A. Surfclam Assessment

[SAW CHAIRMAN EDITOR'S NOTE: Surfclam Figures A8-A10 in this report were corrected by Larry Jacobson after the SARC review meeting. This was done because, during the SARC panel review of assessment working papers (which had no official status), the SARC noted that these figures seemed to have errors related to data coding. In their Reviewer Summary Report, the SARC panel mentioned possible errors in these figures.]

Terms of Reference for Atlantic surfclam

1) Characterize the commercial catch including landings, effort, LPUE and discards. Describe the uncertainty in these sources of data.
2) Characterize the survey data that are being used in the assessment (e.g., regional indices of abundance, recruitment, state surveys, age-length data, etc.). Describe the uncertainty in these sources of data.
3) Estimate annual fishing mortality, recruitment and stock biomass (both total and spawning stock) for the time series, and characterize the uncertainty of those estimates.
4) Update or redefine biological reference points (BRPs; estimates or proxies for B_{MSY}, $B_{THRESHOLD}$, and F_{MSY}; and estimates of their uncertainty). Comment on the scientific adequacy of existing and redefined BRPs.
5) Evaluate stock status with respect to the existing BRPs, as well as with respect to updated or redefined BRPs (from TOR 4).
6) Identify potential environmental, ecological, and fishing-related factors that could be responsible for low recruitment.
7) Develop and apply analytical approaches and data that can be used for conducting single and multi-year stock projections and for computing candidate ABCs (Acceptable Biological Catch; see Appendix to the TORs).
    a) Provide numerical short-term projections (1-5 years; through 2015). Each projection should estimate and report annual probabilities of exceeding threshold BRPs for F, and probabilities of falling below threshold BRPs for biomass. In carrying out projections, consider a range of assumptions about the most important uncertainties in the assessments.
    b) Comment on which projections seem most realistic, taking into consideration uncertainties in the assessment.
    c) Describe this stock's vulnerability to becoming overfished, and how this could affect the choice of ABC.
8) Review, evaluate and report on the status of the SARC and Working Group research recommendations listed in recent SARC reviewed assessments and review panel reports.
9) Identify new research recommendations.

Executive Summary

1) Atlantic surfclams are large, fast growing clams found from the southern Gulf of St. Lawrence to Cape Hatteras. Major concentrations are found on Georges Bank, the south shore of Long Island, New Jersey and the Delmarva Peninsula usually with highest concentrations in medium-grained sand at depths of less than 40m.
2) This stock assessment deals primarily with surfclams in federal waters (outside of 3 nm from shore) and the ITQ fishery that operates in federal waters. However, in

collaboration with state biologists, information about surfclams and fishing in NY and NJ state waters is given in an appendix.

3) Surfclams are the largest bivalves found in the western North Atlantic. They reach a maximum size of at least 22 cm shell length. Growth to commercial size (12 cm) takes about 5-7 years. Surfclams age 20 and older are common in survey catches.
4) Surfclams are not overfished and overfishing is not occurring.
5) The stock as a whole is at a relatively high biomass level and fishing mortality is low for the stock as a whole.
6) However, there are substantial differences in the condition of the stock in different regions. In the southern Delmarva (DMV) and New Jersey (NJ) regions where fishing effort is concentrated, surfclams are growing slowly, recruitment of new surfclams to the fishable stock is low, commercial catch rates are falling and biomass is declining. Conditions in the northern Long Island (LI), Southern New England (SNE), and Georges Bank (GBK) region where relatively little fishing has taken place.
7) About 48% of the current stock is on Georges Bank, which hasn't been fished since 1989 because of paralytic shellfish poisoning (PSP). GBK was reopened for fishing during 2009, provided catches are tested on a routine basis and if no PSP occurs. Very little fishing occurred on GBK during 2009. Industry representative report that fishing operations on Georges Bank may increase in the near future. The shift to fishing on GBK could benefit the stock and fishery if fishing effort is reduced in DMV and NJ.
8) No definite explanation is available for poor recruitment to the fishable stock in DMV and NJ but poor juvenile survival after settlement and slow growth appear to be important contributing factors.
9) The Northeast Fisheries Science Center conducted a surfclam and ocean quahog survey, in cooperation with industry and academic partners from Rutgers University and the Virginia Institute of Marine Science during 2008. The 2008 survey, data from other surveys and the commercial fishery data are used as well.
10) Stock assessments measure surfclam landings and stock size in metric tons (mt) of meats while the industry measures landings in bushels (bu). One bushel is about 17 lbs or 7.71 kg of meats.
11) About 28,000 mt of surfclam meats (22,000 mt from federal waters) were landed during 2008. Dockside prices averaged about $11 per bu. Total revenues from state and federal waters were about $39 million in 2008 making the surfclam fishery one of the most valuable single species commercial fisheries in the US.
12) Landings during 2008 were mostly from the NJ (74%) and DMV (17%) regions. The Long Island (LI) and Southern New England (SNE) regions supplied about 9% of total landings.
13) Fishing effort (hours fished from logbooks) have increased substantially since 1999, particularly in DMV and NJ regions
14) Commercial catch rates measured as landings per hour of fishing effort (LPUE) in DMV, NJ and LI were at or near record lows during 2008 at about 50 to 75 bushels per hour.
15) NEFSC, Industry and academic collaborators plan to transition the NEFSC triennial clam survey to a cooperative survey using a commercial fishing vessel starting in 2010. Plans are tentative because they depend on funding.
16) NEFSC survey trend data (mean number of clams per tow) for small surfclams (50-119 mm shell length) indicate low recruitment to the fishable stock (120+ mm shell length) during recent years in the southern DMV and NJ regions, and about average recent

recruitment levels in the northern LI, SNE and GBK regions.

17) Survey trend data for larger fishable surfclams (120+mm shell length) show low and declining abundance in the southern DMV and NJ regions during recent years. In comparison, trends for large surfclams in the north are either increasing (GBK) or variable (LI and SNE).
18) Based on survey data for the entire stock, recruitment and fishable biomass was at an intermediate level (slightly below average) during 2008.
19) Capture efficiency and size-selectivity estimates for the NEFSC clam survey dredge were revised based on experiments carried out at sea by the *R/V Delaware II* and *F/V Endeavor* during 2008. The estimated capture efficiency of the survey dredge was increased and it was determined that the survey dredge has a "dome shaped" size selectivity pattern. This means that the dredge does not capture large and small surfclams as effectively it captures intermediate size surfclams.
20) Growth curves for surfclams were revised in this assessment using new data. Formulas used to convert shell length to meat weight were revised based on new data from fresh (unfrozen) meats weighed at sea right after shucking.
21) The combined effects of the new capture efficiency estimate, size selectivity estimates, growth curves and shell-length meat weight formulas was somewhat lower biomass estimates for the stock and somewhat higher fishing mortality estimates.
22) The primary stock assessment model used to provide management advice for surfclams in this assessment is the KLAMZ model. Estimates from the KLAMZ model were compared to swept-area biomass estimates. The model and swept-area biomass estimates are not completely independent but the two approaches gave similar results.
23) KLAMZ model results for the entire stock indicate that biomass increased from 1981 until the late 1990s and then declined to about the same level as in 1981. The fishery contributed only modestly to the decline which was mostly due to lower recruitment. It is likely that biomass would have declined even if there had been no fishery. Fishing mortality was about 2.4% per year for the whole stock during 2008.
24) Forecast results for the whole surfclam stock indicate that biomass will probably continue to decline gradually through 2015, primarily due to poor recruitment.
25) KLAMZ model results specifically for the DMV region indicate that biomass declined continuously from relatively high levels during the early 1980s due to rapid declines in recruitment after 1998 and lower growth rates. Fishing mortality rates in the DMV region increased from low levels to about 7% per year during 2008.
26) KLAMZ model results specifically for the NJ region indicate that biomass increased during 1981-1996 and then declined as recruitment fell and growth slowed. Fishing mortality rates in the NJ region increased to about 10% per year during 2008.
27) The recent declines in surfclam biomass in the DMV and NJ regions would probably have occurred even in the absence of fishing. However, the estimated fishing mortality rates in DMV and NJ during 2008 are the highest on record for surfclams and it is likely that fishery impacts will become significant in the near future if surfclam biomass in DMV and NJ continues to decline as expected.
28) Surfclams biomass in DMV and NJ is likely to continue declining during 2010-2015 due to poor recruitment, slow growth and fishing mortality. Forecasts indicate that stock biomass in DMV and NJ may decline by -27% to -43% by 2015. Declines are likely even in the absence of fishing.

Introduction

Distribution and biology

Atlantic surfclams are large fast growing bivalves distributed along the coast of North America from the southern Gulf of St. Lawrence to Cape Hatteras. In US waters, major concentrations occur on Georges Bank, the south shore of Long Island, New Jersey and the Delmarva Peninsula (Figure A1). Surfclams are found from the intertidal zone to a depth of 128m but the highest concentrations in US waters are found at depths of less than 40m. Off of the Delmarva Peninsula where the water is warmest, they are distributed in slightly deeper, cooler water. Surfclams burrow energetically and prefer medium-grained sand, although they can also be found in fine sand and silty sand also. See Cargnelli et al. (1999)[1] for a complete description and review of surfclam biology.

Surfclams are the largest bivalves found in the western North Atlantic, reaching a maximum size of at least 22 cm shell length (Ropes 1980). Individuals larger than 16 cm shell length (SL - the distance across the longest part of the shell) are relatively common in Northeast Fisheries Science Center (NEFSC) surveys. Growth to commercial size (12 cm) takes about 5-7 years depending on region and time period. Weinberg (1998) and Weinberg and Helser (1996) showed that growth rates vary among regions, over time and in response to surfclam density levels. Based on NEFSC clam survey data in this assessment, growth rates appear to have declined for surfclams in the DMV region since 1993 (Figure A2). Slower growth in surfclams in DMV during recent years coincides with mortality in near shore areas off DMV during the early 2000s, probably due to warm water (Weinberg 2005).

In this assessment, rings in the chondrophore are validated as annual marks that can be used to estimate age (Appendix 5). Surfclams taken in the NEFSC clam surveys are aged after each survey using shells sampled on a length- and stratum stratified basis. In the laboratory after the survey, the surfclam shells are sectioned through the chondrophore (the part of the shell that supports the ligament) and the annuli are counted. Annuli form in the fall and the assumed birth date is January 1 so that, for example, a member of the 2007 year class taken during the 2008 NEFSC clam survey would be age 1 at the time of capture and expected to show one ring (Appendix A6). Surfclams age 20+ are relatively common in survey data and the maximum observed age exceeds 35.

Surfclams in US waters can reach sexual maturity at an age of three months (Cargnelli et al.1999). Sexes are separate, but are not distinguished in either commercial or NEFSC survey data. Spawning occurs from late spring through early fall, generally depending on latitude with more southern clams spawning earlier. Eggs and sperm are shed directly into the water column. Recruitment as juveniles to the bottom occurs after 19 to 35 days, depending on temperature. Relationships between age/size, functional maturity and effective fecundity have not been precisely quantified.

There are two subspecies of Atlantic surfclam. The northern offshore subspecies *Spisula solidissima solidissima* are the subject of this assessment. The smaller coastal subspecies (*Spisula solidissima similis*) occupies relatively warm southern inshore habitats (Hare and Weinberg 2005). The geographic distributions of the two subspecies overlap to a limited extent in warm near shore areas (e.g. Long Island Sound). However, *S. s. similis* is reproductively isolated from *S. s. solidissima* and not important to the offshore commercial fishery. It is likely that all *S. s. similis* along the northeast coast belong to the same biological population.

[1] http://www.nefsc.noaa.gov/nefsc/publications/tm/tm142/

Management

Surfclams are common in both state waters (3 miles or less from shore) and federal waters (the Exclusive Economic Zone (EEZ, between 3 and 200 miles from shore). This stock assessment applies only to the segment of the surfclam population in federal waters because the EEZ is the management unit specified in the Atlantic Surfclam Fishery Management Plan (FMP). Surfclams in New Jersey and New York state waters support valuable fisheries that are managed by state authorities. See Appendix A3 for a summary of the condition of surfclams and their fisheries in New York and New Jersey state waters.

Atlantic surfclams in the US Exclusive Economic Zone (EEZ) are considered a single stock for management purposes, though state and federal stocks are not biologically distinguishable. There are, however, substantial regional differences in biological properties and population dynamics. The fishery occurs primarily in the Mid-Atlantic region.

Because the surfclam fishery is regional and the resource is sedentary, stock conditions are often described for regions, rather than the whole stock area. Names and abbreviations for the stock assessment regions are listed from south to north below (see Figure A1).

Abbreviation	Assessment region name
SVA	Southern Virginia and South Carolina
DMV	Delmarva
NJ	New Jersey
LI	Long Island
SNE	Southern New England
GBK	Georges Bank

The Mid-Atlantic Bight (MAB) consists of the regions from SVA to LI. The SVA region is at the southern end of the species range and of relatively little importance to the stock as whole.

Georges Bank has been closed to surfclam harvesting since 1989 due to the presence of paralytic shellfish poisoning (PSP) toxins in surfclam meats. With the recent development of fast, accurate tests for these toxins, fishermen have been able to test catches at sea and determine if they are safe for consumption. Industry sources report that GBK has been opened for fishing, contingent on continuous testing and the absence of PSP, and expect fishing on GBK to increase in the near future. Very little fishing has occurred so far, however, because the region was recently opened, bad weather conditions are common, and the GBK region is relatively far from the nearest useable processing facility (Massachusetts does not currently allow landings from GBK). Fishing operations on Georges Bank will hopefully increase in the near future because stock conditions in southern traditional fishing regions (DMV and NJ) are deteriorating.

The fisheries for Atlantic surfclams and ocean quahogs (*Arctica islandica*) in the EEZ are unique in being the first US fisheries managed under an individual transferable quota (ITQ) system. ITQ management was established during 1990 by the Mid-Atlantic Fishery Management Council under Amendment 8 to the Fishery Management Plan for the Atlantic Surfclam and Ocean Quahog Fisheries (FMP). Management measures include an annual quota for EEZ waters and mandatory logbooks that describe each fishing trip to a spatial resolution of at least one ten-minute square (TMS, 10’ lat. by 10’ longitude).

Murawski and Serchuk (1989) and Serchuk and Murawski (1997) provide detailed information about the history and operation of the fishery.

Previous assessments

Stock assessments are generally done after NMFS clam surveys, which are conducted every 2-3 years. The most recent surfclams assessments are NEFSC (1993; 1995; 1998; 2000; 2003; 2007). The most recent stock assessment for surfclams, NEFSC (2007) concluded that the stock was above the management target level (the stock was not overfished) and that fishing mortality was below the management threshold value (overfishing was not occurring). However, biomass was projected to decline gradually through 2010, because recent recruitment had been low and was likely to remain low over the next five years. The "historical retrospective" analysis in this assessment includes biomass and fishing mortality estimates from previous assessments that can be compared to updated estimates in this assessment.

During the NEFSC clam surveys aboard the R/V Delaware II, clams are sampled with a 3.2 ton hydraulic dredge, similar to that used by industry but about half the size. A submersible pump, mounted above the dredge, shoots water into the sea bottom just ahead of the 1.5m-wide dredge mouth. Commercial dredges have blades 8-12 feet (2.4-3.7m) wide and higher pressure water jets. These jets of water liquefy the sea bottom allowing the clams to be captured more easily.

The dredge has been operated in a consistent fashion using the same survey protocols and gear since 1982. In particular, the criteria used to reject bad tows for trend analysis have not changed. However, survey catch rates were anomalously high during the 1994 survey in some regions, probably due to a change in voltage supplied to the pump on the survey dredge towed by the *R/V Delaware II*. In response to 1994 survey results, sensors were used for the first time in 1997 to monitor the performance of the dredge during each tow. Data collected include ship speed and position, dredge angle, voltage and amperage of electrical current that powers the pump on the dredge, manifold pressure (hydraulic pressure just upstream of the nozzles), water depth and water temperature. The sensor data allow for more accurate estimates of distance towed as well as identification of problematic tows. Sensor data are used most extensively in analysis of depletion study data to estimate capture efficiency, and in estimation of efficiency corrected swept-area biomass since 1997. Sensor data are not used for analysis of long term trends because sensor data are not available prior to 1997.

Cooperative depletion experiments have been an important part of surfclam stock assessments since the NEFSC (2005) assessment following the 1994 survey. Depletion studies are conducted in collaboration with academia and the clam industry. An industry vessel fishes repetitively to "deplete" a site where the *R/V Delaware II* has already made a small number of non-overlapping tows. As described below, a spatially explicit statistical model (the "Patch" model, Rago et al. 2006) is used to analyze the depletion study data and estimate surfclam density and capture efficiency for the survey and commercial vessels. This assessment includes a simulation analysis of Patch model performance (Appendix A2) and analysis of data from five new depletion experiments.

This assessment estimates fishing mortality and stock biomass with efficiency-corrected swept-area biomass calculations and the KLAMZ model. In addition, a Stock Synthesis model is applied experimentally in Appendix A5 for preliminary evaluation. Stock Synthesis (or a similar approach) is expected to be the primary model in the next assessment.

Term of Reference 1: Commercial Catch

Fishery landings in this assessment are reported as meat weights for ease in comparison to survey data and in calculations, but were originally recorded in units of industry cages. One

cage equals 32 industry bushels, and one industry bushel is assumed to produce 17 lbs or 7.711 kg of useable meats. Landings per unit of fishing effort (LPUE) data are reported in this assessment as landings in bushels per hour fished, based on clam logbook reports. The spatial resolution of the clam logbook reports is usually one ten minute square.

Unit	Equivalent
1 cage	32 bushels
1 bushel	1.88 ft^3
1 bushel	17 lbs meats
1 bushel	7.71 kg meats

As in previous assessments (NEFSC 2007), catch in all stock assessment analyses is the sum of landings, plus 12% of landings, plus discards. The 12% figure accounts for potential incidental mortality of clams in the path of the dredge. The 12% estimate is an upper bound; actual incidental mortality is probably lower. Incidental mortality is likely low relative to the surfclam resource as a whole because the total area fished (e.g. 155 km^2 during 2004) is small relative to the geographic distribution of the stock (Wallace and Hoff 2005). The ITQ fishery operates with little or no regulation induced inefficiency (e.g. inefficiency due to area closures, trip limits, size limits, etc.) so that fishing effort and incidental mortality are limited.

Recreational catch is near zero, although small numbers of surfclams are taken recreationally in shallow inshore waters for use as bait. Surfclams are not targeted recreationally for human consumption.

New discard data

Invertebrate Subcommittee members with experience in the fishery estimated discard rates for surfclams during 1979-1981 that are used in this assessment to supplement existing discard data for 1982-1993 (Table A1). Discards during these periods were caused by a series of size limits used to regulate the fishery during 1979 to 1990, when the ITQ program went into effect. Discards were reduced to near zero by 1993 after size limits were eliminated.

Size limits for surfclams were intended to protect strong year classes following a large scale die-off due to hypoxia during 976 that occurred in waters off NJ. These year classes were large, grew quickly and began to recruit to the fishery in about 1979. Discards were small during 1979 because vessels were still targeting relatively dense beds of large surfclams unaffected by the die-off. Discards increased during 1980-1981 as catch rates for large surfclams declined and vessels began to target dense beds of relatively small clams.

Based on this information, the discard rate (discards / landings) was estimated to be zero during 1976-1978, 0.05 during 1979, 0.15 during 1980, and 0.25 during 1981. Assuming that total EEZ landings during 1976-1981 were from the affected area (Table A2), discards were: 0 mt during 1976-1978; 712 mt during 1979; 1,978 mt during 1980; and 3,937 mt during 1981.

Age and size at recruitment to the fishery

Based on both commercial length data and experimental results, NEFSC (2003) determined that surfclams in NJ were became available to the commercial fishery at about 120 mm SL. Commercial length data from all regions showed little evidence that size at recruitment differs among regions. Fishing mortality estimates in this assessment therefore compare total catch (landings plus discards plus an allowance for incidental mortality described below) to the stock greater than 120 mm SL.

Age at recruitment to the surfclam fishery depends on growth rates. It occurs earlier in northern regions where growth is more rapid. Growth curves indicate that surfclams reached 120 mm SL and recruited to the DMV fishery at about age 5 y during 1978-1992 and about age 7 y during 1994-2008 (Figure A2). Growth curves for NJ show surfclams recruited to the fishery at the about age 5 y during 1978-1992 and about 6 y during 1994-2008. Assuming a natural mortality rate of M=0.15 per year, numbers of recruits to the fishery per juvenile would decreased by about 26% due to natural mortality during the two additional years prior to recruitment. This effect is likely compounded by other reductions in productivity in southern regions, which are discussed below.

Landings, fishing effort and prices

Landings and fishing effort data for 1982-2008 were from mandatory logbooks. Data for earlier years were from NEFSC (2003) and MAFMC (2006).

Landings data for surfclams from logbooks are considered accurate in comparison to other fisheries because of the ITQ system. However, effort data are not reliable for 1985-1990 due to effort regulations that restricted the duration of fishing to 6 hours. Effort data are reliable for years before 1985 and after 1990.

Surfclam landings were mostly from the US EEZ during 1965 to 2008 (Tables A2 and Figure A3). EEZ landings peaked during 1973-1974 at about 33 thousand mt, and fell dramatically during the late 1970s and early 1980s before stabilizing beginning in about 1985. The ITQ system was implemented in 1990. EEZ landings were relatively stable and varied between 21 and 25 thousand mt during 1985 to 2008. Landings have not reached the quota of 26,218 mt since it was set in 2004 because of limited markets. The quotas themselves are set at levels much lower than might be permitted under the FMP.

The bulk of EEZ landings were from DMV during 1979-1980. After 1980, the bulk of landings were from the NJ region (Table A3 and Figure A3). During recent years, EEZ landings from the NJ region were about 74% of the total, DMV about 17%, and LI and SNE combined about 9%. Landings from LI were modest but appreciable starting in 2001. Landings from SNE were modest but appreciable starting in 2004. Recent LI and SNE landings reflect a tendency of the fishery to move north towards lightly fished areas where catch rates may be relatively high.

Fishing effort has increased substantially since 1999, particularly in the DMV and NJ regions (Table A4 and Figure A4). The bulk of the fishing effort is in areas where the bulk of landings occur. However fishing effort has increased rapidly in the DMV and NJ regions where LPUE has declined (see below).

Nominal ex-vessel prices for the inshore and EEZ fisheries fluctuated around $9 to $11 per bushel since the mid-1990s (Table A5 and Figure A5). Ex-vessel prices (1991 dollars) have been decreasing steadily in real terms from about $9 per bushel during the mid-1990s to less than $6.50 per bushel during 2005 to 2008. Nominal revenues for surfclam during 2008 were about $39 million, making the ITQ surfclam fishery one of the most valuable single species fisheries in the US. In 2008, the ITQ component accounted for 81% of total landings and revenues (Table A2).

Landings per unit effort (LPUE)

Nominal landings per unit effort (LPUE) based on logbooks was computed as total landings divided by total fishing effort for all vessels and all trips (Table A6 and Figure A6). Standardized LPUE was not estimated in this assessment for lack of time and because NEFSC

(2007) showed that nominal and standardized trends were almost identical when standardized trends were estimated general linear models for each region with vessel and year effects.

Nominal LPUE has been declining steadily in the DMV region since 2001. In the NJ and LI regions, LPUE has been declining steadily since 2000. The SNE region had very low reported LPUE until it experienced a jump beginning in 2001, peaking in 2004 at over 300 bushels per hour, and returning to intermediate levels in 2007. LPUE levels in DMV, NJ and LI during 2008 were at or near record lows at about 50 to 75 bushels per hour.

LPUE is not an ideal measure of fishable biomass trends for sessile and patchy stocks like surfclams because fishermen target high density beds and change their operations to maintain relatively high catch rates as stock biomass declines (Hillborn and Walters 1992). However, trends in LPUE and NEFSC clam survey biomass data are highly correlated for DMV and NJ where fishing has been heaviest and fishing grounds are widespread (NEFSC 2007 and see below).

Spatial patterns in fishery data

Average annual landings, fishing effort and LPUE from logbooks were calculated by ten-minute squares (TMS) for five time periods: 1981-1990, 1991-1995, 1996-2000, 2001-2005 and 2006-2008 (Figures A7-A9). Only TMS with more than one trip per year on average during a time period were included. TMS with fewer than one trip per year on average were probably errors, or from just a few exploratory tows. Inclusion of TMS, with less than trip per year distorted the graphical presentations because the area fished appeared unrealistically large.

Figures A7-A9 show the spatial patterns in the surf clam fishery over the past 28 years. In all the years, the greatest concentration of fishing effort and landings has occurred in about 25 TMS in the NJ region, with fishing activity in other regions occurring more intermittently. For example, during the first ten-year time period, from 1981 to1990, the highest landings and fishing effort were still concentrated off NJ, but there were relatively high levels of landings and fishing effort mostly offshore in DMV and SVA, and some fishing activity in SNE off of Martha's Vineyard (about 41°N 70°W). During 1996-2000, there were little landings or effort in SVA or SNE, reduced activity in DMV, and increased activity in NJ with expansion to offshore regions. During 2001-2005, fishing effort in DMV increased and fishing effort expanded eastward along the south shore of Long Island. During 2006-2008, some landings have come from a small offshore area in DMV, and fishing north of NJ has been mostly limited to the waters adjacent to Long Island.

TMS with the highest LPUE levels over time have been mostly in the NJ and DMV regions. However, LPUE in DMV was relatively low during 2006-2008.

Important TMS

TMS "important" to the fishery were identified by choosing the twenty TMS with the highest mean landings during each of the following time periods 1980-1990, 1991-1995, 1996-2000, 2001-2005 and 2006-2008. For example, a TMS important during 1991-1995 could be selected regardless of its importance during earlier or later time periods. The list for all the time periods contains 41 important TMS that tend to be important in all time periods. The large majority of important TMS were in the NJ region (27 squares), with 10 in the DMV region and SVA, LI, SNE and GBK each with one square. Trends in landings, effort and LPUE were plotted (Figures A10-A12) for each TMS to show changes in conditions over time within individual TMS.

Landings and especially effort have increased recently in two TMS within the DMV region that have historically been lightly fished. The same pattern, but to a lesser degree, seems to be happening within four TMS in NJ. Most other DMV squares have had high levels of landings in the past but very low levels recently. Several have not had any reported landings in recent years. Landings and effort have been increasing recently (although they are still at low levels) from the two NJ TMS that have historically had the highest surfclam landings during 1981-2008. Trend lines from several TMS, especially in the NJ region, show two modes where landings and effort were high, possibly reflecting abundance increases after fishing effort was reduced. Fishing effort is increasing in the single important TMS in the LI region.

There are very few important ten-minute squares in which the LPUE has not trended downwards in recent years, if they are still being fished. Most are currently at or below about 100 bushels per hour.

Fishery length composition

Since 1982, port samplers have routinely collected shell length measurements from ~30 random landed surfclams from selected fishing trips each year (Table A7). During 1982-1986, length data were collected from over 5,000 clams in each of the DMV and NJ regions, where most surfclams are landed. Since 1986 an average of about 1000 lengths from DMV and 1500 from NJ have been collected each year. Surfclams were measured from SNE landings every year from 1982 to 1990, although in small numbers with a maximum of 810 in 1988. There have been no measurements taken from SNE landings since then. Port samplers began taking measurements from landings from the LI region in 2003 and have been collecting them consistently ever since, but only about 400 lengths are measured per year on average.

Port sample length frequency data from the four regions show modest variation in size of landed surfclams over time (Figures A14-A16). Surfclams from the northern SNE region are larger than surfclams from more southern regions. Care should be taken in interpreting these due to small sample sizes in some cases (especially LI and SNE), but in general the data indicate that most landed surfclams have been larger than 120mm SL, with the distribution of sizes being wider some years than others on both ends of the distribution. Port sample data for LI are limited to mostly recent years and samples sizes are modest, but the data, especially from 2005, show substantial numbers of smaller surfclams being landed. However, the data suggest that the majority of the landings in LI are at least 120+ mm SL.

It is possible to see, especially in the DMV graphs, the effect of the minimum-size restriction imposed on the fishery from 1982 through 1990 (Figure A13). The port sample data for the DMV and NJ regions reflect the strong 1991 year class which would have recruited to the fishery during the early and mid-1990s, and the strong 1998 year class which would have recruited to the fishery in 2005 at around age 7 (see below). It also appears that the size of the average surfclam landed from NJ has decreased since 2004, but it is difficult to interpret the trend due to modest sampling.

Term of Reference 2: NEFSC and Cooperative clam surveys

Survey data used in this assessment were from NEFSC clam surveys conducted during 1982-2008 by the *R/V Delaware II* during summer (June-July), using a standard NEFSC survey hydraulic dredge with a submersible pump. The survey dredge has a 152 cm (60 in) blade and 5.08 cm (2 in) mesh liner to retain small individuals of the two target species (surfclams and ocean quahogs). The survey dredge differs from commercial dredges because it is smaller (5 ft instead of 8-12.5 ft blade), has a small mesh liner, and because the pump is mounted on the

dredge instead of the deck of the vessel. The survey dredge is useful for surfclams 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.

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).

NEFSC clam surveys are organized around NEFSC shellfish strata and stock assessment regions (Figure A1). Most surfclam landings originate from areas covered by the survey. The survey did not cover GBK during 1982, 1983, 1984 or 2005. Individual strata in other areas were sometimes missed. Strata and regions 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 these data are available (Table A8). Survey data are never borrowed from surveys behind the previous, or beyond the next survey. Despite research recommendations, a model based approach to filling survey holes has not yet been developed, although the approach appears practical based on results for Atlantic surfclam (NEFSC 2007).

Surveys follow a stratified random sampling design, allocating a pre-determined number of tows to each stratum. A standard tow is nominally 0.125 nm (232 m) in length (i.e. 5 minutes long at a speed of 1.5 knots) although sensor data used on surveys since 1997 show that tow distance increases with depth, varies between surveys and is typically longer than 0.125 nm (Weinberg et al., 2002). For trend analysis, changes in tow distance with depth are ignored and survey catches are adjusted to a standard tow distance of 1.5 nm based on ship's speed and start/ stop times recorded on the bridge.

Stations used to measure trends in ocean quahog abundance are either random or "nearly" random. The few nearly random tows were added in some previous surveys in a quasi-random fashion to ensure that important areas were sampled. Other non-random stations are occupied for a variety of purposes (e.g. depletion experiments) but not used to estimate trends in ocean quahog abundance.

Occasionally, randomly selected stations are found too rocky or rough to tow, particularly on GBK. 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 surfclams. These estimates are used in the calculation of surfclam swept-area biomass (see below).

Following 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 which were updated in this assessment based on fresh meat weight samples obtained during the 1997-2008 surveys (see below).

Locations and catches of all stations in the 2008 survey have been mapped (Figure A17) and maps for previous surveys can be found in Appendix A8. GBK was sampled during 2008 for the first time since 2002.

NEFSC clam survey trends and size composition

NEFSC clam survey data (Table A9) were tabulated for small (50-119 mm SL, Figures A18-A19) and large (120+ mm SL, Figures A20-A21) surfclams by year, region and for the

entire stock. Only trends in mean numbers per tow were plotted because trends in mean kg per tow were similar. Approximate asymmetric 80% confidence intervals were based on the CVs for stratified means assuming that the means were log normally distributed. Survey trend data used in graphs for this assessment are not adjusted for the dome shaped size-selectivity patterns that were identified in this assessment (see below)

Survey trends for small surfclams (Figures A18-A19) show low recruitment levels during recent years in the southern DMV and NJ regions, and approximately average recent recruitment levels in the northern LI, SNE and GBK regions. Survey trends for fishable (120+mm) surfclams (Figures A20-A21) show low and declining abundance in the southern DMV and NJ regions during recent years. In comparison, northern regions are either increasing (GBK) or variable (LI and SNE). Based on survey data for the entire stock, recruitment and fishable abundance was slightly below average during 2008 (Figures A22-A23).

Shell length composition data (Figures A24-A29) are compatible with patterns in trend data. In particular, abundance and recruitment appear low in the southern DMV and NJ regions while abundance is higher and recruitment is at near average levels in the northern LI, SNE and GNK regions.

NEFSC survey age composition

In this assessment, "recognizable" recruitment events are year classes that are strong enough to be detected by visual examination of age composition data for surfclams from the NEFSC clam survey. "Strong" recruitment events are year classes that are obviously large relative to other years.

Survey age-length keys and stratified mean length composition data were used to estimate the age composition of surfclams in NEFSC clam survey catches and the stock as a whole by year and region. Age composition was estimated for the years between 1982 and 2008 when surveys occurred and for regions with at least 100 age samples. Fifteen mm shell length bins starting at 30 mm SL (e.g. 30-44, 45-60 … mm SL) were used in calculations and shell lengths ranged from 10 to 200+ mm SL (200+ mm was a plus group). Ages ranged from 1-30+ y (30+ was a plus group).

Results (Figure A30) for DMV reflect the general decline in abundance, with strong year classes in 1977 and 1981, and recognizable year classes in 1988, 1993, 1999 and 2005. Results for NJ (Figure A31) also reflect the general decline in abundance, with strong year classes in 1978 and 1980, and recognizable year classes in 1983, 1992, 1999 and 2005. Sampling from LI and SNE was not adequate to identify year classes (Figure A32). The 1976 and 1994 year classes were strong on GBK and recruitments appear variable or inconsistent in other years (Figure A33).

Dredge efficiency

Survey dredge efficiency estimates are used in this assessment to estimate biomass and fishing mortality, and to help scale estimates from other assessment models. As in recent surfclam and ocean quahog assessments, the best estimate of survey dredge efficiency for surfclams for this assessment was the median of estimates from all available depletion studies with setup tows (Tables A10-A11). Setup tows are made by the *R/V Delaware* II using the survey dredge prior to the depletion experiment. In particular, the best estimate of efficiency for the survey dredge was the median e=0.256 (mean=0.413 CV=0.16, n=21). For comparison, the median dredge efficiency of commercial dredges was E=0.786 (mean 0.730, CV=0.11, n=24).

The new best estimate for survey dredge efficiency e=0.256 in this assessment was somewhat larger than the value used in the last assessment (e=0.226). Details are given below.

Survey dredge efficiency was estimated using estimates of commercial dredge efficiency from depletion experiments with data from setup tows carried out by the *R/V Delaware II* on the study site using the survey dredge during regular clam surveys. In particular, $e = \bar{d}/D$ where e is the estimated efficiency for the survey dredge, $\bar{d}$ is the mean survey density (average catch per unit area swept) from the setup tows, and D is the density of surfclams in the site.

All commercial dredge efficiency and surfclam density estimates for surfclams in this assessment were from Rago et al.'s (2006) "Patch" model fit to data from depletion studies carried out by commercial vessels. The Patch model is a maximum likelihood approach that considers effects of the spatial distribution of depletion tows and the extent of overlap among tows on the catch from each tow. It assumes that errors in the catch data for each tow come from a negative binomial distribution. The model estimates depletion study (commercial) dredge efficiency (E), the density of surfclams in the study site (D) and a dispersion parameter (k) for the negative binomial distribution that is inversely related to variance.

With one exception described below, Patch model procedures and assumptions in this assessment were the same as for surfclams in the last assessment (NEFSC 2007) and nearly identical to the most recent ocean quahog assessment (NEFSC 2009). In particular, the grid size used in fitting the Patch model was twice the dredge width, the "gamma" parameter was fixed at 0.5, and position data were smoothed and interpolated to a distance of 5 feet. The Patch model was fit to data for surfclams 150+ mm SL that have size-selectivity of at least 0.85 in the all of the commercial in depletion experiments. Detailed simulations to characterize the accuracy of patch model estimates are described in Appendix A2.

Variance of survey dredge efficiency e

The only modification to the Patch model for this assessment was to calculate variance of survey dredge efficiency estimates in the AD Model Builder version of the Patch model. The setup tow data were added to the input file and mean setup survey density was added to the list of parameters estimated in the model. The objective function (negative log likelihood) was:

$$\Lambda = \Delta_P + \Lambda_s$$

where Λ_p and Λ_s are negative log likelihoods for the depletion study data and the setup tow data. The setup tow likelihood Λ_s was calculated:

$$\Lambda_s = n\sum_{j=1}^{n}\frac{\left(d_j - \bar{d}\right)^2}{2}$$

Where n is the number of setup tows. The expression for Λ_s is a "concentrated" negative log likelihood (Harvey 1990). Minimizing the concentrated likelihood is equivalent to minimizing the complete and more complicated negative log likelihood for normally distributed data with unknown variance.

The two likelihood terms Λ_p and Λ_s are completely independent because they do not share data or parameters (i.e. minimizing the likelihood of the setup tows does not affect minimization of the likelihood for the Patch model data). Therefore, the Patch model and setup tow parameters are statistically independent and do not affect one another (this was verified in calculations). With this modification and casting survey dredge efficiency e as an "sd_report" object, the variance of survey dredge efficiency $e = \bar{d} / D$ can be calculated automatically by the AD Model Builder libraries using the delta method. If setup tow data are not available, then e is

not calculated and estimation of Patch model parameters is unaffected. In addition to variances, likelihood profile confidence intervals were calculated for Patch model parameters and survey dredge efficiencies as described by Rago et al. (2006).

New depletion studies

Five new depletion studies were carried out during 2008, all with setup tows made during the NEFSC 2008 clam survey (Tables A10-A11; Figures A34-A37). There were patterns in residuals (predicted – observed catches) in Patch model results for the SC2008-1 and SC2008-2 depletion experiments (Figure A38).

As in previous assessments, there were no clear relationships between Patch model estimates and sediment size (Figure A39). With one exception, there was no clear relationship between estimates and most other environmental variables (Figure A40). The negative correlation between commercial dredge efficiency and density estimates (Figure A40) remains noteworthy. In the last assessment (NEFSC 2007), the correlation was attributed to statistical correlation between efficiency and density estimates in all types of depletion models. The parameters tend to be correlated because a predicted catch value can be duplicated using combinations of relatively high density/low efficiency or low density/high efficiency.

Based on Patch model results for the 2008 depletion experiments, capture efficiency for the commercial dredge was variable (E=0.52 to 0.99). Estimates for the survey dredge were also variable with estimates of e from 0.36 to 2.1, and generally higher than previous estimates. The survey dredge efficiency for the SC2008-1 experiment (2.1) was implausibly high because it was larger than one. The effect of this outlier on median estimates used in further calculations was minimal, however, because the median is not affected by outliers. The implausible efficiency estimate occurred because the mean survey density ($\bar{d}$ =0.020 clams ft^2) was larger than the density estimate from the Patch model (D=0.0093 clams ft^2).

New variance calculations in this assessment indicate that survey dredge capture efficiency estimates are imprecise. CVs for the 2008 survey dredge efficiency estimates ranged from 0.36 to 1.07. The CV for the implausible SC2008-01 estimate was 0.68.

Information about the spatial patterns and variability in surfclam densities within depletion sites is important in evaluating performance of the Patch model. (Appendix A2). Potential effects on survey dredge efficiency estimates is an important topic for future research.

Repeat tow analysis for cable and pump effects

Repeat tow analyses were conducted to estimate effects of different electrical cables and pumps on catch rates on the research vessel during the NEFSC survey. The "old" electrical cable used to send power to the dredge pump at the beginning of the survey was replaced at station 241 because it was too short to accommodate deep stations. The original ("old") pump was replaced and station 170 due to a malfunction. Based on results for ocean quahogs in NEFSC (2009), cable effects are potentially more important than pump effects. Also, the experimental design of repeat station experiments in this analysis was better for detecting potential cable effects.

Two types of repeat tows were carried out. "De2De2" repeat stations were occupied twice by the *R/V Delaware II* (e.g. with the old and then the new cable or pump). "De2Fv" stations were occupied first by the *R/V Delaware II* (with either old or new cable and/or plump) and afterwards by the *F/V Endeavor*. Research and fishing vessel catches were adjusted to the same area swept (423 m^2) based on sensor data. Configuration of the F/V Endeavor is described below in the context of dredge selectivity experiments.

All suitable repeat station pairs were utilized. The most important criterion was that substantial fractions of the tows were no more than 300 m apart. Pairs of stations were omitted if the tow had a database "Haul-Gear" code > 36 (indicating problems with the gear or towing operations), or if the tow was “unsuccessful” based on sensor data (research or fishing vessel tows, see NEFSC 2007). If the sensor based tow distance was missing for a research tow, then the median tow distance for successful random tows during 2008 was used instead.

As described below, potential cable and pump effects were not significant in ratio and linear model analysis using De2De2 paired station.

Background

Both electrical cables used during the 2008 survey were the same type and model. Both were purchased from the same vendor in one order prior to the 2005 clam survey. The old cable used during the 2008 survey was used during the 2005 survey also. It was shortened between surveys by removing a section near the end between the two surveys, however, because the steel cable used to retrieve the dredge during the 2005 survey had shed wire splinters that penetrated the covering of the electric cable on the end near the dredge. All other things equal, shorter cables are expected to generate less resistance, more power to the dredge and higher capture efficiency. However other factors (age, design, brand and condition of the cable may affect electrical resistance and capture efficiency.

Pumps used on survey dredges are rebuilt between surveys and tend to wear somewhat with corresponding changes in pressure as the survey progress. Newer pumps tend to generate slightly higher pressures but the range of variation during a survey of 400-500 tows is considered acceptable (NEFSC 2007). The pumps used at stations 1 and 141 were freshly rebuilt, of the same design, and from the same manufacturer.

De2De2 repeat stations

De2De2 repeats with zero surfclam catch in both tows would not affect estimates and were omitted. Based on this criterion, repeat station data were available for 23 De2De2 repeat stations (Table A12).

All of the original tows were made with the old cable and all of the repeat tows were made with the new cable. Fifteen of the original tows were made with the old pump, eight of the original tows were made with the new pump and all of the repeat tows were made with the new pump (Table A12). Differential pressure data indicate that pump effects were likely minor because differential pressure was within the normal operating range both before and after the new pump was installed (Figure A41 and NEFSC 2009). .

The ratio estimator (Cochran 1977) is the sum of repeat catches with new cable divided by the sum of original catches with old cable. It indicates that potential cable effects were minor or nonexistent. In particular, the ratio estimator for De2De2 repeat stations was 1.05 (SE 0.11) and the 95% confidence interval (0.84, 1.3) (Figure A42). Potential pump effects were ignored in ratio estimator analyses of the De2De2 repeat station data

Linear model analysis indicated that pump and cable effects were minor in De2De2 repeat tows. One pair of observations had zero catch in one tow and had to be omitted from this analysis. A step-wise procedure was used to search for the “best” model based on the AIC statistic. The most complicated model considered was:

Log(Catch) = Pair effect + Pump*Cable effects

where Catch was for a single tow, Pair is an identification number for each pair of original and repeat tows, and Pump*Cable (both either "old" or "new") indicates the main effects and the interaction between pump and cable effects. The simplest model considered was no differences among tows.

Based on AIC, the best model included only Pair effects, indicating that there were significant differences among sites where original and repeat tows were carried out, but not between pump or cable types.

De2Fv repeat stations

Only surfclams 150+ mm SL were used in analysis of De2Fv repeat tows because data from depletion experiments indicate that surfclams are fully recruited to commercial gear by 150 mm SL (NEFSC 2007b). Survey data for surfclams 150+ mm were adjusted for dome shape size selectivity (see below) to approximate catches by hypothetical survey gear with relatively high and constant size-selectivity at 150+ mm SL. Total catches were prorated to 150+ mm SL using subsampled shell length data for fishing vessel catches (all surfclams were measured on research vessel catches).

De2Fv repeat stations (Table A13) were repeat stations which were occupied 1-2 times by the *R/V Delaware II* and then by the *F/V Endeavor*. In addition, tows by the *R/V Delaware II* at the SC2008-1, 2008-2 and SC2008-5 depletion experiment sites were paired with the second depletion tow by the commercial vessel at that site. The second depletion tow (out of typically 17 depletion tows) was used because it was the first depletion tow with subsampled length data. Later depletion tows were ignored because there was two much overlap among depletion tows before the next subsampled tow (tow 7).

Tows at the SC2008-4 depletion experiment were not used in this analysis because of problems with strong currents that prevented successful completion of the experiment. Tows at the SC2008-3 depletion experiment were not used because of high variability in setup tow catches indicating that the distribution of surfclams was extremely variable at the site.

There were a total of 42 pairs of tows potentially useful in the analysis (Table A13). Cable and pump effects were almost completely confounded because seventeen Delaware II tows used the new cable and new pump, 24 used the old cable and old pump and only one tow used the new pump and old cable. Based on results for ocean quahogs (NEFSC 2009), pump effects were unlikely. Therefore, the De2Fv data were used to measure potential cable effects and potential pump effects were ignored.

Graphical analysis (Figure A43) indicated substantial variability in the data. Confidence intervals for the ratio estimators for repeat tows with the old (0.29 to 1.3) and new cables (0.24 to 2.3) overlapped each other and the 1:1 line. The ratio estimator for the entire data set (ignoring potential cable differences) was 0.97 and the 95% confidence interval (0.48 to 1.45). These confidence interval results indicate that the two ratio estimates could not be distinguished statistically.

Linear model analysis indicated that cable effects were minor in De2Fv repeat tows. Two De2Fv observations had zero catch for the research vessel tow and were omitted from linear model analysis. The model considered was:

$$\text{Log Ratio} = \text{Site effect} + \text{Cable effect}$$

The model identified statistically significant differences among sites but the difference between the old and new cables was not statistically significant (Cable effect=0.28, SE=0.46, p=0.56).

Size selectivity

Survey dredge selectivity was calculated using Millar's (1992) SELECT model and reevaluated using Miller's (2009) beta-binomial model. The data were collected by the *R/V Delaware II* and *F/V Endeavor* during cooperative selectivity experiments during 2008. Data from the experiments were used to estimate size-selectivity for the NEFSC clam survey dredge which is used by the *R/V Delaware II*. The data were also used to estimate size selectivity for the "unlined" commercial dredge used by the *F/V Endeavor* when repeating NEFSC 2008 clam survey stations. The unlined commercial dredge was configured for survey operations, rather than commercial fishing operations. Thus, the size selectivity estimates for the unlined dredge used by the *F/V Endeavor* during cooperative survey work are not applicable to commercial catch data. They may be useful, however, in anticipating the size selectivity of commercial dredges configured for use in cooperative surveys.

As described below, the size selectivity experiments analyzed for this assessment had a paired-tow design, because the tows were conduction in the same general area. R/V and F/V stations more than 300 m apart based on GPS position data were not used.

The data available for each selectivity study site included shell length data from: 1-2 R/V tows; one F/V repeat tow with the unlined dredge; and one F/V selectivity tow with the lined dredge. In addition, data for most of the experimental sites included shell lengths for the R/V repeat tow.

The *F/V Endeavor* has two dredges, each 12.5 feet (3.8 m) wide, which can be towed separately or simultaneously. The knives on both dredges were set at 5.25 inches (13.3 cm) for surfclam cooperative survey operations and 4.25 inches (10.8 cm) for ocean quahog operations. The starboard dredge used for F/V selectivity tows was lined with 1-inch hexagonal chicken wire to maximize retention of small surfclams.

After F/V repeat tows, the catch was dumped into the port or starboard hoppers and then moved mechanically onto a larger, centralized belt to a shaker table and then onto a sorting belt where sampling occurred following F/V repeat tows. The large belt before the shaker table was about 4 feet (1.2 m) wide and 10 feet (3 m) long. Alongside the belt was a large metal stand where the catch could be sampled before it reached the shaker table where mechanical sorting occurs. The average spacing between the rolling bars on the shaker table was 0.73 (+/- 0.10) inches which was narrower than during normal commercial operations.

Surfclams were measured to the nearest mm. F/V repeat tows used the port (unlined) commercial dredge. R/V and F/V repeat tows were 5-minutes in duration. F/V repeat tow catches were allowed to run over the shaker table and onto the sorting belt in the normal fashion before sampling to capture effects of both the dredge and shaker table on shell length data. The entire catch was measured following R/V tows following standard protocols. The number of bushels was counted for F/V tows and a subsample of two full bushels was measured.

For F/V selectivity tows, the lined dredge was towed for 30 seconds along a track adjacent to the F/V repeat tow. The catch was sorted before going over the shaker table to avoid loss of small surfclams due to mechanical sorting on deck. All clams in six full bushel samples were measured to the nearest mm. The volume of the catch was too large to sort the entire catch or accurately estimate total catch. Sensor data used elsewhere to measure area swept were not available for F/V selectivity tows with the lined dredge. Positions were measured at the start and stop of each selectivity tow by GPS.

Shell length data from selectivity experiments were tabulated using 10 mm shell length size groups (e.g. 35 for 30-39 mm SL). Survey size selectivity was estimated using data from R/V (survey and repeat) tows and FV selectivity data from 19 sites (Table A14).

SELECT estimates

For simplicity in the SELECT model, all R/V and F/V data were combined so that there was a single set of R/V, F/V repeat and F/V selectivity data (Tables A14-A15; Figure A45). Graphical analysis of the ratios of survey / total catch indicate that a standard logistic shaped selectivity pattern up to 150 mm SL and declining selectivity at larger sizes with an asymptote on the right hand side at about 0.25 (Figure A45). The ratio (1.0) for the largest shell height bin was omitted in modeling because the sample size was small (only four 190-200 mm SL clams were measured).

The increasing selectivity pattern for small sizes is common and was expected based on size selectivity estimates for ocean quahogs (NEFSC 2009). The decreasing selectivity for surfclams 150+ mm SL was surprising. Decreasing selectivity may not have been visible in ocean quahogs because they are smaller (usually less than 120 mm SL). It is difficult to determine the true effective sample size in the selectivity experiments but numbers measured were relatively large for most shell height groups larger than 150 mm (Table A15). Surfclams 150+ mm SL were observed at most sites indicating that the declining pattern was not due to observations at just a few sites (Table A15). Ratios of catches by the R/V and F/V by station were noisy nit do not indicate that the declining ratios for large surfclams were due to just a few tows (Figure A46). Large (160-190 mm SL) surfclams responsible for the dome shape were taken in reasonable numbers at most of the stations (Table A16).

In preliminary analyses, two survey selectivity curves were fit. The first curve assumes a standard logistic selectivity pattern and was fit to data for surfclams less than 150 mm SL only:

$$s_L = \frac{e^{\alpha+\beta L}}{1+e^{\alpha+\beta L}}$$

where shell length (L) is in mm and α= -8.868 and β= 0.14391 are parameters (Figure A45).

The second curve was fit to data for all surfclams less than 190 mm SL (all well sampled shell length groups). It was a modified "double logistic" function that assumed a dome shaped pattern with an increasing logistic selectivity pattern for small sizes and a decreasing logistic pattern for large sizes. An additional parameter was added to the double logistic model so that the descending limb had a non-zero asymptotic lower bound.

$$s'_L = \frac{e^{\alpha+\beta L}}{1+e^{\alpha+\beta L}}\left(1-\frac{e^{\chi+\delta L}}{1+e^{\chi+\delta L}}\right)(1-\varphi)+\varphi$$

$$s_L = s'_L / \max(s'_L)$$

where α= -8.710, β= 0.1409, χ= -40.47, δ= 0.2599 and ϕ= 0.4319 ($0 \le \phi < 1$) are parameters (Figure A45). The unscaled double logistic selectivity s_L' was divided by its maximum value max(s_L') so that the final selectivity curve had a maximum value of one. The split parameter which measures the relative efficiency of the two types of gear in the SELECT model was estimated in both models but the estimates are not presented because the numbers of clams taken in the R/V and F/V gear were not comparable (e.g. the survey and lined dredges differed in area swept and total catch was not recorded for F/V selectivity tows).

Size at 50% selectivity was 62 mm SL for the logistic model and the selectivity range (size at 75% selectivity – size at 25% selectivity) was 15 mm. Size at 50% selectivity for the

right hand ascending limb of the double logistic curve was also about 62 mm SL. The two models fit the selectivity experiment data well (Figure A45).

Beta-binomial estimates

Standard errors are not presented for the SELECT model in this assessment because the statistical properties of the pooled data (e.g. effective sample size) were complicated and uncertain. Instead, the beta-binomial model was used to calculate confidence intervals for the relative capture efficiency of the survey and lined dredges for each shell height bin separately (without making any assumptions about the underlying selectivity pattern). The beta-binomial approach has good statistical properties based on a simulation analysis for survey bottom trawl calibration data (Miller et al. 2009).

According to Miller et al. (2009), if the proportion $p_{s,L}=n_{s,L}/N_{s,L}$ of the total catch in the survey dredge for shell length group L at selectivity site s is binomial distributed with:

$$p_{s,L} = \frac{\rho_{s,L}}{\rho_{s,L}+1}$$

and

$$p_{s,L} \sim Beta(\mu_L, \phi_L)$$

(where μ is the mean of the beta distribution and ϕ is a shape parameter), then the expected catch in the survey dredge $n_{s,L}$ is:

$$E(n_{s,L}) = N_{s,L}\mu_L$$

The quantity of interest is the relative capture efficiency for each shell length group:

$$\rho_L = \frac{\mu_L}{1-\mu_L}$$

There is no analytical solution for the maximum likelihood estimators of ρ_L and ϕ_L so a numerical optimization approach was used to fit the beta-binomial model. For convenience, all parameters were estimated as logs, for example, $X=\ln(\rho)$. Asymmetric confidence 95% intervals for original parameters on the arithmetic scale were calculated by exponentiation of the bounds for 95% confidence intervals around the log scale parameters, for example:

$$CI(\rho) = e^{X \pm 1.96 s_X}$$

Where s_x is the standard error of X. Variances and standard errors for the log scale parameters were calculated by the delta method. Confidence intervals indicate that the apparent dome shaped selectivity pattern was real and not due to noise in the data (Figure A47).

Best estimate of survey dredge selectivity

After considerable discussion, the Invertebrate Subcommittee decided that the dome shaped curve is the best estimate of size selectivity for the NEFSC survey dredge. The domed shape selectivity model (Figure A45) used a wider range of data and there was no reason to discount the shell length data for surfclams 150+ mm SL. Beta-binomial confidence intervals (Figure A47) suggest that the domed shaped pattern is real although most of the evidence is for only two SL groups (160 and 170 mm SL). A detailed examination of the data for each station indicates that large size groups were sampled at most stations and in reasonable numbers (Table A16).

The dome shaped size selectivity curve seems biologically plausible. Large surfclams (150+ mm SL) have long siphons and live deeper in the sediments. They may be difficult to

dislodge using the light survey dredge with relatively low pressure at the nozzles (about 40 psi compared to about 80 psi on a commercial dredge).

Effects of correcting survey length data for survey dredge selectivity using the single and double logistic curves are shown in Figure A48. The apparent abundance of small surfclams (50 to 75 mm SL) increased in both cases. The abundance of large clams (> 150 mm SL) was higher after correcting for dome shaped survey dredge selectivity. Survey selectivity patterns are important in interpreting survey data and have impacts on stock assessment results for surflclams (see below).

The survey dredge selectivity experiments should be repeated if the NEFSC clam survey is carried out again by the *R/V Delaware II*. Current plans are to move the survey to an industry vessel that would lack the electrical equipment necessary to operate the survey dredge.

Unlined commercial dredge

A simple logistic selectivity curve was estimated for the unlined commercial dredge using F/V selectivity and F/V repeat station length composition data (Tables A14-A15). The parameter estimates were α= -10.68 and β= 0.1067. Size at 50% selectivity was 100 mm SL and the selectivity range was 20.1 mm. As expected, the unlined commercial dredge had relatively low selectivity for small surfclams (<100 mm SL) and relatively high selectivity for large (>150 mm SL) surfclams (Figure A45).

Shell length-meat weight relationships

The shell length-meat weight (SLMT) relationships are important because they are used to convert numbers of surfclams in survey catches to meat weight equivalents and to estimate stock biomass. Meat weights for surfclam include all of the soft tissues within the shell. Surfclam SLMT parameters estimates were revised in this assessment based on data from freshly shucked (unfrozen) clam meats collected during the 1997, 2002, 2005 and 2008 NEFSC clam surveys (Table A17). Surfclam assessments prior to 1997 used parameters based on frozen meats (e.g. from Gledhill 1984) collected during NEFSC clam surveys. Frozen samples give different relationships than fresh samples. Subsequent surfclam assessments (NEFSC 1998; 2000; 2003; 2007) used SLMT parameters from fresh meat weight data collected during the 1997 data in combination with estimates from frozen meat weights in Gledhill (1984).

SLMT parameters were estimated from fresh samples for each survey year and stock assessment region (Figure A49). To produce a single curve for each region, predicted weights for each year were calculated for surfclams 0 to 25 cm TL in steps of 0.5 cm. The curves for each different year in each region were averaged. Finally, a SLMT curve for the entire region was fit to the averaged data (Table A18).

SLMW for the entire stock

Assessment models require estimates of SLMW for the stock as a whole (Table A19). Shells for ageing and meat weights are sampled on a non-random length and stratum stratified basis during NEFSC clam surveys and not all regions are sampled in each year. Therefore, simply pooling age and meat weight data would not provide a representative random sample from the population. It was necessary to estimate relationships for the stock as a whole by averaging biological relationships for individual regions using the relative survey abundance in each region as the weights.

As described above, one SLMW curve based on fresh samples is available for each region. The curves for each region were averaged using weights described below to estimate a

single curve for the stock as a whole during each survey year. Average curves changed from year to year as the fraction of the stock in each region changed.

Weights used in averaging the regional SLMW curves were proportional to the regional abundance of surfclams 50+ mm SL:

$$W_{i,j} = N_{i,j}A_i$$

where $W_{i,j}$ was the unscaled weight for area i and year j used in averaging, $N_{i,j}$ was the survey density (mean number of clams per standard tow) and A_j was the area (nm^2) of region i. The weights for each region were rescaled so that they summed to one in each year. Stock-wide parameters were estimated by computing the curve for each region for surfclams 50 to 250 mm in steps of 5 mm, averaging the regional curves using the weights for each region in each year, and fitting a new SLMW curve to the averaged data for each year.

Growth

Surfclams in age and growth samples are measured at sea and the shells are retained for ageing in the laboratory. Shells for ageing are collected based on a length stratified sampling plan. A recent study confirmed that rings on shells collected during the summer clam survey are annuli that can be used to estimate age (see Appendix A6).

Age and length samples are available for most regions but not from every survey (Table A20). DMV and NJ were the most consistently sampled regions (Table A20). GBK was the least consistently sampled.

Plots of age vs. shell length by year and region (Figures A50-A54) indicate that growth patterns have been relatively constant in most regions over time with DMV and NJ being notable exceptions. As described in the last assessment (NEFSC 2007), maximum size was lower after 1994 in DMV and NJ.

Von Bertalanffy parameters for growth in shell length were estimated for each region by combining data sets from different years (Table A21). Growth parameters for DMV and NJ were estimated for three time periods (1978-1992, 1994-2008 and 1978-2008).

Growth in length and weight for whole stock

Von Bertalanffy parameters for growth in shell length and meat weight are used in stock assessment modeling. One von Bertalanffy curve for growth in SL was available for all regions except DMV, where there were two curves to represent growth before and after 1994. The von Bertalanffy growth curve used in most of the calculations was:

$$S_a = S_\infty\left(1 - e^{-K(a-t_o)}\right)$$

Where S_a is size (meat weight in g or SL in mm) at age a, and S_∞, K and t_0 are von Bertalanffy parameters (the curves for growth in SL and weight have different parameter values).

The first step was to compute the average weighted von Bertalanffy growth curve for shell length at ages 0 to 40 y in each region. The second was to convert predicted SL at age in each region to meat weight at age using the regional SLMW parameters for each year (Table A22). The third was to compute curves for growth in shell length and meat weight (separately) for the entire stock in each survey year by averaging the curves for each region using the weights described above. Whole stock von Bertalanffy curves for growth in SL in each year (Table A20) were estimated by fitting the von Bertalanffy equation by least squares to the averaged curves for growth in shell length.

The assessment model used in this assessment (KLAMZ) employs a version of the von Bertalanffy curve for growth in meat weight that has a constant parameter $\rho=\ln(K)$ and time varying parameters $J_t=W_{t-1,k-1}/W_{t,k}$ where k is the age at recruitment to the fishery in year t (assumed to occur at 12 cm SL), and $W_{t,k}$ is predicted meat weight. The age at recruitment to the fishery k was computed for the stock as a whole in each survey year using the whole stock growth curves for SL described above. Von Bertalanffy curves for growth in meat weight (not SL) in the whole stock and each survey year were fit using the averaged growth curves for the stock as a whole. To accommodate requirements of the KLAMZ model, the growth curves for meat weight in the entire stock had the same K parameter in all years and W_∞ and t_0 parameters that varied over time. The growth parameter J_t was calculated using predicted ages when surfclams reached 12 cm during each year (Table A23).

Results indicate that the growth parameter J_t for the whole stock has increased slightly from 1982 to 2008 (Tables A22 and A23). Linear regression was used to smooth the annual estimates of J for use in KLAMZ (Figure A55).

Term of Reference 3: Stock biomass and fishing mortality

Efficiency corrected swept-area biomass

Efficiency corrected swept-area biomass and fishing mortality estimates were calculated with CVs on a regional basis for surfclams during 1997-2008 (years with surveys). Methods were the same as in NEFSC (2007) with one exception. The exception was to use survey data for surfclams greater than 120mm SL adjusted upward to account for dome shaped survey dredge selectivity (Table A24-A25 and Figures A56-A57).

Efficiency corrected swept-area biomass and fishing mortality estimates in this assessment for years prior to 2008 differ from estimates in previous assessments due to: 1) changes after the 2008 survey in the criteria used to judge a "bad" (with poor gear performance) survey tow; 2) the availability of data for 2008 that could be borrowed to help fill "holes" (unsampled strata) in the survey data for 2005; 3) new shell length meat weight relationships based on fresh (unfrozen) samples; 4) the updated estimate of survey dredge capture efficiency; and 5) use of the new survey dredge selectivity curve to calculate stock biomass. Table A26 "builds a bridge" between previous and new efficiency corrected swept-area biomass estimates for surfclams during 2005. Results (Table A26) indicate that the most important changes were using the 2008 survey data to fill holes in the survey for 2005 survey and the updated estimate of dredge efficiency. The relatively large effect on estimated biomass in GBK during 2005 occurred because it was essentially unsampled during 2005. NEFSC (2007) assumed that the biomass in GBK during 2005 was the same as in 2002 (borrowing from 2002 to fill holes in 2005). In this assessment, it was possible to borrow data from both the 2002 and 2008 surveys in filling holes for GBK during 2002. The interpolation using 2002 and 2008 was probably more accurate than using just 2002.

A historical retrospective analysis was carried out to demonstrate the stability of efficiency corrected swept-area biomass estimates used to provide management advice in the last four assessments. Swept-area biomass and fishing mortality calculations have changed from assessment to assessment as additional survey data accumulated and, mainly, as estimates of survey dredge efficiency were refined (Tables A27-A28).

Sensitivity of efficiency corrected swept-area biomass to survey dredge selectivity

Calculations are used in this section to predict and explain effects of dome shape selectivity on capture efficiency estimates for the NEFSC clam dredge and efficiency corrected

swept-area biomass estimates. All other factors equal, survey dredge efficiency estimates are expected to increase by about 46% and stock biomass estimates are expected to decrease by about 14% based on these approximate calculations.

Survey dredge capture efficiency is estimated $e = \bar{n}/N$ where $\bar{n}$ is the average density (number per ft^2) of 150+ mm surfclams in survey dredge tows at the depletion experiment site prior to the experiment and N is the estimated density of 150+ mm surfclams at the site estimated by the Patch model using data from a commercial vessel. Efficiency corrected swept-area biomass is $B = \frac{\bar{b}A}{ae}$ where $\bar{b}$ is the stratified mean biomass density data (kg per ft^2) from the survey, A is the area covered by the survey, and a is the area swept by a survey tow. The ratio of areas A/a is a constant so $B \propto \bar{b}/e$.

The NEFSC surfclam database was reprogrammed to calculate the expected mean numbers per setup tow while accounting for the dome shaped selectivity pattern (i.e., $n_j^* = \sum_L \frac{n_{j,L}}{s_L}$, where n^* is the catch density adjusted for dome shape selectivity from setup tow j, $n_{j,L}$, is the observed (unadjusted) catch density for length L, and s_L is the selectivity. The estimate of capture efficiency using the adjusted data is $e^* = \bar{n}^*/N \propto \bar{n}^*$ and the efficiency corrected swept-area biomass would be $B^* = \frac{\bar{b}^* A}{ae*} = \frac{\bar{b}^* AN}{a\bar{n}^*} \propto \bar{b}^*/\bar{n}^*$.

The ratio of survey efficiency with and without the assumption of dome shaped selectivity is $e^*/e = n^*/n$, which is > 1 if $n^* > n$, as expected after adjusting for selectivity. In fact, based on 21 actual depletion studies with setup tows (Table A29), estimated survey dredge efficiency is expected to increase by about 46% on average.

If survey dredge efficiency estimates increase, then efficiency corrected swept-area biomass must decrease. In algebraic terms, the ratio of swept-area biomass estimates with and without the assumption of dome shaped selectivity is $B^*/B = \bar{n}\bar{b}^*/\bar{b}\bar{n}^*$. Based on the 21 actual depletion studies with setup tows (Table A30), efficiency corrected swept-area biomass is expected to decrease by about 14% on average. The Invertebrate Subcommittee anticipated that biomass estimates would increase after selectivity adjustments. However, the estimates decreased because $\bar{n}^*$ in the denominator increased faster than $\bar{b}^*$ in the numerator.

KLAMZ modeling

The KLAMZ model for the entire surfclam stock during 1982-2008 is the main modeling approach and primary basis for providing management advice in this assessment. KLAMZ model results are also given for surfclams in the DMV and NJ regions, which are of particular interest. Based on the current fishery management plan for surfclams, results for DMV and NJ have no place in status determination for the stock as a whole.

The KLAMZ assessment model is based on the Deriso-Schnute delay-difference equation (Deriso 1980; Schnute 1985; see complete technical documentation in Appendix A4). The delay-difference equation is a relatively simple and implicitly age structured approach. It gives the same results as explicitly age-structured models (e.g. Leslie matrix model) if fishery selectivity is "knife-edged", if somatic growth follows the von Bertalanffy equation, and if natural mortality is the same for all age groups in each year. Natural and fishing mortality rates,

growth parameters and recruitment may change from year to year. Fishery selectivity is not knife-edge for surfclams so the model tracks fishable biomass (the portion of the stock fully recruited in each year). As shown in Appendix 5, the KLAMZ model results for fishable biomass are very similar to estimates from a model that includes fishery selectivity.

There are two age or size groups in KLAMZ, "new" and "old" recruits that together comprise the whole stock. New recruits are surfclams that recruited at the beginning of the current year. Old recruits are all of the older surfclams in the stock that survived from the previous year.

KLAMZ delay-difference models in this assessment were for surfclam biomass dynamics during 1981-2008 and were generally similar to models used in the last surfclam assessment (NEFSC 2007). The first year with survey data was 1982, however the model has an estimable parameter for biomass in 1981 that defines the initial age structure. Landings data are available for earlier years. A number of changes, primarily to input data, for this assessment are described below under "Building a bridge". As in the last assessment, the natural mortality rate is M=0.15 y^{-1} unless stated otherwise (Appendix A4).

Growth patterns were assumed to vary over time in all models because of recent slow growth in the DMV and NJ regions and because of changes in the distribution of the stock among regions which have different SLMW and von Bertalanffy growth patterns. In the KLAMZ model, the growth parameter $J_t = w_{t\text{-}1k\text{-}1}/w_{t,k}$ (where $w_{t,k}$ is the mean body weight of a surfclam at the age of recruitment k in year t) may vary from year to year. The growth parameter J_t represents the combined effects of the traditional von Bertalanffy growth parameters W_∞ and t_0. This approach was adequate for surfclams because much of the variation in growth appeared to be in maximum size W_∞. Predicted J_t values for the whole stock were predicted values for each year from a linear regression analysis of growth parameters estimated from survey age data for the whole stock over time (Table A23). For DMV, J_t=0.815 during 1982-1992, 0.857 during 1993 and 0.899 in subsequent years. For NJ, J_t= 0.802 during 1982-1992, and 0.844 during 1999-2008. J_t values for DMV and NJ during intervening years (1993-1998) were calculated by linear interpolation.

Model configuration

NEFSC clam survey data in the KLAMZ model were for new and old recruits (Table A9). Surveys were assumed to occur in the middle of the year because the NEFSC clam survey is carried out during late May-early July. As in the previous assessment, survey data used in the KLAMZ model were trends after holes (unsampled survey strata in some years) were filled to the extent possible by borrowing data from the previous and successive surveys. Data from all NEFSC clam surveys since 1982 were used in modeling, despite problems with the survey in some years (e.g. changes in dredge efficiency in 1994, a few holes not filled by borrowing, etc.).

Survey trend data (stratified mean kg/tow) for surfclams 120-128 mm SL were assumed to track trends in biomass of new recruits. Survey data for surfclams 120+ mm were assumed to track trends in the entire stock (new + old recruits). Thus, survey data for surfclam 120-128 mm SL were intentionally used in both the new and old recruit survey trend indices. This strategy helped with interpretation of scaling parameters estimated in the model for survey data that were scaled to approximate 120+ mm stock biomass (see below). In practical terms, it had little effect on the survey data themselves because recruit kg/tow was small relative to kg/tow for the remaining fishable size groups.

For convenience in interpreting model results, survey data (mean kg/tow) for fishable surfclams in the entire stock were scaled up to approximate efficiency corrected swept-area

biomass before use in the KLAMZ model. The scaling factor was based on the survey trend data and efficiency corrected swept-area biomass estimates for surveys beginning in 1997 (Table A24). With this adjustment, the survey scaling parameter for fishable biomass trends estimated in the KLAMZ model is expected to be close to one and can be used as a model diagnostic. Scaling the survey trend data did not affect biomass or fishing mortality estimates.

Following NEFSC (2007), efficiency corrected swept-area biomass estimates were included in the assessment model to measure scale but not trends in biomass. Goodness of fit to the swept-area biomass data was given nil weight in the overall objective function. However, the likelihood of the estimated scaling parameter for swept-area biomass was calculated based on a lognormal prior distribution with mean 1.0 and arithmetic CV = 0.14 and the likelihood was added to the objective function used in fitting the model. The CV was estimated by bootstrapping the median of all existing survey dredge efficiency estimates. The CV is relatively small and the prior information had a substantial effect in determining the overall scale of surfclam biomass and fishing mortality estimates. Experience has shown that surfclam stock assessment data, other than efficiency corrected swept-area biomass estimates, are uninformative about the overall scale of biomass but do provide information about trends.

LPUE data were included in the model to facilitate comparisons with model estimates of stock biomass trends. As with swept-area biomass data, LPUE was given nil weight in the likelihood used to fit the model and did not affect estimates.

Following NEFSC (2003) surfclam recruits were estimated in the KLAMZ model as a random walk with steps constrained by a variance parameter. A smooth, random walk process is probably not ideal from a biological perspective because of the evidence in survey age composition data for strong year classes but the approach was necessary because of the lack of annual recruitment data. The random walk approach keeps the recruitment estimate in year t at the same level as in year t-1, unless there is a good reason in terms of goodness of fit to change it. For surfclams in the KLAMZ model, the random walk approach helped avoid excessive variation in recruitment, enhanced model convergence, and ensured that some recruitment was estimated for each year.

It modeling surfclam population dynamics with random walk recruitment, it is important to control the "random walk recruitment variance" σ_R^2 which measures variability in the size of successive steps taken during the random walk (i.e. variance in [$\ln(R_1/R_2)$, $\ln(R_2/R_3)$, $\ln(R_3/R_4)$, etc.], where R_t is the recruitment estimate for year t). As σ_R^2 approaches zero, recruitment estimates become smooth and tend towards a constant value with no changes from year to year. As σ_R^2 becomes large, estimated recruitments will become more variable.

Initial KLAMZ model runs assumed a high CV for steps in the random walk. The assumed CV was gradually decreased in subsequent runs until the model was just able to fit the survey data without pattern in residuals and the model was able to fully converge (the Hessian matrix was invertible). In addition, the CV for fit to the survey data (residual CV) was compared to CVs for the actual survey data to determine if the model was fitting the survey data more closely than should be expected based on the precision of the survey data (implying that σ_R^2 was too large). The goal was basically to find the simplest model (fewest effective recruitment parameters) that would adequately explain the survey data for surfclams. Choices were subjective but had only modest effects on biomass and fishing mortality estimates for surfclams, because many different recruitment patterns can result in similar biomass and recruitment levels. NEFSC (2007) used a different procedure that started with a small variance that was increased until the model fit the survey data with or without full model convergence. The approach used

this year results in smoother recruitment patterns and less variation over time in estimated recruitments.

The random walk approach with σ_R^2 controlled accommodates the limited data for surfclams but probably results in some bias because the model tends to understate year to year variability in recruitment. Detailed simulation analyses have not been carried out, but recruitment estimates tend to be too smooth and biased towards their mean and it is likely that biomass estimates are as well.

Recruitment estimates for surfclam from the KLAMZ model are complicated to interpret because of the constraints on variability and limited survey data. Recruitment estimates in KLAMZ and other models are aliased with model misspecification, survey noise, survey year effects, natural mortality and variability in growth. However, difficulties in interpreting recruitment estimates from the KLAMZ model are exacerbated for surfclams because of the constraint on their variance. The estimates for surfclams are probably best regarded as "nuisance" parameters of less interest than biomass and fishing mortality estimates. The recruitment estimates for surfclams may reflect long term average trends but in no way estimate higher frequency or year to year variation.

Results-whole stock

The KLAMZ model fit survey biomass trend data reasonably well (Figure A58). The model fit the whole stock survey data index better than the index for new recruits, as expected based on the CVs for the two sets of survey data (CVs for the recruit index are higher). Estimated biomass trends from the model were similar to trends in LPUE and trends in swept-area biomass, although trends in these data did not affect model estimates.

The survey scaling parameter for the scaled fishable biomass index was Q=1.19 and reasonably close to one (Figure A58). The survey scaling parameter for efficiency corrected swept-area biomass was Q=1.12 indicating that the trend data, landings and model estimates were compatible with the prior information about Q for efficiency corrected swept-area biomass estimates.

Model results (Table A31 and Figure A59) suggest that surplus production was high during the early 1980s and steadily declined afterwards to negative levels during 2001-2008 as somatic growth and recruitment rates declined. Biomass increased until the late 1990s when surplus production was less than catch. Fishing mortality rates averaged 0.024 during 1982-2008, which is roughly 16% of the assumed natural mortality rate.

The means of bootstrap biomass estimates (2000 iterations) indicated that biomass estimates from the KLAMZ model had a modest positive bias because the mean of bootstrap biomass values was higher than the basecase estimates by about 6% on average (Figure A60). Similarly, fishing mortality estimates were biased low by about 5% on average. In contrast, the median of bootstrap values and basecase estimates were very similar. The positive bias was due to the asymmetric distribution of bootstrap estimates (Figure A61).

Bootstrap and delta method CVs for biomass, fishing mortality and recruitment estimates were < 25% indicating that estimates were reasonably precise (Figure A62). CVs calculated by the delta method were generally larger than CVs from bootstrapping, particularly after 1989 and for recent years. The delta method CV values seem more realistic because they imply greater uncertainty. Therefore, delta methods CVs were used in this assessment to characterize variability in model estimates. The model did not completely converge during a substantial fraction of bootstrap runs (the Hessian matrix was not invertible in roughly 26% of the 2000

bootstrap runs), due to uncertainty in estimated recruitments. In other words, a range of recruitment patterns probably explained the bootstrap survey data equally well.

Basecase retrospective analysis

Retrospective analyses were carried out with the basecase KLAMZ model for terminal years 1999-2008 (Figure A63). There was little evidence of a retrospective problem in either biomass or fishing mortality estimates. Changes in estimates tended to occur when data from an additional NEFSC clam survey (as in the case of 1999, 2002, 2005 and 2008) was dropped. The basecase model demonstrates that projections are relatively stable too because runs with terminal years between surveys are the same as projections.

Historical retrospective analysis

Biomass and fishing mortality estimates from surfclam stock assessments carried out since 1998 were compared to determine the stability of stock estimates used to provide management advice (Figure A64). Biomass and fishing mortality estimates from these assessments were reasonably stable, probably because they were based on efficiency corrected swept-area biomass estimates that change only to the extent that estimates of survey dredge efficiency change over time. The most important aspect of the historical retrospective analysis is the substantial differences between basecase biomass and fishing mortality estimates and estimates from the previous assessment. The factors responsible for these changes are explained below.

Building a bridge

Differences between estimates in the basecase model and last assessment are explained by incorporating modifications to data and modeling procedures one step at a time (Table A32 and Figure A65). This analysis indicates that the most important factors contributing to differences between the basecase model biomass estimates in this assessment and estimates in the previous assessment are: use of updated SLMWT relationships based on fresh (unfrozen) samples (Step 4), the updated estimate of survey dredge efficiency (Step 5), the addition of survey and fishery data through 2008 (Step 9), assumption of a dome shape survey selectivity pattern (Step 11), and adjustment of the variance parameter for recruitments to ensure model convergence (Step 12).

Step 1 was to run the computer program used in the current assessment using data from the last assessment to determine if any new bugs had crept into the model code. Step 2 was to incorporate changes in sensor data criteria used to identify and discard "bad" survey tows for use in estimating efficiency corrected swept-area biomass. The third step was to use survey data for 2008 to fill holes in the 2005 survey data in addition to 2002 survey data (survey data for 2006-2008 were not otherwise included). The fourth step was to incorporate new SLMW relationships estimated from fresh samples. The fifth step was to use updated estimates of survey dredge efficiency in specifying the prior for swept-area biomass data. The sixth step was to assume logistic survey selectivity in calculating survey trend data for the stock (superfluous because a dome shaped selectivity curve was eventually used). The seventh step was to use a single updated growth curve for the entire stock (superfluous because a smoothed, time-varying growth pattern was eventually used). The eighth step was to use one updated growth curve for 1981-1993 and a different updated curve for later years (superfluous because a smoothed, time-varying growth pattern was eventually used). The ninth step was to incorporate fishery and survey data for 2006-2008. The tenth step was to use a smooth time varying growth pattern. The eleventh

step was to adjust the survey data for the dome shaped size selectivity pattern. The base case model (step 12) involved adjusting the recruitment variance parameter σ_R^2 to ensure convergence.

Steps 1-8 involved running the model for 1981-2005, as in the last assessment. Steps 6-8, which involve growth and survey dredge size-selectivity, could have been omitted in presentation of results but it would have been necessary to repeat all subsequent steps. Thus, steps 6-8 reflect steps actually taken by the Invertebrate Subcommittee in completing the assessment but are not meant to convey additional uncertainty about growth or survey dredge selectivity assumptions in the basecase model.

Results-DMV and NJ

The KLAMZ model for DMV fit survey index data reasonably well (Figure A66) although goodness of fit was better for the relatively noisy recruit survey data than for the 120+ mm SL survey data. The survey scaling parameter for the 120+ SL index was substantially larger than one but the scaling parameter for efficiency corrected swept-area biomass was almost exactly one. The model matched trends in swept-area biomass and LPUE quite well, although trends in these data had no effect on model estimates.

The KLAMZ model for NJ fit survey index data reasonably well (Figure A67). The survey scaling parameter for the 120+ SL index was almost exactly one while the scaling factor for efficiency corrected swept-area biomass was larger than one. The model matched trends in swept-area biomass and LPUE data after 2000, although trends in these data had no effect on model estimates.

Model results for DMV indicate that biomass declined continuously from relatively high levels during the early 1980s due to rapid declines in recruitment after 1998, lower average somatic growth rates, and surplus production levels that were negative in most years (Figure A68). Fishing mortality in the DMV region increased to about 0.07 y^{-1} during 2008.

Model results for NJ indicate that biomass increased during 1981-1996 and declined afterwards as recruitment fell and average somatic growth rates declined (Figure A69). Surplus production was positive until 1996 and negative afterwards. Fishing mortality in the NJ region increased to about 0.1 y^{-1} during 2008.

Term of Reference 4: Updated and redefined biological reference points and scientific adequacy of existing and redefined BRPs

According to the FMP for Atlantic surfclams, overfishing occurs whenever the fishing mortality rate on the entire stock is larger than the F_{MSY} proxy. The stock is overfished if total biomass falls below $B_{Threshold}$, which is estimated as of the ½ B_{MSY} proxy. When stock biomass is less than the biomass threshold, the fishing mortality rate threshold is reduced from F_{MSY} to zero in a linear fashion.

The current proxy for $F_{MSY} = M = 0.15$ y^{-1} was not revised in this assessment. The proxy for B_{MSY} is one-half of the estimated fishable biomass during 1999. The 1999 biomass and biological reference points derived from it were re-estimated in this assessment. The original and revised reference point values are shown in the table below.

Reference Point	Last assessment	Revised
F_{MSY}	M=0.15 y^{-1}	Same
B_{1999}	1,460 thousand mt meats	1086 thousand mt meats
B_{MSY} =½B_{1999} (target)	730 thousand mt meats	543 thousand mt meats
$B_{Threshold}$ = ½ B_{MSY}	365 thousand mt meats	271.5 thousand mt meats

Revised biomass reference points are lower than previous values primarily because of new information about the shell length and meat weight relationships, growth and efficiency, size selectivity of the dredge used in NEFSC clam surveys and changes in modeling technique. Conclusions about stock status would not change unless either the mortality estimate or threshold was changed by a factor of 8-9.

Scientific adequacy of reference points

The current proxy for F_{MSY} (M = 0.15) is a common approach used in many fisheries. However, the productivity of the surfclam stock appears low for a species with M=0.15 and surplus production in surfclams may be negative for periods up to one or two decades. The consistently poor performance of the simulated surfclam stock in projection analyses under the F_{MSY} proxy policy indicates that M=0.15 may be a poor proxy for F_{MSY} in the surfclam fishery.

The proxy for F_{MSY} =M =0.15, but there is substantial uncertainty about natural mortality in surfclams, which likely varies temporally and spatially. Reductions in biomass of surfclam in inshore southern regions are probably due partly to changes in environmental conditions and increasing natural mortality. On the other hand, the common occurrence of old clams (i.e. 30+ years) in survey catches imply that the natural mortality rate may be lower than assumed.

The current biomass reference points were based on the observation that the stock was at a high biomass level in 1999. The 1999 estimate is used like an estimate of virgin biomass. In reality, the biomass in 1999 was a relatively high level that occurred following a period of good recruitment after decades of fishing. The adequacy of this *ad-hoc* approach could be reevaluated.

The technical basis of the current biomass reference points for surfclam as B_{MSY} proxies (B_{Target} = ½ estimated B_{2009} and $B_{Threshold}$ = ½ B_{Target}) has been, at least through 2008, undermined by spatial patterns in the fishery and stock. Through 2008, the GBK region was closed to fishing because of PSP. Under these conditions and based on current reference points it would be theoretically possible to eliminate all of the surfclams in southern regions, to the detriment of the stock and fishery, without triggering an overfished stock status condition. In particular, the basecase model estimate of B_{2009} in this assessment is 1,086 thousand mt, the biomass target is 543 thousand mt, and the threshold is 272 thousand mt. Efficiency corrected swept-area biomass estimates (Table A24), indicate that the biomass on GBK in 2008 was 518 thousand mt. Thus, if all surfclams in the SVA, DMV, NJ, LI and SNE regions where the fishery took place prior to 2009 were eliminated, the surfclam stock biomass (518 thousand mt entirely on GBK) would be officially near its biomass target (543 thousand mt). In this hypothetical scenario, the stock would not be overfished ($B<B_{Threshold}$) unless about half of the biomass on GBK were removed as well. These problems are in addition to technical problems in defining and estimating F_{MSY} and B_{MSY} for sessile spatially heterogeneous stocks like surfclams, ocean quahogs (NEFSC 2009) and Atlantic sea scallops (Hart 2003) with differences in biological properties (growth, SLMW, etc.), recruitment patterns and mortality.

These problems will be ameliorated to some extent if the fishery develops as the clam industry expects on GBK in the near future. GBK is currently open for fishing contingent on ongoing testing and absence of PSP. Little or no catch has been taken on GBK to date during 2009, possibly because the region was open to fishing late in the year. A shift in fishing effort onto GBK would almost certainly benefit the stock and fishery by reducing pressure on current fishing grounds in the DMV and NJ regions, where abundance and surplus production have been recently low. However, development of the fishery on GBK is uncertain because PSP may reoccur, most of the processing plants and vessels in the fishery are located in the south close to traditional fishing grounds, weather tends to be inclement on GBK during some seasons, because Massachusetts does not currently allow landings from GBK, and because GBK is relatively distant from other processing plants located in south of Massachusetts.

Term of Reference 5: Stock status evaluation with respect to BRPs

Based on confidence intervals, the Atlantic surfclam stock in the US EEZ has a very low probability of being overfished ($B \leq B_{Threshold}$). The estimated stock biomass during 2008 for surfclams 120+ mm SL was 878 thousand mt meats (CV=0.16) with a 95% confidence interval of approximately 646 to 1,193 mt (Figure A70). The biomass threshold is 1/4 of the biomass estimate for 1999 = 272 thousand mt meats (CV 0.16) with a 95% confidence interval of 200 to 369 thousand mt (Figure A70). In bootstrap analyses with 2000 iterations, biomass during 2008 was never less than the bootstrap estimate of the biomass threshold.

Based on confidence intervals, surfclam biomass in 2008 was probably above its target level ($B \leq B_{Target}$). The biomass target is ½ of the estimated biomass during 1999 = 543 thousand mt (CV 16%) with a 95% confidence interval of 400 to 738 thousand mt (Figure A70).

The estimated fishing mortality during 2008 was F= 0.0272 y^{-1}, which is below the management threshold $F = M = 0.15$ y^{-1}. Confidence interval analysis suggests that there is nil probability that F during 2008 exceeded the threshold reference point (Figure A71). Bootstrap estimates of fishing mortality during 2008 never exceeded the F_{MSY} proxy (0.15) in bootstrap analyses with 2000 iterations.

Term of Reference 6: Potential environmental, ecological and fishing-related factors that could be responsible for low recruitment

This section synthesizes information about surfclams and conditions in state and federal waters to identify factors potentially responsible for recent low recruitment in the DMV and NJ regions (Figure A19). Results provide a clearer picture of the scope and timing of poor recruitment patterns for DMV and NJ surfclams but no definitive conclusions can be reached.

In this section, depending on context, "recruitment" may refer to settlement of larvae on the substrates, recruitment to NEFSC clam survey at about 50 mm SL in offshore federal waters (3-200 nm from shore) or recruitment to the fishable stock at about 120 mm SL. NJ and NY conduct surveys in state waters (≤ 3 nm from shore) with a commercial clam dredge so that recruitment to state surveys also occurs at about 120 mm SL. The NJ survey is inshore but adjacent to the NJ assessment region while the NY survey is along the southern coast of Long Island Sound, which is adjacent to the LI assessment region (Figure A1, Appendix Figures A3-1 and A3-2).

In summary, the available data indicate that the last strong recruitment events in the DMV and NJ regions were the 1993 year class in DMV and the 1992 year class in NJ. Declines in recruitment to the fishable stock (120+ mm SL) began to occur after 2002. Relatively high survey data for small surfclams (<60 mm SL) in the NEFSC offshore clam survey and numbers

of age 0 surfclams in grab samples in the NJ inshore survey support the hypothesis that high mortality between larval settlement and recruitment to the fishery at about 120 mm SL is an important factor. Recruitment patterns in survey data from inshore NJ and NY state surveys and the offshore NEFSC surveys are similar. However, conditions in the offshore DMV region (nearer the southern end of the stock's range) and NJ state waters appear worse than in the offshore NJ region or NY state waters. Slow growth rates exacerbate the problem and reduce recruitment to the fishable stock by approximately 15% in NJ and 26% in DMV. Warm water conditions and a die-off in the DMV region during the early 2000s documented by Weinberg (2005) probably reduced surfclam recruitment, but summer bottom temperature data (which are limited) indicate that the warm water conditions did not occur after 2003 and water temperatures were cool in 2008.

It is not likely that the fishery was responsible for causing the current period of poor recruitment. However, relatively high fishing mortality rates in the DMV and NJ regions (i.e. 0.07 and 0.1 y^{-1} during 2008 and rising) at current low biomass levels and under poor environmental conditions may further reduce recruitment and prolong the period of low productivity for surfclams in the DMV and NJ regions.

Survey data

Based on NEFSC survey age data, recruitment to the fishable stock has been low in DMV and NJ for about at least a decade. The last strong recruitments were the 1993 year class in DMV (Figure A30) and the 1992 year class in NJ (Figure A31) although the 1999 year class was recognizable in survey age data for the NJ region.

NEFSC survey trend data for small surfclams (50-119 mm SL, Table A9 and Figure A19) indicate reduced recruitment to the NEFSC clam survey in about 1997 for NJ and, in particular, DMV. The absence of periodic strong recruitment pulses is particularly evident after 1997.

Recruitment to the fishable surfclam stock in DMV and NJ has been low for at about five years. In particular, NEFSC survey data (Figure A23), NJ survey density data for 1988-2008 (Appendix Figure A3-10) and NJ length data (Appendix Figures A3-5 and A3-7) indicate substantial declines in recruitment to the fishable stock after 2002. Trends in surfclam abundance during 2002-2008 from NY surveys and recent trends in NEFSC and NJ surveys indicate that current conditions are probably similar in the near shore waters of both states and offshore waters of the DMV and NJ regions (Appendix Figure A3-5). However, the time series of NY survey data are too short to determine the onset of declines there.

Two important data sets indicate that recruitment of larvae to the substrate and recruitment of small surfclams to the NEFSC clam survey varied without trend while declines in recruitment to the fishery occurred. Ignoring 1994 (because of problems with dredge efficiency), bearing in mind that DMV was not sampled during 2008, and recognizing the noisy nature of the data, NEFSC survey data for surfclams smaller than 60 mm SL do not show a clear decline during recent years (Figure A22). Juvenile (1-2 cm SL) surfclam counts from NJ grab samples varied without trend during 1995-2009 (Appendix Figure A3-12).

Preliminary results from the NY 2008 survey suggest an increase in “seed” surfclams less than 10 cm SL in NY state waters. The proportion of seed surfclams was 1.7% of the population in 2006 but increased to 10% of the population in 2008. However, the increase is mostly attributable to large catches of seed clams at three stations in one survey stratum (W. Carden, New York State Department of Fish, Wildlife and Marine Resources, pers. comm.).

Growth

As described in "Age and size at recruitment to the fishery", slow somatic growth rates since the mid-1990s exacerbate recent problems because they delay recruitment to the fishery for 1-2 years. If the natural mortality rate is M=0.15 y^{-1}, then these delays result in am approximately 15% (NJ) or 26% (DMV) loss in recruitment to the stock per juvenile that settles on the substrate.

Survey age data indicate some consistency in growth between inshore areas of LI and offshore areas of NJ and DMV. Based on age data from the NY and NEFSC surveys, growth was similar in NY state waters during 2002-2006 and in the offshore DMV and NJ regions (Figure A50-A51).

Water temperatures

Weinberg (2005) documented a die-off of surfclams in the inshore section of NEFSC survey stratum 9 in the DMV region during the early 2000s that was associated with warm water conditions. Summer bottom temperatures collected during a variety of NEFSC surveys in stratum 9 at depths of ≤ 50 m show warm bottom temperatures during the early 2000s as reported (Figure A73). More recent data are limited but water temperatures after 2005 fluctuate around normal levels (Figure A73).

Predator data

Insufficient data exist to characterize potential impacts of predation on surfclam recruitment. The NEFSC food habits database contains stomach content data collected since 1973 during fall, winter and spring bottom trawl surveys. The database contains approximately 600 thousand records of the occurrence of various species in the stomachs of fish sampled. However, there are only 167 records for surfclams. The main predators of surfclams, based on the food habits database are smooth dogfish, spiny dogfish and winter skate. Cargnelli et al. (1999) review additional information about surfclam predators.

Potential fishing effects

Reduced spawning biomass probably did not cause poor recruitment in surfclams, although current low stock biomass in DMV and NJ may contribute to future low recruitment. Surfclams begin to mature at age 0 so fishable stock biomass underestimates spawning stock biomass. Assuming surfclams in DMV and NJ recruit at an average age of 6 y, the fishable stock in 2008 consisted of surfclams from year classes spawned prior to 2008-6=2002. KLAMZ model results indicate that fishable surfclam biomass (120+ mm SL) in DMV during 2002 was 36% of the maximum biomass estimated biomass in 1981 (Figure A68). Thus, problems with recruitment began while the surfclam biomass in DMV was ≥ 36% of its maximum value. Similarly, KLAMZ model results for NJ indicate that stock biomass in 2002 was 76% of its maximum estimated value in 1996 (Figure A69). Most finfish fisheries have relatively high average recruitment and are productive at 36%-74% of maximum biomass, although a comprehensive review of this question has not been carried out for bivalve fisheries.

Disturbance of sediments by dredges is unlikely to have caused problems with surfclam recruitment. Fishing effort has increased substantially in the DMV and NJ regions during recent years (Table A4). Wallace and Hoff (2005) estimate that commercial clam dredges disturbed about 400 nm^2 of substrate within the EEZ and an additional 50 nm^2 in state waters during 2000. Logbook data for 2000 show that there was about 19 thousand hours of fishing effort for surfclams (Table A4) and about 41 thousand hours of fishing effort for ocean quahogs (Table A5 in NEFSC 2009) and that nearly all fishing effort was in the EEZ. Thus, fishing effort for

surfclams in the EEZ probably disturbed about 19/(19+41) x 400=127 nm^2 of substrate during 2000. Surfclam fishing effort in DMV and NJ increased from 19 thousand in 2000 to 45 thousand hours per year in 2008, indicating that the area disturbed by dredges fishing for surfclams in the EEZ may have increased to 45/19 x 127 = 301 nm^2. The area of survey strata for DMV and NJ assumed to be potential surfclam habitat in this assessment comprise about 10,000 nm^2 (Figure A1). The area disturbed by dredges (127 nm^2 during 2000 and 301 nm^2 during 2008) seems minor in comparison to the total potential habitat area in the DMV and NJ regions. However, surfclams have patchy distributions and the fishery operates in areas where surfclam density and recruitment are high (Figure A74).

Recent survey and fishery data for DMV and NJ show that fishing and surfclam recruitment often occur in the same areas. Not all areas with good recruitment are fished extensively (Figure A74). On the other hand, it is impossible to determine if recruitment would have been higher in the areas where good recruitment and the fishery overlap if the fishery had not been present.

Apart from problems with recruitment, declines in the fishable (120+ mm) stock have been exacerbated to a minor degree by fishing because catches were relatively low. Surplus production has been negative and biomass declines would have occurred in the absence of fishing mortality. However, fishing mortality rates in offshore areas increased recently to levels that are high relative to historical estimates (about 0.07 in DMV and 0.1 in NJ during 2008) and likely to increase. Fishing mortality rates may be as high or higher in state waters of NJ and NY (Appendix A3). Fishing mortality rates of $0.1y^{-1}$ or higher, current low biomass levels in DMV and NJ, in combination with apparently unproductive (but unidentified) environmental conditions could reduce spawning biomass and recruitment in the near term. However, surfclam larvae settle 19-35 days after fertilization (depending on water temperature) indicating that recruitment to fished areas in DMV and NJ could originate elsewhere.

Term of Reference 7: Projection and decision table analysis

Projections were used for two purposes in the surfclam stock assessment: 1) to forecast future stock conditions assuming that the basecase model was valid, while accounting for uncertainties in the basecase model (entire stock, DMV only and NJ only); and 2) for decision table analyses for the entire stock in which the relative performance of a range of realistic management policies (quota levels) was evaluated over a range of possible states of nature. Projections of both types were for 2009-2015 and were initialed assuming bootstrap estimates of 2008 stock conditions to help account for uncertainty. There was one projection per bootstrap iteration in all cases.

Landings during 2009 for all projection runs were estimated during October of 2009 based on fishery performance to date. Catches used in simulations included a 12% allowance for incidental mortality.

Projections of both types used four potential management strategies represented by assumptions about landings during 2010-2015 (see below). The "FMP minimum" management strategy assumed that landings during 2010-2015 would be at the minimum quota level specified in the FMP. The "Industry estimated" strategy assumed landings anticipated by industry representatives based on market factors. The "FMP maximum" strategy assumed that landings at the maximum quota level specified in the FMP. The "F_{MSY} proxy" policy assumed catches as managers would calculate them if the target fishing mortality rate was F=M=0.15 y^{-1} (the F_{MSY} proxy). In particular, the basecase model was projected forward assuming F=0.15 in each year and the average projected catches for each were used in all decision table projection runs. The

Industry estimated policy is probably the most realistic. The F_{MSY} proxy policy is the most aggressive in terms of total catches, followed by the FMP maximum, Industry estimate and FMP minimum policies.

Management actions used in projection analyses.

Year	FMP minimum	Industry estimate	FMP maximum	F_{MSY} proxy
Assumed catch in 1000 mt (landings + 12% incidental mortality allowance)				
2008	25.2	25.2	25.2	25.2
2009	20.7	20.7	20.7	20.7
2010	16.0	21.6	29.4	129.3
2011	16.0	23.3	29.4	114.0
2012	16.0	25.0	29.4	102.3
2013	16.0	25.9	29.4	93.4
2014	16.0	25.9	29.4	86.8
2015	16.0	25.9	29.4	73.5

Term of Reference 7a: Forecast projections-whole stock

Simple forecast projections assumed a natural mortality rate M=0.15 and were initialized using results from 2000 bootstrap iterations based on the basecasse KLAMZ model. Bootstrap results indicate that the means of bootstrap biomass estimates were biased high while the means of bootstrap fishing mortality estimates were biased low. Median values for bootstrap biomass and fishing mortality rates were nearly unbiased. Therefore, median values for projected biomass and fishing mortality are used in this assessment to represent the central tendency of projected values.

Forecast results (Figure A75) indicate that biomass for surfclams in the entire stock will continue to decline through 2015 under all but the FMP min harvest policy, which involves the lowest catch levels. Under the FMP min policy, fishing mortality rates are low and the trend in biomass tends to stabilize.

Forecast projections-DMV & NJ

Regional forecast projections were carried out for both DMV and NJ under three harvest policy scenarios: constant catch (landings + incidental mortality) at the mean level during 2003-2008, constant fishing mortality at the 2008 level, and at F=0. Landings in both regions have fluctuated more or less without trend since about 2000, despite large reductions in stock biomass and decreasing LPUE because fishing mortality rates have increased (Table A3, Figures A68-A69, Figure A6). The scenario with zero fishing mortality is used to judge the inherent potential of the regional populations to recover to more productive levels.

As shown below, biomass is projected to decline under most scenarios for both regions. If landings remain the same, and biomass continues to decrease, then fishing mortality rates will continue to increase. Thus, the constant fishing mortality scenario may understate future fishery impacts while the constant landings scenario may overstate future fishery impacts. Given the apparent stability of landings, the constant landings scenario is probably more realistic for both regions.

Forecast results for DMV indicate that biomass will continue to decline under all three scenarios, but to substantially different levels (Figure A76 and see below). Relative to projected biomass under the F=0 scenario, projected biomass in 2015 is 27% lower under the constant F scenario and 43% lower under the constant catch scenario.

Scenarios for DMV	2015 Biomass (1000 mt)	Percent difference relative to F=0
Constant catch (2,300 mt per year)	10.7	-43%
F=0.07	13.8	-27%
F=0	18.9	0%

Forecast results for NJ indicate that biomass will continue to decline under the constant catch and constant F scenarios, but is likely to increase under the F=0 scenario (Figure A77 and see below). Relative to projected biomass under the F=0 scenario, projected biomass in 2015 is 28% lower under the constant F scenario and 38% lower under the constant catch scenario.

Scenarios for NJ	2015 Biomass (1000 mt)	Percent difference relative to F=0
Project landings 18,300 mt	117.4	-38%
Project F=0.1	135.9	-28%
Project F=0	188.6	0%

Term of Reference 7b: Decision tables

Simulations for decision table analyses were more complex. Potential states of nature included three levels of natural mortality (low, medium and high levels of natural mortality M=0.1, 0.15 and 0.2 per year) and three levels of survey dredge catchability (low, medium and high catchability = 0.937, 1.12, and 1.65). In general higher levels of natural mortality imply a larger and more productive stock with a higher F_{MSY} proxy and *vice-versa*. In general, higher levels of survey dredge efficiency imply a smaller, more productive stock and *vice-versa*. The medium levels are the same as in the basecase assessment model run.

On a subjective basis, medium scenarios were assigned a prior probability of 0.5 by the Invertebrate Working Group, while the low and high scenarios were assigned prior probabilities of 0.25. The prior probabilities for natural mortality and catchability are independent of one another so that probabilities can be computed for their combinations (e.g. the prior probability for low levels for both natural mortality and catchability is 0.25 x 0.25 = 0.0625). The prior probabilities for combined scenarios were either 0.0625, 0.125 or 0.25 and used to rank scenarios qualitatively as least, less and most probable.

Qualitative prior probabilities for states of nature and their combinations.

States of nature	Low catchability	Middle catchability	High catchability
Low M	Least	Less	Least
Middle M	Less	Most	Less
Hi M	Least	Less	Least

For decision table analysis, a simulated population was constructed for each of the nine combined states of nature by fitting the KLAMZ model with parameters for natural mortality and survey dredge catchability fixed at the assumed levels. Five hundred bootstrap iterations were generated from the KLAMZ model output for each scenario, to simulate variability in stock assessment results that would arise naturally in each case. Finally, 500 projections (one for each bootstrap) were carried out using each of the possible management strategies. The probability of overfishing ($F_{2015} \geq$ the true M value assumed in the simulation) and overfished stock status conditions ($B_{2015} \leq$ the true B_{1999} /2) was computed from each of the 500 projections for each management approach under each state of nature.

Results (Table A33) generally indicate that overfished stock status and overfishing are unlikely to occur, unless managers decide to harvest surfclams at the maximum allowed level (F_{MSY} proxy=0.15 y^{-1}). Focusing on results for F_{MSY} proxy management, the probability of overfished stock status declines as natural mortality increases (because catches are fixed but stock biomass increases) and as catchability decreases (because stock biomass must be higher if survey catchability is lower). Based on the most probable state of nature (medium natural mortality and medium catchability), under the most aggressive management strategy (F_{MSY} proxy), overfishing would be unlikely to occur but the simulated stock would be almost certain to fall below its biomass target and become overfished. The consistently poor performance of the stock under the F_{MSY} proxy policy indicates that M=0.15 may be a poor proxy for F_{MSY} in the surfclam fishery.

The surfclam resource is not "vulnerable" to becoming overfished or likely to experience overfishing by 2015 based on current FMP specifications because total stock biomass is relatively high, total fishing mortality rates are low (3% per year according to KLAMZ models), the FMP restricts harvest to levels far below the F_{MSY} proxy harvest level, and because the relatively low biomass, slow growth and poor recruitment of stock in the south (DMV and NJ) are offset by high biomass and good biological conditions in the north. However, see comments concerning the current biomass and fishing mortality reference points given above.

Term of Reference 8: Research recommendations

Research recommendations from previous assessments are listed below (not in priority order).

i) Consider using year-, region- or episodic natural mortality rates. *No progress. This was discussed in the working group but deferred until a later assessment.*

ii) Develop a forward casting age-structured, numbers-based stock assessment model. *In progress. A preliminary Stock Synthesis model for surfclams is presented in an appendix to this assessment. Results appear promising and the Stock Synthesis Model is expected to be the principal model in the next assessment. In fact, a Stock Synthesis or similar model that can incorporate spatial heterogeneity in data and biological characteristics may be required because the NEFSC clam survey is expected to transition in 2011 to a cooperative survey carried out by a commercial vessel that would cover one third of the stock each year. It would be difficult using the current assessment model to estimate biomass and fishing mortality for the whole stock using non-synoptic survey data.*

iii) Collect commercial age and length data to monitor and predict recruitment and for use in length and age structured models. *Length data but no age data are currently being collected from port samples. Age data from triennial survey are available*

iv) Reexamine coefficients used to convert commercial catches in bushels to meat weights. *No progress.*

v) Consider using a sensor that tracks dredge position, rather than the ships position, during surveys and depletion studies. *No progress. However, simulation results of Patch model performance indicate that uncertainty in dredge position has relatively minor effects on survey dredge efficiency estimates.*

vi) Conduct surveys more frequently than every three years in critical areas. *No progress. The NEFSC clam survey is expected to transition in 2011 to a cooperative survey carried out by a commercial vessel that would cover one third of the stock each year, a plan that basically amounts to a triennial survey..*

vii) Consider new technological methods that rely less heavily on estimating dredge efficiency. *No progress.*

viii) Consider new methods to estimate variability in the spatial distribution of biomass. *This topic is an important part of ongoing research that involves simulation analyses to evaluate sensitivity of Patch model dredge efficiency estimates to spatial variability and other factors. Results to date are presented in an appendix to this assessment.*

ix) Refine logbook data collection, focusing on spatial details. Resolve apparent problems with locations for some records. Can recent data show patterns on finer spatial scales (e.g. for 1-minute rather than 10-minute squares)? *No progress.*

x) Improve collection and use of port sample data from the commercial fishery. *In progress. The preliminary Stock Synthesis model presented in an appendix makes full use of commercial length data.*

xi) Characterize relationships between shell height, width and length for potential use in understanding the size selectivity of commercial and survey dredges and commercial sorting gear. *No progress. However, survey dredge size-selectivity was estimated using cooperative survey data.*

xii) Test the Patch model for depletion experiments with simulations focusing on potential effects of uncertainty about position data and including all effects of cell size and smoothing. *In progress (see item viii above).*

xiii) Determine the size selectivity of survey and commercial fishing equipment experimentally. *Survey dredge size-selectivity was estimated using cooperative survey data.*

xiv) Improve procedures for filling holes in the survey data using statistical models with year and spatial effects. Determine if filling holes is preferable to borrowing data from previous and subsequent surveys. *No progress.*

xv) Review survey age data carefully to determine if strong year classes can be used to estimate mortality rates outside of a stock assessment model (e.g. "empirical" Z estimates). *A marginal increment analysis study was carried out to show that annuli used to age surfclams are annual marks. Survey age data were used more extensively in the current assessment to identify strong year classes. The preliminary Stock Synthesis model presented in an appendix makes full use of commercial length data.*

xvi) Devote sufficient time and resources to fully develop and improve dynamic population models. *See item ii above.*

xvii) Review the technical basis of the current B_{MSY} proxy given new data and possible climate effects. *No progress.*

xviii) Utilize New Jersey and New York inshore clam survey data more fully in the EEZ surfclam assessment. *Completed. This report includes an appendix containing a summary of stock conditions in state waters that was completed in cooperation with biologists employed by New Jersey, New York and a private consulting firm.*

The following are new research recommendations (not in priority order):

i) Continue surfclam recruitment research.

ii) Port samples should be taken from the SNE and GBK (if fishing resumes there) regions.

iii) Determine how much of Georges Bank is suitable habitat for surfclams, and if depletion and selectivity experiments done in the mid-Atlantic are applicable to the Georges Bank region.

iv) Fecundity and maturity at length information is required to improve reference point calculations and predict management effects.

v) Data on the number of clams per bushel landed at different ports over time would be useful.

vi) Commercial length data for surfclams should be more accessible.

vii) Determine whether the carrying capacity of surfclams has changed over time.

viii) Estimate densities of spawning surfclams necessary for successful reproduction. Is reproduction likely to be impaired if relatively dense beds of surfclams are reduced?

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