A. ASSESSMENT OF OCEAN QUAHOGS [1]

1.0 TERMS OF REFERENCE (TOR)

1. Characterize the commercial and recreational catch including landings and discards.

Completed--Commercial landings were updated through 2005. Discards are negligible. However, a 5% allowance for incidental mortality due to contact with fishing gear is used in all assessment calculations.

2. Estimate fishing mortality, spawning stock biomass, and total stock biomass for the current year and characterize the uncertainty of those estimates. If possible, also include estimates for earlier years.

Completed--Fishing mortality, fishable and total stock biomass were estimated for 1978-2005. Confidence intervals were calculated to characterize uncertainty. Spawning biomass was calculated on an approximate basis after the SARC based on reviewers' suggestions.

3. Either update or re-estimate biological reference points (BRPs; proxies for B_{MSY} and F_{MSY}), as appropriate. Comment on the scientific adequacy of existing and redefined BRPs.

Partially completed—Biomass reference points B_{1978} (a proxy for virgin biomass), the management target $B_{MSY}=1/2\ B_{1978}$ and the management threshold $B_{Threshold}=1/4\ B_{1978}$ were updated based on new information. Fishing mortality reference points ($F_{Target}=F_{0.1}$ and $F_{Threshold}=F_{25\%}$) were updated using new information about fishery selectivity and maturity in a length based per recruit model. Problems with the scientific adequacy of the current existing $F_{Threshold}$ proxy for F_{MSY} are described. However, there was insufficient time to complete analyses required to recommend an optimum alternative. This work was deferred because fishing mortality rates are very low and there was no urgency.

4. Evaluate current stock status with respect to the existing BRPs, as well as with respect to new or re-estimated BRPs (from TOR 3).

Completed—Stock biomass and fishing mortality estimates for 2005 were compared to updated reference points.

5. Recommend what modeling approaches and data should be used for conducting single and multi-year stock projections, and for computing TACs or TALs.

Completed—A simple modeling approach and data were recommended for projecting biomass and fishing mortality of the ocean quahog stock through 2010.

[1] This assessment was prepared by the Invertebrate Subcommittee. Contributing members are listed in INTRODUCTION TO SAW-44 ASSESSMENT REPORT.

6. If possible,

    a) provide numerical examples of short term projections (2-3 years) of biomass and fishing mortality rate, and characterize their uncertainty, under various TAC/F strategies and

    b) compare projected stock status to existing rebuilding schedules as appropriate.

Completed—Example calculations and projections through 2010 were carried out assuming three quota levels and at $F=F_{0.1}$.

7. Review, evaluate and report on the status of the SARC/Working Group Research Recommendations offered in recent SARC-reviewed assessments.

Completed—Several key research recommendations were accomplished in this assessment. In particular: 1) a survey was completed, reference points were calculated and biomass and fishing mortality were estimated for ocean quahog in Maine waters; 2) field data collected during 2002 and new data collected during 2005 were examined to determine if survey and commercial dredge efficiency depends on depth, sediment type or clam density; 3) survey selectivity and fishery selectivity curves were used to better interpret survey data; and 4) reference points were revised in this assessment using a new length based model and new fishery selectivity and maturity at length curves.

2.0 EXECUTIVE SUMMARY

A) This assessment for ocean quahog in the US EEZ is based on fishery data landings and LPUE data for 1978-2005 and NEFSC survey data for 1982-2005. Based on assessment results, the ocean quahog population is a relatively unproductive stock which is being fished down slowly towards its B_{MSY} reference point (½ virgin biomass, estimated as 50% of biomass during 1978) gradually after about three decades of relatively low fishing mortality.

B) Ocean quahog in the US EEZ are not overfished and overfishing is not occurring. Stock biomass during 2005 was 3.039 million mt and above the revised management target of ½ virgin biomass = 1.987 million mt. The fishing mortality rate during 2005 for the exploitable region (all areas but GBK) was $F= 0.0077$ y^{-1} and below the revised management target level $F_{0.1} = 0.0278$ y^{-1}.

C) Depletion experiments carried out during 1997-2005 on a cooperative basis with the fishing industry were used to estimate the efficiency of the NEFSC survey dredge, which is the basis for estimating biomass and fishing mortality. Based on all experiments to date, the NEFSC survey dredge has a capture efficiency of 16.5%, which is less than values used in the earlier assessments ($e = 0.269$ in SARC38, and 0.346 in SARC31).

D) Biomass and fishing mortality estimates were improved in this assessment using new information about size selectivity of survey and commercial clam dredges.

E) The estimates of biomass and fishing mortality in this assessment do not include biomass or landings from Maine waters. However, stock biomass is small (~1%) relative to the rest of the EEZ and calculations would not change appreciably if Maine were included. As described below, the Maine fishery and stock component were assessed separately (Russell 2006). Highlights from the Maine assessment are presented here but interested persons should consult the Maine stock assessment report.

F) Biological reference points based on per recruit models ($F_{0.1}$ and $F_{25\%}$) were recalculated based on new length based per recruit model, and new fishery selectivity and maturity curves (see below).

Reference Point	Old (SARC-38)	New
$F_{0.1}$ (target)	0.0275	0.0278
F_{MAX}	0.1810	0.0760
$F_{25\%}$ (threshold)	0.0800	0.0517
$F_{50\%}$	0.0200	0.0180

G) From a technical perspective, the current threshold reference point for fishing mortality $F_{25\%}$=0.0517 y^{-1} is a poor proxy for F_{MSY} in a long-lived species like ocean quahog with natural mortality rate M=0.02 y^{-1}.

H) Proxies for virgin biomass and B_{MSY} in this assessment are substantially larger than in NEFSC (2003). In particular, the revised proxy in this assessment for B_{MSY} (½ virgin biomass) was 1.987 million mt compared to 1.5 million mt for B_{MSY} in the last assessment. The new estimates are different primarily because revised survey dredge efficiency estimates are smaller (e=0.165 instead of 0.269-0.346).

I) Biomass during 2005 was 76% of biomass during 1978 for the entire stock and 66% for the entire stock less GBK

J) Fishery LPUE, survey trends and assessment model estimates show substantial declines in stock biomass in southern regions (SVA, DMV and NJ) where the fishery has been continually active. In particular, biomass during 2005 was 5%, 34% and 44% of biomass during 1978 for SVA, DMV and NJ. Biomass trends in northern regions which did not support the fishery until recently (LI, SNE and GBK) are relatively flat and stable. Biomass during 2005 was 94%, 75% and 100% of biomass during 1978 for LI, SNE and GBK.

K) An increasingly large fraction of the stock (83% during 2005 compared to 70% during 1978) is in northern regions (LI, SNE) where fishing is relatively recent and in the GBK region, which is not fished due to risk of PSP contamination.

L) Fishing mortality rates for southern areas where the fishery has been continually active (SVA, DMV and NJ) peaked in the late 1980's and early 1990's then declined as fishing effort shifted towards the north. Fishing mortality rates in northern areas were nearly zero before 1990 and increased substantially afterwards as fishing effort shifted towards the north. Fishing mortality rates for the entire stock increased from near zero in 1978 to average about 0.006 y^{-1} (0.010 y^{-1} for the entire stock less GBK) during early 1990 through 2005.

M) Recruitment events appear to be regional and sporadic (i.e. often separated by decades). Survey length composition data show that recruitment occurs throughout the resource sporadically and at an apparently low rate. Based on survey length composition data and published studies, at least some recent recruitment (small ocean quahog) is evident in DMV, NJ, LI, SNE and GBK during recent years. The potential contribution of recent recruitment to stock biomass and productivity is unknown.

Maine waters

N) Ocean quahog in Maine waters are part of the unit stock covered by the FMP and support a small fishery that is managed under limited entry and quota systems that are separate from the individual transferable quota (ITQ) system used for ocean quahog in the rest of the EEZ.

O) The fishery and biological characteristics of ocean quahog in Maine waters are unique. In particular, the Maine fishery targets small ocean quahog for sale on the half shell market at prices roughly ten times the prices paid for larger ocean quahogs taken elsewhere in the EEZ. Management goals have for ocean quahog in Maine waters have not been described.

P) A survey and stock assessment were completed by the State of Maine for the portion of the ocean quahog stock occupying the major fishing grounds in Maine waters (Russell 2006). Most of the results presented here for the Maine fishery are from Russell (2006).

Q) Assessment results for Maine show relatively high levels of fishing effort and landings in recent years. LPUE levels have declined since the peak in 2002, but remain at relatively high levels overall.

R) Based on a per recruit model analysis, F_{MAX} = 0.0561, $F_{0.1}$ = 0.0247 and $F_{50\%}$ = 0.013 y^{-1} for ocean quahog in the major fishing grounds of Maine waters only. These reference points are provided only for comparison and do not have any special status as targets or thresholds.

S) Based on survey results and dredge efficiency estimates for Maine, the biomass of ocean quahog during 2005 that was available to the fishery in Maine waters was

22,493 mt meats. In comparison, catch (landings plus a 5% incidental mortality allowance) during 2005 was 505 mt meats.

T) Fishing mortality during 2005 in the areas surveyed and the principal fishing grounds in Maine waters was estimated to be $F = 505 \div 22{,}493 = 0.022\ y^{-1}$, which is almost equal to $F_{0.1} = 0.0247\ y^{-1}$, a reference point that would provide relatively high levels of yield while preserving some spawning stock.

3.0 INTRODUCTION

Ocean quahog (*Arctica islandica*) in the US Exclusive Economic Zone (EEZ) form a single stock for management purposes. With the exception of a relatively small component off the coast of Maine, the EEZ fishery is managed by under a single individual transferable quota (ITQ) system that was established for ocean quahog and Atlantic surfclam (*Spisula sodidissma*) in 1990. Murawski and Serchuk (1989) and Serchuk and Murawski (1997) provide detailed information about the history and operation of the fishery.

The ocean quahog fishery component off Maine is managed under a relatively small quota that is separate from the quota used to manage the ITQ fishery. The Maine component is of interest because of differences in biological, fishery, market and management characteristics. The ocean quahog assessment this year consists of two reports. The first (Russell 2006) estimates biomass, fishing mortality and per recruit reference points for the stock component in Maine waters based on a survey in 2005 and estimates of survey dredge efficiency. The second (this report) deals with the EEZ as a whole based on the NEFSC clam survey for 1982-2005 and summarized key aspects of the assessment for Maine waters.

Overfishing definitions and other management measures apply at the level of the entire stock although technical information is provided at the level of smaller stock assessment regions (Figure A1 and see below). Georges Bank (GBK) has been closed to ocean quahog harvesting since 1990 when Paralytic Shellfish Poison (PSP) was detected.

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

Categories and units used in this assessment are defined below.

Unit	Equivalent
Industry or Mid-Atlantic bushel (Industry bu)	1.88 ft^3
Maine (US standard) bushel (Maine bu)	1.2448 ft^3
Industry bushels x 10	Pounds meat wt
Industry bushels x 4.5359	Kilograms meat wt
Cage	32 Industry bushels
Vessel ton class 1	1-4 gross registered tons (GRT)
Vessel ton class 2	2-50 GRT
Vessel ton class 3	51-150 GRT
Vessel ton class 4	151-500 GRT
Vessel ton class 5	501-1000 GRT

Previous and current assessments

Stock assessments for ocean quahog in the EEZ were completed by NEFSC (1995; 1998; 2000; 2004). The last assessment (NEFSC 2004) concluded that the EEZ ocean quahog resource was not overfished and that overfishing was not occurring. This stock assessment arrives at the same conclusion.

The last assessment (NEFSC 2004) concluded that the qualitative condition of the stock off the coast of Maine was unknown and recommended that the Maine conduct a comprehensive survey and conduct experiments to estimate survey dredge efficiency. These recommendations were completed in this assessment and are presented in a separate report (Russell 2006).

Biological characteristics[2]

Ocean quahog are 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). They are found at depths of 10-400 m, depending on latitude (Theroux and Wigley 1983; Thompson et al. 1980). The US stock is almost completely within the EEZ outside of state waters at depths of about 20-80 m. In a study of the mitochondrial cytochrome *b* gene, Dahlgren et al. (2000) did not find geographical differentiation between samples taken along the US coast from Maine to Virginia.

Ocean quahog are long-lived with some individuals aged at over 200 yrs (Jones 1983; Steingrimsson and Thorarinsdottir, 1995). Early studies of populations off New Jersey and Long Island (Thompson et al. 1980; Murawski et al. 1982) demonstrate that clams ranging in age from 50-100 years are common. In stock assessment work, adult ocean quahog are assumed to die from natural causes at the rate of about 2% annually (instantaneous rate of natural mortality M=0.02 y^{-1}).

Ocean quahog grow slowly after the first years of life (Lewis et al. 2001, Figure A56). Maximum size is typically about 110 mm in shell length (SL) although larger specimens are common. Individuals large enough to recruit to the fishery grow only 0.51-0.77% per year in meat weight and < 1 mm per year in shell length (NEFSC 2004).

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 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. 1980; Ropes et al. 1984).

[2] See Cargnelli et al. (1999) for additional information.

Females are more common than males among the oldest and largest individuals in the population (Ropes et al. 1984; Fritz 1991). Recruitment events are regional and infrequent in ocean quahog with decadal periods of little or no recruitment (Powell and Mann 2005).

4.0 COMMERCIAL AND RECREATIONAL CATCH (TOR-1)

Landings and quotas for the ITQ segment of the EEZ fishery are reported in different bushel units than landings and quotas for the fishery off Maine (Russell 2006). In particular, "ITQ" bushels are used for the ITQ component and "standard" bushels are used for the Maine component. Biomass and landings from both fishery components are reported in this assessment as meat weights (the weight of marketable product after removal from the shell), unless otherwise noted, because meat weights are directly comparable.

Total EEZ landings (including the ITQ and Maine fishery components) were relatively high during 1987-1996 with a peak of 22.5 thousand mt meats (Tables A1-A2 and Figure A2) or 4.9 million ITQ bushels (Table A3) during 1992. After 1996, landings declined to a low of about 15,000 mt meats (3.3 million ITQ bushels) during 2000 and then increased to about 19,000 mt meats (4.2 million ITQ bushels) during 2003. Landings declined after 2003 to about 14,000 mt meats (3.2 million ITQ bushels) during 2005, which was the lowest level since 1981. Industry sources report that low landings during the most recent years were due to low market demand. The ITQ component accounted for almost all (≥98%) of total EEZ landings during 1990-2005. Landings from Maine waters are minor in comparison to EEZ landings (Tables A2-A3 and Figure A2).

Landings from Maine waters increased steadily after 1990 to relatively high levels (≥ 326 thousand mt meats annually) during 2000-2003 (Tables A2-A3). Landings in Maine waters decreased after 2003 to 294 thousand mt meats during 2005, which was the lowest level since 1999.

Landings by the ITQ component averaged 85% of the EEZ quota during 1990-2005 (Table A1). In contrast, the 100,000 Maine bushel quota allocated for ocean quahog in Maine waters was usually exhausted during 1999-2005 with vessels leasing ITQ shares in some years to harvest more than 100,000 mt meats from Maine waters (Tables A2-A3).

Landings of quahogs from state waters outside of Maine are near zero because ocean quahog are found offshore in relatively deep water. Landings in recreational fisheries are nil because commercial clam dredges are required to harvest ocean quahog and because ocean quahog are an industrial product with no recreational value.

4.1 Prices

Nominal exvessel prices for ITQ ocean quahog landings (expressed as dollars per ITQ bushel) decreased slightly during 2001-2004 (Table A4 and Figure A3). In real terms, prices during 2004 were about the average of real prices during 1994-2004. Prices for ocean quahog harvested in Maine waters (dollars per ITQ bushel) were roughly ten times higher than prices for ocean quahogs harvested in the rest of the EEZ (Table A4 and Figure A3).

4.2 Fishing effort

Total hours fished annually in the ITQ fishery component decreased from a peak of about 40,000 hr y^{-1} during 1991-1994 to about 30,000 hr y^{-1} during 1996-2004 and then decreased to about 20,000 hr y^{-1} during 2005 (Table A5 and Figure A4). The total number of trips in the ITQ fishery decreased steadily from about 3000 trip y^{-1} during 1991 to about 1000 trips y^{-1} during 2005 (Figure A5). In contrast, hours fished and trips increased in the Maine fishery component during 1991-2005. The number of active permits (vessels with landings) remained relatively constant during 1996-2004 but declined slightly during 2005 (Figure A6). Number of active permits, and fishing effort (hours fished and numbers of trips) is high in Maine waters relative to other stock assessment regions in the EEZ (Figure A4-A6).

4.3 Landings per unit effort (LPUE)

It is useful express trends in LPUE in terms of average catch rates for an actual vessel because industry sources report that fishing in the ITQ sector is profitable when LPUE is at least 110-120 bushels h^{-1} (D. Wallace, pers. comm.). The break-even LPUE reported in the last was assessment 80 bushels h^{-1} (NEFSC 2004). The new estimate is higher because of inflation, increased steaming time to relatively distant fishing grounds, operation of new larger vessels, and increased costs for food, fuel, insurance, etc. These estimates are not applicable to fishing in Maine waters.

LPUE (LPUE, bushels landed per hour fished) in the ocean quahog fishery may be a better measure of fishing success than a measure of stock abundance because changes in abundance or biomass for regions as a whole may be masked by concentration and movement of fishing effort between regions where ocean quahog density and catch rates are high (see below). In spite of these potential problems, LPUE and NEFSC clam survey data are highly correlated (see Section 5).

Trends in LPUE were not sensitive to the details of calculation (Table A6 and Figure A7). Three measures of LPUE were calculated for each stock assessment region based on vessel size classes 3-4 for the ITQ fishery and vessel size classes 1-2 for the Maine fishery. The size classes used in calculating LPUE accounted for almost all landings. "Nominal mean LPUE" was the average catch rates for individual trips in each region and year. "Total bushels/total hours" was the ratio of total landings and total hours fished. The "standardized index" for each region was calculated from the year effects estimated in a general linear model (described below).

General linear models (GLM) used to standardize LPUE data for ocean quahog were fit to trip-level log book data. A separate model was run for each stock assessment region because trends differed among regions. The dependent variable in GLM models was log LPUE (ITQ or Maine bushels per hour fished). There was no need to add a constant before taking logs because catch was greater than zero for all trips. The models included categorical year, month and vessel effects, which were statistically significant in every case. Other factors might have been included in GLM models but vessels and months were of special interest and other model formulations gave very similar trends in standardized LPUE.

The time series of standardized LPUE for each region was computed from the back-transformed year effects with adjustments so that the indices for each area were in units of LPUE for a single vessel that fished in each of the DMV, NJ, LI and SNE stock assessment regions. A different vessel was chosen for MNE.

GLM results show that standardized LPUE during 1985 declined in the DMV, NJ and LI stock assessment regions and fluctuated without trend in the SNE region (Table A6 and Figure A8). In the Maine fishery, standardized LPUE increased during 1991-2000, decreased afterwards but was still relatively high during 2005. Differences in trends among regions are discussed in detail below.

GLM results show that LPUE is slightly higher in the DMV, NJ, LI and SNE regions during February-April (Figure A9). LPUE in the Maine fishery peaks in June.

4.4 Spatial patterns in fishery data

Spatial patterns are important in interpreting fishery data and in managing fisheries for sessile and relatively unproductive organisms like ocean quahog. The ocean quahog stock is a complicated spatial mosaic with scattered productive and profitable fishing grounds where abundance is high and where fishing mortality tends to be concentrated. The size of productive fishing grounds for ocean quahog appears to be less than the size of ten minute squares (TNMS, 10' x 10' $\cong$ 100 nm^2), which are the smallest spatial strata consistently reported on logbooks and used in this stock assessment.

As described in NEFSC (2004), spatial patterns in cumulative landings, cumulative effort and LPUE are related. The spatial distribution of landings and fishing effort in the ITQ fishery component changed markedly over time. During the 1980s, nearly all of the landings (Figure A2) and fishing effort (Figure A4-A5) were from the southern DMV and NJ stock assessment regions. As LPUE declined in the southern DMV and NH stock assessment regions (Figure A8), fishing effort and landings shifted offshore and north to the LI and SNE stock assessment regions. During 2005, in particular, the southern DMV and NJ stock assessment regions accounted for less than 20% of landings and fishing effort while the bulk of landings and effort (outside of Maine waters) were from LI (Figures A2 and A4-A6).

<u>Fishery data by ten-minute square (TNMS)</u>

All vessels that fish for ocean quahog in the EEZ use logbooks to report landings and fishing effort by TNMS for each trip. TNMS are identified by six digit numbers. For example, TNMS 436523 is a ten-minute square that lies within the one-degree square with southeast corner at 43^o N and 65^o E. TNMS are formed by dividing one-degree squares further into six columns and six rows that are 10' wide. Columns are numbered 1-6 counting from west to east and the column number is given in the TNMS name before the row number. Rows are numbered 1-6 counting from north to south. Thus, TNMS 436523 is the ten-minute square whose southeast corner is at 43^o 30' N and 65^o 40' E.

Landings (Figure A10) during 1980-1990 were concentrated in relatively few TNMS that were primarily in the south and relatively inshore. Over time, TNMS with highest landings shifted offshore and north. Landings during 2001-2005 were concentrated in the LI stock assessment region.

Fishing effort (Figure A11) was concentrated in a few southern TNMS during 1980-1990 with three adjacent TNMS having effort levels higher than 1,000 h y^{-1} and appreciable fishing effort south of 38^o N. Fishing effort spread into additional offshore and northern TNMS during 1991-1995 and 1996-2000. After 1995, there were few or no TNMS with effort levels above 1000 h y^{-1}. During 2001-2005, there was a no fishing effort south of 38^o N.

LPUE (Figure A12) was relatively high inshore and south during 1980-1990 with ten TNMS that had LPUE $\geq$ 161 ITQ bushels h^{-1}. LPUE in the area below 40^{o} S was generally high. LPUE declined in the south and fishing effort spread northward during 1991-1995 where LPUE was relatively high. During 1996-2000, LPUE declined in both the northern and southern areas. By 2001-2005, LPUE was often $\leq$ 80 ITQ bushels h^{-1} below 40^{o} S.

Trends

Trends in landings and LPUE during 1980-2005 were plotted for individual TNMS that were important in the fishery (Figures A13-A15). Important TNMS were selected by sorting TNMS according to total landings during 1980-1990, 1991-1995, 1996-2000 and 2001-2005 and then selecting the top 20 TNMS during each time period. All of the TNMS selected in this manner were combined to form a single unique set of 79 TNMS that were important to the fishery at some time during 1980-2005.

Trends in LPUE for individual TNMS tend to be relatively high in during the first years of exploitation and then to subsequently decline as effort, annual landings and cumulative landings increase over time (Figures A13-A15). Decreasing trends in LPUE appear strongest in southern areas such as TNMS 377422 to 397326 with the longest history of exploitation. LPUE does not appear to increase in a TNMS once fishing effort decreases.

Unlike LPUE which is highest in the first years of exploitation, landings and fishing effort tend to peak after 5-10 years of exploitation while LPUE is still relatively high and then to decrease over a 5-10 y period as grounds are fished down (Figures A13-A15). In some TNMS with low recent LPUE levels (e.g. TNMS 387443-397316), fishing effort increased during 2001-2005 with some increase in landings.

4.5 Bycatch and discard

Landings and catch are almost equal in the ocean quahog fishery because discards are nil. Discard of ocean quahog in the ocean quahog fishery does not occur because undersize animals are automatically released by automatic sorting equipment. However, some incidental mortality occurs. Based on Murawski and Serchuk (1989), NEFSC (2004) assumed incidental mortality rates of $\leq$ 5% for ocean quahog damaged during fishing but not handled on deck. As in previous assessments, fishing mortality and other stock assessment calculations in this report assume 5% incidental mortality rates (i.e. landings x 1.05 = assumed catch).

Bycatch of ocean quahog probably occurs in fishing for Atlantic surfclam but has not been quantified and is certainly minor. Off DMV and SVA in the southern end of the ocean quahog's range, survey catches including both surfclam and ocean quahog have become more common in recent years as surfclam have shifted towards deeper water in response to warm water conditions (Weinberg et al. 2005). However, mixed loads of surfclam and ocean quahog are not acceptable to processors and it is not practical to sort catches at sea so that vessels would tend to avoid areas where both species might be caught.

Bycatch and discard of ocean quahogs in other fisheries is nil. Ocean quahogs are not vulnerable to bottom trawls, scallop dredges (because they are too deep in sediments), or hook and line gear.

4.6 Commercial size-composition data

Commercial length composition data (shell lengths, SL) for ocean quahogs collected by port agents from landings indicate that the size composition of ocean quahog captured in the DMV stock assessment region differed during 1987-1994, 1995-2000 and 2001-2005 (Figure A16). Lengths for DMV during 1987-1994 and 2001-2005 were similar.

Commercial length composition data for NJ were stable during 1982-2002 with smaller ocean quahog landed during 2003-2005 (Figure A17). Length data for LI include relatively high proportions of large individuals (11-12 cm SL) during 1997-1999 (Figure A18). Length data for SNE during 1998-2005 were generally stable but with smaller ocean quahog landed during 1997-2000 (Figure A19). According to NEFSC (2004), smaller sizes landed from SNE during 1997-2000 were due to vessels targeting specific beds with relatively small ocean quahogs that had relatively high meat yield.

4.7 Fishery selectivity

Commercial fishery selectivity estimates used in this assessment for ocean quahog are from Thorarinsdottir and Jacobson (2005) who estimated selectivity of commercial dredges that harvest ocean quahog off Iceland. The selectivity curve $s_L = 1/\left(1+e^{7.63-0.105L}\right)$, where L is shell length in mm, indicates that about 10%, 50% and 90% of ocean quahog are available to the fishery at 51, 72, and 93 mm SL (9, 28 and 86 y, based on the growth curve in Figure A59).

Dredges and towing speed in the US fishery are very similar to dredges and tow speed used in the selectivity experiments. The dredge used for selectivity experiments was 24 ft (7.35 m) in length, 5 ft (1.5 m) high and 12 ft (3.65 m) wide. The cutting blade was 10 ft (3.05 m) wide and set to penetrate sediments to a depth of 3 in (8 cm). The dredge was made of steel bars with intervening spaces of 1 ¼ in (3.5 cm) and was towed at about 2.1 knots (3.9 km h^{-1}). Water pressure supplied to jets on the dredge from a pump on the ship was about 109 psi (7.5 bars). Water pressure levels in the US fishery are usually lower (~80 psi) but water pressure probably has relatively little effect on size selectivity. Fishery selectivity curves are used in tracking trends in fishable biomass, estimating fishing mortality and in calculating biological reference points.

5.0 MORTALITY AND STOCK BIOMASS (TOR-2)

Mortality and stock biomass estimates for ocean quahog in the US EEZ are based on triennial NEFSC clam surveys, cooperative field studies used to measure survey dredge efficiency, and fishery data.

5.1 NEFSC Clam Surveys-Results

NEFSC clam surveys have been conducted since 1965 and are the main source of fishery-independent information about long term trends in abundance, biomass (Table A7, Figure A20), recruitment (Figure A21), stock distribution (Figures A22-A25 and Appendices A7-A8) and population length composition (Figure A26) for ocean quahog in the EEZ. The small area of coastal Maine waters is not covered by the NEFSC clam survey but it is minor in terms of stock biomass (20 vs. 2,700 thousand mt meats, Russell 2006) and landings (500 vs. 14,000 mt meats).

Based on survey data and in general terms (see below for details), fishable abundance (mean number per tow), stock biomass (mean kg tow) and spawning biomass (mean kg/tow) declined during 1982-2005 in southern areas (SVA, DMV and NJ) where the bulk of fishing has occurred while fishable biomass in northern areas (LI, SNE and GBK) remained relatively high and stable (with the exception of GBK in the 1999 survey). LI is the only area with clear evidence of strong recruitment after 1982 based on survey length and recruit trend data. In particular, length data from LI show ocean quahog at 65 mm SL during 1978 that grew slowly over time and became indistinguishable from the rest of the LI stock by about 1994 (Figure A26). Recruitment trend data for LI are higher prior to 1994 than afterwards and variable in other regions (Figure A21). Trends in spawning and stock biomass were nearly the same.

<u>Survey methods</u>

Survey data used in this assessment were from surveys during 1982-2005 by the *R/V Delaware II*, which were carried out during the summer (June-July), using the standard NEFSC survey hydraulic dredge with a submersible pump, 152 cm (60 in) blade 5.08 cm and small 5.08 cm (2 in) mesh liner. The survey dredge differs from commercial dredges in being smaller, using the small mesh liner, and in having the pump mounted on the dredge, rather than the deck of the vessel. The survey dredge used since 1982 catches ocean quahog as small as 50 mm SL with some reliability.

Surveys prior to 1982 were not used in this assessment because they were carried out during different seasons, used other sampling equipment or, in the case of 1981, have not been integrated into the clam survey database (Table A7 in NEFSC 2004). The last stock assessment for ocean quahog (NEFSC 2004) used survey data for 1978-1980 assuming that catchability was different during than in later surveys. In effect, the data for 1979-1980 were treated as a short separate survey time series that had little or no effects on stock assessment estimates. Catchability coefficients for earlier surveys were much different than for surveys since 1981 (NEFSC 2004).

NEFSC clam surveys are organized around NEFSC shellfish strata which are combined to define stock assessment areas (Figure A1). Most of ocean quahog landings originate from areas covered by the survey. The survey did not cover GBK and SVA completely in all years and strata in other areas are occasionally missed (Table A8). Strata not sampled during a particular survey are filled by borrowing data from the same stratum in the previous and/or next survey, if data are available (NEFSC 2004). Survey data are never borrowed from surveys behind the previous or beyond the next survey.

Surveys follow a stratified random sampling design, allocating a pre-determined number of tows to each stratum. Stations used to measure trends in ocean quahog abundance are either random or nearly random. A few nearly random tows were added in previous surveys to ensure that important areas were sampled. Other non-random stations are occupied for a variety of purposes but not used to estimate relative trends in ocean quahog abundance.

A standard tow is nominally 0.125 nm (m) in length (i.e. 5 minutes long at a speed of 1.5 knots). However, sensor data indicate that the actual tow lengths are greater (Weinberg et al. 2002 and see below).

Occasionally, randomly selected stations are found too rocky or rough to tow. In these cases during surveys since 1999, a search for fishable ground is made in the vicinity (0.5 nm) of the original station (NEFSC 2004). If no fishable ground is located, the station is given a special code (SHG=151) and the research vessel moves on to the next station. The proportion of random stations that cannot be fished is used to estimate the proportion of habitat in a stratum or region that is suitable habitat for ocean quahog, which is used in calculation of ocean quahog biomass from survey data (see below).

Following most survey tows, all ocean quahog and Atlantic surfclam in the survey dredge are counted and shell length is measured to the nearest mm. A few very large catches may be subsampled. Mean meat weight (kg) per tow is computed with shell length-meat weight (SLMW) equations from NEFSC (2004).

SLMW relationships used with survey data to track trends in survey meat weight per tow are region-specific. SLMW relationships used for survey data in this analysis (Table A9) were the same as in the last assessment (NEFSC 2004). They were derived by averaging SLMW curves from the 1997 and 2002 surveys, which were based on fresh tissue minus shell weighed at sea. Samples from earlier surveys were from frozen meats.

NEFSC clam survey require a great deal of additional adjustments after extraction from the database and before they are used in trend or swept-area biomass calculations (e.g. adjustments for tow distance and fishery or survey selectivity). Clam survey database parameters that would be required to replicate each analysis are listed in Table A10).

Survey gear selectivity

NEFSC (2004) estimated selectivity curves for ocean quahog in the NEFSC clam dredge based on catches by a commercial dredge with a small mesh liner during 2003 and survey catches in the same area during 2002. The selectivity curve $s_L = 1/\left(1+e^{8.122-0.119L}\right)$ indicates that 50% of ocean quahog are fully available to the NEFSC clam dredge at about 68 mm SL, which can be compared to 73 mm for commercial dredges (Figure A27). The survey dredge tends to take smaller ocean quahogs than commercial dredges because of the relatively small 2 in liner in the survey dredge. Based on sizes retained by the survey dredge (NEFSC 2004), the survey dredge selectivity curve is reliable for ocean quahog ≥ 50 mm SL.

Survey, stock and fishable abundance and biomass

Catch and length composition data for ocean quahog ≥ 50 mm SL from the NEFSC clam survey were used to estimate abundance and length composition for the stock as a whole. In particular, $N_L = n_L/s_L$ where N_L is mean stock numbers or biomass per tow at length L, n_L is survey catch and s_L is survey selectivity.

Abundance and length composition for the fishable stock (i.e. available to the fishery) were estimated by correcting stock estimates for fishery selectivity. In particular, $\eta_L = \phi_L N_L$ where η_L is fishable abundance and ϕ_L is fishery selectivity. Fishable abundance can be estimated directly from survey data for ocean quahog ≥ 50 mm SL using $\eta_L = n_L \phi_L / s_L$ (Figure A27).

Calculation of stock abundance and biomass occasionally produces very large estimates for small sizes where selectivity is small (near zero) when ratios n_L/s_L become very large. Calculation of fishable abundance and biomass from survey data does not suffer from this problem because the adjustment of small sizes is relatively modest (Figure A27).

Spawning stock biomass

Trends in spawning stock biomass for ocean quahog were estimated based on survey data by applying a maturity at length relationship for ocean quahog from Thorarinsdottir and Jacobson (2005) to survey length composition for the stock as a whole (i.e. after correction for survey dredge selectivity). In particular, $S_L = m_L N_L w_L$ where S_L and w_L are spawning biomass and mean body weight (from a length-weight relationship) See Section 6 for more information about the maturity curve.

2005 Survey

The 2005 NEFSC clam survey was carried out during late May to early June. There were three legs (stations 1-182 during May 24-June 2, stations 183-250 during June 9-June 17, and stations 251-433 during June 22-29). Four hundred and thirty three stations were occupied. Sensor data used to monitor dredge performance were collected at 399 stations. Two hundred and eighty random and nearly random stations were used to calculate trends in ocean quahog abundance. The set of strata covered during the 2005 survey was similar to strata covered during previous surveys except that no stations were occupied in the most northern (GBK) and southern (SVA) stock assessment regions (Table A8).

Trends in survey, stock and fishable mean kg per tow were calculated for ocean quahog ≥ 50 mm SL in each region (Table A7 and Figure A20). Smaller ocean quahog taken in surveys were not included because catches of small individuals is very low and because selectivity curves used to calculate stock and fishable abundance are not valid below 50 mm SL. Trends in survey, stock and fishable numbers and weight per tow for the same region were generally similar.

The precision of survey trend data from the 2005 survey was typical but results for DMV were relatively imprecise with high coefficients of variation (CV) due to a single large tow in stratum 15 (Table A7). CVs for trend data from surveys during 1982-2005 averaged about 0.3, 0.2, 0.2 and 0.3 in the DMV, NJ, LI and SNE regions.

As described below, trends in NEFSC clam survey data are complicated by changes in survey dredge efficiency.[3] In particular, survey data for 1994 were judged not comparable to survey data from other surveys because power to the dredge used to run the submersible pump during 1994 was set to 480 instead of 460 volts and dredge efficiency was artificially increased during 1994.

Dredge performance

After the 1994 survey, sensors were used to monitor depth (ambient pressure), differential pressure, voltage, hertz and amperage of power supplied to the dredge, x-tilt (side to side), y-tilt (front to back) and ambient temperature during survey fishing operations. At the same time, sensors on board the ship monitor electrical frequency, GPS position, vessel bearing and vessel speed. All sensor data are recorded at 1 second intervals.

Good tows have characteristic sensor data patterns that are easy to interpret (Figure A28). Anomalous patterns indicate potential problems with the tow or sensors.

[3] "Efficiency" of a clam dredge is the probability that an ocean quahog in the path of the dredge will be caught. Efficiency of capture may differ between quahog of difference size and the definition used here applies to quahog large enough to be fully available to the sampling gear. Efficiency estimates for the survey dredge are used with a variety of other information to estimate the "catchability" coefficients for NEFSC clam surveys that relate survey catches to stock abundance and biomass.

Differential pressure, amperage and y-tilt are particularly important. Differential pressure is one of the factors affecting the flow of water through the jets in front of the dredge blade. Amperage measures the work done by the pump in moving water through the jets. If water is blocked at the entrance to the pump, then both amperage and differential pressure will be low. If water is blocked downstream of the pump, then amperage will be low and differential pressure will be high. Y-tilt can be used to determine if the dredge is on the bottom with the blade in the sediment.

Differential pressure data collected during the 2005 clam survey show a spike early in the first leg (Figure A29) coinciding with a drop in amperage that was due to a faulty screen on the input to the dredge system that allowed rocks to enter and fill the manifold, which is downstream from the pump. The screen was repaired, rocks removed and the affected stations were reoccupied.

Differential pressure appeared to jump from about 40 to about 50 psi beginning at approximately station 221 during the second leg of the 2005 NEFSC clam survey at the same time that amperage might have declined (Figure A29). The timing of the change coincided with malfunction and repair of electrical equipment on the ship that supplies power to the pump on the dredge.

The apparent jump in differential pressure during the second leg of the 2005 survey triggered a careful analysis of survey sensor data and dredge performance (Appendix A1). The apparent problem with differential pressure was determined to stem from sensor drift. In particular, differential pressure measurements before and after the pump was turned on were generally biased high after station 220 to the same extent at each station. The difference between ambient measurements at the surface and during fishing for each tow (another way to estimate differential pressure) was usually about 40 psi and approximately equal to differential pressures measured in the normal manner during the first leg. The alternate estimates of differential pressure did show a slight but steady decline in differential pressure during the survey presumably due to wear on the pump (Appendix A1).

In the course of investigating the problems with differential pressure, a number of stations with poor dredge performance were identified based on problems with differential pressure, amperage, vessel speed, and y-tilt (Appendix A2). Four of the problematic stations (218, 225, 262 and 282) were in areas of typical ocean quahog habitat and would not have been omitted following standard survey procedures.[4] Stations 218, 225, 262 and 282 from omitted from further analysis. Similar problems may have occurred in earlier surveys but can not be detected or removed for lack of sensor data. Analysis of sensor data from the 2002 survey will be analyzed to determine if similar problems occurred during 2002.

Tow distance

Tow distance was estimated for each station in the 2005 NMFS clam survey based on speed over ground (SOG) data from the ship's GPS and dredge inclinometer data from the SSP. SOG was assumed to be the same for the ship and dredge.

Following NEFSC (2003), the dredge was assumed to be fishing effectively whenever the smoothed y-tilt was $\leq 5.16^o$ (see below). Based on the geometry of the

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[4] Standard survey procedures omit stations with database Station Type-Haul Type-Gear Condition (SHG) codes greater than 136.

dredge, the blade penetrates the sediments to a depth of 1 inch when the y-tilt is 5.16^{o}. Penetration increases as the y-tilt decreases.

Tow distance calculations for the 2005 survey were the same as in NEFSC (2003) except that missing values were interpolated as described below. The first step was to replace missing SOG and inclinometer data for each station with interpolated values from a cubic spline. The second step was to smooth the original plus interpolated SOG and inclinometer data with a centered seven point moving average (e.g. the smoothed value for $t = 3$ was the average for $t = 1$ to 7).[5] The final step was to compute the effective tow distance for each tow d_j using:

$$d = \frac{\sum_t \delta_t s_t}{3600}$$

where t was a one-second interval, δ_t was a dummy variable equal to one when the dredge was fishing effectively (smooth y-tilt $\leq 5.16^{o}$) and zero otherwise, s_t was SOG (knots) and 3600 is the number of seconds per hour. Tow distances calculated in this manner and used in this assessment for surveys during 1997-2002 (see below) were the same as in NEFSC (2003). The median tow distance for 2005 was consistent with median tow distances from the 1999 and 2002 surveys (see below). As pointed out in NEFSC (2003), the median tow distance for 1997 was 0.4-0.7 nm larger than median tow distances from other surveys because a slower winch was used to deploy the survey dredge (Table C7 in NEFSC 2003).

Year	Median Tow Distance (NM)
1997	0.26
1999	0.22
2002	0.19
2005	0.21

Tests showed that the new interpolation procedure had a negligible effect on tow distance estimates for the 2005 survey because missing values were rare. Similar results would likely be obtained for the 2002 survey, which also used the survey sensor package. Effects of interpolation on tow distance estimates were not investigated for 1997 and 1999 surveys but may be larger because sensor data from the 1997 and 1999 surveys were collected using less precise sensors with recording intervals that were sometimes longer than one second. This is a topic for future research.

[5] Steps 1-2 were done in SAS (note that interpolation precedes smoothing).

```
proc expand data=sdata1 out=sdata2 to=second;
    by station;
    ID TowTime;
   convert TiltY=SmoothAngle / transform=(cmovave 7);
    convert GPS1_SOG=SmoothSOG / transform=(cmovave 7);
  run;
```

Tow distance vs. depth

Tow distance is a key variable in estimating swept area biomass (see below). Weinberg et al. (2002) show that tow distance increases with depth for the NEFSC clam survey dredge when the dredge is deployed as in actual clam surveys. Regression analysis was used to determine if depth measurements could be used to infer tow length at survey stations when sensor data are not available. Based on graphical relationships (Figure A30), linear regression models were used, e.g. $d_j = \alpha + \beta D_j$ where d_j was tow distance in nm (calculated from sensor data assuming the dredge was fishing when the smoothed y-tilt was ≤ 5.16°), and D_j was average depth of the tow in meters as measured from the ship. Data used in the analysis were for random survey tows only (tows with database code RANDLIKE > 0). Tows with sensor-based tow distances < 0.125 nm were omitted from the analysis because they were likely aborted or test tows.

A stepwise regression procedure was used to select the best model from a range of models based on the AIC statistic. In the Splus programming language, the simplest model considered was:

```
Smallest <- lm(d~1)
```

where "~1" indicates that the model consists of the mean for the entire data set. The most complicated model was:

```
Biggest<- lm(d ~ CRUISE + D / CRUISE)
```

which is equivalent to a separate regression models relating tow distance and depth in each of the 1997, 1999, 2002 and 2005 surveys (Figure A30).

The most complicated model was selected as the best model by the stepwise procedure based on AIC. The best model was statistically significant (p<0.0001) and all parameters were statistically significant at the p=0.1 level (see below).

	Estimate	Standard Error	t-test	p-value
Survey effects (intercept parameters)				
Intercept	0.182	0.002	91.0098	0
1997	-0.02	0.0028	-7.2647	0
2002	-0.0093	0.0015	-6.1114	0
2005	-0.0046	0.0013	-3.6898	0.0002
Depth effects (slope parameters)				
Depth	0.0009	0	20.0054	0
1997	0.0001	0.0001	1.8697	0.0618
2002	-0.0001	0	-2.7522	0.006
2005	0.0001	0	2.5433	0.0111

```
Residual standard error: 0.02809 on 1179 degrees of freedom
Multiple R-Squared: 0.4634
F-statistic: 145.4 on 7 and 1179 degrees of freedom, the p-value is 0
```

Residual plots indicated reasonably good model fit although distributions of residuals were skewed either to the left or right for some surveys. Based on the regression analysis, tow distance increases by an average of about 0.0009 nm (1.7 m) per meter of depth.

Results show that missing tow distance data for NEFSC clam survey stations could be replaced with estimates based on depth from a survey-specific linear model. Unfortunately, differences among surveys were large enough to be important in estimating tow distance and should not be ignored. It does not appear that a single or average depth-tow distance relationship could be used to estimate tow distance for previous surveys with no sensor data for measurement of tow distances.

Commercial and survey dredge efficiency

Dredge efficiency is defined for this assessment as the probability of capture (i.e. of being handled on deck) for an ocean quahog that is in the path of the dredge and large enough (e.g. 83+ SL in a survey dredge or 90+ mm SL in commercial dredge, see below) to be fully selected by the dredge used in the experiment. Dredge efficiency for smaller ocean quahog is the product of the overall dredge efficiency for fully selected sizes and the selectivity for the particular size.

Collaborative "depletion" experiments were conducted following NEFSC clam surveys in 1997-2005 to estimate commercial and survey dredge efficiency (Figure A31). Commercial dredge efficiency estimates are of considerable interest but are most important in estimating efficiency of the survey dredge deployed from the *R/V Delaware II* during NEFSC clam surveys. Commercial dredges are inherently more efficient than the survey dredge (due to higher pressure water jets) and tend to select larger ocean quahog. In this assessment differences in the size of catches are accommodated by restricting analysis to sizes large enough to be fully selected by survey and commercial gear used in the experiment (see below).

Considerable progress has been made since the last assessment, but efficiency estimates for ocean quahog are still more uncertain and difficult than for Atlantic surfclam (NEFSC 2003). Dredge efficiency is harder to estimate for ocean quahog because they are found in deeper water (which makes dredge position data less reliable) and because they burrow deeper into sediments (and are probably sampled less efficiently) to a degree that depends on environmental conditions.

All depletion experiments for ocean quahog involve fishing repeatedly in the same area, usually until a significant decline in catch per tow is noted. Sensors and GPS equipment are have been used since 1999 to track the performance of the dredge and position of the vessel during each tow (vessel position is used as a proxy for dredge position). Experiments during 1997-1998 used loran positions noted by hand. The accuracy of position information is an important consideration (see below). Catch and position data are used in a statistical analysis (see below) to estimate the efficiency of the dredge used in the experiment.

In a "Delaware II" depletion experiment, the *R/V Delaware II* and NEFSC survey dredge are used to make depletion tows. The efficiency of the survey dredge is estimated from the depletion tow data directly using the "Patch" model (Rago et al., in press and see below). One Delaware II depletion experiment has been completed for ocean quahog (experiment OQ1999-01 DE2 in Table A11).

In "commercial" depletion experiments, a commercial vessel and dredge are used for depletion tows. The efficiency of the commercial dredge is estimated directly using the Patch model.

Commercial depletion experiments can be used to estimate survey dredge efficiency also if the *R/V Delaware II* conducts setup tows prior to the commercial depletion experiment in the same or immediately adjacent area (see below). About five non-overlapping setup tows are typically carried out. Sixteen commercial depletion experiments have been completed by commercial vessels of which thirteen included setup tows (Table A11 and Figure A31).

Patch model

The Patch model was used exclusively to estimate depletion experiment data in this assessment. It has become a standard approach used in NEFSC stock assessment work for a variety of shell- and sedentary demurral finfish including Atlantic sea scallops NEFSC (2004b), ocean quahog (NEFSC 2004), Atlantic surfclam (NEFSC 2003) and goosefish (NEFSC 2005). Other estimators used for ocean quahog in previous assessments were either *ad-hoc* or based on estimators involving assumptions that are tenuous for ocean quahog (e.g. complete mixing after each depletion tow). Now that a sufficient number of depletion experiments have been completed, it is possible to use Patch model estimates exclusively.

The Patch model was used to estimate three parameters for each depletion experiment (initial ocean quahog density, dredge efficiency, and a measure of dispersion) by maximizing the likelihood of the observed catches under the assumptions that the dredge path is known and that the catches are sampled from a negative binomial distribution. The key point is that it is not necessary to assume ocean quahogs mix randomly (except in relatively small cells) after every depletion tow. Ideally, GPS is used to monitor the position of the ship (a proxy for position of the dredge) at one second intervals during each tow (see below). In computing the likelihood for the catch in each tow, the model considers the number of times each grid sampled during the tow had been swept by the dredge in previous tows. Likelihood profiles are used to compute confidence intervals for all model estimates and residual plots (observed – predicted catches) can be used to judge model fit.

Revised estimators for survey dredge efficiency based on setup tows

Efficiency of the NEFSC clam survey dredge is estimated from commercial depletion experiment results by relating densities measured by the *Delaware II* in setup tows to initial density estimated from a commercial depletion experiment by the Patch model (Rago et al., in press). In particular:

$$e = \frac{d}{D}$$

where e is estimated efficiency of the NEFSC survey dredge, d is density (number ft^{-2}) estimated from setup tows by survey dredge, and D is density estimated by the Patch model. In this context, d is understood to measure survey catch rates while D is understood to measure the actual density of quahog on the bottom of the ocean within the boundaries of the depletion experiment site. Previous ocean quahog assessments (NEFSC 1998; NEFSC 2000; NEFSC 2004) used a different formula that is incorrect:

$$e = \frac{d}{D} E$$

where $E \leq 1$ is efficiency of the commercial dredge as estimated by the Patch model (note that this formula is correct if E=1, which is appropriate if D is absolute initial density). For this assessment, all depletion experiments were reanalyzed using the correct formula and other changes described below. All other things being equal, the corrected formula increases research survey dredge efficiency estimates (and decreases swept-area biomass estimates) because $E < 1$ so that $d/D \geq (d/D)E$.

Revised assumptions about dredge selectivity

It is important that data used in the Patch model include only length groups that are (or are nearly) fully selected. For survey efficiency estimates from setup tows and commercial depletion experiments, size groups fully selected by *both* the survey and commercial gear should be used. This restriction is important for two reasons. Firstly, the estimator $e=d/D$ requires that d and D be for the same fully recruited size groups. Secondly, Patch model estimates of E will be biased low if small size groups (with lower selectivity) are included.

Previous assessments (NEFSC 1998; NEFSC 2000; NEFSC 2004) assumed that Patch model estimates were valid as long as the survey dredge and commercial dredge used in the depletion experiment had "similar selectivity" for size groups included in the analysis. Commercial sampling equipment (dredge and shaker table) used in depletion experiments was usually adjusted prior to sampling so that the catch rates for small ocean quahog increased and the modified commercial and survey length composition data were made more similar. Decisions about which size groups to include in an analysis were made in previous assessment after experiments were completed based on length composition data from setup and depletion tows. In practice, length groups actually used in estimation varied from experiment to experiment (e.g. 71+ mm for the OQ2000-1, 76+ mm for the OQ2000-2, and all size groups for the OQ2002-1 to OQ2002-4 depletion studies). In experiments during 1997-1999 that used only one type of gear, all size groups were used.

Revised depletion study catch data

For this assessment, all depletion experiments during 1997-2005 were analyzed or reanalyzed using depletion experiment catch data (numbers of ocean quahog per tow) for size groups that were at least 85% selected by all gear used in the experiment. In particular, catches for commercial depletion experiments and setup tows were for ocean quahog 90+ mm SL and catches for Delaware II depletion experiments were for ocean quahog 83+ mm SL. Based on selectivity curves (Figure A27), 87% and 93% of ocean quahog are selected by commercial and survey dredges at 90 mm SL. As mentioned above, commercial equipment was usually adjusted prior to use in depletion experiments so that commercial selectivity at 90 mm SL was likely higher than 90%. Data analyzed from Delaware II depletion experiments were for ocean quahog 83+ mm SL because survey dredge selectivity is 85% at that size.

The decision to use the size at 85% selectivity as the cutoff was pragmatic. A higher selectivity cutoff level might be preferred on mathematical grounds but the variability of catch data decreased when fewer sizes were included. For example, data from the OQ2000-1 depletion experiment were used to estimate commercial dredge efficiency but could not be used to estimate survey dredge efficiency because relatively few ocean quahog 90+ mm were taken in setup tows. In OQ2000-1 setup tows, large ocean quahog comprised only 6% of the setup catch on average.

Calculation of catch of ocean quahog larger than a specified size (e.g. 90+ mm) requires information about the catch in bushels in each tow, the number of clams per bushel ("bushel counts"), and the proportion of clams larger than 90+ mm (from length measurements. Ideally:

$$n_{t,90+} = B_t n_t p_{t,90+}$$

where B_t is catch in bushels for tow t, n_t is the number of ocean quahogs in a sample bushel and $p_{t,90+}$, is the proportion of the length sample that was at least 90 mm SL.

Bushel counts and length data measurements were not collected from every tow during depletion experiments. During most experiments, one bushel of ocean quahog was counted and one bushel was measured at intervals of 3-5 tows, and occasionally at longer intervals (Table A11). In some cases, the number of broken clams was recorded so that the number measured plus broken provided additional information about numbers per bushel.

A convention was developed to objectively calculate the number of ocean quahog above a specific size for tows without bushel counts or length data. For example, if an experiment consisted of 10 tows with samples taken on tows 2, 6 and 9, then n_2 was used for tows 1-2. The average of n_2 and n_6 was used for tows 3-5. The average of n_6 and n_9 was used for tows 7-8. Finally, n_9 was used for tows 9-10. In previous assessments, a variety of conventions (including the one used in this assessment) was employed for different tows and different depletion experiments.

In theory, bushel counts should increase and proportions of large individuals in catches should decrease as a depletion study is carried out and large ocean quahog are preferentially removed from the study site. This pattern was not, however, consistently observed.

Length and bushel count data from depletion and setup tows appears more important than recognized in previous assessments. More detailed length data (e.g. 1 bushel per tow) should therefore be collected during future depletion experiments. Lengths and bushel counts were likely under-sampled in depletion experiments to date (Table A11)

Accuracy and precision of position data

Cell sizes used in Patch model runs for this assessment are 20-25 ft (Table A11). Previous assessments used 10-25 ft. Position data used in the Patch model for ocean quahog depletion experiments should be recorded at (or interpolated to) intervals ≤ 0.00001 degrees to avoid missing cells (see below). Position data recorded to 0.0001 degrees, for example, are too coarse, because the wrong cell would be assigned frequently due to imprecision in position measurements. This recommendation assumes that vessel position is an accurate proxy for dredge position. The accuracy of GPS data as information about dredge position likely deteriorates with depth. Problems with position information may be exaggerated to some extent for ocean quahog, which are found in relatively deep water. Potential effects of inaccurate position data should be evaluated by simulation analysis. Position data were smoothed prior to use in this assessment to account for imprecise position data from some depletion experiments (see below).

Distance in feet for a change in latitude or longitude at 40° N.

	Distance in Feet	
Degrees	Latitude	Longitude
1	364,560	279,269
0.1	36,456	27,927
0.01	3,646	2,793
0.001	365	279
0.0001	36.5	27.9
0.00001	4	3
0.000001	0.4	0.3

Position data used in the Patch model should be recorded at (or interpolated to) intervals ≤ 4 second intervals to avoid skipping cells too frequently between position observations. The target tow speed for the *R/V Delaware II* during depletion tows is 1.5 knots or 2.5 ft sec^{-1}. Commercial vessels probably average about 2 knots or 3.4 ft sec^{-1} during commercial operations tows (D. Wallace, Wallace and Associates, pers. comm.) and about 3 knots or 5 ft sec^{-1} during depletion tows (E. Powell, Rutgers University, pers. comm..). Thus, sampling (or interplation) at intervals of 1-3 seconds is recommended because the *R/V Delaware II* crosses a 20 ft cell in 8 seconds and a commercial vessel crosses a 20 ft cell in 4 seconds (see below). Smaller cell sizes require more frequent sampling or interpolation. Position data were interpolated in this assessment to account for relatively long sampling intervals in some depletion experiments (se below).

Time in seconds required to cross Patch model cells 15-25 ft wide at vessel speeds of 1.5 and 2 knots.

	Vessel speed (knots)	
Feet	1.5	3
15	5.9	2.9
20	7.9	3.9
25	9.9	4.9

Smoothed position data for depletion experiments

Position data for 1997-2005 depletion experiments were from original Loran or GPS records. Start and stop times for GPS data were the same as used in the last assessment).

Position data from depletion studies during 2000-2005 were recorded to 10^{-6} degrees at one second intervals based on differential GPS or the equivalent (Table A11). However, position data from the 1999 Delaware II depletion study from GPS were recorded to only 0.0001 degrees and position data from loran readings in depletion studies during 1998-1998 were recorded to an accuracy of about 0.0001 degrees.

To avoid problems with erratic "stair pattern" tow tracks from coarse position data, original position data from all depletion experiments were smoothed prior to further analysis (Appendix A3). The smoother was a cubic spline when the number of observations $n \geq 15$, a quadratic polynomial when the number of observations was $5 \leq n < 15$ or a straight line when $2 \leq n < 5$. Smooth lines were fit using latitude or longitude as the dependent variable and order of collection (a crude measure of time) as the independent variable. Smoothed values were used in subsequent calculations, instead of the original data. Decisions about smoothing were ad-hoc but consistently applied and seemed to result in plausible tow paths for further analysis (Appendix A3). Fortunately, survey dredge efficiency estimates were from recent depletion studies with generally accurate position data sampled at relatively frequent intervals. With accurate data at frequent intervals, smoothing had very little effect of tow path data.

No position data were available for 2 out of 60 tows in the 1999 Delaware II depletion experiment. Crude estimates of the start and stop locations for these tows from previous assessments from a previous assessment were used instead.

Before analysis in the patch model, original or smoothed position data were interpolated along straight lines to a distance of 5 ft (~ 1- 2 second intervals) to ensure that all cells that were crossed by the dredge would be recorded as "hits" in the Patch model program. This was apparently not done for all depletion experiments in previous assessments and it is possible that not all hits were included in previous estimates. In future assessments, interpolation should be based on the model (e.g. cubic spline) used to smooth the original position data, rather than by linear interpolation.

Assumptions about cell size

All depletion studies were analyzed or reanalyzed using consistent and updated assumptions about cell size and indirect effects, which are closely related. Rago et al. (in press) suggested that the cell size be set at twice the width of the dredge used in the depletion experiment. They point out that decisions about cell size reflect a compromise between the accuracy of position data and the tenability of the assumption that animals mix within cells after each tow. Dredges used in depletion experiments were mostly ≥ 10 ft wide with the exception of the commercial dredge in the OQ1997-1 commercial depletion experiment and the 5 ft dredge used in the OQ1999-1 (DE-2) Delaware II depletion experiment (Table A11).

In this assessment, the cell size in Patch model analyses was set at twice the dredge width or 20 ft, whichever was larger. This approach basically follows the advice in Rago et al. (in press) for all experiments during 2000-2005 while assuming that positional accuracy (particularly for experiments during 1997-2005) was never better than 20 ft. Patch model estimates for ocean quahog were moderately sensitive to the assumed cell size (Figure A32). In particular, efficiency estimates tend to increase and density estimates tend to decrease as the cell size assumed in the Patch model increase.

Indirect effects

The "gamma" parameter in the Patch model is used to measure indirect effects (ocean quahog lost from the study site without being counted on deck). In this assessment gamma was fixed at the ratio of the dredge width and cell width (γ=0.5) so that no indirect effects were assumed to occur. The gamma parameter is theoretically estimable but estimation has proven difficult in practice because the estimate for gamma is correlated with other estimates in the model and dependent on assumptions about cell size (Rago et al., in press). The previous assessment assumed indirect effects (γ=0.75) in depletion experiments during 1997-2000 and no indirect effects (γ=0.5) in depletion experiments during 2002. As shown in Rago et al. (in press) efficiency and density estimates from the Patch model tend to decrease as the assumed level of γ increases.

Sensitivity to initial parameter estimates

Patch model estimates were not sensitive to the starting values for parameter estimates. After an initial Patch model run for each experiment was completed, the model was rerun several times to determine if results were sensitive to starting parameter values. In particular, the model was rerun at least four times with HD/LE, LD/HE, HD/HE and LD/LE where HD, LD, HE and LE stand for higher and lower starting density values and higher and lower starting efficiency values. In general, higher starting values were 2-3 times higher than the initial estimate and lower starting values were one-half to one-third of the initial estimate. The estimate providing the best fit to the catch data (smallest negative log-likelihood) was the best estimate.

2005 Depletion experiments

In 2005, five new commercial depletion experiments were completed with five setup tows and 17-21 depletion tows per site (Figures A33-A37). No Delaware II depletion studies were carried out for ocean quahog during 2005. Details about depletion studies during 2002 are described in NEFSC 2004, experiments during 1998 and 1999 are described in NEFSC (2000) and experiments during 1997-1998 are described in NEFSC (1998).

Survey sensor package equipment (with the exception of GPS and a backup depth sensor) did not function during ocean quahog depletion tows by the commercial vessel during 2005 due to battery failure, with the exception of initial tows at the OQ2005-6 depletion site.

The survey data that are available for 2005 commercial depletion tows (Figure A38) indicate that the commercial dredge was not always horizontal and hard on bottom at the OQ2005-06 depletion site due to the combined effect of low scope and choppy seas. The estimated efficiency for OQ2005-06 may have been reduced by these factors. The OQ2005-06 site was in the deepest water (65 m, Table A11) and conducted in choppy seas. The commercial dredge was deployed at this site with lower scope because the hose used to supply water to the dredge was relatively short. The sea was calmer and shallower at towing scope was greater at other relatively shallow depletion sites for ocean quahog during 2005. Although no sensor data are available, it is likely that the commercial dredge towed well at the other 2005 ocean quahog depletion sites.

As in previous years, commercial sampling equipment (dredge and shaker table) used in 2005 was adjusted to increase catch of relatively small ocean quahog. However, length composition data for the setup and depletion tows at each site during 2005 indicate that the selectivity of the two dredges differed (Figure A39). Confidence intervals and residual plots (Appendix A4) indicate that efficiency and density estimates from experiments during 2005 were reasonably precise.

Depletion study results

For this assessment, all depletion experiments for ocean quahog during 1997-2005 were analyzed or reanalyzed using the Patch model based on revised data, assumptions and procedures described above. All of the underlying data, with the exception of the raw GPS position information collected during depletion studies during 1999-2005, were reevaluated. Residuals and confidence intervals for Patch model parameters are shown for each depletion experiment in Appendix A4. Estimates and model fit are summarized in Tables A11-A12. To build a bridge between new and old results, differences between efficiency and density estimates in this and previous assessments are summarized in Table A13.

Estimates from commercial depletion experiments during 1997-1998 and the Delaware II depletion experiment during 1999 are probably less reliable than estimates from experiments during 2000-2005. Position data were relatively imprecise in depletion experiments prior to 2000 (Table A11). Goodness of fit to depletion catch data was poor for the OQ1998-1 and OQ1999-1 (DE-2) experiments (Appendix A4). Average annual commercial efficiency estimates from experiments during 1997 (E=0.592) and 1998 (E=0.860) were outside the range of average annual estimates for later years (i.e. E=0.615, 0.588 and 0.559 during 2000-2005). The OQ1999-1 (DE-2) survey dredge efficiency estimate was anomalously high and the corresponding density estimate was anomalously low, relative to estimates from later commercial depletions with setup tows.

There were no clear relationships between dredge efficiency and density or depth (Figure A40). There is, however, a suggestion of a negative correlation between survey dredge efficiency and sediment size.

Revised Patch model estimates of commercial and survey dredge efficiency from historical depletion experiments were smaller than previous estimates with a few exceptions (Table A13). Revised density estimates were always smaller but the revised and previous density estimates are not comparable because they are for different size groups.

The seventeen commercial dredge efficiency estimates indicate that efficiency of commercial dredges is highly variable with E = 0.15 to 1.00 (Tables A11-A12 and Figure A42). The average and median of estimates of commercial efficiency were 0.60 (CV=24%) and 0.66 (CV=14%).

Twelve survey dredge efficiency estimates were available, eleven from commercial depletion experiments with setup tows and one from a depletion study by the *R/V Delaware II* (Tables A11-A12). Survey dredge efficiency estimates were also variable (e = 0.098 to 0.990, Figure A43). Omitting the estimate from the OQ1999-1 (DE-2) experiment, which was anomalously high, survey dredge efficiency estimates ranged 0.098-0.297. The average and median of estimates of survey efficiency were 0.248 (CV=29%) and 0.165 (CV=18%). The ratio of median commercial efficiency and median survey dredge efficiency indicates that the NEFSC survey dredge is about one-quarter as efficient as commercial dredges (Table A12). Survey dredge efficiency estimates did not appear correlated with commercial dredge efficiency estimates (Figure A41).

Density estimates for ocean quahog 90 mm SL (Table A11-A13 and Figure A42) ranged 0.007-0.295 ft^{-2}. The smallest density estimate (0.007 ft^{-2}) was from the OQ1999-1 (DE-2) survey depletion experiment, which gave an anomalously small survey dredge efficiency estimate. The highest density estimates (0.226-0.295 ft^{-2}) were the OQ2002-1 and OQ2002-2 depletion experiments.

Best survey dredge efficiency estimate

The "best" estimates for survey dredge efficiency (e=0.165, CV=18%), commercial dredge efficiency (E=0.66, CV=14%) and ocean quahog density (D=0.082 ocean quahog ft^{-2}, CV=13%) were the medians of all available estimates from ocean quahog depletion experiments during 1999-2005 (Table A12). Medians were used because they are robust to anomalous estimates, such as the high estimate for survey dredge efficiency from the OQ1999-1 (DE-2) experiment and the low estimate of commercial dredge efficiency from the OQ1997-3 experiment (Table A11).

The new best estimate of survey dredge efficiency (*e*=0.165) is smaller than the estimates used in the last assessment NEFSC (2004) for the 1997 survey (*e*=0.346) and for the 1999-2000 surveys (*e*=0.269).

Ideally, efficiency estimates would be survey specific because differences in sampling efficiency are possible. However it is not possible at present to estimate dredge efficiency for each survey with sufficient precision.

Depletion experiments-building a bridge

As described above, factors that contribute to the differences between the previous and revised estimates are:

1) Revised computer programs
2) Corrected formula for survey dredge efficiency based on setup tows.
3) Cell size assumed in the Patch model set to the larger of 20 ft or twice the dredge width (affects OQ1997-01 and OQ1999-1 DE-2 only);
4) Depletion and setup catch data for ocean quahog 90+ mm SL (affects all depletion studies during 1997-2002);
5) Revised position data (new smoothing and interpolation, affects all studies during 1997-2002);
6) No indirect effects, i.e. γ = ratio of dredge width and cell size (affects all depletion studies during 1997-2000);

Not all changes apply to each depletion experiment.

To build a bridge between old and new results, effects on efficiency and density estimates due to individual factors for the OQ1998-1 and OQ2002-1 depletion experiments are shown in Table A14. In the OQ2002-1 experiment, estimates were most sensitive to using the correct formula, revised position data, and revised catch data while the density estimate was most sensitive to using catch data for ocean quahog 90+ mm SL only. In the OQ1998-1 experiment, estimates were most sensitive to using the revised position and catch data.

Repeat stations

Stations from previous and the current survey are repeated during each survey to help detect potential changes in sampling efficiency. Catch data for stations sampled twice during the 2005 survey and during both the 2002 and 2005 surveys were analyzed for this assessment but results are not presented here because the repeat stations were in Atlantic surfclam habitat where ocean quahog catches were very low.

5.2 Efficiency corrected swept area biomass

Efficiency corrected swept area biomass (ESB) estimates were for years (1997, 1999, 2002 and 2005) when NEFSC clam surveys collected sensor data for each tow. Sensor data are important because ESB calculations require accurate measurements of tow distance. Differences in ESB estimates between this assessment and NEFSC (2004) for 1997-2002 are described in detail below under the heading “Building a bridge”.

ESB estimates (Table A15) for ocean quahog were calculated:

$$B = \frac{B'}{e}$$

where:

$$B' = \frac{\bar{\chi} A'}{a}(1+\phi)u$$

In ESB calculations, e is the best estimate of survey dredge efficiency for ocean quahogs, $\bar{\chi}$ is mean catch of fishable ocean quahog 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 u=10^{-6} converts kilograms to thousand metric tons. B' is the minimum swept-area biomass prior to correction for survey dredge efficiency.

The term ϕ used in ESB calculations is new in this assessment. It is the fraction of total biomass in deep water strata off LI (strata 32 and 36), SNE (strata 40, 44, 48) and GBK (strata 56, 58, 60 and 62) that were sampled only during 1999. According to NEFSC (2000), deep water strata accounted for 0%, 2% and 13% of total biomass in the LI, SNE and GBK regions during 2005. Data for deep water strata sampled only during 1999 are otherwise omitted in calculations and, in particular, calculation of mean catch per tow $\bar{\chi}$. NEFSC (2004) used a slightly different approach for GBK in the last assessment which gave essentially the same results.

Habitat area for ocean quahogs in each 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), and A is the total area computed by summing GIS area estimates for each survey stratum in the region. Mean catch per standard tow ($\bar{\chi}$) is the stratified mean catch of fishable ocean quahog for individual tows after adjustment to standard tow distance based on tow distance measurements from sensor data (d_s):

$$\chi_i = \frac{C_i d}{d_s}$$

Only random tows were used in calculations of ESB. Tows without sensor data, with gear damage or poor pump performance were excluded from ESB calculations.

Following NEFSC (2004), and as described above, tow distance was measured for each station assuming that the dredge was fishing when the blade penetrated the sediments to a depth of at least one inch. Thus, the tow distance at each station was the sum of the distance covered while the dredge angle was ≤ 5.2°.

ESB estimates for the entire ocean quahog stock during 1997-2005 (Table A15) were computed using a formula that facilitated variance calculations (see below):

$$B_{total} = \frac{B'_{total}}{e} = \frac{\sum_r B'_r}{e}$$

The 80% confidence intervals for efficiency corrected total fishable biomass during 1997, 1999, 2002 and 2005 overlapped suggesting that the estimates were not significantly different (Table A15).

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 (Table A16). Biomass levels change slowly in ocean quahog, fishing and natural mortality rates are low for ocean quahog, and the survey during June provides a good approximation to average biomass. It was advantageous to use the ratio estimator because the surveys occur in June and because it was easy to include a wide range of uncertainties in variance calculations (see below).

Uncertainty in ESB and mortality estimates

Variance estimates for ESB and related mortality estimates were important in using and interpreting results (Tables A15 and A16). Formulas for estimating ESB and mortality for a single stock assessment region are 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 log normal variables in products and ratios (Deming 1960):

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

where *ln(ab/c)*, *ln(a)*, *ln(b)* and *ln(c)* are normally distributed. The accuracy of Deming's formula for ESB estimates was checked by comparison to simulated estimates (NEFSC 2002). CV's by the two methods were similar as long as variables in the calculation were log normally distributed. In addition, distributions of the simulated products and ratios were skewed to the right and appeared lognormal.

CV estimates for terms used in ESB and related estimates (Tables A15-A16 and Figures A44-A45) were from a variety of sources and were sometimes just educated guesses. The CV for best estimate of survey dredge efficiency (e) was CV=0.177 calculated by bootstrapping the median (15,000 bootstrap iterations) (Table A12). For lack of better information, CVs for sensor tow distances (d), 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.

Uncertainty in estimates for combined assessment regions

ESB for combined stock assessment areas was estimated as described above. Variance calculations accommodated covariance among regional estimates due to using a single estimate of survey dredge efficiency:

$$CV^2(B_{total})=CV^2(e)+CV^2(B'_{total})$$

Previous assessments used the formula:

$$Var(B_{total}) = \sum_r Var(B_r)$$

where $Var(x)$ is the variance of x. The formula used previously was incorrect because it assumed that efficiency and biomass estiamtes for each region were independent. The new formula makes the estimated confidence intervals for ESB and fishing mortality wider.

Building a bridge

Efficiency corrected swept-area biomass estimates in this assessment are almost double the estimates in the previous assessment (Table A19). For example, total stock biomass during 2002 was 2.1 million mt in NEFSC (2004) while the revised estimate in this assessment is 3.8 million mt. Several factors are responsible for this change in the estimates for 2002: 1) changes to spreadsheet software used in computations, 2) an error in the survey data for 2002 (but not for other years); 3) accounting for ocean quahogs on GBK that are too deep to be taken in the survey (13% of total stock biomass); 4) use of fishable biomass rather than 70+ mm biomass, and 5) new estimates of survey dredge efficiency. Of all the factors, the revised survey dredge efficiency (followed by the corrected survey data for 2002) was the most important factor contributing to higher ESB estimates in this assessment (Table A19).

5.3 "VPA" estimates

VPA estimates of biomass and fishing mortality are useful for stock assessment regions where the KLAMZ model (see below) is not applicable. Assuming no recruitment and that growth exactly balances natural mortality, ocean quahog biomass on January 1st and annual fishing mortality rates (Figure A46-A50) can be estimated for each stock assessment region using a simple virtual population analysis or "VPA" approach (NEFSC 2004). Efficiency corrected swept-area biomass estimates for 1999, 2002 and 2005 are averaged and used to anchor the calculations. Averages for 1999-2005 are used because the estimates for individual years are less precise (Table A15).

The VPA biomass estimate for January 1, 2002 is:

$$b_{2002} = \frac{B_{1999} + B_{2002} + B_{2005}}{3} - \frac{C_{2002}}{2}$$

where b_y is the VPA biomass estimate for January 1 in year y, B_y is the efficiency corrected swept area biomass for June in year y, C_{2002} is total catch weight (landings plus a 5% allowance for incidental mortality). The first ratio on the right-hand side is average efficiency corrected swept-area biomass during 1999-2005 and used as an estimate of biomass in June of 2002. Catch for 2002 is divided by two prior to subtraction because NEFSC clam surveys occur during June, when the year is half over.

Biomass estimates for years prior to 2002 were calculated:

$$b_{y<2002} = b_{2002} + \sum_{i=y}^{2001} C_i$$

Biomass estimates for years after 2002 were calculated:

$$b_{y>2002} = b_{2002} - \sum_{i=2002}^{y} C_i$$

Fishing mortality rates from VPA estimates were calculated by solving the catch equation with instantaneous rates for natural mortality and somatic growth both zero.

5.4 KLAMZ Model

KLAMZ (see Appendix A5 for a complete technical description) is a forward projecting stock assessment model based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; Quinn and Deriso 1999). The delay-difference equation is an implicitly age structured population dynamics model that is mathematically identical to explicitly age-structured models if fishery selectivity is "knife-edged", somatic growth follows the von Bertalanffy equation, and natural mortality is the same for all age groups in each year. Knife-edge selectivity means that all individuals alive in the model during the same year experience the same fishing mortality rate. Natural mortality rates and growth parameters can change from year to year in the KLAMZ model but are assumed to be the same for all individuals alive during the same year. The model is implemented in AD Model Builder and Excel but only the AD Model Builder version was used in this assessment.

The main assumptions in the KLAMZ model for ocean quahog are: recruitment is constant over time, fishery selectivity is knife-edged; the natural mortality rate is low or constant, and growth in weight can be described by a von Bertalanffy growth curve. Recruitment is assumed constant (at levels always estimated to be very low) because no recruitment index is available. The assumption of constant recruitment is used for ocean quahog because no reliable recruitment index current exists, recruitment levels are apparently very low, and trends in stock dynamics are appear due primarily to fishing mortality.

KLAMZ model runs for ocean quahog that linked virgin biomass calculations with estimated biomass during 1978 were explored during the SARC review for this assessment. NEFSC (2000) used an equvilent virgin biomass approach. NEFSC (2004) compared several approaches and ultimately rejected the virgin biomass approach due to poor fit to survey data. As shown during the review for this assessment, models for ocean quahog that linked initial and virgin biomass in this assessment did not yield plausible results in some cases and fit to survey data was substantially reduced.

Recruitment to the ocean quahog fishery is not knife-edged but occurs at sizes of 51-86 mm SL (Figure A27). Under these circumstances, KLAMZ is an approximate model can be use to track trends in fishable (instead of total) biomass. Fishable biomass is dominated by relatively large individual ocean quahogs that are readily captured (see research recommendations).

Despite the assumption of knife-edge selectivity, KLAMZ is a relatively robust model (i.e. with little or no retrospective bias) that has been used successfully in previous assessments for ocean quahog (NEFSC 2004) and other species. It provides useful estimates of long-term biomass and fishing mortality, performs relatively well with very limited information about age and growth and when explicitly age-structured models are difficult to apply. One of the chief reasons for the utility of the KLAMZ model is statistical simplicity. The models used for ocean quahog in this assessment, for example, estimates only 2-3 parameters.

Model configurations

Configurations of the KLAMZ model for ocean quahog in each region were similar to the "best" configurations identified in the last assessment (NEFSC 2004) following a thorough analysis of a wide range of alternate configurations. Changes are highlighted in the descriptions below.

KLAMZ model estimates were for ocean quahog in the DMV, NJ, LI and SNE regions during 1977-2005. The model was not used for SVA because survey data for SVA are noisy and incomplete. The KLAMZ model was fit to data for GBK for sensitivity analysis. Following NEFSC (2004), the KLAMZ model was not used to make best estimates for GBK because no fishing occurs there, the survey time series is short (1986-2002) and because apparent trends in stock biomass are not clear (see "GBK at virgin biomass?" below).

Data used in KLAMZ models for ocean quahog in this assessment were: NEFSC clam survey biomass trends and associated CV's for 1982-2005; efficiency corrected swept-area biomass estimates for 1997-2005 (see below); and catch during 1977-2005 (landings plus a 5% allowance for incidental mortality). LPUE data are included in the model but only for comparative purposes (i.e. they had nil effect on model estimates).

NEFSC (2004) chose to omit LPUE data entirely but the decision was unnecessary because it is useful to compare model trends with LPUE data and because the LPUE data have no effect on model estimates. LPUE data did not affect estimates in this assessment because the likelihood component for trends in LPUE data was set to a very low level (10^{-6}) and the survey scaling parameter Q for LPUE was calculated using a closed form maximum likelihood estimator (i.e. Q was not estimated as a formal parameter). LPUE data did not affect variances estimates because LPUE data did not affect goodness of fit to other data.

Catch data for ocean quahog were assumed accurate and not estimated in the model. NEFSC clam survey data were used to measure trends in biomass. NEFSC clam survey data for 1994 were omitted because electrical voltage supplied to the pump on the survey dredge was set to 480 v, rather than 460 v, artificially increasing dredge efficiency during the 1994 survey (NEFSC 2004). Efficiency corrected swept-area biomass estimates for 1997-2005 are used to measure the scale of recent biomass levels but are not used to measure trends. Recruitment is assumed to be constant at some low level or zero. The natural mortality rate was M=0.02 y^{-1}, except in DMV (see below).

As described above, the KLAMZ model in this assessment estimates trends in fishable biomass. In contrast NEFSC (2004) modeled biomass of ocean quahog 70+ mm SL. Survey data used in the model are trends in mean fishable biomass while survey data used by NEFSC (2004) were trends in ocean quahog 70+ mm SL. Based on the fishery selectivity curve for ocean quahog, 50% of ocean quahog are selected by commercial dredges at about 73 mm SL. Thus, the previous and current assumptions about recruitment to the fishable stock are reasonably compatible.

Assumptions about growth are the same as in the last assessment. In particular, the growth parameters $\rho=e^K$ (where K=0.0176 is the von Bertalanffy growth parameter for weight), $J_t= w_{k-1}/w_k = 0.9693$ (where w_j is predicted weight at age j) are constant and the same for all regions (NEFSC 2004). These growth parameters mean that quahogs in the model are slow growing, and that quahog recruit to the fishery (reach 70 mm SL) at age k=26 (Figure A59). Growth patterns differ among regions (Lewis et al. 2001 and Figure A56) but ocean quahog are difficult to age and there is too little information available to use region-specific growth curves (NEFSC 2000). The growth curve used in KLAMZ models for all areas but GBK was estimated from data collected in the Mid-Atlantic Bight where fishing occurs. Lewis et al.'s (2001) growth curve was used for GBK sensitivity analysis runs.

An assumed level of variance in instantaneous somatic growth rates (IGR) for old recruits is used to help estimate the initial age structure of ocean quahogs in the initial years of the model (Appendix A5). For ocean quahog in each region, IGR values during 1979-1980 were estimated assuming a lognormal distribution with arithmetic mean equal to the estimated IGR for 1981 and an arithmetic CV for years 1981-2005 estimated in a preliminary run. For ocean quahog, this constraint is unimportant because estimated age structures were stable due to assumptions about recruitment and low mortality rates.

ESB data are very important in KLAMZ models for ocean quahog as a source of information about biomass scale. Trends in ESB data during 1997-2005 were ignored in modeling because the time series is short (four years) and because information about trends from the NEFSC clam survey is already provided by the clam survey biomass index for 1982-2005. To use ESB data as a measure of scale while ignoring trend (see Appendix A5), the likelihood component for trends in ESB data were set to 10^{-6} so that the survey scaling parameter Q was calculated but the trend was ignored. Information in ESB data about biomass scale is contained in the estimated survey scaling parameter Q.

As described in Appendix A5, the likelihood of the survey scaling factor is calculated assuming that estimates of Q are from a lognormal prior distribution:

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

where L is the negative log likelihood, $\varphi = \sqrt{\ln(1+CV)}$ and $\tau = \ln(\overline{q}) - \frac{\varphi^2}{2}$ is the mean of the log normal distribution. For ocean quahog ESB data, the mean of the prior $\overline{q}$ = $ln(1) = 0$ if ESB data measure stock biomass accurately and CV=0.177 is the bootstrap coefficient of variation (standard deviation / mean) for the median survey dredge efficiency used in calculating ESB (Table A12).

Parameters estimated

KLAMZ models for ocean quahog in this assessment estimate either two or three parameters by maximum likelihood and numerical optimization. The three parameters potentially estimated are logarithms of: 1) biomass at the beginning of 1977, 2) escapement biomass (total biomass less biomass of new recruits) at the beginning of 1978, and 3) annual recruitment biomass (which is assumed constant over time for each region). In models where recruitment estimates were very low, recruitment was fixed at an assumed value that was nearly zero (1 kg y^{-1}) and the other two parameters were estimated.

Fishing mortality rates are calculated solving the catch equation numerically. Survey scaling parameters were calculated using a closed form maximum likelihood estimator.

Variance estimates

Variances for biomass and fishing mortality estimates and for model parameters can be estimated by the delta method using exact derivatives calculated by AD Model Builder libraries or by bootstrapping (Appendix A5). Estimates in this assessment were from the delta method.

KLAMZ Results-DMV

As in the previous assessment (NEFSC 2004), estimated recruitment was near zero and hard to estimate in preliminary runs for DMV. The annual recruitment level was therefore fixed at very low value (1 kg y^{-1}) in final runs.

The KLAMZ model for ocean quahog in the DMV area (Figure A48) fit NEFSC survey and LPUE data well (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (26%) for NEFSC survey data was smaller than the mean CV (32%) for mean kg/tow survey data but within the range of observed values (21%-53%). The estimated survey scaling parameter for ESB data was Q=0.98 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for DMV declined steadily after 1978. Estimated fishable biomass during 2005 was 34% of the estimate for 1978 (Figure A48). During 2005, fishable biomass was 101,000 mt (CV 18%) and mean fishing mortality was 0.0094 y^{-1} (CV 18%).

KLAMZ Results-NJ

The KLAMZ model for ocean quahog in the NJ area (Figure A49) fit NEFSC survey and LPUE data well (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (32%) for NEFSC survey data was larger than the mean (19%) and range (14%-24%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=0.95 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for NJ declined steadily after 1978. Estimated fishable biomass in NJ during 2005 was 44% of the estimate for 1978. During 2005, fishable biomass was 401,000 mt (CV 17%) and mean fishing mortality was 0.0017 y^{-1} (CV 17%).

KLAMZ Results-LI

The KLAMZ model for ocean quahog in the LI area (Figure A50) fit NEFSC survey data well. The model fit LPUE data well (Figure A50) except during early years (1986-1993) when the fishery was becoming established and LPUE was relatively high but falling rapidly reflecting, perhaps, fishing down on the very best ocean quahog beds (LPUE data did not affect model estimates). The CV of arithmetic scale residuals (28%) for NEFSC survey data was larger than the mean (19%) and at the upper bound of the range (14%-28%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=1.0 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for LI increased steadily after 1978 until 1992 when fishing mortality increased to maximum levels. Estimated fishable biomass in LI during 2005 was 94% of the estimate for 1978 and 90% of the maximum estimated biomass during 1992. During 2005, fishable biomass was 678,000 mt (CV 18%) and mean fishing mortality was 0.016 y^{-1} (CV 18%).

KLAMZ Results-SNE

The KLAMZ model for ocean quahog in the SNE area (Figure A51) did not fit NEFSC survey data or LPUE data as well as for other areas (LPUE data did not affect model estimates). Predicted survey values from the KLAMZ model decreased slowly in all years. Trends is fishable biomass based on mean survey kg/tow and LPUE data suggest an increasing trend in biomass before 1994 and a decreasing trend afterwards. These patterns are discussed in detail below.

The CV of arithmetic scale residuals (24%) for NEFSC survey data was smaller than the mean 29%) but within the range (18%-47%) of CV values for mean kg/tow survey data. The estimated survey scaling parameter for ESB data was Q=0.99 indicating that the model was able to match the observed ESB biomass levels on average during 1995-2005 using the catch data and trends in NEFSC survey data.

Biomass estimates for SNE decreased steadily after 1978 until 1996 when landings and fishing mortality increased to peak levels. After 1996, biomass decreased at a slightly faster rate. Estimated fishable biomass in SNE during 2005 was 75% of the estimate for 1978. During 2005, fishable biomass was 595,000 mt (CV 18%) and mean fishing mortality was 0.003 y^{-1} (CV 18%).

Uncertainty about historical estimates and hypotheses about lack of fit

The apparent lack of fit to survey trend and LPUE data for SNE contributes uncertainty to historical biomass estimates but has little effect on estimates for recent years which were anchored by efficiency corrected swept area biomass data. However, future assessments should consider more complicated models that address hypotheses described below that might explain upward trends in fishable biomass prior to 1994 and decreasing trends afterwards.

It is possible that the upward trend in LPUE during 1984-1993 reflects an exploration phase during which the fishery searched for and located prime fishing grounds. However, this explanation does not apply to survey trend data.

Changes in recruitment patterns and the assumption of constant recruitment in the KLAMZ model might explain the difference between trends in KLAMZ model estimates and survey trend and LPUE data. However, survey trends in fishable biomass are not consistent with survey length and recruit trend data. In particular, survey length data (Figure A26) and survey recruit abundance data (Figure A21) do not suggest strong recruitment prior to 1994 and weak recruitment afterwards. Survey length data for 1980-1994 do not show a mode of small ocean quahog recruiting to fishable size while survey trend data and LPUE were increasing. Survey length data after 1994 do not show reductions in recruits while survey trend and LPUE data were decreasing. Survey recruit abundance data seem, in particular, to suggest higher recruitment after 1994.

Changes in landings and fishing mortality may explain the trends in survey trend and LPUE data. Annual landings were low (0 to 1,000 mt) during 1978-1994 while the survey trend and LPUE data were increasing. After 1994, landings increased dramatically (2,000 to 9,000 mt) during while survey trend and LPUE data were decreasing.

KLAMZ–methods for GBK trial and sensitivity runs

For the first time, the KLAMZ model was applied to GBK on a trial basis and to conduct sensitivity analyses. The trial run indicated increasing biomass in GBK since 1986. Rapidly increasing biomass estimates were due to the short and noisy survey trend data for GBK (Figure A20) and in particular the relatively low 1990 survey observation. The sensitivity analysis consisted of a run with the 1990 survey observation omitted.

The KLAMZ model for GBK covered 1986-2002 using NEFSC clam survey data for the same period when sampling was relatively consistent in all strata (Table A8). Survey data for 1994 were excluded due to problems with the pump voltage. Catches were zero in all years. In other respects, the configuration of the KLAMZ model for GBK was identical to the configuration used for ocean quahog in other stock assessment areas.

Based on Lewis et al. (2001), ocean quahog growth is faster on Georges Bank than in southern areas. A von Bertalanffy growth curve was therefore fit to weight at age information for ocean quahog in GBK to obtain growth parameters used in the KLAMZ model. The weight at age information was obtained by converting Lewis et al.'s (2001) growth curve for length to meat weight at age using length-weight parameters for GBK (Table A9). The resulting von Bertalanffy curve for growth in weight ($W_a = 41.07\left(1 - e^{-0.04525(\mathrm{a}-0.3695)}\right)$ where W_a was meat weight (g) at age a years) closely approximated the weight at age information. The growth parameters used in the KLAMZ model were $\rho = e^{-0.04525} = 0.9558$ and $J = {w_{k-1}}/{w_k}$ = 15.59/16.66 = 0.9362 where w_k was the meat weight at age 13 which is approximately when ocean quahog reach 70 mm SL and become available to fishing (if fishing occurs).

Confidence intervals for estimated biomass on GBK were computed assuming that errors were from a lognormal distribution. In particular, the 95% bounds for the biomass estimate B were computed $Be^{\pm 1.96\sigma}$ where $\sigma = \sqrt{\left(1 + CV^2\right)}$ and CV is the arithmetic scale coefficient of variation. The CV was the ratio of the biomass estimate and arithmetic standard deviation estimated in the KLAMZ model using AD-Model builder libraries and the delta method.

Recruitment and surplus production rates from the KLAMZ model for GBK were compared to results from the LI region where a strong recruitment event occurred and where biomass appears to have increased at least slightly during some years (Figure A50). Recruitment estimates (assumed constant) in the two regions were divided by the area (nm^2) of each region to make estimates for the two regions comparable on a per unit area basis. The annual instantaneous surplus production rate for each region is $\overline{P} = \overline{G} + \overline{r} - M$ where $\overline{G}$ and $\overline{r}$ are average rates for somatic growth and recruitment. The average growth rate is the mean of annual rates which are computed automatically in KLAMZ (Appendix A5). The average recruitment rate is the mean of annual recruitment rates which were computed $r_t = R_t / \overline{B}_t$ with the average biomass during each year $\overline{B}_t$ computed automatically in KLAMZ (Appendix A5).

KLAMZ–results for GBK trial and sensitivity runs

The estimated trends from KLAMZ model runs for GBK (Figures A52-A53) were judged implausible and not used for GBK because of the short survey time series (six observations during 1986 to 2002), frequency of survey strata that were not sampled

(Table A8), lack of catch data due to no fishing on GBK, no contrast in biomass levels due to catch that are usually used in stock assessment modeling to measure stock productivity, interannual variability and lack of consistent trend in survey data over time, statistically insignificant trend in survey data (see below under the heading "GBK at virgin biomass?"), lack of LPUE data to serve as corroboration, lack of evidence for recruitment in survey length data, and lack of historical biomass estimates for 1978 that might be used to calculate historical biomass. In addition, KLAMZ model estimates for GBK seemed implausible because the average surplus production rate and average recruitment per unit area for GBK were substantially higher than estimates for LI where a strong recruitment trend occurred and where biomass levels may have increased.

The trial model fit NEFSC clam survey data after 1994 better than before 1994 (Figure A52). With the 1998 survey observation omitted, the model fit was much better (Figure A53). The estimated survey scaling parameter for ESB data was Q=0.98 in both runs indicating that the model was able to match the observed ESB biomass levels during 1995-2005.

In the trial run (Figure A52), estimated biomass increased by about 99% from 735,000 mt during 1985 to 1,466,000 mt during 2002 (5% per year). Means for annual recruitment and surplus production rates on GBK during 1985-2002 were 2.3 and 8.8 times larger than for LI. Mean recruitment per unit area on GBK (Figure A52) was twice as high as on LI. The 95% confidence interval for trends in estimated biomass (Figure A52) was broad and, at the extremes, included scenarios with stable trends.

In the sensitivity run omitting the 1989 survey (Figure A53), the increasing trend in biomass was not as steep. In particular, estimated biomass increased by about 48% from 940,000 mt during 1985 to 1,389,000 mt during 2002 (2.4% per year). Means for annual recruitment and surplus production rates on GBK during 1985-2002 were 1.6 and 5 times larger than for LI. Mean recruitment per unit area on GBK (Figure A54b) was 1.5 times as high as on LI. The 95% confidence interval for trends in estimated biomass (Figure 56) was broad and largely compatible with scenarios with stable trend.

"Best" Estimates

KLAMZ model estimates were used at the best source of information about DMV, NJ, LI, and SNE during 1977-2005. VPA estimates were used for SVA and efficiency correct swept area biomass estimates were used for GBK (VPA and efficiency corrected swept-area biomass estimates for GBK are the same because no fishing has occurred there). NEFSC (2004) used VPA estimates for LI instead of KLAMZ model estimates. However, KLAMZ model estimates appear useful with addition of the 2005 survey data.

Biomass of ocean quahog and the entire stock less GBK during 1978-2005 was estimated by summing best estimates for each stock assessment area. Fishing mortality in large areas was computed by solving the catch equation with total catch, total biomass and M=0.02 y^{-1}. CV's were not calculated for whole stock biomass or fishing mortality estimates because of difficulties accommodating covariance in the estimates for individual area that was due to using the same survey efficiency estimates as prior information.

Best estimates (Table A20 and Figure A54) show declines in ocean quahog biomass for southern regions (SVA, DMV and NJ) where the fishery has been continually active. In particular, biomass during 2005 was 5%, 34% and 44% of biomass during 1978 for SVA, DMV and NJ (Table A21).

Best estimates of biomass in northern regions, which did not support the fishery until recently (LI, SNE and GBK), are relatively flat and stable. LI biomass actually increased during 1978-1992 before fishing occurred. Biomass during 2005 was 94%, 75% and 100% of biomass during 1978 for LI, SNE and GBK (Table A21). Biomass during 2005 was 76% and 66% of biomass during 1978 for the entire stock and the entire stock less GBK (Table A21).

Best estimates of fishing mortality rates (Figure A55) for southern areas where the fishery has been continually active (SVA, DMV and NJ) peaked during the late 1980's and early 1990's then declined as fishing effort shifted towards the north (Figures A4-A6 and A11). Fishing mortality rates in northern areas (Figure A55) were nearly zero before 1990 and increased substantially in later years as fishing effort shifted towards the north. Fishing mortality rates for the entire stock increased from about 0.003 y^{-1} during 1978 to an average of about 0.006 y^{-1} (0.010 y^{-1} for the entire stock less GBK) during the early 1990s through 2005.

Proportions of total fishable biomass at various density levels

Best biomass estimates and survey data were combined to partition best biomass estimates into components found in areas with a range of biomass density levels. Biomass density is important to profitability of the ocean quahog fishery because it determines commercial catch rates. Biomass density was measured as survey catch per tow (fishable kg/tow) because commercial catch rate data for random locations and the entire stock area were not available. The analysis used random NEFSC clam survey tows during 1980-2005 (1994 excluded) that were in areas deep enough (≥20 m) to be ocean quahog habitat. All survey data was from random stations so that the survey data would measure survey catch rates across the study area on average.

Survey data for stock assessment regions other than GBK were grouped into ten-year time intervals to increase sample size. Five surveys during 1980-1989, three surveys during 1990-1999 (excluding 1994), and two surveys during 2000-2005 were used in the analysis. Survey data for GBK were grouped into two intervals 1966-1992 and 1997-2002 and analyzed as a single group (1966-2002) because GBK was covered in fewer surveys and sample size was lower. The 1994 survey was excluded from all analyses because of problems with survey dredge efficiency and electrical voltage of current supplied to the pump.

Survey tow data were grouped by 5 kg/tow biomass density categories (e.g. catches of 0-4.9 kg/tow were assigned to the same biomass density category). The grouped data were used to calculate the proportion of fishing grounds occupied by ocean quahog at each biomass density level, as well as the proportion of fishable biomass on fishing grounds at each biomass density level (see below).

Proportions of fishable biomass in one region during a single time period were calculated:

$$X_L = \frac{p_L K_L}{\sum_j p_j K_j}$$

where p_L is the proportion of random survey tows in biomass density category L, K_L is mean survey fishable kg/tow for random stations in the same biomass density category, and the summation in the denominator is over all biomass density categories. The percentage of random tows in each biomass density category p_L is an estimate of the proportion of fishing grounds in each biomass density category. Total biomass at each density level during 2005 was calculated by multiplying the proportions X_L for each region by the best estimate of total biomass in each region.

Results (Table A17) show reductions in the proportions of areas with high catch rates (p_L) and the proportion of total stock biomass in areas of high catch rates (X_L) within the southern DMV and NJ stock assessment regions where the most of the fishing for ocean quahog occurred historically. Proportions were variable in LI and SNE where less fishing has occurred.

During 2005 (Table A18), the largest component (19% or 575 thousand mt meats) of total fishable stock biomass was on GBK in the highest (25+ kg/tow) biomass density category. In contrast, stock biomass levels in density categories larger than 10 kg/tow were low for other regions.

Building a bridge

Best estimates in this assessment are higher than in the previous assessment (NEFSC 2004) due mostly to the change in estimated survey dredge efficiency (Table 21). As expected, the ratios between current and previous biomass estimates were similar to ratios for efficiency corrected swept area biomass levels (Table A19).

<u>GBK at virgin biomass?</u>

This section describes a hypothesis that fishable biomass on GBK has increased substantially since 1978 due to relatively fast growth and recruitment. The hypothesis is new and untested for GBK which has never been fished and is usually assumed to be at a high “virgin” level. The hypothesis is important because it affects estimates of stock productivity, decisions about biomass reference points (i.e. virgin biomass) and stock status determinations. No fishing occurs on GBK due to potential for PSP contamination, but experimental ocean quahog fisheries in the area are planned. Reviewer’s comments and suggestions are important and will be considered in the next assessment. However, they will not affect choice of the best biomass estimates for this assessment.

Best estimates for GBK in this and recent assessments assume a flat biomass trend since 1978 at an equilibrium “virgin” level (NEFSC 2000; NEFSC 2004). In particular, averages of efficiency corrected swept area biomass estimates during 1997-2002 were used as estimates of average biomass over longer time periods. As described above, preliminary KLAMZ model runs for GBK are not suitable for estimating long term trends in ocean quahog biomass at this time primarily due to limited prior to 1986.

Analysis of NEFSC survey data for GBK is complicated because survey coverage tends to be spotty on GBK (Table A8). During 1986-2002, survey coverage was relatively complete but 14% (18 out of 126) strata had no tows in a given year (Table A8). Only five strata (55, 57, 59, 71 and 73) were sampled during all seven years. As described above, the survey during 1994 is not comparable to other surveys during 1986-2002 because of voltage problems. Thus, only six survey observations are available for analyzing trends in ocean quahog recruitment and biomass on GBK.

Lewis et al. (2001) carried out a spatially detailed analysis of NEFSC survey data for GBK focusing on growth, spatial patterns in length composition and trends in abundance by size. The major finding was that small ocean quahog were present and that recruitment was apparently occurring on GBK during the 1990s. Lewis et al. (2001) noted that size distributions from the 1980s had a single mode and were dominated by large individuals, 75-90 mm SL. In contrast, bimodal size distributions were observed and small individuals (< 70 mm SL) often represented 20-50% of the catch in numbers at stations during the 1990s along the southeast flank of GBK. The small individuals were attributed to spawning during the 1980s. Lewis et al. (2001) did not evaluate the potential contribution of small ocean quahog to the fishable biomass for the stock as a whole.

Lewis et al. (2001) estimated a a von Bertalanffy growth curve for GBK that showed faster growth to maximum size than the growth curve for ocean quahog in the Mid-Atlantic Bight (Figure A56). Faster growth should result in higher productivity on GBK. Based on both growth curves, ocean quahog growth is relatively rapid during the first years of life and much slower in older individuals as they grow large enough to enter the fishery. The size at 50% selectivity to the commercial fishery (72 mm SL) is a reference point that separates recruits and the fishable stock. At 72 mm SL, ocean quahog on GBK grow about 1.5 mm SL per year while ocean quahog in other areas grow about 0.8 mm SL per year (Figure A56). The corresponding percentage increase in meat weight growth at 72 mm is 6% per year for GBK and 3% per year for other areas (Figure A56).

Survey length data

The survey length composition data presented in this assessment and used by Lewis et al. (2001) show that small ocean quahog and presumably recruitment occurs throughout the range of the ocean quahog stock (Figure A26 and see Section 7). The clearest example is in LI where length compositions during the 1970s and 1980s have an obvious mode due to recruitment of small individuals. As pointed out by Lewis et al. (2001), small ocean quahog were more common on GBK after 1990 and this pattern is evident in length composition data used in this assessment (Figure A26). Compared to other areas, however, length composition data for GBK are stable with relatively few small individuals and little apparent recruitment (Figure A26).

It is unlikely that ocean quahog in GBK too small to be taken in the survey (< 50 mm SL) are escaping detection by growing to fishable size during the time between surveys. Annual growth increments in GBK are 3 mm for ocean quahog 50 mm SL and increments decrease with size. Thus, a small 50 mm SL ocean quahog would be expected to growth to no more than 59 mm SL during the three year interval between surveys. Moreover, based on the growth curve for TBK, ocean quahog 50 mm SL are about age 4 y and recruits to the fishable stock at 70 mm SL are about age 14 y so that at least 10 y would be required to grow to fishable size from 50 mm SL.

Trends

Survey trends were computed for 1986-2002 (excluding 1994) using data (uncorrected for survey gear selectivity, Table A23) for ocean quahog < 70 mm SH (mean numbers per tow to measure recruitment) and ≥ 70+ mm (mean weight per tow to measure recruited stock biomass). Strata with no tows were filled by borrowing (see above), which is the standard procedure for ocean quahog.

The time series of mean weight per tow biomass indices for GBK are short (6 data points, Figure A57) but seem to suggest increasing trends. Regression lines fit to the two time series seem to indicate that biomass of ocean quahog 70+ increased rapidly and that biomass of smaller ocean quahog <70 mm increased slowly during 1986-2002. Neither regression was statistically significant (*p-value*=0.43 for ocean quahog < 70 mm SL and *p-value*=0.21 for ocean quahog 70+ mm). The apparently increasing trends were due largely to relatively low mean kg/tow in the 1989 survey (Figure A57).

6.0 BIOLOGICAL REFERENCE POINTS (TOR-3)

The Atlantic Surfclam and Ocean Quahog Fishery Management Plan (FMP, Amendment 12) defines biological reference points used as management targets and thresholds for stock biomass and fishing mortality. Targets are intended to represent desirable stock conditions. Thresholds are intended to identify overfishing (fishing mortality too high) and overfished (stock biomass too low) stock conditions.

Biological reference points used in managing US fisheries including the fishery for ocean quahog are linked in policy and law to maximum sustained yield (MSY) concepts. In particular, the overfishing threshold is meant to be smaller than or equal to F_{MSY}, the fishing mortality rate that provides MSY. Fishing mortality levels higher than F_{MSY} constitute overfishing.

The biomass and fishing mortality targets specified in the FMP for ocean quahogs are $B_{Target} = B_{MSY}$, which is assumed be one-half of the virgin biomass *for the whole stock*, and $F_{Target} = F_{0.1}$ *for the exploited region* (whole stock less GBK) The biomass and fishing mortality thresholds are $B_{Threshold} = ½\ B_{MSY}$ and $F_{Threshold}=F_{25\%}$ (the fishing mortality rate that reduces life time egg production for an average female to 25% of the level with no fishing). The FMP does not specify whether the thresholds apply to the whole stock or exploited region only.

Biological reference points for ocean quahog defined in the FMP were recalculated for this assessment resulting in substantial changes to $F_{25\%}$ and F_{MAX} (the fishing mortality rate that maximizes yield per recruit). The new and old estimates for $F_{0.1}$ are similar (Table A24 and Figure A58). Sensitivity analysis indicates that assumptions about natural mortality had substantial effect on estimated reference points (Table A24).

In recalculating biological reference points, the Invertebrate Subcommittee noted that the current threshold reference point for fishing mortality (new estimate $F_{25\%}$=0.0517 y^{-1}, Table A24) is a poor proxy for F_{MSY} in a long-lived species like ocean quahog with natural mortality rate M=0.02 y^{-1} (Clark 2002; Thorarinsdottir and Jacobson 2005). From a purely technical perspective, it would be advantageous to reconsider biological reference points in the FMP for ocean quahog and their application to the entire or exploited portions of the stock.

Simulation analyses in Clark (2002) show that the highest sustainable catches for long lived stocks like ocean quahog are achieved when lower fishing mortality rates are applied at relatively high stock biomass levels. The same simulations show that fishing at $F_{25\%}$ would eventually depress stock spawning stock biomass to less than 25% of the virgin level, a level likely far below B_{MSY}. In the simulations, long-term yield from unproductive stocks was maximized at fishing mortality rates lower than $F_{50\%}$ (Clark 2002). Fortunately, the ocean quahog fishery is currently managed under an individual ITQ system with a quota on landings that keeps fishing mortality rates lower than both $F_{0.01}$ and $F_{25\%}$. The current quota is based on market demand and other economic factors.

Revised biomass reference points (building a bridge)

New proxies for virgin biomass and B_{MSY} in this assessment are substantially larger than in NEFSC (2003). The proxy for virgin ocean quahog biomass was recalculated using the best estimates of stock biomass during 1978 for each region (3.973 million mt including GBK, Table A20). The proxy for B_{MSY} (½ virgin biomass) in this assessment 1.987 million mt including GBK. Proxies for virgin biomass and B_{MSY} in NEFSC (2004) were smaller (3.3 and 1.5 million mt). The new estimates are larger mainly because of changes in survey dredge efficiency estimates (e=0.165 instead of 0.269-0.346). In addition, the new reference points are fishable biomass rather than biomass 70+ mm SL.

Fishing mortality reference points (building a bridge)

Biological reference points for fishing mortality were calculated for ocean quahog in this assessment using a length-based per-recruit model that is part of the NEFSC Stock Assessment Toolbox.[6] The length-based model is similar to the Thompson and Bell (1934) age-based model except that selectivity, maturity and growth are specified in terms of length, rather than age. The length-based approach is advantageous for ocean quahog because fishery selectivity and maturity are better known in terms of length than age (Figure A59).

Biological assumptions for reference point calculations in this assessment were generally comparable to assumptions in the last assessment (Figure A60). The ascending logistic fishery selectivity curve in per recruit model calculations was the same as in calculation of fishable survey biomass trends. The von Bertalanffy growth curve for length at age was the same as used earlier in this assessment for the MAB (Figure A59). Length-weight parameters ($ln(\alpha)$ = -9.242, β = 2.821) were averages for the stock as a whole.

Maturity at length was from Thorarinsdottir and Jacobson (2005) for ocean quahog in Icelandic waters with 10%, 50% and 90% of female ocean quahog mature at 40, 64, and 88 mm SL (2, 19, and 61 y, based on the growth curve in Figure A59). Based on the size range of samples (G. Thorarinsdottir, pers. comm..), the maturity curve is probably valid for ocean quahog in the size range used to estimate fishing mortality.

Maturity information for ocean quahog in the US EEZ is scant (see review in Cargnelli et al. 1999) but all available information and age-based per-recruit model calculations in the last assessment are compatible with the maturity at length estimates for ocean quahog in Icelandic waters (Figure A60).

7.0 STOCK STATUS (TOR-4)

Ocean quahog in the US EEZ are not overfished and overfishing is not occurring. Stock biomass during 2005 was 3.039 million mt (Table A20) and above the revised management target of ½ virgin biomass = 1.987 million mt (Figure A61). The fishing mortality rate during 2005 (all areas but GBK) was F= 0.0077 y^{-1} (Table A20), which is below the revised management target level $F_{0.1}$ = 0.0278 y^{-1} (Figure A61)

[6] Contact Alan Seaver (Alan.Seaver@noaa.gov), Northeast Fisheries Science Center, Woods Hole, MA, USA for information and access to the Stock Assessment Toolbox.

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

The ocean quahog population is a relatively unproductive with total biomass gradually approaching the B_{MSY} reference point (½ virgin biomass, estimated as 50% of biomass during 1978) gradually after about three decades of relatively low fishing mortality (Table A20 and Figures A54-A55).

Based on survey data (Figure A20), LPUE data (Figure A8) and best estimates for 1977-2005 (Figure A54), declines in stock biomass are most pronounced in southern regions (SVA, DMV and NJ) where the fishery has been active longest. In particular, stock biomass was below the ½ virgin level during 2005 in SVA, DMV and NJ (Table A21).

An increasingly large fraction of the stock (42% during 2005 compared to 38% during 1978, Table A25) is in northern regions (LI and SNE) where fishing is relatively recent and in the GBK region, which is not fished due to risk of PSP contamination (Figure A54).

Fishing effort and mortality

Fishing effort has shifted to offshore and northern grounds over time as catch rates and abundance in the south declined (Figures A2, A4, A8 and A54). Analysis of LPUE data for individual 10' squares indicates considerable fishing down on fishing grounds that historically supplied the bulk of landings (Figures A13-A15). There is no clear indication that LPUE increased on historical grounds after fishing effort was reduced.

Fishing mortality rates during 2005 are relatively low for the entire stock (F=0.0045 y^{-1}) and for the fishable stock (F=0.0077 y^{-1}), which excludes GBK (Figure A55). Fishing mortality rates in the south where biomass was relatively low during 2005 decreased substantially over the last decade to low levels (F = 0.0, 0.0094 and 0.0017 y^{-1} for SVA, DMV and NJ) during 2005. Fishing mortality rates for LI increased abruptly during 1992 as effort increased, declined and then increased to F=0.0145 y^{-1} in 2005. The fishing mortality rate in LI during 2005 is comparable to fishing mortality rates in southern areas as they were fished down to relatively low biomass levels.

Productivity under fishing

Questions about the potential productivity of ocean quahog are becoming important as the stock is fished down from high virgin levels to B_{MSY}. Uncertainties about productivity are close related to choice of an accurate F_{MSY} proxy and other decisions that affect sustainability and fishery profitability.

Ocean quahog in the EEZ do not currently show a clear increase in stock productivity, due to higher recruitment and increased growth rates, that would be expected as biomass declines to B_{MSY} levels. Given the long periods between settlement and recruitment and slow growth once ocean quahog reach fishable size, any increase in stock productivity may be delayed (Powell and Mann 2005).

Recruitment events appear to be regional and sporadic (i.e. often separated by decades). Survey length composition data show that recruitment occurs throughout the resource sporadically and at an apparently low rate. Based on survey length composition data, some recent recruitment is evident in DMV, NJ, LI, SNE and GBK during recent years (Figure A26). Lewis et al. (2001) describe recruitment on GBK during the 1990s. Powell and Mann (2005) used a lined commercial dredge on a directed survey during 2002 and detected recruitment in some regions across the Mid-Atlantic Bight. Slow growth at sizes large enough to recruit to the fishery probably reduces the contribution of new recruits to fishery productivity (A62).

Information about growth of ocean quahog is sparse (Lewis et al. 2001). It is not possible to detect potential changes in growth at this time or to detect differences among regions (other than in GBK).

Biological condition of ocean quahog in Maine waters

The State of Maine carried out a survey and a stock assessment was completed for a portion of the ocean quahog stock in Maine waters (Russell 2006). The survey and assessment cover the principal fishing grounds in Maine waters. The fishery and biological characteristics of ocean quahog in Maine coastal waters are unique. In particular, the fishery targets small ocean quahogs for sale on the half shell market at prices roughly ten times the price paid in the rest of the EEZ. Most of the information in this section is from the assessment report for Maine waters (Russell 2006).

Biological and fishery information for Maine waters were used in the length based per recruit model (also used for the rest of the EEZ, see Section 6) to estimate conventional biological reference points for *Maine waters* only. In particular, F_{MAX} = 0.0561, $F_{0.1}$ = 0.0247 and $F_{50\%}$ = 0.013 y^{-1} for ocean quahog in Maine waters.

Assessment results for Maine show relatively high levels of fishing effort (Figure A4) and landings in recent years (Figure A2). LPUE levels have declined since the peak in 2002, but remain at relatively high levels overall (Figure A8).

Based on survey results and dredge efficiency estimates, stock biomass available to the fishery during 2005 was about 22,493 mt meats. In comparison, catch (landings plus a 5% incidental mortality allowance) during 2005 was 505 mt meats. The biomass estimate and catch data are for the area surveyed which includes the main areas of commercial fishing in Maine waters. Biomass in Maine waters is underestimated to the extent that it excludes ocean quahog outside the area where fishing occurs and the survey was carried out.

Fishing mortality during 2005 the assessed was estimated to be $F = 505 \div 22{,}493 = 0.022$ y^{-1}, which is almost equal to $F_{0.1} = 0.0247^{-1}$ calculated from a per recruit model for ocean quahog in Maine waters. The $F_{0.1}$ estimate for Maine waters has no special significance in policy because, based on the FMP, biological reference points used in defining management targets and thresholds are estimated for and applied to the entire stock.

Management goals have not been described for ocean quahog in Maine waters but maximization of long term catch is a likely candidate. Based on simulation analyses for long-lived and unproductive fish species (Clark 2002), fishing mortality rates as low as $F_{50\%}$ =0.013 y^{-1} may be required if spawning stock must be conserved to maximize long term catch levels.

The importance of maintaining spawning stock in Maine waters may be low if the bulk of recruits originate in the EEZ outside of the relatively small Maine fishing grounds. In that case, $F_{0.1}$=0.0247 y^{-1} might be useful reference point for maximizing long term catch because it would probably provide relatively high levels of yield while preserving some spawning potential. If spawning biomass in Maine waters is completely irrelevant, then long term catch might be maximized by fishing at F_{MAX} = 0.0561 y^{-1}. However, F_{MAX} is likely to require high levels of fishing effort and the estimate of F_{MAX} is sensitive to small changes in growth and fishery selectivity parameters.

8.0 TAL and PROJECTIONS (TOR-5 & 6)

Under current quota regulations, annual total allowable landings (TAL) for ocean quahog during 2007 is 24,190 mt meats (5.333 million bushels). The quota and TAL will result in a fishing mortality rate of approximately $F = 24{,}190 \div 1{,}775{,}000 = 0.014$ y^{-1} for the exploitable portion of the stock (excluding GBK) and $F = 24{,}190 \div 3{,}039{,}000 = 0.008$ y^{-1} for the stock as a whole if biomass during 2007 is similar to biomass during 2005 (1,775 and 2,698 million mt). TAL levels for longer time periods and for constant levels of fishing mortality can be calculated by projection, as described below.

Projections

A simple method for making short term projections for ocean quahog biomass, catch and fishing mortality is demonstrated in this section with example calculations. Example calculations assume either: 1) constant regional catch at 4, 5.33 and 6 million bushels; 2) constant fishing mortality at the manager's target level, $F_{0.1} = 0.0275$ y^{-1}. In the calculations wit $F_{0.1}$, for example, predicted landings could be used as TAL.

All projection calculations use the following equations to represent biomass dynamics:

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

$$B_{t+1} = B_t e^X$$

$$F = \frac{C}{B} \quad or \quad C = FB$$

where X is the net instantaneous annual rate of change, G is the instantaneous rate for somatic growth in weight, r is the rate for recruitment, $M = 0.02$ y^{-1} is the natural mortality rate, C is catch (e.g. quota for landings + 5%), and B is fishable biomass.

When catch is assumed known, the fishing mortality rate F can be calculated iteratively (e.g. Solver in Excel). When F is known, catch can be calculated directly.

Input data for projections are summarized in Table A26. Estimates of initial biomass (in 2005) and fishing mortality during 2005 were best estimates from Table A15. Catches (landings + 5%) in 2006 are assumed to be the same as in 2005. In projections with constant $F = F_{0.01} = 0.0278$ y^{-1} for exploited regions (excluding GBK) the proportions of catch in each region during 2006-2010 are assumed to be the same as in 2005. In projections for GBK, which is virgin and normally assumed to be at equilibrium carrying capacity in stock assessment work, rates for fishing mortality, natural mortality, growth and recruitment were zero so that stock biomass in GBK did not change over time. All of the projections suggest that the stock as a whole will continue to decline gradually over time (Table A27-A30). The decline is relatively rapid with $F = F_{0.01}$ (Table A31).

The method for ocean quahog is deterministic and does not consider natural variability in recruitment, growth or natural mortality. However, uncertainty in short term projections is primarily due to uncertainty in initial biomass estimates. Recruitment, natural mortality and growth of ocean quahog occur at low rates that have little effect on short term projections. Thus, CVs for efficiency corrected swept area biomass during 2005 (see below) can serve as reasonable measures of uncertainty in projections.

CVs for projected biomass levels from Table A15.							
SVA	DMV	NJ	LI	SNE	GBK	Total less GBK	Total
104%	55%	30%	31%	36%	32%	24%	24%

If uncertainty in short-term biomass projections is lognormal, then bounds for an asymmetric 95% confidence interval around projected biomass can be computed $Be^{\pm 1.96\sigma}$ where $\sigma = \sqrt{\ln\left(CV^2 + 1\right)}$.

9.0 RESEARCH RECOMMENDATIONS (TOR-7)

Recommendations from the previous assessment and new research recommendations are described sequentially.

Recommendations from last assessment

- 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.

A directed survey for ocean quahog that covered the main fishing grounds in Maine waters was completed by the Maine Department of Marine Resources during 2005 (Russell 2006). Data from box core and dredge sampling during 2006 were used to estimate survey dredge efficiency. The 2005 survey and efficiency estimate were used to estimate fishing mortality and biomass for ocean quahog in Maine waters (Russell 2006).

- 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 RV DE-II. Also, evaluate non-extractive methods to estimate dredge efficiency and survey the resource.

Data collected during 2002 and new data collected during 2005 were examined in this assessment to determine if dredge efficiency depends on depth, sediment type or clam density. Additional data and analysis are required, however, to address this research recommendation. Non-extractive methods for estimating dredge efficiency were not investigated.

- Identify whether there are major differences in life histories and population dynamics between regions, and consider treating the EEZ stock as metapopulations.

A review of life history characteristics and analysis of population dynamics of ocean quahog in Maine waters was completed (Russell 2006). Alternate spatial based management approaches were not addressed in this assessment.

- 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.

Ecological estimates of carrying capacity were not addressed in this assessment. However, information suggesting that ocean quahog biomass on GBK (a virgin area) is increasing was examined and presented for review.

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

No new field work or data analysis were carried out to address the research recommendation.

- Consider applying the relative selectivity function to the entire survey time series.

A survey selectivity curve was estimated for ocean quahog in the EEZ and a fishery selectivity curve estimated for ocean quahog off Iceland were used to better interpret survey data.

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

No progress.

- 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.

Traditional reference points from per recruit calculations were revised in this assessment using a new length based model and new estimates of fishery selectivity and maturity at length. Recent simulation work for long-lived rockfish and results for Icelandic ocean quahog were reviewed. The simulation results indicate that $F_{0.1}$ and $F_{25\%}$ are likely poor proxies for F_{MSY} in a long-lived organism like ocean quahog. Based on the simulations $F_{50\%}$ may be a better proxy. These issues could be taken up the next time the fishery management plan is revised.

- 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.

GBK was not surveyed during 2005 due to competing priorities for sampling in southern areas. However, this remains an important issue, particularly in view of hypotheses that stock biomass is increasing on GBK. Different stratification schemes were not investigated.

- 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.

The working group discussed this topic but it is not mentioned in the report because the discussions were preliminary.

- Investigate the use of survey data collected prior to 1978.

No progress.

<u>New Recommendations (not prioritized)</u>

- The *R/V Delaware II* may not be available for use on NEFSC clam surveys after 1998 and it appears likely that the clam survey will become a cooperative effort with sampling from a commercial vessel. Both the *R/V Delaware II* and commercial vessel should be used during 1998 so that catch rates, efficiency and selectivity patterns for the two vessels can be compared and calibrated. Planning should commence immediately.
- Fishing mortality and biomass reference points used as proxies for F_{MSY} and B_{MSY} should be reevaluated in the next assessment.
- Additional estimates of survey dredge efficiency from cooperative depletion studies are required.
- Develop a length (and possibly age) structured stock assessment model for ocean quahog that makes better use of survey and fishery length composition data which may provide better estimates of recruitment trends.
- Conduct further experimental work to determine the relationship between dredge efficiency, depth, substrate and clam density. A comprehensive study coincident with the next NEFSC clam survey would be most useful. The experimental design should include sufficient contrast in variables that may affect dredge efficiency.
- Cover GBK in the next NEFSC clam survey.
- Investigate the survey data from GBK during the 1989 survey to determine why it is low relative to survey observations during earlier years. This may be important in determining if biomass is increasing in GBK.
- Survey strata with no tows are a particular problem in the GBK region. The current procedure for filling holes in survey data involves borrowing data from adjacent surveys. This may not be optimal for ocean quahog surveys and GBK in particular. In the next assessment, consider filling holes in the GBK survey data using a model with stratum and year effects.
- Evaluate possible increasing trends in biomass for ocean quahog on GBK.
- Evaluate effects and contribution of recruitment to stock productivity.
- Improve estimates of biological parameters for age, growth (particularly of small individuals), and maturity for ocean quahog in both the EEZ and in Maine waters.
- Survey dredge and commercial dredge efficiency estimates should be reevaluated by field work during the next NEFSC clam survey. The next survey may be the last opportunity to estimate survey dredge selectivity. The commercial dredge selectivity curve was used in this assessment was estimated from field studies done off Iceland

where conditions may differ. Repeat tow experiments (i.e. survey stations reoccupied by commercial vessels) may be useful for this purpose.

- In the next assessment, projection calculations should be carried out using a model that is basically the same as the primary stock assessment model used to estimate biomass and fishing mortality (e.g. delay-difference population model in KLAMZ).
- Recommendations for future depletion studies.
    - It was difficult to find areas with high concentrations of ocean quahog for depletion experiment sites during 2005. However, areas with lower densities of ocean quahog can be used if depletion tow distance is increased.
    - Revised estimators for survey dredge efficiency based on commercial depletion experiments and setup tows use data for relatively large ocean quahog (i.e. 90+ mm) only. Future depletion sites should contain reasonably high densities of large individuals.
    - In future, every effort must be made to collect and record precise location data at short time intervals during depletion studies.
    - Collect length and bushel count data from survey and depletion tows more frequently (e.g. every 1-2 tows). It might be advantageous to measure fewer individuals sampled from more tows.
    - Analyze results from previous depletion studies to determine if differences between bushel counts and length composition data from different tows in the same depletion experiment are significantly different. Use the results to modify sampling protocols as appropriate.
    - Changes in length composition during a depletion experiment might be incorporated into efficiency estimation by, for example, including selectivity parameters in the Patch model. Efficiency estimates (and commercial selectivity) might be more precise because more size groups would be included in catch data.
    - It would be useful to analyze efficiency estimates in terms of season because ocean quahog are believed to change their depth in sediments on a seasonal basis.
- The next stock assessment should review the M=0.02 y-1 assumption for ocean quahog.
- In the next assessment, KLAMZ model runs with two recruitment parameters should be explored for LI and SNE. Survey length composition show more recruitment prior to 1994 than afterwards. Model fit was not as good for SNE as other stock assessment regions.
- KLAMZ model runs for GBK should be explored further in the next assessment.

10.0 ACKNOWLEDGMENTS

The Invertebrate Subcommittee thanks all hands (ship's crew, scientific crew and skipper) on board the F/V Lisa Kim during the cooperative 2005 depletion experiments. The fishing industry funded and carried out a number of key research project that were important to the completion of this assessment. J. Weinberg, P. Rago and C. Pickett (Northeast Fishery Science Center) and R. Marzak (Haskin Shellfish Research Laboratory) made useful contributions.

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