Technical Report

Massachusetts Coastal Commercial Lobster Trap Sampling Program May-November, 2001

Bruce T. Estrella and Robert P. Glenn

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries twenty-first annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 2001, seventy-nine (79) sampling trips were made aboard commercial lobster vessels. A total of 33,150 lobster was sampled from 16,734 trap hauls. The catch rate of marketable lobster, 0.761 lobster per trap, was 14% lower than the 2000 index, 0.885. Commercial lobster landings from territorial waters were 28% lower than in 2000, the lowest landings in the 21-year time series. The proportion of females ovigerous, 18.1%, was higher than in the previous year (15.4%). The coastwide fishing mortality estimate, 1.38, was unchanged from 2000. Exploitation rate, 0.71, increased fractionally, while mean carapace length of marketable lobster, 89.5 mm, and mean size of egg-bearing females, 88.3 mm, were similar to 2000 measurements. The cull rate, 19.7%, increased from the 2000 estimate of 18.2%. Less than 1% of the lobster sampled from traps were dead.

A time series of data from our bottom water temperature monitoring program is presented for seven locations in Buzzards Bay, Cape Cod Bay, and Massachusetts Bay for the period 1985-2001. Data from an additional three shallow water sites (<20'), added during summer 2000, are summarized.

Trends in relative abundance are described on the basis of three stock units which border the Massachusetts coastline.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) twenty-first annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling/survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 2001 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-2001 study period are presented.

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann, Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Where possible, multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations were recorded from LORAN and plotted on nautical charts. Depth information was then estimated from the charts as a coastwide standard to avoid variability from tidal fluctuations.
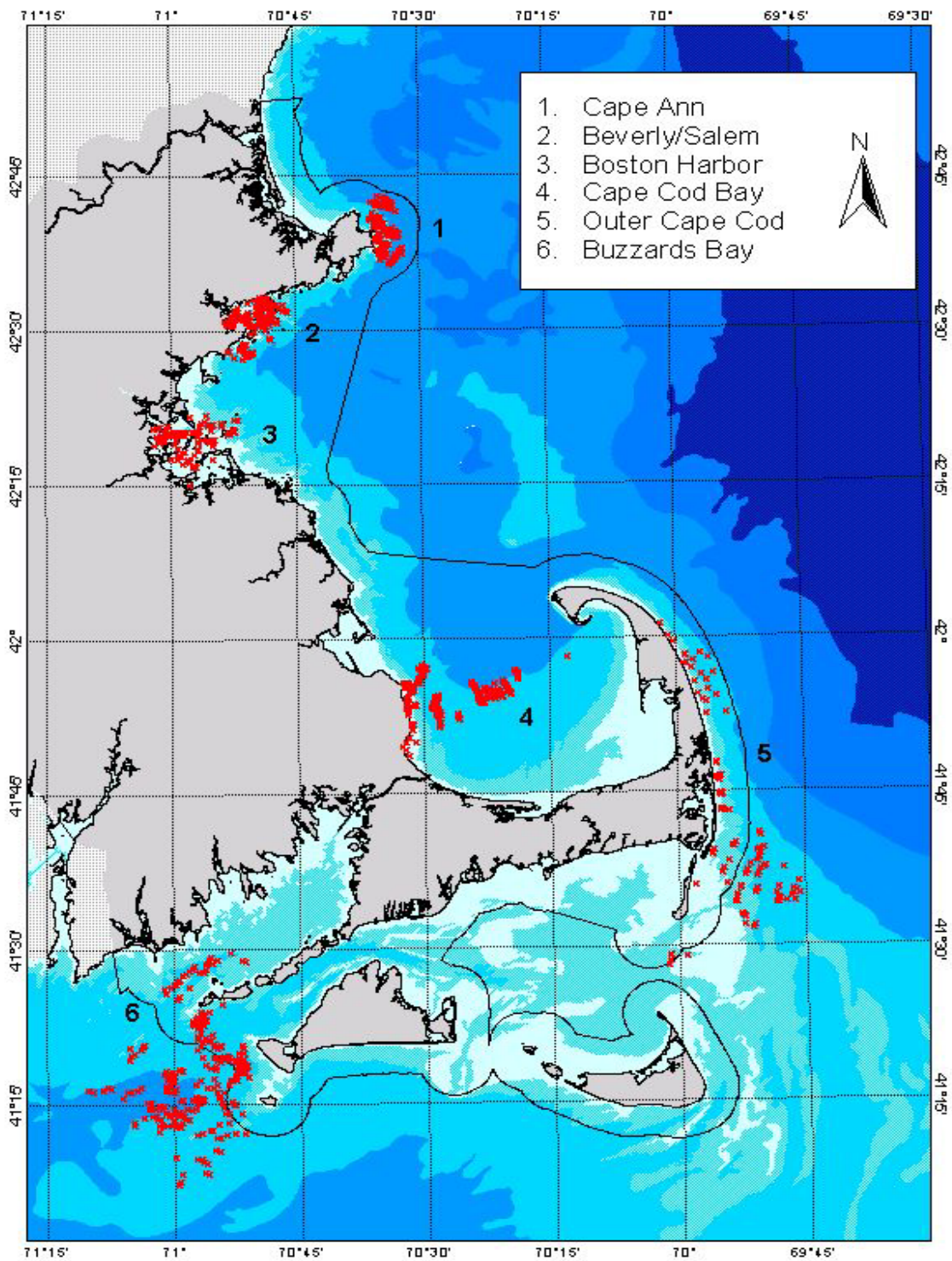
Figure 1. Map of Massachusetts with six sampling regions and trap/trawl locations (X's) sampled during 2001.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred for analysis to the Massachusetts Executive Office of Environmental Affairs' (EOEA) Digital Equipment Corporation VAX-11/780 computer system. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighting scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal-sized" lobster include all lobster larger than the minimum size in effect in 2001 (carapace length category $\geq$ 82.6 mm). The marketable segment of this category, which excludes ovigerous females, is analyzed separately and referred to as "marketable lobster". The sublegal length category includes all lobster less than the 2001 minimum size (82.6 mm).

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A=1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log-transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with cohort analysis (Pope 1972, Jones 1974). Rates of exploitation were calculated with the equation $u=FA/Z$, where F= fishing mortality, A= total annual mortality, and Z= total instantaneous mortality.

Lobster landings data were derived from lobstermen's annual catch reports which are compiled by the DMF Commercial Fisheries Statistics Project.

Since management strategy stressed uniform coastwide regulations during the study period, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species (Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

RESULTS AND DISCUSSION

Commercial Lobster Fishery Performance

During the period of May through November, 2001, seventy-nine (79) sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 33,150 lobster was sampled from 16,734 trap hauls.

The 2001 coastwide mean catch per unit effort index (CTH'$_3$), 0.761 marketable lobster per trap, was 14% lower than the 2000 index, 0.885 (Appendix Table 1). Landings and catch rate trends are depicted in Figure 2. Total Massachusetts commercial landings, 12,141,757 lbs, decreased by 18% from 2000. Landings from territorial waters, 7,147,288 lbs, declined by 28%. These are the lowest landings in the 21-year time series. The coastwide mean catch rates of sublegal lobster decreased by 10% (CTHSOD) and 7% (CTHAUL) from 2000 (Appendix Tables 2 and 3).
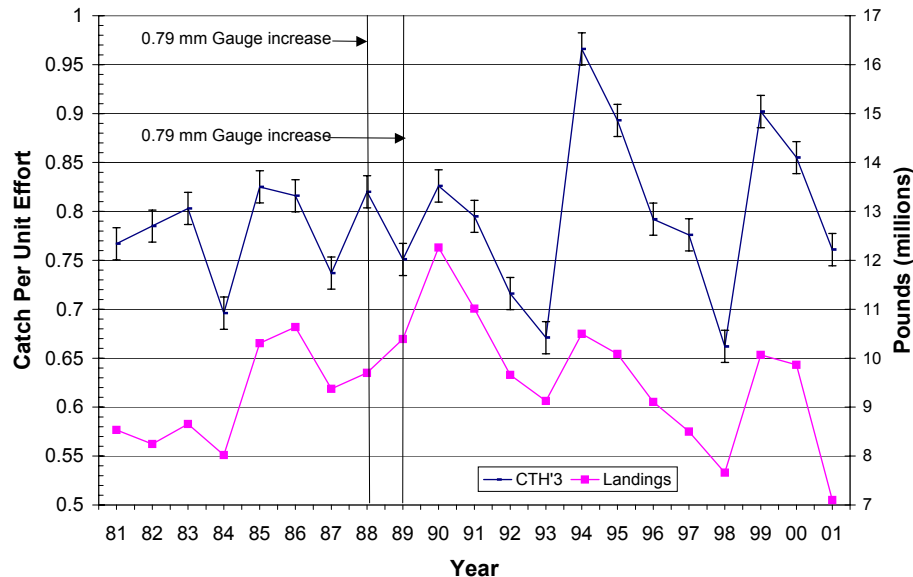
Figure 2 A. Catch per unit effort of marketable American lobster from commercial trap sampling and Massachusetts lobster landings from territorial waters, 1981 - 2001.

Historical landings data provide a perspective on the current condition of the fishery and recent catch trends (Figure 2 B and 2 C). Annual Massachusetts coastal landings (excludes data from beyond territorial waters), which were available only in number of lobster between 1888 and 1921, generally declined between 1888 and 1917 then gradually increased through 1921 (Figure 2B).

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Subsequent landings, available in lbs., increased through 1947, but were relatively stable thereafter through 1974. Major increases in traps and landings occurred between 1975 and 1990. These trends in landings were primarily a reflection of nominal fishing effort (total traps fished), however, they cannot be attributed to greater fishing effort alone. Total lobster landings and effort from all lobster harvesting states also increased between the late 1970's and 1990's, but, in the Canadian Maritimes, where trap limits and license restrictions exist, landings also increased implicating an environmental influence was also involved (Drinkwater et al., 1996).

Since 1990, MA inshore lobster landings have declined dramatically and while nominal effort has also decreased the close correlation evident through the early 1990's has not been maintained.
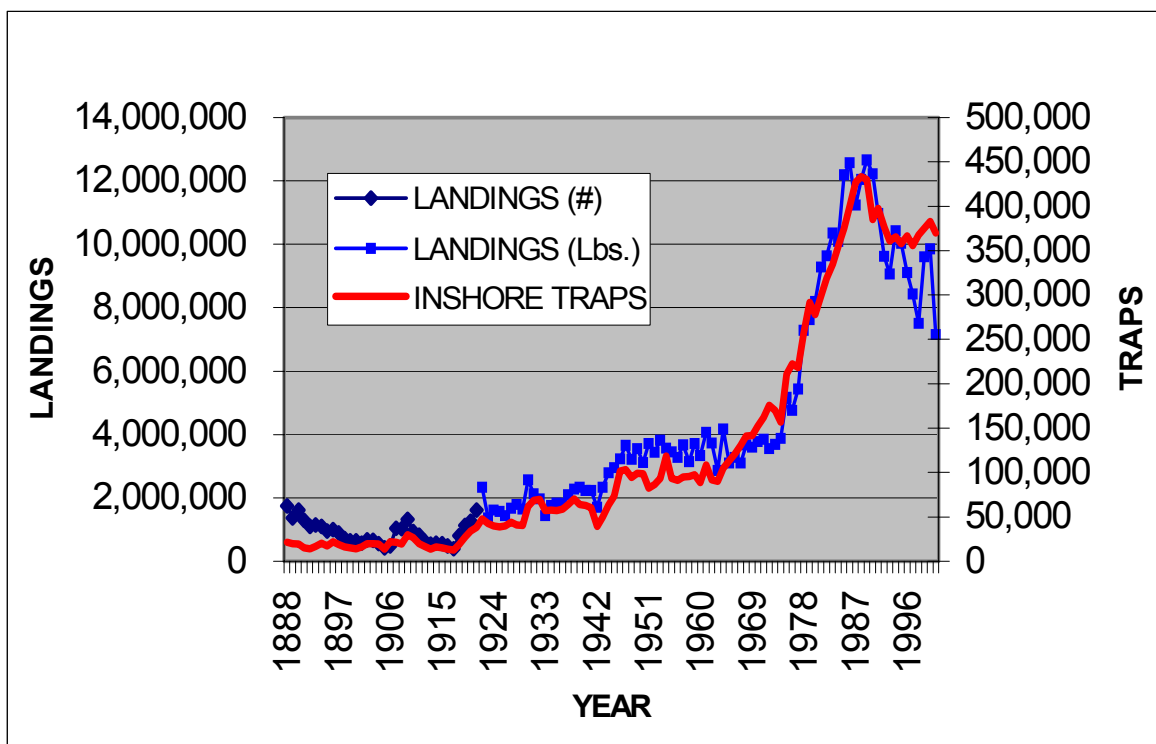
Figure 2 B. American lobster landings and traps fished from Massachusetts territorial waters, 1888-2001. Data are from MA Lobster Fishery Statistics Program.

The average annual pounds per trap (annual landings/total traps fished) generally declined in the Massachusetts inshore fishery since the first year of the series in 1888, but dipped significantly after the mid-1960's (Figure 2C).
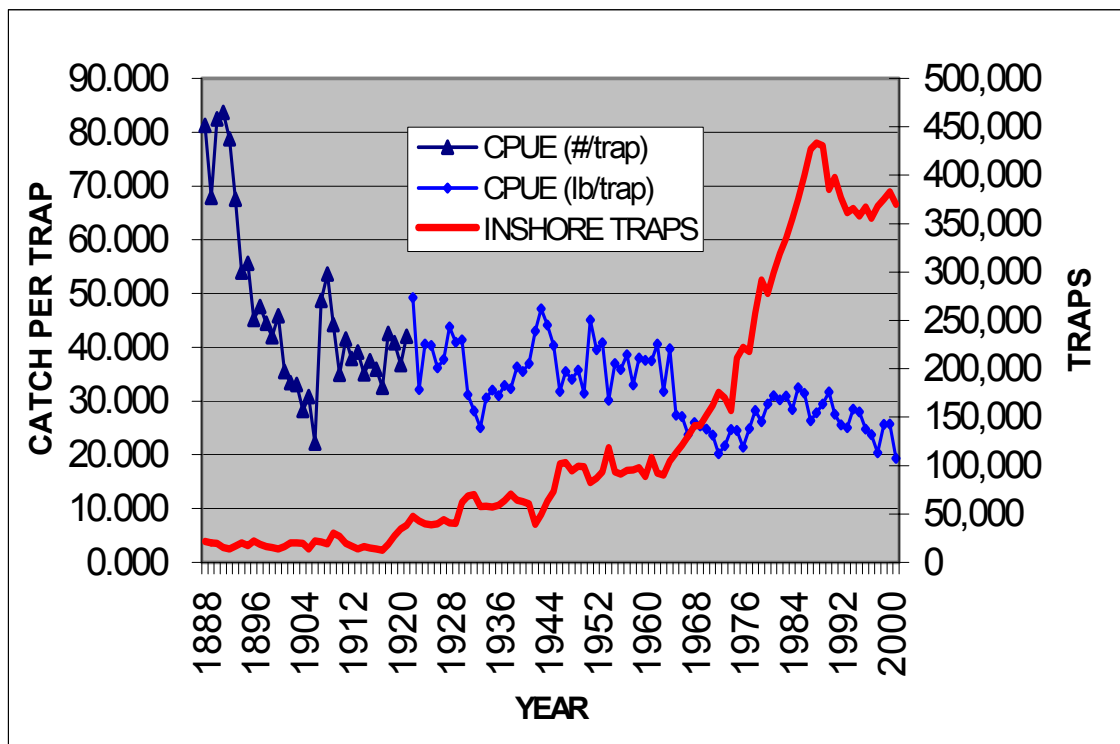
Figure 2 C. Traps fished and catch/trap data from Massachusetts territorial waters, 1888-2001. Data are from MA Lobster Fishery Statistics Program.

Of all females sampled during 2001, 18.1% were ovigerous compared to 15.4% in 2000 (Appendix Table 4). Trends in statewide CPUE of ovigerous females (Appendix Tables 5-6) increased marginally, but the 2001 CTHSOD index was slightly lower than the long term average while CTHAUL was higher (Figure 3).

Approximately 91% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits (83 mm-94 mm CL), i.e., lobster which
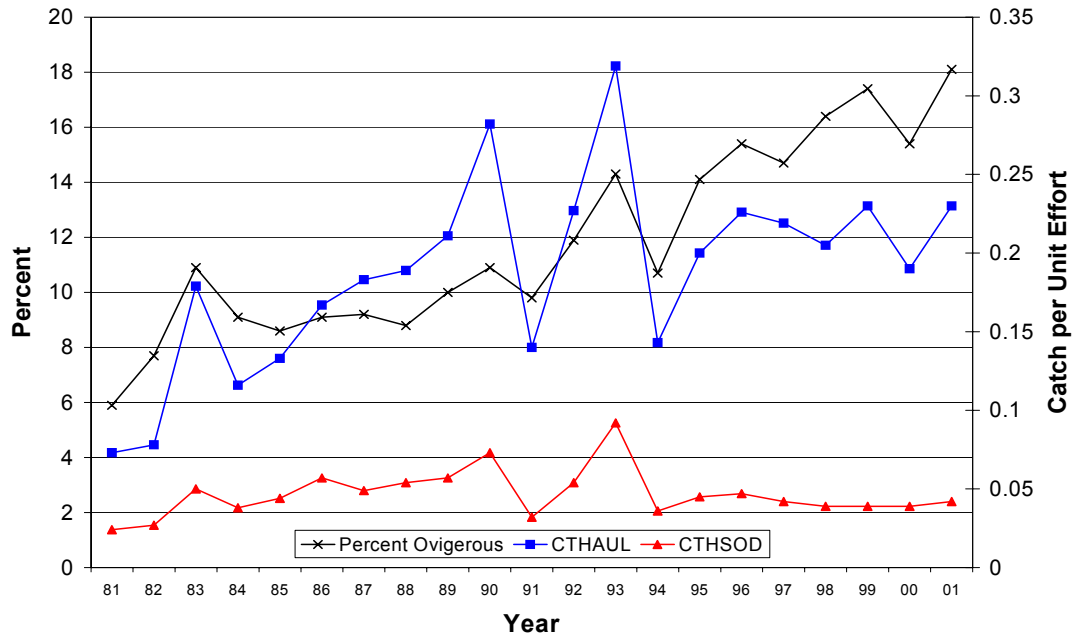
Figure 3. Relative abundance of ovigerous female American lobster in percent total females and catch per effort, Massachusetts coastal waters, 1981 - 2001.

recruited to the legal size range during their most recent molt (Appendix Table 7). This index of the effect of fishing pressure on the size distribution was similar to 2000. The index fluctuated from 51% in 2000 to 49% in 2001 for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) for inshore Gulf of Maine regions (Z = 1.37-3.21, A = 75%-96%) and Buzzards Bay (Z = 1.92-2.82, A = 85%-94%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.76-0.92, A = 53%-60%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8A and 8B).

Estimates from Cohort Analysis of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.68 off outer Cape Cod to 2.11 in Boston Harbor (Appendix Table 9A). Estimates of F using Delta T values in place of von Bertalanffy growth parameters were lower (Table 9B), ranging from 0.43 off outer Cape Cod to 1.41 in Boston Harbor. The latter estimates represent improvements to the Cohort Analysis model and were realized in an earlier coastwide stock assessment (Cadrin and Estrella 1996). Cohort Analysis allows for regional assessments of F from size distribution data and is useful in the absence of bottom trawl survey information, but, without further modification, it is not sensitive to variation in recruitment. Exploitation rates (u), i.e. the fraction of the population that is removed by fishing, increased to 0.71 in 2001 from 0.68 in 2000 (Appendix Table 10).

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing mortality and exploitation rates increased through 1987. Thereafter, increases in mean carapace length of 0.7 mm occurred

in 1988 (mean size = 88.2 mm) and 1989 (mean size = 88.9 mm, Appendix Table 11) which reflected the similar numerical change in the minimum legal size during those years. Carapace length then fluctuated downward until 1994, and increased during 1995 – 1997, reaching a time series high in 1999. The 2001 mean was similar (89.5mm). Fishing mortality rates for all regions combined edged upward to a time-series high of 1.48 in 1993, declined in 1994-1996 along with exploitation rates, then fluctuated without trend from 1997-2001. The relative change in size frequency between 2000 and 2001 is depicted by the overlay in Figure 5.
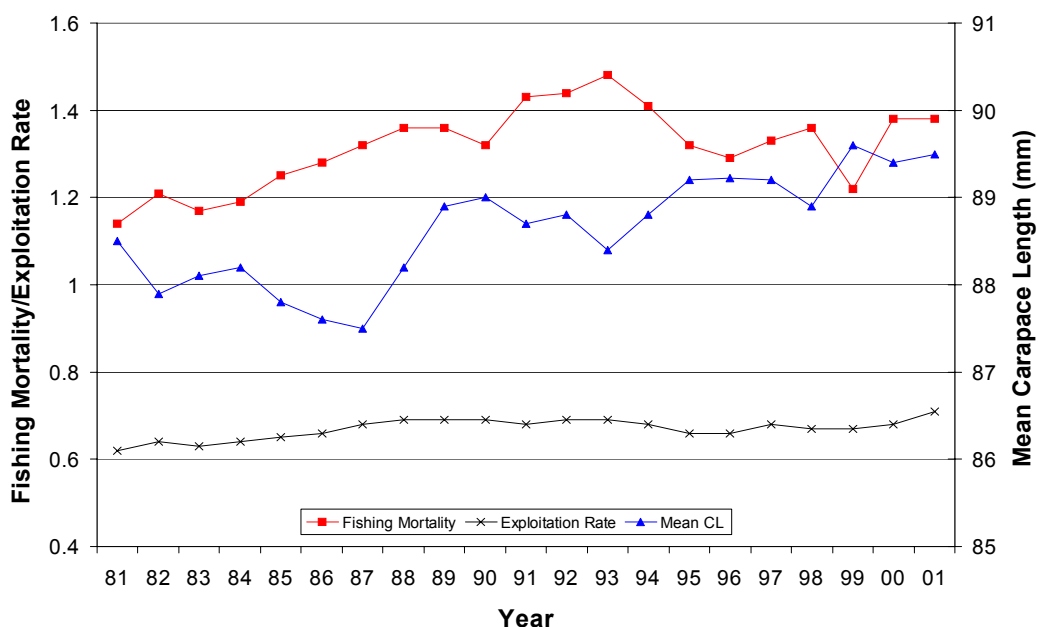
Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal water, 1981 - 2001.

Sublegal sized lobster averaged 76.8 mm carapace length during 2001 compared to 77.1 mm during 2000 (Appendix Table 12). However, sublegal mean size is a function of regulated escape vent size and location which confounds the usefulness of this parameter. The mean size of all ovigerous females was relatively unchanged between 2000 and 2001 at 88.3 mm.

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled was 19.7% in 2001 representing an increase in all areas sampled except Outer Cape Cod (Appendix Table 14). This increase was largely due to an increase in culls observed among sublegal lobsters, since the cull rate for legal and marketable size groups declined (Appendix Tables 15-17).

The coastwide incidence of lobster found dead in traps was 0.13%. This was similar to that of the previous year (Appendix Table 18) and is acceptably low.
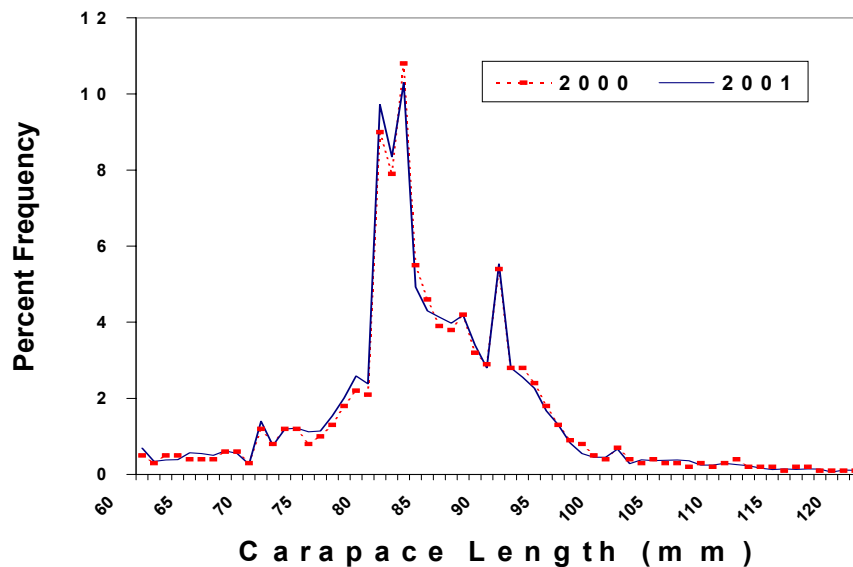
Figure 5. Length frequencies of trap-caught American lobster, Massachusetts coastal waters, 1999 - 2001.

Water Temperature Time Series

In 1985, a coastal bottom water temperature monitoring project was initiated. Temperature monitors (RYAN Tempmentor) have been deployed for various lengths of time at several sites in Cape Cod Bay, outside Boston Harbor, and Buzzards Bay (Figure 6). Some of these sites are located on ship wrecks. Data can be accessed in Technical Reports at the MADMF web site: http://www.state.ma.us/dfwele/dmf/Publications/technical.htm or at: http://www.nefsc.noaa.gov/~jmanning/whwt/newt.html.

The longest time series of bottom temperatures is from Cleveland Light in Buzzards Bay. The last monitor to be deployed was at Rocky Point, off Plymouth. The Rocky Point, Manomet Point, *Endicott*, and *Mars* sites represent the 0-30 ft., 30-60 ft., 61-90 ft., and 91-120 ft. depth strata, respectively, in Cape Cod Bay. The Martin's Ledge (formerly *Romance,* off Boston Harbor), and Buzzards Bay-South (Barge) sites are located at 70-80 ft. and provide data from the north-south extremes in our series. The Cleveland Light monitor is located in 30 feet of water.

Monitors are retrieved and replaced annually by divers. Although the time series contained data from seven monitors at one point, we have collected data from only six sites since 10/5/91 when the monitor at the *Endicott* site was lost and has not been replaced. Figures 7 and 8 present the bottom water temperature at sites in Buzzards Bay and Cape Cod Bay/Massachusetts Bay, respectively. Figure 9 provides a comparison between the annual mean bottom temperature at Cleveland Light, Buzzards Bay-south, Manomet, Rocky Point, *Mars*, and Martin's Ledge, and the annual mean surface temperature at Boston and Woods Hole provided by NOAA/NOS. Three sites (<20 ') were added in summer, 2001 (Onset Stowaway XTI monitors) where suction sampling for EBP lobsters is conducted. These are site #'s 2, 6, and 8 in Buzzards Bay, Cape Cod Bay, and Boston Harbor (Figure 6).

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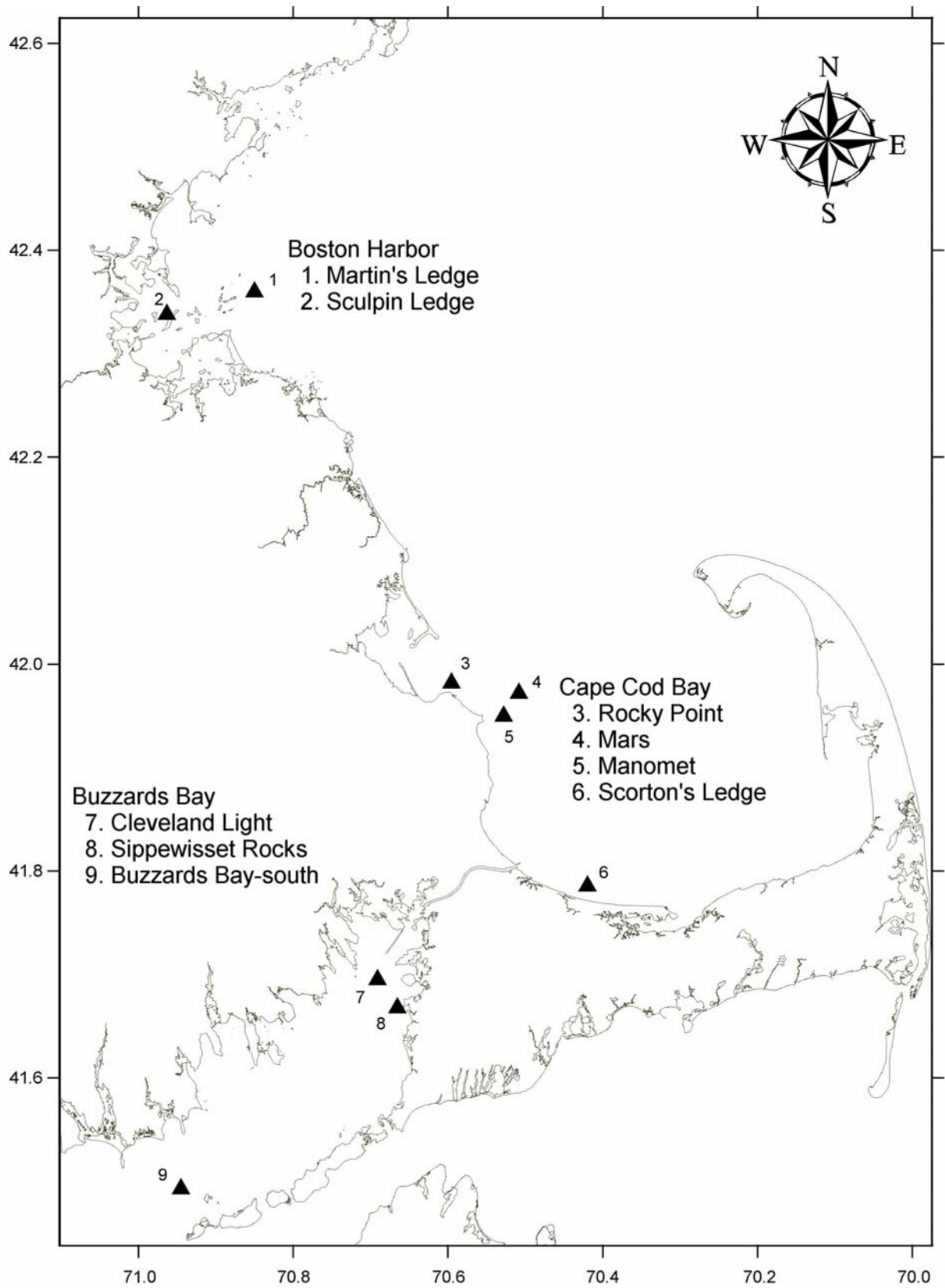
Figure 6. Map of Massachusetts with locations of nine bottom temperature monitors.
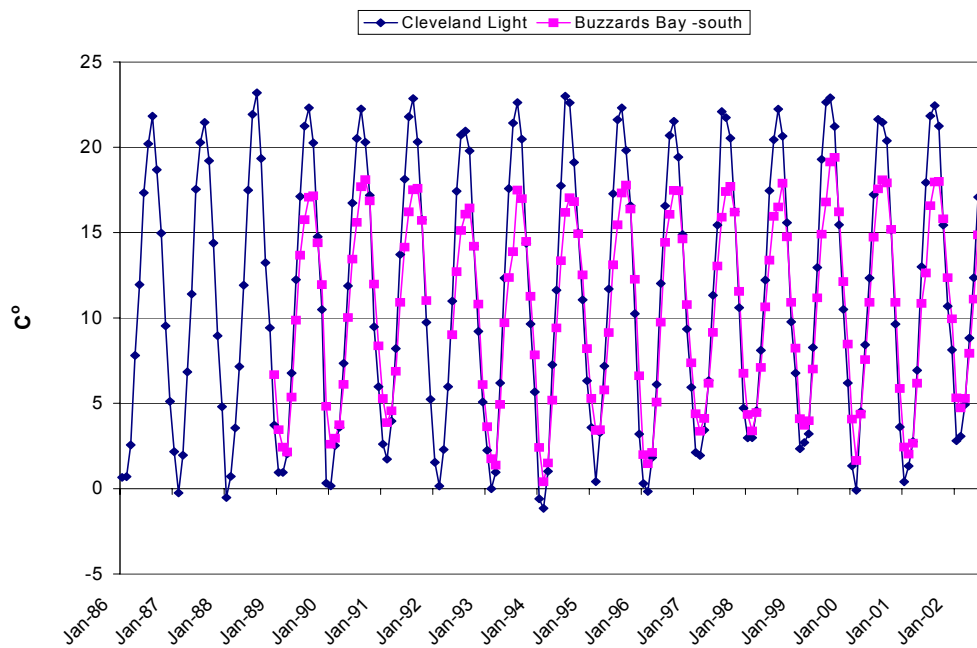
Figure 7. Mean monthly bottom water temperatures at two sites in Buzzards Bay, 1986-2001.
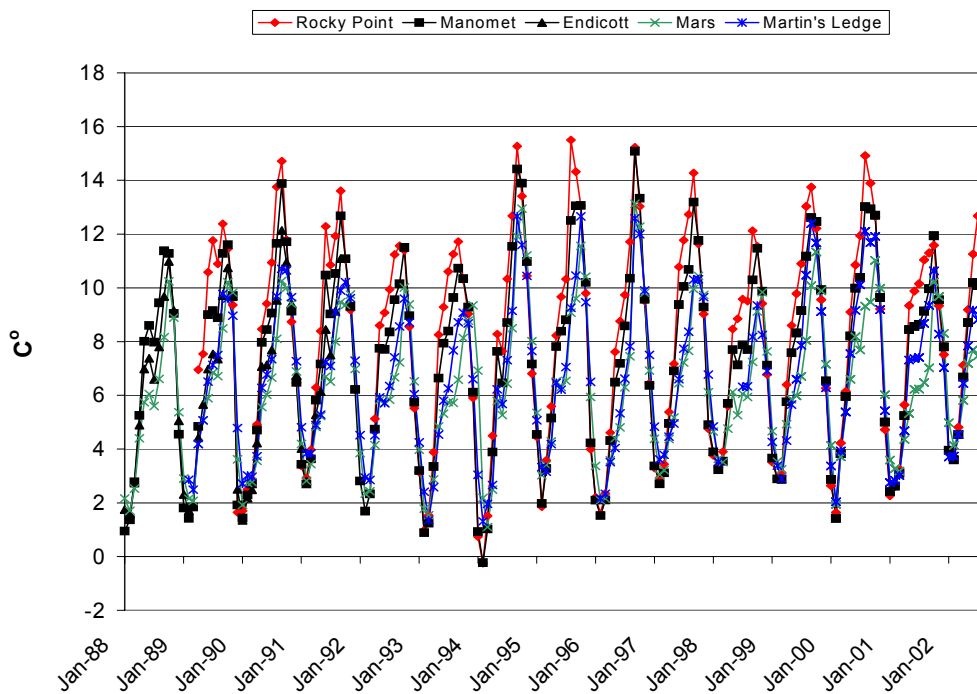
Figure 8. Mean monthly bottom water temperatures at five sites in the Gulf of Maine, 1988-2001.
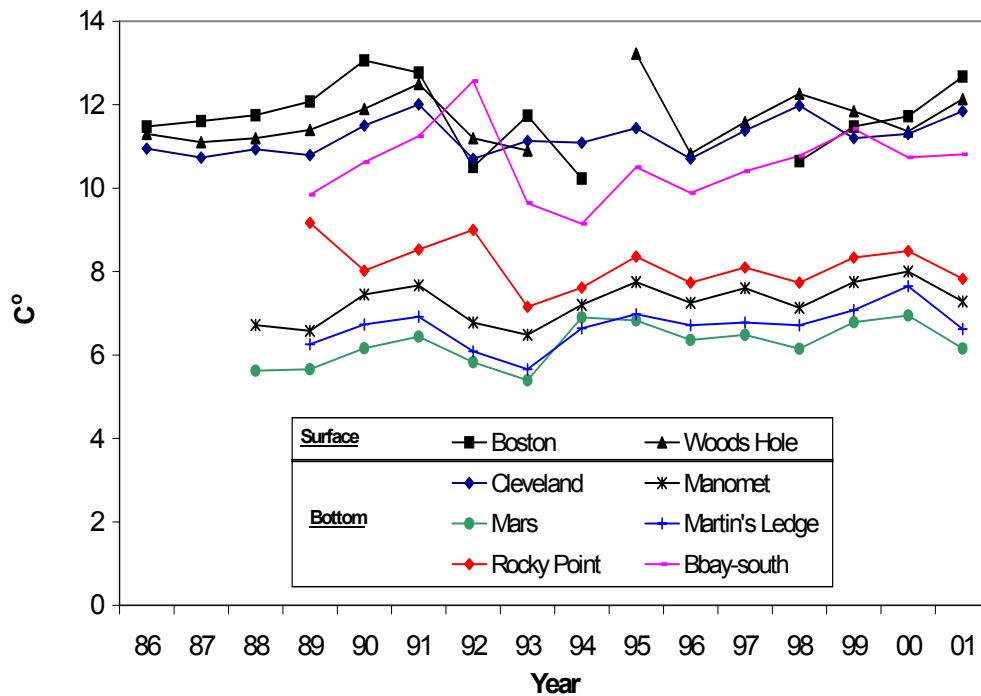
Figure 9. Mean annual bottom water temperatures at four sites monitored by the Coastal Lobster Project and mean annual surface temperature at two sites monitored by NOAA/NOS, 1986 - 2001.

Ocean bottom temperature may be useful in evaluating some aspects of the dynamics of lobster populations, but it is only one of a number of speculated factors which may influence abundance. The relationship between surface water temperature and 1922-1989 Massachusetts lobster landings and catch per trap was previously modelled using transfer function analysis (Estrella and Cadrin 1991). However since only 13-14 years of bottom water temperature are available from sites north of Cape Cod and 13-16 years from sites south of Cape Cod, a similar analysis with local bottom temperature data will not be possible until a longer time series is available.

Status of the Lobster Stocks in Massachusetts and Adjacent Waters

Massachusetts borders on three stock units (Figure 10) which were delineated based on biological and hydrodynamic characteristics to refine stock assessments: Gulf of Maine (GOM), Georges Bank-Offshore-South (GBO), and the Southern Cape Cod to Long Island Sound Stock Unit (SCCLIS). Further partitioning of the lobster's range was recommended to managers by the lobster industry and was realized in the form of seven Lobster Conservation Management Zones which were delineated in Amendment 3 to the ASMFC Lobster Fishery Management Plan (Figure 10). Consequently stock unit boundaries generally exceed those of management zones which complicates evaluation of area management plans. Also differential gauge sizes and other measures will make it more difficult to track statewide trends in the future. The last
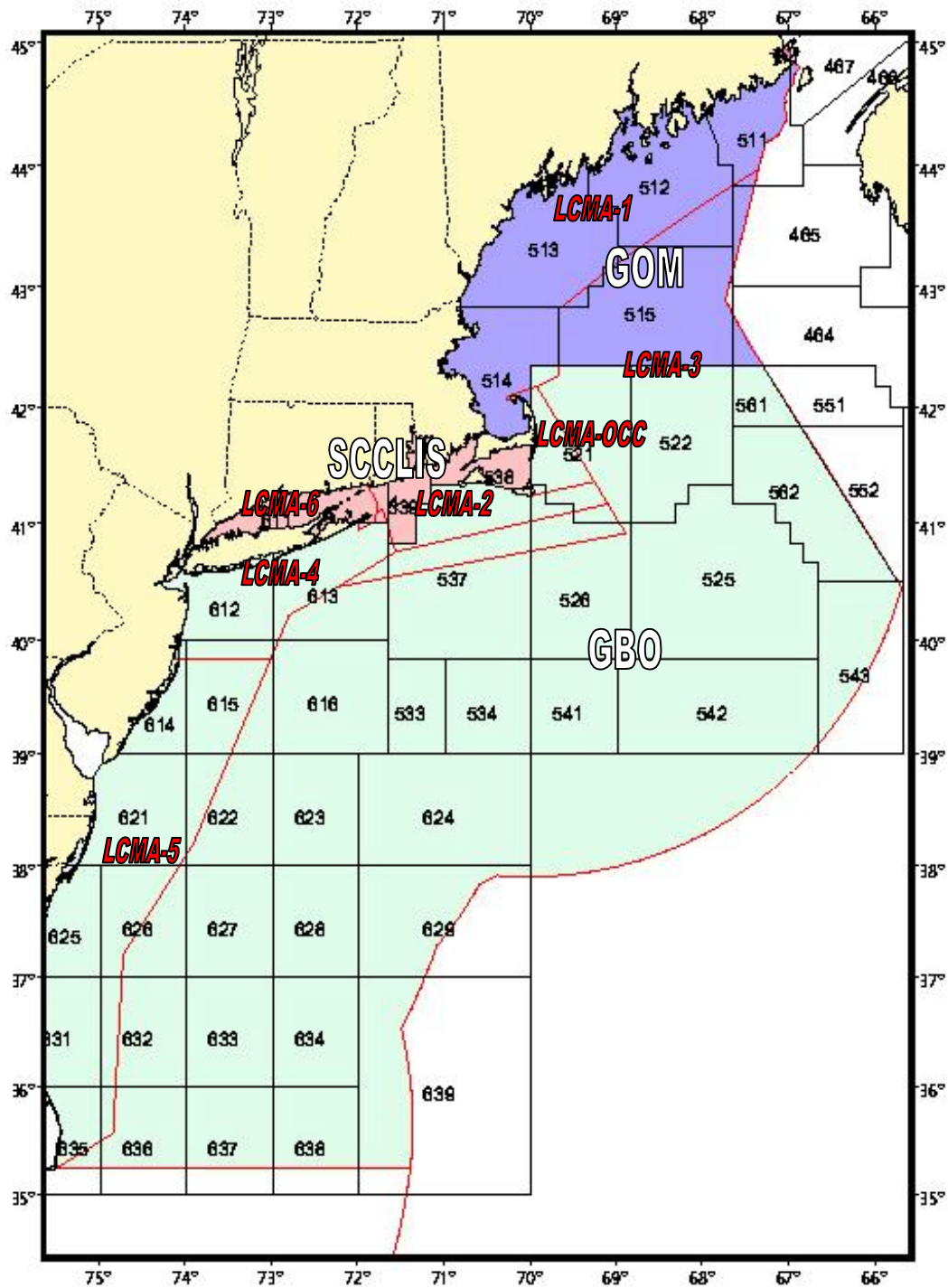
Figure 10. Map of American Lobster stock units (blue = GOM; pink = SCCLIS; and green = GBO) and ASMFC Lobster Conservation Management Areas (LCMA-1, 2, 3, 4, 5, 6, and Outer Cape Cod or OCC). Three digit codes are NMFS Statistical Areas.

coastwide stock assessment was conducted by the Atlantic States Marine Fisheries Commission Technical Committee in 2000 and included data through fall 1998.

Gulf of Maine Stock Unit/LCMA-1

MA bottom trawl survey CPUE has declined to an early 1980's level and commercial landings have fluctuated downward since 1990. Massachusetts Bay CPUE of marketable-size lobsters from commercial sea sampling declined significantly as did sublegal lobster catch rates in most MA LCMT-1 regions. The percentage of females ovigerous and CPUE of egg-bearing females varied without trend during the 1980's before increasing during the 1990's. Fishing mortality rates remain well above that defined by the overfishing definition. EBP suction sampling catch indices were higher in recent years but this time series is not yet long enough to determine how it relates to commercial lobster abundance.

MA Bottom Trawl Survey Trends for Southern GOM/LCMA-1

Relative abundance trends from MA inshore bottom trawl surveys indicate that CPUE has declined to a level similar to that observed in the early 1980's or lower (Figures 11 and 12).

The 2001 MA southern GOM fully-recruited (83+mm) lobster indices were well below their respective time series means, and were close to the lowest values in the 21 year time series for both males and females (Figures 11 and 12).

The 2001 MA GOM pre-recruit (71-82mm) lobster indices were well below their respective time series means, and were the second lowest values in the 21 year time series for both males and females. The 59-70 mm size group followed a similar trend for both sexes.

Figure 11. MA Southern GOM/LCMA-1 Fall Bottom Trawl Survey Indices for Males (Source: MA Resource Assessment Project).

Figure 12. MA Southern GOM/LCMA-1 Fall Bottom Trawl Survey Indices for Females (Source: MA Resource Assessment Project).
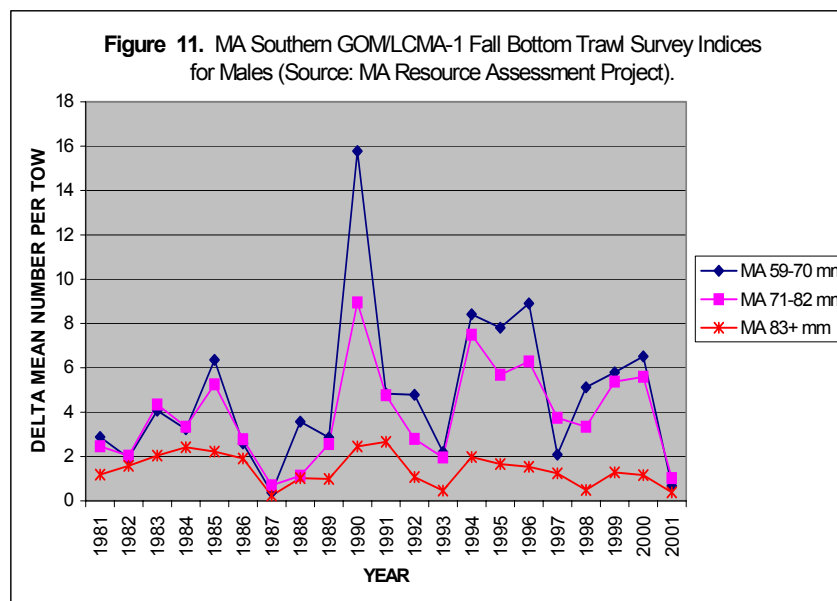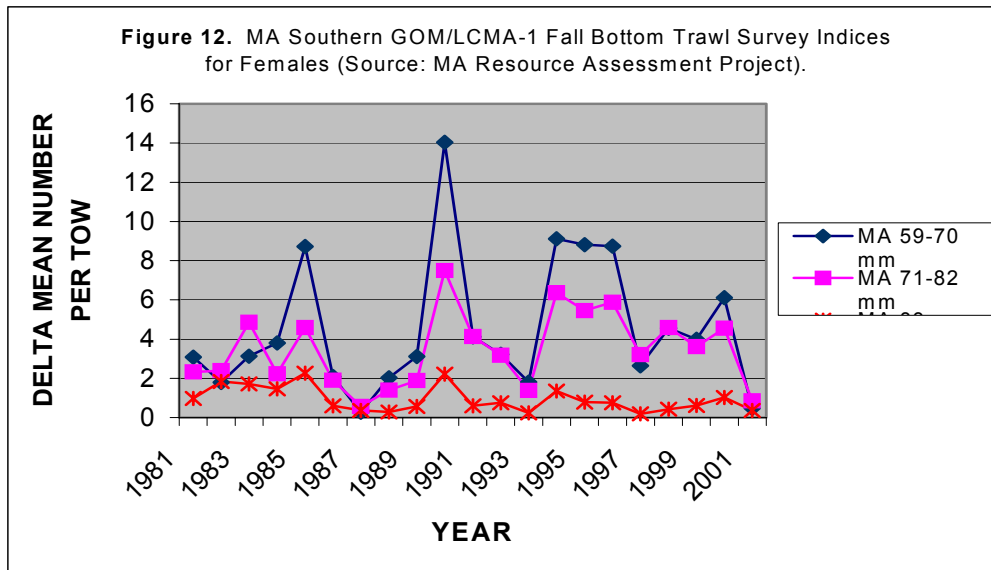
MA Landings Trends for Southern GOM/LCMA-1

Lobster landings fluctuated downward from 1990 to 2001 for inshore StatAreas 1-8 (Figure 13). MA landings from adjacent offshore StatArea 19 gradually increased through 1996 then declined steadily thereafter (Figure 13). MA landings and effort in StatArea 20 were negligible. MA Statistical Area 4 (Massachusetts Bay-Boston Harbor) experienced the most dramatic decline, beginning after 1991. Most other inshore StatAreas mimicked that decline with the exception of northern-most StatAreas 1 and 2 (Cape Ann), southern-most StatAreas 7 and 8 (Cape Cod Bay-Provincetown, Figure 14).

Figure 13. MA LCMA-1 Lobster Landings from Inshore StatAreas 1-8 and Offshore StatAreas 19 and 20, 1990-2001 (Source: Fishermen's catch reports, MADMF Statistics Project).

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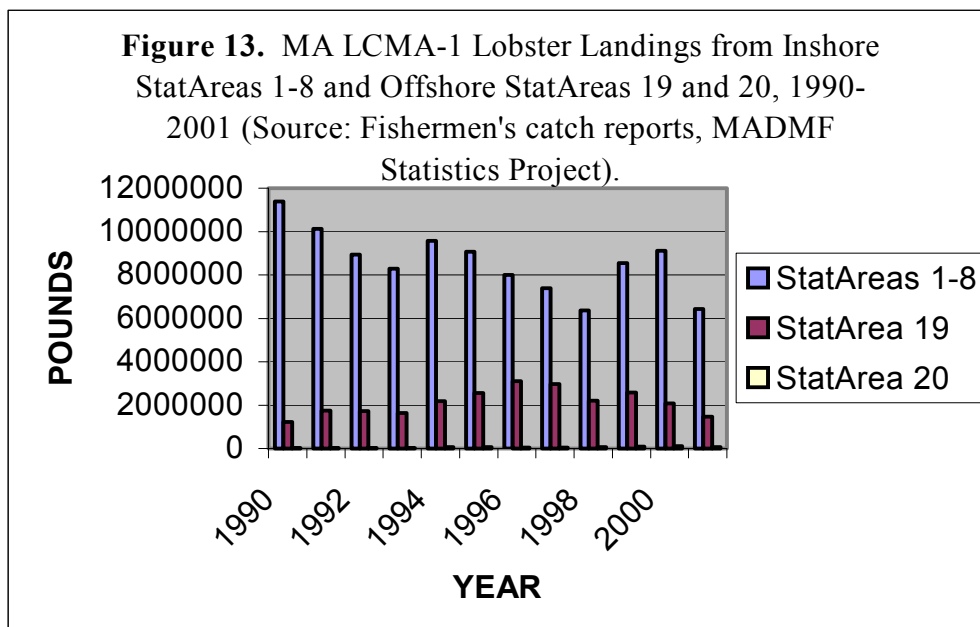
Figure 14. MA Lobster Landings from LCMA-1 Inshore StatAreas 1 thru 8 (Source: Fishermen's catch reports, MADMF Statistics Project).
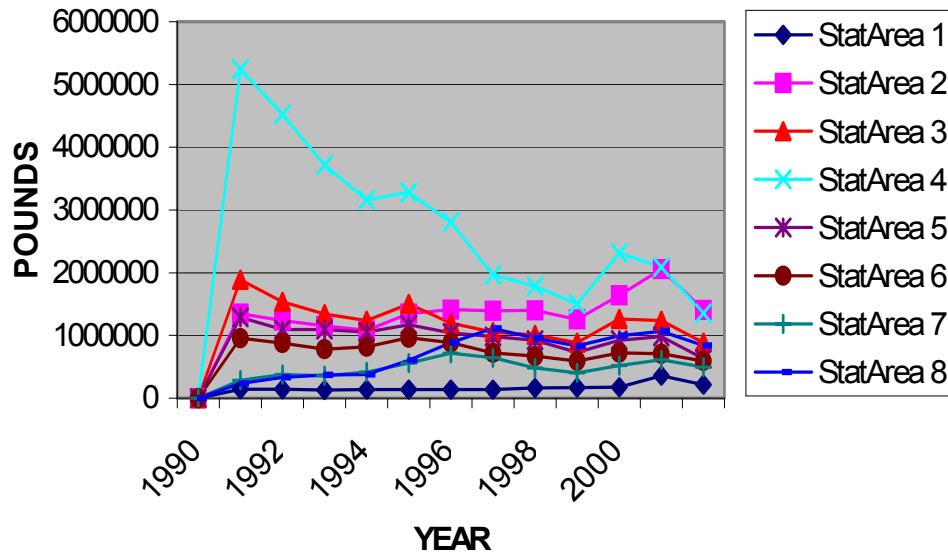
Sea Sampling Data Trends for MA Segment of Southern GOM/LCMA-1

Catch rates of marketable lobsters (CTH'3, Figure 15) showed a significant decline off Boston, but trends were less distinct in other MA GOM regions of Beverly-Salem and Cape Cod Bay where changes in fishing behavior may have helped to counter losses, e.g., a move to deeper water areas. Catches of marketable lobsters from the Cape Ann area fluctuated upward during the mid 1990's before declining in the late 1990's.

CPUE trends of sublegal lobsters from commercial lobster sea sampling (CTHSOD, Figure 16) depict a steady decline in catch rates of pre-recruit and smaller lobster for all MA GOM regions except Cape Ann. Change in escape vent size implemented during the time series showed no apparent affect on the trend.

The percentage of females ovigerous and CPUE of egg bearing females varied without trend during the 1980's before increasing during the 1990's (Figures 17 and 18). The data do not show that more small eggers are available. An analysis of percent ovigerous by 5 mm size groups indicates that the trend is not size-specific which tends to exclude warmer water temperature as a factor in enhancing maturity at small size. Size at maturity is similar to that observed in the late 1800's (Estrella and Cadrin 1995). Nevertheless, since warmer temperatures positively influence molting probability, the effects of temperature may have had a general influence in conjunction with factors such as abundance of females, fishing mortality, lobster behavior relative to traps, commercial lobstering behavior, and management changes. If so, their influence appears to be uniform across the size range.

Although currently declining, female abundance was higher in the 1990's than 1980's which would enhance opportunity for extrusion. It is not clear if lower abundance induces a behavioral effect whereby egg-bearing females are more likely to enter a less crowded trap.

We are unsure if the high removal rates (high F) which characterize the inshore fishery exaggerated the percentage of females with eggs, because eggers remain in the catches as non-egg-bearing females are harvested. However, on a regional basis, CPUE appears to follow a trend similar to percent ovigerous.

Commercial lobstering behavior has changed relative a downturn in abundance and subsequent availability of lobsters. Shoaler waters have not been as productive for marketable lobsters during the 1990's as they were in the previous decade so fishing effort has spread to deeper water areas. This may have benefited egg production of females by allowing those in shoaler, warmer water to extrude eggs. Despite this effort shift, we have attempted to maintain a regimen of monthly sampling in both shoal and deep water areas in order to meet our objective of adequately sampling the coastal lobster fishery in the Massachusetts territorial sea.

Additional analyses of egg-bearing females were conducted with standardized soak time through calculating CTH'3. Catch rates of three size groups beyond minimum legal size indicated that only the first molt group (recruits) increased after 1990, but then leveled off. The remaining two molt groups showed no obvious trend. This may have been related to the minimal vent and carapace size increases implemented between 1988 and 1990.

Fishing mortality (F) rates (Cohort Analysis) are high with calculations at or above 1.0 in most cases (Figures 19 and 20). Trends are difficult to discern, but are higher for Massachusetts Bay regions of Beverly-Salem and Boston Harbor for most years than for Cape Ann and Cape Cod Bay. Delury model estimates of F rates from bottom trawl survey dataare more reliable because they are collected with a stratified-random design and are sensitive to changes in recruitment. Thus they are preferred in stock assessments. Fishing mortality estimated from MA bottom trawl survey data trended upward during the time series and was calculated around 2.0 during the last stock assessment (Figure 21).

Figure 15. CTH'3 For LCMA-1 Regions of MA.
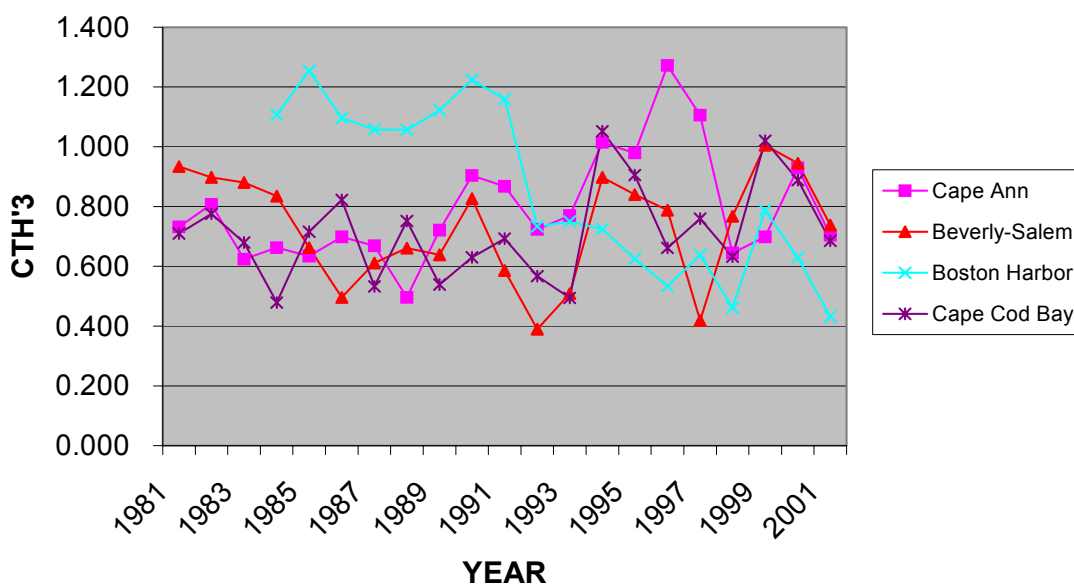
Figure 16. CTHSOD of Sublegals from LCMA-1 Regions of MA.

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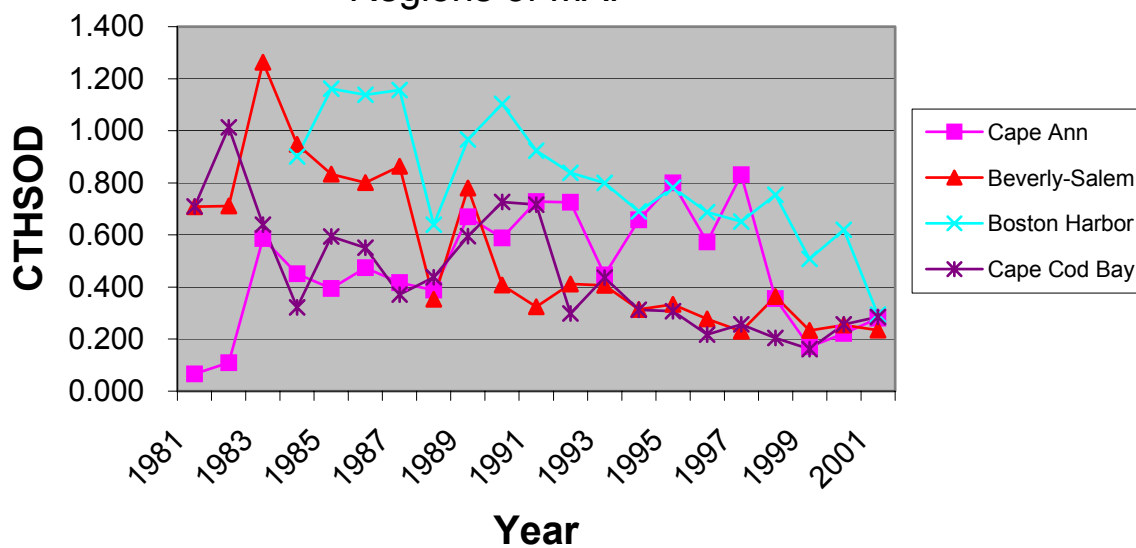
Figure 17. Percent of Females Ovigerous from LCMA-1 Regions of MA.
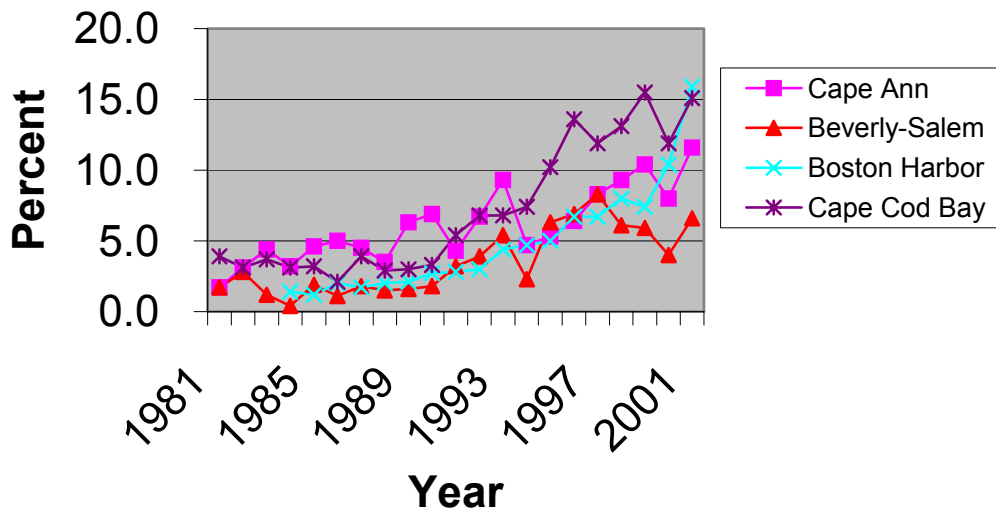
Figure 18. CTHSOD of Eggers from LCMA-1 Regions of MA.
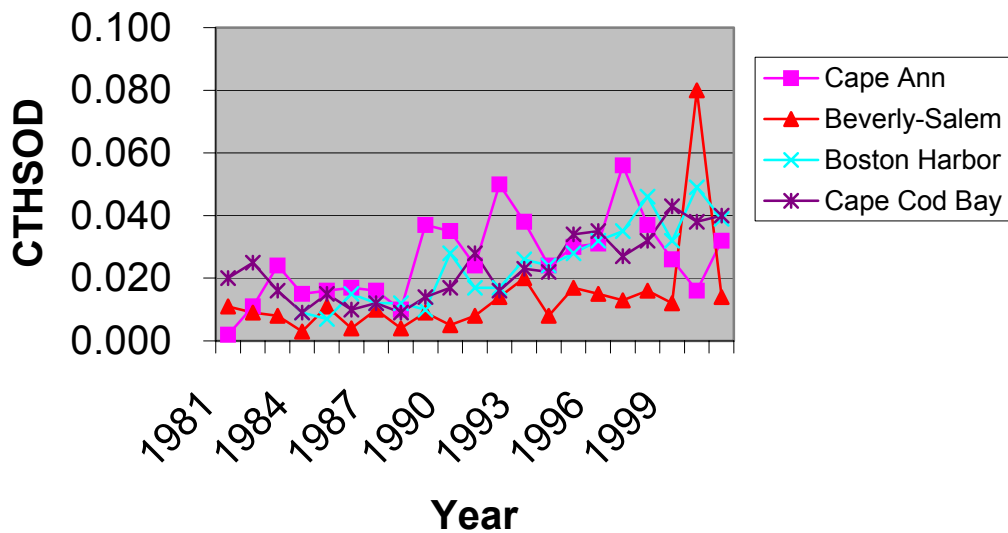
Figure 19. Fishing Mortality (COHORT-Von Bertalanffy) from LCMA-1 Regions of MA.
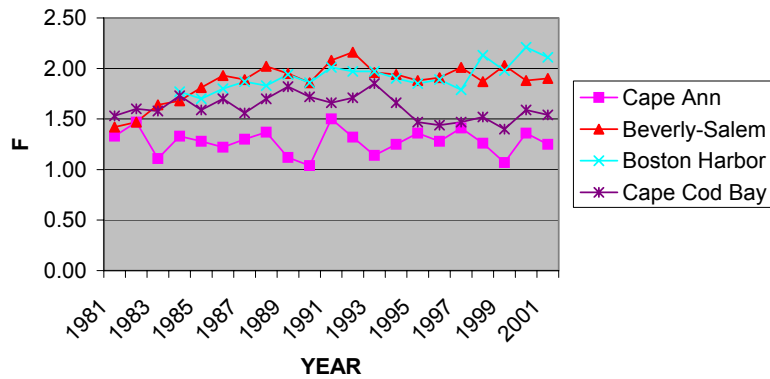
Figure 20. Fishing Mortality Rate (Delta T's) from LCMA-1 Regions of MA.
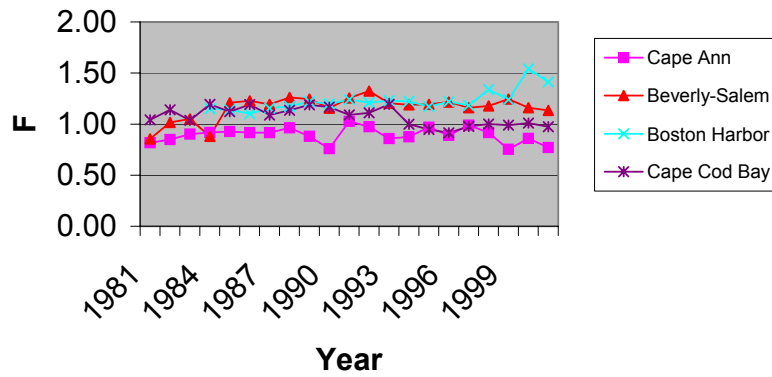
Figure 21. Fishing Mortality Rate Trend (Delury Method) from MA Bottom Trawl Survey in LCMA-1 Regions of MA.

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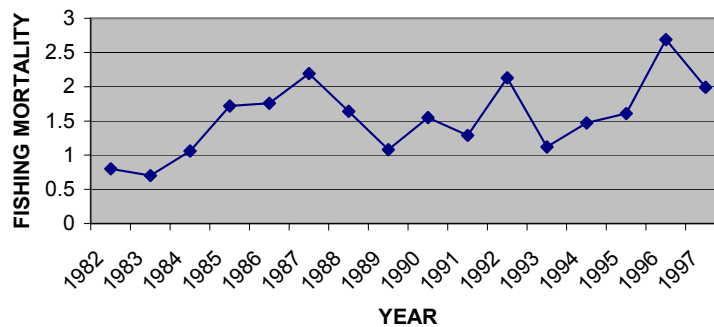
MA EBP Relative Abundance Trends, Diver Suction Sampling in GOM, LCMA-1

Experimental EBP sampling by diver operated suction equipment in MA coastal waters began in 1995. Due to the short length of the time series, indices have yet to be related directly to commercial catch rates or landings. The effects of natural mortality occurring between settlement and recruitment to commercial size are unclear, at this point, making it difficult to interpret these trends. Nevertheless, densities for three size categories sampled in three GOM/LCMA-1 inshore areas exhibited similar trends, and, although Boston and Cape Cod Bay indices were low compared to Salem Sound during most of the time series, all areal indices appeared higher in 2002 for all size groups (Figures 22, 23, and 24).

Figure 22. Density of YOY EBP Lobsters (0 to 12mm) in LCMA-1 Regions of MA.

Figure 23. Density of 0 to 25 mm EBP Lobsters in LCMA-1 Regions of MA.

Figure 24. Density of 0 to 40 mm EBP Lobsters in LCMA-1 Regions of MA.
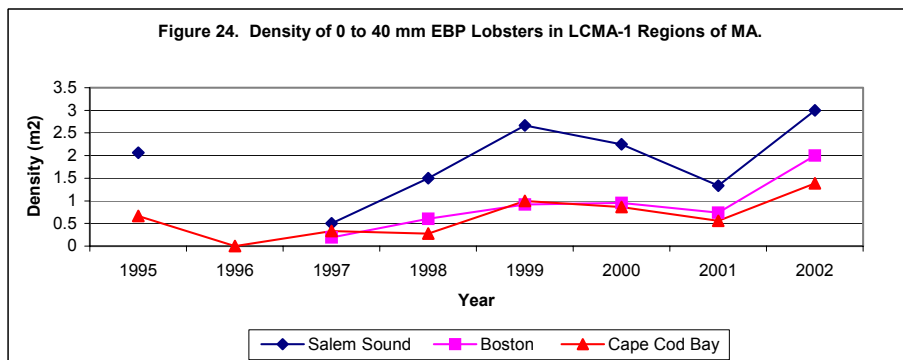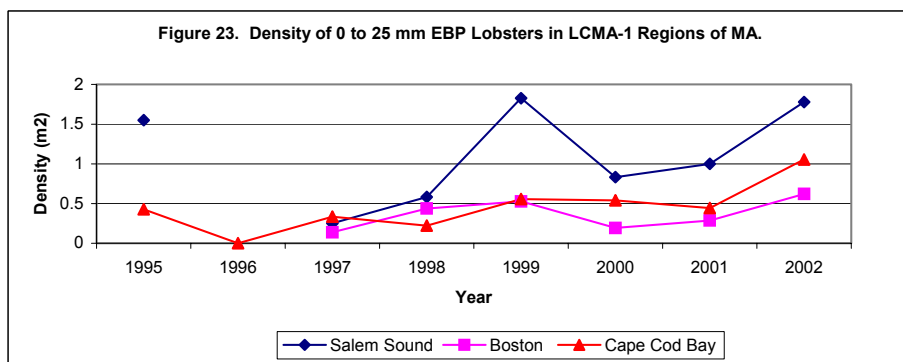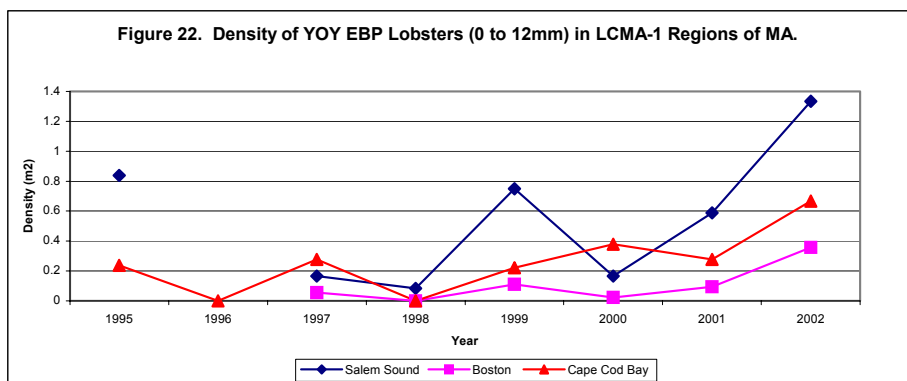
SCCLIS Stock Unit/LCMA-2

MA bottom trawl survey CPUE declined to well below the time series mean. Commercial landings were stable or increasing through 1997, before declining significantly, particularly in inshore areas. CPUE of marketable-size lobsters from commercial sea sampling varied without trend and did not mirror the landings decline in recent years. This may be due to a recent shift in sampling effort to deeper waters areas (Stat Areas 12, 15 and 16) because of the decline of the nearshore fishery. However, sublegal lobster catch rates, percentage of females ovigerous, and CPUE of egg-bearing females declined markedly after 1993. Fishing mortality rates remained well above that defined by the overfishing definition. Although slightly higher in recent years, the EBP suction sampling time series is not yet long enough to determine how it relates to commercial lobster abundance.

MA Bottom Trawl Survey Trends-SCCLIS Stock Unit/LCMA-2

The 2001 Massachusetts Southern New England fully-recruited (83+mm) lobster indices were well below their respective time series means for both males and females (Figures 25 and 26). The pre-recruit (71-82mm) indices, declining since 1991, were near time series lows, and have remained well below that observed in the late 1980's and early 1990's for both sexes. The 59-70 mm size group followed a similar trend for both sexes, peaking in 1993 then declining thereafter.

RI and CT Bottom Trawl Survey data (Figures 27 and 28) were acquired from the ASMFC Lobster Technical Committee Report: Annual State and Federal Trawl Survey Update, February 20, 2002. The RI bottom trawl survey is conducted in both Narragansett Bay and outer coastal waters in the central portion of the SCCLIS stock unit. RI survey data trend similarly to MA data and show a decreasing trend following a 1993 peak (Figure 27).

The CT bottom trawl survey is conducted throughout Long Island Sound (LIS) in the western end of the SCCLIS stock unit. The spring and fall 2001 surveys showed a decrease in abundance for all size classes (Figure 28). LIS fall abundance estimates are comparable to estimates from the late 1980's. Pre-recruit lobster abundance (71-82 mm) dropped considerably its peak in 1998 according to the spring 2000 survey. Recruits (83+ mm) have declined steadily since 1997.

Figure 25. Southern MA Fall Bottom Trawl Survey Catch Indices for Males.

Figure 26. Southern MA Fall Bottom Trawl Survey Catch Indices for Females (Source: MA Resource Assessment Project).

Figure 27. RIDFW Fall Abundance Indices / SCCLIS
American Lobster (sexescombined).

Figure 28. CT DEP Long Island Sound Trawl Survey
Indices of Abundance - Fall Lobster, 1984-2001

23
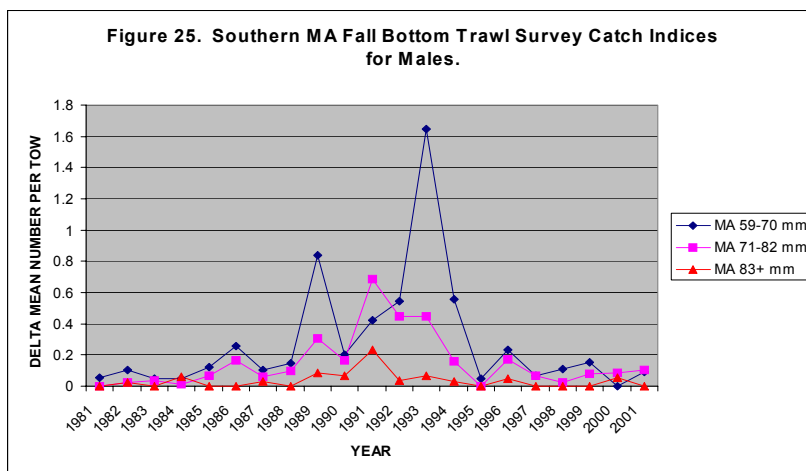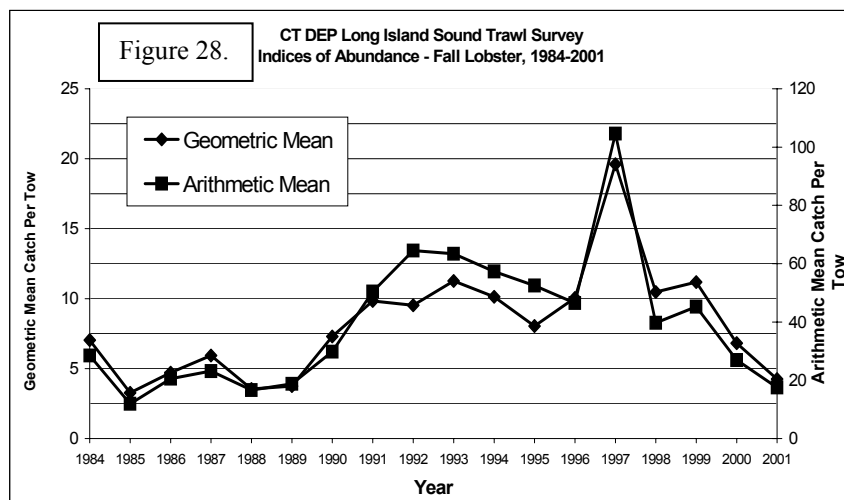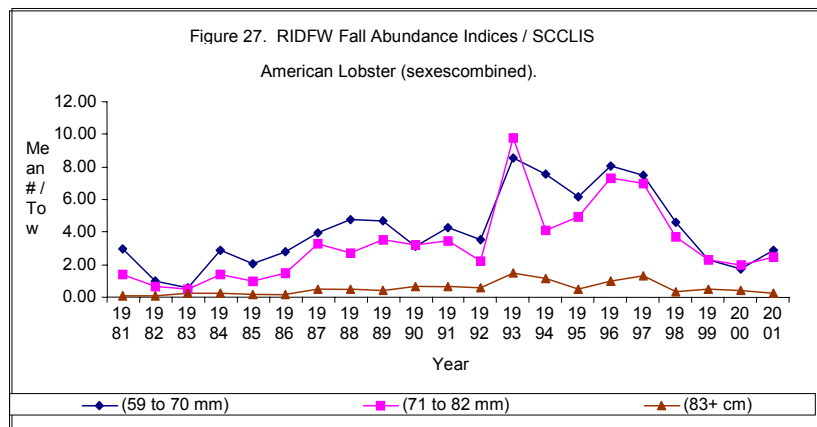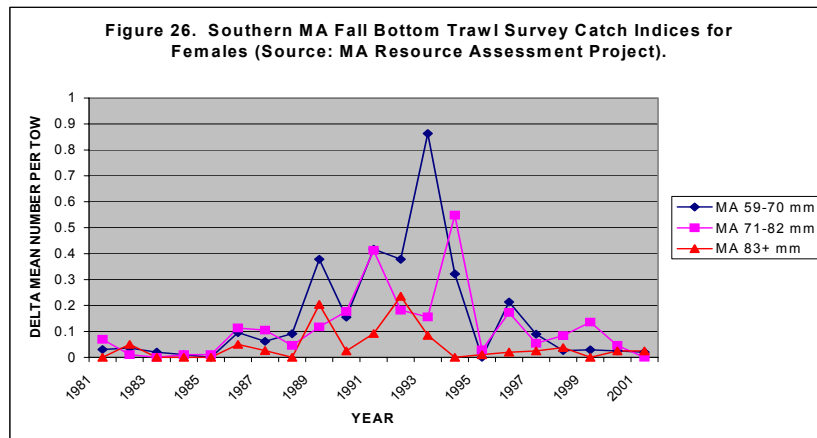
Landings Trends for MA portion of SCCLIS stock unit/LCMA-2

MA landings in LCMA-2 were stable or increasing through 1997, but declined thereafter (Figures 29 and 30). The magnitude of the decline was much more pronounced in the inshore environments of Buzzards Bay and Vineyard Sound (Figures 31). Clearly, this decline, as evidenced by declining bottom trawl survey abundance of pre-recruits (71-82mm) and sub-pre-recruits (59-70mm) several years earlier in the 1990's, pre-dated the significant increase in severity of shell disease symptoms which was most pronounced in Buzzards Bay and which characterized lobsters there and throughout the stock unit in the late 1990's to the present (Figure 32).

Figure 29. Lobster Landings From MA LCMA-2, 1990-2001(Source: Fishermen's catch reports, MADMF Statistics Project).

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Figure 30. Inshore and Offshore Lobster Landings from MA LCMA-2, 1990-2001(Source: Fishermen's catch reports, MADMF Statistics Project).
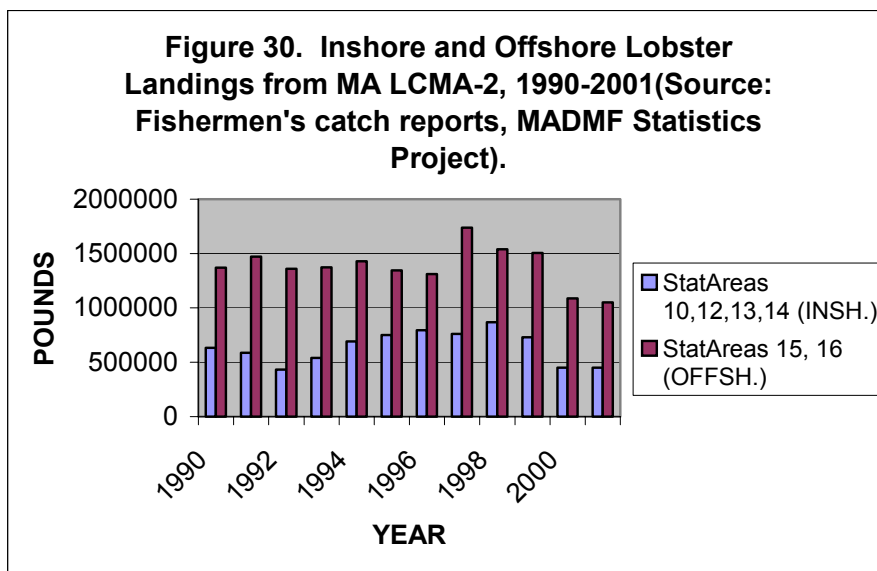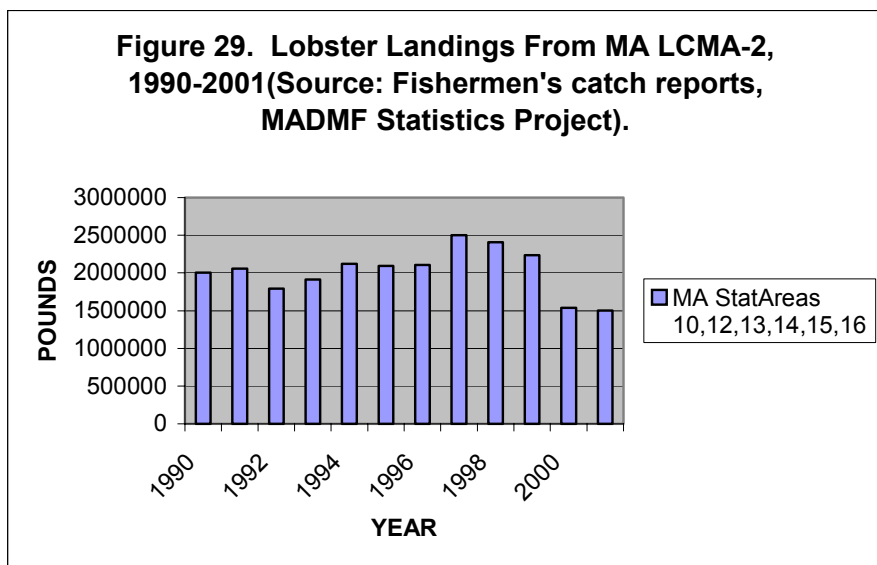
Figure 31. Lobster Landings From Buzzards Bay and Vineyard Sound 1990-2001(Source: Fishermen's catch reports, MADMF Statistics Project).
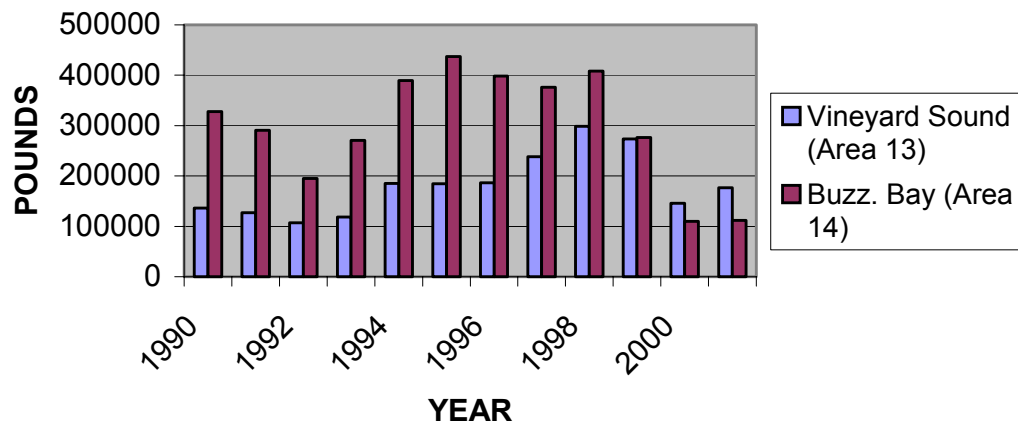
Figure 32. Prevalence of Shell Disease in LCMA-2 (Source: ASMFC TC Report, 10-15-02)

25
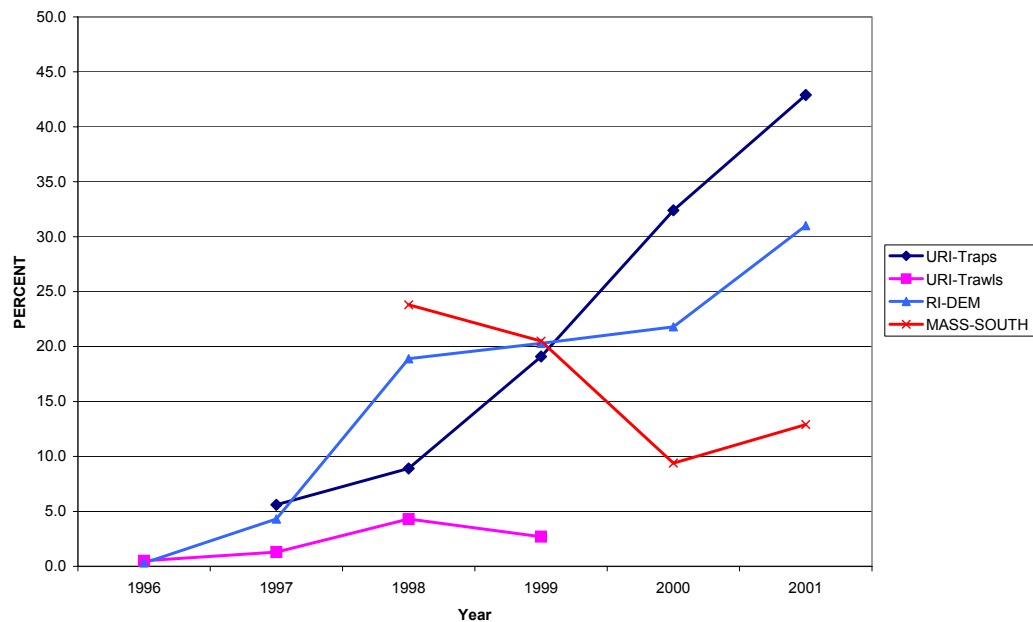
Sea Sampling Data Trends for MA segment of SCCLIS/LCMA-2

CTH'3 of marketable lobster varied without trend during the time series (Figure 33) while a precipitous decline occurred in catch per unit effort of sublegals beginning in the early 1990's (Figures 34). The percentage of females with eggs increased from 1981 to 1993 before declining to an early 1980's level (Figure 35), however CPUE of eggers declined radically after 1993 and has stayed relatively flat through the present (Figures 36). Fishing mortality rates from Cohort Analysis with Von Bertalanffy growth parameters and with delta T adjustments (Figures 37 and 38) varied without trend. Delury Model fishing mortality estimates were not calculated from MA bottom trawl survey data due to the presence of too many zero catches which affects reliability of estimates.

Figure 33. CTH'3 of Marketable Lobsters, MA LCMA-2.
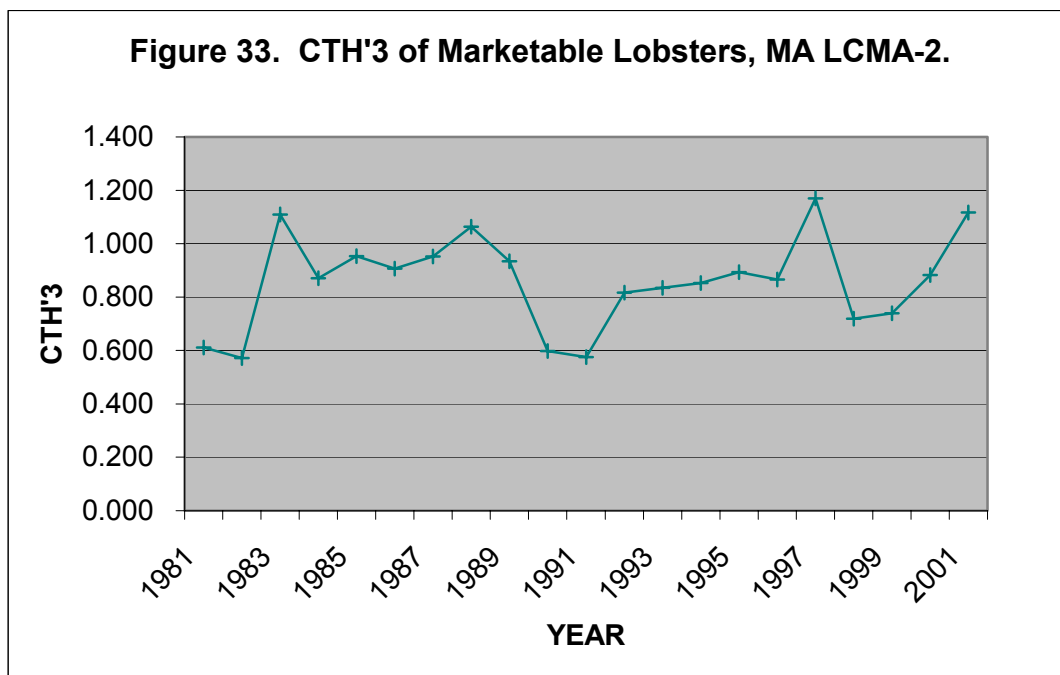
Figure 34. CTHSOD of Sublegals, MA LCMA-2.
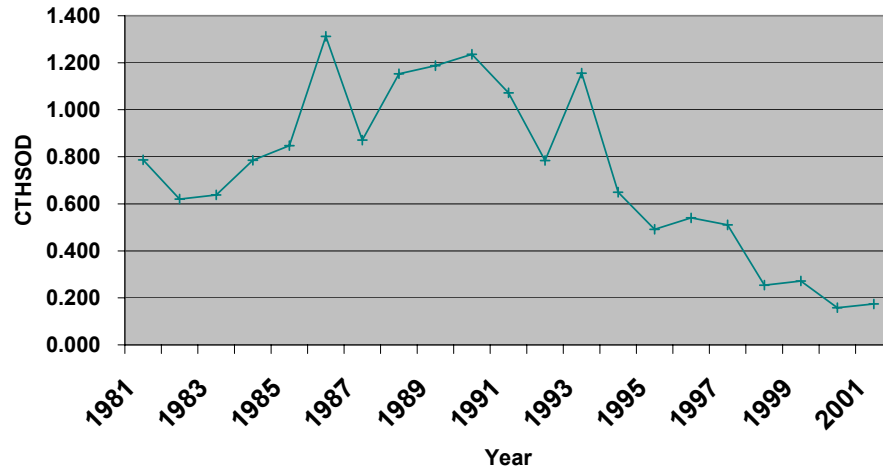
Figure 35. Percent of Females Ovigerous, MA LCMA-2.
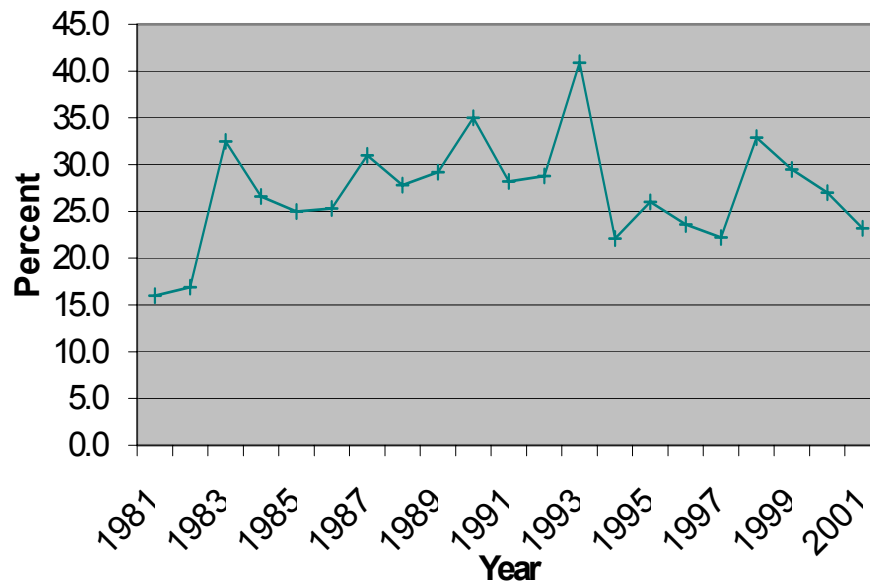
Figure 36. CTHSOD of Eggers, MA LCMA-2.
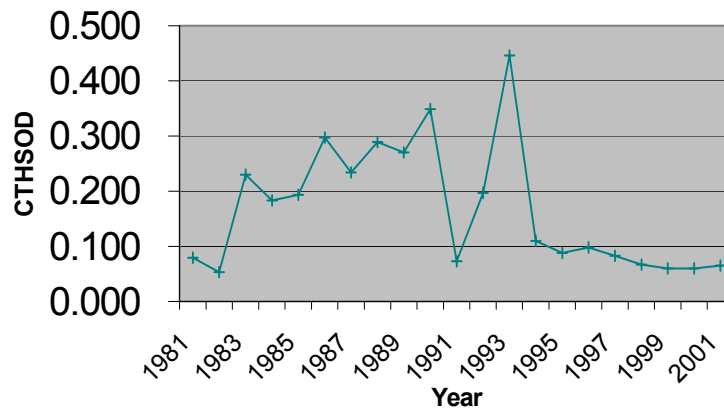
Figure 37. Fishing Mortality (Cohort-Von Bertalanffy), MA LCMA-2.
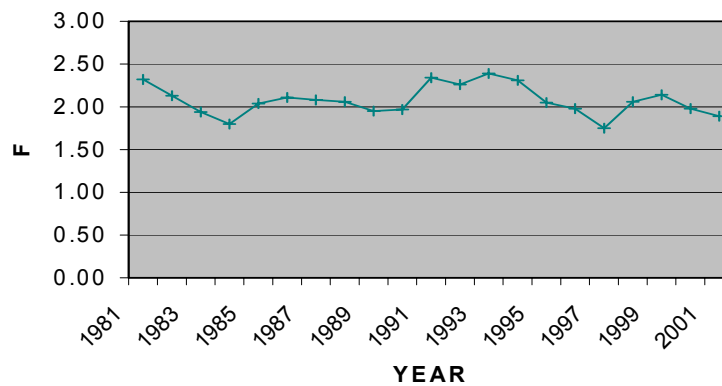
Figure 38. Fishing Mortality (Delta T's), LCMA-2.

28
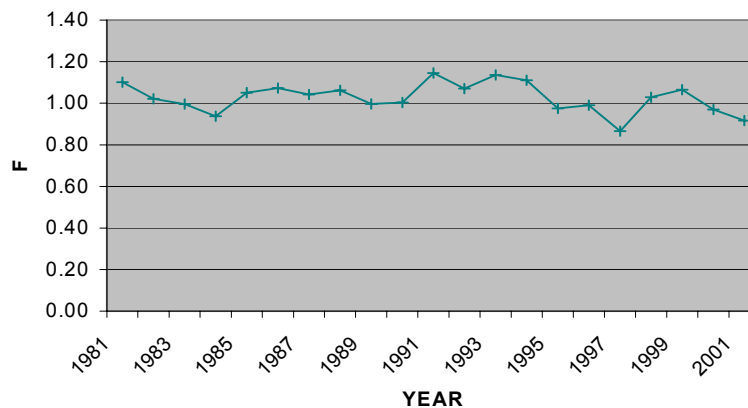
MA EBP Relative Abundance Index Trends from Diver Suction Sampling in SCCLIS Stock Unit/LCMA-2

The EBP densities from Buzzards Bay were extremely low (Figures 39, 40, and 41). This is surprising since historical sampling of pelagic stages in the 1970's showed record levels of 4th stage lobster larvae in this region. Data do not appear to exhibit any definitive trends except that the latter half of the time series appeared higher than the earlier years. The time series is not yet adequate to attempt to relate it to commercial landings.

Figure 39. Density of YOY EBP Lobsters(0 to 12mm), Buzzards Bay, MA.

Figure 40. Density of 0 to 25 mm EBP Lobsters, Buzzards Bay, MA.

Figure 41. Density of 0 to 40 mm EBP Lobsters, Buzzards Bay, MA.
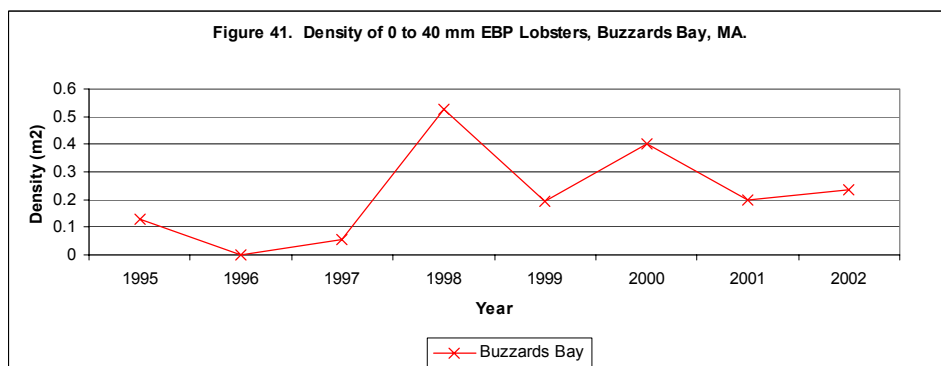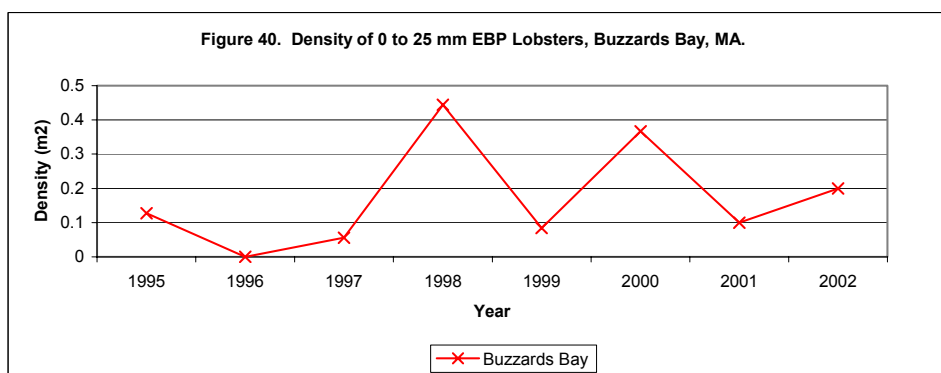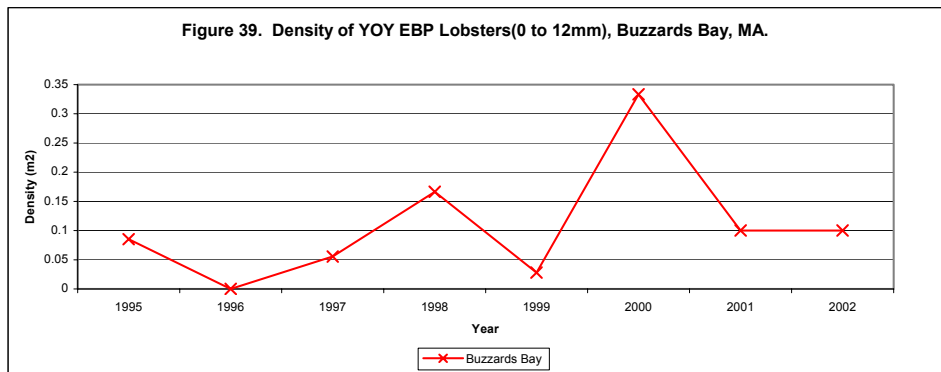
Georges Bank-South Offshore Stock Unit/Outer Cape Cod LCMA

MA bottom trawl survey CPUE is not available for Outer Cape Cod. Commercial landings declining during the time series. CPUE of marketable-size lobsters has been fluctuating downward since the early 1990's and CPUE of sublegals has declined to an early 1980's level. The percentage of females ovigerous and CPUE of egg-bearing females fluctuated upward since 1992. Fishing mortality rates generally increased though the time series and remain well above that defined by the overfishing definition. EBP suction sampling is not conducted in this area because the resource here is largely offshore migratory with minimal local recruitment.

MA Bottom Trawl Survey Trends-GBO Stock Unit/Outer Cape Cod LCMA

MA Bottom Trawl Survey relative abundance information is not reported for the Outer Cape Cod (OCC) area, because lobster catch per tow is prohibitively low.

Landings Trend for MA portion of GBO stock unit/Outer Cape Cod LCMA

Outer Cape Cod landings declined significantly during the time series (Figure 42).

Figure 42. OCC Lobster Landings (StatAreas 9, 11, 17, 18) (Source: Fishermen's catch reports, MADMF Statistics Project).
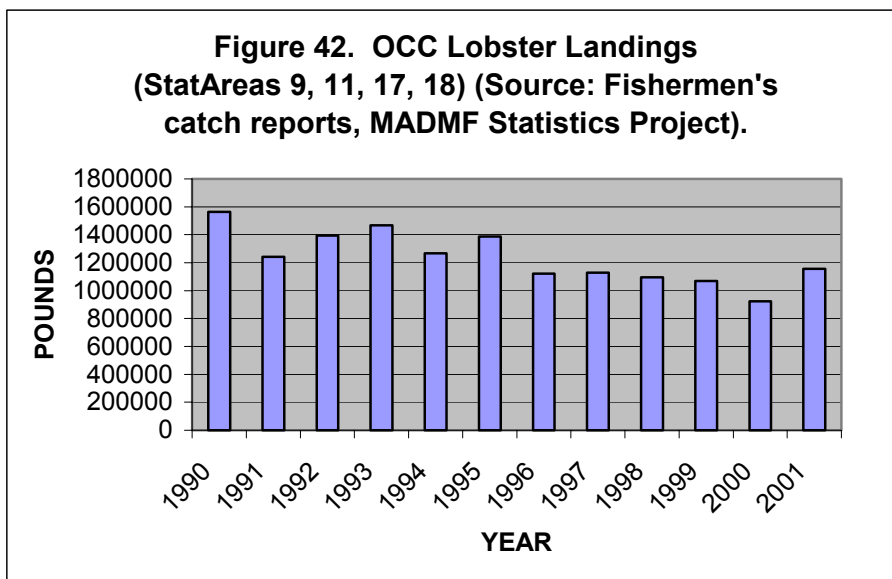
Sea Sampling Data Trends for MA Portion of GBO Stock Unit/Outer Cape Cod

CTH'3 of marketable lobster increased through 1992, declined through 1998, then fluctuated back to a 1993 level (Figure 43). CPUE of sublegals varied low without trend until 1986, increased through the early 1990's, then declined during most of the 1990's, returning to an early 1980's level (Figures 44). The percentage of females with eggs varied without trend through 1992 before fluctuating upward during the remainder of the time series (Figure 45). CPUE of

eggers similarly fluctuated without trend during the 1980's then edged upward during the 1990's (Figures 46). Analytical results were similar to that presented in the Gulf of Maine section. Analyses of CTH'3 of three egger molt groups depicted higher average catch rates during the 1990's than in the previous decade. The effects of temperature, management, fishing mortalty, trapping behavior, and abundance of females are unclear, but may be factors. If so, their influence appears to be uniform across the size range. Fishing mortality rates (Figures 47 and 48) increased throughout the time series.

Figure 43. CTH'3 of Marketable Lobsters from Outer Cape Cod.

Figure 44. CTHSOD of Sublegals from Outer Cape Cod.
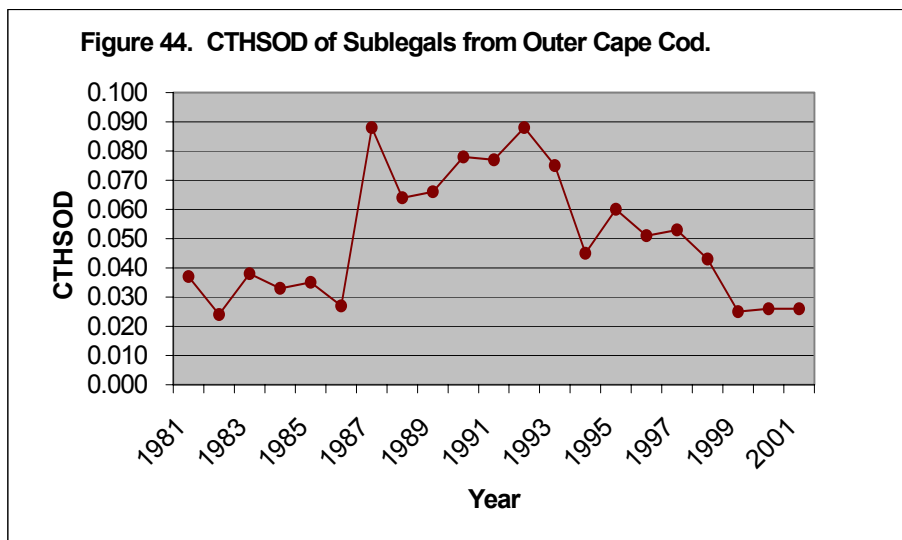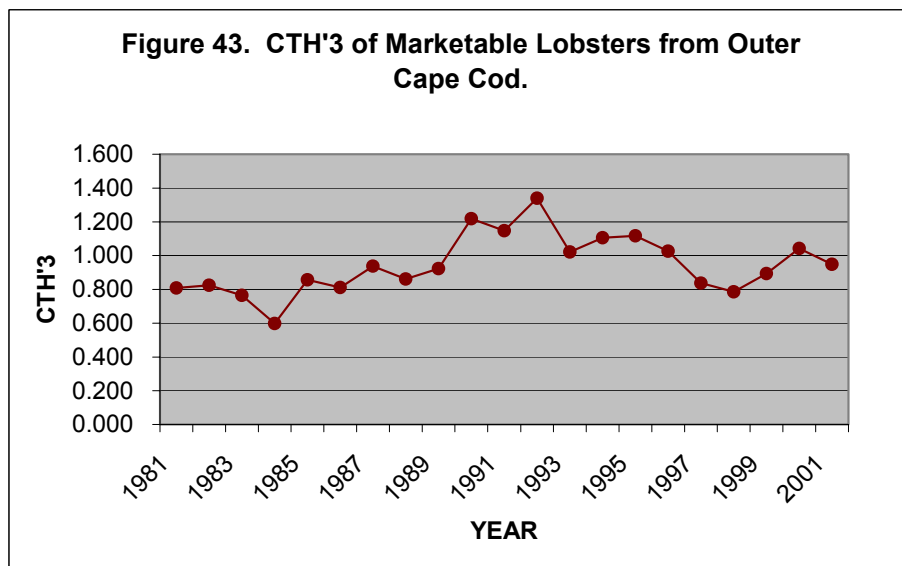
Figure 45. Percent of Females Ovigerous from Outer Cape Cod.
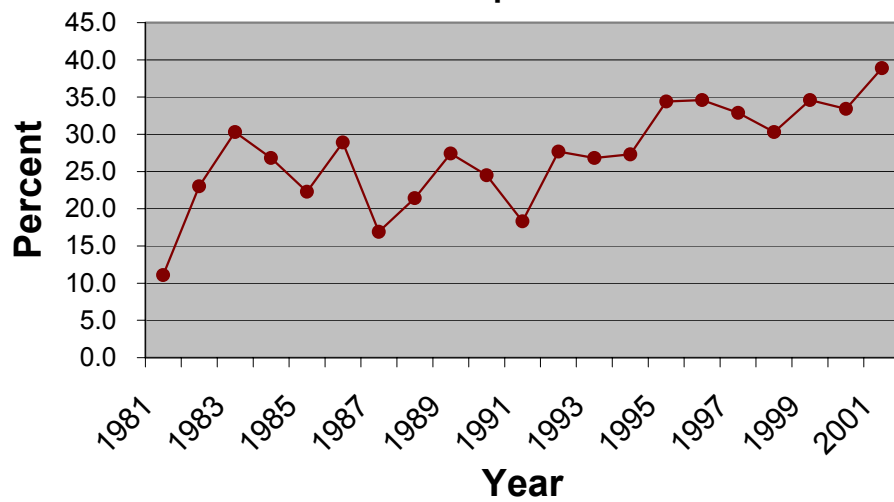
Figure 46 CTHSOD of Eggers from Outer Cape Cod.
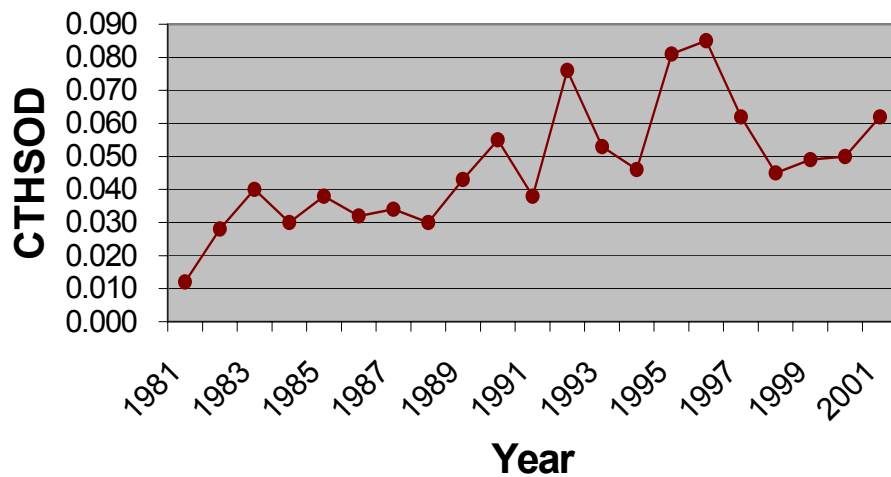
Figure 47. Fishing Mortality (Cohort-Von Bertalanffy) for Outer Cape Cod.
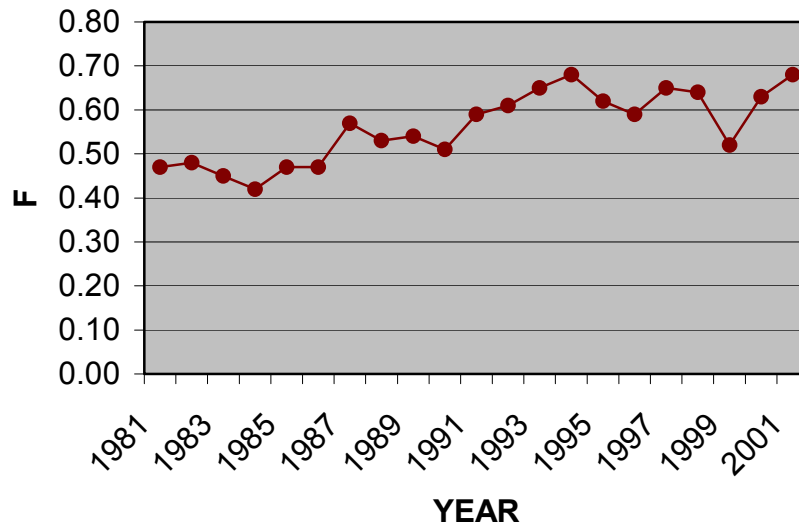
Figure 48. Fishing Mortality (Delta T's) for Outer Cape Cod.
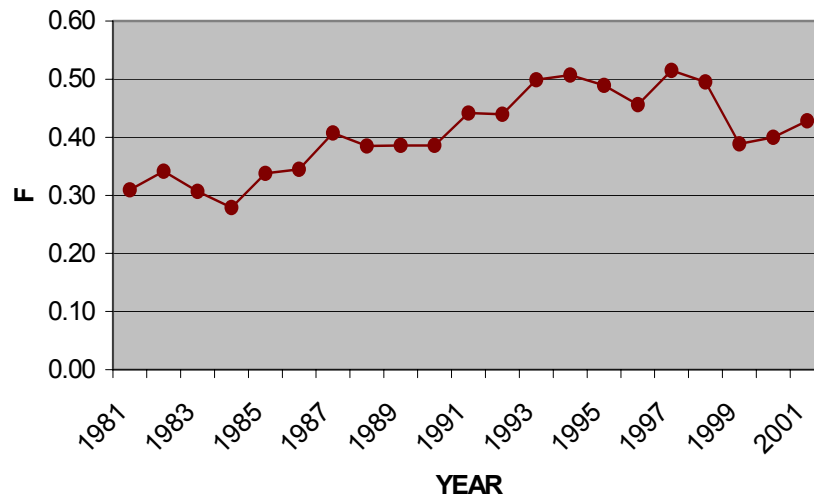
ACKNOWLEDGEMENTS

LITERATURE CITED

Beverton, R. J. H. and S. J. Holt. 1956. A review of methods for estimating mortality rates in exploited populations, with special reference to sources of bias in catch sampling. Reports et Proces-Verbaux des Reunions 140:67-83.

Cadrin, S. and B. Estrella. 1996. Length-Cohort Analyses of U.S. American Lobster Stocks. A report of the 22nd Northeast Regional Stock Assessment Workshop. Northeast Fisheries Science Center Reference Document 96-15. 20p.+ App.

Caputi, N., and R. S. Brown. 1986. Relationship between indices of juvenile abundance and recruitment in the western rock lobster (*Panulirus cygnus*) fishery. Can. J. Fish. Aquat. Sci. 43:2131-2139.

Colton, J. B. 1964. History of oceanography in the offshore waters of the Gulf of Maine. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries No. 496. 18p.

Drinkwater, K. F., G. C. Harding, K.H. Mann, and N. Tanner. 1996. Temperature as a possible factor in the increased abundance of American lobster, *Homarus americanus*, during the 1980's and early 1990's. Fish. Oceanogr. 5:176-193.

Estrella, B. T. and D. J. McKiernan. 1989. Catch-per-unit-effort and biological parameters from the Massachusetts coastal lobster (*Homarus americanus*) resource: description and trends. NOAA Tech. Rep. NMFS 81. 21 p.

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

Estrella, B. T. and S. X. Cadrin. 1991. Massachusetts Coastal Commercial Lobster Trap Sampling Program, May-November 1990. Massachusetts Division of Marine Fisheries. 52 p.

Fair, J. J., Jr. 1977. Lobster investigations in management area I: Southern Gulf of Maine. NOAA, NMFS State-Federal Relationships Division, Mass. Lobster Report No. 8., April 21, 1975 - April 20, 1977, 8 p. and Appendix, 14 p.

Gulland, J. A. 1969. Manual of methods for fish stock assessment. Pt. 1, fish population analysis. FAO Manuals in Fisheries Science 4, 154 p.

Jones, R. 1974. Assessing the long term effects of changes in fishing effort and mesh size from length composition data. ICES CM 1974/F:33.

Nie, N. H. 1983. SPSS: statistical package for the social sciences, McGraw-Hill, New York, 806 p.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using Cohort analysis. Research Bulletin Int. Comm. NW Atlant. Fish. 9:65-74.

Sokal, R.R. and F.J. Rohlf. 1969. Biometry. W.H. Freeman and Company, San Francisco. 776 p.

APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	0.767	0.785	0.803	0.696	0.825	0.816	0.737	0.820	0.751	0.826	0.795	0.716	0.671	0.966	0.893	0.792	0.776	0.662	0.902	0.885	0.761
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721	0.904	0.868	0.724	0.770	1.015	0.979	1.272	1.106	0.645	0.699	0.930	0.704
Beverly-Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639	0.827	0.586	0.390	0.509	0.898	0.840	0.788	0.419	0.767	1.005	0.945	0.738
Boston Harbor	---	---	---	1.108	1.254	1.096	1.058	1.057	1.123	1.224	1.160	0.734	0.750	0.725	0.626	0.534	0.638	0.462	0.787	0.629	0.432
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539	0.630	0.693	0.567	0.494	1.052	0.906	0.662	0.760	0.633	1.021	0.888	0.686
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923	1.219	1.148	1.339	1.021	1.105	1.117	1.027	0.837	0.785	0.893	1.042	0.948
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934	0.598	0.575	0.817	0.834	0.852	0.893	0.866	1.169	0.719	0.740	0.882	1.117

Table 2. CTHSOD, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	0.580	0.672	0.718	0.521	0.647	0.700	0.578	0.509	0.695	0.716	0.665	0.465	0.542	0.402	0.410	0.343	0.363	0.295	0.215	0.255	0.229
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670	0.589	0.728	0.726	0.447	0.658	0.800	0.573	0.831	0.356	0.171	0.222	0.280
Beverly-Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780	0.408	0.324	0.411	0.406	0.314	0.334	0.277	0.231	0.364	0.233	0.254	0.235
Boston Harbor	---	---	---	0.901	1.162	1.138	1.156	0.639	0.966	1.103	0.924	0.839	0.800	0.690	0.782	0.688	0.651	0.754	0.508	0.620	0.294
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595	0.727	0.716	0.298	0.436	0.313	0.307	0.217	0.256	0.204	0.162	0.256	0.285
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066	0.078	0.077	0.088	0.075	0.045	0.060	0.051	0.053	0.043	0.025	0.026	0.026
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188	1.236	1.072	0.784	1.156	0.649	0.492	0.540	0.510	0.254	0.272	0.158	0.174

Table 3. CTHAUL, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	1.473	1.401	1.624	1.389	1.705	1.899	1.873	1.736	2.297	2.216	1.996	1.460	1.720	1.389	1.457	1.332	1.417	1.259	0.967	1.071	0.991
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765	1.782	1.783	1.661	1.562	1.725	2.323	1.660	1.940	1.074	0.606	0.776	1.077
Beverly-Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477	1.867	1.563	1.502	1.540	1.717	1.920	1.654	1.988	2.038	1.577	1.759	1.399
Boston Harbor	---	---	---	2.773	3.038	3.314	3.334	1.959	3.104	3.382	2.451	2.069	2.284	2.189	2.390	2.511	2.258	2.864	1.660	2.286	1.509
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742	1.921	2.086	1.065	1.334	1.033	1.102	0.873	0.926	0.701	0.680	0.857	0.976
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306	0.453	0.452	0.490	0.474	0.288	0.359	0.372	0.354	0.301	0.172	0.163	0.176
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984	3.994	3.181	2.602	3.501	2.179	1.599	1.835	2.051	1.546	1.456	0.927	0.888

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	5.9	7.7	10.9	9.1	8.6	9.1	9.2	8.8	10.0	10.9	9.8	11.9	14.3	10.7	14.1	15.4	14.7	16.4	17.4	15.4	18.1
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3	6.9	4.3	6.7	9.3	4.7	5.3	6.4	8.3	9.3	10.4	8.0	11.6
Beverly-Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6	1.8	3.2	3.9	5.4	2.3	6.3	6.9	8.3	6.1	5.9	4.0	6.6
Boston Harbor	---	---	---	1.4	1.2	2.0	1.7	2.0	2.1	2.7	2.8	3.0	4.4	4.7	5.0	6.7	6.7	8.0	7.4	10.4	15.9
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0	3.3	5.4	6.8	6.8	7.4	10.2	13.6	11.9	13.1	15.5	11.9	15.1
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4	24.5	18.3	27.7	26.8	27.3	34.4	34.6	32.9	30.3	34.6	33.4	38.9
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2	35.0	28.2	28.8	40.9	22.1	26.0	23.6	22.2	32.9	29.5	27.0	23.2

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	0.024	0.027	0.050	0.038	0.044	0.057	0.049	0.054	0.057	0.073	0.032	0.054	0.092	0.036	0.045	0.047	0.042	0.039	0.039	0.039	0.042
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037	0.035	0.024	0.050	0.038	0.024	0.030	0.031	0.056	0.037	0.026	0.016	0.032
Beverly-Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009	0.005	0.008	0.014	0.020	0.008	0.017	0.015	0.013	0.016	0.012	0.080	0.014
Boston Harbor	---	---	---	0.009	0.007	0.015	0.012	0.012	0.010	0.028	0.017	0.017	0.026	0.024	0.028	0.032	0.035	0.046	0.032	0.049	0.039
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014	0.017	0.028	0.016	0.023	0.022	0.034	0.035	0.027	0.032	0.043	0.038	0.040
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043	0.055	0.038	0.076	0.053	0.046	0.081	0.085	0.062	0.045	0.049	0.050	0.062
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270	0.349	0.073	0.197	0.446	0.110	0.088	0.098	0.083	0.067	0.060	0.060	0.065

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	0.073	0.078	0.179	0.116	0.133	0.167	0.183	0.189	0.211	0.282	0.140	0.227	0.319	0.143	0.200	0.226	0.219	0.205	0.230	0.190	0.230
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096	0.109	0.056	0.088	0.135	0.064	0.085	0.081	0.124	0.097	0.096	0.066	0.140
Beverly-Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039	0.023	0.049	0.047	0.067	0.048	0.106	0.103	0.136	0.101	0.094	0.055	0.100
Boston Harbor	---	---	---	0.030	0.025	0.050	0.037	0.038	0.043	0.075	0.064	0.046	0.081	0.088	0.100	0.124	0.132	0.181	0.110	0.190	0.220
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039	0.055	0.091	0.056	0.078	0.075	0.128	0.147	0.130	0.110	0.210	0.140	0.150
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258	0.342	0.251	0.453	0.317	0.306	0.514	0.561	0.408	0.307	0.330	0.340	0.420
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953	1.291	0.359	0.847	1.438	0.383	0.343	0.414	0.477	0.527	0.450	0.390	0.420

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal water, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	86	87	86	86	88	88	89	90	88	87	89	89	90	88	86	86	86	88	88	86	86
Cape Ann	91	92	87	89	87	87	88	90	84	81	90	87	83	86	88	85	88	85	80	83	79
Beverly-Salem	89	92	94	88	96	96	97	98	96	95	97	98	96	96	95	95	96	94	97	95	95
Boston Harbor	---	---	---	93	94	96	96	96	96	95	96	95	96	95	94	95	94	96	97	98	96
Cape Cod Bay	90	93	92	94	93	94	92	94	94	93	91	92	94	90	86	88	87	90	87	88	90
Outer Cape Cod	46	43	42	38	48	46	54	57	47	50	54	57	60	60	55	54	57	58	46	51	49
Buzzards Bay	98	96	96	94	96	97	97	97	95	94	95	97	97	98	96	95	92	96	96	95	95

Table 8A. Total instantaneous (Z)* and total annual (A) mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981-2001.**

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	1.58	* 1.72	1.66	1.66	1.76	1.80	1.90	1.86	1.80	1.76	1.90	1.92	1.86	2.02	1.83	1.79	1.87	1.81	1.81	1.92	1.96
	79%	** 82%	81%	81%	83%	84%	85%	84%	83%	83%	85%	85%	84%	87%	84%	83%	85%	84%	84%	85%	86%
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55	1.39	1.97	1.87	1.51	1.81	1.95	1.90	2.00	1.65	1.48	1.95	2.02
	81%	89%	82%	85%	86%	87%	84%	83%	79%	75%	86%	85%	78%	84%	86%	85%	86%	81%	77%	85%	87%
Beverly-Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59	2.81	3.49	3.12	2.62	3.34	3.10	2.90	2.46	2.81	3.14	2.64	2.71
	86%	88%	91%	93%	97%	97%	97%	96%	97%	94%	97%	96%	93%	96%	95%	94%	91%	94%	96%	93%	93%
Boston Harbor	---	---	---	2.52	3.59	2.60	2.77	2.86	2.96	3.00	3.40	3.54	3.26	3.21	2.87	2.65	2.77	2.59	2.86	3.14	3.21
	---	---	---	92%	97%	93%	94%	94%	95%	95%	97%	97%	96%	96%	94%	93%	94%	92%	94%	96%	96%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43	2.46	2.33	2.58	2.60	3.10	2.35	2.09	2.14	2.02	2.14	2.73	2.29
	92%	93%	91%	92%	90%	94%	90%	94%	91%	91%	90%	92%	93%	95%	90%	88%	88%	87%	88%	93%	90%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62	0.63	0.77	0.78	0.87	0.92	0.74	0.73	0.89	0.86	0.58	0.82	0.92
	35%	37%	34%	28%	41%	40%	55%	51%	46%	47%	54%	54%	58%	60%	52%	52%	59%	58%	44%	56%	60%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13	2.60	3.50	3.81	3.03	3.58	3.34	2.84	2.74	3.27	3.81	2.70	2.82
	95%	95%	99%	96%	97%	98%	97%	96%	96%	93%	97%	98%	95%	97%	96%	94%	94%	96%	98%	93%	94%

Table 8B. Total instantaneous (Z)* and total annual (A)** mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	1.35	*1.45	1.39	1.41	1.47	1.49	1.54	1.56	1.53	1.50	1.73	1.70	1.79	1.67	1.57	1.54	1.55	1.62	1.62	1.53	1.49
	74%	**77%	75%	76%	77%	78%	79%	79%	78%	78%	82%	82%	83%	81%	79%	79%	79%	80%	80%	78%	77%
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27	1.66	1.77	1.57	1.38	1.48	1.62	1.49	1.67	1.52	1.14	1.33	1.37
	73%	75%	74%	78%	74%	73%	75%	78%	72%	81%	83%	79%	75%	77%	80%	77%	81%	78%	68%	74%	75%
Beverly-Salem	1.59	1.70	1.85	1.78	1.96	1.99	2.16	1.98	2.01	1.83	2.29	2.50	2.23	2.18	2.09	2.11	2.28	2.18	2.08	2.18	1.92
	80%	82%	84%	83%	86%	86%	88%	86%	87%	84%	90%	92%	89%	89%	88%	88%	90%	89%	88%	89%	85%
Boston Harbor	---	---	---	1.82	1.75	1.92	1.88	1.84	1.94	1.87	2.19	2.14	2.33	2.28	2.09	2.18	2.09	2.63	2.12	2.73	2.31
	---	---	---	84%	83%	85%	85%	84%	86%	85%	89%	88%	90%	90%	88%	89%	88%	93%	88%	94%	90%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97	1.95	1.96	2.01	2.14	1.93	1.65	1.66	1.57	1.65	1.41	1.63	1.61
	81%	85%	82%	87%	85%	85%	83%	85%	86%	86%	86%	87%	88%	86%	81%	81%	79%	81%	76%	80%	80%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62	0.63	0.71	0.72	0.78	0.79	0.72	0.68	0.76	0.76	0.59	0.66	0.76
	42%	42%	41%	41%	43%	42%	48%	48%	46%	47%	51%	51%	54%	55%	51%	49%	53%	53%	45%	48%	53%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14	2.27	3.08	2.70	3.11	2.85	2.44	2.37	2.14	2.57	2.42	2.38	1.92
	95%	92%	90%	89%	91%	91%	91%	94%	88%	90%	95%	93%	96%	94%	91%	91%	88%	92%	91%	91%	85%

Table 9A. Instantaneous fishing mortality estimates (F),COHORT analysis (von Bertalanffy), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	1.14	1.21	1.17	1.19	1.25	1.28	1.32	1.36	1.36	1.32	1.43	1.44	1.48	1.41	1.32	1.29	1.33	1.36	1.22	1.38	1.38
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12	1.04	1.50	1.32	1.14	1.25	1.36	1.28	1.41	1.26	1.07	1.36	1.25
Beverly-Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95	1.86	2.08	2.16	1.96	1.94	1.88	1.91	2.01	1.87	2.03	1.88	1.90
Boston Harbor	---	---	---	1.77	1.70	1.80	1.87	1.83	1.94	1.86	2.01	1.97	1.97	1.90	1.85	1.89	1.79	2.13	1.98	2.21	2.11
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82	1.72	1.66	1.71	1.85	1.66	1.47	1.44	1.47	1.52	1.40	1.59	1.54
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54	0.51	0.59	0.61	0.65	0.68	0.62	0.59	0.65	0.64	0.52	0.63	0.68
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95	1.97	2.34	2.26	2.39	2.31	2.05	1.98	1.75	2.06	2.14	1.98	1.89

Table 9B. Instantaneous fishing mortality estimates (F), COHORT analysis with Delta T's, by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	0.82	0.88	0.86	0.87	0.91	0.95	0.96	0.97	0.96	0.93	0.99	0.99	1.04	0.98	0.93	0.92	0.94	0.97	0.89	0.91	0.90
Cape Ann	0.82	0.85	0.90	0.92	0.93	0.92	0.92	0.96	0.88	0.76	1.03	0.97	0.86	0.88	0.97	0.89	0.99	0.92	0.75	0.86	0.77
Beverly-Salem	0.86	1.02	1.05	0.88	1.21	1.23	1.19	1.26	1.25	1.16	1.26	1.32	1.21	1.19	1.19	1.22	1.16	1.18	1.25	1.16	1.13
Boston Harbor	---	---	---	1.15	1.14	1.10	1.15	1.17	1.22	1.20	1.24	1.21	1.23	1.22	1.17	1.22	1.18	1.34	1.24	1.54	1.41
Cape Cod Bay	1.04	1.14	1.04	1.19	1.12	1.19	1.09	1.13	1.19	1.17	1.09	1.11	1.19	1.00	0.95	0.91	0.98	1.00	0.99	1.01	0.97
Outer Cape Cod	0.31	0.34	0.31	0.28	0.34	0.34	0.41	0.38	0.39	0.39	0.44	0.44	0.50	0.51	0.49	0.46	0.52	0.50	0.39	0.40	0.43
Buzzards Bay	1.10	1.02	1.00	0.94	1.05	1.07	1.04	1.06	1.00	1.00	1.15	1.07	1.14	1.11	0.98	0.99	0.87	1.03	1.07	0.97	0.92

Table 10. Estimated exploitation rate (u), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	0.62	0.64	0.63	0.64	0.65	0.66	0.68	0.69	0.69	0.69	0.68	0.69	0.69	0.68	0.66	0.66	0.68	0.67	0.67	0.68	0.71
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63	0.51	0.70	0.67	0.62	0.65	0.67	0.66	0.68	0.65	0.64	0.74	0.68
Beverly-Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76	0.85	0.82	0.79	0.78	0.79	0.79	0.80	0.79	0.76	0.86	0.74	0.84
Boston Harbor	---	---	---	0.82	0.81	0.80	0.84	0.84	0.86	0.85	0.82	0.81	0.76	0.75	0.78	0.77	0.75	0.75	0.82	0.74	0.82
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79	0.76	0.73	0.74	0.76	0.74	0.72	0.70	0.74	0.75	0.75	0.76	0.77
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40	0.38	0.42	0.44	0.45	0.47	0.44	0.43	0.45	0.45	0.40	0.45	0.47
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80	0.78	0.72	0.78	0.74	0.76	0.76	0.76	0.72	0.74	0.80	0.73	0.84

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	88.5	87.9	88.1	88.2	87.8	87.6	87.5	88.2	88.9	89.0	88.7	88.8	88.4	88.8	89.2	89.2	89.2	88.9	89.6	89.4	89.5
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3	90.3	88.4	88.8	89.6	89.6	88.7	89.5	88.7	89.0	90.8	90.1	90.1
Beverly-Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7	88.3	87.5	87.2	87.5	87.8	88.0	87.9	87.5	87.7	87.6	87.8	88.0
Boston Harbor	---	---	---	86.8	86.9	86.4	86.6	87.5	88.0	88.1	87.8	87.9	87.5	87.5	88.0	87.7	87.8	87.0	87.5	86.8	87.1
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7	87.7	88.1	88.2	87.7	88.3	89.2	89.0	89.4	89.0	89.4	89.1	89.0
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5	96.1	95.3	95.2	93.8	94.2	94.2	94.9	93.9	94.1	96.6	96.1	95.7
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4	87.0	86.4	86.9	86.5	86.5	87.4	87.3	87.8	87.0	87.0	87.4	88.0

Table 12. Mean carapace length (mm), by state and region for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	75.8	76.3	76.2	76.1	76.3	76.1	76.1	76.3	77.5	77.6	76.7	76.2	76.9	77.5	77.8	78.2	77.8	77.2	77.4	77.1	76.8
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3	78.8	78.7	77.9	78.3	78.0	77.2	77.3	77.3	77.8	76.8	75.1	76.6
Beverly-Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4	76.1	73.4	73.5	75.1	75.8	76.2	76.8	76.0	74.9	75.4	75.6	74.8
Boston Harbor	---	---	---	77.1	76.9	76.9	76.5	75.6	76.8	77.4	75.4	74.6	75.3	76.0	77.3	76.9	76.3	72.7	74.9	74.4	73.7
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9	77.8	77.4	76.8	76.7	78.6	78.6	79.8	79.1	79.3	78.9	78.6	78.6
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8	78.8	78.8	79.0	79.4	78.3	80.0	79.9	80.0	79.6	79.6	79.7	79.6
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7	77.4	76.6	77.1	78.3	77.6	77.7	77.5	78.2	78.9	78.7	79.6	78.2

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	88.5	87.6	88.6	87.4	87.9	88.1	87.1	87.2	88.5	88.0	86.0	85.5	85.3	86.3	86.6	86.7	86.7	86.4	88.1	88.1	88.3
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4	95.1	91.7	91.9	91.0	92.7	93.3	91.5	90.7	91.3	94.7	95.7	96.3
Beverly-Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2	85.5	83.8	81.6	82.6	83.1	83.3	83.0	82.5	83.0	83.0	83.1	85.2
Boston Harbor	---	---	---	82.1	84.0	81.3	82.3	83.7	83.0	83.8	82.0	82.0	80.8	80.9	81.5	82.4	82.2	79.8	81.2	81.3	81.6
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1	85.0	83.9	84.1	83.0	84.8	85.2	85.7	85.8	86.1	87.3	86.5	86.4
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4	104.6	101.9	99.2	100.7	100.0	100.6	99.6	98.9	98.3	104.7	103.7	102.7
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3	80.8	79.8	79.9	81.0	81.5	81.8	82.6	84.0	82.7	82.8	84.5	85.0

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal water, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	10.0	10.8	10.7	14.8	18.1	20.9	17.0	18.2	19.2	18.6	18.1	18.5	20.3	21.9	22.0	17.1	20.4	20.9	20.8	18.2	19.7
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7	16.7	19.7	18.2	19.2	17.1	19.6	18.0	18.9	17.6	16.7	18.8	19.0
Beverly-Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6	27.3	28.9	22.7	28.3	30.8	25.1	24.6	23.4	25.1	23.6	21.8	23.7
Boston Harbor	---	---	---	13.3	19.3	19.1	16.9	16.3	13.8	14.7	13.5	17.2	23.4	23.0	22.2	17.8	19.8	17.4	17.7	15.3	21.8
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8	20.5	18.9	18.3	18.1	19.4	21.5	16.2	23.6	25.6	24.6	20.0	21.8
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0	15.5	13.2	15.7	17.3	20.1	19.0	13.3	14.5	14.2	14.9	16.4	13.2
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6	13.6	13.9	19.3	20.5	24.0	24.4	15.0	15.6	16.2	18.5	14.5	15.2

Table 15. Cull rate (percent), by state and region, for all legal-sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	8.1	9.7	9.2	12.7	14.8	17.0	14.7	15.7	14.9	15.4	15.6	17.1	17.4	21.2	20.9	15.1	19.3	19.5	19.1	17.8	16.6
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9	13.7	16.8	18.3	16.3	16.5	16.2	14.7	15.7	16.3	13.7	15.8	15.6
Beverly-Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7	25.6	22.8	19.9	24.6	25.4	18.8	20.2	17.2	20.0	18.2	17.8	19.4
Boston Harbor	---	---	---	10.1	16.2	15.8	12.9	13.1	9.9	9.9	12.3	14.0	17.5	18.0	20.1	17.3	17.3	14.2	14.0	15.6	18.7
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0	16.3	17.8	16.8	16.3	21.7	23.3	16.0	25.3	26.2	24.3	20.9	19.4
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3	14.1	12.8	15.3	16.4	19.9	18.3	12.6	13.6	13.5	14.5	16.4	12.6
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6	12.6	11.5	22.2	18.9	23.5	22.6	12.9	15.3	14.4	17.8	14.6	14.1

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	8.2	9.9	9.2	13.2	16.2	17.6	14.7	16.0	15.2	15.6	16.1	17.6	17.6	21.9	21.5	15.6	19.2	19.7	19.6	18.4	17.5
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0	14.2	16.8	18.1	13.7	16.7	16.0	14.5	15.3	16.3	14.1	18.9	16.8
Beverly-Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9	23.8	23.1	20.0	24.7	25.5	19.0	20.0	17.0	20.1	18.0	21.7	19.5
Boston Harbor	---	---	---	10.2	16.2	15.7	12.8	13.1	9.9	9.9	12.4	14.0	17.5	18.0	20.1	17.4	17.4	14.5	14.2	15.6	19.9
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1	16.2	17.8	16.7	16.2	22.3	23.3	16.6	25.5	26.1	24.7	21.1	20.2
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9	14.6	14.1	16.8	17.3	21.6	20.4	14.0	13.7	14.0	15.6	17.2	14.3
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0	12.4	11.7	22.5	19.4	23.7	23.0	13.1	14.5	15.1	17.7	14.6	14.7

Table 17. Cull rate (percent), by state and region, for sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	11.2	11.5	11.6	16.1	20.2	23.2	18.2	19.6	21.1	20.2	19.2	19.3	21.8	22.5	22.9	18.5	21.3	21.9	22.7	18.6	23.0
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9	18.3	21.0	18.2	20.9	17.4	21.2	20.6	20.8	18.4	20.5	23.0	22.0
Beverly-Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8	29.2	31.6	23.5	29.5	33.8	28.2	26.7	25.5	27.2	27.5	24.2	26.4
Boston Harbor	---	---	---	14.5	20.5	20.0	18.0	18.0	15.2	16.4	13.9	18.3	25.3	24.7	22.8	17.9	20.6	18.0	19.6	15.1	22.9
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0	21.8	19.2	19.0	18.8	17.8	20.1	16.3	22.2	25.2	25.1	19.0	23.9
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1	20.7	14.3	17.1	20.2	21.3	21.8	15.7	17.9	16.6	18.3	16.1	18.0
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6	13.9	14.5	18.3	21.0	24.2	25.6	16.4	15.8	17.4	19.1	14.5	17.1

Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-2001.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
State	0.15	0.04	0.22	0.15	0.18	0.20	0.10	0.15	0.12	0.17	0.37	0.08	0.13	0.22	0.21	0.18	0.10	0.15	0.18	0.18	0.13
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13	0.09	0.48	0.10	0.11	0.14	0.28	0.17	0.04	0.13	0.40	0.16	0.49
Beverly-Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14	0.29	0.41	0.13	0.19	0.13	0.74	0.49	0.37	0.31	0.39	0.41	0.28
Boston Harbor	---	---	---	0.00	0.03	0.03	0.23	0.09	0.03	0.04	0.01	0.03	0.06	0.04	0.01	0.04	0.08	0.08	0.19	0.11	0.12
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02	0.05	0.02	0.02	0.02	0.00	0.03	0.03	0.03	0.08	0.04	0.07	0.05
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47	0.62	0.35	0.24	0.30	0.58	0.38	0.43	0.21	0.25	0.25	0.15	0.06
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11	0.18	1.74	0.10	0.29	0.71	0.16	0.21	0.00	0.19	0.20	0.34	0.08