Contents

EXECUTIVE SUMMARY

This assessment update for ocean quahog in the US EEZ is based on fishery-dependent data from 1978 through 2011, NEFSC clam survey data from 1982 through 2011, and biological information. Since this is an assessment update, there are no specific terms of reference addressed. In addition, shell length-meat weight relationships, survey and commercial dredge efficiency, and size selectivity estimates were not updated to include new depletion experiment data collected in 2011, and assessment models were configured in the same way as in the previous assessment (NEFSC 2009). These types of auxiliary information will be updated in the next ocean quahog benchmark assessment.

According to the most recent data, ocean quahogs in the US EEZ are not overfished, and overfishing is not occurring. Total fishable stock biomass (all regions) during 2011 was 2.961 million mt of meats, which is above both the biomass target (1.73 million mt) and biomass threshold (1.39 million mt). The fishing mortality rate during 2011 for the exploited region (all areas but GBK) was $F = 0.01\ y^{-1}$, which is below the overfishing threshold $F_{45\%} = 0.022\ y^{-1}$.

Landings and status table (weights in thousands of mt meats): Ocean quahog

Year:	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	[1]Min	Max	Mean
[2]Quotas:													
ITQ fishery	20.4	20.4	22.7	24.2	24.2	24.2	24.2	24.2	24.2	24.2	15.9	27.2	22.2
Maine	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
[3]Landings:													
ITQ fishery	17.9	18.8	17.7	13.6	14.3	15.6	15.5	15.9	16.1	14.1	12.1	22.4	17.7
Maine	0.39	0.36	0.31	0.30	0.37	0.31	0.20	0.17	0.17	0.20	0.01	0.72	0.36
Total	18.3	19.2	18.0	13.9	14.7	15.9	15.7	16.1	16.3	14.3			
Biomass (whole stock):	3,431	3,378	3,324	3,270	3,221	3,170	3,119	3,067	3,014	2,961	2,961	3,946	3,557
Fishing mortality (exploited area):	0.0102	0.0109	0.0105	0.0083	0.0088	0.0098	0.0101	0.0107	0.0112	0.0101	0.0050	0.0110	0.0090
Fishing mortality (whole stock):	0.0052	0.0055	0.0053	0.0041	0.0044	0.0049	0.0049	0.0052	0.0054	0.0049	0.0030	0.0060	0.0050
[4]Recruitment:	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	78.74	N/A

[1]Min, max & mean: Maine quota & landings = 1990-2011; EEZ quota & landings = 1980-2011; EEZ B, F & recruitment = 1978-2011.

[2] Quotas, landings, stock biomass and recruitment expressed in thousands of metric tons meats.

[3] Landings not adjusted for incidental mortality, which is assumed to be 5% of landings. Discards are very low.

[4] Recruitment is an estimated average assuming zero recruitment in DMV and SVA. 78.74 was the level estimated before 1993.

ocean quahog stock assessment region	abbreviation
U.S. Exclusive Economic Zone	EEZ
Maine	MNE
Georges Bank	GBK
southern New England	SNE
Long Island	LI
New Jersey	NJ
Delaware/Maryland/Virginia	DMV
southern Virginia and North Carolina	SVA

In 2009, the ocean quahog Stock Assessment Review Committee (SARC) recommended new, more conservative reference points for the biomass threshold, fishing mortality threshold, and target fishing mortality. The proposed reference points were approved by the Mid Atlantic Fishery Management Council (MAFMC) in October 2009 for inclusion in Amendment 15 to the ocean quahog and surfclam Fishery Management Plan (FMP) expected to be implemented in 2013. The newly recommended $B_{Threshold}$ of 1.39 million mt is 40% of the 1978 (considered pre-fishery) biomass and the recommended biomass target is 1.73 million mt, which is one-half of the 1978 biomass. $F_{45\%}$ was recommended as a better F_{MSY} proxy for an exceptionally long-lived species with a very low natural mortality rate like ocean quahogs. The current status of the ocean quahog stock remains not overfished and without overfishing relative to these proposed new reference points.

The current FMP requires comparison of the overfishing threshold reference point to fishing mortality occurring in the exploited portion of the stock only, which currently includes the SVA, DMV, NJ, LI, and SNE regions. The GBK region, which has not been open to ocean quahog fishing since 1990 due to the risk of paralytic shellfish poison (PSP) contamination, contains about 43% of total ocean quahog fishable biomass (2011 NEFSC survey data). However, much of Georges Bank has reopened for both ocean quahog and surfclam, as effective new at-sea PSP testing protocols have been developed. Harvest policies for ocean quahog may need to be reconsidered if a fishery develops on Georges Bank. However, there have never been any appreciable ocean quahog landings from GBK due to the distance from processing plants and difficult fishing conditions there.

The ocean quahog fishery has shifted north over the last three decades as catch rates decreased on the original fishing grounds off Delmarva and New Jersey. In the 1980s, the bulk of the fishing effort was off Delmarva and southern New Jersey. In the 1990s, effort fell by half in Delmarva, as effort moved northward to the Long Island and Southern New England regions. For the past ten years, the majority of fishing effort has been in the Long Island region.

Fishing effort has declined in the ocean quahog fishery from a high of over 40,000 hours per year during the 1990s to about 25,000 hours per year recently. The number of active vessels in the EEZ in 2011 was the lowest on record, but the average size of ocean quahog vessels has also increased over time. LPUE for the EEZ stock as a whole has been fairly stable since 1982, but is currently higher in northern areas (LI and SNE) than in the south (NJ and DMV). Landings have declined since the peak of almost 22,500 mt in 1992 to a little more than 14,000 mt in 2011.

Based on assessment data, the ocean quahog population is an unproductive stock with infrequent recruitment, and thus vulnerable to overfishing. After three decades of fishing at a low *F*, the stock as a whole is being fished down. In 2011, fishable stock biomass in the southernmost regions of SVA, DMV and NJ was less than half of 1978 pre-fishery levels. (Recommended target biomass for the stock as a whole is 50% of the pre-fishery biomass.) Biomass in the more northern regions of LI and SNE increased after 1978 to due to a recruitment event and growth, but then began to decrease in the early 1990s when recruitment declined, and the fishery gradually began to move north into these regions. Recruitment events appear to be localized and separated by decades, although survey length frequencies show that a low level of recruitment occurs on a continuous basis.

Using updated survey and fishery data, the KLAMZ model was run for the whole stock, the exploited part of the stock only, and each individual assessment region except for SVA. For both the exploited part of the stock (SVA, DMV, NJ, LI, and SNE combined) and the whole stock (exploited regions plus GBK), fishable biomass continued to trend downward. Fishing mortality trended upward from 1978 through 1990 in the exploited region, but has been fairly stable since, as catches and biomass have both fallen. Estimates of fishable biomass are decreasing in all regions. KLAMZ biomass estimates for GBK in the last assessment showed a slight upward trend, but a smaller estimated survey swept-area biomass in 2011 affected the model trends in biomass and surplus production negatively.

The estimates of biomass and fishing mortality for the EEZ stock in this assessment update do not include the Maine mahogany quahog fishery, which started in inshore Maine but now takes place almost entirely in federal waters using 100,000 (Maine) bushels of the EEZ quota. The Maine stock biomass is small (~1% relative to the rest of the EEZ with landings of about 322 mt meats during 2012) and fishing effort is concentrated in a small area: just two beds separated by a few miles. Appendix 1, which was prepared in collaboration with Robert Russell of the Maine Department of Marine Resources, gives updated stock assessment information about ocean quahogs in Maine waters.

INTRODUCTION

Ocean quahog (*Arctica islandica*) in the US EEZ is regarded as a single stock. The EEZ fishery (with landings of about 14,300 mt meats during 2011) is managed under a single individual transferable quota (ITQ) system that was established for ocean quahogs and Atlantic surfclams (*Spisula solidissima*) in 1990. Murawski and Serchuk (1989) and Serchuk and Murawski (1997) provide detailed information about the history and operation of the EEZ fishery, which began around 1975. The estimates of biomass and fishing mortality for the EEZ stock in this assessment update do not include the Maine mahogany quahog fishery, which started in inshore Maine but now takes place almost entirely in federal waters. The Maine stock biomass is small (~1% relative to the rest of the EEZ) and fishing effort is concentrated in a small area: just two beds separated by a few miles. The rest of the EEZ and the Maine ocean quahog populations have different biological characteristics, support fisheries that are managed separately, use different vessels and gear, and provide different products. Updated information for the Maine fishery is presented as Appendix 1. Landings from Maine are included when total EEZ landings are calculated. Annually, 100,000 Maine bushels from the EEZ quota are allocated to the Maine fishery. Since about 1999, the Maine quota has often been exhausted and Maine fishermen have leased ITQ shares in order to exceed the Maine allocation.

The ocean quahog stock is often broken down into smaller regions (listed below) based on biology, fishery characteristics, and history (Figure 1). These designated regions are important in understanding the fishery but have no legal meaning.

Region	**Abbreviation**
US exclusive economic zone	EEZ
Maine	MNE
Georges Bank	GBK
Southern New England	SNE
Long Island	LI
New Jersey	NJ
Delmarva	DMV
Southern Virginia and North Carolina	SVA
mid-Atlantic Bight	MAB

Entire stock vs. the exploited region

Data and analysis for both the entire stock of ocean quahogs in the EEZ and the “exploited region” are presented in this assessment update. The entire stock refers to ocean quahogs in all six assessment regions: SVA, DMV, NJ, LI, SNE, and GBK. The “exploited region,” by contrast, excludes GBK, as it has been closed to ocean quahog harvesting since 1990 as a precaution against paralytic shellfish poison (PSP). Data from the 2011 NEFSC clam survey indicate that 43% of ocean quahog biomass is found in the GBK region. As of December 2012, much of Georges Bank reopened for both ocean quahog and surfclam fishing as effective new at-sea PSP testing protocols have been developed and tested. However, as of this assessment update GBK has not been fished for ocean quahogs. The reason for the distinction between the whole stock and the exploited region is that certain management limits apply only to the exploited region, such as the $F_{threshold}$.

Fishable stock

Fishable ocean quahogs are animals large enough to be taken by the fishery based on the size selectivity curve of commercial gear. Stock biomass is always larger than fishable biomass, as it includes the quahogs that are too small to be taken by the fishery.

Units of measurement

Body size in ocean quahogs is measured in terms of shell length (SL), which is the longest distance along the vertical axis of an intact specimen.

Units of measure for ocean quahogs used in this assessment update are described below. Commercial data are reported in industry bushels in logbooks, and often converted to meat weight (which includes all soft tissue within the shell) for use in this assessment update.

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
Maine bushel	0.662 industry bushels
Cage	32 Industry bushels

Previous assessments

Stock assessments for ocean quahog in the EEZ were completed by the NEFSC in 1995, 1998, 2000, 2004, 2007, and 2009. The last assessment (NEFSC 2009) concluded that the EEZ ocean quahog resource was not overfished and that overfishing was not occurring.

Biological characteristics

Ocean quahogs are found in the north Atlantic, from Spain on the east side, up to Iceland, and down to Cape Hatteras NC on the west side (Theroux and Wigley 1983; Thorarinsdottir and Einarsson 1996; Lewis et al. 2001). They are found at depths of 10-400 m, depending on latitude. Shallower water habitats, such as the waters around Iceland, are utilized in the northern end of their range (Theroux and Wigley 1983; Thompson et al. 1980). The US stock is mostly found at depths of 25-95 m. Dahlgren et al. (2000) found no genetic differences between samples taken along the US coast from Maine to Virginia, based on mitochondrial cytochrome *b* gene frequencies.

The natural mortality rate and longevity of ocean quahogs are uncertain. Ocean quahogs are extremely long-lived. Individual specimens are commonly aged at over 200 years (Jones 1980; Steingrimsson and Thorarinsdottir 1995; Kilada et al. 2007; Strahl et al. 2007). Ageing studies of ocean quahogs off New Jersey and Long Island (Thompson et al. 1980; Murawski et al. 1982) established that clams ranging in age from 50-100 years are common. Recently, Wanamaker et al. (2008) aged two ocean quahogs at 287 and 405 years, and Butler et al. (2012) aged one at 507 years, possibly the oldest non-colonial animal ever documented. Based on mean longevity estimates of around 200 years, adult ocean quahogs in the EEZ and off Iceland are assumed to die from natural causes at the rate of about 2% annually (instantaneous rate of natural mortality *M* of 0.02 per year). When M=0.02, about 1% of a cohort is expected to survive after 230 years. Estimates of M for two different unexploited populations of ocean quahogs from Canadian waters (Sable Bank and St Mary's Bay) were 0.03 and 0.10 respectively based on age-frequency data for unexploited populations (Kilada et al. 2007), which suggests there is some variation in natural mortality among locations.

Ocean quahogs grow slowly after the first few years of life (Lewis et al. 2001; Kilada et al. 2007) and typically reach a maximum size of about 110 mm SL, although larger specimens are found in small numbers. Individuals large enough to recruit to the fishery grow less than one percent per year in meat weight and less than 1 mm per year in shell length. Growth has been found to be faster on GBK than further south in the mid-Atlantic Bight (MAB). Ocean quahogs reach 73 mm (50% commercial selectivity) at age 13 years in GBK and 28 years in MAB (NEFSC 2009).

Maturity information specifically for ocean quahogs in the US EEZ is limited (see review in Cargnelli et al. 1999), but size and age at maturity appear to be variable. Off Long Island, the smallest mature ocean quahogs found were 36-41 mm SL and 6 years old, but some were also found to be still sexually immature at the age of 14 years (Thompson et al. 1980; Ropes et al. 1984). Females are more common than males among the oldest and largest individuals in the population (Ropes et al. 1984; Fritz 1991).

The SL/maturity relationship used in the KLAMZ model runs for this assessment update (Figure 2) is from Icelandic ocean quahogs (Thorarinsdottir and Jacobson 2005). The curve indicates 50% of female ocean quahogs are mature at 64 mm (19 years, based on the growth curve in Lewis et al. 2001 for MAB) and 90% are mature at 88 mm SL and 61 years old. Based on the commercial selectivity curve (Figure 2), about 50% of ocean quahogs are selected by the fishery at 72 mm SL (28 years, based on the growth curve for MAB) and 90% are selected by 93mm (86 years). The majority of ocean quahogs have likely reached maturity before recruitment to the fishery.

Shell length-meat weight (SLMW) relationships are important for ocean quahogs because survey catches in number are converted to meat weights based on shell length for many analyses. The SLMW relationships used for this assessment update, estimated using a mixture of frozen and fresh meat samples, are region-specific and have been used since the 2004 assessment (Table 1). A large number of fresh meat samples (which may yield a more accurate weight than frozen samples) have been collected during recent surveys, which will allow the SLMW relationships to be re-estimated in the near future.

Recruitment

Ocean quahog recruitment events are regional and infrequent (Powell and Mann 2005; Harding et al. 2008). The regular presence of small ocean quahogs in survey length frequencies indicates that low-level recruitment is continually occurring, particularly in the northern regions. But thirty years of survey data (1982-2011) show only a few regional-scale recruitment events occurring over this time where there has been a distinct mode of smaller quahogs visible in the survey length frequency (for example, see Figure 32D: SNE survey length frequencies for 1997 and 2005). Because growth is so slow, there is a delay of one to three decades between larval settlement and production of recruits to the fishery. Ocean quahog recruitment patterns at biomass levels reduced by fishing are a major uncertainty for the fishery (NEFSC 2007).

COMMERCIAL FISHERY DATA

There are no recreational landings of ocean quahogs, as they are found far offshore in deep water, require expensive gear and vessels to harvest, and provide essentially the same product recreational fishermen can get from inshore quahogs (*Mercenaria mercenaria*) with less effort. Landings of ocean quahogs from state waters (inshore of three miles) are effectively zero.

Since 1980, ocean quahog and surfclam vessel captains have been required to fill out specialized trip logbooks, and these are the primary source of landings, location, and effort data for ocean quahogs. Landings and quotas for the ITQ fishery are usually reported in industry bushels (each industry bushel holds 1.88 ft^3 of quahogs, about 10 lbs of meats), as clams are offloaded in cages that hold 32 bushels each, and these serve as a unit of measure for processors and vessel operators. For this assessment update, biomass and landings have been converted to meat weights unless otherwise noted.

Total EEZ landings were relatively high during the late 1980s through the mid-1990s, with a peak of 22,500 mt meats (or 4.9 million ITQ bushels) during 1992 (Figure 3; Table 2). After 1996, landings began a steady decline that lasted until 2002, when they increased again by about a third and stayed high for three years. It was in 2002 that the majority of ocean quahog landings began to come from the LI region. After 2004, landings dropped off again and have been fairly stable since. Industry sources report that lower landings during the most recent years have been due to reduced market demand. Landings averaged 91% of the EEZ quota during 1990-2000 and 71% of the EEZ quota during 2001-2011.

Prices

Nominal ex-vessel prices for ITQ ocean quahog landings, expressed as dollars per pound of meats (Figure 4; Table 3) have doubled since the mid 1980s from 31 cents to 65 cents. Adjusted for inflation, prices have been stable or increased slightly during this time.

Fishing effort

Total days (24 hours) fished by the ITQ fishery have decreased from a high of more than 1900 days per year in the early 2000s to less than 1000 days per year in 2011 (Figure 5; Table 4), which is roughly the same as the early 1980s. The total number of trips taken by the ITQ fishery has decreased steadily from about 3,500 trips per year in 1989 to about 1,000 trips in 2011 (Figure 6). In 2009, however, there appeared to be an unusual number of trips into the SNE region, which effectively doubled the total number of ocean quahog trips compared to the year before or the year after. As the number of trips per year has declined, trip duration has increased (Figure 7). The number of vessels active in the ITQ ocean quahog fishery has declined since

2003 (Figure 8), but the average ocean quahog vessel has gotten larger (Figure 9) and landings per trip have doubled since the 1980s (Figure 10).

Landings per unit effort (LPUE)

LPUE (measured as bushels landed per hour fished) for the ocean quahog fishery is mostly a measure of fishing success rather than stock abundance, as any negative change in stock abundance can be masked by the transfer of fishing effort to areas where ocean quahog density remains high. In spite of this, LPUE and NEFSC clam survey data are highly correlated for southern areas (DMV and NJ), where significant levels of fishing have occurred over the longest period of time (NEFSC 2007).

Because the fishery can move to new areas when LPUE begins to decline, LPUE for the ITQ fishery as a whole has been basically stable since 1980, between 100 and 150 bushels per hour (Figure 11; Table 5). Since 1980, LPUE has declined in the traditional southern fishing grounds of DMV and NJ to around 60-80 bushels per hour, but LPUE in the LI and SNE regions, where the majority of fishing effort has been since 1990, has been stable or increasing.

The break-even LPUE for ocean quahogs (where variable costs and revenues are the same) was 80 bushels per hour in 2004 (NEFSC 2004). Inflation, increased steaming time to offshore fishing grounds, operation of new larger vessels, increased costs for food, insurance, etc., and especially the variability in the price of fuel, make it difficult to estimate a current break-even LPUE, but it is probably higher than it was in 2004.

For the 2006 assessment (NEFSC 2007), LPUE data were standardized by adjusting for individual vessel, vessel size, and month to see if these variables would have an effect on the trends. Estimated standardized trends were very similar to trends in nominal (unadjusted) LPUE. Following NEFSC (2009), the LPUE data presented in this assessment update have not been standardized.

Spatial patterns in fishery data

Interpreting spatial patterns in fishery data is important, especially for managing sessile and unproductive organisms like ocean quahogs. The ocean quahog stock is a complicated spatial mosaic, with scattered productive and profitable areas where abundance is high and where fishing mortality tends to be concentrated. The size of a productive ocean quahog bed appears to be less than the size of a ten-minute square (TMSQ, 10 minutes longitude x 10 minutes latitude ≅ 100 nm^2), which is the smallest unit used to report fishing location in logbooks.

Spatial patterns in landings, effort, and LPUE reflect a shift in the distribution of the fishery northward and offshore over time. During the 1980s, nearly all of the landings and fishing effort were from the southern DMV and NJ regions (Figure 12; Tables 6 and 7). Landings are assigned to assessment region by statistical area (Figure 13). As LPUE declined in DMV and NJ, fishing effort and landings shifted to the LI and SNE regions. In 1980, 35% of landings were from DMV, 65% were from NJ, and less than one percent was from LI. In 1990, 18% of landings were from DMV, 74% of landings were from NJ, 4% were from LI, and 4% were from SNE. During 2011, 2% of landings were from DMV, 13% were from NJ, 72% were from LI and 12% were from SNE. Percentage of fishing effort by region mirrors the percentage of landings, as vessels have adjusted fishing locations fast enough to keep the LPUE for the stock as a whole stable (Table 4).

Most ocean quahog boats have fished in two assessment regions over the course of a year since 2003 (Figure 14), and about 10% of vessels fished in three regions. If they only fished in one region (between 20% and 40% of vessels in any one year), it was most likely to be LI. Vessels that fished in two regions were most likely to be in the LI and SNE regions. Interestingly, in 2011 more vessels fished in NJ and LI than SNE and LI.

Fishery data by ten-minute square (TMSQ)

Vessels that fish for ocean quahogs in the EEZ are required to report landings and fishing effort by TMSQ for each trip in mandatory logbooks. TMSQ are formed by dividing one-degree squares 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 TMSQ name before the row number. Rows are numbered 1-6 counting from north to south. Thus, TMSQ 436523 is the ten-minute square whose southeast corner is at 43°30’ N and 65°40’ E.

Landings during 1980-1990 were concentrated in a few TMSQ that were primarily in the south and relatively inshore (Figure 15). Over time, TMSQ with highest landings shifted offshore and north. Landings during 2001-2011 were concentrated in the LI region.

Fishing effort was concentrated in a few southern TMSQ during 1980-1990, with several adjacent TMSQ in the DMV assessment region having effort levels higher than 1,000 hours per year, and appreciable fishing effort south of 38°N (Figure 16). Fishing effort spread into additional offshore and northern TMSQ during 1991-2000. After 1995, there were few or no TMSQ with effort levels above 1000 hours per year.

Like landings and effort, LPUE was high inshore and south during 1980-1990, with at least ten TMSQ that had LPUE $\geq$ 200 ITQ bushels per hour fished (Figure 17). LPUE in the area below 40°S was generally high. During 1991-1995, LPUE declined in the south and fishing effort spread northward above the 40° line into the LI region, where LPUE was still over 200 bushels per hour in many TMSQ. During 1996-2005, the fishery continued to move northward into the SNE region where catches were profitable. By the 2006-2011 time period, LPUE was less than 100 ITQ bushels per hour in all TMSQ below 39°S where fishing was reported by more than three vessels.

Trends for important TMSQ

Trends in landings, fishing effort, and LPUE during 1980-2011 were plotted for individual TMSQ that were considered important to the fishery. “Important” TMSQ include those where landings were greater than 100,000 bushels in one year during the time period, so even if they are no longer fished or if they have not been fished until recently, they were important to the fishery at some time during 1980-2011. These TMSQ plots have been divided up into assessment regions (Figure 18A-D).

Trends in LPUE for individual TMSQ tend to be high during the first years of exploitation and then tend to decline as effort, annual landings, and cumulative landings increase over time.

Unlike LPUE, which is highest in the first years of exploitation, landings and fishing effort tend to peak after 5-10 years of exploitation as LPUE stays high and then begins to decrease as beds are fished down. Decreasing trends in LPUE appear strongest in the DMV and NJ areas with the longest history of exploitation. However, in some important TMSQ where fishing effort and landings have declined over the years (e.g. TMSQ 387314 and 387443 in DMV, and 407336 in NJ), LPUE appears to have increased slightly recently under light fishing effort.

Bycatch and discard

Discard of ocean quahogs occurs at a minimal level, since the bars of the dredge are set to retain quahogs of the desired size and let the smaller ones fall through. Some incidental mortality occurs when the dredge breaks clams while fishing that are not retained. Based on Murawski and Serchuk (1989), it was assumed starting with the 2004 assessment that incidental mortality rates are ≤ 5% for ocean quahogs 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).

A small amount of bycatch of ocean quahog occurs in the Atlantic surfclam fishery, although there is strong incentive not to fish in areas where both species occur: mixed loads of surfclams and ocean quahogs are not acceptable to processors, and it is not practical to sort catches at sea. Fisheries Observers were aboard 16 surfclam trips between 2004 and 2008, and reported discarded ocean quahogs averaged about 100 pounds per surfclam trip. 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 surfclams have shifted towards deeper water in response to warm water conditions (Weinberg 2005). This may change discard patterns in the future if processors continue to refuse mixed catches.

Bycatch and discard of ocean quahogs in other fisheries are zero. Ocean quahogs are not vulnerable to bottom trawls, scallop dredges (they are too deep in the sediment), gillnets, or hook and line gear.

Data from 30 observed ocean quahog trips indicate bycatch by the ocean quahog fishery includes mainly scallops (mean of 855 pounds per trip), skates (mean of 331 pounds per trip), monkfish (mean of 92 pounds per trip), unclassified snails (mean of 43 pounds per trip), spiny dogfish (mean of 22 pounds per trip), and crabs (mean of 30 pounds per trip). Summer flounder, ocean pout, longhorn sculpin, and smooth dogfish are caught incidentally at a mean of less than five pounds per trip. Fourspot flounder, striped sea robin, windowpane flounder, witch flounder, American lobster, northern sea robin, sea raven, black sea bass, red hake, and silver hake are caught incidentally at a mean of less than one pound per trip.

Commercial size selectivity

The commercial fishery selectivity curve used in this assessment update (Figure 2) is from Thorarinsdottir and Jacobson (2005), who estimated selectivity of commercial dredges that harvest ocean quahogs off Iceland. Based on this commercial selectivity curve

$$s_L = 1/\left(1 + e^{7.63 - 0.105L}\right)$$

where *L* is shell length in mm, and about 10%, 50%, and 90% of ocean quahogs are available to the fishery at 51, 72, and 93 mm SL (9, 28, and 86 years, based on the growth curve for MAB).

Dredges and towing speeds used in the US fishery are very similar to those 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 1¼ in (3.5 cm), and was towed at about 2.1 knots (3.9 km h^{-1}). The vessel used for the experiment pumped water to jets on the dredge at about 109 psi (7.5 bars), similar to many vessels in the US fishery. Fishery selectivity curves are used in tracking trends in fishable biomass, estimating fishing mortality, and calculating biological reference points.

Commercial size-composition data

Commercial length composition data are collected by port agents from landed ocean quahogs (Table 8). The data indicate that the size composition of ocean quahogs harvested in all regions can vary from year to year due to both population dynamics of the ocean quahogs and fishing behavior (Figure 19A-D). The largest quahogs have been harvested recently from the DMV and NJ regions; those from the LI and SNE regions are about a centimeter smaller on average.

Smaller ocean quahogs were landed from the SNE and LI regions during 1997-2000 due to vessels targeting specific beds of small ocean quahogs with a high meat yield. When the port sample length frequencies from the LI and SNE regions are plotted together for recent years (Figure 20A-B), it is possible to see the smaller landed ocean quahogs in 1999.

FISHERY INDEPENDENT DATA

NEFSC clam survey

NEFSC clam survey data from 1982 through 2011 were used for this assessment update. From 1978 to 1997, clam surveys were conducted during the summer on an irregular schedule; since 1999 they have been conducted regularly every three years. Clam survey data prior to 1982 were not used for this assessment update because the surveys were done during different seasons, used other sampling equipment, or are otherwise inconsistent with the rest of the time series. Since 1982 the surveys have been conducted from the R/V *Delaware II* using a standard NEFSC hydraulic dredge with a submersible pump, a 152 cm (60 in) blade, and a 5.08 cm (2 in) mesh liner to retain small ocean quahogs and Atlantic surfclams. The survey dredge differs from commercial dredges in that it is smaller (5 ft blade instead of 8 to 12.5 ft), has a small-mesh liner, and the pump is mounted on the dredge instead of the deck of the vessel. The survey dredge retains ocean quahogs as small as 50 mm SL (size selectivity described below). Changes in ship construction, winch design, winch speed, and pump voltage that may have affected survey dredge efficiency are summarized in Table A7 of NEFSC (2004). Each of these factors has been constant since the 2002 survey.

NEFSC clam surveys are organized around NEFSC shellfish strata and stock assessment regions (Figure 1). Most ITQ ocean quahog landings originate from the area covered by the survey. The survey did not cover GBK during 1982, 1983, 1984, or 2005, and individual strata in other areas were sometimes missed. Strata not sampled during a particular survey are "filled" for assessment purposes by borrowing data from the same stratum in the previous and/or next survey, if data are available (Table 9). Survey data are never borrowed from surveys further back than the previous survey or beyond the next survey.

Surveys follow a stratified random sampling design, allocating a pre-determined number of tows to each stratum. The data used to measure trends in ocean quahog abundance are only from stations that were random or nearly random. A small number of nearly random tows are added to some surveys in a quasi-random fashion to ensure that important areas are sampled well. Non-random stations are occupied for a variety of purposes, such as repeat tows and depletion experiment setups, but are not used to estimate relative trends in ocean quahog abundance.

A standard tow is nominally 0.125 nm (232 m) in length (5 minutes towing at a speed of 1.5 knots). However, sensor data indicate actual tow lengths depend on depth and are generally slightly longer than 0.125 nm (Weinberg et al. 2002).

Occasionally, randomly selected stations are too rocky or rough to tow. Beginning in 1999, these cases trigger a search for fishable ground 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 an estimate of the proportion of habitat in a stratum or region that is not suitable habitat for ocean quahog. These estimates of the proportion of unsuitable habitat are used for calculating ocean quahog swept-area biomass.

Following all successful survey tows, all ocean quahogs and Atlantic surfclams in the survey dredge are counted, and shell length is measured to the nearest mm. A few very large catches are subsampled. Mean meat weight (kg) per tow is computed with shell length-meat weight (SLMW) equations from NEFSC (2004; Table 1).

Survey tow distance and gear performance based on sensor data

Since the 1997 survey, sensors attached to the survey dredge have been used to monitor depth, temperature, differential pressure, voltage, frequency and amperage of power supplied to the dredge, *x*-tilt (port-starboard angle), and *y*-tilt (fore-aft angle, effectively the "angle of attack" of the dredge) during survey fishing operations. At the same time, sensors on board the ship monitor electrical frequency, GPS position, vessel bearing, and vessel speed. Most of the sensor data are averaged and recorded at 1-second intervals.

Differential pressure, amperage, and *y*-tilt can be particularly important. Differential pressure is the pressure of water pumped through jets in front of the dredge blade to loosen the sediments. Amperage measures the work done by the pump in moving water through the jets. If there is a blockage at the pump entrance, then both amperage and differential pressure will be low. If there is a blockage downstream from the pump, then amperage will be low and differential pressure will be high. As described below, *y*-tilt can be used to determine if the dredge is on the bottom with the blade in the sediment.

A quantitative system for identifying and eliminating tows with poor performance based on sensor data has been used since the 2005 survey. (See Appendix A2 in NEFSC 2007 and Appendix B3 in NEFSC 2009 for details on the development of this system.) Before 2005 (the 1997, 1999, and 2002 surveys), the sensor data were primarily used to get a more accurate estimate of tow distance.

Survey tow distance and gear performance in trend analysis

Sensor data are not used to calculate tow distances for long-term trend analyses because sensor data are not available prior to 1997. For trend analysis, tow distances are based on start and stop locations recorded for each tow instead of sensor data. The catch at each station is then standardized to a nominal tow distance of 0.125 nm. Tows suitable for trend analysis (gear functioned well; no problems at station) are identified using database codes, which are recorded at sea by the watch chief following each tow, based on criteria used consistently since the late 1970s. Sensor data are used, however, to calculate tow distance and monitor gear performance during tows for depletion, repeat station, and other types of experimental studies conducted since 1997.

Survey gear selectivity

A selectivity curve for ocean quahogs by the NEFSC clam dredge was estimated in NEFSC (2004). Catches by a commercial dredge with a chicken-wire mesh liner (theoretically, to retain all but the smallest juvenile ocean quahogs) during 2003, compared with survey dredge catches in the same area during 2002, served as a basis for the curve, which estimates probability of capture based on shell length (Figure 21). The resulting selectivity curve,

$$s_L = 1 / \left(1 + e^{8.122 - 0.119L}\right)$$

indicates that 50% of ocean quahogs are fully available to the NEFSC dredge at about 68 mm SL, compared to about 72 mm for commercial dredges. The survey dredge tends to retain smaller ocean quahogs than commercial dredges because of the 50 mm mesh liner in the survey dredge.

Survey catch used to make stock and fishable abundance/biomass estimates

The survey catch data for ocean quahogs were adjusted to estimate relative abundance and biomass of both the whole stock and fishable stock. Abundance and length composition of the whole stock were estimated by adjusting the number of quahogs at sizes not fully selected by the survey dredge upward, by applying the survey dredge selectivity curve. Abundance and length composition for the fishable stock (quahogs large enough to be caught in a commercial dredge) were estimated by adjusting the whole stock estimates downward, by applying the commercial dredge selectivity curve. Calculations of whole stock abundance occasionally produce large estimates for very small ocean quahogs, since survey selectivity is near zero, and the number caught is adjusted upward by a large factor. Calculation of fishable abundance and biomass from ocean quahog survey data is not affected by this problem, since fishable clams are larger and the adjustments made for selectivity are small.

Depletion studies and survey dredge efficiency

Survey dredge efficiency estimates are important because they help scale relative trends to actual biomass levels in modeling, and because they can be used to estimate swept-area biomass of ocean quahogs directly. Dredge efficiency is the proportion of all ocean quahogs living in the path of the dredge that are captured (actually brought on board) by the dredge as it passes over them. This proportion serves as a "conversion factor" between the number of ocean quahogs brought up in the dredge and the actual number of ocean quahogs living in the path of the dredge. Depletion study analysis and efficiency estimates only include ocean quahogs 90 mm SL or larger, which have high selectivity (≥ 0.85) in both survey and commercial clam dredges, and reduce the effects of shell length and size selectivity on efficiency estimates.

Depletion experiments are the first step in estimating survey dredge efficiency. Depletion experiments begin with a closely-spaced group of setup tows (usually 4) taken with the survey dredge at a particular site. "Survey density" of ocean quahogs at the site is then calculated for each setup tow by dividing the catch by area swept (dredge width times the distance traveled while the dredge was effectively fishing). Mean survey density for each depletion experiment site was calculated by averaging the survey density from each setup tow. After the setup tows are completed, many tows are made in quick succession along the same path (or as close as possible) perpendicular to the setup tows, slowly depleting the ocean quahogs until a sufficient decline in catch per tow is noted (Figure 22). Vessel position is used as a proxy for dredge position during depletion experiments. One *Delaware II* ocean quahog depletion experiment has been completed in which the research vessel carried out both the setup and depletion tows, and the survey dredge efficiency was estimated directly. For the rest of the depletion experiments, the setup tows were done by the research vessel and the depletion tows were done with a commercial vessel. In these cases the estimated survey dredge efficiency (e) is:

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

where D is the estimated density from the Patch model (see below) and d is the mean survey density for the site.

Patch model

The Patch model (Rago et al. 2006; Hennen et al. 2012) is used to estimate three parameters for each depletion experiment: initial ocean quahog density D; depletion dredge efficiency e; and a measure of variance k in catch data. The model uses a gridded rectangular plot populated with simulated quahogs, with the depletion tow paths overlaid to determine (1) how many times each grid was crossed by a dredge and (2) what the underlying density would have to be to match the catches from the depletion tows. The Patch model is used in NEFSC stock assessment work for a variety of shellfish and sedentary demersal finfish. The most important characteristic of the Patch model is that the unique path of each tow is used to interpret declines in the catch, so it is not necessary to assume that the ocean quahogs mix randomly across the entire site after each depletion tow.

Some sources of uncertainty in the Patch model are variations in substrate and gear performance. For instance, the area in Long Island where two depletion experiments were conducted has a relatively thin layer of sand on top of peat. The thin layer of sand may concentrate ocean quahogs near the surface, where they are easier to catch (Pers. comm., E. Powell, University of Southern Mississippi). Also, newly replaced electrical cables (or any other gear differences) may cause changes in actual dredge efficiency if pump voltage and pressure change. Dredge efficiency is harder to estimate for ocean quahogs than surfclams because quahogs live in deeper water, where dredge position data are less reliable, and quahogs sometimes burrow out of range of the dredge. For these reasons, it is probably better to view the full set of depletion experiment dredge efficiency estimates as a distribution with an underlying mean and variance. Individual estimates and estimates for a single survey are too imprecise to be used directly in making survey-specific estimates of survey dredge efficiency. Commercial and survey selectivity estimates used in this assessment update are the same as in NEFSC (2009). New data collected during 2011 were not used, as the process required to produce new estimates is improved by the input of a working group, which will be convened for the next benchmark assessment.

Nineteen depletion experiments for ocean quahog were carried out between 1997 and 2008. Based on these experiments, the median NEFSC survey dredge efficiency is 0.169, with 90% confidence intervals of 0.154-0.285. See NEFSC (2007; 2009) for more detailed information on the efficiency estimates and individual depletion experiments, including details of the Patch model procedure, evaluating uncertainty, and sensitivity analyses.

BIOMASS AND FISHING MORTALITY

Mortality and stock biomass estimates for ocean quahog in the US EEZ are based on NEFSC clam surveys, cooperative survey studies (including depletion experiments used to measure survey dredge efficiency), fishery data, and biological data.

Survey Results

The most recent NEFSC clam survey was conducted during the summer of 2011; it was the last clam survey to use the R/V *Delaware II* as a platform before her retirement in 2012. The 2011 survey made 391 random tows and had good coverage of all regions except SVA, which has been inhabited by so few clams recently (both ocean quahogs and surfclams) that resources have been reallocated to increase coverage of other regions. Cooperative work with an industry vessel during the survey included paired tows and depletion experiments. Ocean quahogs were most abundant, based on number per 2011 survey tow, in the LI, SNE and GBK regions (Figure 23). The abundance of recruited (70+ mm SL) ocean quahogs mirrored this distribution (Figure 24), while pre-recruits (less than 70mm SL) were most abundant on GBK (Figure 25). See Appendix 2 for maps of ocean quahogs caught per tow from all surveys since 1982.

By region, survey trends in abundance and biomass of fishable quahogs have been fairly stable since the early 2000s in GBK, SNE, LI, NJ, and DMV (Figures 26 and 27; Table 10). However, out of those regions, all have seen an overall loss of both biomass and numbers between the 1980s and early 2000s except GBK, where ocean quahog fishing has not occurred (Figures 28 and 29). The survey has caught very low numbers of ocean quahogs in the SVA region since the late 1970s. This region was probably never good habitat for ocean quahogs and was mainly surveyed for surfclams.

Even though the survey dredge does not retain them fully, the presence of ocean quahogs smaller than 40mm SL in a tow can be a good indicator of an area that will experience recruitment into the fishery in future decades. Quahogs less than 40mm will be at least double the size and 60-80 years old when they finally recruit to the fishery. On GKB, the 2011 survey caught large numbers of these small quahogs that had grown enough since 2008 to be captured more efficiently by the survey dredge (Figure 30). Looking back on the occurrence of quahogs less than 40mm in survey tows since the 1970s, the large recruitment event on GBK can be seen, as well as evidence of low-level but consistent recruitment in the LI region, which now supplies the vast majority of landed ocean quahogs (Figure 31 A-C).

Changes in survey length composition over the years provide additional information about recruitment (Figure 32 A-E). In particular, survey length composition data from DMV, NJ, SNE, and GBK show evidence of recent recruitment events in these regions. Even though the overall density of ocean quahogs is low in the DMV region, it appears juveniles can successfully settle there. The smaller mode in the 2011 DMV length composition plot averages around 72 mm SL, which translates to about 30 years old and 50% commercial selectivity. Because ocean quahogs grow so slowly, recruitment events do not become apparent for some years. The survey dredge only begins to retain ocean quahogs when they are already at least ten years old, and even then they are not fully selected.

The spatial distribution of the ocean quahog resource on the east coast of the U.S. does not appear to have changed since the fishery began in the mid 1970s (Figure 33), but over time densities have declined where the bulk of fishing has occurred (NJ and DMV). The recent recruitment of small ocean quahogs on GBK can be seen clearly in the survey data, but any trends in SNE and LI are not as clear. The extent and number of the surveys used for each time period map are not exactly the same, but each survey does attempt to cover the same area, except for some years when there was no (or incomplete) coverage of GBK.

Efficiency-corrected swept area biomass

Efficiency-corrected swept area biomass (ESB) has been estimated since 1997, when NEFSC clam surveys began collecting dredge sensor data, which are needed to estimate area swept as they determine the amount of time the dredge was fishing during a tow (Table 11). Estimates of ESB are used primarily as scaling information in stock assessment models, since they are a direct estimate of biomass. ESB estimates are only made for the fishable ocean quahog population, sizes at which selectivity is high for the survey dredge.

ESB for ocean quahog is calculated:

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

where:

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

In ESB calculations, e is the best estimate of survey dredge efficiency for ocean quahogs, $\bar{\chi}$ is mean catch in kilograms of fishable ocean quahogs per standard tow based on sensor data, A' is habitat area (nm^2), a is the area that would be covered by the 5 ft wide survey dredge during a standard tow of 0.15 nm (0.00012405 nm^2 tow^{-1}), and u converts kilograms to thousand metric tons (10^{-6}). B' is the minimum swept-area biomass prior to correction for survey dredge efficiency.

The term ϕ used in ESB calculations 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). In 1999, special tows were made in these areas to approximate the ocean quahog biomass and improve the ESB estimates. According to NEFSC (2000), deep water strata accounted for 0%, 2%, and 13% of ocean quahog biomass in the LI, SNE, and GBK regions. Data for these deep water strata that were only sampled once are otherwise omitted in calculations and, in particular, calculation of mean catch per tow $\bar{\chi}$.

Habitat area for ocean quahogs in each region was estimated as

$$A' = Au$$

where u is the proportion of random tows in the region not precluded by rocky or rough ground (ocean quahogs are generally found in smooth sandy habitats), and A is the total area computed by summing GIS area estimates for each survey stratum in the region. Estimates for u in this assessment update are the same as in NEFSC (2007; 2009).

Mean catch per standard tow ($\bar{\chi}$) is the stratified mean catch of fishable ocean quahogs (C_i) for tow i after adjustment to standard tow distance (d) 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 with 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 substrate to a depth of at least one inch. Thus, the tow distance at each station was the sum of the distance covered while the sensor data show the dredge angle was $\leq 5.16^{\circ}$.

ESB-based fishing mortality estimates

Fishing mortality rates are estimated directly from the ratio of catch (landings plus an assumed 5% incidental mortality) and ESB data for each region and year (Table 12). The primary purpose for these calculations is to check on model-based fishing mortality estimates. The NEFSC clam survey provides a good approximation of average yearly biomass, because ocean quahog biomass levels change slowly as fishing, growth, and natural mortality rates are low, and the surveys occur approximately halfway through the year.

Uncertainty in ESB and ESB-based fishing mortality estimates

Variance estimates for ESB and ESB-based fishing mortality estimates are important for using and interpreting results. The formulas for estimating ESB and fishing mortality are products and ratios of constants and random variables. The random variables used in the calculations are typically non-negative and can be assumed to be approximately lognormal; therefore, we estimated uncertainty in ESB and related mortality estimates using a formula for independent lognormal 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. 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 were from a variety of sources, and were sometimes just educated guesses. The CV for best estimate of survey dredge efficiency (*e*) was 0.21, calculated by bootstrapping the median of the set of individual estimates (15,000 iterations). 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.

For a more detailed discussion of uncertainty in estimates of ESB and ESB-based fishing mortality, see NEFSC (2009).

KLAMZ model

KLAMZ (for complete technical description see NEFSC 2009, Appendix B6) 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 common age-structured models if fishery selectivity is “knife-edged,” somatic growth follows the von Bertalanffy equation, and natural mortality is the same for all individuals in the modeled population. Knife-edge selectivity means that as soon as an ocean quahog reaches a minimum fishable size, it is considered fully available the fishery, rather than having the selectivity increase gradually to one as the quahog grows. All ocean quahogs over the minimum size experience the same fishing mortality in the model. 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 each year. The model is implemented in AD Model Builder.

The main assumptions in the KLAMZ model for ocean quahog are: recruitment follows a “step” pattern with the possibility of moving from one level before 1993 and a different level after; fishery selectivity is knife-edged; the natural mortality rate is a constant $0.02y^{-1}$; and growth in weight can be described by a von Bertalanffy growth curve. Recruitment is assumed to follow a simple mean (estimated to be low for ocean quahogs) because no reliable recruitment index currently exists, recruitment levels appear to be very low based on survey data, and trends in stock dynamics are driven primarily by fishing mortality.

Recruitment to the ocean quahog fishery is not knife-edged and actually occurs over a range of sizes from 50 to 95 mm SL, with the smallest quahogs having the least chance of retention in a commercial dredge (Figure 2). Under these circumstances, KLAMZ can be used to track trends in fishable biomass, not total biomass. The fishable biomass of ocean quahogs is dominated by larger individuals that are readily captured by the survey dredge. Survey data used in the KLAMZ model are mean kg per standard tow of fishable ocean quahogs.

Despite some simplifying assumptions, KLAMZ has proven to be a relatively robust model with little or no retrospective bias, which has been used successfully for a number of stocks. It provides useful estimates of long-term biomass and fishing mortality, performs 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 model used for ocean quahog, for example, estimates only 2-4 parameters.

The NEFSC clam survey was changed in 2012. It is now carried out from an industry vessel using modified commercial gear, with one-third to one-half of the ocean quahog range surveyed each year rather than the whole range every three years. Future ocean quahog stock assessment models will have to be configured to handle these multiple survey areas while providing an estimate of total abundance for all areas in the terminal year. This capability already exists in the Stock Synthesis model (SS3), used in the most recent benchmark assessment for Atlantic surfclams (NEFSC 2013). SS3 uses both age (when available) and size data to provide better information about trends in individual year class strength and mortality. A revised version of KLAMZ as well as SS3 may be used for ocean quahogs in the next benchmark assessment, and estimated trends in biomass and mortality may change if it is decided SS3 makes better use of size composition data. However, age data are not available for quahogs, suggesting that changes in estimated trends would be modest.

KLAMZ model configurations

Since this is an assessment update, the KLAMZ model was run with the same configurations used for the last ocean quahog assessment (NEFSC 2009). Only data from the 2011 survey and landings since 2008 were added to the model runs.

Data used in the KLAMZ model for this assessment update were: NEFSC clam survey biomass and associated CVs for 1982-2011; efficiency corrected swept-area biomass estimates for 1997-2011; and catch during 1977-2011 (landings plus a 5% allowance for incidental mortality). LPUE data are included in the model for comparative purposes, but have no effect on model estimates. Catch data for ocean quahogs were assumed accurate and not estimated in the model. Survey kg/tow data provide the trend information for the model estimates, while the efficiency corrected ESB estimates for 1997-2011 are used for scale only (trends are ignored). ESB estimates are calculated using a scaling parameter Q which is derived from the survey dredge efficiency experiments.

NEFSC clam survey and swept-area biomass data for 1994 were omitted, because an inadvertent increase in the voltage to the dredge pump apparently increased dredge efficiency during the 1994 survey (NEFSC 2004). In addition, survey and swept area biomass data for GBK during 1982, 1983, 1984, 1989, 2002, and 2005 were also omitted because of poor survey coverage during those years.

The KLAMZ model assumes ocean quahogs recruit to the fishery (reach 70 mm SL) at about age 26. In reality, growth patterns differ among regions (Lewis et al. 2001), but there is too little age information available to use region-specific growth curves (NEFSC 2000). A growth curve for ocean quahogs from the mid-Atlantic Bight was used for DMV, NJ, LI, and SNE, and a separate GBK curve was used for that region (Lewis et al. 2001; Figure 34). Variance in instantaneous somatic growth rates is used to help estimate the initial age structure of ocean quahogs in the initial years of the model, but this constraint is unimportant because estimated age structures are stable due to assumptions about recruitment and low mortality rates.

Separate KLAMZ model runs were done for ocean quahogs in each of the DMV, NJ, LI, SNE, and GBK regions; for the stock in the exploited region (DMV, NJ, LI, and SNE regions combined); and for the entire stock (DMV, NJ, LI, SNE, and GBK regions combined) during 1977-2011. The model was not used for the SVA region because survey data are noisy and sparse.

Parameters estimated

KLAMZ models for ocean quahogs estimate four parameters by maximum likelihood and numerical optimization. The parameters estimated are logarithms of: (1) biomass at the beginning of 1977; (2) escapement biomass at the beginning of 1978 (biomass in 1977 that survived until the beginning of 1978); and (3) annual recruitment biomass (a constant for each of two time periods). Fishing mortality rates were calculated by solving the catch equation numerically (see NEFSC 2009, Appendix B6). Survey scaling parameters were calculated using a closed form maximum likelihood estimator.

Variance estimates

Variances for biomass, fishing mortality estimates, and model parameters were estimated by the delta method using exact derivatives calculated by AD Model Builder libraries, or by bootstrapping.

KLAMZ results

This portion of the assessment update is intended to be no more than a report of model results using new survey and catch data, so the model configurations used were not substantively changed from the last assessment. The only change made was to allow a second recruitment parameter to be estimated in the models for DMV, NJ, and GBK. Using this configuration, the model could estimate two separate recruitment constants: one for annual recruitment from 1977 until 1993, and another for recruitment from1994 forward. It was not, however, necessary for the model the estimate two recruitment constants if only one recruitment constant was supported by the data. Therefore, the changes made to the model in this assessment were not considered substantive, since a one-parameter recruitment was a possible outcome of the current model configuration. Despite these changes, which were intended to improve the probability of model convergence, KLAMZ runs for the NJ and SNE regions did not converge (which also often occurred in the previous assessment).

DMV region

The KLAMZ model for ocean quahogs in the DMV area (Figures 35 and 36) fit NEFSC survey data well, and KLAMZ biomass matched the trends in observed LPUE (LPUE data do not affect model estimates). The estimated survey scaling parameter for ESB data was Q=0.999, indicating that the model was able to match the scale of the observed ESB on average during 1997-2011 using the catch data and trends in NEFSC survey data. Recruitment was near zero in runs for DMV. Survey data generally indicate that recruitment has been low in DMV since 1978, although some small ocean quahogs are present.

Based on KLAMZ model results, the biomass of ocean quahogs in DMV has been in decline since 1978, but the decline has not been as steep in recent years. Estimated fishable biomass is approximately 28% of 1978 biomass.

NJ region

KLAMZ model results for ocean quahogs in the NJ area (Figure 37) fit NEFSC survey index data well even though the model did not converge. The estimated survey scaling parameter for ESB data was Q=0.98, indicating that the model was able to scale with the observed ESB.

Based on KLAMZ model results, the biomass of ocean quahogs in NJ has been declining steadily since 1978. Estimated fishable biomass in NJ during 2011 was approximately 38% of the estimate for 1978.

LI region

A particularly strong year class recruited to the LI fishery in the years leading up to 1994, so the recruitment step function was influential in the model runs for LI.

The current results of the model (Figure 38) show ocean quahog biomass in LI increasing steadily from 1978 until 1993, when recruitment decreased, fishing mortality increased, and biomass began to drop, following the recruitment pattern. The estimated scaling parameter for ESB data Q was 0.91, indicating that the model was able to match the observed ESB levels on average. The model fit to survey indices was good, as they also show the results of increased recruitment in the years before 1994.

The correlation between LPUE predicted by KLAMZ (based on observed catch/predicted biomass) and observed LPUE is poor, because the fishery has moved into the region fairly recently compared to the regions to the south. The vessels are able to keep the LPUE high by selecting areas of high relative density, even though the exploitation rate for the entire region is increasing.

Based on the most recent KLAMZ model results, biomass of ocean quahogs in LI has decreased since 1978. Estimated fishable biomass in LI during 2011 was approximately 78% of the estimate for 1978.

SNE region

The KLAMZ model output for SNE (Figure 39) did not fit NEFSC survey data well, but the estimated survey scaling parameter for ESB data was *Q*=1.04, indicating the model matched the scale of observed ESB levels on average during 1997-2011. The KLAMZ predicted LPUE based on catch and biomass estimates did not follow the trends of observed LPUE, but this region has a fishery pattern similar to LI, where the vessels are able to move around and keep LPUE high as the region has not been heavily exploited.

Based on KLAMZ model results, biomass of ocean quahogs in the SNE region have been declining steadily since 1978. Estimated fishable biomass in SNE during 2011 was approximately 47% of the estimate for 1978.

GBK region

The KLAMZ model for ocean quahogs in the GBK region fit NEFSC survey kg/tow data reasonably, although only six survey observations were available (Figure 40) and the recruitment step function was influential. Only four ESB observations were available for GBK, and the estimated scaling parameter was *Q*=1.01. Since there has been no ocean quahog fishing on GBK, there is no LPUE or fishing mortality estimated.

Based on KLAMZ model results, biomass of ocean quahogs on GBK has been decreasing slowly since the early 1990s, but the model fit to survey biomass was poor (Figure 41). Estimated fishable biomass during 2011 was about 6% higher than the estimate for 1978.

Exploited area and entire stock

The KLAMZ model for ocean quahogs in the exploited stock area (all regions except for GBK, where the population of ocean quahogs is not fished) fit NEFSC survey kg/tow reasonably well (Figures 42, 43, and 44). The biomass estimates from the exploited area model correlated poorly with LPUE, probably because the area modeled is so large that the fishery can easily shift its distribution within it (for example, from NJ to LI) to maintain high catch rates, whereas the single-region models containing historical ocean quahog fishing grounds (DMV, NJ) observed LPUE tracks biomass estimates well. The estimated survey scaling parameter for ESB data was *Q*=1.18, indicating that the model believes there is somewhat less biomass on average during 1997-2011 than the observed ESB biomass levels indicate.

Based on KLAMZ model results (Figure 42), biomass of ocean quahogs in the exploited area was stable from 1978 to 1993, and then began to decline when recruitment dropped and fishing mortality was relatively high. Estimated fishable biomass for the exploited area during 2011 was approximately 70% of the estimate for 1978.

Biomass estimates from the KLAMZ model for the exploited region were about 4% smaller than the sum of biomass estimates from regional KLAMZ models for DMV, NJ, LI, and SNE. Confidence intervals of the KLAMZ biomass estimates for the exploited regions were slightly narrower than the previous assessment after the addition of the latest survey data, though there is still considerable uncertainty in the estimate (Figure 45, bottom).

The biomass estimate for the whole stock (Figure 45, top) shows almost the same trend as the estimate for the exploited area, but with a more pronounced increase during the earlier period. The KLAMZ model estimates the biomass of the whole stock to be almost double the estimate for the exploited area, although the uncertainty is higher for the whole stock. The whole stock biomass is estimated to be approximately 86% of the biomass in 1978. The fit to the survey data is not as good as the exploited regions model, but the data from GBK are sparser and less consistent spatially (Figures 46, 47, and 48).

KLAMZ estimates of fishing mortality (Figure 49) for both the exploited regions and the whole stock show the same trends but on a different scale, as the model is removing the same catch from the whole stock as it is from about half the stock in the case of the exploited regions. Time-series estimates of fishing mortality for the single-region KLAMZ models, especially the regions more recently exploited like LI and SNE, have undergone significant changes over time. The fishing mortality estimates for the entire exploited area are quite stable as the fishery moves around within a large range – the same reason LPUE is often stable despite declines in biomass.

Historical retrospective analyses

KLAMZ model results from this assessment update and the previous 5 or 6 assessments (for SARC 27, in 1998, the regional biomass estimates were single points and fishing mortality was not estimated) are interesting to compare, and reflect the changes that have been made to the model configurations over the years, as well as changes in the input time series, as data is accumulated over time. Changes in survey dredge efficiency estimates have altered the scale of the biomass and fishing mortality estimates to some degree for all regions. With each passing year, more depletion experiments are done and the survey dredge efficiency estimates improve. The more recent model results have used a lower survey dredge efficiency, which translates into a higher biomass estimate. Recent changes in how recruitment has been modeled in KLAMZ (using a step function) have affected the trend for the first half of the time series for some regions.

For the DMV and NJ regions, historically fished the hardest, KLAMZ biomass estimates have been trending downward for the whole time series in every instance (Figure 50). The estimates for the LI area have been influenced by the change in recruitment assumptions (Figure 51). In the SNE region, the KLAMZ results from this assessment update show a higher biomass at the beginning of the time series and a faster rate of decline, probably due to a combination of recent low survey kg/tow data points and the decrease in dredge efficiency (Figure 51). The trends in biomass for both the exploited area and the whole stock have been affected by the recruitment step function, peaking during the year the model recruitment decreased (Figures 52 and 53).

KLAMZ estimates of fishing mortality have also changed as a result of the newer survey dredge efficiency estimates. As the biomass estimates have scaled higher, the fishing mortality estimates have scaled lower, as the same catch removed from a larger biomass translates into a lower F value. Otherwise, KLAMZ results for fishing mortality have followed the same trends over the last five assessments (Figures 54-56).

REFERENCE POINTS AND STOCK STATUS

Biological Reference Points

Biological reference points (BRPs) for fishing mortality (F) and biomass (B) are required to manage the ocean quahog stock. Targets are BRPs that represent desirable stock conditions, and thresholds are BRPs that identify undesirable stock conditions.

BRPs for US fisheries are generally linked to the theoretical maximum sustainable yield (MSY) of a stock. MSY theory is probably not applicable to ocean quahogs, because their very low productivity may preclude economically viable levels of sustained catch. Productivity is low because recruitment events have been infrequent and localized, growth is slow, and there is a long time between settlement and recruitment to the spawning population or fishable stock. Ocean quahogs have also not shown an increase in productivity from higher recruitment and faster growth as biomass has been fished down, which would be typical for a species operating under the MSY principle. For these reasons, recommended reference points are described as thresholds and targets but not as proxies for F_{MSY} or B_{MSY} related reference points.

During SARC 48 (NEFSC 2009), BRPs for ocean quahogs were revisited and changes were recommended based on the unique population dynamics of very long-lived species with low rates of adult natural mortality. The revised BRPs are peer reviewed and considered the best science, but they are not incorporated in the FMP as an amendment or framework process has not taken place. Details of the reasoning behind the BRP revisions and analysis done to explore the implications of a range of potential BRP values can be found in the last assessment (NEFSC 2009).

B_{target}

The ocean quahog biomass target used to be $B_{Target} = B_{MSY}$, which is assumed to be half the virgin biomass of the whole stock. This was revised to be half of the fishable fraction of the whole stock biomass during 1978 (considered pre-fishery). The revised biomass target value is 1.73 million metric tons of meats.

$B_{threshold}$

The biomass threshold used to be $B_{Threshold} = ½ B_{MSY}$ (or ¼ the virgin biomass of the whole stock). The revised $B_{threshold}$ is 40% of the 1978 whole stock biomass, which was judged to be more realistic. The revised biomass threshold value for the whole stock is 1.39 million metric tons of meats.

F_{target}

F_{Target} was originally $F_{0.1}$, and applied to the exploited area only. The revised F_{target} is a value of F below the threshold, but in an ITQ fishery this is determined by the quota set for the year and therefore at the discretion of the managers. By default it applies to the exploited area only.

$F_{threshold}$

$F_{Threshold}$ used to be $F_{25\%}$ (the fishing mortality rate that reduces lifetime egg production to 25% of its potential). It was decided to revise $F_{threshold}$ to $F_{45\%}$ (egg production at 45% of potential) as it was better suited to unproductive stocks. The revised fishing mortality threshold for the exploited area is 0.022 y^{-1}.

	Revised BRPs	Value
B_{target}	50% 1978 fishable biomass (whole stock)	1.73 million mt
$B_{threshold*}$	40% 1978 fishable biomass (whole stock)	1.39 million mt
F_{target}	$F_{target} < F_{threshold}$ (exploited area)	set by quota
$F_{threshold*}$	$F_{45\%}$ (exploited area)	0.022 y^{-1}
	Current whole stock fishable biomass	**Current exploited area F**
	2.96 million mt	0.010 y^{-1}

STOCK STATUS

Ocean quahogs in the US EEZ are not overfished and overfishing is not occurring. Whole stock fishable biomass during 2011 was 2.96 million mt (Table 13), which is above the revised B_{target} of 1.73 million mt and the revised $B_{threshold}$ of 1.39 million mt. The fishing mortality rate during 2011 for the stock in the exploited region was F= 0.010 y^{-1} (Table 14), below the revised $F_{threshold}$ of 0.022 y^{-1}. Fishing mortality for the exploited area of the stock was also below the previous $F_{threshold}$ of 0.08 y^{-1}, and whole stock biomass was above the previous $B_{threshold}$ of 0.89 million mt.

PROJECTIONS

Ocean quahog biomass, fishing mortality, and catch were projected through 2026 using the KLAMZ model and associated bootstrap/projection software (Figures 57A-C). The projections were run for three scenarios with different assumptions about catch. The probabilities of overfishing or overfished status were calculated for each year. Bootstrap KLAMZ model runs were used as starting points for five thousand projections, to accommodate uncertainty about current biomass. For the first "status quo catch" scenario, yearly fishery removals were fixed at 15,400 mt. For the second "quota catch" scenario, yearly fishery removals were fixed at the level of the current quota, 24,190 mt. The third scenario fixed annual fishing mortality at the overfishing threshold, $F_{45\%}$ or 0.022y^{-1}. Recruitment was constant and derived from KLAMZ base runs for recent years. Status quo catch was determined by averaging ITQ ocean quahog landings from 2006 through 2011. Catches used in simulations were reported landings with 5% added to account for incidental mortality. All three scenarios were run for both the whole stock (all EEZ ocean quahogs with the exception of Maine) and the exploited area (SVA, DMV, NJ, LI, and SNE). All projections were started in 2011, the last year with biomass estimates from stock assessment models for ocean quahogs and complete landings data.

Stochastic models were used as this approach allows confidence intervals to be calculated, and give almost identical median estimates as the single set of estimates from deterministic models.

A single value of natural mortality (0.02) was used for all projections for this update, instead of running three different sets of projections using 0.015, 0.02, and 0.025. The different values of M affect both the starting biomass and the rate of change in the population over the length of the projection, but in the case of ocean quahogs these rates are low and the differences between runs were predictable. For this update, three different fishery scenarios were projected instead of four, as the minimum landings scenario from the last assessment was determined not to be useful. However, the projections made for this assessment update cover a longer period of time (fifteen years versus five).

The current fishing mortality threshold $F_{45\%} = 0.022y^{-1}$ applies to the exploited region only. The current biomass threshold of 1,390 mt (40% of the 1978 biomass) applies to the whole stock. The recent opening of the GBK region to surfclam and potential ocean quahog fishing may necessitate changes to the way biological reference points are applied to determine stock status. Even though there has been no ocean quahog fishing on GBK since the opening, it is possible there may not be an "exploited" subarea of the ocean quahog range in the EEZ in the future.

The status quo catch scenario (Figure 57A) represents the lowest catch level projected. At this catch level there is little chance of the whole stock becoming overfished between 2011 and 2026 (Table 15). However, the bootstrap estimates indicate there is a very small probability that overfishing may occur in the exploited area by 2020, even at this lowest level of catch.

The full quota catch scenario (Figure 57B) would also probably not lead to the stock becoming overfished, but would generate a more rapid decrease in biomass leading to overfishing in the exploited area (the probability of overfishing is estimated to be 50% by 2024).

The overfishing threshold scenario by definition had overfishing occurring in all years (Figure 57C). The probability of the whole stock reaching an overfished state after 15 years of fishing at $0.022y^{-1}$ is still small, but biomass would be reduced considerably and catches would begin to decrease around 2020.

In all three scenarios, ocean quahog biomass is projected to decline continuously through 2026. If recruitment levels remain as low as they have been in recent years and fishing continues at the status quo rate, there is a reasonable chance there will be overfishing in the exploited area and the whole stock will lose 20% of its biomass within the next ten or twelve years.

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