -0.011 |
| 1.38 | 601.7 | 0.561 | 1.035 | 0.962 | 0.005323 | 0.073 |
| 0.64 | 929.8 | 0.561 | 0.813 | 1.410 | 0.302773 | -0.550 |
| 1.00 | 965.8 | 0.561 | 1.225 | 0.933 | 0.07395 | 0.272 |
| 1.82 | 941.6 | 0.561 | 1.679 | 1.264 | 0.080343 | 0.283 |
| 0.96 | 1061.6 | 0.561 | 1.259 | 1.887 | 0.163323 | -0.404 |
| 1.33 | 1034.7 | 0.561 | 1.517 | 1.306 | 0.022569 | 0.150 |
| 2.32 | 1018.2 | 0.561 | 2.094 | 1.561 | 0.086223 | 0.294 |
| 2.02 | 1401.8 | 0.561 | 2.082 | 2.335 | 0.013184 | -0.115 |
| 2.88 | 1830.5 | 0.561 | 2.815 | 2.339 | 0.034381 | 0.185 |
| 3.64 | 1989.1 | 0.561 | 3.619 | 2.663 | 0.094018 | 0.307 |
| 4.60 | 1365.1 | 0.561 | 3.973 | 2.726 | 0.141782 | 0.377 |
| 1.96 | 1472.1 | 0.561 | 2.614 | 2.692 | 0.00088 | -0.030 |
| 7.27 | 1465.4 | 0.561 | 5.179 | 2.525 | 0.515991 | 0.718 |
| 3.51 | 1209.2 | 0.561 | 3.364 | 3.271 | 0.000783 | 0.028 |
| 3.51 | 1265.5 | 0.561 | 3.069 | 2.982 | 0.000826 | 0.029 |
| 5.56 | 1257.1 | 0.561 | 4.404 | 3.064 | 0.131552 | 0.363 |
| 5.68 | 1161.9 | 0.561 | 4.398 | 3.550 | 0.045955 | 0.214 |
| 2.71 | | 0.561 | 2.508 | 3.558 | 0.122288 | -0.350 |
| 2.34 | | 0.561 | 2.385 | 2.642 | 0.010428 | -0.102 |

Survey relative abundance data and observed catches

Optimization Model 4.37407 (process)

Find q such that residual sum of squares is minimized

## Observation Error Terms in Biomass Dynamic Model

| | Abundance b(t) | | | |
|---|---|---|---|---|
| | estimated | observed | resid^2 | Resid |
| 62 | 0.44869 | 0.42 | 0.00438 | -0.066 |
| 63 | 0.456255 | 0.43 | 0.00292 | -0.054 |
| 64 | 0.560943 | 0.55 | 0.00080 | -0.028 |
| 65 | 0.763733 | 0.65 | 0.02366 | -0.154 |
| 66 | 1.711694 | 2.06 | 0.03502 | 0.187 |
| 67 | 1.739055 | 1.62 | 0.00512 | -0.072 |
| 68 | 2.489349 | 2.68 | 0.00518 | 0.072 |
| 69 | 2.07221 | 2.07 | 0.00000 | -0.001 |
| 70 | 1.660007 | 1.55 | 0.00483 | -0.069 |
| 71 | 1.792285 | 1.70 | 0.00263 | -0.051 |
| 72 | 2.031697 | 1.97 | 0.00086 | -0.029 |
| 73 | 3.515713 | 3.79 | 0.00564 | 0.075 |
| 74 | 3.399458 | 3.43 | 0.00009 | 0.010 |
| 75 | 2.587865 | 2.65 | 0.00063 | 0.025 |
| 76 | 1.660294 | 1.67 | 0.00005 | 0.007 |
| 77 | 1.126001 | 1.05 | 0.00489 | -0.070 |
| 78 | 1.090 | 1.20 | 0.00970 | 0.098 |
| 79 | 0.756177 | 0.58 | 0.07152 | -0.267 |
| 80 | 0.87028 | 0.75 | 0.02079 | -0.144 |
| 81 | 1.034725 | 1.38 | 0.08145 | 0.285 |
| 82 | 0.813316 | 0.64 | 0.06093 | -0.247 |
| 83 | 1.224699 | 1.00 | 0.04043 | -0.201 |
| 84 | 1.678548 | 1.82 | 0.00685 | 0.083 |
| 85 | 1.259485 | 0.96 | 0.07547 | -0.275 |
| 86 | 1.517363 | 1.33 | 0.01693 | -0.130 |
| 87 | 2.093656 | 2.32 | 0.01016 | 0.101 |
| 88 | 2.081794 | 2.02 | 0.00096 | -0.031 |
| 89 | 2.815262 | 2.88 | 0.00054 | 0.023 |
| 90 | 3.618679 | 3.64 | 0.00003 | 0.006 |
| 91 | 3.972685 | 4.60 | 0.02128 | 0.146 |
| 92 | 2.613643 | 1.96 | 0.08387 | -0.290 |
| 93 | 5.179393 | 7.27 | 0.11540 | 0.340 |
| 94 | 3.364287 | 3.51 | 0.00169 | 0.041 |
| 95 | 3.069359 | 3.51 | 0.01767 | 0.133 |
| 96 | 4.404293 | 5.56 | 0.05412 | 0.233 |
| 97 | 4.398367 | 5.68 | 0.06558 | 0.256 |
| 98 | 2.508036 | 2.71 | 0.00627 | 0.079 |
| 99 | 2.38517 | 2.34 | 0.00042 | -0.020 |
| | | | **0.859** | |

Auxiliary F tuning from RI Survey

| Aux F | Resid^2 | Resid |
|---|---|---|
| 0.961 | 0.292 | -0.541 |
| 1.173 | 0.174 | -0.417 |
| 1.482 | 0.347 | 0.589 |
| 1.373 | 0.037 | -0.192 |
| 0.961 | 0.357 | -0.597 |
| 0.803 | 0.080 | -0.284 |
| 1.000 | 0.279 | -0.529 |
| 1.125 | 0.083 | -0.288 |
| 0.901 | 0.006 | 0.077 |
| 0.935 | 0.017 | 0.131 |
| 1.000 | 0.029 | 0.170 |
| 0.832 | 0.002 | -0.039 |
| 1.135 | 0.083 | 0.288 |
| 0.495 | 0.371 | -0.609 |
| 1.042 | 1.010 | 1.005 |
| 0.820 | 0.031 | 0.176 |
| 1.366 | 0.694 | 0.833 |
| 0.910 | 0.732 | 0.855 |
| 1.105 | 1.116 | 1.056 |
| 1.334 | 0.325 | 0.570 |
|  | 6.064 |  |

# APPENDIX F

## MINORITY REPORT

## Examination of Assumptions to the Egg-Per-Recruit Model (EPR) and Development of Alternative Stock Biomass and Fishing Mortality (F) Thresholds

By Victor Crecco

## APPENDIX F: Minority Report

# Examination of Assumptions to the Egg-Per-Recruit Model (EPR) and Development of Alternative Stock Biomass and Fishing Mortality (F) Thresholds

By

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## INTRODUCTION

Under the previous management regime in 1993, the two nearshore lobster stock units (Gulf of Maine (GOM) and South Cape Cod Long Island Sound (SCCLIS)) were considered to be recruitment overfished if the magnitude of current F (average 1995-97 F) on female lobsters had exceeded the overfishing definitions (F10%) for each stock unit. The F10% levels, derived from a steady-state egg-per-recruit (EPR) model (Fogarty and Idoine 1986), is the fishing mortality (F) rate that generated an egg/recruit value that corresponds to 10% of virgin (F = 0) egg/recruit. Another relative measure of stock status is the percentage of virgin egg production (MEP). MEP estimates were derived for each stock unit as the ratio of egg-per-recruit at current F levels to virgin (F = 0) egg-per-recruit. In the 1998 assessment, current estimates of F10% for the GOM (F10% = 0.32) and SCCLIS (F10% = 0.84) stocks were far below current female F estimates for these stock units (Table 1). Current MEP levels range from 3.5% to 8%, suggesting that current egg production and stock biomass levels are about 15 to 20 times below the expected levels at F = 0. Taken alone, these low MEP levels suggest that the GOM and SCCLIS lobster stocks are at high risk of recruitment failure since recruitment levels have been sustained by only about 3-9% of maximum egg production from 1982 to 1998. Yet when stock abundance and landings trends were examined, a persist rise in lobster recruitment and landings were evident in the GOM and SCCLIS since 1990, coupled with stable spawning stock biomass since 1982. Given that trends in theses data are not consistent with a recruitment overfished stock, the Lobster Technical Committee concluded that USA lobster stocks were growth overfished but not recruitment overfished.

Growing skepticism concerning the usefulness of F10% and MEP levels as recruitment overfishing thresholds exists among some scientists (Addison 1986), particularly over the two principal predictions of the EPR model: 1) that lobster stocks have been maintained for at least 20 years by only 3-9% MEP; and 2) that lobster egg production would escalate about 20 fold over current levels if F was reduced to zero. Many lobster scientists are dubious of the first prediction because they recognize that the suite of life history traits associated with lobster population dynamics (long-lived, delayed reproduction and low natural mortality) are not particularly suited to high (F>0.8) fishing mortality rates and low MEP levels for very long. Other scientists (Crecco and

Gottschall 1999; Gibson 1999, 2000) have noted that record high lobster recruitment and landings have taken place recently in the GOM and SCCLIS since 1993 under only 3 to 8% MEP, implying the existence of strong density dependent processes. The second prediction of the EPR model, that lobster egg production and stock biomass could rise nearly 20 fold over current levels if F dropped to zero, seems implausible in light of constrains imposed on stock growth due to limits in food and space. A 15-20 fold predicted rise in lobster egg production or stock biomass over current levels would not likely be sustained since such a enormous rise would soon exhaust all of the secondary benthic production. It is clear that either the assumption(s) underlying MEP calculations in the EPR model have been severely violated due to density-dependent effects, or that lobsters possess some innate capacity to alter their life history (ie become more r-selected) in response to rising trap utilization as was noted recently (Momot 1998) for northern crayfish (Orconectes virilis).

One of the major assumptions underlying the accuracy of F10% and MEP estimates is that the input parameters in the EPR model (growth, fecundity, recruitment and natural mortality (M)) remain constant as fishing mortality (F) rates approach zero. Recall, that in order to establish the magnitude of F10% and MEP for each stock, egg-per-recruit levels were derived at current F estimates, and compared as a ratio to virgin egg-per-recruit with only natural mortality (M = 0.15) (ie F equal zero). Constant growth, egg production and recruitment are assumed to hold here, despite a predicted twenty-fold rise in virgin lobster biomass and egg production per recruit when current F levels (F range: 0.5 to 1.4) drop to zero in the model. In fact the use of the virgin (F = 0) egg-per-recruit concept in the EPR model is very much analogous to the carrying capacity or virgin (F = 0) stock size (Binf) underlying stock-recruitment (Shepherd 1982) and surplus production (Jensen 1986) models. If density-dependent processes become evident as lobster abundance rises (ie as F approaches zero), lobster growth rates might slow, natural mortality (M) of new recruits (75-85 mm CL) to the fishery would rise and recruitment levels could fall significantly due to limits imposed by inter and intra-specific competition for food and space, as well as from increased adverse interactions with large (>140 mm CL) male lobsters. If so, virgin egg-per-recruit levels predicted from the EPR model would be proportionally much greater than true virgin egg production levels under the assumption of strong compensation. Since in many ways, the magnitude of F10% and MEP levels is inversely related to the magnitude of virgin egg production at F = 0, overestimating virgin egg production, when equilibrium conditions are violated in the EPR model, would result in F10% and MEP levels that are far too low. This in turn would severely overestimate the risk of American lobsters to recruitment failure at current fishing mortality rates (F).

For these reasons, the aforementioned two predictions underlying the EPR model were examined here based on historic lobster size frequency data taken from lobster traps in 1894 (Figure 2 females only taken from Table 9, Herrick 1909) and USA landings data in 1894 (Figure 1). Specifically, average stock biomass (mt) and abundance (millions of lobsters) of newly recruited lobsters (75-85 mm CL) from 1995 to 1998 were estimated when size was severely truncated and F was high. These current stock data were then compared to stock biomass (mt) and recruitment levels in 1894 when there was an extented size structure (Figure 2), relatively high landings (Figure 1), and very low (F<0.20) fishing mortality (F) levels. Since fishing rates were low in 1894, these early data were used to backcalculate the carrying capacity (virgin (F = 0) stock biomass). If the predictions underlying the MEP calculations are correct, estimated virgin stock biomass (mt) should be about 15-20 times greater than the 1995-98 average stock biomass level.

Secondly, since recruitment levels are assumed to be constant in the EPR model, the magnitude of newly recruited (75-85 mm CL) lobster abundance in 1894 should be similar to average recruitment levels from 1995-98. Since the offshore trap fishery did not begin until about 1960 (Miller 1995), the 1894 commercial landings were composed mainly from traps fished within State waters (< 3 miles) from New York to Maine. For this reason, only data from the nearshore stock units (GOM and SCCLIS) were used here to compare the magnitude of stock biomass and recruitment in 1894 and between 1995 and 1998.

## METHODS

Length frequency measurements (in. TL) of all (2,637 lobsters) lobsters captured from baited traps between Dec. 1,1893 to June 30, 1894 have been reported in Table 9 of Herrick (1909). To convert the 1894 total lengths (both sexes combined) to carapace length in mm, each length interval (in.) in Table 9 of Herrick (1909) was first converted to mm by multiplying inches by 25.4. Secondly, total lengths in mm were converted to carapace lengths (mm,CL) by multiplying total lengths by 0.44 (see Table 2). A conversion rate of 0.44 was used in order to transform the largest female lobster in the sample (total length = 381 mm) to 168 mm (CL), which represents the largest female given in Figure 2. When these length frequencies (Figure 2) were compared to those in 1997, there is clear evidence in 1997 of severe truncation of the size structure toward smaller lobsters, indicating the presence of growth overfishing. Because the lobster gauge size (mm) imposed by most New England states was around 79 mm (CL) during the late nineteenth century (Miller 1995), the average size from the 1894 data (Table 2) set was based on lobster that were 79 mm+. The arithmetic mean size of a lobster from this 1894 data set was 111.1 mm (CL) (SE = 0.53 mm), which was considerably higher than the average size (mean size = 88.6 mm) of lobster taken in 1997 (Figure 2).

In order to compare the magnitude of standing stock biomass (mt) between 1894 and for recent (1995-98) years, it was necessary to estimate fishing mortality (F) in 1894 and from 1995-97. The 1995-97 average fishing mortality (F = 1.00) (both sexes) was based on the DeLury model within the GOM and SCCLIS (Table 1). The fishing mortality (F = Z-M)) rate in 1894 was estimated indirectly from total mortality (Z) using the 1894 length frequency (Table 2) and a length-based model (Hoenig 1987):

$$Z = \log((\exp - K*(Lmean - Linf) + (Linf - Lfull))/(Lmean - Lfull) \tag{1}$$

**where: Lmean = mean carapace length (111.1 mm);**

**K,Linf = von Bertalanffy growth parameters (k=0.094, Linf = 225 mm) based on average values reported from GOM and SCCLIS (Table 3, Fogarty (1995));**

**Lfull = carapace length corresponding to the gauge size (79 mm) in 1894.**

Since natural mortality (M) for lobster was assumed to be 0.15, the F estimate in 1894 was derived by subtracting M = 0.15 from the Z estimate from equation 1.

Average lobster standing stock biomass (STSB,mt)(sexes combined) was estimated in 1894 based on the 1894 harvest rate (u) and the the average 1887-1892 landings (Land)(Table 3):

$$\mathbf{STSB = LAND / u} \qquad (2)$$

**where:** $\mathbf{u = (F*(1\text{-}exp\ (-F+M)) / (F+M);}$

**M = natural mortality rate = 0.15;**

**F = average fishing mortality from DeLury (1995-97) or in 1894 based on equation 1.**

Comparable STSB levels in 1997 was estimated from equation 2 based on the average F (avF = 1.00) (sexes combined) from Delury between 1995-97 for the GOM and SCCLIS (Table 1), and on the 1995-98 commercial landings (mt) from the SCCLIS and GOM stock units (Table 3). Average Standing stock biomass (STSB) from 1995-98 consisted of total biomass of legal-size (83+mm, CL) lobsters each year from 1995 to 1998. Since the STSB value may contain prespawning female lobsters, especially from the GOM, the magnitude of STSB should slightly exceed the Potential Spawning Stock Biomass (PSSB), which traditionally includes only mature female lobsters.

The lobster trap fishery usually occurs throughout the year, so that fishing (F) and natural mortality (M) operate concurrently. Thus, some fraction of the standing stock biomass (STSB) would be harvested before they could spawn. In an attempt to reflect the effects of inseason exploitation on potential spawning, Available Spawning Stock Biomass (ASSB mt) levels for lobsters in 1894 and from 1995-98 were estimated by subtracting one-half the annual landings (LAND) (Table 3) from the corresponding annual STSB level:

$$\mathbf{ASSB = STSB - (0.5*LAND).} \qquad (3)$$

There are two advantage of using a more general proxy for spawning stock size such as ASSB. Firstly, since STSB and ASSB levels are easily calculated (equations 2-3) and include biomass from both male and female lobsters, there is no need to use sea sampling data in order to separate commercial landing and survey data by sex. Secondly, given that mature male and female spawners are always contained within the STSB estimate, maturity ogives and power regressions of egg production as a function of female lobster size (mm,CL) are not needed to measure relative reproductive effort.

To assess the steady-state assumption in the EPR model that newly recruited (size: 75-85 mm) abundance is constant under all fishing mortality (F) levels, recruitment levels in millions of lobsters (REC) were estimated in 1894 and from 1995-98 by:

**REC = Frac*(STSB in kg/avwt in kg) (4)**

**where: Frac = fraction of lobster length frequency in 1894 and 1997 (Figure 5.1-2) between 75 and 85 mm (CL);**

**avwt = average weight (kg) of a lobster from the landings in 1894 (1.5 kg) and 1997 (0.5 kg).**

If the steady-state assumption for constant recruitment holds for lobsters, the magnitude of recruitment (REC) in 1894 should closely approximate current (1995-98) recruitment levels.

The carrying capacity estimate (Binf) can be used to establish stock biomass and F thresholds. Having estimates of available spawning stock biomass (ASSB) from equation 3 in 1894 and from 1995-98 plus the corresponding fishing mortality rates (F) in 1894 and 1997 (Table 4), the Binf estimate can be easily extrapolated to F = 0 by direct proportion. Recall that the Binf parameter is directly proportional to the virgin egg-per-recruit estimate from the EPR model. As such, the Binf level can be used to assess the second prediction of the EPR model that egg production and stock biomass should rise nearly twenty fold over current biomass levels. Moreover, the Binf level can also be used to directly set spawning stock biomass (ASSB) thresholds such as B10% or B20% by simply multiplying the Binf level by either 0.10 or 0.20, respectively. As a result, the magnitude of the current (1995-98) available spawning stock biomass (ASSB) levels can be compared to biomass levels that correspond to B10% and B20% values. This will determine whether or not current stock biomass levels are below or above this biomass threshold for recruitment overfishing.

The maximum spawning potential (MSP), can be computed as a ratio between the available spawning stock size (ASSB) in either 1894 or 1997 and Binf:

**MSP = ASSB / Binf (5)**

The MSP level derived from equation 5 is analogous to the percent maximum egg production levels (MEP) (Table 1) based on the EPR model. Note that one of the primary predictions of the EPR model was that the nearshore lobster fisheries (GOM and SCCLIS stocks) were producing recruits under only about 5.6% of MEP. If this prediction is correct, the magnitude of MSP in 1997 should appproach the 5.6% MEP predicted by the EPR model.

## RESULTS AND DISCUSSION

Based on the 1894 length frequency (Table 2) and corresponding mean length (mm,CL) data (Table 4), the fishing mortality (F) rate in 1894 based on the Hoenig model (equation 1) was about 0.09 (Table 4). This was about ten times lower than the current (1995-98) average (F = 1.00) fishing mortality rate based on DeLury in the GOM and SCCLIS stock units (Tables 1 and 4). The resulting standing stock biomass (STSSB,mt) in 1894 was 156,250 mt as compared to an average STSSB of 51,634 mt from 1995-98 (Table 5). Available spawning stock biomass (ASSB) in the combined GOM and SCCLIS was about four times higher in 1894 (150,00 mt) than the current average (36,402 mt). However, based on a virgin (F=0) stock biomass of 161,235 mt (Table 5), current (1995-98) MSP was 22.6% (from equation 5) of virgin biomass (Table 5). This MSP level is about four times greater than the predicted average MEP level (MEP=5.6%) from the EPR model for the combined GOM and SCCLIS stocks (Table 1). That current MSP approaches 23% not 5.6% is consistent with recent results of Gibson (200U), who reported that current (1997-99) MSP levels for lobsters within Rhode Island waters approached 38% using a Discrete Biomass Dynamic model based on the 1962 to 1999 landings. Moreover, Jensen (1986) used landings (mt) and fishing effort data on the Maine lobster fishery from 1928-72 to estimate effort at maximum sustainable yield and the carrying capacity (Binf) using stock production models. Jensen (1986) reported that Binf for the Maine lobster fishery was estimated to be 80,000 mt. The current (1995-98) ASSB estimate for the Maine fishery was about 30,974 mt from equation 3 (mean landings = 18,504 mt, F = 0.67). This indicated a current MSP level of 39% (ie 30,974mt/80,000mt), which was 10 times greater than the predicted MEP of 3.5% for the GOM (Table 1) based on the EPR model. Unlike the expected 20 fold rise in egg production and stock biomass at F = 0 predicted by the EPR model, these findings and those of Gibson (2000) and Jensen (1986) strongly suggest that current stock biomass in the GOM and SCCLIS would rise about three to four-fold if F dropped to zero.

The comparison between length frequencies in 1894 to those from 1997 (Figure 2) revealed that about 8.5% (Table 2) of the lobsters sampled in 1894 were newly recruited (size:75-85 mm CL) to the fishery. This was in sharp contrast to the 1997 data (Figure 2) in which about 90% of the lobsters were new recruits to the fishery. As a result, estimated recruitment (REC = 93.0 million lobsters)) during recent years (1995-98) (from equation 4) was about ten times higher than new recruit abundance (REC = 8.9 million lobsters) in 1894 (Table 5). Given the striking disparity between recruitment levels (REC = 93.0 million lobsters), these findings strongly suggest that the EPR assumption of constant recruitment has been violated. Due to increases in recruitment during the mid-1990's, maximum spawning potential (MSP = 22.6%) in 1998 (Table 5) was much greater than the predicted MEP level (MEP = 5.6% (Table 1) based on the EPR model. Violation of the constant recruitment assumption is the major reason why current MSP levels (MSP = 22.6%) (Table 5) are so much higher than the EPR predicted mean MEP levels (MEP = 5.6%) (Table 1). Record high recruitment after 1995 has largely compensated for the loss in biomass and egg production from larger (>140 mmCL) lobsters.

Since the fishing mortality (F) rate on nearshore lobsters in 1894 was only 0.09 (Table 4), the MSP level in 1894 approached that (MSP = 96.9%) of a virgin stock (Table 5). Two spawning stock biomass thresholds (SSB10% and SSB20%) which corresponds to 10% and 20% MSP, respectively, were derived by multiplying the virgin biomass level (161,235 mt) for the combined GOM and SCCLIS stocks by 0.10 and 0.20. The resulting spawning biomass thresholds (ASSB10% = 16,124 mt, SSB20% = 32,247 mt) were below the average 1995-98 ASSB level of 36,402 mt (Table 5), indicating that lobsters spawning stock sizes within nearshore management units (GOM and SCCLIS) are high enough to ensure good recruitment when environmental conditions are favorable.

The MSP estimates in 1894 (MSP = 96.9%) and from 1995-98 (MSP = 22.6%)(Table 5) can also be used in conjunction with corresponding fishing mortality rates (F) (Table 4) to generated adjusted fishing mortality thresholds (ie adjF10%, adjF20%) for recruitment overfishing. These thresholds (F10%, F20%) correspond to MSP levels of 10% and 20%, respectively, and can be easily calculated by direct proportion. The resulting adjF10% estimate of 1.16 exceeded the average nearshore F of 1.00 (Table 1) by about 14% (Table 5), although the adjF20% threshold of 1.04 was only slightly above the current F of 1.00. Based on these analyses, I would recommend that the nearshore lobster stocks be assessed for recruitment overfishing based on a dual threshold approach. Specifically, the nearshore lobster stocks (GOM,SCCLIS) would be regarded as recruitment overfished if they satisfy two criteria: 1) current average (mean F 1995-97) F must exceed the adjF10% threshold of 1.16; and 2) current spawning stock biomass (mt) levels must fall below the 10% spawning stock biomass threshold (SSB10% = 16,124 mt). Neither of these preconditions are currently met for the combined nearshore lobster fisheries.

The lobster length frequency distribution in 1997 (Figure 2) contained very few large (>140 mm CL) lobsters, suggesting that the nearshore fishery is currently sustained by one or two year-classes. The argument has been made that lobster stocks are particularly susceptible to recruitment overfishing without the buffering afforded by the presence of an extended size structure as per 1894 (Figure 1). This size structure problem, however, may be overstated in light of the new aging study (Sheehy el al. 1999) conducted on European lobster (Homarus gammerus), a clawed lobster species whose life history properties are very similar to those of American lobster. Sheehy et al. (1999) aged European lobsters with the aid of eyestalk ganglion and reported the startling conclusion that newly recruited (gauge size 85mm CL) lobsters off the United Kingdom are composed annually of at least seven year-classes (ie ages 3 to 12). They reported that annual molt frequency and growth rates were so erratic that size alone was a poor indicator of true age. If American lobsters grow and molt in a similar fashion as European lobsters, then as many as seven year-classes recruit annually to the gauge size (83 mm CL) rather than two year-classes as is currently assumed in the DeLury and EPR models. This platoon-type recruitment strategy would spread the risk of exploitation across many year-classes, thereby reducing the overal risk of recruitent failure at current fishing mortality rates. Moreover, if molt frequencies and growth rates currently assumed for American lobsters are measured with high error, then fishing mortality (F) from the DeLury model would be too high, and F10% estimates (Table 1) from the EPR model would be too low.

The accuracy of current average MSP (22.6%) levels between 1995 and 1998 depend heavily on the assumption that average lobster landings between 1887 and 1892 (12,500 mt) are as accurate as those from 1995 to 1998 (30,464 mt) (Table 3). If the early (1887-92) landings were underestimated by about 400%, then current MSP (MSP = 22.6%) would match the average MEP level (MEP = 5.6%) from the EPR model. There are several reasons to doubt that historic nearshore landings could have approached 50,000 mt. Firstly, Miller (1995) noted that Canada had been exporting lobsters to the United States since 1860. By 1890, total Canadian lobster landings in 1890 were about 40,000 mt (Figure 6, Miller 1995). Given a USA population of about 90 million people in 1890, it is doubtful that Canada would be exporting large numbers of lobsters to the USA if the true USA lobster landings were about 50,000 mt. Secondly, with only about 125,000 traps fished in Maine during 1890 as compared to about 2.5 million traps fished in 1997 (Figure 3, Fogarty 1995), it would be difficult to believe that the 1890's landings would be nearly twice the current landings. Thirdly, if the 1890's USA landings were in fact approaching 50,000 mt rather than 12,500 mt, there would be about a 400% systematic error persumably due to underreporting. Modern fishermen usually underreport their landings to minimize their tax burden, but in 1890 there was no Federal income tax. The Federal income tax was first established in 1915. Given the much higher tax burden that exists on lobster fishermen during the 1990's, it seems that the level of underreporting of landings would be higher today than during the 1890's. Finally, the fact that the current MSP level measured here (MSP = 22.9) for the combined GOM and SCCLIS is considerably lower than those measured by Gibson (2000. MSP = 38%) and Jensen (1986, MSP = 39%) suggests that current (1995-98) landings may be too low (Table 3) relative to the early (1887-92) landings.

The findings from this report that abundance of newly recruited (size: 75-85 mm CL) lobsters in 1894 (8.9 million recruits), when F was 0.09, was about ten times less than current recruitment levels (93.0 million recruits), when F was about 1.00 (Table 5), have important assessment and management implications. In the first place, a pronounced drop in recruitment abundance as spawning stock biomass approached the carrying capacity (Binf) is consistent with the hypothesis that the presence of large (>140 mm CL), dominant male lobsters (Cowan and Atema 1990), say in 1894, may have had an adverse impact on recruitment survival. This hypothesis is directly supported by recent findings based on controlled fishing experiments (Momot 1998) for the northern crayfish (Oronectes virilis). Momot (1998) reported that in an unfished lake, antagonistic behavior by large male crayfish had strongly inhibited the survival of juvenile crayfish by denying them access to preferred habitat and food supply. Yet in the exploited lake, the removal of large male crayfish resulted in enormous increases in juvenile recruitment that completely offset the high fishing mortality (F>0.8) rates experienced by adult male and female crayfish.

Although behavioral interactions between large male lobsters and juveniles may retard overall recruitment levels across a wide temporal scale (ie 1894 vs 1997), this hypothesis would not account for the steady rise in lobster recruitment within the GOM and SCCLIS over a more restricted time frame (from 1990 to 1998) when F was persistently high (F> 0.7). It is very likely that some suite of environmental factors favorable to lobster recruitment success has taken place during the last eight years. Whether these forcing variables are climatic in nature, or are related to the selective removal of key lobster predators (ie cod, haddock) is not known at this time.

If lobster recuitment levels to the nearshore stock drops dramatically at low F levels (F<0.2) and at high spawning stock biomass (Figure 1), the shape of the theoretical stock-recruitment (S-R) relationship for lobster should be strongly dome-shaped (parabolic, Ricker type)) at extremely high levels of egg production. Previous stock-recruitment curves for American lobster (Fogarty and Idoine 1986; Ennis and Fogarty 1997) were distinctly flat-topped (Beverton-Holt type) with a very steep ascending limb (high compensatory reserve). The flat-topped nature of these S-R curves may be an artifact due to the lack of contrast in egg production estimates since 1980. During this period, egg production levels remained relatively stable under high fishing mortality rates (F). As pointed out by Addison and Bannister (1998), exploited crustaceans, whose S-R curve are distinctly parabolic, generate higher Fmsy levels and can accommodate higher levels of exploitation than stocks with flat-topped S-R curves.

The bias associated with low MEP (Table 1) estimates based on the current EPR model (Table 1) can be adjusted upward to reflect more reasonable MEP levels using three approaches.

Firstly, the F10% threshold from the EPR model could be replaced by MSP levels from carrying capacity estimates (Binf) derived by a Discrete Biomass Dynamic Model (Gibson 2000) using historic landings, fishing effort and tuning indices. Secondly, the output (egg-per-recruit, E/R) from the EPR model could be merged with the Shepherd S-R model (Shepherd 1982) parameters using the compensatory reserve parameter (alpha) from Ennis and Fogarty (1997) and a dome-shaped (B>1.5)) parameter based on the sharp decline in lobster recruits at low F reported here (Table 5). This Shepherd approach would generate virgin (F = 0) egg production at the carrying capacity (Einf) by:

$$\mathrm{Einf} = K*((\mathrm{alpha})* E/R-1)**1/B \tag{6}$$

**where: E/R= egg-per-recruit at F=0;**

**K = egg production at which density-dependent effects take place.**

MSP levels would then be derived as a ratio of the current egg production to the carrying capacity (Einf) from equation 6. In the final approach, which to my knowledge has never been used, is to generate E/R values at each F with the current EPR model, but instead of using constant recruitment at each F, scale the recruitment level (one lobster) down as F in the model approaches zero. This scaling technique would reduce the magnitude of the current virgin egg-per-recruit level, making the current MEP levels of 3.5% and 8.0% (Table 1) more consistent to MSP levels reported here (MSP = 22.6%) and elsewhere (MSP = 38 or 39%) (Gibson 2000; Jensen 1986).

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**Table 1**. Summary of percent maximum egg production (MEP), 1995-1997 average fishing mortality (F) rate (sexes combined), F10% level and percentage of total lobster landings in 1997 for the GOM and SCCLIS stock units. The weighted average levels were based on the percentage landings for the GOM and SCCLIS.

| Stock Unit | MEP | F 1995-97 | F10% | % Landings |
|---|---|---|---|---|
| GOM | 3.2% | 0.67 | 0.34 | 79% |
| SCCLIS | 8.0% | 1.33 | 0.84 | 21% |
| Weighted avg. | 5.6% | 1.00 | 0.59 | - |

**Table 2**. Length frequencies of all (2,657 lobsters) male and female lobsters taken from baited traps between Dec. 1,1893 and June 30, 1894 at Woods Hole Harbor, MA (data from Table 9, in Herrick (1909)). Length data were originally expressed as in. TL, but were transformed to approximate carapace (CL) length (mm) by multiplying total lengths by 25.4 mm and then by 0.44.

| Size mm CL | Frequency | Size mm CL | Frequency |
|---|---|---|---|
| 67 | 7 | 109 | 56 |
| 70 | 1 | 112 | 351 |
| 73 | 7 | 113 | 1 |
| 75 | 5 | 115 | 133 |
| 78 | 93 | 117 | 182 |
| 80 | 1 | 120 | 36 |
| 81 | 14 | 123 | 93 |
| 84 | 113 | 126 | 21 |
| 87 | 29 | 129 | 41 |
| 89 | 308 | 131 | 4 |
| 91 | 1 | 134 | 23 |
| 92 | 73 | 137 | 1 |
| 95 | 258 | 140 | 11 |
| 98 | 53 | 142 | 1 |
| 101 | 336 | 145 | 8 |
| 102 | 1 | 151 | 1 |
| 103 | 70 | 156 | 1 |
| 106 | 317 | 162 | 3 |
| | | 168 | 3 |
| | | Total | 2,657 |

**Table 3.** Commercial lobster landings (mt) from the GOM and SCCLIS from 1995 to 1998 and from 1887 to 1892.

| Years | Comm. Landings | Years | Comm. Landings |
|---|---|---|---|
| 1995 | 27,983 | 1887 | 12,997 |
| 1996 | 28,435 | 1888 | 12,549 |
| 1997 | 33,124 | 1889 | 13,824 |
| 1998 | 32,315 | 1890 | no data |
| | | 1891 | no data |
| | | 1892 | 10,628 |
| Average | 30,464 mt | | 12,500 mt |

**Table 4.** Estimates of mean carapace length (mm) of lobsters measured in 1894 (Table 2), estimated 1890-95 USA commercial landings (mt), estimated 1990-98 GOM and SCCLIS commercial landings (mt), 1894 fishing mortality (F = Z-0.15) estimate based on the method of Hoenig (1987), average 1997 fishing mortality (F) (sexes combined) from the DeLury model.

| Parameter | Estimate |
|---|---|
| Mean Length (mm CL) | 111.1 mm (SE = 0.53) |
| 1890-95 Commercial landings | 12,500 mt |
| 1995-98 GOM and SCCLIS landings | 30,464 mt |
| 1894 F [1/] | 0.09 |
| 1995-97 Average F (sexes combined) | 1.00 |

1/ Estimate of total mortality (Z) in 1894 based on Hoenig (1987) equation:

$$Z = \log((\exp{-K}*(Lmean-Linf)+(Linf-Lfull))/(Lmean-Lfull)$$

where: K=0.094,

Linf=225mm;

Lmean = average length (111.1 mm);

Lfull = length at full recruitment (76 mm);

F = Z - 0.15.

**Table 5**. Estimates of total lobster stock biomass (STSSB,mt), spawning stock biomass (ASSB,mt) and potential recruitment abundance (REC in millions of 75-85mm CL lobsters) in 1894 and from 1995-98 and their respective equations in the combined GOM and SCCLIS. Estimates of virgin stock biomass (F = 0), F10%, F20% and current maximum spawning potential (MSP) estimated spawning stock size (mt) corresponding to F10% and F20% for the combined GOM and SCCLIS.

| **Parameter** | **Estimate** | **Equation** |
|---|---|---|
| Total stock (STSSB)in 1894 | 156,250 mt | 2 |
| Total stock (STSSB) from 1995-98 | 51,634 mt | 2 |
| Spawning stock (ASSB) in 1894 | 150,000 mt | 3 |
| Spawning stock (ASSB) from 1995-98 | 36,402 mt | 3 |
| Recruitment (REC) in 1894 | 8.9 million | 4 |
| Recruitment (REC) from 1995-98 | 93.0 million | 4 |
| Virgin stock biomass (F=0) | 161,235 mt | * [1]/ |
| Current MSP | 22.6% | 5 |
| MSP in 1892 | 96.9% | 5 |
| F10% for combined GOM and SCCLIS | 1.16 | see Results |
| F20% for combined GOM and SCCLIS | 1.04 | see Results |
| Spawning Stock at F10% for combined | 16,124 mt | *[2]/ |
| Spawning Stock at F20% for combined | 32,247 mt | *[3]/ |

[1]/ Binf estimated by setting F=0 and using the direct proportion between F estimates in 1894 and 1997 (Table 4) and the available spawning stock in 1894 (150,000 mt) and from 1995-98 (36,402 mt);

[2]/spawning stock biomass at F10% = Binf*0.10.

spawning stock biomass at F20% = Binf*0.20.

**Figure 1.**

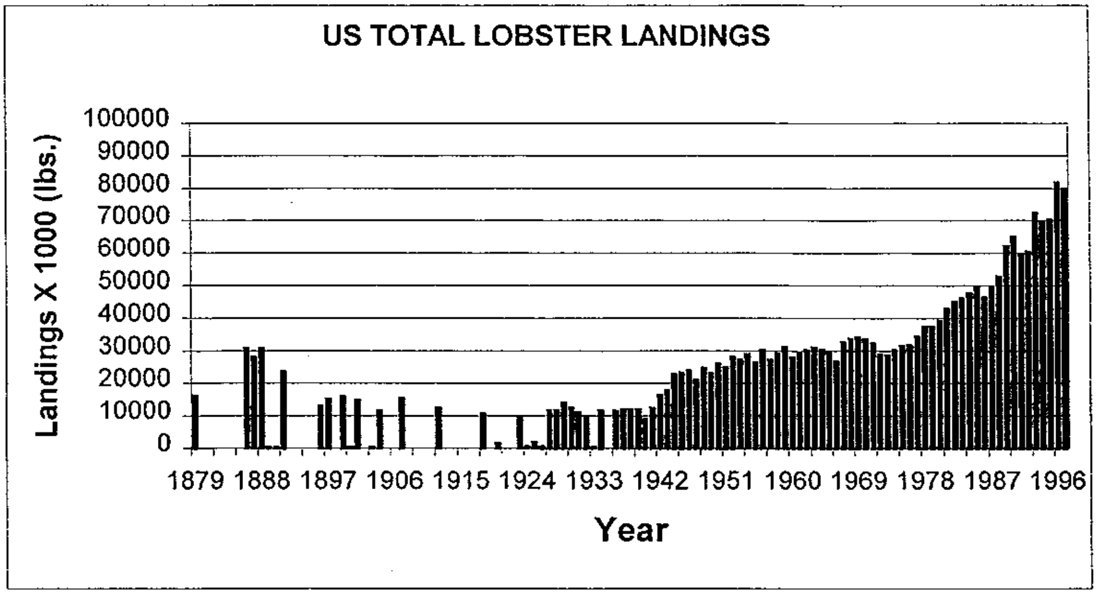
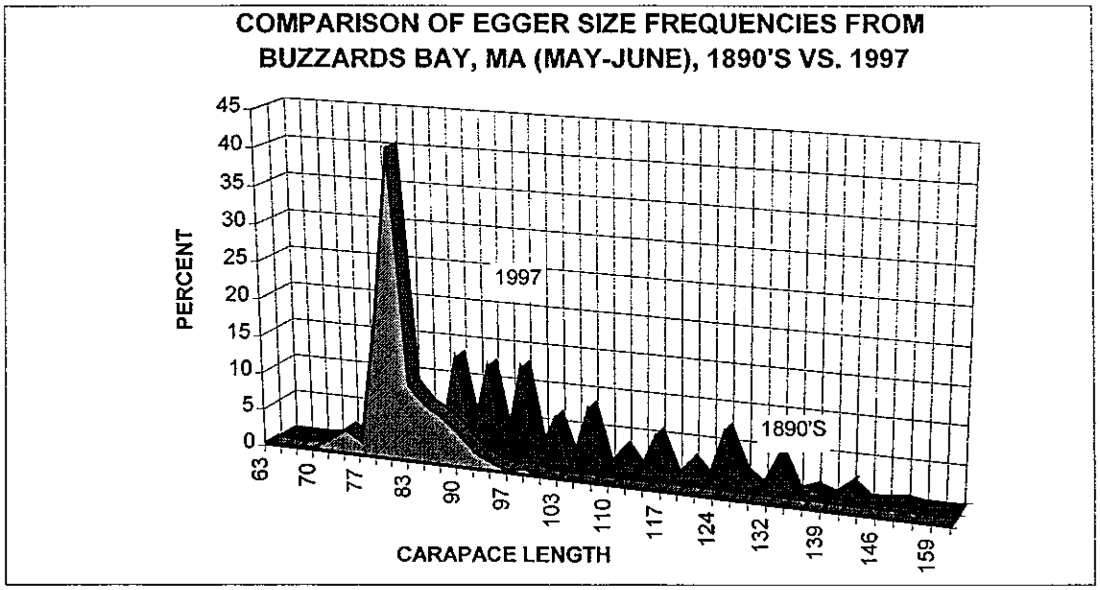


**Figure 2**



# APPENDIX G

## MINORITY REPORT

## The Effect of Intense Gear Saturation on the Assessment and Management of American Lobster (*Hommarus americanus*)

By Victor Crecco

# APPENDIX G: Minority Report

## The Effects of Intense Gear Saturation on the Assessment and Management of American lobster (*Hommarus americanus*)

By

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## INTRODUCTION

Since 1980, USA commercial lobster (*Hommarus americanus*) landings have increased steadily from about 21.0 thousand metric tons (mt) in 1986 to over 36.0 thousand mt in 1998. These historic high landings have recently occurred, despite a persistent rise in lobster fishing effort (trap hauls, number of licensed traps) within most inshore areas from Maine to New York. By contrast, fishing mortality estimates (F) on American lobster from 1982 to 1997 for the SCCLIS, GOM and GBK stocks have remained relatively stable in the face of recent escalating trends in landings and fishing effort. Based on these data, there appears to be a major divergence in trends between F and fishing effort (f) at least during the last 16 years. This lack of linearity between F and f may have resulted from gear saturation in the commercial trap fishery. Intense gear saturation in stationary baited traps have been reported for a variety of crustaceans including American lobsters in Maine waters (Waltz 1989), European lobster off the United Kingdom (*Hommarus gammerus*) (Addison 1995; Addison and Bannister 1998), blue crab (*Callinectes sapidus*) and was clearly demonstrated from controlled fishing experiments on two crayfish populations (*Oronectes virilus*) (Momot 1998).

The lack of proportionality between trends in F and fishing effort (f) suggests that the catchability coefficient ($q = F/f$) has not remained constant as in most surplus production and egg-per-recruit models (Addison and Bannister 1998), but had fallen steadily as fishing effort rose during the 1990's. The test of gear saturation and its implications on the usefulness of effort controls (f) is examined for the SCCLIS, GOM and GBK lobster stocks using updated fishing effort (f) and fishing mortality (F) rates from 1982 to 1997.

## METHODS

### Gear Saturation Test

In most finfish and decapod fisheries, it is assumed that fishing mortality rates (F) display some positive linear or nonlinear change with fishing effort (f) via a scalar (constant) known as the catchability coefficient (q):

$$\mathbf{F = q * f} \qquad (1)$$

When (q) is constant as in equation (1), landings (C) can be expressed as the product of the constant catchability coefficient (q), fishing effort (f) and population size (N):

$$\mathbf{C = q * f * N} \qquad (2)$$

and relative changes in stock abundance can be monitored as catch-per-unit-effort (C/f):

$$\mathbf{C/f = q * N} \qquad (3)$$

To test for gear saturation for the SCCLIS, GOM and GBK stocks, median fishing mortality rates (F) based on boot-strapped DeLury runs from 1982 to 1997 were regressed separately against nominal fishing effort (f) from several data sources in a log-log linear regression:

$$\mathbf{\log F = \log A + B * \log f} \qquad (4)$$

The use of a log-log regression is justified here, because the log transformed power function:

$$\mathbf{F = A * F^{B}} \qquad (5)$$

always rises from the origin (zero intercept). As in all fisheries, the fishing mortality rate (F) on lobsters is assumed to be zero when fishing effort (f) is zero. In an untransformed linear regression:

$$\mathbf{F = A + B * f} \qquad (6)$$

it is possible to generate a positive intercept (A) value (some F at f of zero) which is unrealistic in any fishery.

If the catchabilty coefficient (q) is constant as in equations (1-3), the slope (B) of equation (4) from each data set would not differ significantly ($P<0.05$) from 1.0 based on a one tailed t-test at (n-2) degrees of freedom:

$$\mathbf{t = 1.0 - B / SE_B} \qquad (7)$$

where: $SE_B$ = standard error on B.

A slope (B) of 1.0 would indicate that gear saturation was not present and that annual changes in F and f are directly proportional. This would allow for efficient controls of F in the lobster fishery via proportional reductions in fishing effort (f).

In the second condition, if gear saturation has been operating in the USA lobster fishery, the slope (B) of equation (4) should be significantly ($P< 0.05$) less than 1.0 (equation 7), indicating that reductions in fishing effort (f) would not lead to proportional drops in fishing mortality (F). Negative values for the slope (B) are possible over a limited range of effort data. This occurs when q drops proportionately at a faster rate as fishing effort (f) rises, indicating the presence of hypersaturation. This condition suggests that small (5-10%) reductions in current fishing effort (f) might result in a small (5-10%) rise in lobster fishing mortality (F). Since a log-log regression of F on f (equation 4) always rises from the origin with a positive slope (B), when B is negative, the true functional relationship between F and f is parabolic rather than a power function (equation 5). It follows that a negative slope (B) of F on f only occurs over a limited range of data such as the period 1982-97, and it can be very misleading to extrapolate the F versus f relationship beyond the range of observed data.

In the third condition, there may be a complete lack of fit (i.e. B value not significantly different ($P>0.05$) from zero) between F and f, indicating a "flat-line" relationship between F and f. Lack of fit can also be tested by a two tailed t-test:

$$\mathbf{t = B / SE_B} \qquad \mathbf{(8)}$$

Because when $B = 0.0$, F levels are independent of changes in fishing effort (f), intense gear saturation would still be operating in this fishery. In this case, a strategy of effort reduction (say 10%) will have no effect on the magnitude of fishing mortality (F). It should be noted that the degree of statistical significance about the slope (B) estimate, like in any regression analysis, can be greatly affected by the length (number of years) of the data set, and the degree of contrast between the F and f estimates. Relatively short (<15 years) data sets, such as these for lobsters, with limited contrast between F and f, can produce artificially low statistical fits.

## Data Source

### Gulf of Maine Stock (GOM)

The 1982-97 fishing mortality ($F = Z - 0.15$) estimates on GOM male and female lobsters were based on median F values from the DeLury model (Table 1). Fishing effort (f) on GOM lobsters was expressed as annual trap hauls (TH) between 1982-97 recorded by the state of Maine (Kevin Kelly, Maine DMR, pers. comm.), and between 1985-97 for the state of Massachusetts (Bob Glenn, Mass. DMR, pers. comm.) (Table 1). The number of GOM trap hauls (TH) in Massachusetts are only available from 1990 to 1998, but total inshore TH are available from 1985 to 1998. To estimate TH levels in the GOM from Massachusetts between 1985 and 1989, a linear regression was developed between the total inshore trap hauls (TITH) and the trap hauls from the GOM (TH) from 1990 to 1998:

$$\mathbf{TH = -5.09 + 1.206 * TITH \qquad (r^2 = 0.98) \qquad (9)}$$

Having total inshore trap hauls (TITH) from 1985 to 1989, GOM trap hauls (TH) were hindcast by substituting TITH values from 1985 to 1989 into equation 9.

To test for gear saturation for the GOM stock, the DeLury-based male and female F estimates from 1982-97 were fitted separately to Maine and Massachusetts fishing effort (f) using the log-log regression (equation 4).

## South Cape Cod Long Island Sound (SCCLIS)

The 1982-97 fishing mortality (F = Z - 0.15) estimates on SCCLIS male and female lobsters were based on a weighted average of boot-strapped median F values from several DeLury model runs (Table 2). Fishing effort (f) on SCCLIS lobsters was expressed from 1982-97 based on pots fished within eastern and western LIS from New York (Graulich 1999), licensed traps (T) fished in Connecticut and trap hauls (TH) from Rhode Island taken from Table 1 of Gibson (1999)(Table 2). Attempts were made to derive a trap haul effort index between 1985-97 from Massachusetts using the linear regression approach outlined previously for the GOM. However, the regression of total inshore TH and SCCLIS TH from 1990-97 was not significant (P>0.05) and therefore could not be used to hindcast TH in the SCCLIS from 1985-89.

To test for gear saturation for the SCCLIS stock, the DeLury-based male and female F estimates from 1982-97 were fitted separately to New York, Rhode Island and Connecticut fishing effort (f) (Table 2) using the log-log regression (equation 4).

## Georges Bank and Offshore (GBK)

The 1982-97 fishing mortality (F = Z - 0.15) estimates on GBK male and female lobsters were based on boot-strapped median values from the DeLury model (Table 3). Fishing effort (f) on GBK lobsters was expressed as annual trap fished offshore between 1982-97 from the state of New York (Graulich 1999), and as trap hauls (TH) fished offshore between 1985-97 from the state of Massachusetts (Bob Glenn, Mass. DMR, pers. comm.).

To test for gear saturation for the GBK stock, the DeLury-based male and female F estimates from 1982-97 were fitted separately to New York and Massachusetts fishing effort (f) using the log-log regression (equation 4).

## RESULTS

### Gulf of Maine (GOM)

Fishing effort (f) in the GOM expressed as Maine trap hauls (TH) varied without trend from 1982 to 1993, but TH levels rose thereafter to over 37.0 million TH in 1997 (Figure 1). By contrast, fishing effort (f) from the GOM based on Massachusetts TH data was relatively stable from 1985 (16.3 million TH) to 1993 (15.1 million TH) (Figure 2) before fishing effort (TH) declined thereafter by 25-35%.

Estimated fishing mortality (F) rates on female lobsters based on DeLury varied without trend (F range: 0.62-1.08) from 1982-97 (Table 1), despite a 25% rise in fishing effort (TH) based on Maine data (Figure 1). Fishing mortality rates (F) on male lobsters showed no apparent trend (F range: 0.60 to 1.02) from 1982 to 1988, after which F rates on male lobsters fell below 0.77 (Table 1).

The slope (B) estimates for the log-log regressions between F rates and Maine TH were negative, significantly ($P<0.05$) below 1.0 and significantly different from zero for both male ($B = -1.29$) and female ($B = -0.98$) lobsters (Table 4, Figures 3 and 4). This indicated the presence of hypersaturation in GOM trap fishery, at least over the range of Maine fishing effort (f) examined from 1982-97. When the slope (B) is negative and differs significantly from zero, the catchability coefficient (q) falls at a faster rate as fishing effort rose from 1990 to 1997 (Figures 5 and 6). Based on the inverse relationship between F and Maine f, a trap haul reduction strategy of 10-20 %, would result in a slight rise (2-5%) in fishing mortality rates (F) on GOM lobsters.

Evidence for gear saturation differed between male and female lobsters when F estimates were related to Massachusetts fishing effort (f). The estimated slopes (B) for the log-log regression between lobster F rates and Massachusetts TH from 1985-97 were positive for both male ($B = 0.763$) and female ($B = 0.422$) lobsters (Table 4, Figures 7 and 8). The slope estimate for male lobsters ($B = 0.763$) did not differ significantly ($P<0.05$) from 1.0, indicating that catchability (q) values were generally constant across all fishing effort levels (f) from 1985 to 1997 (Figure 10). Thus for male lobsters in the GOM, there is no evidence for gear saturation using Massachusetts fishing effort (f). Although the slope estimate for female lobsters ($B = 0.422$) was positive, it was significantly below 1.0 and not significantly different from zero (Table 4), indicating the presence of gear saturation on female lobsters. Catchability levels (q) for female lobsters declined when fishing effort rose (Figure 9). Linearity between F on male lobsters and Massachusetts fishing effort (f) suggests that any proposed reductions in fishing effort (f) should result in proportional reductions in F on male lobsters but not on female lobsters in the GOM over the range of Massachusetts effort from 1985 to 1997 (Figure 2).

## South Cape Cod long Island Sound (SCCLIS)

Fishing effort (f) in the SCCLIS expressed as Connecticut traps exhibited a ten-fold rise between 1982-97 from a low of 14.8 thousand traps in 1982 to a high of 108.5 thousand traps in 1997 (Figure 11). This exponential rise in Connecticut fishing effort is consistent with the steady rise in trap hauls (f) observed from Rhode Island (Figure 12) and a nine fold rise in licensed traps in New York waters from 1982 to 1997 (Figure 13).

DeLury-based fishing mortality (F) rates on male and female lobsters from the SCCLIS stock varied erratically from 1982-97 (Table 2), but the magnitude of F estimates generally rose from 1986 to 1997.

The estimated slope (B) estimates for all six log-log regressions were below 0.45 (Table 5, Figures 14-19), and were significantly ($P<0.05$) below 1.0 for both male and female lobsters (Table 5). In addition, the slope estimates (B) for all six regressions differed significantly ($P<0.05$) from zero. The fact that the slope estimates (B) were well below 1.0 indicated the presence of intense gear saturation in the SCCLIS trap fishery at least over the range of fishing effort (f) examined from 1982-97. When the slope estimates (B) are below 0.45, the catchability coefficients (q) fell proportionately as fishing effort rose from 1990 to 1997 (Figures 20-25). Recall that slope (B) estimates of 1.0 indicates a one to one relationship between reductions in F and fishing effort (f). However, since the slope estimates (B) for six data sets in the SCCLIS (Table 5) differed from zero, a 20% reduction in the 1998 fishing effort (f) would produce, on average, between a 5-7% drop in fishing mortality (F) on SCCLIS lobster.

## Georges Bank and Offshore (GSK)

Fishing effort (f) in the GBK expressed as Massachusetts TH exhibited about a five-fold rise between 1985-97 from a low of 862 thousand TH in 1987 to a high of 4.3 million TH in 1997 (Figure 26). By contrast, the trend in GBK fishing effort, expressed by New York licensed traps that fished offshore, was more variable and rose at a much lower rate from 1982 to 1997 (Figure 27).

Delury-based fishing mortality (F) rates on female lobsters from the GBK stock were below 0.531 and varied without trend from 1982-97 (Table 3). By contrast, F estimates on male lobsters rose from 1987 ($F = 0.49$) to peak levels in 1994 ($F = 1.16$), then F estimates fell below 0.70 from 1995 to 1997 (Table 3).

The estimated slope (B) estimates for the log-log regressions ranged between 0.10 and 0.33 (Table 4, Figures 28-31), and were all significantly ($P<0.05$) below 1.0. The slope (B) estimate between F levels for female lobsters and New York traps was significantly greater than zero (Table 4), whereas the slope estimates for the other three regressions did not differ significantly from zero. The fact that the slope estimates (B) were all well below 1.0 indicated the presence of intense gear saturation in the GBK trap fishery at least over the range of fishing effort (f) examined from 1982-97. The catchability coefficients (q) for the GBK stock fell proportionately as fishing effort rose from 1990 to 1997 (Figures 32-35). Given slope estimates (B) between 0.10 and 0.33 for lobsters in the GBK (Table 4), a 20% reduction in the 1997 fishing effort (f) would produce little if any reduction in the fishing mortality (F) rate on GBK lobster stock.

## DISCUSSION

The results of this analysis indicate widespread and persistent evidence of intense gear saturation in the USA lobster commercial fishery at least since 1982 (note the exception for GOM males with Massachusetts fishing effort). The observed decoupling between trends in F and f was manifested for all three lobster stocks (Tables 4 and 5). Intense gear saturation has also been reported earlier for American lobster along the Maine coast (Waltz 1989), and for blue crab pot fishery, (*Callinectes sapidus*), in Chesapeake Bay (Rugolo et al 1997). Momot (1998) conducted controlled fishing experiments on crayfish from two ponds from 1977 to 1990. He reported that fishing mortality rates (F) rose steadily when the number of minnow traps increased from 150 in 1977 to 4000 in 1982, but further increases in effort to 6000 traps from 1985 to 1990 resulted in no further rise in F. The presence of gear saturation has also been demonstrated from 1978 to 1998 within the SCCLIS lobster stock in LIS commercial trap fishery (Crecco and Gottschall 1999) and from 1960 to 1998 for the Rhode Island trap fishery (Gibson 1999).

Widespread gear saturation has important management implications. Since trends in F and fishing effort (f) are largely independent from 1982 to 1997 for all three stocks (Table 4 and 5), a strategy to significantly (20-40%) reduce F on USA lobsters via reductions in licensed traps or trap hauls will probably fail unless fishing effort is drastically reduced to levels that occurred well before 1982. Recent attempts at effort reductions (40% reduction in traps between 1991 and 1995) in the spiny lobster fishery (*Panulirus argus*) off the Florida Keys (Muller et al 1997) resulted in only a 5-19% reduction in fishing mortality (F).

Since catchability (q) for the lobster trap fishery, rather than remaining constant as in equation (1), dropped steadily as fishing effort (f) rose, catch-per-unit-effort levels (CPUE) would seriously underestimate true trends in relative stock abundance. When q is inversely related to fishing effort (f), a plot of lobster commercial landings over time should serve as a more accurate relative index of stock trends than CPUE.

The implications of gear saturation in lobster management extend far beyond their impact on the usefulness of trap reductions. Addison and Bannister (1998) reported that nonlinearity between F and fishing effort (f) in exploited crustacean stocks can greatly alter the relationship between egg-per-recruit (E/R) and changes in the current fishing effort patterns. They found, for example, that Fmax and F10% levels, when F and f are nonlinear, could be much higher than Fmax and F10% levels under the conventional assumption that F is linearly related to f. Perhaps their (Addison and Bannister 1998) most interesting finding was that the magnitude of Fmsy and the overall resiliency of lobster stocks were greatly improved in stock-recruit models if the catchability coefficient (q) was inversely related to lobster stock size. An inverse relationship between q and stock size (N) has been reported for many heavily exploited finfish stocks harvested with pursuit gear (i.e. otter trawl, purse seines and drift gill nets) (Winters and Wheeler 1985; Crecco and Savoy 1985; Crecco and Overholtz 1990). However, for exploited crustacean stocks harvested by stationary traps, this phenomenon has not yet been reported (Addison and Bannister 1998).

The root cause(s) for the wide discrepancies in trends between catchability (q) and fishing effort (f) for GOM male lobsters (Figures 6 and 10) are not completely understood at this time. The outcome entirely depended on whether Massachusetts or Maine trap hauls (f) were used in the analysis (Table 1). When Massachusetts fishing effort (f) were employed for the GOM analysis, changes in fishing mortality (F) on male lobsters were linearly related to changes in fishing effort (f) from 1985 to 1997 (Figure 8). This indicated that catchability (q) was constant across all levels of fishing effort (f), resulting in the conclusion that gear saturation was not present for male lobsters in the GOM. Yet when Maine trap haul data was used instead of Massachusetts effort in the GOM analysis, male fishing mortality (F) rates exhibited a clear inverse relationship to Maine fishing effort (F) from 1982 to 1997 (Figure 4), indicating the strong presence of gear saturation.

The regressions of fishing mortality (F) and Maine fishing effort (f) should better reflect gear saturation effects in the GOM than regressions using Massachusetts fishing effort for several reasons. Firstly, Maine fishing effort (f) extents over a longer time series (1982-97) than does the Massachusetts data (1985-97), thus creating greater contrast in the F and f variables. Secondly, gear saturation effects on male lobsters using Maine trap hauls are consistent with gear saturation effects noted for both male and female lobsters for the GBK and SCCLIS stocks and for female lobsters in the GOM (Table 4 and 5). Finally, since Maine lobster landings comprise about 80% of the entire GOM lobster landings from 1982 to 1997, the inverse trend in male F and Maine fishing effort (f) (Figure 4) probably reflect gear saturation conditions better in the GOM than does the Massachusetts data.

With the exception of stable or dropping trends in fishing effort (THSOD) in the GOM stock from 1985 to 1997 based on Massachusetts data (Table 1, Figure 2), lobster nominal fishing effort (f) for all three stocks (Tables 1 to 3, Figures 1, 11, 12, 13, 26 and 27) has been rising since 1982. Despite this widespread rise in fishing effort, fishing mortality rates (F) on USA lobsters have either have risen slightly (SCCLIS stock), remained stable (GBK stock), or have recently declined (GOM stock) (Tables 1 to 3). As a result of gear saturation, fishing mortality rates (F) on the USA lobster fishery would not be expected to rise further in concert with greater expansion of the trap fishery. Short-term fluctuations in lobster commercial landings would be expected via changes in recruitment. However, future landings would not be expected to rise or fall following increases in fishing effort (f) because F on USA lobsters has been relatively stable for nearly two decades and decoupled from rising fishing effort due to gear saturation (Tables 4 and 5). Undoubtedly, measurement errors in the estimated landings (C), F and f values could alter these conclusions. Also, annual fluctuations in biotic (food supply) and abiotic (temperature and advection) variables would presumably influence lobster catchability (q) in the trap fishery. Despite these caveats, which plague the conclusions of all fisheries assessments, the preponderance of the evidence from this analysis strongly suggests that fishing mortality (F) rates are not likely to increase in the future in concert with expanding fishing effort (f) due to severe gear saturation.

Although lobster fishing mortality rates (F) on the SCCLIS stock that exceed 1.0 would place most finfish stocks at high risk of recruitment failure, the relative risk of fisheries-induced stock collapse for the SCCLIS lobsters may be minimized by several factors related to lobster behavior and how this interacts with stationary gear. Firstly, severe discard mortality among finfish species is a real problem with mobile gear such as trawls and purse seines, but there is little or no discard mortality among sublegal lobsters taken from stationary traps. Secondly, the occurrence of intensive gear saturation shown here, within LIS (Crecco and Gottschall 1999), within Rhode Island waters (Gibson 1999) and for Chesapeake Bay blue crabs (Rugolo et al 1997) is more likely to occur for stationary gear fisheries, where the crab and lobster voluntarily enter baited traps in order to be harvested. This mode of capture is in sharp contrast to those for most finfish fisheries, which employ mobile gear (i.e. trawls and purse seines). In these modern fisheries, the mechanism of capture involves search (with the aid of sonar), pursuit and, ultimately, entrapment of finfish that attempt to escape. In contrast to the observed decoupling between F and f arising from gear saturation in decapod trap fisheries, the use of mobile or pursuit gear in finfish fisheries can be highly destabilizing. This is particularly so at low stock sizes, where search and pursuit by mobile gear often causes the catchability coefficient (q) and fishing mortality (F) rates to rise in concert at alarmingly high rates as stock size declines (Crecco and Overholtz 1990).

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**Table 1.** Male and female median fishing mortality (F) rates based on the DeLury model and nominal fishing effort (f) from the states of Maine (TH * millions) and Massachusetts (TH * millions) on GOM lobsters from 1982 to 1997. Note that Massachusetts trap hauls (TH) from 1985 to 1989 were hindcast based on a linear regression of total inshore trap hauls and GOM trap hauls from 1990 to 1997.

| | | GOM STOCK | | |
|---|---|---|---|---|
| **Year** | **Female F** | **Male F** | **Maine TH** | **MA TH** |
| 1982 | 0.81 | 0.86 | 34.7 | - |
| 1983 | 0.62 | 0.60 | 32.3 | - |
| 1984 | 0.75 | 0.90 | 34.9 | - |
| 1985 | 0.90 | 0.66 | 31.6 | 16.3 |
| 1986 | 0.80 | 0.92 | 31.3 | 18.1 |
| 1987 | 1.08 | 1.02 | 29.5 | 17.5 |
| 1988 | 0.85 | 0.79 | 28.1 | 19.3 |
| 1989 | 0.80 | 0.65 | 32.1 | 19.4 |
| 1990 | 0.96 | 0.69 | 33.0 | 17.4 |
| 1991 | 0.88 | 0.76 | 32.1 | 16.3 |
| 1992 | 0.85 | 0.72 | 33.6 | 16.3 |
| 1993 | 0.71 | 0.61 | 31.9 | 15.1 |
| 1994 | 0.65 | 0.56 | 38.5 | 14.9 |
| 1995 | 0.68 | 0.52 | 37.6 | 13.8 |
| 1996 | 0.80 | 0.62 | 33.2 | 12.4 |
| 1997 | 0.74 | 0.57 | 37.4 | 11.3 |

**Table 2.** Median male and female fishing mortality (F) based on the DeLury model and nominal fishing effort (f) from the states of Connecticut (licensed traps * 1000) Rhode Island (TH*1000) and New York (licensed traps*1000) on SCCLIS lobsters from 1982 to 1997.

| SCCLIS STOCK | | | | | |
|---|---|---|---|---|---|
| **Year** | **Female F** | **Male F** | **CT Traps** | **RI TH**[1/] | **NY Traps** |
| 1982 | 0.81 | 1.05 | 14.8 | 147.4 | 31.1 |
| 1983 | 1.00 | 1.02 | 20.0 | 164.2 | 26.4 |
| 1984 | 1.08 | 0.83 | 50.1 | 246.4 | 36.9 |
| 1985 | 1.35 | 0.67 | 49.2 | 251.6 | 53.9 |
| 1986 | 0.69 | 0.77 | 49.5 | 269.8 | 67.9 |
| 1987 | 1.04 | 0.83 | 54.4 | 318.0 | 56.7 |
| 1988 | 1.54 | 1.07 | 62.6 | 330.3 | 60.3 |
| 1989 | 1.40 | 1.16 | 64.5 | 351.1 | 72.5 |
| 1990 | 1.32 | 1.10 | 77.1 | 373.1 | 86.9 |
| 1991 | 1.10 | 1.08 | 81.0 | 383.9 | 99.0 |
| 1992 | 1.27 | 1.53 | 81.4 | 460.9 | 116.3 |
| 1993 | 1.46 | 1.46 | 88.0 | 489.5 | 139.3 |
| 1994 | 1.76 | 1.41 | 86.7 | 550.2 | 181.4 |
| 1995 | 1.25 | 1.20 | 97.0 | 475.4 | 203.7 |
| 1996 | 1.34 | 1.20 | 107.0 | 540.4 | 190.0 |
| 1997 | 1.53 | 1.97 | 108.5 | 651.9 | 243.4 |

1/ Rhode Island trap hauls are from Table 1 of Gibson (1999).

**Table 3.** Median male and female fishing mortality (F) based on the DeLury model and nominal fishing effort (f) from the states of Massachusetts (TH * 1000) and New York (licensed traps*1000) on GBK lobsters from 1982 to 1997.

| GBK STOCK | | | | |
|---|---|---|---|---|
| **Year** | **Female F** | **Male F** | **NY Traps** | **MA TH** |
| 1982 | 0.33 | 0.65 | 9.25 | - |
| 1983 | 0.33 | 0.53 | 9.59 | - |
| 1984 | 0.43 | 0.77 | 10.74 | - |
| 1985 | 0.40 | 0.75 | 11.25 | 1016 |
| 1986 | 0.44 | 0.66 | 9.41 | 912 |
| 1987 | 0.32 | 0.49 | 8.63 | 862 |
| 1988 | 0.35 | 0.61 | 5.35 | 863 |
| 1989 | 0.35 | 0.72 | 7.03 | 721 |
| 1990 | 0.52 | 0.71 | 14.18 | 2829 |
| 1991 | 0.46 | 0.82 | 12.40 | 2988 |
| 1992 | 0.33 | 0.98 | 10.74 | 3567 |
| 1993 | 0.30 | 1.00 | 9.90 | 3323 |
| 1994 | 0.50 | 1.16 | 17.25 | 4145 |
| 1995 | 0.44 | 0.65 | 20.86 | 3923 |
| 1996 | 0.47 | .67 | 17.57 | 4225 |
| 1997 | 0.44 | 0.58 | 18.69 | 4373 |

**Table 4.** Test for gear saturation for the GOM and GBK stocks using the slope (B) estimates and standard errors (SE) for the log-log regression between fishing mortality (F) rates for male and female lobsters and fishing effort (f) (Figures 3, 4, 7, 8, 28, 29, 30 and 31). The null hypothesis is that changes in F are directly proportional to changes in fishing effort (ie B = 1.0), or that the slope (B) differs significantly from zero. The t-statistics ($t_{b=1.0}$, $t_{B>0}$) refer to the statistical tests between the estimated B level and expected B = 1.0 and B = 0.0.

| **Data Set** | **Sex** | **B$^{1/}$** | **SE** | **$t_{B=1.0}$** | **$t_{B=0.0}$** |
|---|---|---|---|---|---|
| | | | **GOM Stock** | | |
| Maine<br>TH, 1982-97 | male | -1.293 | 0.517 | 4.43* | 2.50* |
| | female | -0.978 | 0.369 | 5.36* | 2.65* |
| MA male<br>TH, 1985-97 | 0.763 | 0.278 | 0.853 | 2.74* | |
| | female | 0.422 | 0.228 | 2.06* | 1.85 |
| | | | **GBK Stock** | | |
| New York<br>Pots, 1982-97 | male | 0.125 | 0.164 | 5.33* | 0.77 |
| | female | 0.326 | 0.094 | 7.17* | 3.44* |
| MA<br>THSOD, 1985-97 | male | 0.143 | 0.088 | 9.73* | 1.63 |
| | female | 0.102 | 0.067 | 13.40* | 1.52 |

1/ $F = A * \text{Effort}^B$
Log Tranformed: Log F = Log A + B * Log Effort.

* statistically ($P < 0.05$) different from B = 1.0 or B = 0.

**Table 5.** Test for gear saturation for the SCCLIS stock using the slope (B) estimates and standard errors (SE) for the log-log regression between fishing mortality (F) rates for male and female lobsters and fishing effort (f) (Figures 14, 15, 16, 17, 18 and 19). The null hypothesis is that changes in F are directly proportional to changes in fishing effort (ie B = 1.0), or that the slope (B) differs significantly from zero. The t-statistics ($t_{b=1.0}$, $t_{B>0}$) refer to the statistical tests between the estimated B level and expected B = 1.0 and B = 0.0.

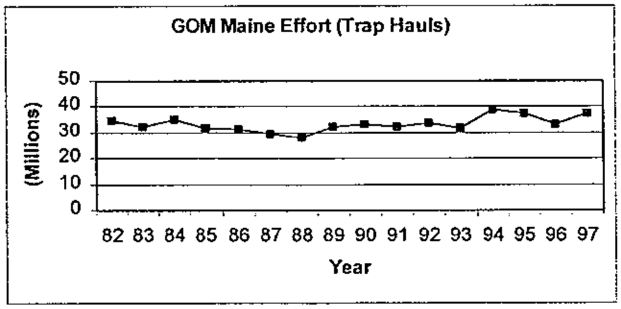
| **Data Set** | **Sex** | **$B^{1/}$** | **SE** | **$t_{B=1.0}$** | **$t_{B=0.0}$** |
|---|---|---|---|---|---|
| | | | **SCCLIS Stock** | | |
| CT<br>THSOD, 1982-97 | male | 0.238 | 0.115 | 6.63* | 2.07* |
| | female | 0.284 | 0.089 | 8.04* | 3.19* |
| RI<br>TH, 1982-97 | male | 0.444 | 0.127 | 4.38* | 3.50* |
| | female | 0.401 | 0.111 | 5.39* | 3.62* |
| New York<br>Pots, 1982-97 | male | 0.279 | 0.077 | 9.36* | 3.60* |
| | female | 0.209 | 0.077 | 10.27* | 2.73* |

1/ $F = A * \text{Effort}^{B}$
Log Transformed: Log F = Log A + B * Log Effort.

* statistically ($P < 0.05$) different from B = 1.0 or B = 0.
B = 0.

# FIGURES 1-35

Figure 1.



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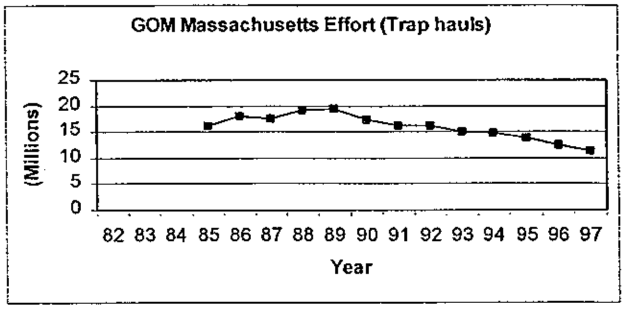

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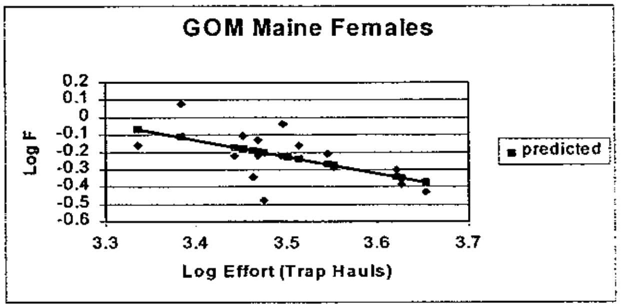

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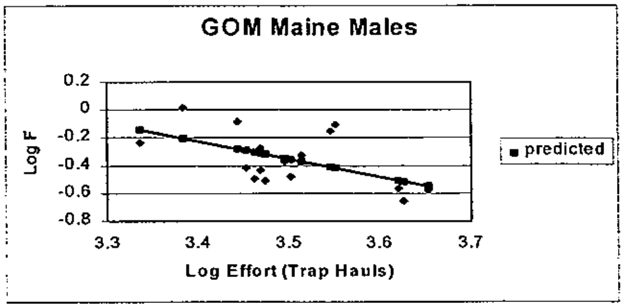

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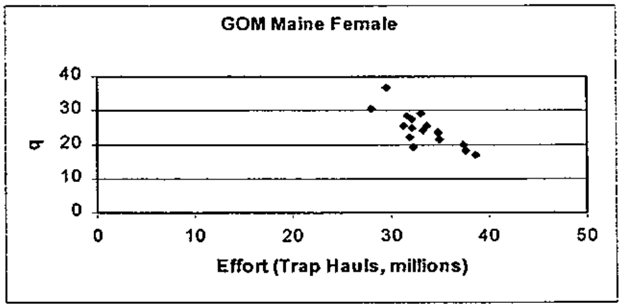

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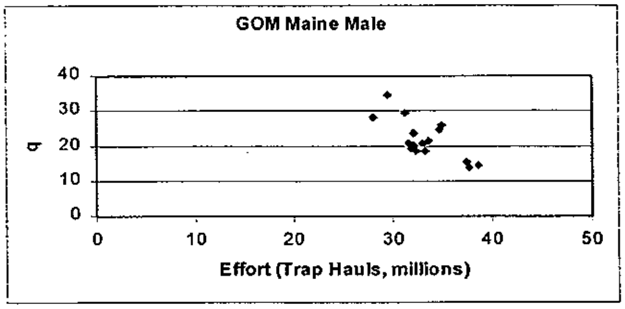

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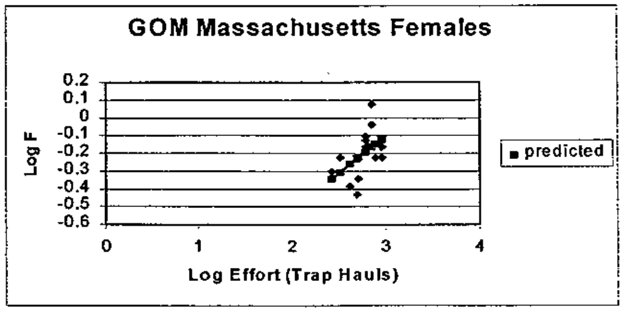

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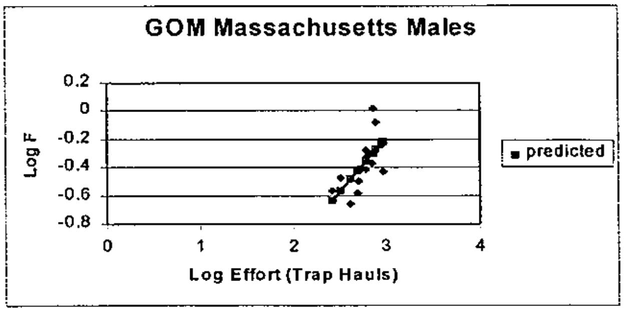

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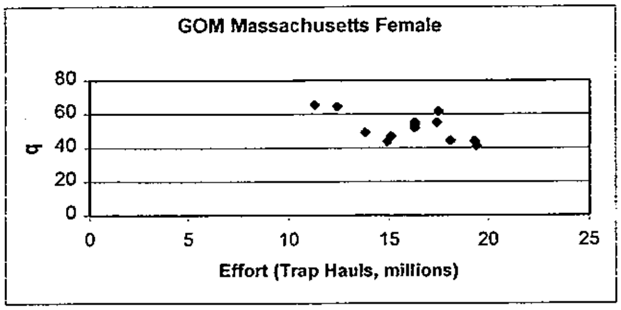

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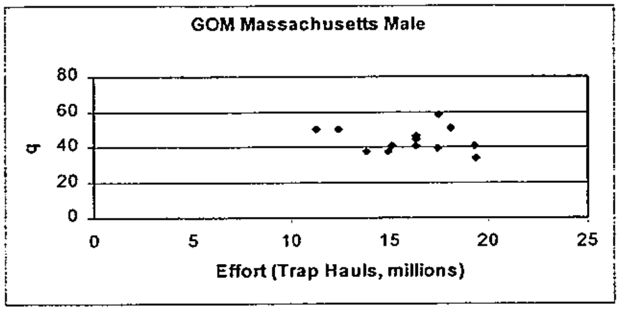

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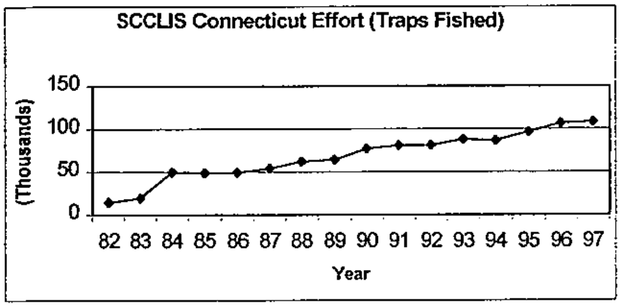

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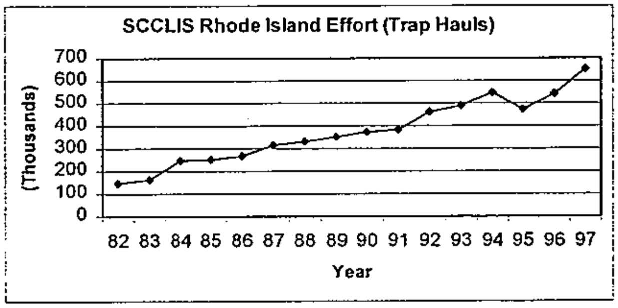

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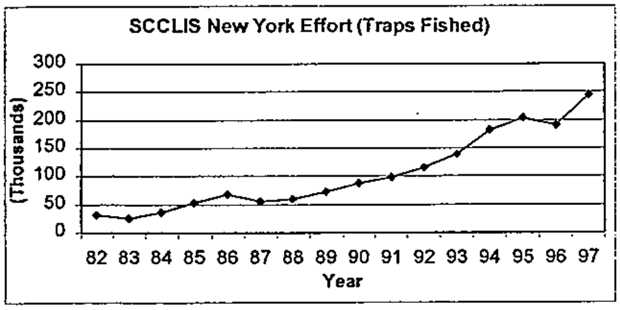

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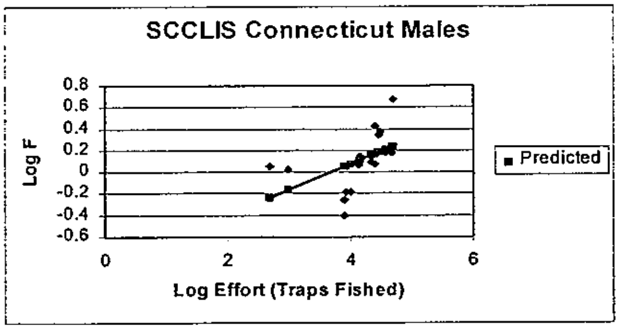

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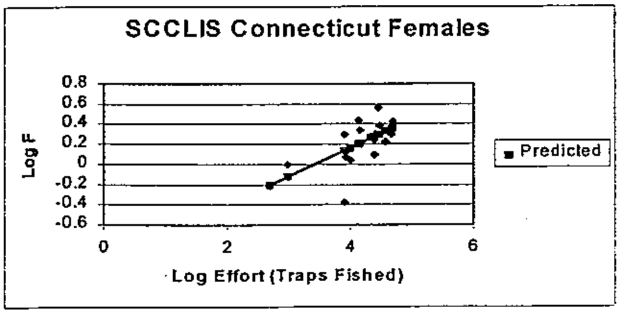

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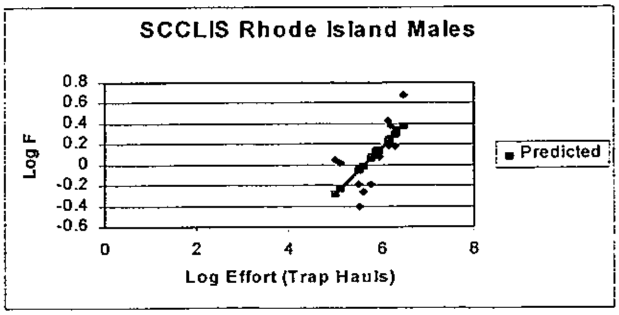

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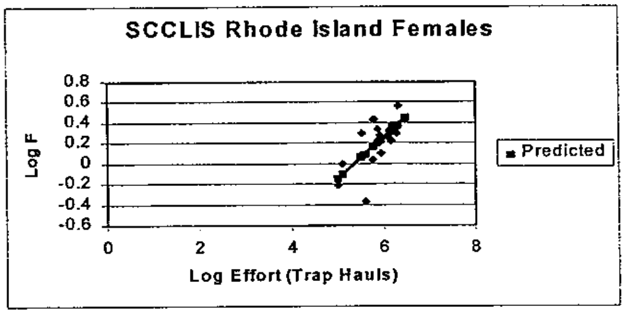

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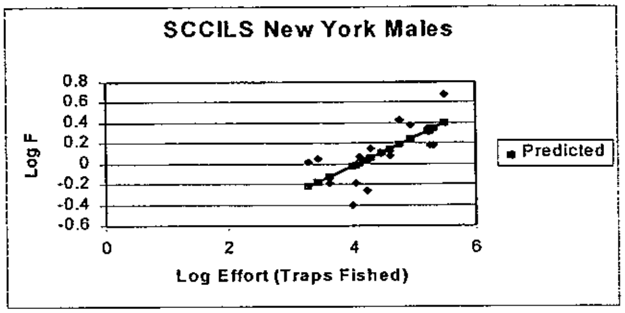

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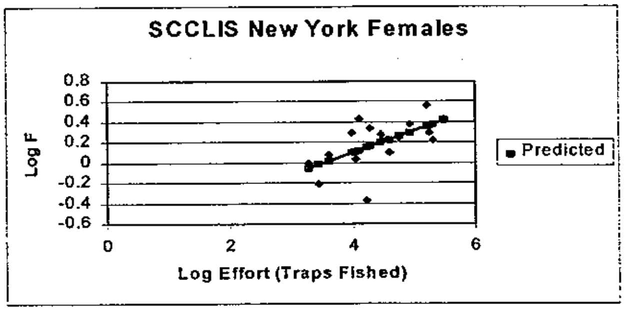

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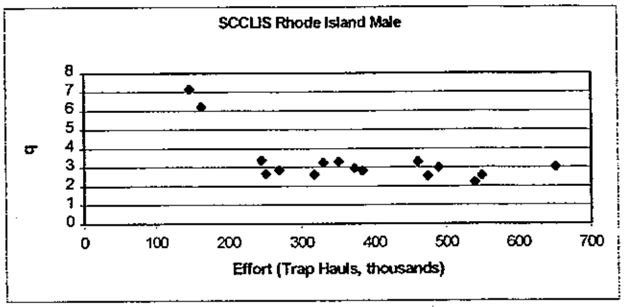

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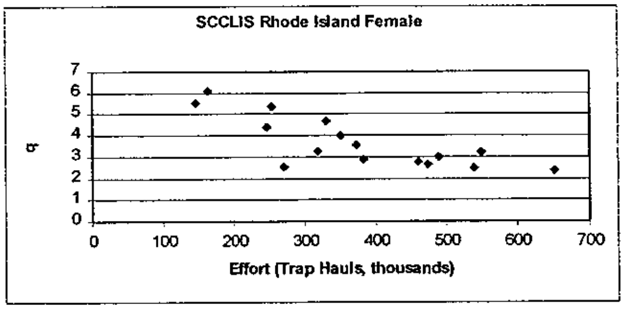

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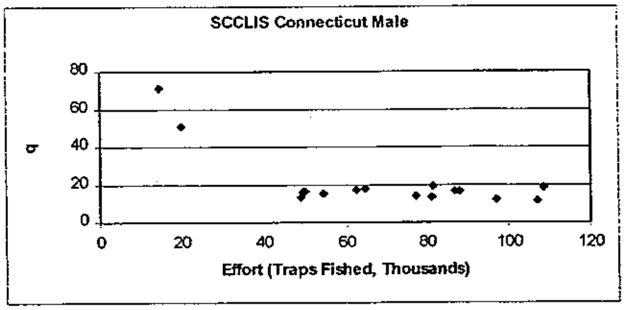

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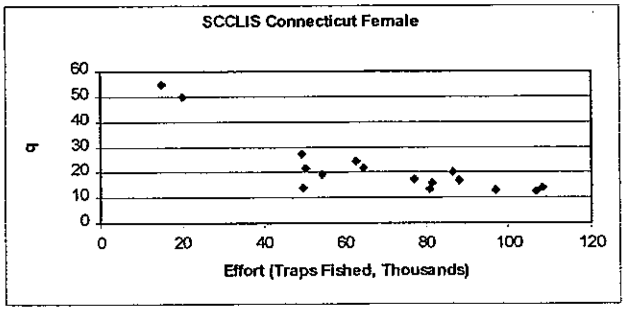

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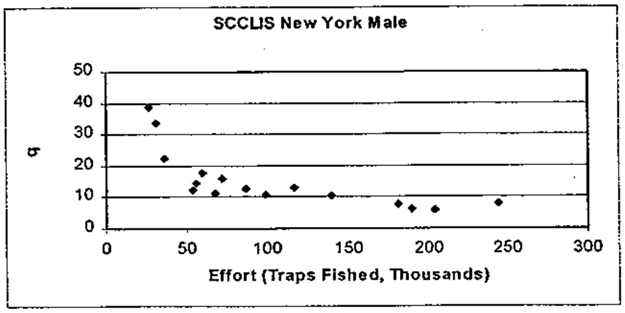

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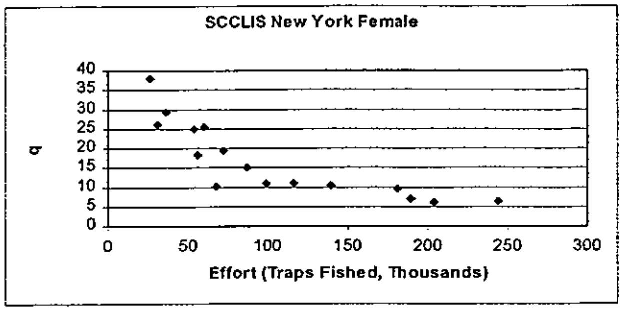

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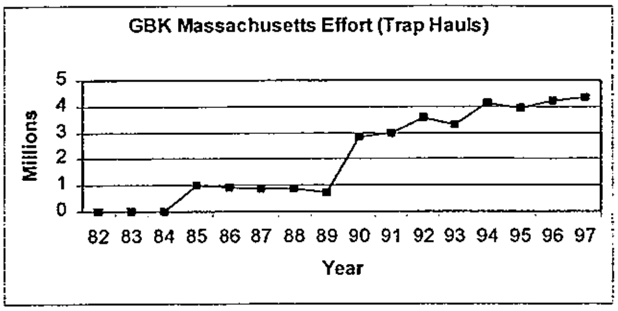

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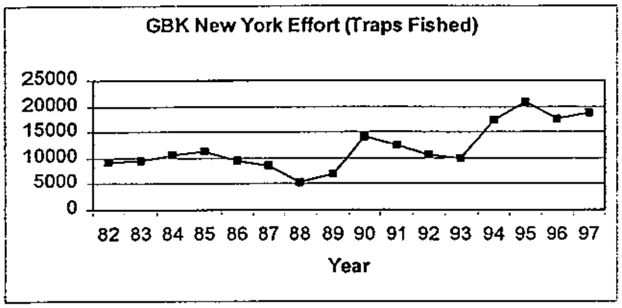

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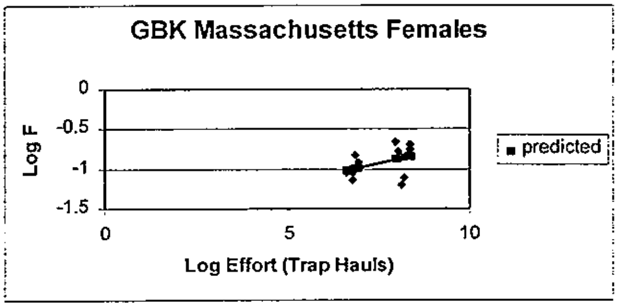

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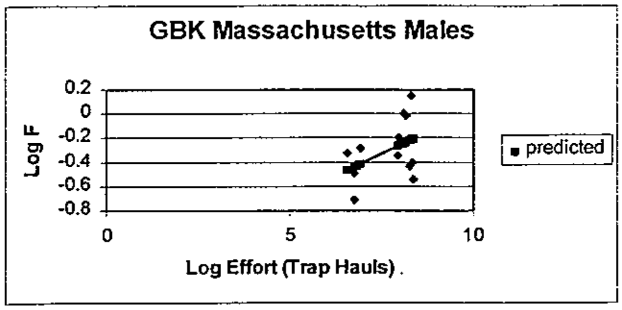

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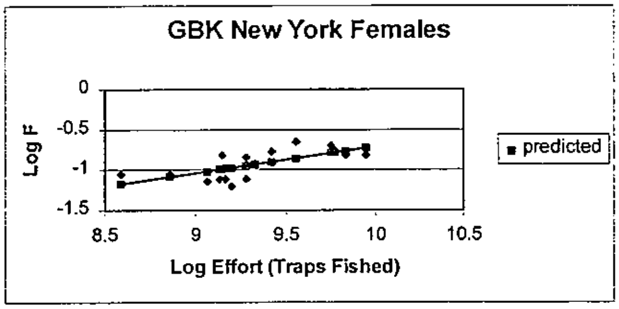

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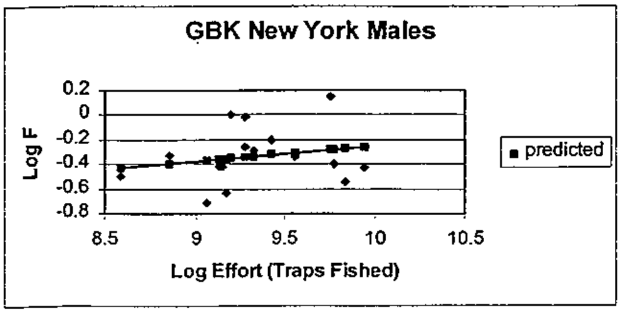

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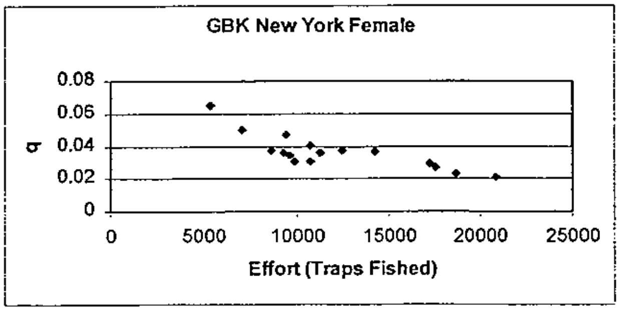

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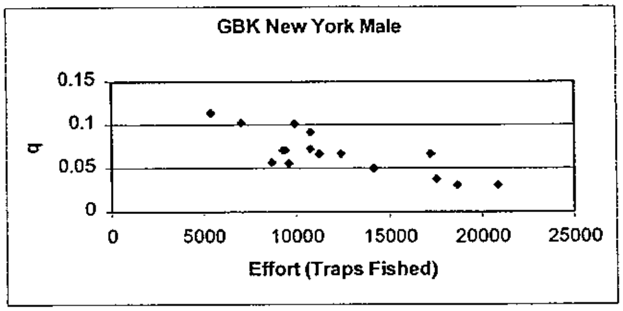

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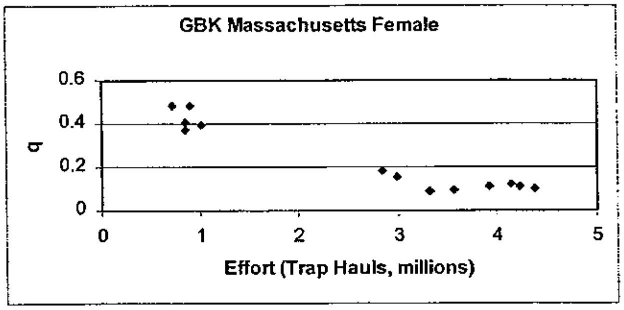

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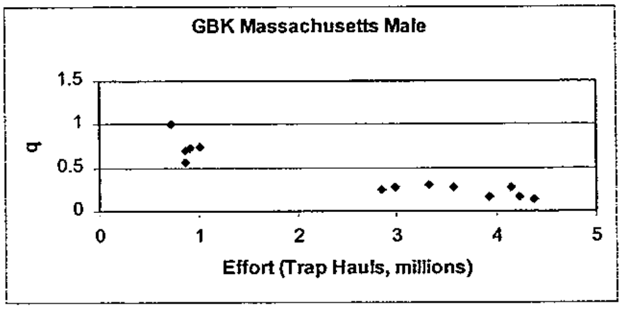

# APPENDIX H

## Exerts relating to the overfishing definition from:

## "A Review of the Population Dynamics of American Lobster in the Northeast"

## ASMFC 1996

### 3.4 STOCK AND RECRUITMENT

For the fisheries scientist and the manager, the critical problem when effort expands is to achieve realistic safeguards against the occurrence of a stock collapse, without curtailing the socio-economic activity of the fishery unnecessarily early. The point is illustrated by considering how the stock-recruitment and the recruitment-spawning stock relationships interact. As presented to the panel by Fogarty, the stock-recruit relationship shows the degree to which declining stock affects the number of recruits produced (Figure 2a). As exploitation increases, these recruits replace less and less spawning stock (Figure 2b). Taken together, the replacement point, where the two relationships intersect, moves steadily towards the collapse point, determined by the slope of the stock-recruitment curve near the origin (Figure 2c). Figures 2a-c are copied from the presentation by Fogarty.

The difficulty is to establish the likely form of these relationships from real data. As with most species,

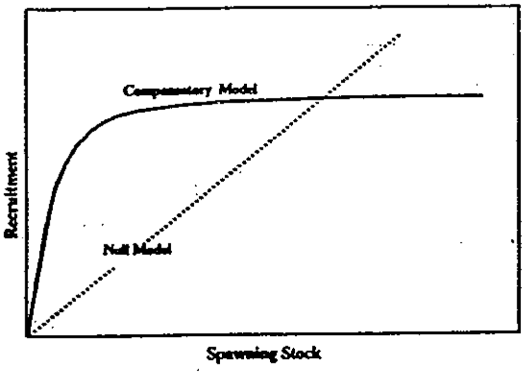

**Figure 2a.** *Hypothetical curve showing the effect on recruitment of changes in spawning*

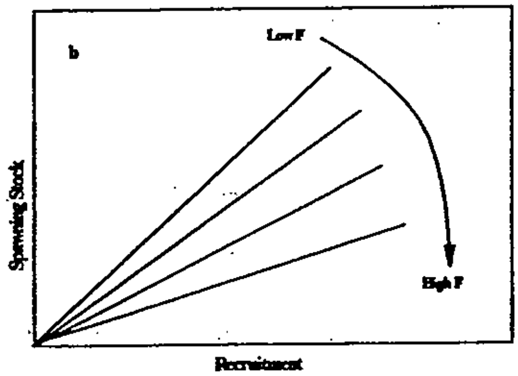

**Figure 2b.** *Hypothetical curves showing how the spawning stock derived from each recruitment changes with the level of fishing mortality.*

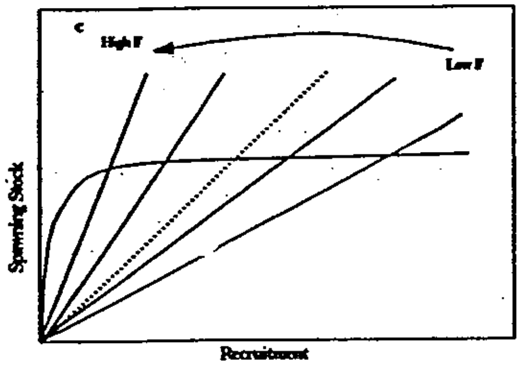

**Figure 2c.** *Hypothetical curves of the interaction between Figures 2a and 2b, showing how fishing mortalith affects the replacement point.*

*Figure 2a-c is from presentation by M. Fogarty, March 25, 1996.*

definitive stock-recruitment information is not available for lobsters in US waters, but two sets of data from Canadian waters provide information to show that the relation is likely to be non-linear, involving some form of density-dependence. In one case, data on late stage larvae and subsequent stock size for the Northumberland State, Canada, were analysed by Fogarty and Idoine (1986). They showed that over a wide range the amount of input (stage IV larvae) had very little influence on the resultant stock size, but that very near the origin, when the abundance of stage IV larvae was reduced to about a tenth of the average for the eleven year period, the 6 year lagged stock was suppressed by about a half. A process operating from settlement to recruitment that involves density-dependence is stabilising, in that exploitation can increase substantially before affecting recruitment, but on the other hand if the descending limb of the curve is very close to the origin, and very steep, the effect on recruitment could occur suddenly and without warning, and lead to a rapid collapse.

At the Review, the Panel were given preliminary evidence of a similar relationship, using data on lobster egg production and recruitment for Arnold's Cove, Newfoundland (Ennis and Pezzak, pers. comm., as presented by Fogarty). In these data, recruitment is independent over a wide range of egg production, with the potential for a very steep slope near the origin at an exploitation level of F=2.0, indicating that collapse could occur suddenly. Data for the Bristol Bay Red Crab were also presented to illustrate an actual collapse, which occurred within two years, after a 15 year trend of increasing landings.

Although these examples for the Northumberland Strait and Arnold's Cove areas do not provide a predictive solution for management of the U.S. lobster, their pattern is similar and may well illustrate the likely general form of the lobster stock-recruitment relationship. They serve to focus the mind on the inherent dangers of high exploitation rates. For the U.S. lobster the position is further compounded by the metapopulation problem discussed in section 2, where the possible critical role of an offshore subsidy was postulated

### 3.5 The Overfishing Definition

The previous paragraphs illustrate just why an overfishing definition is necessary. For the lobster, it is likely that the threshold where egg production falls so low as to affect recruitment, can only be investigated with real data by allowing the level of exploitation to reach very high levels near the collapse point. Even then a collapse would only be detectable five or six years later because of the time taken for lobsters to reach legal size. Further, detection in real data will be masked by natural fluctuations in recruitment resulting from environmental variation. The justification for an overfishing definition is that it is just too dangerous and costly to wait until recruitment collapses, then try to reduce effort and rebuild the stock. It is much more prudent to estimate a safe level of fishing mortality on a pragmatic basis, and then avoid going below that level. Although there is a well developed theory underlying the setting of overfishing thresholds, the essential basis for these thresholds is comparison with other fisheries or similar stocks. Comparisons among similar species have shown that an F level that results in 30-40 % EPR (i.e. egg production per recruit which is 30-40 % of that at zero fishing mortality) is an appropriate level for finfish, and that F values corresponding to 5% or 10% EPR ($F_{5\%}$EPR, or $F_{10\%}$EPR) are appropriate for many crustaceans. Such definitions are widely applied in the management of fisheries in the U.S., and the Panel supports the adoption of such an overfishing definition for the lobster.

We stress that the overfishing F threshold is not the target level at which a fishery should be managed. It is specifically identified as the 'danger' level which, when approached or reached, should give rise to management action to move the fishery away from the danger area. The benefit of taking such action is not necessarily any overt benefit in yield, particularly in the lobster fishery, where the mortality rate is so far in excess of the maximum on the yield per recruit curve. The benefit is the reduction or avoidance of the risk of collapse, and the preservation of the existing social and economic order.