A: OCEAN QUAHOG

TERMS OF REFERENCE

The following Terms of Reference were addressed:

1) Characterize fishery performance since the last assessment.

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

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

4) Evaluate stock status relative to current reference points.

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

EXECUTIVE SUMMARY

Fishery performance

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

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

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

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

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

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

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

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

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

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

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

Ocean quahog surveys and dredge efficiency

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

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

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

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

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

- In addition to the depletion experiments, data from fixed stations that are resampled during each survey by the DE-II were used to infer whether dredge efficiency changed from survey to survey. This analysis suggested that dredge efficiency was lower in 1999 than in 1997. It also suggested that dredge efficiency had not changed from 1999 to 2002.

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

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

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

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

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

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

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

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

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

Stock biomass and fishing mortality

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

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

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

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

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

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

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

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

Stock status relative to current reference points

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

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

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

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

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

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

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

INTRODUCTION

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

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

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

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

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

Surveys of the stock from Georges Bank to S. Virginia/N. Carolina are conducted every 2-3 years by NMFS with the *R/V Delaware II* (DE-II). The clam dredge has a submersible hydraulic pump which shoots water into the bottom to loosen the clams from the substrate. In 1997, bottom contact sensors were used on the survey dredge for the first time to get a direct estimate of tow length. In previous surveys, tow length was estimated by doppler distance readings of the vessel's movement over bottom during the 5-min tow. The sensor data provide a better estimate of tow distance and of minimum swept-area biomass (NEFSC 1998, 2000a,b, 2003; Weinberg et al. 2002). The sensors used at sea and the data collected with them are described in previous reports (NEFSC 1998a, 1998c, 2000a,b, 2003).

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

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

FISHERY DATA

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

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

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

MidAtlantic: Landings and Fishing Effort

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

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

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

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

MidAtlantic: Landings per unit Effort (LPUE)

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

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

Maps of LPUE by TNMS for large vessels (Fig. A9) suggest that 1)in some TNMSs in DMV, catch rates were very high in 1985, but declined after that and have remained low through 2002, a time span of almost 20 years, 2)declines in catch rates, similar to those in DMV, took place in the NJ region over time, 3)there were very high catch rates in 1991 in the inshore Long Island region, but by 1997 those rates declined and have remained at the lower level through 2002, 4)the highest catch rates in 2002 took place in deep waters (offshore) of the Long Island region.

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

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

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

An additional analysis was done to determine how the commercial LPUE was changing over time in each region, as reflected by catch rates within TNMSs that were being fished in each year. Figures A14-A17 show the probability density function (pdf) of catch rates by TNMS within each year/region combination. Bins on the x-axis correspond to 3 levels of commercial catch rate (bushels/hr) that can be interpreted in terms of profitability to the industry: Catch rates in bin 1 are not profitable. Catch rates in bin 2 are marginal. Catch rates in bin 3 are profitable. For each region (DMV, NJ, LI, SNE), the plots indicate a general trend toward lower LPUE over time.

Maine's Ocean Quahog Fishery

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

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

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

Size Composition of Landings by Region

Length frequency distributions for ocean quahogs landed between 1982 and 2003 are presented for the Delmarva, New Jersey, Long Island, and S. New England regions in Figures A22 – A25, respectively. The data are summarized in Table A6. Between 1982 and 2003, average length of clams landed from New Jersey (approximately 90 mm - 95 mm) was greater than that from other regions (typically 80 mm - 90 mm; Table A6). Mean length of clams landed from the New Jersey region has remained relatively steady. Mean length of clams landed from the Delmarva region decreased steadily from 92.5 mm in 1994 to 83 mm in 1999, but increased in 2002 and 2003. Although mean shell size from the S. New England landings declined in 1997 and 1998, this was due to targeting of specific beds with high meat yield, and does not represent a shift in mean shell size of the exploited stock throughout that region. In the LI region, mean length harvested declined by almost a centimeter, from 89 mm in 1997-1998 to about 81 mm in 2002-2003 (Table A6, Fig. A24).

RESEARCH SURVEYS

History of Changes Made to NMFS Clam Survey Gear

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

Sensor data (1997, 1999, 2002)

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

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

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

Sensors for calculation of tow distance

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

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

Dredge Calibration

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

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

Analytical Models

Dr. Paul Rago (NEFSC) developed a model for estimating dredge efficiency that explicitly consider spatial overlap of tows as a depletion experiment progresses (described in NEFSC, 1998a, 2000a, 2003, and Rago *et. al*. submitted). This model was used in two previous ocean quahog stock assessments (NEFSC, 1998a, 2000a) to obtain efficiency estimates from commercial clam dredges as well as for the NMFS clam dredge on the DE-II (Table A9).

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

2002 Calibration Experiments and Results

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

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

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:

$$b_{r,y} = \bar{c}_{r,y}\Omega_r$$

where $\bar{c}_{r,y}y$ was the survey trend value (stratified mean kg/tow, adjusted to the standard 0.15 nmi tow distance based on doppler distance measurements) and Ω_r was the region-specific scaling factor. Region-specific scaling factors were:

$$\Omega_r = \frac{A'_r u}{\bar{r}a'\bar{e}}$$

where $\bar{e}$ is the average efficiency estimate for ocean quahog during 1997-2002 (Table A17), and $\bar{r} = d_s / d_d$ is the average ratio of sensor and doppler distance measurements for individual tows in surveys during 1997-2002 (Table A20). Survey trend data ($\bar{c}_{r,y}$) were already standardized in the database to a 0.15 nm tow based on Doppler distance data so that the product $\bar{r}a'$ 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:

---

[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.

Recruitment modeling in KLAMZ

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

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

Equilibrium initial biomass

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

“VPA”

KLAMZ model output for ocean quahog shows results from the simple “VPA” model used by NEFSC (1998) to estimate pristine biomass in 1976. NEFSC (1998) used one set of VPA calculations for the entire stock, but VPA calculations in this assessment were for each region in this assessment. Moreover, NEFSC (1998) focused on the estimate of pristine biomass but trends in VPA biomass are presented in this assessment as well. VPA calculations had no effect on KLAMZ model results.

Model scenarios

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

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

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

KLAMZ Model Results

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

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

---

[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.

Biological condition of the stock

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.

REFERENCES

Dahlgren, T, J. Weinberg, and K. Halanych. 2000. Phylogeography of the ocean quahog (*Arctica islandica*): influences of paleoclimate on genetic diversity and species range. Mar. Bio. 137: 487-495.

Deming, W. E. 1960. Sample design in business research. Wiley and Sons, NY. 517 pp.

Fritz, L. 1991. Seasonal change, morphometrics, growth and sex ratio of the ocean quahog, *Arctica islandica* (Linneaus, 1767) off New Jersey, U.S.A. J. Shellf. Res. 10(1): 79-88.

Gabriel, W. L., M. P. Sissenwine, and W. J. Overholtz. 1989. Analysis of spawning stock biomass per recruit: an example for Georges Bank haddock. N. Amer. J. Fisheries Man. 9: 383-391.

Jones, D. S. 1983. Sclerochronolgy: Reading the record of the molluscan shell. Amer. Scient. 71: 384-391.

Lewis, C., J. Weinberg, and C. Davis. 2001. Population structure and recruitment of *Arctica islandica* (Bivalvia) on Georges Bank from 1980-1999. J. Shellfish Res. 20: 1135-1144.

MAFMC (Mid-Atlantic Fishery Management Council). 1998. Amendment 12 to the Atlantic surfclam and ocean quahog fishery management plan. Mid-Atlantic Fishery Management Council. Dover, DE. 254 pp.

Maine Department Natural Resources. 2003. Gulf of Maine ocean quahog (Arctica islandica) assessment. Completion report. S. Feindel and D. Schick.

Murawski SA, Serchuk FM (1989) Mechanized shellfish harvesting and its management: the offshore clam fishery of the eastern United States. In: Caddy JF (ed.) Marine Invertebrate Fisheries: Their Assessment and Management. Wiley, New York, pp. 479-506.

Murawski, S.A. and F.M. Serchuk. 1979. Shell length - meat weight relationships of ocean quahogs, *Arctica islandica*, from the middle Atlantic shelf. Nat. Shellf. Assoc. 69: 40-46.

Murawski, S.A. J.W. Ropes, and F.M. Serchuk. 1982. Growth of the ocean quahog, *Arctica islandica*, in the middle Atlantic Bight. Fish. Bull. 80: 21-34.

Myer T.L., R. A. Cooper, and K. J. Pecci (1981) The performance and environmental effects of a hydraulic clam dredge. Mar. Fish. Rev. 43(9): 14-22.

NEFSC (Northeast Fisheries Science Center). 1995) Report of the 19th Northeast Regional Stock Assessment Workshop (19th SAW). D. Ocean quahog assessment. pp 177-199. NEFSC Ref. Doc. 95-08.

NEFSC (Northeast Fisheries Science Center). 1996a. 22nd Northeast Regional Stock Assessment Workshop (22th SAW). D. Surfclam and Ocean quahog. pp. 173-242. NEFSC Ref. Doc. 96-13.

NEFSC (Northeast Fisheries Science Center). 1996b. 22nd Northeast Regional Stock Assessment Workshop (22th SAW), Public Review Workshop. D. Surfclam and Ocean Quahog Advisory Report. pp. 33-37. NEFSC Ref. Doc. 96-16.

NEFSC (Northeast Fisheries Science Center). 1998a. 27th Northeast Regional Stock Assessment Workshop (27th SAW). Concensus summary of assessments. E. Ocean Quahogs. pp 171-244. NEFSC Ref. Doc. 98-15.

NEFSC (Northeast Fisheries Science Center). 1998b. 27th Northeast Regional Stock Assessment Workshop (27th SAW). Advisory Report on Stock Status. E. Ocean Quahogs. pp. 26-36. NEFSC Ref. Doc. 98-14.

NEFSC (Northeast Fisheries Science Center). 1998c. 26th Northeast Regional Stock Assessment Workshop (26th SAW). B. Surfclam assessment. pp. 51-169. NEFSC Ref. Doc. 98-03.

NEFSC (Northeast Fisheries Science Center). 2000a. 31st Northeast Regional Stock Assessment Workshop (31st SAW). C: Ocean quahog. pp.172-304. NEFSC Ref. Doc. 00-15.

NEFSC (Northeast Fisheries Science Center). 2000b. 31st Northeast Regional Stock Assessment Workshop (31st SAW). Advisory Report on Stock Status.C. Ocean Quahog Advisory Report. pp. 24-32. NEFSC Ref. Doc. 00-14.

NEFSC (Northeast Fisheries Science Center). 2000c. 30th Northeast Regional Stock Assessment Workshop (30th SAW). E. Surfclams. pp. 311-477. NEFSC Ref. Doc. 00-03.

NEFSC (Northeast Fisheries Science Center). 2003. 37th Northeast Regional Stock Assessment Workshop (37th SAW). C. Atlantic Surfclam. pp.284-433. NEFSC Ref. Doc. 03-16.

Powell, E. and R. Mann. (in prep.) Evidence of recent recruitment in the ocean quahog *Arctica islandica* in the Mid-Atlantic Bight.

Rago, P., J. R. Weinberg, and C. Weidman. (submitted). A spatial model to estimate gear efficiency and animal density from depletion experiments.

Ropes, J.W. and G. R. Shepherd. (1988) Age determination methods for northwest Atlantic species. USDOC. NOAA Tech. Rept. NMFS 72.

Ropes, J.W., S.A. Murawski, and F.M. Serchuk. 1984. Size, age, sexual maturity, and sex ratio in ocean quahogs, *Arctica islandica* Linne, off Long Island, New York. Fish. Bull. 82: 253-267.

Schnute, J. 1985. A general theory for analysis of catch and effort data. Can. J. Fish. Aquat. Sci. 42: 414-429.

Serchuk, F.M. and S. Murawski. 1980. Assessment and status of surf clam *Spisula solidissima* (Dillwyn) populations in offshore middle Atlantic waters of the United States. US DOC/NMFS. Lab. Ref. Doc. 80-33.

Serchuk F. and S. Murawski 1997. The offshore molluscan resources of the Northeastern Coast of the United States: surfclams, ocean quahogs, and sea scallops, pp. 45-62. IN: C.L. MacKenzie, Jr., V.G. Burrell, Jr., A. Rosenfield and W.L. Hobart (Eds). The History, Present Condition, and Future of the Molluscan Fisheries of North and Central America and Europe, Volume 1, Atlantic and Gulf Coasts. U.S. Dep. Commer., NOAA Tech. Rep. 127, 234 p.

Smolowitz, R. J. and V. E. Nulk. 1982. The design of an electrohydraulic dredge for clam surveys. Mar. Fish. Rev. 44(4):1-18.

Steingrimsson S.A. and G.Thorarinsdottir. 1995. Age structure, growth and size at sexual maturity in ocean quahog *Arctica islandica* (Mollusca: Bivalvia), off NW - Iceland. ICES CM 1995/K:54.

Theroux R. B. and R. L. Wigley 1983. Distribution and abundance of east coast bivalve mollusks based on specimens in the National Marine fisheries Service Woods Hole collection. U.S. NOAA Tech. Rep. NMFS SSRF768: 172 p.

Thompson, I., D.S. Jones, and D. Dreibelbis. 1980a. Annual internal growth banding and life history of the ocean quahog *Arctica islandica* (Mollusca: Bivalvia). Mar. Biol. 57: 25-34.

Thompson, I., D.S. Jones, and J.W. Ropes. 1980b. Advanced age for sexual maturity in the ocean quahog *Arctica islandica* (Mollusca: Bivalvia). Mar. Biol. 57: 35-39.

Thorarinsdottir, G.G. and S. Tr. Einarsson 1996. Distribution, abundance, population structure and meat yield of the ocean quahog, *Arctica islandica*, in Icelandic waters. J. Mar. Biol. Assoc. U. K. 76: 1107-1114.

Weinberg, J. R., P. Rago, W. Wakefield, and C. Keith. 2002. Estimation of tow distance and spatial heterogeneity using data from inclinometer sensors: an example using a clam survey dredge. Fisheries Res. 55:49-61.

West, C. W. and J. R. Wallace. 2000. Measurements of distance fished during the trawl retrieval period. ICES Ann. Sci. Conference. Bruges, Belgium, Sept. 2000. Incorporation of external factors in marine resource surveys. ICES CM 2000/K:37, 14 p.

ACKNOWLEDGMENTS

This assessment was supported in diverse ways by many individuals and groups. We gratefully acknowledge: Captain and crew of the *R/V Delaware II,* NEFSC Invertebrate (Clam) Working Group, NEFSC staff - Chris Pickett, Paul Rago, Victor Nordahl, Paul Kostovick, Blanche Jackson, David Hiltz, Joan Palmer, Charles Keith, John Galbraith, and Russ Brown, Tom Hoff, MAFMC, Scott McEntire, NOAA, Survey Unit and Fishery Biology Investigation (NEFSC). Contributors to research, sensor package and funding of commercial vessels: Capt. Joe Karsh, Mate Bryon Salmonn, Bob Walton, and Steve Kaukman, (FV Jersey Girl); Blount Seafood - Todd Blount, Cape May Foods - Dan LaVecchia, Doxsee Sea Clam Co. - Bob Doxsee, Eastern Shore Seafood - Rick Myers, Fair Tide Shellfish - Tom Slaughter, Galilean Seafood - Jerry Montopoli, J. H. Miles - Jack Miles, Point Pleasant Packing - Dan Cohen, Surfside Seafood - Pete LaMonica, Sea Watch - Bob Brennen, Snows/Doxsee - Steve Kowalski, Barney Truex, Martin Truex, Vern Conway, Jim Meyers, Tom Alspach, John Kelleher, Dave Wallace, John Womack, Norman Pennypacker, Ed Plat, Capt., Jeff Shell, Mate, John Kelleher, operator and crew (FV Lisa Kim); Rob Jarmol, Capt., Elwood Wilkins, Mate, Lesley Rohn, and Jack Miles, owner (FV Christy); Eric Powell, Kathryn Alcox, Allison Bonner, and Bruce Muller (Rutgers Univ.) Roger Mann, VIMS, Peter Kingsley-Smith, Juliana Harding, and Melissa Southworth.