Northeast Fisheries Science Center Reference Document 04-03

38th Northeast Regional Stock Assessment Workshop (38th SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

January 2004

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03-17 **Report of the 37th Northeast Regional Stock Assessment Workshop (37th SAW): Advisory Report.** [By Northeast Regional Stock Assessment Workshop No. 37.] September 2003.

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Northeast Fisheries Science Center Reference Document 04-03

A Report of the 38th Northeast Regional Stock Assessment Workshop

38th Northeast Regional Stock Assessment Workshop (38th SAW)

Stock Assessment Review Committee (SARC) Consensus Summary of Assessments

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

January 2004

Northeast Fisheries Science Center Reference Documents

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MEETING OVERVIEW

The Stock Assessment Review Committee (SARC) meeting of the 38th Northeast Regional Stock Assessment Workshop (38th SAW) was held in the Aquarium Conference Room of the Northeast Fisheries Science Center's Woods Hole Laboratory, Woods Hole, MA November 17-19, 2003. The SARC Chairman was Dr. Jean-Jacques Maguire, Halieutikos Inc, Quebec, Canada (CIE). Members of the SARC included scientists from the NEFSC, the NMFS's Northeast Regional Office, the New England Fishery Management Council (NEFMC), the MidAtlantic Fishery Management Council (MAFMC), Canada's Department of Fisheries and Oceans (DFO), and the Southeast Fisheries Science Center's Pascagoula MS laboratory (Table 1). In addition, twenty other persons attended some or all of the meeting (Table 2). The meeting agenda is presented in Table 3.

Table 1. SAW-38th SARC Composition.

Jean-Jaques Maguire (Halieutikos Inc., Quebec, Canada; (CIE), **Chairman**

Northeast Fisheries Science Center:
Jon Brodziak
Steve Cadrin
Anne Richards

Regional Fishery Management Councils:
Andy Applegate, (NEFMC)
Tom Hoff, (MAFMC)

Other experts:
Joe Cafone, NMFS, Gloucester
Chris Gledhill, SEFSC, Pascagoula
Dale Roddick, DFO, Halifax
Peter Shelton, DFO, Newfoundland; (CIE)

Table 2. List of Participants.

NMFS, Northeast Fisheries Science Center	Universities/Industry
Col, Laurel	Powell, Eric – Rutgers/HSRL
Idoine, Joseph	Wallace, Dave – Wallace Associates
Jacobson, Larry	Womack, John – Wallace Associates
Legalt, Chris	Bence, Jim – Michigan State
Murawski, Steve	
Nitschke, Paul	
O'Brien, Loretta	
Overholtz, Bill	
Rago, Paul	
Serchuk, Fred	
Shepard, Gary	
Sosebee, Katherine	
Sutherland, Sandy	
Terceiro, Mark	
Waring, Gordon	
Yoos, Patricia	

Table 3. Agenda of the 38th Northeast Regional Stock Assessment Workshop (SAW-38) Stock Assessment Review Committee (SARC) Meeting

Aquarium Conference Room - NEFSC Woods Hole Laboratory
Woods Hole, Massachusetts
November 17-19, 2003

TOPIC	WORKING GROUP &PRESENTER(S)	SARC LEADER	RAPPORTEURS

<u>MONDAY, 17 November</u> (1:00 PM - 6:00 PM)..

Opening			
Welcome	Gordon T. Waring, SAW Chairman		
Introduction	Jean-Jacques Maguire, SARC Chairman		
Ocean quahog (A)	SAW Invertebrate Subcommittee J. Weinberg/ L. Jacobson	D. Roddick	

<u>TUESDAY, 18 November</u> (8:30 AM - 5:30 PM)..

Ocean quahog (A)	SAW Invertebrate Subcommittee J. Weinberg/L. Jacobson	D. Roddick	L. Col K. Sosebee
Atlantic butterfish (B)	SAW Pelagic/Coastal Subcommittee B. Overholtz/ L. Jacobson	S. Cadrin	P. Nitschke

Review Draft Advisory Reports and Consensus Summary Sections for the Ocean Quahog SARC Report

Informal reception **(6:00 PM)** at SWOPE Building (Marine Biological Laboratory)

<u>WEDNESDAY, 19 November</u> (8:30 AM - 6:00PM)..

Review Draft Advisory Reports and Consensus Summary Sections for the Atlantic Butterfish SARC Report

SARC comments, research recommendations and 2nd drafts of Advisory Reports

Other business G. Waring

The Process

The Northeast Regional Coordinating Council, which guides the SAW process, is composed of the chief executives of the five partner organizations (NMFS/NEFSC, NMFS/NER, NEFMC, MAFMC, Atlantic States Marine Fisheries Commission (ASMFC). Working groups assemble the data for assessments, decide on methodology, and prepare documents for SARC review. The SARC members have a dual role – panelists are both reviewers of assessments and drafters of management advice. As products of the meeting, the Committee prepares two reports: a summary of the assessments with advice for fishery managers knows as the *Advisory Report on Stock Status*; and a more detailed report of the assessment, results, discussions and recommendations known as the *Consensus Summary of Assessments* (this report).

Assessments for SARC review were prepared at meetings listed in Table 4.

Table 4. SAW-38 Working Group meetings and participants.

Working Group and Participants		**Stock/Species**	**Meeting Date**
Invertebrate Subcommittee			
		Ocean quahog	September 29-30, 2003 October 27-29, 2003
Jim Weinberg	NEFSC		
Larry Jacobson	NEFSC		
Tom Hoff	MAFMC		
Douglas Christel	NERO		
John Womack	Wallace & Associates		
Tom Alspach	Sea Watch Int., Ltd.		
Paul Rago	NEFSC		
Roger Mann	VIMS		
Dave Wallace	Wallace & Associates		
Eric Powell	Rutgers/HSRL		
Chris Picket	NEFSC		
Pelagic/Coastal Subcommitte		Atlantic butterfish	October 22, 2003; October 30, 2003 (telecom)
Bill Overholtz	NEFSC		
Mark Terciero	NEFSC		
Paul Rago	NEFSC		
Larry Jacobson	NEFSC		
Sandy Sutherland	NEFSC		
Rich Seagraves	MAFMC		
Jim Ruhle	MAFMC		

Agenda and Reports

The 38th SARC included presentations on assessments for Atlantic butterfish and ocean quahog. These species were last assessed, respectively, in 1993 (SAW-17) and 2000 (SAW-31).

Current SARC documentation includes two reports in draft form: one containing the assessments, SARC comments, and research recommendations (Draft SARC Consensus Summary – this report), and another produced in a standard format which includes standard information on stock status and management advice (Draft SARC Advisory Report). The draft reports will be given to the NEFMC, MAFMC, and ASMFC in January 2004. Presentations to the Councils will occur in January 2004 (MAFMC, 21 January, Atlantic City, NJ; NEFMC, 27 January, Newport, RI). Following review by the Councils the documents will be finalized and published in the NEFSC Reference Document series as the 38th *SARC Consensus Summary of Assessments* and the 38th *SAW Advisory Report*.

A chart of US commercial statistical areas used to report landings in the Northwest Atlantic is presented in Figure 1. A chart showing the sampling strata used in NEFSC bottom trawl surveys is presented in Figure 2.

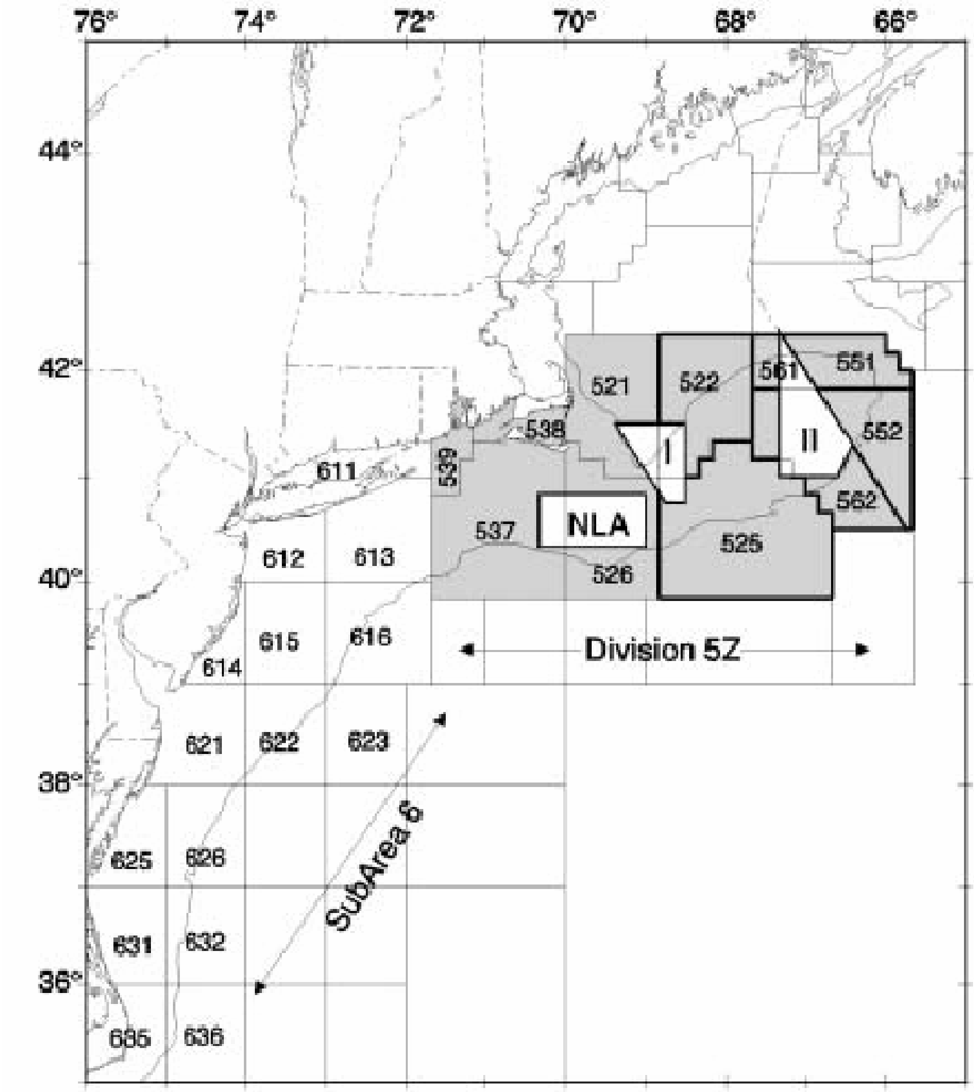

Figure 1. Statistical areas used for catch monitoring in offshore fisheries in the Northeast United States.

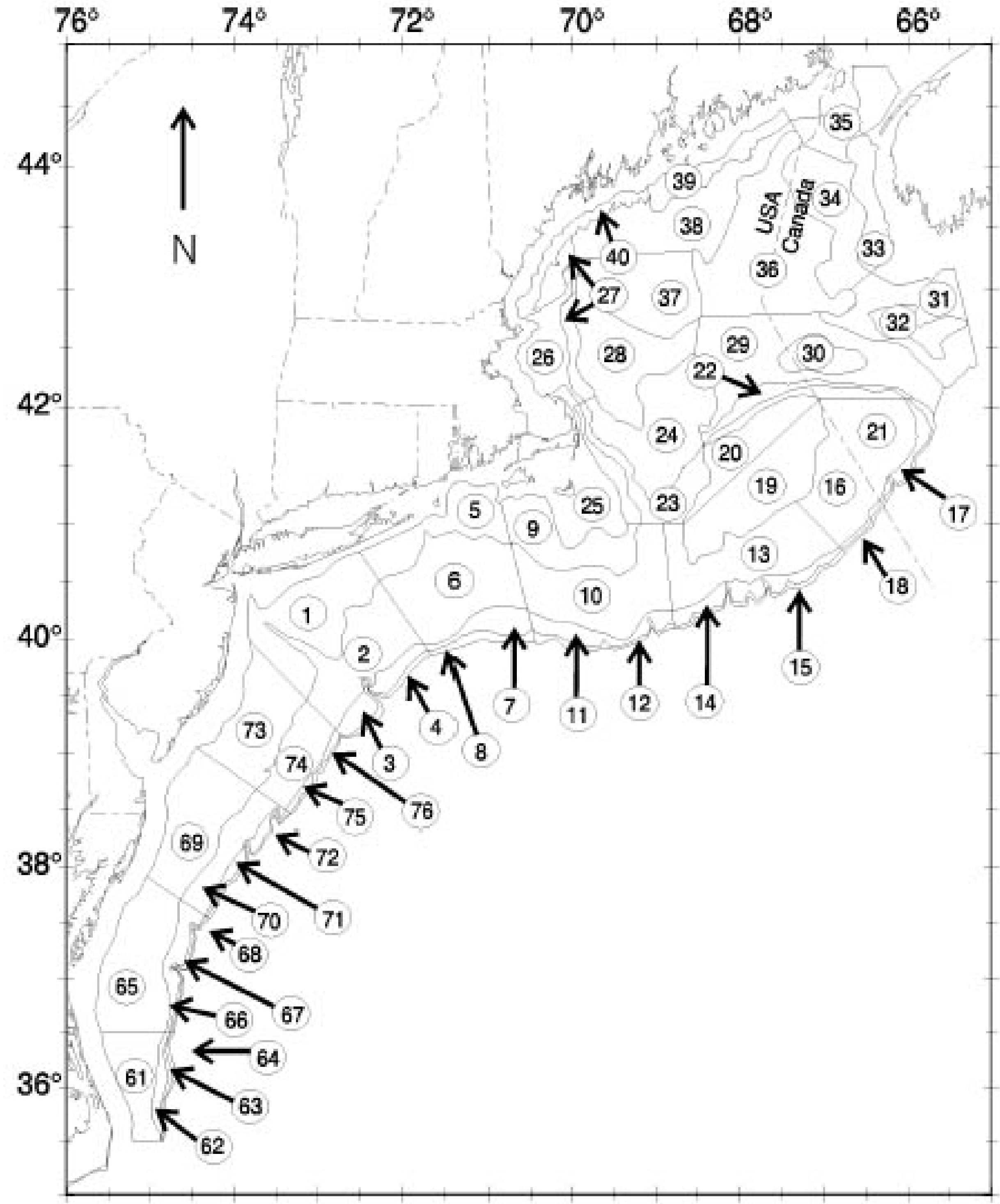

Figure 2. Offshore sampling strata used in NEFSC bottom trawl surveys.

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.

<u>Ocean quahog surveys and dredge efficiency</u>

- 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:

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

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 2nd 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 (χ_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 $\overline{c}_{r,y}$ was the survey trend value (stratified mean kg/tow, adjusted to the standard 0.15 nmi tow distance based on doppler distance measurements) and Ω_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 Ω_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_{Ω}^{2}, where CV_{Ω} is the coefficient of variation for Ω. Assuming log normality, arithmetic CVs were converted to log-scale standard deviations using $\sigma^2 = \ln\left(CV^2 + 1\right)$. 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 θ 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.

<u>Recruitment modeling in KLAMZ</u>

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

[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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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.																				
	DMV					NJ					LI					SNE				
	Nominal	GLM #1		GLM #2		Nominal	GLM #1		GLM #2		Nominal	GLM #1		GLM #2		Nominal	GLM #1		GLM #2	
Year		GLM 1. (Yr, Subreg)	CV	GLM 2. (Yr, Vessel, Subreg)	CV		GLM 1. (Yr, Subreg)	CV	GLM 2. (Yr, Vessel, Subreg)	CV		GLM 1. (Yr, Subreg)	CV	GLM 2. (Yr, Vessel, Subreg)	CV		GLM 1. (Yr, Subreg)	CV	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	Mean Length (mm)	Min L	Max L	Number of Measured Clams
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	Mean Length (mm)	Min L	Max L	Number of Measured Clams
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	Lisa Kim	Delaware	Delaware	Delaware	Delaware vs Lisa Kim
		Density (#/ft^2)	Efficiency	Station #	Density (#/ft^2)	Density (#/ft^2)	Relative Efficiency
		Model	Model		Setup Tows	Setup Tows	
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 .

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.		
Count	DE-II Eff.	Source
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].

		Cruise															
Region	Stratum	7801	7807	7901	8001	8006	8105	8204	8305	8403	8604	8903	9203	9404	9704	9903	200206
	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
DMV	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
	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
GBK	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
	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
LI	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
	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
NJ	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
	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
SNE	45						**3**	3	7	9	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

Cruise	KG Meats Per Tow	CV	Number Per Tow	CV	Number tows	Number Positive Tows	Number Strata Sampled
NJ							
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							
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
SNE							
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							
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 uncertainy 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	Estimate	CV
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*)	Estimate	CV
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)	Estimate	CV
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)	**Estimates for 1997**	**Estimates for 1999**	**Estimates for 2002**
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)			
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})						
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 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.

Region	N Tows	Mean Sensor Distance (nm)	Mean Doppler Distance (nm)	Mean Sensor/ Doppler	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%

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 (Ω, 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%	475,680	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
```

AGE	FPATTERN	MPATTERN	MATURITY	WEIGHT IN THE CATCH	WEIGHT IN THE STOCK	RELATIVE 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.

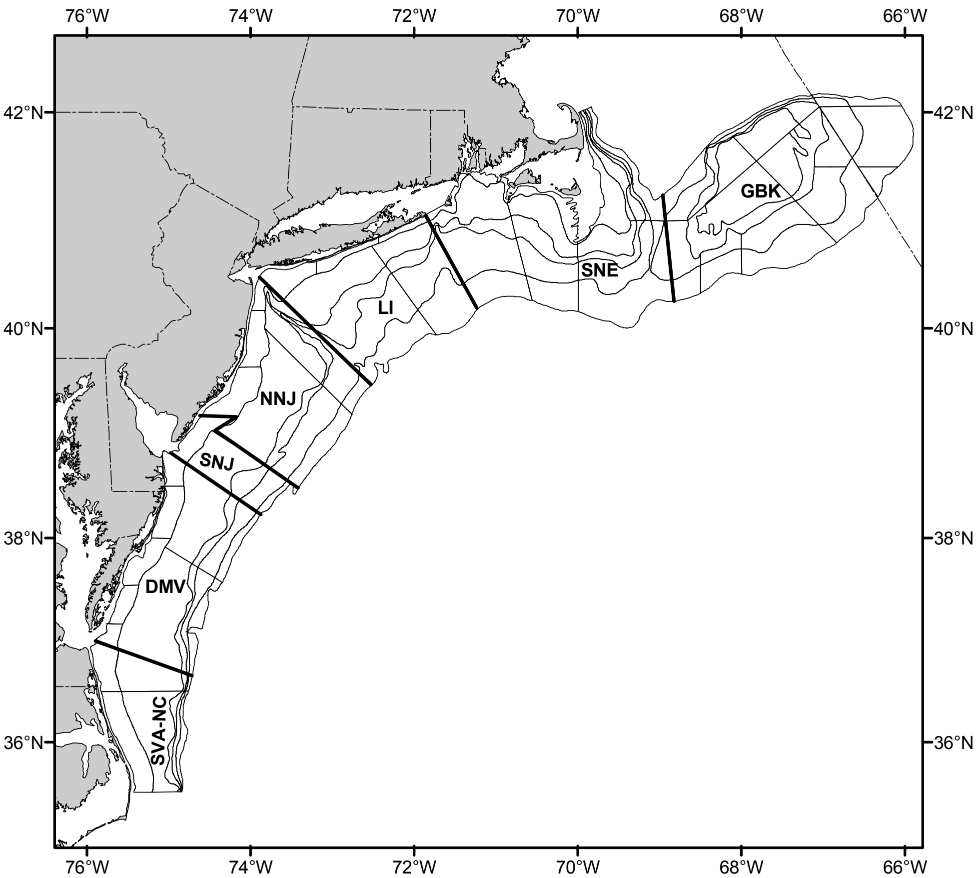
Year	SVA	DMV	NJ	LI	SNE	GBK	Total Less GBK	Total
Somatic growth rate (G y^{-1})								
2002	0.0080	0.0045	0.0099	0.0076	0.0096	0.0000	not used	not used
Recruitment rate (r = Recruitment / Average Biomass in 2002 y^{-1})								
2002	0.0101	0.0000	0.0168	0.0094	0.0136	0.0000	not used	not used
Natural 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

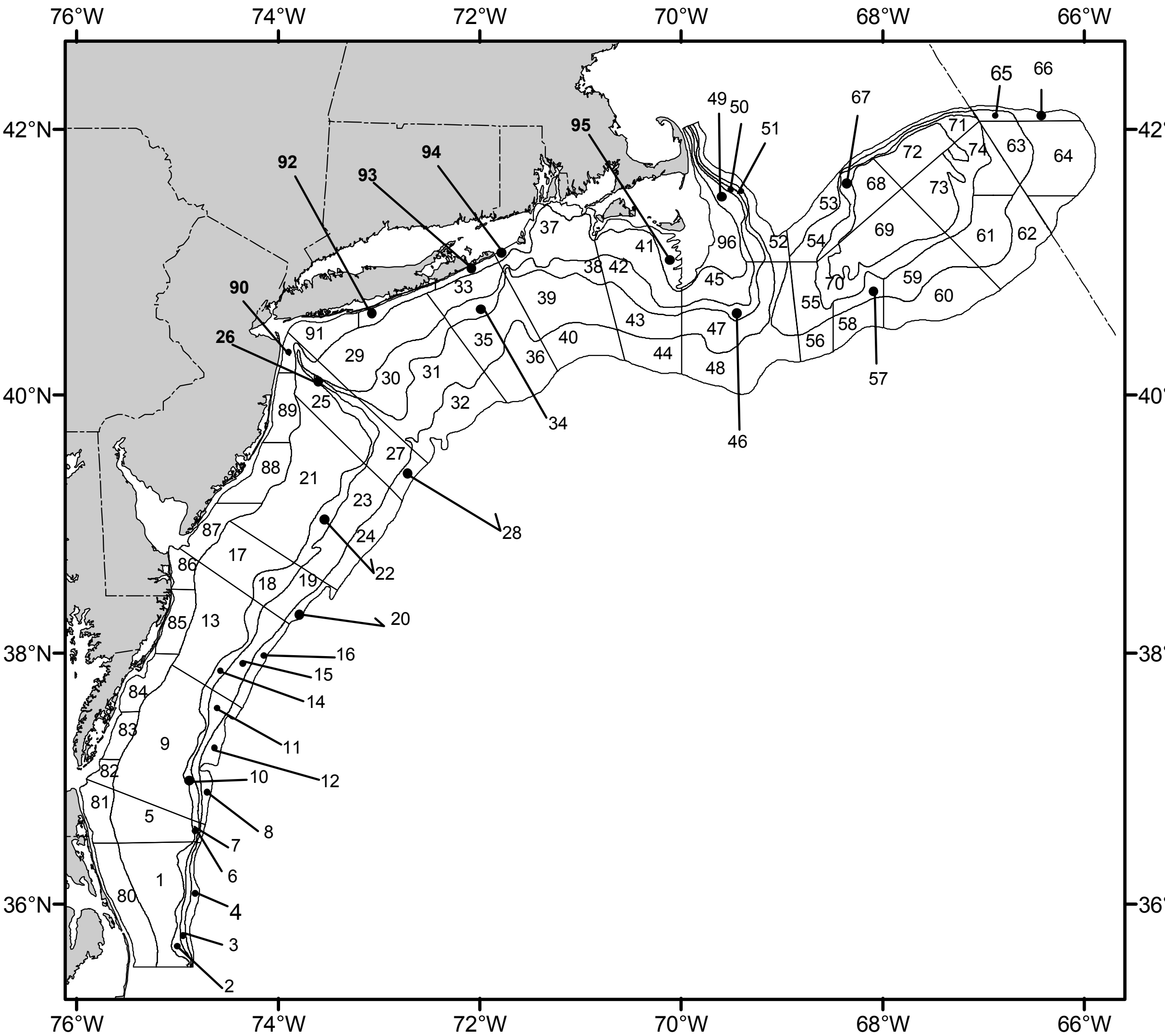
Table A30. Projection of B, F and landings, assuming constant fishing at $F_{0.1}$.

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.





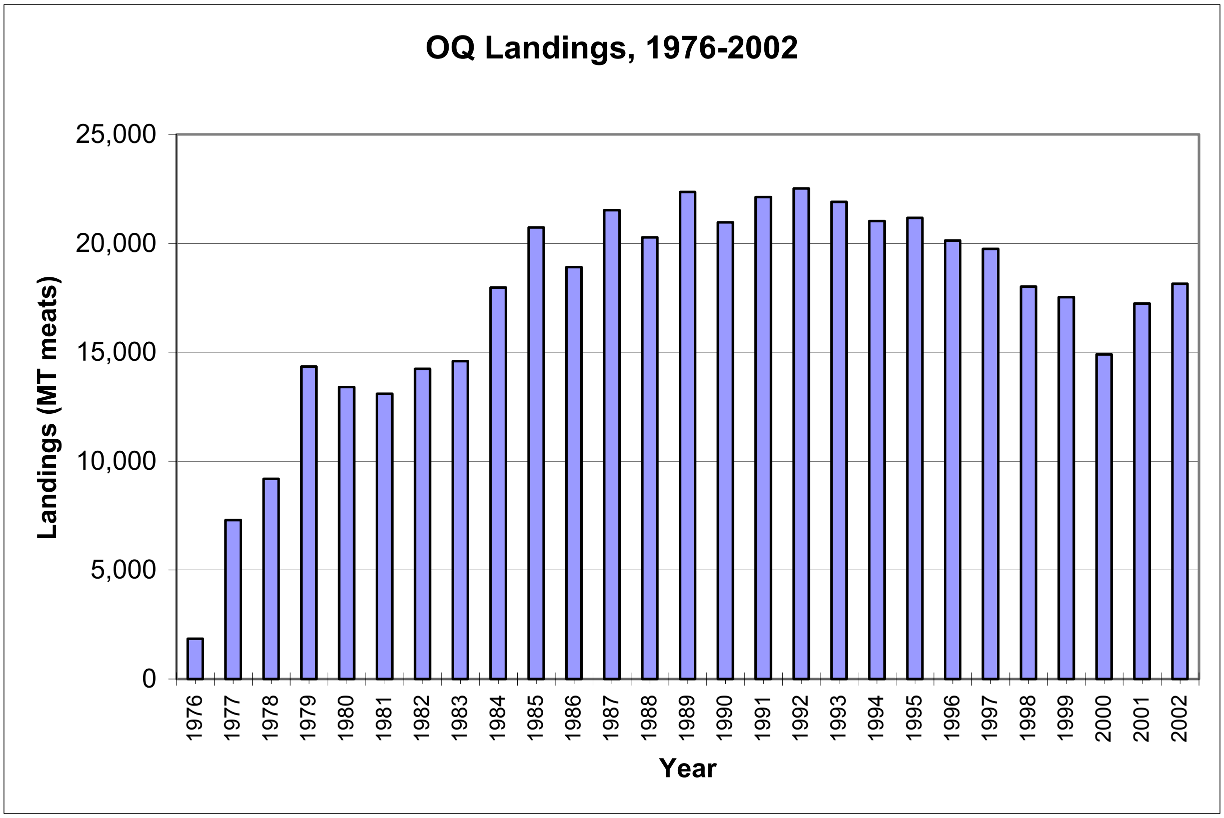


Figure A2. Landings of ocean quahogs from EEZ waters, 1976-2002.

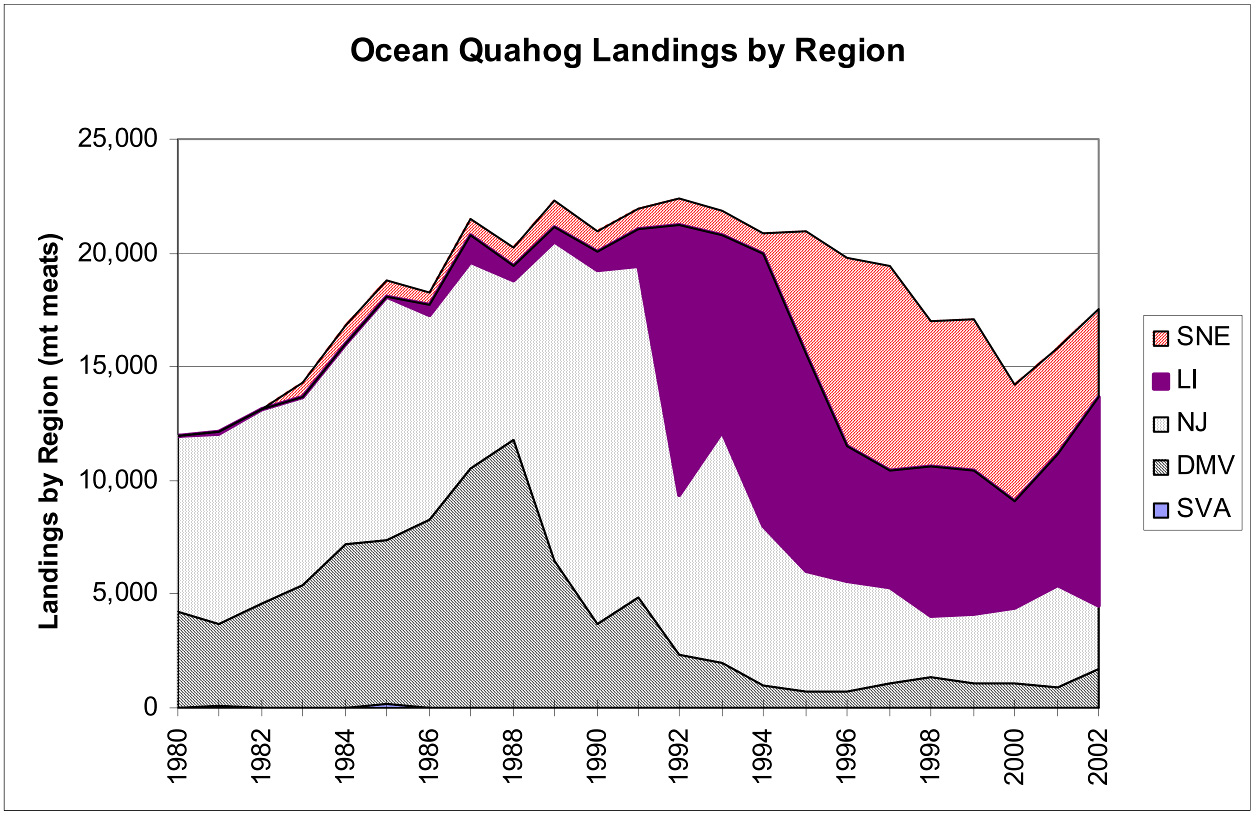


Figure A3. Ocean quahog landings in weight (calculated from number of bushels reported in logbooks) for the US EEZ, by stock assessment region. GBK not shown because the landings and effort were zero.

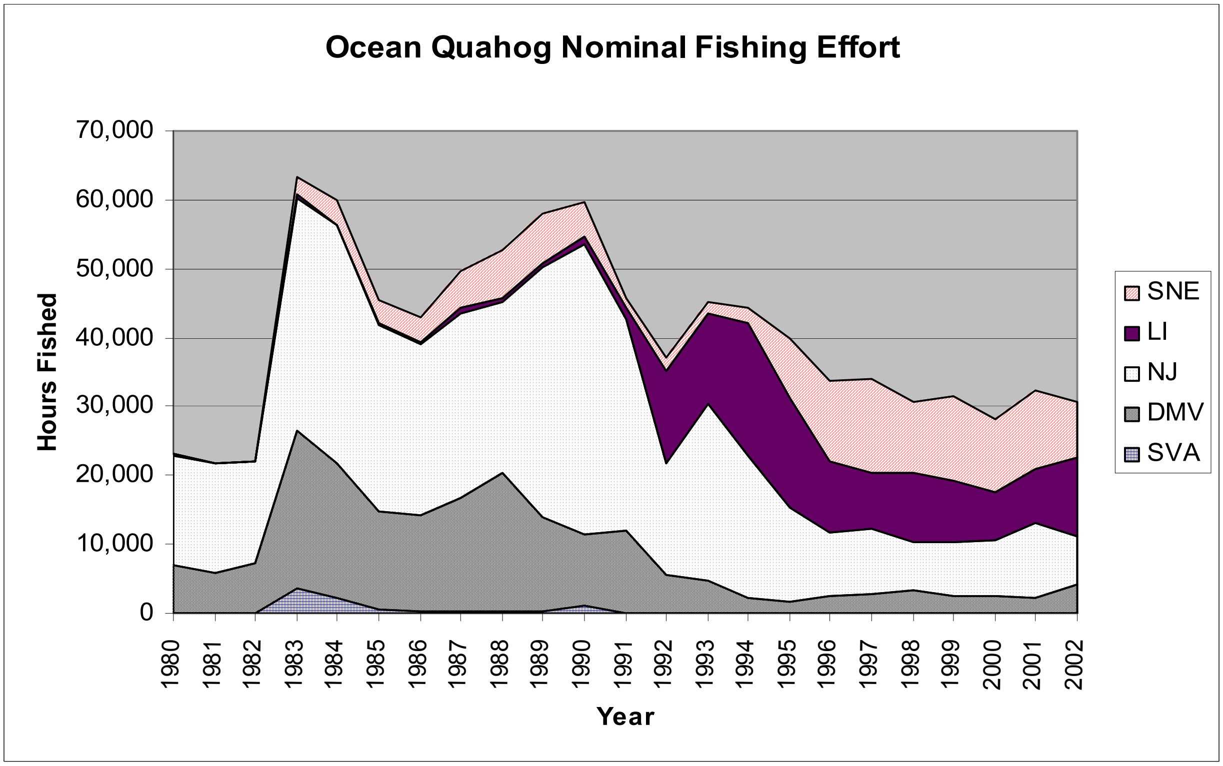


Figure A4. Nominal fishing effort for ocean quahogs in the US EEZ, by stock assessment region from logbooks. GBK not shown because the landings were zero.

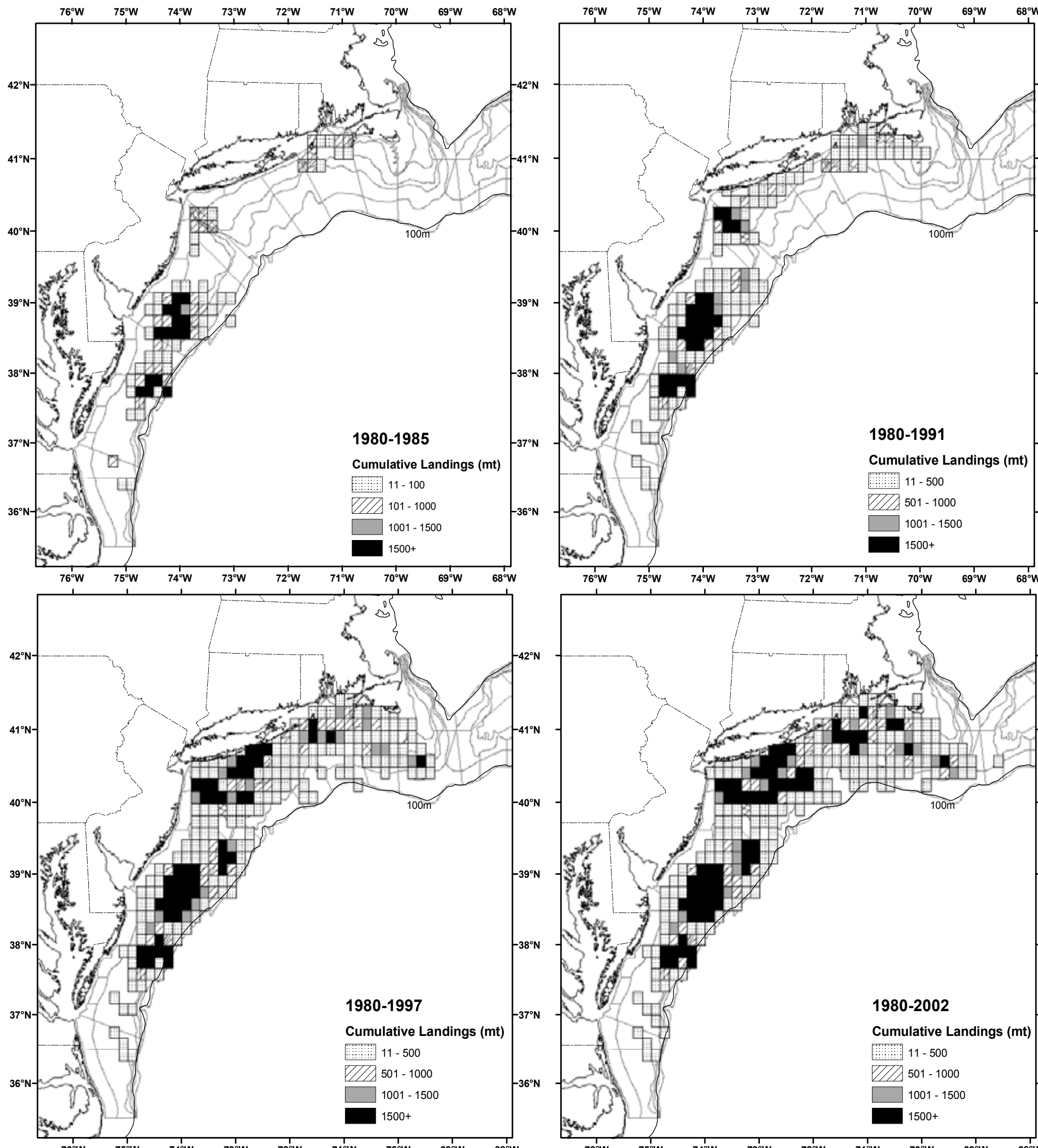


Figure A5. Cumulative landings of ocean quahogs from the EEZ, by TNMS.

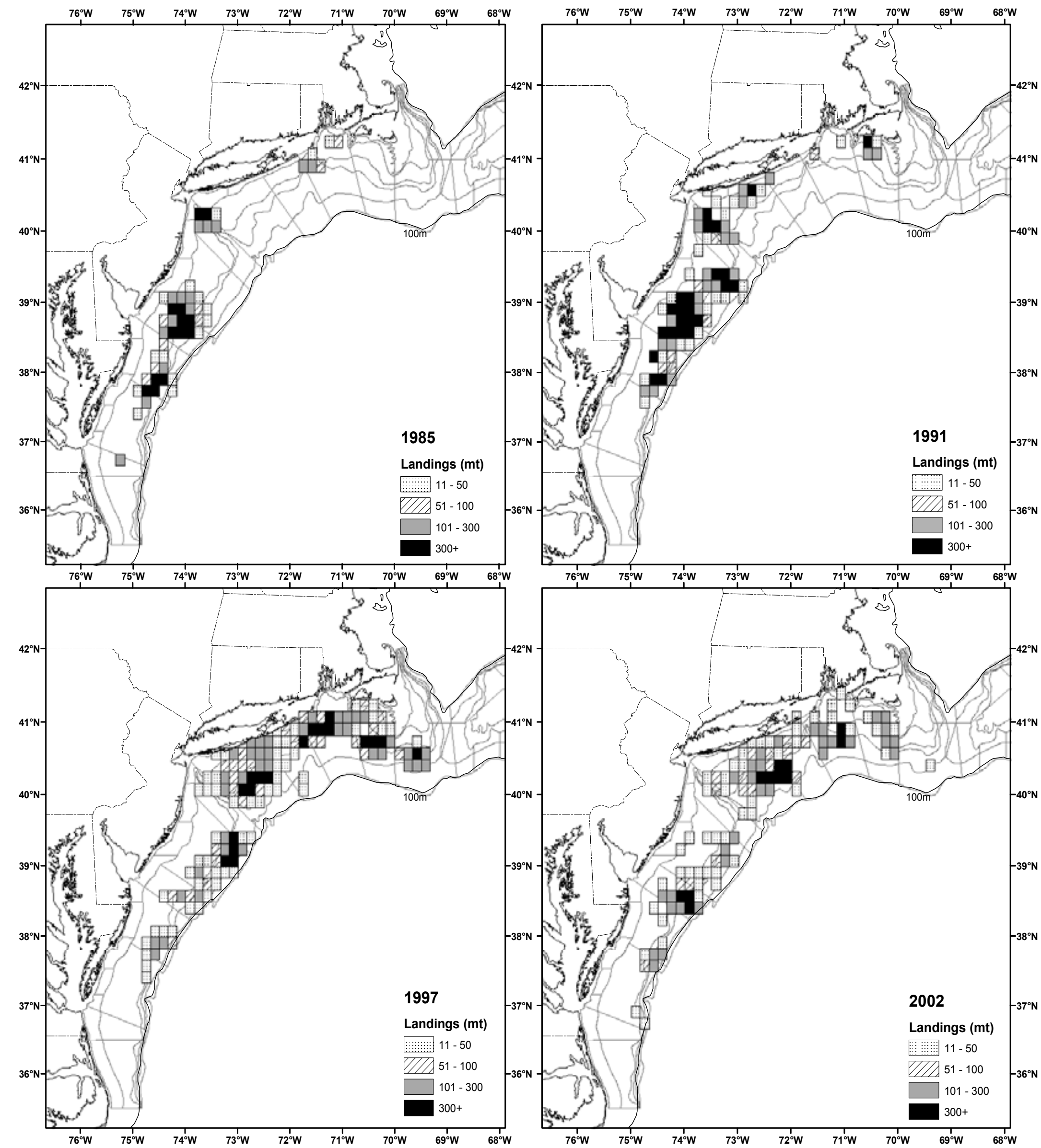


Figure A6. Annual landings of ocean quahogs from the EEZ, by TNMS.

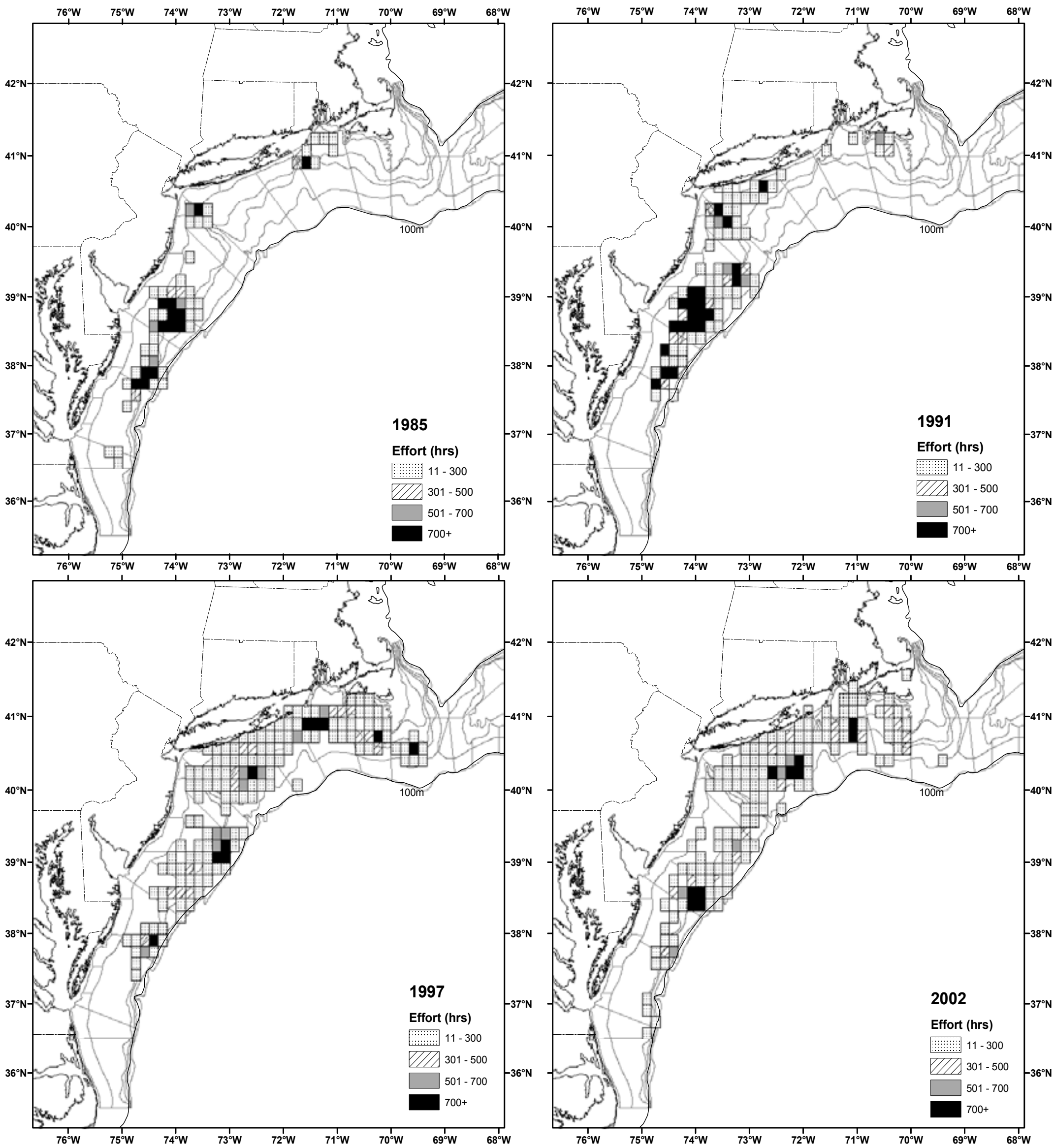


Figure A7. Annual fishing effort for ocean quahogs from the EEZ, by TNMS.

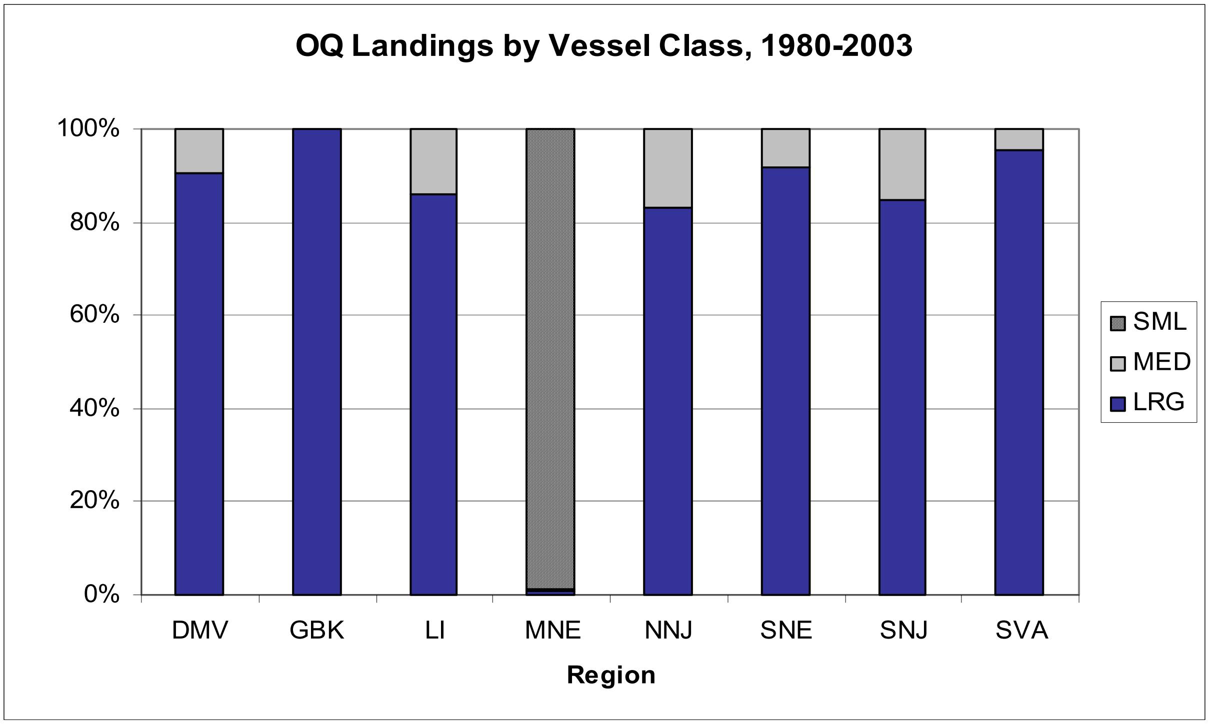


Figure A8. Landings by vessel class.

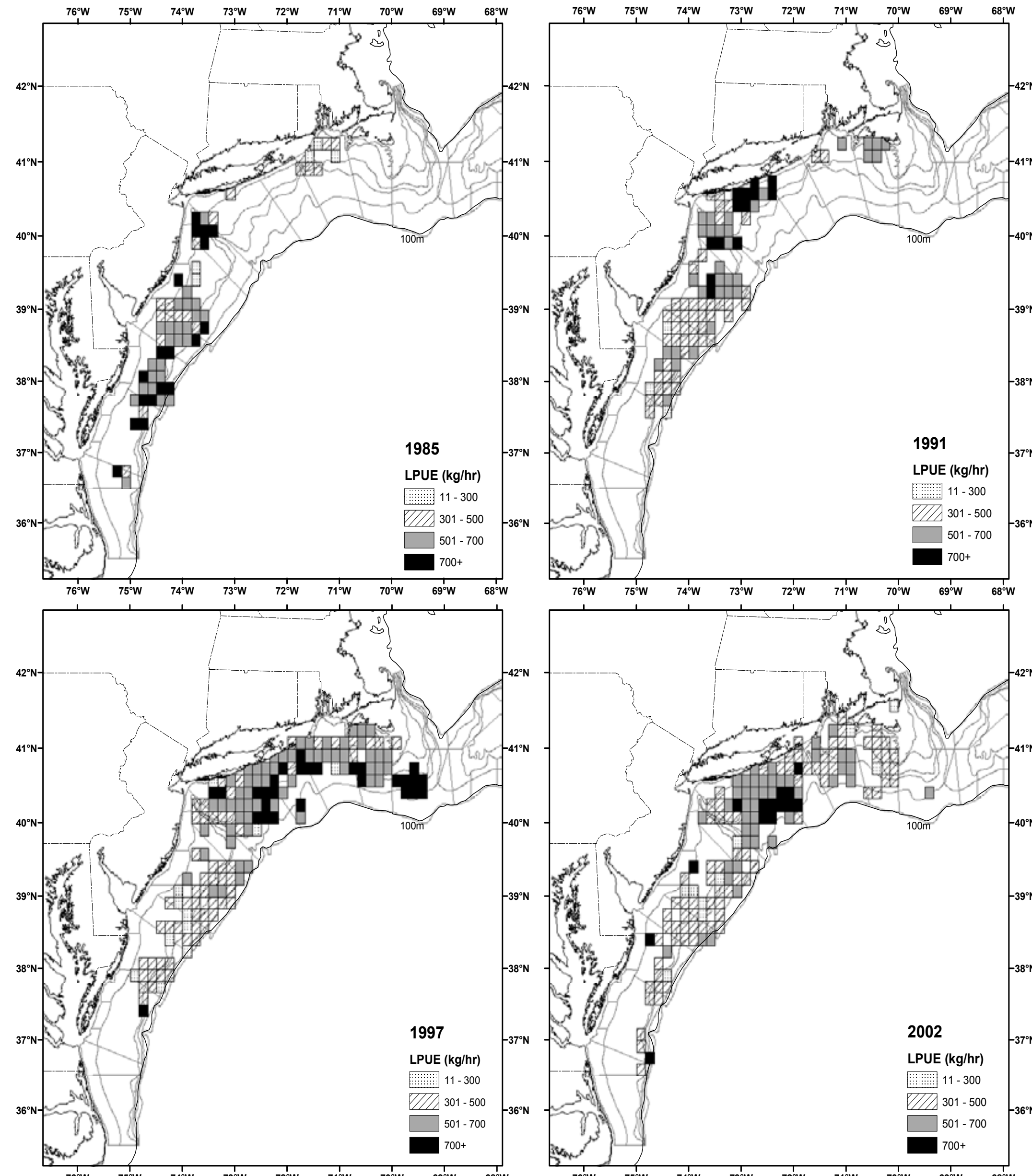


Figure A9. Landings per unit effort, by year and TNMS.

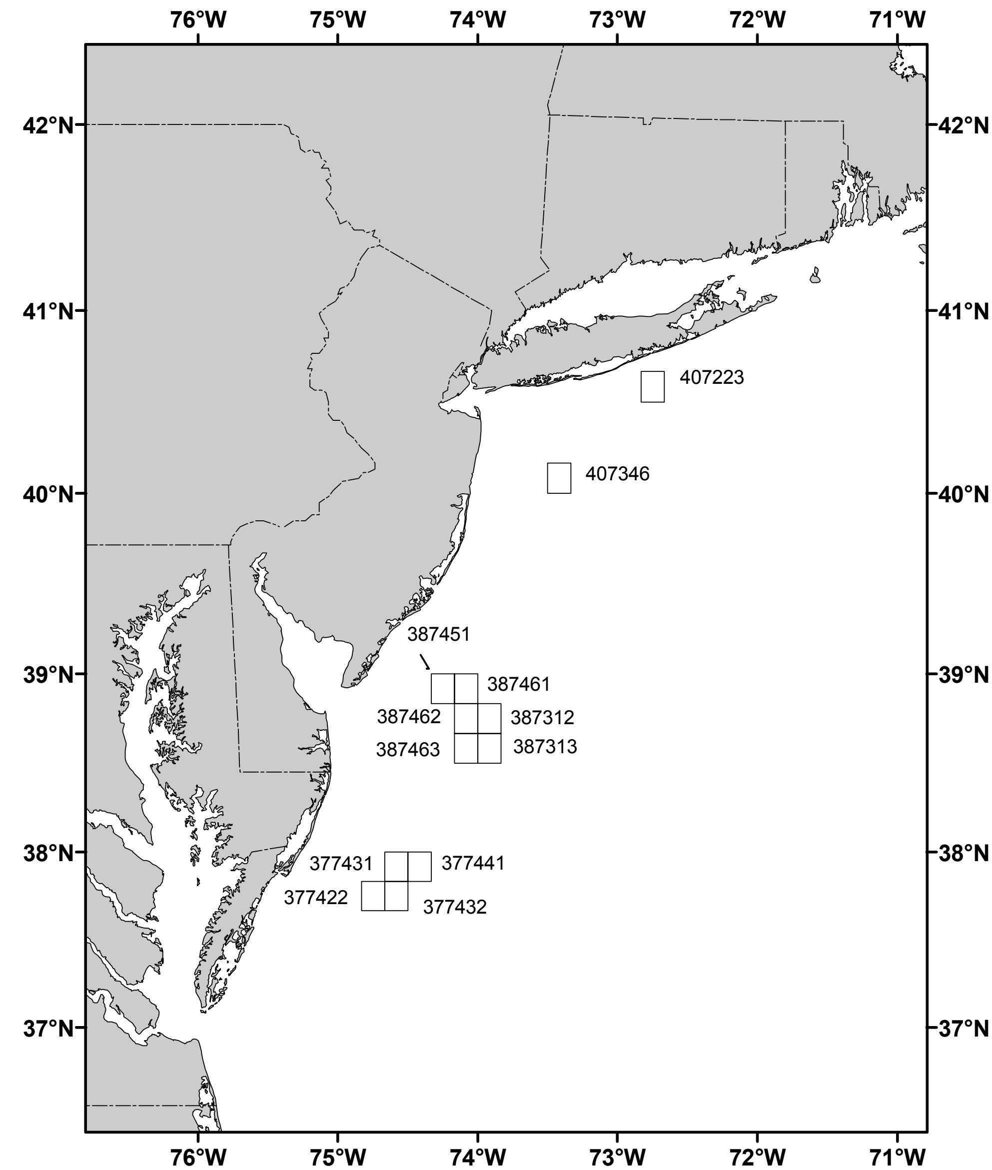


Figure A10. 12 ten-minute squares in the EEZ that have had the largest cumulative catch of ocean quahogs , 1980-2002.

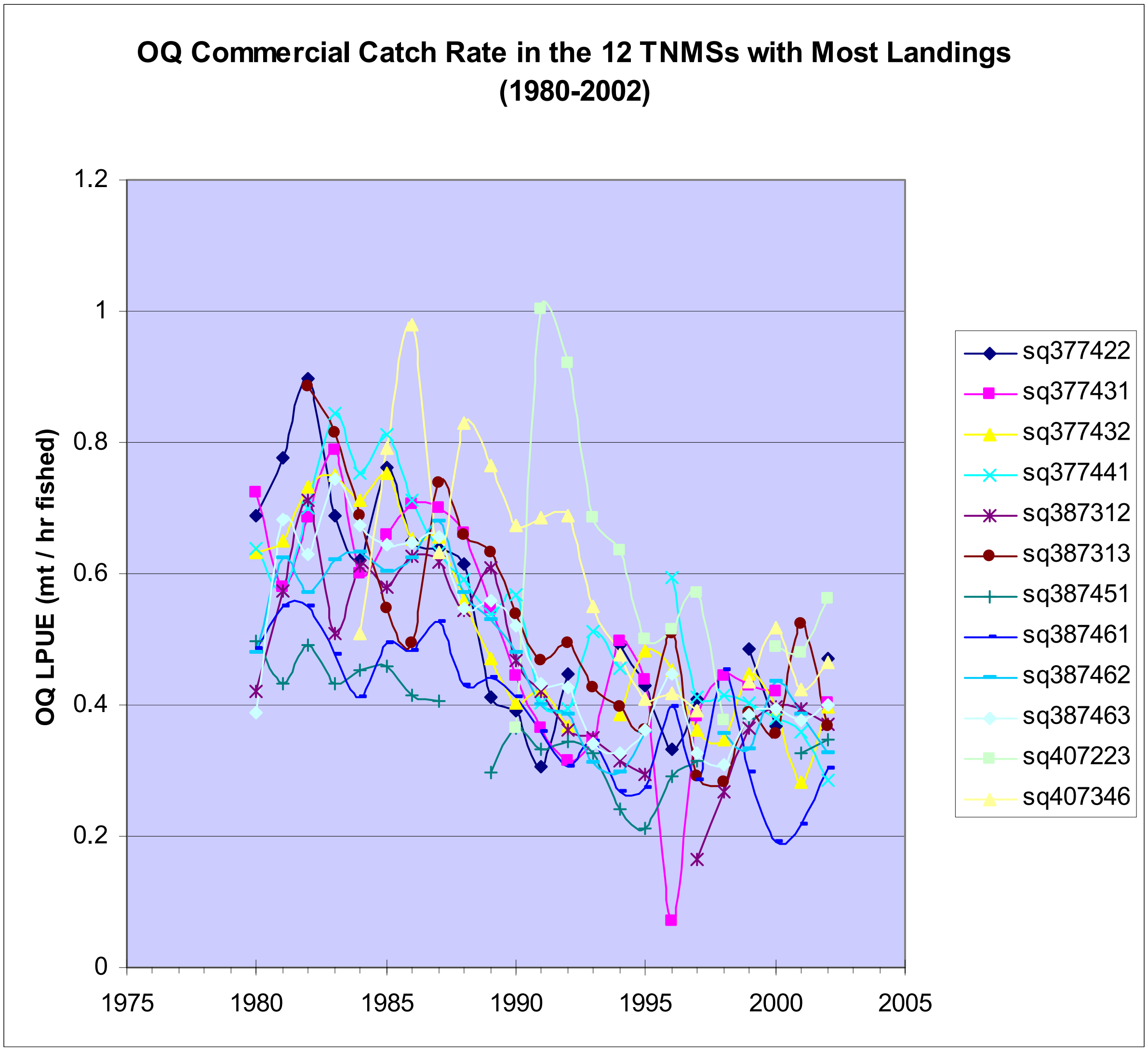
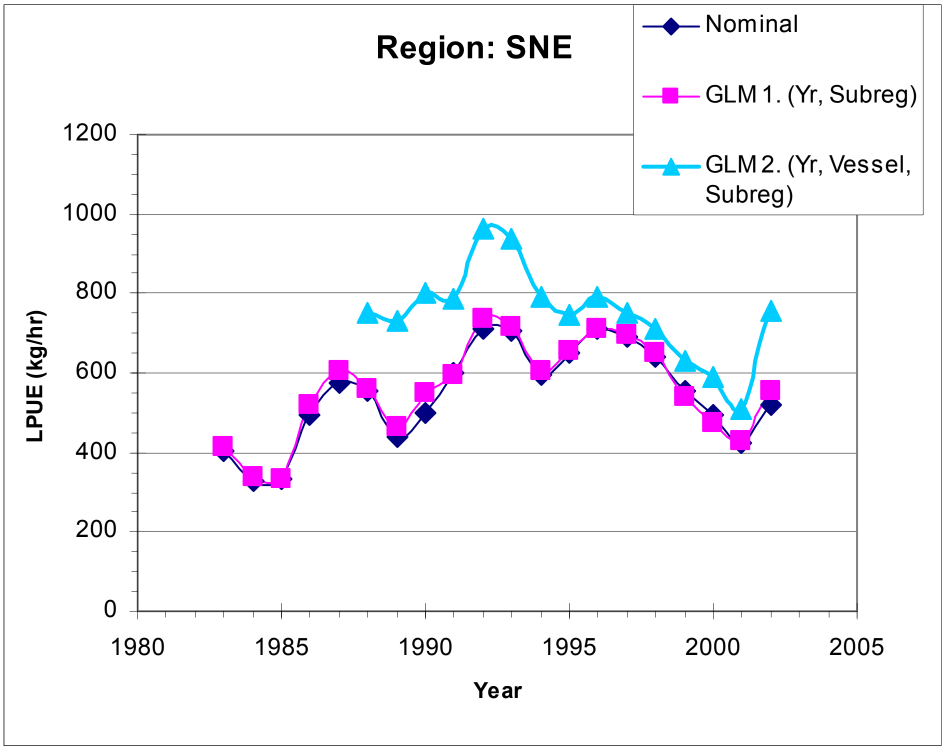


Figure A11. Commercial catch rates of large vessels in the 12 ten-minute squares in the EEZ that have had the largest cumulative catch of ocean quahogs , 1980-2002.



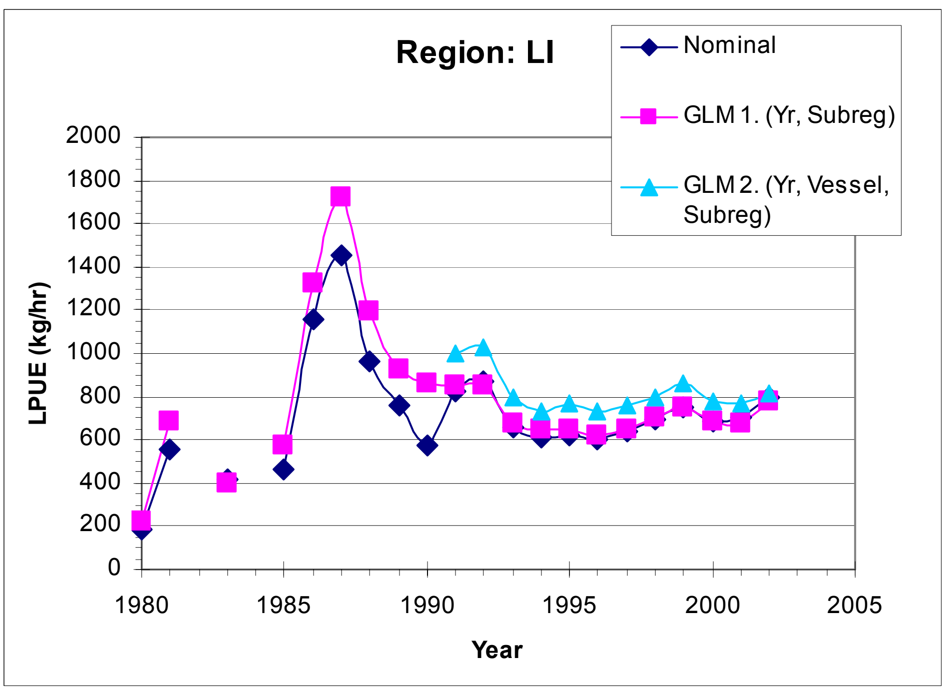
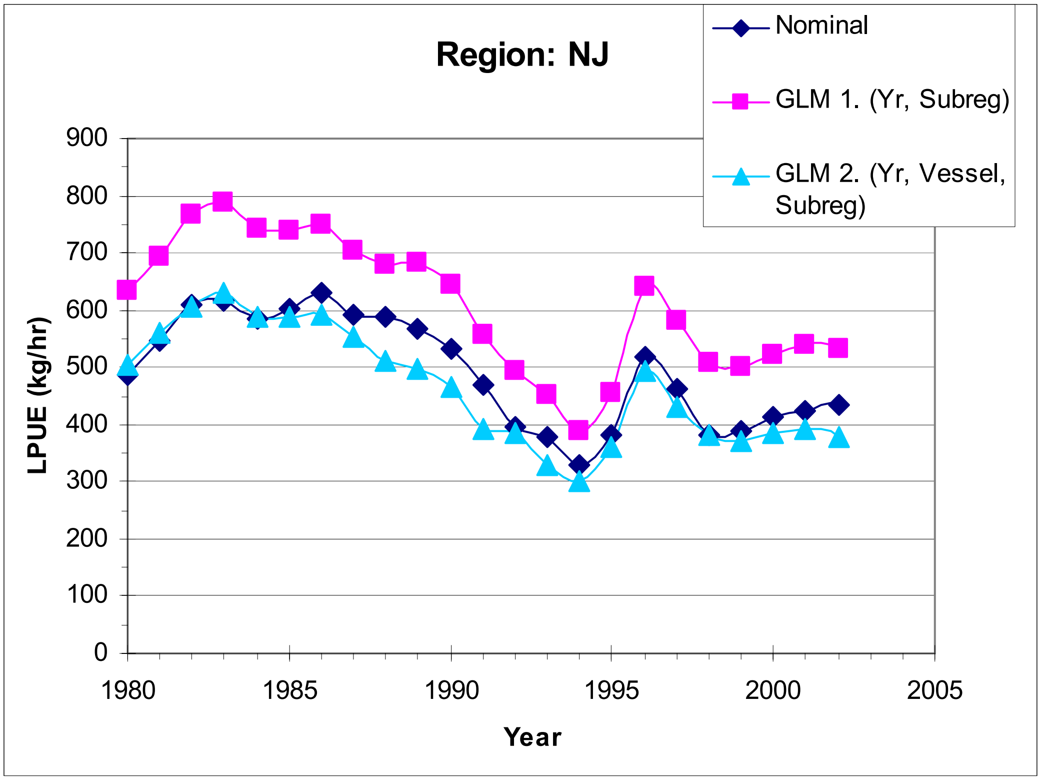


Figure A12. Landings per unit effort based on nominal values and 2 general linear models. Northern Regions.



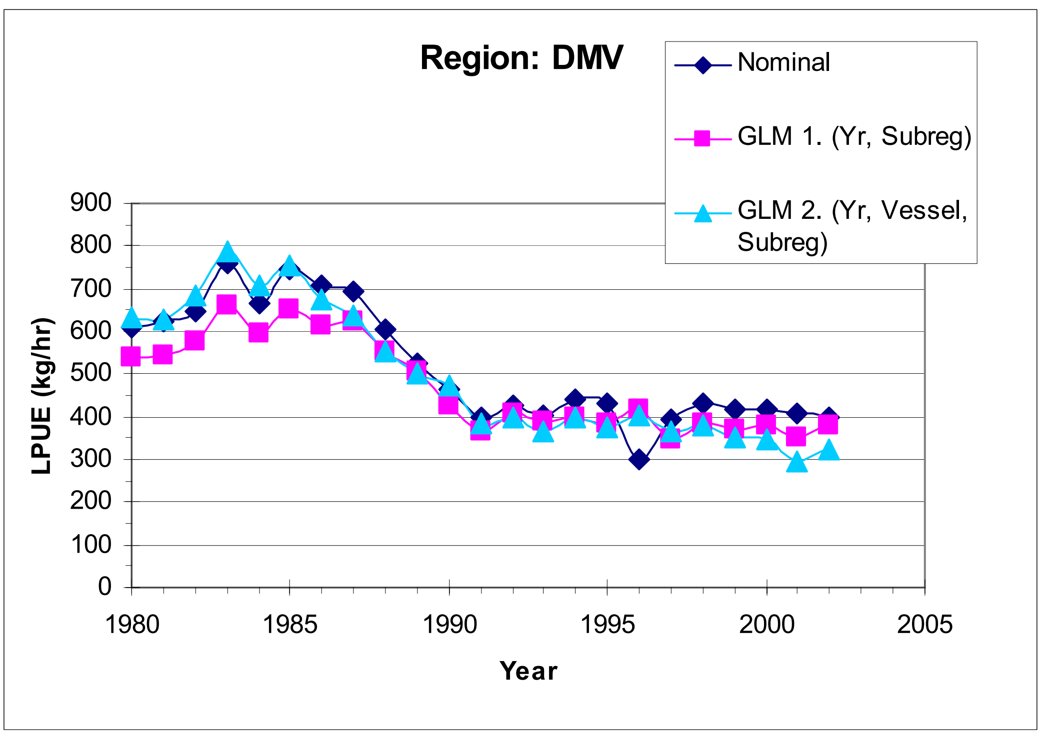


Figure A13. Landings per unit effort based on nominal values and 2 general linear models. Southern Regions.

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

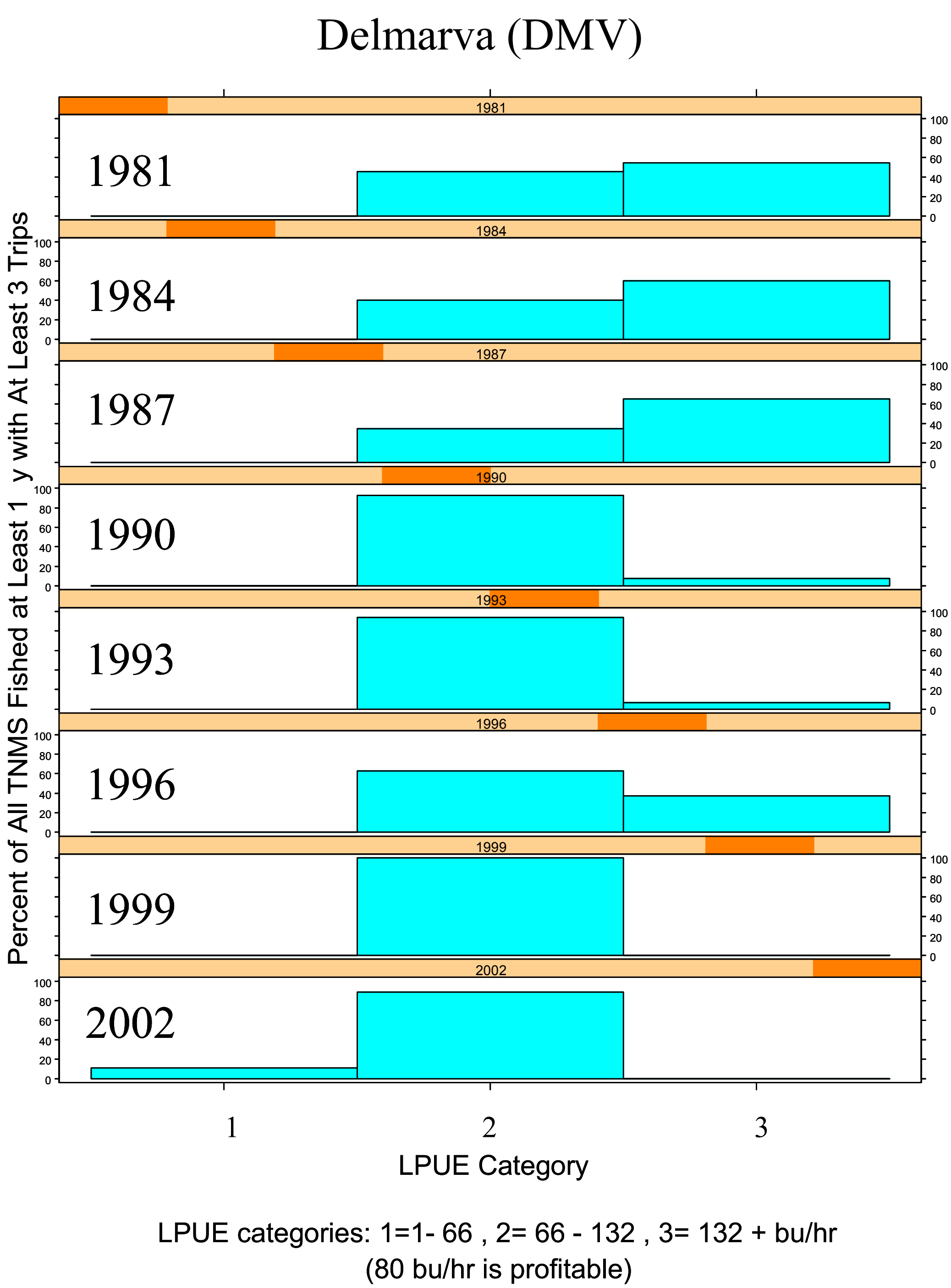
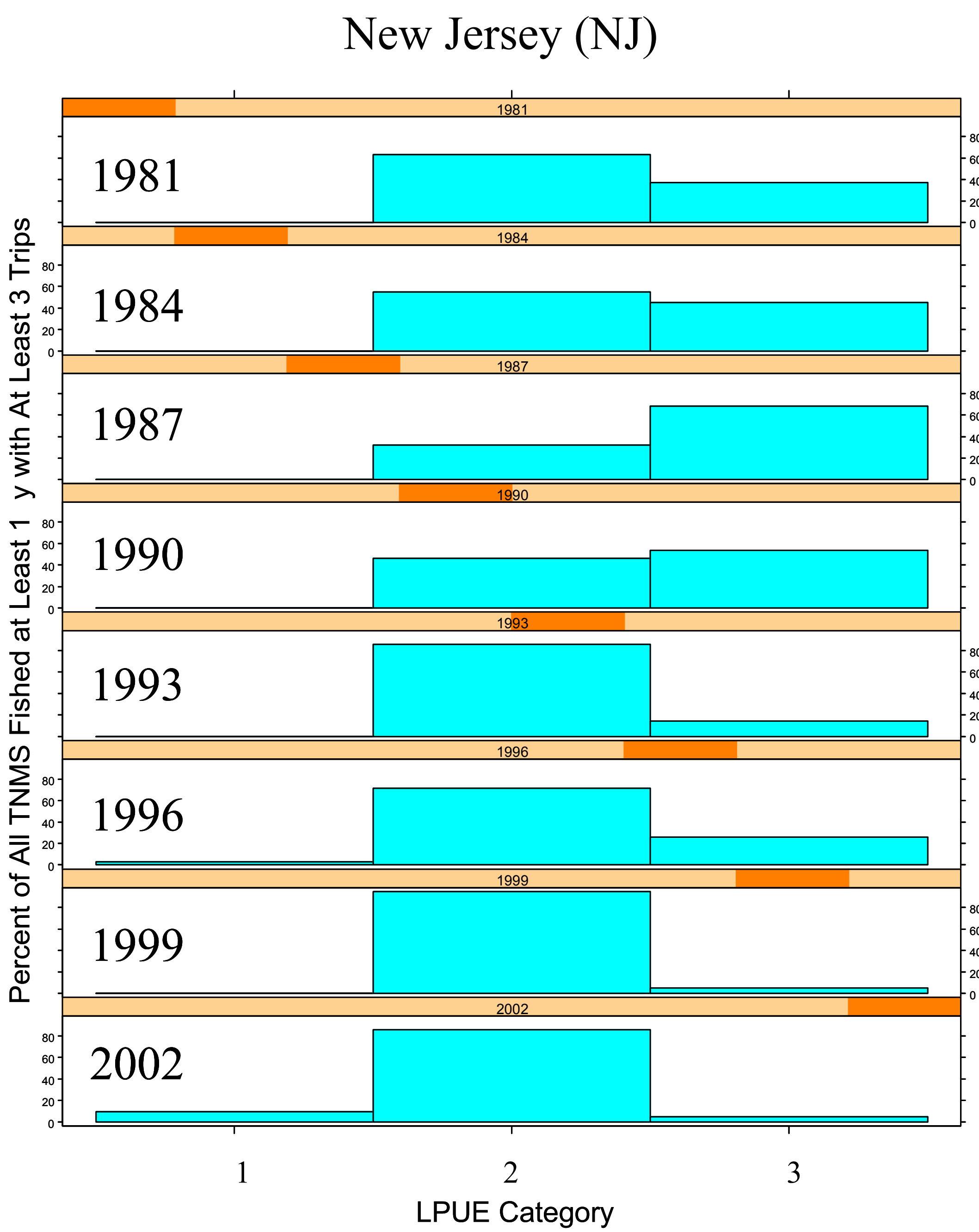
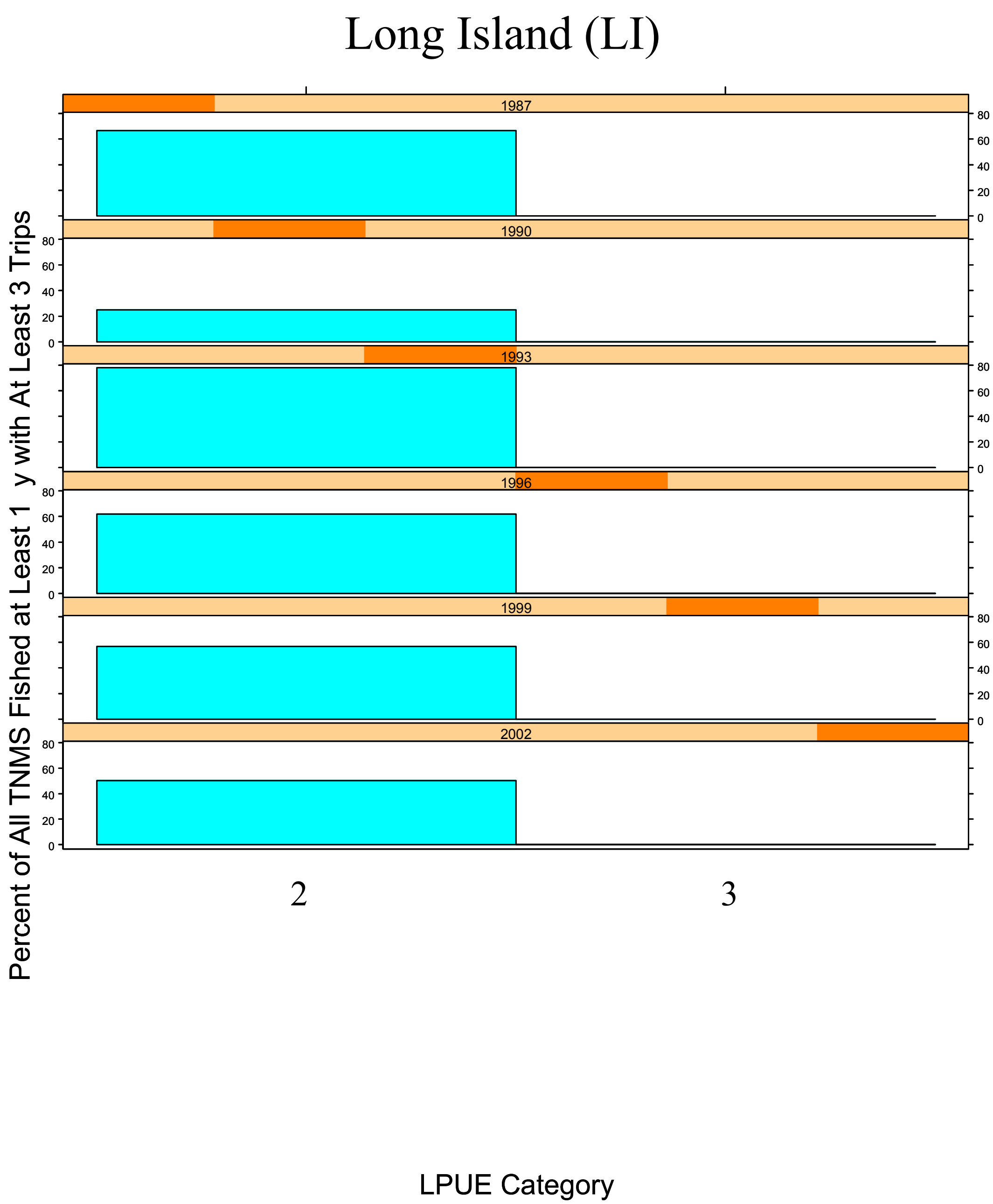


Figure A15. Frequency distribution of commercial catch rates, by TNMS, over time (NJ).



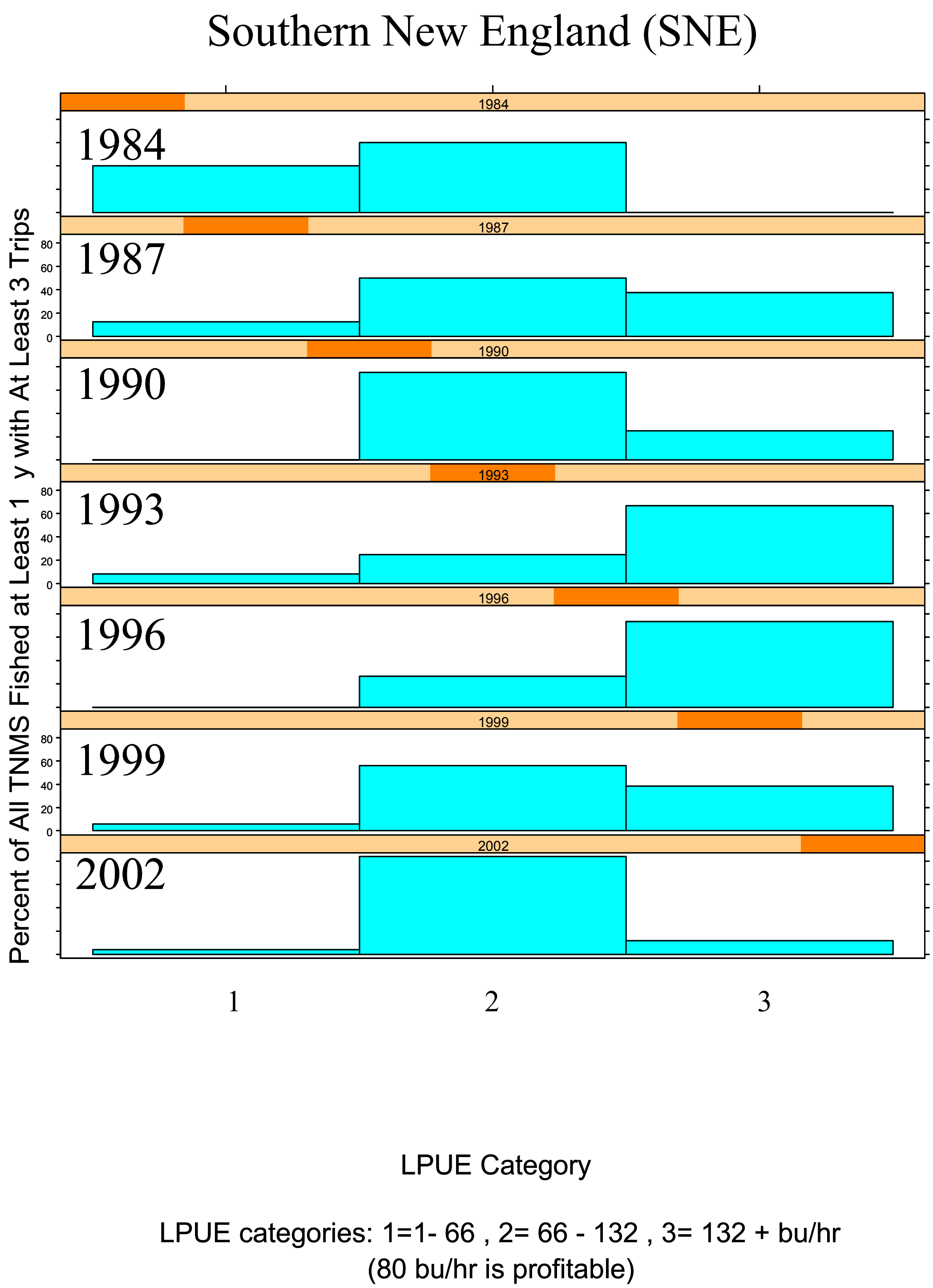
LPUE categories: 1=1- 66 , 2= 66 - 132 , 3= 132 + bu/hr
(80 bu/hr is profitable)

Figure A16. Frequency distribution of commercial catch rates, by TNMS, over time (LI).



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).



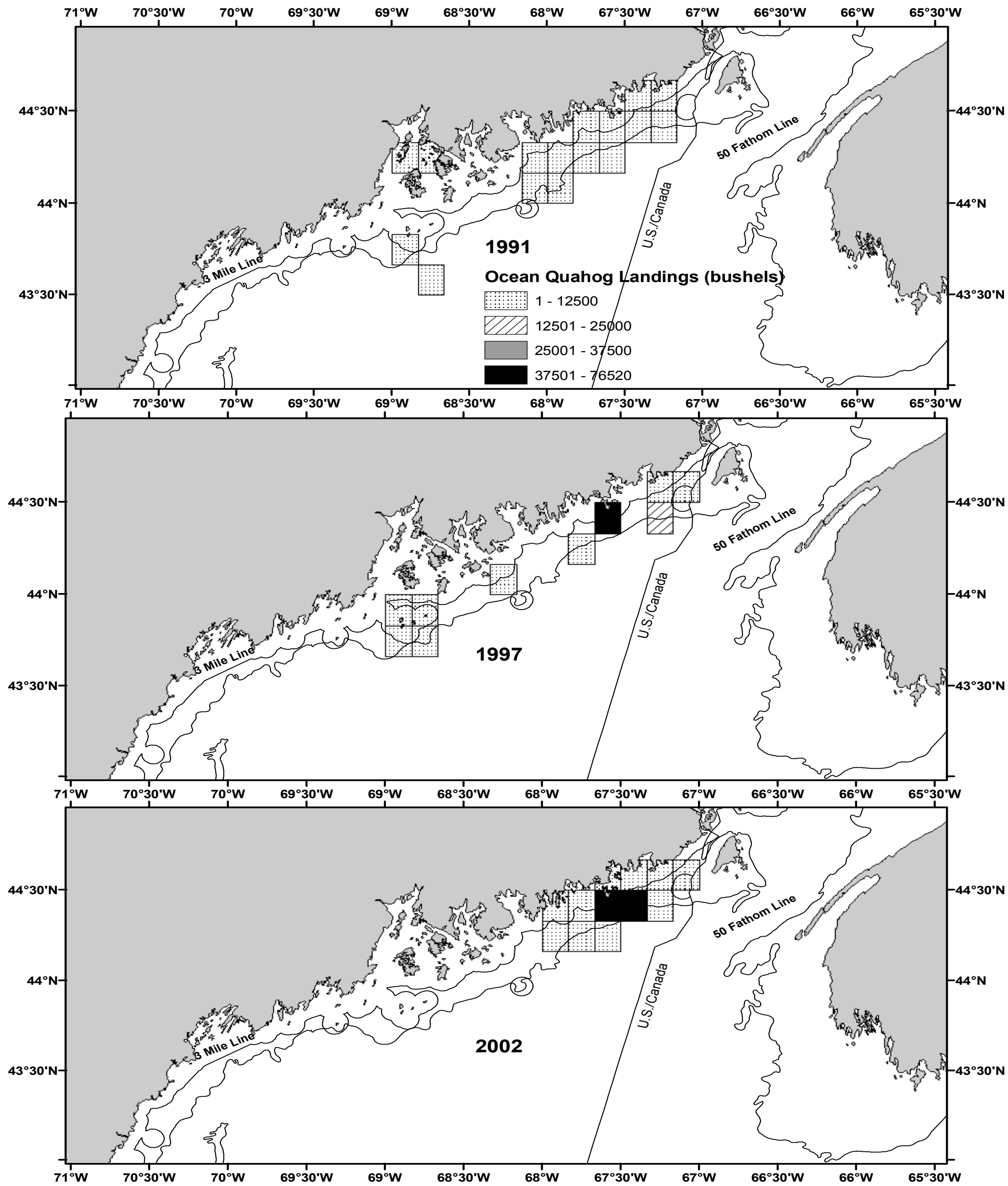


Figure A18. Ocean quahog landings from Ten Minute Squares (TNMS) off the coast of Maine.

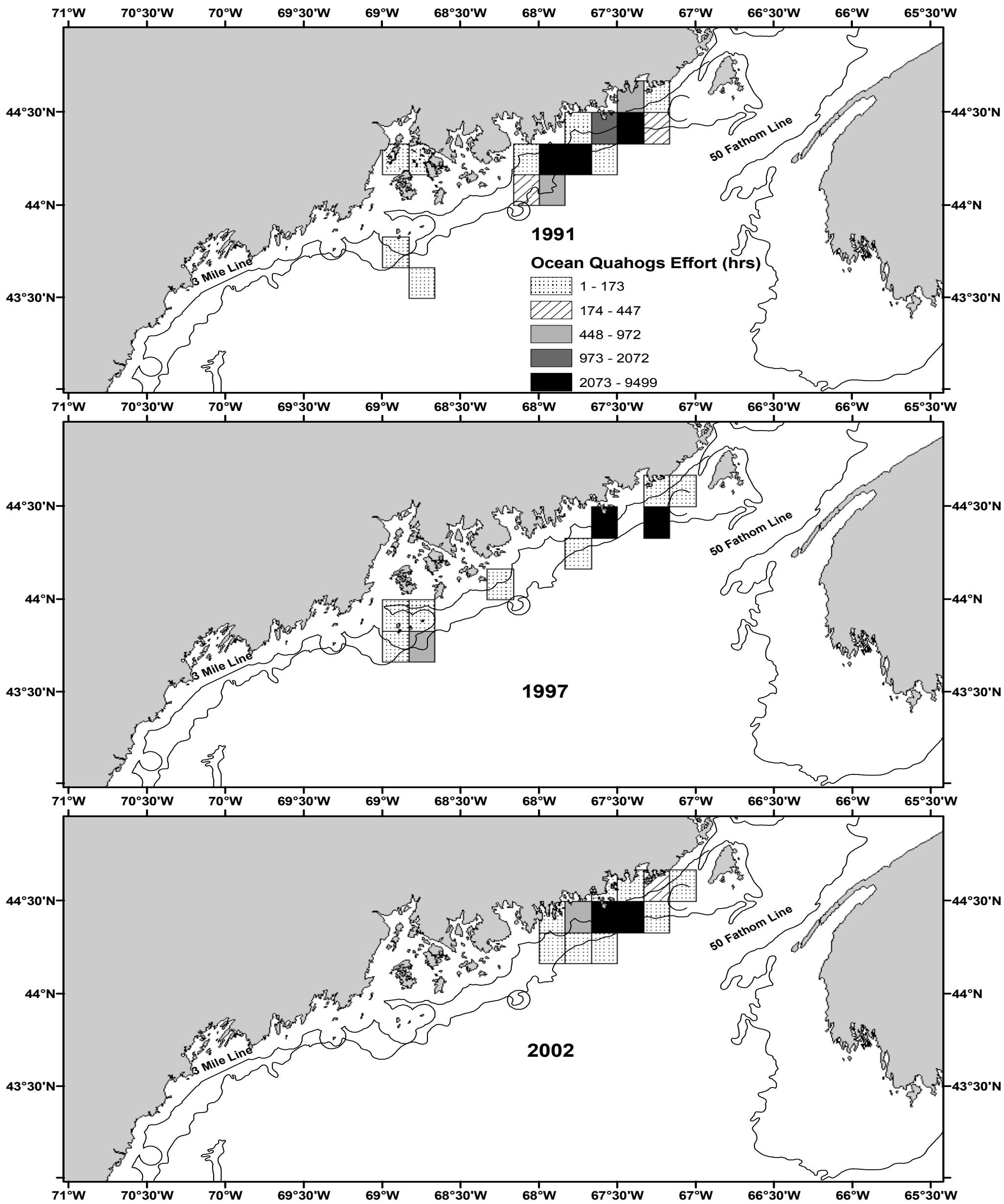


Figure A19. Ocean quahog fishing effort from Ten Minute Squares (TNMS) off the coast of Maine.

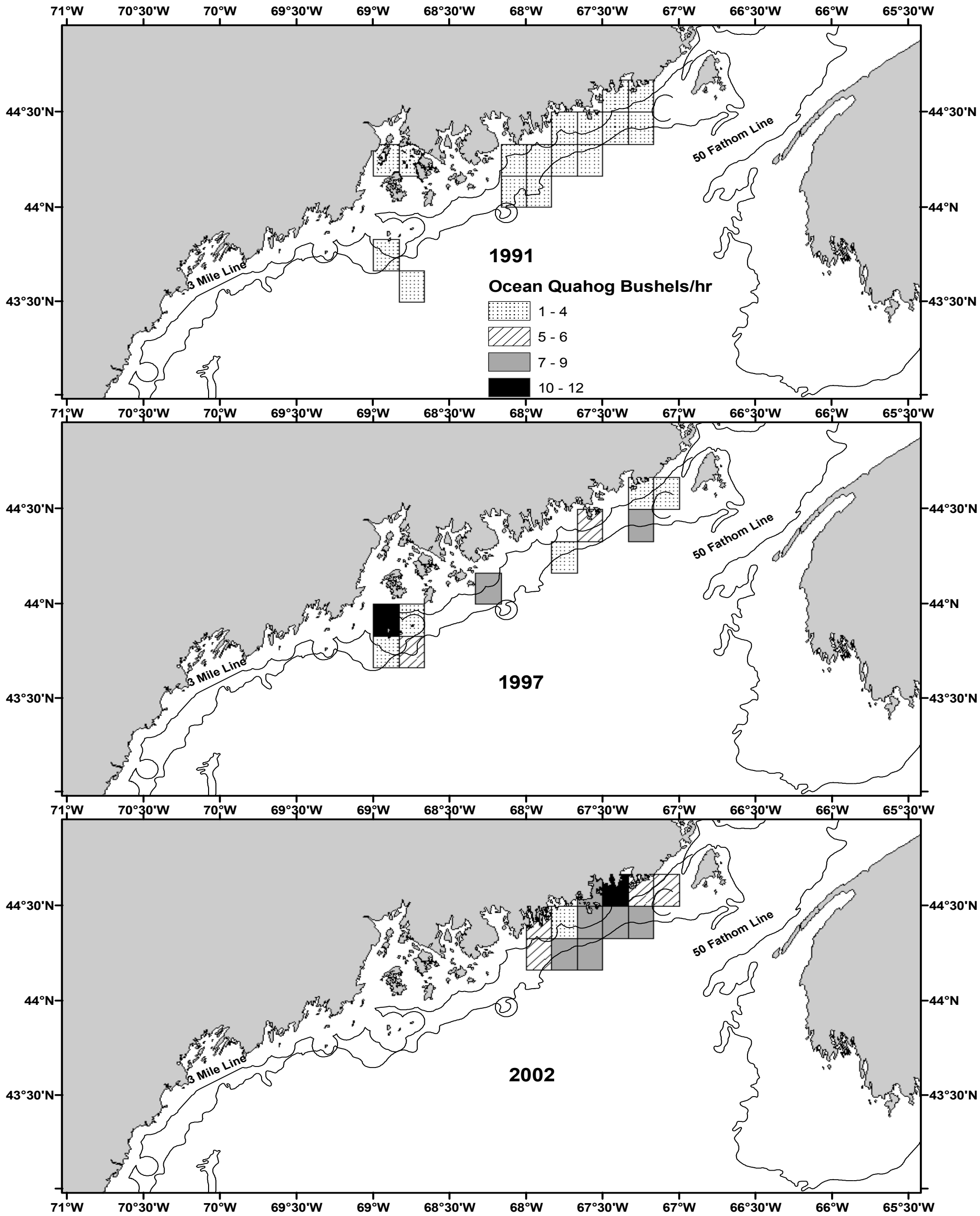


Figure A20. Ocean quahog landings per unit effort from Ten Minute Squares (TNMS) off the coast of Maine.

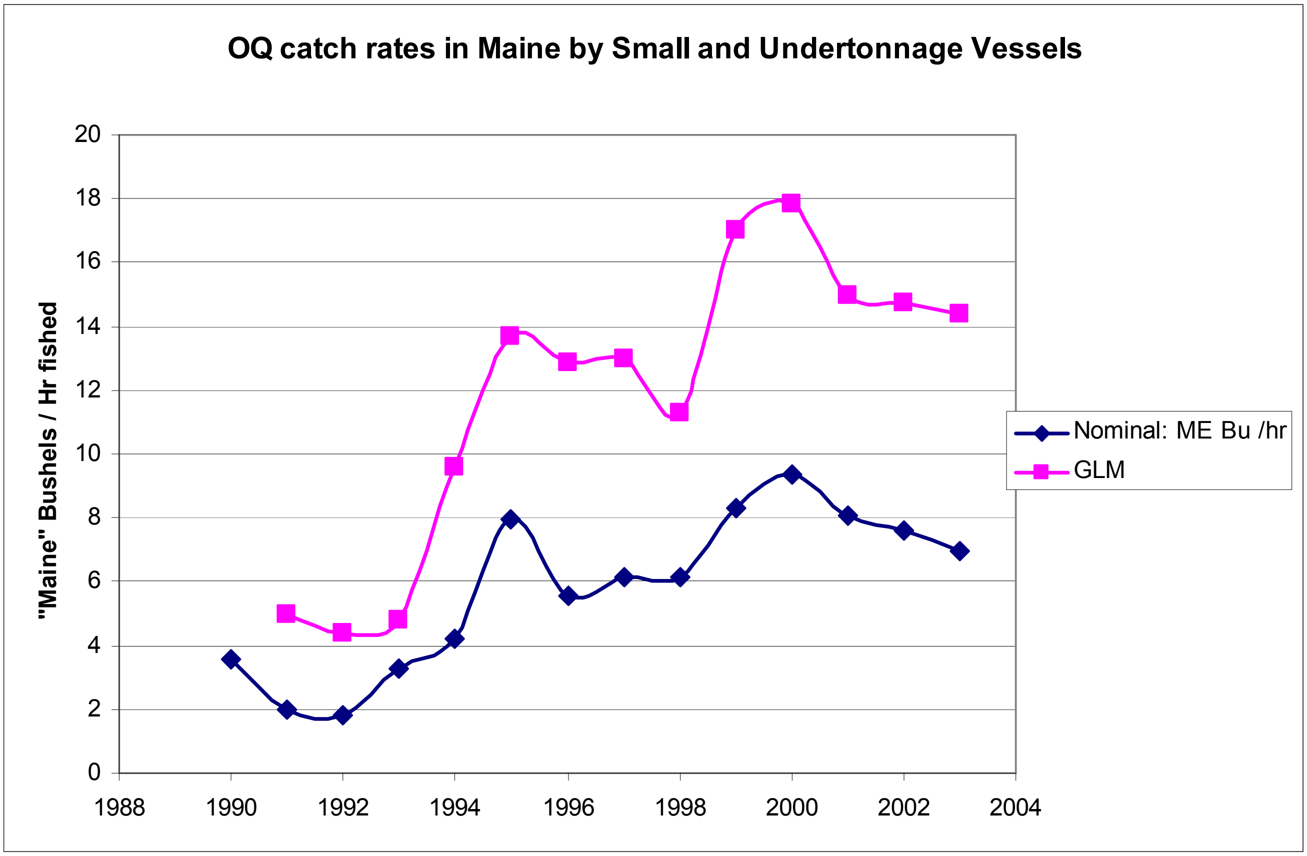


Figure A21. Ocean quahog landings per unit effort from off the coast of Maine. There are nominal values as well as standardized values from a General Linear Model (GLM).

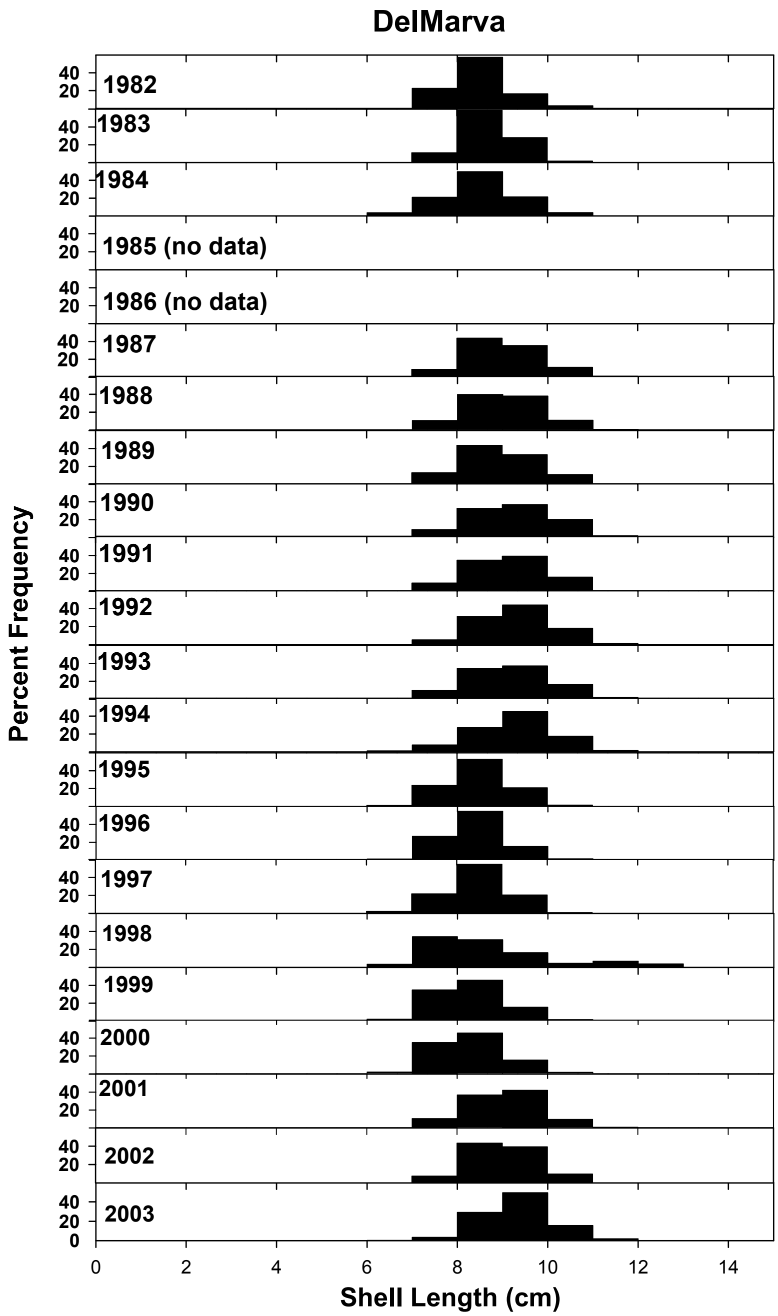


Figure A22. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.

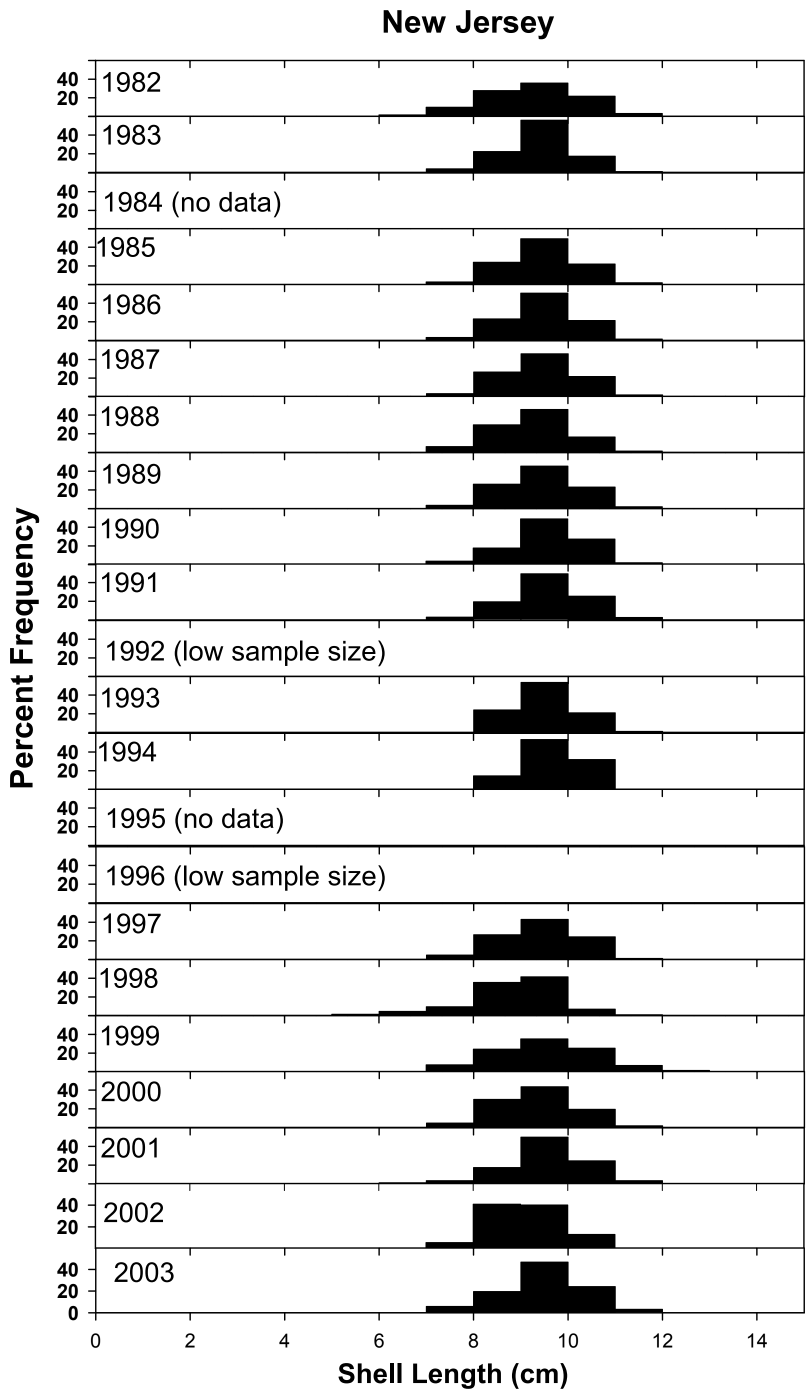


Figure A23. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.

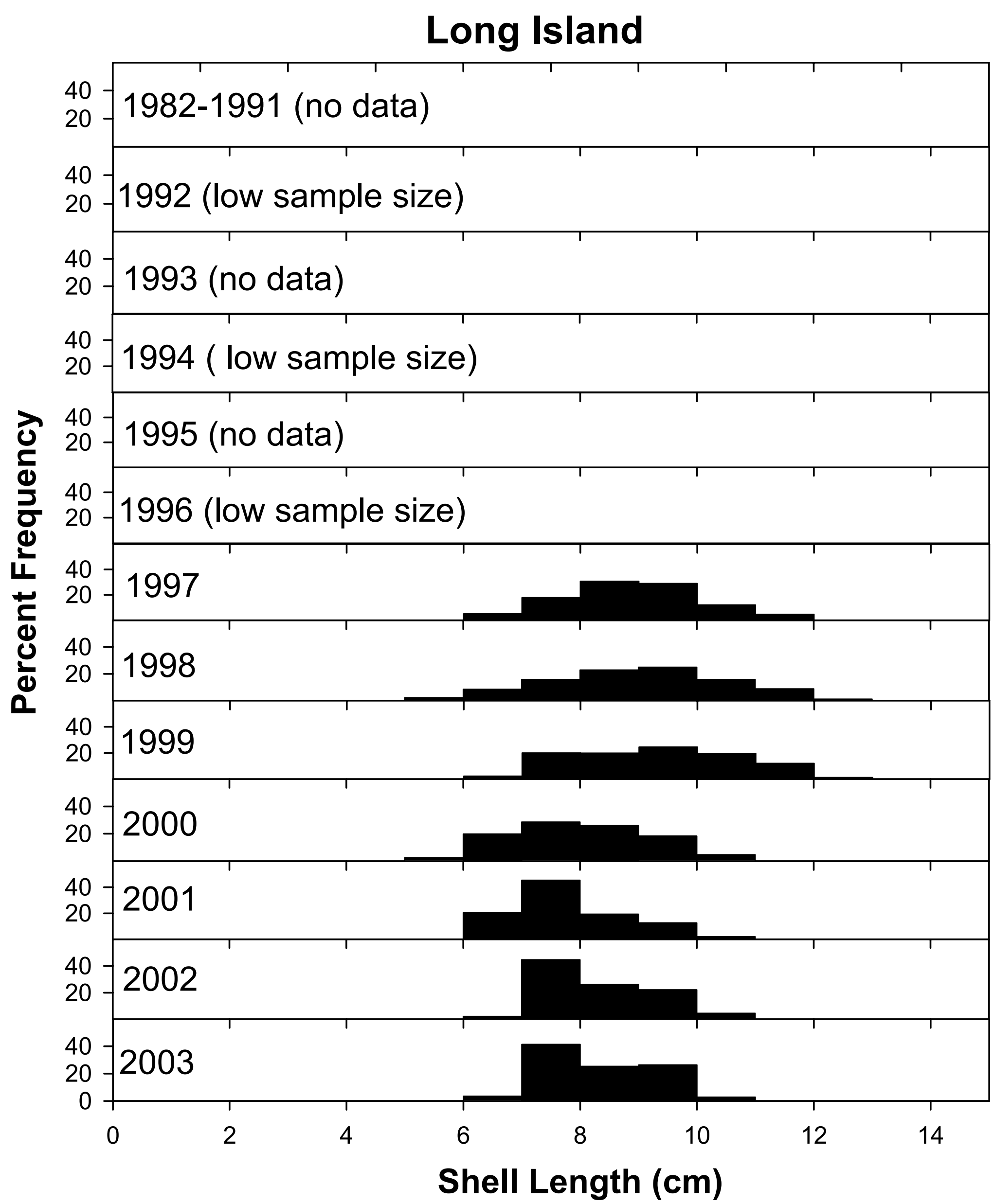


Figure A24. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.

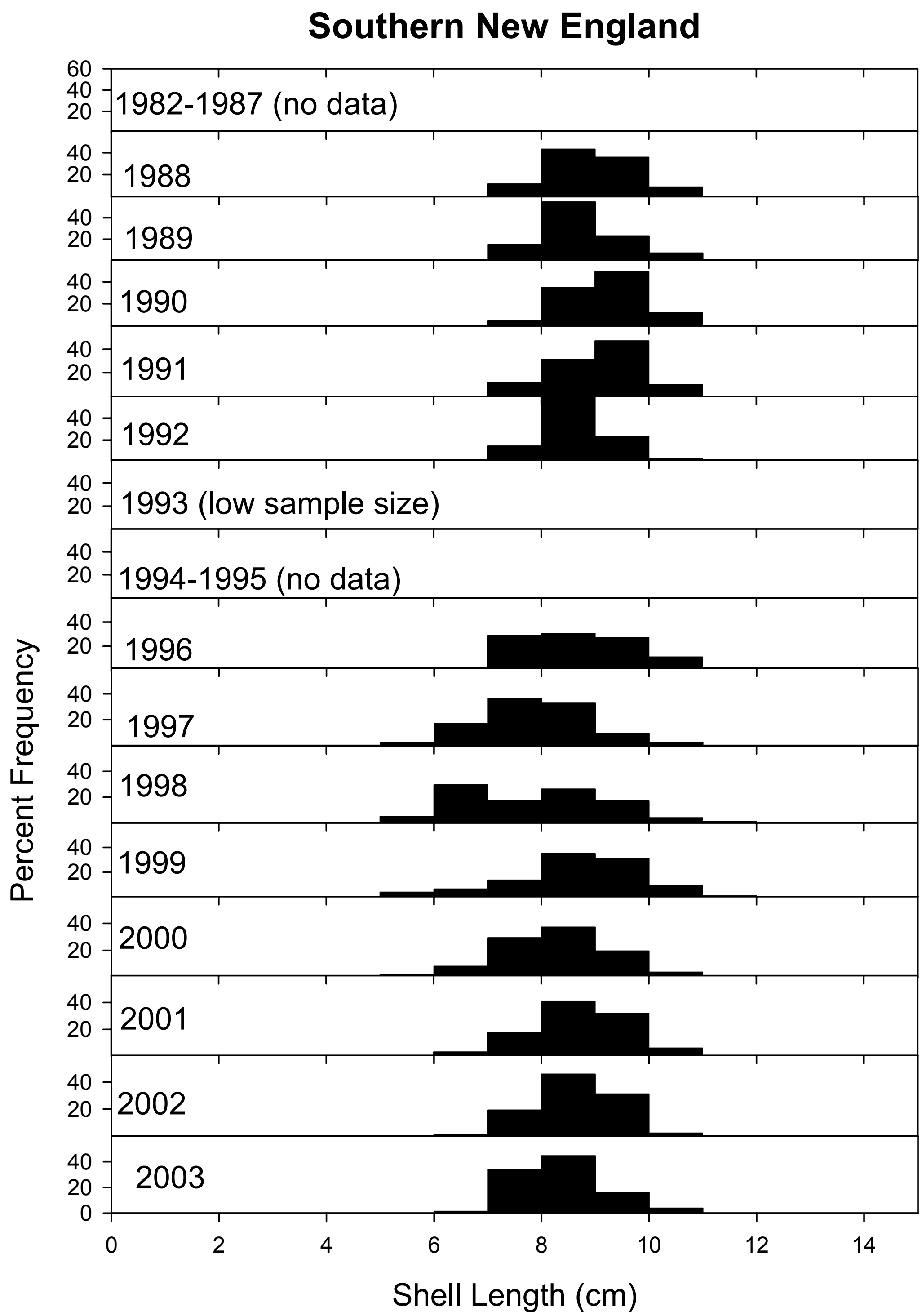


Figure A25. Length frequencies of ocean quahogs from port samples. Trips were catch-weighted.

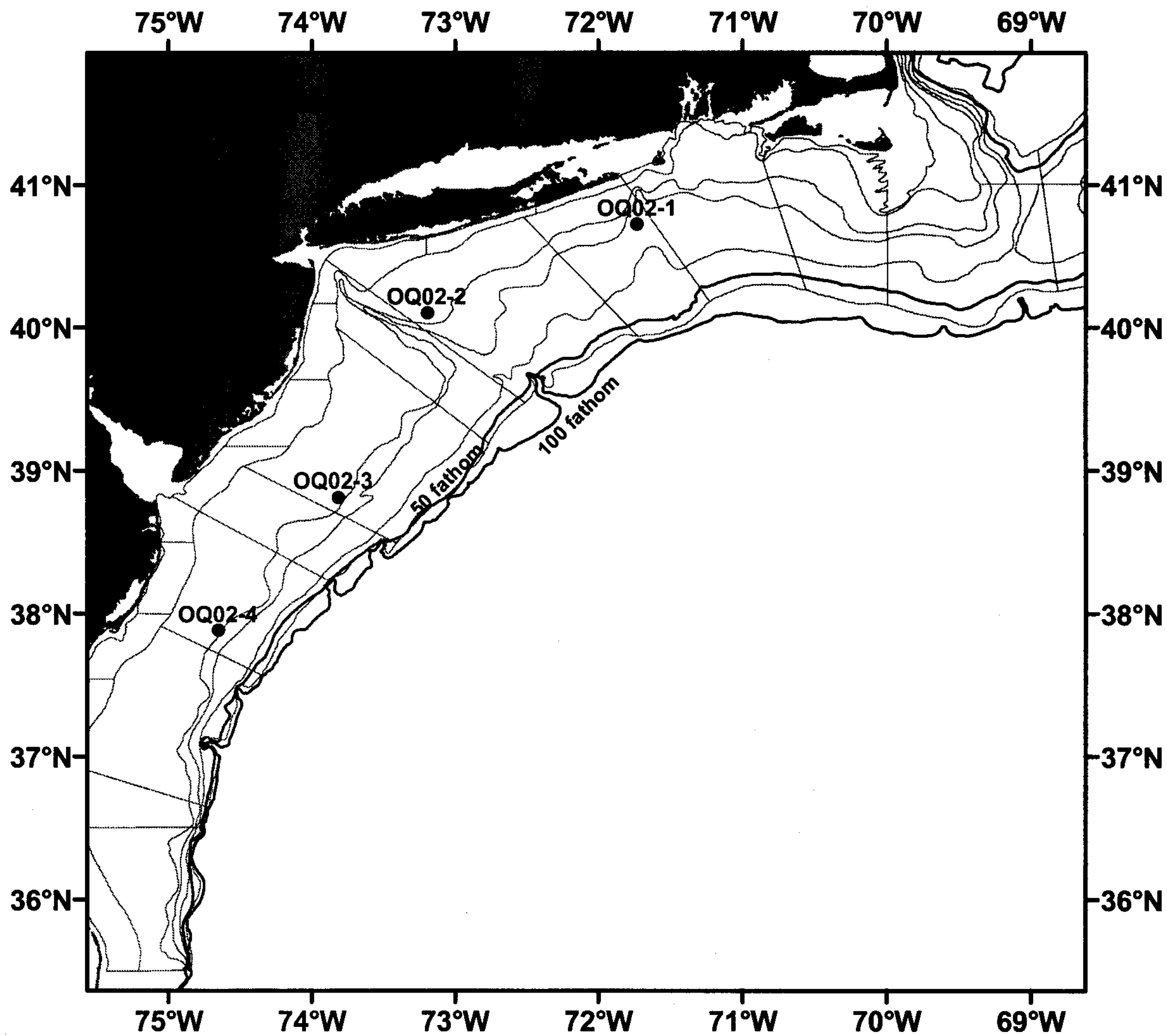


Figure A26.
Sites of ocean quahog depletion experiments with FV Lisa Kim in 2002.

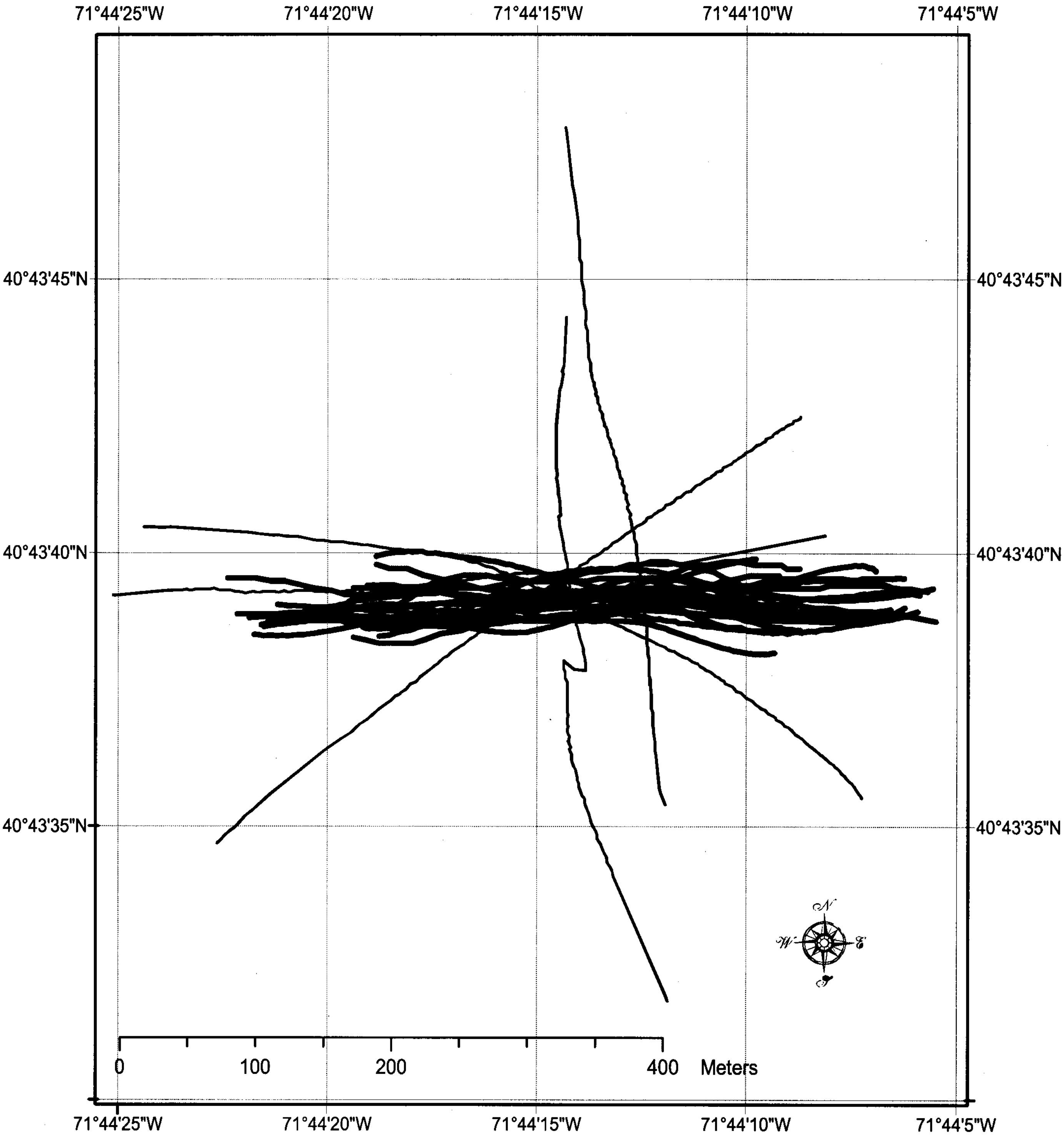


Fig. A27. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Lisa Kim* (darker lines), 2002, off LI (E) at site: oq02-1.

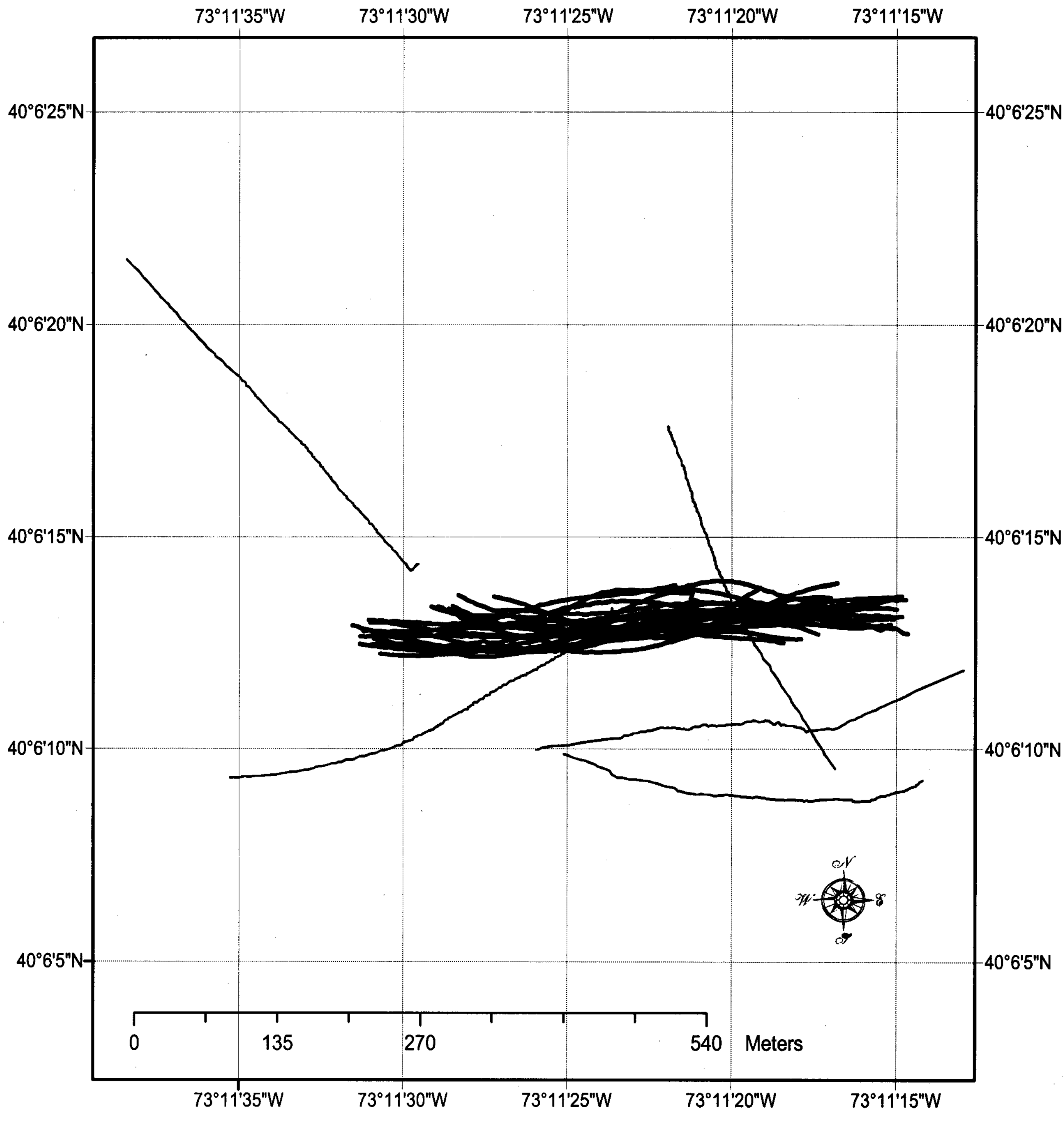


Fig. A28. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Lisa Kim* (darker lines), 2002, off LI (W) at site: oq02-2.

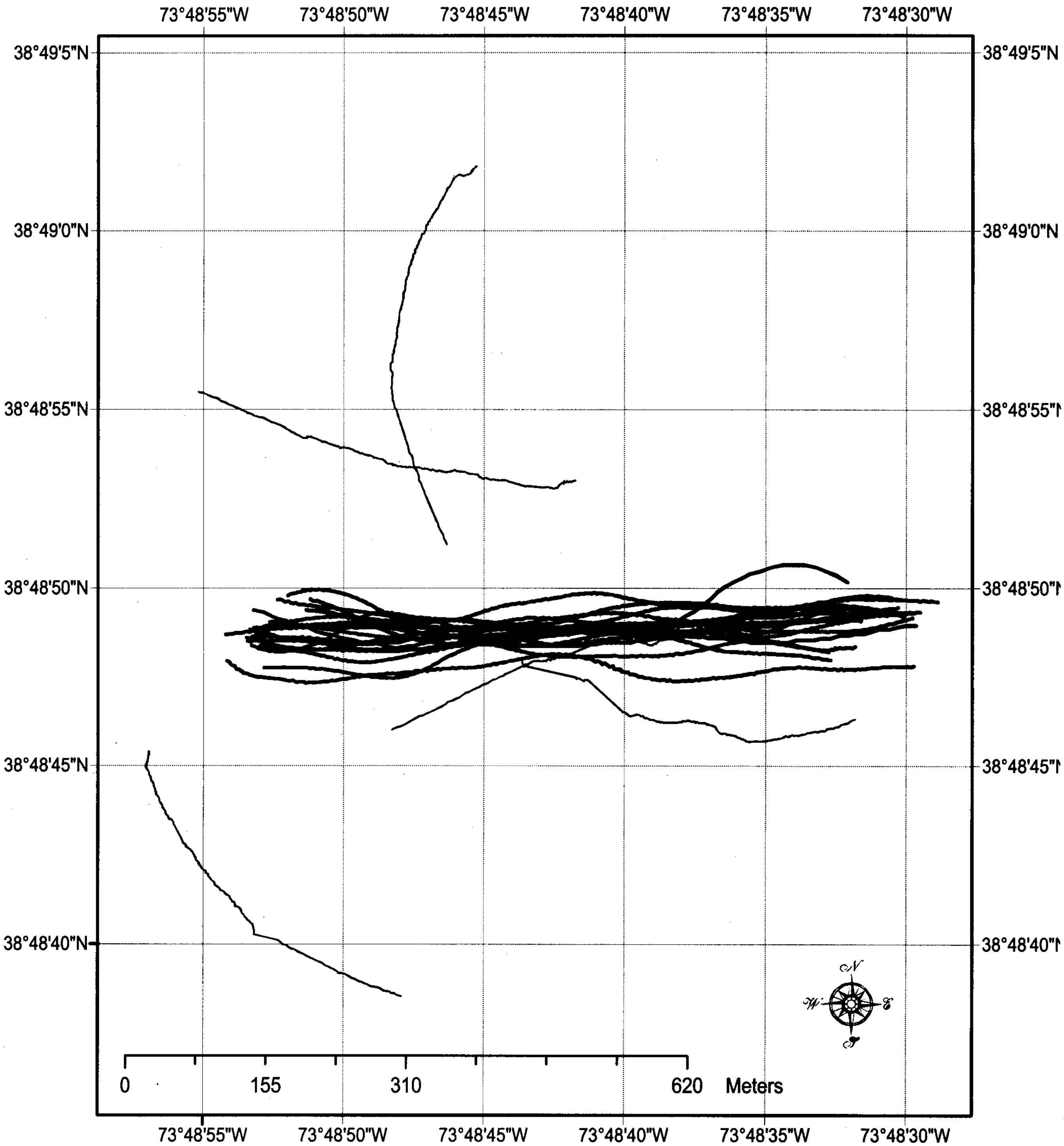


Fig. A29. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Lisa Kim* (darker lines), 2002, off SNJ at site: oq02-3.

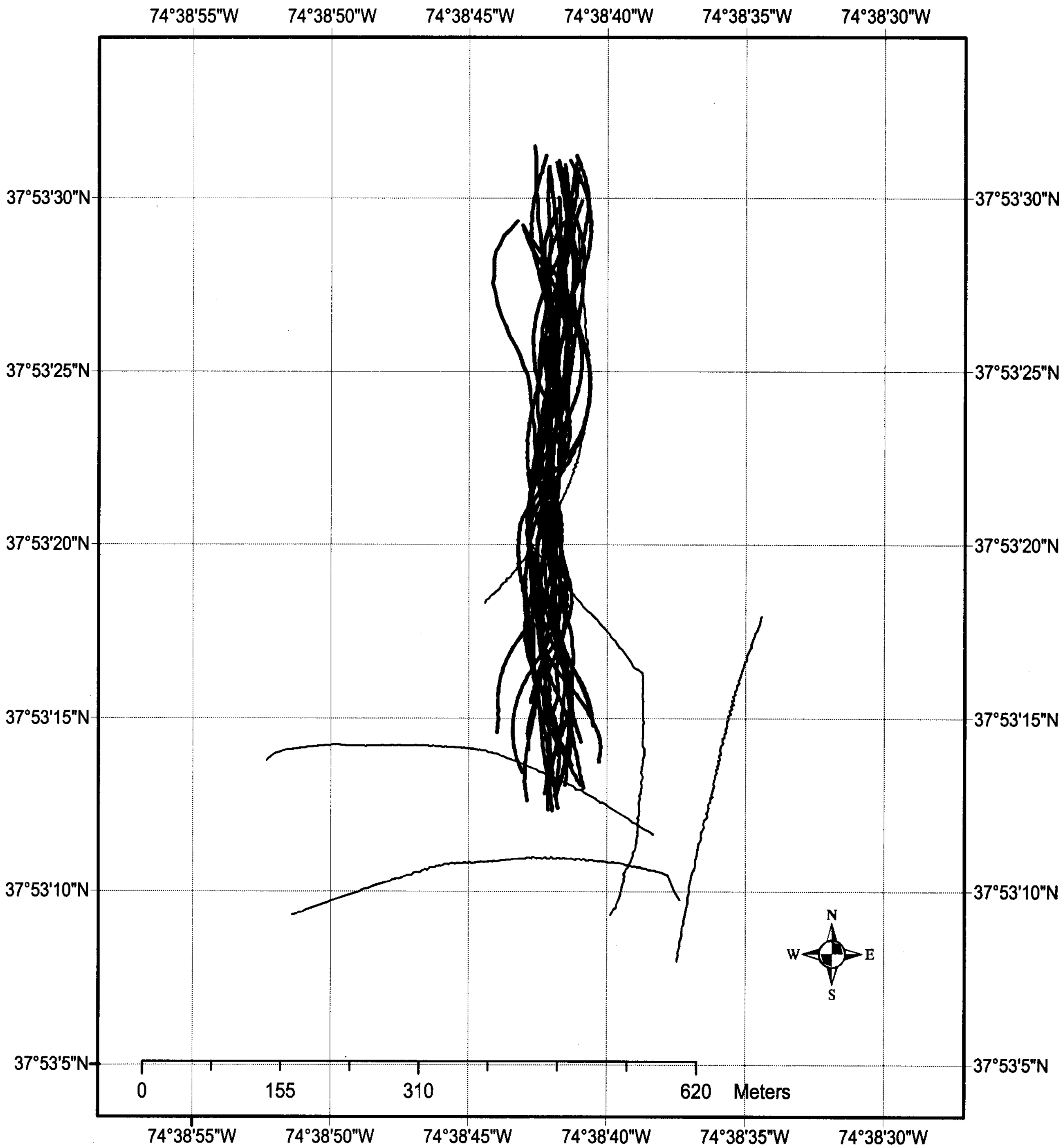
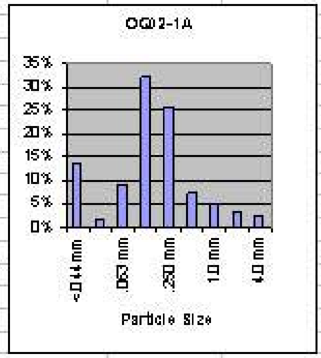
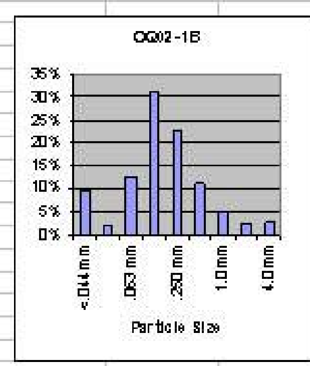


Fig. A30. Towpaths by the *R/V Delaware-II* setup tows (lighter lines) and the *F/V Lisa Kim* (darker lines), 2002, off Delmarva at site: oq02-4.

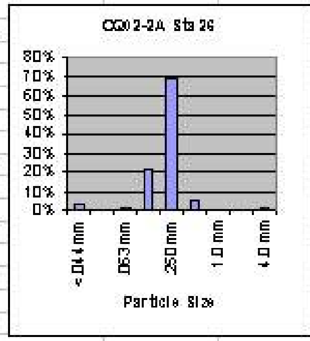
Particle Size	Q02-1A Mass	Percent
<.044mm	64.123	13.6%
.044mm	7.746	1.6%
.063mm	42.113	8.9%
.125mm	150.437	31.9%
.250mm	120.824	25.6%
.500mm	34.695	7.4%
1.0 mm	24.424	5.2%
2.0 mm	15.303	3.2%
4.0 mm	12.066	2.6%
Total Mass	471.731	100.0%



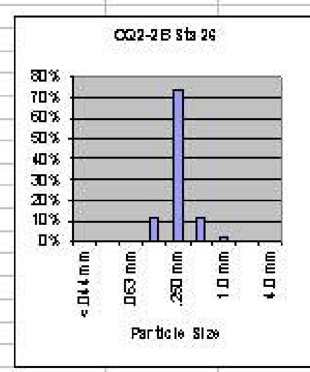
Particle Size	Q02-1B Mass	Percent
<.044mm	51.890	9.8%
.044mm	10.479	2.0%
.063mm	67.260	12.6%
.125mm	164.839	31.0%
.250mm	120.946	22.7%
.500mm	60.455	11.4%
1.0 mm	28.353	5.3%
2.0 mm	12.508	2.4%
4.0 mm	15.311	2.9%
Total Mass	532.041	100.0%



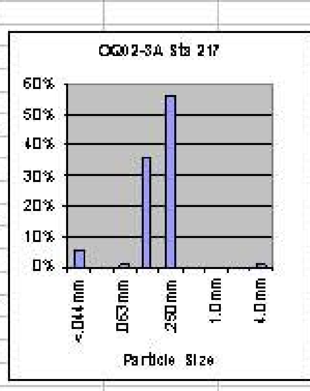
Particle Size	Q02-2A Sta 26 Mass	Percent
<.044mm	11.135	2.8%
.044mm	0.311	0.1%
.063mm	6.677	1.7%
.125mm	83.066	20.7%
.250mm	275.183	68.5%
.500mm	21.239	5.3%
1.0 mm	1.010	0.3%
2.0 mm	0.963	0.2%
4.0 mm	1.901	0.5%
Total Mass	401.485	100.0%



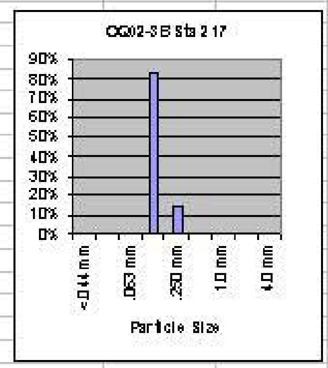
Particle Size	Q02-2B Sta 26 Mass	Percent
<.044mm	4.812	1.0%
.044mm	0.538	0.1%
.063mm	3.873	0.8%
.125mm	53.236	10.8%
.250mm	359.471	73.2%
.500mm	58.116	11.8%
1.0 mm	6.018	1.2%
2.0 mm	3.728	0.8%
4.0 mm	1.016	0.2%
Total Mass	490.808	100.0%



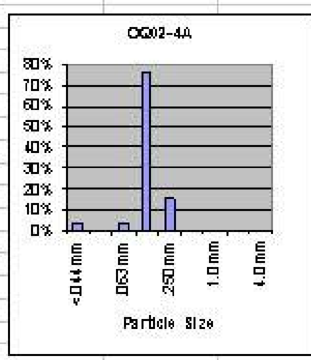
Particle Size	Q02-3A Sta 217 Mass	Percent
<.044mm	19.272	5.4%
.044mm	0.126	0.0%
.063mm	2.810	0.8%
.125mm	127.733	35.9%
.250mm	201.327	56.5%
.500mm	0.638	0.2%
1.0 mm	0.121	0.0%
2.0 mm	0.450	0.1%
4.0 mm	3.670	1.0%
Total Mass	356.147	100.0%



Particle Size	0Q02-3B Sta 217 Mass	Percent
<.044mm	2.902	0.9%
.044mm	0.200	0.1%
.063mm	3.107	1.0%
.125mm	260.436	83.5%
.250mm	44.546	14.3%
.500mm	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%



Particle Size	0Q02-4A Mass	Percent
<.044mm	24.093	4.0%
.044mm	0.911	0.2%
.063mm	23.894	4.0%
.125mm	451.165	75.7%
.250mm	94.877	15.9%
.500mm	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%



Particle Size	0Q02-4B Mass	Percent
<.044mm	3.976	0.9%
.044mm	0.468	0.1%
.063mm	18.515	4.1%
.125mm	426.709	93.4%
.250mm	6.662	1.5%
.500mm	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%

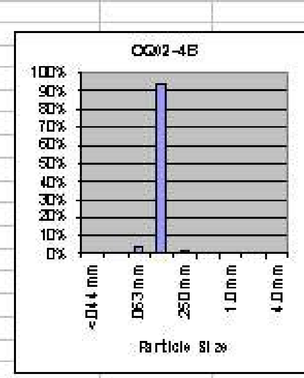


Fig. A31. Grain size analysis for the 4 sites where ocean quahog depletion experiments were carried out in 2002.

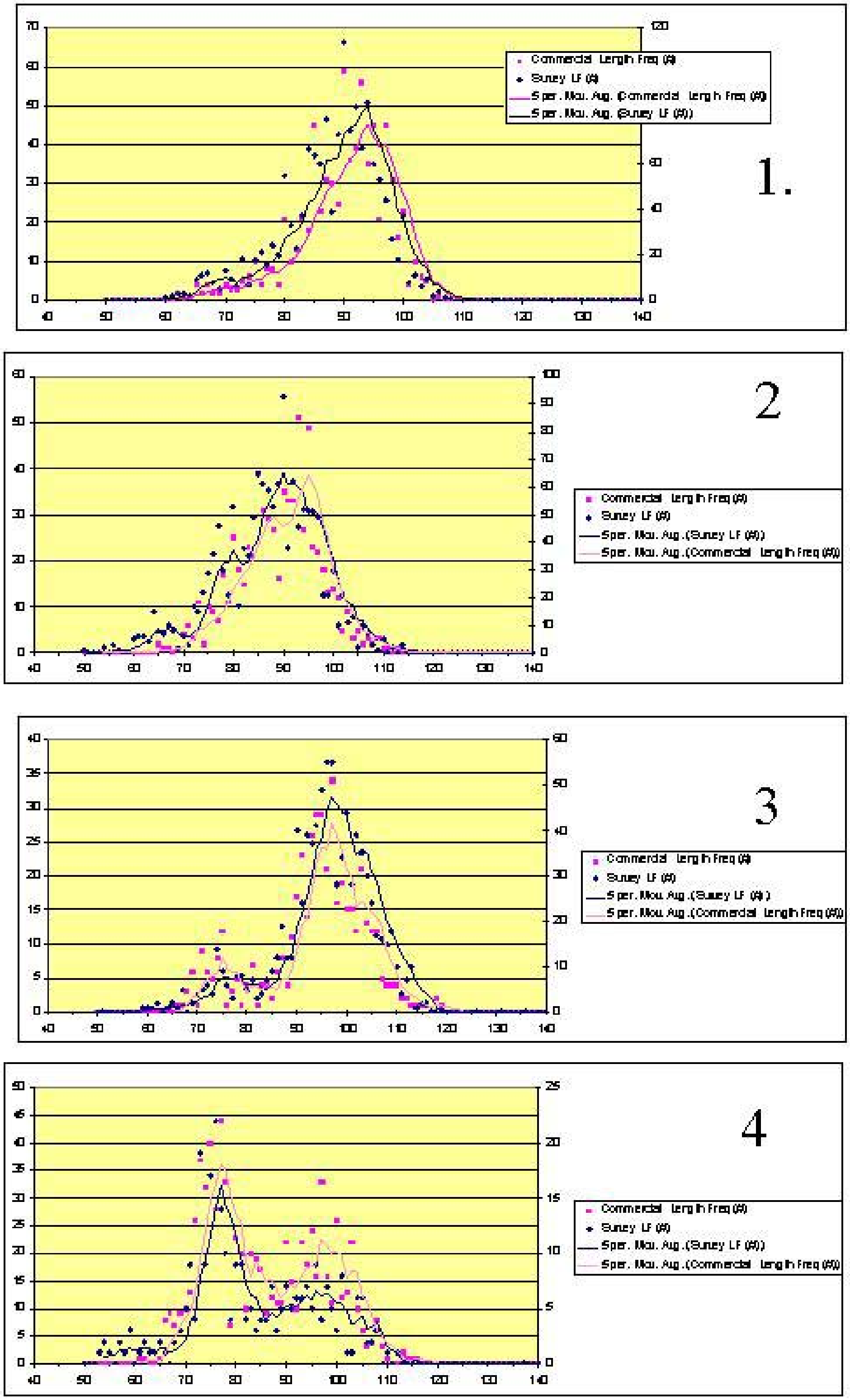


Fig. A32. Comparison of Raw Catch Length Freq. By the DE-II and FV Lisa Kim in 4 depletion exps in 2002.

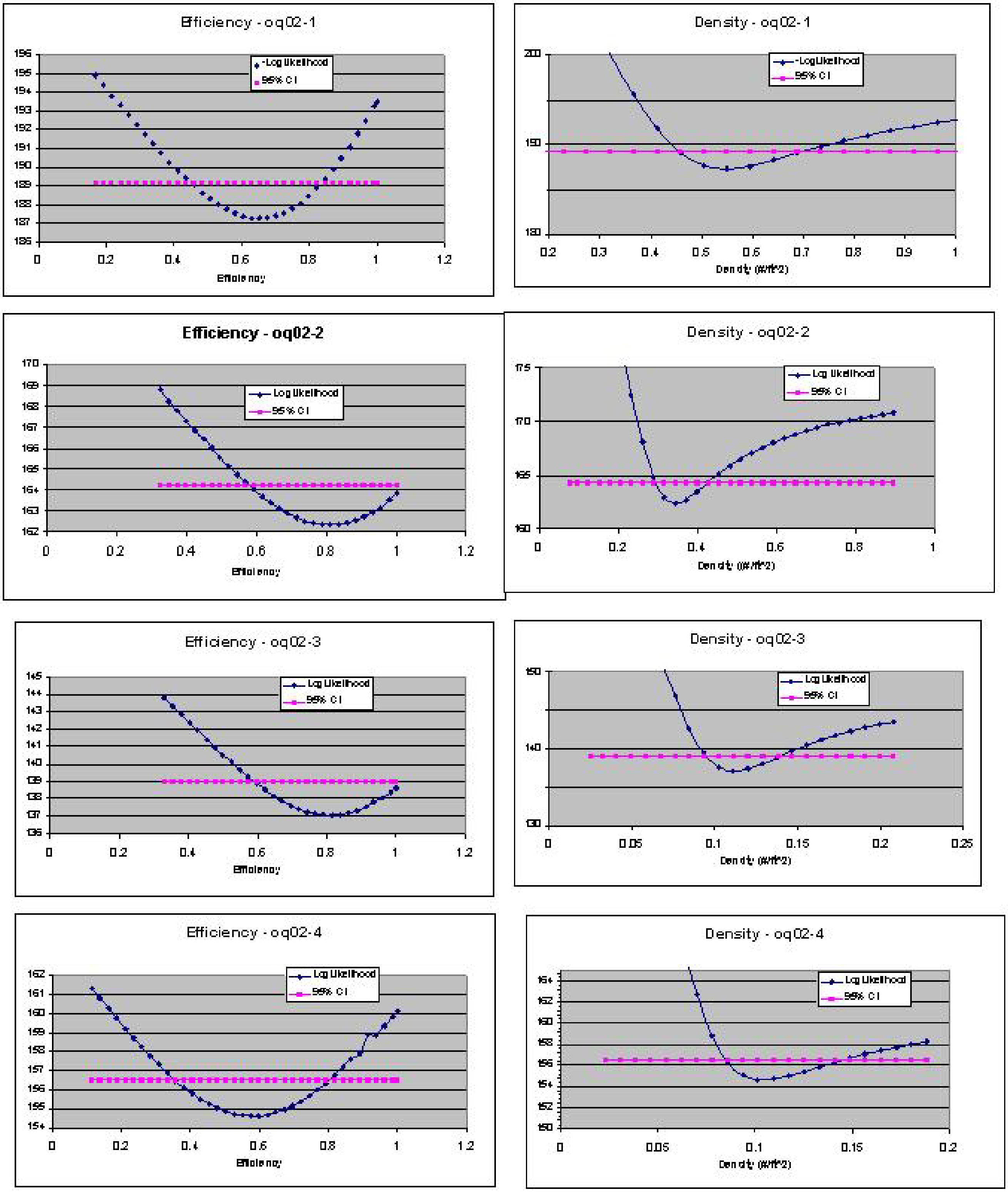


Fig. A33. 95% CI's for Efficiency and Density estimates for the FV Lisa Kim catching ocean quahogs in 4 depletion exps in 2002.

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

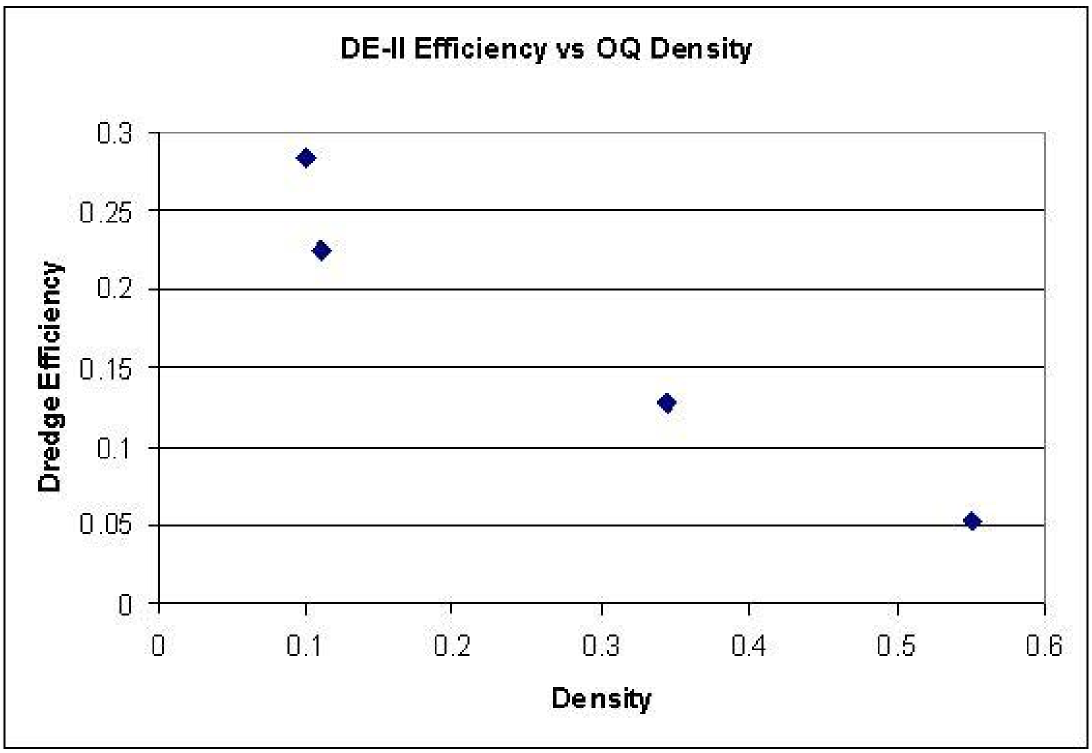
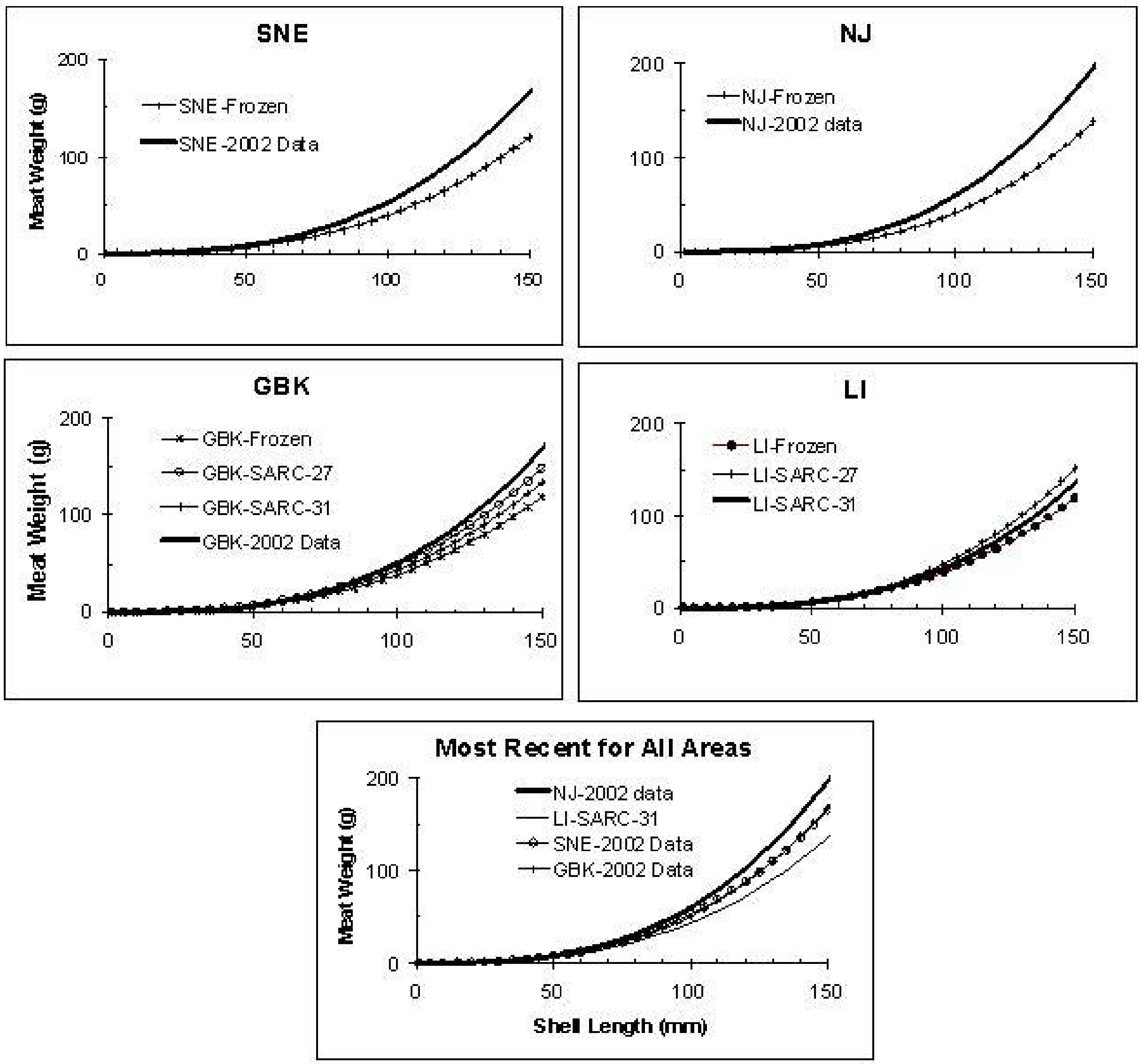


Figure A34.

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).



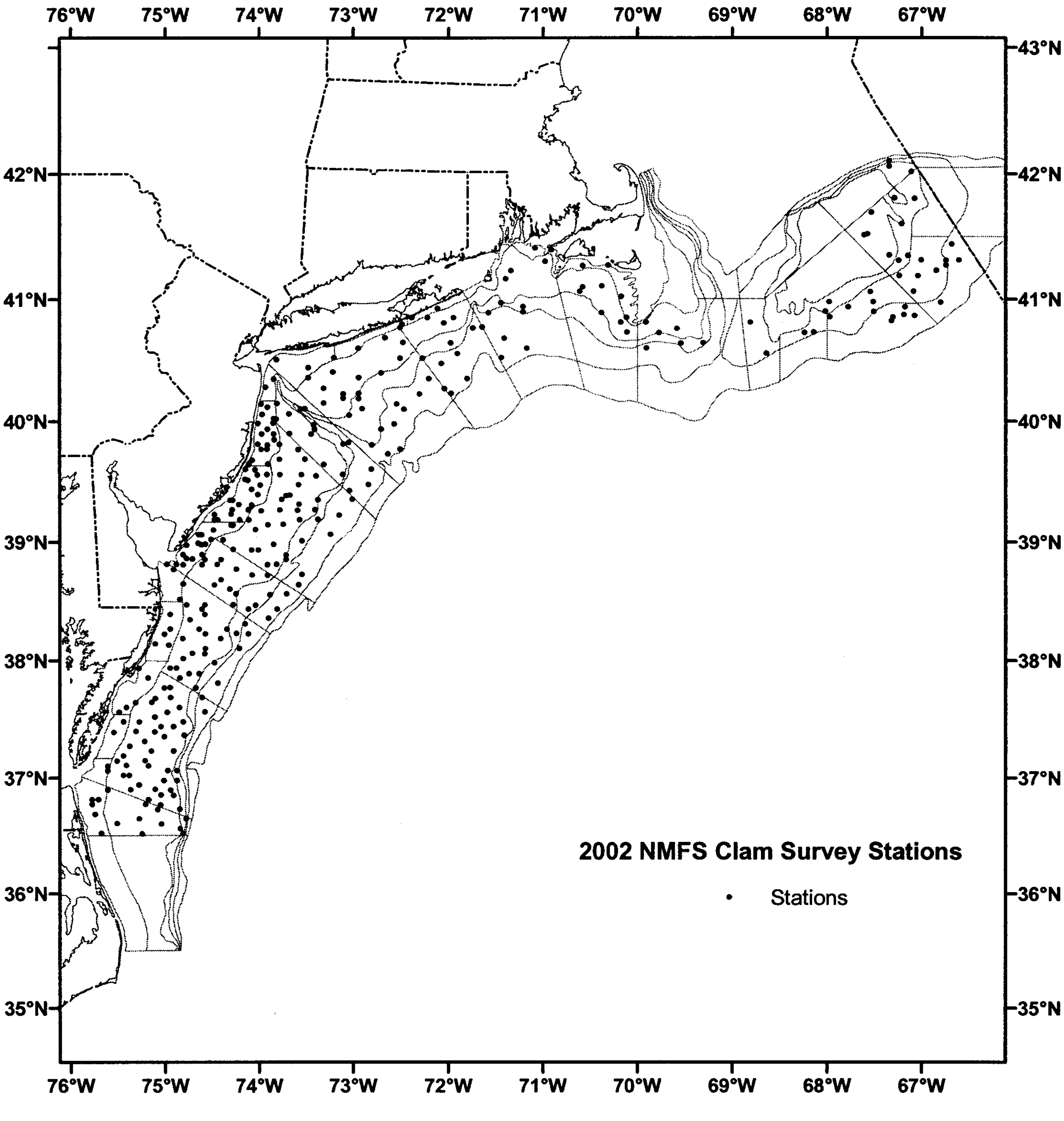


Fig. A36. NMFS clam survey station locations in 2002.

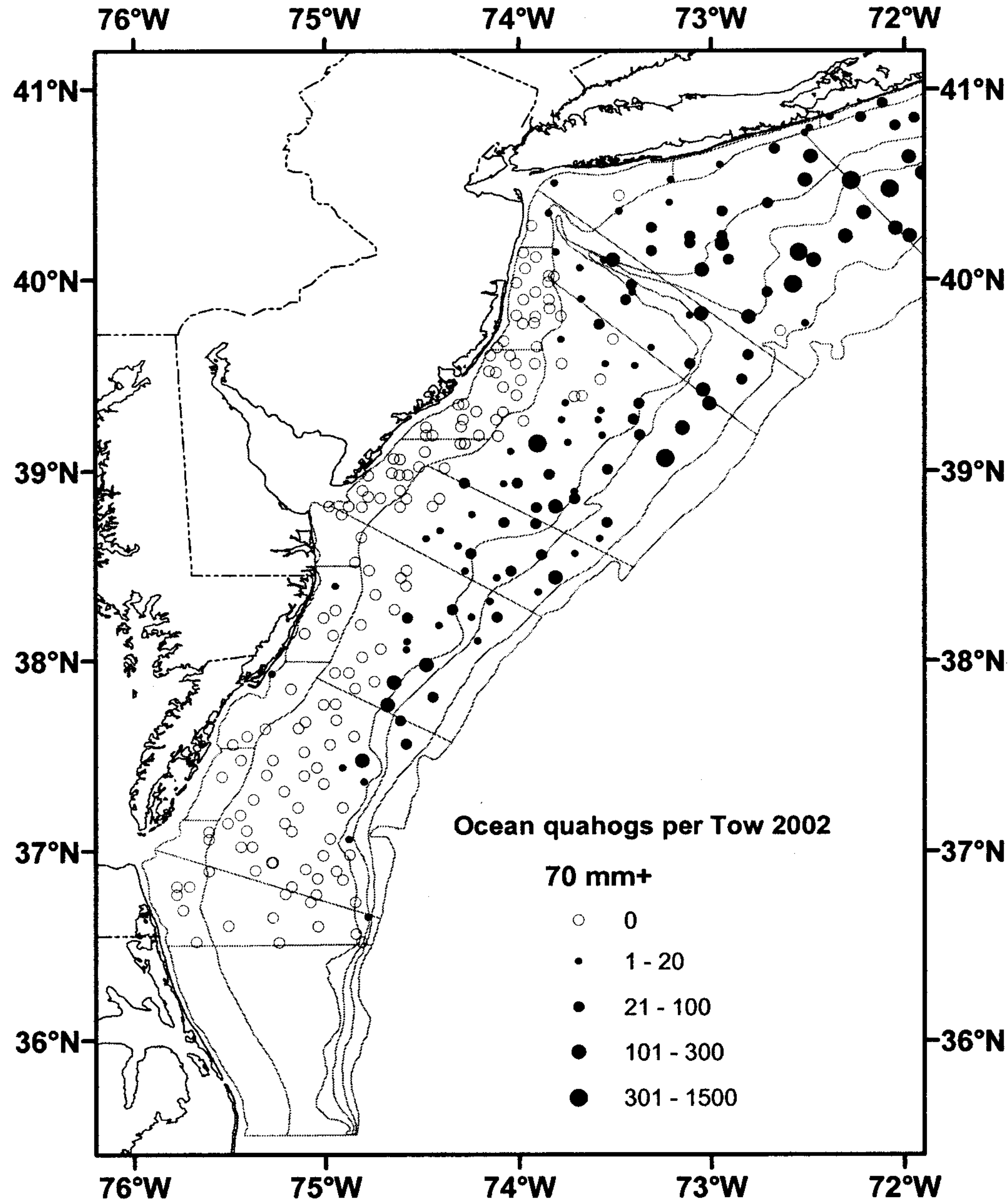


Fig. A37. Distribution of ocean quahog abundance per tow (>=70 mm), during the 2002 NEFSC survey, adjusted to 0.15nmi tow distance with sensor data. Clam strata boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-120m.

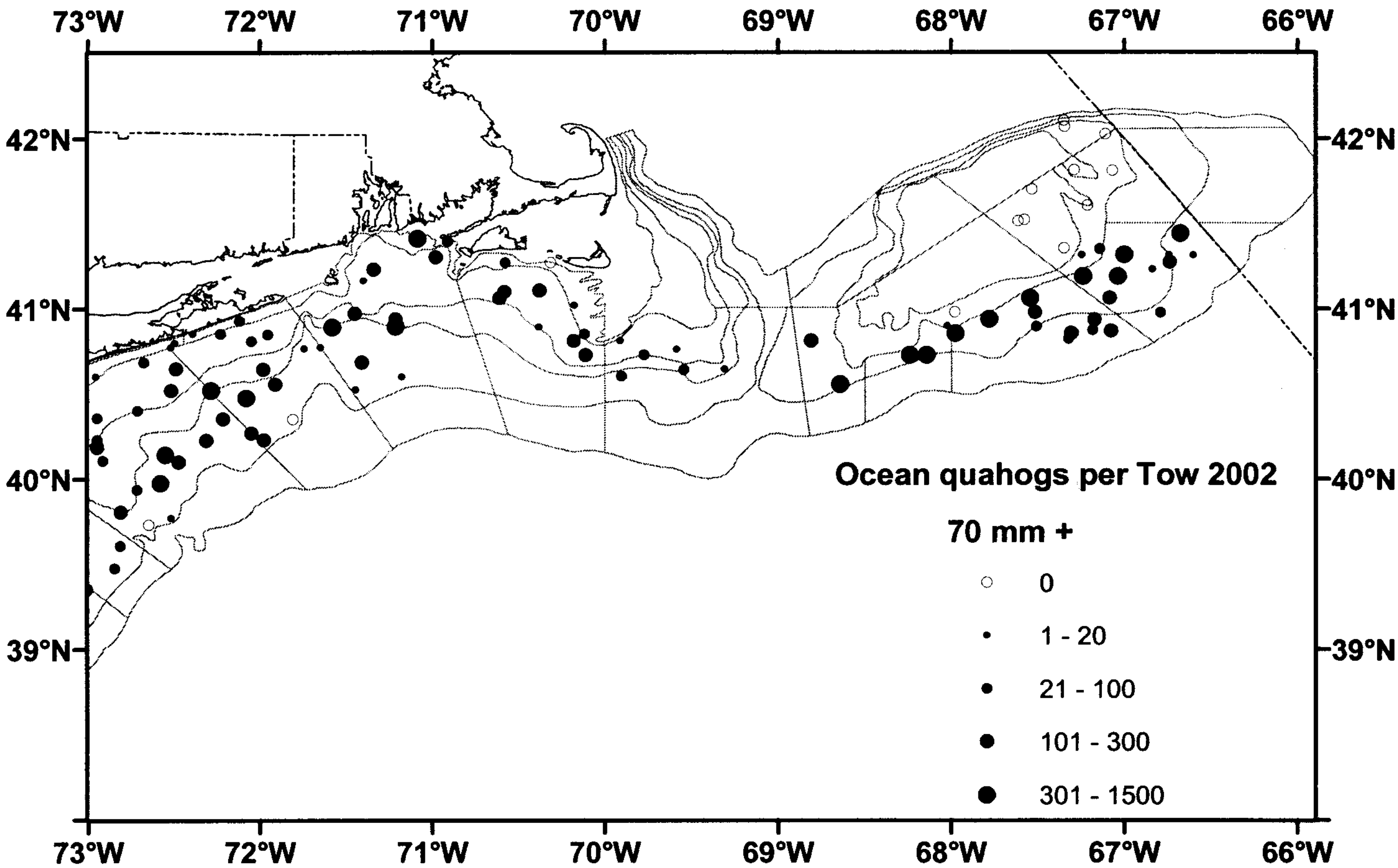


Fig. A38. Distribution of ocean quahog abundance per tow (>=70 mm), during the 2002 NEFSC survey, adjusted to 0.15nmi tow distance with sensor data. Clam strata boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-120m.

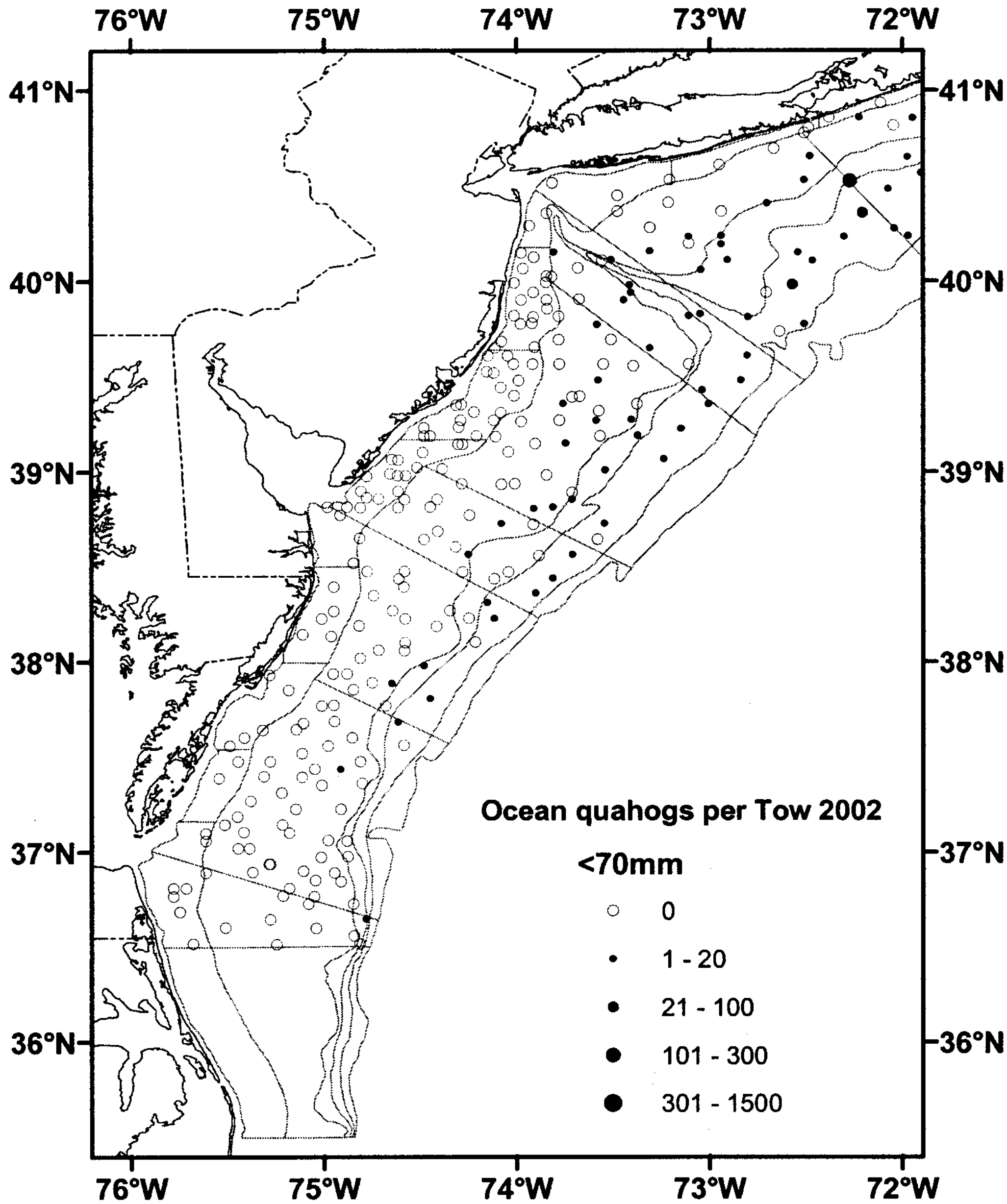


Fig. A39. Distribution of ocean quahog abundance per tow (<70 mm), during the 2002 NEFSC survey, adjusted to 0.15nmi tow distance with sensor data. Clam strata boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-120m.

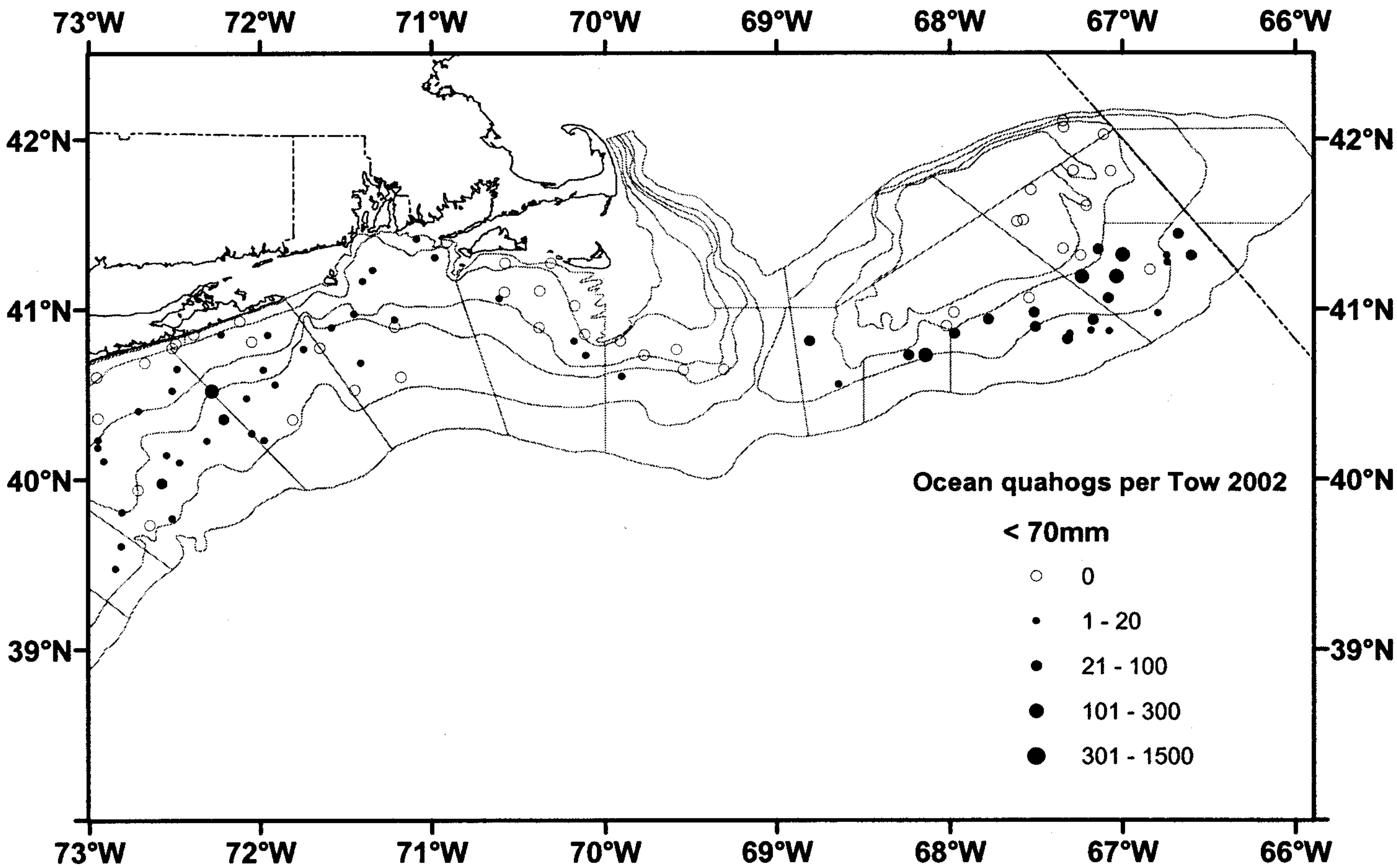


Fig. A40. Distribution of ocean quahog abundance per tow (<70 mm), during the 2002 NEFSC survey, adjusted to 0.15nmi tow distance with sensor data. Clam strata boundaries are 10-31m,31-50m, 51-60m,61-80m and 81-120m.

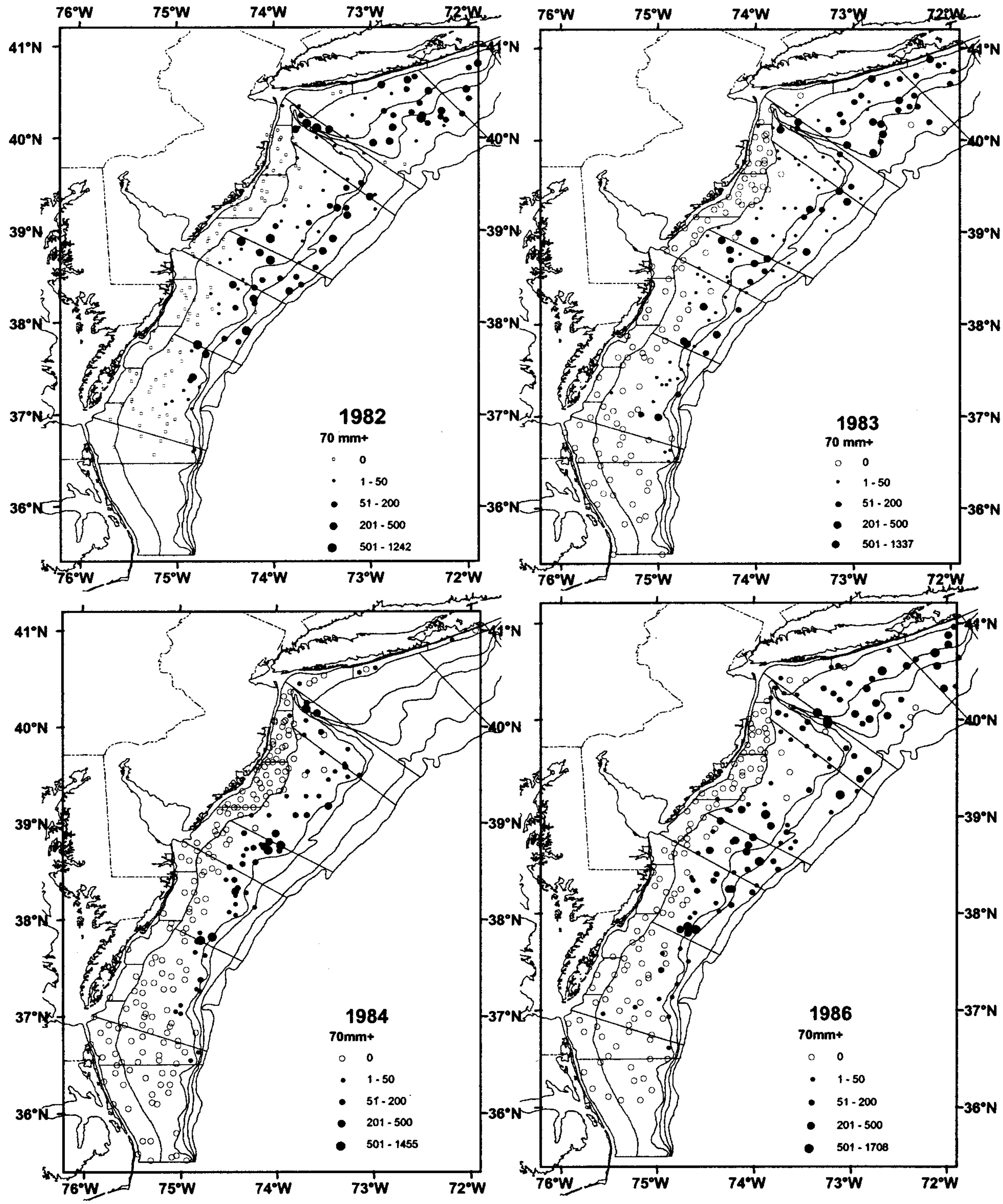


Fig. A41. Catch per tow of ocean quahogs (70mm+) in NMFS clam surveys. 1982 – 1986.

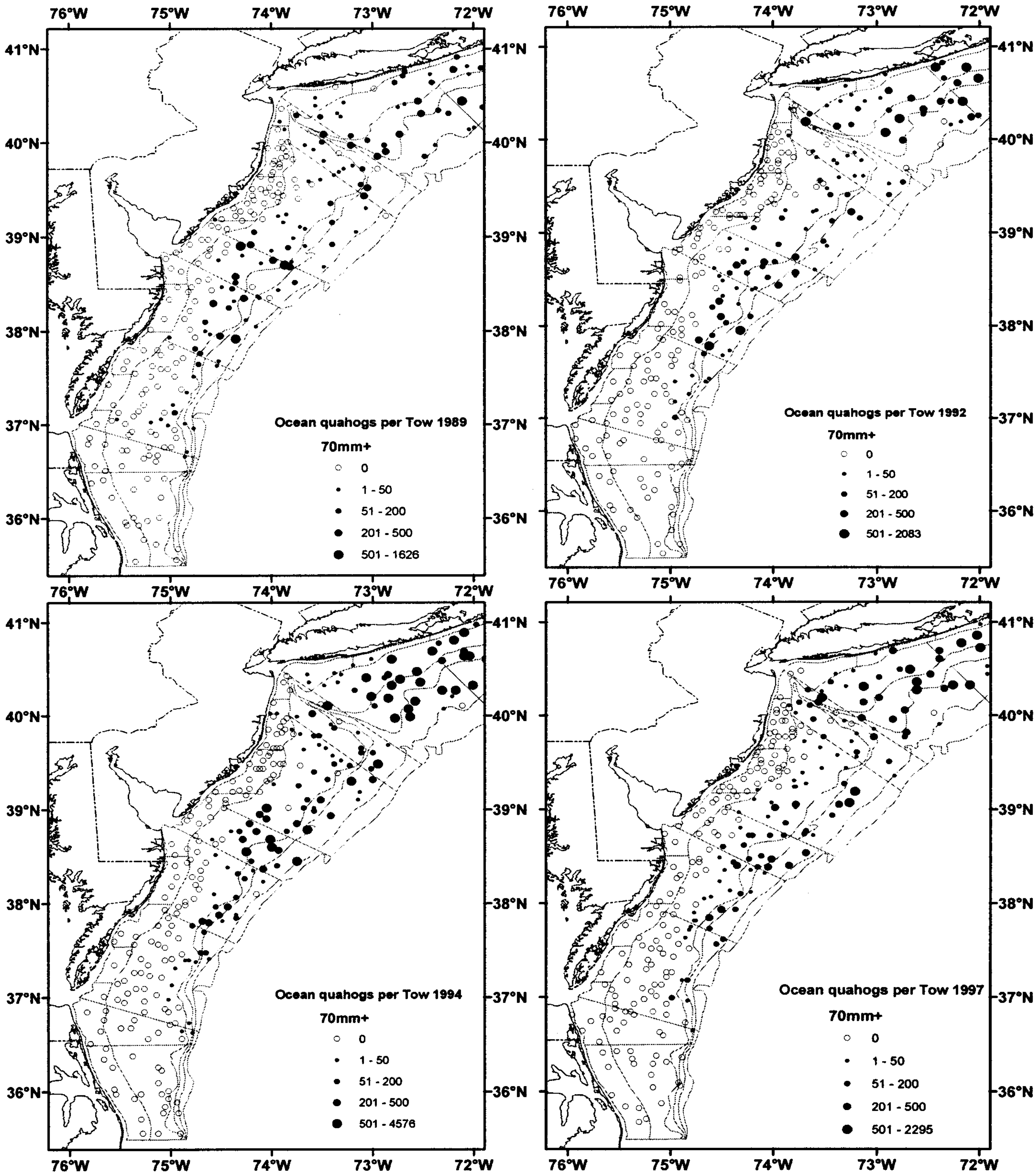


Fig. A42. Catch per tow of ocean quahogs (70mm+) in NMFS clam surveys. 1989 – 1997.

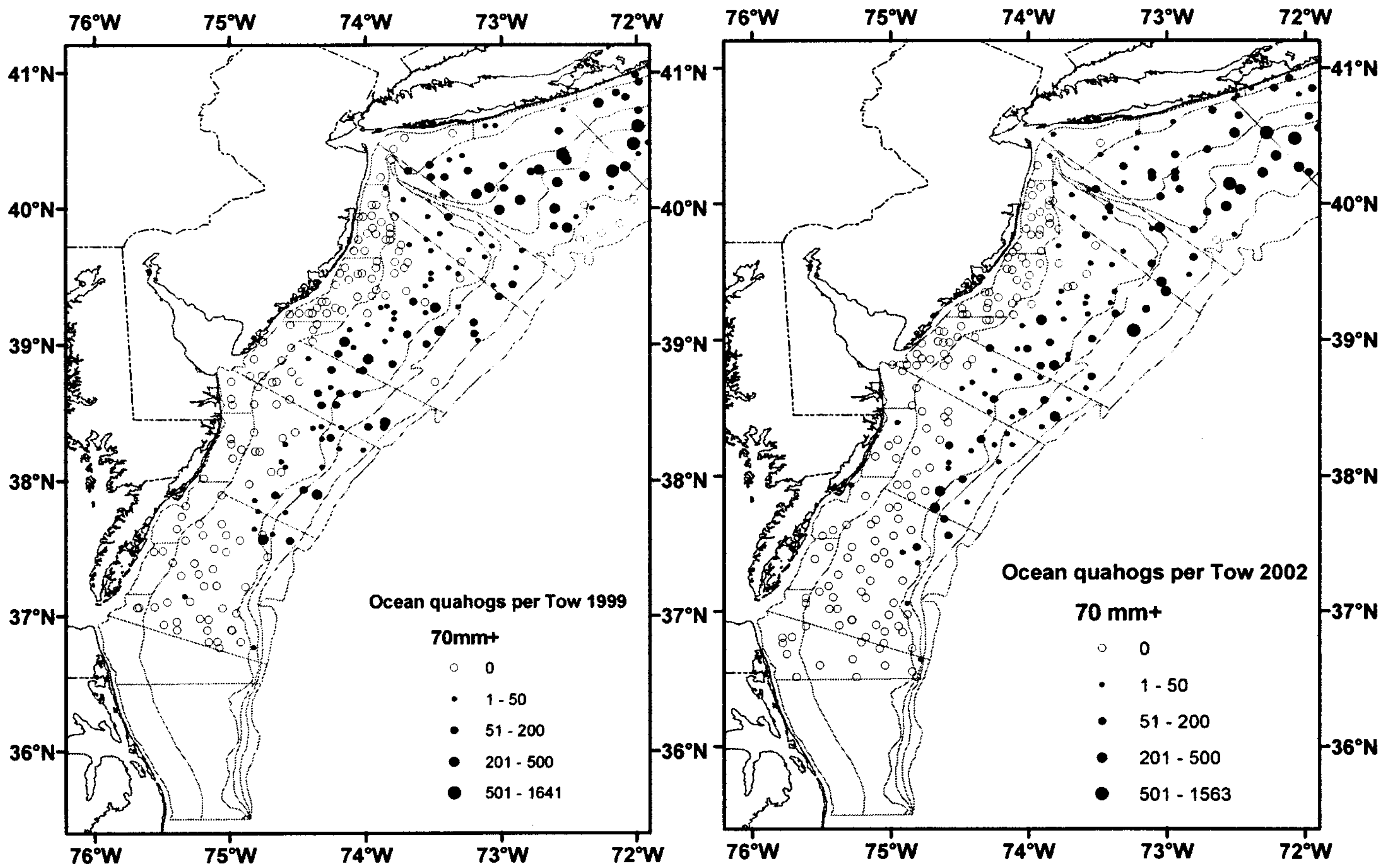


Fig. A43. Catch per tow of ocean quahogs (70mm+) in NMFS clam surveys. 1999 and 2002.

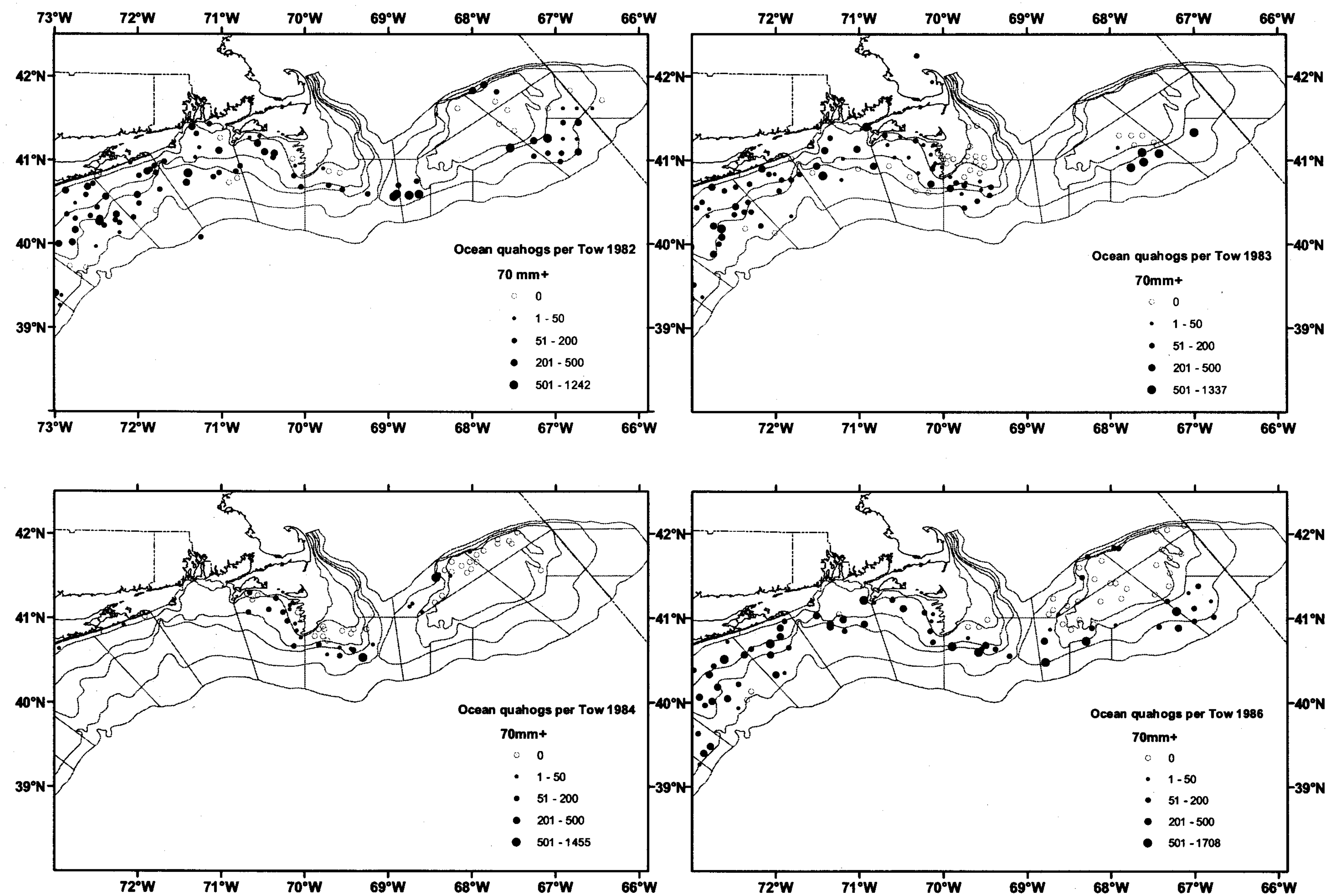


Fig. A44. Catch per tow of ocean quahogs. 1982 – 1986.

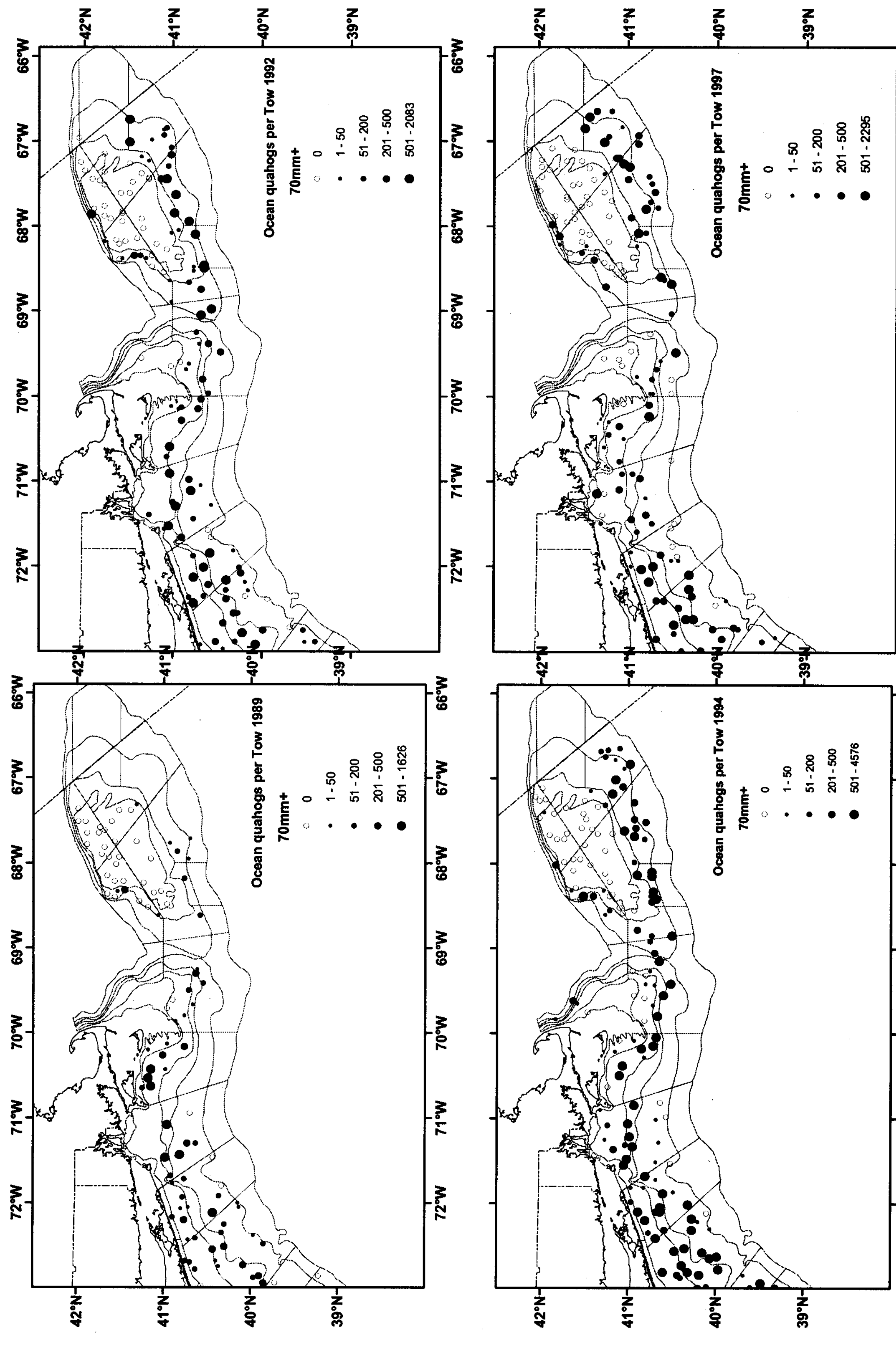


Fig. A45. Catch per tow of ocean quahogs, 1989-1997.

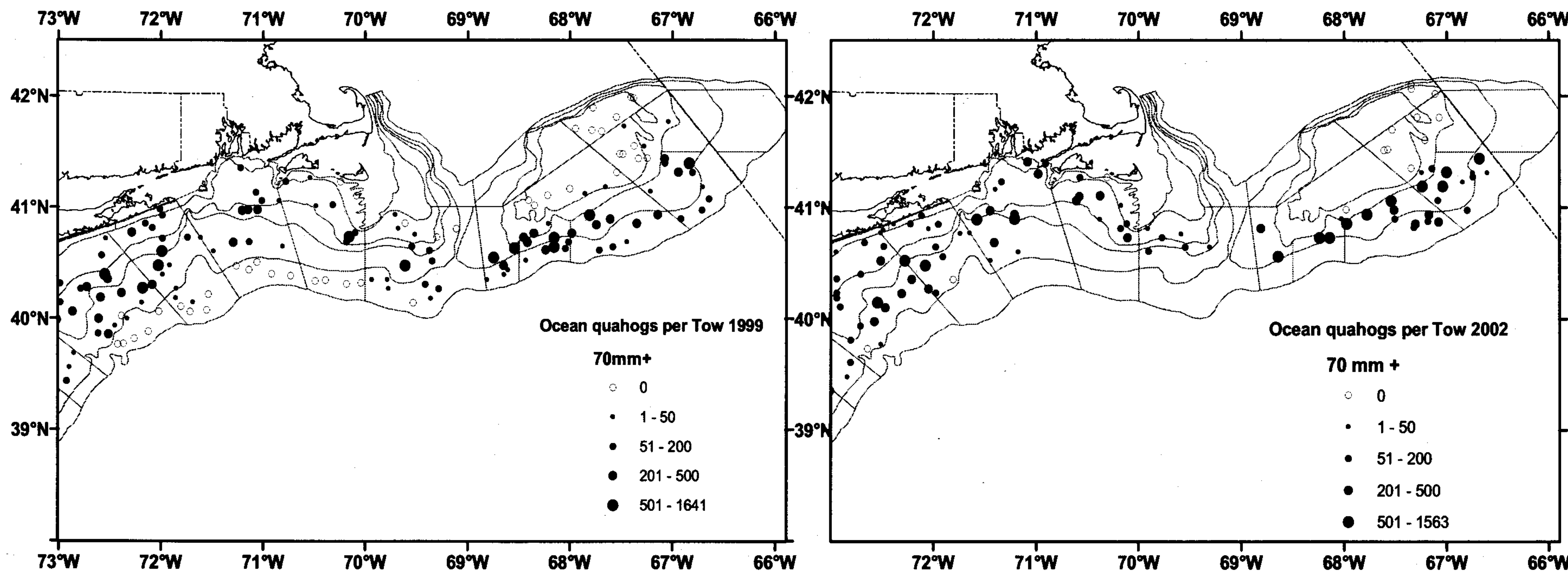


Fig. A46. Catch per tow of ocean quahogs, 1999-2002.

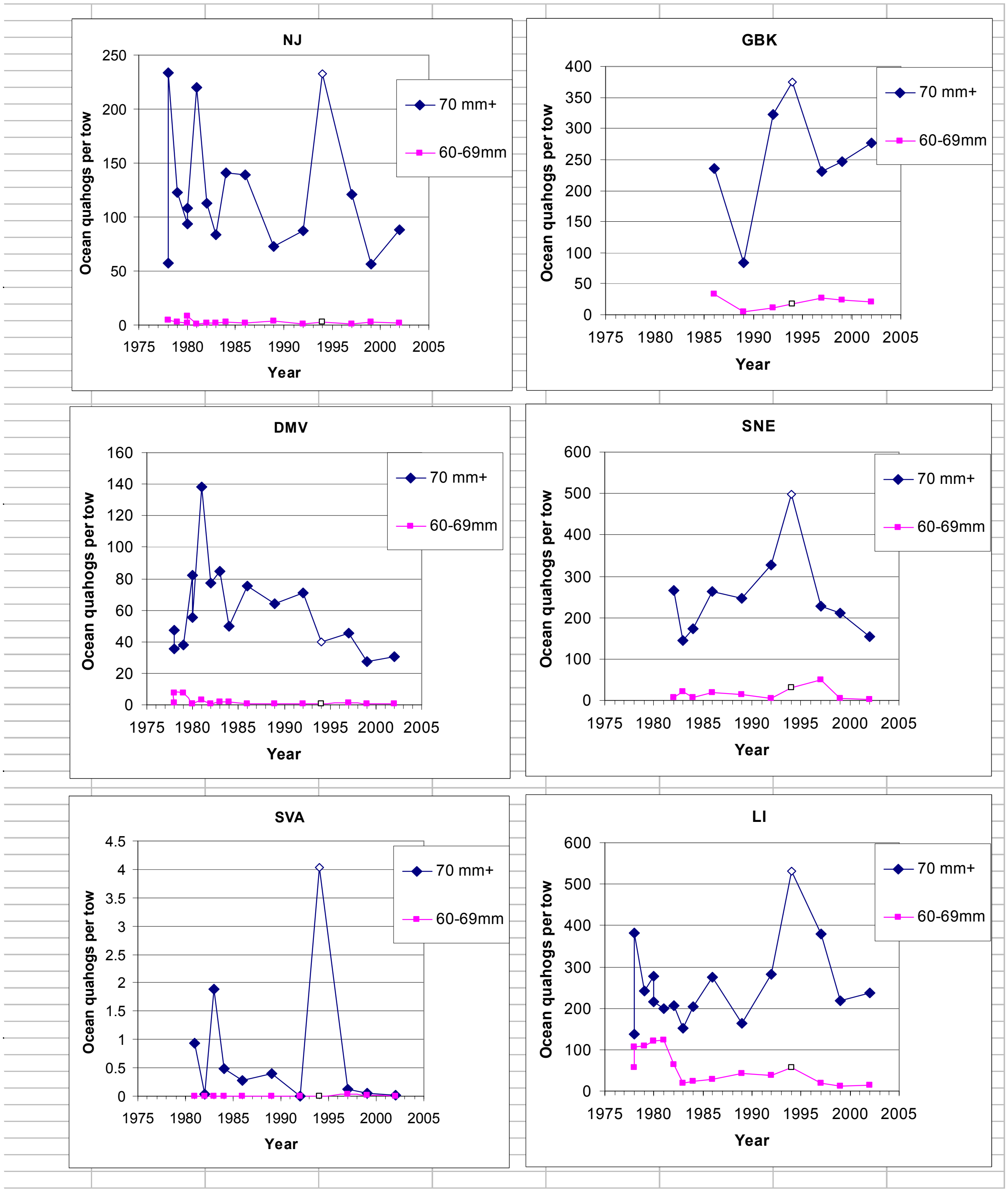


Fig. A47.

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.

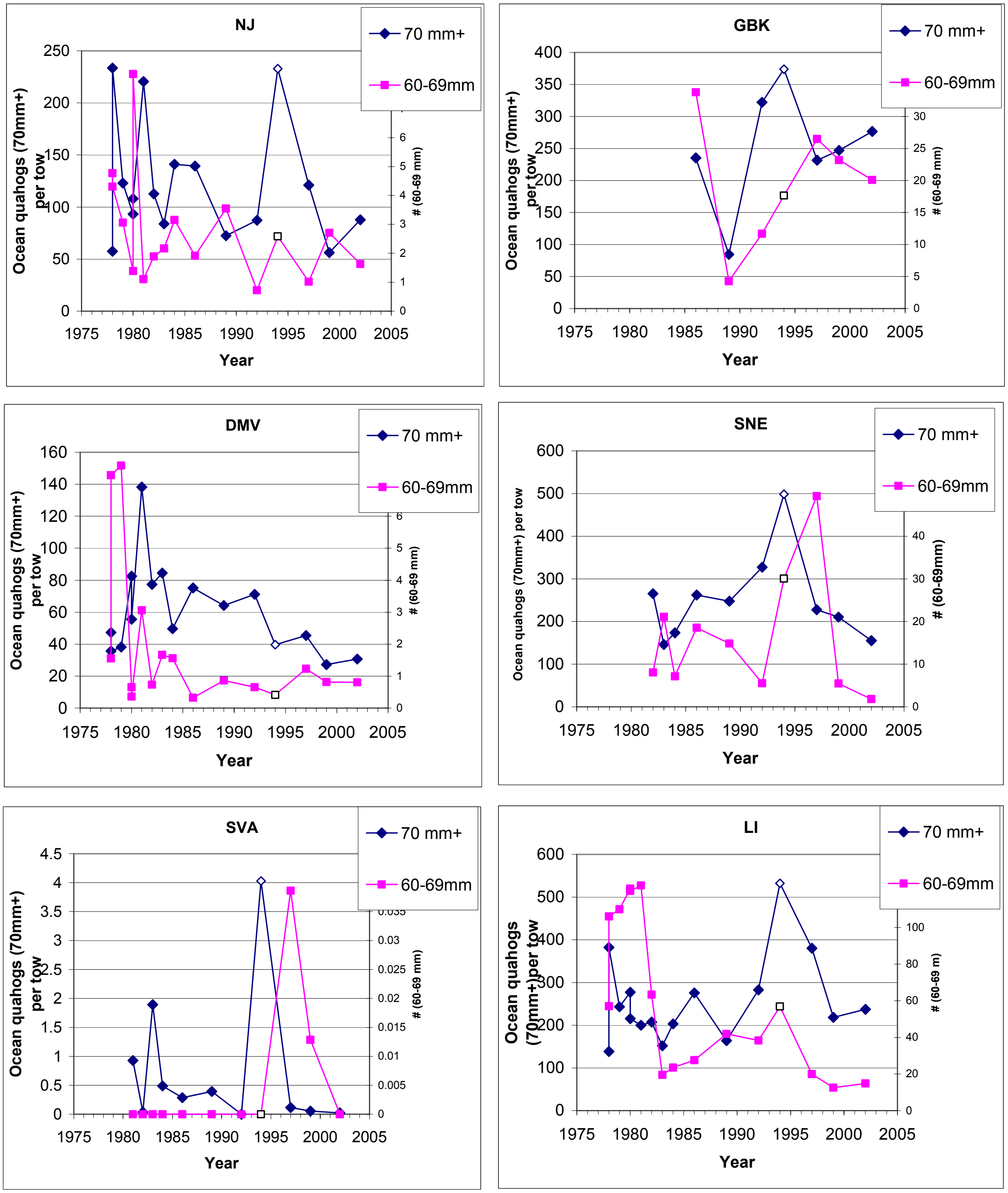
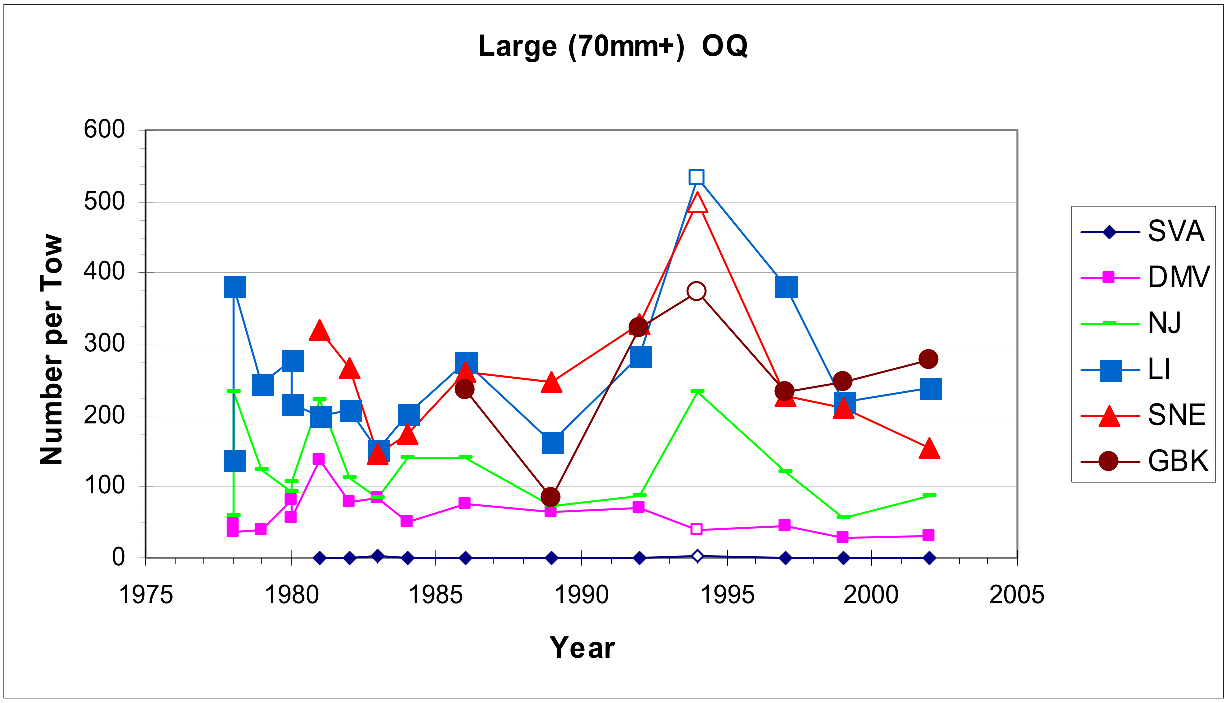


Fig. A48.

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).



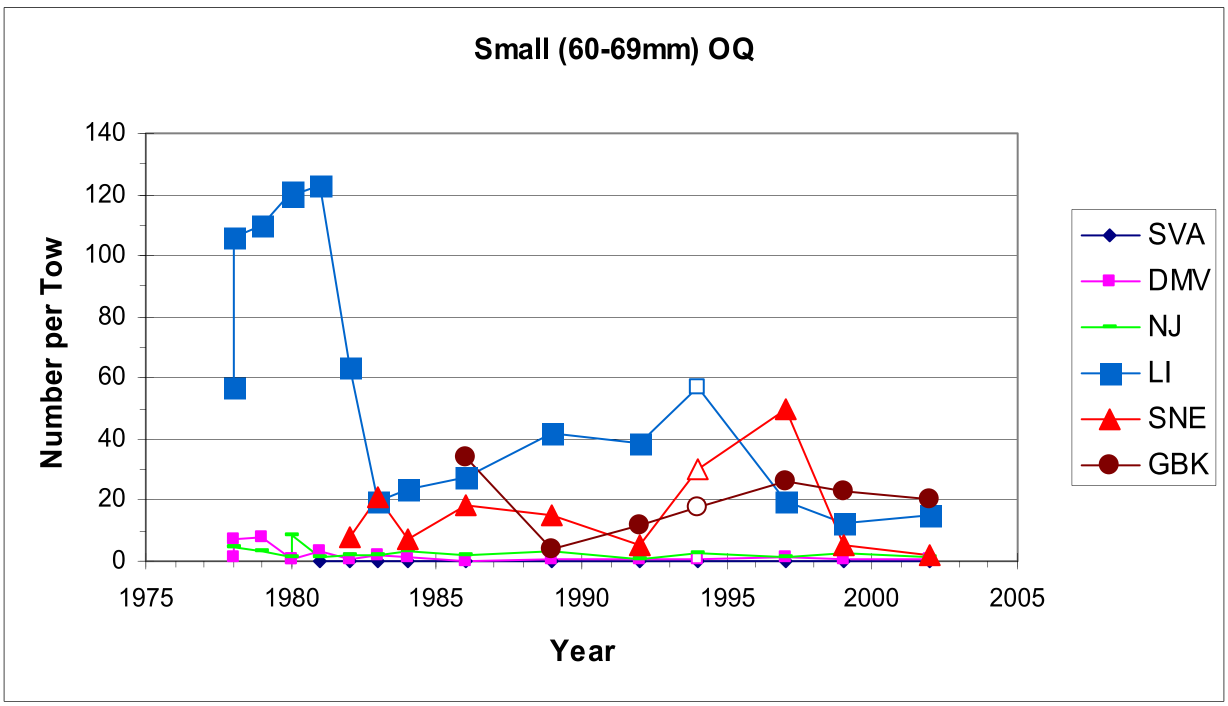


Fig. A49.

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.

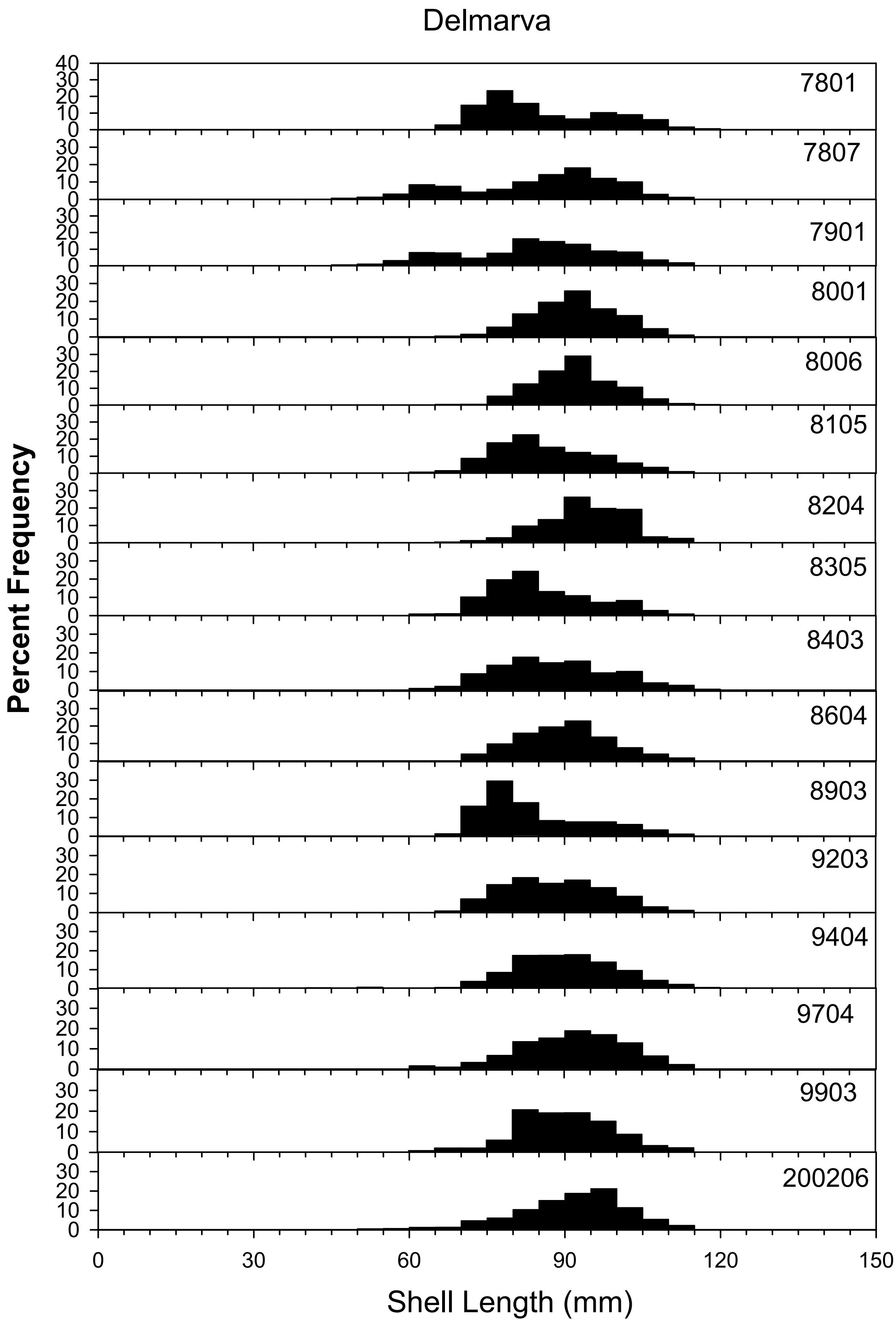


Fig. A50. Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: DMV

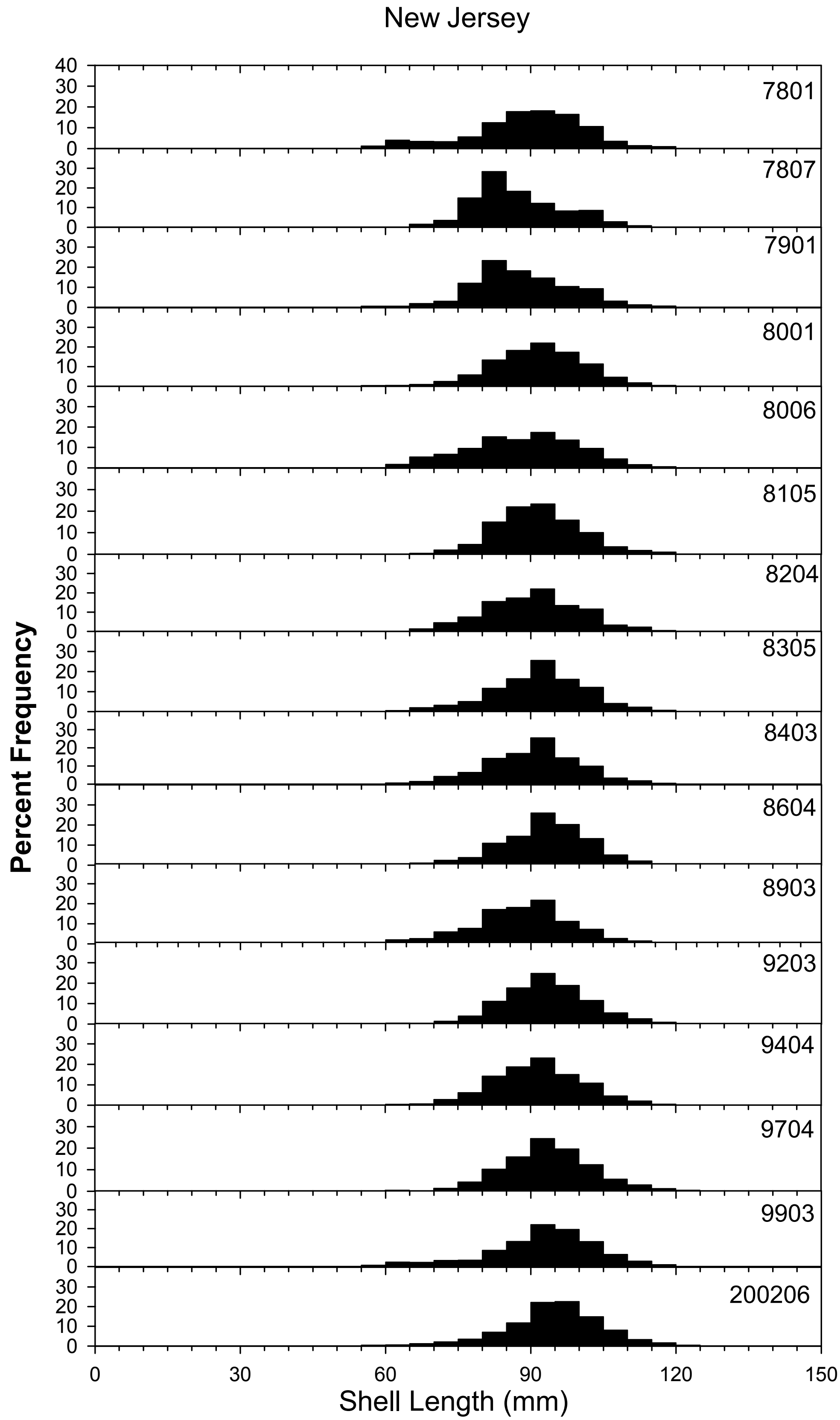


Fig. A51. Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: NJ .

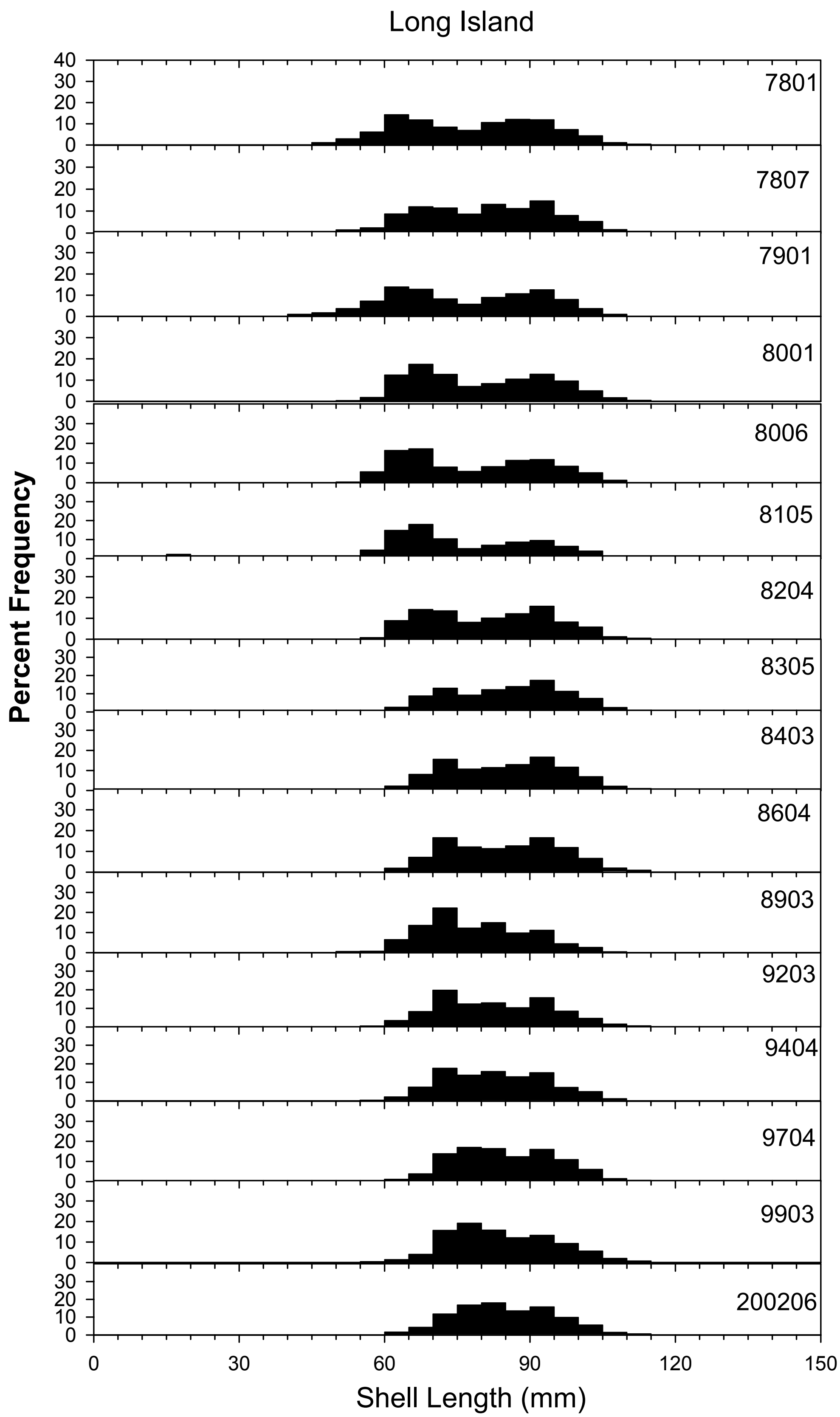


Fig. A52. Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: LI .

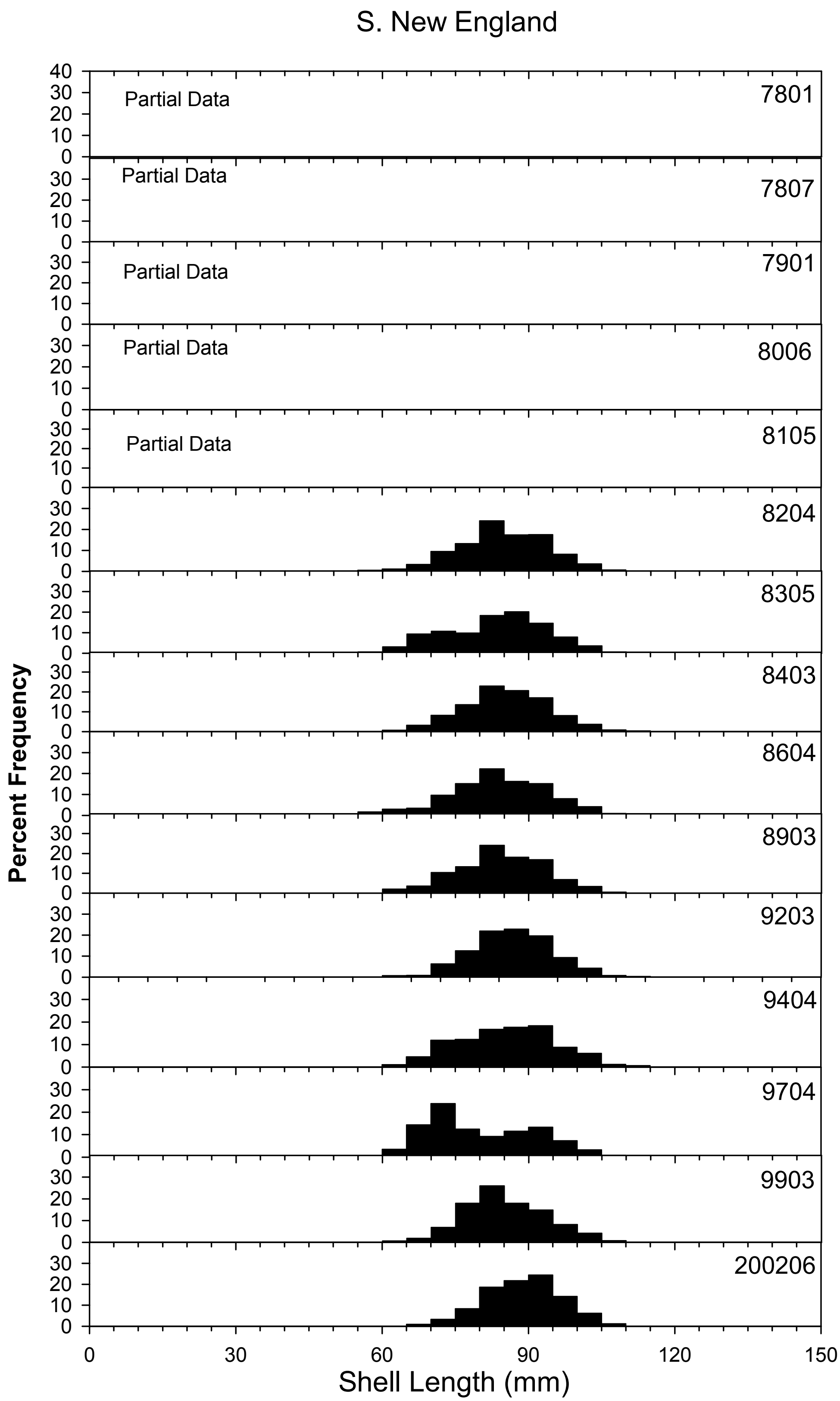


Fig. A53. Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: SNE .

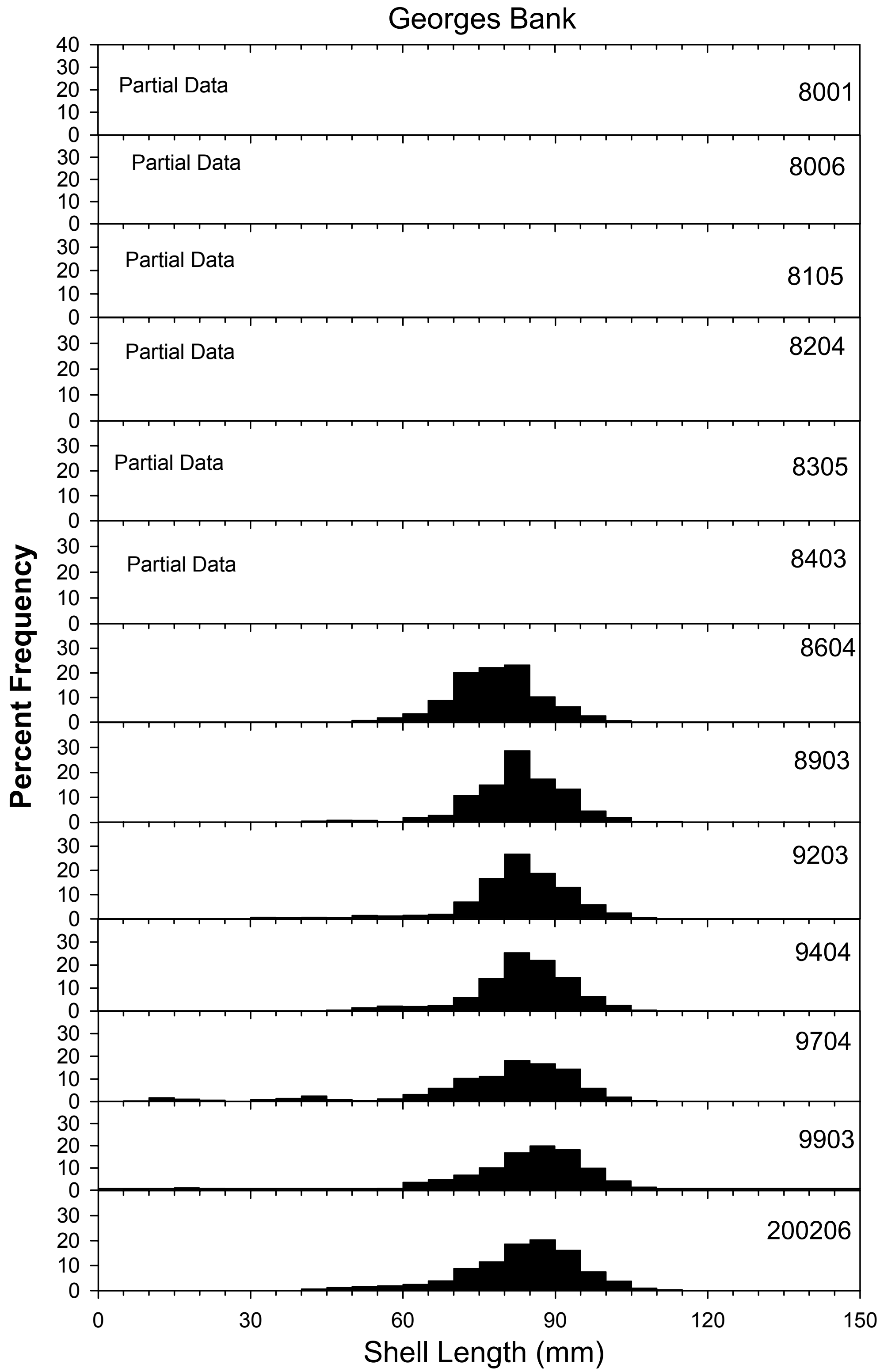


Fig. A54. Ocean quahog length frequency distributions over time, based on NMFS survey data. Region: GBK .

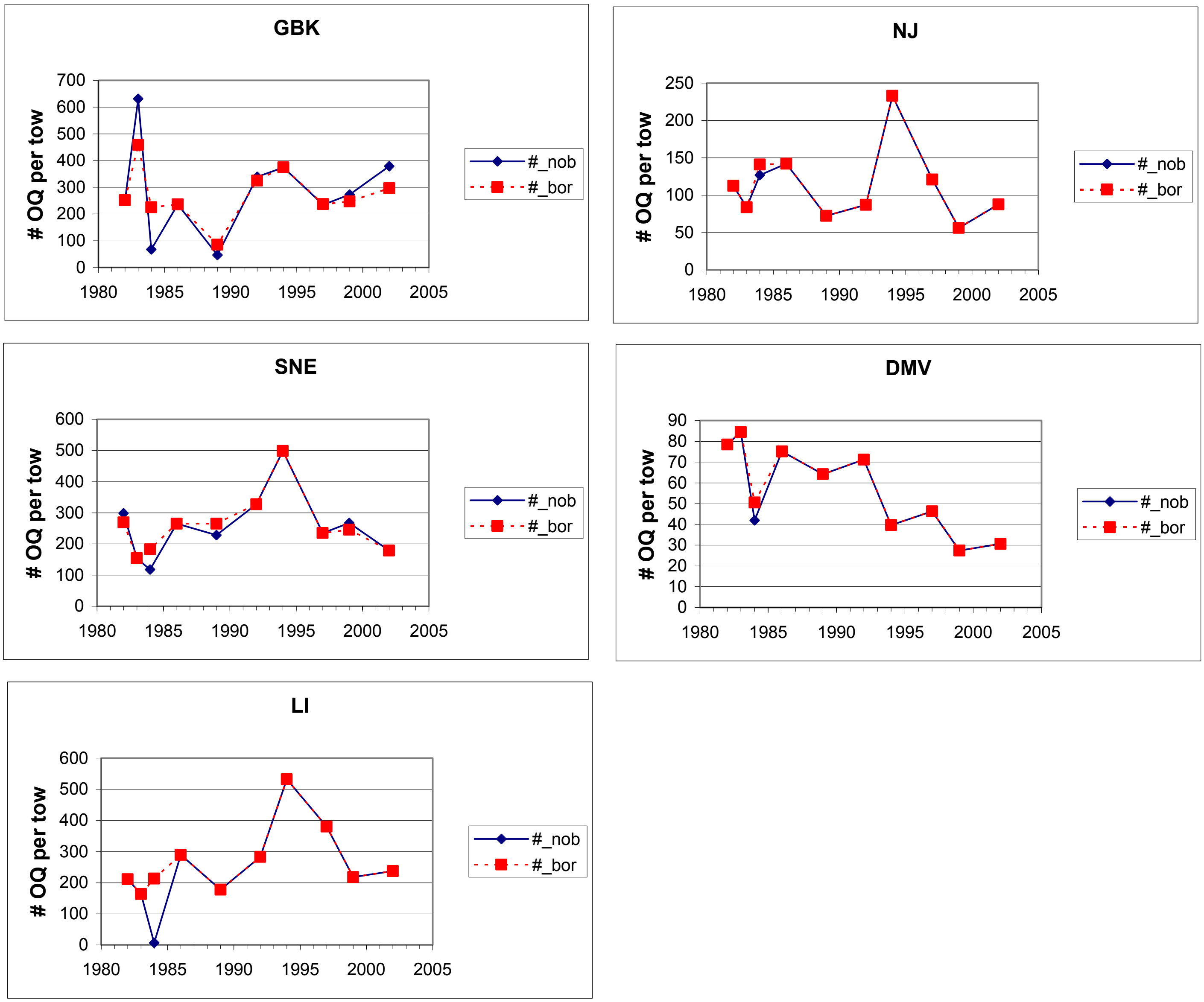
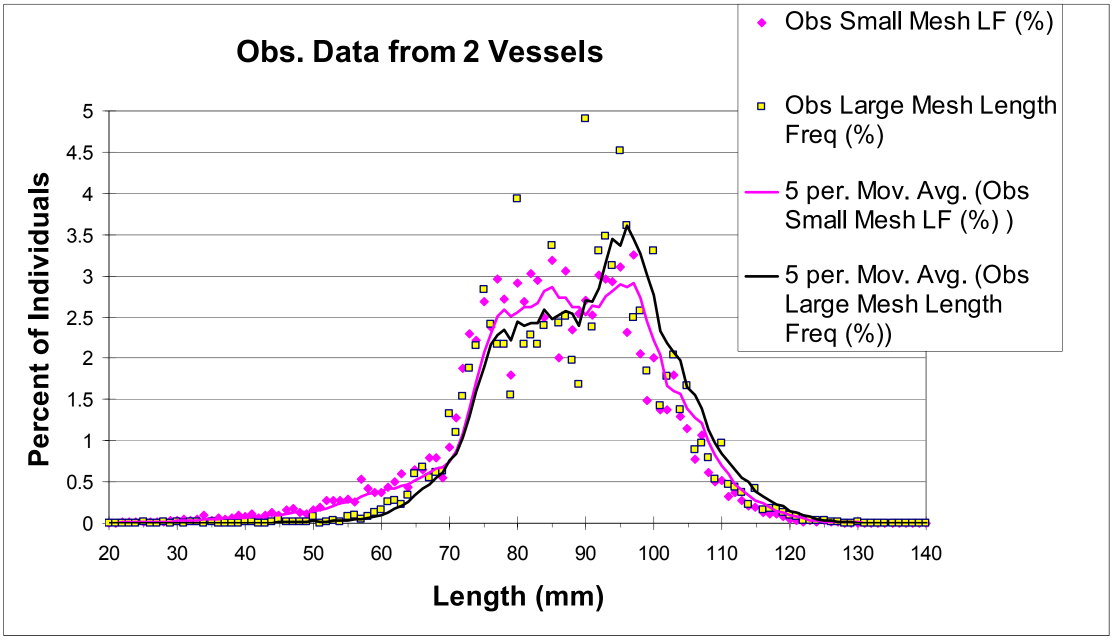


Figure A55.
Sensitivity analysis about "borrowing" to fill survey holes (results from Table A16).



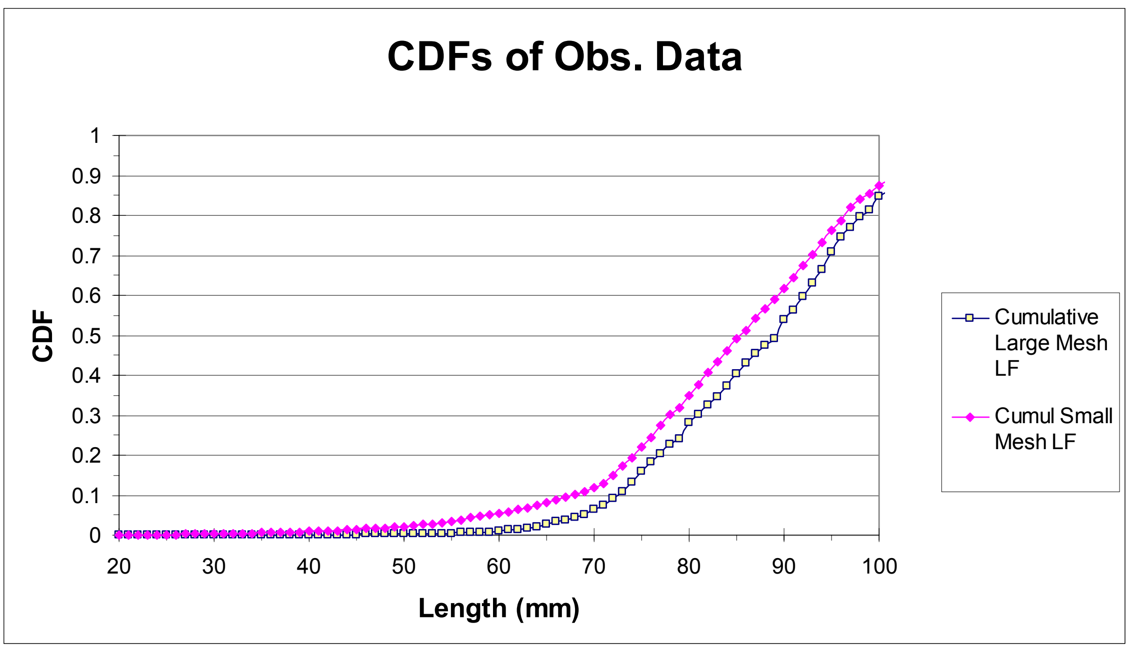


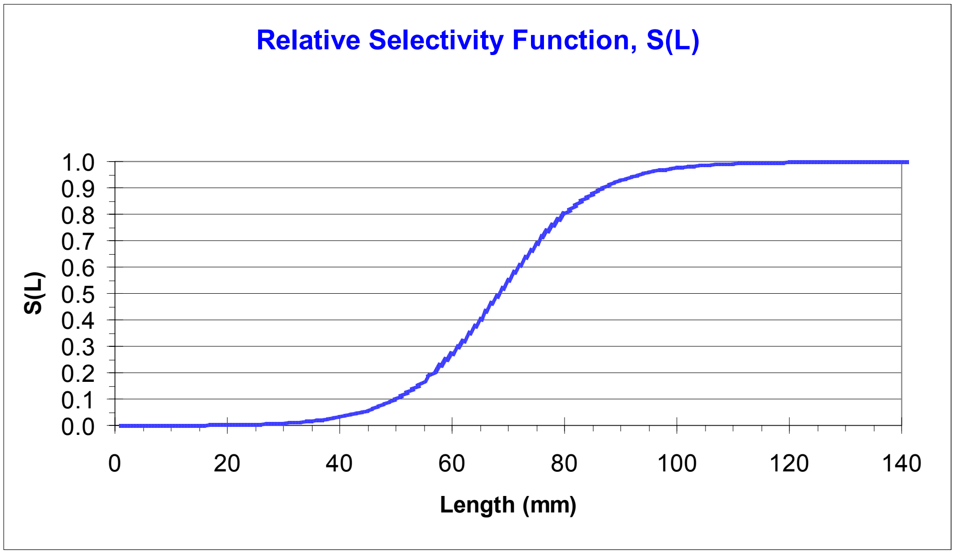
Fig. A56.

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.



B.

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

C.

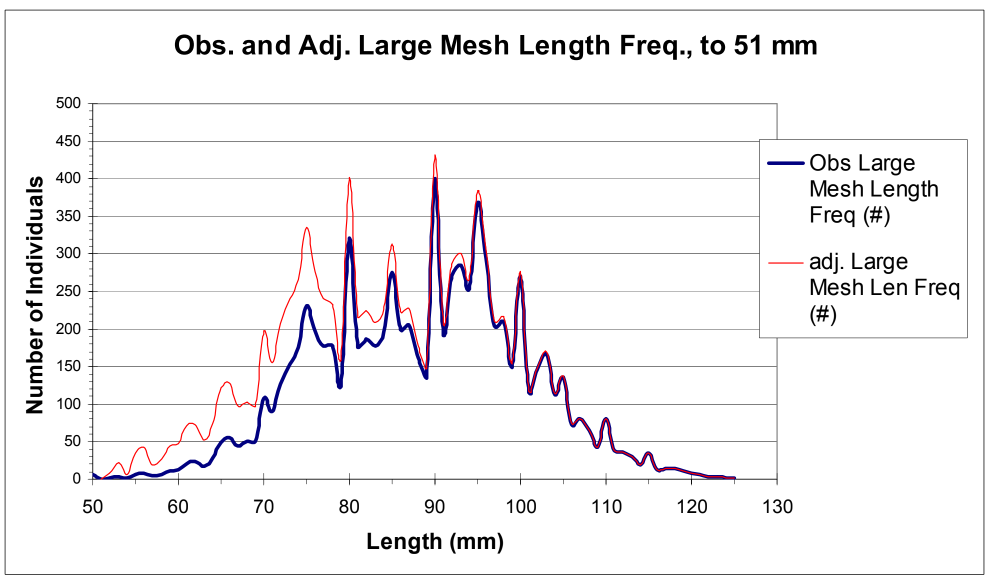


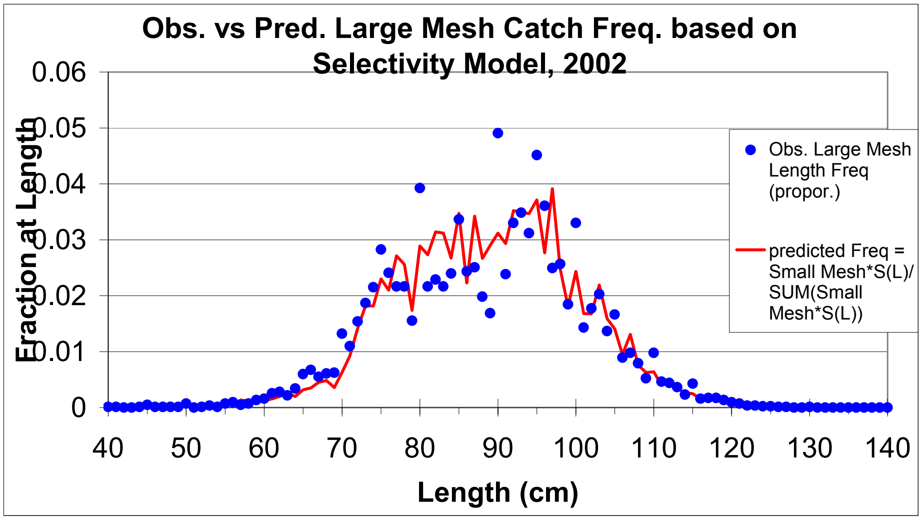
Fig. A57.

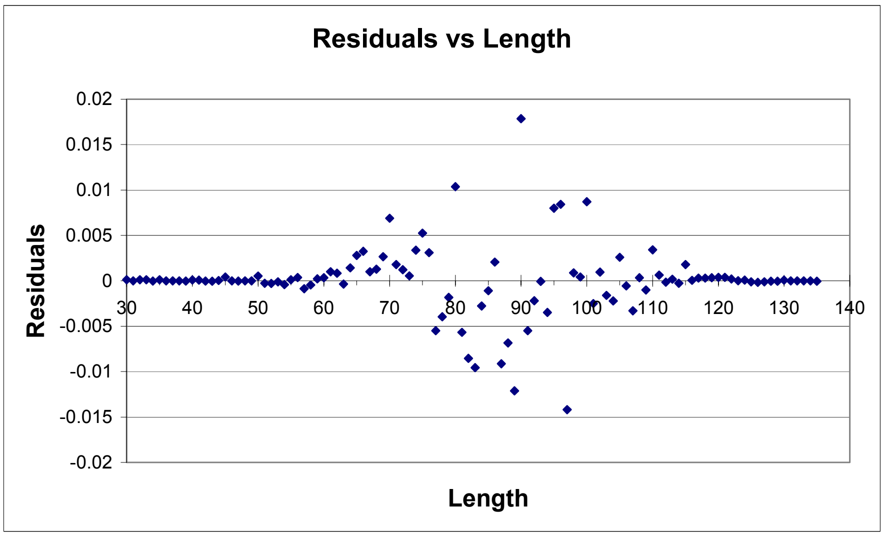
Model results and adjusted DE-II length frequency.

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.





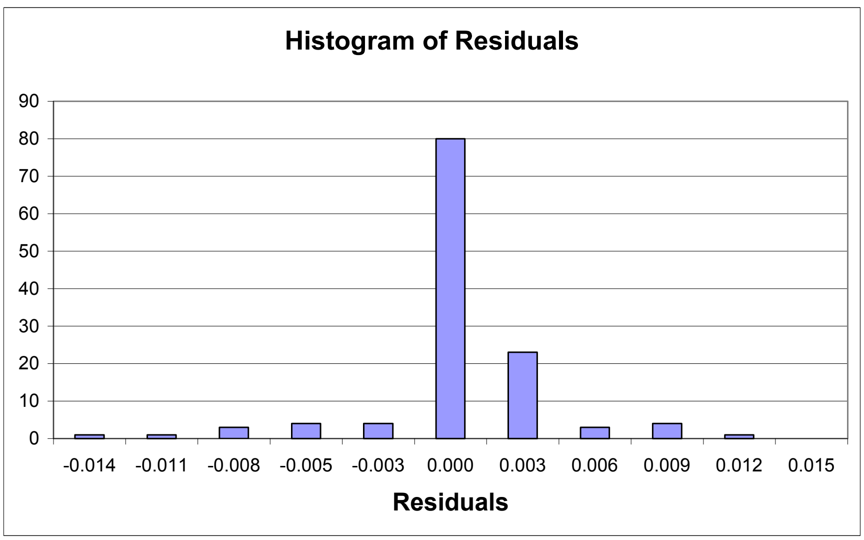


Fig. A58. Fit of the relative selectivity model using data from the paired stations.

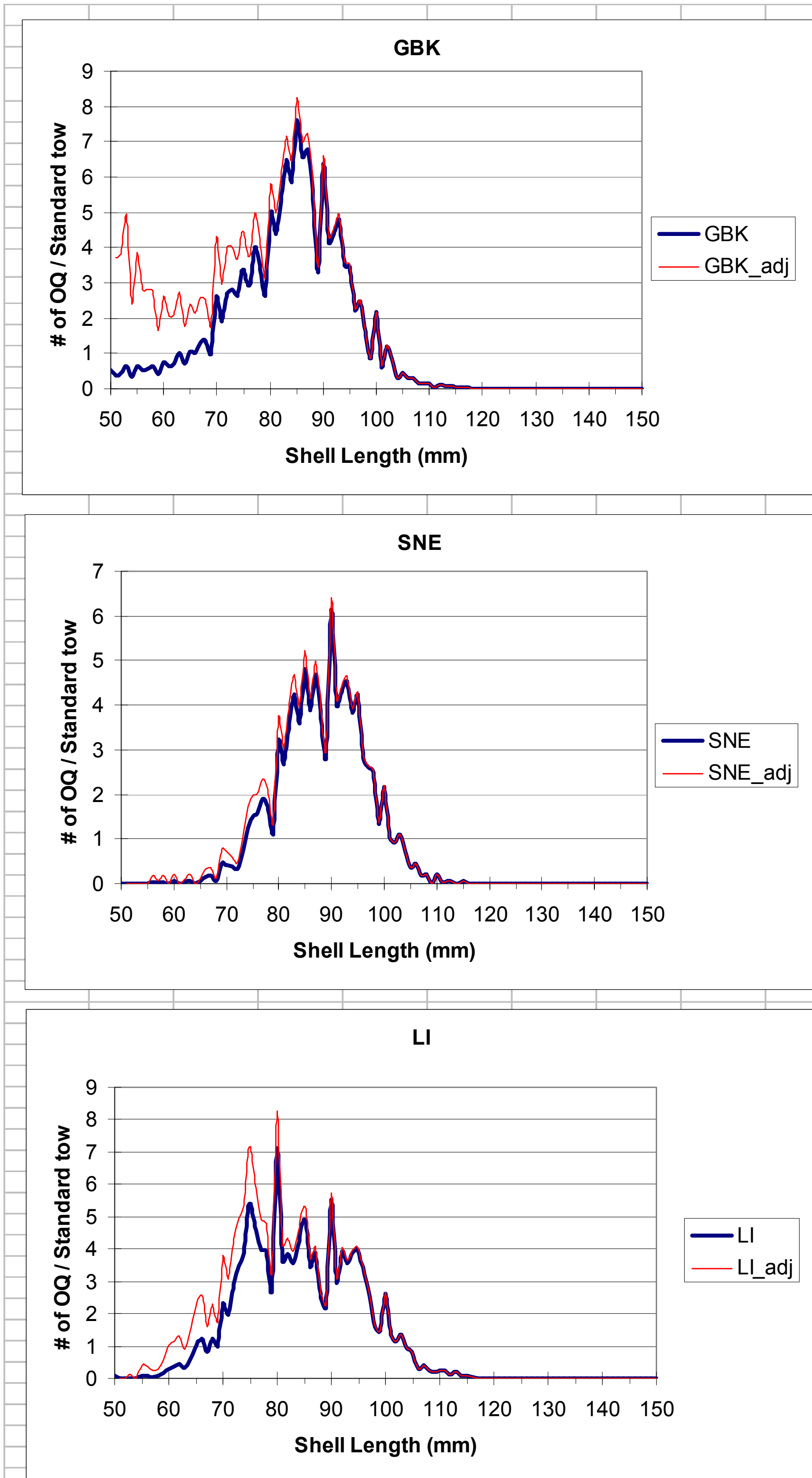
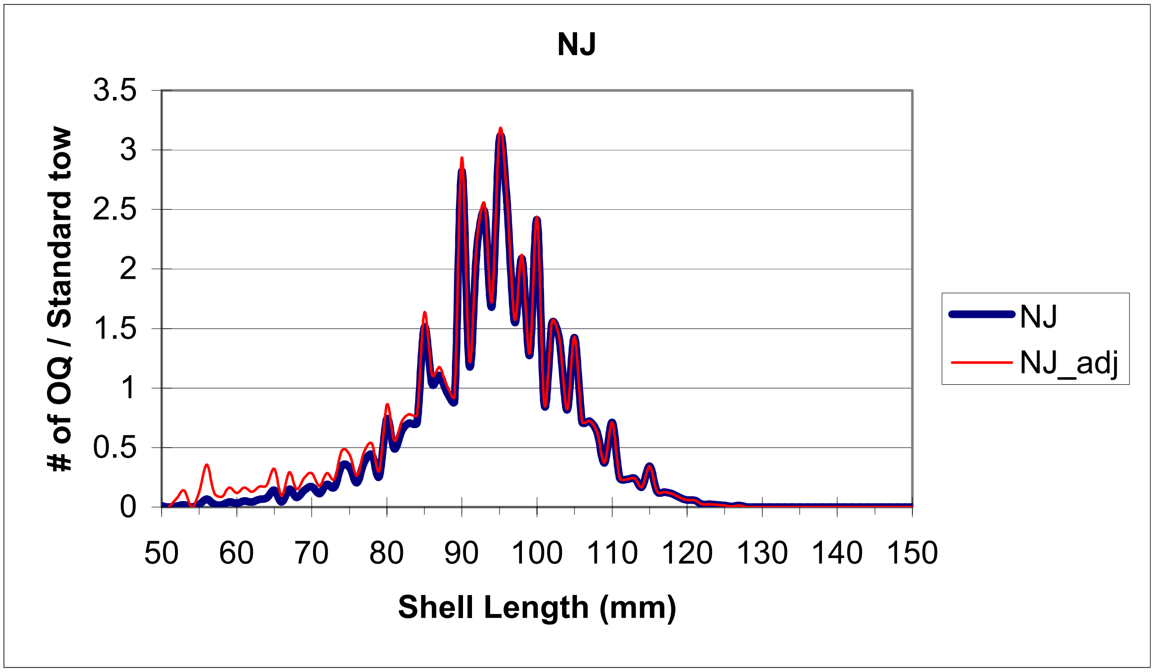


Fig. A59.

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.



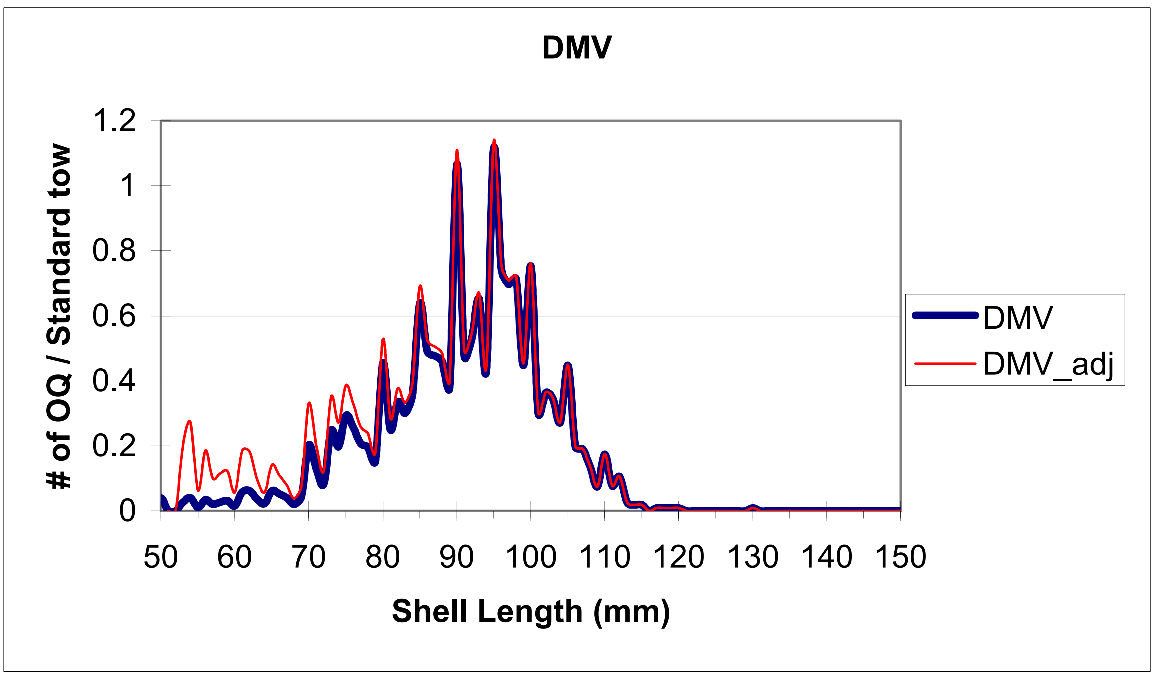


Fig. A60.

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.

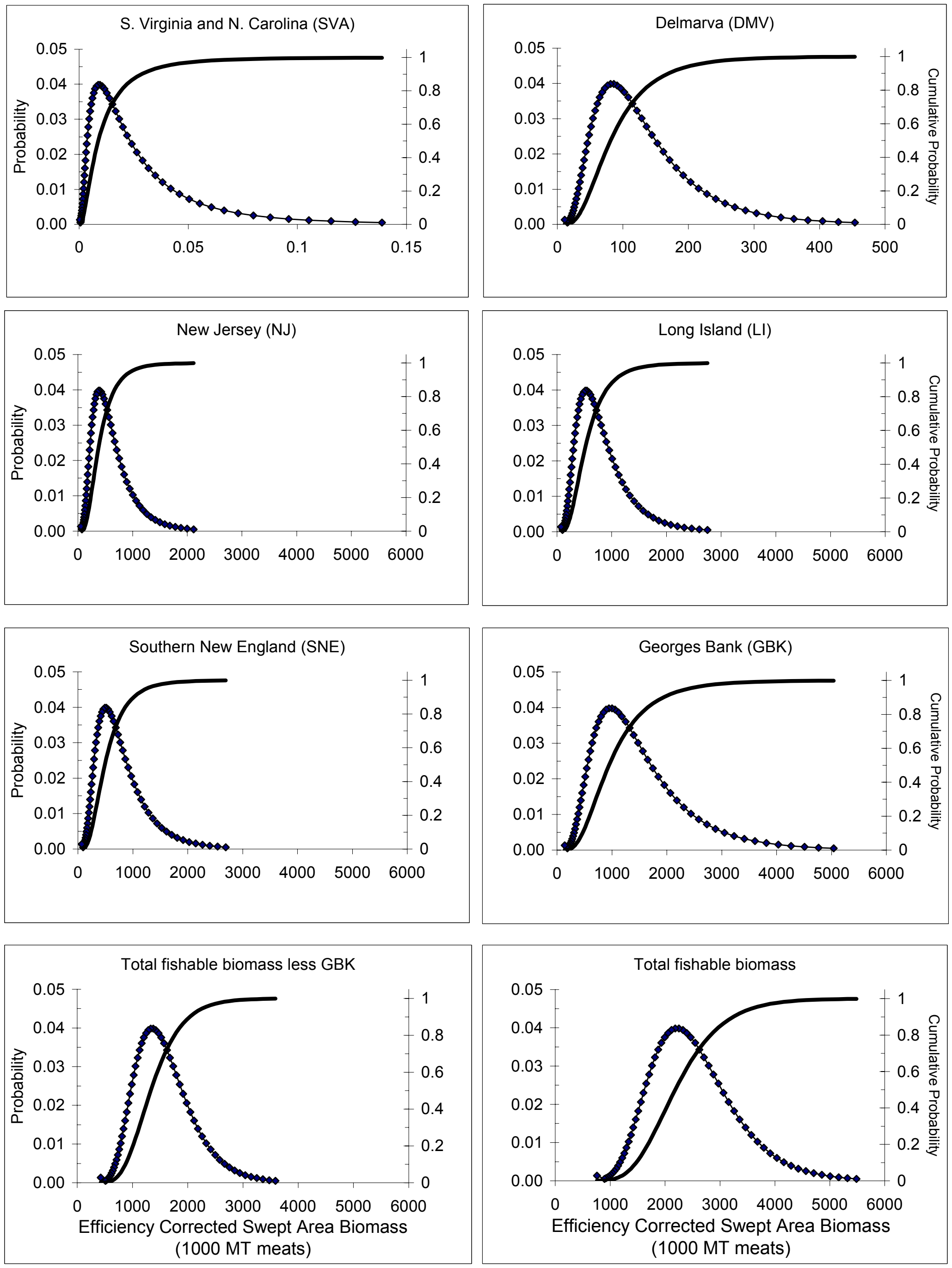


Fig. A61.

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.

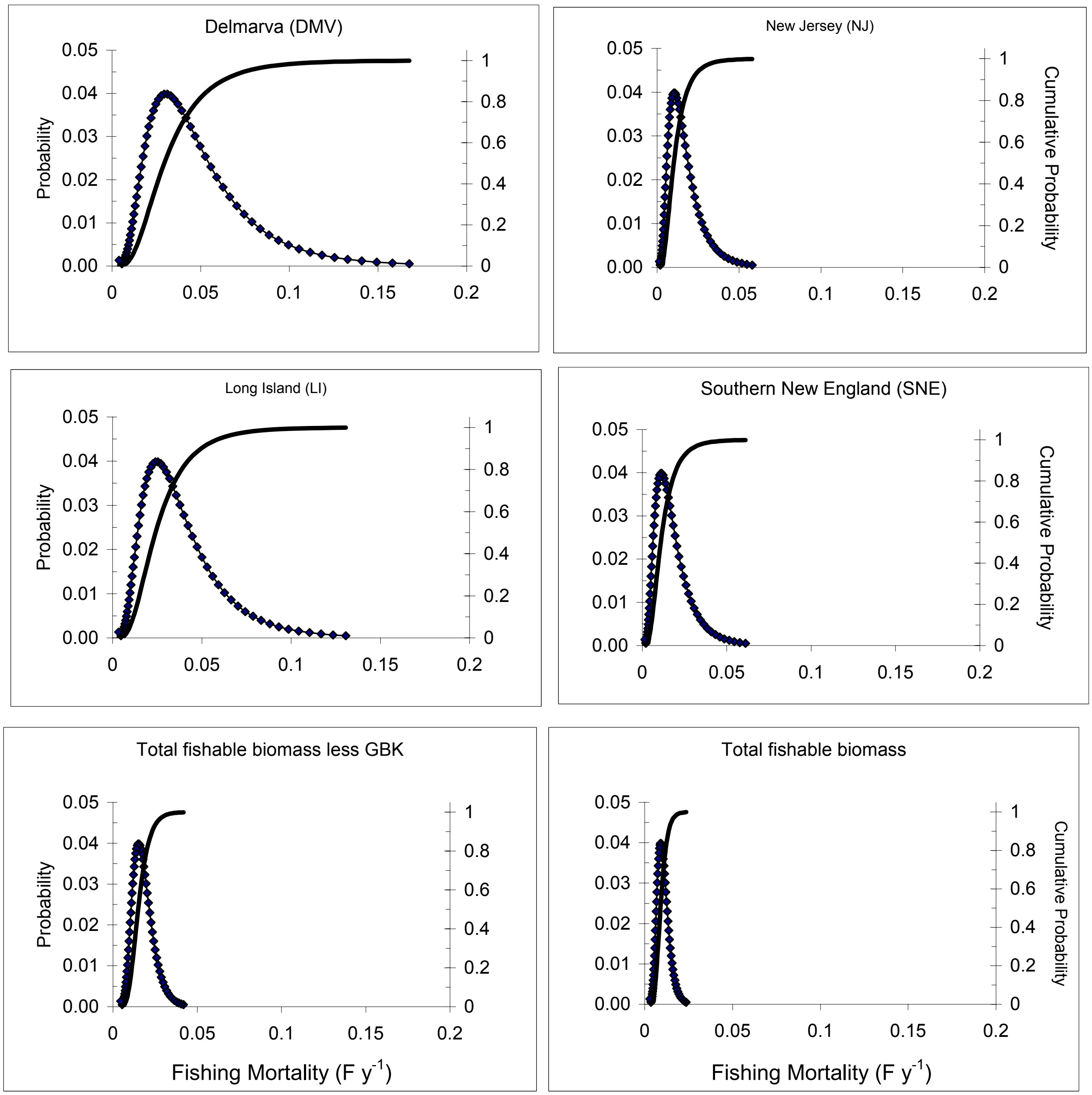


Fig. A62.

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.

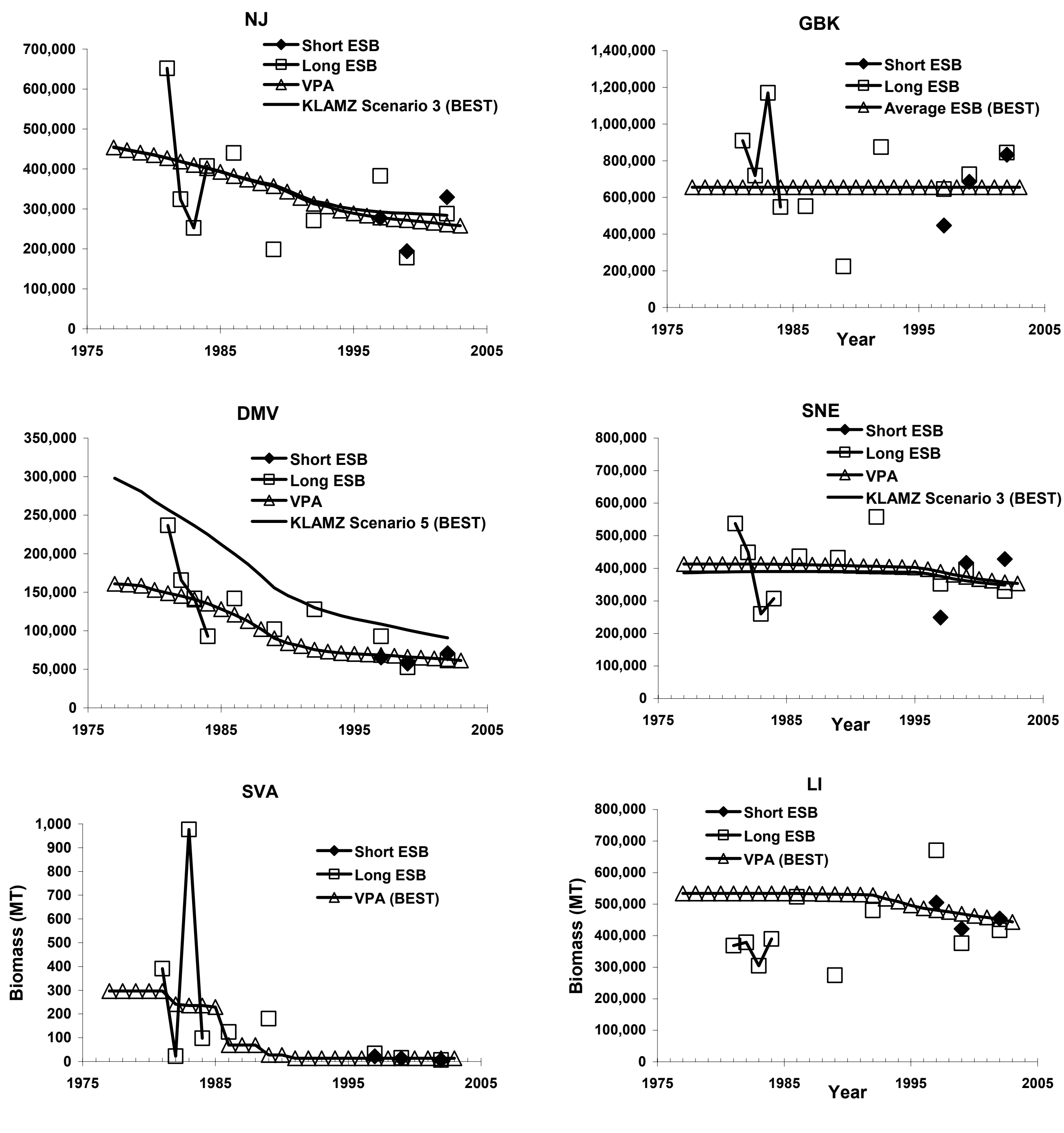


Figure A63. Results of models estimating ocean quahog biomass.

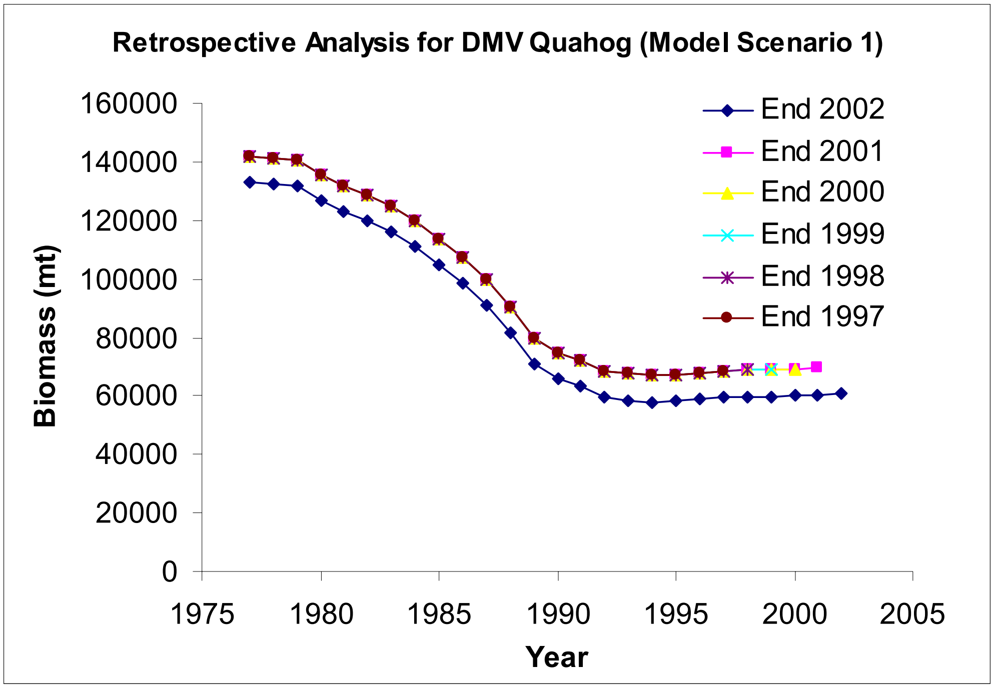


Figure A64. Delmarva region, retrospective analysis.

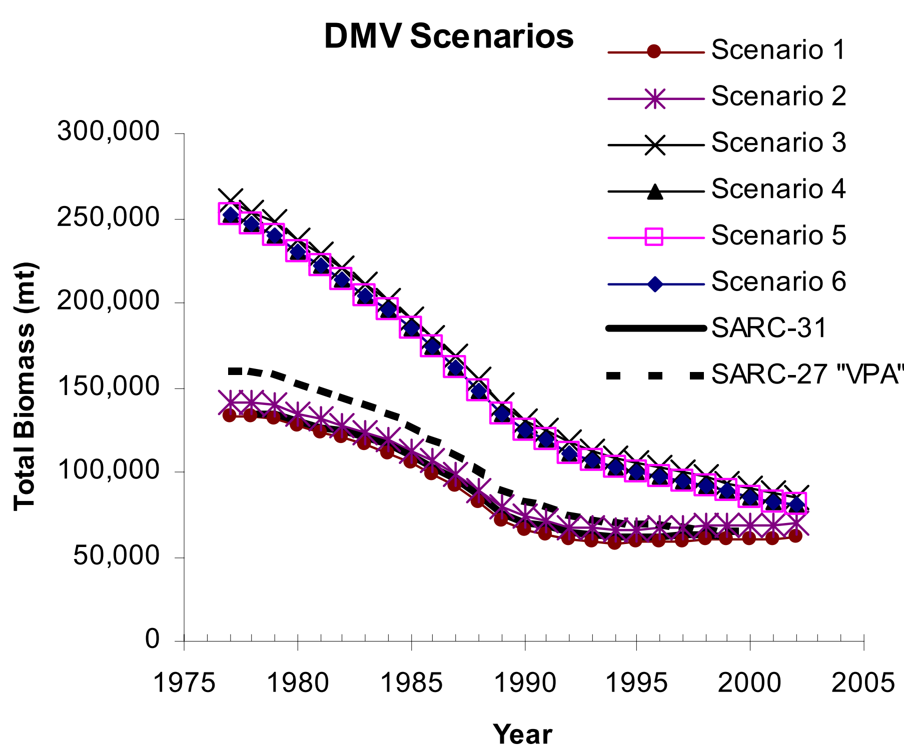


Figure A65. Delmarva region, biomass scenarios.

DMV - Scenario 5

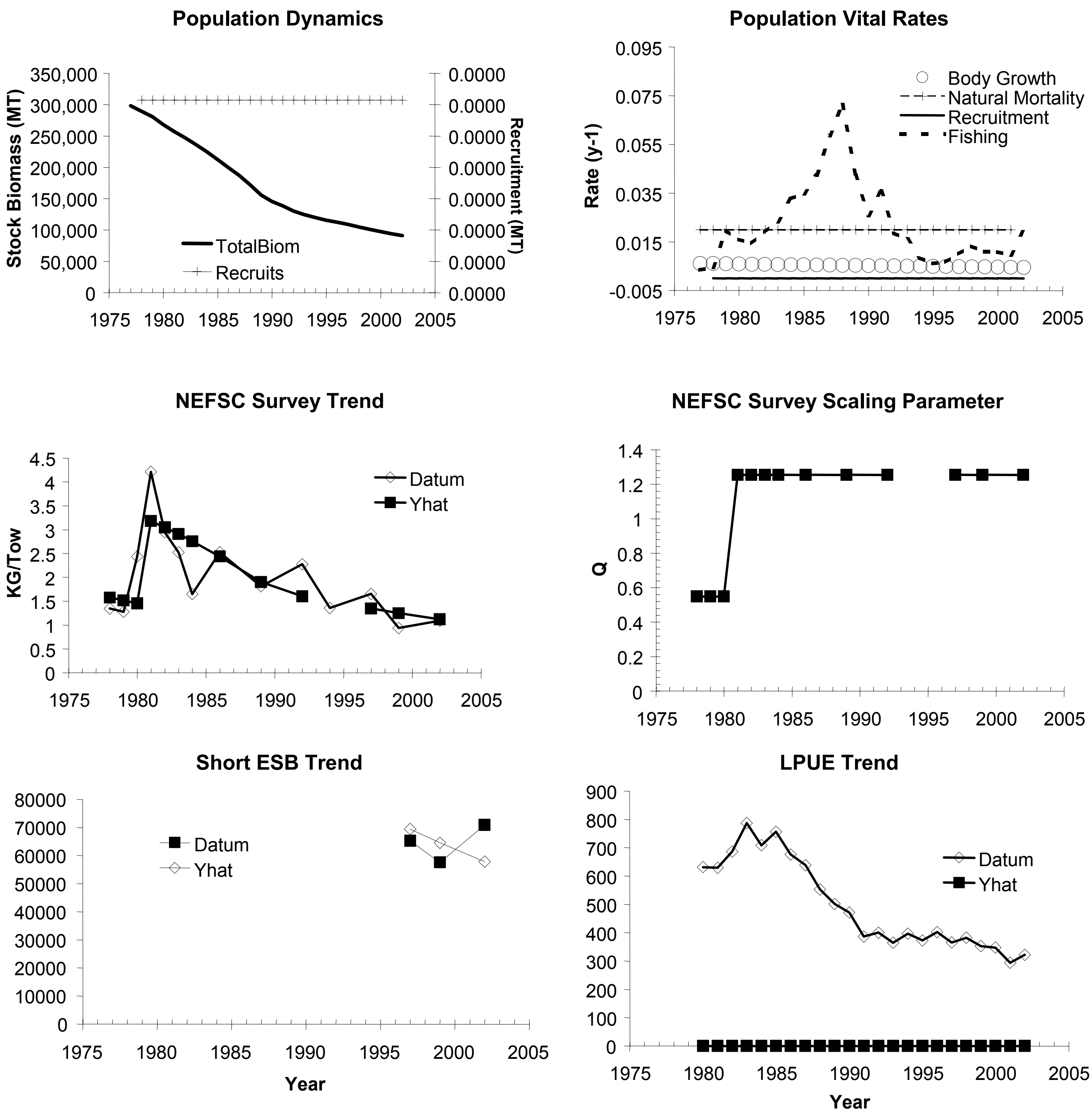


Figure A66. Delmarva region, Scenario 5.

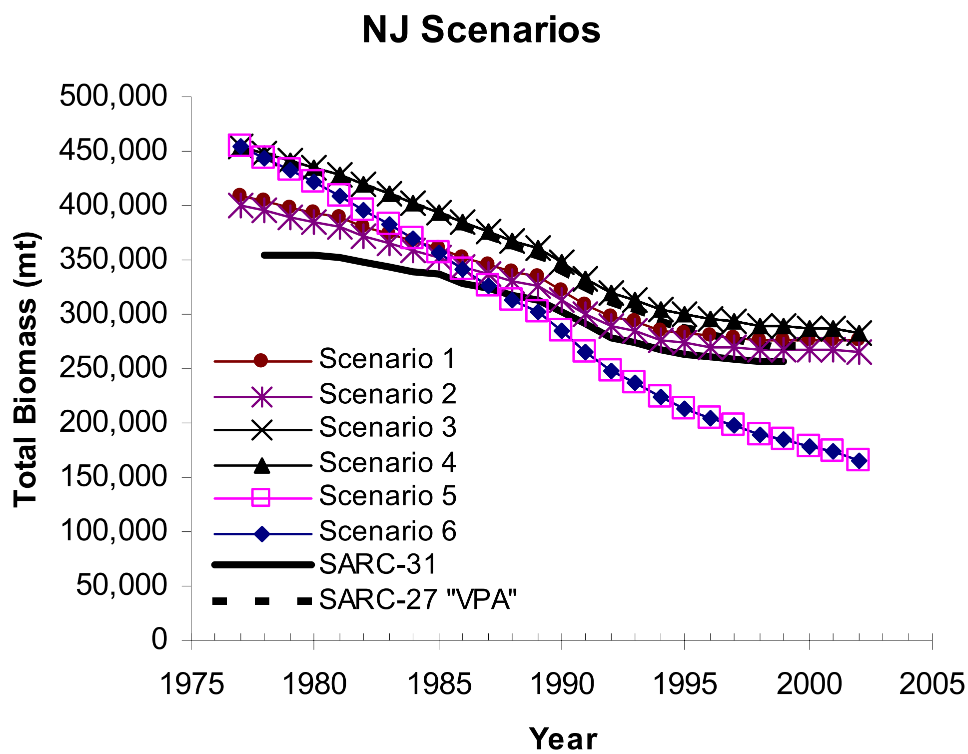


Figure A67. New Jersey region, biomass scenarios.

NJ - Scenario 3

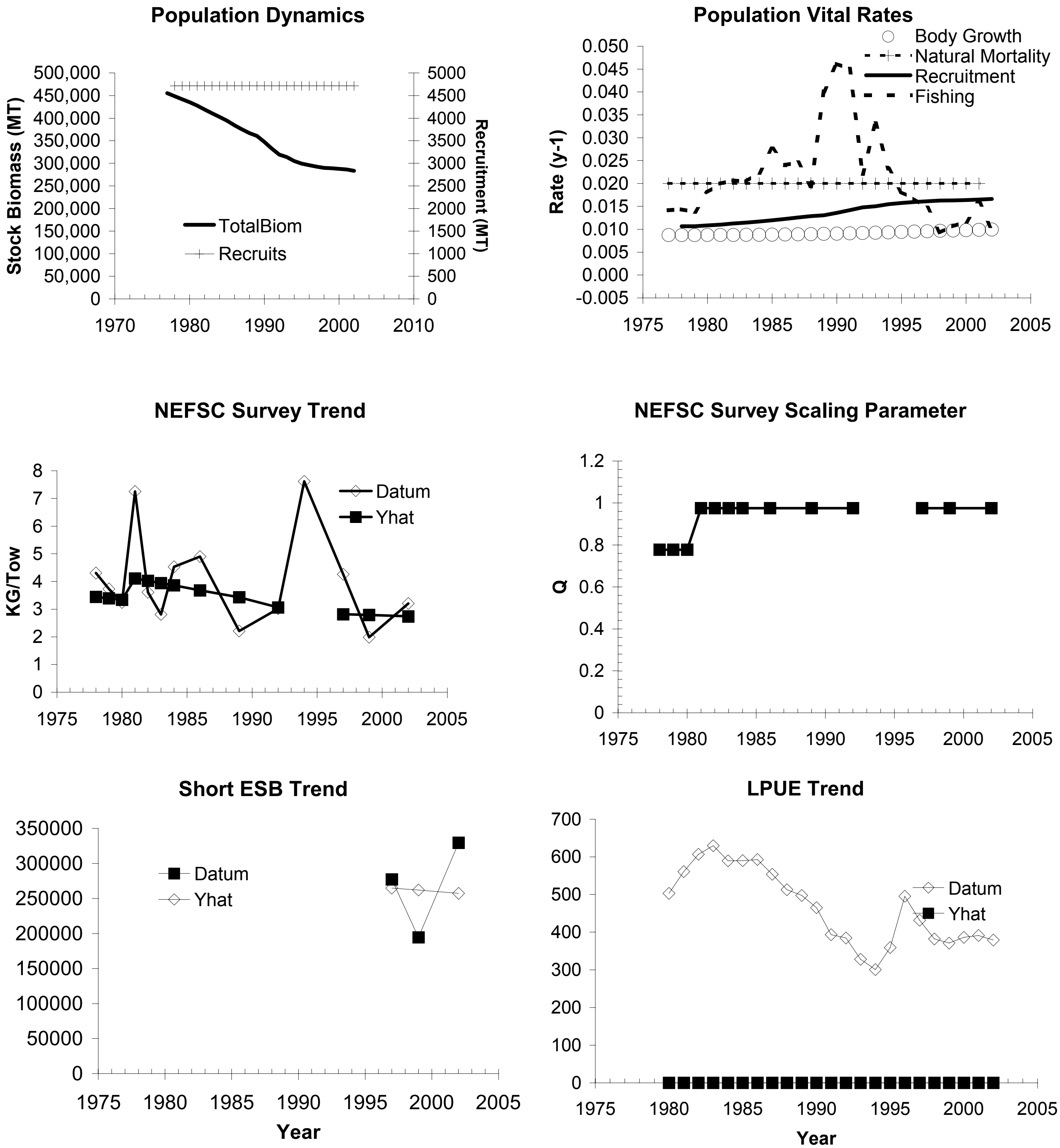


Figure A68. New Jersey region, Scenario 3.

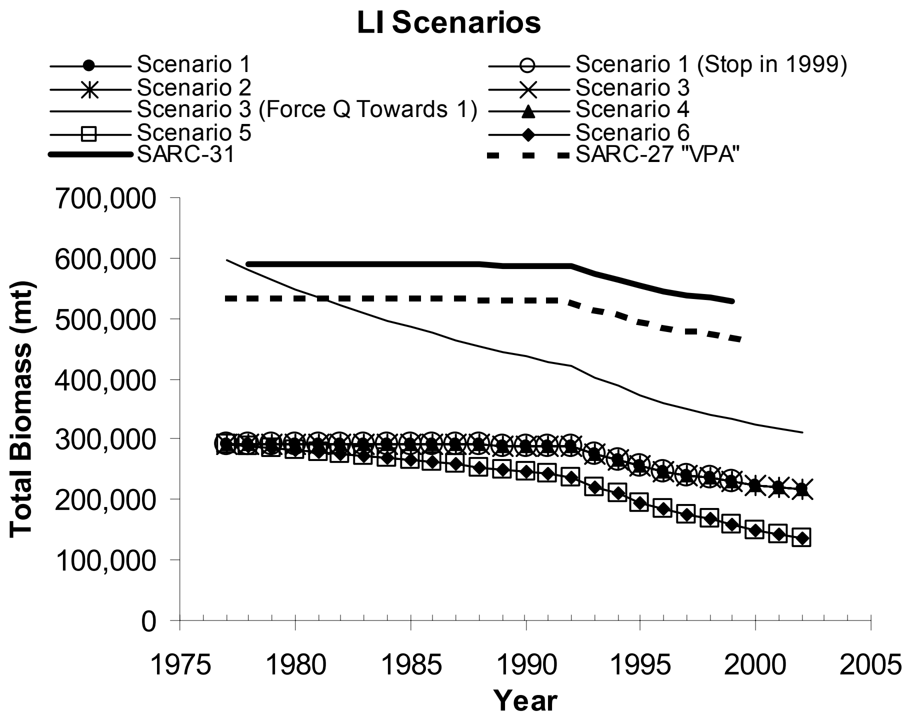


Figure A69. Long Island region, biomass scenarios.

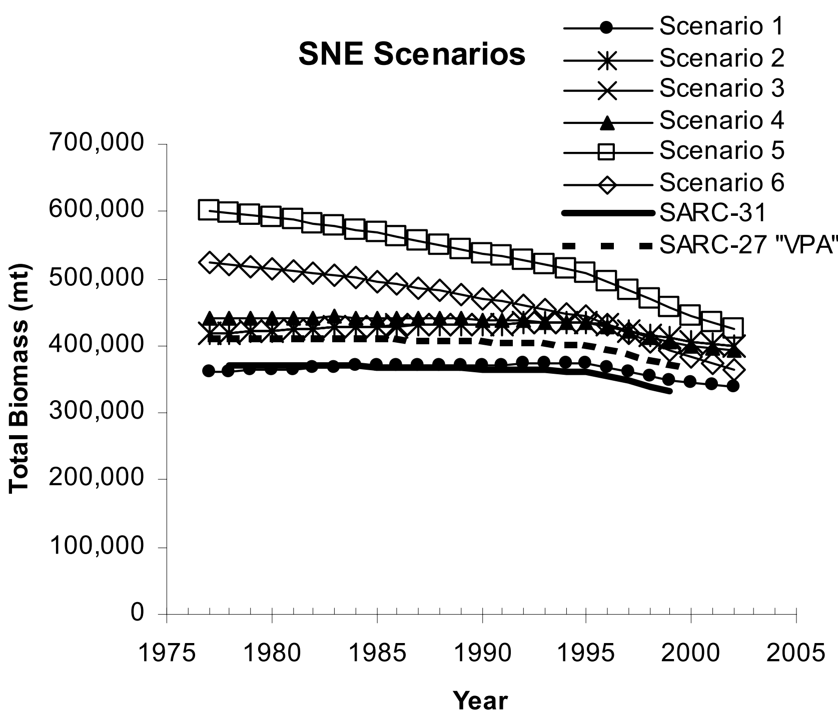


Figure A70. Southern New England region, biomass scenarios.

SNE - Scenario 3

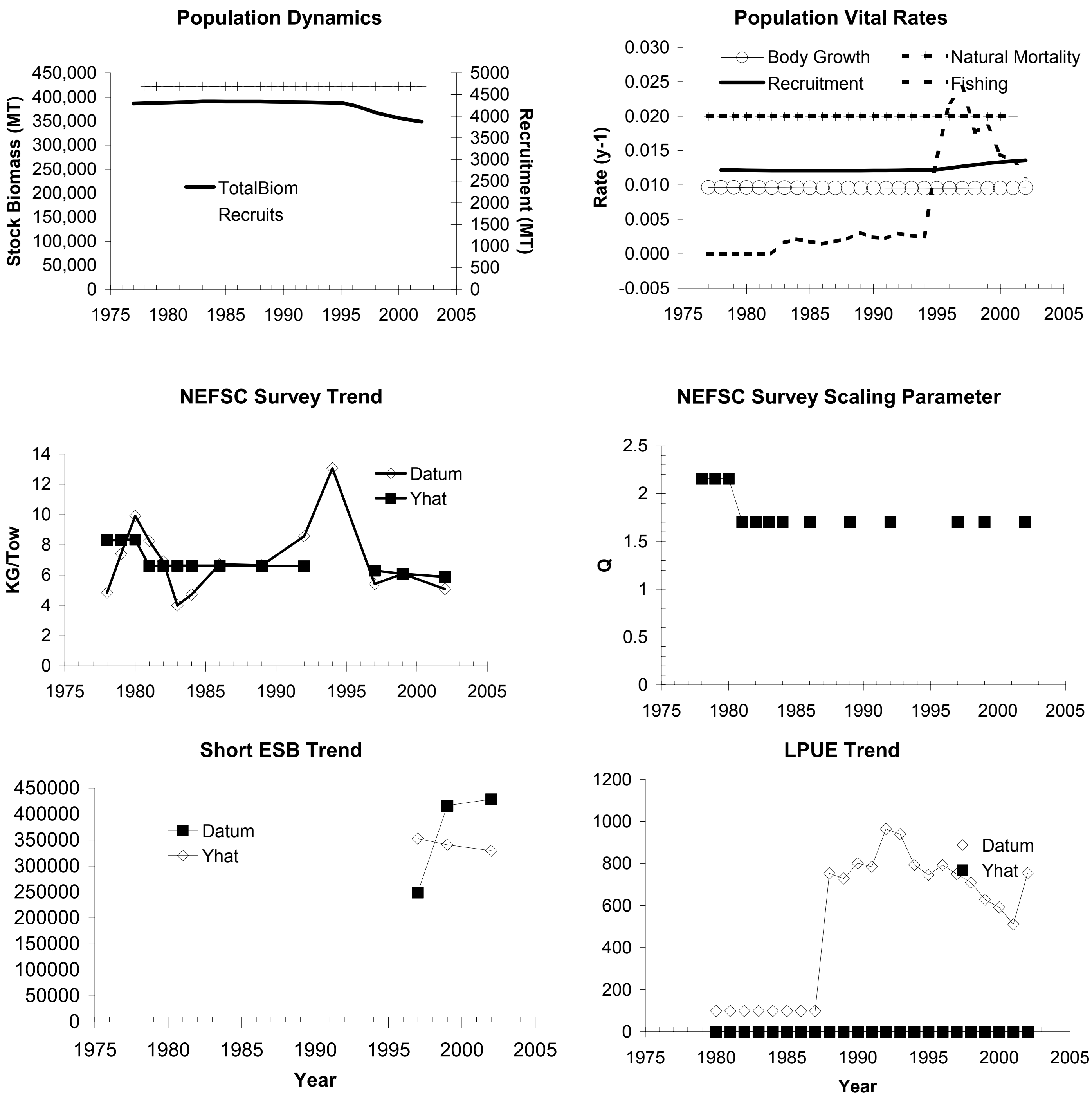


Figure A71. Southern New England region, Scenario 3.

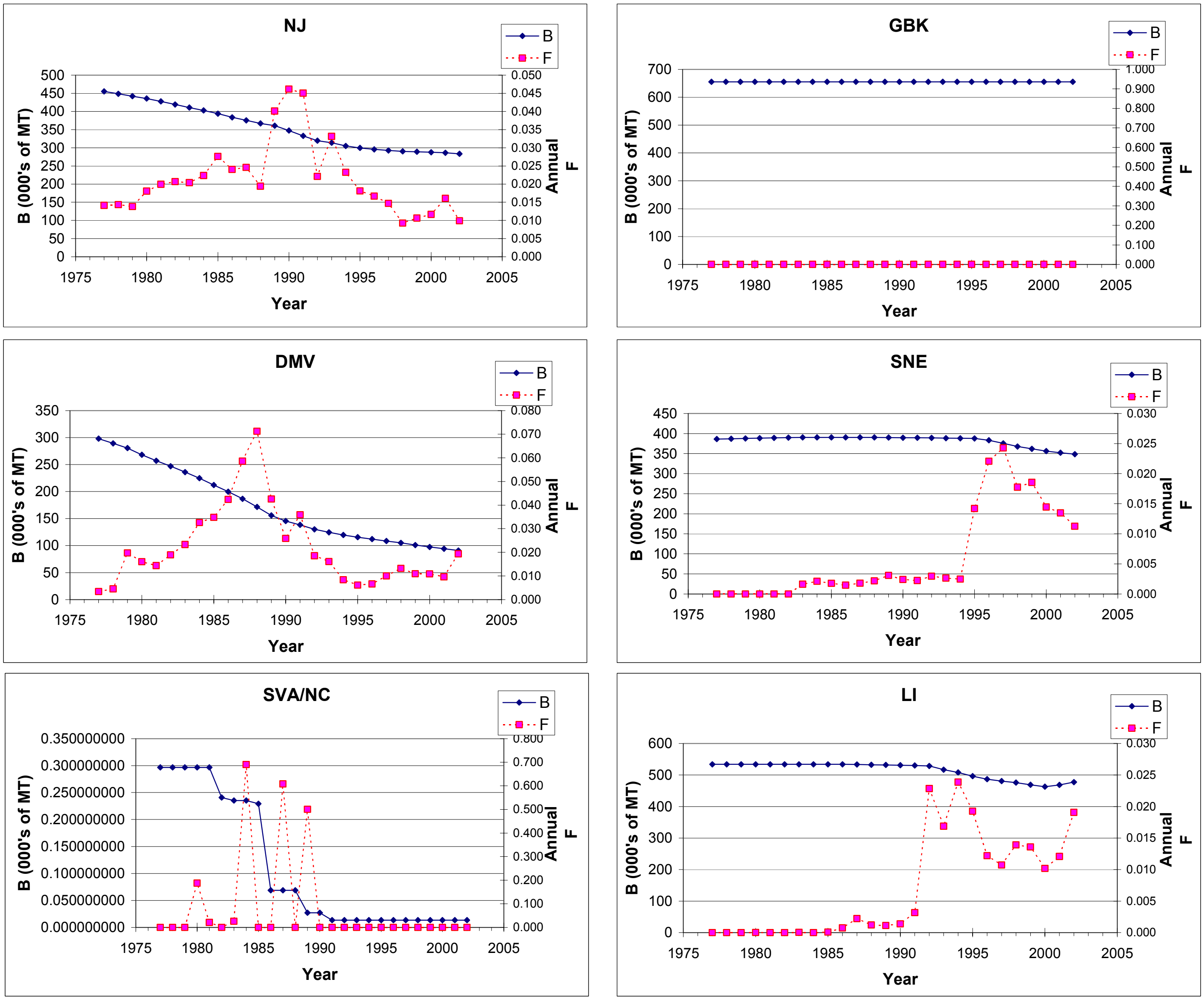
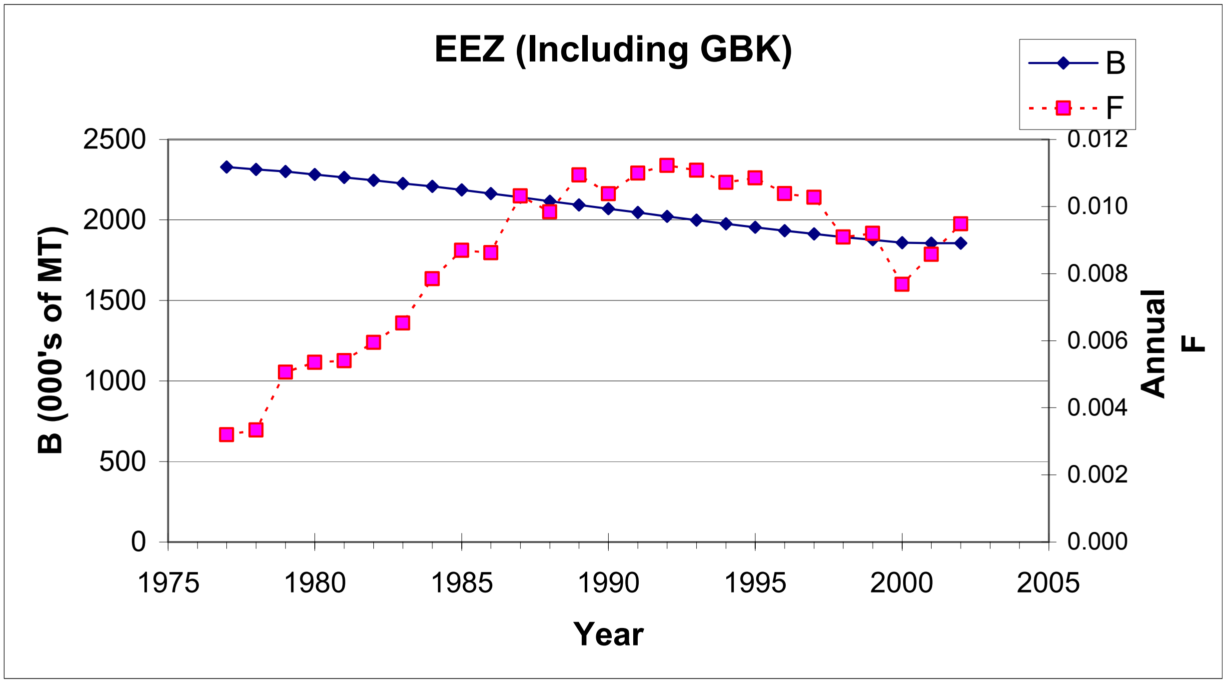


Figure A72. Regional biomass and annual fishing mortality rate over time based on KLAMZ and other models. Values are from Table A24.



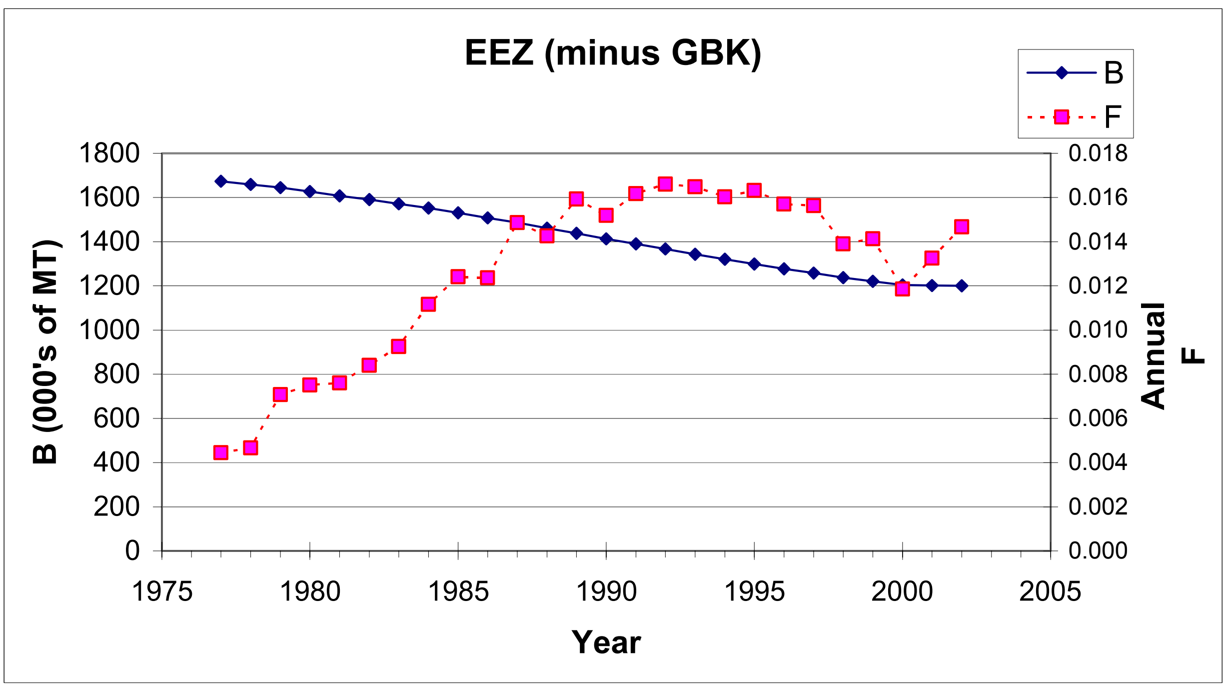


Figure A73. Biomass and annual fishing mortality rate over time based on KLAMZ and other models, for the EEZ and the EEZ less GBK. Values are from Table A24.

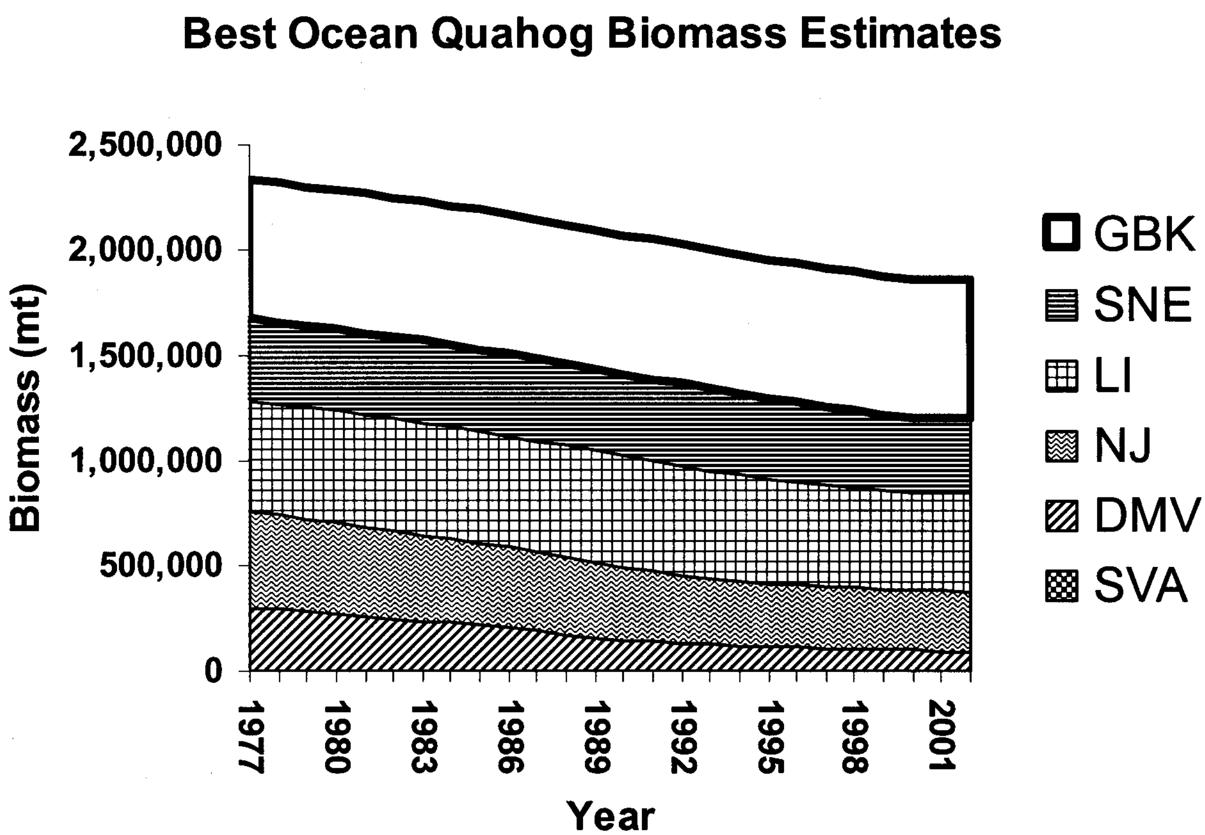
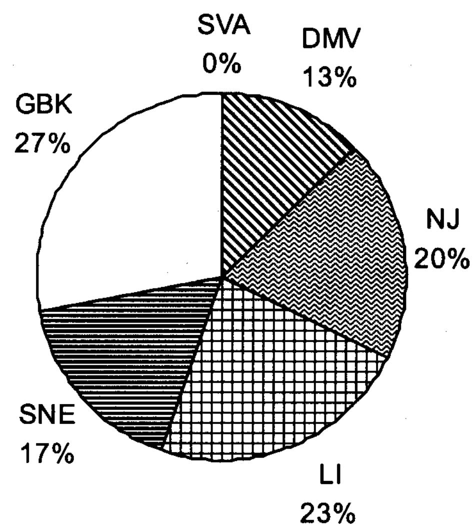


Figure A74. Temporal trends in ocean quahog biomass, Based on Table A24.

Best 1977 Quahog Biomass Estimates



Best 2002 Quahog Biomass Estimates

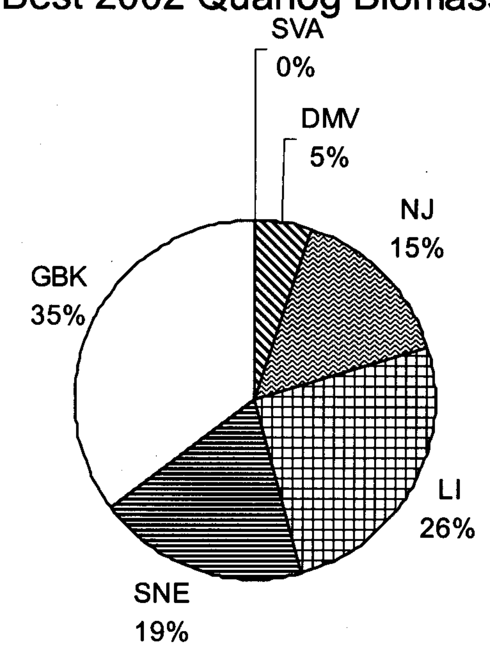
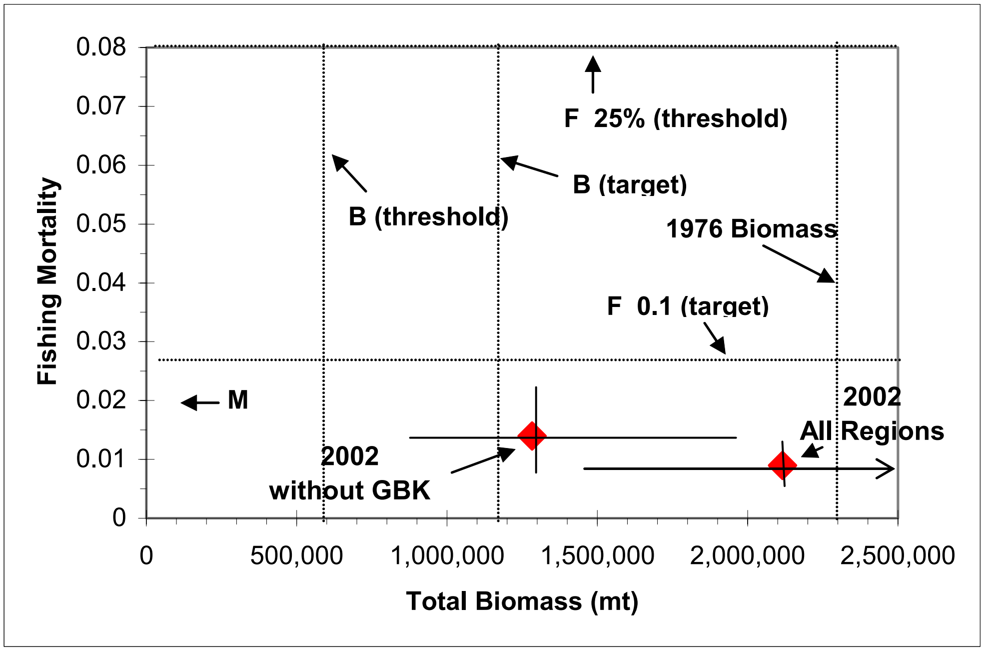


Figure A75. Percentage ocean quahog biomass by region, 1977 and 2002. Based on values in Table A24.

A.



B.

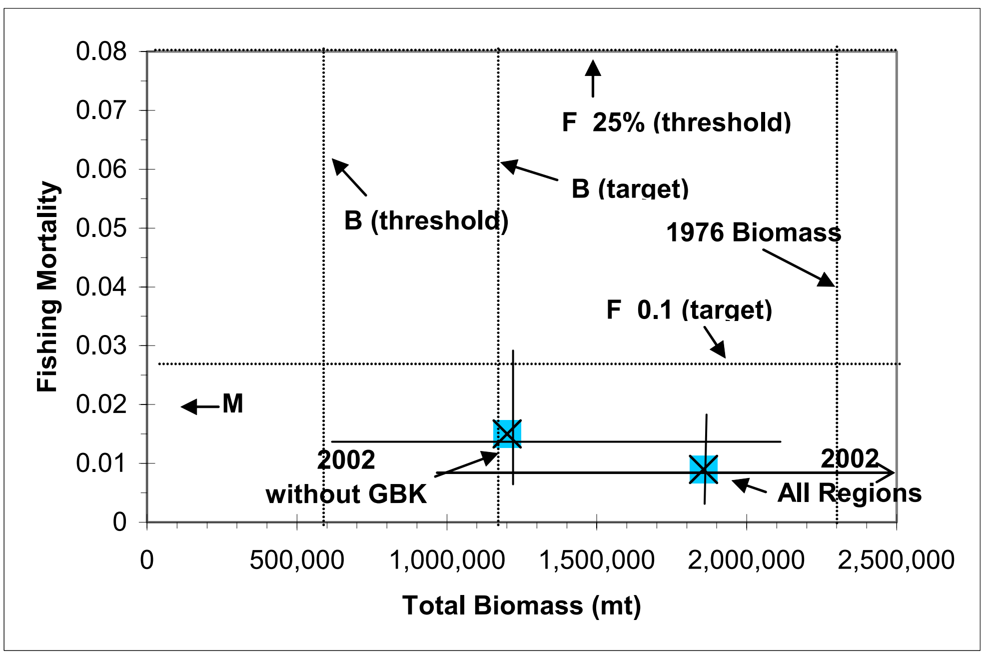


Figure A76. Ocean quahog biomass and fishing mortality rate in relation to updated Biological Reference Points. Biomass and F estimates for 2002, as well as the 80% CIs, are from the A. ESB model or B. KLAMZ model.

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.

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[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 Π_{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; ρ 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 ρ=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 ρ=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 ρ is constant.   Use of time-variable J_t values with ρ 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 $G_t^{Old} = \ln\left(S_t^*/S_t\right)$. 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 Ω_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 (μ) and a set of annual log scale deviation parameters (ω_t):

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

The deviations ω_t are constrained to average zero.[g] With the constraint, estimation of μ and the set of ω_t values (1+ n years parameters) is equivalent to estimation of the smaller set (n years) of Ω_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, π is a model parameter that may be estimated (in principal but not in practical terms), and ϖ_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 π 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 κ_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 (λ = 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 (Φ) and a set of annual log scale deviation parameters (ψ_t):

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

where the deviations ψ_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 ≥ 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:

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

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 (ρ 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:

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

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 $\overline{F}_{Recent}$ and biomass $\overline{B}_{Recent}$ levels. These status determination variables are used in calculation of status ratios such as $\overline{F}_{Recent}/F_{MSY}$ and $\overline{B}_{Recent}/B_{MSY}$.

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_Ξ is the number of NLL components (L_v) and the λ_v are emphasis factors used as weights. The objective function Ξ 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 (λ_v) are usually set to one. An arbitrarily large weighting factor (e.g. λ_v =1000) is used for "hard" constraints that must be satisfied in the model. Arbitrarily small weighting factors (e.g. λ_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 (λ_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~N(μ,σ^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(σ) 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 σ. 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 Φ and ψ_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:

$$g(F_t) = C_t + \frac{F_t \left(1 - e^{X_t}\right)}{X_t} B_t = 0$$

where $X_t = G_t - M_t - F_t$. If $X_t = 0$, then $\overline{B}_t = B_t$ 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:

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

where $g'\left(F_t^i\right)$ 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 $g\left(F_t^i\right)$ and $abs\left[g\left(F_t^{i+1}\right) - g\left(F_t^{i+1}\right)\right]$ are both less than a small number (e.g. ≤ 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):

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

F for landings versus F for discards

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 ${}^D F_t = \frac{L_t}{C_t} F_t$.

Predator consumption as discard data

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.).

Effort calculations

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 κ_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.

Initial population age structure

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 (τ_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 σ_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 σ_G for the first few years. The constraint on initial IGRs should probably be "soft" and non-binding ($\lambda \approx 1$) 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. λ=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:

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

[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_I is small while the latter is effective when S_I is large. Constants and details in calculation of NLL for the constraint are not important because the constraint is binding (e.g. λ=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 (λ) 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 (ϖ_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 π 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 σ_{ϖ} 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.

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

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:

[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:

$$Q_v = e^{\frac{\sum_{i=1}^{N_v} \left[\ln\left(\frac{I_{v,i}}{A_{v,i}}\right) / \sigma^2_{v,j} \right]}{\sum_{j=1}^{N_j} \left(1/\sigma^2_{v,j} \right)}}$$

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

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

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

[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/ ^{o}C if the covariate is mean centered temperature in ^{o}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 γ 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 σ_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:

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

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:

$$E[\ln(R_t)] = \ln\left[e^a T_{t-\ell} / \left(e^b + T_{t-\ell}\right)\right]$$

where $a=e^{\alpha}$ and $b=e^{\beta}$, the parameters α and β 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^{α} and e^{β}) 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:

$$E[\ln(R_t)] = \ln\left(S_{t-\ell} e^{a-bS_{t-\ell}}\right)$$

where $a=e^{\alpha}$ and $b=e^{\beta}$, and the parameters α and β 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:

$$L = \sum_{t=t_{first}}^{N} w_t \left[\ln(\sigma_r) + 0.5 \left({r_t}/{\sigma_r} \right)^2 \right]$$

where λ_t is an instance-specific weight usually set equal one. The additional term in the NLL [$ln(\sigma_r)$] is necessary because the variance σ_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 ℓ (see below). The biased maximum likelihood estimate for σ^2 (with N in the divisor instead of the degrees of freedom) is used because actual degrees of freedom are unknown. The variance term σ^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:

$$NLL = \sum_{t=1}^{t_{first}-1} w_t \left\{ \ln(\sigma_r + 0.5 \left[\frac{\ln\left(R_t / E\left(R_{t_{first}}\right)\right)}{\sigma_r} \right]^2 \right\}$$

where t_{first} is the first year for which expected recruitment $E(R_t)$ 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:

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

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 $\tau = \ln(\bar{q}) - \frac{\varphi^2}{2}$ 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.

<u>Surplus production modeling</u>

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 σ 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:

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

with the threshold value κ normally set by the user to about 0.95. Values for κ 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]

[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:

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

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.

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

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B. ATLANTIC BUTTERFISH

TERMS OF REFERENCE

1) Characterize the commercial catch including landings and discards.

2) Provide time series of survey catch (numbers and weight indices) for NMFS and appropriate state surveys.

3) Explore the influence of environmental factors on survey catch rates.

4) Conduct exploratory stock assessment modeling utilizing fishery catch and survey data sets.

5) If possible estimate fishing mortality, spawning stock biomass, and total stock biomass during the current year and characterize the uncertainty of those estimates.

6) Update, as appropriate, estimates of biological reference points.

INTRODUCTION

Butterfish (*Peprilus triacanthus*) are distributed from Florida to Nova Scotia, occasionally straying as far north as the Gulf of St Lawrence (Bigelow and Schroeder 2002). Butterfish are a fast growing species that undergo seasonal inshore and offshore movements. This schooling species seldom attains an age greater than 6 and often schools by size. Butterfish mature at age 1, spawn during the summer months (June-August), and begin schooling at about 60 mm (Bigelow and Schroeder 2002). They exhibit a planktivorous diet, feeding mainly on zooplankton, ctenophores, chaetognaths, euphasids. Butterfish are preyed upon by a large number of medium-sized predatory fishes such as bluefish, weakfish, and spiny dogfish; marine mammals such as pilot whales and common dolphins; seabirds such as greater shearwaters and northern gannets; and large pelagic fish such as swordfish, throughout their range.

The Mid Atlantic Fishery Management Council manages butterfish as part of the Atlantic mackerel, Squid, and Butterfish (MSB) Fishery Management Plan. Overfishing for this species is defined as occurring when Fmsy is exceeded, but an estimate of Fmsy is currently not available. The current overfishing definition is based on an MSY of 16,000 mt and a fishing rate of Fmsy. An MSY of 16,000 mt represents the current estimate of long-term potential catch for the stock and was used in previous amendments to the FMP. The target fishing rate for this stock is defined as 75% Fmsy which gives a target yield of 12,000 mt, well above the current quota specification of 5,900 mt. The biomass target for this stock is defined as Bmsy and the minimum biomass threshold is defined as ½ Bmsy. There have been a series of amendments to the MSB Fishery Management Plan; the most recent amendment (Amendment 9) does not propose any changes for butterfish.

The most recent assessment for this stock was completed in 1993 (SARC 17). Conclusions were that the stock was at a medium level of biomass and that catches were well below the MSY of 16,000 t. There was no information about exploitation rates available, but recruitment appeared to be at a high level.

Survey indices indicated a decline in 1992-93 from 1990 and adult stock had declined and was well below average.

THE FISHERY

Commercial Landings

Commercial landings by the United States have remained below about 5000 mt from 1960-2002 except for a period during the mid 1980s when landings increased to over 9,000 mt during 1982 and over 11,000 mt in 1984 (Table B1; Figure B1). Butterfish landings averaged 2,171 mt during 1965-1979 without any trend. During 1980-1989 landings increased sharply to over 9,000 mt in 1982, declined, and then increased to over 11,000 mt in 1984. This rapid increase in the 1980s occurred due to heavy demand for butterfish in the Japanese market. Demand waned and landings averaged only 2,790 mt during 1990-1999. More recently landings have declined markedly, averaging only 1,731 mt during 2000-2003, with very low totals in 2002 and 2003 (Table B1; Figure B1).

Reported foreign landings were much smaller than actual landings during 1965-1986 and were adjusted upward by Murawski and Waring (1979) for the years 1968-1976. . Adjusted landings from Murawski and Waring (1979) for 1968-1986 were used in the current assessment and the average ratio for adjusted landings (1968-1976; 1.437) was used to adjust reported foreign landings upward for the period 1977-1986. Since foreign landings were relatively small during this period only a small adjustment was necessary (Table B2).

Landings from the foreign fishery during 1965-1986 were relatively much larger than the USA fishery during this time, averaging over 6,800 t. Foreign landings varied from a low of 749 t in 1965 to 5,437 t in 1968 and increased the next year to 15,378 t. Foreign landings declined for a few years and peaked at 31,679 t in 1973, declining thereafter to a low of only 236 t in 1986 (Table B1).

Commercial Length Composition

Size composition from commercial samples of butterfish ranged between 12-25 cm during 1995-2003 with a modal length at 16-17 cm, depending on the year (Figure B2). The number of fish measured was higher during the earlier years, declining during 2000-2003 (Figure B2).

Commercial Fishery Discards

Previous assessments suggested that discarding of butterfish in the various fisheries might be a problem and recommendations by the SARC suggested that discards should be quantified if possible in future assessments. Several sources of information are available for the analyses of discards in the USA fishery. The vessel trip report (VTR) database, available since 1994, has been used to document discard rates and amounts in various assessments. Discard estimates from the VTR have not been used in assessments because it is felt that they underestimate the actual level of discards. Another source of information on discarding is the NMFS Observer program database. This source of information includes vessel trips with an observer on board the vessel with many if not most of the tows actually observed by the recorder. The general problem with this data has been the lack of a statistical design for sampling and the small number of trips that are actually covered in any given year. Previous to 1994 port agents interviewed vessel captains at the conclusion of the trip and estimates of discards for some stocks and areas fished were obtained and logged in a vessel trip file, but this source of information is no longer available.

Butterfish are caught in a variety of fisheries and may be retained or discarded depending on the particular demand in that fishery. Butterfish are often unwanted by-catch in many fisheries such as squid, silver hake, and mixed groundfish. Discards from these sources can be substantial and the total from all such fisheries can be large. To obtain information on the source of discards from various sources, several fisheries were defined based on a target species or mix of species (10 fisheries) and the percent and frequency of butterfish catches in those fisheries during 1989-2002 was calculated. Butterfish were caught frequently in the Fluke, squid, mixed groundfish, and silver hake fisheries (Table B2). These results of course varied by year and were often related to the demand for butterfish and also the other species during that particular year.

On an annual basis the fishery for squid produced the highest level of butterfish discards over the entire period (Table B3). Other important categories were mixed groundfish, Fluke, and Other. Discards in the silver hake target fishery were relatively large during 1989-1993, but declined considerably thereafter (Table B3).

Patterns in butterfish landings were examined by aggregating over a set of observed trips that caught butterfish during 1989-2003. The distribution of landings was highly skewed so upon examination of the data an arbitrary cutoff of 600 lbs was chosen to stratify butterfish trips for analysis (Figure B3). The distribution suggested that a large number of trips landed a small amount of butterfish and many fewer trips accounted for the largest landings.

Discard ratios were calculated using the VTR database for 1994-2002. Only trips that reported some discard of any species were used in the analysis. Initially all gears that captured butterfish were examined for discards, but only data for otter trawls were included in subsequent analyses because discards by other gears such as gill nets were negligible. The data were stratified into half-year intervals and two categories of landings, 600 lbs or less and greater than 600 lbs. An aggregate approach was used to allocate landings and discards into the appropriate categories, so that all trips with some amount of landings or discard were included in the analyses. Sample sizes in each cell were relatively large under this stratification scheme. Discard ratios were calculated by dividing discard by landings.

Results from this approach indicate that discard ratios averaged less than 1 for both categories of landings (Table B4). In many cases discard rates were very small on an annual basis indicating that reporting rates for discards in vessel logbooks may be relatively low. These results have been reported for others species in similar analyses of vessel logbook data. (NEFSC 2002). Therefore we did not use the VTR data to estimate discards in this assessment.

Another analysis was completed using the NMFS Observer database. Only data from observed tows were used in the analysis and only otter trawl trips were analyzed for the same reason as above. Data were stratified into half-year intervals and categories of 600 lbs or less and greater than 600 lbs. An aggregate approach including all trips with some landings or discard of butterfish was used to allocate trips into one of the four cells for each year during 1989-2002. Under this scheme since only observed trips were used, sample sizes were much smaller (Table B5).

Results showed that on average discard ratios were greater than 1 and in most cases significantly greater. With a few exceptions such as for some of the larger cells during 1997-2001, discard rates were greater than 1 (Table B5). Discard ratios in the 600 or less category during 1998-2002 were largest.

Since the data are skewed another, perhaps more appropriate analysis, using a log transformation, was completed. Only trips with matched landings and discard were used with the same four categories of season and trip size. The data were log transformed (ln(x+1)), and discard ratios were calculated on a per trip basis. Discard ratios were averaged in each cell and retransformed to the arithmetic scale. No correction for transformation bias was attempted since earlier studies indicated that variances were relatively high and the retransformed discard ratios would be too high to be useful (NEFSC 2002). It is likely that the backtransformed values are biased low so that discards are underestimated. Since only matched trips were used for this analysis fewer samples were available for this analysis, especially in the higher categories (Table B6).

Results from this approach produced discard ratios that were much less variable ranging from 0.47-4.61, and averaging 4.16 for <600 lbs and 1.67 for > 600 lbs (Table B6). These discard ratios were used along with otter trawl landings by half year and the same landings categories to estimate discards (tonnes) for each cell in each year and then totaled for the year. Discards ranged between 1,809-8,599 mt during 1989-2002 (Table B7). Discards were 4,442 mt in 1989, declined to 3,020 mt in 1990 and then increased steadily to 8,478 mt in 1993. After a decline to 3,701 mt in 1994, discards increased to 8,599 mt in 1995, followed by an almost steady decline to 2,427 mt in 2000 (Table B7). After increasing to 7,262 mt in 2001, discards declined to 1,809 mt in 2002.

Discards for1965-1988 were estimated by calculating an average discard ratio for each half year and landings category for 1989-2002. These average ratios were multiplied times otter trawl landings using the same stratification to produce an estimate of discard (tonnes) during 1965-1988. Discards were low, less than 2000 mt during 1965-1977 and increased markedly from the early to mid 1980s (Figure B4). Discards reached a peak in 1984 of 18,959 mt.

Size Composition of Discards

Data from observed otter trawl trips were assembled to examine the size composition of the discarded and kept fraction of trips where butterfish were caught. The size composition of discarded butterfish ranged form 4-24 cm depending on the year and the fishery, but discarded fish were generally less than 16 cm (Figure B5). The kept fraction of trips ranged from 10-22 cm and usually had a modal length from 16-18 cm (Figure B5). Sampling intensity was generally moderate to high during 1989-1991, low in 1992, and moderate from 1993-2000. Sampling intensity declined during 2001-2002, but may have increased in 2003 due to more trips being observed.

Total Catch

Landings from the USA, USA discards, and foreign landings during 1965-2002 were summed to estimate total catch over that period (Figure B6). Catches increased steadily from 1965-1973, reaching a peak of 34,265 mt in 1973. Catches declined after 1973 reaching about 7,200 mt in 1977 and then began another increasing period starting in 1979, reaching 31,500 mt in 1984 (Figure B6). After 1984 catches declined and stayed in a fairly steady pattern between 5,000 and 13,000 mt during 1987-2002. Recent catches have all been around 5,000 mt except during 2001 when the catch reached 11,700 mt (Figure B6).

RESEARCH SURVEY ABUNDANCE AND BIOMASS INDICES

Research survey abundance and biomass indices are available form several sources for assessing the status of the butterfish resource. Survey indices are available from NMFS surveys for the winter 1992-2002, Spring 1968-2002, and Autumn 1968-2002. The autumn period during 1963-1966 was not covered in the southern Mid-Atlantic Bight region so no indices are available for butterfish during this period. A new set of survey strata were used in this assessment because the set in the previous stock assessment included inshore strata 1-46 for the period 1968-1993. These inshore strata were not covered during 1968-1972 and were sporadically covered thereafter, so a set of offshore strata (1-14, 16,19,23,25,61-76) was used instead. Indices are also available for several state survey programs, notably Massachusetts DMF, Rhode Island DFW, Connecticut DEP, New Jersey BMF, and Virginia Institute of Marine Science (VIMS). The annual coverage for these surveys spans the period from 1978-2002 although some do not start until after 1978. In the short time available for this assessment, only data for the MA, RI, CT, and VIMS surveys were available, so only these surveys will be presented.

NEFSC Surveys

The NEFSC winter survey covers 1992-2002 with number per tow ranging from 38-169 and weight per tow from 0.8-6.2 (Table B8; Figure B7). With the exception of 1994-1995 and 2000 relative abundance has been moderate during this period and biomass has been moderate with a few low years (Table B8). The spring survey in number per tow ranged from a low of 9.9 to a high of 228 during 1968-1979, from 13.4-66.2 during 1980-1989, 8-9-112.9 during 1990-1999 and 36.8-61.2 for 2000-2002 (Table B8; Figure B7). Spring indices in wt/tow (kg) were generally higher in the early 1970s and early to mid 1980s than during the late 1980s and early 1990s (Table B8; Figure B8). Spring wt/tow (kg) indices increased slightly in the late 1990s and then declined again. Autumn survey indices in number/tow were generally much higher than the winter and spring indices because of the presence of the age 0 fish in the autumn. Catch per tow in number was moderately high but fluctuating during 1968-1978 and very high from 1979-1990 (Table B8; Figure B7). Indices declined slightly during 1991-2000 and then declined again in 2001-2002. Autumn indices in wt/tow (kg) were highest during 1979-1990, declining during 1991-1999 and then dropping to lower levels in 2001-2002 (Table B8; Figure B8).

Aged NEFSC Survey Indices

Aged butterfish survey data from NEFSC Spring and autumn surveys are available from 1982-2002. The delay difference biomass model used in this assessment is a partial age structured model, utilizing biomass per tow indices for two age groups, at age 0 and age 1+. Survey indices in both number and weight per tow (kg) at age were run to allow for the estimation of survey Z's and for use in the delay difference model.

Spring survey number-per-tow at age is shown in Table (B9). This survey generally catches age groups 1-3 and some fish from age group 4. Survey indices in number-per-tow at age for the autumn during

1982-2002 are shown in Table (B10). This survey generally catches age groups 0-3 with the age 0 catch dominating the total catch in number.

The autumn survey catch in weight per tow (kg) is shown in Table (B11) for age groups 0-3. Indices in weight for age 0 and aggregated 1+ for 1982-2002 were calculated from the table. Indices for 1968-2002 were calculated from the relative proportion of age 0's from Table E5 from the last assessment (NEFSC 1993). The relative proportions were applied to the catch/tow from the new strata set to get the numbers of 0's. These numbers were converted to weight (kg) by applying the average weight of an age 0 butterfish and then subtracting this wt from the total 1+ weight. The values for age 0 and 1+ were calculated for 1968-1981 and are shown in Table (B11).

<u>Additional Survey Analyses</u>

Several additional analyses were performed on the NEFSC spring and autumn survey time-series. Survey wt/tow indices were bootstrapped using the method of Smith (1997) to produce confidence intervals for spring and autumn during 1968-2002. Results indicate that both series have prominent confidence bands around their mean values (Figures B9;10). It also appears that the variance of the wt/tow values increases with increases in the mean. A plot for the autumn survey, showing the relationship between mean wt/tow and variance in mean wt/tow, confirms this (Figure B11). This is a common result, variance often increases as populations grow larger. The effect of stratification and sample allocation was also investigated. Results from this approach indicate that there were no persistent gains in efficiency for butterfish from the stratification scheme that is currently employed in the groundfish survey for spring and fall (Figure B12). This result is not surprising because the survey was not necessarily designed to sample species like butterfish. Depth, temperature, and day/night differences were also examined for possible links to the high variability in butterfish survey catches. No strong relationships were detected for either depth or temperature, but a reasonably strong relationship was indicated for day/night catches during the autumn. In most years survey wt/tow (kg)was higher during the daytime in the fall survey (Figure B13). There was very little difference in spring day/night catches. (Figure B13).

<u>State Surveys</u>

MADMF Survey

The Massachusetts survey during Autumn 1982-2002 was relatively flat from 1978-1991, and then increased considerably to a peak of 14.5 kg/tow in 1998, declining after that (Table B12; Figure B14). Survey catch rates from this survey are comparable to the NEFSC surveys.

RIDFW Survey

The Rhode Island survey covered the period from 1981-2002 with survey trends from 1981-1991 also being relatively flat (Table B12; Figure B14). Survey indices increased slightly to a peak of 9.3 kg/tow in 1997 and then declined to much lower levels after that. Survey catch per tow from this survey are about the same magnitude as the NMFS surveys although they cover a much smaller area.

CTDEP Survey

The Connecticut bottom trawl survey that was available had available indices in number/tow during 1984-2002. These indices were converted to wt/tow by multiplying by the average weight (0+) from the NMFS Autumn surveys for each year. Since this survey catches relatively large numbers of butterfish, the indices in weight are relatively large (Table B12; Figure B14). This survey shows a variable but increasing trend from 1984-2002.

VIMS Survey

The Virginia Institute of Marine Science bottom trawl survey in Chesapeake Bay catches a small number of age 0 butterfish during the autumn. This survey was available for the period from 1988-2001 and also was converted to a weight/tow index by applying the USA Autumn age 0 weight to each year. This survey shows a variable, but downward trend in biomass from 1988-2001 (Table B12; Figure B15).

<u>Survey Indices for Scale</u>

It is often necessary, especially for age-structured models, to constrain solutions to feasible regions so that useful results are produced. Several time-series were available for possible scaling of model results for the butterfish stock assessment. Murawski and Waring (1979) produced biomass estimates in a butterfish stock assessment (Figure B16). Minimum swept-area biomass estimates from the NEFSC Autumn survey were also prepared as a possible scale variable for the model. Waring (1970) used a ratio between day and total survey catch to produce a minimum biomass estimate for butterfish. The ratio of survey day catches (07:00-17:00) to total survey catch for each year in the autumn survey was computed. These ratios were averaged and each annual minimum biomass estimate was multiplied by this average ratio (1.54). Autumn survey minimum biomass tracks the autumn survey wt/tow index, but is scaled upward (Figure B17). The final series of data that are available is a set of autumn survey survival rates computed from the autumn survey number/tow indices. This index is calculated as a Heinke ratio between age 1+ in year t+1 and age 0+ in year t. These estimates are shown in Figure (B18).

BIOLOGICAL DATA AND ANALYSES

<u>Growth</u>

Starting in 1992 butterfish have been individually weighed while at sea during groundfish cruises. This database was used to fit Length-Weight equations for each year and each survey from 1992-2002. Plots of spring and Autumn LW relationships suggest that there were no changes in patterns of growth fro this species during this period (Figures B19; 20). On this basis common LW relationships were computed for spring and autumn as a weighted average of the a and b parameters for each year. These average LW parameters were used in SURVAN runs to produce mean wt/tow for 1982-2002.

We also needed to estimate Von-Bertalanffy growth parameters for use in the delay-difference model so we used an aggregate approach for all the data. Butterfish spawn during June-August and are assigned ages based on calendar years. Young-of-year butterfish born in the second half of 1983, for example, reach *nominal* age 1 on January 1, 1984 at a *biological* age of no more than 6 months. Butterfish grow rapidly and significant numbers are taken in commercial fisheries at nominal age zero as bycatch primarily during the second half of the year. Age data given in this report are nominal ages (as assigned by readers) unless otherwise specified.

The KLAMZ (FPA) model for butterfish was set up on a calendar year basis using nominal ages. In the model, new recruits are age 0 butterfish that recruit to the stock on January 1. Estimates of total biomass (ages 0+) on January 1 from the FPA model for butterfish are hypothetical figures that include the amount of hypothetical age zero biomass necessary (considering growth and mortality) to explain subsequent catch data and survey trend data. To avoid using hypothetical biomass levels, it is probably better to track butterfish population dynamics in terms of average annual total biomass (ages 0+ at some point mid-year) or escapement biomass (ages 1+ on January 1) which are also estimated in the FPA model. Approaches to modeling growth and population dynamics for species like butterfish that recruit at age zero and grow quickly is a topic for future research.

Butterfish in NEFSC fall and spring surveys have been individually weighed at sea since 1992. A length-weight relationship was estimated based on all available length and individual weight data (see below).

```
       *** Nonlinear Regression Model ***

Formula: INDWT ~ alpha * LENGTH^beta

Parameters:
             Value   Std. Error  t value
alpha 0.0000158953 3.50244e-007  45.3836
 beta 3.0854500000 7.90770e-003 390.1830

Residual standard error: 0.00771297 on 11552 degrees of freedom

Correlation of Parameter Estimates:
      alpha
beta -0.998
```

The estimated length-weight parameters were used to calculate individual body weights for all butterfish taken in spring, fall and winter surveys and aged since 1963. Records for eleven age 0 butterfish from winter and spring surveys were omitted because age 0 butterfish should not be available until after June. Data from a total of 21,765 butterfish ages 0.78-6.3 years were used to estimate growth curves (Figure B21).

The average Julian date of survey tows in butterfish strata for spring surveys during 1968-2002 was 95 days and the average Julian date for fall surveys was 284 days. Therefore, ages used in fitting growth models were adjusted by increasing the nominal age by 95/365=0.26 y for butterfish taken in spring surveys, by 47/365=0.13 y in winter surveys, and by 284/365=0.78 y for butterfish taken in fall surveys (see below).

Schnute's (1985) general growth model used in derivation of the delay difference model in FPA is:

$$w_a = v + (V - v)\frac{1-\rho^{1+a-k}}{1-\rho}$$

where k is the age at recruitment, w_a is weight at age $a \geq k$, v is the predicted value of w_{k-1}, V is the predicted value of w_k, and $\rho=e^{-K}$ where K is the parameter for von Bertalanffy growth in weight. The FPA model, in turn, uses the growth parameters ρ and $J=v/V$.

Modeling butterfish growth in the FPA model is complicated by the differences between nominal age (based on calendar years used in the model) and biological age, and because recruitment occurs at age zero and growth is rapid. As shown above, the growth parameter v should be a positive number that estimates body weight at age k-1 one year prior to recruitment. In theory, the parameter v for butterfish would be body size at age k-1 = –1 during the January of the year before spawning occurs. Moreover v for butterfish is negative when $k = 0$ (see below).

To obtain useful growth parameters for modeling butterfish, we estimated growth parameters in Schnute's model by nonlinear regression assuming that butterfish recruit at a nominal age of 1.5 in nominal years (age 1 in biological years). Results (see below) were statistically significant although butterfish growth is highly variable. Growth parameters used in the FPA model for butterfish were ρ=0.81605800 and J=v/V=0.09675675 (see below).

```
    *** Nonlinear Regression Model ***

Formula: calcwt ~ schnute(newage, littlev, bigv, rho, k = 1.5)

Parameters:
             Value  Std. Error  t value
littlev 0.00507862 0.000375370  13.5296
   bigv 0.05248860 0.000230723 227.4960
    rho 0.81605800 0.009812100  83.1685

Residual standard error: 0.0229647 on 21762 degrees of freedom

Correlation of Parameter Estimates:
     littlev   bigv
bigv -0.318
 rho  0.729  -0.728
```

Our approach to estimating growth parameters may underestimate the growth rate and biological productivity of age zero butterfish in the FPA model. Nevertheless, the parameter J=0.09675675 implies that body weight of young-of-year butterfish increases quickly by about 1/J=10.3 times per year during the first year of life. In addition, growth curve predicted weights for age zero butterfish during the second half of the year (when age zero butterfish tend to be taken by the fishery) and weight at age for all subsequent ages appears reasonable (see below).

For potential future use, we fit a conventional von Bertalanffy growth model using nonlinear regression and the same data (see below). As expected (Schnute 1985), the resulting von Bertalanffy growth curve was indistinguishable from the Schnute growth curve.

```
    *** Nonlinear Regression Model ***

Formula: calcwt ~ vb(newage, winf, vbk, tzero)

Parameters:
         Value Std. Error t value
 winf 0.262838 0.01167340 22.5160
  vbk 0.203254 0.01202370 16.9045
tzero 0.403999 0.00840727 48.0535

Residual standard error: 0.0229647 on 21762 degrees of freedom

Correlation of Parameter Estimates:
        winf    vbk
  vbk -0.996
tzero -0.742  0.787
```

Natural Mortality

Natural mortality rates for butterfish were investigated in Murawski and Waring (1979). The best estimate from this study was M=0.8, and this value was also used in the present stock assessment. Other supporting evidence suggests that natural mortality rates for this species may be high. Overholtz and Link (2000) studied consumption of pelagic fishes and squids in the Northeast shelf ecosystem. This study suggested that butterfish were not only important in the diets of predatory fish in the region in general, but that during 1977-1997 butterfish may have been very important to predators during years when herring and mackerel biomass was low. Consumption by predators as a group and as individual species was certainly important during this time. For example, a significant amount of butterfish is consumed by weakfish, spiny dogfish, and silver hake (Figures B22-24).

ESTIMATES OF MORTALITY AND STOCK SIZE

Total Instantaneous Mortality from Surveys.

Total mortality rates (Z) were estimated from both spring and autumn bottom trawl survey number/tow at age data from 1982-2002 assuming all age groups were equally available to NEFSC survey gear. Since total mortality is so high over each age group for butterfish, it is possible to estimate age specific values rather than the traditional Heinke aggregated estimate. Survey Z's were very high in the Spring survey, ranging from 0.451-3.65 for age 1, 0.381-3.965 for age 2 and averaging greater than 1.7 for ages 1-2 (Table B13). Estimates for age 3 ranged form .096-4.673, averaging almost 3.0 (Figure B13). Survey Z's followed a similar pattern for the autumn survey. Estimates of Z ranged from 0.822-4.139 for age 0, .0689-3.294 for age 2, averaging 1.789 for age 1 and 1.487 for age 2 (Table B14). Estimates for age 3 ranged from 1.296-6.332, averaging 2.335. These total mortality rates indicate that few butterfish survive beyond age 4 in the spring.

Survey Exploitation Rate Index

Survey exploitation rate indices were calculated by dividing annual butterfish catch by survey indices for spring and autumn. These indices were calculated by using the spring age 1+ wt/tow indices and the autumn age 0+ wt/tow indices for 1968-2002.

The spring exploitation index is variable, but relatively flat over the period (Figure B25). There is some indication that exploitation rates have dropped in the more recent years from 1997-2002. The autumn exploitation index is also variable, but appears to have declined over time through 1990 (Figure B26). More recently, the index is again variable, increasing to a higher point in 1996 and 2001, but otherwise less than half of some of the values observed in the late 1960s and early 1970s.

An Index Method (AIM)

An Index Method (AIM), part of the Woods Hole Toolbox modeling package, provides a more formal method for investigating the relationship between catch and survey indices than the simple exploitation index method. AIM allows for an investigation of the relationship based on a statistical fitting procedure and for the estimation of a replacement level of F to serve as a reference point for a stock. Butterfish catch and spring and autumn survey indices in wt/tow for 1968-2002 were used in the method to discover if any useful signal was present in these data. Auto-correlation analysis indicated that several significant lags were present between the replacement ratios and the relative F's for butterfish from both the surveys and especially the fall (Figure B27). Randomization tests indicated that this relationship was not significant for both surveys. The relationship between relative F and replacement ratio was reasonably good for the spring and the relative F was estimated as F=6.06 (Figure B28). The bootstrap distribution of relative F was fairly broad with an 80% confidence interval between 4.98-7.26 (Figure B28). The relationship between relative F and replacement ratio was somewhat poorer for the fall with the replacement F estimated as 1.50 (Figure B29). The bootstrap distribution of relative F was tighter than the spring with and 80% confidence band between 1.02-2.01 (Figure B29). The six-panel plot for the spring suggests that replacement ratios have been variable over time, and the current relative F is below the replacement F (Figure B30). The corresponding plot for the fall suggests that the replacement ratio has declined steadily over time and the current relative F is slightly above the replacement F (figure B31).

Forward Projection Analysis (FPA) Description

Details of the FPA approach are provided in Appendix A1 (Ocean quahogs). The analysis starts in 1965 and projects forward through 2002. Total biomass, average biomass, recruitment biomass, fishing mortality, and surplus production are estimated in the model.

Growth

Growth is modeled as a Von-Bertalanffy process with k=0.2033 and a constant J ratio of J=0.09677 for 1965-2002.

Maturity

Maturity was assumed to be 0 at age 0 and 1 for age 1+ butterfish.

Natural Mortality

Natural mortality was assumed to be 0.8 as in previous assessments. The FPA allows for the estimation of annual changes in M by modeling it as deviations from a mean value (see appendix A1), but this feature was not used in the current approach.

Recruitment

Recruitment can be modeled in several ways in the FPA. A Beverton-Holt stock-recruitment model was used to model recruitment with the alpha and beta parameters estimated internally in the model (see appendix A1 for details). This formulation was used in initial model runs, but was not used in the final model formulation. The final model estimated recruitment biomass as deviations around the mean recruit biomass during 1965-2002.

Surplus Production

Surplus production for the butterfish stock was estimated with an external Fox (1975) model fit to surplus production and average biomass estimates (Jacobson et al. 2002).. Parameters were estimated internally and lambda was set at 0.0001. This allows the parameters to be estimated, but not influence the model fit to any appreciable degree.

Catch

The total estimated catch (Figure B6) including components for landings and discards was used in the FPA model.

Research Surveys for Trend

The four NMFS surveys were used to tune the butterfish FPA model. These surveys included a Winter 1+ survey, a Spring 1+ survey, an autumn age 0 survey, and an Autumn 1+ survey. The four state surveys were added to the model formulation, but due to time constraints and unresolved residual patterns they were not used in final model runs. This however, does not preclude their use in future modeling exercises for butterfish.

Time-Series for Scale

Three time-series were available for scaling model results in the FPA runs. The biomass estimates from Murawski and Waring (1979) for 1968-1976 (Figure B16), the minimum swept area biomass estimates for the autumn survey for 1968-2002 (Figure B17), and the survey survival rates (S) for the autumn survey 1982-2002 (Figure B18). Although these scalar series were not used in the final model run, they were very useful in profile analyses for determining the best overall model.

Survey Covariates

We hypothesized that the inclusion of the polyvalent doors in 1985 may have affected the catch of butterfish in the spring and autumn surveys. The coefficient for weight per tow for butterfish was not significant (p=.866) (Byrne and Forrester 1991) from the door conversion experiments that were conducted. However, the experiments were not designed to estimate the effects of the door change on pelagic fishes such as butterfish and herring. So, we used a covariate for the door conversion for butterfish; an indicator variable approach was chosen for introducing this variable to the likelihood function as:

$$q' = qe^{\delta D}$$

Where δ is the estimated parameter and D is 1 during 1985-2002 and 0 for all other years in the spring and autumn surveys. Door parameters for the spring and Fall 1+ were examined and found to not be significant and therefore were not included in the final model. A door parameter for the fall age 0 was retained because it was significant and the adjustment in catchability that was predicted was in the correct direction (Figure B32).

We also added a covariate for the change in gear that took place in the spring survey during 1977-1981. In gear comparison studies on the difference between the 36 and 41 trawl; the 41 net caught significantly more butterfish (p=0.05) (Sissenwine and Bowman 1978). This covariate was also added as an indicator variable. The parameter for Spring1+ net was significant and the adjustment for the change to the 41 net was also in the correct direction (Figure B33). The addition of these two survey covariates improved the model fits and residual patterns for the spring age 1+ and especially for the fall age 0 surveys.

FPA RESULTS

Profile and Sensitivity Analysis Results

A series of profile and sensitivity runs were completed to narrow model choices to a few candidates for a final model. Choices included an unconstrained run, runs constrained to particular values of q for Survey Survival (S) and runs that allowed catch to be estimated. The Working Group felt that a profile run over M would also be useful. Values of emphasis coefficients (lamda's) that were used to accomplished these various runs are listed in Table (B15).

Natural Mortality

Since the assumed natural mortality rate in the FPA model for butterfish is very high (M=0.8), a profile analysis was completed to decide if this rate is reasonable. The model was run in increments of M of 0.1, from 0.6-1.4. Results show that the model fits, based on total survey likelihood (Surveys-All) and total likelihood (Total Log Likelihood) were better for values of M of 0.8 or greater (Table B16). When M was reduced below 0.8, the total negative log likelihood increased rapidly. The Working Group concluded that a value for M of 0.8 was reasonable for modelling the butterfish stock.

Survey Survival Rates

One important time-series of information available for scaling model results are survey survival rates (S) (Figure B18). The model was run by placing a large emphasis coefficient (lambda) on q (q=10000) for survival rates and completing a series of model runs. The q for Survival rate parameter was incremented by 0.1 from q=0.2-1.0 and survey covariates for net and doors were switched on. Likelihood terms for the total survey likelihood (Survey_trends), individual surveys (for example Trend_Winter.Survey.Age.1+) and the total likelihood (Total_LogLikelihood) were examined. Values for MSY, Bmsy, average biomass during 2000-2002 (av biomass last 3 yrs) and average F (av F last 3 yrs) were also scrutinized by the Working Group. There is a pronounced bottom in both total survey and total likelihood at a q=0.4 (Table B17). Values of MSY, Bmsy etc are also infeasible at q's < 0.4, and total likelihood increases beyond a q of 0.4. On this basis the Working group concluded that a model run using unconstrained results (q=0.446) would be a possible candidate for a final model.

Estimation of Catches

The Working Group also wanted to examine a set of model runs that allowed for the assumption that catch is measured without error to be relaxed. Since discards are such an important component of the catch in the butterfish assessment, this is a very important issue to resolve. A sensitivity analysis was conducted on the coefficient of variation (CV) of catch to determine the best model and appropriate CV to use if catch is estimated. The model was stepped through CV's of 0.1-0.5 in 0.1 increments and survey covariates for net and doors were switched on.

The model had trouble converging at CV's greater than 0.3, giving infeasible results (Table B18). After examining the feasible runs between 0.1-0.3, the Working Group concluded that a model run with a CV=0.1 was the best case for an overall model that estimates catches with some error. This model was chosen based on the catch likelihood term (0.259), and its relative stability for biomass and F. When trends in average biomass and fishing mortality were examined, runs with CV's greater than 0.1 were rejected (Figures B34; 55).

The Working Group also looked at a sensitivity run for catch CV's with the survey covariates switched off. The total likelihood was much larger for these runs indicating that including these covariates provided for better model fits. Model goodness of fit measures are better as well as residual patterns for model formulations with the survey covariates for net and doors included.

Final Model

Model outputs for the no constraints case and the catch CV=0.1 case are very similar (Table B19). The Working Group decided that the model that estimated catch with some error was a better choice than the model scaled to survey survival rates (S) because discards play a major role in this assessment. However, although initial runs for the catch estimation model converged, later runs with average biomass, spawning biomass, and recruitment did not converge. Therefore, the SARC decided to accept the unconstrained run as the final model (Table B19). Values of lamda's used in the final model run are shown in Table (B20). Parameter values estimated in the final model run are shown in Table (B21).

Average Biomass

Average biomass was variable during 1968-2002, reaching numerous short-term peaks and lows during the period (Figure B36). Average biomass ranged between 7,817-77,189 mt and averaged 33,399 mt during this period (Figure B36). Average total biomass during 2000-2002 was 18,714 mt and 7,817 mt in 2002.

Spawning Biomass

Spawning biomass was also variable during 1968-2002 reaching several periodic peaks and lows during this period (Figure B37). Spawning biomass ranged between 7,843-62,914 mt and averaged 23,239 mt during this period (Figure B37). Spawning biomass averaged 19,100 mt during 2000-2002 and was 8,681 mt in 2002.

Fishing Mortality

Fishing mortality was relatively high during 1968-1976, dropping after that to an average of about 0.3 during 1977-2002 (Figure B38). Fishing rates were more variable recently, from a low of 0.12 in 2000 to a high of 0.70 in 2001 (Figure B38). The average fishing rate during 2000-2002 was 0.39 and F in 2002 was 0.34..

Stock Recruitment-Recruitment Biomass

Recruitment biomass has been highly variable for the butterfish stock over a range of spawning biomass between about 10,000-50,000 t (Figure B39). Recruitment biomass ranged between 2,812-61,062 mt during 1968-2002 and averaged 23,179 mt (Figure B40). The recent average was 7,988 mt and recruitment biomass in 2002 was 2,974 mt (Figure B40). Recent recruitment has been below average and recruitment in 2001 and 2002 are among the lowest in the series.

Surplus Production

Surplus production was estimated with an asymmetric Fox (1975) model. Reference points for this model were MSY=12,175 mt, Bmsy=22,798 mt and Fmsy=0.38 (Figure B41).

Loss to Natural Mortality

For many fish stocks it is common for landings to greatly exceed losses to natural mortality, not so for pelagic species. Natural mortality rates are generally higher, hence a much larger fraction of the stock is removed by natural causes, usually predation, but disease and other causes can be important. Since this component of total mortality can be important for butterfish, it is worth quantifying this loss. Biomass lost to M ranged from 5,237-42,323 mt and averaged 21,382 mt during 1968-2002 (Figure B42). This metric is useful for understanding the large fluctuations in biomass and relatively low surplus production for this stock.

Precision of FPA Estimates

The relative precision of the estimates for average biomass and fishing mortality and their 80% confidence intervals were calculated using a bootstrap procedure. One thousand bootstrap runs were completed and the results were summarized in frequency and cumulative distribution plots. Results indicate that estimates for both average biomass and F are relatively imprecise. Estimates for average biomass ranged from 655-49,127 mt with an 80% CI between 2,606-10,874 mt (Figure B43). Estimates for F ranged from 0.055-4.08 with an 80% CI between 0.246-1.03 (Figure B44). Although the percent of bias was not specifically estimated, results suggest that average biomass was biased low and F was biased high.

Model Diagnostics

Plots of survey residuals for the four NEFSC surveys used to tune the FPA model for trend were produced as a diagnostic measure of goodness of fit. Plots of observed vs. predicted data series and residual trajectories (residuals vs. time), and residuals vs. predicted values were produced and are shown in Figure (B45).

SARC COMMENTS

The SARC discussed the methods used for estimating discards. Discards were estimated as a significant proportion of the total catch (about 2/3 of the total catch since 1980). Examination of alternative stratification of the discard data should be made in future assessments. Stratification by target species and/or combining data temporally to increase the sample size may provide better discard estimates. Variance estimates of discard ratios can be used as a diagnostic for determining the reliability of the estimates. A plot of estimated ratios revealed little trend over time and suggested that time averaging of the ratio may be appropriate. Statistical tests between the stratified discard estimates should be made to justify the stratification used. The discard estimate should be considered a minimum estimate of discards since the estimate was limited to observer trips, which possessed both, landed and discards of butterfish. The SARC noted that the high 1995 discard ratio was primarily due to several trips, which landed a relatively small amount of butterfish landings. Although there is uncertainty in the discard estimates the SARC felt the scale of the discards is clear. The SARC accepted the use of the discard estimates for the assessment while recommending further investigation on discards be done in future assessments.

The SARC reviewed an index method (AIM) for assessing butterfish. The SARC noted the relatively weak correlation between the replacement ratio and the relative F in the model and questioned the utility of the model for this species. It was suggested that limiting the survey index to fully recruited fish (omitting age 0 fish in the Fall survey) might result in a better relationship between the biomass index and the rate of removals by the fishery.

The SARC reviewed a delay-difference model for butterfish. A profile on natural mortality suggests an improvement in model fit as M increases, indicating that M was not estimable. The SARC suggested exploring alternative methods for estimating natural mortality external from the model. Given the uncertainty in estimated discards it was thought that a model with estimation of catch with error is warranted. However, a profile on changes in the assumed CV on catch (estimated with error) estimated Qs for adjusted biomass, which were biologically unrealistic (>1). Questions on the proportion of the stock coverage by the survey and day night differences in catch should result in a lower estimate of Q in the absence of herding.

It was noted that very similar fits to the data exist in the final set of model runs but these runs produced very different stock status determinations. The SARC questioned whether the number of parameters in the model allows for alternative states of nature to be fit equally well particularly with a species that possesses large fluctuations in the survey indices. The SARC requested that the diagnostics for using survey covariates be included in the document. It was noted that the final model run proposed by the working group does produce estimates of average biomass in the last three years which match the estimates of Fall minimum swept area biomass. The SARC noted a lack of coherence between the spring and fall survey by age (0 and 1+).

The SARC requested a table of estimated model parameters and CVs. The lack of convergence for the model run, which estimated catch with error, deemed this run as unreliable. The SARC noted that the estimated net covariate parameter from the model was very similar to the published Yankee 44 net conversion factor. However the SARC felt the door covariates parameters where not significant and should be omitted in the final run. The SARC concluded that the status determination of the stock should be made by using the ratios of the point estimates to the reference point.

SOURCES OF UNCERTAINTY

1) The estimate of natural mortality is uncertain.

2) Observer sampling of the trawl fishery has been low and increases the uncertainty of the discard estimates.

3) The lack of coherence between the spring and fall surveys is a source of uncertainty.

4) The new model based estimates of biological reference points are uncertain

RESEARCH RECOMMENDATIONS

1) A study of the characteristics of inshore and offshore components should be initiated. A study of growth, morphometrics, distribution and other factors related to inshore and offshore butterfish should be conducted.

2) Further work on potential information (for example the VTR database) for the estimation of discards of butterfish from all sources should be undertaken. Other methods and stratification and time averaging of the discard data for estimating discards should be explored.

3) A close examination of the NMFS Observer data from 2003 was warranted for its application in the next butterfish assessment. Observer coverage was transferred to only a few vessels in the Illex fishery and hence was greatly expanded because of the transfer of effort into the scallop fishery by large Mid-Atlantic trawlers.

4) Explore alternative methods for estimating natural mortality.

5) Explore using landings of target species as a denominator in the discard ratio, based on VTR matched trips (trips with reported landings of target species and butterfish discards).

6) Explore the utility of incorporating into the assessment model ecological relationships, predation, and oceanic events that influence butterfish population size on the continental shelf and its availability to the resource survey.

7) Explore the use of an age-based model for future assessments.

8) Further investigate the estimation of suitable biological reference points. Stock status determination is currently based on an Fmsy proxy (F0.1=1.01, Bmsy has not been previously estimated). New biological reference points were estimated in the delay-difference model for butterfish. However, there is considerable uncertainty in these estimates and they are subject to change

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Table B1. Butterfish USA landings (tonnes), USA discards, Foreign landings, and total catch during 1965-2002

Year	USA landings	USA discards	Foreign landings	Total catch
1965	3340	833	749	4922
1966	2615	846	3865	7326
1967	2452	991	2316	5759
1968	1804	770	5437	8011
1969	2438	968	15378	18784
1970	1869	569	12450	14888
1971	1570	866	8913	11349
1972	819	293	12221	13333
1973	1557	1030	31679	34266
1974	2528	1409	15465	19402
1975	2088	1478	12764	16330
1976	1528	969	14309	16806
1977	1448	1172	4607	7228
1978	3676	5237	1906	10819
1979	2831	3452	1207	7491
1980	5356	7802	1264	14422
1981	4855	7412	1345	13612
1982	9060	12906	907	22873
1983	4905	6421	906	12231
1984	11972	18959	617	31547
1985	4739	7134	1156	13029
1986	4418	7249	236	11902
1987	4508	7168		11676
1988	2001	3224		5225
1989	3203	4442		7645
1990	2295	3020		5315
1991	2149	3451		5600
1992	2752	5698		8450
1993	4604	8478		13082
1994	3631	3701		7332
1995	2080	8599		10679
1996	3547	6823		10370
1997	2784	3852		6636
1998	1956	3274		5230
1999	2103	4115		6218
2000	1422	2427		3849
2001	4396	7262		11658
2002	867	1809		2676

Table B2. Observed tows with butterfish catch for target species or groups including target, number of trips, percent trips, cumulative frequency of trips, and cumulative percent of trips from the USA observer program database during 1989-2003.

Target	Frequency	Percent	Cumulative F	Cumulative P
None	206	3.7	206	3.7
Scup	83	1.5	289	5.2
Fluke	818	14.6	1107	19.8
Other	971	17.3	2078	37.1
Squid	2120	37.9	4198	75.0
Butter	233	4.2	4431	79.1
Finfish	136	2.4	4567	81.6
Mix Flnd	21	0.4	4588	81.9
Mix Grnd	391	7.0	4979	88.9
Silver Hake	620	11.1	5599	100.0

Table B3. Target species or group, number of trips, landings (kg), and discards (kg) during 1989-1993.

Year	Target	Trips	Landings	Discard
1989	None	7	8996	8333
	Scup	2	640	315
	Fluke	12	294	679
	Other	12	3996	6316
	Squid	11	6016	10691
	Finfish	2	75	625
	Mix groundfish	13	10592	1387
	Silver hake	20	8960	21660
1990	None	1	53	565
	Fluke	11	1096	684
	Other	15	1209	2139
	Squid	11	9561	3750
	Finfish	8	4251	3861
	Mix flounder	2	2	2
	Mix groundfish	5	1870	2716
	Silver hake	11	618	239
1991	None	9	3832	13052
	Fluke	11	77	3623
	Other	24	34277	21549
	Squid	25	6432	45113
	Butter	6	45622	8574
	Finfish	6	806	9389
	Mix flounder	3	51	176
	Mix groundfish	17	10142	19043
	Silver hake	21	3308	5708
1992	None	1	1149	4502
	Fluke	23	1491	7795
	Other	9	267	5602
	Squid	11	7133	31467
	Finfish	2	15	22
	Mix groundfish	20	10429	58545
	Silver hake	13	1661	1208
1993	Fluke	8	1274	4000
	Other	7	2731	19417
	Squid	7	2617	30910
	Butter	3	108738	19436
	Finfish	1	370	17
	Mix flounder	1	0	1
	Mix groundfish	5	7404	15417
	Silver hake	17	1289	6770

Table B3. Continued; 1994-1998

Year	Target	Trips	Landings	Discard
1994	None	2	250	336
	Scup	2	515	3407
	Fluke	14	179	812
	Other	7	2183	10787
	Squid	9	3965	7155
	Butter	2	94957	1682
	Finfish	1	7	7
	Mix groundfish	5	4115	3773
	Silver hake	2	27	178
1995	Scup	1	330	365
	Fluke	21	192	3280
	Other	10	10965	14730
	Squid	7	127	3734
	Mix groundfish	3	52	22
	Silver hake	21	1581	324
1996	Fluke	11	1443	3172
	Other	25	37852	4331
	Squid	9	3041	21874
	Butter	1	2351	1591
	Mix groundfish	1	0	1
	Silver hake	26	74	73
1997	Scup	2	20	210
	Fluke	5	2385	1597
	Other	13	14040	34947
	Squid	24	7755	6781
	Butter	5	33088	9691
	Finfish	2	0	71
	Mix flounder	1	2	4
	Mix groundfish	1	0	1
	Silver hake	4	554	68
1998	None	3	1026	1694
	Fluke	5	1245	1619
	Other	6	1433	15381
	Squid	14	6273	5301
	Mix flounder	1	0	1
	Silver hake	4	781	2821

Table B3. Continued; 1999-2003

Year	Target	Trips	Landings	Discard
1999	None	3	91	42
	Scup	1	200	118
	Fluke	1	398	7050
	Other	10	18133	59380
	Squid	33	3296	121022
	Butter	1	3850	2050
	Mix groundfish	1	0	1
	Silver hake	11	61	131
2000	Scup	3	25	59
	Fluke	4	0	12
	Other	22	38237	120912
	Squid	26	5310	46843
	Mix flounder	1	0	13
	Mix groundfish	4	36	20
	Silver hake	6	280	18
2001	Scup	4	205	135
	Fluke	7	5	59
	Other	14	245	7360
	Squid	40	15508	80234
	Butter	1	0	160
	Silver hake	9	2169	3351
2002	Scup	4	15	2
	Fluke	21	115	75
	Other	18	420	745
	Squid	36	6731	23726
	Butter	1	67	96
	Silver hake	10	529	160
2003	Scup	5	126	11
	Fluke	17	115	85
	Other	6	278	7517
	Squid	12	812	5693
	Silver hake	3	123	508

Table B4. Landings, discards, discard ratios, and sample size (N) during 1994-2002 from the NMFS VTR database (for half year intervals and trips 600 lbs or less and greater than 600 lbs) using an aggregate approach (summed discards/ summed landings) with all trips included.

Year	Half	600				>600			
		Landings	Discard	Dratio	N	Landings	Discard	Dratio	N
1994	1	42.0	15.4	.367	756	64.7	100.1	1.547	1028
	2	56.1	8.0	.143	83	281.9	60.4	.214	217
1995	1	32.7	49.4	1.511	580	40.1	43.8	1.092	819
	2	200.0	88.4	.442	155	118.9	50.1	.421	89
1996	1	35.0	69.5	1.985	552	52.3	22.7	.434	1048
	2	930.3	99.6	.107	147	142.0	33.5	.236	165
1997	1	37.2	17.5	.471	556	57.3	21.7	.378	1116
	2	317.2	37.7	.119	154	101.2	11.4	.113	103
1998	1	31.5	22.6	.716	502	36.1	17.4	.481	853
	2	313.6	41.6	.132	127	43.1	5.5	.127	54
1999	1	33.2	9.7	.293	534	33.1	37.8	1.142	821
	2	133.8	5.1	.038	73	83.2	6.9	.082	101
2000	1	30.2	20.0	.663	607	39.0	13.8	.354	855
	2	26.6	4.9	.185	43	111.5	19.0	.170	87
2001	1	34.0	10.2	.301	528	36.3	13.5	.371	757
	2	1464.1	39.4	.027	162	69.4	8.7	.126	119
2002	1	24.3	22.7	.932	491	22.4	30.8	1.374	597
	2	119.3	5.3	.044	62	26.2	2.2	.085	38

Table B5. Landings, discards, discard ratios, and sample size (N) during 1989-2002 from observed tows in the NMFS observer program (for half year intervals and trips 600 lbs or less and greater than 600 lbs) using an aggregate approach (summed discards/ summed landings) with all trips included.

Year	Half	600				>600			
		Land	Discard	Dratio	N	Land	Discard	Dratio	N
1989	1	1642	5066	3.08526	26	15621	962	0.06158	3
	2	1584	8254	5.21086	39	20257	34192	1.68791	12
1990	1	808	3337	4.12995	22	13262	4419	0.33321	9
	2	1514	4178	2.75958	31	3058	1978	0.64683	3
1991	1	3332	23654	7.12041	45	43992	2183	0.04962	3
	2	4650	41101	8.83892	70	52583	59313	1.12799	9
1992	1	1816	10539	5.8034	52	14213	36990	2.6025	7
	2	2365	19342	8.1784	36	3936	42307	10.7487	4
1993	1	1996	6304	3.1583	22	13986	16496	1.1795	3
	2	1718	21208	12.3446	20	106723	51958	0.4868	5
1994	1	56	11.5	0.2054	4	na	na	na	Na
	2	1594	7055	4.4268	17	4426	13837	3.1263	2
1995	1	3336	11263	33.5012	42	10668	12005	1.1253	1
	2	3532	6281	1.7785	91	na	na	na	Na
1996	1	2526	11939	4.7257	37	4494	16041	3.56982	3
	2	3343	5203	1.55647	92	41216	7934	0.19251	8
1997	1	1458	3109	2.13317	37	51919	45294	0.87241	11
	2	1188	3265	2.7484	17	3599	1759	0.48875	2
1998	1	2363	4081	1.72704	18	6584	18465	2.80453	5
	2	1311	3336	2.54424	21	2292	1510	0.65881	2
1999	1	3231	33517	10.372	27	8151	17152	2.104	4
	2	780	132355	169.687	34	13870	6790	0.490	2
2000	1	1400	39346	28.105	33	4684	8458	1.806	3
	2	386	85939	222.639	31	37460	34175	0.912	2
2001	1	1530	44277	28.9392	38	16117	32360	2.0078	6
	2	632	15075	23.853	34	na	na	na	Na
2002	1	153	1301	8.5318	29	6318	10625	1.6817	1
	2	1609	13005	8.08272	65	1460	1651	1.13082	1

Table B6. Discard ratios , and sample size (N) during 1989-2002 from observed tows in the NMFS observer program (for half year intervals and trips 600 lbs or less and greater than 600 lbs) using a geometric mean discard ratio (retransformed, mean D/L by trip) for matched trips with landings and discards only.

Year	Half	600	N	>600	N
1989	1	2.531255	17	0.989597	3
	2	4.347187	20	1.593124	12
1990	1	2.681034	12	1.240319	8
	2	3.62086	15	1.478619	3
1991	1	3.795113	32	1.231818	3
	2	4.607233	42	1.806282	9
1992	1	3.142323	15	2.025193	7
	2	2.29842	15	2.49667	4
1993	1	2.793747	16	1.441397	3
	2	3.222019	13	2.011631	5
1994	1	0.471726	3	na	na
	2	2.702608	9	2.082737	2
1995	1	39.94192	18	1.753105	1
	2	2.793871	32	na	Na
1996	1	2.51086	18	2.208343	3
	2	3.403395	29	1.204729	7
1997	1	1.814747	16	1.504132	11
	2	2.220992	7	1.404974	2
1998	1	1.938916	12	1.723983	5
	2	3.548073	8	1.181671	2
1999	1	3.048545	16	2.090695	3
	2	3.636889	10	1.512366	2
2000	1	3.036537	14	1.926607	3
	2	1.660259	7	1.807028	2
2001	1	2.132316	19	1.734414	6
	2	1.418301	5	na	na
2002	1	4.240989	9	1.884612	1
	2	2.924087	13	1.764504	1

Table B7. Discard ratios (retransformed), otter trawl landings (tonnes), discard by otter trawls (tonnes) for half year and landings category (<600, >600), and total otter trawl discards (tonnes) during 1989-2002.

Year	Half	Dratio		Landings		Discard		Total Discard
		600	>600	600	>600	600	>600	
1989	1	2.531	0.989	63.9	1097.9	161.7	1086.5	4441.9
	2	4.347	1.593	97.0	1740.0	421.7	2772.0	
1990	1	2.681	1.240	86.8	978.4	232.7	1213.5	3019.7
	2	3.621	1.479	98.6	822.7	357.0	1216.5	
1991	1	3.795	1.232	72.6	1092.3	275.5	1345.5	3451.5
	2	4.607	1.806	87.3	790.7	402.2	1428.2	
1992	1	3.142	2.025	70.2	1692.2	220.6	3427.0	5697.9
	2	2.298	2.497	93.3	735.3	214.4	1835.8	
1993	1	2.794	1.441	83.0	824.1	231.9	1187.9	8477.8
	2	3.222	2.012	95.1	3356.3	306.4	6751.6	
1994	1	0.472	0.472	102.6	2082.2	48.4	982.2	3700.7
	2	2.703	2.083	107.2	1142.9	289.7	2380.4	
1995	1	39.942	1.753	119.8	1065.0	4785.0	1867.1	8599.1
	2	2.794	2.794	182.2	514.7	509.0	1438.0	
1996	1	2.511	2.208	167.2	2222.7	419.8	4908.5	6822.8
	2	3.403	1.205	198.0	681.2	673.9	820.7	
1997	1	1.815	1.504	172.5	1435.2	313.0	2158.7	3852.2
	2	2.221	1.405	227.1	623.5	504.4	876.0	
1998	1	1.939	1.724	179.6	1140.9	348.2	1966.9	3274.4
	2	3.548	1.182	176.5	281.8	626.2	333.0	
1999	1	3.049	2.091	190.1	1023.2	579.5	2139.2	4115.4
	2	3.637	1.512	154.2	552.7	560.8	835.9	
2000	1	3.037	1.927	131.6	227.3	399.6	437.9	2427.0
	2	1.660	1.807	151.5	740.4	251.5	1337.9	
2001	1	2.132	1.734	156.1	3562.8	332.9	6179.4	7261.7
	2	1.418	1.418	147.6	380.8	209.3	540.1	
2002	1	4.240	1.885	123.8	371.3	525.0	699.8	1809.2
	2	2.924	1.765	114.6	141.3	335.1	249.3	

Table B8. NEFSC indices in number and weight per tow (kg) for the Spring 1968-2002, Winter 1992-2002, and Autumn 1968-2002.

	Spring		Winter		Fall	
Year	# Spr	wt Spr	#Win	wt Win	#Fall	wt Fall
1968	33.139	1.956			90.838	7.86
1969	30.771	3.082			55.986	3.936
1970	9.871	0.515			35.235	2.282
1971	21.721	0.762			180.352	4.313
1972	228.075	6.643			68.976	2.767
1973	68.697	5.354			128.94	6.161
1974	25.258	1.72			86.845	4.06
1975	121.071	3.997			41.939	2.56
1976	31.148	1.308			122.304	5.671
1977	7.013	0.559			78.6	5.088
1978	4.654	0.25			78.272	3.614
1979	12.855	1.047			312.721	12.703
1980	58.182	3.197			313.711	15.06
1981	43.805	2.474			249.5	9.259
1982	49.188	2.549			88.393	4.134
1983	64.743	3.897			398.308	12.454
1984	15.837	0.711			332.506	11.243
1985	37.842	1.601			402.648	15.77
1986	66.206	2.784			162.941	5.967
1987	15.619	0.574			119.979	5.106
1988	13.353	0.478			268.748	7.277
1989	32.311	0.761			383.507	11.783
1990	8.928	0.36			406.732	9.899
1991	27.836	1.009			127.086	4.045
1992	17.949	0.607	20.099	0.769	263.224	4.917
1993	26.684	0.807	117.86	2.623	269.281	10.821
1994	36.294	1.45	169.513	6.255	542.882	13.81
1995	42.105	2.205	139.746	3.516	114.738	5.843
1996	11.47	0.512	67.663	1.351	72.479	2.867
1997	112.867	3.414	38.056	1.8	123.46	2.756
1998	41.07	2.144	40.123	0.975	231.036	7.097
1999	76.227	2.457	42.732	1.433	257.115	4.93
2000	36.773	0.99	153.673	5.07	181.611	7.515
2001	61.21	1.888	69.338	3.403	59.671	2.541
2002	46.572	1.705	44.859	1.925	36.411	1.29
2003	47.697	1.394				

Table B9. Catch per tow in number for NEFSC Spring surveys during 1982-2002 for ages 1-4.

Year	1	2	3	4
1982	36.0963	10.3065	2.3095	0.376
1983	33.815	22.9983	7.0392	0.8807
1984	10.8769	3.9009	0.9936	0.0658
1985	30.1886	4.9152	2.2178	0.464
1986	53.0479	12.0466	1.0129	0.0986
1987	13.9306	1.4298	0.2285	0.0228
1988	11.2921	1.8751	0.175	0.0113
1989	25.6435	5.7061	0.955	0.0059
1990	7.2205	1.3561	0.322	0.0297
1991	25.6657	1.4995	0.6257	0.0189
1992	16.0983	1.6132	0.2277	0.0098
1993	23.5588	2.7051	0.4205	0
1994	29.5594	5.6517	1.0395	0.0439
1995	26.5474	12.9457	2.6121	0
1996	7.7336	2.4142	1.2748	0.0477
1997	107.6083	4.6109	0.6476	0
1998	18.3203	21.5421	1.2072	0
1999	64.9677	9.2975	1.9621	0
2000	34.7082	1.6964	0.3287	0.0399
2001	49.2793	11.1395	0.7916	0
2002	38.1848	6.0295	2.1145	0.2429

Table B10. Catch per tow in number for NEFSC Autumn surveys during 1982-2002 for ages 0-3.

1982	57.752	24.9283	5.449	0.263
1983	303.883	82.9381	12.5132	1.4906
1984	282.965	39.0889	9.4107	1.0415
1985	319.562	74.7958	7.0782	1.1762
1986	126.467	24.8369	10.718	0.7787
1987	80.054	32.4701	7.1747	0.2803
1988	227.351	26.9924	14.2919	0.1126
1989	329.203	43.8711	10.2556	0.1772
1990	374.130	28.7001	3.4882	0.4142
1991	107.044	17.7069	2.0452	0.0194
1992	248.296	11.1541	3.7618	0.0117
1993	214.428	49.0602	5.4212	0.365
1994	504.598	26.917	10.6311	0.7043
1995	28.798	55.9273	29.9941	0.0189
1996	55.105	12.653	4.522	0.1984
1997	106.028	15.1555	2.0254	0.2516
1998	184.755	39.9448	5.3688	0.9673
1999	252.689	2.944	1.4821	0
2000	120.217	54.662	6.4658	0.2662
2001	29.317	18.3819	11.7222	0.2503
2002	28.921	4.6756	2.7507	0.0638

Table B11. Catch per tow in weight (kg) at age for NEFSC Autumn survey during 1982-2002 and for age 0 and 1+ during 1968-2002.

Year	0	1	2	3	0	1+
1968					0.2721	7.5879
1969					0.5397	3.3963
1970					0.8697	1.4123
1971					3.5352	0.7778
1972					2.2240	0.5430
1973					2.1216	4.0394
1974					1.9627	2.0973
1975					0.4952	2.0648
1976					1.9865	3.6845
1977					0.6372	4.4508
1978					2.4720	1.1420
1979					8.4353	4.2677
1980					4.5015	10.5585
1981					5.4677	3.7913
1982	1.5889	1.9977	0.5113	0.0364	1.5889	2.5454
1983	6.0358	5.1317	1.1389	0.1413	6.0358	6.4119
1984	7.3119	2.9419	0.8813	0.1083	7.3119	3.9315
1985	9.9567	4.9959	0.6987	0.1106	9.9567	5.8135
1986	3.1965	1.6832	0.9635	0.1093	3.1965	2.7702
1987	2.4951	2.056	0.5186	0.0362	2.4951	2.6108
1988	4.8221	1.4363	1.0035	0.0156	4.8221	2.4554
1989	8.3915	2.5959	0.7731	0.0222	8.3915	3.3912
1990	7.8038	1.7182	0.3318	0.0453	7.8038	2.0953
1991	2.6807	1.205	0.1565	0.0025	2.6807	1.3640
1992	3.9053	0.7087	0.3017	0.0019	3.9053	1.0123
1993	7.0499	3.2878	0.4401	0.0433	7.0499	3.7712
1994	11.0023	1.7917	0.9472	0.0647	11.0023	2.8080
1995	0.6757	3.3177	1.8463	0.003	0.6757	5.1670
1996	1.8175	0.6851	0.3494	0.0155	1.8175	1.0500
1997	1.5989	0.9855	0.1527	0.0185	1.5989	1.1567
1998	3.7522	2.7767	0.4712	0.0971	3.7522	3.3450
1999	4.676	0.1557	0.0978		4.6760	0.2535
2000	2.8136	4.1282	0.542	0.0311	2.8136	4.7013
2001	0.8906	0.9876	0.6409	0.0233	0.8906	1.6518
2002	0.8257	0.2412	0.2149	0.0082	0.8257	0.4643

Table B12. Indices in weight-per-tow for Rhode Island (1981-2002), Massachusetts (1982-2002), Connecticut (1984-2002) and the Virginia Institute of Marine Science (1988-2001).

Year	RI	MA	CT	VIMS
1981	1.200			
1982	1.200	2.790		
1983	1.200	2.787		
1984	3.000	1.787	8.639	
1985	1.100	1.433	16.770	
1986	4.200	4.414	10.978	
1987	2.500	0.688	7.856	
1988	12.300	11.684	15.412	0.008
1989	2.900	2.523	17.760	0.037
1990	5.500	2.552	13.318	0.025
1991	2.000	3.174	15.011	0.029
1992	3.500	8.874	22.623	0.010
1993	5.300	10.306	22.304	0.026
1994	5.600	7.286	11.130	0.008
1995	4.600	5.328	41.030	0.004
1996	2.800	6.605	23.016	0.025
1997	9.300	7.904	16.559	0.005
1998	4.600	14.479	51.376	0.015
1999	3.300	7.788	44.908	0.009
2000	0.880	3.175	27.605	0.016
2001	2.200	1.771	22.128	0.019
2002	2.000	3.844	26.520	na

Table B13 Estimates of instantaneous total mortality rates from spring survey catch per tow (number) at age (age 1-3) during 1982-2002.

Year	Age-1	Age-2	Age-3
1982-1983	0.451	0.381	.0964
1983-1984	2.160	3.142	4.673
1984-1985	0.794	0.565	0.761
1985-1986	0.919	1.580	3.113
1986-1987	3.614	3.965	3.794
1987-1988	2.005	2.101	3.007
1988-1989	0.683	0.675	3.390
1989-1990	2.940	2.875	3.471
1991-1992	1.572	0.773	2.835
1992-1993	2.767	1.885	4.156
1993-1994	1.784	1.345	Na
1994-1995	1.428	0.956	2.260
1995-1996	0.826	0.772	Na
1996-1997	2.398	2.318	4.003
1997-1998	0.517	1.316	Na
1998-1999	1.608	1.340	Na
1999-2000	0.678	2.396	Na
2000-2001	3.645	3.342	3.895
2001-2002	1.136	0.762	Na
	2.101	1.662	1.181
Average 1982-2001	1.701	1.707	2.965

Table B14. Estimates of instantaneous total mortality rates from autumn surveys catch per tow (number) at age (age 0-2) during 1982-2002.

Year	Age-0	Age-1	Age-2
1982-1983	-0.362	0.689	1.296
1983-1984	2.051	2.176	2.486
1984-1985	1.331	1.709	2.080
1985-1986	2.555	1.943	2.207
1986-1987	1.360	1.242	3.644
1987-1988	1.087	0.821	4.154
1988-1989	1.645	0.968	4.390
1989-1990	2.440	2.532	3.209
1990-1991	3.051	2.641	5.192
1991-1992	2.261	1.549	5.164
1992-1993	1.622	0.721	2.333
1993-1994	2.075	1.529	2.041
1994-1995	2.200	-0.108	6.332
1995-1996	0.822	2.515	5.018
1996-1997	1.291	1.832	2.889
1997-1998	0.976	1.038	0.739
1998-1999	4.139	3.294	Na
1999-2000	1.531	-0.787	1.717
2000-2001	1.878	1.540	3.252
2001-2002	1.836	1.900	5.213
Average 1982-2001	1.789	1.487	3.335

Table B15. Table of Lamdas used in profile and model runs to decide on final FPA model for butterfish.

	Profile over M	Profile over S	Estimate Catch	NO Constraints
NEFSC Surveys	1	1	1	1
Catch Deviations	10000	10000	1	10000
Natural Mortality	10000	0	0	0
Survey Survival Rates	0	10000	0	0
Minimum Swept Area Biomass	0	0	0	0
Constraint on C/B *	10000	10000	10000	10000
Constraint on IGR **	10000	10000	10000	10000
Fox Surplus Production	0.0001	0.0001	0.0001	0.0001

* Catch/ Biomass
** Initial Growth Rate

Table B16. Profile table for values of natural mortality (M) from 0.6-1.4

	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	
OBJ Function Major components									
Surveys-All	157.2683	155.2894	154.4288	153.4335	152.645977	152.1255	151.7644	151.5903	151.4414
Fit to recruitment model	4.338488	3.730925	2.417835	1.355338	0.380699673	-0.55549	-1.47755	-2.43697	-3.3003
Estimate some catches	2065.235	2065.235	2065.235	2065.235	2065.235267	2065.235	2065.235	2065.235	2065.235
Prior Q min swept biomass	0	0	0	0	0	0	0	0	0
Prior on log(variance recruit residuals)	0	0	0	0	0	0	0	0	0
Prior Q on Survey Z's	0	0	0	0	0	0	0	0	0
--Not used--	0	0	0	0	0	0	0	0	0
--Not used--	0	0	0	0	0	0	0	0	0
--Not used--	0	0	0	0	0	0	0	0	0
Constrain initial IGR values	2.861435	2.898323	2.416549	2.115867	1.81203703	1.535867	1.297357	1.07773	0.879218
--Not used--	0	0	0	0	0	0	0	0	0
Constrain B-zero	3.57E-05	4.04E-07	5.37E-09	2.15E-05	1.51284E-07	3.82E-06	2.28E-06	2.07E-10	5.22E-07
--Not used--	0	0	0	0	0	0	0	0	0
--Not used--	0	0	0	0	0	0	0	0	0
--Not used--	0	0	0	0	0	0	0	0	0
Pella and Tomlinson Production Model	0	0	0	0	0	0	0	0	0
Shaeffer Production Model	0.002271	0.004296	0.006613	0.009453	0.01315071	0.017264	0.021574	0.02537	0.029099
--Not used--	0	0	0	0	0	0	0	0	0
Max C/B	0	0	0	0	0	0	0	0	0
--Not used--	0	0	0	0	0	0	0	0	0
Total Log Likelihood (weighted sum)	164.4718	161.9187	159.2632	156.9069	154.838742	153.1063	151.5844	150.231	149.0204
Schaefer model parameters									
External or internal?	Internal	Internal	Internal	Internal	Internal	Internal	Internal	Internal	Internal
Alpha	0.627703	0.591564	0.618506	0.627018	0.628474389	0.63078	0.631489	0.629397	0.629407
Beta	-8.84157	-7.54804	-7.35774	-6.80587	-6.22094039	-5.7597	-5.35834	-5.04647	-4.83736
Log Likelihood	0.002271	0.004296	0.006613	0.009453	0.01315071	0.017264	0.021574	0.02537	0.029099
RMS Residuals	0.011232	0.015448	0.019167	0.022917	0.027029521	0.030969	0.03462	0.037543	0.040207
Carrying Capacity (K)	0.070994	0.078373	0.084062	0.092129	0.101025625	0.109516	0.117852	0.12472	0.130114
Bmsy (units=1000)	0.035497	0.039187	0.042031	0.046065	0.050512812	0.054758	0.058926	0.06236	0.065057
MSY (units=1000)	0.011141	0.011591	0.012998	0.014442	0.015873004	0.01727	0.018606	0.019625	0.020474
Fmsy	0.313851	0.295782	0.309253	0.313509	0.314237194	0.31539	0.315744	0.314699	0.314703
Recent Mean F / Fmsy	1.393003	0.883073	0.673704	0.58118	0.520863075	0.484367	0.462432	0.455616	0.452324
Recent Mean B / Bmsy	23.40385	38.21355	49.58598	59.36334	69.35057221	78.09034	85.77665	91.52304	96.51873
Recent Mean C/ MSY	0.659315	0.97517	1.179747	1.288699	1.372930333	1.426098	1.455671	1.467652	1.483606

Table B17. Values for profile of q on survey survival rates (S) for q=.2-1.0.

	q=.2	q=.3	q=.4	q=.5	q=.6	q=.7	q=.8	q=.9	q=1.0
Survey_trends	155.07	155.028	150.843	152.475	154.966	157.494	159.925	162.274	164.548
Fox_surplus_production	287.7	284.828	-56.5606	-76.7152	-82.3336	-84.832	-87.0526	-89.4808	-91.4909
Catch	1.7224E-12	1.6371E-12	2.46252E-08	1.25464E-07	2.22628E-07	2.9364E-07	3.46571E-07	3.91211E-07	4.31633E-07
Trend_Winter.Survey.Age.1+	7.21195	7.21216	6.72445	6.3539	6.41156	6.53163	6.69042	6.89332	7.12136
Trend_Spring.Survey.Age.1+	62.5476	62.528	57.3501	55.1018	54.2918	54.1205	54.1257	54.1949	54.3097
Trend_Fall.Survey.Age.0	20.8195	20.8042	27.2192	35.4202	40.375	43.6616	46.1282	48.1598	49.9286
Trend_Fall.Survey.Age.1+	64.4899	64.4823	59.5485	55.5977	53.8863	53.1789	52.9795	53.0243	53.1873
Trend_Fall.Survey.Min.Biomass.0+	43.5104	43.5036	51.8364	59.4435	64.918	68.9716	72.2249	74.9924	77.3955
Trend_Murawski.and.Waring.1979	15.6572	15.6484	28.5482	35.0743	37.7288	39.307	40.3508	41.0771	41.5941
Trend_Fall.survey.RI.1+	239.301	240.134	236.282	288.535	326.214	357.559	385.793	411.427	434.427
Trend_Fall.Survey.MA.1+	281.521	282.132	281.287	317.833	343.918	365.473	385.032	403.037	419.401
Trend_Fall.Survey.CT.1+	141.598	141.91	145.325	169.407	186.547	200.342	212.293	222.88	232.264
Trend_Fall.survey.VIMS.age.0	196.815	196.842	189.725	177.992	167.992	160.834	156.649	154.271	152.861
Trend_Survey.Survival.Ratio	21.6794	21.6794	22.62	24.3249	25.6297	26.668	27.5499	28.3375	29.0614
Total_LogLikelihood	3554.78	437.043	159.233	159.498	161.26	163.286	165.344	167.4	169.433
Target	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Residual	0.150941	0.0509412	0.000183598	-0.00014306	-0.00026006	-0.00033764	-0.00040197	-0.00045819	-0.00050401
Weight	10000	10000	10000	10000	10000	10000	10000	10000	10000
Q_for_adj_biomass	0.00014424	0.000141783	1.81411	5.23293	8.42295	11.4491	14.3475	17.1416	19.8508
Q_for_adj_biomass	0.350941	0.350941	0.400184	0.499857	0.59974	0.699662	0.799598	0.899542	0.999496
Bmsy=	8.17936E+25	421.368	0.046822	0.0288417	0.0250699	0.0232438	0.0222597	0.0216458	0.0211955
MSY=	9.89103E-34	150.466	0.0238747	0.0149227	0.0133047	0.0125389	0.0120472	0.0118163	0.0116405
Fmsy=	1.20927E-59	0.35709	0.509903	0.517399	0.530705	0.539452	0.541213	0.545892	0.549195
Recent_F/Fmsy=	7.21418E+53	2.60087E-05	0.239964	0.687924	1.04468	1.33497	1.59235	1.80553	1.99476
Recent_B/Bmsy=	1.14387E-23	2.25819	1.66893	1.06632	0.857803	0.748092	0.675702	0.625452	0.589705
AveBiomass	400413	407198	28.5609	8.5467	4.97495	3.58286	2.85392	2.40857	2.11068
av biomass last 3 yrs	703668.6667	715637	56.35876667	20.6328	13.59465	10.42220333	8.59135	7.40651	6.57822
av F last 3 yrs	9.44528E-06	9.28746E-06	0.122358733	0.355931333	0.554416667	0.720154	0.861802333	0.985623667	1.095515667

Table B18. Profile table of sensitivity of model results to changes in the CV (0.1-0.5) of catch (catches estimated with error) for the FPA model.

	catch cov on cv=0.1	catch cov on cv=0.2	catch cov on cv=0.3	catch cov on cv=0.4	catch cov on cv=0.5
Time	10/27/03 9:39	10/27/03 9:38	10/27/03 9:36	10/27/03 9:35	10/27/03 9:34
Survey_trends	150.768	148.617	138.098	129.411	123.695
Fox_surplus_production	-69.6275	-79.8233	-93.8058	-94.0182	-92.62
Catch	0.259454	2.16052	9.97362	11.8942	12.0244
Trend_Winter.Survey.Age.1+	6.43476	6.0129	5.57008	5.11559	4.82419
Trend_Spring.Survey.Age.1+	56.1161	54.9585	54.4983	54.8833	55.0064
Trend_Fall.Survey.Age.0	30.9963	33.9404	32.6911	28.2863	25.309
Trend_Fall.Survey.Age.1+	57.2196	53.7041	45.337	41.1251	38.5546
Trend_Fall.Survey.Min.Biomass.0+	55.4735	60.3136	67.2707	67.3579	67.0014
Trend_Murawski.and.Waring.1979	32.2986	35.019	35.9879	34.4148	33.2191
Trend_Fall.survey.RI.1+	259.516	279.896	291.11	314.179	317.262
Trend_Fall.Survey.MA.1+	297.593	311.755	324.056	341.34	342.446
Trend_Fall.Survey.CT.1+	156.275	167.007	180.568	187.51	187.508
Trend_Fall.survey.VIMS.age.0	184.218	174.745	155.835	149.603	145.231
Trend_Survey.Survival.Ratio	23.2842	23.3919	21.0917	17.8768	15.8297
Total_LogLikelihood	158.658	157.52	153.231	146.708	141.352
Q_Scaled_For_Calcs	NA	NA	NA	NA	NA
Target	NA	NA	NA	NA	NA
GOF	NA	NA	NA	NA	NA
Q_for_adj_biomass	3.31625	5.79431	12.3871	14.3822	14.4204
Q_for_adj_biomass	0.442758	0.514011	0.691449	0.702151	0.664409
Bmsy=	0.0340772	0.0272124	0.0227296	0.0228949	0.024381
MSY=	0.0175955	0.0137463	0.00991316	0.00975001	0.00968692
Fmsy=	0.516342	0.505148	0.436134	0.425859	0.397315
Recent_F/Fmsy=	0.437924	0.755526	1.53507	1.6421	1.72614
Recent_B/Bmsy=	1.32094	1.02484	0.633107	0.53394	0.49644
AveBiomass	14.491	7.68074	3.48882	3.13679	3.21028
av biomass last 3 yrs	31.41143333	18.60518	8.921896667	7.585903333	7.599196667
av F last 3 yrs	0.226118367	0.381652	0.669496	0.699302	0.68582

Table B19. Values for Goodness of Fit values for final set of model runs and final model chosen by the Working Group.

Final Run

covariates on
covariates on
covariates on
covariates on

Son=.4 No Cv on catch
noS noCV on catch
Son=.6 No CV on catch
noS Cv on catch=.1

Time
11/13/03 14:10
11/13/03 14:02
11/13/03 14:16
11/13/03 14:23

Survey_trends
152.949
153.043
155.516
152.488

Fox_surplus_production
-63.9732
-80.0318
-91.3943
-83.2247

Catch
1.11635E-11
3.52805E-11
9.45914E-11
0.443018

Trend_Winter.Survey.Age.1+
7.00817
6.60443
6.48451
6.45534

Trend_Spring.Survey.Age.1+
58.0204
56.2417
54.3275
55.7888

Trend_Fall.Survey.Age.0
27.3662
32.6738
40.5746
33.8033

Trend_Fall.Survey.Age.1+
60.5531
57.5225

54.1283
56.4399

Trend_Fall.Survey.Min.Biomass.0+

63.5605
77.547
106.233
81.8751

Trend_Murawski.and.Waring.1979

51.6593
57.4801
62.8181
58.5762

Trend_Fall.survey.RI.1+

228.49
259.753
312.097
266.092

Trend_Fall.Survey.MA.1+

274.961
296.725
332.926
300.989

Trend_Fall.Survey.CT.1+

141.38
155.989
180.549
159.254

Trend_Fall.survey.VIMS.age.0

191.81
184.591
170.106
181.776

Trend_Survey.Survival.Ratio

22.6327
23.723
25.729
23.8611

Total_LogLikelihood

162.351
161.513
162.838
161.118

Q_Scaled_For_Calcs

0.4
NA
0.6
NA

Target

0.000285961
NA
-0.000193041
NA

GOF

10000
NA
10000

NA

Q_for_adj_biomass

0.689267
1.29052
2.41649
1.49401

Q for Survival S

0.400286
0.458972
0.599807
0.480088

Bmsy=

0.0442258
0.0315659
0.0265243
0.0299606

MSY=

0.0193932
0.0137439
0.0114972
0.0128212

Fmsy*0.71=

0.438503
0.435403
0.433458
0.427937

Recent_F/Fmsy=

0.267727
0.583193
1.24839
0.70419

Recent_B/Bmsy=

1.73588
1.21776
0.779495
1.10563

av biomass last 3 yrs

57.32266667
27.5442
13.68610667
23.4252

Av F last 3 yrs

0.1173994
0.2539237
0.541126667
0.301348833

Table B20. Table of emphasis coefficients used in the final model for butterfish.

Likelihood Term	Emphasis Coefficient
NEFSC Surveys	1
Catch	10000
Constraint C/B	10000
Constraint IGR	10000
Fox Surplus Production	0.0001

Table B21. Parameters estimated in the final model for butterfish.

index	name	point est	STD	CV
1	log_escapement_fyear	3.21	1.0959	0.341402
2	log_total_biom_prior_fyear	3.8105	0.94801	0.248789
3	log_mean_recr	2.9126	0.16296	0.05595
4	recruit_devs	0.059098	0.88869	15.03756
5	recruit_devs	1.3582	0.3287	0.242011
6	recruit_devs	-1.4008	0.74111	-0.52906
7	recruit_devs	-0.45544	0.24054	-0.52815
8	recruit_devs	-0.063293	0.19722	-3.11598
9	recruit_devs	0.48946	0.18373	0.375373
10	recruit_devs	0.99078	0.22346	0.225539
11	recruit_devs	0.69755	0.25023	0.358727
12	recruit_devs	0.95444	0.13958	0.146243
13	recruit_devs	-0.030495	0.20942	-6.86736
14	recruit_devs	0.36343	0.1504	0.413835
15	recruit_devs	-1.1016	0.22435	-0.20366
16	recruit_devs	0.48848	0.12249	0.250757
17	recruit_devs	1.1992	0.19574	0.163225
18	recruit_devs	0.27621	0.32175	1.164875
19	recruit_devs	0.81819	0.22257	0.272027
20	recruit_devs	0.38571	0.24297	0.629929
21	recruit_devs	0.75779	0.16815	0.221895
22	recruit_devs	1.0741	0.14009	0.130425
23	recruit_devs	0.37073	0.16984	0.458123
24	recruit_devs	-0.40332	0.18793	-0.46596
25	recruit_devs	-0.25577	0.19725	-0.7712
26	recruit_devs	-0.08615	0.15187	-1.76286
27	recruit_devs	-0.20331	0.1734	-0.85288
28	recruit_devs	-0.11532	0.15347	-1.33082
29	recruit_devs	-1.3695	0.27641	-0.20183
30	recruit_devs	0.28039	0.13957	0.497771
31	recruit_devs	0.48256	0.15242	0.315857
32	recruit_devs	0.52908	0.16039	0.303149
33	recruit_devs	-1.8786	0.27804	-0.148
34	recruit_devs	-0.14247	0.16866	-1.18383
35	recruit_devs	-0.67568	0.18474	-0.27341
36	recruit_devs	-0.65381	0.17138	-0.26213
37	recruit_devs	0.56656	0.24952	0.440412
38	recruit_devs	-0.12354	0.24039	-1.94585
39	recruit_devs	-1.3599	0.36529	-0.26862
40	recruit_devs	-1.8229	0.28466	-0.15616
41	fox_production_log_msy	-4.4084	27.287	-6.18977
42	fox_production_log_bmax	-2.7814	17.194	-6.18178
43	logmeanf	-1.0642	0.32497	-0.30537
44	fdevs	-0.71112	0.83749	-1.17771
45	fdevs	-0.30284	0.97281	-3.21229
46	fdevs	-1.3726	0.15061	-0.10973
47	fdevs	-0.64979	0.14017	-0.21572

Table B21. Cont.

48	fdevs	0.80285	0.11128	0.138606
49	fdevs	0.99409	0.13491	0.135712
50	fdevs	0.28979	0.17815	0.614756
51	fdevs	-0.25261	0.18506	-0.73259
52	fdevs	0.85729	0.1505	0.175553
53	fdevs	0.20487	0.11111	0.542344
54	fdevs	0.46813	0.11939	0.255036
55	fdevs	0.58046	0.12266	0.211315
56	fdevs	0.3421	0.10352	0.302602
57	fdevs	0.11903	0.11511	0.967067
58	fdevs	-1.1009	0.13277	-0.1206
59	fdevs	-0.28058	0.13335	-0.47527
60	fdevs	-0.41052	0.13732	-0.3345
61	fdevs	0.37596	0.11591	0.308304
62	fdevs	-0.3387	0.12312	-0.36351
63	fdevs	0.43158	0.11401	0.264169
64	fdevs	-0.19048	0.10146	-0.53265
65	fdevs	0.16412	0.1083	0.659883
66	fdevs	0.49783	0.10263	0.206155
67	fdevs	-0.35178	0.11395	-0.32392
68	fdevs	0.028659	0.11251	3.925817
69	fdevs	-0.40229	0.10581	-0.26302
70	fdevs	0.12839	0.11432	0.890412
71	fdevs	0.018151	0.12125	6.680073
72	fdevs	0.14334	0.12374	0.863262
73	fdevs	-0.66283	0.11006	-0.16605
74	fdevs	0.36937	0.12667	0.342935
75	fdevs	0.51154	0.10862	0.212339
76	fdevs	0.37879	0.11638	0.307241
77	fdevs	0.2296	0.1271	0.553571
78	fdevs	-0.56275	0.16484	-0.29292
79	fdevs	-1.0407	0.097159	-0.09336
80	fdevs	0.70227	0.097423	0.138726
81	fdevs	-0.0077181	0.17762	-23.0134
82	survey_covariate_pars[1]	0.13958	0.15552	1.1142
83	survey_covariate_pars[4]	-1.0566	0.1188	-0.11244
84	f	0.16944	0.17188	1.0144
85	f	0.25487	0.29001	1.137874
86	f	0.087445	0.022912	0.262016
87	f	0.18015	0.047374	0.26297
88	f	0.77004	0.22384	0.290686
89	f	0.93233	0.25208	0.270376
90	f	0.46099	0.1593	0.345561
91	f	0.268	0.086857	0.324093
92	f	0.81313	0.23371	0.28742
93	f	0.42346	0.11596	0.273839
94	F	0.551	0.16589	0.301071
95	F	0.61649	0.15816	0.256549

Table B21. Continued

96	F	0.48575	0.16343	0.336449
97	F	0.38863	0.12221	0.314464
98	F	0.11474	0.038463	0.335219
99	F	0.26061	0.095212	0.365343
100	F	0.22885	0.082895	0.362224
101	F	0.50248	0.16912	0.336571
102	F	0.24589	0.082366	0.334971
103	F	0.53122	0.16616	0.312789
104	F	0.28518	0.096322	0.337759
105	F	0.40655	0.14778	0.363498
106	F	0.56761	0.18944	0.33375
107	F	0.2427	0.078441	0.323201
108	F	0.35505	0.1196	0.336854
109	F	0.23074	0.075035	0.325193
110	F	0.39229	0.14596	0.372072
111	F	0.35134	0.1148	0.326749
112	F	0.39819	0.1267	0.31819
113	F	0.17782	0.052209	0.293606
114	F	0.49918	0.18532	0.371249
115	F	0.57544	0.17391	0.302221
116	F	0.5039	0.15614	0.309863
117	F	0.43407	0.1492	0.343723
118	F	0.19654	0.081109	0.412684
119	F	0.12186	0.037325	0.306294
120	F	0.69636	0.23541	0.338058
121	F	0.34236	0.15302	0.446956
122	average_biom	33.962	34.451	1.014398
123	average_biom	32.062	36.483	1.137889
124	average_biom	77.183	20.223	0.262014
125	average_biom	48.744	12.818	0.262966
126	average_biom	25.651	7.4563	0.290683
127	average_biom	16.578	4.4824	0.270382
128	average_biom	26.499	9.1566	0.345545
129	average_biom	50.844	16.478	0.324089
130	average_biom	43.406	12.476	0.287426
131	average_biom	49.147	13.458	0.273832
132	average_biom	32.319	9.7307	0.301083
133	average_biom	28.833	7.3971	0.25655
134	average_biom	14.879	5.006	0.336447
135	average_biom	27.839	8.7542	0.314458
136	average_biom	65.284	21.885	0.335228
137	average_biom	55.34	20.218	0.365342
138	average_biom	59.481	21.545	0.362217
139	average_biom	45.52	15.321	0.336577
140	average_biom	49.743	16.662	0.334962
141	average_biom	59.387	18.575	0.312779
142	average_biom	45.686	15.431	0.337762
143	average_biom	29.277	10.642	0.363494

Table B21. Continued

144	average_biom	20.57	6.8653	0.333753
145	average_biom	21.527	6.9576	0.323203
146	average_biom	21.532	7.2533	0.336861
147	average_biom	23.033	7.4901	0.32519
148	average_biom	14.277	5.3121	0.372074
149	average_biom	24.051	7.8587	0.326751
150	average_biom	32.853	10.453	0.318175
151	average_biom	41.232	12.106	0.293607
152	average_biom	21.393	7.9424	0.371262
153	average_biom	18.021	5.4461	0.302209
154	average_biom	13.17	4.0807	0.309848
155	average_biom	12.05	4.1418	0.343718
156	average_biom	31.64	13.057	0.412674
157	average_biom	31.585	9.674	0.306285
158	average_biom	16.741	5.6593	0.33805
159	average_biom	7.8169	3.4937	0.446942
160	spawning_biom	24.78	27.157	1.095924
161	spawning_biom	22.613	29.211	1.291779
162	spawning_biom	62.914	16.405	0.260753
163	spawning_biom	33.956	9.6241	0.283429
164	spawning_biom	12.75	5.2643	0.412886
165	spawning_biom	8.0333	3.2638	0.406284
166	spawning_biom	17.686	7.6615	0.433196
167	spawning_biom	37.61	13.942	0.370699
168	spawning_biom	22.649	9.488	0.418915
169	spawning_biom	32.963	10.958	0.332433
170	spawning_biom	19.154	7.4136	0.387052
171	spawning_biom	16.986	5.7037	0.335788
172	spawning_biom	8.9683	3.7709	0.42047
173	spawning_biom	19.248	7.2716	0.377785
174	spawning_biom	52.617	18.673	0.354885
175	spawning_biom	38.586	16.114	0.417613
176	spawning_biom	43.181	17.422	0.403464
177	spawning_biom	27.734	11.694	0.421649
178	spawning_biom	36.19	13.502	0.373086
179	spawning_biom	37.009	14.849	0.401227
180	spawning_biom	31.796	12.154	0.382249
181	spawning_biom	18.417	8.0321	0.436124
182	spawning_biom	12.083	5.1372	0.425159
183	spawning_biom	15.681	5.6008	0.357171
184	spawning_biom	14.566	5.806	0.398599
185	spawning_biom	16.784	6.0351	0.359575
186	spawning_biom	8.9826	4.0245	0.448033
187	spawning_biom	16.859	6.4827	0.384525
188	spawning_biom	22.272	8.5654	0.384582
189	spawning_biom	31.302	9.9205	0.316929
190	spawning_biom	12.357	5.8554	0.473853
191	spawning_biom	10.76	4.1491	0.385604

Table B21. Continued

192	spawning_biom	8.1352	3.1472	0.386862
193	spawning_biom	7.8433	3.3032	0.421149
194	spawning_biom	24.504	11.182	0.456334
195	spawning_biom	24.114	7.589	0.314713
196	spawning_biom	8.6812	4.0326	0.464521

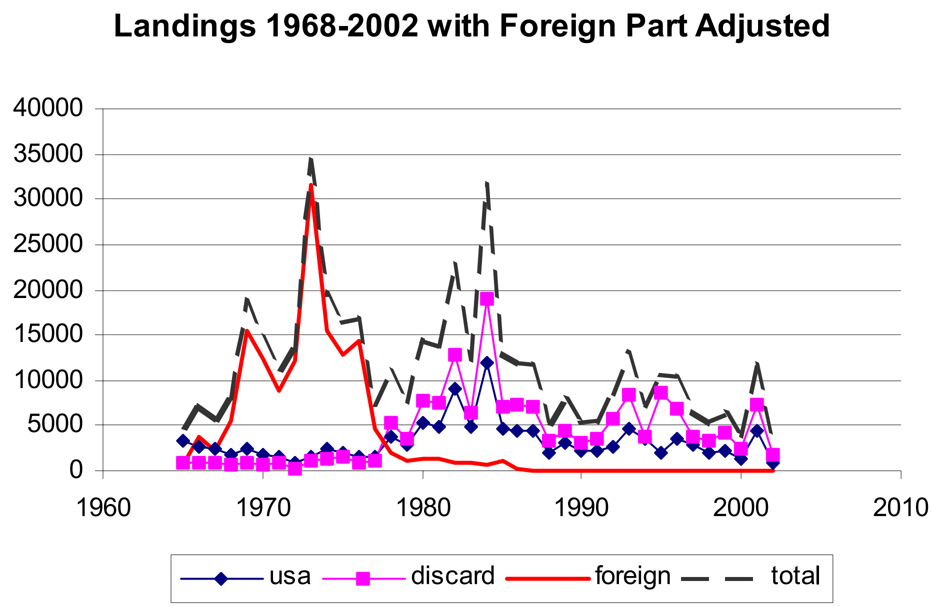


Figure B1. Landings and discards from the USA fishery, foreign landings, and total catch of butterfish during 1965-2002.

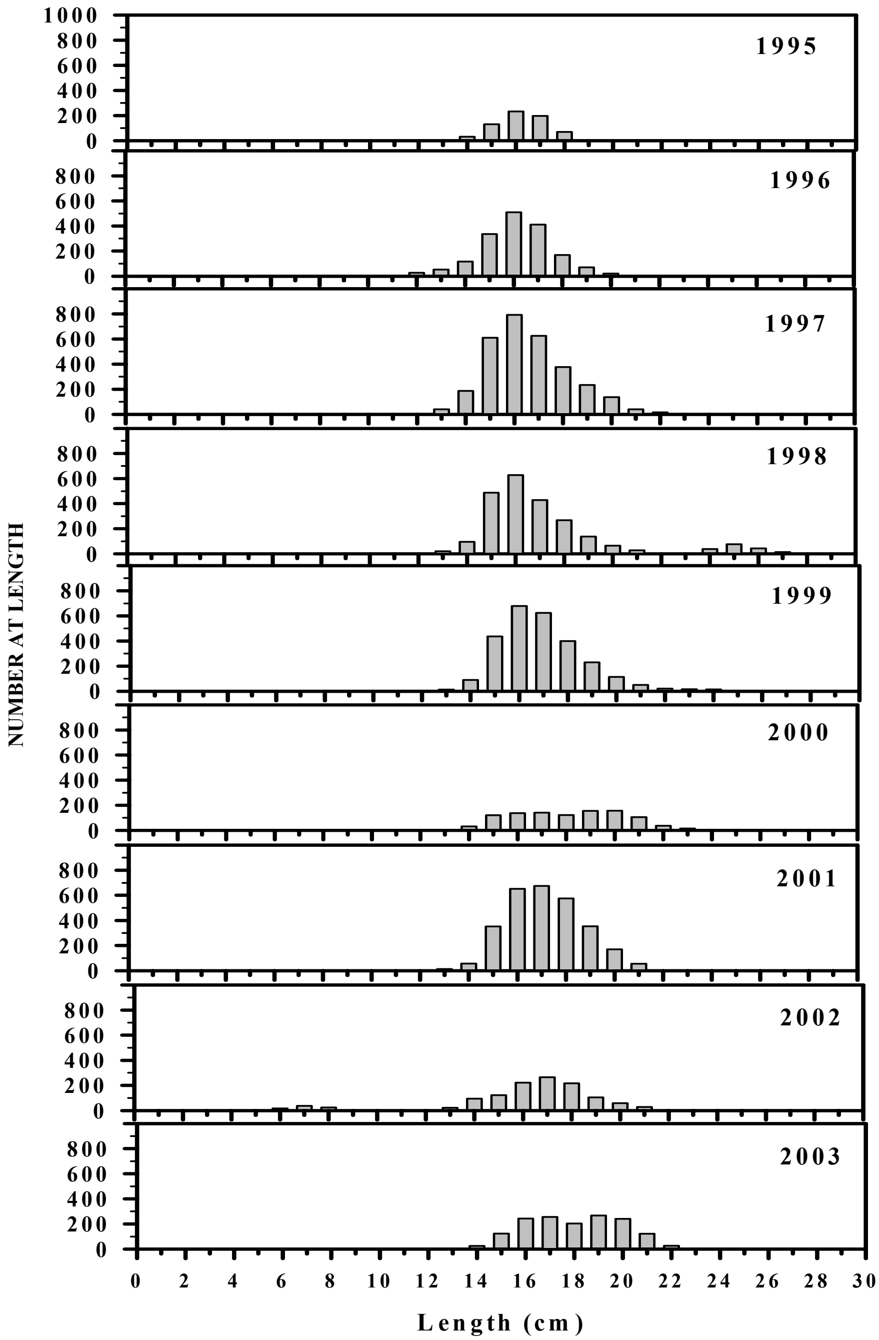


Figure B2. Size composition data from commercial landings of butterfish during 1995-2003.

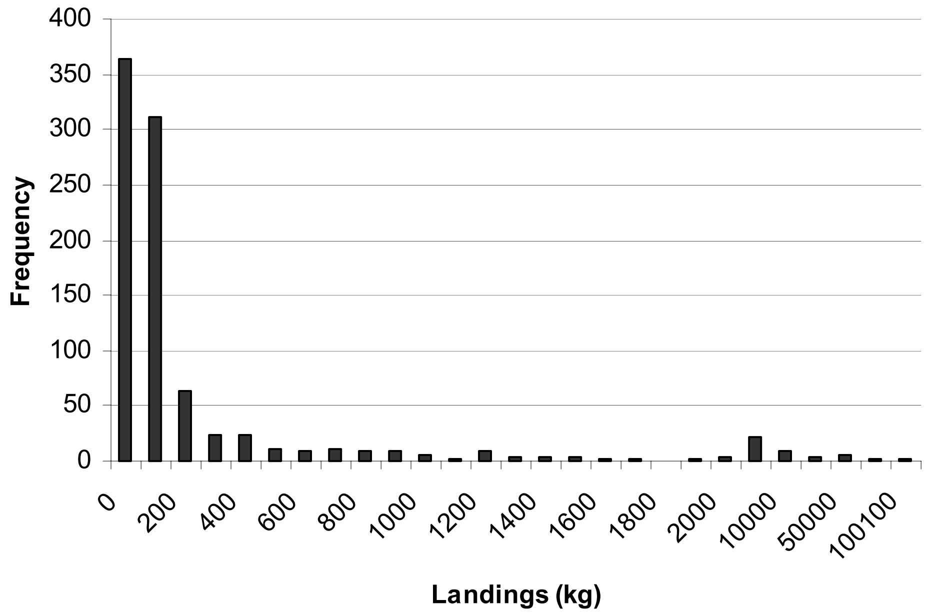


Figure B3. Distribution of landings of butterfish in otter trawls trips during 1989-2003.

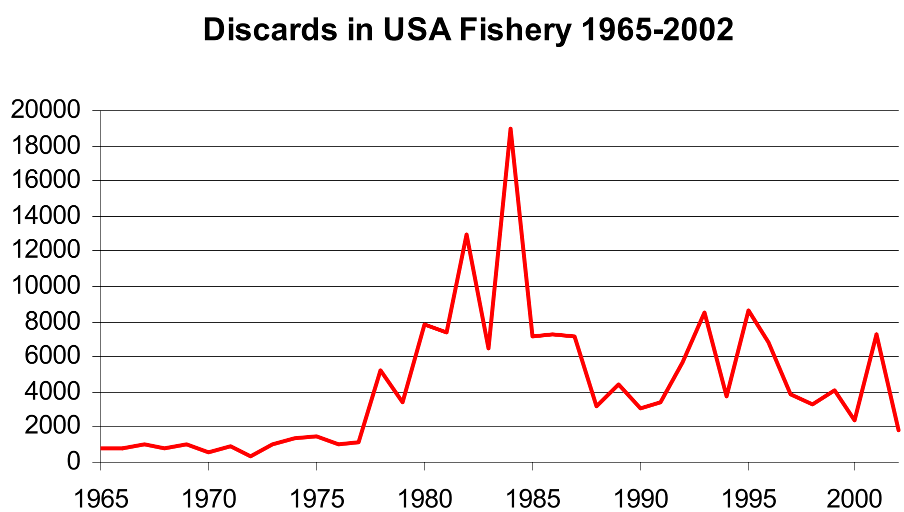


Figure B4. Estimated discards (mt) in the USA otter trawl fishery during 1965-2002.

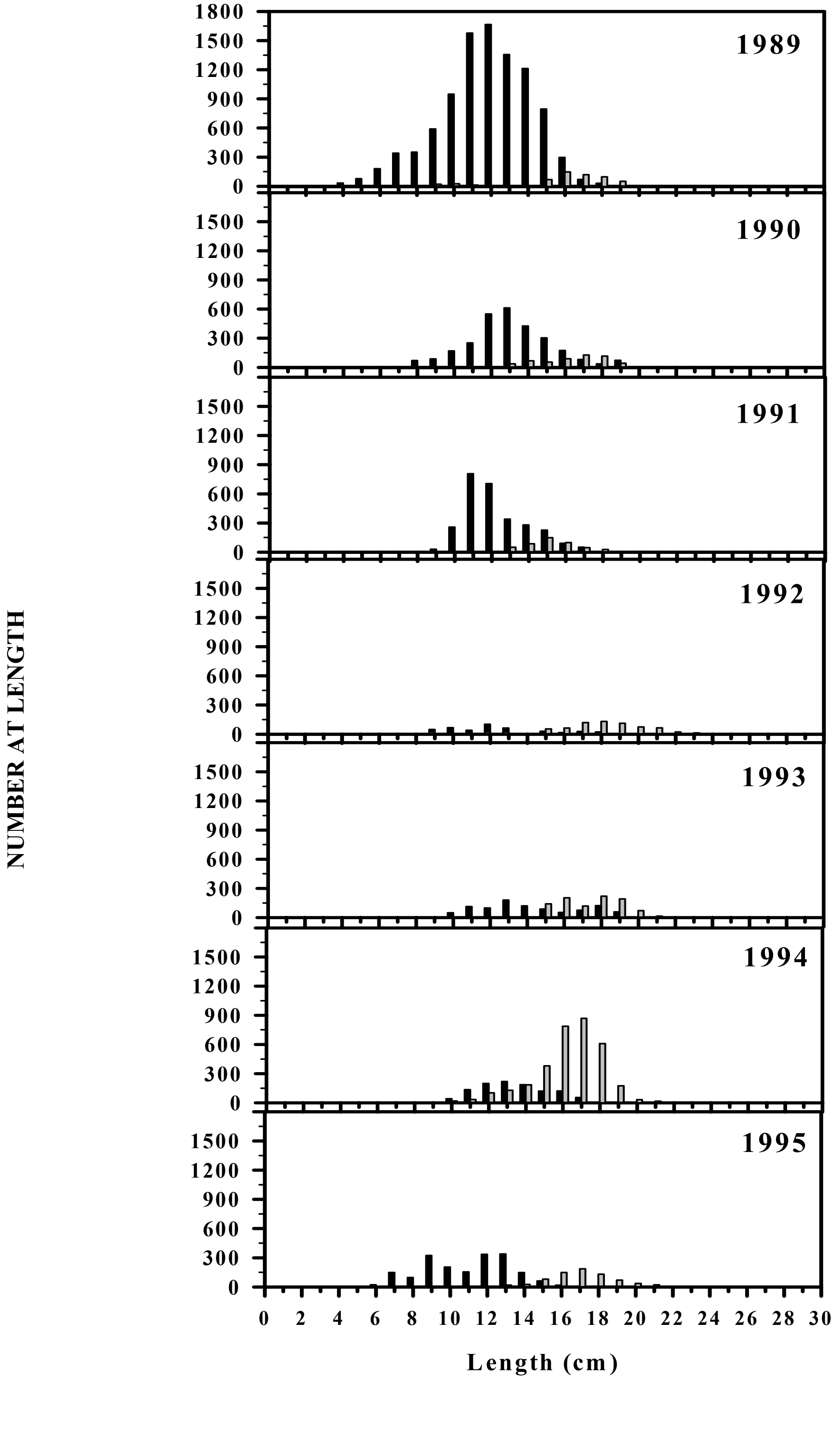
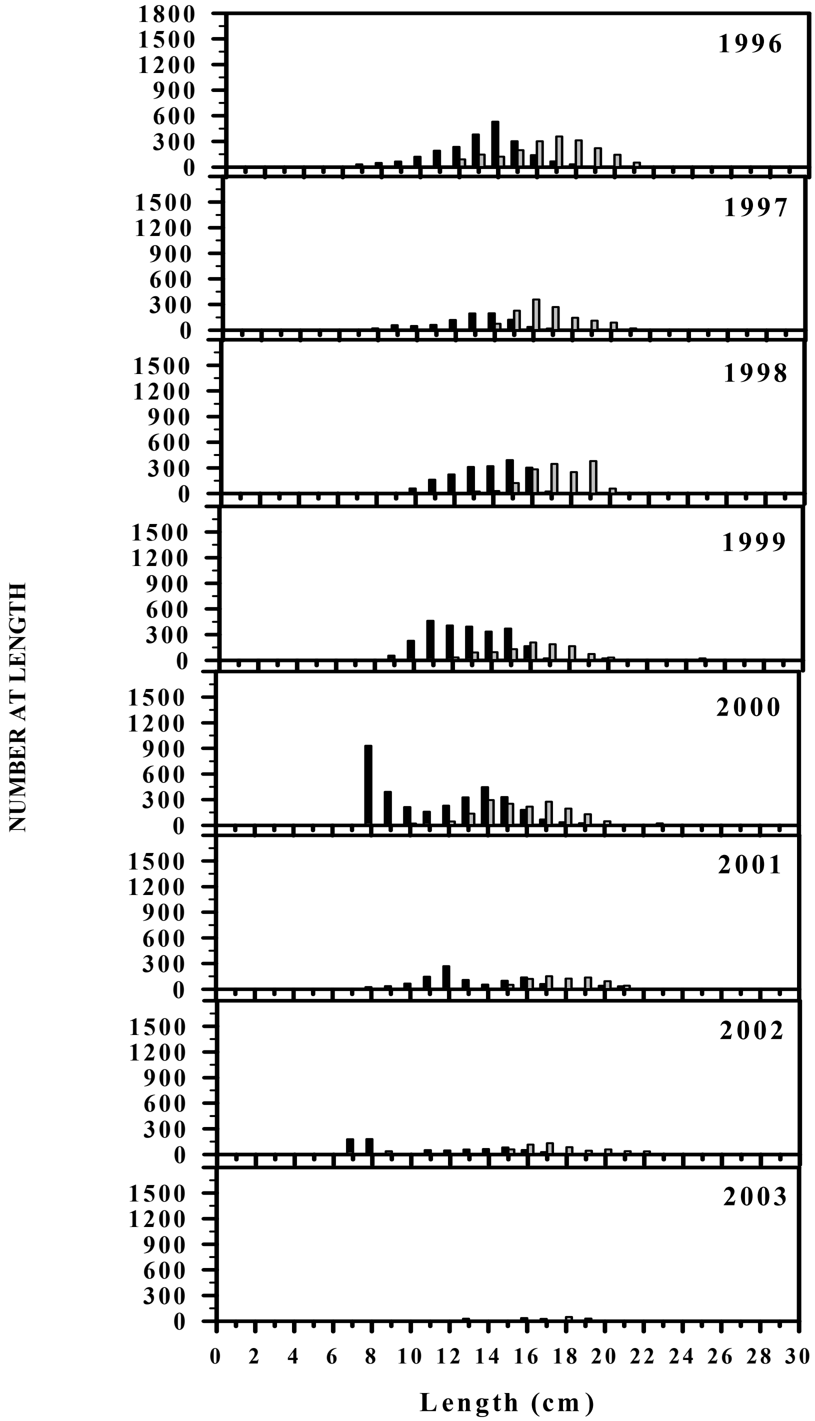


Figure B5. Length composition for NMFS Observer Program for butterfish during 1989-1995 with kept fish in gray and discard in black.

Figure B5. Continued, 1996-2003



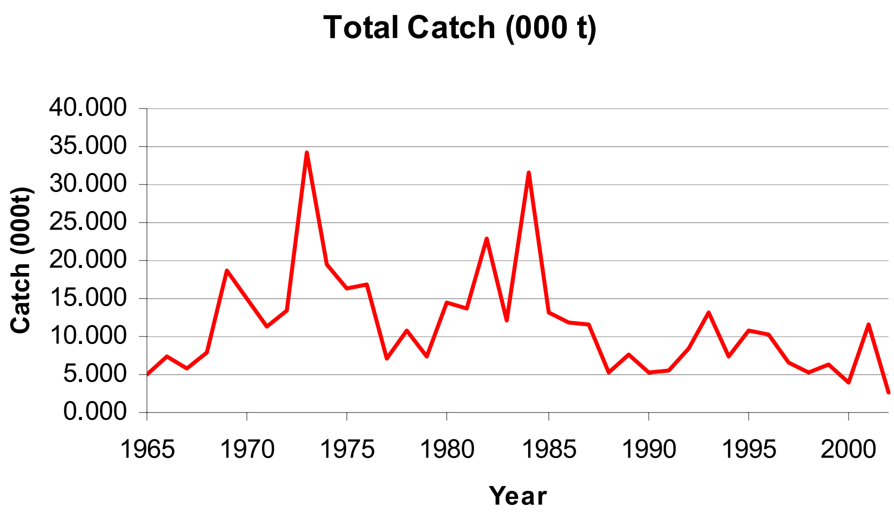


Figure B6. Total catch of butterfish during 1965-2002, includes USA landings, USA discards, and foreign landings.

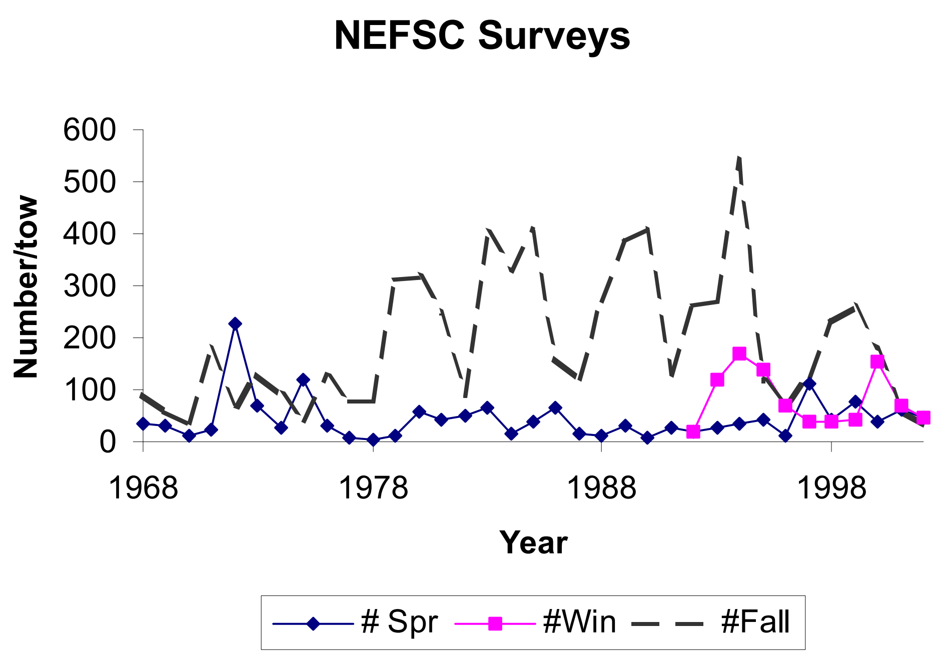


Figure B7. Research survey catch per tow in number for Winter 1994-2002, Spring 1968-2002, and Autumn 1968-2002 for NEFSC surveys for Strata 1-14, 16,19,23,25,61-76.

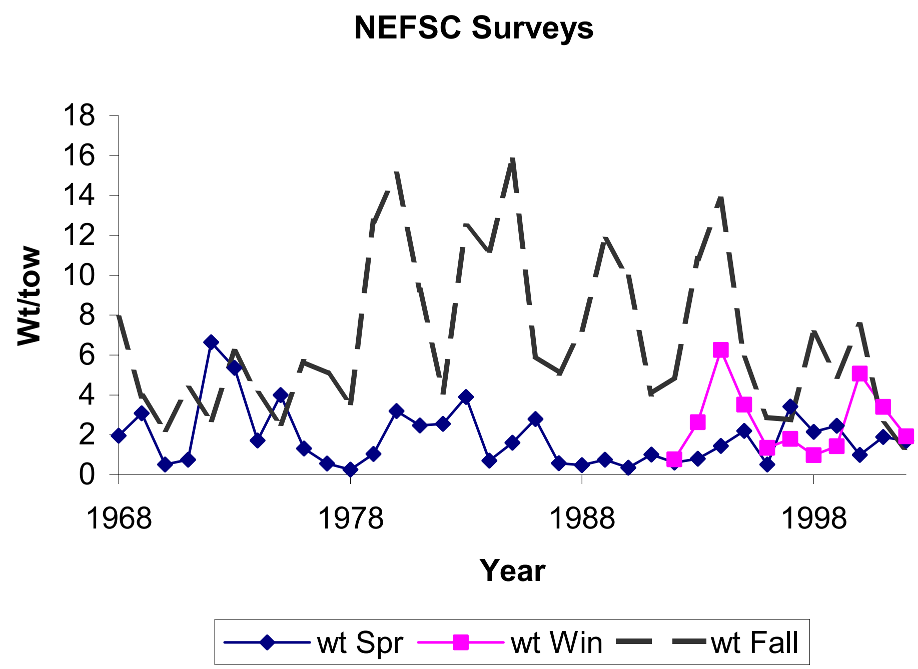


Figure B8. Research survey catch per tow (kg) for Winter 1994-2002, Spring 1968-2002, and Autumn 1968-2002 for NEFSC surveys for strata 1-14, 16,19,23,25,61-76.

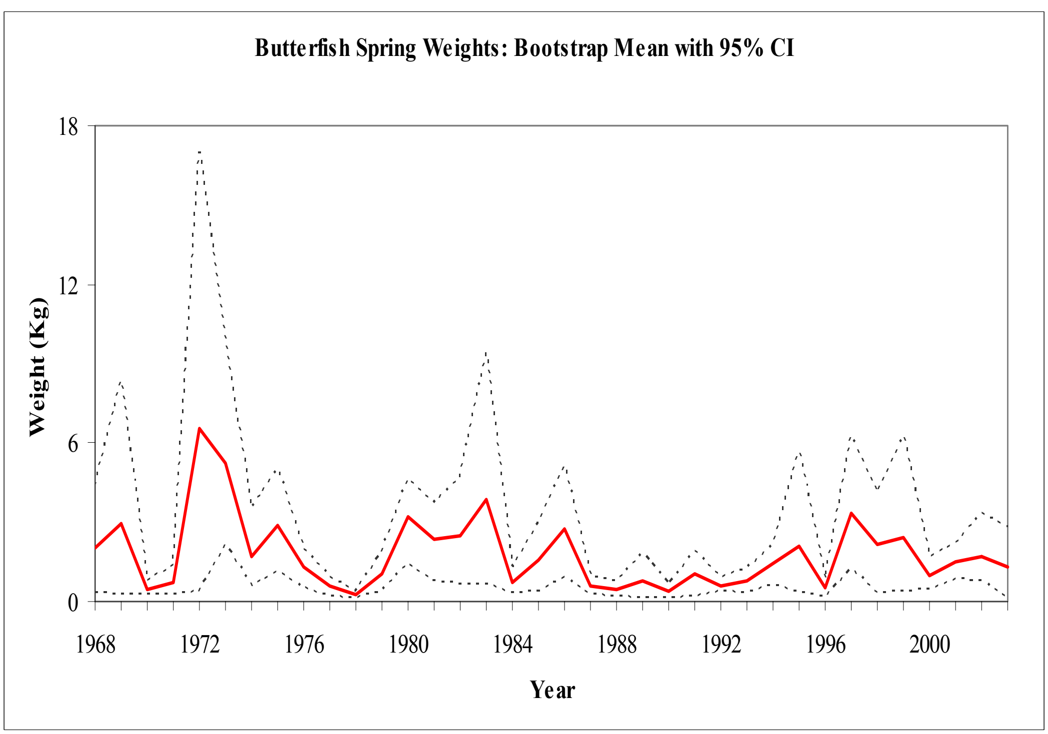


Figure B9. Catch in wt/tow and 95% confidence intervals (bootstrap analysis) for the spring NEFSC survey during 1968-2002.

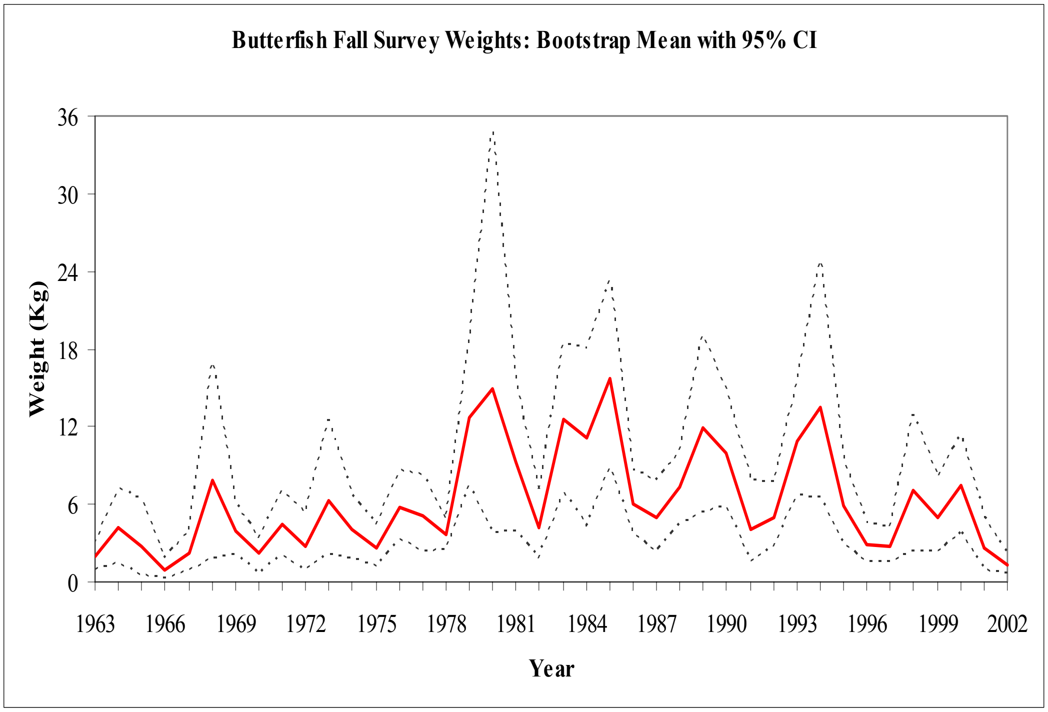


Figure B10. Catch in wt/tow and 95% confidence intervals (bootstrap analysis) for the fall NEFSC survey during 1968-2002.

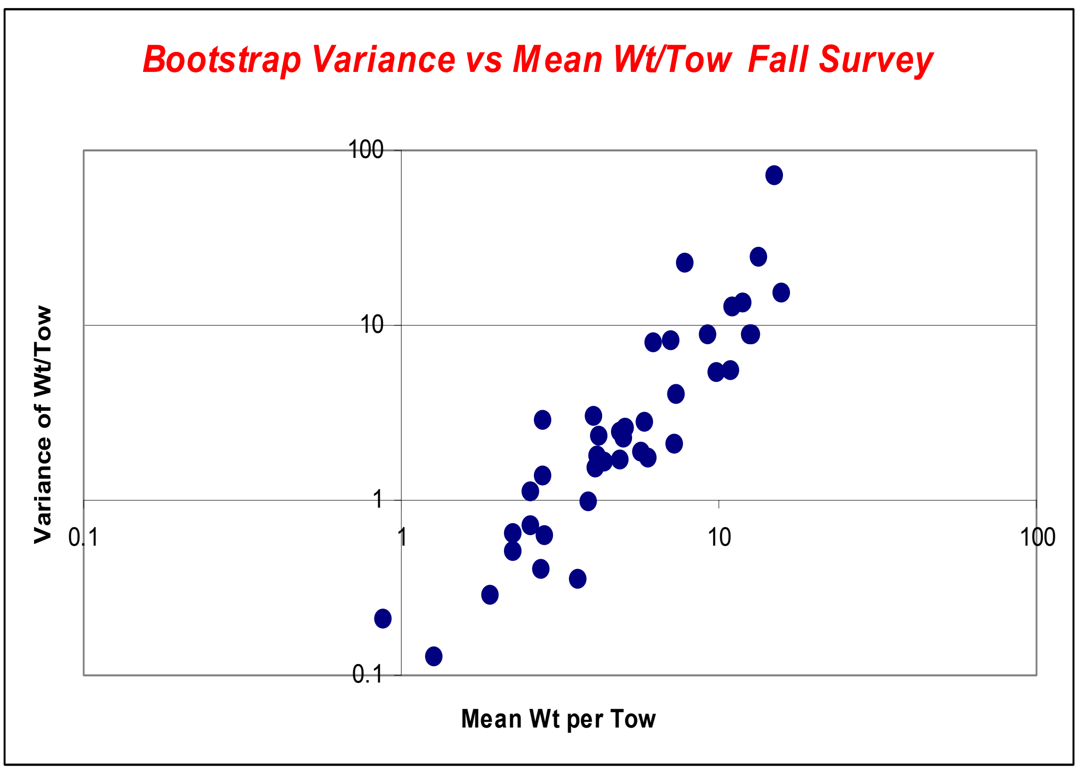


Figure B11. Relationship between fall survey wt/tow and variance in wt/tow during 1968-2002.

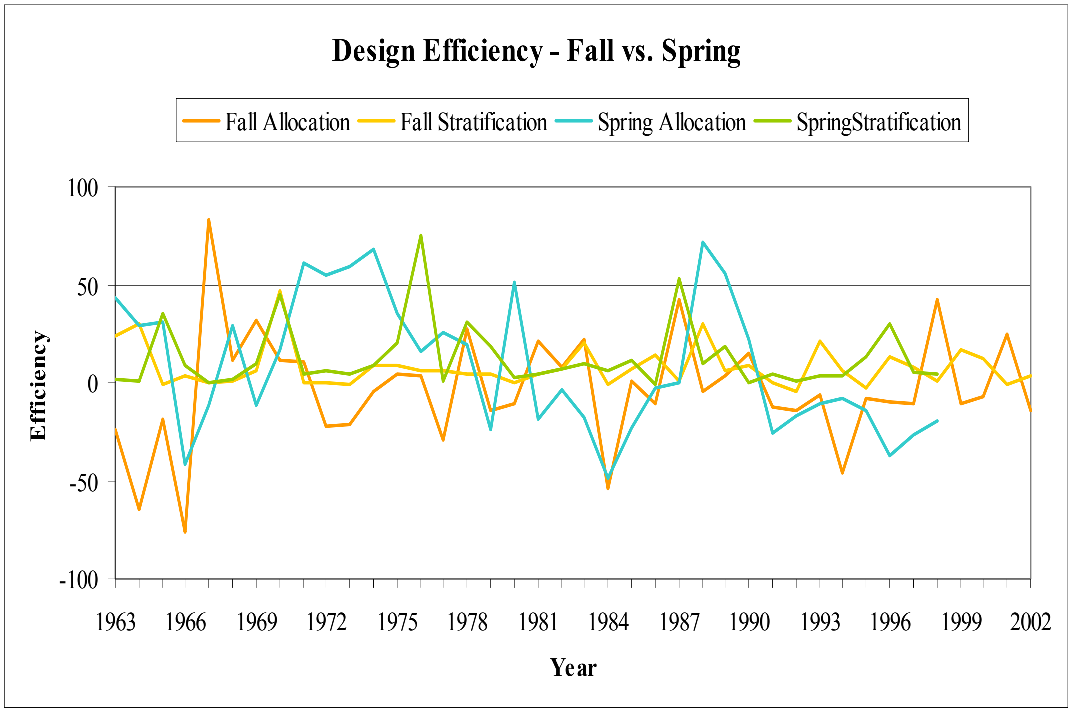


Figure B12. Design efficiency for stratification and allocation for the spring and fall NEFSC survey during 1963-2002.

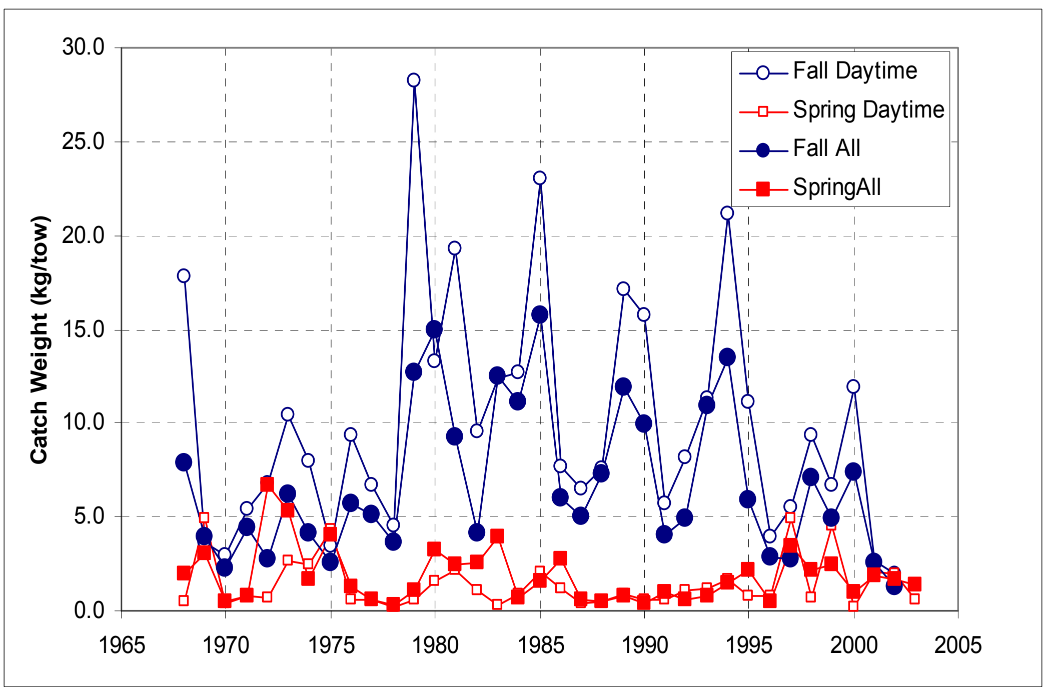


Figure B13. Spring and fall daytime and total wt/tow indices during 1968-2002.

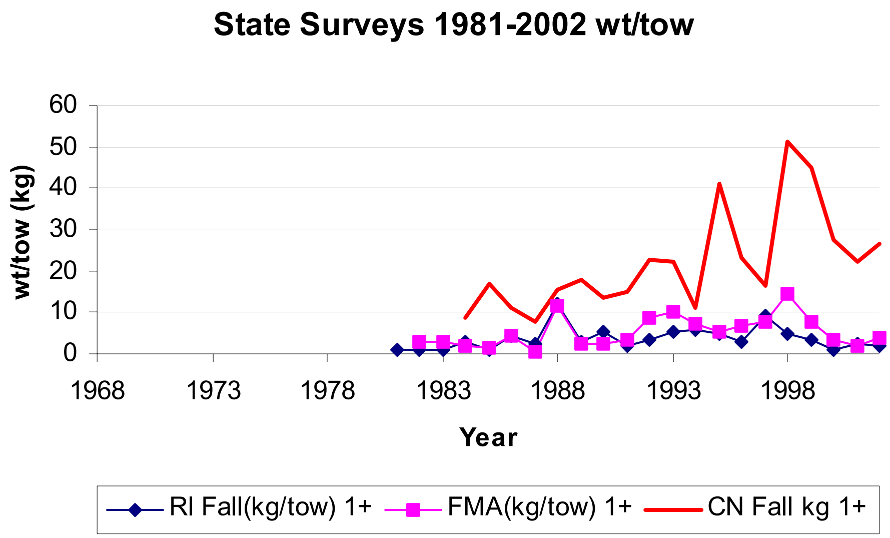


Figure B14. Catch-per-tow in weight for Rhode Island (1981-2002), Massachusetts (1982-2002), and Connecticut (1984-2002) bottom trawls surveys.

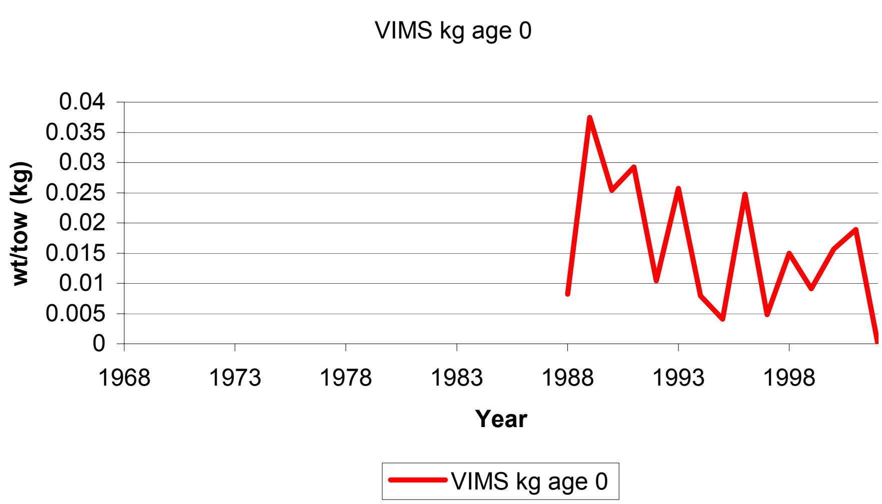


Figure B15. Catch-per-tow in weight for the VIMS bottom trawl survey age 0 during 1988-2001.

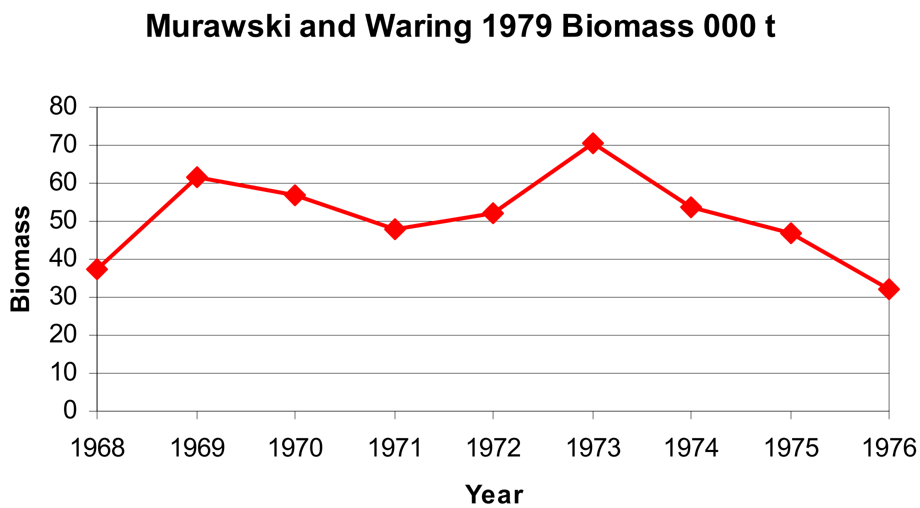


Figure B16. Estimates of butterfish biomass during 1968-1976 from VPA.

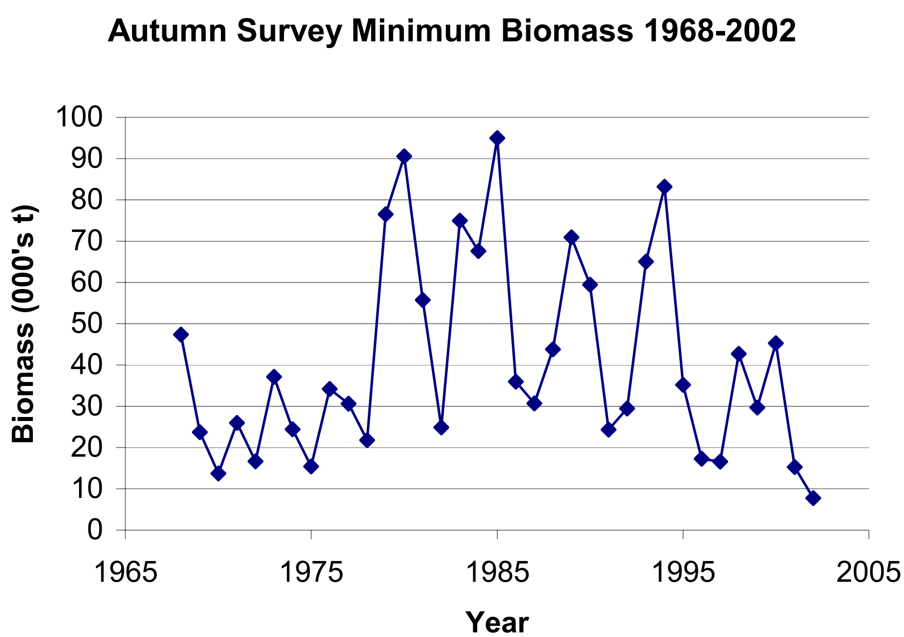


Figure B17. Autumn survey minimum swept area biomass during 1968-2002.

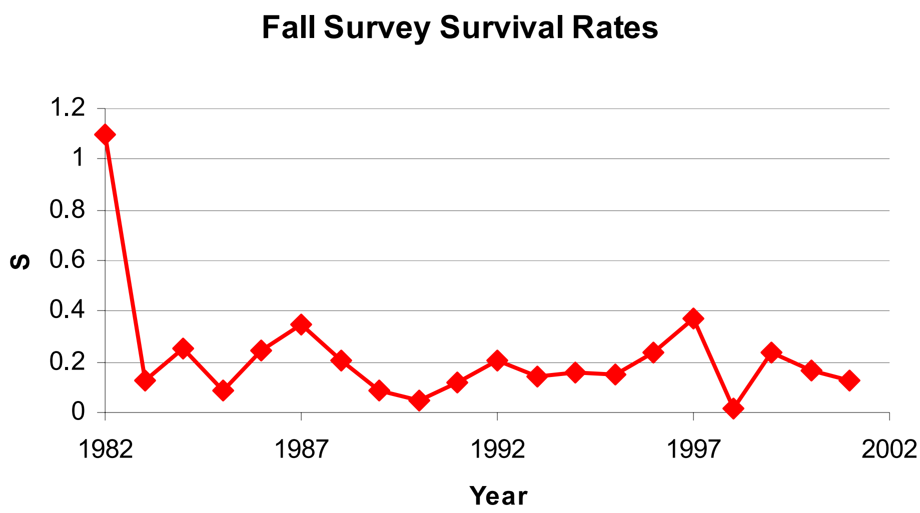


Figure B18. Survival estimates from autumn survey number/tow indices during 1982-2002.

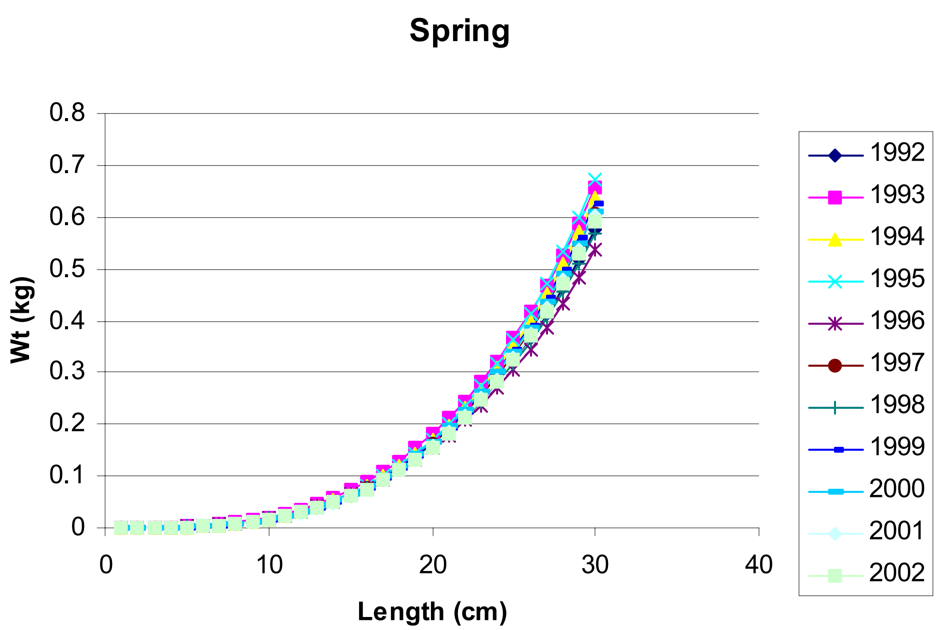


Figure B19. Length-Weight relationships for butterfish from spring bottom trawl surveys during 1992-2002.

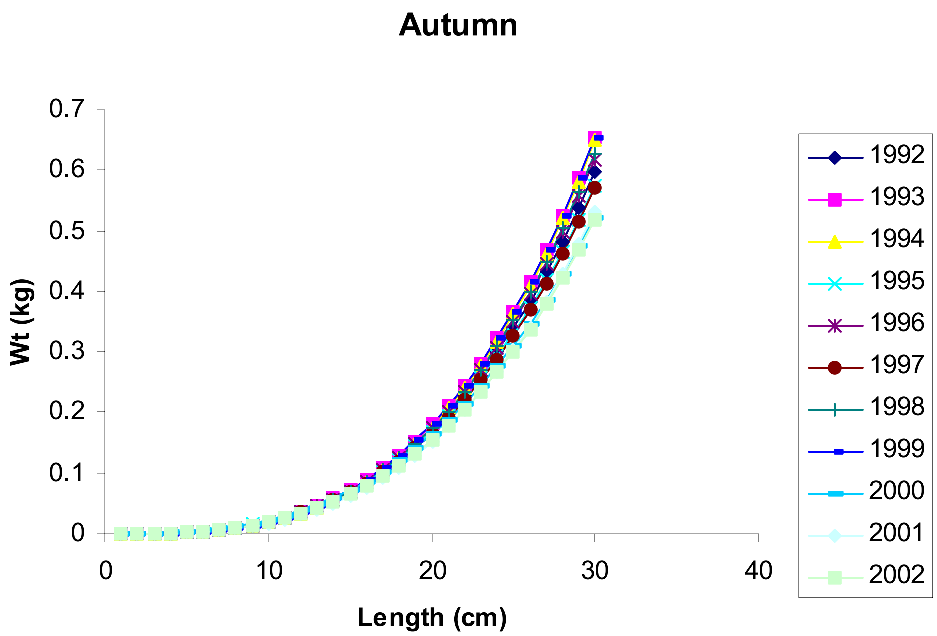


Figure B20. Length-Weight relationships for butterfish from autumn bottom trawl surveys during 1992-2002.

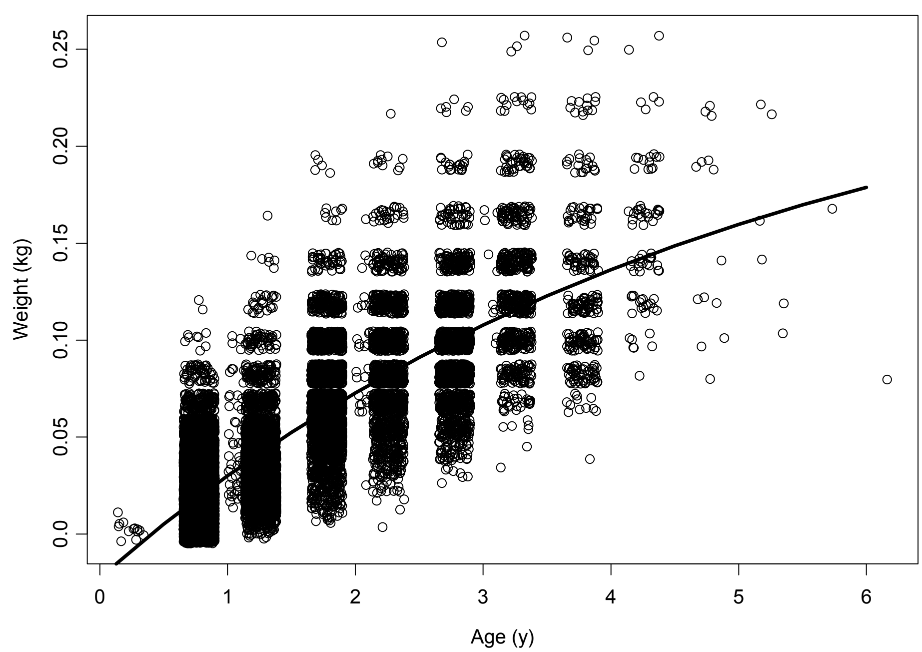


Figure B21. Von-Bertalanffy growth model fit to winter, spring, and Autumn NEFSC survey data from 1992-2003.

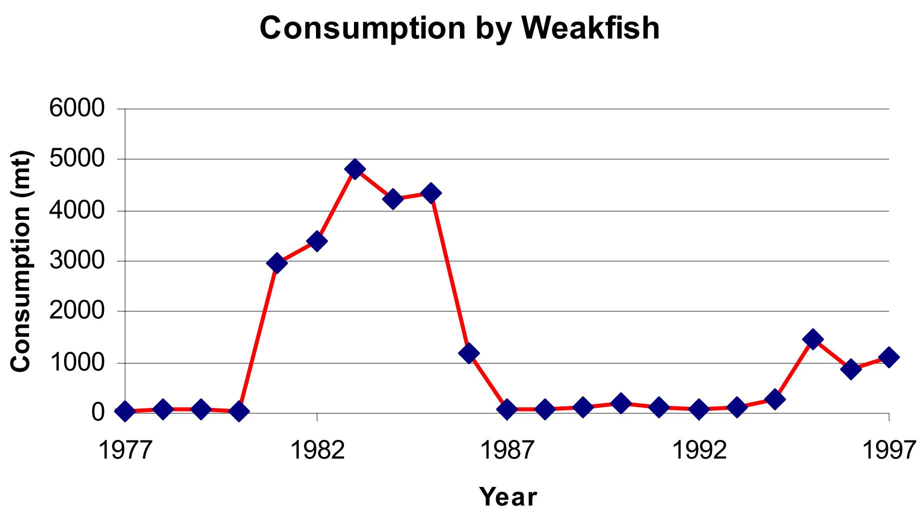


Figure B22. Consumption of butterfish (tonnes) by weakfish during 1977-1997.

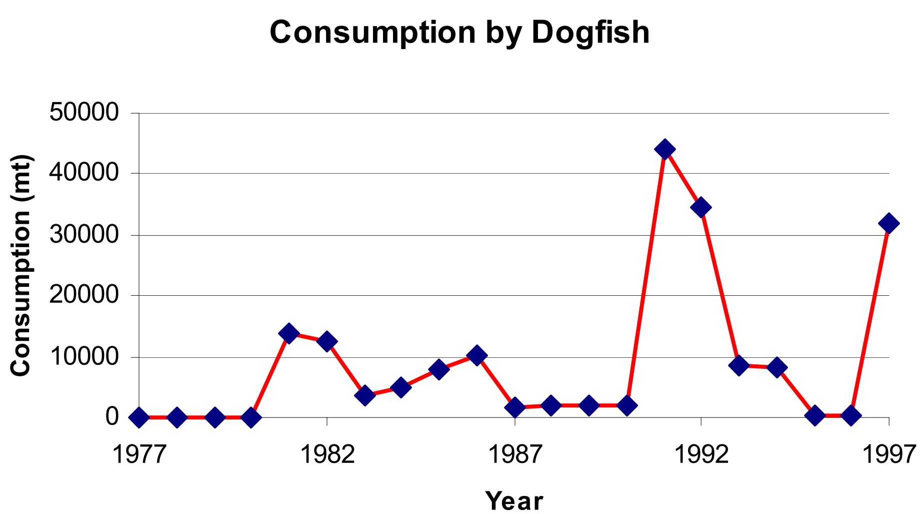


Figure B23. Consumption of butterfish (tonnes) by Spiny Dogfish during 1977-1997.

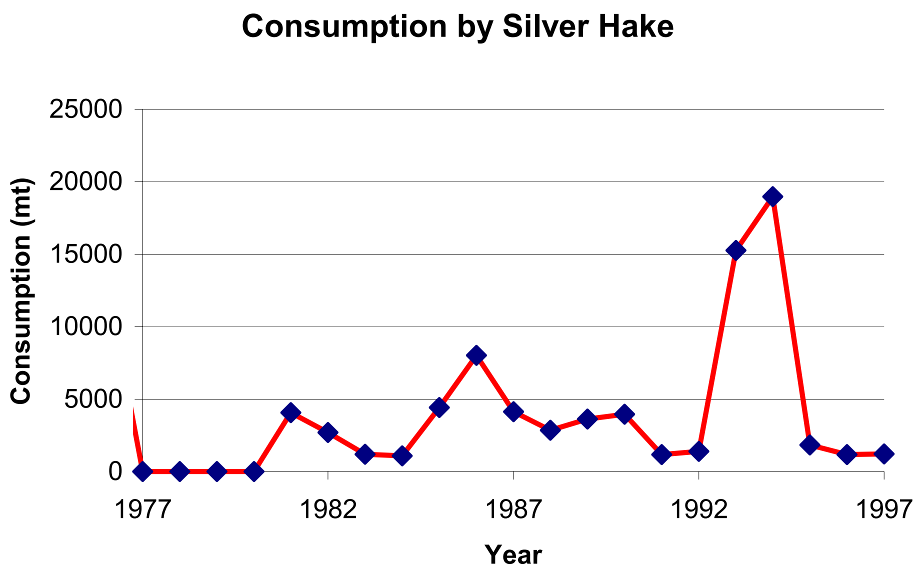


Figure B24. Consumption of butterfish (tonnes) by Silver Hake during 1977-1997.

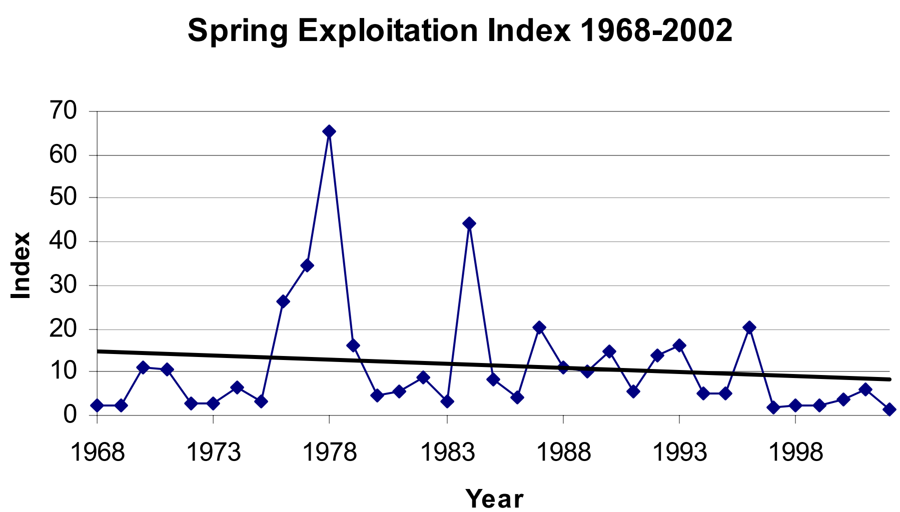


Figure B25. Exploitation indices for butterfish from the NEFSC Spring bottom trawl survey and catch during 1968-2002.

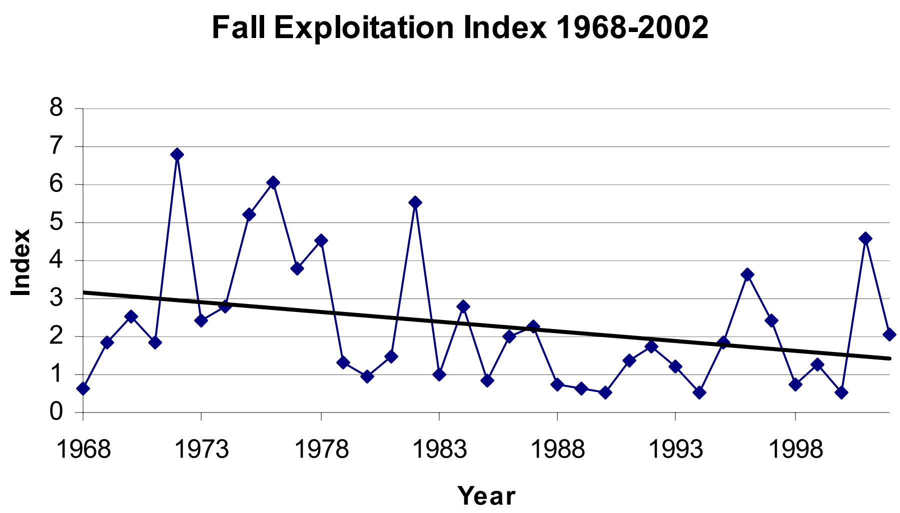


Figure B26. Exploitation indices for butterfish from the NEFSC Autumn bottom trawl survey and catch during 1968-2002.

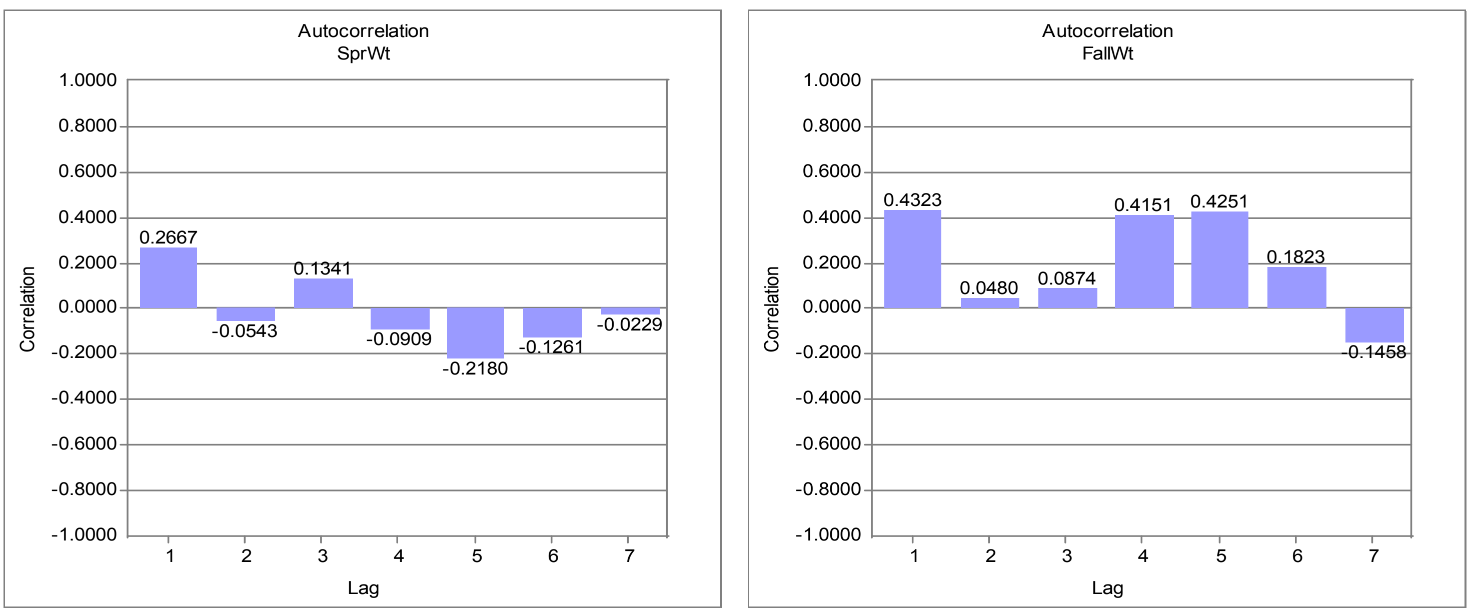


Figure B27. Autocorrelation plots for relationship between the replacement ratio and relative F for the spring and fall NEFSC surveys during 1968-2002.

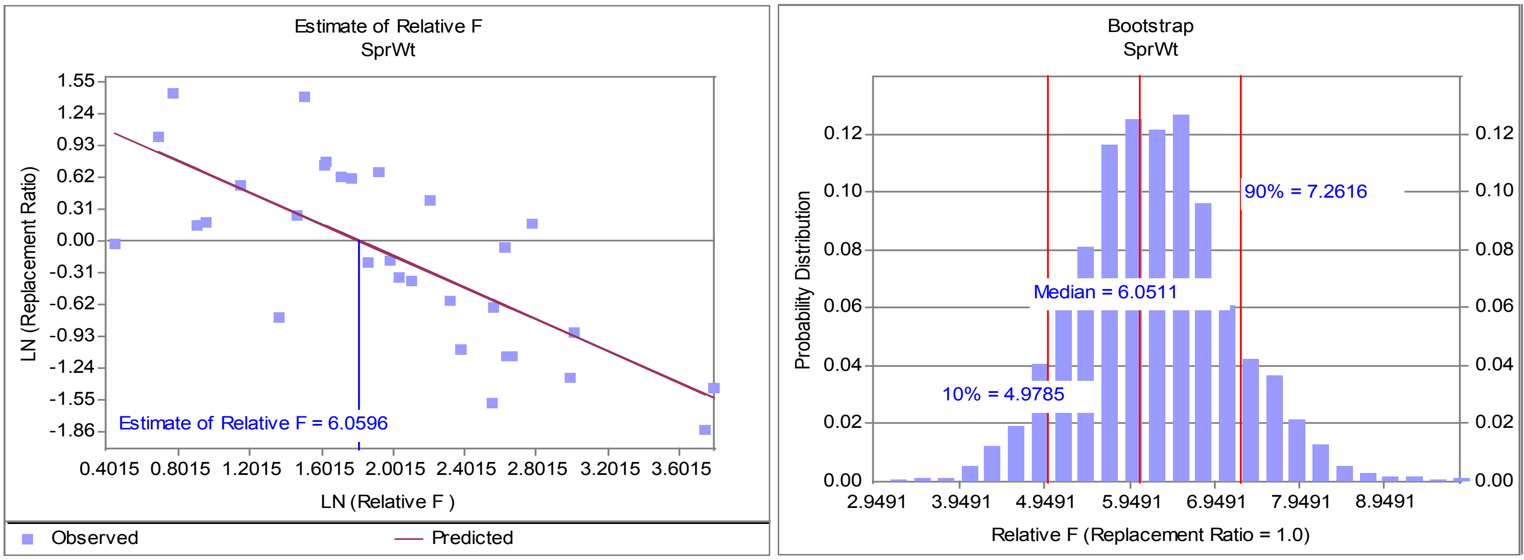


Figure B28. Plots of relative F and replacement ratio and bootstrap distribution of relative F for butterfish from the spring NEFSC survey during 1968-2002.

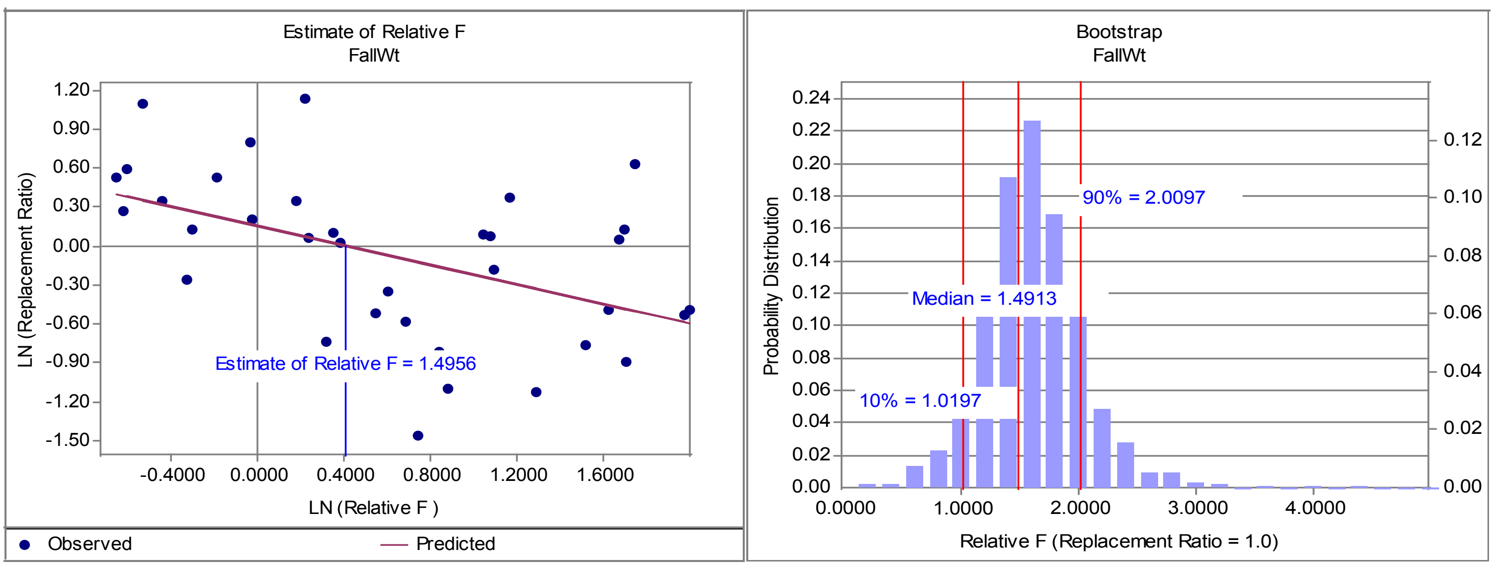


Figure B29. Plots of relative F and replacement ratios and bootstrap distribution of relative F for butterfish from the fall NEFSC survey during 1968-2002.

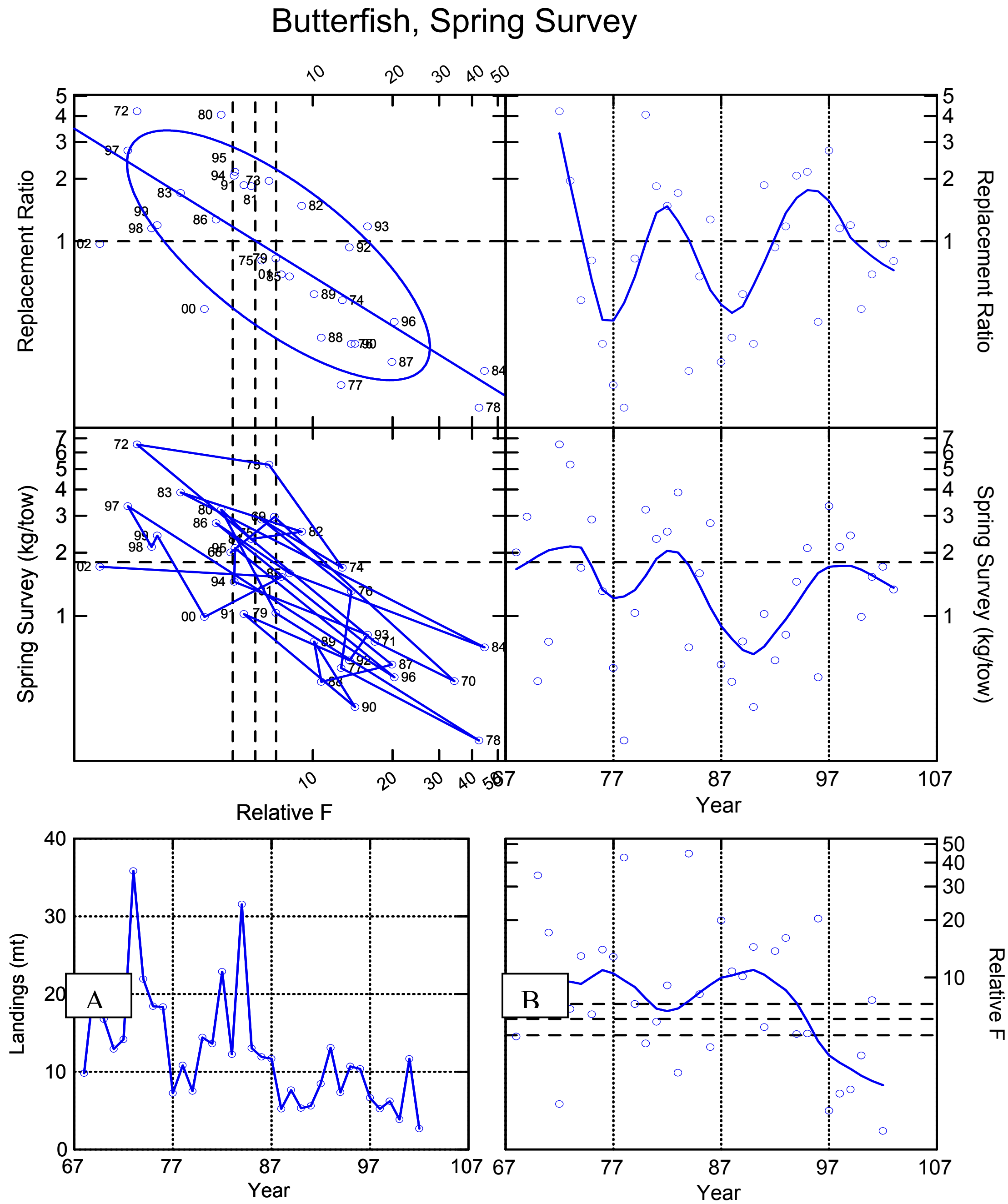


Figure B30. Six panel plot depicting trends in relative biomass, landings, relative fishing mortality rate (landings/abundance index) and replacement ratios for butterfish using NMFS spring bottom trawl survey. Lowess smooth lines are based on a tension factor of 0.3. Vertical dashed lines in panel A and C represent the point and 80% CI of relative F at replacement. Horizontal dashed lines in panel F represents same quantities. The horizontal line in panels C and D represent the arithmetic average of fall survey weight per tow (6.23 kg/tow).

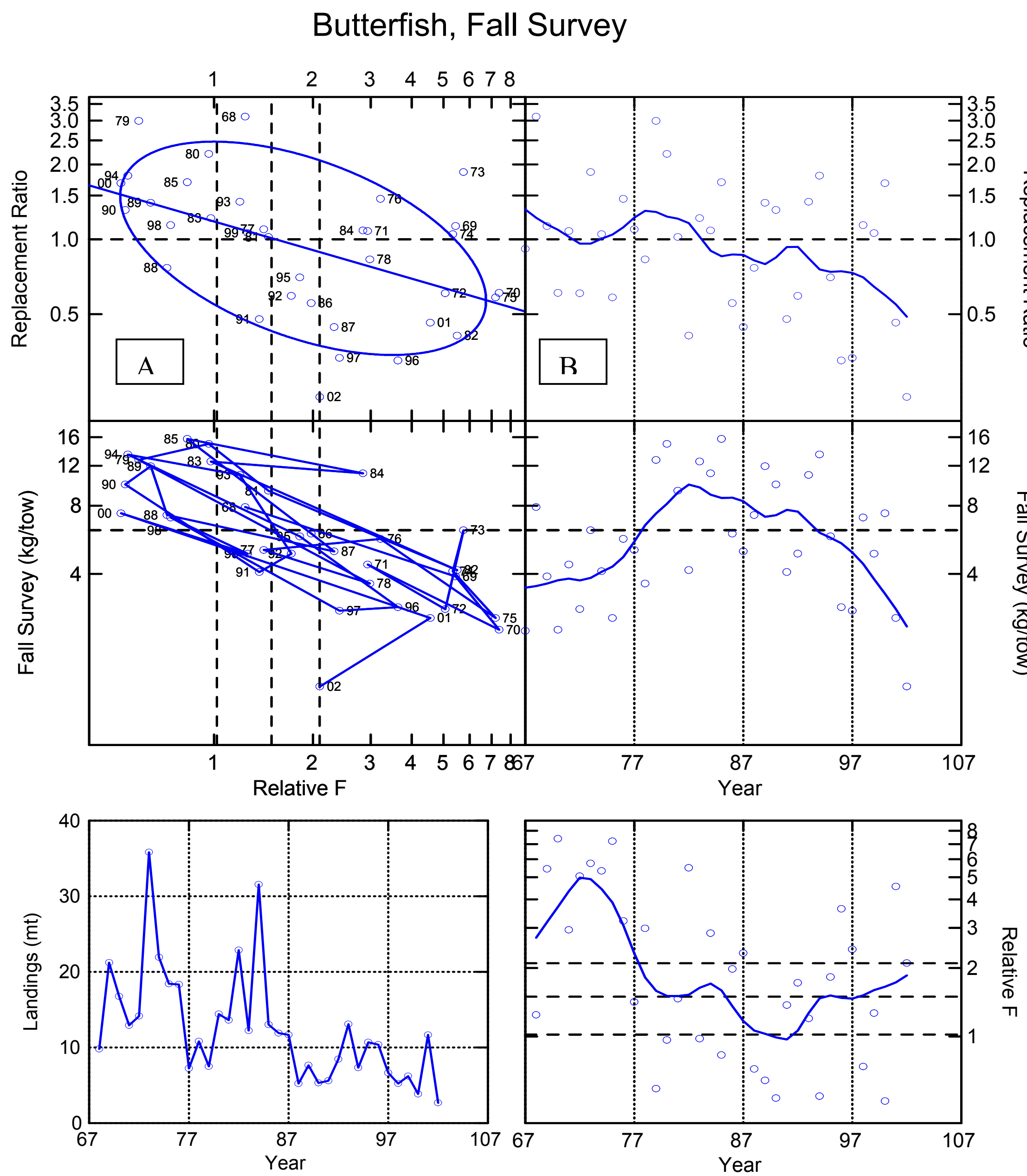


Figure B31. Six panel plot depicting trends in relative biomass, landings, relative fishing mortality rate (landings/abundance index) and replacement ratios for butterfish using NMFS fall bottom trawl survey. Lowess smooth lines are based on a tension factor of 0.3. Vertical dashed lines in panel A and C represent the point and 80% CI of relative F at replacement. Horizontal dashed lines in panel F represents same quantities. The horizontal line in panels C and D represent the arithmetic average of fall survey weight per tow (6.23 kg/tow).

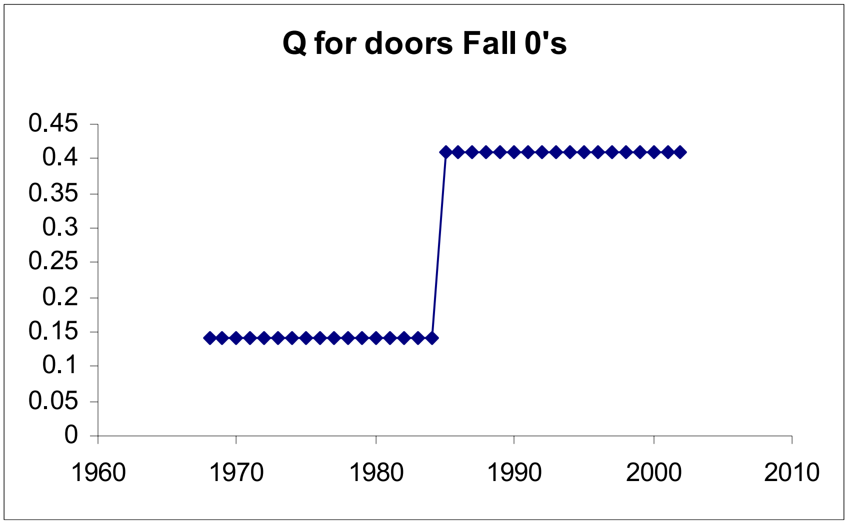


Figure B32. Q for the door adjustment that was estimated from a covariate that was added for the door conversion in 1985 for the fall age 0 index.

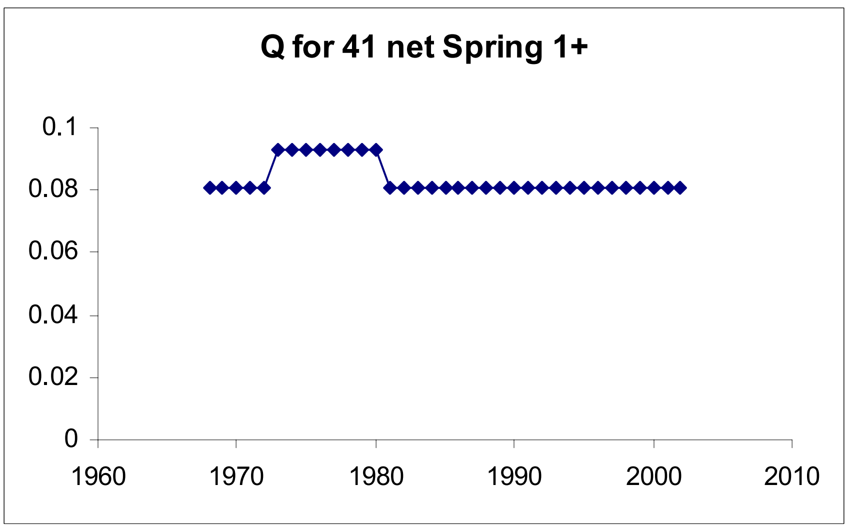


Figure B33. Q for the net adjustment that was estimated from a covariate that was added for the change in net that occurred during 1977-1981 for the spring age 1+ index.

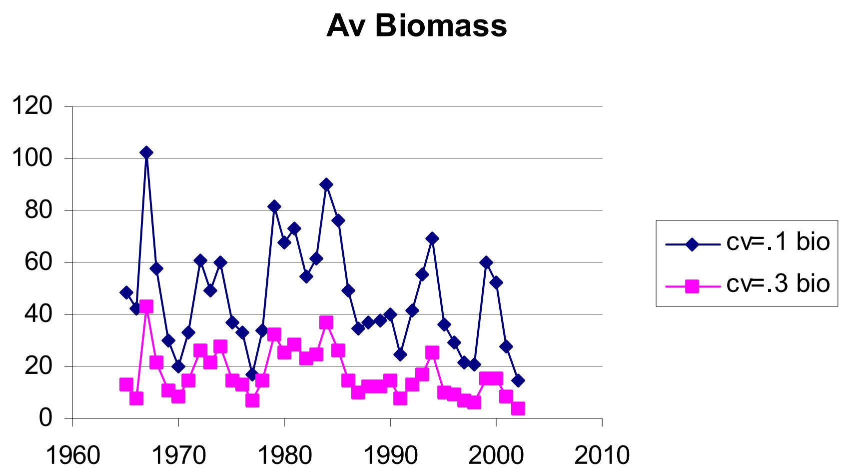


Figure B34. Average biomass for catch CV's of 0.1 and 0.3 during 1965-2002.

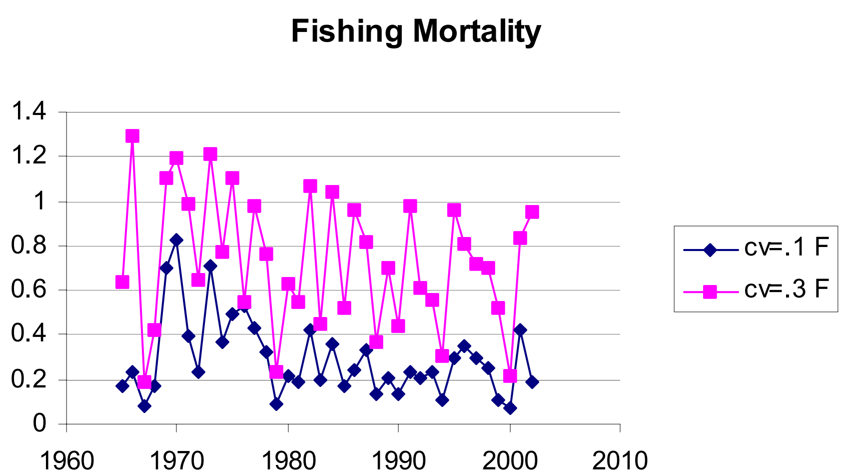


Figure B35. Fishing Mortality for catch CV's of 0.1 and 0.3 during 1965-2002.

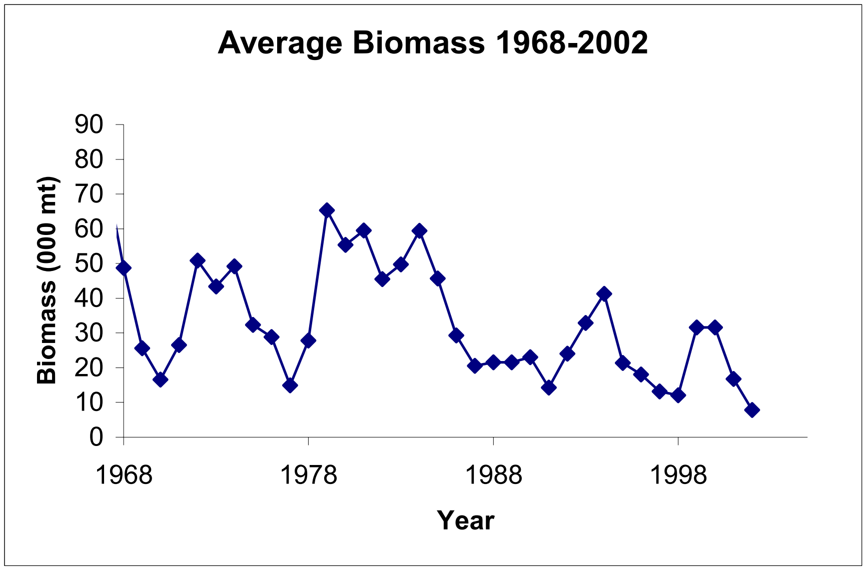


Figure B36. Average biomass of butterfish during 1968-2002.

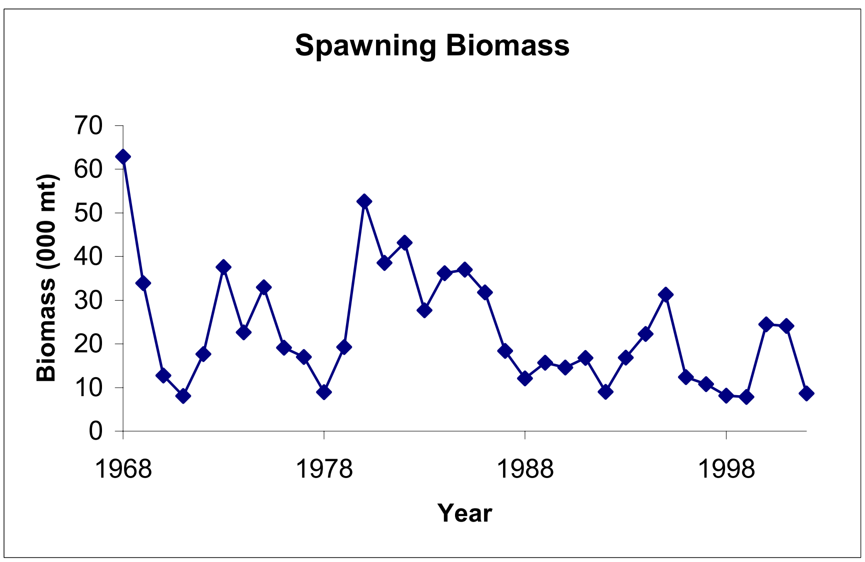


Figure B37. Spawning biomass of butterfish during 1968-2002

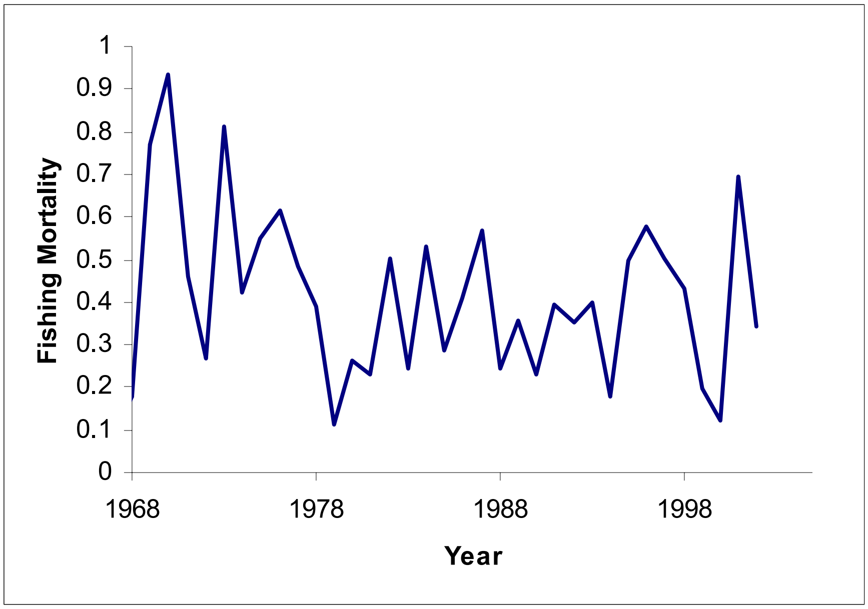


Figure B38. Fishing mortality rates on the butterfish stock during 1968-2002.

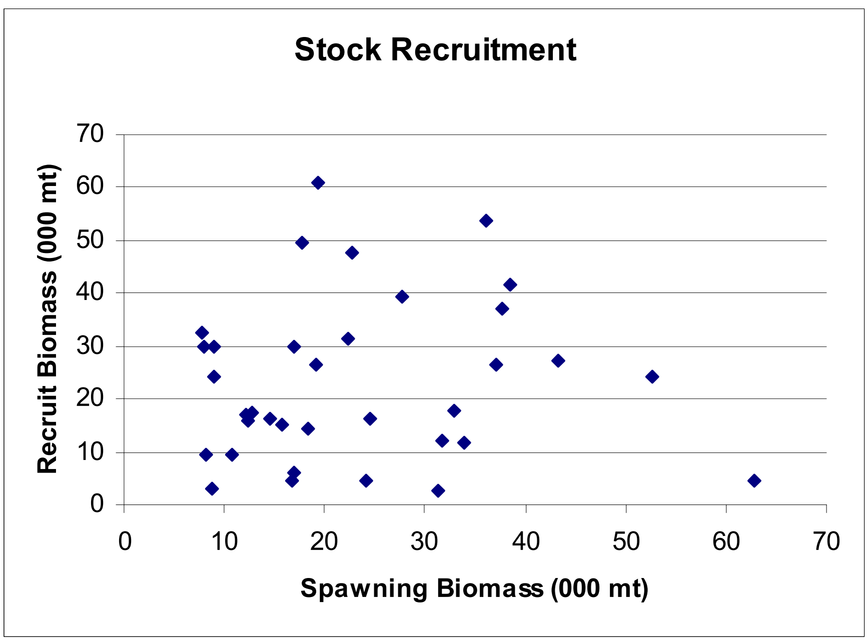


Figure B39. Spawning stock biomass and recruitment biomass (000's t) during 1968-2002.

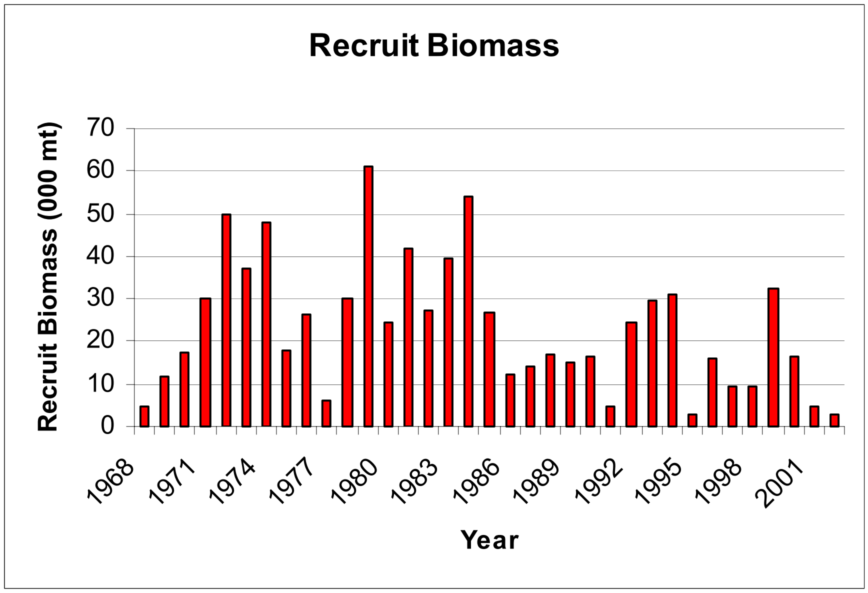


Figure B40. Recruit biomass of butterfish during 1968-2002.

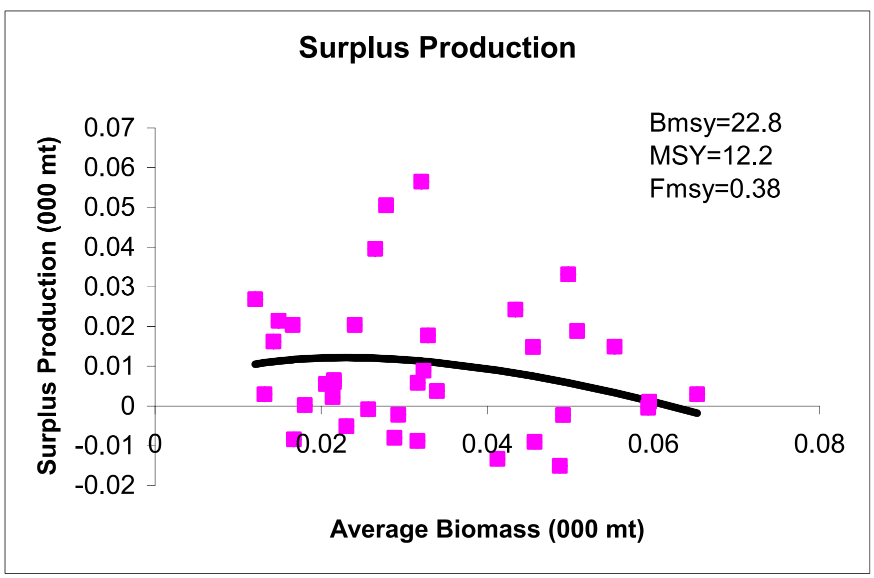


Figure B41. Average biomass and surplus production for butterfish during 1968-2002.

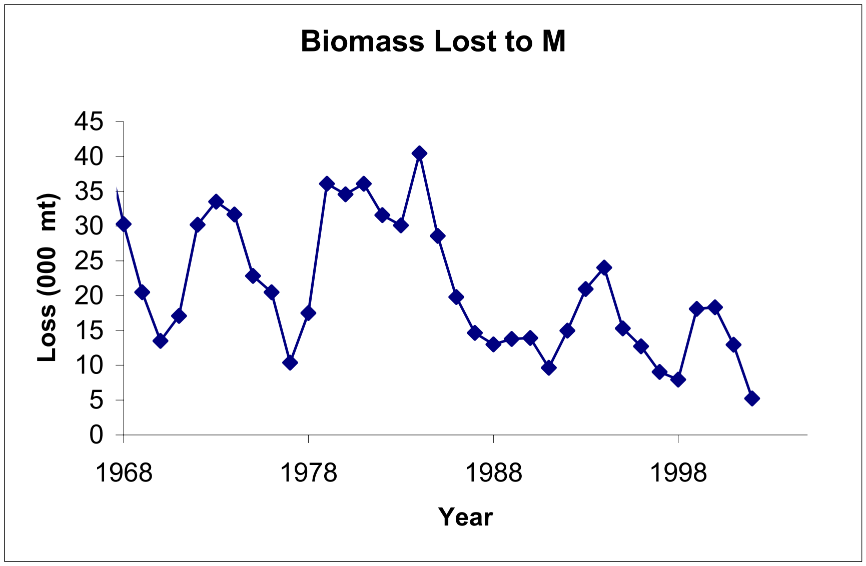


Figure B42. Biomass lost to natural mortality, all sources, during 1968-2002.

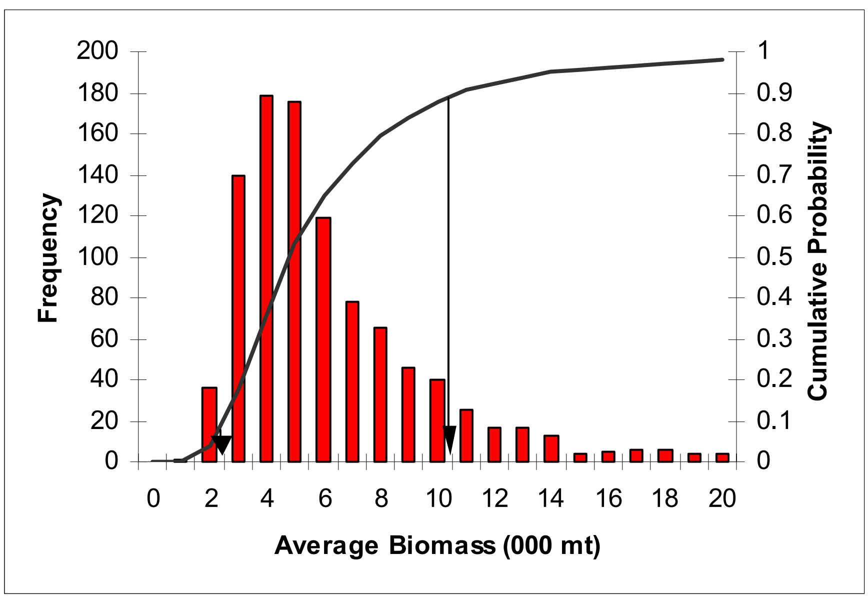


Figure B43. Estimates of precision and 80% CI of average biomass in 2002.

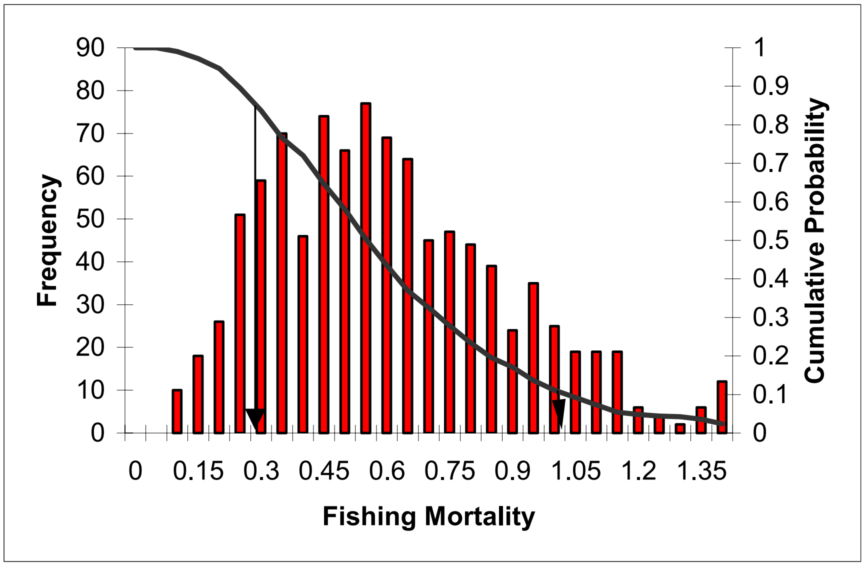


Figure B44. Estimates of precision and 80 % CI of Fishing Mortality I.

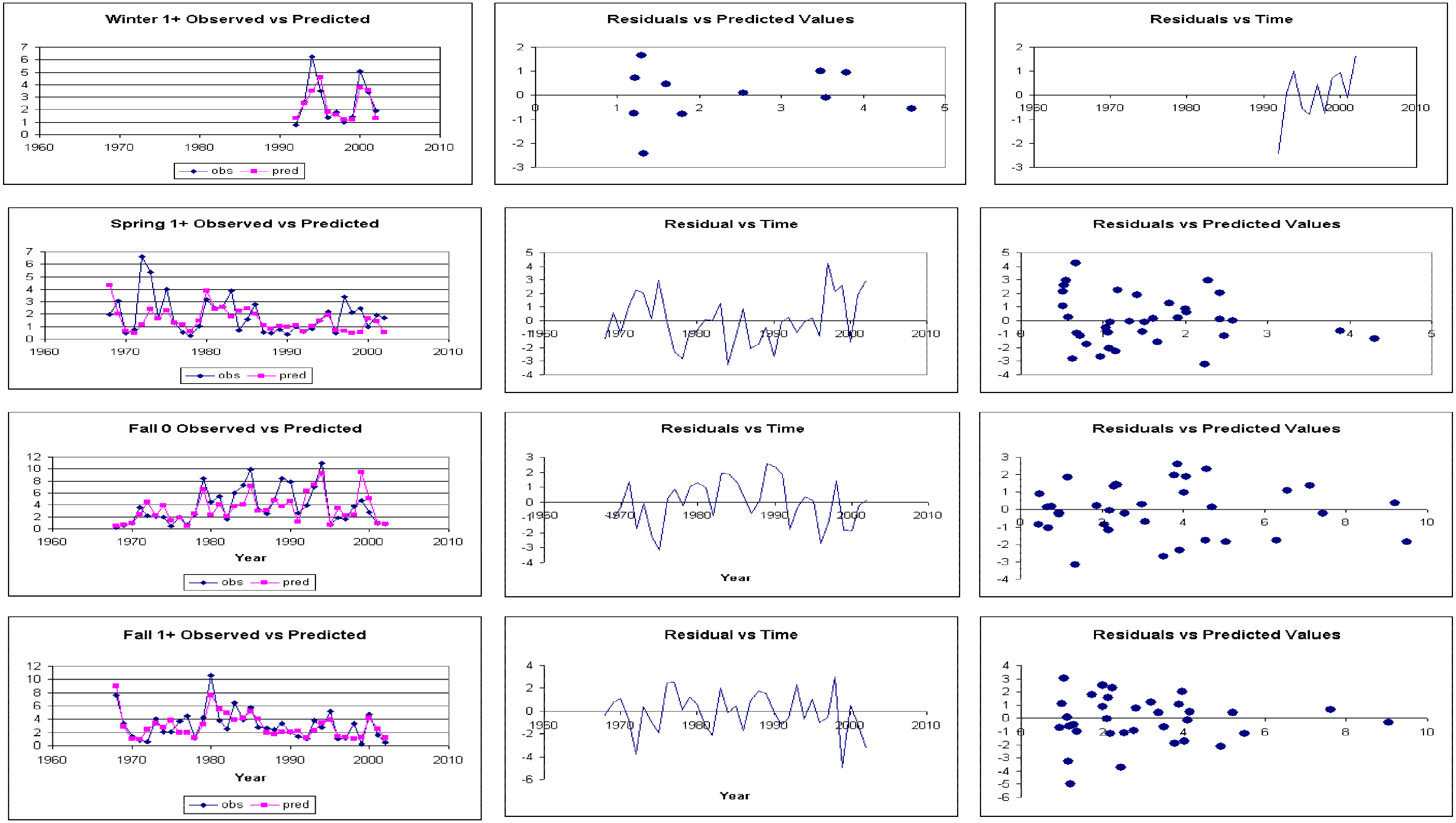


Figure B45. Plots of observed vs. predicted, residual vs. time, and residuals vs. predicted for winter 1+, spring 1+, and fall 0 and 1+ during 1968-2002.

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Currently, there are three such media:

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