# A: OCEAN QUAHOG

## TERMS OF REFERENCE

The following Terms of Reference were addressed:

1) Characterize fishery performance since the last assessment.

2) Analyze results of most recent NEFSC survey and review results of other surveys and studies, as appropriate.

3) Estimate fishing mortality rates and stock biomass in absolute or relative units. Characterize uncertainty in estimates.

4) Evaluate stock status relative to current reference points.

5) Estimate TAC or TAL based on projected stock status and target fishing mortality rates for 2004-2007.

## EXECUTIVE SUMMARY

Fishery performance

▸ Ocean quahogs in federal waters (the EEZ) are treated as a single stock. Due to its unique characteristics, the resource off the coast of Maine has its own quota. This report describes the fishery in seven regions:

| Abbreviation | Region |
|---|---|
| SVA | Southern Virginia and North Carolina |
| DMV | Delmarva |
| NJ | New Jersey |
| LI | Long Island |
| SNE | Southern New England |
| GBK | Georges Bank |
| ME | Maine |

▸ Annual EEZ landings from SNE to SVA generally track annual EEZ quotas.  Annual EEZ landings have been > 17,000 MT meats since 1985, with the exception of the year 2000 when 14,900 MT were landed.

▸ In the 1980s, the EEZ fishery took place in the DMV and NJ regions.  The fishery moved northward to the LI region in 1992, and to SNE in 1995. The fishery moved back to the LI region in 2002.  GBK is closed to ocean quahog harvesting. In 2002, the percentage of EEZ landings by region were: S. Virginia (0%), Delmarva (10%), New Jersey (16%), Long Island (52%), S. New England (22%).

▸ In the MidAtlantic region, over 80% of the landings from 1980-2003 were made by large vessels.  Over 95% of the landings from the coast of Maine were made by undertonnage and small vessels.

▸ Due to the slow growth rate of adult ocean quahogs, areas do not recover quickly after dense clam beds have been harvested.

▸ Three analyses were done to examine regional trends in LPUE over time (nominal values and 2 general linear models).  Results from the 3 approaches were similar, suggesting that the results are robust and are not due to changes in vessels over time.

- Nominal LPUE declined in DMV from over 700 kg/hr in 1983-1986 to approximately 400 kg/hr from 1991 to 2003. The pattern in NJ was similar to DMV. In LI, catch rates were relatively high in 1991-1992 (800+ kg/hr), somewhat lower until 2002, and they have increased to about 800 kg/hr in 2002-2003. This is related to the harvesting of smaller individuals, further offshore, in that region. In SNE, nominal catch rate fell from a high of about 700 kg/hr in 1992-1993 to about 500 kg/hr in 2002-2003.

- The majority of the TNMSs that are currently being fished in each region have lower LPUEs than the catch rates of 10-20 years ago.

- The Maine region was given its own annual quota of 100,000 bushels, which is approximately 2% of the total quota for the entire EEZ. Annual reported landings from Maine have matched or exceeded the quota, and fishing effort has increased steadily from 1993 to 2002. The nominal catch rate for the Maine region increased between 1990-1993 and 1999-2001. The catch rate dropped in 2002-2003.

- Average length of clams landed from NJ (approximately 90 mm - 95 mm) was greater than that from other regions (typically 80 mm - 90 mm). In the LI region, mean length harvested declined recently by almost a centimeter, from 89 mm in 1997-1998 to about 81 mm in 2002-2003.


Ocean quahog surveys and dredge efficiency

- Since 1997, NMFS clam surveys have achieved better monitoring of dredge performance by using the *RV Delaware II*'s (DE-II) Shipboard Computing System (SCS) and Dredge Survey Sensor Package (SSP) to perform continuous monitoring of variables that are critical to operations.

- For each random DE-II survey tow taken between 1997-2002, distance sampled by the dredge was calculated as the sum of distance traveled per second, during those times when the dredge was potentially fishing.

- Calibration or "depletion" field experiments were used to estimate efficiency of the NMFS survey dredge. These experiments were analyzed with a model that explicitly considers spatial overlap of tows as a depletion experiment progresses.

- Four ocean quahog depletion experiments were carried out in 2002 to estimate efficiency of the clam dredge on the DE-II. The *FV Lisa Kim* collaborated in those experiments.

- From the depletion experiments in 2002, the lowest estimate of DE-II dredge efficiency was at the site located in deepest water, with finer sediments, and a higher ocean quahog density than other sites.

- In addition to the depletion experiments, data from fixed stations that are resampled during each survey by the DE-II were used to infer whether dredge efficiency changed

from survey to survey. This analysis suggested that dredge efficiency was lower in 1999 than in 1997. It also suggested that dredge efficiency had not changed from 1999 to 2002.

▸ For this assessment, the point estimates and CV's of DE-II dredge efficiency, for ocean quahogs, were 0.346 (CV = 40%), 0.269 (CV=55%), and 0.269 (CV=55%) for 1997, 1999, and 2002, respectively. The 1999 value for efficiency was revised from the previous assessment (SARC-31; NEFSC 2000), when it was assumed to be 0.346.

▸ Based on NMFS clam surveys during 1982 – 2002, there were no major changes in the distribution of ocean quahogs over time.

▸ Individuals recruit to the ocean quahog fishery at about 70 mm length, growing <1 mm per year. In the 2002 NMFS survey, clams >=70mm were more abundant from Georges Bank to Long Island than in regions further south. The largest concentrations of "small" clams (i.e., <70 mm) were on Georges Bank.

▸ Abundance per tow of both 60-69 mm and 70 mm+ ocean quahogs is consistently greater in GBK, LI and SNE than in NJ, DMV and SVA. Regions differ in the ratio of small to large ocean quahogs, but the smaller size class usually makes up only 1-4% of the catch per tow.

▸ Based on the DE-II survey, recruitment is not apparent in the New Jersey region from 1978-2002. The length composition over time of clams off Long Island and on Georges Bank has been more dynamic and suggests that recruitment events occurred there.

▸ An ocean quahog recruit survey was carried out with a commercial vessel (*FV Christie*) in 2002 to catch small ocean quahogs that are not sampled very effectively by the RV DE-II. The recruit survey was carried out cooperatively between Rutgers University (Dr. E. Powell, Chief Sci.) and the clam industry.

▸ Data from the recruit survey were combined with RV DE-II 2002 survey data to adjust the regional ocean quahog length frequency distributions. The adjusted distribution for GBK indicated many more small ocean quahogs than indicated by DE-II data alone. The analysis suggested a moderate number of additional small ocean quahogs in the LI and DMV regions. There was little difference between the original and adjusted distributions in SNE and NJ.

▸ In 2002, the State of Maine carried out a survey of the ocean quahog resource along that coast. Their report concluded that: "The preliminary estimate of relative abundance for the currently fished bed was 1,288,564 "Maine" bushels (1 Maine bushel = 35.25 L). This number is not corrected for dredge efficiency, which is believed to be low for the dry dredge used in these surveys".

▸ There is insufficient information on the efficiency of the dredge used in the State of Maine survey to estimate the total stock size or fishing mortality rate in the Maine region.

Stock biomass and fishing mortality

▸ Efficiency corrected swept area biomass (000s of mt of meats for ocean quahogs >=70mm) estimates (ESB) for NMFS surveys in 1997, 1999, and 2002 were:

| Region | 1997 | 1999 | 2002 |
|---|---|---|---|
| SVA | 0 | 0 | 0 |
| DMV | 65 | 58 | 71 |
| NJ | 277 | 194 | 330 |
| LI | 505 | 422 | 454 |
| SNE | 249 | 416 | 428 |
| GBK | 447 | 686 | 833 |
| All Regions | 1544 | 1776 | 2116 |
| All Regions less GBK | 1097 | 1090 | 1283 |

▸ 80% Confidence Intervals for efficiency corrected, total swept area biomass (000s of mt of meats for ocean quahogs >=70mm) from 1997, 1999, and 2002, had high overlap, suggesting that the three ESB estimates were not significantly different. There appears to have been an increase over time in ESB on GBK.

▸ Annual fishing mortality rate estimates, based on catch and the efficiency corrected swept area biomass estimates, were:

| Region | 1997 | 1999 | 2002 |
|---|---|---|---|
| SVA | 0.000 | 0.000 | 0.000 |
| DMV | 0.017 | 0.020 | 0.026 |
| NJ | 0.016 | 0.016 | 0.009 |
| LI | 0.011 | 0.016 | 0.021 |
| SNE | 0.038 | 0.017 | 0.010 |
| GBK | 0.000 | 0.000 | 0.000 |
| All Regions | 0.013 | 0.010 | 0.009 |
| All Regions less GBK | 0.019 | 0.016 | 0.014 |

The KLAMZ assessment model was also used to estimate B and F. KLAMZ is based on the Deriso-Schnute delay-difference equation.

Stock biomass (mt) and annual fishing mortality rate estimates, based on KLAMZ and other models, were:

| Year | SVA | DMV | NJ | LI | SNE | GBK | Total less GBK | Total |
|---|---|---|---|---|---|---|---|---|
| | | | | **Model (scenario #)** | | | | |
| | VPA | KLAMZ 5 | KLAMZ 3 | VPA | KLAMZ 3 | Aver. ESB | NA | NA |
| | | | | **Total Biomass (mt)** | | | | |
| 1977 | 297 | 297,990 | 455,110 | 534,059 | 386,310 | 655,426 | 1,673,766 | 2,329,192 |
| 1978 | 297 | 289,320 | 448,410 | 534,059 | 387,040 | 655,426 | 1,659,126 | 2,314,552 |
| 1979 | 297 | 280,620 | 441,790 | 534,059 | 387,760 | 655,426 | 1,644,526 | 2,299,952 |
| 1980 | 297 | 268,080 | 435,560 | 534,059 | 388,460 | 655,426 | 1,626,456 | 2,281,882 |
| 1981 | 297 | 257,070 | 427,690 | 534,054 | 389,150 | 655,426 | 1,608,260 | 2,263,687 |
| 1982 | 241 | 246,940 | 419,260 | 534,050 | 389,830 | 655,426 | 1,590,321 | 2,245,748 |
| 1983 | 235 | 236,150 | 410,800 | 534,050 | 390,500 | 655,426 | 1,571,736 | 2,227,162 |
| 1984 | 235 | 224,860 | 402,730 | 534,029 | 390,530 | 655,426 | 1,552,384 | 2,207,811 |
| 1985 | 229 | 212,140 | 394,150 | 534,029 | 390,370 | 655,426 | 1,530,918 | 2,186,345 |
| 1986 | 69 | 199,720 | 383,860 | 533,989 | 390,330 | 655,426 | 1,507,968 | 2,163,394 |
| 1987 | 69 | 186,610 | 375,320 | 533,593 | 390,420 | 655,426 | 1,486,012 | 2,141,438 |
| 1988 | 69 | 171,570 | 366,870 | 532,413 | 390,370 | 655,426 | 1,461,292 | 2,116,718 |
| 1989 | 27 | 155,770 | 360,570 | 531,773 | 390,170 | 655,426 | 1,438,310 | 2,093,736 |
| 1990 | 27 | 145,550 | 347,310 | 531,168 | 389,620 | 655,426 | 1,413,675 | 2,069,101 |
| 1991 | 13 | 138,300 | 332,740 | 530,429 | 389,330 | 655,426 | 1,390,812 | 2,046,238 |
| 1992 | 13 | 130,110 | 319,350 | 528,755 | 389,110 | 655,426 | 1,367,338 | 2,022,764 |
| 1993 | 13 | 124,550 | 313,720 | 516,815 | 388,620 | 655,426 | 1,343,719 | 1,999,145 |
| 1994 | 13 | 119,530 | 304,960 | 508,163 | 388,250 | 655,426 | 1,320,916 | 1,976,343 |
| 1995 | 13 | 115,600 | 299,500 | 496,180 | 387,940 | 655,426 | 1,299,234 | 1,954,660 |
| 1996 | 13 | 112,070 | 295,730 | 486,716 | 383,170 | 655,426 | 1,277,699 | 1,933,126 |
| 1997 | 13 | 108,600 | 292,520 | 480,810 | 375,590 | 655,426 | 1,257,534 | 1,912,960 |
| 1998 | 13 | 104,890 | 289,970 | 475,680 | 367,460 | 655,426 | 1,238,014 | 1,893,440 |
| 1999 | 13 | 100,980 | 289,040 | 469,110 | 361,920 | 655,426 | 1,221,064 | 1,876,490 |
| 2000 | 13 | 97,450 | 287,780 | 462,782 | 356,270 | 655,426 | 1,204,295 | 1,859,722 |
| 2001 | 13 | 94,051 | 286,270 | 468,498 | 352,200 | 655,426 | 1,201,032 | 1,856,458 |
| 2002 | 13 | 90,891 | 283,580 | 477,610 | 348,570 | 655,426 | 1,200,665 | 1,856,091 |
| 2003 | 13 | NA | NA | 468,498 | NA | 655,426 | NA | NA |
| | | | | **Fishing Mortality (y$^{-1}$)** | | | | |
| 1977 | 0.000 | 0.003 | 0.014 | 0.000 | 0.000 | 0.000 | 0.004 | 0.003 |
| 1978 | 0.000 | 0.005 | 0.014 | 0.000 | 0.000 | 0.000 | 0.005 | 0.003 |
| 1979 | 0.000 | 0.020 | 0.014 | 0.000 | 0.000 | 0.000 | 0.007 | 0.005 |
| 1980 | 0.188 | 0.016 | 0.018 | 0.000 | 0.000 | 0.000 | 0.008 | 0.005 |
| 1981 | 0.021 | 0.014 | 0.020 | 0.000 | 0.000 | 0.000 | 0.008 | 0.005 |
| 1982 | 0.000 | 0.019 | 0.021 | 0.000 | 0.000 | 0.000 | 0.008 | 0.006 |
| 1983 | 0.026 | 0.023 | 0.020 | 0.000 | 0.002 | 0.000 | 0.009 | 0.007 |
| 1984 | 0.690 | 0.033 | 0.022 | 0.000 | 0.002 | 0.000 | 0.011 | 0.008 |
| 1985 | 0.000 | 0.035 | 0.028 | 0.000 | 0.002 | 0.000 | 0.012 | 0.009 |
| 1986 | 0.000 | 0.042 | 0.024 | 0.001 | 0.001 | 0.000 | 0.012 | 0.009 |
| 1987 | 0.608 | 0.059 | 0.025 | 0.002 | 0.002 | 0.000 | 0.015 | 0.010 |
| 1988 | 0.000 | 0.071 | 0.019 | 0.001 | 0.002 | 0.000 | 0.014 | 0.010 |
| 1989 | 0.501 | 0.043 | 0.040 | 0.001 | 0.003 | 0.000 | 0.016 | 0.011 |
| 1990 | 0.000 | 0.026 | 0.046 | 0.001 | 0.002 | 0.000 | 0.015 | 0.010 |
| 1991 | 0.000 | 0.036 | 0.045 | 0.003 | 0.002 | 0.000 | 0.016 | 0.011 |
| 1992 | 0.000 | 0.019 | 0.022 | 0.023 | 0.003 | 0.000 | 0.017 | 0.011 |
| 1993 | 0.000 | 0.016 | 0.033 | 0.017 | 0.003 | 0.000 | 0.016 | 0.011 |
| 1994 | 0.000 | 0.008 | 0.023 | 0.024 | 0.002 | 0.000 | 0.016 | 0.011 |
| 1995 | 0.000 | 0.006 | 0.018 | 0.019 | 0.014 | 0.000 | 0.016 | 0.011 |
| 1996 | 0.000 | 0.007 | 0.017 | 0.012 | 0.022 | 0.000 | 0.016 | 0.010 |
| 1997 | 0.000 | 0.010 | 0.015 | 0.011 | 0.024 | 0.000 | 0.016 | 0.010 |
| 1998 | 0.000 | 0.013 | 0.009 | 0.014 | 0.018 | 0.000 | 0.014 | 0.009 |
| 1999 | 0.000 | 0.011 | 0.011 | 0.014 | 0.019 | 0.000 | 0.014 | 0.009 |
| 2000 | 0.000 | 0.011 | 0.012 | 0.010 | 0.014 | 0.000 | 0.012 | 0.008 |
| 2001 | 0.000 | 0.010 | 0.016 | 0.012 | 0.013 | 0.000 | 0.013 | 0.009 |
| 2002 | 0.000 | 0.019 | 0.010 | 0.019 | 0.011 | 0.000 | 0.015 | 0.009 |

Stock status relative to current reference points

Biomass and fishing mortality "targets" for the EEZ stock of ocean quahogs are $B_{MSY}$= (1/2 the virgin biomass) and the $F_{0.1}$ level of fishing mortality (a proxy for $F_{MSY}$) in the exploited region. Overfishing definition "thresholds" are 1/2 $B_{MSY}$ (or 1/4 the virgin biomass) and $F_{25\%MSP}$. Reference points and virgin biomass were re-estimated for this SARC. Revised values are $F_{0.1}$= 0.0275 $y^{-1}$, $F_{25\%MSP}$=0.080 $y^{-1}$, and $B_{MSY}$= 1.15 million mt. Natural mortality rate, M, is assumed to be 0.02 $y^{-1}$.

Ocean quahog biomass is above the $B_{MSY}$ target level and the stock is not overfished. Fully recruited biomass estimates for 2002 are 1.8 million mt (KLAMZ model) and 2.1 million mt (ESB model). Based on the ESB model, the 80% confidence interval for biomass in 2002 ranged 1.4 to 3.1 million mt.

Overfishing is not occurring on the total ocean quahog stock. The fishing mortality rate in 2002 for the whole EEZ stock was estimated at 0.009 $y^{-1}$ (KLAMZ)and 0.009 $y^{-1}$ (ESB). Based on the ESB model, the 80% CI for F in 2002 for the total ranged from 0.006 to 0.013 $y^{-1}$.

The GBK region, which is closed to fishing due to the risk of paralytic shellfish poison, accounts for about 35% of the biomass. For the exploited region only (i.e., total minus GBK), $B_{2002}$ is 1.2 million mt (KLAMZ model) and 1.3 million mt (ESB model). For the exploited region only (i.e., total minus GBK), the fishing mortality rate in 2002 was estimated at 0.015 $y^{-1}$ (KLAMZ) and 0.014 $y^{-1}$ (ESB).

Estimate TAC based on projected stock size and target fishing mortality rates for 2004-2007

Annual projections of fully recruited (>=70 mm shell length) biomass, catch, landings, and fishing mortality rate were made for each region, for the entire stock minus GBK, and for the entire stock through 2007. Four different projection scenarios were conducted.

All projections suggest that the stock will continue to decrease gradually over time. TAC varies among projection scenarios.

# INTRODUCTION

The ocean quahog (*Arctica islandica*: Bivalvia) occurs in the North Atlantic Ocean.  It is common around Iceland, in the eastern Atlantic as far south as Spain, and in the western Atlantic as far south as Cape Hatteras (Theroux and Wigley 1983; Thorarinsdottir and Einarsson 1996; Lewis *et al*. 2001).  Its depth range is from 10 m to 200-400 m, and this varies with latitude (Theroux and Wigley 1983; Thompson *et al*. 1980a).  Throughout the MidAtlantic region, this species occurs almost entirely in EEZ waters.  On the south flank of Georges Bank, ocean quahogs occur in deep (75 m+) water.  In a study of the mitochondrial cytochrome b gene, Dahlgren *et al*. (2000) did not find geographical differentiation between populations along the US coast from Maine to Virginia.

This bivalve has a slow growth rate and extreme longevity; some individuals have been aged at over 200 yrs (Jones 1983; Steingrimsson and Thorarinsdottir, 1995).  Early studies of populations off New Jersey and Long Island (Thompson *et al*. 1980a; Murawski *et al*. 1982) demonstrated that clams ranging in age from 50-100 years were common.  Although they can grow to approximately 110 mm in shell length, the growth rate of fully recruited ocean quahogs is 0.51-0.77% in meat weight per year and < 1 mm in shell length per year, which is an order of magnitude slower than for Atlantic surfclams (SARC-22, NEFSC 1996).

Size and age at maturity are variable.  Off Long Island, the smallest mature quahog found was a male 36 mm long and 6 years old; the smallest and youngest mature female found was 41 mm long and 6 yr old  (Ropes *et al*. 1984).  Some clams in this region are still sexually immature at ages of 8-14 years (Thompson *et al*. 1980b; Ropes *et al*. 1984).  Females are more common than males among the oldest and largest individuals in the population (Ropes *et al*. 1984; Fritz 1991; Thorarinsdottir and Einarsson 1994).

The history of surfclam and ocean quahog management along the Atlantic coast of the United States is summarized in Murawski and Serchuk (1989) and Serchuk and Murawski (1997).  An individual transferable quota (ITQ) system was established in 1990.  Georges Bank has been closed to ocean quahog harvesting since 1990 when Paralytic Shellfish Poison (PSP) was detected. With one exception, the entire USA EEZ stock is treated as one management unit with an annual quota.  A small but valuable fishery has developed off the coast of Maine, and that area has had its own quota since 1999.

Ocean quahogs were recently assessed in 1994, 1997, and 1999 (NEFSC 1995, 1998a,b, 2000a,b) for SARC/SAW-19, -27 and -31 respectively.   The last assessment (NEFSC 2000a,b) concluded that the ocean quahog resource in surveyed EEZ waters from Georges Bank to Delmarva was not overfished and that overfishing was not occurring.  The current assessment has the same conclusion.  The last assessment (NEFSC 2000a,b) concluded that the condition of the stock off the coast of Maine was unknown. The current assessment updates and summarizes what is known about the stock in Maine.

Surveys of the stock from Georges Bank to S. Virginia/N. Carolina are conducted every 2-3 years by NMFS with the *R/V Delaware II* (DE-II).  The clam dredge has a submersible hydraulic pump which shoots water into the bottom to loosen the clams from the substrate.  In 1997,

bottom contact sensors were used on the survey dredge for the first time to get a direct estimate of tow length. In previous surveys, tow length was estimated by doppler distance readings of the vessel's movement over bottom during the 5-min tow. The sensor data provide a better estimate of tow distance and of minimum swept-area biomass (NEFSC 1998, 2000a,b, 2003; Weinberg et al. 2002). The sensors used at sea and the data collected with them are described in previous reports (NEFSC 1998a, 1998c, 2000a,b, 2003).

The present assessment is based on data from multiple sources including: annual commercial landings and effort (time fishing), port samples of shell lengths from the commercial catch, experiments to estimate efficiency and relative efficiency of the NMFS dredge, NMFS surveys, a survey in 2002 of ocean quahog recruitment by Rutgers University and the clam industry, and a survey by the State of Maine. Biomass and fishing mortality rates were determined from 1) recent commercial landings, 2) efficiency corrected survey swept-area biomass (ESB) from NMFS surveys, and 3) a stock assessment model, known as KLAMZ, that is based on historical survey and commercial data.

Region-specific parameters relating shell length to meat weight from Murawski and Serchuk (1979) were derived from samples obtained in winter. Revised length/weight data were collected during the summers of 1997 and 2002 during resource surveys aboard the *R/V Delaware II*. Values of the Biological Reference points were computed for SARC-27 (NEFSC, 1998a) and were revised for this assessment. Length/weight relationships in 1997 and 2002 were similar.


## FISHERY DATA

In most cases this report uses the metric system. Managers and the clam industry tend to use other units. Some conversion factors between units of measure are listed below.

| | | |
|---|---|---|
| "MidAtlantic" bushels of ocean quahogs x 10 | = | lbs meat. |
| "MidAtlantic" bushels of ocean quahogs x 4.5359 | = | kg meat. |
| 1 "MidAtlantic" ( = "Industry")  bushel | = | 1.88 cubic ft. |
| 32 "MidAtlantic" bushels | = | 1 cage. |
| 1 "Maine"  ( = "US Standard")  bushel | = | 1.2448 cubic ft. |
| "Undertonnage" vessel | = | 1-4.9 GRT |
| "Small" vessel | = | 5-49.9 GRT |
| "Medium" vessel | = | 50-104.9 GRT |
| "Large" vessel | = | 105+ GRT |
| Fathoms x 6 | = | ft. |
| Meters x 3.28 | = | ft. |
| 1 nautical mile (nmi) | = | 1 minute of latitude |
| 1 nautical mile (nmi) | = | 1852 meters |

Regions from Georges Bank to S. Virginia are shown in Figure A1. Figure A1 also shows the strata used in the NMFS stratified random clam survey.

MidAtlantic: Landings and Fishing Effort

Total landings were partitioned into state (0-3 mi) and Exclusive Economic Zone (EEZ) components (Table A1). The EEZ fishery started in 1976 and, in most years, over 90% of the landings were from the EEZ. EEZ landings increased rapidly from 1976 to 1979 (Figure A2). Annual landings from the EEZ generally track annual EEZ quotas. Annual EEZ landings have been > 17,000 MT meats since 1985, with the exception of the year 2000 when 14,900 MT were landed. There were several accidents at sea and that was one factor responsible for the lower landings in that year.

Throughout the MidAtlantic region, this species occurs offshore (i.e., beyond state waters). While the total annual EEZ catch has been fairly stable, it has been taken from different regions through time. In the 1980s, almost the entire EEZ fishery took place in the southern regions, Delmarva and New Jersey (Tables A2, A3; Fig. A3, Fig. A4). The fishery moved northward to the Long Island region in 1992, and to S. New England in 1995. Georges Bank, further to the east, is closed to ocean quahog harvesting. The fishery then moved back to the Long Island region in 2002. In 2002, the percentage of EEZ landings by region were: S. Virginia (0%), Delmarva (10%), New Jersey (16%), Long Island (52%), S. New England (22%).

These movements by the fishery are evident in maps of cumulative landings, annual catch, and annual fishing effort by ten-minute square (TNMS) (Fig. A5, Fig. A6, Fig. A7). Landings have been taken from depths shallower than 100 m.

In the MidAtlantic region, over 80% of the landings from 1980-2003 were made by large vessels (Fig. A8). In contrast, over 95% of the landings from the coast of Maine were made by undertonnage and small vessels,

MidAtlantic: Landings per unit Effort (LPUE)

The Logbook database for ocean quahogs contains data on hours fished and landings (bushels of whole clams) for all fishing activity in federal waters. Landings data for quahogs are reported in bushels but can be converted approximately to meat weights using conversion factors described above. Catch rate for the MidAtlantic region is reported here either in units of kg or bushels per hour fished.

Several factors affect interpretation of LPUE data. First, industry sources suggest that fishers work grounds until abundance is reduced and catch rates fall below the level that makes fishing profitable (80 bushels or 400 kg per hour fishing). Second, fishing grounds can be smaller than a ten-minute square (TNMS), the spatial unit within which we have characterized LPUE. Some areas have few fishing trips, making it difficult to calculate catch rates that represent every TNMS. Furthermore, it is possible that commercial catch rates "saturate" ( Hilborn and Walters 1992) and decline more slowly than biomass.

Maps of LPUE by TNMS for large vessels (Fig. A9) suggest that 1)in some TNMSs in DMV, catch rates were very high in 1985, but declined after that and have remained low through 2002, a time span of almost 20 years, 2)declines in catch rates, similar to those in DMV, took place in

the NJ region over time, 3)there were very high catch rates in 1991 in the inshore Long Island region, but by 1997 those rates declined and have remained at the lower level through 2002, 4)the highest catch rates in 2002 took place in deep waters (offshore) of the Long Island region.

Due to the slow growth rate of adult ocean quahogs, areas are not expected to recover quickly after dense clam beds have been harvested. This pattern has been documented in the three previous ocean quahog assessments (NEFSC 1995, 1998a, 2000a), and it was reexamined here with additional data. The 12 TNMSs with the greatest cumulative landings were identified (Fig. A10) and their annual LPUEs were plotted over time (Fig. A11). In each of these squares, the catch rate was high initially (approximately 600 kg/hr fished) for about 5 years, after which catch rates declined and remained low (approximately 300-400 kg/hr) for more than 10 years. Fishing effort also declined in each of these squares over time. It is likely that the most efficient vessels left these areas when catch rates declined, which may partially explain the drop in catch rate over time.

Nominal landings per unit fishing effort (LPUE) by large vessels for each MidAtlantic assessment region was calculated by dividing total landings by total hours fished (Table A4, Fig. A12, Fig. A13). In addition, two general linear models (GLM) were used to compute a standardized LPUE time series for each MidAtlantic region. This is a "large" vessel fishery, and these GLMs were based only on data from "large" vessels. GLM-1 included two explanatory variables: Year and Subregion. Regions were split in half, either north to south or east to west to create subregions. GLM-2 included three explanatory variables: Year, Subregion, and Vessel. "Vessel" was included as a factor in GLM-2 model to account for potential differences in fishing power among vessels in the fishery through time. Data from years when the fishery was "starting up", and effort was still low, were excluded from GLM-2. GLMs were fit by linear regression with the logarithm of LPUE for each trip as the dependent variable. Back transformed (arithmetic scale) year parameter estimates (with no bias adjustment) from the GLM model represent trends in LPUE. Based on an examination of the residuals from each GLM, model fits were acceptable.

Trends in LPUE over time from all three analyses (nominal, GLM-1 and GLM-2) are similar, suggesting that the results (Table A4, Figures A12, A13) are robust and are not due to changes in vessels over time. Nominal LPUE declined in DMV from over 700 kg/hr in 1983-1986 to approximately 400 kg/hr from 1991 to 2003. The pattern in NJ was similar to DMV, although there was an increase around 1996 followed by a leveling out at about 400 kg/hr from 1998 to 2003. The fishery off Long Island became well established in 1991. In LI, catch rates were relatively high in 1991-1992 (800+ kg/hr), somewhat lower until 2002, and they have increased to about 800 kg/hr in 2002-2003. This is related to the harvesting of smaller individuals in that region (see section on "Size Composition of Landings by Region"). In SNE, nominal catch rate fell from a high of about 700 kg/hr in 1992-1993 to about 500 kg/hr in 2002-2003. For DMV and NJ, the trends in LPUE seen at the regional spatial scale are similar to the pattern described earlier for the much smaller, heavily fished TNMSs (Fig. A11).

An additional analysis was done to determine how the commercial LPUE was changing over time in each region, as reflected by catch rates within TNMSs that were being fished in each year. Figures A14-A17 show the probability density function (pdf) of catch rates by TNMS

within each year/region combination. Bins on the x-axis correspond to 3 levels of commercial catch rate (bushels/hr) that can be interpreted in terms of profitability to the industry: Catch rates in bin 1 are not profitable. Catch rates in bin 2 are marginal. Catch rates in bin 3 are profitable. For each region (DMV, NJ, LI, SNE), the plots indicate a general trend toward lower LPUE over time.

Maine's Ocean Quahog Fishery

Along the coast of Maine, the resource straddles state and EEZ waters. Maps of landings, effort, and LPUE over time are shown in Figs. A18-A21. The landings are difficult to partition between the state and EEZ (Figure A18). As of 1999, that region was given its own quota of 100,000 bushels, which is approximately 2% of the total quota for the entire EEZ. Annual reported landings have matched or exceeded the quota (Table A5). The ocean quahog fishery off the coast of Maine is distinct because ocean quahogs are harvested at a smaller size for the half-shell market, rather than the canned chowder market. The volume of quahogs captured per trip is much smaller than in other regions, and the units reported here are "Maine" bushels. In contrast to the MidAtlantic regions, almost all of the landings from Maine have been made by small and undertonnage vessels. Fishing effort has increased steadily from 1993 to 2002 (Table A5). The nominal catch rate increased from about 3 bushels/hr in 1990-1993, to a high of 8-9 bushels per hr in 1999-2001. The catch rate recently dropped to about 7 bushels/hr in 2002-2003 (Fig. A21, Table A5).

NMFS has not conducted a quantitative survey, with stratified random sampling, in this region. However, the State of Maine recently carried out a survey of the ocean quahog resource along the coast of Maine in spring, 2002 (Maine DMR, 2003). The report concluded that: "The preliminary estimate of relative abundance for the currently fished bed was 1,288,564 "Maine" bushels (1 Maine bushel = 35.25 L). This number is not corrected for dredge efficiency, which is believed to be low for the dry dredge used in these surveys".

Several factors make it very difficult to estimate clam dredge efficiency off the coast of Maine. Some of the factors include: the clam beds are in deep water, the dredge is small so its position on the bottom is uncertain, the position of the dredge on the bottom is difficult to control, the bottom is heterogeneous with boulders, rocks, and patches of sand and mud. At this time, there is insufficient information to estimate the stock size and fishing mortality rate in this region.

Size Composition of Landings by Region

Length frequency distributions for ocean quahogs landed between 1982 and 2003 are presented for the Delmarva, New Jersey, Long Island, and S. New England regions in Figures A22 – A25, respectively. The data are summarized in Table A6. Between 1982 and 2003, average length of clams landed from New Jersey (approximately 90 mm - 95 mm) was greater than that from other regions (typically 80 mm - 90 mm; Table A6). Mean length of clams landed from the New Jersey region has remained relatively steady. Mean length of clams landed from the Delmarva region decreased steadily from 92.5 mm in 1994 to 83 mm in 1999, but increased in 2002 and 2003. Although mean shell size from the S. New England landings declined in 1997 and 1998, this was due to targeting of specific beds with high meat yield, and does not represent a shift in

mean shell size of the exploited stock throughout that region. In the LI region, mean length harvested declined by almost a centimeter, from 89 mm in 1997-1998 to about 81 mm in 2002-2003 (Table A6, Fig. A24).


## RESEARCH SURVEYS

History of Changes Made to NMFS Clam Survey Gear

The NMFS clam survey has been conducted since 1965. Clam survey data must be used carefully because significant methodological changes have taken place over time. Table A7 summarizes changes that took place in the early years, including changes in and to research vessels, sampling in different seasons, changing dredges, mesh sizes, etc. Changes that have taken place in the last decade are listed in Table A8. Factors that changed recently include refitting the *RV Delaware II* research vessel (which affected how it rides in the water), new winches which operate at different speeds and affect tow distance, and voltage on the ship powering the pump on the dredge.

Sensor data (1997, 1999, 2002)

Uncertainty following the 1994 survey highlighted problems in interpretation of survey indices. To reduce this uncertainty, changes to operational procedures at sea were implemented in 1997 and have continued to the present. Better monitoring of dredge performance was achieved via the *RV DE II*'s Shipboard Computing System (SCS), which permits continuous monitoring of variables that are critical to operations. In addition to the SCS sensors, sensors were attached to the clam dredge. During most tows, these sensors collected data on ship's speed, ship's position, dredge angle, power to the hydraulic pump, and water pressure from the pump at depth. Depending on the sensor, the sampling interval in 1997 and 1999 varied from once per second to once per ten seconds. The smallest time unit for analysis was one second, and all sensor data collected in 2002 used this sampling frequency.

Types of sensors and the data they collect have evolved over time. In 1997 and 1999 "old" inclinometers were used to measure dredge angle. In 2002, both "old" inclinometers and a new integrated Survey Sensor Package (SSP) were used. The SSP was developed by collaborative effort between NEFSC and the clamming industry.

Examples of new (SSP) sensor data collected at every station in 2002 were given in the most recent assessment of Atlantic surfclams (NEFSC 2003). These data were used to compute tow distance and to monitor electrical power and differential pressure from the dredge manifold. Differential pressure in the manifold remained fairly stable during the entire 2002 clam survey. The survey sampled stations across a wide range of depths (10-90m). Differential pressure was usually about 35 – 40 PSI (Figure C20 in NEFSC 2003), implying relatively consistent sampling performance. For comparison with the NMFS clam dredge, commercial clam boats operate with much higher differential pressure, 80 – 100 PSI.

*Sensors for calculation of tow distance*

For each random survey tow, distance sampled by the dredge was calculated as the sum of distance traveled per second, during those times when the dredge was potentially fishing (i.e., when dredge angle was ≤5.2°) (Figure C21 in NEFSC 2003). Distance traveled during each second was determined from data on ship's speed, assuming this represented the movement of the dredge. This method may tend to overestimate tow distance due to this assumption. However, tow distance is grossly underestimated by nominal distance. Dredge inclinometer data had been smoothed with a 7-s moving average to eliminate high frequency shocks. Dredge angles >5.2° represented times when the dredge was probably not fishing, either because it was not near the bottom or because it had hit a large boulder and bounced up.

The use of sensor data has a major effect on estimated tow distance (Table C9 of NEFSC 2003; also see Weinberg *et al*. 2002; West and Wallace 2000). Nominal tow distance (i.e., 0.125 nmi) is a hypothetical calculation that assumes towing for exactly 5-min at 1.5 knots. Median doppler estimates of the distance traveled by the ship during the 5-min tow (0.124 – 0.130 nmi) are similar to the nominal distance. Doppler distances are close to nominal distances because the former measures distance of the ship over ground only during the 5-min, timed tow. Both measures underestimate total distance sampled. Estimates of tow distance derived from the sensor data are longer, and for the three surveys the median distances ranged from 0.20 – 0.25 nmi. Sensor-based distances are longer because they include any fishing that occurs during the 5-min tow, as well as when the dredge is being set out and hauled back. The higher value in 1997 was due to use of a slower winch on the *R/V DE-II* in that year. Confidence intervals for the median tow distance of each survey, based on sensors, were given in Table C9 of NEFSC 2003.

Dredge Calibration

Early studies of clam dredge efficiency (Meyer *et al*., 1981; Smolovitz and Nulk , 1982) did not obtain reliable estimates of dredge efficiency or carry out there studies where the clam survey is conducted. Thus, it has been necessary to carry out new studies in 1997, 1999 and 2002. Results from 1997, 1999 and the surfclam studies of 2002 are described in previous reports (NEFSC 1998a,c; 2000a,c; 2003).

Calibration or "depletion" field experiments were used to estimate efficiency of the survey dredge. At the most basic level, a depletion study repeatedly samples a closed population in a small area and uses the rate of decline in catch per unit effort to measure population abundance. The total population is estimated from the rate of decline in catch over successive samples and the total quantity caught.

*Analytical Models*

Dr. Paul Rago (NEFSC) developed a model for estimating dredge efficiency that explicitly consider spatial overlap of tows as a depletion experiment progresses (described in NEFSC, 1998a, 2000a, 2003, and Rago *et. al*. submitted). This model was used in two previous ocean

quahog stock assessments (NEFSC, 1998a, 2000a) to obtain efficiency estimates from commercial clam dredges as well as for the NMFS clam dredge on the DE-II (Table A9).

DE-II dredge efficiency for the 1997 ocean quahog survey was first estimated to be 0.430 (SARC-27, NEFSC 1998a).  That estimate was very uncertain because it was based entirely on data from commercial clam dredges; no ocean quahog depletion experiments were carried out with the DE-II at that time.  Subsequently, ocean quahog experiments that involved the DE-II were carried out.  Based on efficiency experiments done in 1999 and 2000, the efficiency of the DE-II dredge during the 1999 ocean quahog survey was 0.346.  Because there was no direct data about DE-II dredge efficiency during the 1997 ocean quahog survey, the estimate of efficiency for the 1999 survey was also applied to the 1997 ocean quahog survey in SARC-31 (NEFSC, 2000a).

*2002 Calibration Experiments and Results*

Ocean quahog depletion experiments were carried out between June and September, 2002 (Figure A26, Table A10).  The main purpose of the experiments was to estimate efficiency of the clam dredge on the DE-II.  All four depletion experiments involved the DE-II making 5 "setup" tows at a site and then having the commercial clamming vessel *F/V Lisa Kim*, perform a depletion experiment at that site.  The DE-II ocean quahog minimum density estimate (from its "setup" tows) and the Rago model's estimate of total density and efficiency, from the commercial vessel's data set, were used to compute an "indirect" estimate of DE-II dredge efficiency:

$$EFF_{(DE-II)} = EFF_{(LK,model)} * [MinDensity_{(DE-II)}] / Density_{(LK,model)}] .$$

In 2002, four estimates of DE-II efficiency were obtained in this manner at sites called: oq02-1, oq02-2, oq02-3, and oq02-4. The FV Lisa Kim made 24, 22, 20, and 24 tows at these 4 experimental sites.  Site oq02-1 was located in deeper water (60 m) than the other 3 sites (48 m) (Table A10).

For each experiment, tracks of the DE-II and commercial vessel are shown (Figures A27-A30). In general, the DE-II setup tows and FV Lisa Kim depletion tows were done at the same general area, as intended (Figures A27-A30).

Because dredge efficiency probably varies with bottom type, bottom characteristics were measured.  Two independent sediment samples, from the top 4 cm, were collected from two VanVeen grab samples at each depletion site (Figure A31, Table A10).  Particle sizes in the sediment samples typically ranged from 0.063 – 0.5 mm.  In addition to being deeper than the other sites, Site oq02-1 had finer grained sediment (Fig. A31).

To analyze the depletion experiments, it was necessary to compare clam density estimates from the two vessels at each site, restricting that calculation to clams selected equally by both dredges. After comparing the size structure of ocean quahogs in the catch (Fig. A32) and exploring those data with a program for estimating relative selectivity, we concluded that the two vessels had very similar selectivity.  This was not unexpected because the bar spacing on an ocean quahog

dredge is "shut down" to approximately the size of the mesh used to line the RV DE-II. Therefore, all sizes of ocean quahogs from both vessels were included in the analyses.

The Rago model was used to analyze each of the 4 ocean quahog depletion experiments from 2002. The cell size used in the model was twice the width of the commercial dredge, and no indirect losses (defined as clams lost but not counted as part of the catch) were assumed. Model estimates for dredge efficiency and density are listed in Table A11, and profile likelihood confidence intervals for the parameters are shown in Figure A33. The estimate of dredge efficiency for the DE-II was lowest at Site oq02-1, which was in deeper water and had finer sediments than other sites.

*DE-II Resampled Stations from its Earlier Surveys*

Twelve fixed stations in the GBK region have been resampled with standard methods in each NMFS clam survey since 1997 to indicate whether dredge efficiency changed radically between surveys (Table A12). Commercial ocean quahog fishing did not occur at these sites because GBK has been closed to clamming for over a decade because of the risk of PSP. Changes in abundance over time due to growth and mortality were not considered in this analysis because the annual rates are very low (about 1 mm shell length per year, and m=0.02), and are likely to be insignificant compared with variance in the catch between any 2 tows collected 2-3 years apart. Data collected from the 12 resampled stations were analyzed using two approaches: a simple ratio based on sums of the catches from all 12 stations between time t and t-1, and a bootstrap ratio estimator based on the 12 ratios comparing 1999:1997 or comparing 2002:1999. The two approaches gave similar results (Table A12). Based on the bootstrap method, the relative efficiency of the NMFS clam dredge in 1999 compared to 1997 was 0.758, with a 90% CI of 0.323 – 0.856. Because the CI did not include 1, this analysis supported the conclusion that the efficiency of the dredge was lower in 1999 than in 1997. A similar calculation for 2002 and 1999 data gave a median ratio of 0.845 and a wide 90% CI of 0.56 – 1.878. Because the CI was wide and included 1, this did not suggest that dredge efficiency had changed from 1999 to 2002.

*DE-II Dredge Efficiency Estimates*

The analysis of repeat stations from the GBK region suggested that there was not a significant difference between the 1999 and 2002 DE-II dredge efficiency, with respect to ocean quahogs. Therefore, the available estimates of dredge efficiency from 1999 and 2002 were combined to get a single estimate of efficiency for both years (Table A13). These included 4 estimates from 2002 and 5 estimates from the 1999 survey (NEFSC 2000a). The average of the 9 estimates of DE-II dredge efficiency for ocean quahogs was 0.269 and the sample standard deviation was 0.149.

Furthermore, the analysis of repeat stations suggested that efficiency during the 1997 survey was greater than that in 1999. Data were collected in 1997 on efficiency of commercial dredges, but none of the efficiency studies from that year used the DE-II dredge. Given the data poor situation regarding an estimate for 1997, we are assuming DE-II dredge efficiency for 1997 to be 0.346, which is the value used in the previous stock assessment (NEFSC, 2000a). It is important

to note that this value (0.346) is consistent with the estimate which can be derived by applying the relative efficiency (0.758) from repeated stations on GBK to the estimate of efficiency in 1999 (0.269); that approach gives a 1997 efficiency estimate of 0.354 (=0.269/0.758).

*Empirical Relationship between Clam density and Dredge Efficiency*

A negative relationship was observed between ocean quahog density and efficiency of the DE-II clam dredge (Fig. A34). It is too early to draw any conclusions about whether efficiency changes with density, or whether there is a cause-effect relationship. Because of the small sample size (n=4), this could have occurred by chance. Furthermore, there is some evidence that other factors are probably correlated with ocean quahog density, including station depth and sediment type (Table A10, Fig. A31). Future studies are needed to examine relationships between these variables in more detail.

## SURVEY RESULTS

Description of Surveys

A series of 23 research vessel survey cruises were conducted between 1965 and 2002 to evaluate the distribution, relative abundance and size composition of surf clam and ocean quahog populations in the Mid- Atlantic, Southern New England and Georges Bank (Figure A1). Assessment regions were defined by groups of strata which remain fixed through time (Figure A1). Surveys are performed using a stratified random sampling design, allocating a pre-determined number of tows to each stratum. One tow is collected per station, and nominal tow duration and speed are 5 minutes and 1.5 knots, respectively. Catch in meat weight per tow is computed by applying length-weight equations to numbers caught in each 1 mm size category. Ocean quahogs were measured and weighed during several DE-II clam surveys to determine the shell length meat weight relationship for important regions (see Table A14 and Fig. A35 for parameter estimates). Values used in the 2000 ocean quahog stock assessment were an average of fitted curves from the 1997 survey and the earlier relationships reported by Murawski and Serchuk (1979). Although new data were collected during the 2002 survey (Table A14 and Fig. A35), due to the seasonal and annual variability that is possible in ocean quahog length-weight, and for consistency, we have assumed the same length/weight relationship as in the previous assessment (NEFSC, 2000a,b).

By computing simple unweighted averages from all tows within a stratum, size frequency distributions per tow were computed by stratum. Size frequency distributions and mean number of clams per tow were computed for each region by averaging over strata, weighted by stratum area.

In surveys conducted prior to 1997, doppler distance was used to standardize every tow's catch to a common tow distance (0.15 n. mi). As described in previous sections, tow distances in the 1997, 1999 and 2002 surveys were standardized by calculating tow distance from ship's velocity (measured by GPS) and contact by the dredge on the bottom as measured by the inclinometer. For the purpose of computing swept area biomass, distance-standardized catches per tow from

1997 - 2002 were computed by multiplying catch at each station by the ratio of (0.15/sensor tow distance).  For analysis of trend, catches were standardized by the ratio 0.15/Doppler distance.

Locations of random stations in the 2002 clam survey are shown in Figure A35.  Sampling intensity was greater in some areas (e.g. NJ) because estimation of population abundance via area-swept methods was anticipated (Table A17).  Samples were not collected in 2002 from the lower part of the S. Virginia - N. Carolina region, the Great S. Channel just to the west of Georges Bank, or from the NW corner of Georges Bank (Strata 67, 72).  This was necessary to allocate enough cruise time for dredge calibration experiments.

In 1999, a new sampling policy was adopted regarding randomly chosen stations with rocky bottom that could not be sampled with the clam dredge without a high risk of severe gear damage.  If the bottom was too rocky, pilots were told to search for towable bottom within 0.5 nmi of the station.  If the search was unsuccessful, the log sheet for that station was filled out with a special code (SHG = 151), and the vessel moved on to the next random station.  In previous surveys, pilots may have searched for good bottom and then taken a tow, even if it was a considerable distance from the original station location, without keeping a record.  This procedural change in 1999 is important in providing a better estimate of the area of clam habitat on Georges Bank (NEFSC 1998a,c).  In the current assessment, nominal individual stratum areas on Georges Bank were reduced in proportion to the fraction of tows from GBK that had been assigned code 151 (Table A17).  The effect of this was to reduce the biomass estimate.

Abundance Indices and Distribution

Locations of random stations in the 2002 clam survey are shown in Figure A36.  Ocean quahog abundance per tow data from the 2002 survey were partitioned into two size classes based on shell length: small (1-69 mm) and large (>= 70 mm).   Individuals recruit to the fishery at about 70 mm.  Detailed distribution data by size class are plotted in Figures A37-A340.  Clams in the "large" class were more abundant from Georges Bank to Long Island than in regions further south.  The largest concentrations of "small" clams were on Georges Bank.

Certain strata of special concern were surveyed in 1999, using stratified random sampling, for the first time.  Few (usually zero) ocean quahogs were captured at random stations in deep water south of Long Island and S. New England (Figures C34 - C37 in SARC-31, NEFSC 2000a).  This area consists of green mud with few macrobenthic organisms.  In addition, an industry vessel collected 12 samples in 1999 from random stations in Strata #42 and 43 (Figure A1), and caught zero ocean quahogs at 10 of the stations (Figure C38 in SARC-31, NEFSC 2000a).  Commercial landings have been reported from the northern edge of these strata; however, data from the random stations suggest that the ocean quahog stock is not very large or widely distributed in strata #42 and #43.

Ocean quahog catches from DE-II clam surveys are shown in maps for the period 1982 – 2002 for the MidAtlantic (Figs. A41-A43) and Georges Bank regions (Figs. A44-A46).  No major changes in the distribution of ocean quahogs over time are apparent from examining these figures.

The number of NMFS clam survey tows during 1978-2002 is shown in Table A15.  Dates when specific regions and or strata were not sampled are easily identified by the dark, filled blocks. Borrowing can change terminal year estimates from one assessment to the next.  The legend gives additional details regarding how data were "borrowed" from adjacent surveys to obtain estimates in missing years for examining survey trends (Table A16).

Survey data are plotted (Figs. A47-A49) to show trends in two size groups (60-69 mm, and >=70mm) over time.  At this size, the growth rate is < 1 mm per year. Figs. A47 and A48 show the same information, but the latter figure has the smaller size class plotted on a 2$^{nd}$ y-axis to show the data, no matter how low the abundance.  A smaller liner was in the dredge before 1980, so smaller sizes were more likely to be captured in 1978-1979.  Abundance per tow of both 60-69 mm and 70 mm+ ocean quahogs is consistently greater in GBK, LI and SNE than in NJ, DMV and SVA.  Regions differ in the ratio of small to large ocean quahogs, but the smaller size class usually makes up only 1-4% of the catch per tow.

The catch in 1994 was relatively high in most regions, and this was likely caused by the use of higher voltage to the hydraulic pump on the dredge during that survey (Tables A7 and A8).

Size Frequency Distributions

Size frequency distributions from surveys conducted between 1978 and 2002 are plotted by region in Figures A50-A54.  Data in the graphs were standardized to a common doppler distance, and "borrowing" (sensu Table A15) was used to fill some periods without survey samples. Borrowing had little effect on the outcome (Figure A55).  A smaller liner was in the dredge before 1980, so smaller sizes were more likely to be captured in 1978-1979.  The size structure of clams changed little over time in most regions, and this could be due to partial selectivity of small individuals by the clam dredge, particularly those below 70 mm in length.

The modal size in the New Jersey and Delmarva regions is 90-100 mm shell length.  Recruitment is not apparent in the New Jersey region from 1978-2002 (Fig. A51).  The length composition of clams off Long Island and on Georges Bank has been more dynamic and suggests that recruitment events occur.  Length structure off Long Island was bimodal from 1978 to 2002. Over this 25 year period, individuals in the smaller mode grew and eventually merged with the larger mode in 2002 (Figure A52).  The smaller mode grew from approximately 60 mm to 80 mm in 25 years (< 1 mm per year), which is consistent with previous studies of growth rate.  The other notable result is the increase in the catch of small (<60 mm) ocean quahogs on Georges Bank in the 1990s (Figure A54; and Lewis *et al*. 2001.).

Special Survey for Ocean Quahog Recruits

An ocean quahog survey was carried out with a commercial vessel (*FV Christie*) in Sept. 2002 to catch small ocean quahogs which are not sampled very effectively by the RV DE-II.  The commercial dredge was lined with chicken wire of 2.54 cm diameter.  The survey resampled approximately 100 NMFS survey stations from 2002 that captured ocean quahogs.  The recruit survey resampled the DE-II stations south of Hudson Canyon and a selection of stations north and east off Long Island.  The survey was carried out cooperatively between Rutgers University

and the clam industry, and the results have been written up in a draft manuscript (Powell and Mann). The results will not be described in detail here. The paper attempts to recreate patterns of recruitment that have taken place in recent decades in various regions.

The data from the *FV Christie* were used in this stock assessment to extend the length frequency distributions based on the DE-II survey, which uses a liner that is 5.1 x 2.5 cm, into smaller size classes. The DE-II dredge retains ocean quahogs that are >78 mm in length, and has partial retention of smaller individuals (NEFSC, 1998a). A comparison of the observed catches from the two vessels demonstrates that the *Christie* captured a higher percentage of small individuals (Fig. A56). These length frequency data were used to estimate the relative size-selectivity of the dredges on the two vessels (Fig. A57). The vessels had similar selectivity above 90 mm. The relative selectivity of the DE-II to the Christie was 50% at 68 mm. The Solver function in Excel was used to estimate the two parameters in the relative selectivity function, S(L),

$$S(L) = 1 / [1 + \exp(alpha + (beta * L))] .$$

The objective function involved minimizing a sum of squares between observed and predicted proportions at length. The logit transformation was applied to the proportions; this resulted in a reasonable model fit (Fig. A58) and gave results that made sense given results from previous empirical studies on selectivity (NEFSC, 1998a).

The relative selectivity function was then applied to the size frequency distributions from the 2002 DE-II ocean quahog survey, down to a minimum length of 51 mm (Figs. A59 and A60). Applying the function to smaller lengths is inappropriate because the DE-II rarely caught individuals that were <51 mm and because the S(L) values get very small, and would have a huge scaling effect.

The adjusted length frequency distribution indicates the presence of many more small ocean quahogs on GBK than indicated by the DE-II data alone (Fig. A59). The plots suggest an intermediate number of previously underestimated small ocean quahogs in LI and DMV. There is little difference between the original and adjusted distributions in SNE and NJ (Figs. A59 and A60), which suggests that small individuals truly are rare in those regions.

## STOCK SIZE MODELS

Efficiency Adjusted Swept Area Biomass (ESB) and Mortality Estimates

Following NEFSC (2000a; 2003), stock biomass and fishing mortality for ocean quahogs were estimated using efficiency corrected swept area biomass (ESB) calculations and landings information. The KLAMZ delay-difference model (Appendix A) was used to estimate time series of biomass and fishing mortality estimates for ocean quahogs during 1978-2002 (NEFSC 2000a). ESB and KLAMZ estimates for recent years tend to agree because ESB-related information is used in tuning the KLAMZ model. Finally, for comparison, a simple "VPA" model (NEFSC 1998) was used to estimate "pristine" biomass and biomass trends since 1978.

In biomass and mortality calculations, catch data were landings plus an assumed 5% upper bound incidental mortality allowance. The incidental mortality allowance accounts for clams that may have been damaged by hydraulic clam dredges during fishing, but never handled on deck. The last assessment (NEFSC 2000a) did not use an incidental mortality allowance. NEFSC (2003) used an upper bound incidental mortality allowance of 10% value for Atlantic surfclams. The allowance used in this assessment (5%) is a new upper bound estimate for quahogs based on Murawski and Serchuk (1989) who noted incidental mortality in ocean quahog that was "significant" and larger than their estimate of incidental mortality for sea scallops (which was <5%). Discard has been very low and was ignored in estimating mortality.

Whole-stock biomass and fishing mortality estimates are not available or are difficult to interpret for early years because of strata that were not sampled in the NEFSC clam survey. In particular, there were strata in the GBK, SNE and SVA regions during early surveys that could not be filled by borrowing (Table A15).

For consistency with the previous assessment and for consistency in comparison of catch with biomass, region-specific length-weight parameters used to calculate survey mean kg per tow for ESB were the same as in NEFSC (2000, database code REV_DATE_FOR_LW = 2000, Table A14). For GBK and LI, where data for comparisons are available, length-weight relationships indicate that meat weights during 2002 were similar to recent years (Table A14 and Fig. A35).

*Efficiency corrected swept-area biomass (ESB)*

There were two time series of ESB data. The relatively "short" ESB time series was for years (1997, 1999 and 2002) when NEFSC clam surveys collected sensor data for each tow and when field experiments were used to estimate gear efficiency during each survey. The short ESB time series is equivalent to ESB data used in the last assessment (NEFSC 2000a). The short ESB explicitly accommodates survey-specific changes in dredge efficiency.

The less precise "long" ESB time series was calculated simply by scaling survey trend data up to units of stock biomass. Scaling factors for calculating the long ESB time series were based on sensor and other data from surveys during 1997, 1999 and 2002 but are meant to represent average conditions. Trends in the long ESB time series are exactly parallel to trends in survey data, only the scale is different. In calculating the long ESB series, changes in survey dredge efficiency are ignored.

*Short ESB time series*

ESB estimates (Table A17, Fig. A61) for ocean quahogs 70+ mm were calculated:

$$B = \frac{\overline{\chi} A'}{ae} \times 10^{-6}$$

where $e$ is the best estimate of survey-specific dredge efficiency for ocean quahogs (Table A13), $\overline{\chi}$ is mean catch per standard tow based on sensor data (kg tow$^{-1}$, see below), $A'$ is habitat area (nm$^2$), $a = 0.0008225$ nm$^2$ tow$^{-1}$ is the area that would be covered by the 5 ft wide survey dredge

during a standard tow of 0.15 nm, and the factor $10^{-6}$ converts kilograms to thousand metric tons.

Habitat area for ocean quahogs in the region was estimated:
$$A' = Au$$
where $\underline{u}$ is the proportion of random tows in the region not precluded by rocky or rough ground (ocean quahogs occupy smooth sandy habitats, NEFSC 2000a), and $A$ is the total area computed by summing GIS area estimates for each survey stratum in the region. Mean catch per standard tow ($\overline{\chi}$) is the stratified mean catch for individual tows ($\chi_i$) after adjustment to standard tow distance based on tow distance measurements from sensor data ($d_s$):
$$\chi_i = \frac{C_i d}{d_s}$$
A few tows without sensor data were excluded from ESB calculations.

As in previous assessments, short ESB estimates for the entire ocean quahog stock during 1997-2002 (Table A17) were computed by adding estimates for individual regions (similar results, but with possibly higher variances, would be expected if mean catch per standard tow were calculated for the entire stock area). Survey data used in estimating ESB for 1997-2002 were from tows for which sensor data were available (database code DISTANCE_TYPE = SENDIST_NEG1, for other database information, see Table A19). The 80% confidence intervals for efficiency corrected, total swept area biomass (ocean quahogs >=70mm) from 1997, 1999, and 2002, had high overlap, suggesting that the three estimates were not significantly different (Table A17). Most of the change is due to an increase over time in the estimate for GBK.

### Long ESB time series

Approximate region- and year-specific biomass estimates in the long ESB series ($b_{r,y}$; Table A21) were computed by rescaling survey trend data:
$$b_{r,y} = \overline{c}_{r,y}\Omega_r$$

where $\overline{c}_{r,y}$ $_y$ was the survey trend value (stratified mean kg/tow, adjusted to the standard 0.15 nmi tow distance based on doppler distance measurements) and $\Omega_r$ was the region-specific scaling factor. Region-specific scaling factors were:
$$\Omega_r = \frac{A'_r u}{\overline{r}a'\overline{e}}$$

where $\overline{e}$ is the average efficiency estimate for ocean quahog during 1997-2002 (Table A17), and $\overline{r} = d_s/d_d$ is the average ratio of sensor and doppler distance measurements for individual tows in surveys during 1997-2002 (Table A20). Survey trend data ($\overline{c}_{r,y}$) were already standardized in the database to a 0.15 nm tow based on Doppler distance data so that the product $\overline{r}a'$ is, approximately, the average area actually swept during a survey tow. In addition to being used for long ESB calculations, the scaling factors for each region $\Omega_r$ proved useful in KLAMZ modeling (see below).

*Catch-ESB Mortality estimates*

Fishing mortality rates were estimated directly from the ratio of catch (landings plus an assumed 5% incidental mortality allowance) and ESB data for each region and year. Both the short and long ESB time series were used to calculate fishing mortality but estimates based on the short series (Table A18, Fig. A62) are probably more accurate than those based on the long time series.

*Uncertainty in ESB and related mortality estimates*

Variance estimates for ESB and related mortality estimates were important in using and interpreting results (Tables A17 and A18). Formulas for estimating ESB and mortality are basically products and ratios of constants and random variables. Random variables in calculations are typically non-zero (or at least non-negative) and can be assumed to be approximately log normal. Therefore, we estimated uncertainty in ESB and related mortality estimates using a formula for independent variables in products and ratios (Deming 1960):

$$CV\left(\frac{ab}{c}\right) = \sqrt{CV^2(a) + CV^2(b) + CV^2(c)}$$

The accuracy of Deming's formula for ESB estimates was checked by comparison to parametric bootstrap estimates in NEFSC (2002a). CV's by the two methods were similar as long as variables in the calculation were log normally distributed. In addition, the distribution of the resulting products and ratios was skewed to the right and appeared lognormal.

CV estimates for terms used in ESB and related estimates (Tables A17, A18, A21; Figs. A61, A62) were from a variety of sources and were sometimes just educated guesses. The CV for best estimates of survey-specific dredge efficiency ($e$) was from the standard deviation for all individual efficiency estimates used to compute the best estimate for that survey (Table A13).[a] The CV for average efficiency ($\bar{e}$) in long ESB estimates was from the standard deviation of all individual efficiency estimates for ocean quahog (Table A13).[b] For lack of better information, CVs for sensor tow distances ($d_s$), area swept per standard tow ($a$), total area of region ($A$), percent suitable habitat ($u$), and catch were all assumed to be 10%. The CV for area swept ($a$) is understood to include variance due to Doppler distance measurements and variability in fishing power during the tow due, for example, to rocky or muddy ground.

*Simple "VPA" estimates*

Assuming no recruitment and that growth exactly balances natural mortality, quahog biomass can be estimated by adding catch data to an estimates of recent biomass. We used the average efficiency corrected swept-area biomass for 1997, 1999 and 2002 to estimate recent biomass (in June of 1999). Biomass estimates for previous years were calculated:

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[a] The standard deviation, rather than the standard error, was used to avoid understating the true uncertainty about dredge efficiency.

[b] The standard deviation for all estimates, rather than the standard error, was used to avoid understating the true uncertainty which includes changes in efficiency from year to year.

$$B_{y<1999} = \overline{B}_{1999} + \sum_{i=y}^{1998} C_i + \frac{C_{1999}}{2}$$

where $\overline{B}_{1999}$ is recent biomass, $C_y$ is catch (landings plus 5% allowance for incidental mortality) for year $y$. Catch for 1999 is divided by two because NEFSC clam surveys occur during June, when the year is half over. "VPA" estimates and trends were for comparisons only and are not meant as best estimates. "VPA" results are shown with KLAMZ model results (see below).

KLAMZ Modeling Methods

The KLAMZ model used in this assessment was the C++ version using AD-Model Builder libraries, rather than the Excel version used previously (NEFSC 2000). The C++ version incorporates a number of improvements and new features (details in Appendix A).

One major challenge in modeling ocean quahog population dynamics is estimating the overall biomass level (scale). Three modeling techniques were used to deal with this technical problem: 1) assumption of virgin, equilibrium biomass prior to fishing; 2) constraints on survey scaling parameters for short ESB estimates; and 3) constraints on survey scaling parameters for survey trend data. The first two of these were also used in the previous assessment (NEFSC 2000a)

The natural mortality $M$=0.02 $y^{-1}$ was used in all assessment calculations for ocean quahog (NEFSC 2000). $M$ is low because ocean quahogs are long-lived. Based on the "3/$M$ rule" (Gabriel et al., 1989), 5% of ocean quahogs would reach age 150 y if no fishing occurred.

The KLAMZ model assumes von Bertalanffy growth in weight. Following NEFSC (2000a), the growth parameters $\rho=e^K$ (where $K$=0.0176 is the von Bertalanffy growth parameter for weight) and $J_t= w_{k-1}/w_k$=0.9693 (where $w_j$ is predicted weight at age $j$) are constant and the same for all regions (NEFSC 2000). These growth parameters mean that quahogs in the model are slow growing, and that they reach 70 mm (the assumed size at recruitment in the model) at about age $k$=26. Growth differs among regions (NEFSC 2000a) and this is a topic for future research.

Catch data (landings plus a 5% allowance for incidental mortality) were assumed to be accurate in KLAMZ model runs for ocean quahog. This means that the fishing mortality rates estimated in the model produce catch levels exactly equal to the catch data.

Modeling the very low catch levels for quahog for some regions required modifications to the C++ version of the KLAMZ model because very low fishing morality levels were hard to parameterize numerically. To deal with this issue, the C++ model was reprogrammed to solve the generalized catch equation numerically as an option (Appendix A). When the catch equation is solved numerically, it is not possible to estimate catches but the number of formal parameters estimated in the model by numerical optimization is reduced. The Excel version used in the last assessment (NEFSC 2000) also calculated fishing mortality rates numerically.

An assumed level of variance in instantaneous somatic growth rates (IGR) for old recruits is used in the KLAMZ model to help estimate the initial age structure of ocean quahogs in 1978. For ocean quahog, IGR values during 1978-1979 were estimated assuming a lognormal distribution

with arithmetic mean equal to the estimated IGR for 1980 ($G_{1980}^{Old}$) and an arithmetic CV for years 1980-2002, which was estimated in a preliminary run. For ocean quahog, this constraint was unimportant because age structure tends to be stable when recruitment is assumed to be low and constant and when mortality is low.

*Survey trends*

Following NEFSC (2000a), survey data for 1994 were omitted from modeling because of anomalously high catches. High catches in 1994 were probably due to changes in voltage of electrical power to submersible pumps on the dredge (480 v instead of 460 v).
Survey data for 1978 and 1980 used in the KLAMZ model for quahog were averages for two surveys during each year. The two surveys during 1978, single survey during 1979, and two surveys during 1980 were carried out at different times of the year and with various types of gear (Tables A7 and A8). The main purpose of including data for 1978 and 1980 was to estimate changes in relative efficiency that may have occurred when the current NEFSC survey dredge equipment was first used in 1981. Survey data for years prior to 1981 had little effect on estimates because the time series for 1978-1980 is short.

Survey data for 1978-2002 were used as measures of trend only, measures of scale, or measures of both trends and scale. When used to measure scale, survey scaling parameters for each region (i.e. $Q_{t,r}$ in $I_t=Q_r B_t$, where $I_t$ is the survey trend index and $B$ is biomass) were constrained around a lognormal prior with arithmetic mean $1/\Omega_r$ and arithmetic CV= $CV_\Omega^2$, where $CV_\Omega$ is the coefficient of variation for $\Omega$. Assuming log normality, arithmetic CVs were converted to log-scale standard deviations using $\sigma^2 = \ln(CV^2 + 1)$. This constraint was ignored when survey data were used as a measure trend only.
CV's for stratified random means were used in calculating goodness of fit to survey and LPUE trend data in the KLAMZ model. The alternative internal-weighting approach based on residual variance (Appendix A) was not used because there was only one survey in the model and because the number of survey observations was relatively low.

*Short ESB*

Short ESB data were used in the KLAMZ model to estimate scale (absolute biomass level) but not trend because other survey data in the model contain the same information about trends during 1997-2002. Tuning the KLAMZ model to scale information in ESB data assumed that estimates of the survey scaling parameter for ESB data ($Q_{ESB}$) were from a lognormal distribution with an arithmetic mean of 1.0 and arithmetic CV equal to the largest CV for ESB in the same region during 1997-2002.

*LPUE*

Standardized landings per unit fishing effort (LPUE) data were from generalized linear models (GLMs) fit to trip level logbook data with year, individual vessels and subregion as factors (Table A4). LPUE measures catch rates on fishing grounds where clams are relatively dense. LPUE is unlikely, therefore, to measure quahog biomass in a simple and proportional manner.

To deal with this issue, standardized LPUE data were modeled as nonlinear measures of trends in stock biomass (i.e. $I=QB^\theta$). Following NEFSC (2000), CVs in goodness of fit calculations for LPUE data were assumed to be 40%.
Preliminary model runs indicated that LPUE probably provide information about region-wide trends in stock biomass for the DMV and NJ regions, where fishing was carried out extensively over long periods of time, but not for other regions. However, there were pathological problems in residual plots for LPUE in preliminary runs for DMV and NJ. Therefore LPUE data were given nil weight in goodness of fit calculations and included in preliminary model runs for comparison to estimated trends only. With nil weight, it was still possible to estimate the exponent parameter $\theta$ for LPUE in $I=QB^\theta$ numerically. LPUE data were omitted entirely from final runs, based on reviewer recommendations, to simplify interpretation of variance estimates.

Recruitment modeling in KLAMZ

Recent fieldwork (Powell and Mann, in prep.) indicates that significant recruitment events at local to regional levels may be separated by decades. This possibility was addressed in KLAMZ modeling because it has important management implications that are too important to ignore. In particular, the KLAMZ model was generalized to include "mining" models used previously (NEFSC 1998) and recruitment in some model runs was assumed to be zero so that regional quahog biomass was fished down over the history of the fishery from relatively high starting values. In other model runs, and as in the previous assessment (NEFSC 2000a), ocean quahog recruitment was assumed to be constant at a low level in each year.

The "trickle" recruitment assumption (constant low levels of recruitment) is simplistic but useful in modeling ocean quahog because there is no abundance index for new recruits. It might be realistic for relatively large stock assessment regions given smooth patterns in survey length composition data (implying more or less continuous recruitment), difficulty in identifying new recruits in survey and fishery length composition data due to slow growth, and because of the apparently smooth population dynamics in ocean quahog. Ocean quahogs recruit to the fishable stock at 70 mm (average 26 y) so that new recruits in each year are a weighted average of quahog from many year classes.

*Equilibrium initial biomass*

As in the previous assessment (NEFSC 2000a), some model runs assumed that ocean quahog in a region were at an equilibrium "virgin" level at the outset of fishing in the first year of the model. The initial virgin equilibrium biomass level was calculated based on the model's estimate of average (constant) recruitment assuming no fishing mortality (Appendix A).

*"VPA"*

KLAMZ model output for ocean quahog shows results from the simple "VPA" model used by NEFSC (1998) to estimate pristine biomass in 1976. NEFSC (1998) used one set of VPA calculations for the entire stock, but VPA calculations in this assessment were for each region in this assessment. Moreover, NEFSC (1998) focused on the estimate of pristine biomass but

trends in VPA biomass are presented in this assessment as well. VPA calculations had no effect on KLAMZ model results.

*Model scenarios*

A range of KLAMZ modeling scenarios were used for quahog in each region (see below). All of the model scenarios were relatively simple with five or fewer parameters to estimate by optimization. In some cases, as described below, the number of parameters was reduced further.

| Scenario | Recruitment | Virgin Biomass | Short ESB for scale | Survey for Scale | Number Model Parameters[c] |
|----------|-------------|----------------|---------------------|------------------|----------------------------|
| 1 | Constant | Yes | Yes | No | 5 |
| 2 | Constant | Yes | No | Yes | 5 |
| 3 | Constant | No | Yes | No | 5 |
| 4 | Constant | No | No | Yes | 5 |
| 5 | None | No | Yes | No | 4 |
| 6 | None | No | No | Yes | 4 |

Scenarios that assume no recruitment do not assume equilibrium virgin starting conditions because there was no estimate of average recruitment to use in calculating virgin biomass. Different scenarios may give very similar results. For example, if the constant level of recruitment in scenario 3 with constant recruitment is very low, then results of scenario 3 will be almost identical to results from scenario 6 with no recruitment.

KLAMZ Model Results

Based on reviewer recommendations, KLAMZ model estimates from scenario 3 model runs were used as the best available information for NJ and SNE (Table A22, A24). For DMV, KLAMZ model estimates from scenario 5 were used as the best available information because the estimated recruitment parameter in scenario 3 was very close to zero. Best estimates for other regions were from VPA calculations or short ESB data (Table A22, A24). Biomass and fishing mortality for the entire EEZ ocean quahog stock and entire EEZ stock less GBK were sums and averages of estimates for individual regions (Table A24). In most regions, biomass estimates based on KLAMZ, ESB, and VPA calculations were similar (Fig. A63). Possible exceptions include DMV, where the KLAMZ model gave higher estimates of biomass, and LI and GBK, where survey data were noisy.

With the exception of DMV, KLAMZ model scenarios with recruitment performed better than scenarios that assumed no recruitment. However, the estimated level of recruitment was always small, usually amounting to a few percent of stock biomass. Based on the available information, somatic growth rates are low even for new recruits. Recruitment levels and somatic growth rates may increase as biomass is reduced but density-dependent responses to fishing will be delayed

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[c] In the most complex model: one parameter for average recruitment, one parameter for 1978 old recruit biomass, one parameter for 1977 total biomass, one survey covariate parameter, and one exponent parameter for LPUE data (LPUE used in preliminary but not final model runs).

by the time required (roughly 26 y at current growth rates) for quahog larvae to settle and grow to fishable size. In general, recruitment and growth appear sufficient to support only low levels of fishing.

*Uncertainty*

Several factors enhance the stability of modeling results (accurate catch data, low fishing mortality and stable populations dynamics) but substantial uncertainty about quahog biomass and trends is unavoidable due to data limitations. The principal support for estimating the overall scale of quahog biomass in each region was prior information about survey scaling parameters ($Q$) for ESB data. CVs for prior distributions on annual estimates of $Q$ for short ESB ranged 60-70% for DMV, NJ, LI, SNE and GBK. The CV for prior distributions on average $Q$ for long ESB data was 40%.

Estimated trends tend to be uncertain for ocean quahog because there is a single survey abundance index for each region, which is noisy and available only on a triennial basis during recent years. In the case of LI, for example, perception of the direction of overall trend in biomass hinges on a single survey data point (Figure A47). LPUE data corroborate trends in survey data for some regions (e.g. DMV and NJ) but are relatively difficult to interpret.

It was difficult to evaluate uncertainty in this assessment quantitatively because a large number of models are involved for each region. However, as a rule of thumb, it is probably reasonable for managers to assume that true biomass levels might fall anywhere between half and double the best estimates from this assessment. For example, if the best estimate is 200, the "half or double" rule means that the true value could lie anywhere between 100 and 400.

*SVA*

The KLAMZ model was not used for quahog in the SVA area due limitations in the data. For example, catch in some years exceeds estimates of recent ESB but survey trends do not seem to reflect any declines in abundance. The best available estimates for biomass during 1995-2002 are VPA estimates. Survey data suggest quahog biomass is low in the SVA area and catches are generally near zero.

*DMV*

Preliminary model runs for scenario 1 indicated little or no retrospective bias in KLAMZ model results for DMV quahog (Figure A64). There was, however, a tendency for estimates to change with the omission of the 2002 ESB datum.

LPUE, survey and results from all scenarios indicate that biomass has declined in the DMV region (Figure A65). Biomass estimates for scenarios 3-6 were similar because estimated recruitment was either nearly zero (scenarios 3-4 with recruitment) or assumed zero (scenarios 5-6 with no recruitment). Results from scenarios 1-2 with recruitment were similar to VPA and estimates from the last assessment. Scenarios 3-6 with no recruitment fit NEFSC survey and LPUE data better (lower negative log likelihood).

Scenarios 1-2 with recruitment had scaling parameters ($Q$) for short ESB data closest to one indicating that biomass estimates from scenarios 1-2 were closer to the scale suggested by NEFSC survey dredge efficiency studies during 1997-2002. Scenarios 3-6 with recruitment had scaling parameters ($Q$) for long ESB data closest to the target value indicating that biomass estimates from scenarios 3-6 were closer to the scale suggested by average dredge efficiency calculations ($Q=1/\Omega$). Trends in the scaling parameter ($Q$) for NEFSC survey data indicate that dredge efficiency increased in 1981, as expected, when the current survey dredge was introduced.

Goodness of fit CVs for NEFSC survey data were about the same as the mean CV for the survey data indicating an appropriate mix of measurement and process error in each of the models. LPUE was a nonlinear function of biomass (exponent parameters < 1) in all scenarios and appears to provide information about trends in DMV quahogs. Residual patterns for survey and LPUE data were reasonably good for all scenarios (Figure A66).

Scenario 5 (with zero recruitment) was selected by reviewers as providing the best available estimates for DMV quahog because recruitment estimates were essentially zero in scenario 3, which was the scenario that used short ESB for scale and was least constrained by assumptions.

*NJ*

LPUE, survey and results from all scenarios indicate that biomass has declined in the NJ region. Biomass estimates from scenarios 1-4 with recruitment were similar to one another as were estimates from scenarios 5-6 with no recruitment (Figure A67). Equilibrium virgin biomass estimates from scenarios 1-2 were similar to estimates from scenarios 3-4 which did not assume initial equilibrium. Results from scenarios 1-4 with recruitment (all years) and scenarios 5-6 (prior to 1988) were higher than biomass estimates from the last assessment. Estimates from scenarios 1-4 were almost indistinguishable from VPA estimates. Scenarios 1-4 with recruitment fit NEFSC survey and LPUE (not used in tuning) data substantially better (lower negative log likelihood) than scenarios without recruitment. The log-likelihood was lowest for scenario 3 with recruitment and without equilibrium initial conditions.

Scenarios 1-4 with recruitment had scaling parameters ($Q$) for short ESB data close to 1.0 indicating that biomass estimates were close to the scale suggested by NEFSC survey dredge efficiency studies during 1997-2002. Scenarios 1-2 with recruitment and equilibrium starting conditions had scaling parameters ($Q$) for long ESB data closest to the target value. Trends in the scaling parameter (Q) for NEFSC survey data indicate that dredge efficiency increased in 1981 as expected when the current survey dredge was introduced.

Goodness of fit CVs for NEFSC survey data were about the same as the mean CV for the survey data indicating an appropriate mix of measurement and process error in each of the scenarios. LPUE was a nonsensical increasing function of biomass (exponent parameters > 1) in all scenarios. Residual patterns for survey and LPUE data were quite good for scenarios 1-4 but not as good for scenarios 5-6 (Figure A68).

Reviewers chose scenario 3 as providing the best available information about ocean quahog in NNJ  Biomass and F estimates from NJ model scenarios 1-4 were similar after 1995.

*LI*

Inconsistencies in data trends and model structure were not resolved entirely for LI quahog (Figure A69).  Reviewers therefore chose to use VPA estimates as the best available information.

*SNE*

Biomass estimates for SNE quahogs from scenarios 1-4 with recruitment were similar to one another as were estimates from scenarios 5-6 with no recruitment (Figure A70).  Results from all scenarios were similar to VPA estimates and estimates from the last assessment.  Scenarios 5-6 did not fully converge indicating that at least some recruitment was required to model SNE quahog.  As in the LI region, the fishery for quahog in SNE was relatively modest until recently, with catches not exceeding 1,000 mt per year on a regular basis until 1992.  SNE quahog were much easier to model than LI quahog, however, because the trend in SNE survey data is easier to interpret.

Scenarios 1-4 with recruitment fit NEFSC survey data slightly better (lower negative log likelihood) than scenarios 5-6 with no recruitment but differences in negative log-likelihood were not significant.  Scenarios 1-6 had scaling parameters (*Q*) for short ESB data that were somewhat less than 1.0 indicating that SNE quahog biomass was a bit larger than suggested by NEFSC survey dredge efficiency studies during 1997-2002.  Scenarios 2-4 had scaling parameters (*Q*) for long ESB data closest to the target value.  Goodness of fit CVs for NEFSC survey data were about the same as the mean CV for the survey data indicating an appropriate mix of measurement and process error in each of the scenarios.  LPUE was a poor index of biomass (exponent parameters near zero) in all scenarios, possibly due to the relatively high LPUE value for 2002.  Residual patterns for survey and LPUE data were quite good (Figure A71).  Trends in the scaling parameter (*Q*) for NEFSC survey data indicate that dredge efficiency decreased in 1981 when the current survey dredge was introduced but this result was likely due to noise in the data.

Reviewers chose scenario 3 as providing the best available information for SNE quahog.

*GBK*

With no fishing on GBK and information about scale coming primarily from short ESB data, there was no reason to use the KLAMZ model for GBK.  Reviewers chose to use average ESB during 1997, 1999 and 2002 as the best available information about ocean quahog biomass in the GBK area during 1977-2002.

Quahogs in GBK are unfished and the stock might be expected to have been at equilibrium virgin biomass throughout the last several decades.  However, the relatively limited survey data for GBK after 1984 indicate that stock biomass is increasing (Figure A47).  In addition, survey

length composition data not used in the KLAMZ model indicate that recruitment has occurred over the last two decades in the GBK region.

## Summary of KLAMZ Results

Average best annual estimates of ocean quahog biomass and fishing mortality rate (F) from the KLAMZ model are in Table A24 and Figs. A72, A73, A74.  Estimates of stock biomass in 2002, with and without GBK, were 1,856,000 mt and 1,201,000 mt.  Estimates of F in 2002, with and without GBK, were 0.009 y$^{-1}$ and 0 .015 y$^{-1}$.   Fs have increased gradually since 2000.  The percent of ocean quahog biomass in each region is shown in Fig. A75.  GBK, which is closed to clamming, had 35% of the biomass in 2002.  Other regions contained 19% (SNE), 15% (NJ), 26% (LI), and 5% (DMV) of total biomass in 2002.


# BIOLOGICAL REFERENCE POINTS AND STOCK STATUS

## Overfishing Status Determination

According to the Atlantic Surfclam and Ocean Quahog Fishery Management Plan (FMP), the biomass and fishing mortality "targets" (approved in Amendment 12) for ocean quahogs are $B_{MSY}$ = (1/2 the virgin biomass) and the $F_{0.1}$ level of fishing mortality in the exploited region.  The Amendment does not state whether $B_{target}$ should be based on 1/2 the virgin biomass of the entire region or of the exploited region only (i.e., Total less GBK).

Based on the FMP, the overfishing definition "thresholds" are 1/2 $B_{MSY}$ (or 1/4 the virgin biomass) and $F_{25\%MSP}$.  Both of these apply to the entire stock.

Reference points and virgin biomass were estimated for SARC-31 (NEFSC, 2000a,b) to be $F_{0.1}$ = 0.022 y$^{-1}$, $F_{25\%MSP}$=0.042 $y^{-1}$ and $B_{MSY}$= 1 million mt.  Reference points and virgin biomass were re-estimated for this SARC to be $F_{0.1}$ = 0.0275 y$^{-1}$, $F_{25\%MSP}$=0.080 $y^{-1}$, and $B_{MSY}$= 1.15 million mt. $B_{MSY}$ was re-estimated by taking ½ of the 1977 biomass estimate in Table A24.  $F_{0.1}$ and $F_{25\%MSP}$ were re-estimated from a yield-per-recruit analysis (Table A25, A26) that assumed full recruitment to the fishery at age 26 y (70 mm shell length), which is consistent with assumptions made in latest KLAMZ models.  BRP's  presented in SARC-31 were also derived from YPR analysis, but it had assumed an earlier age of recruitment to the fishery, 17 y (60 mm shell length).

Ocean quahog biomass is above the $B_{MSY}$ target level and the stock is not overfished (Fig. A76).  The current best estimate of $B_{MSY}$ =1.15 million mt can be compared to updated estimates of recent biomass for fully recruited (>= 70 mm shell length) quahogs in the EEZ (1.8 million mt during 2002  from the KLAMZ model (Table  A24), and 2.1 million mt during 2002 from ESB data (Table A17).  Eighty-percent confidence intervals ranged from 1.4 to 3.1 million mt for ESB estimates.

Based on the best available information, exploitation levels for quahog in the exploited region (total less GBK) are below the $F_{0.1}$=0.0275 y$^{-1}$ target.  Updated estimates of fishing mortality

during 2002 for the exploited portion of the resource in the EEZ were 0.015 $y^{-1}$, from the KLAMZ model (Table A24), and 0.014 $y^{-1}$ based on catch and ESB data (Table A18). Eighty-percent confidence intervals ranged from 0.009 to 0.022 $y^{-1}$ based on ESB estimates.

Based on the best available information, overfishing is not occurring in the ocean quahog fishery. Updated estimates of recent fishing mortality for the whole EEZ stock (0.009 $y^{-1}$ during 2002 from the KLAMZ model, Table A24, and 0.009 $y^{-1}$ during 2002 based on ESB data, Table A18) are both below the $F_{25\%MSP}=0.080\ y^{-1}$ threshold. Eighty-percent confidence intervals for $F_{2002}$ ranged from 0.006 to 0.013 $y^{-1}$ based on ESB estimates.

<u>Biological condition of the stock</u>

The ocean quahog stock is at a high biomass level (approximately 80% of the estimated 2.3 million mt biomass prior to fishing). An increasingly large fraction of the stock (about 35% in 2002) is on Georges Bank, which is unfishable due to a risk of PSP contamination. Survey data, LPUE and model results suggest that biomass has declined substantially in DMV and to a lesser extent in NJ since the inception of the fishery.

Exploitation levels for the entire quahog resource are low, and in the exploited region are at approximately one-half of the target, $F_{0.1} = 0.0275\ y^{-1}$. Fishing mortality rates during recent years from the KLAMZ model and based on ESB data indicate that exploitation levels are near the $F_{0.1}$ target in DMV and LI. Analysis of LPUE data for individual 10' squares indicates considerable fishing down on fishing grounds that have historically supplied the bulk of the catch.

Recent fieldwork and NEFSC survey data suggests that some recruitment has occurred throughout the range of the stock since the inception of the fishery. It appears, however, that large recruitment pulses are probably rare and regional. Model results indicate that recruitment is, at most, only a few percent of stock biomass in each year. Somatic growth is slow (1-2% in weight per year). Current high biomass is due to recruitment and growth accumulating over many decades. The significance of slow growth and low recruitment in ocean quahogs is that it would require decades for biomass in areas such as DMV to increase to prefished levels.

In contrast to Atlantic surfclams (NEFSC 2003), there is no evidence of increased natural mortality for quahogs in southern portions of their habitat. Recent survey data indicate that condition factors (meat weights) are not at low levels.


**TOTAL ALLOWABLE CATCH (TAC) BASED ON STOCK SIZE AND $F_{TARGET}$**

Annual projections of fully recruited (>=70 mm shell length) biomass (B), catch (C), landings (C - 0.05C), and fishing mortality rate (F) were made for each region, for the entire stock minus GBK, and for the entire stock through 2007 (Tables A27 – A30).

Projections assumed either:
        A. constant regional catch at 2002 levels,
        B. constant regional fishing mortality at 2002 levels,

C. constant regional catch at quota levels, or
D. constant regional fishing mortality, $F_{0.1} = 0.0275$ y$^{-1}$.

Projections were based on:

$$X = G + r - M - F,$$

$$B_{t+1} = B_t e^x, \quad \text{and}$$

$$F \approx C / (B e^x),$$

where $X$ = net instantaneous rate of change, $G$ = annual instantaneous rate of change for somatic growth in weight, $r$ = recruitment biomass, $M$ = natural mortality. Estimates of initial biomass (in 2002) and $F_{2002}$ were taken from Table A24. All of the projections suggest that the stock will continue to decline gradually over time. TAC varied depending on the projection assumptions.

## SARC DISCUSSION

The Maine survey results cannot be scaled to absolute abundance due to the lack of dredge efficiency estimates.

The increasing biomass estimates in Georges Bank do not appear to be plausible given the longevity and low recruitment of the species. It is unlikely that the recent closure of Georges Bank to quahog fishing could explain the size of the increase, although it is somewhat more plausible for Georges Bank due to the greater recruitment and faster growth rates in the region. The increases could also be a result of the estimated changes in dredge efficiency.

The SARC questioned whether the four DE-II dredge efficiency estimates may be affected by density. This would be a large concern in a stock assessment, but it was brought up that differences in sediment and depth might account for this apparent trend. It was concluded that although there is uncertainty in this estimate, the dredge efficiency was based on the average of the four depletion experiments, which were taken over varying sediment types and depths. Further analysis is needed to consider the multiple effects of density and other covariates (e.g., depth, grain size).

The SARC was concerned that estimates of dredge efficiency are based on numbers of animals, whereas biomass is calculated based on weight. Due to the small size range of quahogs, this may not be a problem.

## SOURCES OF UNCERTAINTY

1) The SARC noted considerable uncertainty in estimating variance in quahog survey data. A best estimate of survey variability could not be agreed upon.

2) The SARC questioned the consistency of averaging different KLAMZ scenarios for different regions. The SARC decided to provide scenario 3 models for biomass estimates over all regions for consistency, except for Georges Bank where there is no fishery and for Long Island where the fishery is recent. The ESB estimates were used for these regions. The SARC discussed whether the LPUE could be used in future assessments.

3) The SARC questioned the use of borrowing survey results from neighboring years to fill in missing strata. A presentation of the results with and without borrowing showed there is little effect in the present assessment.

4) There was concern over the low sampling of commercial catches.


## RESEARCH RECOMMENDATIONS

1) A complete survey and a valid survey dredge efficiency estimate are needed by the State of Maine to assess ocean quahogs off the coast of Maine.

2) Explore whether efficiency of the DE-II dredge and commercial dredges are affected by depth, sediment type, and clam density. This could be examined experimentally, or by having an efficient commercial dredge repeat stations sampled by the DE-II. Also, evaluate non-extractive methods to estimate dredge efficiency and survey the resource.

3) Identify whether there are major differences in life histories and population dynamics between regions, and consider treating the EEZ stock as a metapopulation.

4) Consider using ecological estimates of carrying capacity (based on available food, maximum size, predation, amount of suitable habitat) to evaluate/validate model estimates of virgin biomass.

5) Re-examine the rate of incidental mortality to ocean quahogs caused by commercial dredges.

6) Progress was made at utilizing data from the ocean quahog recruit survey. Consider applying the relative selectivity function to the entire survey time series.

7) Consider whether future stock assessment models should be based on age and abundance, rather than shell length and weight.

8) There is little information regarding $F_{MSY}$ and $B_{MSY}$ or suitable proxies for long lived species like ocean quahog. Traditional proxies (e.g., $F_{MSY} = F_{25\% MSP}$, $F_{MSY} = M$, $F_{MSY} = F_{0.1}$ and $B_{MSY}$

at one-half virgin biomass) may be inappropriate for long lived organisms.  The question of $F_{MSY}$ and $B_{MSY}$ proxies should be considered.

9) Survey coverage of Georges Bank needs to be a priority in NMFS EEZ survey.  Strata along the Hague line may need to be re-stratified and biomass estimates recalculated to include only US areas.

10) If the management system requires accurate position information (e.g. VMS) from fishery vessels, evaluate the possible improvements to assessments using catch and location information from this source.

11)  Investigate the use of survey data collected prior to 1978.

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# ACKNOWLEDGMENTS

Table A1. Annual landings of ocean quahog (metric tons, meats) from state waters and the Exclusive Economic Zone, and annual quotas.

| Year | State Water | EEZ | Total | Percent EEZ | EEZ Quota[4] |
|------|------------|------|-------|-------------|-----------|
| 1967[1] | 20 | - | 20 | 0 | - |
| 1968 | 102 | - | 102 | 0 | - |
| 1969 | 290 | - | 290 | 0 | - |
| 1970 | 792 | - | 792 | 0 | - |
| 1971 | 921 | - | 921 | 0 | - |
| 1972 | 634 | - | 634 | 0 | - |
| 1973 | 661 | - | 661 | 0 | - |
| 1974 | 365 | - | 365 | 0 | - |
| 1975 | 569 | - | 569 | 0 | - |
| 1976 | 656 | 1,854 | 2,510 | 74 | - |
| 1977 | 1,118 | 7,293 | 8,411 | 87 | - |
| 1978 | 1,218 | 9,197 | 10,415 | 88 | 13,608 |
| 1979 | 1,404 | 14,344 | 15,748 | 91 | 13,608 |
| 1980[2] | - | 13,407 | 11,623 | - | 15,876 |
| 1981 | - | 13,101 | 11,202 | - | 18,144 |
| 1982 | 2,244 | 14,234 | 16,478 | 86 | 18,144 |
| 1983 | 1,614 | 14,586 | 16,200 | 90 | 18,144 |
| 1984 | - | 17,974 | 17,939 | 100 | 18,144 |
| 1985 | 1,309 | 20,726 | 22,035 | 94 | 19,958 |
| 1986 | 1,683 | 18,902 | 20,585 | 92 | 27,215 |
| 1987 | 1,204 | 21,514 | 22,718 | 95 | 27,215 |
| 1988 | 734 | 20,273 | 21,006 | 96 | 27,215 |
| 1989 | 787 | 22,359 | 23,146 | 97 | 23,587 |
| 1990 | 268 | 20,966 | 21,234 | 99 | 24,040 |
| 1991 | - | 22,119 | 22,118 | 100 | 24,040 |
| 1992 | 357 | 22,514 | 22,871 | 98 | 24,040 |
| 1993 | 2,933 | 21,909 | 24,843 | 88 | 24,494 |
| 1994 | 140 | 21,017 | 21,158 | 99 | 24,494 |
| 1995 | 2,087 | 21,166 | 23,252 | 91 | 22,226 |
| 1996 | 990 | 20,132 | 21,122 | 95 | 20,185 |
| 1997 | 190 | 19,739 | 19,929 | 99 | 19,581 |
| 1998 | 90 | 18,007 | 18,097 | 100 | 18,140 |
| 1999 | 33 | 17,523 | 17556 | 100 | 20,411 |
| 2000 | 0 | 14,904 | 14,898 | 100 | 20,411 |
| 2001 | 0 | 17,234 | 17,234 | 100 | 20,411 |
| 2002 | 0 | 18,144 | 18,144 | 100 | 20,411 |
| 2003[3] | - | 10,932 | - | - | 20,411 |

[1] Values from 1967-1979 are from NEFSC 90-07.
[2] From 1980-2003, "totals" are from the CFDETS database, EEZ landings are from logbooks (SFyyVR), and state landings are by taking the difference. Values assume 1 "Industry" bushel OQ = 4.5359 kg meats. "Landings" reported in table do not take indirect mortality into account.
[3] 2003 has a partial year of data.
[4] An additional quota of 100,000 "Maine" bushels began in 1999. See Table A5 for those landings.

Table A2. Ocean quahog landings in metric tons of meats (calculated from number of bushels reported in logbooks) for the US EEZ, by stock assessment region. GBK not shown because landings were zero. 2003 is a partial year of data.

| YEAR | SVA | DMV | NJ | LI | SNE | Other EEZ | EEZ Total |
|------|-----|-----|-----|-----|-----|-----------|-----------|
| 1980 | 0 | 4,230 | 7,750 | 6 | 0 | 1,421 | 13,407 |
| 1981 | 56 | 3,637 | 8,402 | 3 | 0 | 1,003 | 13,101 |
| 1982 | 6 | 4,598 | 8,538 | 0 | 0 | 1,092 | 14,234 |
| 1983 | 0 | 5,396 | 8,249 | 21 | 629 | 291 | 14,586 |
| 1984 | 6 | 7,164 | 8,858 | 0 | 822 | 1,124 | 17,974 |
| 1985 | 160 | 7,200 | 10,679 | 40 | 693 | 1,954 | 20,726 |
| 1986 | 0 | 8,231 | 9,061 | 396 | 562 | 652 | 18,902 |
| 1987 | 0 | 10,540 | 9,070 | 1,180 | 696 | 28 | 21,514 |
| 1988 | 42 | 11,715 | 7,014 | 640 | 841 | 21 | 20,273 |
| 1989 | 0 | 6,439 | 14,100 | 605 | 1,196 | 19 | 22,359 |
| 1990 | 14 | 3,691 | 15,583 | 739 | 934 | 5 | 20,966 |
| 1991 | 0 | 4,839 | 14,575 | 1,674 | 865 | 166 | 22,119 |
| 1992 | 0 | 2,378 | 6,942 | 11,939 | 1,143 | 112 | 22,514 |
| 1993 | 0 | 1,975 | 10,172 | 8,652 | 1,020 | 90 | 21,909 |
| 1994 | 0 | 992 | 6,970 | 11,983 | 954 | 118 | 21,017 |
| 1995 | 0 | 699 | 5,356 | 9,464 | 5,443 | 204 | 21,166 |
| 1996 | 0 | 736 | 4,864 | 5,905 | 8,319 | 308 | 20,132 |
| 1997 | 0 | 1,072 | 4,249 | 5,130 | 8,958 | 330 | 19,739 |
| 1998 | 0 | 1,365 | 2,664 | 6,570 | 6,433 | 975 | 18,007 |
| 1999 | 0 | 1,090 | 3,038 | 6,328 | 6,619 | 448 | 17,523 |
| 2000 | 0 | 1,048 | 3,318 | 4,745 | 5,083 | 710 | 14,904 |
| 2001 | 0 | 894 | 4,536 | 5,716 | 4,694 | 1,394 | 17,234 |
| 2002 | 0 | 1,732 | 2,781 | 9,113 | 3,884 | 634 | 18,144 |
| 2003 | 0 | 822 | 2,090 | 6,085 | 1,560 | 375 | 10,932 |

Table A3.  Reported fishing effort (hours fished) for ocean quahog in the US EEZ, by stock assessment region, from logbooks. GBK not shown because fishing effort was zero.

| YEAR | SVA | DMV | NJ | LI | SNE | Row Total |
|------|-----|-----|-----|-----|-----|-----------|
| 1980 | 0 | 6,942 | 16,039 | 32 | 0 | 23,014 |
| 1981 | 73 | 5,864 | 15,949 | 6 | 0 | 21,892 |
| 1982 | 7 | 7,241 | 14,737 | 0 | 0 | 21,985 |
| 1983 | 3,495 | 23,095 | 33,735 | 497 | 2,502 | 63,324 |
| 1984 | 2,351 | 19,434 | 34,499 | 24 | 3,657 | 59,965 |
| 1985 | 556 | 14,196 | 27,143 | 87 | 3,559 | 45,541 |
| 1986 | 223 | 13,984 | 24,785 | 397 | 3,587 | 42,975 |
| 1987 | 262 | 16,589 | 26,731 | 812 | 5,110 | 49,503 |
| 1988 | 386 | 19,861 | 24,898 | 615 | 6,990 | 52,750 |
| 1989 | 228 | 13,738 | 36,099 | 797 | 7,159 | 58,021 |
| 1990 | 1,175 | 10,258 | 42,018 | 1,283 | 4,870 | 59,603 |
| 1991 | 0 | 12,065 | 30,476 | 1,899 | 1,433 | 45,874 |
| 1992 | 0 | 5,513 | 16,150 | 13,501 | 1,976 | 37,141 |
| 1993 | 0 | 4,731 | 25,737 | 13,043 | 1,783 | 45,295 |
| 1994 | 0 | 2,260 | 20,674 | 19,282 | 2,088 | 44,303 |
| 1995 | 0 | 1,621 | 13,598 | 16,011 | 8,601 | 39,830 |
| 1996 | 0 | 2,450 | 9,382 | 10,206 | 11,843 | 33,882 |
| 1997 | 0 | 2,742 | 9,426 | 8,295 | 13,550 | 34,014 |
| 1998 | 0 | 3,225 | 6,960 | 10,171 | 10,289 | 30,646 |
| 1999 | 0 | 2,595 | 7,623 | 9,132 | 12,276 | 31,626 |
| 2000 | 0 | 2,517 | 8,013 | 7,071 | 10,562 | 28,163 |
| 2001 | 0 | 2,190 | 10,857 | 7,938 | 11,404 | 32,389 |
| 2002 | 0 | 4,303 | 6,733 | 11,686 | 7,829 | 30,551 |
| 2003 | 0 | 2,298 | 5,739 | 7,476 | 3,172 | 18,685 |

[1]2003 is a partial year.

Table A4.

| Summary of annual, large vessel, commercial catch rates (kg meat/hr) of ocean quahogs, by region (assuming 1 bu = 10 lbs = 4.5359 kg). |
| A separate GLM on ln(LPUE) was run for each region.  SVA was excluded due to small sample size. |
| GLM #1 models include year and subregion as explanatory variables.  They include all trips. |
| GLM #2 models include vessel, year and subregion as explanatory variables. They omit annual data from fishery startup years and from vessels with <25 trips within a year. |

| Year | DMV Nominal | GLM #1 GLM 1. (Yr, Subreg) | CV | GLM #2 GLM 2. (Yr, Vessel, Subreg) | CV | NJ Nominal | GLM #1 GLM 1. (Yr, Subreg) | CV | GLM #2 GLM 2. (Yr, Vessel, Subreg) | CV | LI Nominal | GLM #1 GLM 1. (Yr, Subreg) | CV | GLM #2 GLM 2. (Yr, Vessel, Subreg) | CV | SNE Nominal | GLM #1 GLM 1. (Yr, Subreg) | CV | GLM #2 GLM 2. (Yr, Vessel, Subreg) | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1980 | 608.53 | 537.241 | 0.245 | 631.487 | 0.245 | 486.399 | 635.216 | 0.233 | 503.186 | 0.264 | 183.14 | 226.129 | 0.672 | | | | | | | |
| 1981 | 621.29 | 544.146 | 0.246 | 629.068 | 0.246 | 546.889 | 694.881 | 0.233 | 560.694 | 0.264 | 556.4 | 686.978 | 0.672 | | | | | | | |
| 1982 | 647.42 | 576.798 | 0.245 | 686.336 | 0.244 | 611.063 | 767.421 | 0.233 | 606.853 | 0.264 | | | | | | | | | | |
| 1983 | 757.83 | 659.576 | 0.245 | 787.469 | 0.244 | 614.742 | 788.755 | 0.233 | 629.481 | 0.264 | 420.93 | 401.575 | 0.454 | | | 400.921 | 413.509 | 0.239 | | |
| 1984 | 664.85 | 594.973 | 0.244 | 708.751 | 0.243 | 583.724 | 742.736 | 0.233 | 589.504 | 0.264 | | | | | | 326.735 | 337.827 | 0.233 | | |
| 1985 | 746.04 | 650.575 | 0.245 | 756.326 | 0.243 | 603.909 | 738.403 | 0.232 | 589.791 | 0.263 | 462.35 | 573.688 | 0.358 | | | 335.186 | 333.369 | 0.232 | | |
| 1986 | 708.1 | 615.469 | 0.244 | 676.076 | 0.243 | 631.02 | 747.983 | 0.233 | 592.837 | 0.264 | 1159.11 | 1322.442 | 0.250 | | | 493.941 | 521.523 | 0.243 | | |
| 1987 | 693.65 | 622.677 | 0.243 | 638.299 | 0.242 | 591.949 | 704.401 | 0.233 | 553.480 | 0.264 | 1453.74 | 1721.910 | 0.206 | | | 572.92 | 604.592 | 0.237 | | |
| 1988 | 606.66 | 553.135 | 0.243 | 552.744 | 0.242 | 589.112 | 679.055 | 0.234 | 512.579 | 0.264 | 963.76 | 1191.574 | 0.240 | | | 552.675 | 560.008 | 0.238 | 752.993 | 0.237 |
| 1989 | 523.2 | 505.072 | 0.244 | 501.446 | 0.242 | 568.287 | 681.653 | 0.232 | 497.583 | 0.263 | 758.86 | 930.368 | 0.223 | | | 437.949 | 461.430 | 0.230 | 728.736 | 0.233 |
| 1990 | 463.51 | 426.080 | 0.247 | 471.437 | 0.244 | 532.868 | 643.898 | 0.232 | 465.043 | 0.263 | 576.5 | 860.130 | 0.225 | | | 497.907 | 551.271 | 0.234 | 800.716 | 0.236 |
| 1991 | 397.01 | 367.778 | 0.245 | 386.077 | 0.243 | 468.862 | 556.598 | 0.232 | 393.614 | 0.263 | 819.81 | 848.479 | 0.210 | 1001.963 | 0.219 | 598.657 | 596.864 | 0.231 | 784.662 | 0.232 |
| 1992 | 426.45 | 409.600 | 0.251 | 399.749 | 0.247 | 397.201 | 494.193 | 0.234 | 384.750 | 0.264 | 870.11 | 854.487 | 0.167 | 1028.605 | 0.191 | 712.962 | 736.070 | 0.227 | 963.822 | 0.227 |
| 1993 | 401.41 | 389.355 | 0.250 | 364.593 | 0.248 | 377.707 | 452.653 | 0.233 | 328.006 | 0.263 | 657.14 | 677.662 | 0.169 | 796.102 | 0.191 | 706.506 | 715.271 | 0.229 | 939.242 | 0.230 |
| 1994 | 440.88 | 399.591 | 0.258 | 396.544 | 0.253 | 329.983 | 387.131 | 0.234 | 300.717 | 0.264 | 615.01 | 648.662 | 0.167 | 733.556 | 0.189 | 593.141 | 603.831 | 0.231 | 793.167 | 0.231 |
| 1995 | 430.93 | 384.360 | 0.264 | 372.672 | 0.258 | 382.477 | 456.100 | 0.235 | 359.352 | 0.264 | 620.71 | 643.573 | 0.168 | 768.406 | 0.190 | 650.609 | 654.160 | 0.211 | 744.940 | 0.217 |
| 1996 | 300.42 | 417.895 | 0.264 | 401.844 | 0.258 | 519.089 | 640.699 | 0.238 | 495.504 | 0.266 | 605.06 | 617.973 | 0.170 | 733.239 | 0.191 | 709.095 | 712.088 | 0.210 | 791.508 | 0.215 |
| 1997 | 392.51 | 346.067 | 0.258 | 365.361 | 0.253 | 463.504 | 581.458 | 0.238 | 431.927 | 0.266 | 637.85 | 650.393 | 0.173 | 757.129 | 0.193 | 690.272 | 696.233 | 0.211 | 749.646 | 0.215 |
| 1998 | 431.95 | 383.297 | 0.258 | 381.972 | 0.253 | 380.099 | 508.365 | 0.242 | 382.202 | 0.268 | 693.91 | 702.060 | 0.175 | 796.318 | 0.193 | 642.66 | 650.164 | 0.212 | 709.184 | 0.216 |
| 1999 | 417.7 | 370.396 | 0.259 | 352.218 | 0.253 | 390.013 | 499.392 | 0.242 | 370.923 | 0.268 | 746.33 | 748.803 | 0.174 | 863.935 | 0.193 | 552.507 | 537.267 | 0.211 | 628.244 | 0.215 |
| 2000 | 416.22 | 380.240 | 0.258 | 347.104 | 0.253 | 414.076 | 520.799 | 0.239 | 386.338 | 0.266 | 688.19 | 682.587 | 0.179 | 775.917 | 0.196 | 491.894 | 472.576 | 0.212 | 591.276 | 0.216 |
| 2001 | 406.95 | 351.925 | 0.263 | 293.901 | 0.256 | 425.326 | 538.499 | 0.237 | 391.467 | 0.265 | 699.64 | 673.930 | 0.178 | 768.241 | 0.196 | 421.963 | 426.384 | 0.213 | 510.781 | 0.216 |
| 2002 | 398.41 | 379.475 | 0.254 | 322.193 | 0.248 | 433.116 | 532.641 | 0.245 | 379.214 | 0.269 | 797.56 | 780.584 | 0.172 | 814.961 | 0.189 | 517.175 | 556.111 | 0.213 | 754.344 | 0.218 |
| 2003 | 347.77 | 328.869 | | 279.719 | | 356.319 | 437.553 | | 285.799 | | 837.76 | 837.743 | | 860.494 | | 548.802 | 572.908 | | 701.548 | |

Table A5.

Commercial logbook data about ocean quahogs from Maine. Landings are in units of "Maine bushels (1 Maine bushel = 1.2448 c. ft.).
Effort is in hours fished. LPUE = "Maine" bushels/hour fished.
 Only records with both catch and effort > 0, were included. 2003 is a partial year of data.
Logbook  data (sfYYvr tables) from Maine are included regardless of whether they came from state or federal waters.
Undertonnage: 0-5 gross tons, Small: 5-50 gross tons, Medium: 51-104 gross tons, Large: >104 gross tons.
The GLM of catch rate included factors: year, subregion, vessel. Only vessels with at least 25 trips in a year were included.

| Year | Landings (Maine bushels), by vessel class: | | | | | Effort (hrs fished) | Nominal LPUE (ME bu / hr) | GLM: Catch rate | GLM: CV |
|---|---|---|---|---|---|---|---|---|---|
| | Undertonnage | Small | Med | Large | Small + Underton | Small + Underton | Small + Underton | Small + Underton | Small + Underton |
| 1990 | 1,018 | | -- | -- | 1,018 | 286 | 3.56 | -- | -- |
| 1991 | 17,778 | 16,533 | 49 | -- | 34,360 | 17,107 | 2.01 | 4.96 | 0.230 |
| 1992 | 13,141 | 11,310 | 68 | -- | 24,519 | 13,402 | 1.83 | 4.37 | 0.230 |
| 1993 | 10,052 | 7,092 | 1,568 | -- | 18,712 | 5,748 | 3.26 | 4.78 | 0.241 |
| 1994 | 9,960 | 11,520 | -- | -- | 21,480 | 5,101 | 4.21 | 9.62 | 0.233 |
| 1995 | 20,339 | 17,573 | -- | 7,840 | 45,752 | 5,747 | 7.96 | 13.71 | 0.230 |
| 1996 | 28,194 | 16,697 | -- | -- | 44,891 | 8,083 | 5.55 | 12.85 | 0.230 |
| 1997 | 45,158 | 27,489 | -- | -- | 72,647 | 11,829 | 6.14 | 12.96 | 0.226 |
| 1998 | 43,444 | 25,364 | -- | -- | 68,808 | 11,155 | 6.17 | 11.30 | 0.227 |
| 1999 | 64,464 | 27,750 | -- | -- | 92,214 | 11,136 | 8.28 | 17.01 | 0.227 |
| 2000 | 76,375 | 41,306 | -- | -- | 117,681 | 12,575 | 9.36 | 17.86 | 0.225 |
| 2001 | 68,309 | 39,273 | -- | -- | 107,582 | 13,309 | 8.08 | 14.99 | 0.225 |
| 2002 | 80,139 | 48,570 | -- | -- | 128,709 | 16,981 | 7.58 | 14.73 | 0.224 |

Table A6. Summary statistics on ocean quahog commercial length frequency data by year/area. Data were collected by port agents taking random samples from catches.

| Area/Year Clams | Mean Length (mm) | Min L | Max L | Number of Measured |
|---|---|---|---|---|
| **Delmarva** | | | | |
| 1982 | 85.0 | 65 | 115 | 2611 |
| 1983 | 87.0 | 65 | 115 | 1716 |
| 1984 | 85.2 | 65 | 125 | 3116 |
| 1985 | - | - | - | - |
| 1986 | - | - | - | - |
| 1987 | 90.2 | 65 | 115 | 900 |
| 1988 | 90.1 | 55 | 115 | 780 |
| 1989 | 89.3 | 75 | 115 | 899 |
| 1990 | 92.4 | 75 | 125 | 900 |
| 1991 | 91.4 | 35 | 117 | 3331 |
| 1992 | 92.9 | 66 | 118 | 1668 |
| 1993 | 91.6 | 64 | 115 | 850 |
| 1994 | 92.5 | 65 | 115 | 120 |
| 1995 | 84.8 | 65 | 105 | 420 |
| 1996 | 84.0 | 65 | 115 | 635 |
| 1997 | 84.6 | 55 | 105 | 570 |
| 1998 | 86.9 | 65 | 125 | 480 |
| 1999 | 83.0 | 65 | 115 | 810 |
| 2000 | 83.1 | 37 | 111 | 605 |
| 2001 | 88.9 | 65 | 117 | 715 |
| 2002 | 89.1 | 66 | 109 | 300 |
| 2003 | 92.2 | 59 | 112 | 330 |
| | | | | |
| **New Jersey** | | | | |
| 1982 | 92.6 | 65 | 125 | 779 |
| 1983 | 93.9 | 75 | 115 | 1980 |
| 1984 | - | - | - | - |
| 1985 | 94.5 | 65 | 125 | 900 |
| 1986 | 94.5 | 75 | 125 | 870 |
| 1987 | 94.2 | 65 | 115 | 900 |
| 1988 | 92.6 | 65 | 115 | 933 |
| 1989 | 94.3 | 65 | 115 | 900 |
| 1990 | 95.5 | 55 | 115 | 870 |
| 1991 | 95.5 | 65 | 117 | 658 |
| 1992 | 90.4 | 77 | 108 | 90 |
| 1993 | 94.8 | 78 | 112 | 300 |
| 1994 | 96.9 | 85 | 115 | 90 |
| 1995 | - | - | - | - |
| 1996 | 92.0 | 75 | 105 | 60 |
| 1997 | 93.9 | 65 | 115 | 540 |
| 1998 | 88.4 | 45 | 115 | 240 |
| 1999 | 95.4 | 75 | 125 | 270 |
| 2000 | 91.7 | 65 | 115 | 510 |
| 2001 | 93.9 | 65 | 123 | 689 |
| 2002 | 89.8 | 62 | 117 | 390 |
| 2003 | 93.3 | 73 | 115 | 206 |
| | | | | |
| **Long Island** | | | | |
| 1992 | 87.3 | 70 | 98 | 30 |
| 1993 | - | - | - | - |
| 1994 | 89.7 | 75 | 105 | 30 |
| 1995 | - | - | - | 0 |
| 1996 | 83.1 | 65 | 105 | 79 |
| 1997 | 89.0 | 55 | 135 | 840 |
| 1998 | 89.9 | 55 | 125 | 660 |
| 1999 | 75.4 | 51 | 106 | 180 |
| 2000 | 77.6 | 48 | 105 | 366 |
| 2001 | 77.0 | 61 | 101 | 150 |
| 2002 | 81.5 | 63 | 108 | 270 |
| 2003 | 81.9 | 63 | 111 | 270 |

## Table A6. (cont.)

| Area/Year Clams | Mean Length (mm) | Min L | Max L | Number of Measured |
|---|---|---|---|---|
| S. New England | | | | |
| 1988 | 89.1 | 65 | 105 | 150 |
| 1989 | 87.3 | 75 | 115 | 240 |
| 1990 | 91.8 | 75 | 105 | 120 |
| 1991 | 90.5 | 70 | 109 | 121 |
| 1992 | 86.4 | 70 | 105 | 150 |
| 1993 | 85.3 | 72 | 99 | 30 |
| 1994 | - | - | - | - |
| 1995 | - | - | - | - |
| 1996 | 86.7 | 65 | 115 | 356 |
| 1997 | 78.7 | 55 | 105 | 310 |
| 1998 | 78.7 | 55 | 125 | 630 |
| 1999 | 81.2 | 57 | 104 | 90 |
| 2000 | 81.0 | 52 | 110 | 734 |
| 2001 | 85.3 | 52 | 111 | 766 |
| 2002 | 85.1 | 65 | 114 | 1011 |
| 2003 | 82.5 | 65 | 108 | 332 |

[1] Mean Length is the expected value from the length frequency distribution.  Length frequency distributions were derived  by weighting trips by their respective catches.
[2] Typically, 30 clams are measured per trip.  The minimum and maximum lengths of measured clams are reported.
[3] Values for 1982-1983 are from NEFSC LDR 83-25.  Values from 1985-1990 and 1994 are from subsamples of the data. Subsamples contain data  from 30 randomly selected trips, when available.

Table A7. List of research clam surveys and gear changes from 1965-1981, and 1997-2002. Column entries are shifted to accentuate changes. Changes in the gear and survey season did not occur from August, 1980 to 1992. Sources of information for 1978 - 1981 are Smolovitz and Nulk 1982 and NEFSC Cruise Reports. Sources of information for 1965 - 1977 are NEFSC 1995a and NEFSC Survey Reports. "Sensors Used" : refers to the velocity, tilt and pump pressure sensors, used in computing tow distance and pump performance. These were used for the first time in 1997. "-" : undetermined.

| Cruise | Date | Vessel | Season | Purpose | Pump Type | Dredge Width(cm) | Mesh Size (cm) | Doppler Measured | Sensor Used |
|--------|------|--------|--------|---------|-----------|------------------|----------------|------------------|-------------|
| 65- | 5/65 | Undaunted | Spring | Survey | Surface | 76 | 5.1 | - | | No |
| 65-10 | 10/65 | Undaunted | Fall | Survey | Surface | 76 | 5.1 | | - | No |
| 66-6,11 | 8/66 | Albatross IV | Summer | Survey | Surface | 76 | 5.1 | | - | No |
| 69-1,7 | 6/69 | Albatross IV | Summer | Survey | Surface | 76 | 5.1 | | - | No |
| 70-6 | 8/70 | Delaware | Summer | Survey | Surface | 122 | 3 | | - | No |
| SM742 | 6/74 | Delaware | Summer | Survey | Surface | 76 | 5.1 | | - | No |
| 76-1 | 4/76 | Delaware | Spring | Survey | Surface | 122 | 3 | | - | No |
| 77-2 | 1/77 | Delaware | Winter | Survey | Surface | 122 | 3 | | - | No |
| 7801 | 1/78 | Delaware | Winter | Survey | Surface | 122 | 1.91 | No | No |
| 7807 | 12/78 | Delaware | Winter | Survey | Surface | 122 | 1.91 | Yes | No |
| 7901 | 1/79 | Delaware | Winter | Survey | Submerse | 152 | 2.54 | Yes | No |
| 7908 | 8/79 | Delaware | Summer | Gear test | Submerse | 152 | 2.54 & 5.08 | Yes | No |
| 8001 | 1/80 | Delaware | Winter | Survey | Submerse | 152 | 5.08 | Yes | No |
| 8006 | 8/80 | Delaware | Summer | Survey | Submerse | 152 | 5.08 | Yes | No |
| 8105 | 8/81 | Delaware | Summer | Survey | Submerse | 152 | 5.08 | Yes | No |
| 9704 | 7/97 | Delaware | Summer | Survey | Submerse | 152 | 5.08 | Yes | Yes[1] |
| 9903 | 7/99 | Delaware | Summer | Survey | Submerse | 152 | 5.08 | Yes | Yes[2] |
| 200206 | 6/02 | Delaware | Summer | Survey | Submerse | 152 | 5.08 | Yes | Yes[3] |

[1]. Individual sensors were used.
[2]. A protoptype integrated sensor package was used for the first 2/3 of the cruise. After that, individuals sensors were used.
[3]. First use of Survey Sensor Package (SSP) from Woods Hole Group. Used for entire cruise. Individ. sensors used as backup.

Table A8.  Recent gear changes related to the NMFS Clam Survey, 1992-2002. Column entries were shifted to accentuate changes.  Changes in the gear and survey season did not occur from August, 1980 to 1992, or from 1999 to 2002. Sources of information are NEFSC Cruise Meetings. "-" : undetermined.

| Cruise | Date | Vessel | Ship Modified | Winch Changed | Winch Speed Out (met/min) | Winch Speed In (met/min) | Voltage to Pump |
|--------|------|--------|---------------|---------------|---------------------------|--------------------------|-----------------|
| pre-92 |      | Delaware II |          |          | 60         | 60    | 460 |
| 9203   | 6/92 | Delaware II |          | --       | --         | 80    | 460 |
| 9404   | 8/94 | Delaware II |          |          | Free spool | 80    | 480 |
| 9704   | 7/97 | Delaware II | 1/97     | 1/97     | 20         | 20    | 460 |
| 9903   | 7/99 | Delaware II |          | 5/99     | 50-60      | 50-60 | 460 |
| 200206 | 7/02 | Delaware II |          | 5/99     | 50-60      | 50-60 | 460 |

Table A9.  Historical estimates of efficiency of the DE-II dredge catching OQ.

| Year | Eff of DE-II for OQ | Description/Source |
|------|---------------------|--------------------|
| 1997 | 0.430 | Value used in SARC27 (median of estimates from 5 OQ depletion exps using commercial dredges in 1997, 1998.  **No** DE-II depl experiment or setup tows available.) |
| 1997 | 0.346 | Value used in 1999 for SARC31 (see below) |
| 1999 | 0.346 | Value used in SARC31 (Table C13. From OQ depletion exps with DE-II setup tows in 1999, 2000, and 1 DE-II depl. experiment.) |

Table A10.  Locations and depths of NMFS ocean quahog dredge calibration experiments
and sediment samples during the 2002 Delaware-II clam survey.

| Site | Latitude (dd) | Longitude (dd) | Depth (m) |
|------|---------------|----------------|-----------|
| OQ02-1 | 40.727620 | 71.737299 | 60 |
| OQ02-2 | 40.103116 | 73.191079 | 48 |
| OQ02-3 | 38.814912 | 73.813348 | 50 |
| OQ02-4 | 37.887552 | 74.644855 | 48 |

Table A11. Summary of *Delaware-II* **dredge efficiency** for ocean quahogs in 2002 (Cruise 200206), inferred by comparing catches in DE-II S
Tows with Patch Model Estimates, assuming no indirect losses, from data collected with commercial clam vessel *F/V Lisa Kim*.

Formula used to compute DEL-II dredge efficiency (EFF) in experiments with the Lisa Kim (LK):

$$EFF(DEL) = [EFF(LK,model)*MinDensity(DEL)] / Density(LK,model)$$

| Experiment | Region | Lisa Kim Density (#/ft^2) Model | Lisa Kim Efficiency Model | Delaware Station # | Delaware Density (#/ft^2) Setup Tows | Delaware Density (#/ft^2) Setup Tows | Delaware vs Lisa Kim Relative Efficiency |
|---|---|---|---|---|---|---|---|
| OQ02-1 | LI-E | | | 5 | 0.0863 | | |
| | | | | 6 | 0.0337 | | |
| | | | | 7 | 0.0403 | | |
| | | | | 8 | 0.0295 | | |
| | | | | 9 | 0.0317 | | |
| | | 0.55 | 0.653 | | Average: | 0.0443 | 0.081 |
| | | | | | SD of samples: | 0.0238 | |
| OQ02-2 | LI-W | | | 25 | 0.0676 | | |
| | | | | 26 | 0.0341 | | |
| | | | | 27 | 0.0377 | | |
| | | | | 28 | 0.0482 | | |
| | | | | 29 | 0.0855 | | |
| | | 0.345 | 0.81 | | Average: | 0.0546 | 0.158 |
| | | | | | SD of samples: | 0.0216 | |
| OQ02-3 | SNJ | | | 213 | 0.0448 | | |
| | | | | 214 | 0.0272 | | |
| | | | | 215 | 0.0422 | | |
| | | | | 216 | 0.0052 | | |
| | | | | 217 | 0.0335 | | |
| | | 0.111 | 0.816 | | Average: | 0.0305 | 0.275 |
| | | | | | SD of samples: | 0.0158 | |
| OQ02-4 | DMV | | | 272 | 0.0440 | | |
| | | | | 273 | 0.0401 | | |
| | | | | 274 | 0.0507 | | |
| | | | | 275 | 0.0622 | | |
| | | | | 276 | 0.0425 | | |
| | | 0.101 | 0.599 | | Average: | 0.0479 | 0.474 |
| | | | | | SD of samples: | 0.0089 | |
| | | | | | Grand Mean | | |
| | | | | | SD of 4 averages: | | |
| | | | | | N | | |

For both Commercial Tows and the DE-II Dist. Calc. Is based on: Distance between Points program.
Survey setup tows: use neg1 inch, de2setuptows02_neg1in.xls.      C:\depletion\2002dat\blade1in\GE130\      /deplresults_field2002.xls
Commercial tows: used 1inch, and were run 1/31/03. ~survey/surv_2002/comm…/oq…/sensors/. Positions use a blend of SSP data and Eric's
Vessels had approx. = selectivity, so all shell sizes were included.

Table A12 . Analysis of Repeated DE-II stations, by the DE-II.

**Estimates of Relative Efficiency for the DE-II Dredge over time, based on OQ catches at DE-2 Repeat Stations on GBK (standardized to 0.15nmi with sensors; 70mm+ only)**
**Method 2: bootstrapped the 12 ratios, computed and saved the median, repeated for 100,000 trials.**

| | | Method 1 | Method 2 | | |
|---|---|---|---|---|---|
| | Sum of catches (12 tows) | Ratio of Sums of Catches ( T/T-1 ) | Bootstrap Ratio Estimator T:T-1 | | |
| Time (T) | | | Median | 5%LL | 95%UL |
| 1997 | 6381.6 | | | | |
| 1999 | 5141.4 | 0.806 | 0.758 | 0.323 | 0.856 |
| 1999 | 5141.4 | | | | |
| 2002 | 4279.4 | 0.832 | 0.845 | 0.56 | 1.878 |

9/11/2003
~sarc/sarc38oq/tabs/effsummary97_2002.xls

Table A13 .

| | Count | DE-II Eff. | Source |
|---|---|---|---|
| Estimate of DE-II dredge efficiency for ocean quahogs in 1999 and 2002. Results were used in ESB model (Tables A17, A18) and in KLAMZ. | | | |
| | 1 | 0.053 | OQ02-1, 2002 depletion exp., setups |
| | 2 | 0.128 | OQ02-2, 2002 depletion exp., setups |
| | 3 | 0.225 | OQ02-3, 2002 depletion exp., setups |
| | 4 | 0.284 | OQ02-4, 2002 depletion exp., setups |
| | 5 | 0.569 | SARC31 (T. C13), 1999 DE-II depletion |
| | 6 | 0.227 | SARC31 (T. C13), 2000 depletion exp., setups |
| | 7 | 0.313 | SARC31 (T. C13), 2000 depletion exp., setups |
| | 8 | 0.239 | SARC31 (T. C13), 2000 depletion exp., setups |
| | 9 | 0.384 | SARC31 (T. C13), 2 boat, density ratio |
| Average: | | 0.269 | |
| sd | | 0.149 | |
| CV | | 0.552 | |

Table A14.  Parameter estimates for the relationship between drained meat weight (gr) and shell length (mm) in **ocean quahogs**, by region and time.  Samples collected in 1997 and 2002 include all fresh tissue minus shell, weighed at sea. Earlier samples were frozen before weighing. Weight = (e^alpha)*(L^beta).

| REGION | ALPHA | BETA | Year Data Collected or Source of Data |
|---|---|---|---|
| DMV | -9.042313 | 2.787987 | Murawski and Serchuk (1979) |
| NJ | -9.847183 | 2.94954 | Murawski and Serchuk (1979) |
| LI | -9.124283 | 2.774989 | Murawski and Serchuk (1979) |
| LI | -9.310191 | 2.860486 | 1997 Survey |
| GBK | -8.833807 | 2.761124 | 1997 Survey |
| NJ | -9.40911 | 2.93204 | 2002 Survey |
| SNE | -9.0439 | 2.82375 | 2002 Survey |
| GBK | -9.66701 | 2.95215 | 2002 Survey |
| SVA | -9.042313 | 2.787987 | Values used in SARC-31 (NEFSC,  2000a)and SARC-38 |
| DMV | -9.042313 | 2.787987 | Values used in SARC-31 (NEFSC,  2000a)and SARC-38 |
| NJ | -9.847183 | 2.94954 | Values used in SARC-31 (NEFSC,  2000a)and SARC-38 |
| LI | -9.233646317 | 2.822474034 | Values used in SARC-31 (NEFSC,  2000a)and SARC-38 |
| SNE | -9.124283 | 2.774989 | Values used in SARC-31 (NEFSC,  2000a)and SARC-38 |
| GBK | -8.969072506 | 2.767282187 | Values used in SARC-31 (NEFSC,  2000a)and SARC-38 |

Table A15. NEFSC clam survey data for ocean quahog used in survey database trend calculations, by stock assessment area and cruise. Figures in each cell are the number of tows in calculations for each combination of stratum and cruise. Figures in plain text are the number of original tows (without borrowing). Bold and outlined figures are for cells with zero tow originally that were filled by borrowing tows from the same strata during previous or subsequent cruises. Black cells are cells zero with zero tows that could not be filled because there was no original data for previous or subsequent cruises. Borrowing was forward only (e.g. stratum 67 during the 9903 cruise), backward only (e.g. stratum 60 during the 8403 cruise), or both forward and backward (stratum 11 during the 8403 cruise). Tows originally in one cell may be borrowed forward and backward, but borrowed tows are never borrowed again in the same direction[1].

| Region | Stratum | 7801 | 7807 | 7901 | 8001 | 8006 | 8105 | 8204 | 8305 | 8403 | 8604 | 8903 | 9203 | 9404 | 9704 | 9903 | 200206 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DMV | 9 | 20 | 20 | 22 | 32 | 21 | 21 | 30 | 26 | 35 | 29 | 37 | 37 | 39 | 39 | 38 | 39 |
|  | 10 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
|  | 11 | 5 | 2 | 1 | **1** | **2** | 2 | 2 | 2 | **4** | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
|  | 13 | 19 | 10 | 5 | 16 | 12 | 10 | 19 | 18 | 25 | 20 | 20 | 20 | 21 | 22 | 19 | 20 |
|  | 14 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 5 | 3 | 3 | 3 |
|  | 15 | 6 | 3 | **3** | **4** | 4 | 4 | 4 | 4 | **8** | 4 | 4 | 4 | 5 | 4 | 5 | 4 |
| GBK | 54 |  |  |  |  |  |  |  | **3** | 3 | 3 | **6** | 3 | 3 | 3 | **3** |  |
|  | 55 |  |  |  |  |  |  | **3** | **3** | **3** | 3 | 1 | 3 | 3 | 3 | 2 | 2 |
|  | 56 |  |  |  |  |  |  |  |  |  |  |  |  |  | **4** | 4 | **4** |
|  | 57 |  |  |  | **1** | 1 | **1** |  |  | **2** | 2 | 1 | 2 | 5 | 2 | 2 | 2 |
|  | 58 |  |  |  |  |  |  |  |  |  |  |  |  |  | **5** | 5 | **5** |
|  | 59 |  |  |  | **5** | 5 | **6** | 1 | 4 | **5** | 1 | 2 | 6 | 5 | 5 | 4 | 5 |
|  | 60 |  |  |  | **1** | 1 | **1** |  |  | **2** | 2 | 2 | **4** | 2 | 5 | 5 | 5 |
|  | 61 |  |  |  | **3** | 3 | **11** | 8 | 1 | **6** | 5 | **12** | **7** | 6 | 6 | 6 | 6 |
|  | 62 |  |  |  | **1** | 1 | **1** |  |  | **1** | 1 | **1** | **4** | 4 | 4 | 4 | 4 |
|  | 65 |  |  |  |  |  |  |  |  | **3** | 3 | **5** | 2 | 2 | 3 | **4** | 1 |
|  | 67 |  |  |  |  |  |  |  | **5** | 5 | 5 | 7 | 7 | 7 | 7 | **7** |  |
|  | 68 |  |  |  |  |  | **1** | 1 | **8** | 7 | 3 | 6 | 6 | 5 | 5 | **5** |  |
|  | 69 |  |  |  |  |  | **2** | 2 | 5 | **11** | 6 | 6 | 6 | 7 | 6 | 7 | **7** |
|  | 70 |  |  |  |  |  | **1** | 1 | 2 | **6** | 4 | **8** | 4 | 4 | 4 | 3 | 2 |
|  | 71 |  |  |  |  |  |  |  | **2** | 2 | 3 | 1 | 2 | 3 | 3 | 1 | 2 |
|  | 72 |  |  |  |  |  | **2** | 2 | **10** | 8 | 1 | 8 | 8 | 8 | 8 | 6 | **6** |
|  | 73 |  |  |  |  |  | **1** | 1 | 1 | **4** | 3 | 6 | 6 | 6 | 6 | 5 | 6 |
|  | 74 |  |  |  |  |  | **3** | 3 | **4** | 1 | 3 | **7** | 4 | 4 | 4 | 3 | 3 |
| LI | 29 | 16 | 7 | 13 | 8 | 11 | 10 | 11 | 10 | **20** | 10 | 10 | 10 | 10 | 10 | 11 | 10 |
|  | 30 | 10 | 2 | 6 | 6 | 7 | 7 | 7 | 8 | **14** | 6 | 6 | 6 | 6 | 6 | 7 | 6 |
|  | 31 | 10 | **13** | 3 | 2 | 9 | 9 | 9 | 7 | **12** | 5 | 7 | 8 | 8 | 8 | 9 | 8 |
|  | 33 | 3 | 2 | 4 | 3 | 2 | 4 | 4 | 4 | **8** | 4 | 4 | 4 | 5 | 4 | 4 | 4 |
|  | 34 | 3 | 2 | 1 | 2 | **4** | 2 | 2 | 2 | **4** | 2 | 2 | 2 | 5 | 2 | 2 | 2 |
|  | 35 | 8 | 4 | **4** |  |  | 6 | 4 | 2 | **4** | 2 | 5 | 6 | 6 | 6 | 6 | 6 |
|  | 91 | 4 | 5 | 4 | 3 | 3 | 3 | 3 | 2 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
|  | 92 | 6 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
|  | 93 | 4 | 2 | 3 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 2 |
| NJ | 17 | 16 | 5 | 5 | 12 | 12 | 10 | 11 | 11 | 18 | 12 | 12 | 12 | 12 | 14 | 12 | 12 |
|  | 18 | 4 | 2 | **5** | 3 | 3 | 3 | 3 | 3 | **6** | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
|  | 19 | 5 | 1 | **1** | **3** | 3 | 3 | 3 | 3 | **6** | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
|  | 21 | 30 | 14 | 16 | 20 | 18 | 10 | 18 | 18 | 22 | 19 | 20 | 20 | 23 | 26 | 39 | 29 |
|  | 22 | 5 | 4 | 1 | 3 | 3 | 3 | 3 | 3 | **6** | 3 | 3 | 3 | 5 | 3 | 3 | 3 |
|  | 23 | 13 | 6 | **6** | **6** | 6 | 7 | 7 | 6 | **11** | 5 | 4 | 5 | 5 | 5 | 5 | 5 |
|  | 25 | 12 | 6 | 8 | 12 | 9 | 9 | 9 | 9 | 13 | 8 | 9 | 9 | 9 | 12 | 8 | 9 |
|  | 26 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | **5** | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
|  | 27 | 5 | 2 | **2** | **3** | 3 | 4 | 4 | 4 | **8** | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
|  | 87 | 10 | 6 | 5 | 6 | 6 | 6 | 8 | 7 | 10 | 9 | 9 | 9 | 9 | 9 | 9 | 16 |
|  | 88 | 12 | 8 | 6 | 12 | 11 | 10 | 15 | 15 | 24 | 17 | 20 | 20 | 20 | 21 | 22 | 20 |
|  | 89 | 9 | 8 | 4 | 13 | 10 | 10 | 15 | 15 | 21 | 15 | 18 | 17 | 17 | 19 | 18 | 18 |
|  | 90 | 4 | 4 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| SNE | 37 | 5 | **5** |  |  | **2** | 2 | 7 | 4 | **7** | 3 | **6** | 3 | 5 | 4 | 4 | 3 |
|  | 38 | 4 | **5** | 1 | 2 | **5** | 3 | 3 | 2 | **5** | 3 | 3 | 3 | 5 | 3 | 3 | 3 |
|  | 39 | 14 | **20** | 6 | 1 | **11** | 10 | 6 | 4 | **6** | 2 | 5 | 5 | 5 | 5 | 5 | 5 |
|  | 41 | 3 | **4** | 1 | 5 | 6 | 6 | 6 | 5 | 7 | 5 | 6 | 6 | 6 | 6 | 5 | 6 |
|  | 45 |  |  |  |  | **3** | 3 | 7 | 9 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
|  | 46 |  |  |  |  | **2** | 2 | 5 | 5 | 3 | 2 | 3 | 5 | 3 | 3 | 2 |  |
|  | 47 |  |  |  | **1** | 1 | **5** | 4 | 3 | 4 | 2 | 2 | 4 | 5 | 4 | 3 | 1 |
|  | 94 | 1 | **1** | **1** | 1 | **1** | 2 | 1 | 2 | **2** |  | **1** | 1 | 2 | 2 | **4** | 2 |
|  | 95 | 2 | **2** | **6** | 6 | 4 | 4 | 4 | 14 | 11 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
|  | 96 |  |  |  |  |  | **12** | 12 | **13** | 1 | 1 | 3 | 2 | 4 | **4** |  |  |
| SVA | 5 | 11 | **11** | 8 | 8 | **12** | 4 | 4 | 9 | 13 | 8 | 8 | 8 | 8 | 8 | **16** | 8 |
|  | 6 |  |  |  |  | **1** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | **3** | 2 |

[1] For example, 1 tow originally in stratum 62 during the 8604 survey was borrowed both forward and backward. However the borrowed tow in stratum 62 during the 8403 cruise was not borrowed again to fill the zero for the 8305 cruise. Tows from the 810? cruise were not borrowed forward becauase data base codes (for the variables STATYPE, HAUL and GEARCOND) used to select records beginning with the 8204 cruise are not available for previous cruises. However, tows from the 8204 cruise were borrowed backwards because the 8204 cruise was included in database runs for previous cruises with criteria based on STATYPE, HAUL and GEARCOND turned off

Table A16. NEFSC clam survey trend data for ocean quahog. All columns reflect original plus borrowed tows. For example, "Number of Strata Sampled" includes strata not originally surveyed and included in calculations due to borrowing. Catches standardized to a 0.15 nm tow distance based on doppler distance measurements. Differences in SVA data for cruises 8305-9704 between this table and Table C14 in NEFSC (2000) are due to errors in the latter.

| Cruise | KG Meats Per Tow | CV | Number Per Tow | CV | Number tows | Number Positive Tows | Number Strata Sampled |
|---|---|---|---|---|---|---|---|
| | | | SVA | | | | |
| 7801 | 0.000 | 0% | 0.000 | 0% | 11 | 0 | 1 |
| 7807 | 0.000 | 0% | 0.000 | 0% | 11 | 0 | 1 |
| 7901 | 0.000 | 0% | 0.000 | 0% | 8 | 0 | 1 |
| 8001 | 0.000 | 0% | 0.000 | 0% | 8 | 0 | 1 |
| 8006 | 0.040 | 0% | 0.927 | 0% | 13 | 1 | 2 |
| 8105 | 0.040 | 0% | 0.927 | 0% | 5 | 1 | 2 |
| 8204 | 0.002 | 0% | 0.039 | 0% | 5 | 1 | 2 |
| 8305 | 0.099 | 58% | 1.892 | 58% | 10 | 3 | 2 |
| 8403 | 0.010 | 87% | 0.189 | 85% | 14 | 2 | 2 |
| 8604 | 0.013 | 0% | 0.285 | 0% | 9 | 1 | 2 |
| 8903 | 0.018 | 0% | 0.392 | 0% | 9 | 1 | 2 |
| 9203 | 0.000 | 0% | 0.000 | 0% | 9 | 0 | 2 |
| 9404 | 0.202 | 79% | 4.028 | 76% | 9 | 2 | 2 |
| 9704 | 0.003 | 0% | 0.116 | 0% | 9 | 1 | 2 |
| 9903 | 0.002 | 64% | 0.053 | 63% | 19 | 2 | 2 |
| 200206 | 0.001 | 100% | 0.022 | 100% | 10 | 1 | 2 |
| | | | DMV | | | | |
| 7801 | 1.456 | 46% | 47.309 | 61% | 55 | 30 | 6 |
| 7807 | 1.234 | 19% | 35.659 | 23% | 39 | 16 | 6 |
| 7901 | 1.277 | 41% | 38.177 | 42% | 35 | 12 | 6 |
| 8001 | 2.914 | 38% | 82.480 | 40% | 57 | 26 | 6 |
| 8006 | 1.957 | 54% | 55.557 | 59% | 43 | 21 | 6 |
| 8105 | 4.211 | 33% | 138.269 | 32% | 41 | 21 | 6 |
| 8204 | 2.946 | 34% | 78.424 | 32% | 59 | 24 | 6 |
| 8305 | 2.525 | 42% | 84.486 | 49% | 54 | 28 | 6 |
| 8403 | 1.649 | 30% | 50.559 | 34% | 78 | 34 | 6 |
| 8604 | 2.525 | 22% | 75.139 | 23% | 61 | 27 | 6 |
| 8903 | 1.814 | 45% | 64.189 | 56% | 69 | 31 | 6 |
| 9203 | 2.275 | 31% | 71.214 | 36% | 69 | 25 | 6 |
| 9404 | 1.359 | 22% | 39.647 | 24% | 75 | 28 | 6 |
| 9704 | 1.651 | 21% | 46.269 | 21% | 73 | 28 | 6 |
| 9903 | 0.936 | 27% | 27.419 | 30% | 70 | 23 | 6 |
| 200206 | 1.092 | 23% | 30.621 | 25% | 71 | 19 | 6 |

Table 16. Continued

*NJ*

| Cruise | KG Meats Per Tow | CV | Number Per Tow | CV | Number tows | Number Positive Tows | Number Strata Sampled |
|---|---|---|---|---|---|---|---|
| 7801 | 1.898 | 14% | 57.581 | 15% | 126 | 73 | 13 |
| 7807 | 6.707 | 74% | 233.413 | 78% | 68 | 32 | 13 |
| 7901 | 3.730 | 54% | 122.955 | 60% | 63 | 32 | 13 |
| 8001 | 3.096 | 19% | 93.267 | 20% | 97 | 52 | 13 |
| 8006 | 3.385 | 18% | 107.930 | 19% | 87 | 52 | 13 |
| 8105 | 7.253 | 29% | 220.418 | 29% | 79 | 43 | 13 |
| 8204 | 3.606 | 19% | 112.557 | 20% | 100 | 50 | 13 |
| 8305 | 2.807 | 21% | 83.890 | 21% | 98 | 55 | 13 |
| 8403 | 4.528 | 24% | 141.127 | 24% | 153 | 79 | 13 |
| 8604 | 4.896 | 22% | 142.243 | 23% | 103 | 52 | 13 |
| 8903 | 2.209 | 21% | 72.384 | 22% | 110 | 50 | 13 |
| 9203 | 3.015 | 17% | 87.169 | 18% | 110 | 52 | 13 |
| 9404 | 7.616 | 20% | 232.844 | 22% | 115 | 59 | 13 |
| 9704 | 4.260 | 15% | 121.034 | 15% | 124 | 59 | 13 |
| 9903 | 1.984 | 14% | 56.179 | 15% | 131 | 61 | 13 |
| 200206 | 3.206 | 24% | 87.732 | 24% | 127 | 59 | 13 |

*LI*

| Cruise | KG Meats Per Tow | CV | Number Per Tow | CV | Number tows | Number Positive Tows | Number Strata Sampled |
|---|---|---|---|---|---|---|---|
| 7801 | 4.099 | 14% | 138.173 | 14% | 64 | 53 | 9 |
| 7807 | 11.193 | 37% | 382.081 | 38% | 40 | 30 | 9 |
| 7901 | 7.231 | 20% | 242.826 | 21% | 40 | 29 | 9 |
| 8001 | 8.262 | 13% | 277.090 | 14% | 28 | 24 | 8 |
| 8006 | 6.547 | 23% | 214.972 | 23% | 45 | 38 | 9 |
| 8105 | 5.982 | 23% | 200.219 | 22% | 44 | 38 | 9 |
| 8204 | 6.149 | 16% | 210.924 | 16% | 43 | 36 | 9 |
| 8305 | 4.940 | 21% | 163.753 | 20% | 38 | 35 | 9 |
| 8403 | 6.320 | 16% | 213.203 | 17% | 71 | 62 | 9 |
| 8604 | 8.484 | 20% | 289.641 | 22% | 36 | 31 | 9 |
| 8903 | 4.450 | 26% | 177.443 | 29% | 40 | 36 | 9 |
| 9203 | 7.789 | 16% | 282.678 | 17% | 42 | 35 | 9 |
| 9404 | 14.571 | 16% | 532.170 | 16% | 46 | 44 | 9 |
| 9704 | 10.872 | 16% | 380.161 | 16% | 42 | 35 | 9 |
| 9903 | 6.100 | 14% | 218.212 | 17% | 45 | 41 | 9 |
| 200206 | 6.763 | 20% | 237.190 | 21% | 43 | 40 | 9 |

Table 16. Continued

| Cruise | KG Meats Per Tow | CV | Number Per Tow | CV | Number tows | Number Positive Tows | Number Strata Sampled |
|---|---|---|---|---|---|---|---|
| 7801 | 4.575 | 26% | 185.849 | 25% | 29 | 21 | 6 |
| 7807 | 5.104 | 19% | 212.112 | 18% | 37 | 26 | 6 |
| 7901 | 7.405 | 17% | 327.322 | 19% | 15 | 9 | 5 |
| 8001 | 11.704 | 8% | 457.197 | 8% | 16 | 11 | 6 |
| 8006 | 8.134 | 12% | 326.935 | 13% | 30 | 23 | 7 |
| 8105 | 8.263 | 19% | 321.633 | 20% | 37 | 32 | 9 |
| 8204 | 6.895 | 25% | 269.090 | 27% | 48 | 30 | 10 |
| 8305 | 3.994 | 30% | 154.351 | 29% | 58 | 36 | 10 |
| 8403 | 4.714 | 29% | 182.628 | 26% | 69 | 37 | 10 |
| 8604 | 6.703 | 29% | 265.389 | 28% | 27 | 23 | 9 |
| 8903 | 6.644 | 18% | 264.888 | 18% | 34 | 29 | 10 |
| 9203 | 8.566 | 20% | 327.171 | 19% | 36 | 31 | 10 |
| 9404 | 13.062 | 20% | 498.326 | 21% | 43 | 32 | 10 |
| 9704 | 5.411 | 41% | 234.894 | 48% | 39 | 27 | 10 |
| 9903 | 6.087 | 48% | 245.663 | 53% | 39 | 30 | 10 |
| 200206 | 5.076 | 22% | 178.532 | 22% | 29 | 28 | 9 |

*GBK*

| Cruise | KG Meats Per Tow | CV | Number Per Tow | CV | Number tows | Number Positive Tows | Number Strata Sampled |
|---|---|---|---|---|---|---|---|
| 8001 | 13.926 | 35% | 574.585 | 35% | 11 | 11 | 5 |
| 8006 | 13.926 | 35% | 574.585 | 35% | 11 | 11 | 5 |
| 8105 | 9.357 | 13% | 349.304 | 15% | 33 | 27 | 12 |
| 8204 | 7.390 | 11% | 251.539 | 12% | 22 | 16 | 9 |
| 8305 | 12.035 | 19% | 458.844 | 19% | 48 | 19 | 12 |
| 8403 | 5.635 | 26% | 224.868 | 25% | 69 | 30 | 16 |
| 8604 | 5.679 | 17% | 236.060 | 16% | 48 | 21 | 16 |
| 8903 | 2.308 | 26% | 85.452 | 27% | 79 | 38 | 16 |
| 9203 | 8.995 | 21% | 325.218 | 22% | 74 | 41 | 16 |
| 9404 | 10.564 | 21% | 373.952 | 21% | 74 | 38 | 16 |
| 9704 | 6.638 | 19% | 236.570 | 19% | 83 | 44 | 18 |
| 9903 | 7.471 | 19% | 247.053 | 18% | 76 | 47 | 18 |
| 200206 | 8.689 | 20% | 296.141 | 20% | 60 | 38 | 15 |

Table A17. Efficiency corrected swept-area biomass estimates (1000 mt) and CVs for ocean quahog (70+ mm) during 1997, 2000 and 2002, by stock assessment area. Data for deep strata in the Long Island, Southern New England and Georges Bank assessment areas first sampled in 2002 were "borrowed" for calculation of swept-area biomass during 1997 (NEFSC 2003). The CV for survey catch per tow in the S. Virginia and N. Carolina area during 1997 (originally 0%) was set to 100%. CV's are based on analytical variance calculations assuming log normality, and include uncertainty in survey data, swept-area amount of suitable habitat and survey dredge efficiency. The original CV for survey data in the SVA region (0%) was set to 100% in calculations.

| | Estimate | CV |
|---|---|---|
| **INPUT: Nominal tow distance ($d_n$, *nm*) and CV for Doppler tow distance** | 0.15 | |
| **INPUT: Dredge width (nm)** | 0.0008225 | |
| Area swept per standard tow ($a$, nm$^2$) | 1.23375E-04 | 10% |

**Area of assessment region ($A$, nm$^2$) - no correction for stations with unsuitable clam habitat**

| | | |
|---|---|---|
| S. Virginia and N. Carolina (SVA) | 712 | 10% |
| Delmarva (DMV) | 4,071 | 10% |
| New Jersey (NJ) | 6,510 | 10% |
| Long Island (LI) | 4,463 | 10% |
| Southern New England (SNE) | 4,922 | 10% |
| Georges Bank (GBK) | 7,821 | 10% |
| Total | 28,499 | |

**INPUT: Fraction suitable habitat ($u$)**

| | | |
|---|---|---|
| S. Virginia and N. Carolina (SVA) | 100% | 10% |
| Delmarva (DMV) | 100% | 10% |
| New Jersey (NJ) | 100% | 10% |
| Long Island (LI) | 100% | 10% |
| Southern New England (SNE) | 96% | 10% |
| Georges Bank (GBK) | 90% | 10% |

**Habitat area in assessment region ($A'$, nm2)**

| | | |
|---|---|---|
| S. Virginia and N. Carolina (SVA) | 712 | 14% |
| Delmarva (DMV) | 4,071 | 14% |
| New Jersey (NJ) | 6,510 | 14% |
| Long Island (LI) | 4,463 | 14% |
| Southern New England (SNE) | 4,714 | 14% |
| Georges Bank (GBK) | 7,039 | 14% |

| **INPUT: Original survey mean survey catch (kg/tow, for tows adjusted to nominal tow distance using sensors)** | **Estimates for 1997** | **CV** | **Estimates for 1999** | **CV** | **Estimates for 2002** | **CV** |
|---|---|---|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0.0013 | 100% | 0.0006 | 60% | 0.0003 | 100% |
| Delmarva (DMV) | 0.6847 | 22% | 0.4692 | 27% | 0.5784 | 24% |
| New Jersey (NJ) | 1.8182 | 15% | 0.9911 | 14% | 1.6801 | 24% |
| Long Island (LI) | 4.8327 | 17% | 3.1377 | 14% | 3.3762 | 18% |
| Southern New England (SNE) | 2.2539 | 35% | 2.9315 | 46% | 3.0163 | 22% |
| Georges Bank (GBK) | 2.7119 | 17% | 3.2341 | 19% | 3.9284 | 18% |

| **INPUT: Survey dredge efficiency ($e$)** | 0.346 | 40% | 0.269 | 55% | 0.269 | 55% |
|---|---|---|---|---|---|---|

**Efficiency adjusted swept area biomass (B, 1000 mt)**

| | **Estimates for 1997** | **CV** | **Estimates for 1999** | **CV** | **Estimates for 2002** | **CV** |
|---|---|---|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0.021 | 109% | 0.013 | 83% | 0.006 | 115% |
| Delmarva (DMV) | 65 | 49% | 58 | 64% | 71 | 62% |
| New Jersey (NJ) | 277 | 46% | 194 | 59% | 330 | 62% |
| Long Island (LI) | 505 | 47% | 422 | 59% | 454 | 60% |
| Southern New England (SNE) | 249 | 56% | 416 | 74% | 428 | 62% |
| Georges Bank (GBK) | 447 | 47% | 686 | 61% | 833 | 60% |
| Total fishable biomass less GBK | 1,097 | 28% | 1,090 | 38% | 1,283 | 34% |
| Total fishable biomass | 1,544 | 24% | 1,776 | 33% | 2,116 | 31% |

| **Lower bound for 80% confidence intervals on biomass (1000 mt, for lognormal distribution with no bias correction)** | **Estimates for 1997** | **Estimates for 1999** | **Estimates for 2002** |
|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0.007 | 0.005 | 0.002 |
| Delmarva (DMV) | 36 | 27 | 34 |
| New Jersey (NJ) | 158 | 96 | 158 |
| Long Island (LI) | 285 | 209 | 222 |
| Southern New England (SNE) | 127 | 179 | 207 |
| Georges Bank (GBK) | 253 | 335 | 408 |
| Total fishable biomass less GBK | 772 | 681 | 841 |
| Total fishable biomass | 1,140 | 1,176 | 1,429 |

| **Upperbound for 80% confidence intervals on biomass (1000 mt, for lognormal distribution with no bias correction)** | | | |
|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0.066 | 0.033 | 0.020 |
| Delmarva (DMV) | 118 | 121 | 148 |
| New Jersey (NJ) | 488 | 393 | 687 |
| Long Island (LI) | 896 | 852 | 927 |
| Southern New England (SNE) | 487 | 969 | 887 |
| Georges Bank (GBK) | 792 | 1,404 | 1,701 |
| Total fishable biomass less GBK | 1,558 | 1,745 | 1,958 |
| Total fishable biomass | 2,091 | 2,683 | 3,135 |

Table A18.

Ocean quahog (70+ mm) **fishing mortality** estimates based on catch and efficiency corrected swept-area biomass estimates for 1997, 1999 and 2002. CV's are based on analytical variance calculations assuming log normality, and include uncertainty in catch, survey data, swept-area, amount of suitable habitat, and survey dredge efficiency.

| **INPUT: Upper bound incidental mortality allowance** | 5% | | |
|---|---|---|---|
| **INPUT: Assumed CV for catch** | 10% | | |

| **INPUT: Landings (1000 mt, discard ~ 0)** | Estimates for 1997 | Estimates for 1999 | Estimates for 2002 |
|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0.000 | 0.000 | 0.000 |
| Delmarva (DMV) | 1.072 | 1.090 | 1.732 |
| New Jersey (NJ) | 4.249 | 3.038 | 2.781 |
| Long Island (LI) | 5.130 | 6.328 | 9.113 |
| Southern New England (SNE) | 8.958 | 6.619 | 3.884 |
| Georges Bank (GBK) | 0.000 | 0.000 | 0.000 |
| Total | 19.409 | 17.075 | 17.509 |

**Catch (1000 mt, landings + upper bound incidental mortality allowance)**

| | Estimates for 1997 | Estimates for 1999 | Estimates for 2002 |
|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0.000 | 0.000 | 0.000 |
| Delmarva (DMV) | 1.126 | 1.145 | 1.818 |
| New Jersey (NJ) | 4.461 | 3.190 | 2.920 |
| Long Island (LI) | 5.387 | 6.644 | 9.569 |
| Southern New England (SNE) | 9.406 | 6.950 | 4.078 |
| Georges Bank (GBK) | 0.000 | 0.000 | 0.000 |
| Total | 20.380 | 17.929 | 18.384 |

| **INPUT: Efficiency Corrected Swept Area Biomass (1000 mt)** | Estimates for 1997 | CV | Estimates for 1999 | CV | Estimates for 2002 | CV |
|---|---|---|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0 | 109% | 0 | 83% | 0 | 115% |
| Delmarva (DMV) | 65 | 49% | 58 | 64% | 71 | 62% |
| New Jersey (NJ) | 277 | 46% | 194 | 59% | 330 | 62% |
| Long Island (LI) | 505 | 47% | 422 | 59% | 454 | 60% |
| Southern New England (SNE) | 249 | 56% | 416 | 74% | 428 | 62% |
| Georges Bank (GBK) | 447 | 47% | 686 | 61% | 833 | 60% |
| Total fishable biomass less GBK | 1,097 | 28% | 1,090 | 38% | 1,283 | 34% |
| Total fishable biomass | 1,544 | 24% | 1,776 | 33% | 2,116 | 31% |

**Fishing mortality (y$^{-1}$)**

| | Estimates for 1997 | CV | Estimates for 1999 | CV | Estimates for 2002 | CV |
|---|---|---|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 0.000 | 110% | 0.000 | 84% | 0.000 | 116% |
| Delmarva (DMV) | 0.017 | 50% | 0.020 | 64% | 0.026 | 63% |
| New Jersey (NJ) | 0.016 | 47% | 0.016 | 60% | 0.009 | 63% |
| Long Island (LI) | 0.011 | NA | 0.016 | NA | 0.021 | 61% |
| Southern New England (SNE) | 0.038 | 57% | 0.017 | 75% | 0.010 | 63% |
| Georges Bank (GBK) | 0.000 | NA | 0.000 | NA | 0.000 | NA |
| Total fishable biomass less GBK | 0.019 | 30% | 0.016 | 39% | 0.014 | 35% |
| Total fishable biomass | 0.013 | 26% | 0.010 | 35% | 0.009 | 33% |

| **Lower bound for 80% confidence intervals for fishing mortality (y$^{-1}$, for lognormal distribution with no bias correction)** | Estimates for 1997 | Estimates for 1999 | Estimates for 2002 |
|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | NA | NA | NA |
| Delmarva (DMV) | 0.009 | 0.009 | 0.012 |
| New Jersey (NJ) | 0.009 | 0.008 | 0.004 |
| Long Island (LI) | NA | NA | 0.010 |
| Southern New England (SNE) | 0.019 | 0.007 | 0.005 |
| Georges Bank (GBK) | NA | NA | NA |
| Total fishable biomass less GBK | 0.013 | 0.010 | 0.009 |
| Total fishable biomass | 0.010 | 0.007 | 0.006 |

| **Upper bound for 80% confidence intervals for fishing mortality (y$^{-1}$, for lognormal distribution with no bias correction)** | | | |
|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | NA | NA | NA |
| Delmarva (DMV) | 0.032 | 0.042 | 0.054 |
| New Jersey (NJ) | 0.029 | 0.033 | 0.019 |
| Long Island (LI) | NA | NA | 0.043 |
| Southern New England (SNE) | 0.075 | 0.039 | 0.020 |
| Georges Bank (GBK) | NA | NA | NA |
| Total fishable biomass less GBK | 0.027 | 0.027 | 0.022 |
| Total fishable biomass | 0.018 | 0.016 | 0.013 |

Table A19.

| Database parameters used in this assessment to extract NEFSC clam survey data for ocean quahog from the revised clam survey database. Database parameters for extracting data like those used in the last assessment (NEFSC 2000) are listed also. Parameters were the same for all regions. Negative parameter values are ignored in database calculations. |
|---|

| Database Parameter | For comparison to "KG/Tow" for 1978-1981 in SARC-31 (Table C14) | For comparison to "KG/Tow" for 1982-1999 in SARC-31 (Table C14) | Survey trends during 1978-1981 for this assessment | Survey trends during 1982-2002 for this assessment | Survey data for short efficiency corrected swept-area biomass (ESB) |
|---|---|---|---|---|---|
| DISTANCE_TYPE | TREND | TREND | TREND | TREND | SENDIST_NEG1 |
| LENGTH_BIN_SIZE_MM | 1000 | 1000 | 1000 | 1000 | 1000 |
| FIRST_LENGTH_MM | 70 | 70 | 70 | 70 | 70 |
| FIRST_BIN_IS_PLUSGROUP | -1 | -1 | -1 | -1 | -1 |
| LAST_LENGTH_MM | 250 | 250 | 250 | 250 | 250 |
| LAST_BIN_IS_PLUSGROUP | -1 | -1 | -1 | -1 | -1 |
| SVSPP_TO_USE | 409 | 409 | 409 | 409 | 409 |
| AREAKIND | GIS | GIS | GIS | GIS | GIS |
| REV_DATE_FOR_AREAS | 1998 | 1998 | 2002 | 2002 | 2002 |
| REV_DATE_FOR_LW | 2000 | 2000 | 2000 | 2000 | 2000 |
| FIRST_JWSTCODE | 1 | 1 | -1 | -1 | -1 |
| LAST_JWSTCODE | 151 | 151 | -1 | -1 | -1 |
| FIRST_RANDLIKE | -1 | -1 | 1 | 1 | 1 |
| LAST_RANDLIKE | -2 | -2 | 2 | 2 | 2 |
| FIRST_STATION | -1 | 1 | -1 | -1 | -1 |
| LAST_STATION | -1 | 1 | -1 | -1 | -1 |
| FIRST_HAUL | -1 | 1 | -1 | 1 | 1 |
| LAST_HAUL | -3 | 3 | -3 | 3 | 3 |
| FIRST_GEARCOND | -1 | 1 | -1 | 1 | 1 |
| LAST_GEARCOND | -6 | 6 | -6 | 6 | 6 |
| FIRST_STRATUM | 1 | 1 | 1 | 1 | 1 |
| LAST_STRATUM | 96 | 96 | 96 | 96 | 96 |
| FIRST_REGION_CODE | 1 | 1 | 1 | 1 | 1 |
| LAST_REGION_CODE | 7 | 7 | 6 | 6 | 6 |
| WRITE_TOW_DATA | 1 | 1 | -1 | -1 | -1 |
| WRITE_STRATUM_DATA | 1 | 1 | -1 | -1 | -1 |
| FIRST_CRUISE | -9700 | -9700 | -7800 | 8200 | 9700 |
| LAST_CRUISE | -9800 | -9800 | 8200 | -8200 | -9800 |
| NOMINAL_TOW_DISTANCE_NM | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| FILLHOLZ | -1 | -1 | 1 | 1 | 1 |

Table A20.

| | | Mean Sensor Distance (nm) | Mean Doppler Distance (nm) | Mean Sensor/ Doppler | | | |
|---|---|---|---|---|---|---|---|
| Region | N Tows | | | | SD | SE | CV |
| S. Virginia and N. Carolina (SVA) | 218 | 0.23 | 0.12 | 1.97 | 0.50 | 0.030 | 2% |
| Delmarva (DMV) | 173 | 0.27 | 0.13 | 2.15 | 0.42 | 0.030 | 2% |
| New Jersey (NJ) | 130 | 0.25 | 0.13 | 2.02 | 0.43 | 0.040 | 2% |
| Long Island (LI) | 381 | 0.23 | 0.12 | 1.93 | 1.17 | 0.060 | 3% |
| Southern New England (SNE) | 104 | 0.26 | 0.13 | 1.98 | 0.46 | 0.050 | 2% |
| Georges Bank (GBK) | 19 | 0.25 | 0.13 | 1.96 | 0.48 | 0.110 | 6% |
| All | 1025 | 0.24 | 0.12 | 1.99 | 0.8 | 0.030 | 1% |

Mean doppler distance, sensor distance and sensor/doppler ratio for tows in NEFSC clam surveys in quahog strata during 1997, 1999 and 2002. SD is the standard deviation for tow-by-tow sensor/ doppler ratios. The standard error (SE) and CV are for mean tow-by-tow sensor/doppler ratios.

Table A21.

Long times series of efficiency corrected swept-area biomass estimates ("Long ESB"), landings, fishing mortality and CVs. Data for 1978-1980 and 1994 omitted due to likely changes in NEFSC dredge efficiency. A 5% upper bound incidental mortality abundance was added to landings during computation of fishing mortality. A CV=10% was assumed for landings data. CV's for ESB in SVA during 1981-1982 were orignally zero but 80% was substituted in variance calculations.

| Year | Long ESB (1000 mt) | CV | Landings (1000 mt) | Fishing Mortality (y-1) | CV | Year | Long ESB (1000 mt) | CV | Landings (1000 mt) | Fishing Mortality (y-1) | CV |
|------|------|------|------|------|------|------|------|------|------|------|------|
| *DMV* | | | | | | *SNE* | | | | | |
| 1981 | 237 | 33% | 3.637 | 0.0161 | 35% | 1981 | 538 | 19% | 0.000 | 0.0000 | NA |
| 1982 | 166 | 34% | 4.598 | 0.0292 | 36% | 1982 | 449 | 25% | 0.000 | 0.0000 | NA |
| 1983 | 142 | 42% | 5.396 | 0.0399 | 43% | 1983 | 260 | 30% | 0.629 | 0.0025 | 32% |
| 1984 | 93 | 30% | 7.164 | 0.0811 | 32% | 1984 | 307 | 29% | 0.822 | 0.0028 | 30% |
| 1986 | 142 | 22% | 8.231 | 0.0609 | 24% | 1986 | 436 | 30% | 0.562 | 0.0014 | 31% |
| 1989 | 102 | 45% | 6.439 | 0.0663 | 46% | 1989 | 433 | 18% | 1.196 | 0.0029 | 21% |
| 1992 | 128 | 31% | 2.378 | 0.0195 | 32% | 1992 | 558 | 20% | 1.143 | 0.0022 | 22% |
| 1997 | 93 | 21% | 1.072 | 0.0121 | 23% | 1997 | 352 | 41% | 8.958 | 0.0267 | 42% |
| 1999 | 53 | 27% | 1.090 | 0.0218 | 29% | 1999 | 396 | 48% | 6.619 | 0.0175 | 49% |
| 2002 | 61 | 23% | 1.732 | 0.0296 | 25% | 2002 | 330 | 22% | 3.884 | 0.0123 | 24% |
| *LI* | | | | | | *SVA* | | | | | |
| 1981 | 369 | 23% | 0.003 | 0.0000 | 25% | 1981 | 0.391 | 80% | 0.056 | 0.1495 | 81% |
| 1982 | 379 | 17% | 0.000 | 0.0000 | NA | 1982 | 0.023 | 80% | 0.006 | 0.2626 | 81% |
| 1983 | 304 | 21% | 0.021 | 0.0001 | 23% | 1983 | 0.976 | 59% | 0.000 | 0.0000 | NA |
| 1984 | 389 | 16% | 0.000 | 0.0000 | NA | 1984 | 0.097 | 88% | 0.006 | 0.0655 | 88% |
| 1986 | 523 | 21% | 0.396 | 0.0008 | 23% | 1986 | 0.125 | 0% | 0.000 | 0.0000 | NA |
| 1989 | 274 | 26% | 0.605 | 0.0023 | 28% | 1989 | 0.181 | 0% | 0.000 | 0.0000 | NA |
| 1992 | 480 | 16% | 11.939 | 0.0261 | 19% | 1994 | 1.990 | 79% | 0.000 | 0.0000 | NA |
| 1997 | 670 | 16% | 5.130 | 0.0080 | 19% | 1997 | 0.034 | 0% | 0.000 | 0.0000 | NA |
| 1999 | 376 | 15% | 6.328 | 0.0177 | 18% | 1999 | 0.015 | 65% | 0.000 | 0.0000 | NA |
| 2002 | 417 | 20% | 9.113 | 0.0230 | 23% | 2002 | 0.006 | 101% | 0.000 | 0.0000 | NA |
| *NJ* | | | | | | *GBK* | | | | | |
| 1981 | 652 | 29% | 8.402 | 0.0135 | 30% | 1981 | 909 | 26% | 0.000 | 0.0000 | NA |
| 1982 | 324 | 19% | 8.538 | 0.0277 | 22% | 1982 | 718 | 25% | 0.000 | 0.0000 | NA |
| 1983 | 252 | 21% | 8.249 | 0.0343 | 24% | 1983 | 1170 | 30% | 0.000 | 0.0000 | NA |
| 1984 | 407 | 24% | 8.858 | 0.0228 | 26% | 1984 | 548 | 34% | 0.000 | 0.0000 | NA |
| 1986 | 440 | 22% | 9.061 | 0.0216 | 24% | 1986 | 552 | 29% | 0.000 | 0.0000 | NA |
| 1989 | 199 | 21% | 14.100 | 0.0745 | 23% | 1989 | 224 | 35% | 0.000 | 0.0000 | NA |
| 1992 | 271 | 17% | 6.942 | 0.0269 | 20% | 1992 | 874 | 31% | 0.000 | 0.0000 | NA |
| 1997 | 383 | 15% | 4.249 | 0.0117 | 18% | 1997 | 645 | 30% | 0.000 | 0.0000 | NA |
| 1999 | 178 | 14% | 3.038 | 0.0179 | 17% | 1999 | 726 | 30% | 0.000 | 0.0000 | NA |
| 2002 | 288 | 24% | 2.781 | 0.0101 | 26% | 2002 | 844 | 30% | 0.000 | 0.0000 | NA |

Table A22.

| | KLAMZ model parameter estimates and standard errors for ocean quahog in the DMV, NJ and SNE regions. Arithmetic values and CVs for each log scale parameter are also shown. Log scale standard errors calculated by the delta method. Arithmetic CVs calculated assuming log-normal distributions. |
|---|---|

| Parameter | DMV (Scenario 5) | NJ (Scenario 3) | SNE (Scenario 3) |
|---|---|---|---|
| **Parameters** | | | |
| Ln(Covariate Effect) | -0.8252 | -0.2272 | 0.2358 |
| Ln(Biomass$_{1977}$) | 12.6050 | 13.0280 | 12.8640 |
| Ln(Escapement$_{1978}$) | 12.5750 | 13.0030 | 12.8540 |
| Ln(Geom. Mean Recruitment) | NA | 8.4585 | 8.4530 |
| **Standard Errors for Parameters** | | | |
| Ln(Covariate Effect) | 0.2993 | 0.2031 | 0.1662 |
| Ln(Biomass1977) | 0.5198 | 0.5552 | 0.7884 |
| Ln(Escapement1978) | 0.5052 | 0.5589 | 0.7854 |
| Ln(Geom. Mean Recruitment) | NA | 0.5126 | 0.7061 |
| **Arithmetic Estimates** | | | |
| Covariate Effect | 0.44 | 0.80 | 1.27 |
| Biomass$_{1977}$ (mt) | 298,045 | 454,976 | 386,157 |
| Escapement$_{1978}$ (mt) | 289,237 | 443,743 | 382,315 |
| Geom. Mean Recruitment (mt) | NA | 4,715 | 4,689 |
| **Arithmetic CV** | | | |
| Covariate Effect | 31% | 21% | 17% |
| Biomass1977 | 56% | 60% | 93% |
| Escapement1978 | 54% | 61% | 92% |
| Geom. Mean Recruitment | NA | 55% | 80% |

Table A23.

| | Calculations to estimate region specific scaling factors used to adjust survey trend data up to units of approximate stock biomass. CV's for the scaling factors do not include process errors calculated elsewhere. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| Region Name | Available Habitat ($A'$, nm$^2$) | CV | Average Efficiency ($e$) | CV | Area swept per standard tow ($a$, nm$^2$) | CV | Average Sensor/ Doppler Ratio | CV | Adjust KG to 1000 MT ($u$) | Scaling Factor ($\Omega$, 1000 mt tow kg$^{-1}$) | Survey Scaling Parameter in KLAMZ Model (Q=1/$\Omega$, kg tow$^{-1}$ 10$^{-3}$ mt$^{-1}$) | CV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S. Virginia and N. Carolina (SVA) | 712 | 14% | 0.2947 | 15% | 1.2338E-04 | 10% | 1.992 | 1% | 1.0E-06 | 9.832 | 0.10171 | 23% |
| Delmarva (DMV) | 4,071 | 14% | 0.2947 | 15% | 1.2338E-04 | 10% | 1.992 | 1% | 1.0E-06 | 56.215 | 0.01779 | 23% |
| New Jersey (NJ) | 6,510 | 14% | 0.2947 | 15% | 1.2338E-04 | 10% | 1.992 | 1% | 1.0E-06 | 89.894 | 0.01112 | 23% |
| Long Island (LI) | 4,463 | 14% | 0.2947 | 15% | 1.2338E-04 | 10% | 1.992 | 1% | 1.0E-06 | 61.628 | 0.01623 | 23% |
| Southern New England (SNE) | 4,714 | 14% | 0.2947 | 15% | 1.2338E-04 | 10% | 1.992 | 1% | 1.0E-06 | 65.094 | 0.01536 | 23% |
| Georges Bank (GBK) | 7,039 | 14% | 0.2947 | 15% | 1.2338E-04 | 10% | 1.992 | 1% | 1.0E-06 | 97.197 | 0.01029 | 23% |

Table A24.  Summary of Biomass (mt) and fishing mortality (F) estimates from regional KLAMZ, and other, models.

Best biomass and fishing mortality estimates for ocean quahog during 1977-2003.  "VPA" biomass estimates for 1999 are the average of efficiency corrected swept-area biomass (ESB) for 1997, 1999 and 2002; biomass estimates for other years computed by forward or backward VPA (see text).  "VPA" fishing mortality estimates are the ratio of catch and average biomass during the same and subsequent years.  For example, fishing mortality in SVA during 1977 is the catch during 1977 divided by the average biomass for 1977 and 1978.  For 2002, fishing mortality in SVA is catch over 2002 biomass.  "ESB" for Georges Bank is the average ESB estimate and the CV is the standard error for mean ESB.

| Year | SVA | DMV | DMV CV | NJ | NJ CV | LI | SNE | SNE CV | GBK | GBK CV | Total less GBK | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Model* | | | | | | |
| | VPA | KLAMZ Scenario 5 | | KLAMZ Scenario 3 | | VPA | KLAMZ Scenario 3 | | Average ESB | | NA | NA |
| | | | | | | *Recruitment* | | | | | | |
| All | NA | 0 | NA | 4,715 | 51% | NA | 4,689 | 71% | NA | NA | NA | NA |
| | | | | | | *Total Biomass (mt)* | | | | | | |
| 1977 | 297 | 297,990 | 52% | 455,110 | 56% | 534,059 | 386,310 | 79% | 655,426 | 17% | 1,673,766 | 2,329,192 |
| 1978 | 297 | 289,320 | 51% | 448,410 | 55% | 534,059 | 387,040 | 78% | 655,426 | 17% | 1,659,126 | 2,314,552 |
| 1979 | 297 | 280,620 | 49% | 441,790 | 54% | 534,059 | 387,760 | 77% | 655,426 | 17% | 1,644,526 | 2,299,952 |
| 1980 | 297 | 268,080 | 49% | 435,560 | 54% | 534,059 | 388,460 | 76% | 655,426 | 17% | 1,626,456 | 2,281,882 |
| 1981 | 297 | 257,070 | 48% | 427,690 | 53% | 534,054 | 389,150 | 75% | 655,426 | 17% | 1,608,260 | 2,263,687 |
| 1982 | 241 | 246,940 | 47% | 419,260 | 53% | 534,050 | 389,830 | 74% | 655,426 | 17% | 1,590,321 | 2,245,748 |
| 1983 | 235 | 236,150 | 46% | 410,800 | 53% | 534,050 | 390,500 | 73% | 655,426 | 17% | 1,571,736 | 2,227,162 |
| 1984 | 235 | 224,860 | 46% | 402,730 | 53% | 534,029 | 390,530 | 73% | 655,426 | 17% | 1,552,384 | 2,207,811 |
| 1985 | 229 | 212,140 | 46% | 394,150 | 53% | 534,029 | 390,370 | 72% | 655,426 | 17% | 1,530,918 | 2,186,345 |
| 1986 | 69 | 199,720 | 46% | 383,860 | 53% | 533,989 | 390,330 | 71% | 655,426 | 17% | 1,507,968 | 2,163,394 |
| 1987 | 69 | 186,610 | 47% | 375,320 | 52% | 533,593 | 390,420 | 71% | 655,426 | 17% | 1,486,012 | 2,141,438 |
| 1988 | 69 | 171,570 | 48% | 366,870 | 52% | 532,413 | 390,370 | 70% | 655,426 | 17% | 1,461,292 | 2,116,718 |
| 1989 | 27 | 155,770 | 50% | 360,570 | 52% | 531,773 | 390,170 | 70% | 655,426 | 17% | 1,438,310 | 2,093,736 |
| 1990 | 27 | 145,550 | 51% | 347,310 | 53% | 531,168 | 389,620 | 69% | 655,426 | 17% | 1,413,675 | 2,069,101 |
| 1991 | 13 | 138,300 | 51% | 332,740 | 54% | 530,429 | 389,330 | 69% | 655,426 | 17% | 1,390,812 | 2,046,238 |
| 1992 | 13 | 130,110 | 52% | 319,350 | 55% | 528,755 | 389,110 | 68% | 655,426 | 17% | 1,367,338 | 2,022,764 |
| 1993 | 13 | 124,550 | 52% | 313,720 | 54% | 516,815 | 388,620 | 68% | 655,426 | 17% | 1,343,719 | 1,999,145 |
| 1994 | 13 | 119,530 | 51% | 304,960 | 54% | 508,163 | 388,250 | 68% | 655,426 | 17% | 1,320,916 | 1,976,343 |
| 1995 | 13 | 115,600 | 51% | 299,500 | 54% | 496,180 | 387,940 | 67% | 655,426 | 17% | 1,299,234 | 1,954,660 |
| 1996 | 13 | 112,070 | 50% | 295,730 | 54% | 486,716 | 383,170 | 68% | 655,426 | 17% | 1,277,699 | 1,933,126 |
| 1997 | 13 | 108,600 | 49% | 292,520 | 53% | 480,810 | 375,590 | 69% | 655,426 | 17% | 1,257,534 | 1,912,960 |
| 1998 | 13 | 104,890 | 49% | 289,970 | 52% | 475,580 | 367,460 | 70% | 655,426 | 17% | 1,238,014 | 1,893,440 |
| 1999 | 13 | 100,980 | 48% | 289,040 | 51% | 469,110 | 361,920 | 70% | 655,426 | 17% | 1,221,064 | 1,876,490 |
| 2000 | 13 | 97,450 | 48% | 287,780 | 50% | 462,782 | 356,270 | 71% | 655,426 | 17% | 1,204,295 | 1,859,722 |
| 2001 | 13 | 94,051 | 48% | 286,270 | 49% | 468,498 | 352,200 | 72% | 655,426 | 17% | 1,201,032 | 1,856,458 |
| 2002 | 13 | 90,891 | 47% | 283,580 | 49% | 477,610 | 348,570 | 72% | 655,426 | 17% | 1,200,665 | 1,856,091 |
| 2003 | 13 | NA | NA | NA | NA | 468,498 | NA | NA | 655,426 | 17% | NA | NA |
| | | | | | | *Fishing mortality* (y⁻¹) | | | | | | |
| 1977 | 0.000 | 0.003 | 52% | 0.014 | 56% | 0.000 | 0.000 | 0% | 0.000 | 0.000 | 0.004 | 0.003 |
| 1978 | 0.000 | 0.005 | 51% | 0.014 | 55% | 0.000 | 0.000 | 0% | 0.000 | 0.000 | 0.005 | 0.003 |
| 1979 | 0.000 | 0.020 | 50% | 0.014 | 55% | 0.000 | 0.000 | 0% | 0.000 | 0.000 | 0.007 | 0.005 |
| 1980 | 0.188 | 0.016 | 49% | 0.018 | 54% | 0.000 | 0.000 | 0% | 0.000 | 0.000 | 0.008 | 0.005 |
| 1981 | 0.021 | 0.014 | 48% | 0.020 | 54% | 0.000 | 0.000 | 0% | 0.000 | 0.000 | 0.008 | 0.005 |
| 1982 | 0.000 | 0.019 | 47% | 0.021 | 54% | 0.000 | 0.000 | 0% | 0.000 | 0.000 | 0.008 | 0.006 |
| 1983 | 0.026 | 0.023 | 47% | 0.020 | 54% | 0.000 | 0.002 | 73% | 0.000 | 0.000 | 0.009 | 0.007 |
| 1984 | 0.690 | 0.033 | 47% | 0.022 | 53% | 0.000 | 0.002 | 73% | 0.000 | 0.000 | 0.011 | 0.008 |
| 1985 | 0.000 | 0.035 | 47% | 0.028 | 53% | 0.000 | 0.002 | 72% | 0.000 | 0.000 | 0.012 | 0.009 |
| 1986 | 0.000 | 0.042 | 47% | 0.024 | 53% | 0.001 | 0.001 | 71% | 0.000 | 0.000 | 0.012 | 0.009 |
| 1987 | 0.608 | 0.059 | 48% | 0.025 | 53% | 0.002 | 0.002 | 71% | 0.000 | 0.000 | 0.015 | 0.010 |
| 1988 | 0.000 | 0.071 | 50% | 0.019 | 53% | 0.001 | 0.002 | 70% | 0.000 | 0.000 | 0.014 | 0.010 |
| 1989 | 0.501 | 0.043 | 52% | 0.040 | 53% | 0.001 | 0.003 | 70% | 0.000 | 0.000 | 0.016 | 0.011 |
| 1990 | 0.000 | 0.026 | 52% | 0.046 | 54% | 0.001 | 0.002 | 69% | 0.000 | 0.000 | 0.015 | 0.010 |
| 1991 | 0.000 | 0.036 | 52% | 0.045 | 55% | 0.003 | 0.002 | 69% | 0.000 | 0.000 | 0.016 | 0.011 |
| 1992 | 0.000 | 0.019 | 53% | 0.022 | 55% | 0.023 | 0.003 | 68% | 0.000 | 0.000 | 0.017 | 0.011 |
| 1993 | 0.000 | 0.016 | 52% | 0.033 | 55% | 0.017 | 0.003 | 68% | 0.000 | 0.000 | 0.016 | 0.011 |
| 1994 | 0.000 | 0.008 | 52% | 0.023 | 55% | 0.024 | 0.002 | 68% | 0.000 | 0.000 | 0.016 | 0.011 |
| 1995 | 0.000 | 0.006 | 51% | 0.018 | 55% | 0.019 | 0.014 | 68% | 0.000 | 0.000 | 0.016 | 0.011 |
| 1996 | 0.000 | 0.007 | 50% | 0.017 | 54% | 0.012 | 0.022 | 68% | 0.000 | 0.000 | 0.016 | 0.010 |
| 1997 | 0.000 | 0.010 | 49% | 0.015 | 53% | 0.011 | 0.024 | 69% | 0.000 | 0.000 | 0.016 | 0.010 |
| 1998 | 0.000 | 0.013 | 49% | 0.009 | 52% | 0.014 | 0.018 | 70% | 0.000 | 0.000 | 0.014 | 0.009 |
| 1999 | 0.000 | 0.011 | 49% | 0.011 | 51% | 0.014 | 0.019 | 71% | 0.000 | 0.000 | 0.014 | 0.009 |
| 2000 | 0.000 | 0.011 | 48% | 0.012 | 50% | 0.010 | 0.014 | 72% | 0.000 | 0.000 | 0.012 | 0.008 |
| 2001 | 0.000 | 0.010 | 48% | 0.016 | 50% | 0.012 | 0.013 | 72% | 0.000 | 0.000 | 0.013 | 0.009 |
| 2002 | 0.000 | 0.019 | 48% | 0.010 | 49% | 0.019 | 0.011 | 73% | 0.000 | 0.000 | 0.015 | 0.009 |

Table A25. Inputs (shown up to age 28) to updated Yield per Recruit analysis for ocean quahog, with full recruitment at age 26 y and shell length approximately 70 mm. Growth parameters are from SARC-31 (NEFSC 2000a, p.198) and represent average growth across regions.

```
 TITLE FOR RUN:
 YPR-Quahog-like-delay-difference-for-SARC

 TITLE FOR DATA:
 Ocean-Quahog-Like-Delay-Difference


 ----------------------------------------------------------------------------
  ***INPUT DATA***
 NATURAL MORTALITY COEFFICIENT (M) =   0.02000


           PRICE PER UNIT WEIGHT =   1.00000


 FIRST AGE GROUP:  LAST AGE GROUP:  LAST GROUP IS PLUS:
      1              150                 YES
 PROPORTION F MORTALITY BEFORE SPAWNING SEASON:
    0.75
 PROPORTION M MORTALITY BEFORE SPAWNING SEASON:
    0.75
                                   WEIGHT IN    WEIGHT IN    RELATIVE
  AGE    FPATTERN   MPATTERN   MATURITY   THE CATCH    THE STOCK     VALUE
   1     0.0000     1.000     0.0000      1.2002       1.2002      1.0000
   2     0.0000     1.000     0.0000      1.9665       1.9665      1.0000
   3     0.0000     1.000     0.0000      2.7191       2.7191      1.0000
   4     0.0000     1.000     0.0000      3.4583       3.4583      1.0000
   5     0.0000     1.000     0.0300      4.1842       4.1842      1.0000
   6     0.0000     1.000     0.0300      4.8973       4.8973      1.0000
   7     0.0000     1.000     0.0300      5.5976       5.5976      1.0000
   8     0.0000     1.000     0.0300      6.2854       6.2854      1.0000
   9     0.0000     1.000     0.0300      6.9610       6.9610      1.0000
  10     0.0000     1.000     0.5000      7.6245       7.6245      1.0000
  11     0.0000     1.000     1.0000      8.2761       8.2761      1.0000
  12     0.0000     1.000     1.0000      8.9162       8.9162      1.0000
  13     0.0000     1.000     1.0000      9.5448       9.5448      1.0000
  14     0.0000     1.000     1.0000     10.1622      10.1622      1.0000
  15     0.0000     1.000     1.0000     10.7686      10.7686      1.0000
  16     0.0000     1.000     1.0000     11.3642      11.3642      1.0000
  17     0.0000     1.000     1.0000     11.9491      11.9491      1.0000
  18     0.0000     1.000     1.0000     12.5237      12.5237      1.0000
  19     0.0000     1.000     1.0000     13.0879      13.0879      1.0000
  20     0.0000     1.000     1.0000     13.6421      13.6421      1.0000
  21     0.0000     1.000     1.0000     14.1865      14.1865      1.0000
  22     0.0000     1.000     1.0000     14.7211      14.7211      1.0000
  23     0.0000     1.000     1.0000     15.2461      15.2461      1.0000
  24     0.0000     1.000     1.0000     15.7618      15.7618      1.0000
  25     0.0000     1.000     1.0000     16.2683      16.2683      1.0000
  26     1.0000     1.000     1.0000     16.7658      16.7658      1.0000
  27     1.0000     1.000     1.0000     17.2544      17.2544      1.0000
  28     1.0000     1.000     1.0000     17.7343      17.7343      1.0000
```

Table A26.   Results of updated Yield per Recruit analysis for ocean quahog, with full recruitment at age 26 y and shell length approximately 70 mm. Growth parameters are from SARC-31 (NEFSC 2000a, p.198) and represent average growth across regions.

| $F_{0.1}$ | 0.0275 |
|---|---|
| $F_{MAX}$ | 0.1812 |

| %MSP | F |
|---|---|
| 15% | 0.441 |
| 20% | 0.138 |
| 25% | 0.080 |
| 30% | 0.055 |
| 35% | 0.041 |
| 40% | 0.032 |
| 45% | 0.025 |
| 50% | 0.020 |
| 55% | 0.016 |
| 60% | 0.013 |
| 65% | 0.011 |
| 70% | 0.008 |
| 75% | 0.007 |
| 80% | 0.005 |
| 85% | 0.004 |
| 90% | 0.002 |
| 95% | 0.001 |
| 100% | 0.000 |

Table A27. Projection of B and F assuming constant catches at 2002 levels.

Projected biomass and fishing mortality for ocean quahog during 2002-2007 based on best estimates for 2002 and assuming constant regional catch at 2002 levels. Projections use annual instantaneous rates of change for somatic growth in weight (G), recruitment biomass (r), natural mortality (M) and fishing (F) based on population dynamics equations givenin the text. Instantaneous rates for DMV, NJ, SNE are KLAMZ model estimates for 2002. Rates for other regions are averages of estimates for DMV, NJ and SNE except that G=0 for GBK because quahogs in GBK are unfished and assumed at carrying capacity. Projected biomass for the total area and for the total area less Georges Bank are sums of regional biomass levels. Similarly, projected fishing mortality rates are biomass weighted averages. Approximate 80% confidence intervals have endpoints that are half and double the projected values.

| Year | SVA | DMV | NJ | LI | SNE | GBK | Total Less GBK | Total |
|---|---|---|---|---|---|---|---|---|
| | | | | *Somatic growth rate (G y$^{-1}$)* | | | | |
| 2002 | 0.0080 | 0.0045 | 0.0099 | 0.0076 | 0.0096 | 0.0000 | not used | not used |
| | | | *Recruitment rate (r = Recruitment / Average Biomass in 2002 y$^{-1}$)* | | | | | |
| 2002 | 0.0101 | 0.0000 | 0.0168 | 0.0094 | 0.0136 | 0.0000 | not used | not used |
| | | | | *Natural mortality (M y$^{-1}$)* | | | | |
| 2002 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | not used | not used |
| | | *Net instantaneous rate of change, less fishing (X - F = G + r - M y$^{-1}$)* | | | | | | |
| 2002 | -0.0019 | -0.0155 | 0.0067 | -0.0030 | 0.0032 | -0.0200 | not used | not used |
| | | | | *Landings (mt meats y$^{-1}$)* | | | | |
| 2002 | 0 | 1,732 | 2,781 | 9,113 | 3,884 | 0 | 17509 (not used) | 17509 (not used) |
| | | *Catch (mt meats y$^{-1}$, landings+ 5% allowance for incidental mortality)* | | | | | | |
| 2002 | 0 | 1,818 | 2,920 | 9,569 | 4,078 | 0 | 18384 (not used) | 18384 (not used) |
| | | | | *Initial Biomass* | | | | |
| 2002 | 13 | 90,891 | 283,580 | 477,610 | 348,570 | 655,426 | 1,200,665 | 1,856,091 |
| | | | | *Projected biomass (mt meats)* | | | | |
| 2003 | 13 | 87,688 | 282,564 | 466,625 | 345,602 | 642,448 | 1,182,492 | 1,824,940 |
| 2004 | 13 | 84,534 | 281,540 | 455,673 | 342,625 | 629,727 | 1,164,385 | 1,794,112 |
| 2005 | 13 | 81,428 | 280,510 | 444,753 | 339,639 | 617,257 | 1,146,344 | 1,763,601 |
| 2006 | 13 | 78,371 | 279,473 | 433,866 | 336,643 | 605,035 | 1,128,366 | 1,733,400 |
| 2007 | 13 | 75,360 | 278,429 | 423,012 | 333,637 | 593,054 | 1,110,451 | 1,703,505 |
| | | | | *Projected fishing mortality rate (F y$^{-1}$)* | | | | |
| 2003 | 0.000 | 0.021 | 0.010 | 0.021 | 0.012 | 0.000 | 0.016 | 0.010 |
| 2004 | 0.000 | 0.022 | 0.010 | 0.021 | 0.012 | 0.000 | 0.016 | 0.010 |
| 2005 | 0.000 | 0.023 | 0.010 | 0.022 | 0.012 | 0.000 | 0.016 | 0.010 |
| 2006 | 0.000 | 0.023 | 0.010 | 0.022 | 0.012 | 0.000 | 0.016 | 0.011 |
| 2007 | 0.000 | 0.024 | 0.010 | 0.023 | 0.012 | 0.000 | 0.017 | 0.011 |

Table A28. Projection of B, F, and landings, assuming constant F's at 2002 levels.

| Projected biomass and fishing mortality for ocean quahog during 2002-2007 based on best estimates for 2002 and assuming constant regional fishing mortality at 2002 levels. Projections use annual instantaneous rates of change for somatic growth in weight (G), recruitment biomass (r), natural mortality (M) and fishing (F) based on population dynamics equations given in the text.  Instantaneous rates G, r and M for DMV, NJ, SNE are KLAMZ model estimates for 2002.  Rates for other regions are averages of estimates for DMV, NJ and SNE except that G=0 for GBK because quahogs in GBK are unfished and assumed at carrying capacity.  Projected biomass, catch and landings for the total area and for the total area less Georges Bank are sums of regional biomass levels. Approximate 80% confidence intervals have endpoints that are half and double the projected values. |
|---|

| Year | SVA | DMV | NJ | LI | SNE | GBK | Total Less GBK | Total |
|---|---|---|---|---|---|---|---|---|
| Somatic growth rate (G y$^{-1}$) | | | | | | | | |
| 2002 | 0.0080 | 0.0045 | 0.0099 | 0.0076 | 0.0096 | 0.0000 | not used | not used |
| Recruitment rate (r = Recruitment / Average Biomass in 2002  y$^{-1}$) | | | | | | | | |
| 2002 | 0.0101 | 0.0000 | 0.0168 | 0.0094 | 0.0136 | 0.0000 | not used | not used |
| Natural mortality (M y$^{-1}$) | | | | | | | | |
| 2002 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | not used | not used |
| Fishing mortality  (F  y$^{-1}$) | | | | | | | | |
| 2002 | 0.0000 | 0.0194 | 0.0099 | 0.0191 | 0.0113 | 0.0000 | not used | not used |
| Net instantaneous rate of change X = G + r - F - M  y$^{-1}$) | | | | | | | | |
| 2002 | -0.0019 | -0.0349 | -0.0032 | -0.0221 | -0.0081 | -0.0200 | not used | not used |
| Initial Biomass | | | | | | | | |
| 2002 | 13 | 90,891 | 283,580 | 477,610 | 348,570 | 655,426 | 1,200,665 | 1,856,091 |
| Projected biomass (mt meats) | | | | | | | | |
| 2003 | 13 | 87,774 | 282,680 | 467,180 | 345,770 | 642,448 | 1,183,417 | 1,825,865 |
| 2004 | 13 | 84,764 | 281,782 | 456,977 | 342,993 | 629,727 | 1,166,529 | 1,796,256 |
| 2005 | 13 | 81,856 | 280,887 | 446,997 | 340,239 | 617,257 | 1,149,993 | 1,767,250 |
| 2006 | 13 | 79,049 | 279,995 | 437,235 | 337,506 | 605,035 | 1,133,799 | 1,738,833 |
| 2007 | 13 | 76,338 | 279,106 | 427,686 | 334,795 | 593,054 | 1,117,939 | 1,710,993 |
| Catch (landings + 5% allowance for incidental mortality, mt y$^{-1}$) | | | | | | | | |
| 2003 | 0 | 1,672 | 2,795 | 8,816 | 3,879 | 0 | 17,162 | 17,162 |
| 2004 | 0 | 1,615 | 2,786 | 8,624 | 3,848 | 0 | 16,872 | 16,872 |
| 2005 | 0 | 1,560 | 2,777 | 8,435 | 3,817 | 0 | 16,589 | 16,589 |
| 2006 | 0 | 1,506 | 2,769 | 8,251 | 3,786 | 0 | 16,312 | 16,312 |
| 2007 | 0 | 1,454 | 2,760 | 8,071 | 3,756 | 0 | 16,041 | 16,041 |
| Landings (95% of catch, mt y$^{-1}$) | | | | | | | | |
| 2003 | 0 | 1,589 | 2,655 | 8,375 | 3,685 | 0 | 16,304 | 16,304 |
| 2004 | 0 | 1,534 | 2,647 | 8,193 | 3,655 | 0 | 16,029 | 16,029 |
| 2005 | 0 | 1,482 | 2,638 | 8,014 | 3,626 | 0 | 15,760 | 15,760 |
| 2006 | 0 | 1,431 | 2,630 | 7,839 | 3,597 | 0 | 15,496 | 15,496 |
| 2007 | 0 | 1,382 | 2,622 | 7,667 | 3,568 | 0 | 15,239 | 15,239 |

Table A29. Projection of B and F assuming constant catches at the annual quotas.

**Projected biomass and fishing mortality** for ocean quahog during 2002-2007 based on best estimates for 2002 and **assuming constant regional catch at quota levels** (4.5 million bushels=20,412 mt during 2003 and 5.0 million bushels=22,680 mt during 2004-2007). Proportions of total catch in each year for each region are the same as in 2002. Projections use annual instantaneous rates of change for somatic growth in weight (G), recruitment biomass (r), natural mortality (M) and fishing (F) based on population dynamics equations given in the text. Instantaneous rates for DMV, NJ, SNE are KLAMZ model estimates for 2002. Rates for other regions are averages of estimates for DMV, NJ and SNE except that G=0 for GBK because quahogs in GBK are unfished and assumed at carrying capacity. Projected biomass for the total area and for the total area less Georges Bank are sums of regional biomass levels. Similarly, projected fishing mortality rates are biomass weighted averages. Approximate 80% confidence intervals have endpoints that are half and double the projected values.

| Year | SVA | DMV | NJ | LI | SNE | GBK | Total Less GBK | Total |
|------|-----|-----|----|----|-----|-----|----------------|-------|
| *Somatic growth rate (G y$^{-1}$)* | | | | | | | | |
| 2002 | 0.0080 | 0.0045 | 0.0099 | 0.0076 | 0.0096 | 0.0000 | not used | not used |
| *Recruitment rate (r = Recruitment / Average Biomass in 2002 y$^{-1}$)* | | | | | | | | |
| 2002 | 0.0101 | 0.0000 | 0.0168 | 0.0094 | 0.0136 | 0.0000 | not used | not used |
| *Natural mortality (M y$^{-1}$)* | | | | | | | | |
| 2002 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | not used | not used |
| *Net instantaneous rate of change, less fishing (X - F = G + r - M y$^{-1}$)* | | | | | | | | |
| 2002 | -0.0019 | -0.0155 | 0.0067 | -0.0030 | 0.0032 | -0.0200 | not used | not used |
| *Landings (mt meats y$^{-1}$)* | | | | | | | | |
| 2002 | 0 | 1,732 | 2,781 | 9,113 | 3,884 | 0 | 17,509 | 17,509 |
| 2003 | 0 | 2,019 | 3,242 | 10,624 | 4,528 | 0 | 20412 (Quota) | 20412 (Quota) |
| 2004-2007 | 0 | 2,243 | 3,602 | 11,804 | 5,031 | 0 | 22680 (Quota) | 22680 (Quota) |
| *Catch (mt meats y$^{-1}$, landings+ 5% allowance for incidental mortality)* | | | | | | | | |
| 2002 | 0 | 1,818 | 2,920 | 9,569 | 4,078 | 0 | 18,384 | 18,384 |
| 2003 | 0 | 2,120 | 3,404 | 11,155 | 4,754 | 0 | 21,432 | 21,432 |
| 2004-2007 | 0 | 2,355 | 3,782 | 12,394 | 5,282 | 0 | 23,813 | 23,813 |
| *Initial Biomass* | | | | | | | | |
| 2002 | 13 | 90,891 | 283,580 | 477,610 | 348,570 | 655,426 | 1,200,665 | 1,856,091 |
| *Projected biomass (mt meats)* | | | | | | | | |
| 2003 | 13 | 87,688 | 282,564 | 466,625 | 345,602 | 642,448 | 1,182,492 | 1,824,940 |
| 2004 | 13 | 84,235 | 281,055 | 454,089 | 341,948 | 629,727 | 1,161,340 | 1,791,066 |
| 2005 | 13 | 80,601 | 279,156 | 440,352 | 337,753 | 617,257 | 1,137,876 | 1,755,134 |
| 2006 | 13 | 77,024 | 277,245 | 426,657 | 333,545 | 605,035 | 1,114,484 | 1,719,518 |
| 2007 | 13 | 73,501 | 275,320 | 413,003 | 329,323 | 593,054 | 1,091,161 | 1,684,215 |
| *Projected fishing mortality rate (F y$^{-1}$)* | | | | | | | | |
| 2003 | 0.000 | 0.021 | 0.010 | 0.021 | 0.012 | 0.000 | 0.016 | 0.010 |
| 2004 | 0.000 | 0.025 | 0.012 | 0.025 | 0.014 | 0.000 | 0.018 | 0.012 |
| 2005 | 0.000 | 0.029 | 0.014 | 0.028 | 0.016 | 0.000 | 0.021 | 0.014 |
| 2006 | 0.000 | 0.031 | 0.014 | 0.029 | 0.016 | 0.000 | 0.021 | 0.014 |
| 2007 | 0.000 | 0.032 | 0.014 | 0.030 | 0.016 | 0.000 | 0.022 | 0.014 |

Table A30. Projection of B, F and landings, assuming constant fishing at $F_{0.1}$.

> **Projected biomass and fishing mortality** for ocean quahog during 2002-2007 based on best estimates for 2002 and **assuming constant regional fishing mortality $F_{0.1}$= 0.0275 $y^{-1}$** (except on GBK where fishing mortality is zero). Projections use annual instantaneous rates of change for somatic growth in weight (G), recruitment biomass (r), natural mortality (M) and fishing (F) based on population dynamics equations given in the text. Instantaneous rates G, r and M for DMV, NJ, SNE are KLAMZ model estimates for 2002. Rates for other regions are averages of estimates for DMV, NJ and SNE except that G=0 for GBK because quahogs in GBK are unfished and assumed at carrying capacity. Projected biomass, catch and landings for the total area and for the total area less Georges Bank are sums of regional biomass levels. Approximate 80% confidence intervals have endpoints that are half and double the projected values.

| Year | SVA | DMV | NJ | LI | SNE | GBK | Total Less GBK | Total |
|---|---|---|---|---|---|---|---|---|
| *Somatic growth rate (G $y^{-1}$)* |
| 2002 | 0.0080 | 0.0045 | 0.0099 | 0.0076 | 0.0096 | 0.0000 | not used | not used |
| *Recruitment rate (r = Recruitment / Average Biomass in 2002 $y^{-1}$)* |
| 2002 | 0.0101 | 0.0000 | 0.0168 | 0.0094 | 0.0136 | 0.0000 | not used | not used |
| *Natural mortality (M $y^{-1}$)* |
| 2002 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | 0.0200 | not used | not used |
| *Fishing mortality (F $y^{-1}$)* |
| 2002 | 0.0275 | 0.0275 | 0.0275 | 0.0275 | 0.0275 | 0.0000 | not used | not used |
| *Net instantaneous rate of change X = G + r - F - M $y^{-1}$)* |
| 2002 | -0.0294 | -0.0430 | -0.0208 | -0.0305 | -0.0243 | -0.0200 | not used | not used |
| *Initial Biomass* |
| 2002 | 13 | 90,891 | 283,580 | 477,610 | 348,570 | 655,426 | 1,200,665 | 1,856,091 |
| *Projected biomass (mt meats)* |
| 2003 | 13 | 87,065 | 277,749 | 463,263 | 340,202 | 642,448 | 1,168,291 | 1,810,739 |
| 2004 | 13 | 83,399 | 272,038 | 449,346 | 332,034 | 629,727 | 1,136,830 | 1,766,556 |
| 2005 | 12 | 79,888 | 266,444 | 435,847 | 324,062 | 617,257 | 1,106,254 | 1,723,512 |
| 2006 | 12 | 76,525 | 260,965 | 422,754 | 316,282 | 605,035 | 1,076,539 | 1,681,574 |
| 2007 | 12 | 73,303 | 255,599 | 410,055 | 308,689 | 593,054 | 1,047,658 | 1,640,712 |
| *Catch (landings + 5% allowance for incidental mortality, mt $y^{-1}$)* |
| 2003 | 0 | 2,344 | 7,559 | 12,547 | 9,243 | 0 | 31,693 | 31,693 |
| 2004 | 0 | 2,245 | 7,404 | 12,170 | 9,021 | 0 | 30,840 | 30,840 |
| 2005 | 0 | 2,150 | 7,252 | 11,805 | 8,804 | 0 | 30,011 | 30,011 |
| 2006 | 0 | 2,060 | 7,103 | 11,450 | 8,593 | 0 | 29,206 | 29,206 |
| 2007 | 0 | 1,973 | 6,956 | 11,106 | 8,387 | 0 | 28,423 | 28,423 |
| *Landings (95% of catch, mt $y^{-1}$)* |
| 2003 | 0 | 2,226 | 7,181 | 11,920 | 8,781 | 0 | 30,109 | 30,109 |
| 2004 | 0 | 2,133 | 7,034 | 11,562 | 8,570 | 0 | 29,298 | 29,298 |
| 2005 | 0 | 2,043 | 6,889 | 11,215 | 8,364 | 0 | 28,511 | 28,511 |
| 2006 | 0 | 1,957 | 6,747 | 10,878 | 8,163 | 0 | 27,746 | 27,746 |
| 2007 | 0 | 1,874 | 6,609 | 10,551 | 7,967 | 0 | 27,002 | 27,002 |

Figure A1. Regions and strata used in NMFS clam surveys and assessments. USA – Canada border is shown. Depths of strata, in fathoms, are: 5-15, 16-25, 26-30, 31-40, and 41-60.
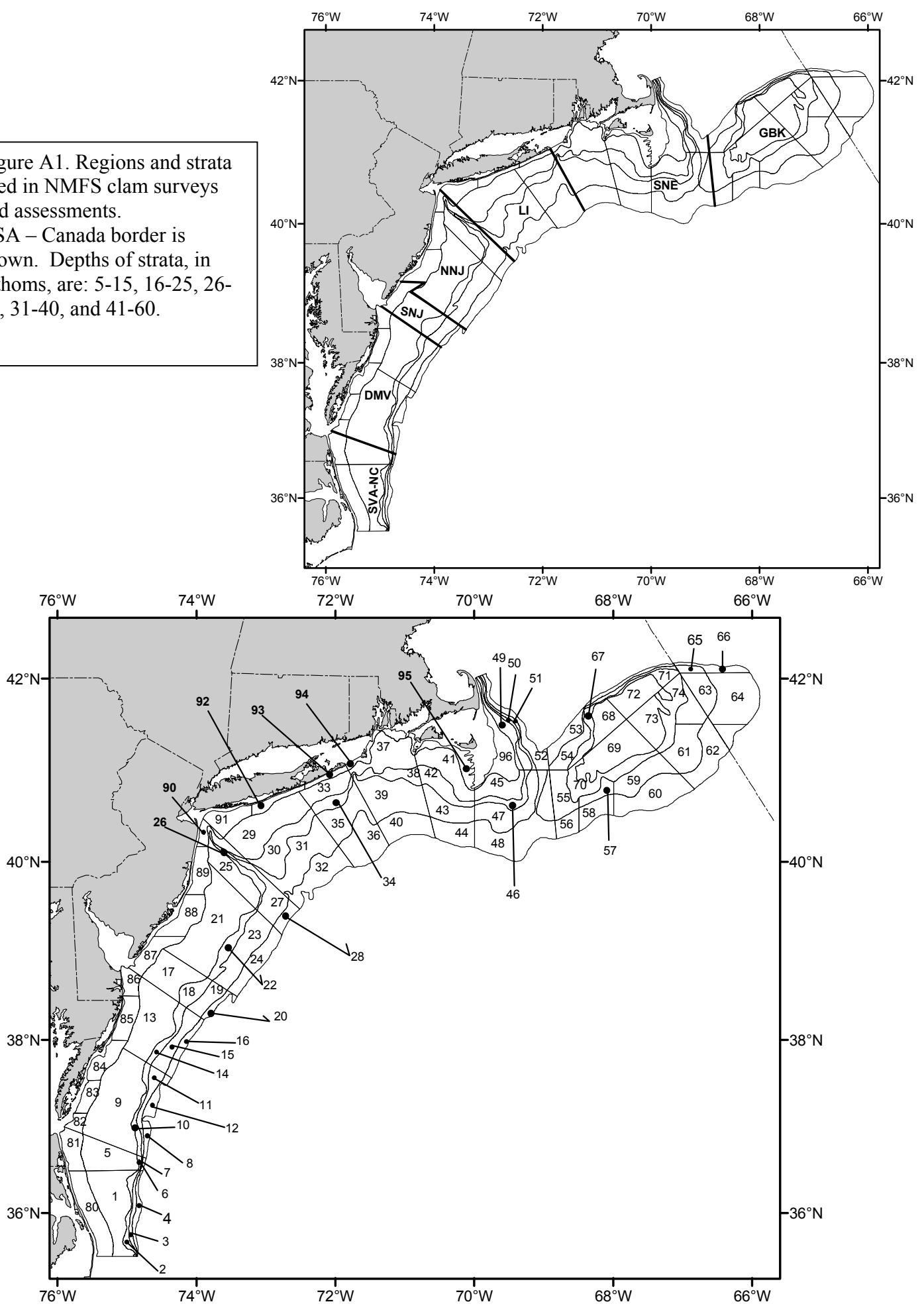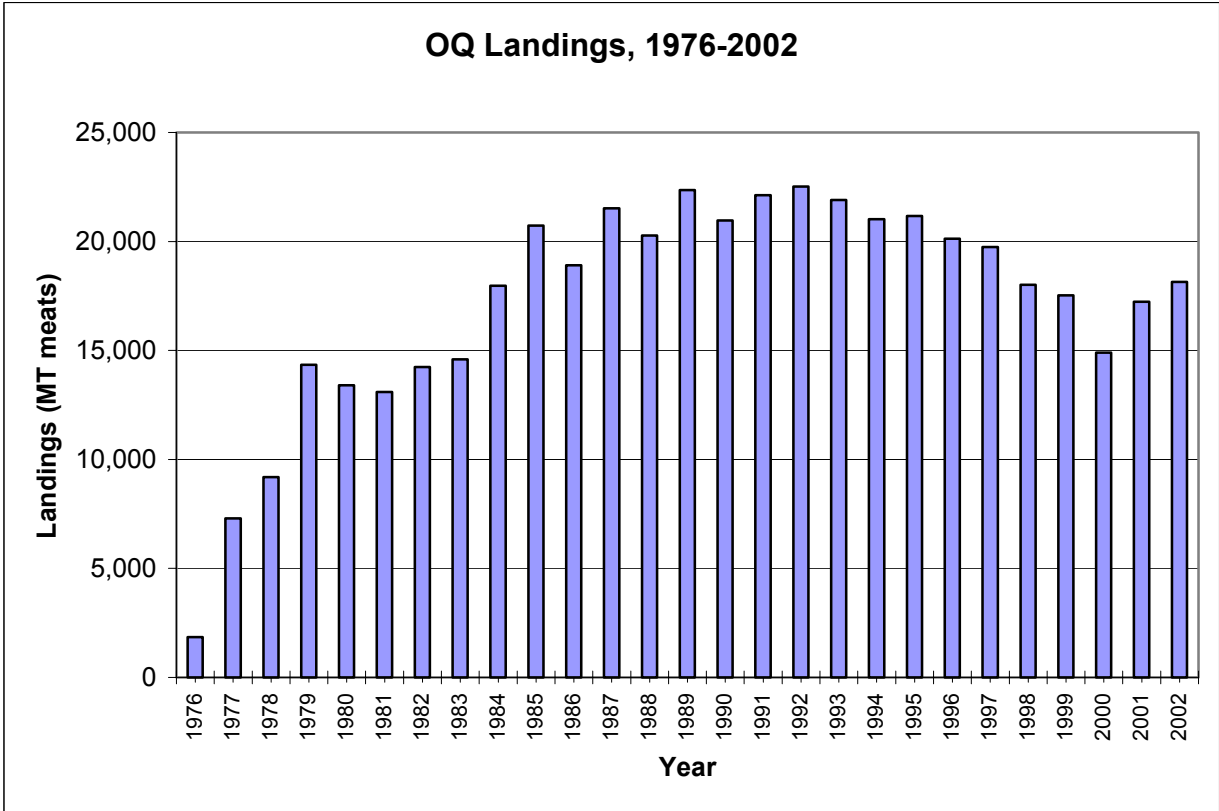
Figure A2. Landings of ocean quahogs from EEZ waters, 1976-2002.
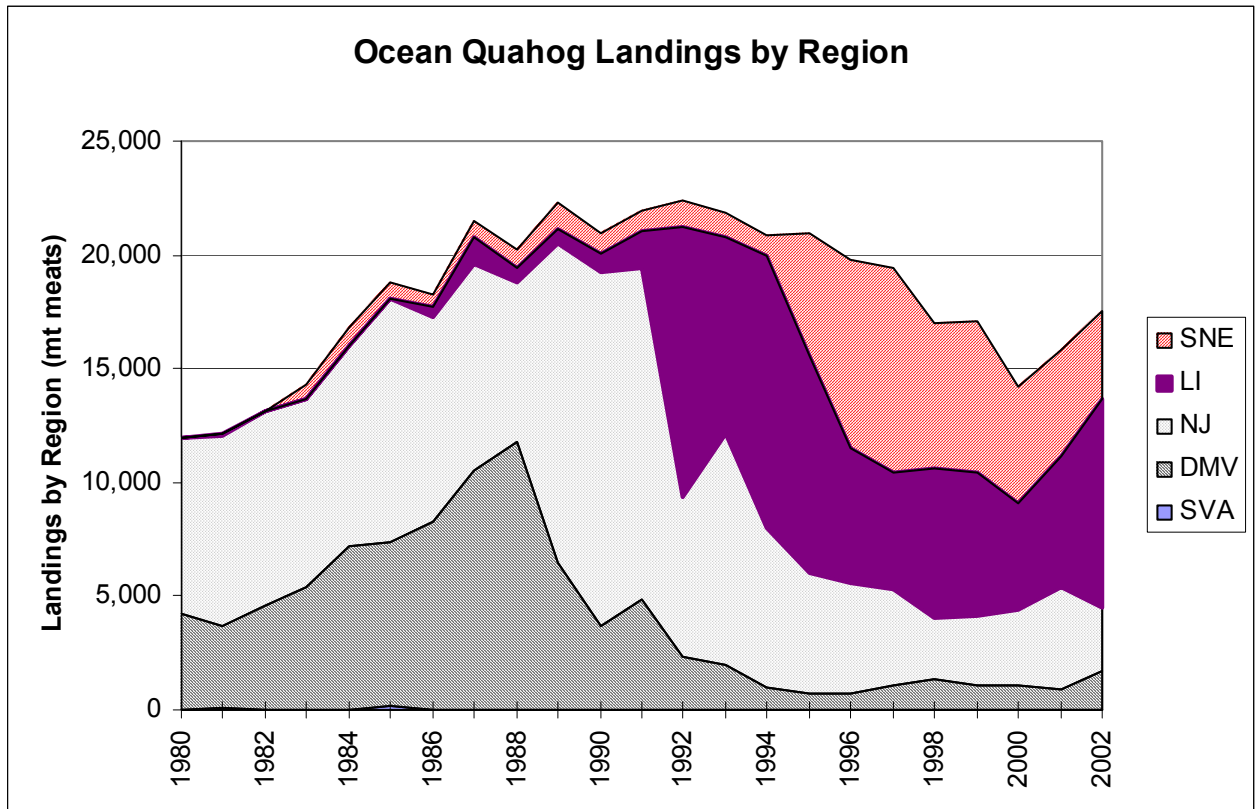
Figure A3. Ocean quahog landings in weight (calculated from number of bushels reported in logbooks) for the US EEZ, by stock assessment region. GBK not shown because the landings and effort were zero.
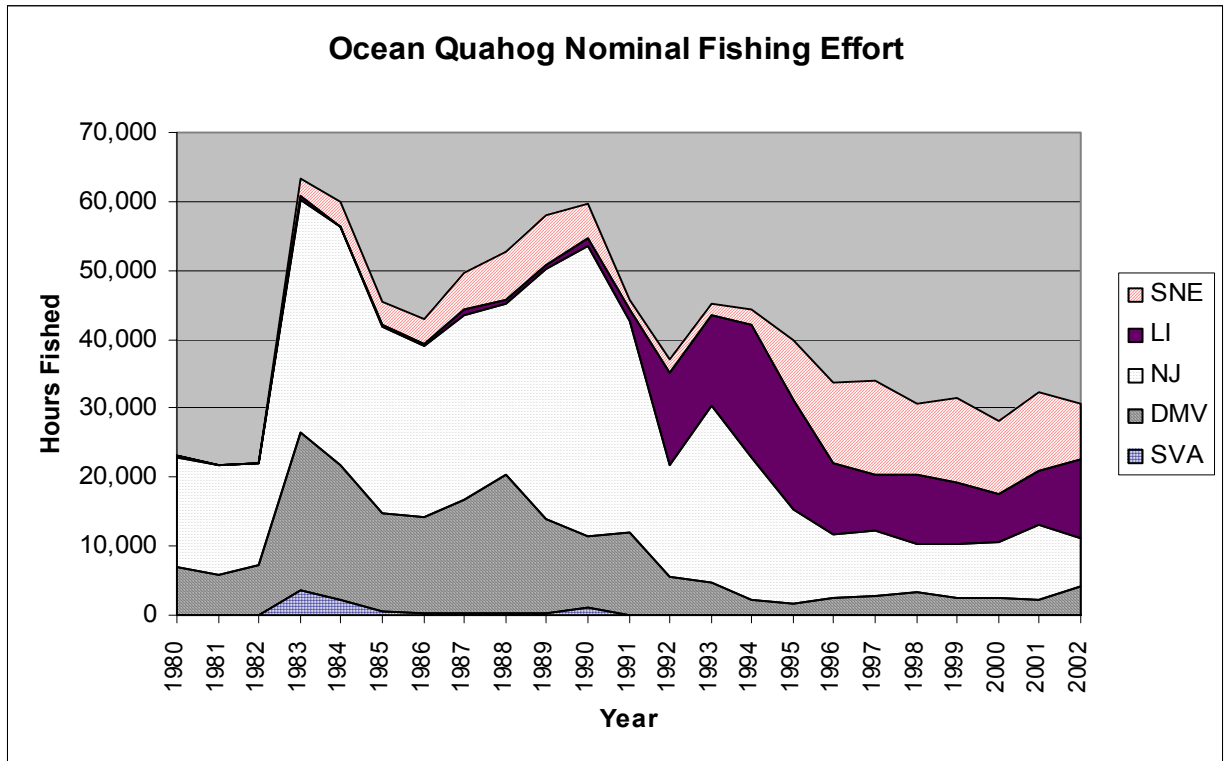
Figure A4. Nominal fishing effort for ocean quahogs in the US EEZ, by stock assessment region from logbooks. GBK not shown because the landings were zero.
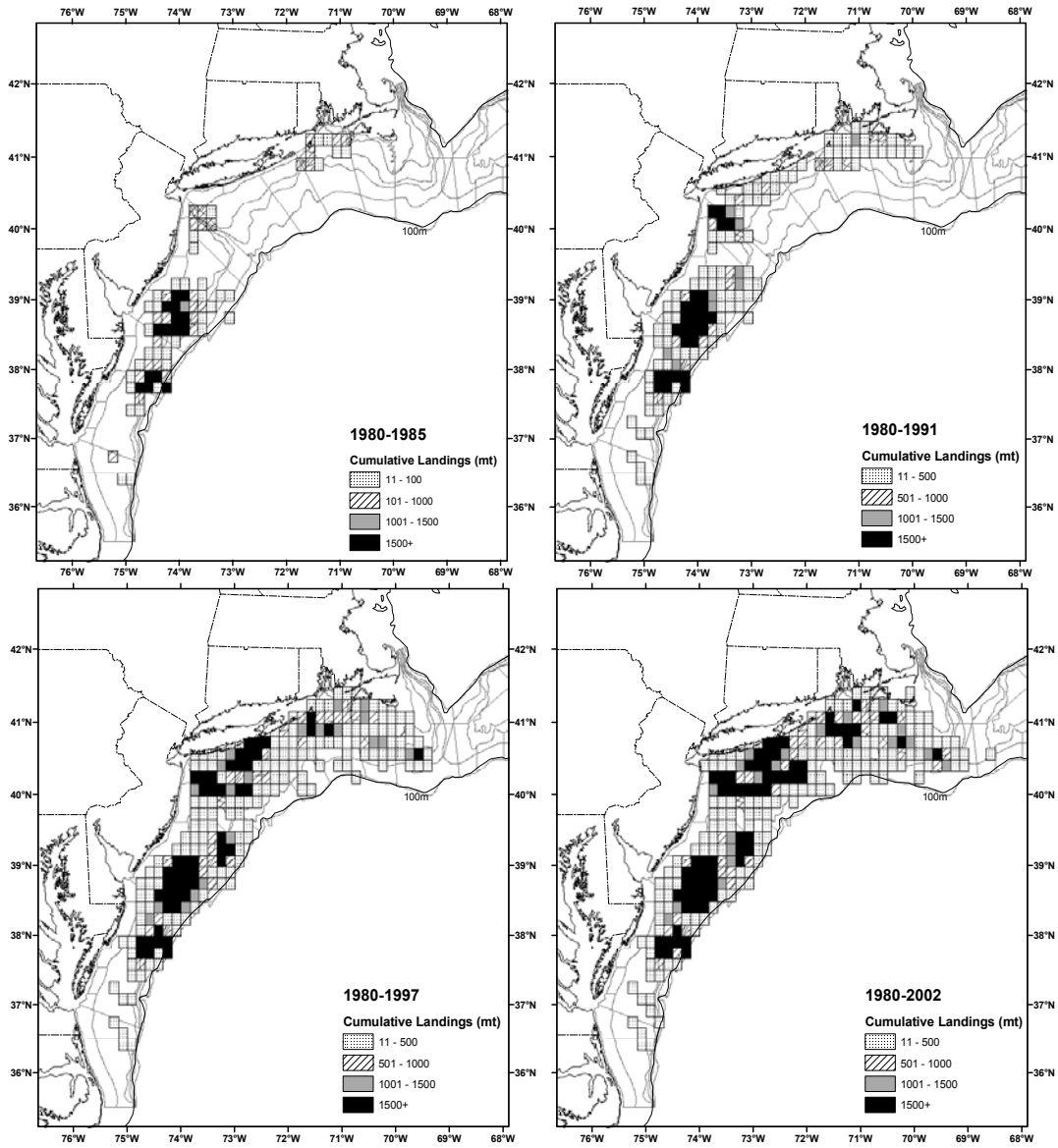
Figure A5.  Cumulative landings of ocean quahogs from the EEZ, by TNMS.
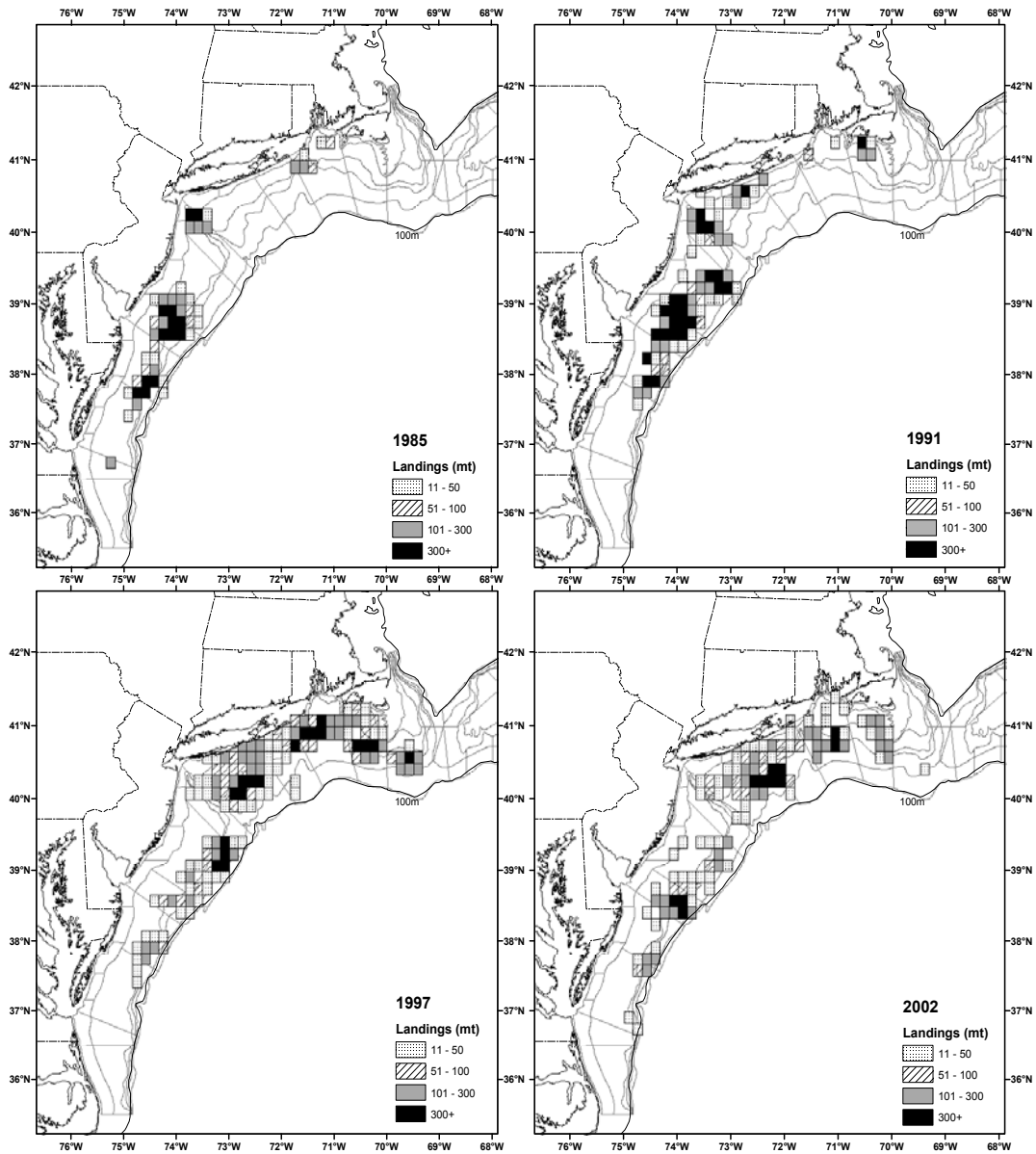
Figure A6.  Annual landings of ocean quahogs from the EEZ, by TNMS.
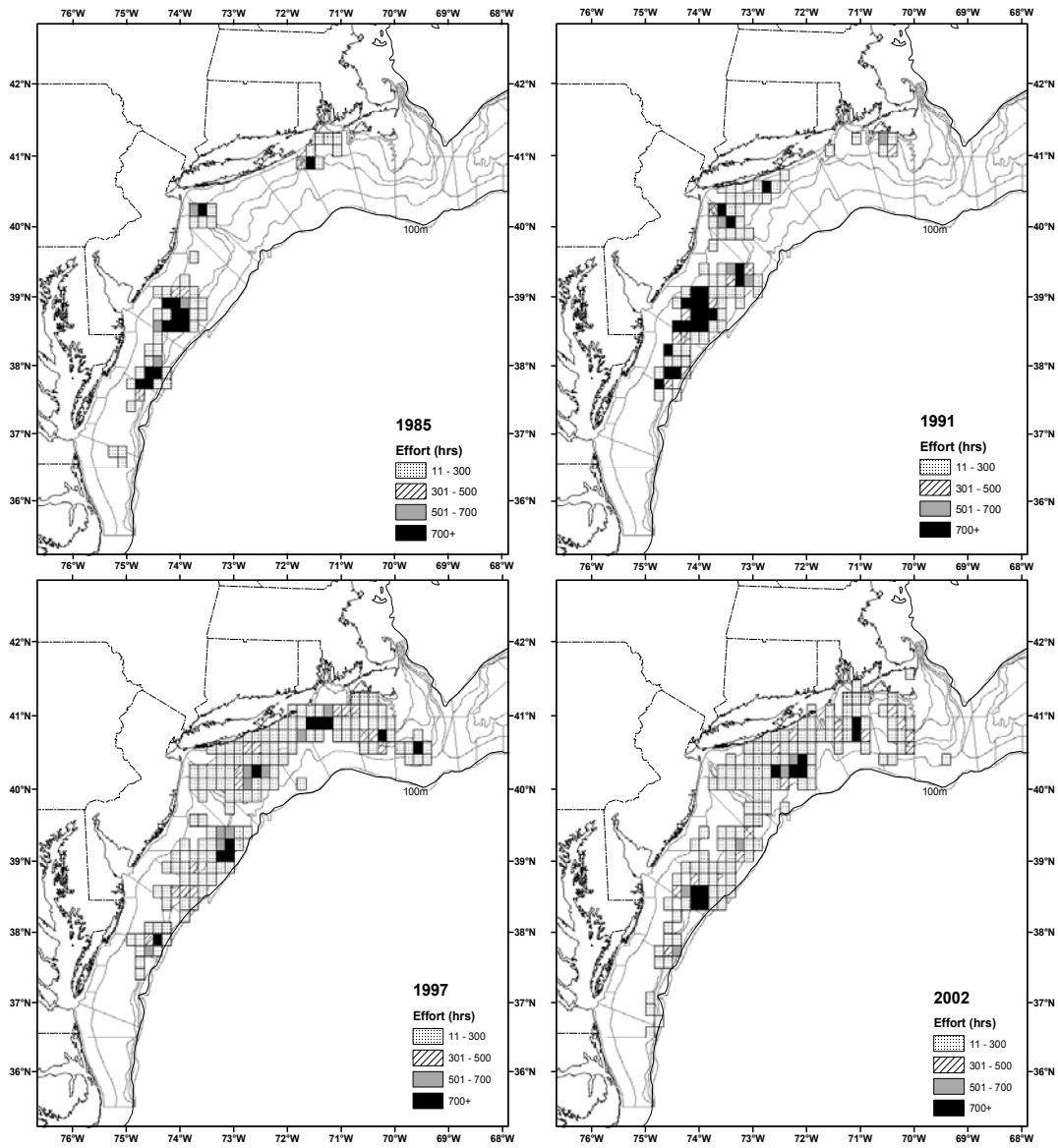
Figure A7.  Annual fishing effort for ocean quahogs from the EEZ, by  TNMS.
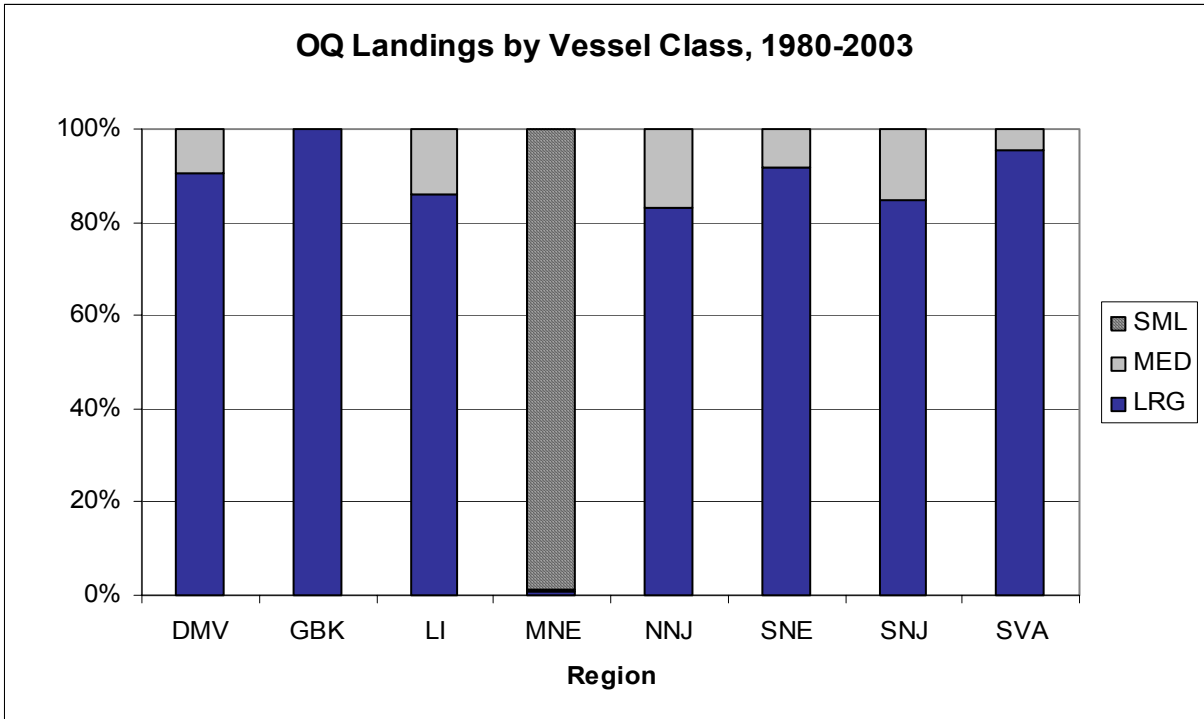
Figure A8.  Landings by vessel class.
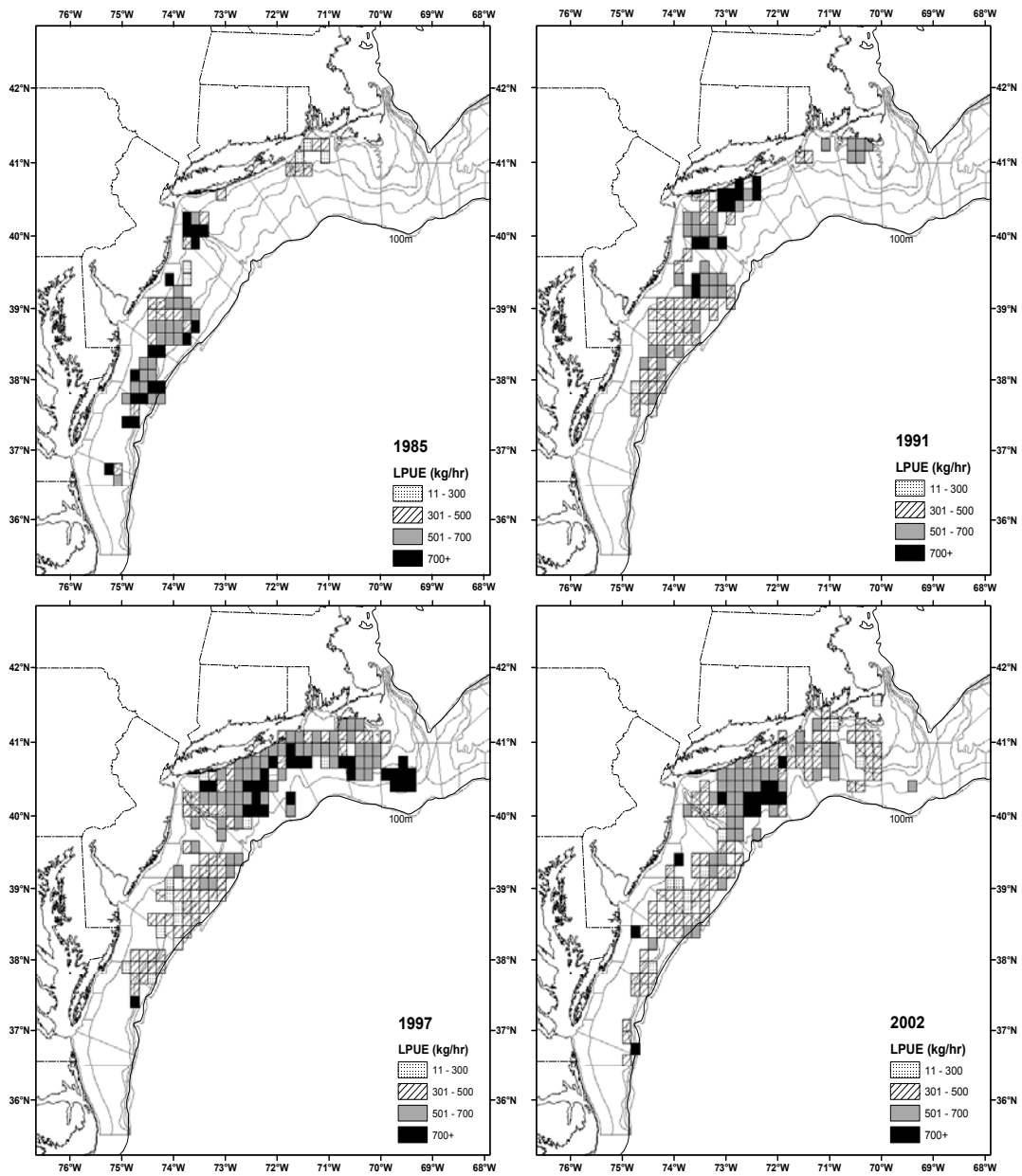
Figure A9. Landings per unit effort, by year and TNMS.
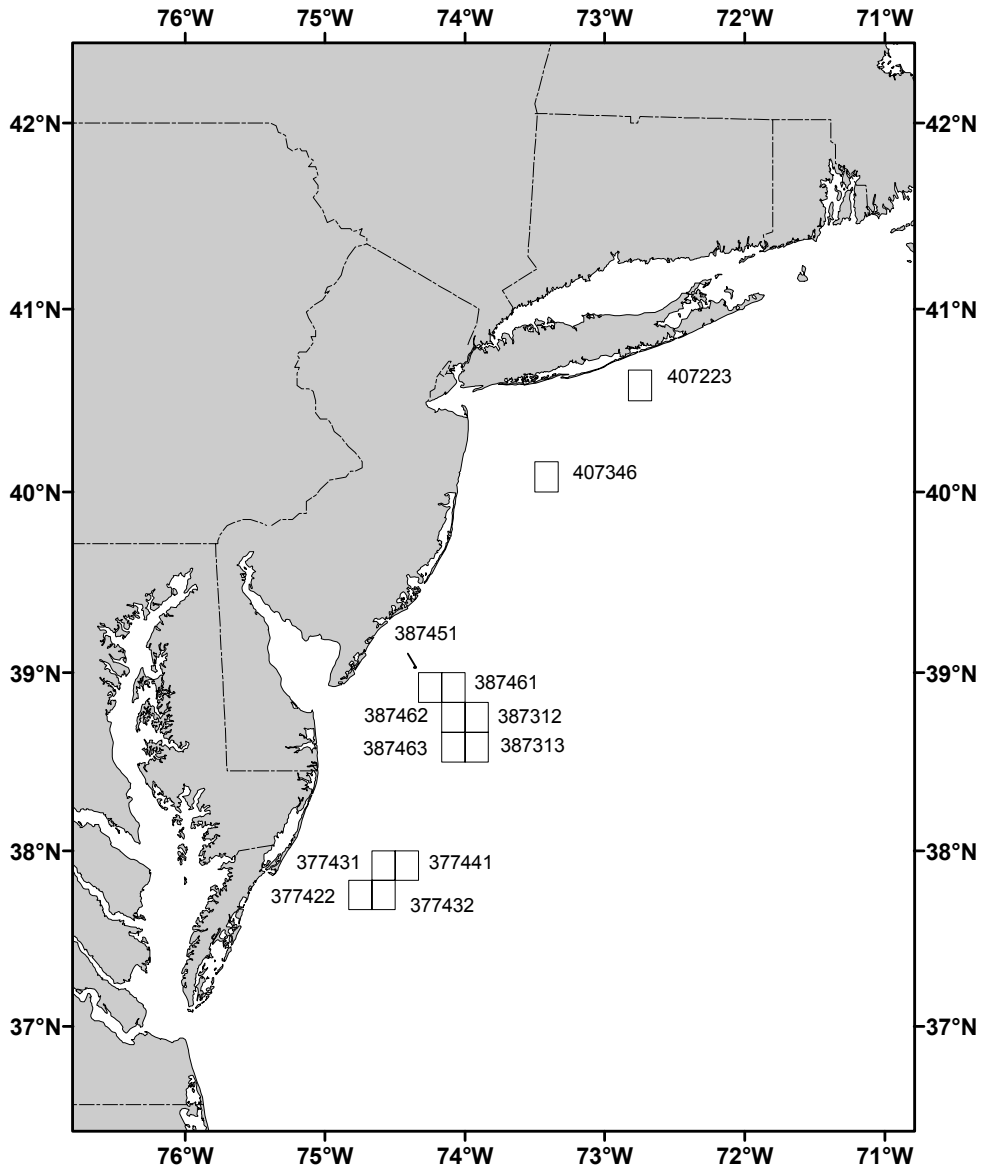
Figure A10.  12 ten-minute squares in the EEZ that have had the largest cumulative catch of ocean quahogs , 1980-2002.
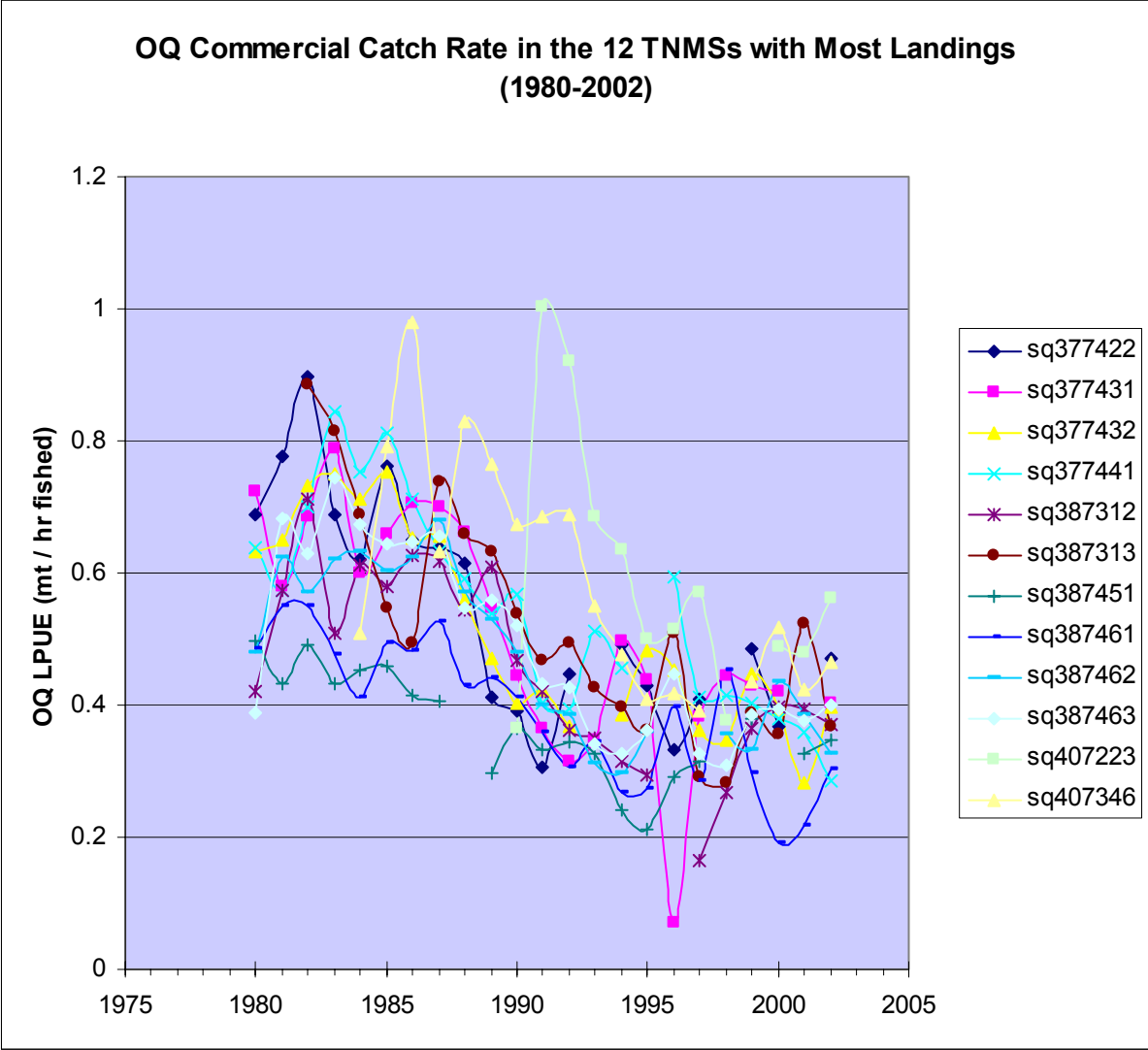
Figure A11. Commercial catch rates of large vessels in the 12 ten-minute squares in the EEZ that have had the largest cumulative catch of ocean quahogs , 1980-2002.
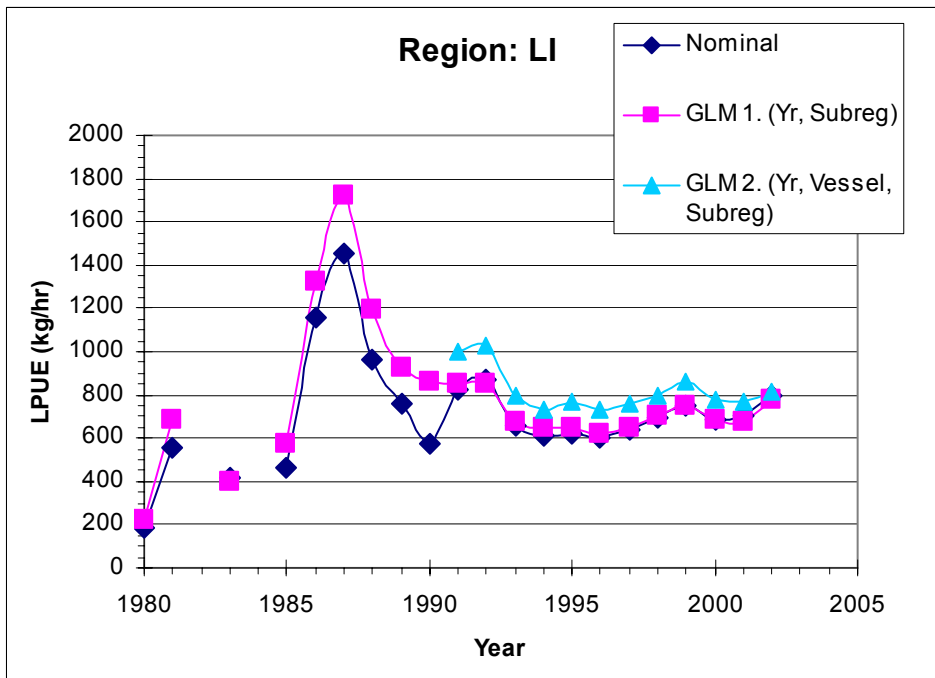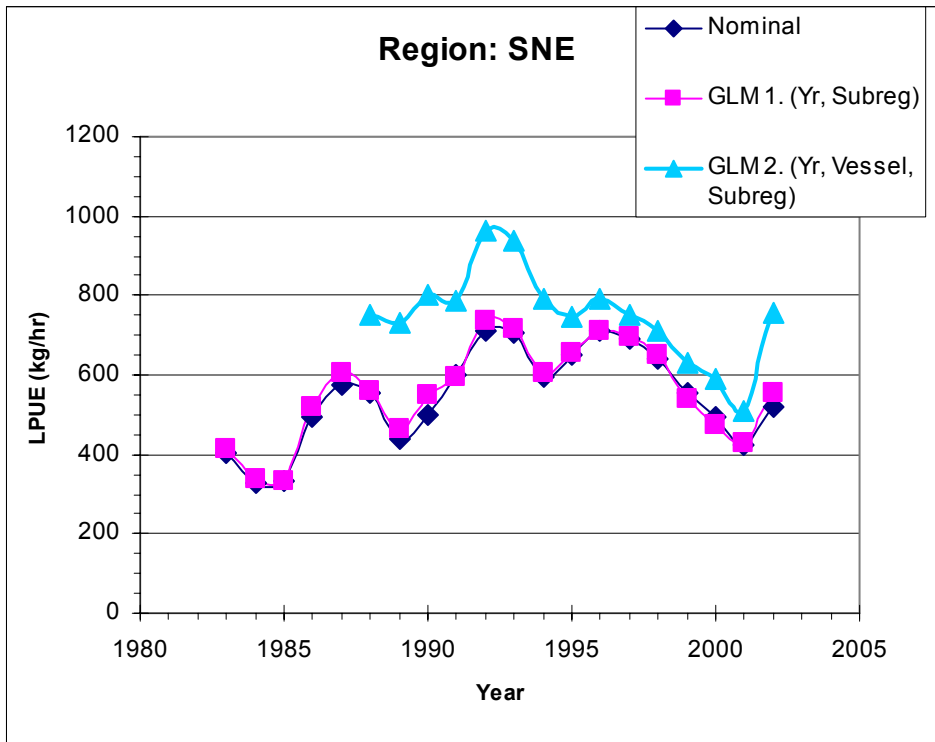
Figure A12. Landings per unit effort based on nominal values and 2 general linear models. Northern Regions.
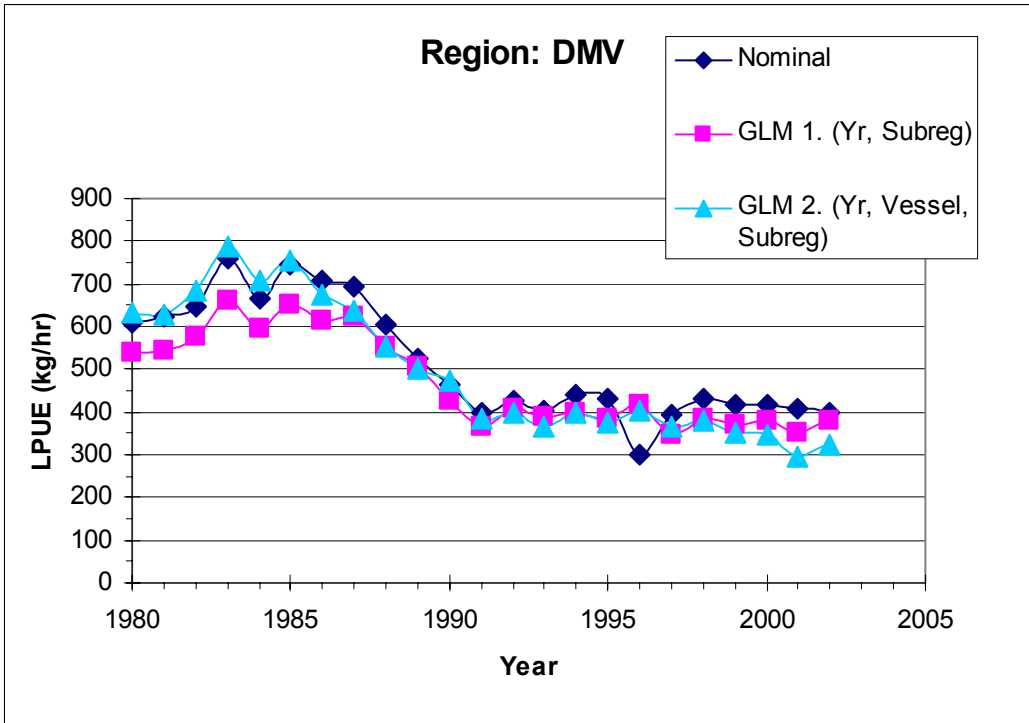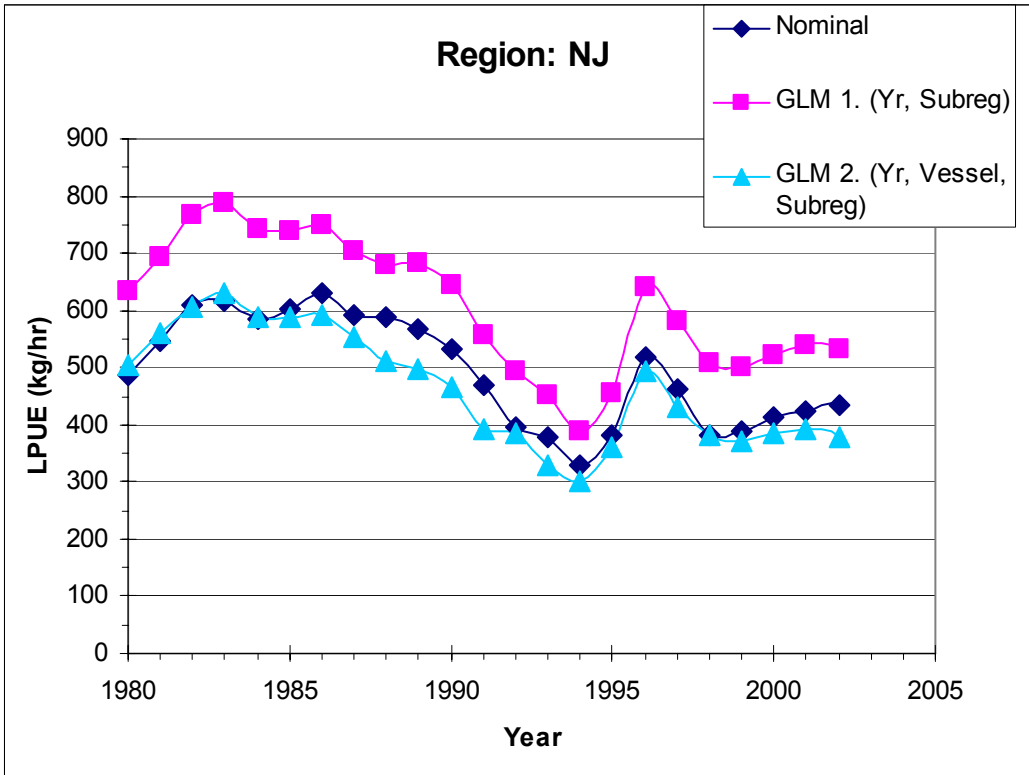
Figure A13.  Landings per unit effort based on nominal values and 2 general
linear models. Southern Regions.

Figure A14. Frequency distribution of commercial catch rates, by TNMS, over time (DMV).

## Delmarva (DMV)
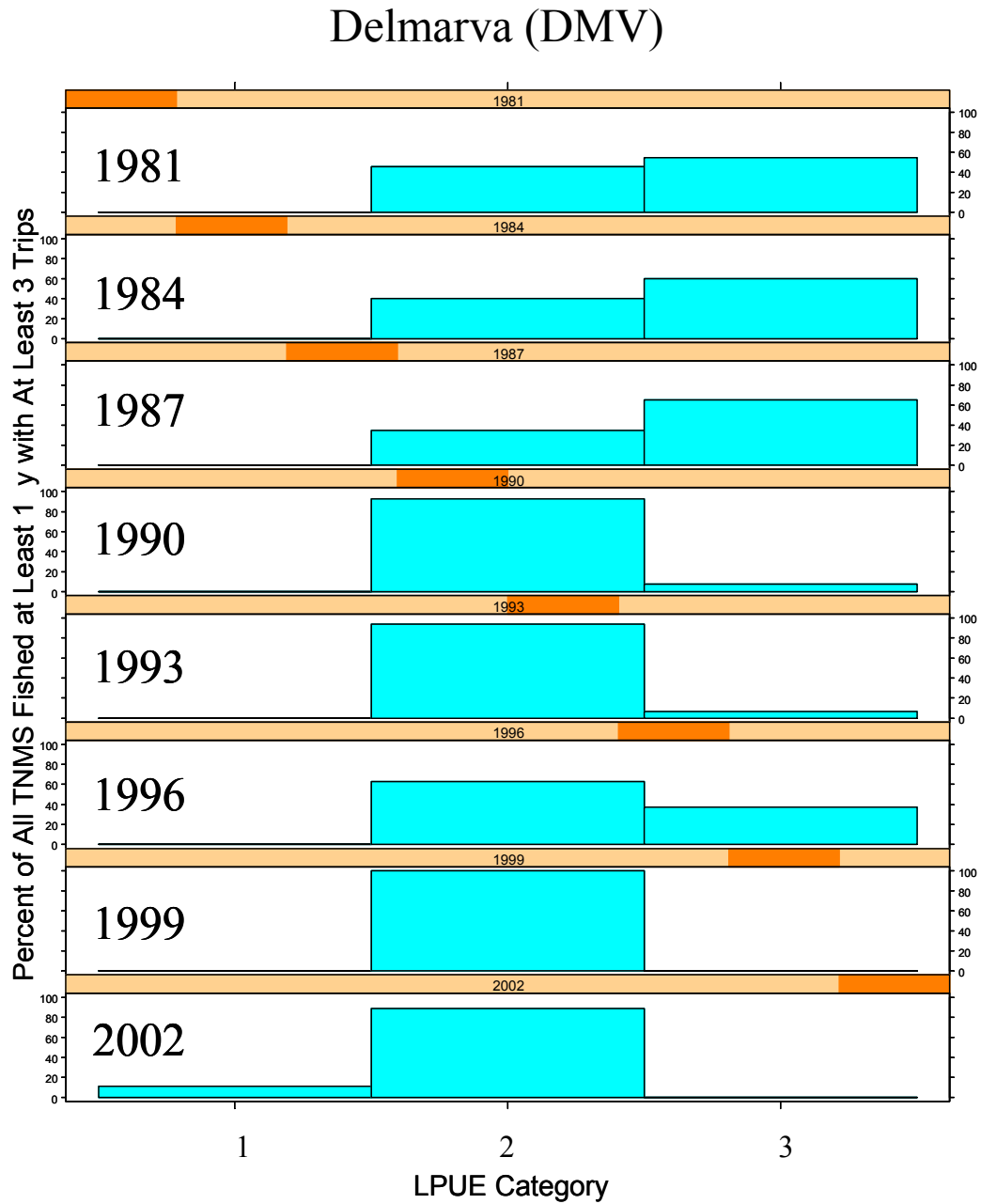


LPUE categories: 1=1- 66 , 2= 66 - 132 , 3= 132 + bu/hr
(80 bu/hr is profitable)

Figure A15. Frequency distribution of commercial catch rates, by TNMS, over time (NJ).

## New Jersey (NJ)



LPUE categories: 1=1- 66 , 2= 66 - 132 , 3= 132 + bu/hr
(80 bu/hr is profitable)
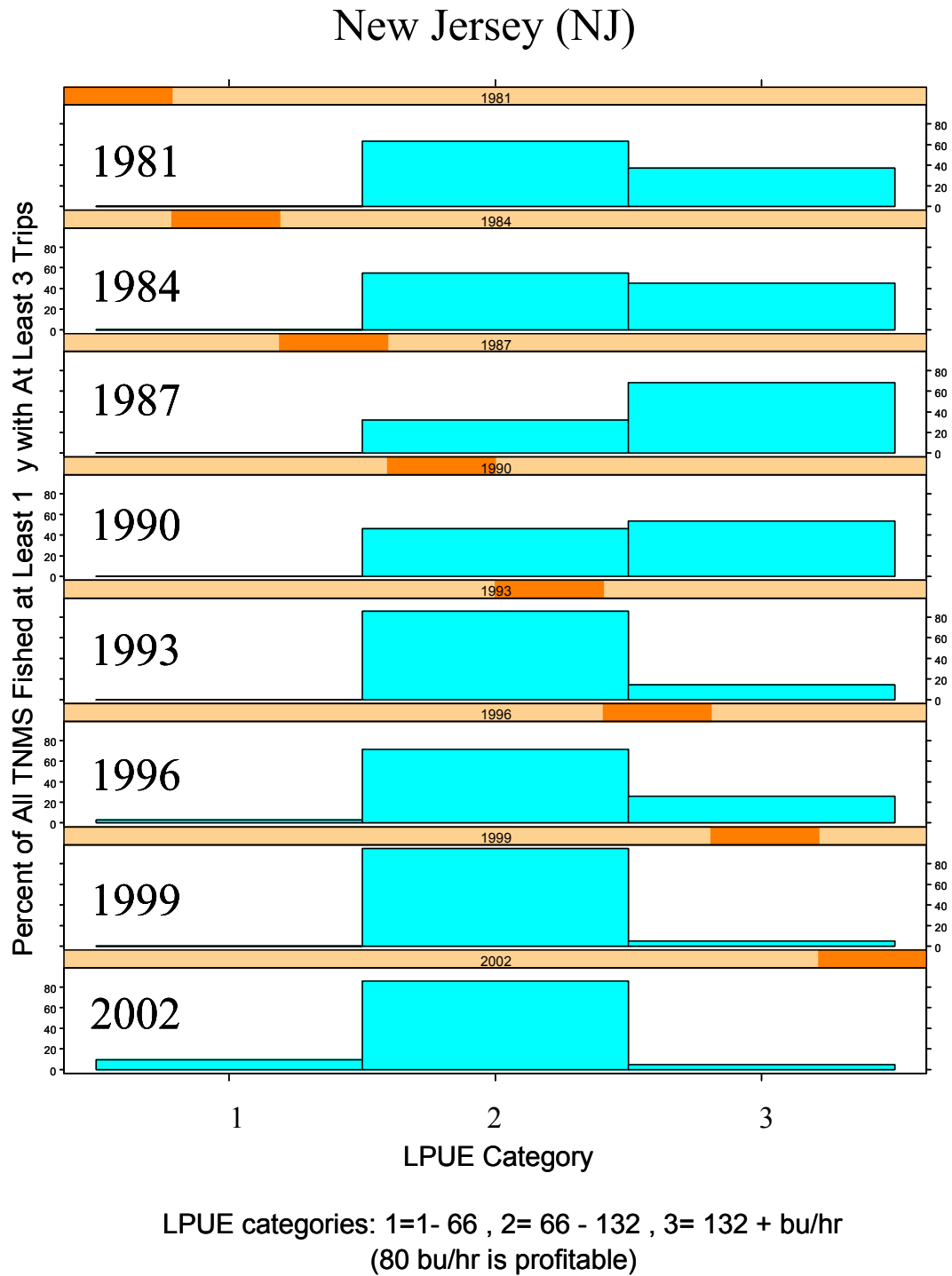
Figure A16. Frequency distribution of commercial catch rates, by TNMS, over time (LI).

# Long Island (LI)



LPUE Category

LPUE categories: 1=1- 66 , 2= 66 - 132 , 3= 132 + bu/hr
(80 bu/hr is profitable)
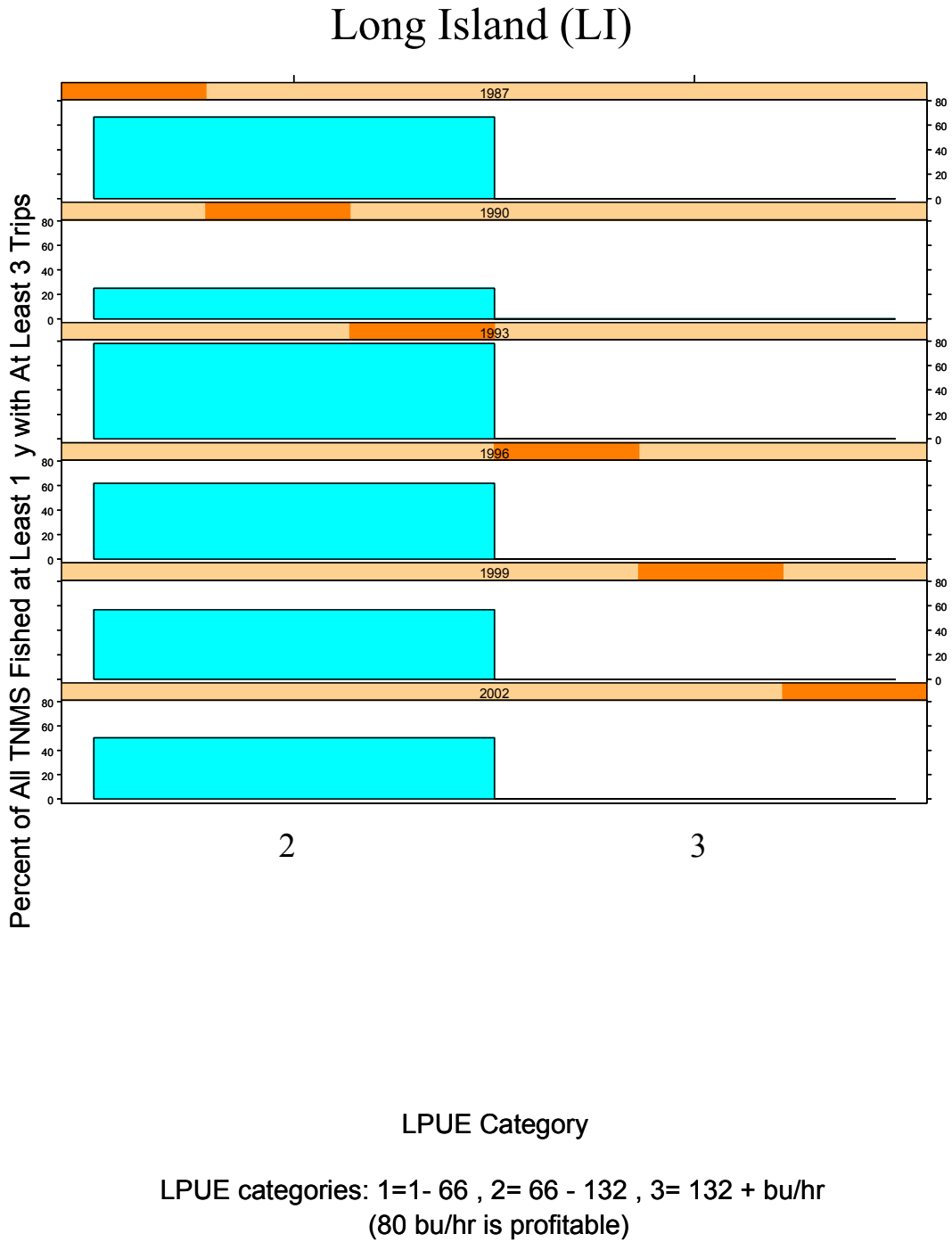
Figure A17.  Frequency distribution of commercial catch rates, by TNMS, over time (SNE).



## Southern New England (SNE)
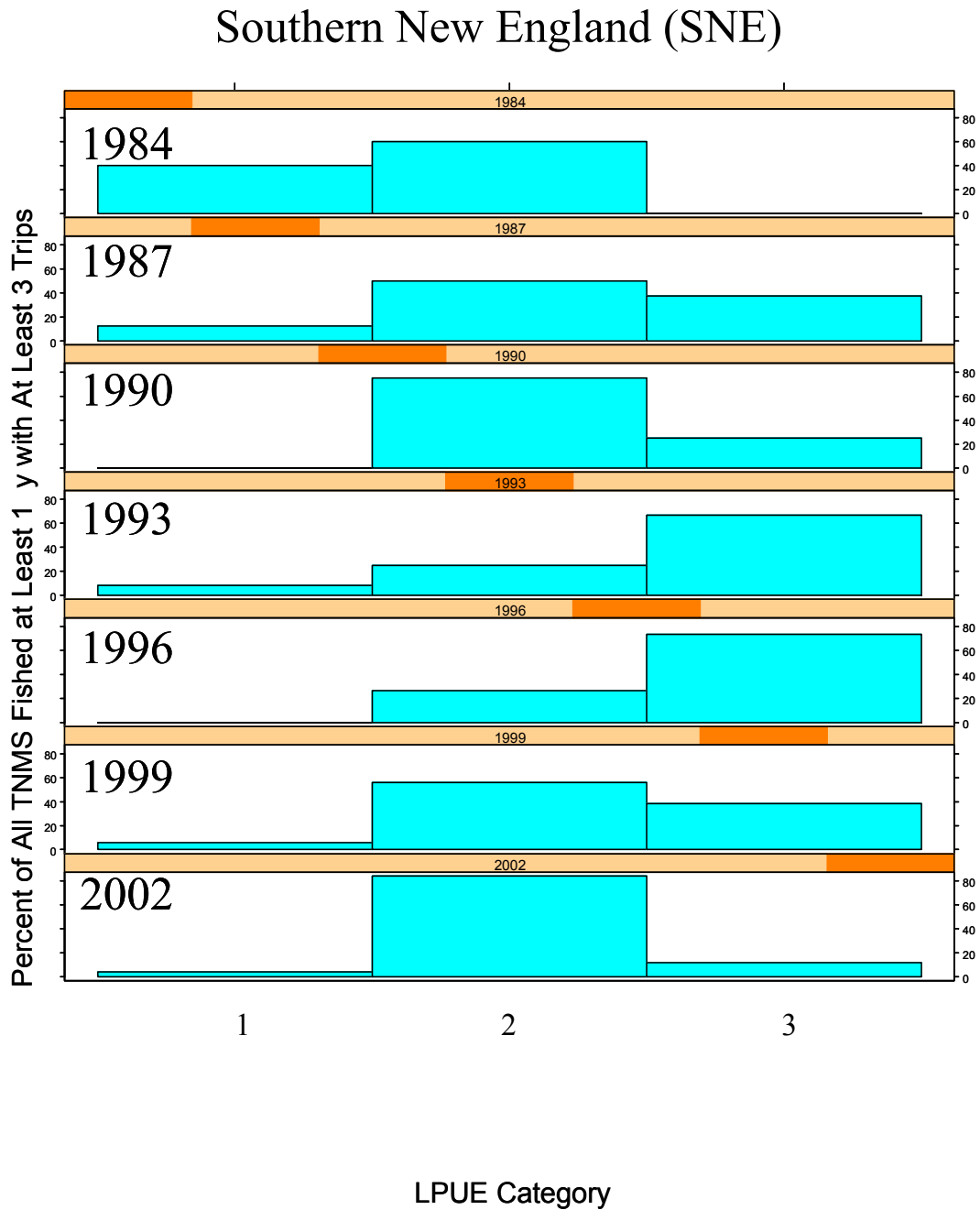
LPUE Category

LPUE categories: 1=1- 66 , 2= 66 - 132 , 3= 132 + bu/hr
(80 bu/hr is profitable)
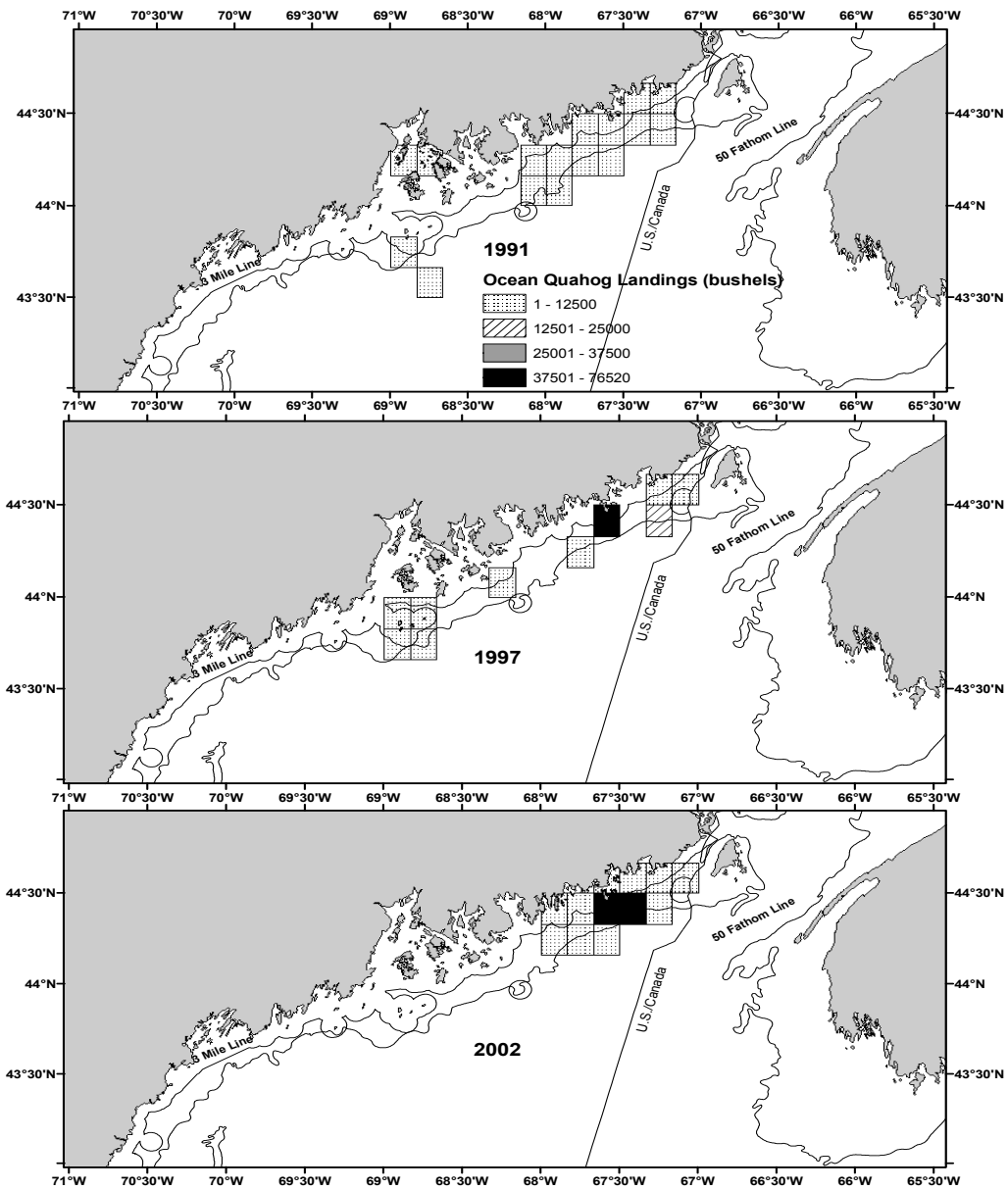
Figure A18.  Ocean quahog landings from Ten Minute Squares (TNMS) off the coast of Maine.
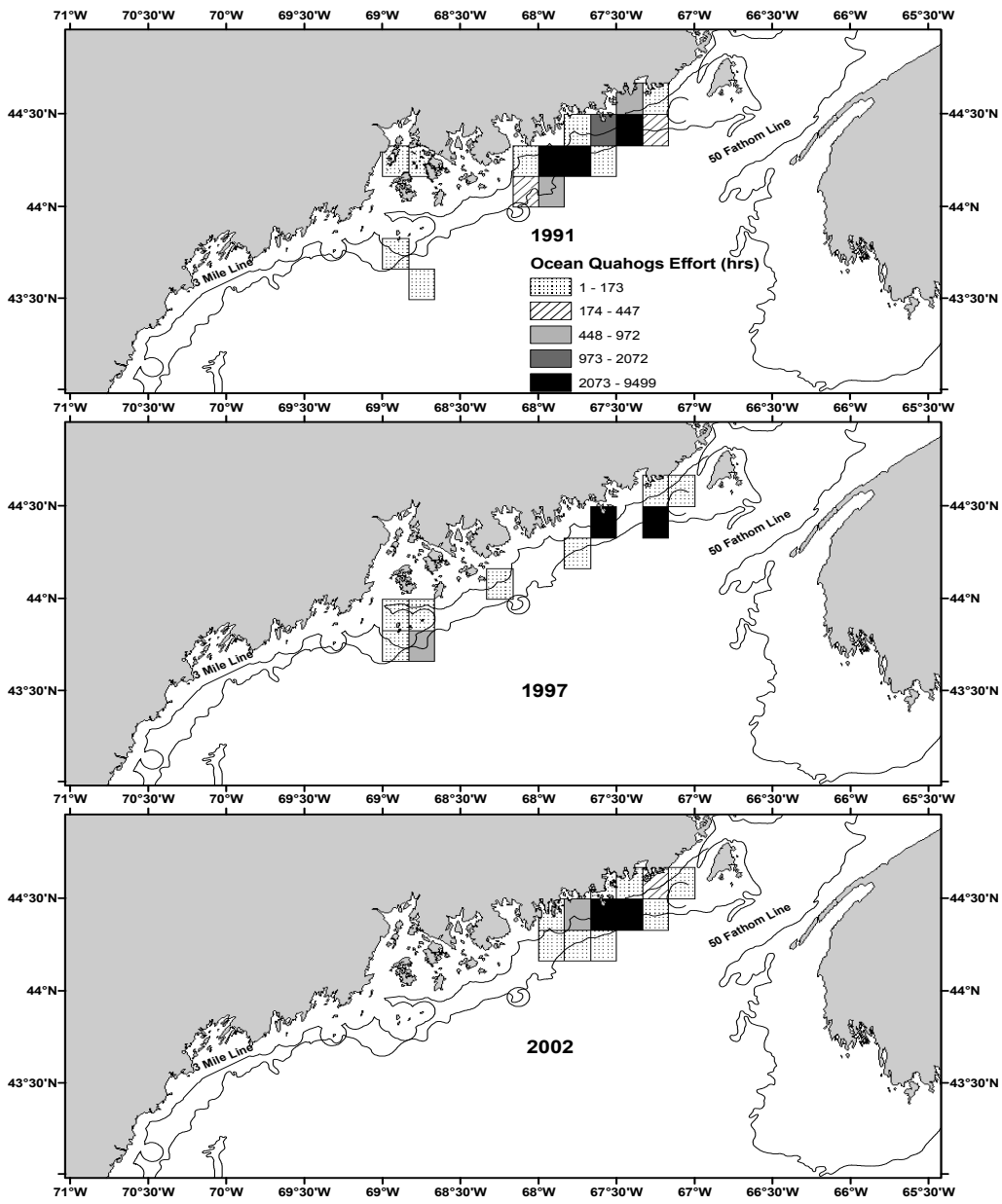
Figure A19.  Ocean quahog fishing effort from Ten Minute Squares (TNMS) off the coast of Maine.
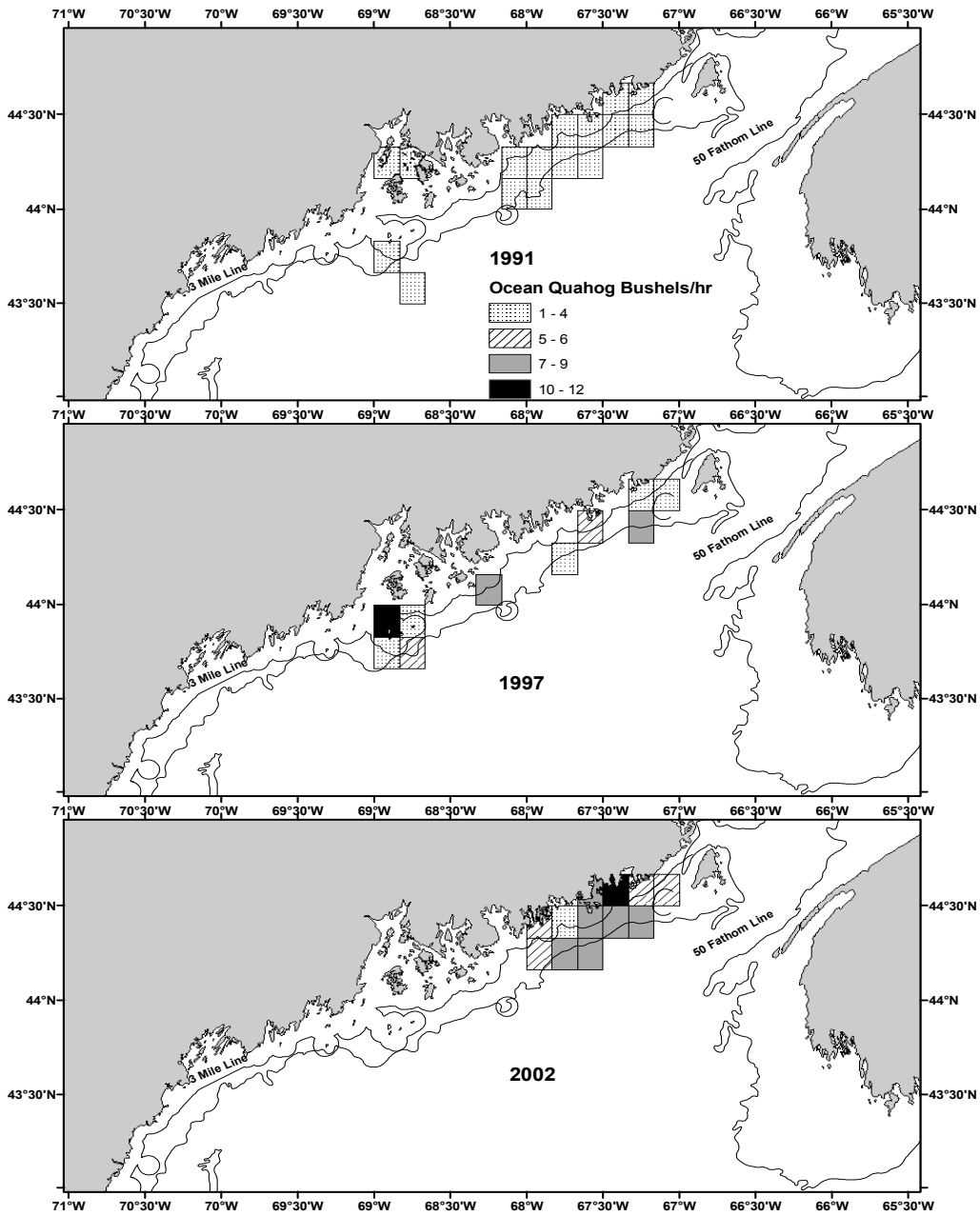
Figure A20. Ocean quahog landings per unit effort from Ten Minute Squares (TNMS) off the coast of Maine.
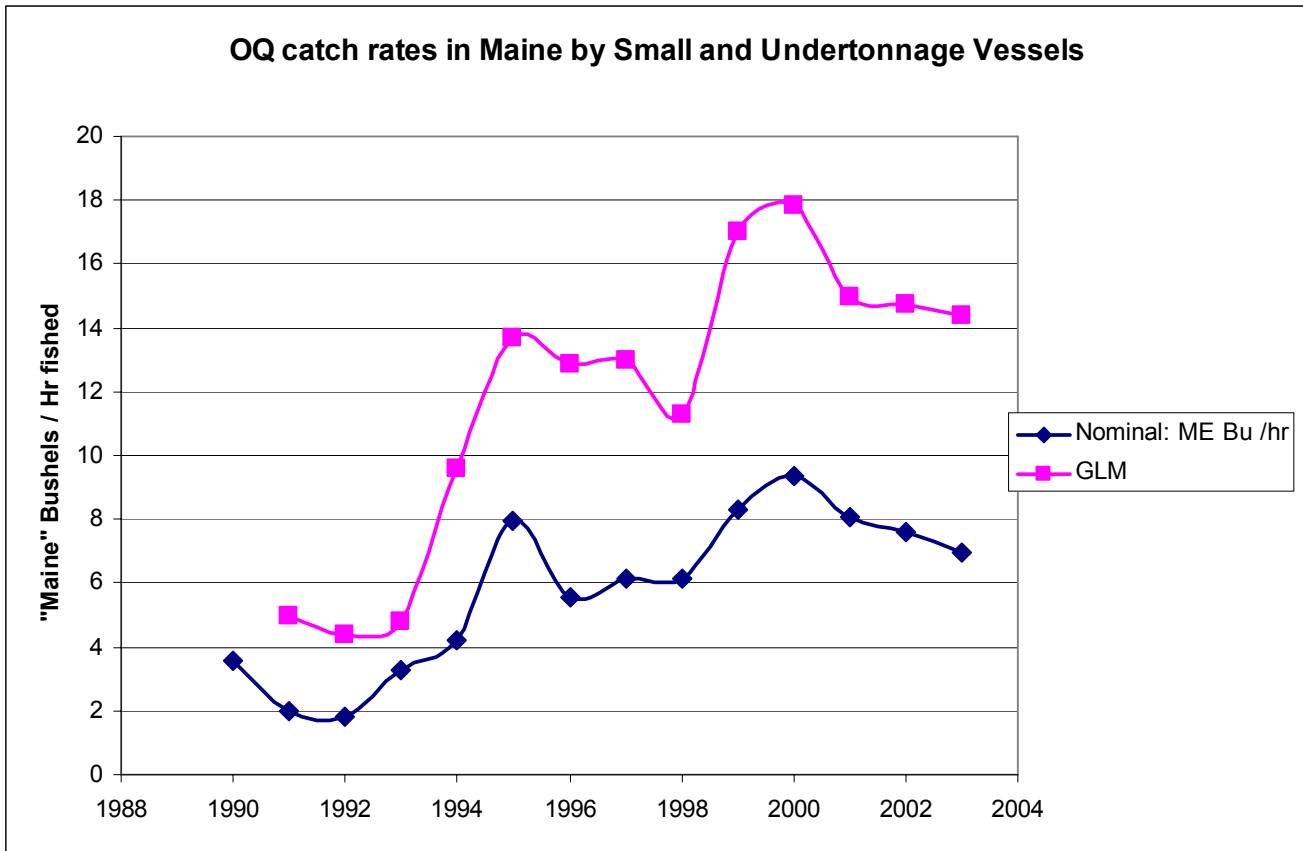
Figure A21. Ocean quahog landings per unit effort from off the coast of Maine. There are nominal values as well as standardized values from a General Linear Model (GLM).

## DelMarva
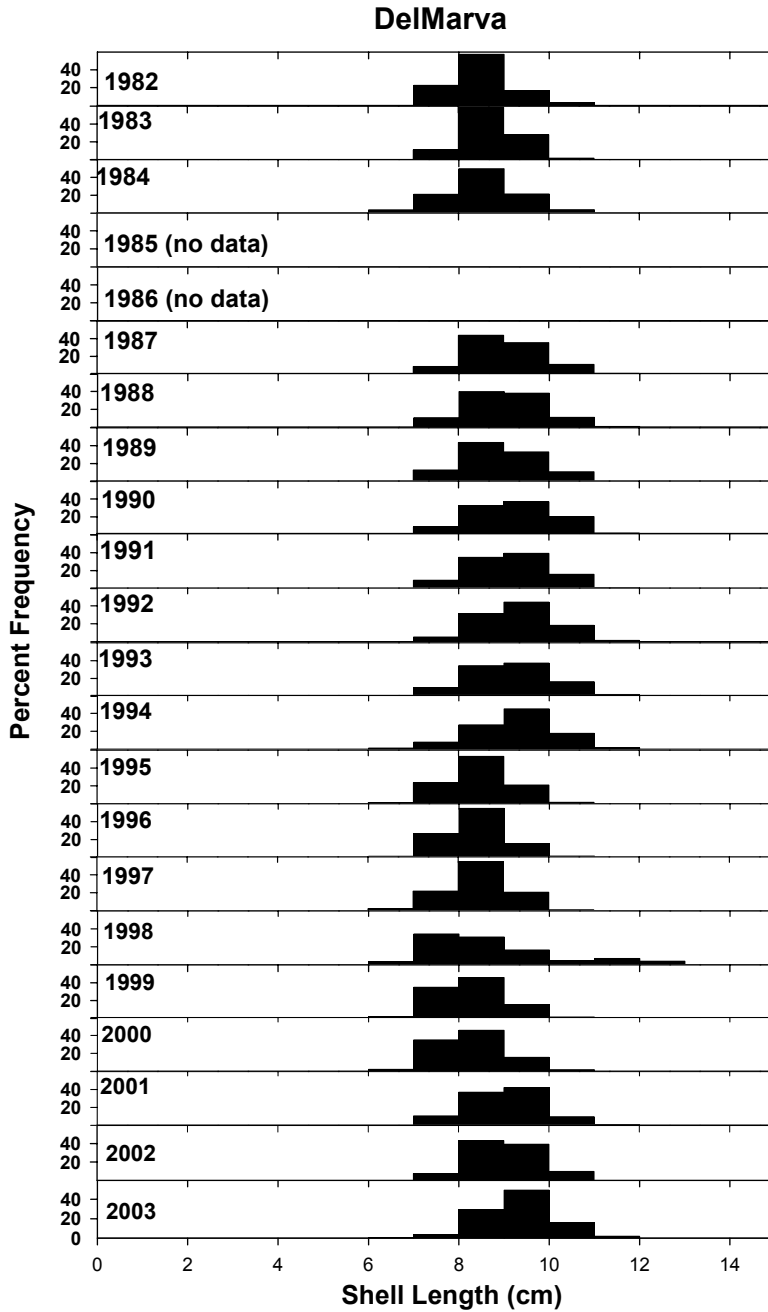


Figure A22. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.
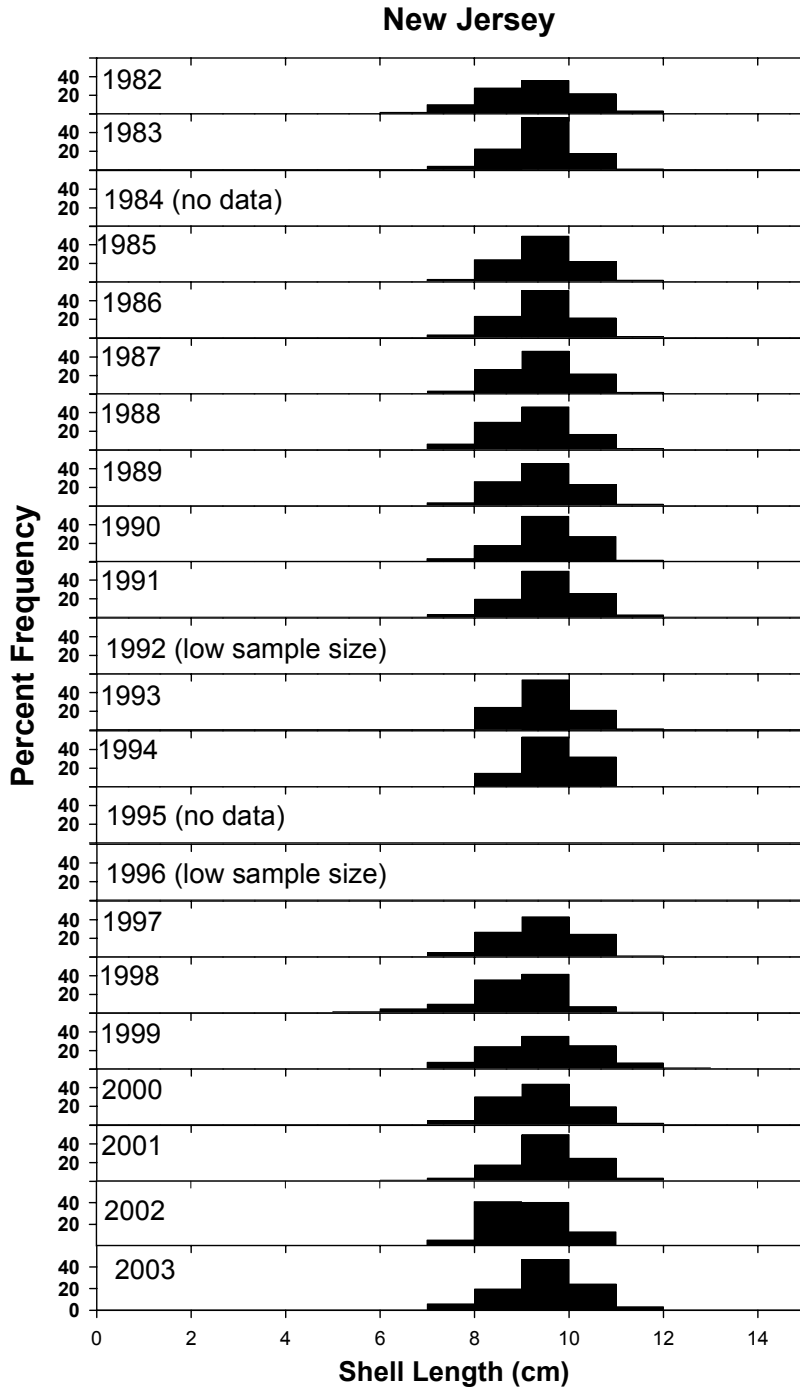
Figure A23. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.
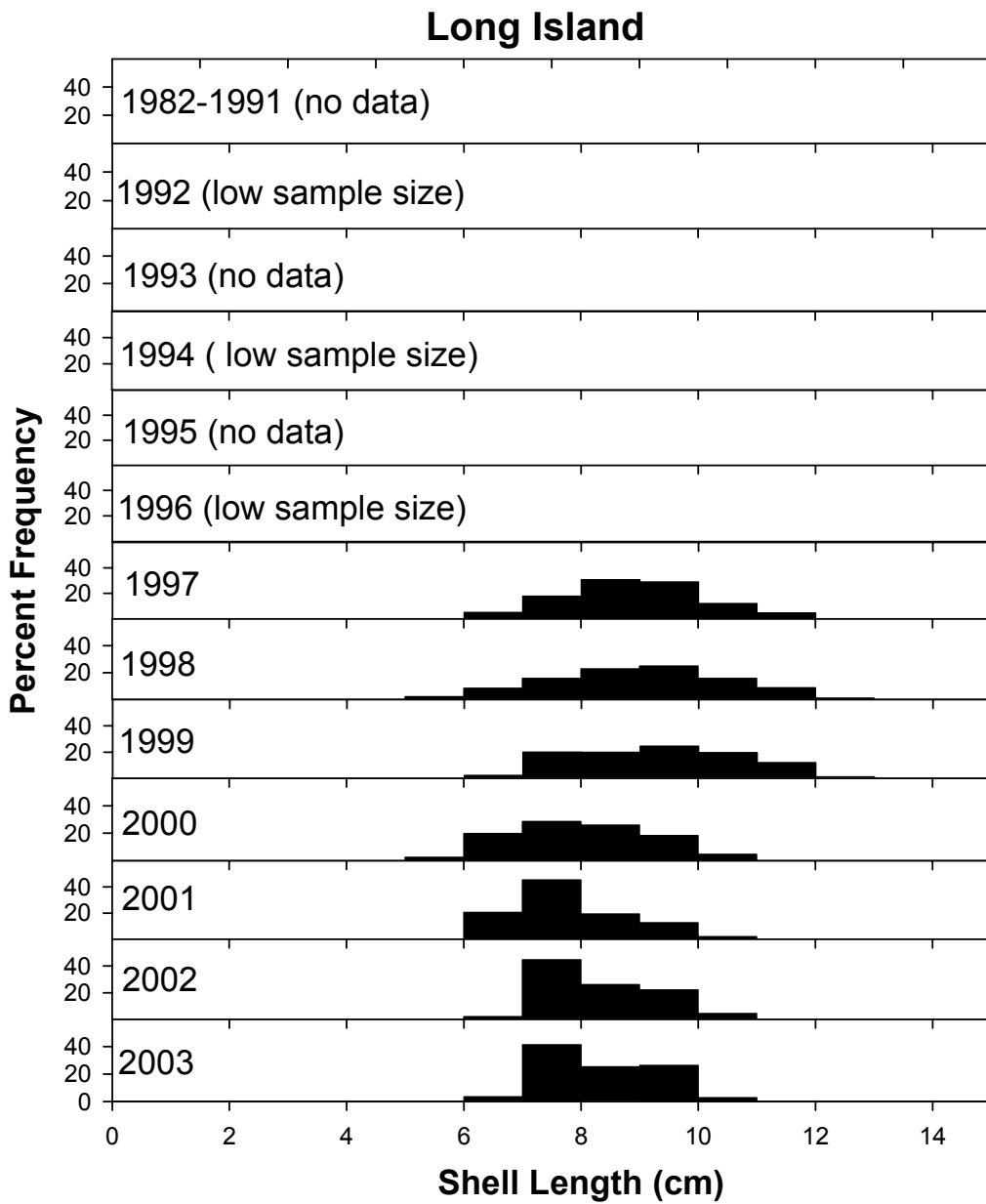
Figure A24. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.

## Southern New England
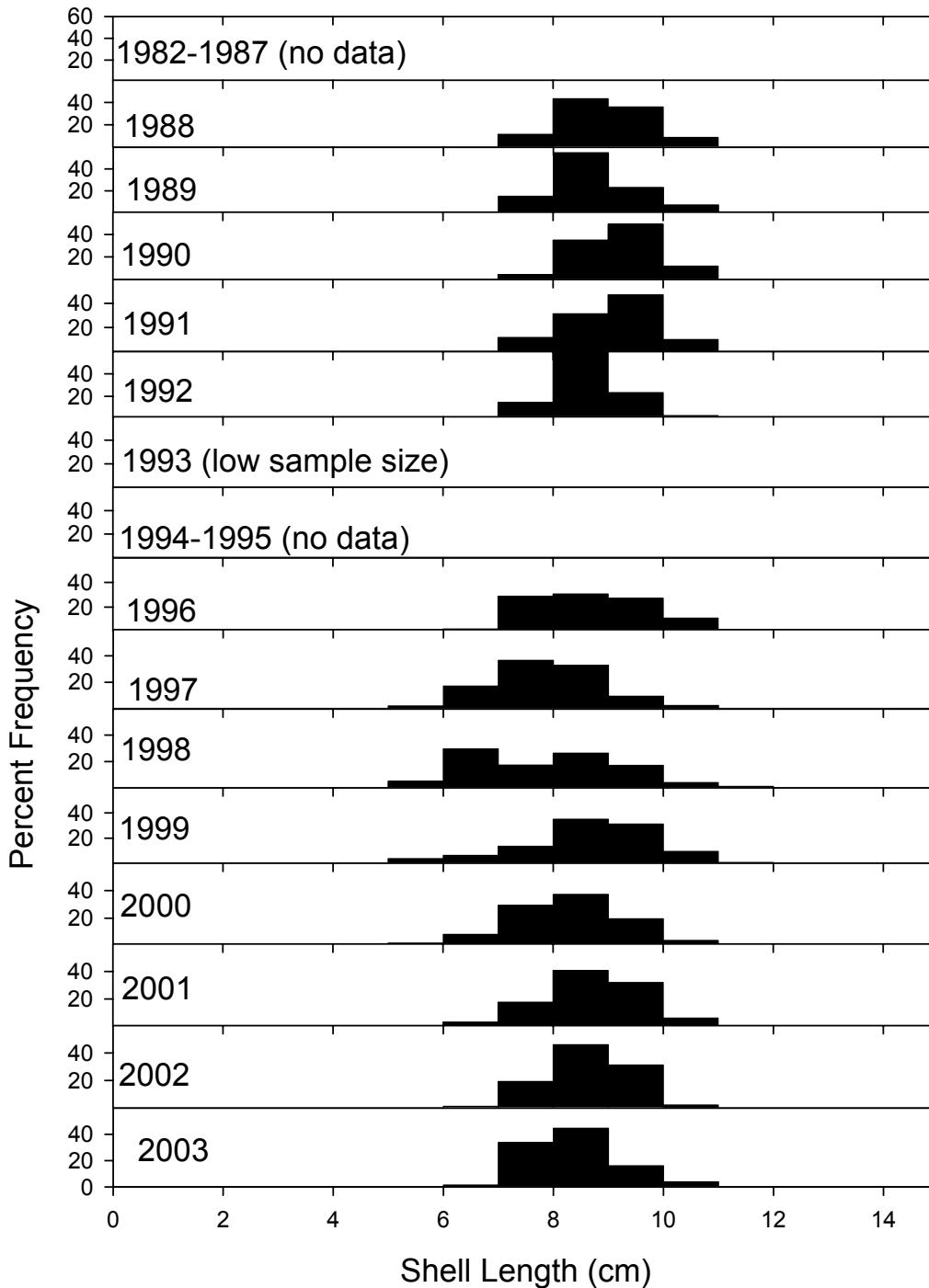


Figure A25. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.
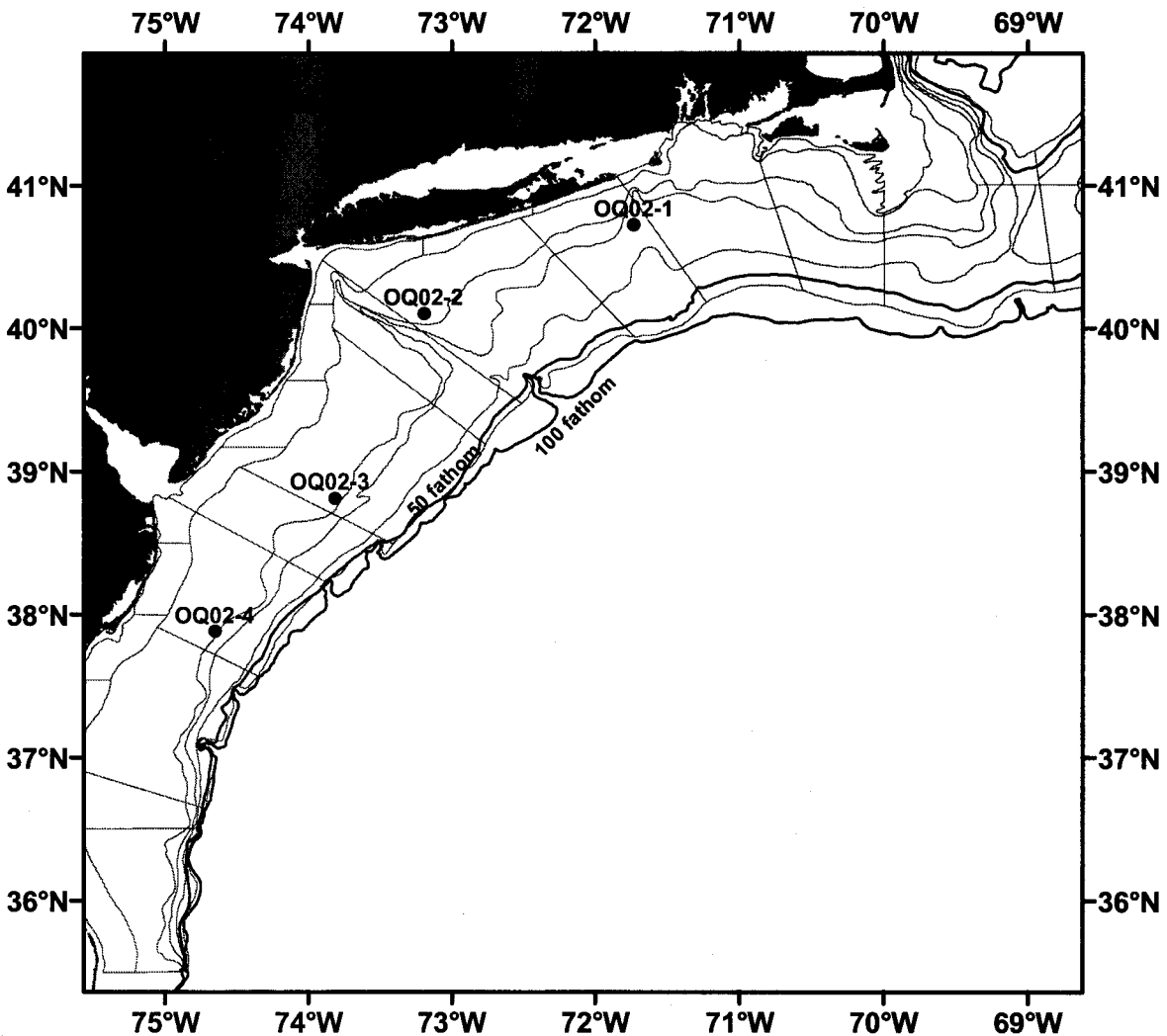
Figure A26.
Sites of ocean quahog depletion experiments
with FV Lisa Kim in 2002.
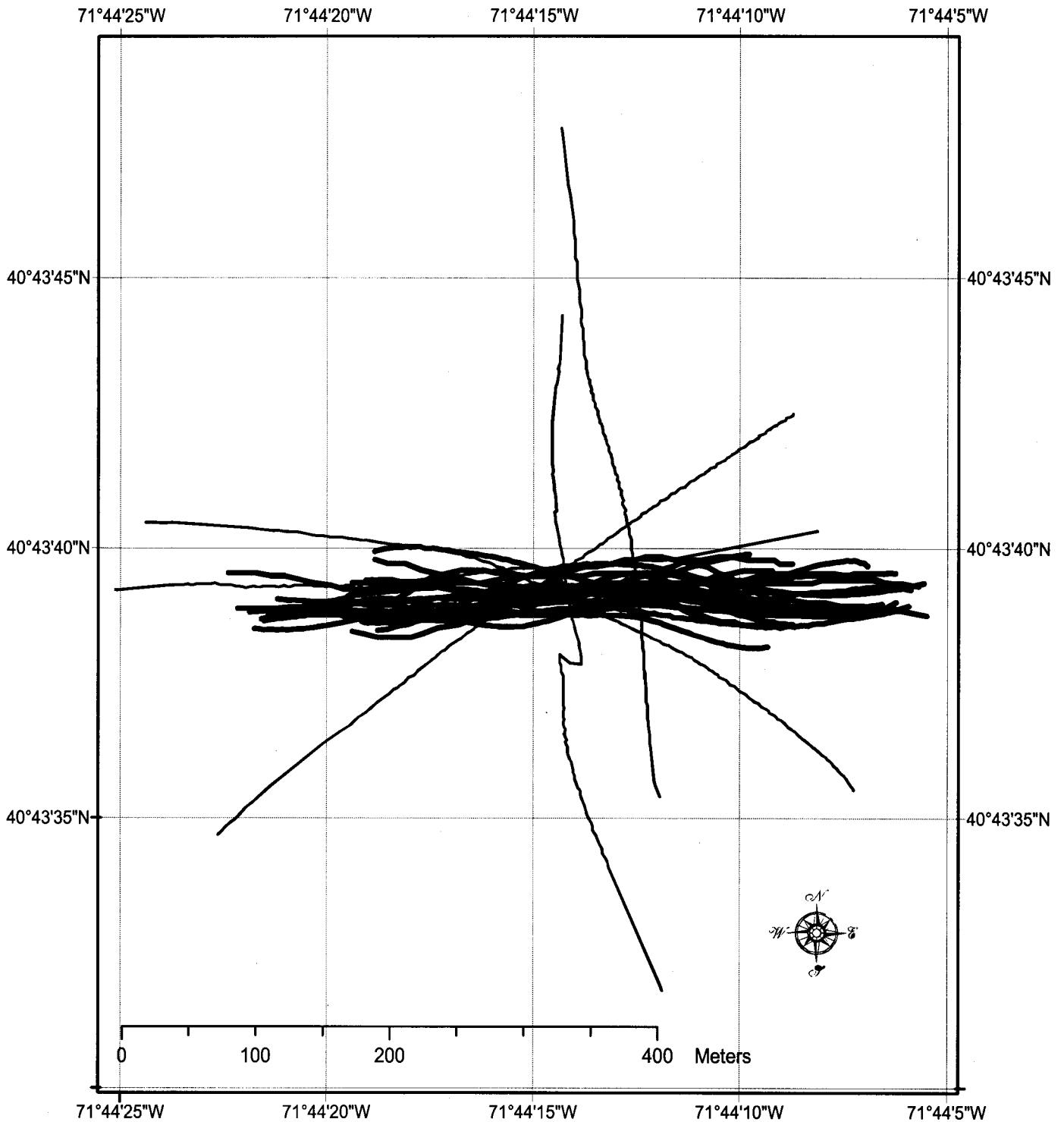
Fig. A27.    Towpaths by the *R/V Delaware-II* setup tows (lighter lines)

and the *F/V Lisa Kim* (darker lines), 2002,  off  LI (E) at site: oq02-1.
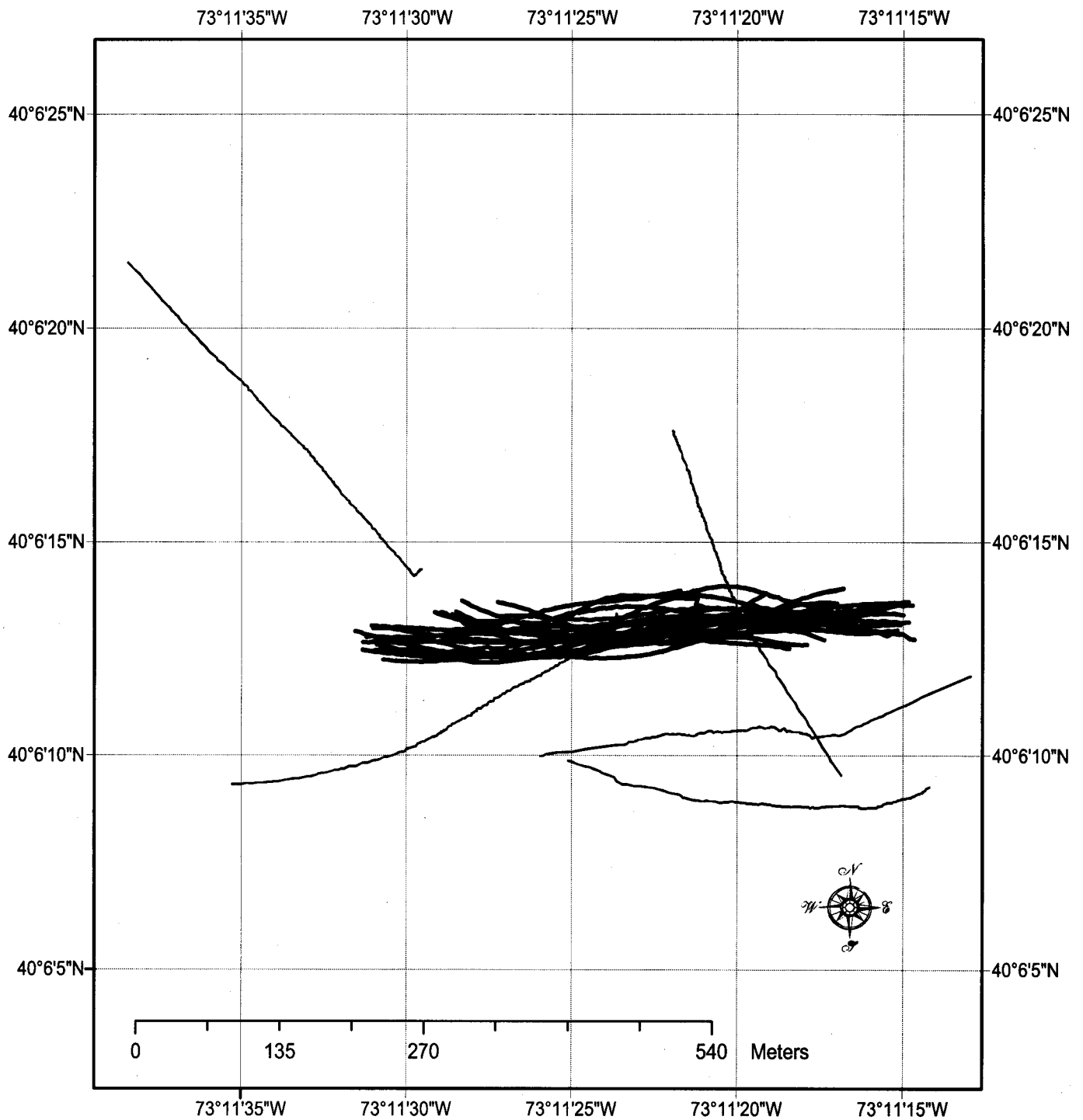
Fig. A28. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Lisa Kim* (darker lines), 2002, off LI (W) at site: oq02-2.
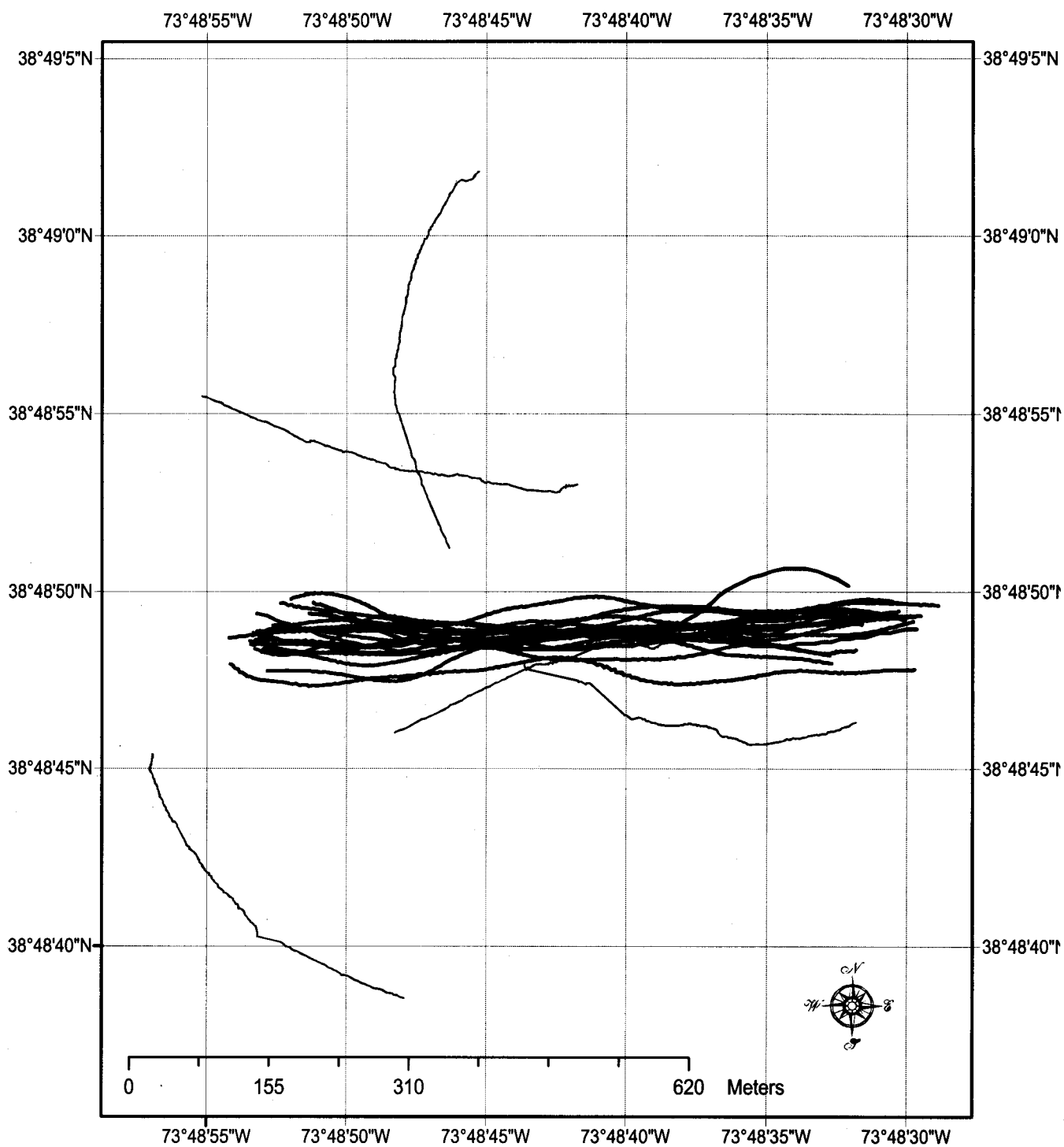
Fig. A29. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Lisa Kim* (darker lines), 2002, off SNJ at site: oq02-3.
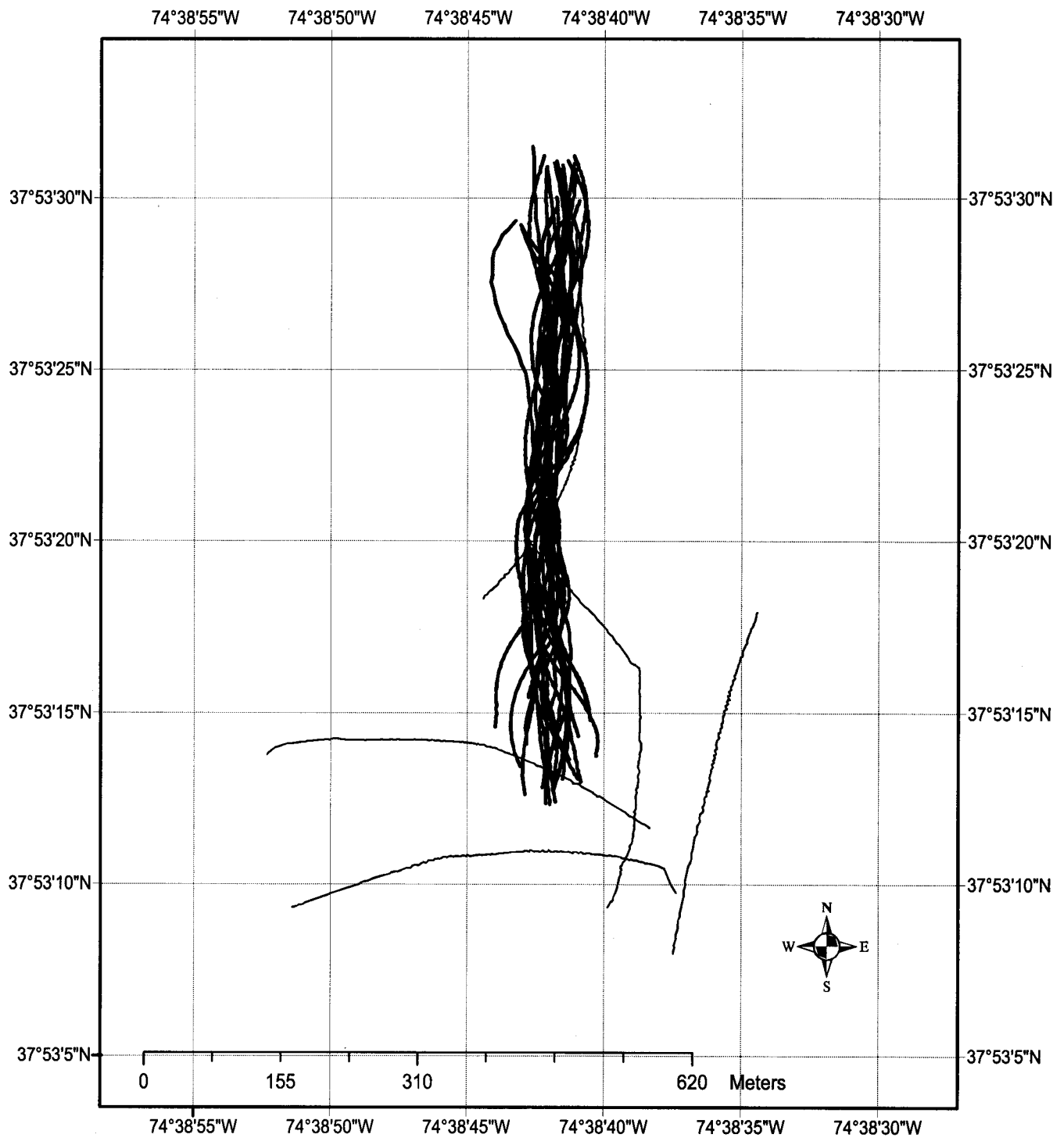
Fig. A30. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Lisa Kim* (darker lines), 2002, off Delmarva at site: oq02-4.

**Q02-1A**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 64.123 | 13.6% |
| .044 mm | 7.746 | 1.6% |
| .063 mm | 42.113 | 8.9% |
| .125 mm | 150.437 | 31.9% |
| .250 mm | 120.824 | 25.6% |
| .500 mm | 34.695 | 7.4% |
| 1.0 mm | 24.424 | 5.2% |
| 2.0 mm | 15.303 | 3.2% |
| 4.0 mm | 12.066 | 2.6% |
| Total Mass | 471.731 | 100.0% |

**Q02-1B**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 51.890 | 9.8% |
| .044 mm | 10.479 | 2.0% |
| .063 mm | 67.260 | 12.6% |
| .125 mm | 164.839 | 31.0% |
| .250 mm | 120.946 | 22.7% |
| .500 mm | 60.455 | 11.4% |
| 1.0 mm | 28.353 | 5.3% |
| 2.0 mm | 12.508 | 2.4% |
| 4.0 mm | 15.311 | 2.9% |
| Total Mass | 532.041 | 100.0% |

**Q02-2A Sta 26**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 11.135 | 2.8% |
| .044 mm | 0.311 | 0.1% |
| .063 mm | 6.677 | 1.7% |
| .125 mm | 83.066 | 20.7% |
| .250 mm | 275.183 | 68.5% |
| .500 mm | 21.239 | 5.3% |
| 1.0 mm | 1.010 | 0.3% |
| 2.0 mm | 0.963 | 0.2% |
| 4.0 mm | 1.901 | 0.5% |
| Total Mass | 401.485 | 100.0% |

**Q02-2B Sta 26**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 4.812 | 1.0% |
| .044 mm | 0.538 | 0.1% |
| .063 mm | 3.873 | 0.8% |
| .125 mm | 53.236 | 10.8% |
| .250 mm | 359.471 | 73.2% |
| .500 mm | 58.116 | 11.8% |
| 1.0 mm | 6.018 | 1.2% |
| 2.0 mm | 3.728 | 0.8% |
| 4.0 mm | 1.016 | 0.2% |
| Total Mass | 490.808 | 100.0% |

**Q02-3A Sta 217**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 19.272 | 5.4% |
| .044 mm | 0.126 | 0.0% |
| .063 mm | 2.810 | 0.8% |
| .125 mm | 127.733 | 35.9% |
| .250 mm | 201.327 | 56.5% |
| .500 mm | 0.638 | 0.2% |
| 1.0 mm | 0.121 | 0.0% |
| 2.0 mm | 0.450 | 0.1% |
| 4.0 mm | 3.670 | 1.0% |
| Total Mass | 356.147 | 100.0% |

**Q002-3B Sta 217**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 2.902 | 0.9% |
| .044 mm | 0.200 | 0.1% |
| .063 mm | 3.107 | 1.0% |
| .125 mm | 260.436 | 83.5% |
| .250 mm | 44.546 | 14.3% |
| .500 mm | 0.377 | 0.1% |
| 1.0 mm | 0.152 | 0.0% |
| 2.0 mm | 0.100 | 0.0% |
| 4.0 mm | 0.108 | 0.0% |
| Total Mass | 311.928 | 100.0% |

**Q002-4A**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 24.093 | 4.0% |
| .044 mm | 0.911 | 0.2% |
| .063 mm | 23.894 | 4.0% |
| .125 mm | 451.165 | 75.7% |
| .250 mm | 94.877 | 15.9% |
| .500 mm | 0.557 | 0.1% |
| 1.0 mm | 0.299 | 0.1% |
| 2.0 mm | 0.345 | 0.1% |
| 4.0 mm | 0.051 | 0.0% |
| Total Mass | 596.192 | 100.0% |

**Q002-4B**

| Particle Size | Mass | Percent |
|---|---|---|
| <.044 mm | 3.976 | 0.9% |
| .044 mm | 0.468 | 0.1% |
| .063 mm | 18.515 | 4.1% |
| .125 mm | 426.709 | 93.4% |
| .250 mm | 6.662 | 1.5% |
| .500 mm | 0.566 | 0.1% |
| 1.0 mm | 0.052 | 0.0% |
| 2.0 mm | 0.103 | 0.0% |
| 4.0 mm | 0.000 | 0.0% |
| Total Mass | 457.051 | 100.0% |

Fig. A31. Grain size analysis for the 4 sites where ocean quahog depletion experiments were carried out in 2002.
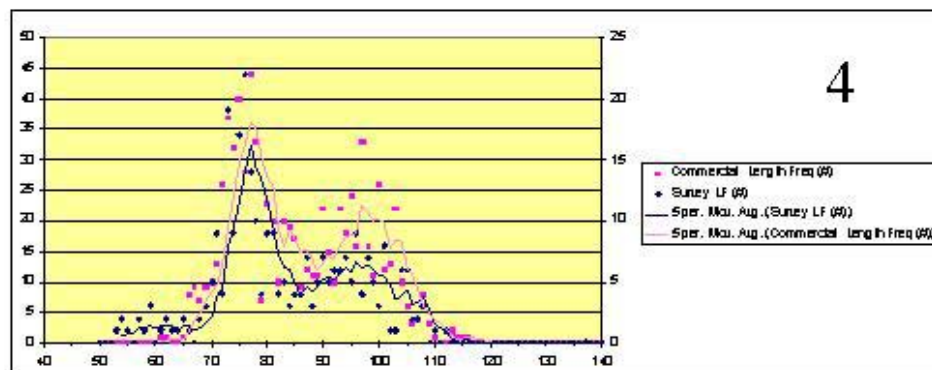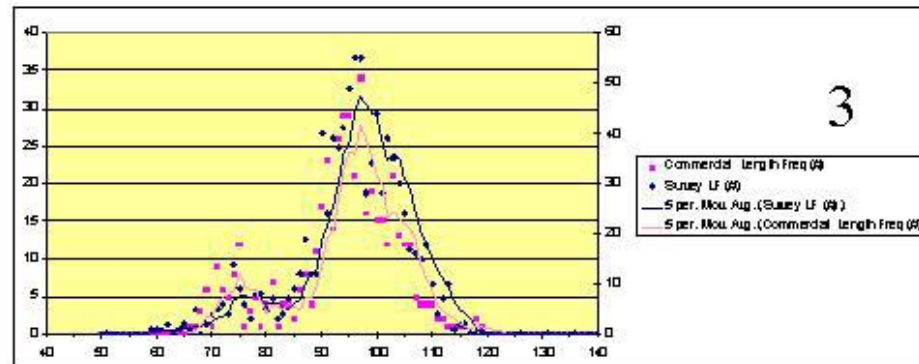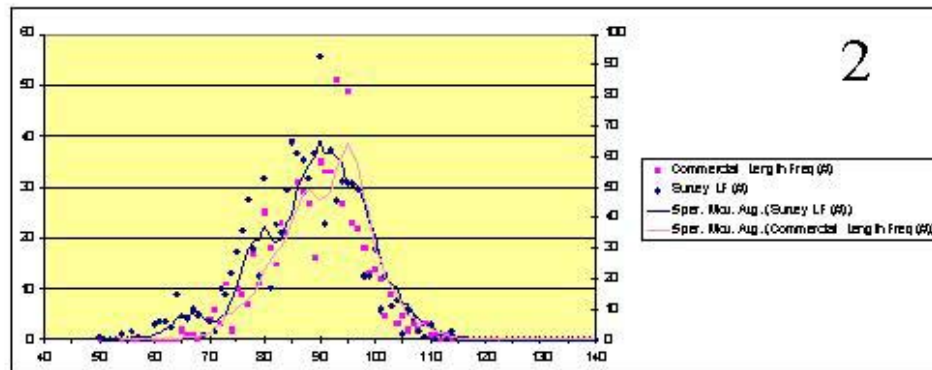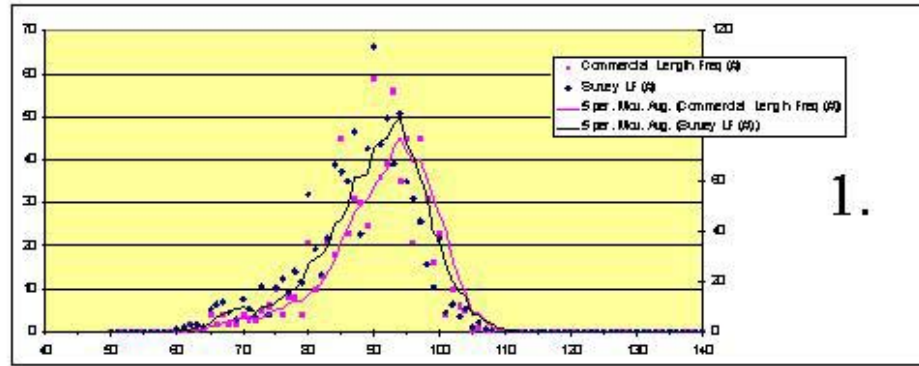
Fig. A32. Comparison of Raw Catch Length Freq. By the DE-II and FV Lisa Kim in 4 depletion exps in 2002.
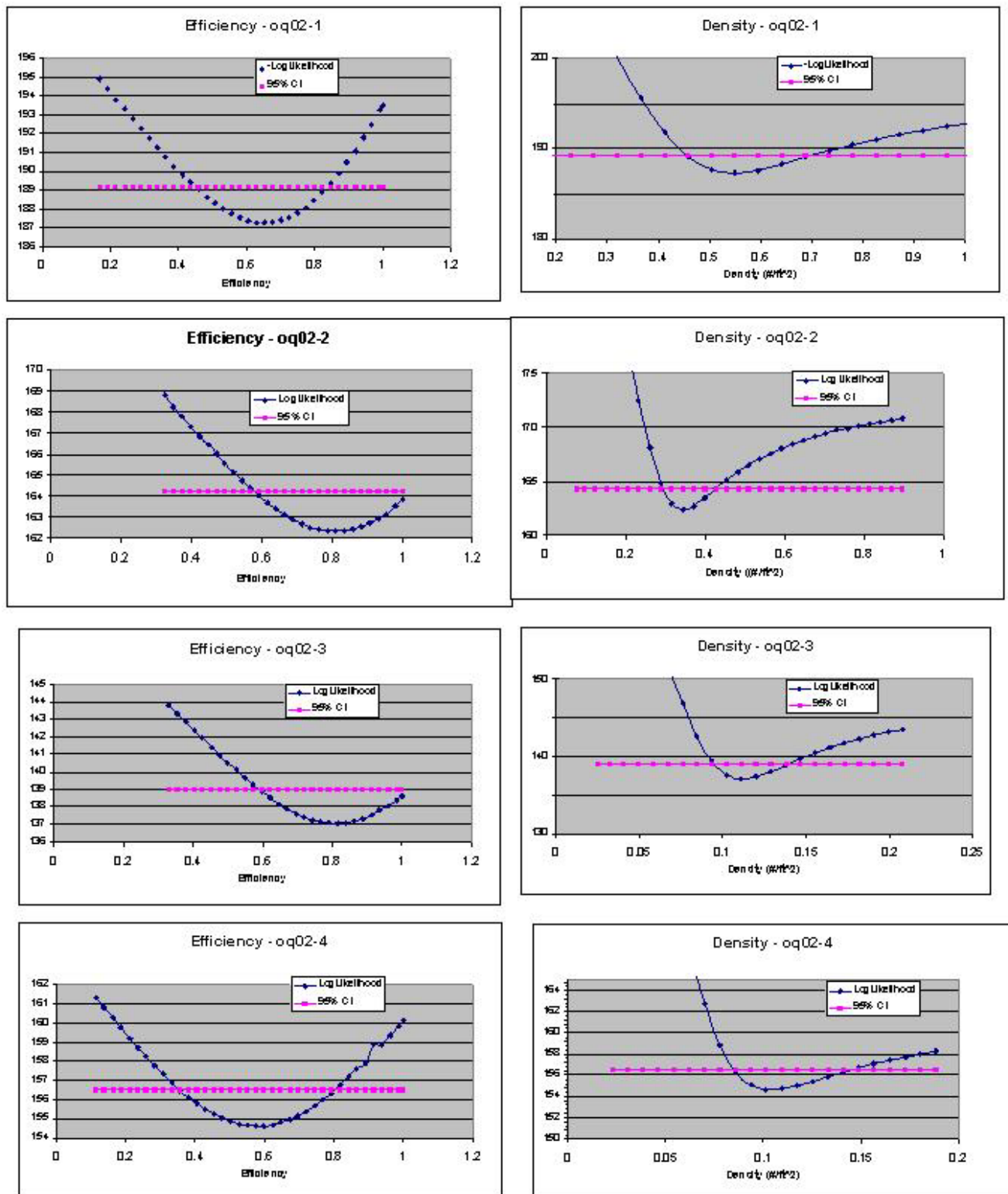
Fig. A33. 95% CI's for Efficiency and Density estimates for the FV Lisa Kim catching ocean quahogs in 4 depletion exps in 2002.

| OQ02 Site | Density (#/ft^2) (Patch Model) | DE-II Efficiency |
|---|---|---|
| 1 | 0.55 | 0.053 |
| 2 | 0.345 | 0.128 |
| 3 | 0.111 | 0.225 |
| 4 | 0.101 | 0.284 |
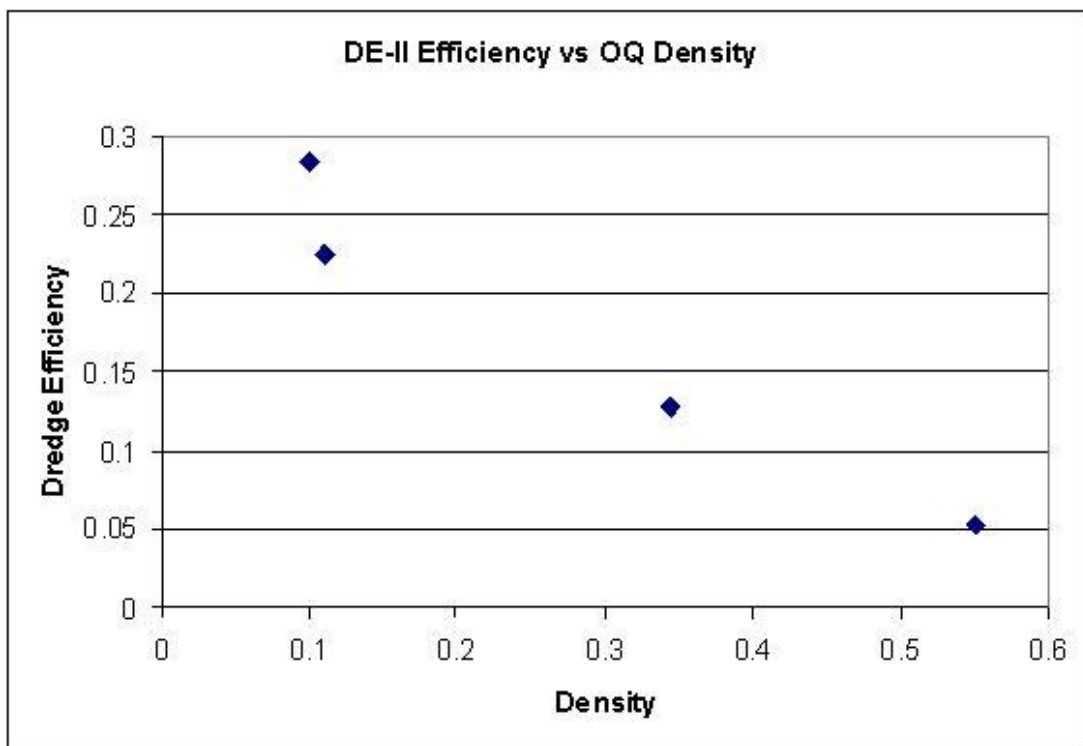


Figure A34.

Data from 2002 relating ocean quahog density to DE-II dredge efficiency.

## Fig. A35.

Shell length-tissue weight relationships for ocean quahog from NEFSC clam surveys. "Frozen" weights were based on frozen samples (Murawski and Serchuk, 1979). All other relationships based on fresh samples collected during NEFSC clam surveys in 1997 and 2002 (NEFSC 1998; 2000). Data from frozen samples are not directly comparable to data from fresh samples. "NJ-2002 data" is the relationship for quahogs in the NJ area based on samples from the 2002 clam survey. "GBK-SARC-27" is the relationship for GBK used at SARC-27 (NEFSC 1998) and "GBK-SARC-31" is the relationship used at SARC-31 (NEFSC 2000).
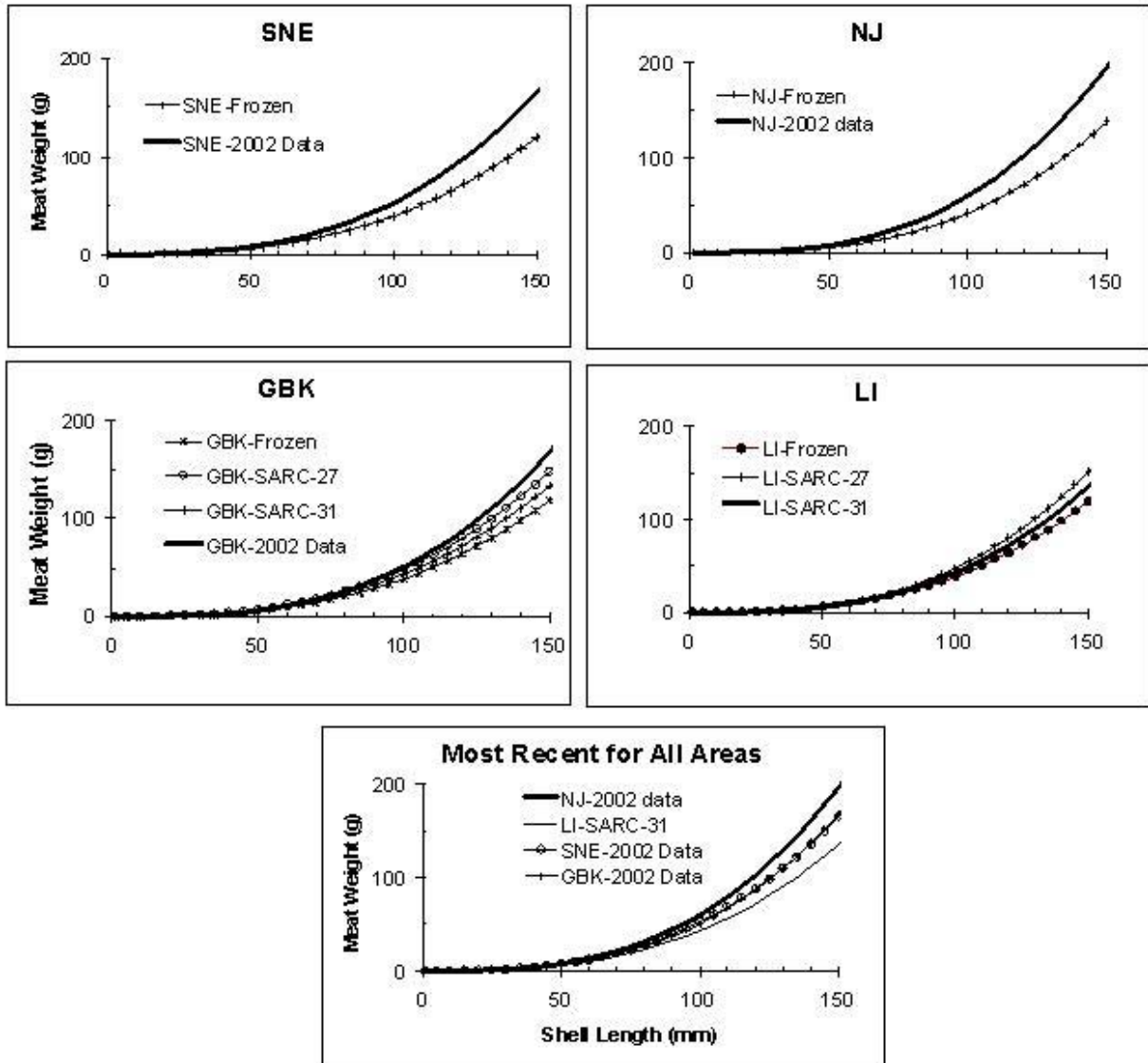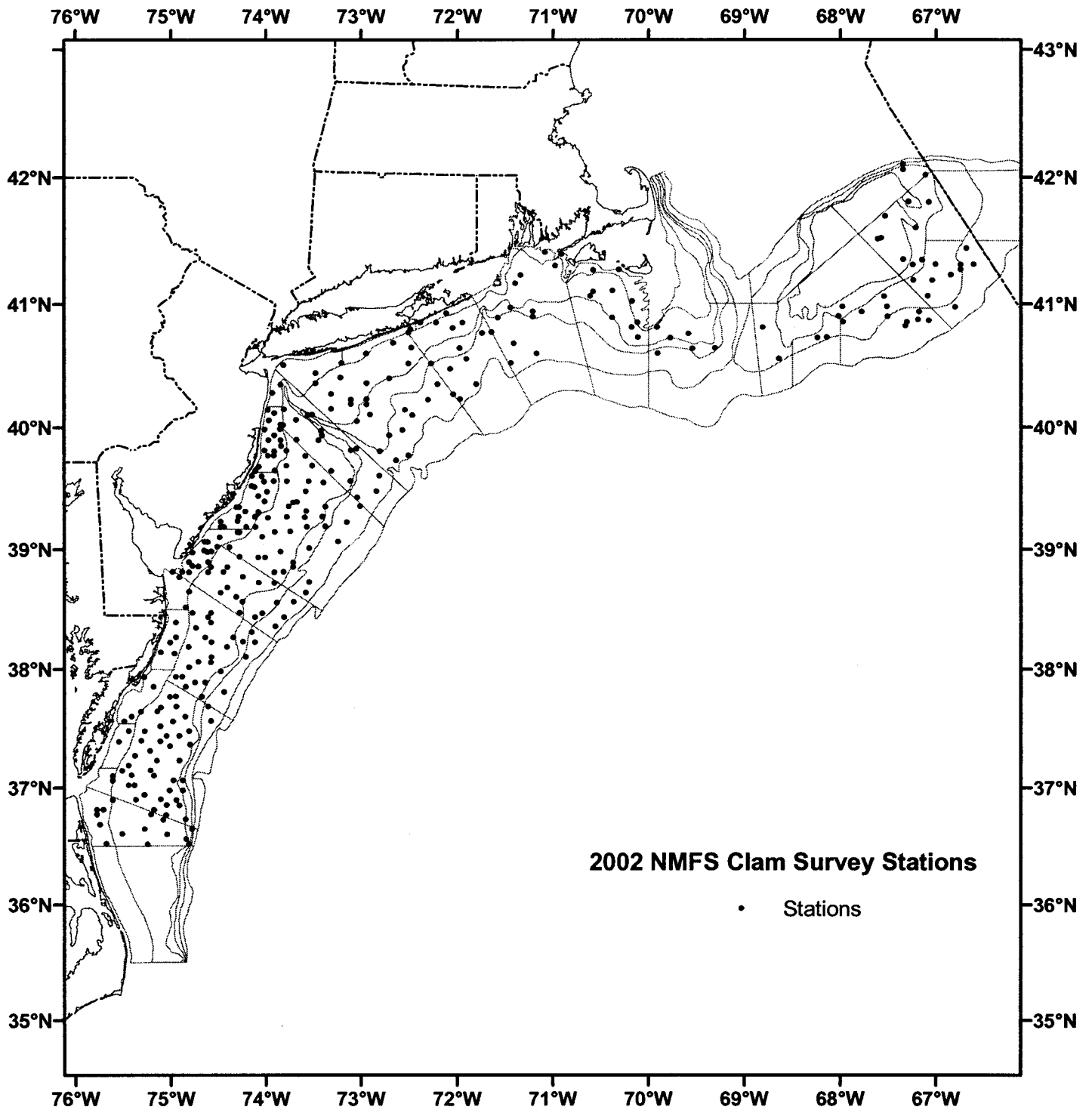
Fig. A36. NMFS clam survey station locations in 2002.
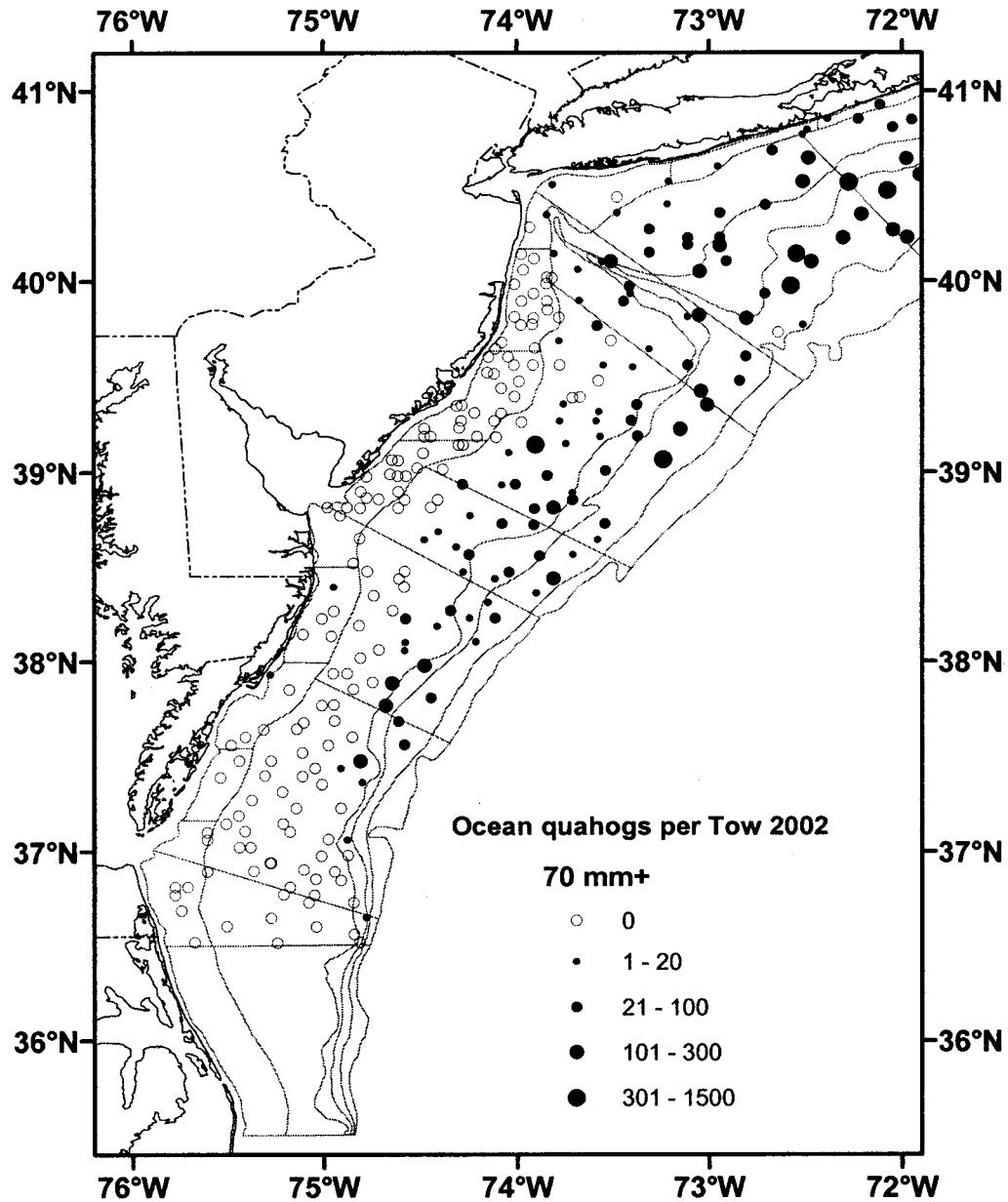
Fig. A37. Distribution of ocean quahog abundance per tow (>=70 mm), during the 2002 NEFSC survey, adjusted to 0.15nmi tow distance with sensor data. Clam strata boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-120m.
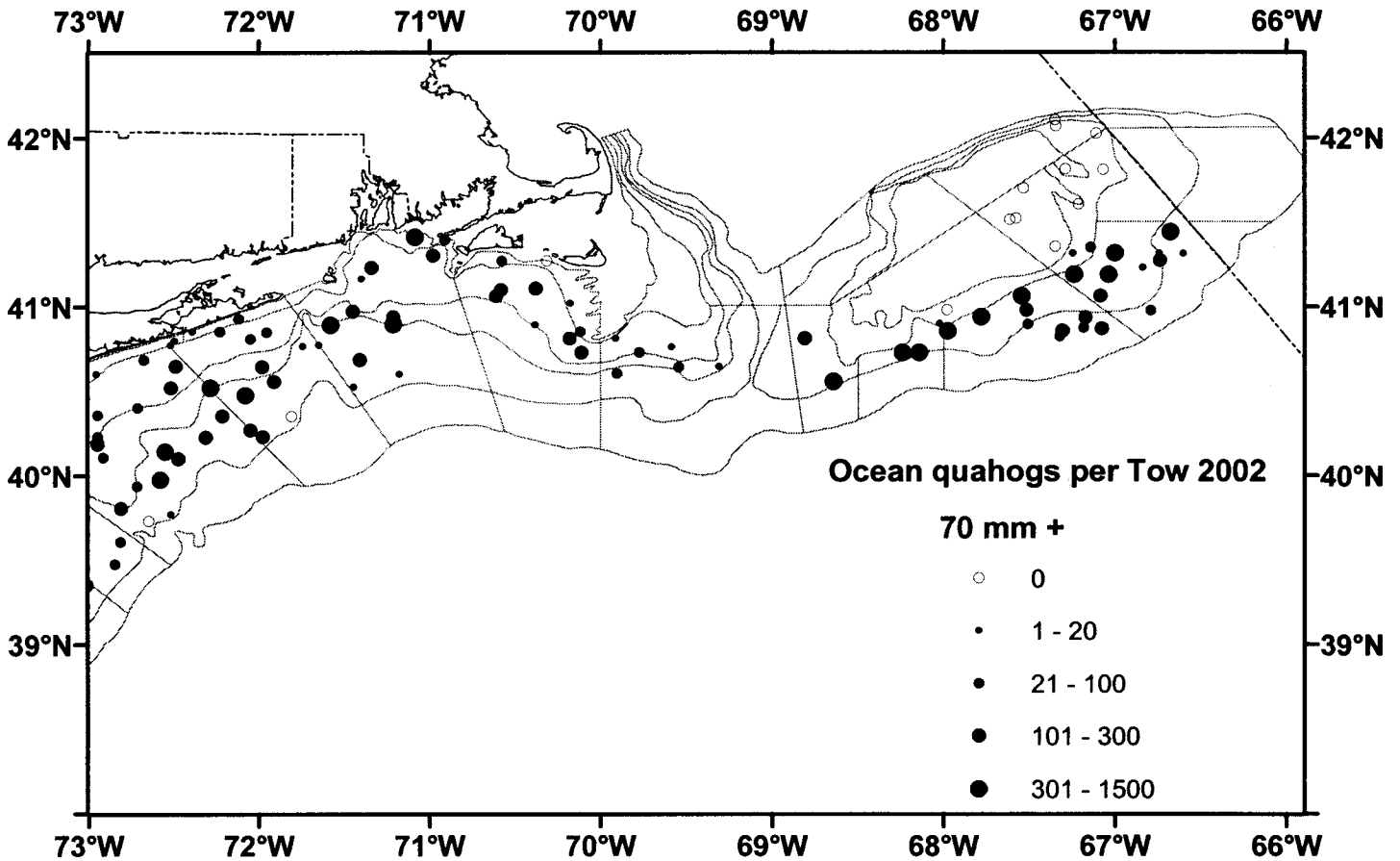
Fig. A38. Distribution of ocean quahog abundance per tow
(>=70 mm), during the 2002 NEFSC survey, adjusted to
0.15nmi tow distance with sensor data. Clam strata
boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-
120m.
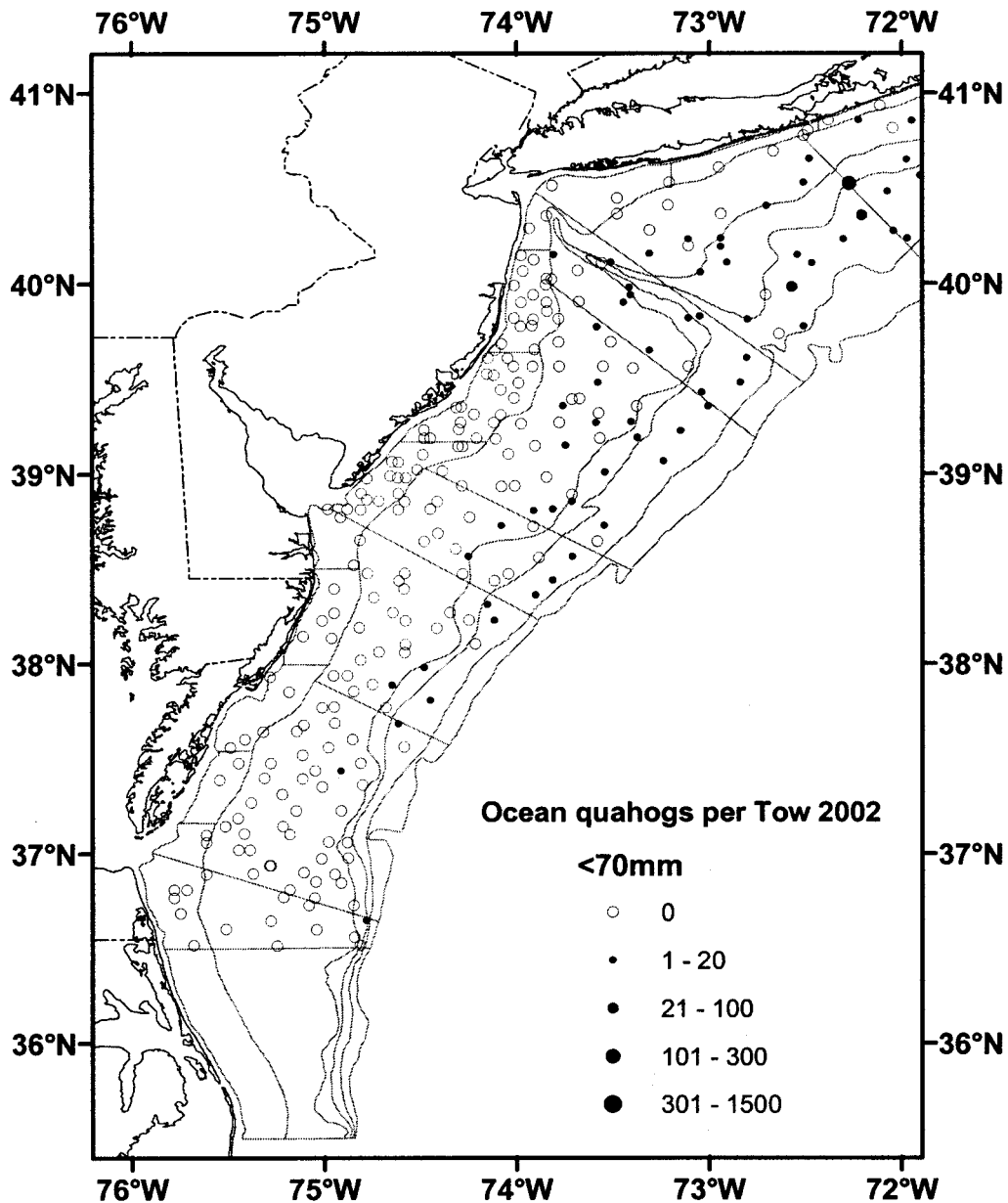
Fig. A39. Distribution of ocean quahog abundance per tow (<70 mm), during the 2002 NEFSC survey, adjusted to 0.15nmi tow distance with sensor data. Clam strata boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-120m.
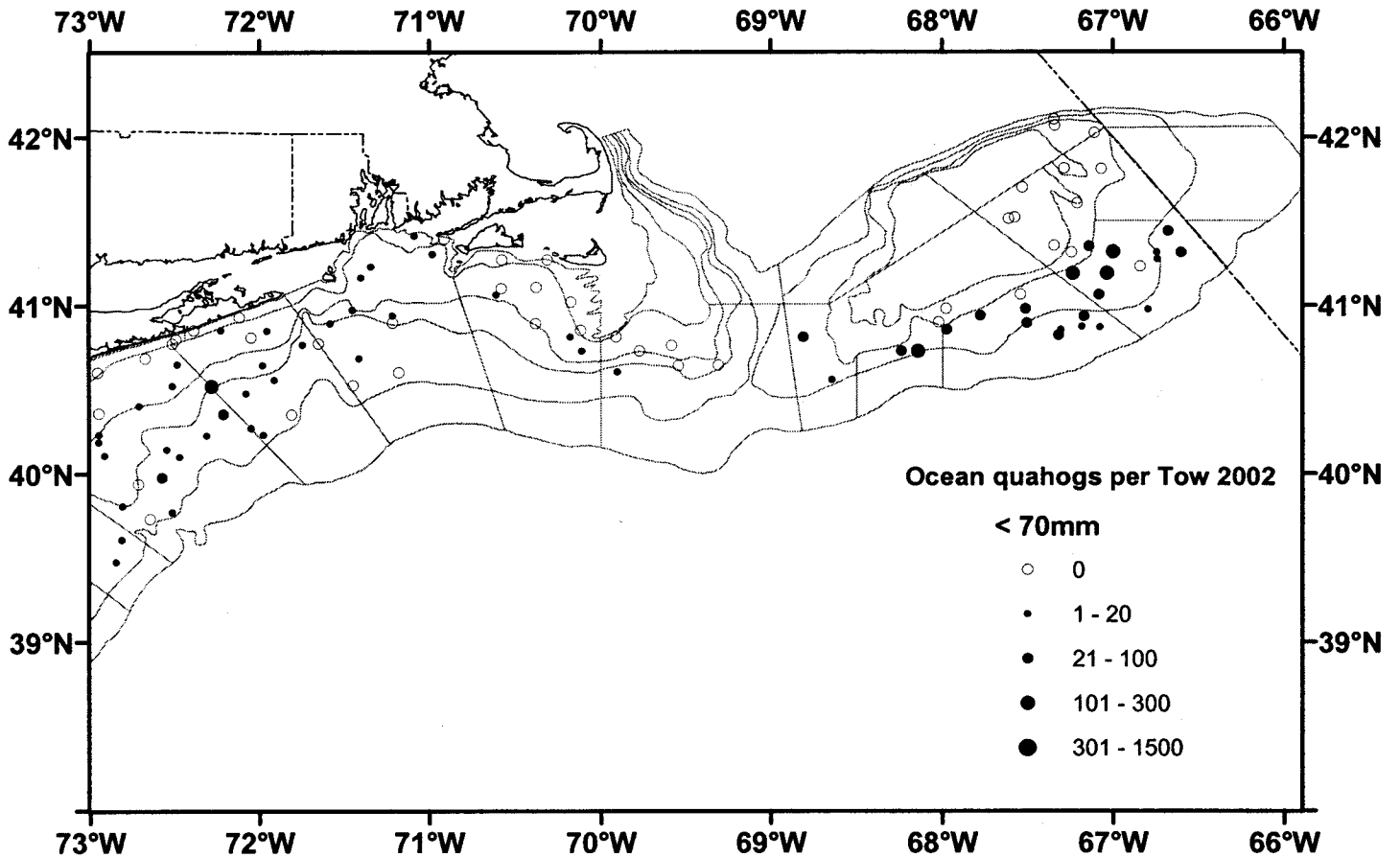
Fig. A40. Distribution of ocean quahog abundance per tow (<70 mm), during the 2002 NEFSC survey, adjusted to 0.15nmi tow distance with sensor data. Clam strata boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-120m.
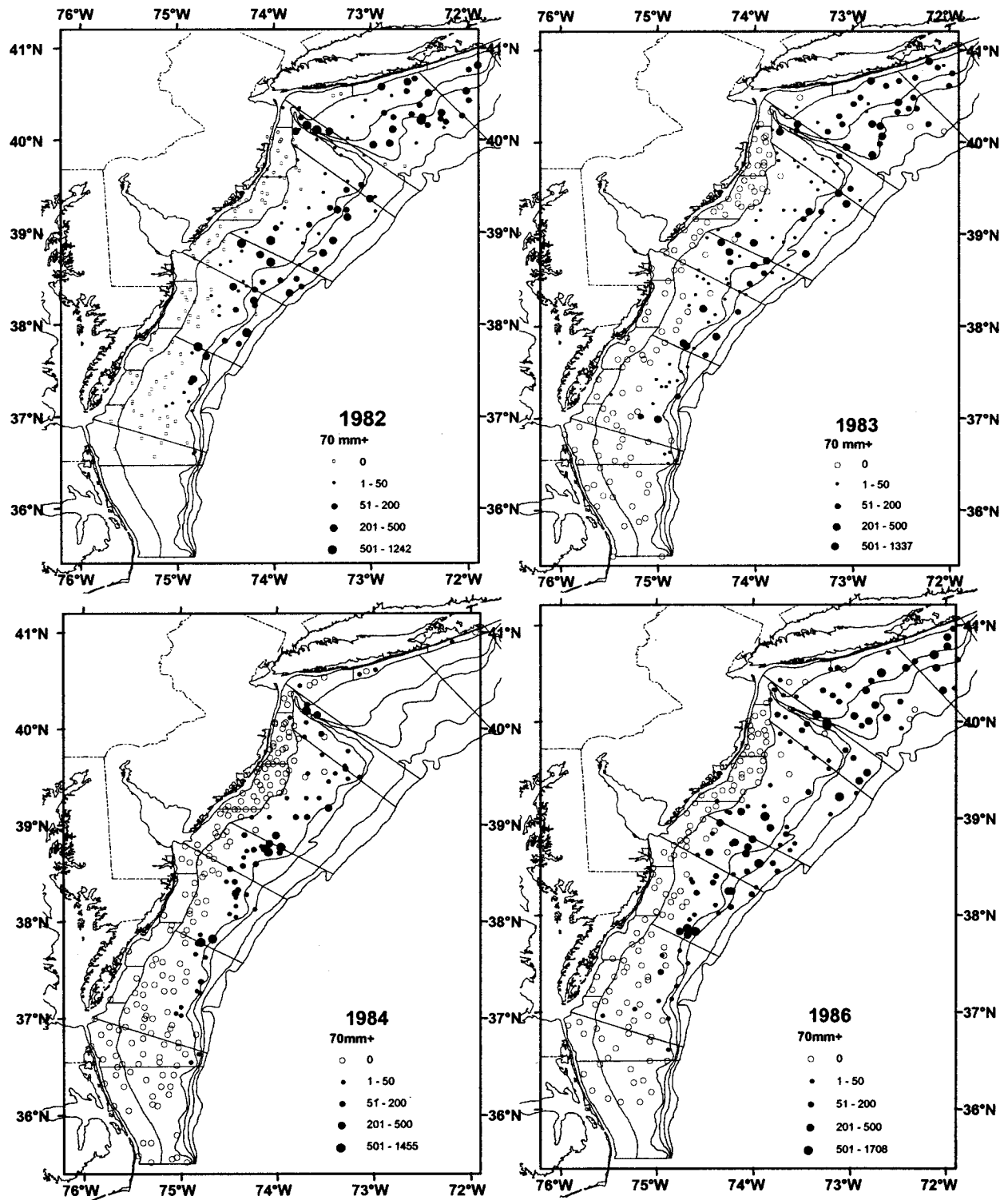
Fig. A41. Catch per tow of ocean quahogs (70mm+) in NMFS clam surveys. 1982 – 1986.
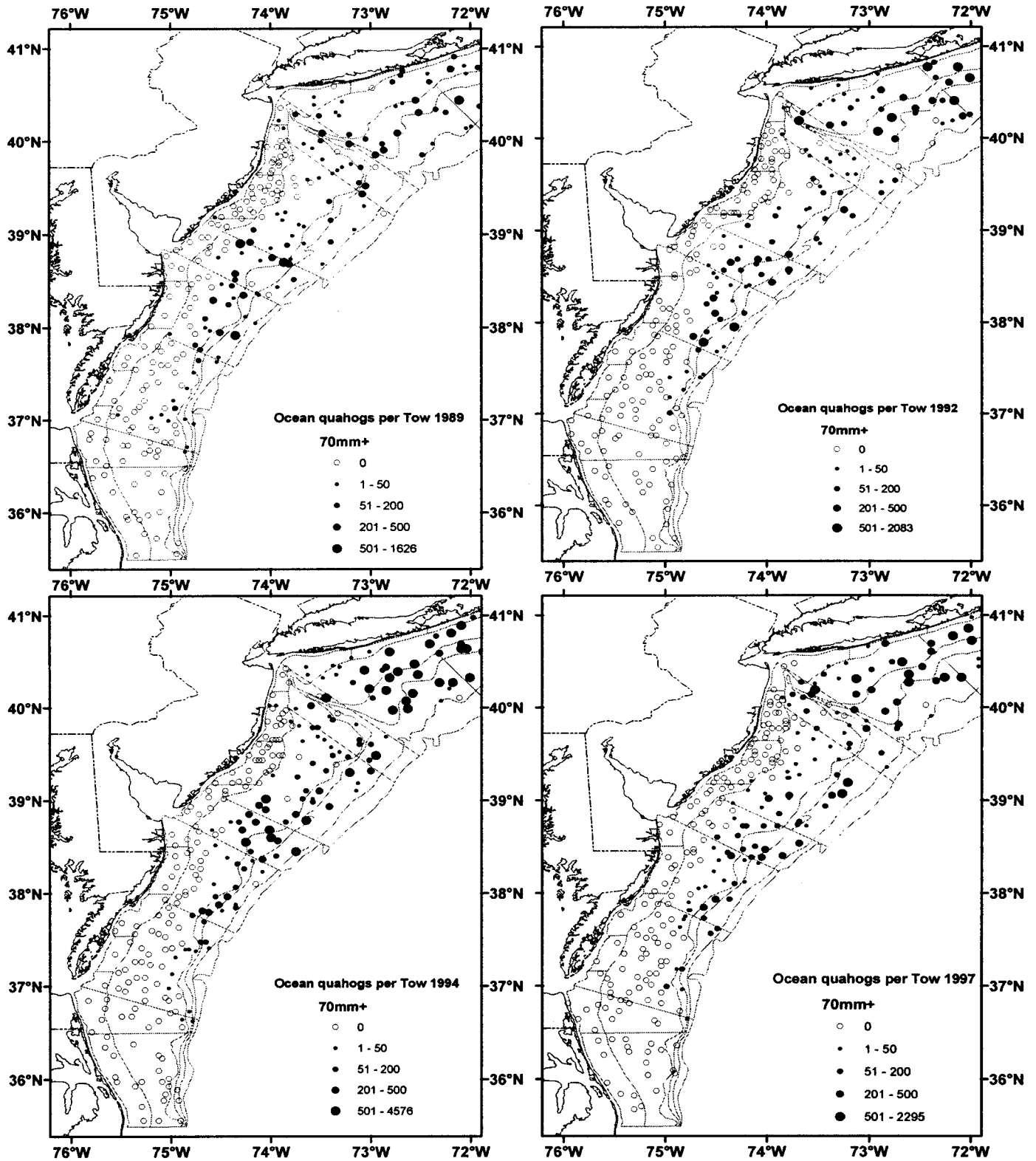
Fig. A42.   Catch per tow of ocean quahogs (70mm+) in NMFS clam surveys.  1989 – 1997.
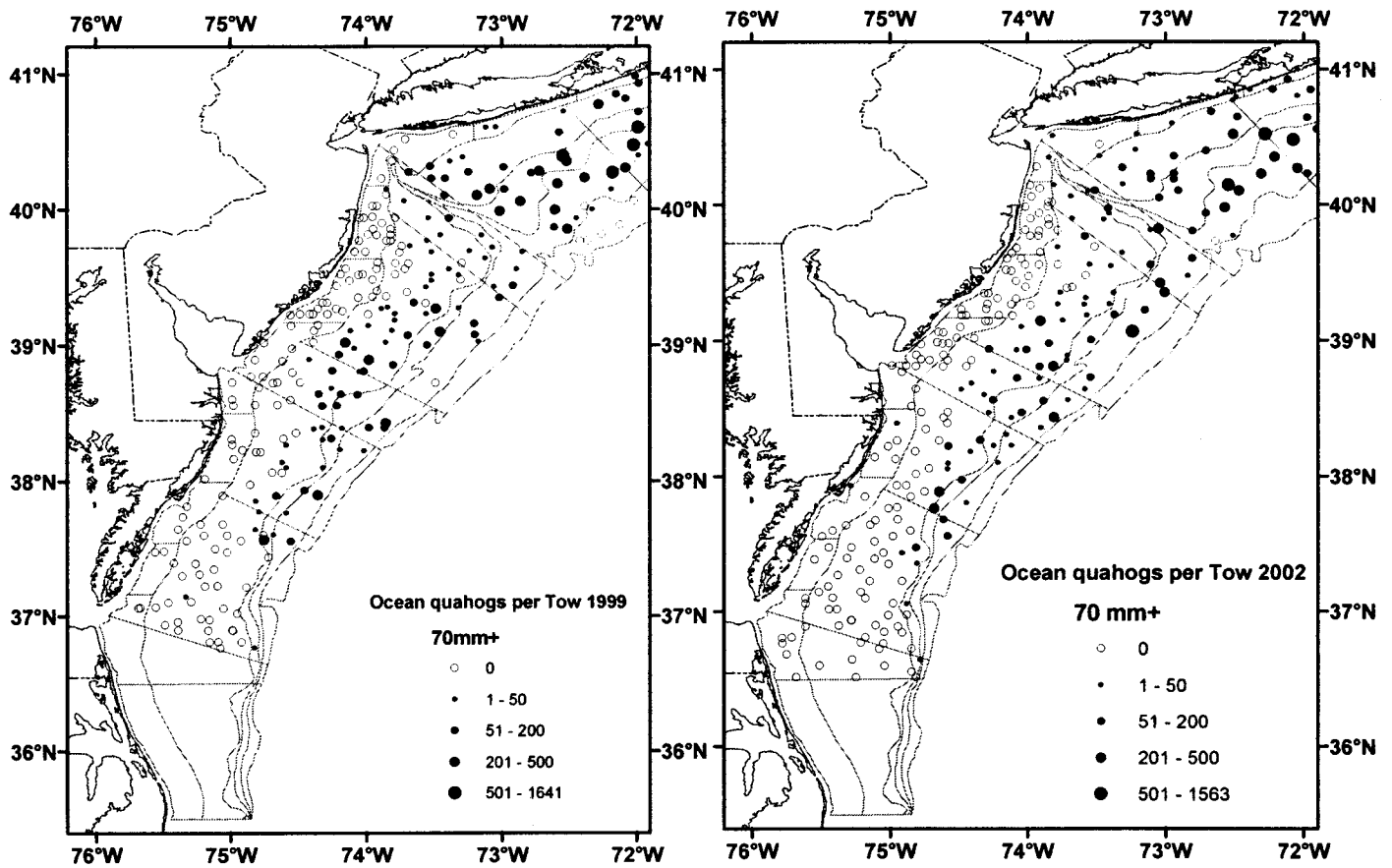
Fig. A43. Catch per tow of ocean quahogs (70mm+) in NMFS clam surveys. 1999 and 2002.
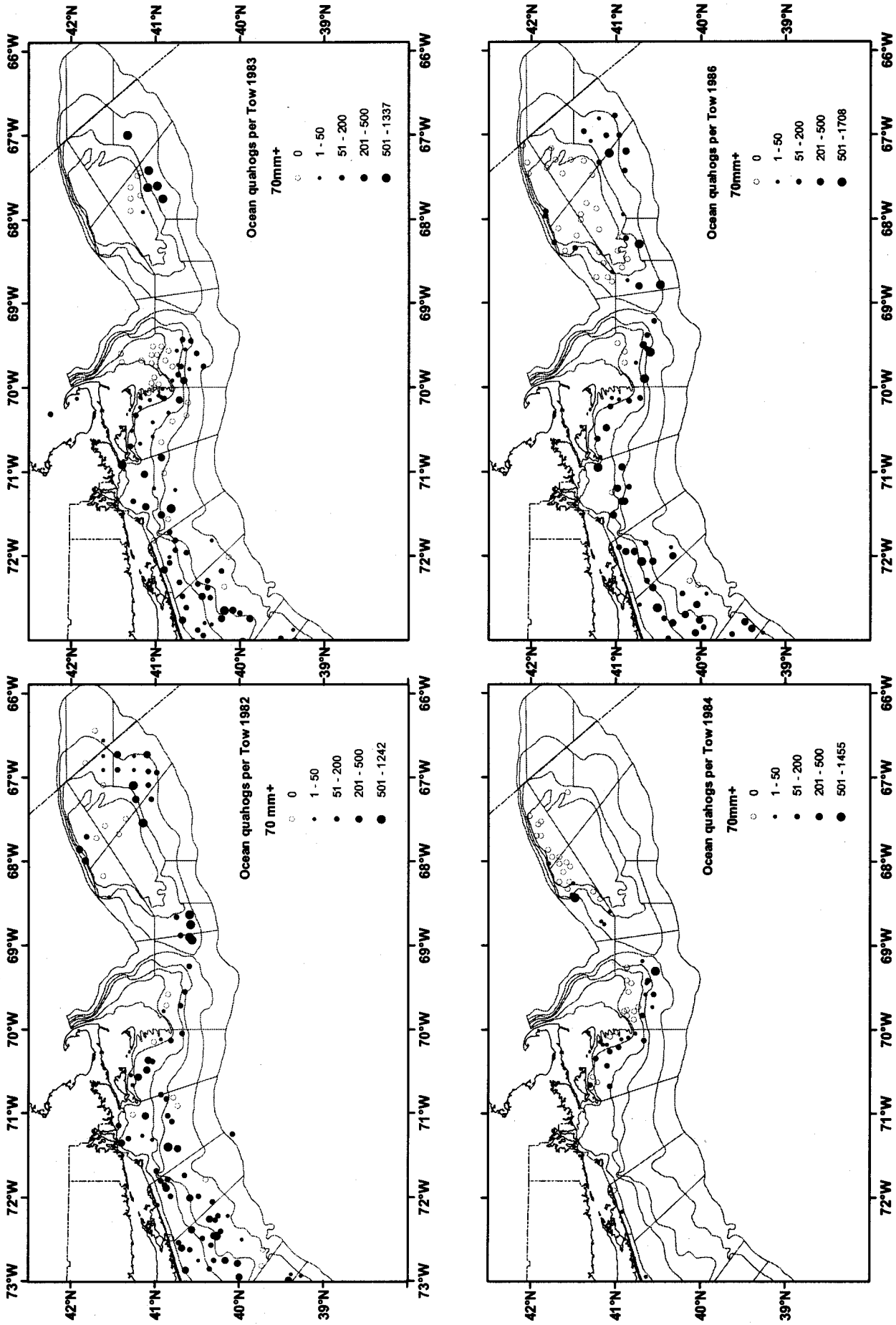
Fig. A44. Catch per tow of ocean quahogs. 1982 – 1986.
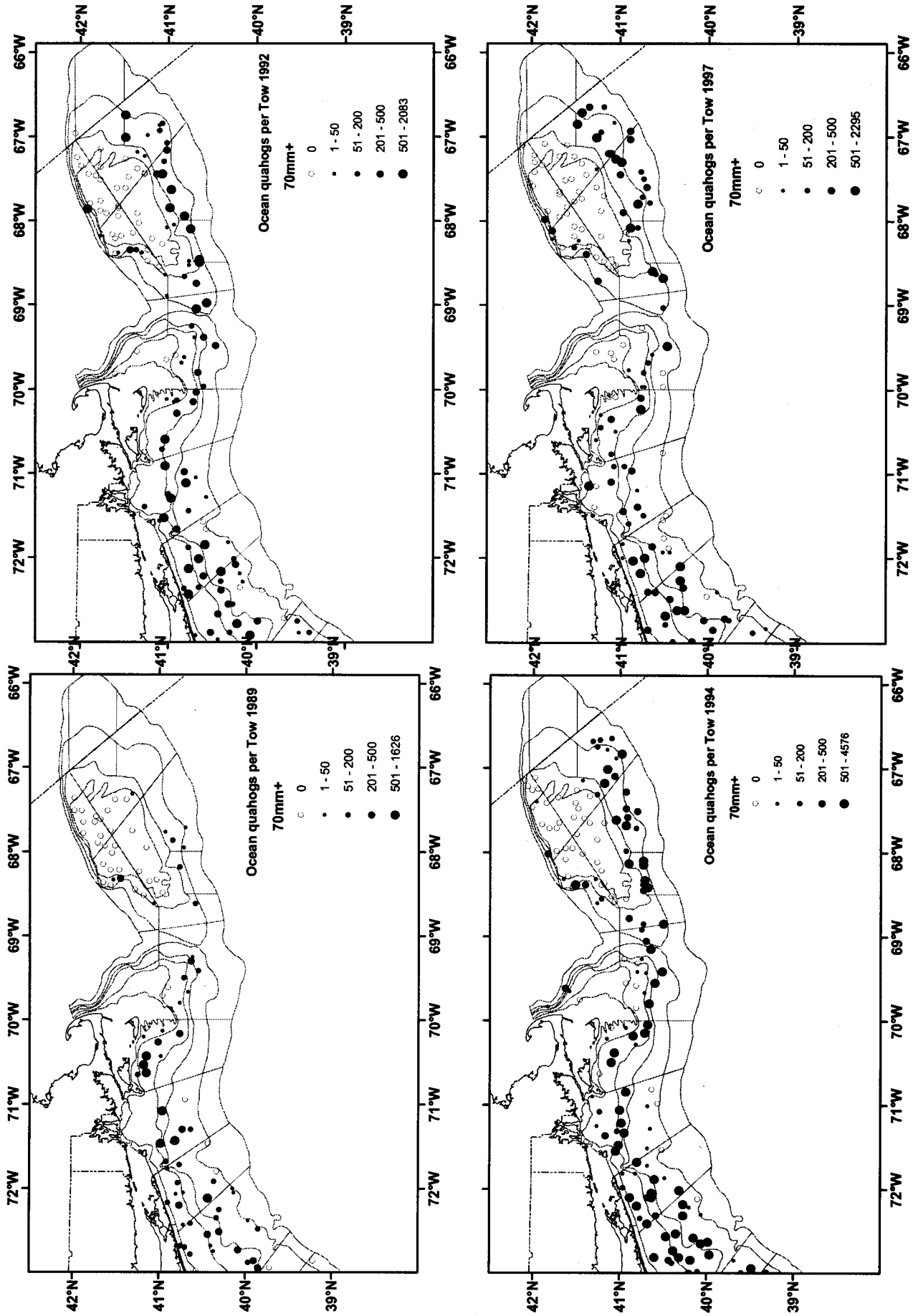
Fig. A45. Catch per tow of ocean quahogs, 1989-1997.
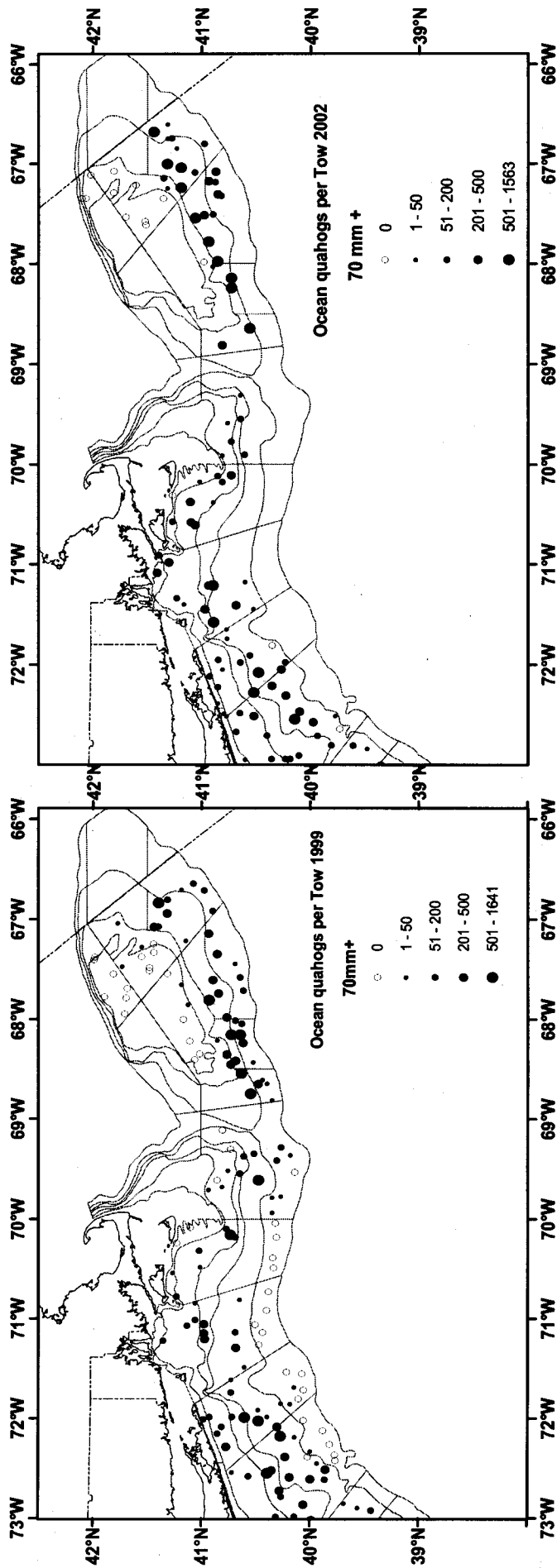
Fig. A46. Catch per tow of ocean quahogs, 1999-2002.
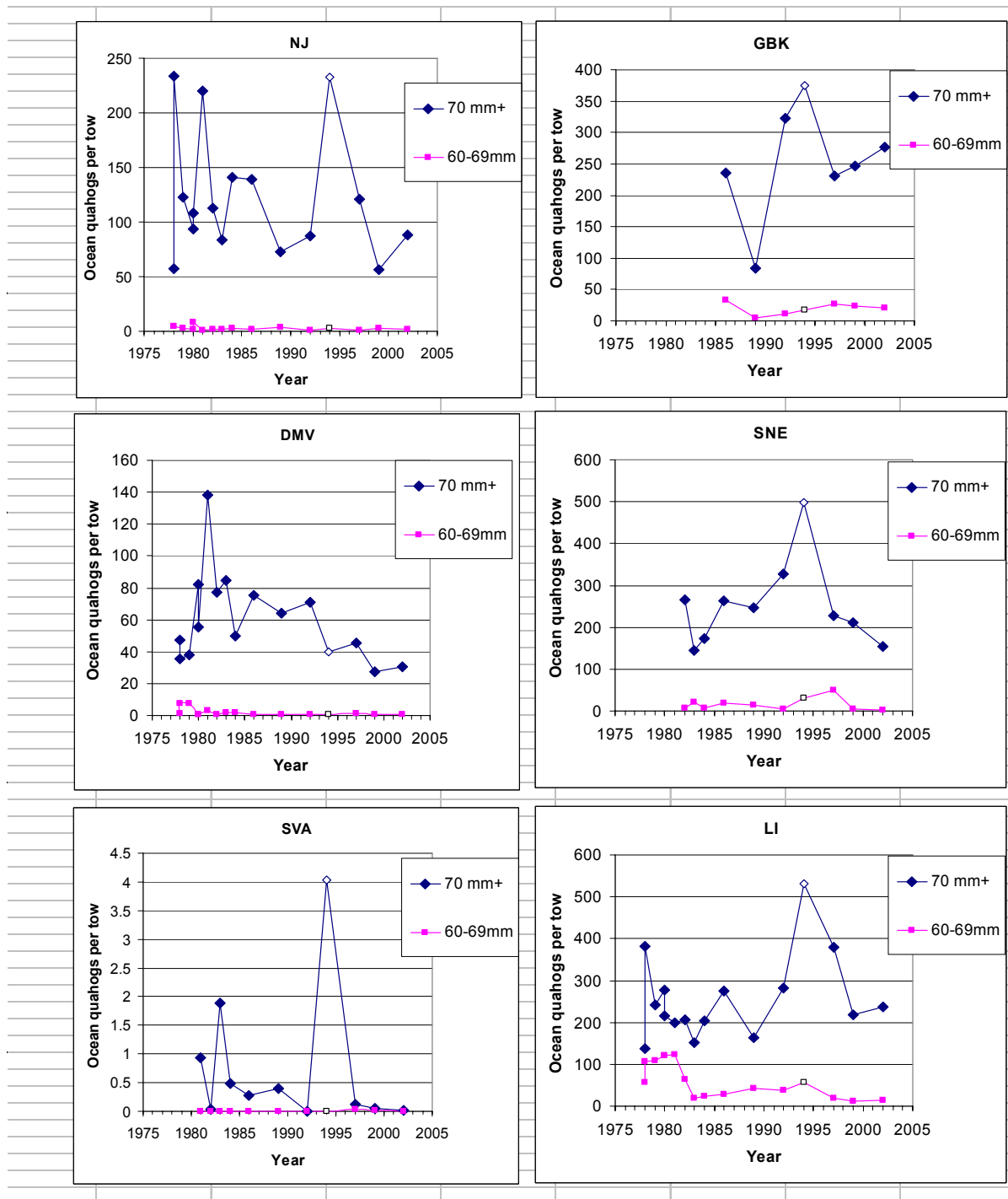
Fig. A47.

Stratified mean number of ocean quahogs per tow over time, by region, based on the NMFS survey.
Data were not adjusted for gear efficiency.
Catch was standardized to a 0.15nmi tow distance, based on doppler distance.
The 1994 survey was done with a voltage > the standard operating procedure, and catch was often high.
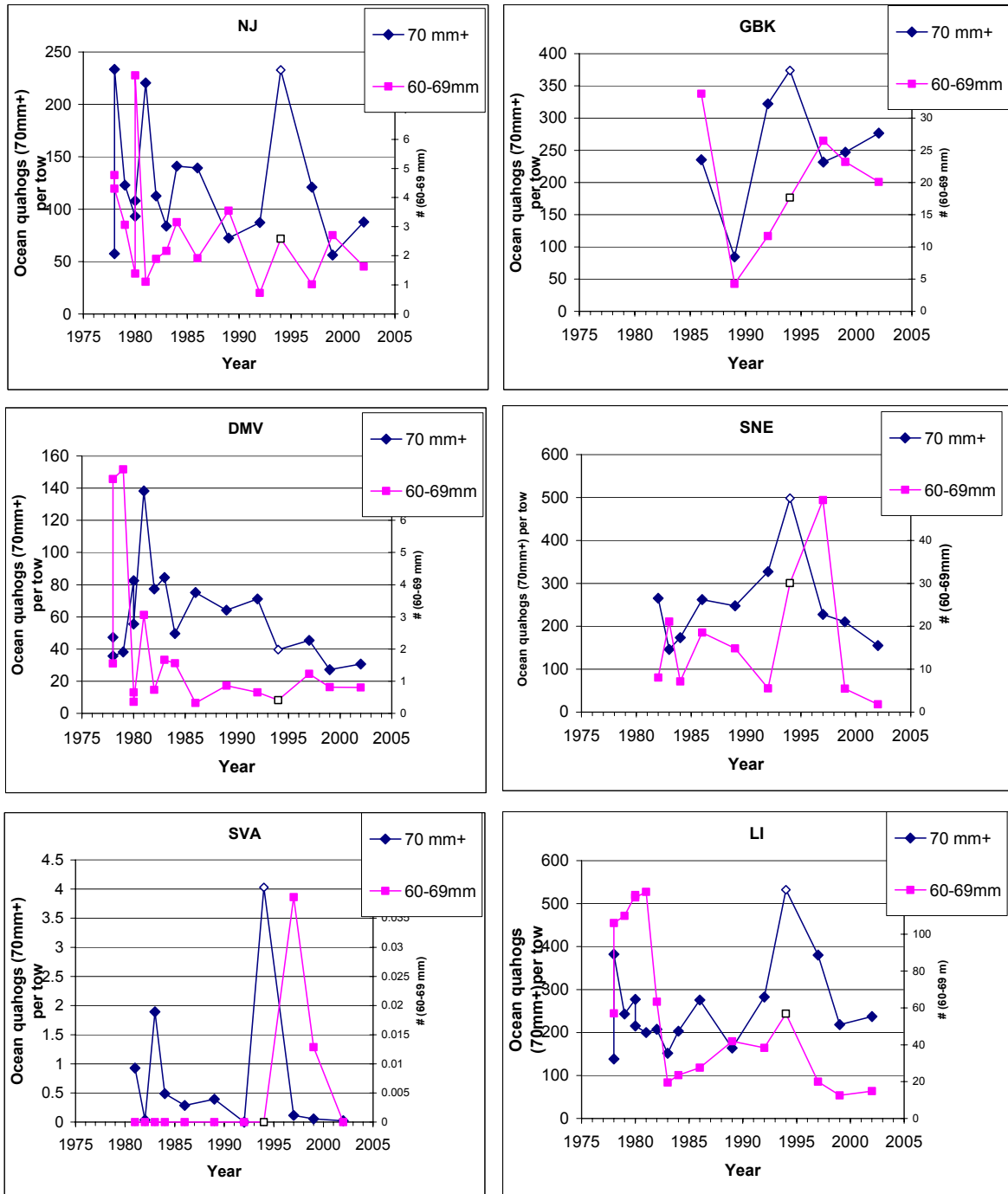
Fig. A48.

Stratified mean number of ocean quahogs per tow over time, by region, based on the NMFS survey.
Data were not adjusted for gear efficiency.
Catch was standardized to a 0.15nmi tow distance, based on doppler distance.
The 1994 survey was done with a voltage > the standard operating procedure, and catch was often high.
(same as previous Fig., but with 2 y-axes).
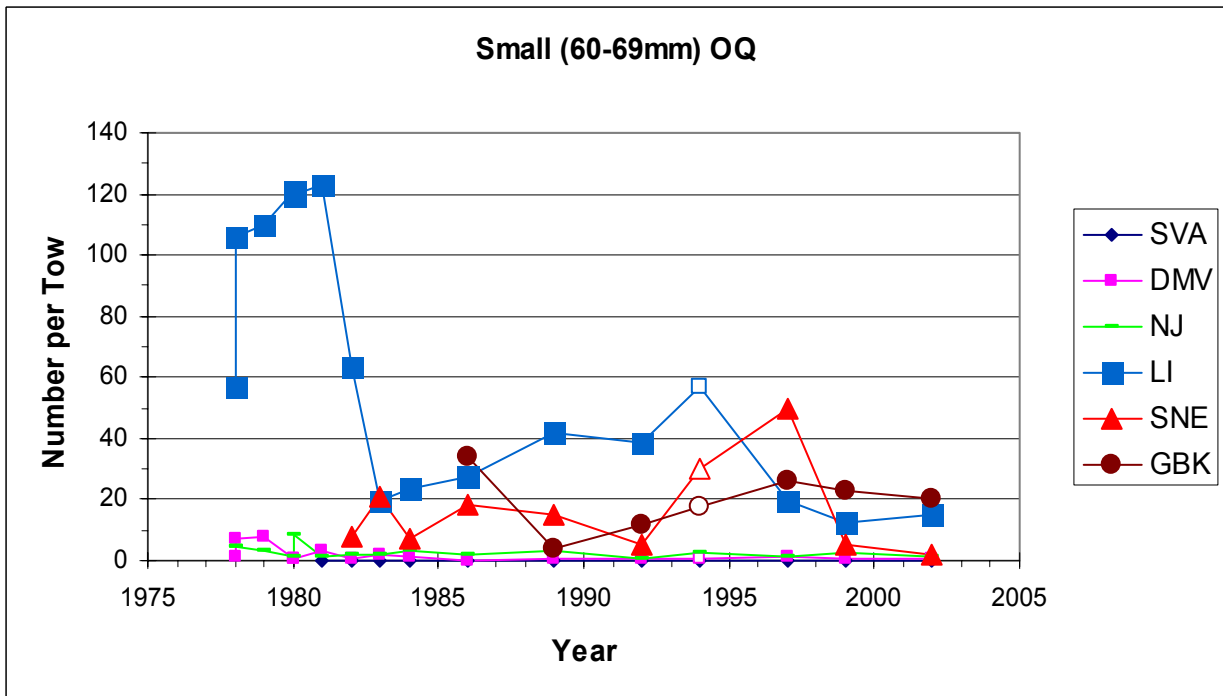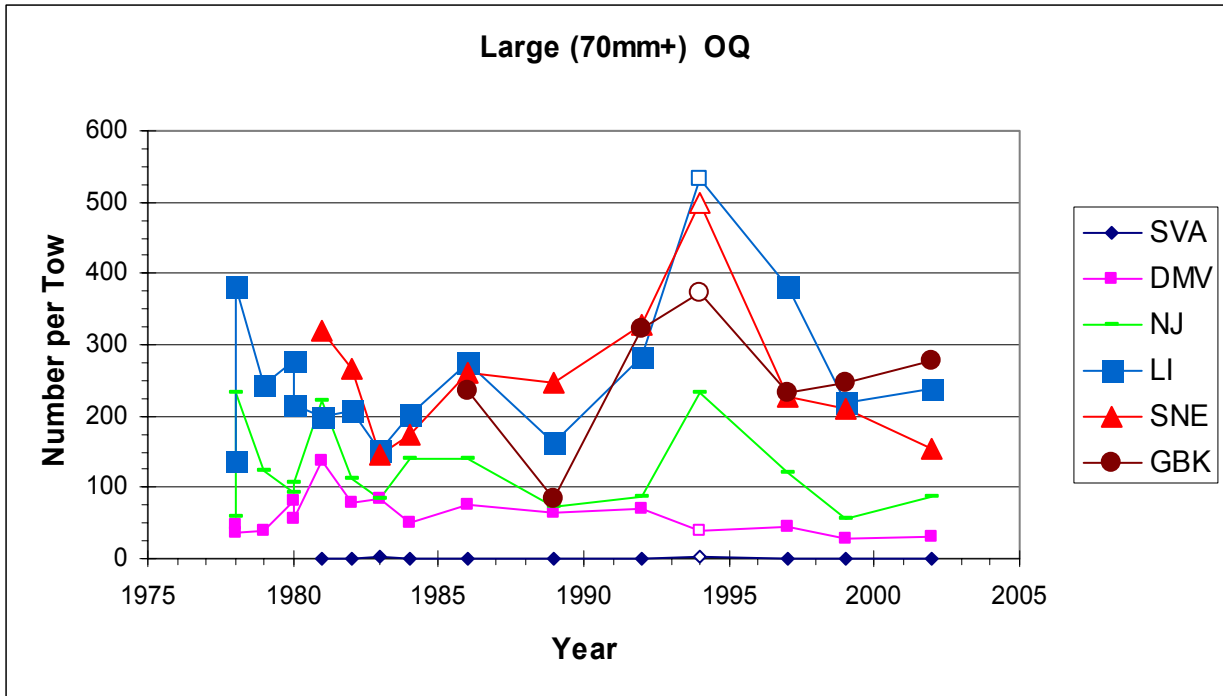
**Fig. A49.**

Comparison of NMFS survey ocean quahog catches across regions.
Shown are the stratified mean number per tow over time.
Data were not adjusted for gear efficiency.
Catch was standardized to a 0.15nmi tow distance, based on doppler distance.
The 1994 survey was done with a voltage > the standard operating procedure, and catch was often high.
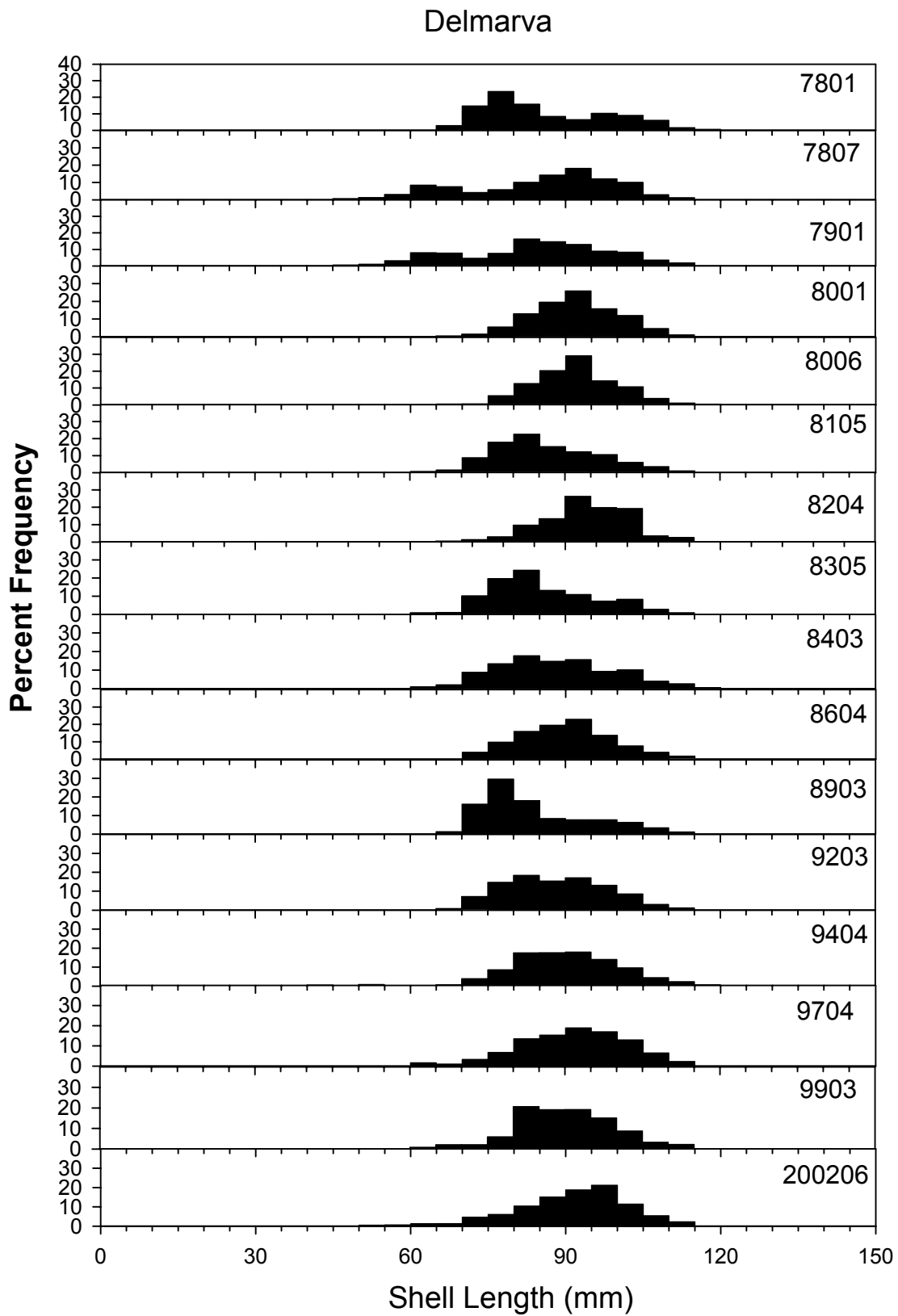
Fig. A50.    Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: DMV

# New Jersey
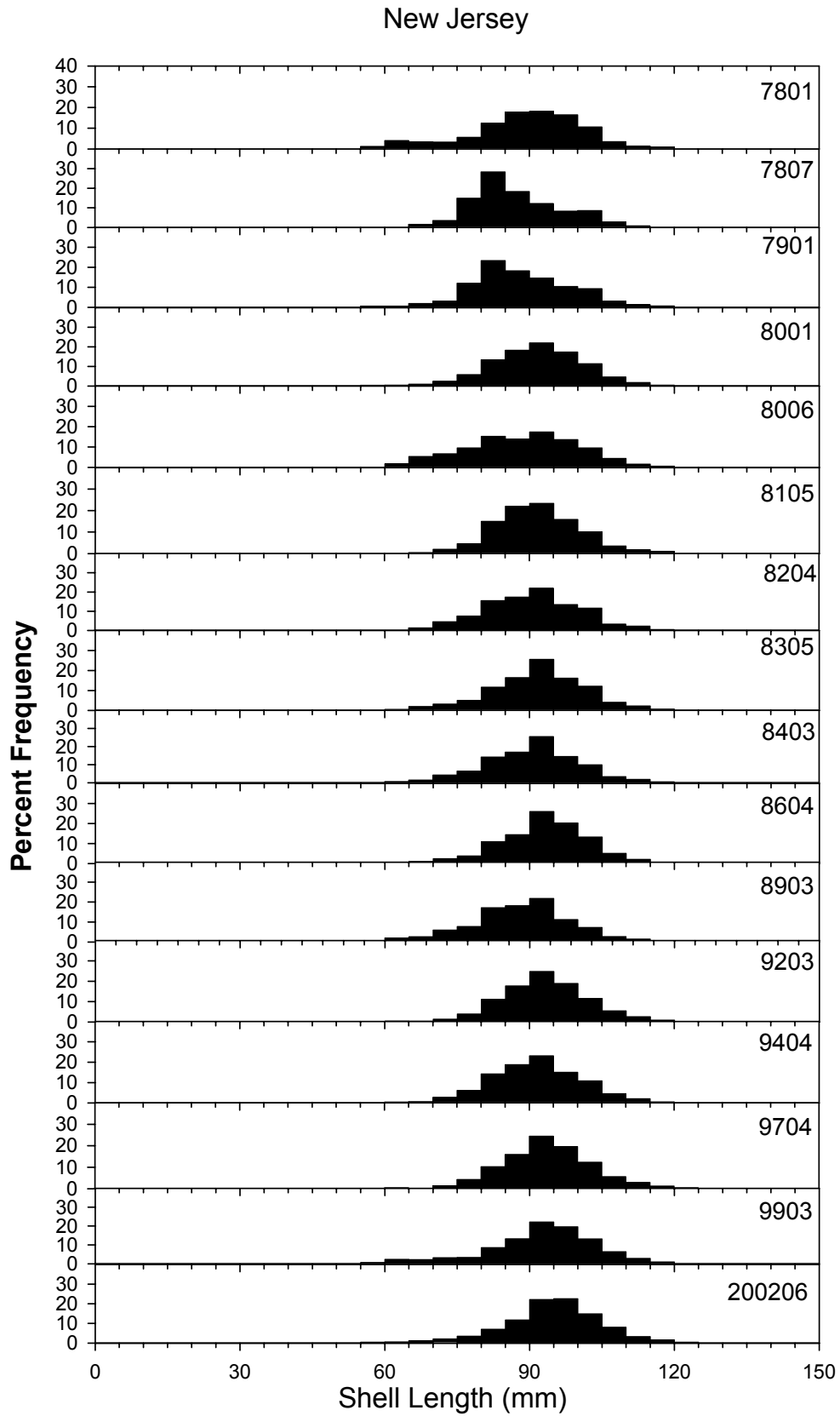


Fig. A51.    Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: NJ .

# Long Island
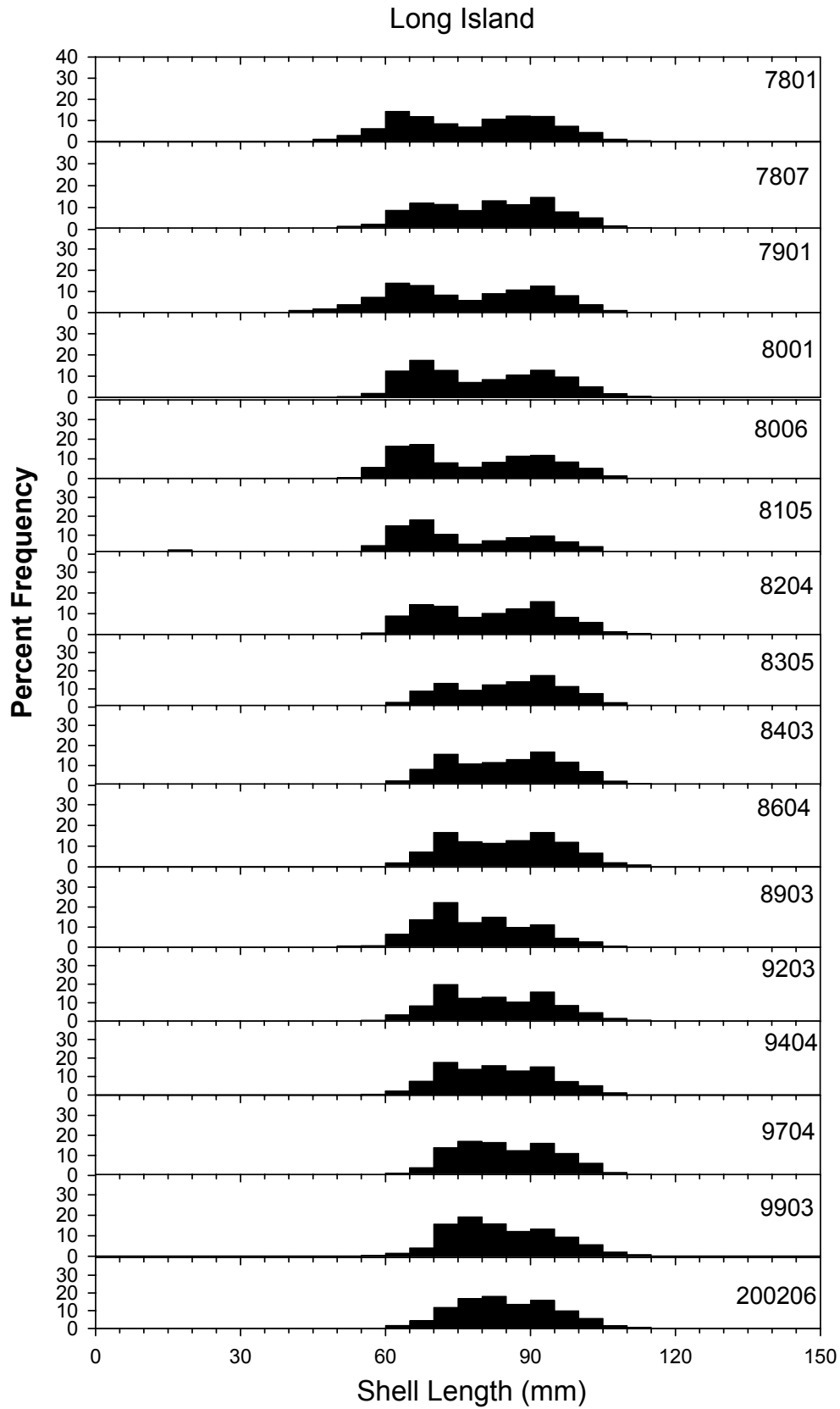


Fig. A52.   Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: LI .
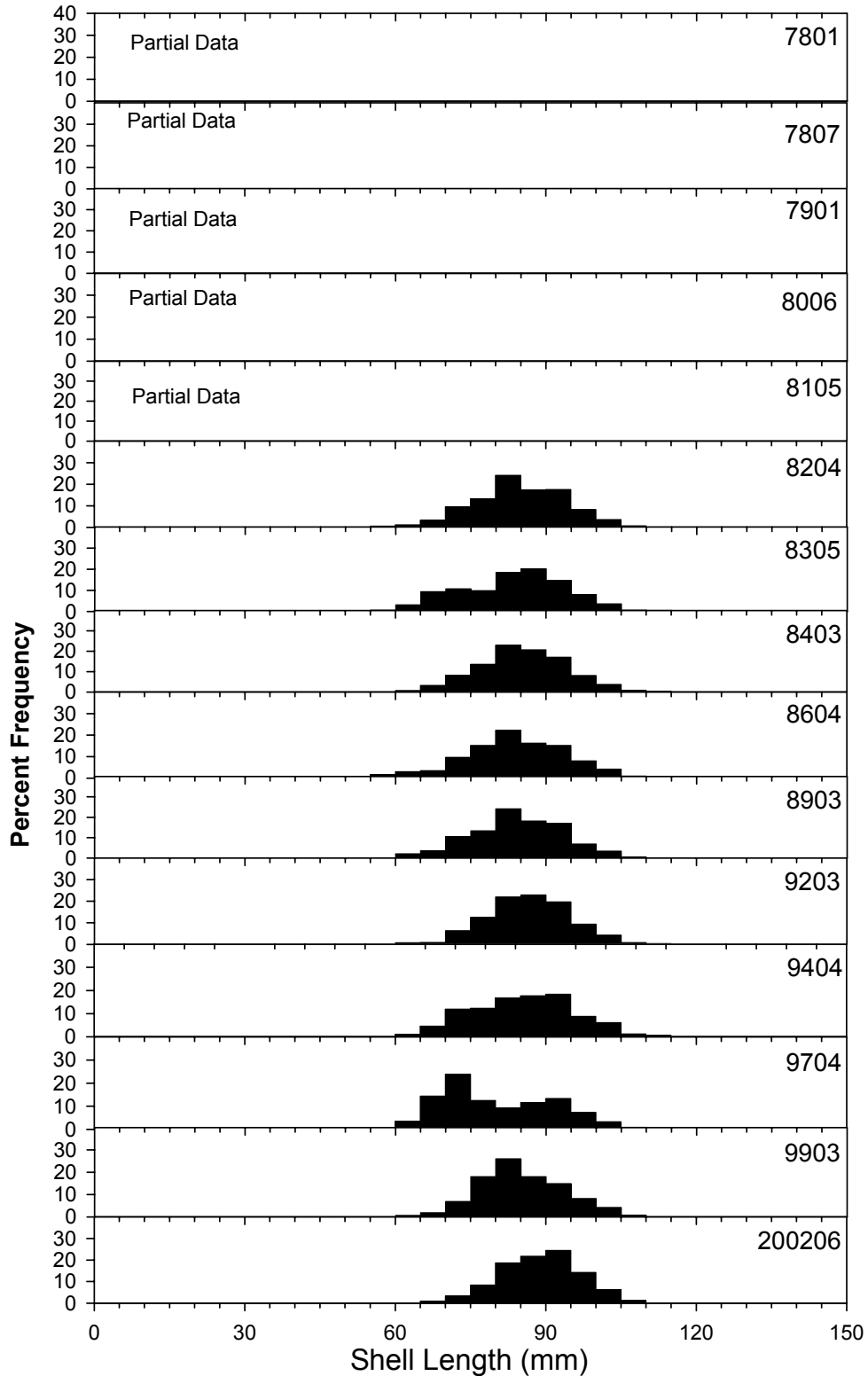
Fig. A53. Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: SNE .
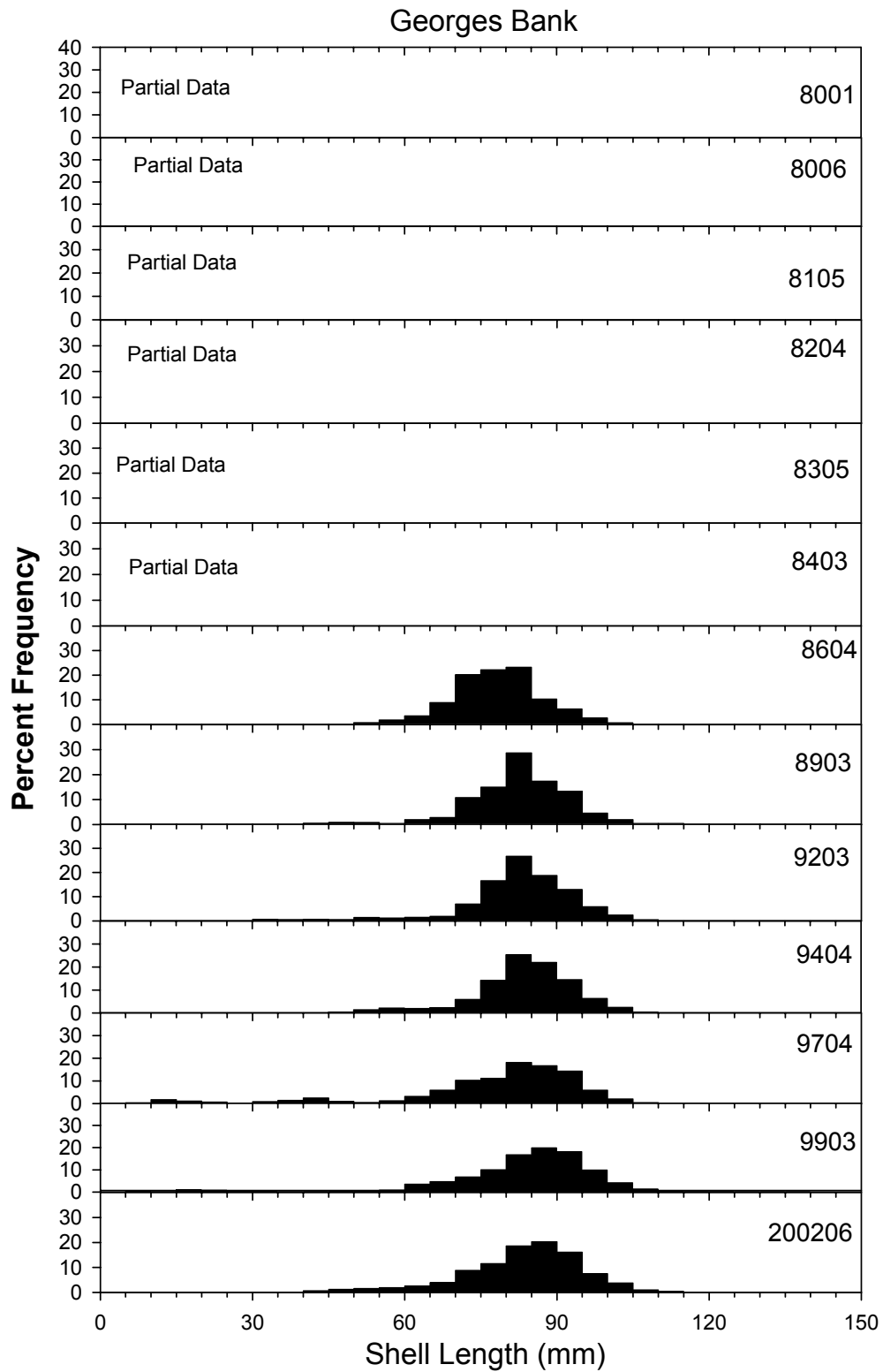
Fig. A54.  Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: GBK .
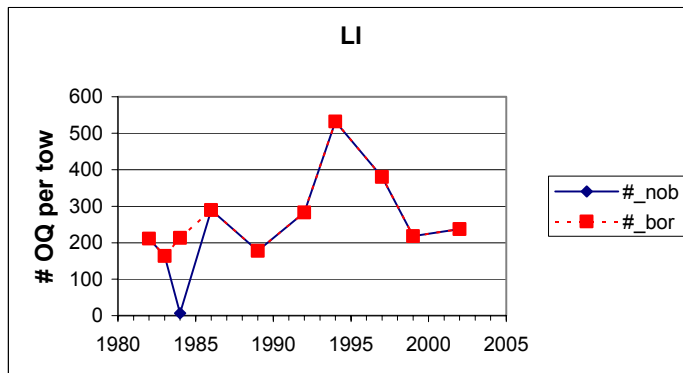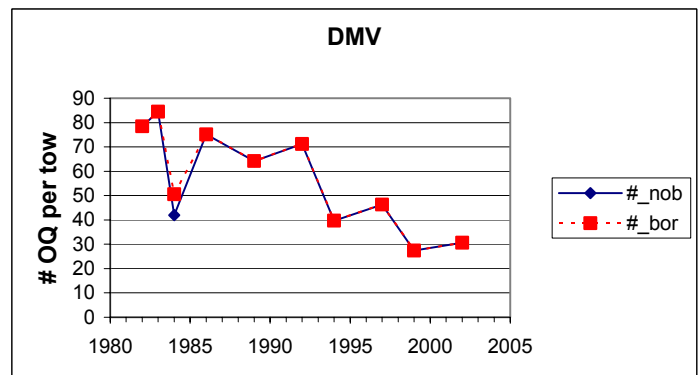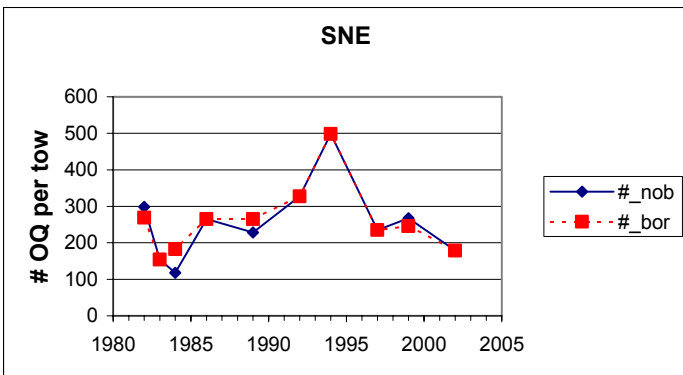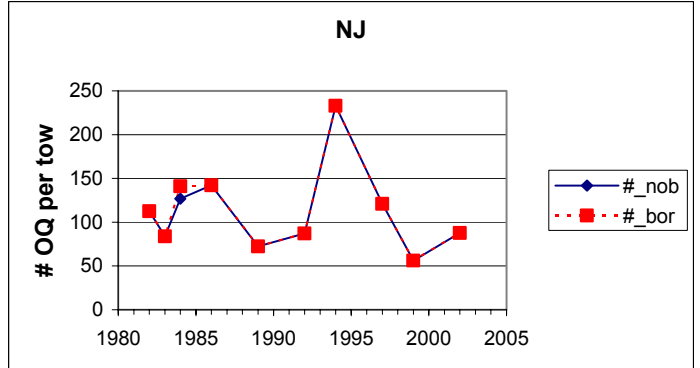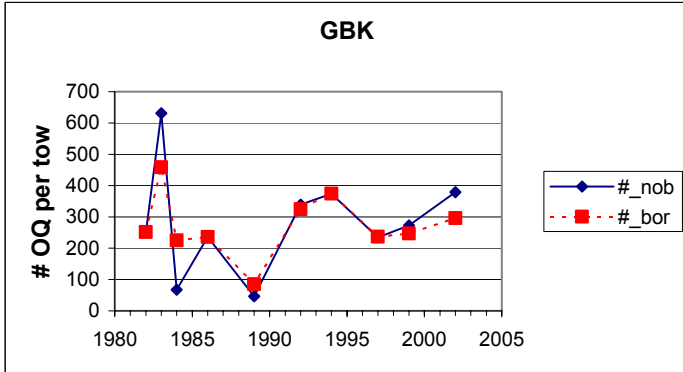
**Figure A55.**
**Sensitivity analysis about "borrowing" to fill survey holes (results from Table A16).**

## Obs. Data from 2 Vessels



## CDFs of Obs. Data
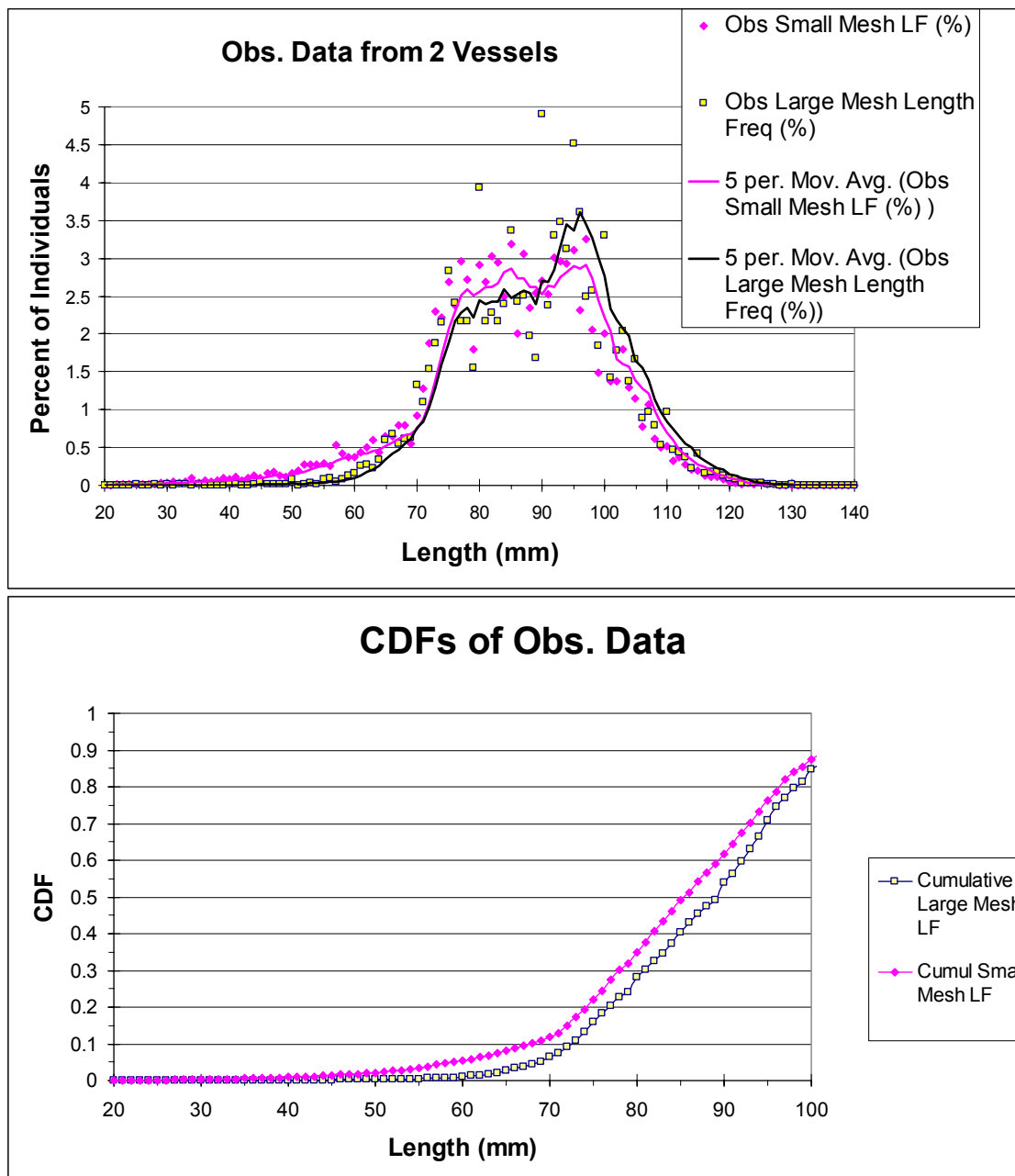


Fig. A56.

**Ocean quahog recruit survey:**

**Observed ocean quahog length frequencies and cumulative distribution functions (CDF) from the NMFS dredge (2" mesh) and the commercial dredge (1" mesh).**

**Data were collected at approximately 100 stations, sampled by both the *RV Delaware II* in June-July and the *FV Christie* in Sept. 2002. All tows from each vessel were pooled.**

A.



Relative Selectivity Function, S(L)
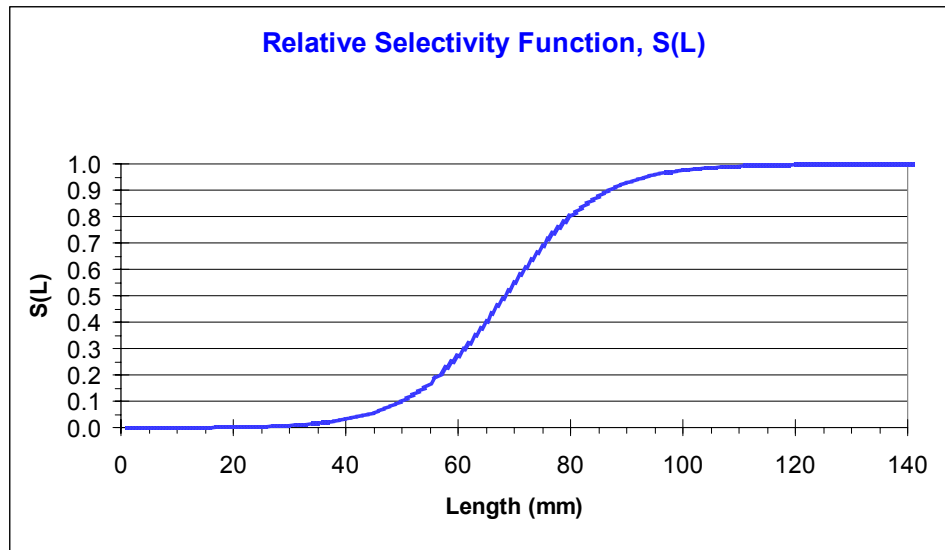
B.

| alpha | beta | L50%ile | Konst. |
|-------|------|---------|--------|
| 8.122 | -0.119 | 68.368 | 5E-06 |

C.



Obs. and Adj. Large Mesh Length Freq., to 51 mm
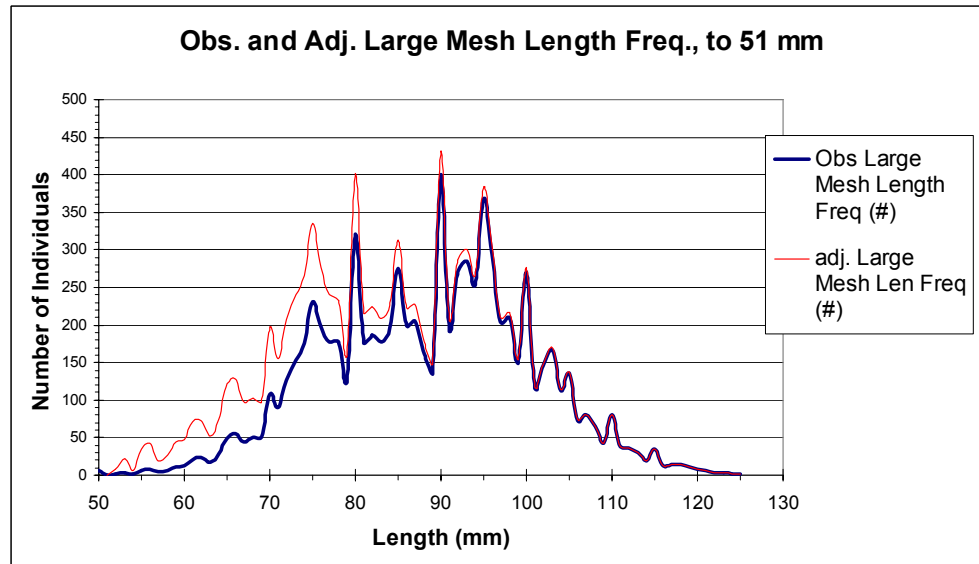
Fig. A57.
**Model results and adjusted DE-II length frequency**.
A.   Relative size selectivity of the *RV DE-II* to the *FV Christie* catching ocean quahogs in summer 2002.

B.   Parameter estimates for Model: S(L) = 1/( 1+exp(alpha+ (beta * L)) ) .

C.   Observed DE-II length frequency and the same data (upper red line) after adjustment for relative size selectivity, down to 51 mm shell length.
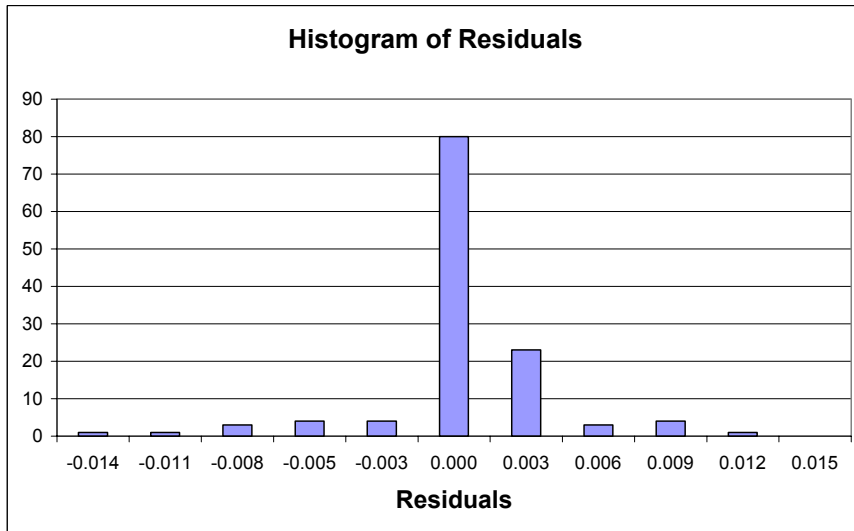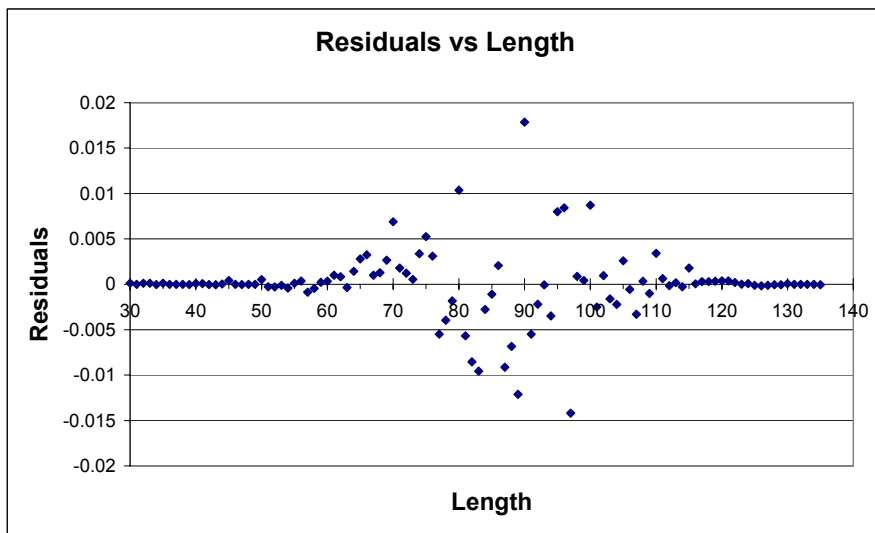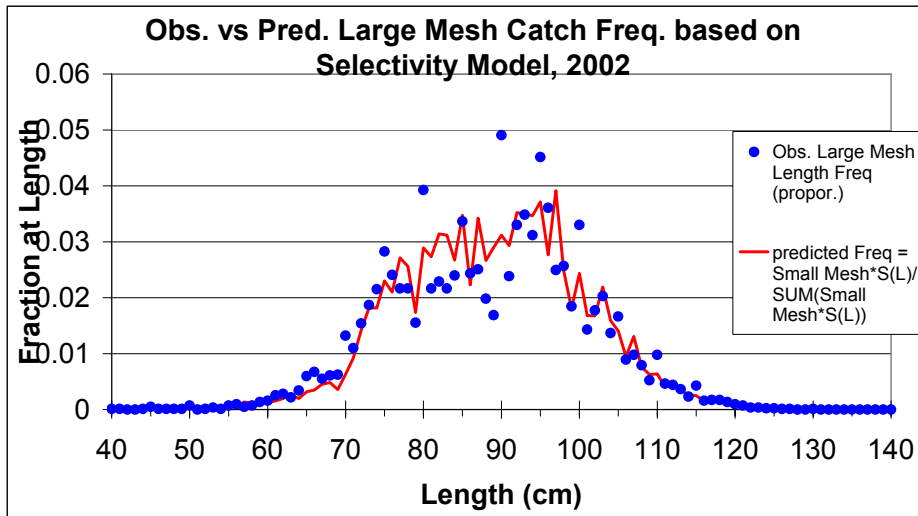
Fig. A58. Fit of the relative selectivity model using data from the paired stations.
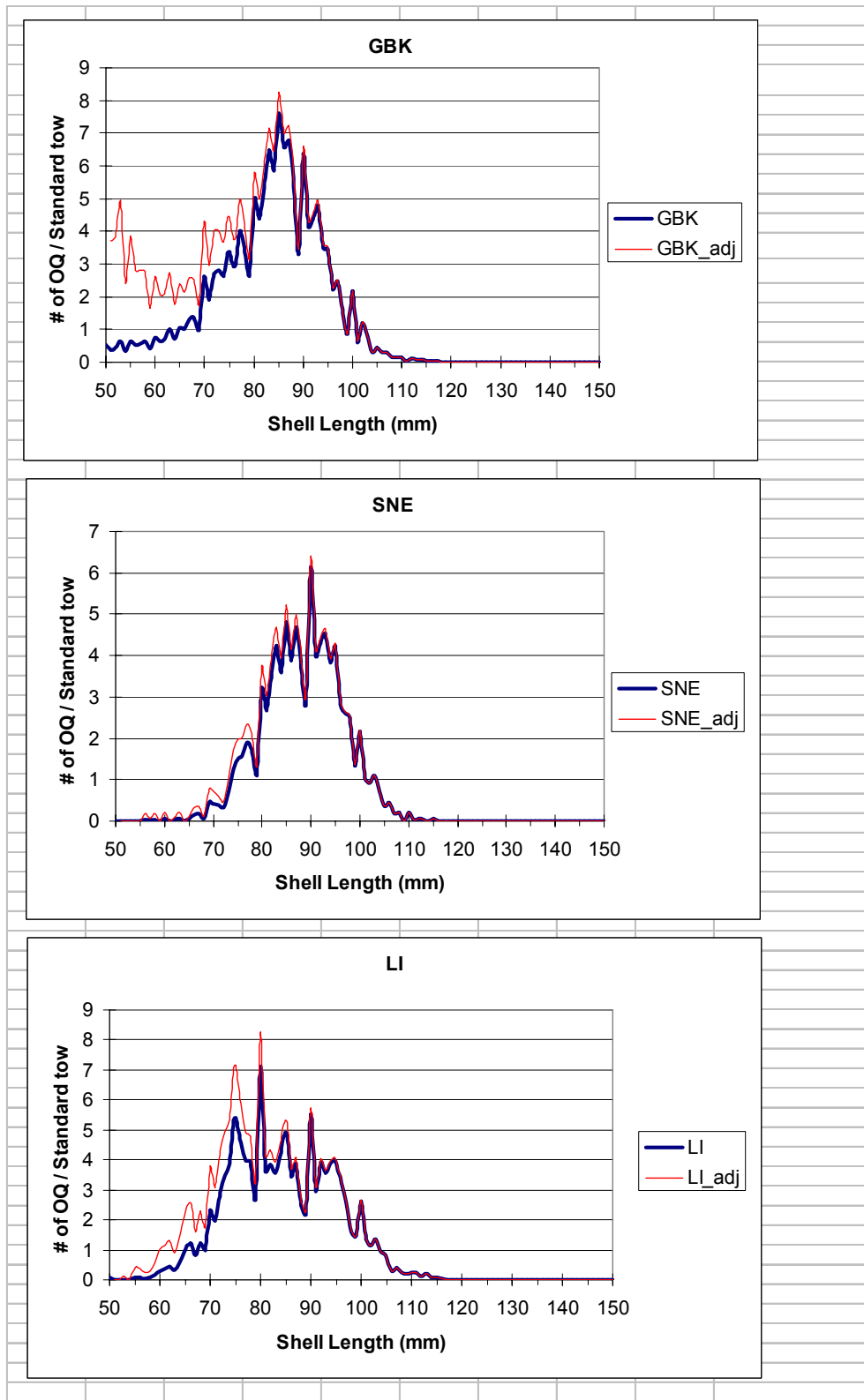
**Fig. A59.**

Ocean quahog length frequency distributions in 2002; **Northern Regions**.
The thick blue line is based only on *RV Delaware-II* data. The thin red line
is adjusted for dredge selectivity, down to a shell length of 51 mm,
using data from the *FV Christie* 2002 "recruit" survey.
Data were standardized to a common distance of 0.15 nmi based on sensors.
The catches have not been adjusted for dredge efficiency.
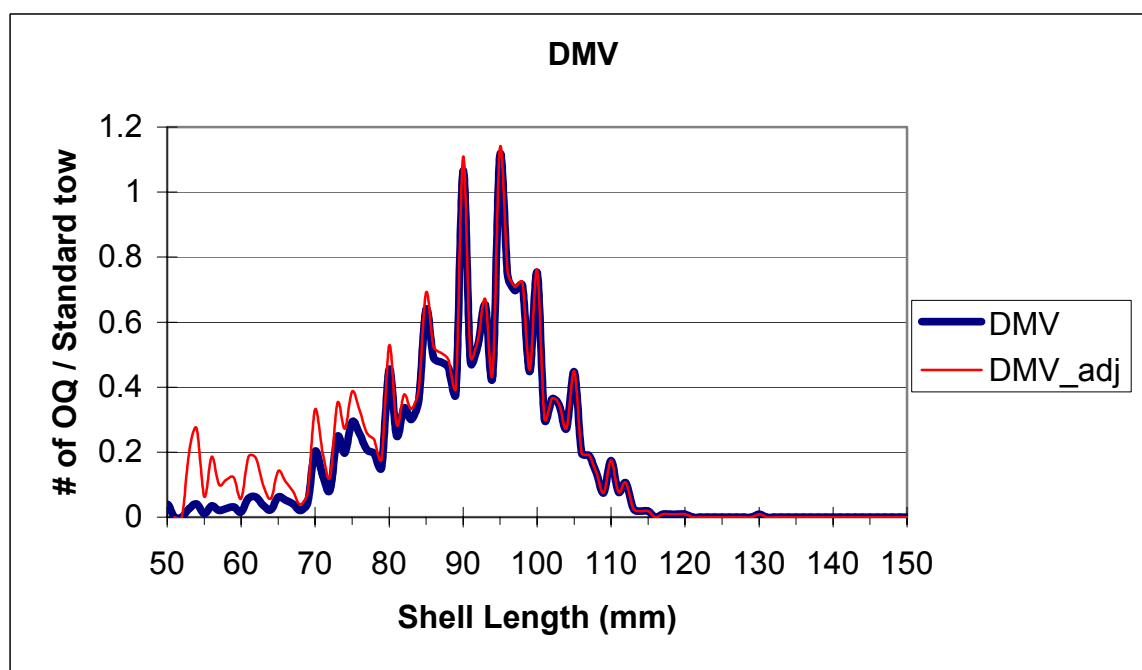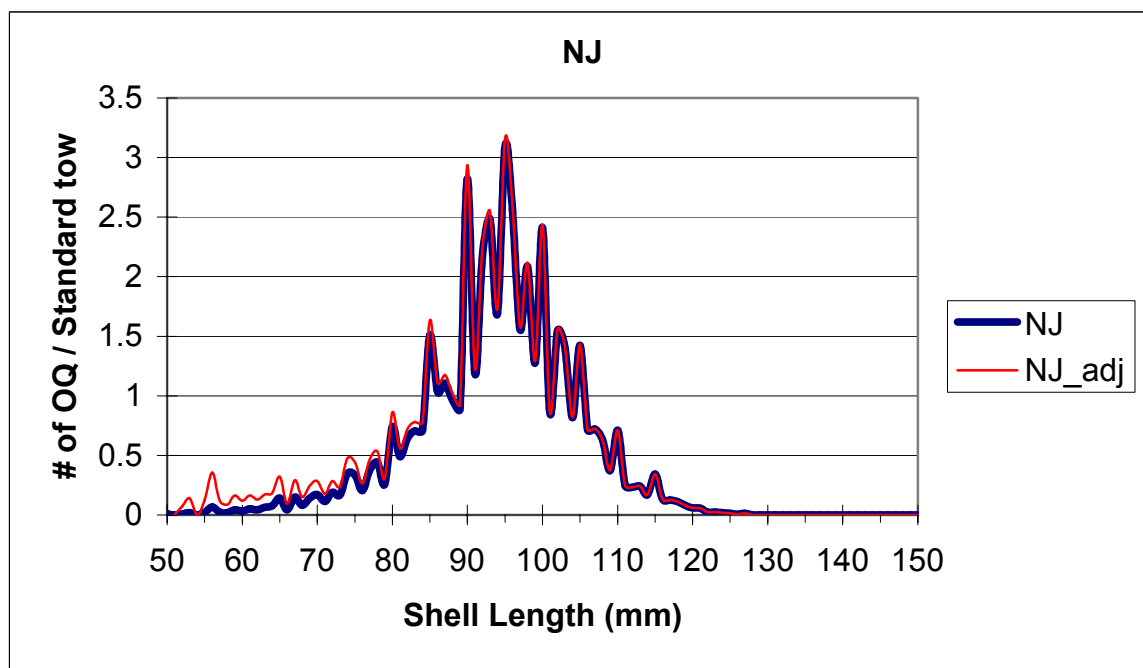
Fig. A60.

Ocean quahog length frequency distributions in 2002; **Southern Regions**.
The thick blue line is based only on *RV Delaware-II* data.  The thin red line
is adjusted for dredge selectivity, down to a shell length of 51 mm,
using data from the *FV Christie* 2002 "recruit" survey.
Data were standardized to a common distance of 0.15 nmi based on sensors.
The catches have not been adjusted for dredge efficiency.
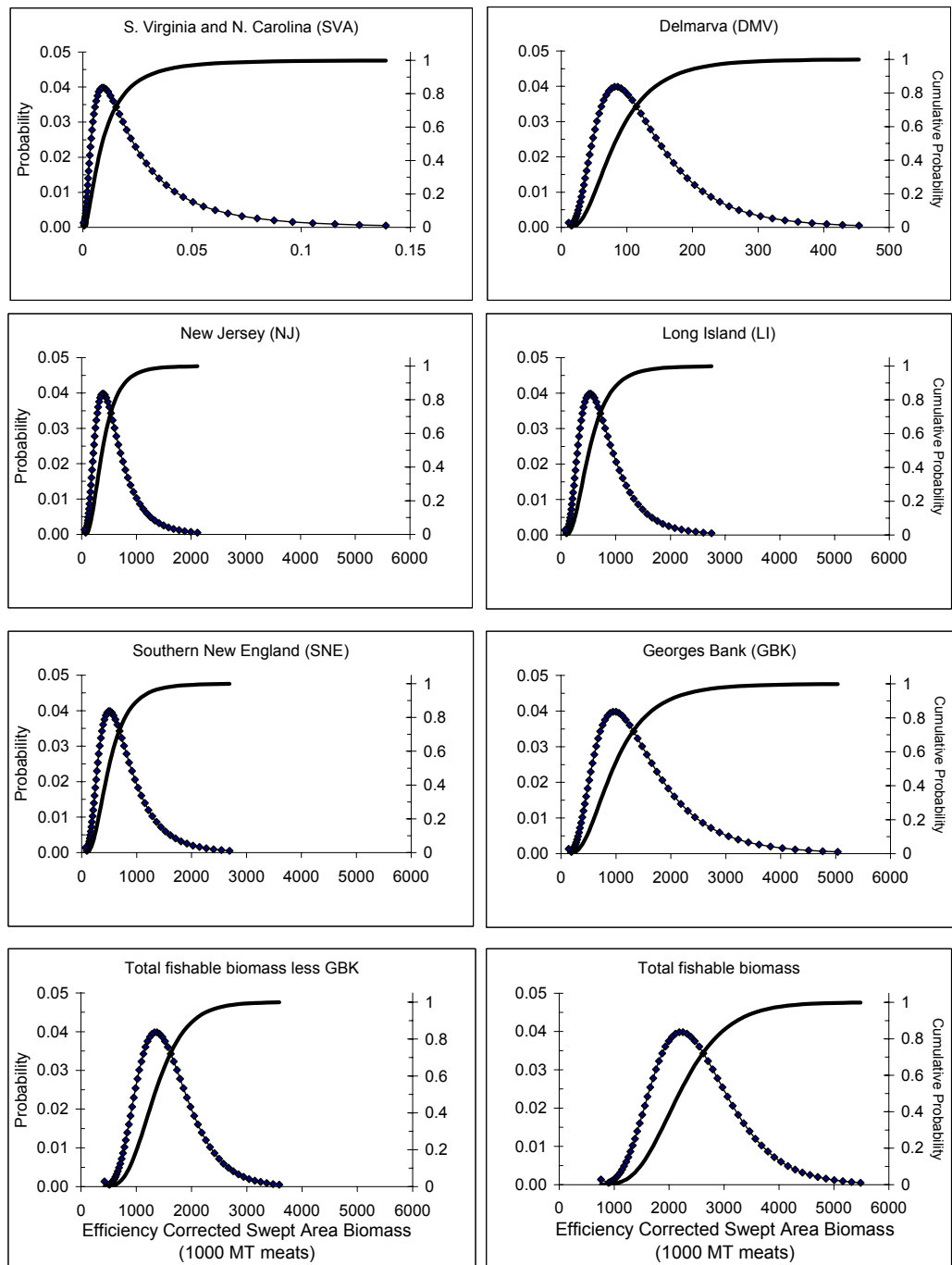
## Fig. A61.

Uncertainty in ocean quahog (70+ mm) efficiency corrected swept area **biomass** estimates in 2002. Uncertainty distributions are based on analytical variance calculations assuming log normality, and include uncertainy in survey data, swept-area, amount of suitable habitat and survey dredge efficiency. The x-axis in most graphs scaled to the same maximum value to facilitate comparisons.
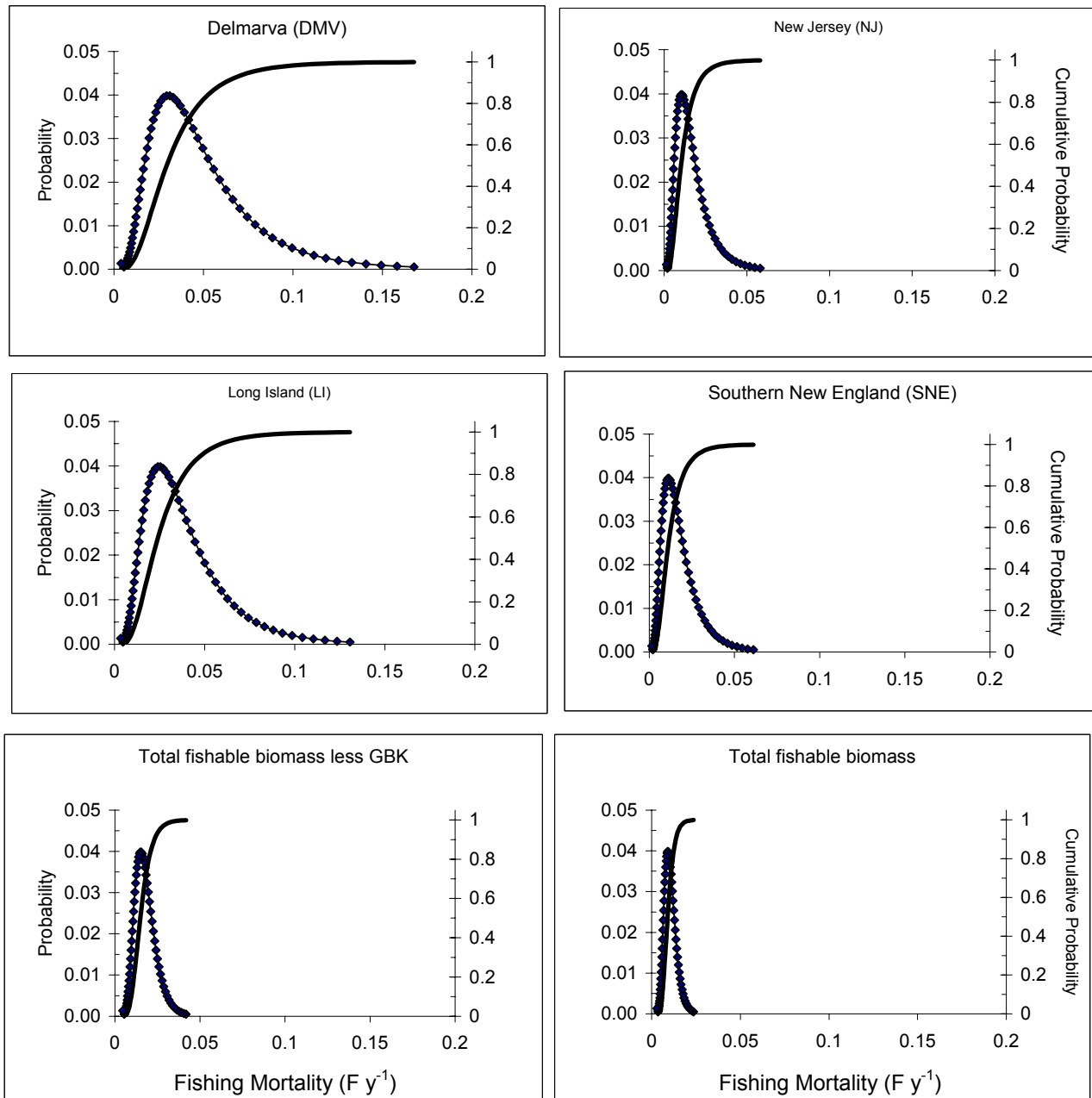
## Fig. A62.

Uncertainty in ocean quahog (70+ mm) **fishing mortality** estimates for 2002 based on catch data and efficiency corrected swept-area biomass. Uncertainty calculations are based on analytical variance calculations that assume log normality, and include uncertainty in catch, survey data, swept-area, amount of suitable habitat, and survey dredge efficiency. X-axes are scaled to the same maximum to facilitate comparisons.
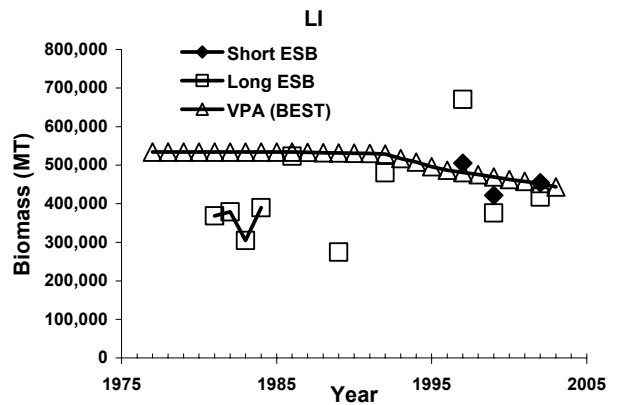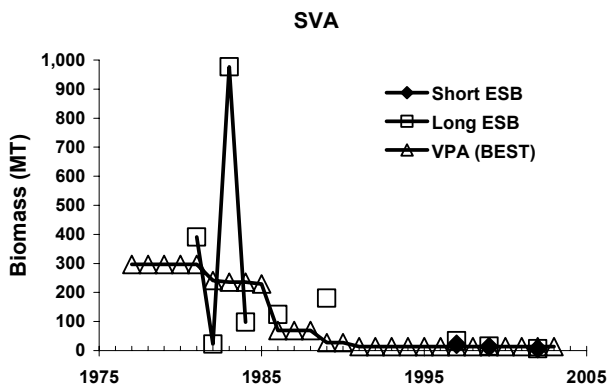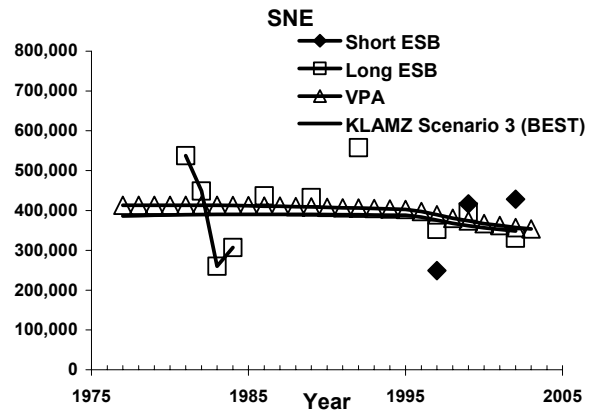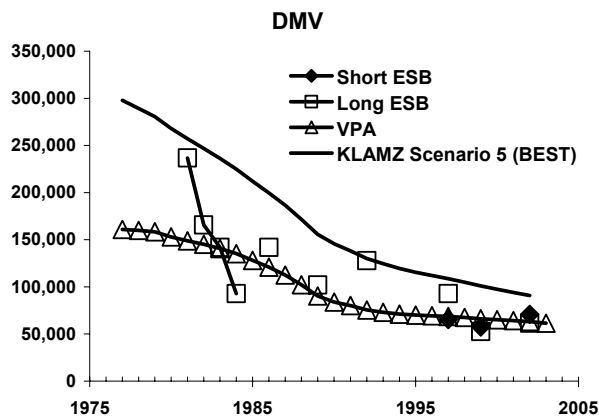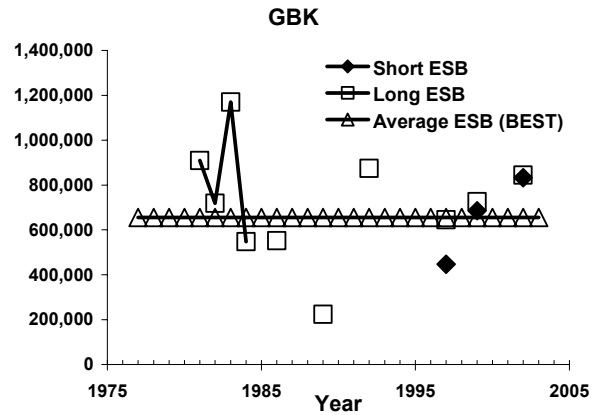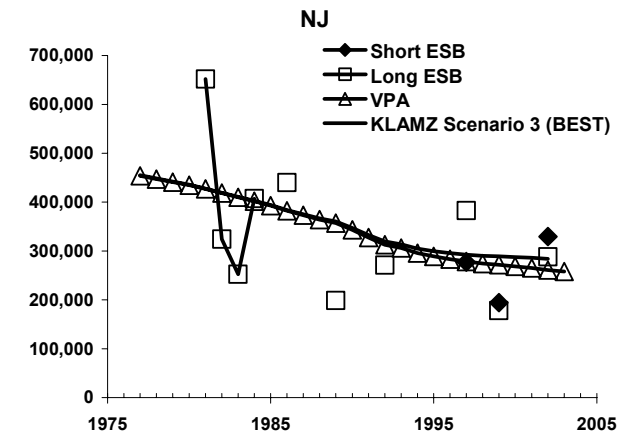
Figure A63.  Results of models estimating ocean quahog biomass.
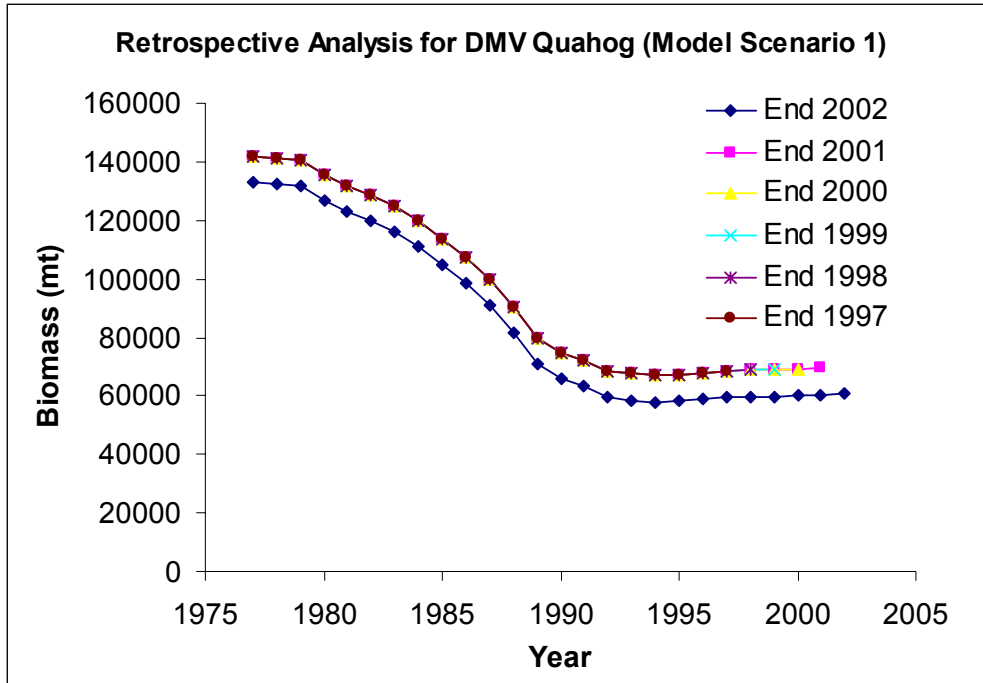
**Figure A64. Delmarva region, retrospective analysis.**
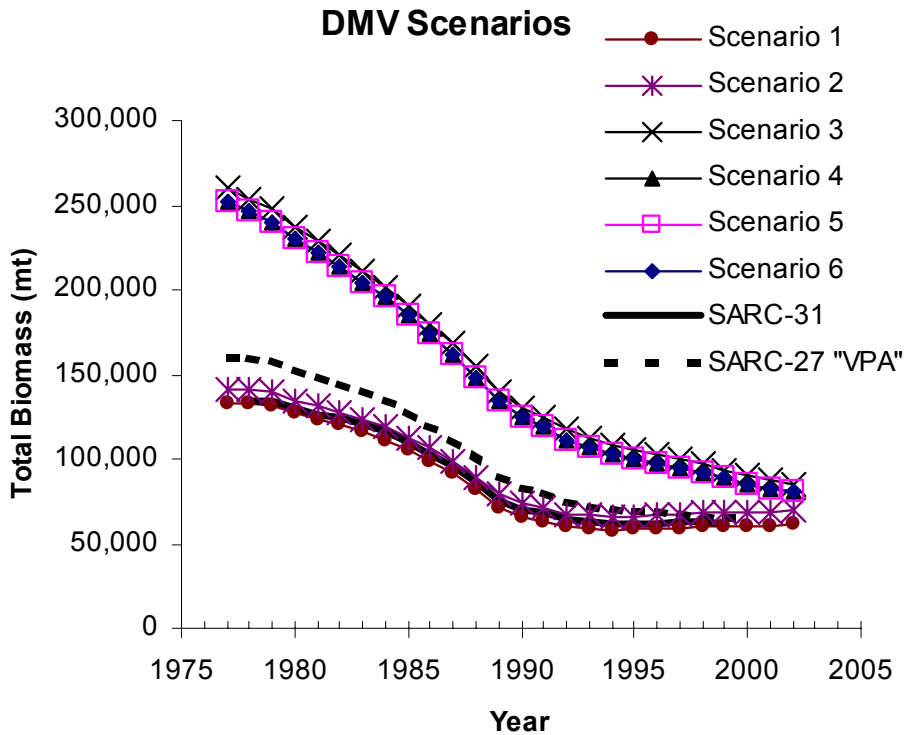


**Figure A65. Delmarva region, biomass scenarios.**

# DMV - Scenario 5

## Population Dynamics



## Population Vital Rates



## NEFSC Survey Trend



## NEFSC Survey Scaling Parameter



## Short ESB Trend



## LPUE Trend
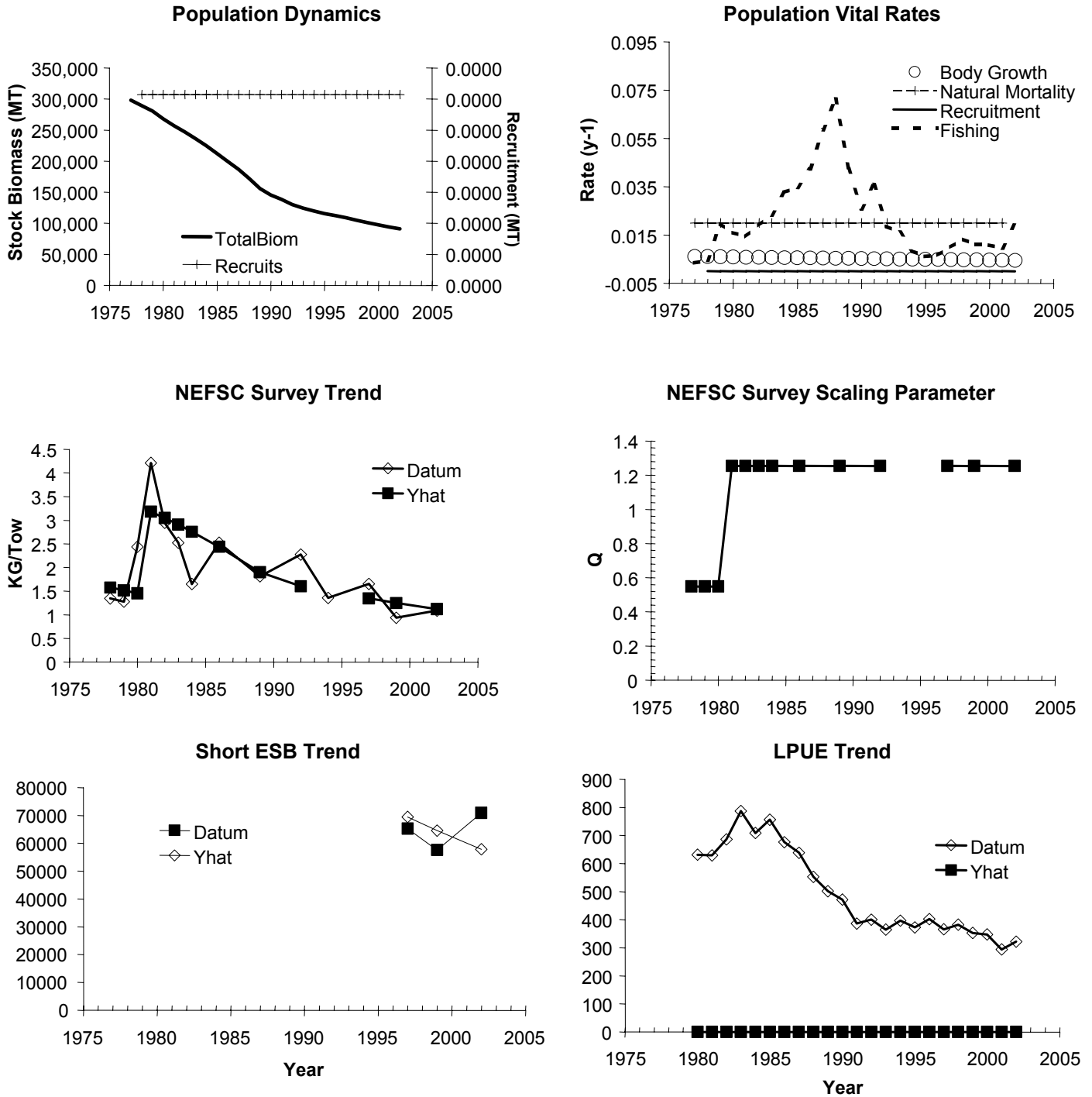


Figure A66. Delmarva region, Scenario 5.
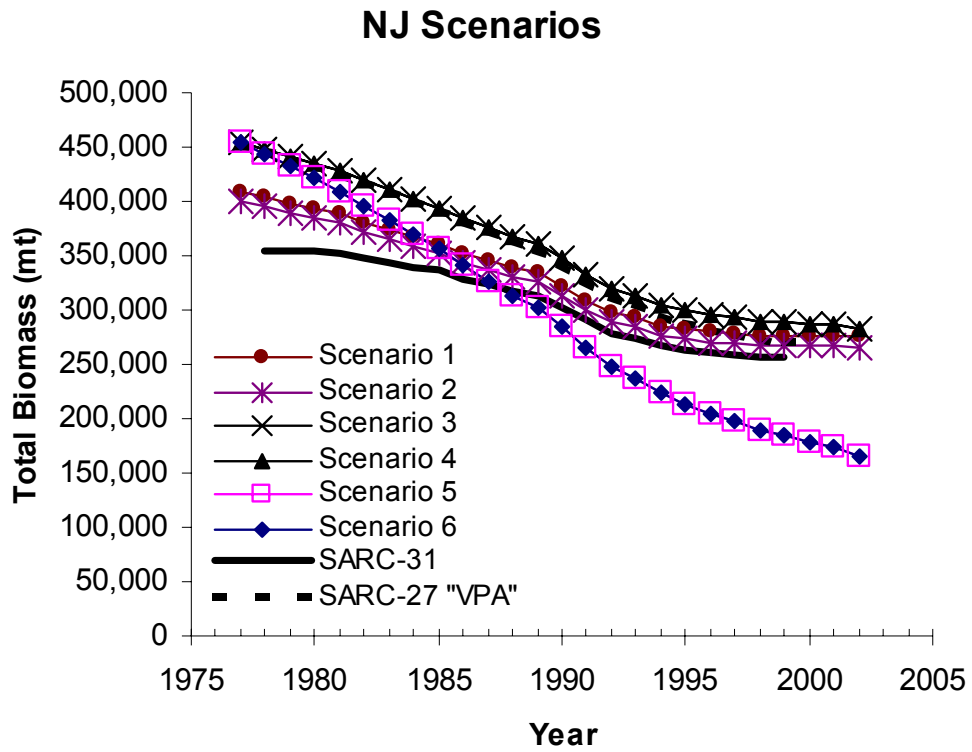
Figure A67. New Jersey region, biomass scenarios.

# NJ - Scenario 3

## Population Dynamics



## Population Vital Rates



## NEFSC Survey Trend



## NEFSC Survey Scaling Parameter



## Short ESB Trend



## LPUE Trend
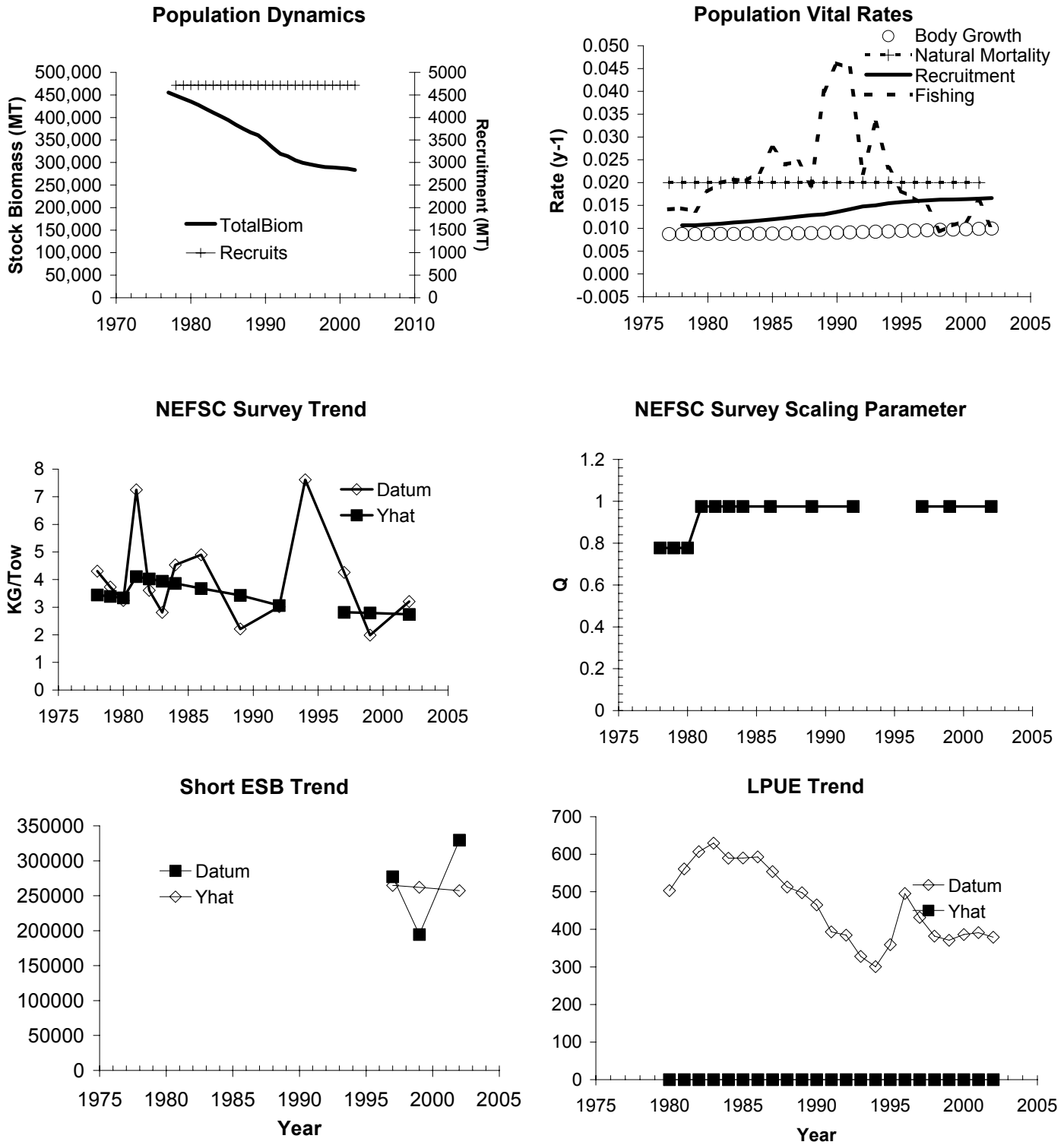


Figure A68. New Jersey region, Scenario 3.
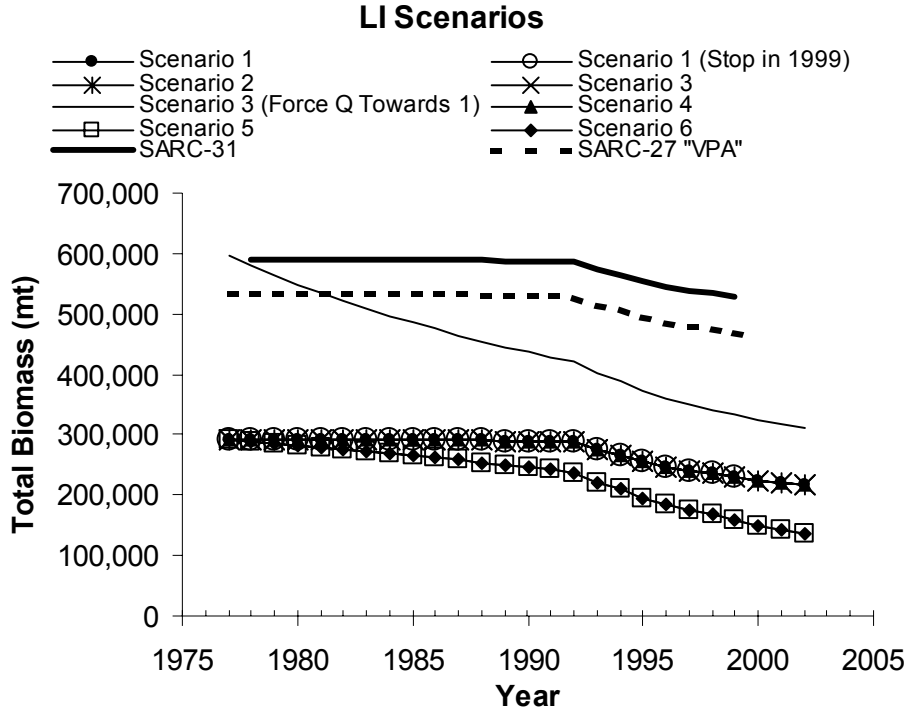
Figure A69.  Long Island region, biomass scenarios.
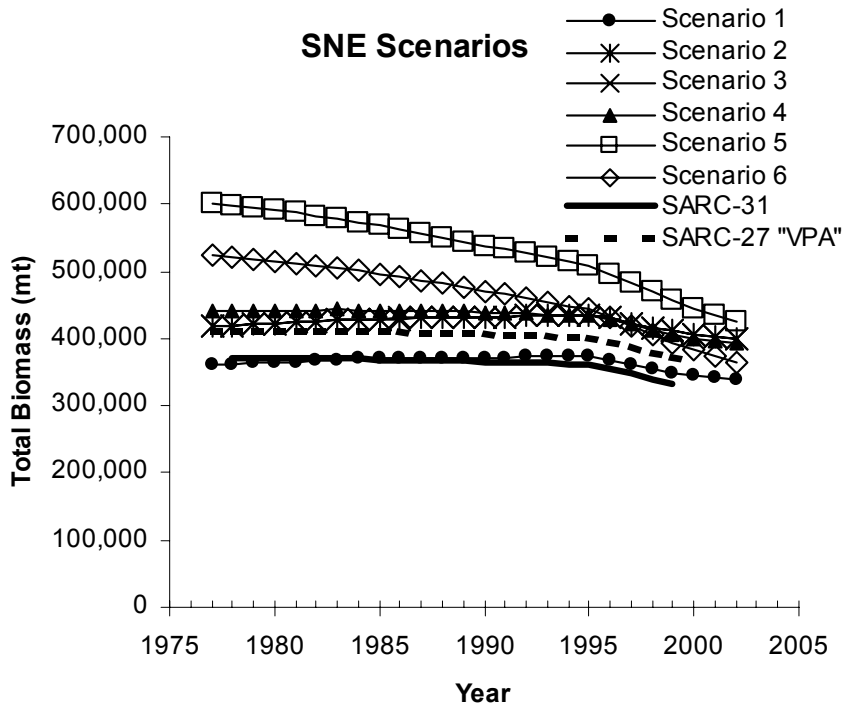


Figure A70. Southern New England region, biomass scenarios.

# SNE - Scenario 3

### Population Dynamics



### Population Vital Rates



### NEFSC Survey Trend



### NEFSC Survey Scaling Parameter



### Short ESB Trend



### LPUE Trend
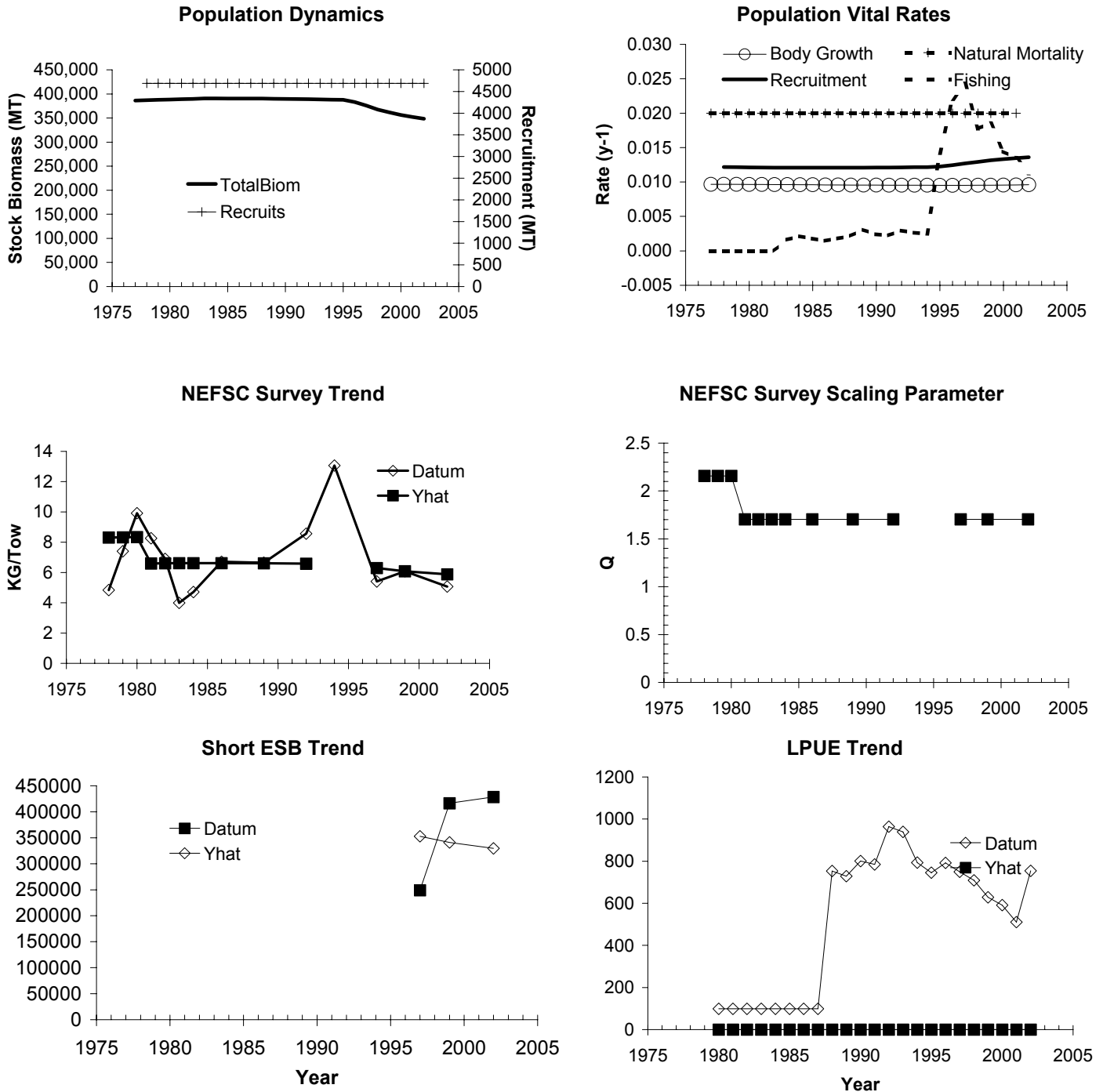


Figure A71. Southern New England region, Scenario 3.
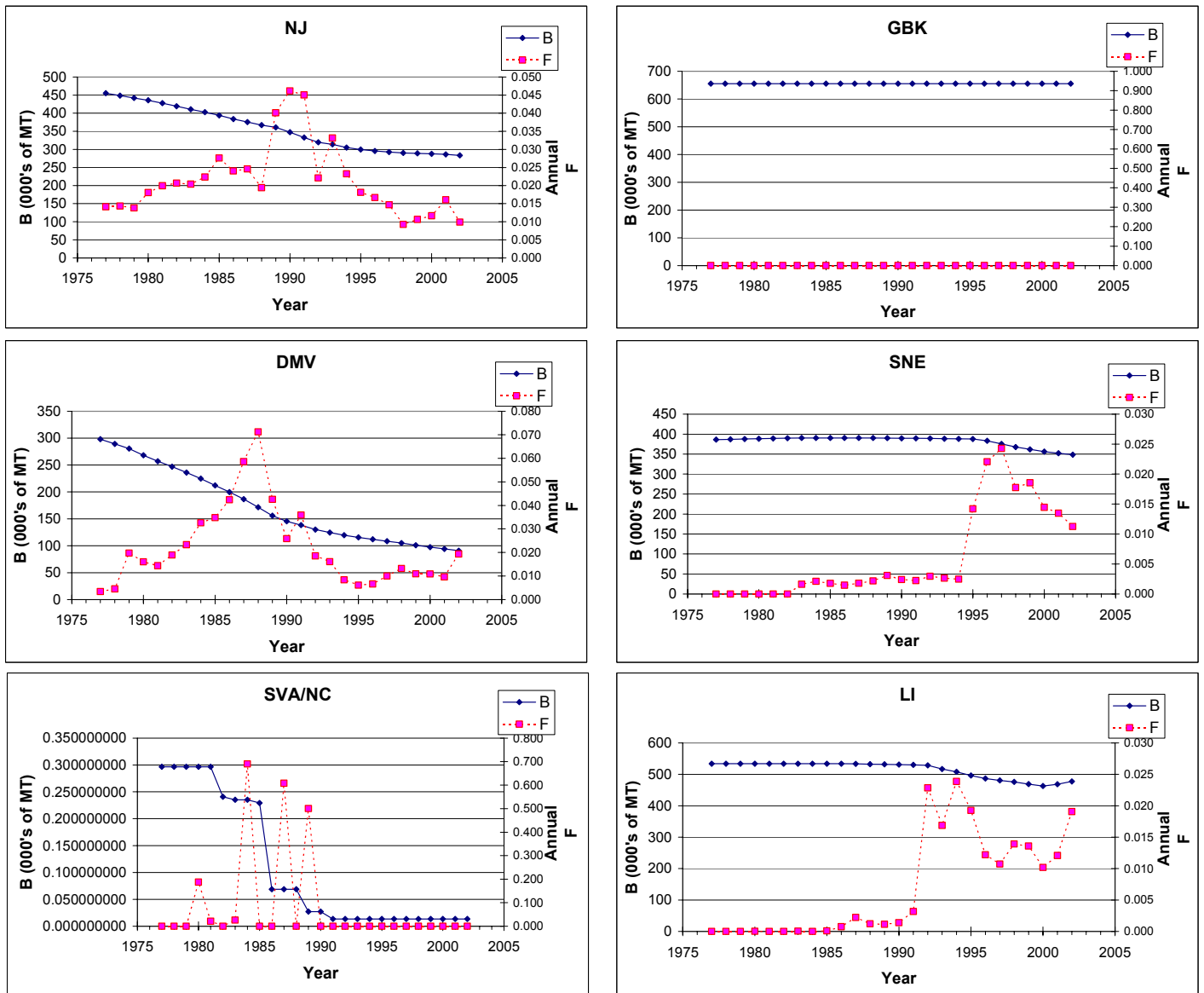
Figure A72. Regional biomass and annual fishing mortality rate over time based on KLAMZ and other models.  Values are from Table A24.
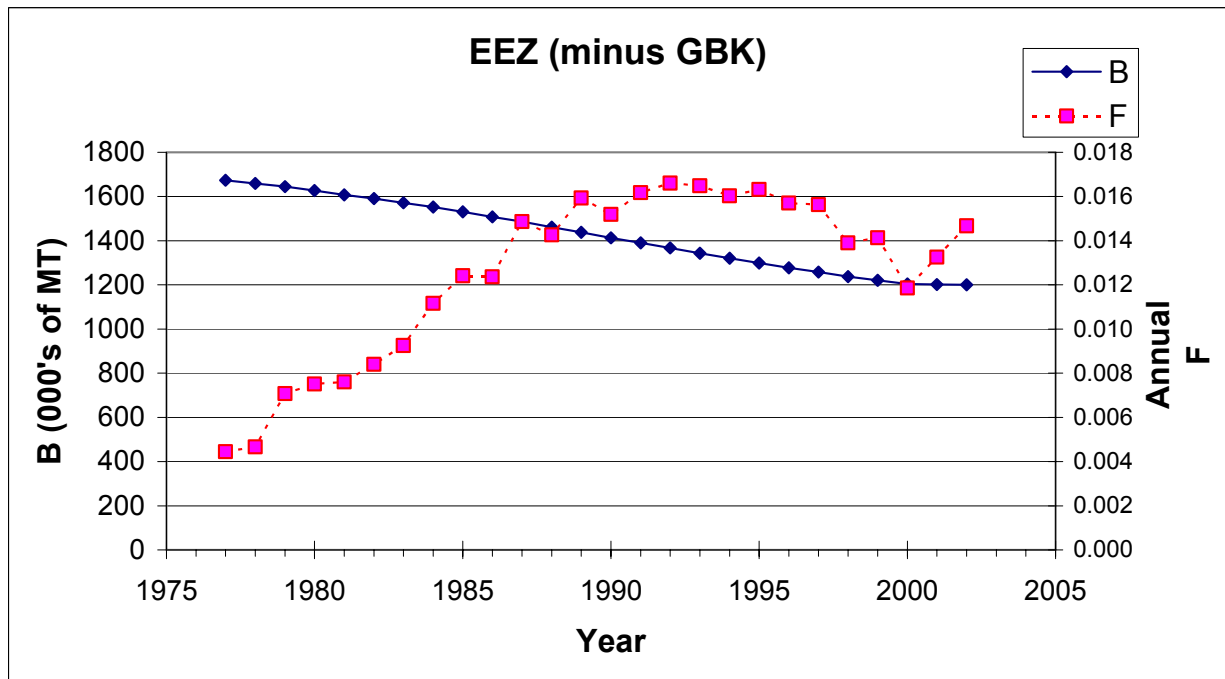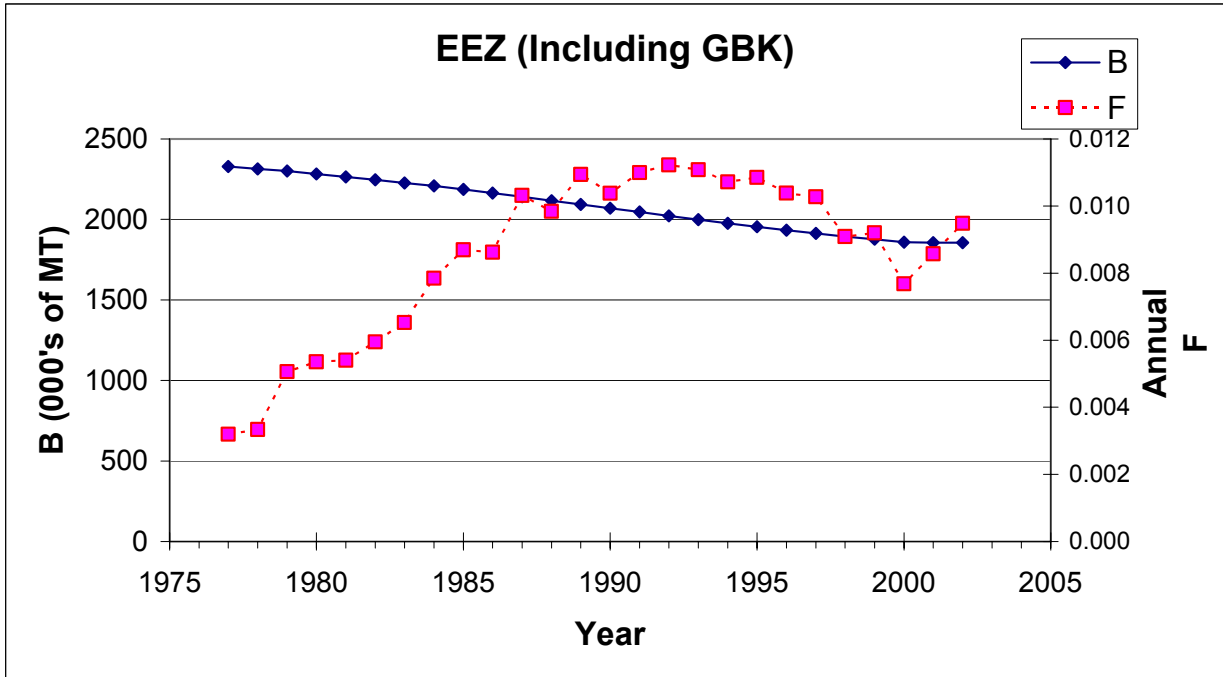
Figure A73. Biomass and annual fishing mortality rate over time based on KLAMZ and other models, for the EEZ and the EEZ less GBK. Values are from Table A24.

# Best Ocean Quahog Biomass Estimates
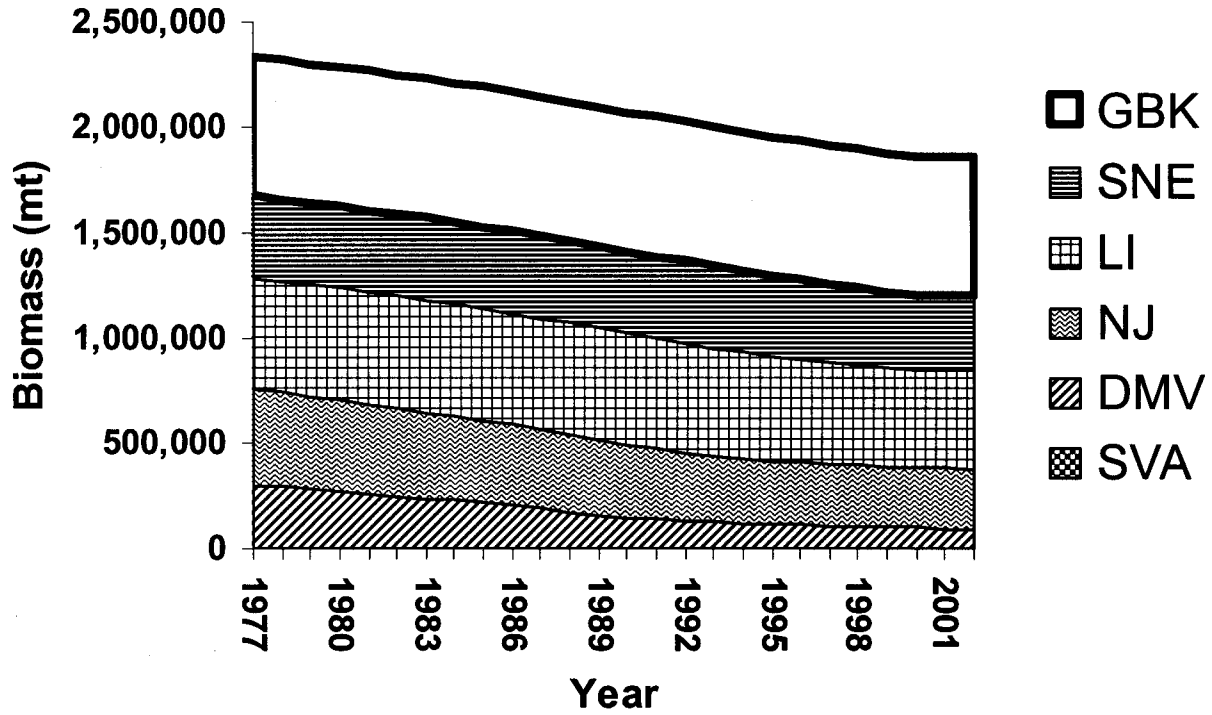


Figure A74. Temporal trends in ocean quahog biomass, Based on Table A24.

# Best 1977 Quahog Biomass Estimates



SVA 0%
DMV 13%
GBK 27%
NJ 20%
LI 23%
SNE 17%
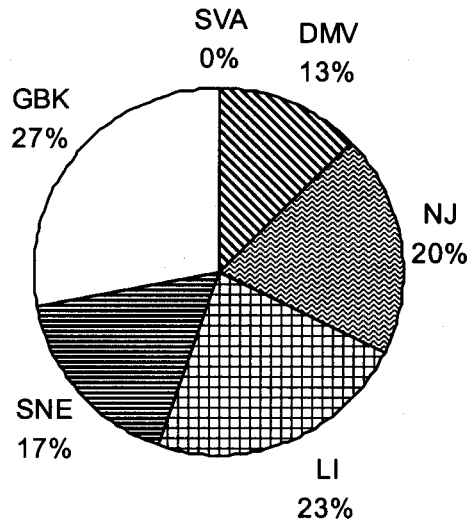
# Best 2002 Quahog Biomass Estimates



SVA 0%
DMV 5%
NJ 15%
GBK 35%
LI 26%
SNE 19%
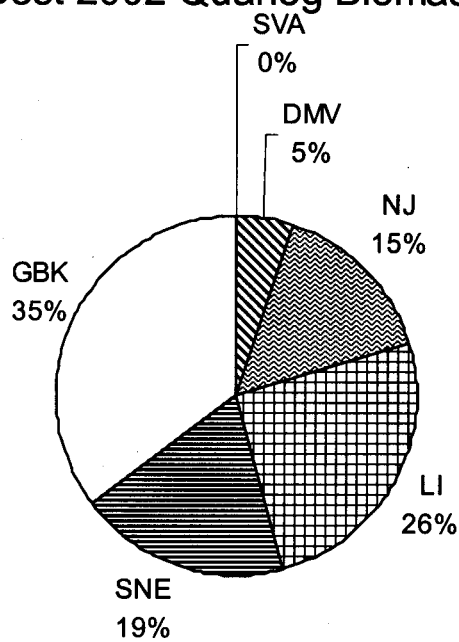
Figure A75.  Percentage ocean quahog biomass by region, 1977 and 2002. Based on values in Table A24.
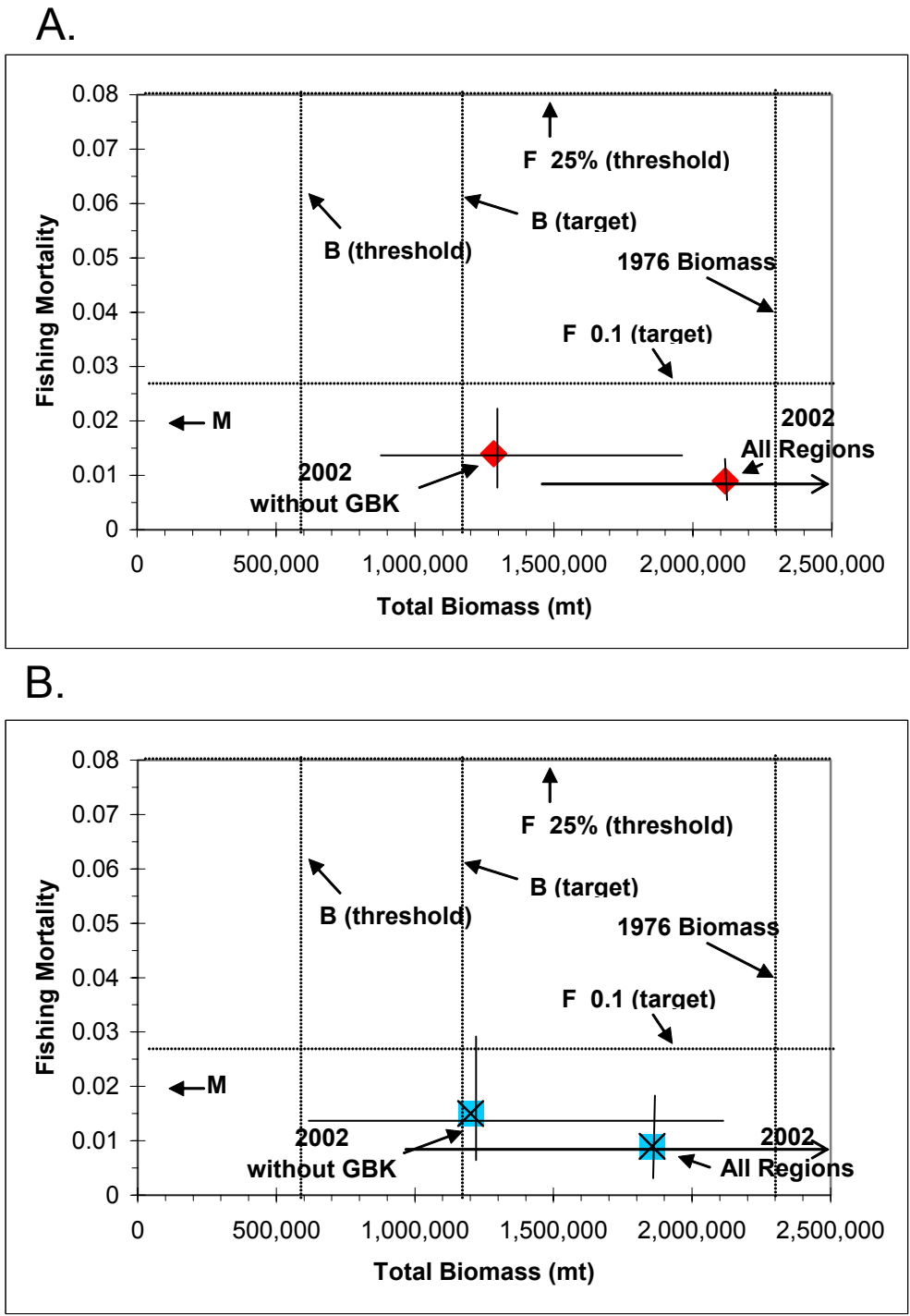
Figure A76.  Ocean quahog biomass and fishing mortality rate in relation to updated Biological Reference Points. Biomass and F estimates for 2002, as well as the 80% CIs, are from the A. ESB model or B. KLAMZ model.

**Appendix A. (Ocean quahog) KLAMZ Assessment Model – Technical Documentation**

The KLAMZ assessment model is based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; Quinn and Deriso 1999).  The delay-difference equation is a relatively simple and implicitly age structured approach to counting fish in either numerical or biomass units.  It gives the same results as explicitly age-structured models (e.g. Leslie matrix model) if fishery selectivity is "knife-edged", if somatic growth follows the von Bertalanffy equation, and if natural mortality is the same for all age groups in each year.  Knife-edge selectivity means that all individuals alive in the model during the same year experience the same fishing mortality rate.[d]  Natural and fishing mortality rates, growth parameters and recruitment may change from year to year, but delay-difference calculations assume that all individuals share the same mortality and growth parameters within each year.  The KLAMZ model includes simple numerical models (e.g. Conser 1995) as special cases because growth can be turned off so that all calculations are in numerical units (see below).

As in many other simple models, the delay difference equation explicitly distinguishes between two age groups.  In KLAMZ, the two age groups are called "new" recruits ($R_t$ in biomass or numerical units at the beginning of year $t$) and "old" recruits ($S_t$) that together comprise the whole stock ($B_t$).  New recruits are individuals that recruited at the beginning of the current year (at nominal age $k$).[e]  Old recruits are all older individuals in the stock (nominal ages $k+1$ and older, survivors from the previous year).  As described above, KLAMZ assumes that new and old recruits are fully vulnerable to the fishery.  The most important differences between the delay-difference and other simple models (e.g. Prager 1994; Conser 1995; Jacobson et al. 1994) are that von Bertalanffy growth is used to calculate biomass dynamics and that the delay-difference model captures transient age structure effects due to variation in recruitment, growth and mortality exactly.  Transient effects on population dynamics are captured exactly because, as described above, the delay-difference equation is algebraically equivalent to an explicitly age-structured model with von Bertalanffy growth.

The KLAMZ model incorporates a few extensions to Schnute's (1985) revision of Deriso's (1980) original delay difference model.  Most of the extensions facilitate tuning to a wider variety of data that anticipated in Schnute (1985).  The KLAMZ model is programmed in both Excel and in C++ using AD Model Builder[f] libraries.  The AD Model Builder version is faster, more reliable and probably better for producing "official" stock assessment results.  The Excel version is slower and implements fewer features, but the Excel version remains useful in developing prototype assessment models, teaching and for checking calculations.

---

[1]In applications, assumptions about knife-edge selectivity can be relaxed by assuming the model tracks "fishable", rather that total, biomass (NEFSC 2000a; 2000b).  An analogous approach assigns pseudo-ages based on recruitment to the fishery so that new recruits in the model are all pseudo-age $k$.  The synthetic cohort of fish pseudo-age $k$ may consist of more than one biological cohort.  The first pseudo-age ($k$) can be the predicted age at first, 50% or full recruitment based a von Bertalanffy curve and size composition data (Butler et al. 2002).  The "incomplete recruitment" approach (Deriso 1980) calculates recruitment to the model in each year $R_t$ as the weighted sum of contributions from two or more biological cohorts (year-classes) from spawning during successive years (i.e. $R_t = \sum_{a=1}^{k} r_a \Pi_{t-a}$ where k is the age at full recruitment to the fishery, $r_a$ is the contribution of fish age $k$-$a$ to the fishable stock, and $\Pi_{t-a}$ is the number or biomass of fish age $k$-$a$ during year $t$).

[2]In some applications, and more generally, new recruits might be defined as individuals recruiting at the beginning or at any time during the current time step (e.g. NEFSC 1996).

[3]Otter Research Ltd., Box 2040, Sydney, BC, Canada V8L 3S3 (otter@otter-rsch.com).

The most significant disadvantage in using the KLAMZ model and other delay-difference approaches, beyond the assumption of knife-edge selectivity, is that age and length composition data are not used in tuning. However, one can argue that age composition data are used indirectly to the extent they are used to estimate growth parameters or if survey survival ratios (e.g. based on the Heinke method) are used in tuning (see below).

Population dynamics

The assumed birth date and first day of the year are assumed the same in derivation of the delay-difference equation. It is therefore natural (but not strictly necessary) to tabulate catch and other data using annual accounting periods that start on the assumed biological birthday of cohorts.

Biomass dynamics

As implemented in the KLAMZ model, Schnute's (1985) delay-difference equation is:

$$B_{t+1} = (1 + \rho)\, \tau_t\, B_t - \rho\, \tau_t\, \tau_{t-1}\, B_{t-1} + R_{t+1} - \rho\, \tau_t\, J_t\, R_t$$

where $B_t$ is total biomass of individuals at the beginning of year $t$; $\rho$ is Ford's growth coefficient (see below); $\tau_t = exp(-Z_t) = exp[-(F_t + M_t)]$ is the fraction of the stock that survived in year $t$, $Z_t$, $F_t$, and $M_t$ are instantaneous rates for total, fishing and natural mortality; and $R_t$ is the biomass of new recruits (at age $k$) at the beginning of the year. The natural mortality rate $M_t$ may vary over time. Instantaneous mortality rates in KLAMZ model calculations are biomass-weighted averages if von Bertalanffy growth is turned on in the model. However, biomass-weighted mortality estimates in KLAMZ are the same as rates for numerical estimates under the assumption of knife-edge selectivity because all individuals are fully recruited. The growth parameter $J_t = w_{t-1,k-1} / w_{t,k}$ is the ratio of mean weight one year before recruitment (age $k$-1 in year $t$-1) and mean weight at recruitment (age $k$ in year $t$).

It is not necessary to specify body weights at and prior to recruitment in the KLAMZ model (parameters $v_{t-1}$ and $V_t$ in Schnute 1985) because the ratio $J_t$ and recruitment biomass contain the same information. Schnute's (1985) original delay difference equation is:

$$B_{t+1} = (1 + \rho)\, \tau_t\, B_t - \rho\, \tau_t \tau_{t-1}\, B_{t-1} + w_{t+1,k} N_{t+1} - \rho \tau_t w_{t-1,k-1}\, N_t$$

To derive the equation used in KLAMZ, substitute recruitment biomass $R_{t+1}$ for the product $w_{t+1,k} N_{t+1,k}$ and adjusted recruitment biomass $J_t R_t = (w_{t-1,k-1}/w_{t,k})\, w_{t,k}\, N_{t,k} =$
$w_{t-1,k-1}\, N_t$ in the last term on the right hand side. The advantage in using the alternate parameterization for biomass dynamic calculations in KLAMZ is that recruitment is estimated directly in units of biomass and the number of growth parameters is reduced. The disadvantage is that numbers of recruits are not estimated directly by the model. When required, numerical recruitments must be calculated externally as the ratio of estimated recruitment biomass and the average body weight for new recruits.

*Numerical population dynamics*

Growth can be turned on off so that abundance, rather than biomass, is tracked in the KLAMZ model. Set $J_t$=1 and $\rho$=0 in the delay difference equation, and use $N_t$ (for numbers) in place of $B_t$ to get:

$$N_{t+1} = \tau_t\, N_t + R_{t+1}$$

Mathematically, the assumption $J_t=1$ means that no growth occurs  the assumption $\rho=0$ means that the von Bertalanffy $K$ parameter is infinitely large (Schnute 1985).  All tuning and population dynamics calculations in KLAMZ for biomass dynamics are also valid for numerical dynamics.

Growth

As described in Schnute (1985), biomass calculations in the KLAMZ model are based on Schnute and Fournier's (1980) re-parameterization of the von Bertalanffy growth model:

$$w_a = w_{k-1} + (w_k - w_{k-1})(1+\rho^{1+a-k})/(1-\rho)$$

where $w_k=V$ and $w_{k-1}=v$.  Schnute and Fournier's (1980) growth model is the same as the traditional von Bertalanffy growth model $\{W_a= W_{max} [1 - exp(-K(a-t_{zero})] $ where $W_{max}$, $K$ and $t_{zero}$ are parameters$\}$.  The two growth models are the same because $W_{max} = (w_k - \rho w_{k-1})/(1-\rho)$, $K = -ln(\rho)$ and $t_{zero} = ln[(w_k - w_{k-1})/(w_k - \rho w_{k-1})] / ln(\rho)$.

In the KLAMZ model, the growth parameters $J_t$ can vary with time but $\rho$ is constant.   Use of time-variable $J_t$ values with $\rho$ is constant is the same as assuming that the von Bertalanffy parameters $W_{max}$ and $t_{zero}$ change over time.  Many growth patterns can be mimicked by changing $W_{max}$ and $t_{zero}$ (Overholtz et al., 2003).  $K$ is a parameter in the C++ version and, in principal, estimable.  However, in most cases it is necessary to use external estimates of growth parameters as constants in KLAMZ.

Instantaneous growth rates

Instantaneous growth rate (IGR) calculations in the KLAMZ model are an extension to the original Deriso-Schnute delay difference model.  IGRs are used extensively in KLAMZ for calculating catch biomass and projecting stock biomass forward to the time at which surveys occur.  The IGR for new recruits depends only on growth parameters:

$$G_t^{New} = ln\left(\frac{w_{k+1,t+1}}{w_{k,t}}\right) = ln(1 + \rho - \rho J_t)$$

IGR for old recruits is a biomass-weighted average that depends on the current age structure and growth parameters.  It can be calculated easily by projecting biomass of old recruits $S_t=B_t-R_t$ (escapement) forward one year with no mortality:

$$S_t^* = (1+\rho)S_t - \rho\tau_{t-1}B_{t-1}$$

where the asterisk (*) means just prior to the start of the subsequent year $t+1$.  By definition, the IGR for old recruits in year $t$ is $G_t^{Old} = ln(S_t^*/S_t)$.  Dividing by $S_t$ gives:

$$G_t^{Old} = ln\left[(1+\rho) - \rho\tau_{t-1}\frac{B_{t-1}}{S_t}\right]$$

IGR for the entire stock is the biomass weighted average of the IGR values for new and old recruits:

$$G_t = \frac{R_t G_t^{New} + S_t G_t^{Old}}{B_t}$$

All IGR values are zero if growth is turned off.

## Recruitment

In the Excel version of the KLAMZ model, annual recruitments are calculated $R_t = e^{\Omega_t}$ where $\Omega_t$ is a log transformed annual recruitment parameter, which is estimated in the model. In the C++ version, recruitments are calculated based on log geometric mean recruitment ($\mu$) and a set of annual log scale deviation parameters ($\omega_t$):

$$\Omega_t = \mu + \omega_t$$

The deviations $\omega_t$ are constrained to average zero.[g] With the constraint, estimation of $\mu$ and the set of $\omega_t$ values (1+ $n$ years parameters) is equivalent to estimation of the smaller set ($n$ years) of $\Omega_t$ values.

## Natural mortality

Natural mortality rates ($M_t$) are assumed constant in the Excel version of the KLAMZ model. In the C++ version, natural mortality rates may be estimated as a constant value or as a set of values that vary with time. In the model:

$$M_t = me^{\varpi_t}$$

where $m=exp(\pi)$ is the geometric mean natural mortality rate, $\pi$ is a model parameter that may be estimated (in principal but not in practical terms), and $\varpi_t$ is the log scale year-specific deviation. Deviations may be zero (turned off) so that $M_t$ is constant, may vary in a random fashion due to autocorrelated or independent process errors, or may based on a covariate.[h] Model scenarios with zero recruitment may be initializing the parameter $\pi$ to a small value (e.g. $10^{-16}$) and not estimating it.

Random natural mortality process errors are effects due to predation, disease, parasitism, ocean conditions or other factors that may vary over time but are not included in the model. Calculations are basically the same as for survey process errors (see below).

Natural mortality rate covariate calculations are similar to survey covariate calculations (see below) except that the _user should standardized covariates to average zero over the time period included in the model_:

$$\kappa_t = K_t - \overline{K}$$

where $\kappa_t$ is the standardized covariate, $K_t$ is the original value, and $\overline{K}$ is the mean of the original covariate for the years in the model. _Standardization to mean zero is important because otherwise m is not the geometric mean natural mortality rate_ (the convention is important in some calculations, see text).

Log scale deviations that represent variability around the geometric mean are calculated:

$$\varpi_t = \sum_{j=1}^{n} p_j \kappa_t$$

where $n$ is the number of covariates and $p_j$ is the parameter for covariate $j$. These conventions mean that the units for the covariate parameter $p_j$ are 1/units of the original covariate, the parameter $p_j$ measures the

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[g] The constraint is implemented by adding $L = \lambda \overline{\varpi}^2$ (where $\overline{\varpi}$ is the average deviation) to the objective function, generally with a high weighting factor ($\lambda = 1000$) so that the constraint is binding.

[h] Another approach to using time dependent natural mortality rates is to treat estimates of predator consumption as discarded catch (see "Predator consumption as discard data"). In addition, estimates of predator abundance can be used in fishing effort calculations (see "Predator data as fishing effort").

log scale effect of changing the covariate by one unit, and the parameter $m$ is the log scale geometric mean.

Fishing mortality and catch

Fishing mortality rates ($F_t$) are calculated so that predicted and observed catch data (landings plus estimated discards in units of weight) "agree" to the extent specified by the user. It is not necessary, however, to assume that catches are measured accurately (see "Observed and predicted catch").

Fishing mortality rate calculations in Schnute (1985) are exact but relating fishing mortality to catch in weight is complicated by continuous somatic growth throughout the year as fishing occurs. The KLAMZ model uses a generalized catch equation that incorporates continuous growth through the fishing season. By the definition of instantaneous rates, the catch equation expresses catch as the product:

$$\hat{C}_t = F_t \overline{B}_t$$

where $\hat{C}_t$ is predicted catch weight (landings plus discard) and $\overline{B}_t$ is average biomass.

Following Chapman (1971) and Zhang and Sullivan (1988), let $X_t = G_t - F_t - M_t$ be the net instantaneous rate of change for biomass.[i] If the rates for growth and mortality are equal, then $X_t = 0$, $\overline{B}_t = B_t$ and $C_t = F_t B_t$. If the growth rate $G_t$ exceeds the combined rates of natural and fishing mortality ($F_t + M_t$), then $X_t > 0$. If mortality exceeds growth, then $X_t < 0$. In either case, with $X_t \neq 0$, average biomass is computed:

$$\overline{B}_t \approx -\frac{\left(1 - e^{X_t}\right) B_t}{X_t}$$

When $X_t \neq 0$, the expression for $\overline{B}_t$ is an approximation because $G_t$ approximates the rate of change in mean body weight due to von Bertalanffy growth. However, the approximation is reasonably accurate and preferable to calculating catch biomass in the delay-difference model with the traditional catch equation that ignores growth during the fishing season.[j] Average biomass can be calculated for new recruits, old recruits or for the whole stock by using either $G_t^{New}$, $G_t^{Old}$ or $G_t$.

In the KLAMZ model, the modified catch equation may be solved analytically for $F_t$ given $C_t$, $B_t$, $G_t$ and $M_t$ (see the "Calculating $F_t$" section below). Alternatively, fishing mortality rates can be calculated using a log geometric mean parameter ($\Phi$) and a set of annual log scale deviation parameters ($\psi_t$):

$$F_t = e^{\Phi + \psi_t}$$

where the deviations $\psi_t$ are constrained to average zero. When the catch equation is solved analytically, catches must be assumed known without error but the analytical option is useful when catch is zero or very near zero, or the range of fishing mortality rates is so large (e.g. minimum F=0.000001 to maximum F=3) that numerical problems occur with the alternative approach. The analytical approach is also useful if the user wants to reduce the number of parameters estimated by nonlinear optimization. In any case, the two methods should give the same results for catches known without error.

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[i] By convention, the instantaneous rates $G_t$, $F_t$ and $M_t$ are always expressed as numbers $\geq 0$.

[j] The traditional catch equation $C_t = F_t(1 - e^{-Z_t})B_t/Z_t$ where $Z_t = F_t + M_t$ underestimates catch biomass for a given level of fishing mortality $F_t$ and overestimates $F_t$ for a given level of catch biomass. The errors can be substantial for fast growing fish, particularly if recent recruitments were strong.

## Surplus production

Annual surplus production is calculated "exactly" by projecting biomass at the beginning of each year forward with no fishing mortality:

$$B_t^* = (1+\rho)\,e^{-M}\,B_t - \rho\,e^{-M}\,L_{t\text{-}1}\,B_{t\text{-}1} - \rho\,e^{-M}\,J_t\,R_t$$

By definition, surplus production $P_t = B_t^* - B_t$ (Jacobson et al. 2002).

## Per recruit modeling

Per recruit model calculations in the Excel version of the KLAMZ simulate the life of a hypothetical cohort of arbitrary size (e.g. $R=1000$) starting at age $k$ with constant $M_t$, $F$ (survival) and growth ($\rho$ and $J$) in a population initially at zero biomass. In the first year:

$$B_1 = R$$

In the second year:

$$B_2 = (1+\rho)\,\tau\,B_1 - \rho\,\tau\,J\,R_1$$

In the third and subsequent years:

$$B_{t+1} = (1+\rho)\,\tau\,B_t - \rho\,\tau^2\,B_{t\text{-}1}$$

This iterative calculation is carried out until the sum of lifetime cohort biomass from one iteration to the next changes by less than a small amount (0.0001). Total lifetime biomass, spawning biomass and yield in weight are calculated by summing biomass, spawning biomass and yield over the lifetime of the cohort. Lifetime biomass, spawning biomass and yield per recruit are calculated by dividing totals by initial recruitment ($R$).

## Status determination variables

The user may specify a range of years (e.g. the last three years) to use in calculating recent average fishing mortality $\overline{F}_{\text{Recent}}$ and biomass $\overline{B}_{\text{Recent}}$ levels. These status determination variables are used in calculation of status ratios such as $\overline{F}_{\text{Recent}} / F_{MSY}$ and $\overline{B}_{\text{Recent}} / B_{MSY}$.

## Goodness of Fit and Parameter Estimation

Parameters estimated in the KLAMZ model are chosen to minimize an objective function based on a sum of weighted negative log likelihood (NLL) components:

$$\Xi = \sum_{v=1}^{N_\Xi} \lambda_v L_v$$

where $N_\Xi$ is the number of NLL components ($L_v$) and the $\lambda_v$ are emphasis factors used as weights. The objective function $\Xi$ may be viewed as a NLL or a negative log posterior (NLP) distribution, depending on the nature of the individual $L_v$ components and modeling approach. Except during sensitivity analyses, weighting factors for objective function components ($\lambda_v$) are usually set to one. An arbitrarily large weighting factor (e.g. $\lambda_v = 1000$) is used for "hard" constraints that must be satisfied in the model. Arbitrarily small weighting factors (e.g. $\lambda_v = 0.0001$) can be used for "soft" model-based constraints. For example, an internally estimated spawner-recruit curve or surplus production curve might be estimated with a small weighting factor to summarize stock-recruit or surplus production results with minimal

influence on biomass, fishing mortality and other estimates from the model.  Use of a small weighting factor for an internally estimated surplus production or stock-recruit curve is equivalent to fitting a curve to model estimates of biomass and recruitment or surplus production in the output file, after the model is fit (Jacobson et al. 2002).

Likelihood component weights vs. observation-specific weights

Likelihood component weights ($\lambda_v$) apply to entire NLL components.  Entire components are often computed as the sum of a number of individual NLL terms.  The NLL for an entire survey, for example, is composed of NLL terms for each of the annual survey observations.  In KLAMZ, observation-specific (for data) or instance-specific (for constraints or prior information) weights (usually $w_j$ for observation or instance $j$) can be specified as well.  Observation-specific weights for a survey, for example, might be use to increase or decrease the importance of one or more observations in calculating goodness of fit.

NLL kernels

NLL components in KLAMZ are generally programmed as "concentrated likelihoods" to avoid calculation of values that do not affect derivatives of the objective function.[k]  For $x \sim N(\mu, \sigma^2)$, the complete NLL for one observation is:

$$L = \ln(\sigma) + \ln\left(\sqrt{2\pi}\right) + 0.5\left(\frac{x-u}{\sigma}\right)^2$$

The constant $\ln\left(\sqrt{2\pi}\right)$ can always be omitted because it does not affect derivatives.  If the standard deviation is known or assumed known, then $\ln(\sigma)$ can be omitted as well because it is a constant that does not affect derivatives.  In such cases, the concentrated negative log likelihood is:

$$L = 0.5\left(\frac{x-\mu}{\sigma}\right)^2$$

If there are $N$ observations with possible different variances (known or assumed known) and possibly different expected values:

$$L = 0.5\sum_{i=1}^{N}\left(\frac{x_i - \mu_i}{\sigma_i}\right)^2$$

If the standard deviation for a normally distributed quantity is not known and is (in effect) estimated by the model, then one of two equivalent calculations is used.  Both approaches assume that all observations have the same variance and standard deviation.  The first approach is used when all observations have the same weight in the likelihood:

$$L = 0.5N \ln\left[\sum_{i=1}^{N}(x_i - u)^2\right]$$

where $N$ is the number of observations.  The second approach is equivalent but used when the weights for each observation ($w_i$) may differ:

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[k] Unfortunately, concentrated likelihood calculations cannot be used with MCMC and other Bayesian approaches to characterizing posterior distributions.  Therefore, in the near future, concentrated NLL calculations will be replaced by calculations for the entire NLL.  At present, MCMC calculations in KLAMZ are not useful.

$$L = \sum_{i=1}^{N} w_i \left[ \ln(\sigma) + 0.5 \left( \frac{x_i - u}{\sigma} \right)^2 \right]$$

In the latter case, the maximum likelihood estimator:

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{N} (x_i - \hat{x})^2}{N}}$$

(where $\hat{x}$ is the average or predicted value from the model) is used for $\sigma$. The maximum likelihood estimator is biased by $N/(N-d_f)$ where $d_f$ is degrees of freedom for the model. The bias may be significant for small sample sizes but $d_f$ is usually unknown.

Landings, discards, catch

Discards are from external estimates ($d_t$) supplied by the user. If $d_t \geq 0$, then the data are used as the ratio of discard to landed catch so that:

$$D_t = L_t \Delta_t$$

where $\Delta_t = D_t/L_t$ is the discard ratio. If $d_t < 0$ then the data are treated as discard in units of weight:

$$D_t = abs(d_t).$$

In either case, total catch is the sum of discards and landed catch ($C_t = L_t + D_t$). It is possible to use discards in weight $d_t < 0$ for some years and discard as proportions $d_t > 0$ for other years in the same model run. If catches are estimated (see below) so that the estimated catch $\hat{C}_t$ does not necessarily equal observed landings plus discard, then estimated landings are computed:

$$\hat{L}_t = \frac{\hat{C}_t}{1 + \Delta_t}$$

and estimated discards are:

$$\hat{D}_t = \Delta_t \hat{L}_t.$$

Calculating $F_t$

As described above, fishing mortality rates may be estimated based on the parameters $\Phi$ and $\psi_t$ to satisfy a NLL for observed and predicted catches:

$$L = 0.5 \sum_{t=0}^{N} w_t \left( \frac{\hat{C}_t - C_t}{\kappa_t} \right)^2$$

where the standard error $\kappa_t = CV_{catch} \hat{C}_t$ with $CV_{catch}$ and weights are $w_t$ supplied by the user. The weights can be used, for example, if catch data in some years are less precise than in others. Using observation specific weights, any or every catch in the time series can potentially be estimated.

The other approach to calculating $F_t$ values is by solving the generalized catch equation (see above) iteratively. Subtracting predicted catch from the generalized catch equation gives:

$$g(F_t) = C_t + \frac{F_t(1 - e^{X_t})}{X_t} \bar{B}_t = 0$$

where $X_t = G_t - M_t - F_t$. If $X_t = 0$, then $\bar{B}_t = B_t$ and $F_t = C_t/B_t$.

If $X_t \neq 0$, then the Newton-Raphson algorithm is used to solve for $F_t$ (Kennedy and Gentle 1980). At each iteration of the algorithm, the current estimate $F_t^i$ is updated using:

$$F_t^{i+1} = F_t^i - \frac{g(F_t^i)}{g'(F_t^i)}$$

where $g'(F_t^i)$ is the derivative $F_t^i$. Omitting subscripts, the derivative is:

$$g'(F) = -\frac{Be^{-F}\left[\left(e^F - e^\gamma\right)\gamma + e^\gamma F\gamma - e^\gamma F^2\right]}{X^2}$$

where $\gamma = G - M_t$. Iterations continue until $g(F_t^i)$ and $abs\left[g(F_t^{i+1}) - g(F_t^{i+1})\right]$ are both less than a small number (e.g. $\leq 0.00001$).

Initial values are important in algorithms that solve the catch equation numerically (Sims 1982). If $M_t + F_t > G_t$ so that $X_t < 0$, then the initial value $F_t^0$ is calculated according to Sims (1982). If $M_t + F_t < G_t$ so that $X_t > 0$, then initial values are calculated based on a generalized version of Pope's cohort analysis (Zhang and Sullivan 1988):

$$F_t^0 = \gamma_t - \ln\left[\frac{\left(B_t e^{0.5\gamma_t} - C_t\right)e^{0.5\gamma_t}}{B_t}\right]$$

<u>F for landings versus F for discards</u>

The total fishing mortality rate for each year can be partitioned into a component due to landed catch $^L F_t = \frac{D_t}{C_t} F_t$, and a component due to discard $^D F_t = \frac{L_t}{C_t} F_t$.

<u>Predator consumption as discard data</u>

In modeling population dynamics of prey species, estimates of predator consumption can be treated like discard in the KLAMZ model as a means for introducing time dependent natural mortality. Consider a hypothetical example with consumption data (mt y$^{-1}$) for three important predators. If the aggregate consumption data are included in the model as "discards", then the fishing mortality rate for discards $^d F_t$ (see above) would be an estimate of the component of natural mortality due to the three predators. In using this approach, the average level of natural mortality $m$ would normally be reduced (e.g. so that $m_{new} + ^d \overline{F} = m_{old}$) or estimated to account for the portion of natural mortality attributed to bycatch.

Surplus production calculations are harder to interpret if predator consumption is treated as discard data because surplus production calculations assume that $F_t = 0$ (see above) and because surplus production is defined as the change in biomass from one year to the next in the absence of fishing (i.e. no landings or bycatch). However, it may be useful to compare surplus production at a given level of biomass from runs with and without consumption data as a means of estimating maximum changes in potential fishery yield if the selected predators were eliminated (assuming no change in disease, growth rates, predation by other predators, etc.).

<u>Effort calculations</u>

Fishing mortality rates can be tuned to fishing effort data for the "landed" catch (i.e. excluding discards). Years with non-zero fishing effort used in the model must also have landings greater than zero. Assuming that effort data are lognormally distributed, the NLL for fishing effort is:

$$NLL = 0.5 n_{eff} \ln \left[ \sum_{y=1}^{n_{eff}} w_y \ln \left( \frac{E_y}{\overline{E}_y} \right)^2 \right]$$

where $n_{eff}$ is the number of effort observations, $w_y$ is an observation-specific weight, $E_y$ and $\overline{E}_y$ are observed and predicted fishing effort data, and the log scale variance is estimated internally. Predicted fishing effort data are calculated:

$$\overline{E}_y = \zeta F_y^{\vartheta}$$

where $\zeta = e^u$, $\vartheta = e^b$, and $u$ and $b$ are parameters estimated by the model. If the parameter b is not estimated, then $=1$ so that the relationship between fishing effort and fishing mortality is linear. If the parameter b is estimated, then $1$ and the relationship is a power function.

*Predator data as fishing effort*

As described under "Predator consumption as discard data", predator consumption data can be treated as discard. If predator abundance data are available as well, and assuming that mortality due predators is a linear function of the predator-prey ratio, then both types of data may be used together to estimate natural mortality. The trick is to: 1) enter the predator abundance data as fishing effort; 2) enter the actual fishery landings as "discard"; 3) enter predator consumption estimates of the prey species as "landings" so that the fishing effort data in the refer to the predator consumption data; 4) use an option in the model to calculate the predator-prey ratio for use in place of the original predator abundance "fishing effort" data; and 5) tune fishing mortality rates for landings (a.k.a. predator consumption) to fishing effort (a.k.a. predator-prey ratio).

Given the predator abundance data $\kappa_y$, the model calculates the predator-prey ratio used in place of fishing effort ($E_y$) as:

$$E_y = \frac{\kappa_y}{B_y}$$

where $B_y$ is the model's current estimate of total (a.k.a "prey") biomass. Subsequent calculations with $E_y$ and the model's estimates of "fishing mortality" ($F_y$, really a measure of natural mortality) are exactly as described above for effort data. In using this approach, it is probably advisable to reduce $m$ (the estimate of average mortality in the model) to account for the proportion of natural mortality due to predators included in the calculation. Based on experience to date, natural mortality due to consumption by the suite of predators can be estimated but only if $m$ is assumed known.

<u>Initial population age structure</u>

In the KLAMZ model, old and new recruit biomass during the first year ($R_1$ and $S_1 = B_1 - R_1$) and biomass prior to the first year ($B_0$) are estimated as log scale parameters. Survival in the year prior to the first year ("year 0") is $\tau_0 = e^{-F_0 - M_1}$ with $F_0$ chosen to obtain catch $C_0$ (specified as data) from the estimated biomass $B_0$. IGRs during year 0 and year 1 are assumed equal ($G_0 = G_1$) in catch calculations.

Biomass in the second year of as series of delay-difference calculations depends on biomass ($B_0$) and survival ($\tau_0$) in year 0:

$$B_2 = (1+\rho)\,\tau_1\,B_1 - \rho\,\tau_1\,\tau_0\,B_0 + R_2 - \rho\,\tau_1\,J_1\,R_1$$

There is, however, there is no direct linkage between $B_0$ and escapement biomass ($S_1=B_1-R_1$) at the beginning of the first year.

The missing link between $B_0$, $S_1$ and $B_1$ means that the parameter for $B_0$ tends to be relatively free and unconstrained by the underlying population dynamics model. In some cases, $B_0$ can be estimated to give good fit to survey and other data, while implying unreasonable initial age composition and surplus production levels. In other cases, $B_0$ estimates can be unrealistically high or low implying, for example, unreasonably high or low recruitment in the first year of the model ($R_1$). Problems arise because many different combinations of values for $R_1$, $S_1$ and $B_0$ give similar results in terms of goodness of fit. This issue is common in stock assessment models that use forward simulation calculations because initial age composition is difficult to estimate. It may be exacerbated in delay-difference models because age composition data are not used.

The KLAMZ model uses two constraints to help estimate initial population biomass and initial age structure.[1] The first constraint links IGRs for escapement ($G^{Old}$) in the first years to a subsequent value. The purpose of the constraint is to ensure consistency in average growth rates (and implicit age structure) during the first few years. For example, if IGRs for the first $n_G$ years are constrained[m], then the NLL for the penalty is:

$$L_G = 0.5\sum_{t=1}^{n_G}\left[\frac{\ln\!\left(G_t^{Old}/G_{n_G+1}^{Old}\right)}{\sigma_G}\right]^2$$

where the standard deviation $\sigma_G$ is supplied by the user. It is usually possible to use the standard deviation of $Q_t^{Old}$ for later years from a preliminary run to estimate $\sigma_G$ for the first few years. The constraint on initial IGRs should probably be "soft" and non-binding ($\lambda\approx1$) because there is substantial natural variation in somatic growth rates due to variation in age composition.

The second constraint links $B_0$ to $S_1$ and ensures conservation of mass in population dynamics between years 0 and 1. In other words, the parameter for escapement biomass in year 1 is constrained to match an approximate projection of the biomass in year 0, accounting for growth, and natural and fishing mortality. The constraint is intended to be binding and satisfied exactly (e.g. $\lambda=1000$) because incompatible values of $S_1$ and $B_0$ are biologically impossible. In calculations:

$$S_1^p = B_0 e^{G_1-F_0-M_1}$$

where $S_1^p$ is the projected escapement in year 1 and $B_0$ is the model's estimate of total biomass in year 0. The instantaneous rates for growth and natural mortality from year 1 ($G_1$ and $M_1$) are used in place of $G_0$ and $M_0$ because the latter are unavailable. The NLL for the constraint:

$$L = \left[\ln\!\left(\frac{S_1^p}{S_1}\right)^2\right]^2 + \left(S_1^p - S_1\right)^2$$

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[1] Quinn and Deriso (1999) describe another approach attributed to a manuscript by C. Walters.
[m] Normally, $n_G$ 2.

uses a log scale sum of squares and an arithmetic sum of squares. The former is effective when $S_l$ is small while the latter is effective when $S_l$ is large. Constants and details in calculation of NLL for the constraint are not important because the constraint is binding (e.g. $\lambda = 1000$).

Equilibrium pristine biomass

It may be useful to constrain the biomass estimate for the first year in a model run towards an estimate of equilibrium pristine biomass if, for example, stock dynamics tend to be stable and catch data are available for the first years of the fishery, or as an alternative to the approach described above for initializing the age structure of the simulated population in the model. Equilibrium pristine biomass $\widetilde{B}_0$ is calculated based on the model's estimate of average recruitment and with no fishing mortality (calculations are similar to those described under "Per-recruit modeling" except that average recruitment is assumed in each year).[n] The NLL term for the constraint is:

$$ L = \ln\left(\frac{\widetilde{B}_0}{B_0}\right)^2 $$

Pristine equilibrium biomass is used as a hard constraint with a high emphasis factor ($\lambda$) so that the variance and constants normally used in NLL calculations are not important.

Estimating natural mortality

As described above, natural mortality calculations involve a parameter for the geometric mean value ($m$) and time dependent deviations ($\varpi_t$, which may or may not be turned on). Constraints on natural mortality process errors and natural mortality covariates can be used to help estimate the time dependent deviations and overall trend. The geometric mean natural mortality rate is usually difficult to estimate and best treated as a known constant. However, in the C++ version of the KLAMZ model, $m = e^\pi$ (where $\pi$ is an estimable parameter in the model) and estimates of $m$ can be conditioned on the constraint:

$$ L = 0.5\left[\frac{\ln\left(w/w_{Target}\right)}{\sigma_\varpi}\right]^2 $$

where $w_{Target}$ is a user supplied mean or target value and $\sigma_\varpi$ is a log scale standard deviation. The standard deviation is calculated from an arithmetic scale CV supplied by the user. Upper and lower bounds for $m$ may be specified as well.

Goodness of fit for trend data

Assuming lognormal errors[o], the NLL used to measure goodness-of-fit to "survey" data that measure trends in abundance or biomass (or survival, see below) is:

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[n] Future versions of the KLAMZ model will allow equilibrium initial biomass to be calculated based on other recruitment values and for a user-specified level of F (Butler et al. 2003).

[o] Abundance indices with statistical distributions other than log normal may be used as well, but are not currently programmed in the KLAMZ model. For example, Butler et al. (2003) used abundance indices with binomial distributions in a delay-difference model for cowcod rockfish. The next version of KLAMZ will accommodate presence-absence data with binomial distributions.

$$L = 0.5 \sum_{j=1}^{N_v} \left[ \frac{\ln\left( I_{v,j} \middle/ \hat{I}_{v,j} \right)}{\sigma_{v,j}} \right]^2$$

where $I_{v,t}$ is an index datum from survey $v$, hats "^" denote model estimates, $\sigma_{v,j}$ is a log scale standard error (see below), and $N_v$ is the number of observations. There are two approaches to calculating standard errors for log normal abundance index data in KLAMZ and it is possible to use different approaches for different types of abundance index data in the same model (see below).

*Standard errors for goodness of fit*

In the first approach, all observations for one type of abundance index share the same standard error, which is calculated based on overall goodness of fit. This approach implicitly estimates the standard error based on goodness of fit, along with the rest of the parameters in the model (see "NLL kernels" above).

In the second approach, each observation has a potentially unique standard error that is calculated based on its CV. The second approach calculates log scale standard errors from arithmetic CVs supplied as data by the user (Jacobson et al. 1994):

$$\sigma_{v,t} = \sqrt{\ln\left(1 + CV_{v,t}^2\right)}$$

Arithmetic CV's are usually available for abundance data. It may be convenient to use $CV_{v,t}$=1.31 to get $\sigma_{v,t}$=1.

There are advantages and disadvantages to both approaches. CV's carry information about the relative precision of abundance index observations. However, CV's usually overstate the precision of data as a measure of fish abundance[p] and may be misleading in comparing the precision of one sort of data to another as a measure of trends in abundance (e.g. in contrasting standardized LPUE that measure fishing success, but not abundance, precisely with survey data that measure trends in fish abundance directly, but not precisely). Standard errors estimated implicitly are often larger and more realistic, but assume that all observations in the same survey are equally reliable.

*Predicted values for abundance indices*

Predicted values for abundance indices are calculated:

$$\hat{I}_{v,t} = Q_v A_{v,t}$$

where $Q_v$ is a survey scaling parameter (constant here but see below) that converts units of biomass to units of the abundance index. $A_{v,t}$ is available biomass at the time of the survey.

In the simplest case, available biomass is:

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[p] The relationship between data and fish populations is affected by factors (process errors) that are not accounted for in CV calculations.

$$A_{v,t} = s_{v,New}R_t e^{-X_t^{New}\Delta_{v,t}} + s_{v,Old}S_t e^{-X_t^{Old}\Delta_{v,t}}$$

where $s_{v,New}$ and $s_{v,Old}$ are survey selectivity parameters for new recruits ($R_t$) and old recruits ($S_t$); $X_t^{New} = G_t^{New} - F_t - M_t$ and $X_t^{Old} = G_t^{Old} - F_t - M_t$; $j_{v,t}$ is the Julian date at the time of the survey, and $\Delta_{v,t}=j_{v,t}/365$ is the fraction of the year elapsed at the time of the survey.

Survey selectivity parameter values ($s_{v,New}$ and $s_{v,Old}$) are specified by the user and must be set between zero and one. For example, a survey for new recruits would have $s_{v,New}=1$ and $s_{v,Old}=0$. A survey that measured abundance of the entire stock would have $s_{v,New}=1$ and $s_{v,Old}=1$.

Terms involving $\Delta_{v,t}$ are used to project beginning of year biomass forward to the time of the survey, making adjustments for mortality and somatic growth.[q] As described below, available biomass $A_{v,t}$ is adjusted further for nonlinear surveys, surveys with covariates and surveys with time variable $Q_{v,t}$.

Scaling parameters (Q) for log normal abundance data

Scaling parameters for surveys with lognormal statistical errors were computed using the maximum likelihood estimator:

$$Q_v = e^{\dfrac{\sum\limits_{i=1}^{N_v}\left[\ln\left(\dfrac{I_{v,i}}{A_{v,i}}\right)\middle/\sigma_{v,j}^2\right]}{\sum\limits_{j=1}^{N_j}\left(1\middle/\sigma_{v,j}^2\right)}}$$

where $N_v$ is the number of observations with individual weights greater than zero. The closed form maximum likelihood estimator gives the same answer as if scaling parameters are estimated as free parameters in the assessment model assuming lognormal survey measurement errors.

*Survey covariates*

Survey scaling parameters may vary over time based on covariates in the KLAMZ model. The survey scaling parameter that measures the relationship between available biomass and survey data becomes time dependent:

$$\hat{I}_{v,t} = Q_{v,t}A_{v,t}$$

and

$$Q_{v,t} = Q_v e^{\sum\limits_{r=1}^{n_v}d_{r,t}\theta_r}$$

with $n_v$ covariates for the survey and parameters $\theta_r$ estimated in the model. Covariate effects and available biomass are multiplied to compute an adjusted available biomass:

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[q] It may be important to project biomass forward if an absolute estimate of biomass is available (e.g. from a hydroacoustic or daily egg production survey), if fishing mortality rates or high or if the timing of the survey varies considerably from year to year.

$$A'_{v,t} = A_{v,t} e^{\sum_{r=1}^{n_v} d_{r,t}\theta_r}$$

The adjusted available biomass $A'_{v,t}$ is used instead of the original value $A_{v,t}$ in the closed form maximum likelihood estimator described above.

Covariates might include, for example, a dummy variable that represents changes in survey bottom trawl doors or a continuous variable like average temperature data if environmental factors affect distribution and catchability of fish schools. Dummy variables are usually either 0 or 1, depending on whether the effect is present in a particular year. With dummy variables, $Q_v$ is the value of the survey scaling parameter with no intervention ($d_{r,t}=0$).

For ease in interpretation of parameter estimates for continuous covariates (e.g. temperature data), it is useful to center covariate data around the mean:

$$d_{r,t} = d'_{r,t} - \overline{d'_r}$$

where $d'_{r,t}$ is the original covariate. When covariates are continuous and mean-centered, $Q_v$ is the value of the survey scaling parameter under average conditions ($d_{r,t}=0$) and units for the covariate parameter are easy to interpret (for example, units for the parameter are $1/^{\circ}C$ if the covariate is mean centered temperature in $^{\circ}C$).

It is possible to use a survey covariate to adjust for differences in relative stock size from year to year due to changes in the timing of a survey. However, this adjustment may be made more precisely by letting the model calculate $\Delta_{v,t}$ as described above, based on the actual timing data for the survey during each year.

Nonlinear abundance indices

With nonlinear abundance indices, and following Methot (1990), the survey scaling parameter is a function of available biomass:

$$Q_{v,t} = Q_v A_{v,t}^{\Gamma}$$

so that:

$$\hat{I}_{v,t} = \left(Q_v A_{v,t}^{\Gamma}\right) A_{v,t}$$

Substituting $e^{\gamma}=\Gamma+1$ gives the equivalent expression:

$$\hat{I}_{v,t} = Q_v A_{v,t}^{e^{\gamma}}$$

where $\gamma$ is a parameter estimated by the model and the survey scaling parameter is no longer time dependent. In calculations with nonlinear abundance indices, the adjusted available biomass:

$$A'_{v,t} = A_{v,t}^{e^{\gamma}}$$

is computed first and used in the closed form maximum likelihood estimator described above to calculate the survey scaling parameter. In cases where survey covariates are also applied to a nonlinear index, the adjustment for nonlinearity is carried out first.

*Survey Q process errors*

The C++ version of the KLAMZ model can be used to allow survey scaling parameters to change in a controlled fashion from year to year (NEFSC 2002):

$$Q_{v,t} = Q_v e^{\varepsilon_{v,t}}$$

where the deviations $\varepsilon_{v,t}$ are constrained to average zero. Variation in survey Q values is controlled by the NLL penalty:

$$L = 0.5 \sum_{j=1}^{N_v} \left[ \frac{\varepsilon_{v,j}}{\sigma_v} \right]^2$$

where the log scale standard deviation $\sigma_v$ based on an arithmetic CV supplied by the user (e.g. see NEFSC 2002). In practice, the user increases or decreases the amount of variability in Q by decreasing or increasing the assumed CV.

Survival ratios as surveys

In the C++ version of KLAMZ, it is possible to use time series of survival data as "surveys". For example, an index of survival might be calculated using survey data and the Heinke method (Ricker 1975) as:

$$A_t = \frac{I_{k+1,t+1}}{I_{k,t}}$$

so that the time series of $A_t$ estimates are data that may potentially contain information about scale or trends in survival. Predicted values for an a survival index are calculated:

$$\hat{A}_t = e^{-Z_t}$$

After predicted values are calculated, survival ratio data are treated in the same way as abundance data (in particular, measurement errors are assumed to be lognormal). Selectivity parameters are ignored for survival data but all other features (e.g. covariates, nonlinear scaling relationships and constraints on Q) are available.

Recruitment models

Recruitment parameters in KLAMZ may be freely estimated or estimated around an internal recruitment model, possibly involving spawning biomass. An internally estimated recruitment model can be used to reduce variability in recruitment estimates (often necessary if data are limited), to summarize stock-recruit relationships, or to make use of information about recruitment in similar stocks. There are four types of internally estimated recruitment models in KLAMZ: 1) random variation around a constant mean; 2) random walk around a constant mean (autocorrelated variation); 3) random variation around a Beverton-Holt recruitment model; and 4) random variation around a Ricker recruitment model. The user must specify a type of recruitment model but the model is not active unless the likelihood component for the recruitment model is turned on ($\lambda > 0$).

The first step in recruit modeling is to calculate the expected log recruitment level $E[ln(R_t)]$ given the recruitment model. For random variation around a constant mean, the expected log recruitment level is the log geometric mean recruitment:

$$E[\ln(R_t)] = \sum_{j=1}^{N} \ln(R_j) \bigg/ N$$

For a random walk around a constant mean recruitment, the expected log recruitment level is the logarithm of recruitment during the previous year:

$$E[\ln(R_t)] = \ln(R_{t-1})$$

with no constraint on recruitment during the first year $R_1$.

For the Beverton-Holt recruitment model, the expected log recruitment level is:
$$E[\ln(R_t)] = \ln[e^a T_{t-\ell}/(e^b + T_{t-\ell})]$$

where $a = e^\alpha$ and $b = e^\beta$, the parameters $\alpha$ and $\beta$ are estimated in the model, $T_t$ is spawning biomass, and is the lag between spawning and recruitment. Spawner-recruit parameters are estimated as log transformed values ($e^\alpha$ and $e^\beta$) to enhance model stability and ensure the correct sign of values used in calculations. Spawning biomass is:
$$T_t = m_{new} R_t + m_{old} S_t$$

where $m_{new}$ and $m_{old}$ are maturity parameters for new and old recruits specified by the user. For the Ricker recruitment model, the expected log recruitment level is:
$$E[\ln(R_t)] = \ln(S_{t-\ell} e^{a-bS_{t-\ell}})$$

where $a = e^\alpha$ and $b = e^\beta$, and the parameters $\alpha$ and $\beta$ are estimated in the model.

Given the expected log recruitment level, log scale residuals for the recruitment model are calculated:
$$r_t = \ln(R_t) - E[\ln(R_t)]$$

Assuming that residuals are log normal, the NLL for recruitment residuals is:
$$L = \sum_{t=t_{first}}^{N} w_t \left[ \ln(\sigma_r) + 0.5 \left( \frac{r_t}{\sigma_r} \right)^2 \right]$$

where $\lambda_t$ is an instance-specific weight usually set equal one. The additional term in the NLL $[\ln(\sigma_r)]$ is necessary because the variance $\sigma_r^2$ is estimated internally, rather than specified by the user.

The log scale variance for residuals is calculated using the maximum likelihood estimator:
$$\sigma_r^2 = \frac{\sum_{j=t_{first}}^{N} r_j}{N}$$

where $N$ is the number of residuals. For the recruitment model with constant variation around a mean value, $t_{first} = 1$. For the random walk recruitment model, $t_{first} = 2$. For the Beverton-Holt and Ricker models, $t_{first} = \ell + 1$ and the recruit model imposes no constraint on variability of recruitment during years 1 to $\ell$ (see below). The biased maximum likelihood estimate for $\sigma^2$ (with $N$ in the divisor instead of the degrees of freedom) is used because actual degrees of freedom are unknown. The variance term $\sigma^2$ is calculated explicitly and stored because it is used below.

Constraining the first few recruitments

It may be useful to constrain the first years of recruitments when using either the Beverton-Holt or Ricker models if the unconstrained estimates for early years are erratic. In the KLAMZ model, this constraint is calculated:
$$NLL = \sum_{t=1}^{t_{first}-1} w_t \left\{ \ln(\sigma_r + 0.5 \left[ \frac{\ln(R_t/E(R_{t_{first}}))}{\sigma_r} \right]^2 \right\}$$

where $t_{first}$ is the first year for which expected recruitment $E(R_l)$ can be calculated with the spawner-recruit model. In effect, recruitments that not included in spawner-recruit calculations are constrained towards the first spawner-recruit prediction. The standard deviation is the same as used in calculating the NLL for the recruitment model.

Prior information about abundance index scaling parameters ($Q$)

A constraint on one or more scaling parameters ($Q_v$) for abundance or survival indices may be useful if prior information is available (e.g. NEFSC 2000; NEFSC 2001; NEFSC 2002). In the Excel version, it is easy to program these (and other) constraints in an *ad-hoc* fashion as they are needed. In the AD Model Builder version, log normal and beta distributions are preprogrammed for use in specifying prior information about $Q_v$ for any abundance or survival index.

The user must specify which surveys have prior distributions, minimum and maximum legal bounds ($q_{min}$ and $q_{max}$), the arithmetic mean $(\bar{q})$ and the arithmetic CV for the prior the distribution. Goodness of fit for $Q_v$ values outside the bounds ($q_{min}$, $q_{max}$) are calculated:

$$L = \left| \begin{array}{l} 10000\,(Q_v - q_{max})^2 \; if \; Q_v \geq q_{max} \\ 10000\,(q_{min} - Q_v)^2 \; if \; Q_v \leq q_{min} \end{array} \right.$$

Goodness of fit for $Q_v$ values inside the legal bounds depend on whether the distribution of potential values is log normal or follows a beta distribution.

*Lognormal case*

Goodness of fit for lognormal $Q_v$ values within legal bounds is:

$$L = 0.5\left[ \frac{\ln(Q_v) - \tau}{\varphi} \right]^2$$

where the log scale standard deviation $\varphi = \sqrt{\ln(1 + CV)}$ and $\tau = \ln(\bar{q}) - \dfrac{\varphi^2}{2}$ is the mean of the corresponding log normal distribution.

*Beta distribution case*

The first step in calculation goodness of fit for $Q_v$ values with beta distributions is to calculate the mean and variance of the corresponding "standardized" beta distribution:

$$\bar{q}' = \frac{\bar{q} - q_{min}}{D}$$

and

$$Var(q') = \left( \frac{\bar{q}\,CV}{D} \right)^2$$

where the range of the standardized beta distribution is $D = q_{max} - q_{min}$. Equating the mean and variance to the estimators for the mean and variance for the standardized beta distribution (the "method of moments") gives the simultaneous equations:

$$\bar{q}' = \frac{a}{a + b}$$

and

$$Var(q') = \frac{ab}{(a+b)^2(a+b+1)}$$

where $a$ and $b$ are parameters of the standardized beta distribution.[r] Solving the simultaneous equations gives:

$$b = \frac{(\bar{q}'-1)[Var(q') + (\bar{q}'-1)\bar{q}']}{Var(q')}$$

and:

$$a = \frac{b\bar{q}'}{1-\bar{q}'}$$

Goodness of fit for beta $Q_v$ values within legal bounds is calculated with the NLL:

$$L = (a-1)\ln(Q'_v) + (b-1)\ln(1-Q'_v)$$

where $Q'_v = Q_v/(Q_v - q_{min})$ is the standardized value of the survey scaling parameter $Q_v$.

Surplus production modeling

Surplus production models can be fit internally to biomass and surplus production estimates in the model (Jacobson et al. 2002). Models fit internally can be used to constrain estimates of biomass and recruitment, to summarize results in terms of surplus production, or as a source of information in tuning the model. The NLL for goodness of fit assumes normally distributed process errors in the surplus production process:

$$L = 0.5 \sum_{j=1}^{N_P} \left( \frac{\tilde{P}_j - P_j}{\sigma} \right)^2$$

where $N_p$ is the number of surplus production estimates (number of years less one), $\tilde{P}_t$ is a predicted value from the surplus production curve, $P_t$ is the assessment model estimate, and the standard deviation $\sigma$ is supplied by the user based, for example, on preliminary variances for surplus production estimates.[s] Either the symmetrical Schaefer (1957) or asymmetric Fox (1970) surplus production curve may be used to calculate $\tilde{P}_t$ (Quinn and Deriso 1999).

It may be important to use a surplus production curve that is compatible with recruitment patterns or assumptions about the underlying spawner-recruit relationship. More research is required, but the asymmetric shape of the Fox surplus production curve appears reasonably compatible with the assumption that recruitment follows a Beverton-Holt spawner-recruit curve (Mohn and Black 1998). In contrast, the symmetric Schaefer surplus production model appears reasonably compatible with the assumption that recruitment follows a Ricker spawner-recruit curve.

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[r] If $x$ has a standardized beta distribution with parameters $a$ and $b$, then the probability of $x$ is $P(x) = \frac{x^{a-1}(1-x)^{b-1}}{\Gamma(a,b)}$.

[s] Variances in NLL for surplus production-biomass models are a subject of ongoing research. The advantage in assuming normal errors is that negative production values (which occur in many stocks, e.g. Jacobson et al. 2001) are accommodated. In addition, production models can be fit easily by linear regression of $P_t$ on $B_t$ and $B_t^2$ with no intercept term. However, variance of production estimate residuals increases with predicted surplus production. Therefore, the current approach to fitting production curves in KLAMZ is not completely satisfactory.

The Schaefer model has two log transformed parameters that are estimated in KLAMZ:

$$\widetilde{P}_t = e^\alpha B_t - e^\beta B_t^2$$

The Fox model also has two log transformed parameters:

$$\widetilde{P}_t = -e\left(e^{e^\alpha}\right)\frac{B_t}{e^\beta}\log\left(\frac{B_t}{e^\beta}\right)$$

See Quinn and Deriso (1999) for formulas used to calculate reference points ($F_{MSY}$, $B_{MSY}$, $MSY$, and $K$) for both surplus production models.

Catch/biomass

Forward simulation models like KLAMZ may tend to estimate absurdly high fishing mortality rates, particularly if data are limited. The likelihood constraint used to prevent this potential problem is:

$$L = 0.5\sum_{t=0}^{N} d_t^2$$

where:

$$d_t = \left|\begin{array}{l}(C_t/B - \kappa)\,if\ \ C_t/B > \kappa \\ \quad 0\ otherwise\end{array}\right.$$

with the threshold value $\kappa$ normally set by the user to about 0.95. Values for $\kappa$ can be linked to maximum F values using the modified catch equation described above. For example, to use a maximum fishing mortality rate of about $F$ 4 with $M$=0.2 and $G$=0.1 (maximum $X$=4+0.2-0.1=4.1), set $\kappa \approx F/X(1-e^{-X})$=4 / 4.1 (1-e$^{-4}$)=0.96.

Uncertainty

The AD Model Builder version of the KLAMZ model automatically calculates variances for parameters and quantities of interest (e.g. $R_t$, $F_t$, $B_t$, $F_{MSY}$, $B_{MSY}$, $\overline{F}_{Recent}$, $\overline{B}_{Recent}$, $\overline{F}_{Recent}/F_{MSY}$, $\overline{B}_{Recent}/B_{MSY}$, etc.) by the delta method using exact derivatives. If the objective function is the log of a proper posterior distribution, then Markov Chain Monte Carlo (MCMC) techniques implemented in AD Model Builder libraries can be used estimate posterior distributions representing uncertainty in the same parameters and quantities.[t]

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[t] MCMC calculations are not available in the current version because objective function calculations use concentrated likelihood formulas. However, the C++ version of KLAMZ is programmed in other respects to accommodate Bayesian estimation.

## Bootstrapping

A FORTRAN program called BootADM can be used to bootstrap survey and survival index data in the KLAMZ model. Based on output files from a "basecase" model run, BootADM extracts standardized residuals:

$$r_{v,j} = \frac{\ln\left(I_{v,j} \middle/ \hat{I}_{v,j}\right)}{\sigma_{v,j}}$$

along with log scale standard deviations ($\sigma_{v,j}$, originally from survey CV's or estimated from goodness of fit), and predicted values $\left(\hat{I}_{v,j}\right)$ for all active abundance and survival observations. The original standardized residuals are pooled and then resampled (with replacement) to form new sets of bootstrapped survey "data":

$$^x I_{v,j} = \hat{I}_{v,j} e^{r\sigma_{v,j}}$$

where $r$ is a resampled residual. Residuals for abundance and survival data are combined in bootstrap calculations. BootADM builds new KLAMZ data files and runs the KLAMZ model repetitively, collecting the bootstrapped parameter and other estimates at each iteration and writing them to a comma separated text file that can be processed in Excel to calculate bootstrap variances, confidence intervals, bias estimates, etc. for all parameters and quantities of interest (Efron 1982).

## Projections

Stochastic projections can be carried out using another FORTRAN program called SPROJDDF based on bootstrap output from BootADM. Basically, bootstrap estimates of biomass, recruitment, spawning biomass, natural and fishing mortality during the terminal years are used with recruit model parameters from each bootstrap run to start and carryout projections.[u] Given a user-specified level of catch or fishing mortality, the delay-difference equation is used to project stock status for a user-specified number of years. Recruitment during each projected year is based on simulated spawning biomass, log normal random numbers, and spawner-recruit parameters (including the residual variance) estimated in the bootstrap run. This approach is similar to carrying out projections based on parameters and state variables sampled from a posterior distribution for the basecase model fit. It differs from most current approaches because the spawner-recruit parameters vary from projection to projection.

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[u] At present, only Beverton-Holt recruitment calculations are available in SPROJDDF.

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